CHARACTERIZATION OF HYBRID FREQUENCY SELECTIVE SURFACE (FSS)

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ABSTRACT

This paper presents the characterization of Frequency Selective Surface (FSS) on hybrid materials to minimize the signal loss in a wireless medium using various objects at 2.4 GHz. The FSS structure is designed in two basic configurations; rectangular FSS and trapezoid FSS. In each design have three types of structures, single FR4 substrate, dual FR4 substrates and dual hybrid substrates. The results show that rectangular FSS with dual hybrid substrates (Rogers RO3010 + Glass) without any gap has the highest inductive effect of $(0.865i + 0.251j)$ to load impedance, while rectangular FSS with dual hybrid substrates (Rogers RO3010 + Glass) with dual FSS has the highest resistive effect of $(0.795i + 0.183j)$ to the load impedance. Also trapezoid FSS on dual hybrid substrates (FR4 + Glass) has highest capacitive effect of $(0.886i + 0.324j)$ to the load impedance. These results help in achieving the matching for the materials in order to reduce the losses and to enhance the performance of signal power in wireless system.

Key words: Frequency Selective Surface (FSS) · Hybrid substrates · Simulation ·

INTRODUCTION

A periodic surface is basically an assembly of identical elements arranged in a one or two-dimensional infinite array. Frequency Selective Surfaces (FSS) or dichroic are periodic arrays consisting of conducting patch or aperture elements designed to reflect or transmit electromagnetic waves with frequency discrimination (Wu, 1995), (Munk, 2005). One of the main features of FSS's is that they operate on a non-confined propagating beam rather than on an RF signal brought in through a guided wave structure such as waveguide, microstrip or strip-line.

Frequency selective surfaces can be composed of passive or active elements. Passive elements are excited by incident plane waves. More recently, capabilities of FSS's have been extended by the addition of active devices embedded in the unit cell. These structures are also known as active grid arrays (Wu, 1995), (Munk, 2005), (Tennat and Chambers, 2003), (Richards, 2008).

The signal power is reduced when the signal transmits in wireless medium from transmitter to receiver with various objects because of the wireless medium losses that occur due to the reflections and transmissions. Therefore, by using FSS with different materials a higher matching between the incident signal and the FSS hybrid structure will reduce reflection signal by transmiting the signal depending on the formula that can be defind as

$$T = 1 - \Gamma \qquad (1)$$

Where Γ is reflection coefficient and T transmission coefficient, so the full matching occurs when Γ equal zero, it means that the load impedance of material is equal to the impedance of the air $Z_o = 377\ \Omega$, and this is the ideal case but good results can be quite close to the ideal case.

Changing the parameter in FSS will affect the load impedance. If the real part of load impedance is affected, it is known as resistive effect. On the other hand, if the imaginary part of the load impedance is increasing or decreasing, they are known as inductive effect and capacitive effect respective affected, it is known as inductive effect and capacitive effect respectively.

When the signal incidents to any object, part of the signal will be reflected and rest of the signal will be transmitted to the receiver depending on the object properties, in this case the received signal will have lesser power, so the objective is to put FSS with hybrid materials to make the signal power higher at the receiver.

Frequency Selective Surface

An FSS is consisting of aperture or patch elements. Aperture element FSS reflects at low frequencies and transmits at high frequencies as in high-pass filters while patch element FSS transmits at low frequencies and reflects at high frequencies (as in low-pass filters). If the FSS is made of freestanding grids without dielectrics, the performance of a patch FSS exactly complements that of the aperture FSS.

An FSS can also be classified as thick or thin screen. Thin screen FSS's are lightweight, small in volume and easy to fabricate with the conventional printed circuit technology. Thick screen FSS's are made of array elements with electrically larger thickness, and are mostly apertures used for high-pass applications, then become heavy and more difficult to fabricate. Waveguide stacks are an example of thick screen FSS. The main advantage of thick screen FSS is that the ratio of transmission to the reflection frequency is much smaller compared to thin screen FSS. Thick screen FSS's are used in advanced multi-frequency communication satellite antennas.

FSS in dual substrate layer

An effort is made to enhance the gain to show improved performance analysis based on the design through the implementation of FSS structured superstrate layer with circular microstrip patch antenna operating at frequency of 5.8 GHz for Industrial, Scientific and Medical (ISM) Band applications (James and Hall, 1989). In this proposed antenna, coaxial feeding technique is used for having better matching effects of impedance (Çakir and Sevgi, 2005).

In order to show their results is better, they have made a comparative analysis with the conventional microstrip patch antenna at the same frequency band to increase the gain, directivity and minimize the return loss of the desired antenna. In addition to this, it shows the advantages of utilizing the ISM band and FSS superstrate layers compared to other frequency bands (Alam et al, 2009). The procedure assumes that the specified information includes the dielectric constant of the substrate (ε_r), the resonant frequency (f_r) and the height of the substrate (h). For the rectangular patch (Hamad , 2006), fringing makes the patch look electrically larger and it was taken into account by introducing a length correction factor (Pirhadi et al, 2012).

FSS characterization

Characterization of FSS using two basic FSS shapes; rectangular FSS and trapezoid FSS. In each shape, FSS is designed and simulated for single FR4 substrate, dual FR4 substrates and dual hybrid substrates. For the single FR4 substrate, FR4 is used with 1.6 mm of thickness and the dielectric constant is 4.4. In the step of dual substrates have two cases, for dual FR4 substrates, by using FR4 with dielectric constant (ε_r = 4.4) and thickness of (1.6 mm) as square array with dimensions 240x240 mm^2.

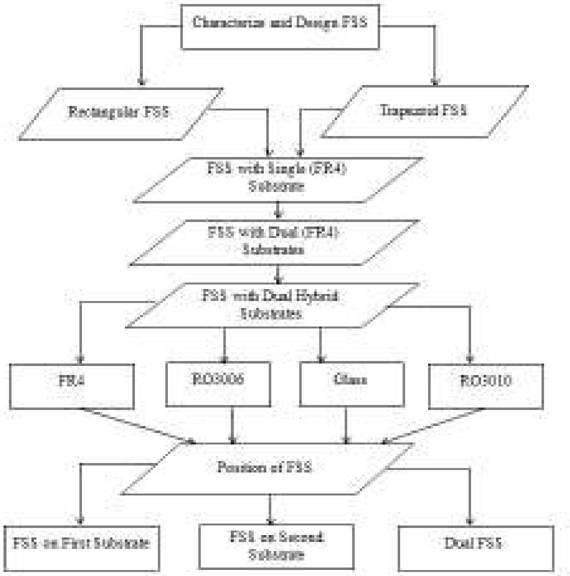

Figure 1: Flowchart of FSS.

In dual hybrid substrates have four types of materials (FR4, Rogers RO3006, Glass and Rogers RO3010). The Rogers series have two different kinds of materials.

Rogers RO3006 has thickness 1.6 mm and dielectric constant of (ε_r = 6.15). Rogers RO3010 has 1.6 mm as a thickness with dielectric constant (ε_r = 10.2). Then for Glass, the thickness is 5mm and dielctric constant is (ε_r = 6.9). Simualtions were carried out at three positions of FSS with hybrid substrates, which are FSS on the first substrate, FSS on the second substrate and dual FSS, as shown in the flowchart in Figure 1.

FSS design

There are two types of FSS shapes used, which are rectangular FSS and trapezoid FSS. The FSS elements comprising the square array, every element of the array is shown, containing rectangular FSS.

In the square array a 0.035 mm copper rectangular layer is placed on a 1.6 mm dielectric square surface of FR4 (ε_r = 4.4). Each copper rectangular layer is containing width (40mm) and length (60mm). The square dielectric surface has dimensions 240x240 mm^2 as shown in Figure 2.

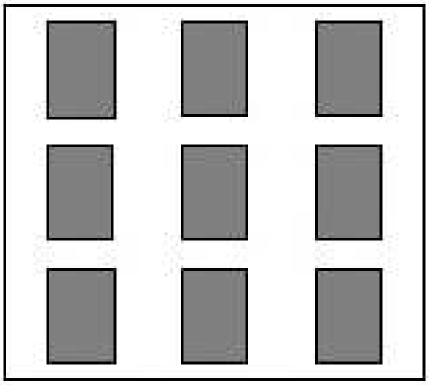

Figure 2: Rectangular FSS of 3x3 array elements (MWS, 2011).

The FSS elements comprising the square array, every element of the array is shown, containing trapezoid FSS. In the square array a 0.035 mm copper trapezoid layer is placed on a 1.6 mm dielectric square surface of FR4 (ε_r = 4.4). Each copper trapezoid layer is containing (a= 30 mm) and (b =60 mm). The square dielectric surface has dimensions 240x240 mm^2, there are 9 FSS elements varies as 3x3 square array in Figure 3.

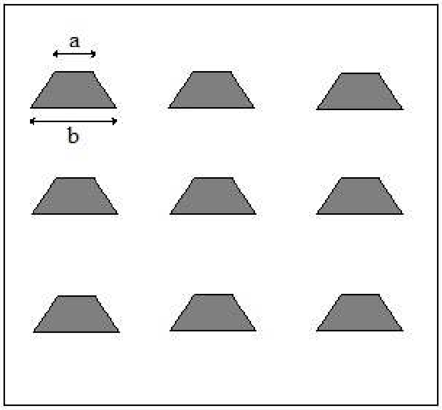

Figure 3: Trapezoid FSS of 3x3 array elements (MWS, 2011).

FSS Design with Dual substrates

FSS is designed with dual substrates firstly, depending on the type of material that is used as a substrate. There is dual (FR4) substrates, used same dielectric constant, and there is dual hybrid substrates, used (FR4, Rogers RO3006, Glass and Rogers RO3010) with different configurations. Secondly, FSS is designed with dual substrates depending on position of FSS. There are three types for FSS positions, which are FSS on first substrate, FSS on second substrate and dual FSS.

RESULTS AND DISCUSSIONS

Trapezoid FSS Structure

The FSS was simulated in CST (MWS, 2011) to verify its performace. The result show that FSS rejects the signals at 2.4 GHz with a maximum attenuation and passes higher and lower frequency signals. Here, the resonance frequency is 2.4 GHz at -37 dB, Figure 4 shows the transmission (S_{21}) for trapezoid FSS on single FR4 substrate in the frequency range (1- 4) GHz.

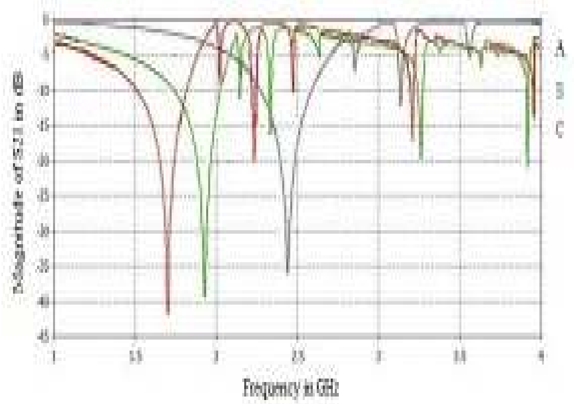

Figure 4: Magnitude of S_{21} parameters for;
(A) Trapezoid FSS on single substrate,
(B) Trapezoid FSS on dual FR4 substrates,
(C) Trapezoid FSS on hybrid substrates (FR4 + Glass).

FSS on Dual FR4 Materials

In the characterization of FSS on dual FR4 materials with no gap, indicates that resonance frequency is shifted from 2.4 GHz to 1.9 GHz at -39 dB, with narrow bandwidth as shown in Figure 4.

Position of FSS on Hybrid Materials

The characterization of FSS in this analysis was carried out depending on the position of FSS on hybrid materials and distance between both substrate. The two materials used are FR4 on first substrate and Glass on the second substrate. Initially FSS was placed on the second substrate (Glass). Then it can be noticed that the resonance frequency shifts from 2.4 GHz to 1.7 GHz at -42 dB as shown in Figure 4.

The reflection coefficient of FSS is calculated by eq. (2) based on simulated results.

$$Z_L = Z_O \frac{\Gamma+1}{\Gamma-1} \qquad (2)$$

Where Γ is reflection coefficient, Z_o is free space impedance and its 377 Ω and $Z_L$is the load impedance.

After doing the calculation of reflection coefficient at the resonance frequency (2.4 GHz), a summary is given for overall performance of FSS depending on material of substrate for single and then for dual substrates with no gap for two shapes of FSS and it is shown in Table 1.

Table 1: Reflection coefficient of FSS depending on the substrate material for single and dual substrate with no gap.

Configuration	Rectangular FSS		Trapezoid FSS	
	Real	Imag.	Real	Imag.
Single substrate	0.314	0.427	0.908	0.102
Dual (FR4), with no gap	0.460	0.433	0.912	-0.330
(FR4 + RO3006), with no gap	0.491	0.440	0.778	-0.477
(RO3006 + FR4), with no gap	0.556	0.426	0.633	-0.527
(FR4 + Glass), with no gap	0.772	0.350	0.310	0.167
(Glass + FR4), with no gap	0.578	0.329	0.015	0.184
(RO3010 + Glass), with no gap	0.865	0.251	0.367	0.345

In single substrate, use FR4 as a material, and for dual substrates are using four types of different materials (FR4, Rogers RO3006, Glass and Rogers RO3010). Then there are two structures; dual FR4 materials and hybrid dual materials, there are six different configurations as show in Table 1, and there is no separation (gap) in all these configurations. Then can be noticed that the highest inductive effect is obtained of load impedance with a rectangular FSS on dual hybrid substrates (Rogers RO3010 + Glass) without gap and it is (0.865*i* + 0.251*j*).

Table 2 shows the reflection coefficient by depending on substrate material for dual substrates when FSS placed on the first substrate for both shapes of FSS (rectangular and trapezoid) at resonance frequency of (2.4 GHz). Then can be noticed that in the trapezoid FSS on dual FR4 substrates is showed highest capacitive effect (0.936*i* - 0.260*j*).

Table 2: Reflection coefficient of FSS depend on substrate material for dual substrate, FSS on second substrate.

Configuration	Rectangular FSS		Trapezoid FSS	
	Real	Imag.	Real	Imag.
Dual (FR4), FSS on 2nd substrate	0.572	0.432	0.936	-0.260
(FR4 + RO3006), FSS on 2nd substrate	0.642	0.428	0.753	-0.490
(RO3006 + FR4), FSS on 2nd substrate	0.631	0.433	0.792	-0.472
(FR4 + Glass), FSS on 2nd substrate	0.886	0.324	0.071	0.186
(Glass + FR4), FSS on 2nd substrate	0.750	0.393	-0.227	-0.090
(RO3010 + Glass), FSS on 2nd substrate	0.763	0.291	0.048	0.254

Table 3 shows the the reflection coefficient of FSS with dual substrates when dual FSS are placed on both substrates for two shapes of FSS (rectangular and trapezoid) at resonance frequency of (2.4 GHz). The highest resistive result can be obtained that in rectangular FSS on dual hybrid substrates (Rogers RO3010 + Glass) materials with dual FSS that has (0.795*i* + 0.183*j*).

Table 3: Reflection coefficient of FSS for dual FSS position at frequency 2.4 GHz.

Configuration	Rectangular FSS		Trapezoid FSS	
	Real	Imag.	Real	Imag.
Dual (FR4), Dual FSS	0.406	0.779	0.904	-0.272
(FR4 + RO3006), Dual FSS	0.392	0.818	0.833	-0.467
(RO3006 + FR4), Dual FSS	0.386	0.072	0.797	-0.508
(FR4 + Glass), Dual FSS	-0.456	0.320	0.279	-0.024
(Glass + FR4), Dual FSS	0.404	0.268	0.320	-0.507
(RO3010 + Glass), Dual FSS	0.795	0.183	0.214	0.223

CONCLUSION

In this work, the performance of FSS with different configurations (FSS with single FR4 substrate, FSS with dual FR4 substrates, FSS with dual hybrid substrates and position of FSS on the substrates) of FSS and hybrid materials containing rectangular and trapezoid. The shapes of FSS is investigated to see the effect of changing the shape of FSS. All these configurations were simulated in the specific frequency range (in wireless system) at 2.4 GHz.

It is found that the highest inductive effect was obtained of load impedance with a rectangular FSS on dual hybrid substrates (Rogers RO3010 + Glass) without gap and it is (0.865*i* + 0.251*j*). While rectangular FSS on dual hybrid substrates (Rogers RO3010 + Glass) materials with dual FSS has the highest resistive effect (0.795*i* + 0.183*j*). Moreover, the trapezoid FSS on dual FR4 substrates showed highest capacitive effect (0.936*i* – 0.260*j*) .

In future, the researchers can use combination of simple elements of FSS to produce a multiple resonance structure substrate that has a significant reflection normal to the surface. This idea can be used to further design surfaces that resonate at particular frequencies to provide unique signatures. The surface can also be modeled as an equivalent circuit composed of lumped elements that resonate at the same frequencies. This circuit can older additional insights on the design of the FSS and can be used to modify the resonant properties as required.

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