A Novel Single Layer Frequency Selective Surface Design for Ultra-Wide Band Antenna Gain Enhancement

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Abstract

In this study, a novel single layer band stop Frequency Selective Surface (FSS) for gain enhancement of Ultra-Wide Band (UWB) antenna is presented. The proposed FSS unit cell consists of a conventional square loop (CSL), a ring and cross dipole elements and printed on a single side of 15mm × 15mm dielectric substrate. The -10dB frequency band relies on 3.02GHz and 11.79GHz and fractional bandwidth is %128. Also, effects of the unit cell parameters over the transmission performances are investigated and conclusions are presented. In order to showgain enhancement performance, the FSS with the designed high gain UWB antenna were simulated by CST MWS. The antenna with FSS has a maximum gain of 14dB.The FSS shows a linear reflection phase variation within the operation range and can be good candidate for enhancing the printed antennas gain.

1. Introduction

The FCC allocated the frequency band between 3.1 and 10.6 GHz for unlicensed ultra-wideband transmission in 2002 [1]. Thus, ultra-wide band applications have been become an attractive research area over the recent years some reason such as higher data rates, low power consumption. The printed antennas usually are taken part in UWB technology, because they have some suitable features compact size, low cost and impedance bandwidth. However, these antennas have low gain due to its nature. In many applications it is substantial to be high directivity such as wall radars, medical imaging systems etc. So this reason it is necessary the antennas to own high directivity and high gain.

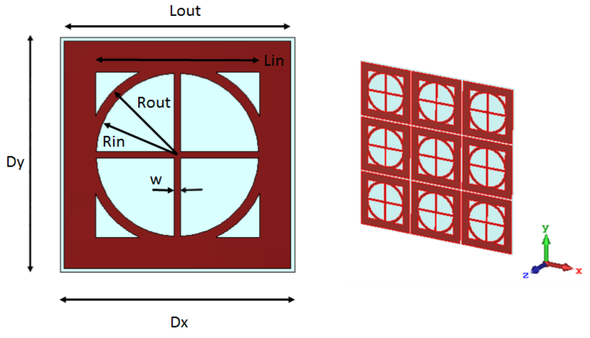
The frequency selective surface (FSS) can be used for enhancing printed antenna gain and directivity. The FSSs are periodic arrays consisting of conductive patches or aperture elements to reflect or transmit electromagnetic waves depend on frequency [2]. They act as spatial filter to allow electromagnetic wave pass through or reflect. Thus, FSSs have been commonly used in radomes, filter, reflector, gain enhancement, and radar cross section (RCS) reduction. All these features make FSS productive end remarkable subject for researchers. The behavior of FSS depends on geometry and size of unit cell, inter-element space, substrate thickness and relative permittivity, and incidence angle of the incoming wave. The unit cell is described as the basic structure of the array that recurring itself infinitely. Unit cell element shapes mainly define the filtering type. For example, an aperture-element FSS transmits at high frequencies as in high-pass filters and patch-element FSS transmits at low frequencies as in low-pass filters.

Generally, FSSs have narrow bandwidth and theoretically they are an infinite periodic array. On the contrary, the FSSs are finite size as implementation. These factors limit the FSS performance. It is not simple to design a small size UWB FSS using single substrate layer. In literature, there are many different type of investigated FSS for multi-layer as well as single layer. To obtain wider bandwidth and a sharper filter it has been used multi-layer concept. This leads to increase the fabrication costs and it is required to more space. In [3-4] dual layer and [4] multi-layer UWB FSS have been presented. There has many study with single layer UWB band stop FSS. In [5-7] it has used single layer FSS for UWB applications. Most of these studies are wide band, but it is not suitable for bandwidth range defined FCC UWB standards exactly.

The band stop FSS can be used for reflecting the electromagnetic waves to provide gain enhancement. In this study, a novel single layer FSS for gain enhancement of UWB antennas is presented. Parametric studies are simulated to investigate effects on transmission performance by using CST Microwave Studio. The unit cell size is 15mm × 15mm that correspond to 0.15λ × 0.15λ, where λ refers to free space wavelength of the lower frequency 3GHz. The proposed FSS demonstrates excellent band stop filtering response in whole UWB frequency range. In section 2, the unit cell geometry of designed FSS is explained. In section 3 the simulation results of transmission coefficients and parametric studies are presented. In section 4 it has been presented the high gain UWB antenna design and gain obtained by using FSS below the antenna and gain obtained without FSS have been compared. At the end section 5, conclusions have been discussed.

2. Unit Cell Design

The unit cell geometry of FSS is Show in Fig.1a. The FSS structure is consists of a single layer of metallic conventional square loop (CSL), a ring and cross dipole elements and etched on a single side of 15mm × 15mm dielectric substrate that Arlon AD600, with dielectric constant $\varepsilon_r = 6.15$ and thickness $h = 0.508$mm. The periodicity of the unit cell is 15mm × 15mm along the x and y directions respectively. The size of unit cell for the lower UWB frequency corresponds to 0.15λ × 0.15λ, where λ refers to free space wavelength.



(a) (b)

Fig. 1(a). Unit cell geometry **(b)** Perspective view of periodic designed FSS

When designing FSS, it is chosen geometric shapes that filtering characteristics has known. For instance, square loop or ring acts like band stop filter. In this design it has started CSL element. As it is known CSL element has narrow bandwidth. The outer size of CSL is 14.5mm × 14.5mm and inner aperture size is 10.5mm × 10.5mm. To cover whole UWB range, unit cell geometry must be modified by adding new geometric element. When a ring element is added to the CSL element, the transmission characteristic bandwidth expands. Adding the ring element to unit cell structure has caused resonance frequency shifting to right, increasing the low frequency bigger than 3.1GHz and the high frequency bigger than 10.7GHz. Although a wide band is obtained, the modification should be carried on to accomplish the exact lower and upper frequencies. A cross dipol element is used for our final design and at the last case -10dB transmission bandwidth is between 3.02GHz and 11.79GHz. To ensure a good transmission response over UWB range, too many trials have been simulated by changing the unit cell structure parameters. The unit cell parameters are given in Table 1 and dimensions are in mm. Also, the unit cell structure is designed symmetric with respect to both x and y axis to eliminate polarization sensitivity.

Table 1. Unit cell parameters

Parameters	Dimension [mm]
Dx	15
Dy	15
Lout	14.5
Lin	10.5
Rout	5.8
Rin	5.2
w	0.4

3. Simulation of Parametric Study Results

Fig.2 illustrates the computed transmission and reflection coefficients of the designed FSS, performed by CST MWS using the unit cell boundary conditions with Floquet Modes. It can be shown that the FSS exhibits a band stop filter response between 3.02GHz and 11.79GHz below -10 dB under normal incidence. The resonance frequency of stop band is 6.8GHz for normal incidence.

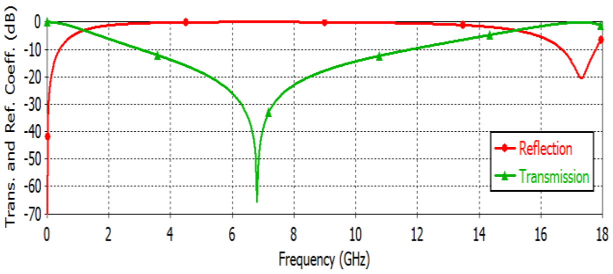


Fig. 2 Simulated transmission (S21) and reflection (S11) coefficients of designed FSS

The reflection phase is a significant factor for allowing the FSS to be used in antenna gain enhancement applications. The reflection phase of the FSS should be linearly decreased. Fig. 3 depicts the reflection phase of proposed FSS. In order to be use the FSS as a reflector, distance between antenna and FSS is determined by zero-degree reflection phase frequency, which is computed to be 8.68GHz. The distance between the antenna and the FSS is should be 17.78 mm (λ/2).

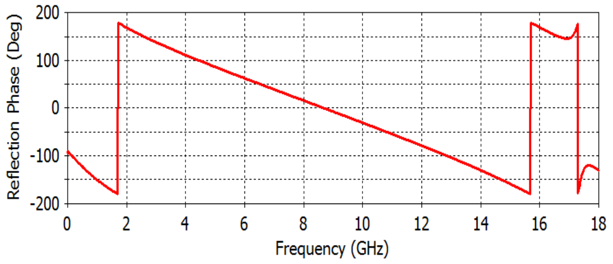


Fig.3 Simulated reflection (S11) phase of designed FSS

In order to clearly understand the design operation of the unit cell, some important parameters have been changed and these simulation results are given in this section. The CSL element width has been changed by keeping the CSL outer dimension constant. It can be seen in Fig 4 how the changing of CSL element width affects the transmission characteristic. As inner dimension of CSL L_{in} decreases, the lower frequency has not changed too much, but the upper frequency and resonance frequency have increased. Also the bandwidth has increased too.

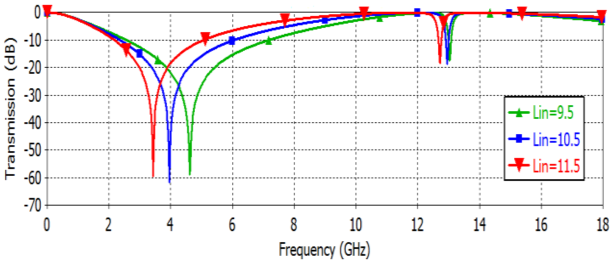


Fig.4 Simulated transmission (S21) coefficients for different CSL element width

The next step is adding a ring element to unit cell structure. In this step unit cell consists of a CSL element and a ring element. The outer radius of the ring element is kept constant and the inner radius R_{in} is reduced. In Fig.5 transmission coefficients according to variation of inner radius of ring element. As the ring element width has increased, the band width has increased too. But the resonance frequency, lower frequency and upper frequency shift towards to right.

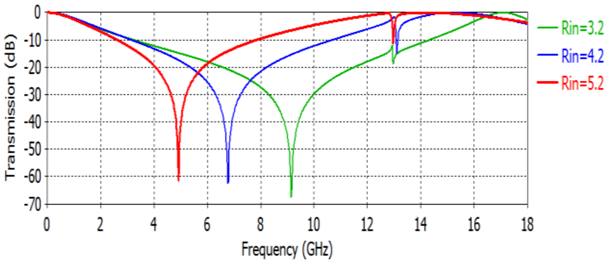


Fig.5 Simulated transmission (S21) coefficients according to variation of ring element width

Final step is adding cross dipol element into unit cell structure. Adding cross dipole provides to tune the lower and upper frequency of the designed FSS to UWB range. With the cross dipole element width, the bandwidth of the transmission can be adjusted. When the cross dipole element length equals to inner dimension of CSL, if cross dipole element width w has decreased the bandwidth is decreased. The effect of the variation of the cross dipole width on the transmission coefficients can be shown in Figure 6. After the simulations the best parameters have been chosen to final design and it is summarized to evolution of the designed FSS in Fig.7.

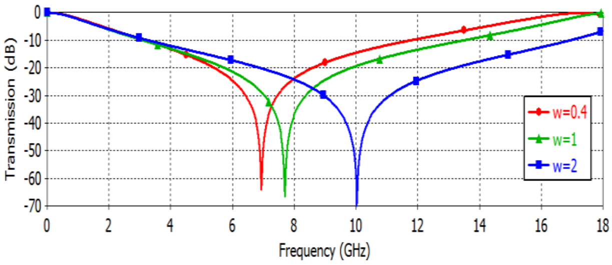


Fig.6 Simulated transmission (S21) coefficients according to variation of cross dipole width

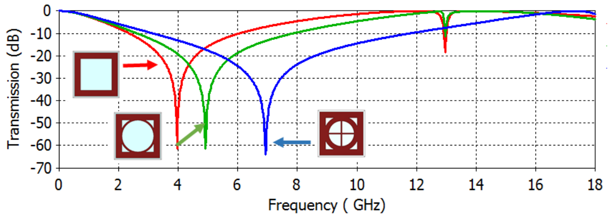


Fig.7 Evolution of the design FSS

4. Gain Enhancement

In order to demonstrate gain enhancement performance of the designed FSS it has used UWB high gain antenna shown in Fig.8. Antenna is designed using an Arlon AD300A dielectric substrate with relative permittivity of 3 and has dimension of 84×75mm². The antenna radiates at 2- 11GHz). The patch of the antenna consists of two elliptic parts which symmetric to each other with respect to x axis. The center of the elliptic part $E_c(x,y)$ is located at x=6mm and y=33mm with respect to O origin point. The elliptic part is rotated at its center with E_d=50°. There are two ring slots which are symmetric to each other at each elliptic part. The center of the left ring slot is located at $C_c(x,y)$ with x=-4.5mm and y=33mm. The radius of the ring is C_R=3,2mm. Two separate strips are found on the butterfly patch, and these strips are symmetrical with respect to the x-axis. The distance between the strips is S_D = 16.5mm, S_W width is 0.5mm and the S_L height of the strips is 4.1mm. The flat width F_P = 5.9 mm, where the butterfly structure meets the feed line. In order to adapt the feed line to 50 Ohm input, F_L = 5mm length, width dimension F_W = 7.5mm and F_G gap to 0.5mm. The center of the elliptical structure surrounding the butterfly patch is 38 mm away from the center T_C (x, y). The radius of the same ellips T_{R1} is 25mm and the radius of T_{R2} is 23mm. G_1 = 3mm, G_2 = 2mm, G_W = 22mm, G_{L1} = 5mm and G_{L2} = 11mm for the rectangular geometries that are opened on the antenna line of the antenna. D_1 = 8.5mm, D_2 = 3.5mm and D_3 = 1mm for block strips added to the left and right sides of the antenna.

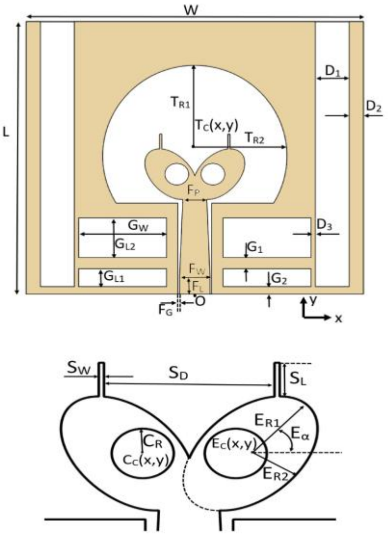


Fig.8 The geometric structure of the designed high gain microstrip antenna

The distance between the antenna and the FSS is 17.78 mm. In Fig.9 it is depicted simulation of reflection coefficients UWB antenna and UWB antenna with FSS. In Fig. 10 it is given the peak gain of UWB antenna and UWB antenna with FSS.

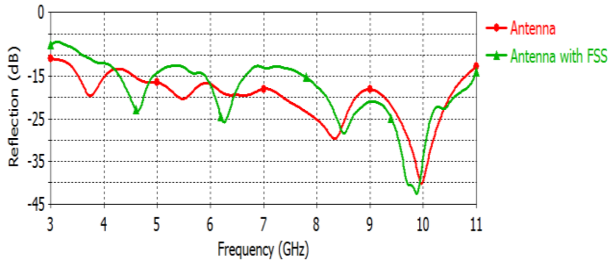


Fig.9 The simulation of reflection coefficients UWB antenna and UWB antenna with FSS

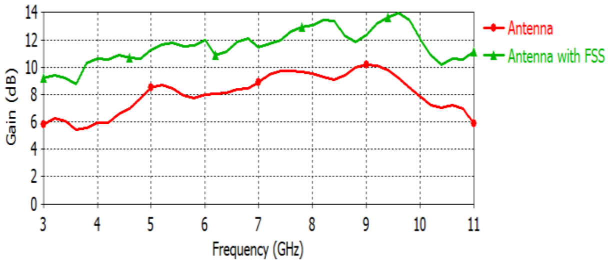


Fig.10 The peak gain of UWB antenna and UWB antenna with FSS.

The average of designed antenna is 7.5 dB and the peak gain varies 10.1dB at 9GHz and 5.8 dB at 3GHz. When the FSS is used below the antenna, the average gain of the antenna is 11.2 dB and the peak gain varies 14 dB at 9GHz and 7.7 dB at 3GHz. So enhancement of the average gain is 3.7 dB and maximum enhancement is 3,9 dB at the 9 GHz.

Fig. 11 shows the simulated radiation patterns of the UWB antenna with and without FSS at 7 GHz and 9 GHz. When the FSS is used to improve directivity, it can be understood that the antenna has radiated nearly same direction. So it can be said that radiation patterns become highly directional after using of the FSS below the UWB antenna.

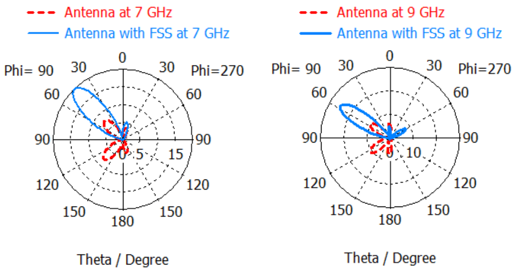


Fig.11 The simulated radiation patterns of the UWB antenna with and without FSS at 7 GHz and 9 GHz.

6. Conclusions

In this study, a novel single layer band stop FSS design for UWB antenna gain enhancement is presented. The designed FSS has an excellent reflection phase for use as a reflector for printed UWB antennas. The proposed FSS unit cell consists of a conventional square loop (CSL), a ring and cross dipole elements and printed on a single side of dielectric substrate. Using of the FSS below the UWB antenna provides enhancement of the average gain is 3.7 dB and maximum enhancement is 3,9 dB at the 9 GHz. Compared to other studies at the literature it has obtained high gain improvements. Moreover, it has been achieved that the UWB antenna radiate to nearly same direction.

Acknowledgement

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