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FSS Wall Design for High Isolation MIMO Antenna Array

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Antenna Array,
FSS,
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Abstract: In MIMO antennas, mutual coupling that adversely effects antenna performance is due to the surface currents. To date, many techniques such as Electromagnetic Band Gap (EBG) structures, metamaterial unit cell, band-stop filters and Frequency Selective Surfaces (FSS) have been proposed to suppress these surface currents. FSSs, when properly designed, can act as a band-stop filter in a given frequency range and thus prevent the propagation of these surface waves in the microstrip patch arrays. In this study, a new FSS unit cell is designed to reduce the mutual coupling effect caused by surface currents between two identical 2x1 patch antenna arrays with a 3.49 GHz operating frequency. These designed FSS unit cells are placed between the patches with a 1x5 periodic sequence. According to the simulation results, mutual coupling effect decreased by 26.6 dB without any shift in the transmission band with only 0.48 dB change in S_{11}. Finally, Envelope Correlation Coefficient-ECC curves are plotted separately for the antenna array with and without the FSS wall. It is observed that the ECC of the antenna array is dropped from 0.16 to 0.07 by applying the proposed isolation wall.

Yüksek İzolasyonlu MIMO anten dizisi için FSY duvar tasarımı

Anahtar Kelimeler
Dizi Anten,
FSY,
Karşılıklı Kuplaj

Öz: MIMO antenlerinde, anten performansını olumsuz etkileyen karşılıklı kuplaj, yüzey akımlarından kaynaklanır. Bugüne kadar bu yüzey akımlarını bastırmak için, Elektromanyetik Bant Boşluğu (EBB) yapıları, metamalzeme birim hücresi, bant durdurma filtreleri ve Frekans Seçici Yüzeyler (FSY) gibi birçok teknikler önerilmiştir. FSY'ler, uygun şekilde tasarlandıklarında, belirli bir frekans aralığında bir bant durdurma filtresi olarak işlev görebilir ve bu nedenle bu yüzey dalgalarının mikro şerit yama dizilerinde yayılmasını önlerler. Bu çalışmada, 3.49 GHz çalışma frekansına sahip iki özdeş 2x1 yama anten dizisi arasındaki yüzey akımlarının neden olduğu karşılıklı eşleştirme etkisini azaltmak için yeni bir FSS birim hücresi tasarlanmıştır. Bu tasarlanan FSY birim hücreleri, 1x5 periyodik diziyle yamalar arasına yerleştirilir. Simülasyon sonuçlarına göre, karşılıklı bağlantı etkisi, iletim bandında herhangi bir kayma olmadan 26,6 dB azaldı ve S_{11}'de ise sadece 0,48 dB'lik bir değişim gözlendi. Son olarak, Zarf Korelasyon Sabiti (ZKS) eğrileri FSY duvarı olan ve olmayan anten dizisi için ayrı ayrı çizildi. Anten dizisinin ZKS' sinin, önerilen yalıtkan duvarı uygulanarak 0.16'dan 0.07'ye düşürüldüğü gözlendi.

1. INTRODUCTION

Multi-Input Multi-Output (MIMO) antenna systems have been developed to overcome multipath wave propagation distortions in Single-Input Single-Output (SISO) antennas, which are conventional antenna structures. Although MIMO technology offers a high data transmission speed, it has some disadvantages that must be overcome. In MIMO devices, it is important to obtain high isolation between close-range antennas in terms of antenna performance. This isolation can be achieved by reducing mutual coupling effect caused by surface currents between the array antenna elements [1]. To date, many techniques have been introduced to reduce the effect of this undesirable mutual coupling effect. Negative index metamaterials [2], Electromagnetic Band Gap (EBG) structures [3], band stop filters [4], and frequency selective surfaces (FSSs) [5,6] are commonly used methods. One of the most interesting feature of FSSs is the controllability of the operating band when designed as fractal structures. In this case, researchers can achieve the desired operating bands by scaling the geometric parameters of a particular FSS unit cell to a certain level. Therefore, when an FSS is needed for a new desired transmission band, no additional experiment is required. In literature, several FSS examples are presented using periodic fractal resonant element arrays [7-9]. In this study, a new FSS unit cell is designed to reduce the mutual coupling effect caused by surface currents between 2x1 identical array patch antennas with a 3.49 GHz operating frequency. Initially, two identical microstrip patch antennas with 3.5 GHz resonance frequency are designed on the same dielectric layer using Computer Simulation Technology (CST) Microwave Studio program. Reflection and transmission characteristics of the array antenna are investigated by plotting S_{11} and S_{21} curves. Then, an FSS unit cell that acts as a band stop filter in the same frequency region is designed and placed between the two patches with a 1x5 periodic array. Afterwards, the effect of this proposed FSS isolation wall on mutual coupling reduction is validated by re-plotting the transmission and reflection curves. According to the simulation results, a 26.6 dB decrease is observed in mutual coupling without any shift in the transmission band. Finally, based on the S parameters, the ECC of the antenna array is calculated and the curve is plotted against the frequency. It is observed that ECC has been reduced from 0.16 to 0.07 at center frequency with FSS application.

2. MATERIAL AND METHODS

2.1. Microstrip Array Antenna Design

CST Microwave Studio is used for design, optimization and analysis. Figure 1 shows the shape and dimensions of the array antenna with two identical patches operating at a 3.49 GHz central frequency. FR4 is used as a substrate; with a relative dielectric permeability $\epsilon r = 4.3$, thickness $h = 1.6$ mm, loss tangent $\delta = 0.025$. The distance between the two patches is 12 mm. Antenna feedings are provided with microstrip lines on the same surface and two parallel slits are used for 50 Ω impedance matching for each patch. These slit distances and the width of the feed line calculated as described in [10]. As shown in Figure 2, S_{11} and S_{21} graphs are plotted to examine the transmission and reflection characteristics of the array antenna. As seen <-10 dB bandwidth is between 3.43 GHz and 3.54 GHz. At 3.49 GHz (center frequency), S_{11} is -29.91 dB and S_{21} is -18.64 dB. Mutual coupling reduction between two closely placed radiated patches can be confirmed by decreasing the S_{21}. Because S_{21} is the expression of the signal power received from port 2 when excited from port 1[11].

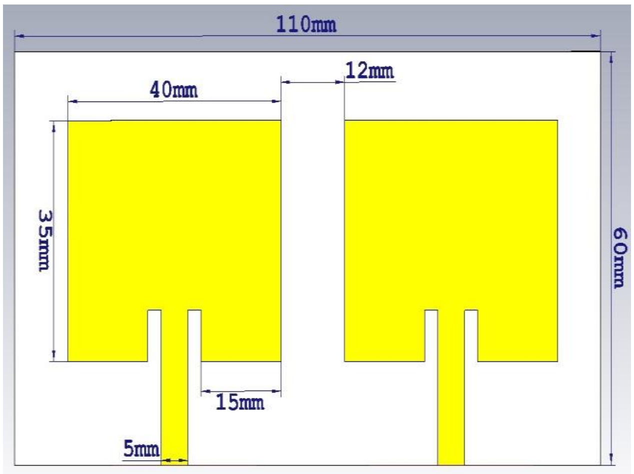

Figure 1. CST model and dimensions of the microstrip array antenna

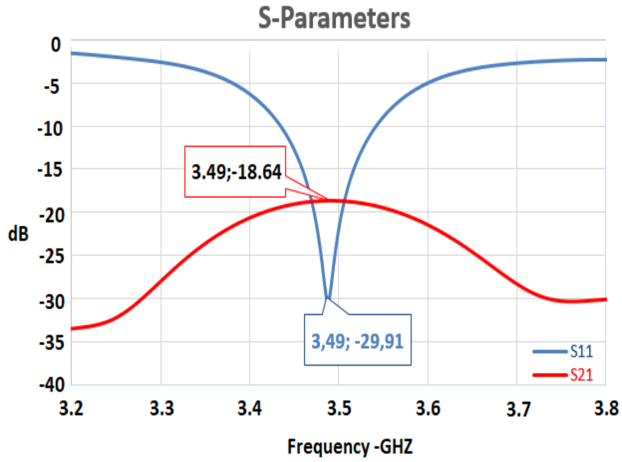

Figure 2. S_{11} and S_{21} curves of the microstrip array antenna

2.2 FSS Unit Cell Design and Implementation in the Array Patches

Figure 3 shows the dimensions and the shape of the proposed FSS unit cell, optimized to have band-stop characteristics at 3.49 GHz. The scaling is performed by using the optimization tab on CST Microwave Studio. The structure is designed symmetrically with respect to the y-axis, thus making it sensitive to the excitations from both port 1 and port 2 [12]. Afterwards these FSS unit cells are placed as a 1x5 periodic array between two patches to examine their effect on near field mutual coupling reduction. Figure 4 shows the new 2x1 array antenna structure with proposed FSS wall.

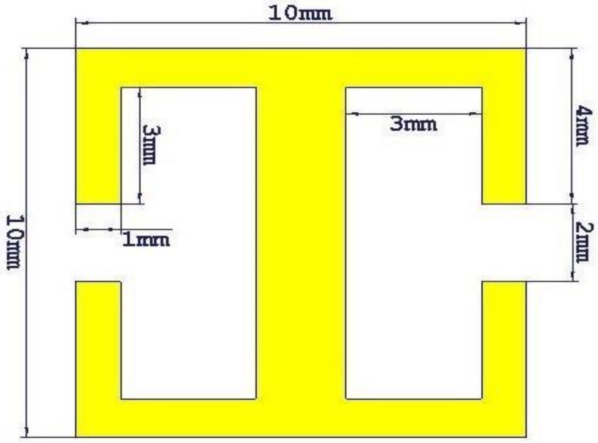

Figure 3. FSS Unit Cell shape and dimensions

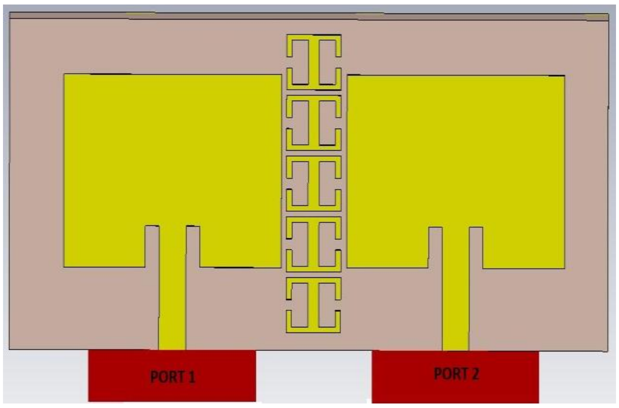

Figure 4. 2x1 microstrip array antenna structure with proposed FSS wall.

3. RESULTS AND DISCUSSION

3.1. Scattering Parameters

In order to examine the effect of the proposed FSS unit cell on the mutual coupling reduction, transmission and reflection characteristics of the array antenna with FSS wall are re-examined. MC reduction between two closely placed radiated patches can be verified by S21, which is the expression of the signal strength received from port 2, when excited from port 1. Figure 5 shows the S_{11} and S_{21} curves of the array antenna with FSS wall. S_{21} decreases by about 26.6 dB, while S_{11} shows little variation with 0.48 dB. In Table 1, S_{21} and S_{11} of the 2x1 array antenna at 3.49 GHz are compared with/without the FSS wall and the results are clearly shown.

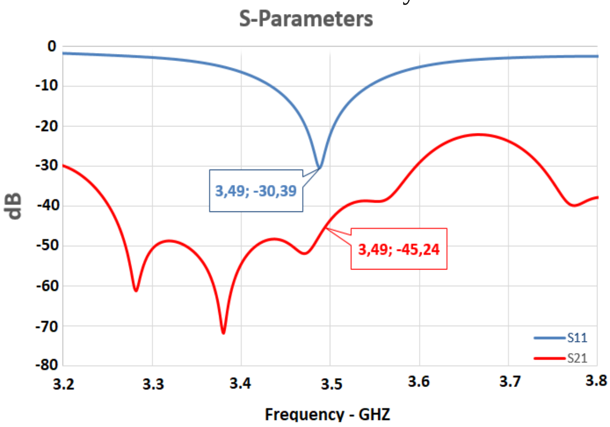

Figure 5. S_{11} and S_{21} curves of 2x1 array antenna with FSS wall

Table 1. S_{11} and S_{21} values of the array antenna at 3.49 GHz with and without FSS wall.

S parameter	Array Antenna	Array Antenna +FSS	Change
S_{11}	-29.91 dB	-30.39 dB	+0.48 dB
S_{21}	-18.64 dB	-45.24 dB	-26.6 dB

3.2. Envelope Correlation Coefficient

Envelope Correlation Coefficient (ECC) determines how independent two antennas' radiation patterns are. It ranges from 0 to 1; where 0 means no correlation so the best MIMO (diversity) gain, and 1 means identical patterns, so there is no MIMO gain. Therefore, another parameter of a good isolation between the two radiated patch antennas in MIMO systems is a low ECC. For MIMO antenna systems, ECC can be calculated as in Equation 1 [13];

$$\rho_{ij} = \frac{\left|\iint_{4\pi} \vec{F}_i\ (\theta,\emptyset) \bullet \vec{F}_j(\theta,\emptyset) d\Omega\right|^2}{\iint_{4\pi}\left|\vec{F}_i(\theta,\emptyset)\right|^2 d\Omega . \iint_{4\pi}\left|\vec{F}_j(\theta,\emptyset)\right|^2 d\Omega} \qquad (1)$$

$\vec{F}_i\,(\theta,\emptyset)$ refers to the far-field radiation pattern for the ith port, Ω is the solid angle and the operator • refers to the Hermitian product. Antenna radiation patterns need to be measured to calculate Equation 1, and, as predicted, it becomes a difficult process. To overcome this problem and to make the ECC calculation easier, in ref. [14] Equation 2 has been proposed, so the ECC can be calculated using only S-parameters:

$$\rho_{ij} = \frac{\left|\sum_{n=1}^{N} S_{ni}{}^{*} S_{nj}\right|}{\sqrt{\left(1-\sum_{n=1}^{N}|S_{ni}|^2\right)\left(1-\sum_{n=1}^{N}\left|S_{nj}\right|^2\right)}} \qquad (2)$$

It is clear that the necessity of the radiation model in Equation 1 becomes more complex than envelope correlation calculations based on Equation 2, which only requires scattering parameters. In [15], the ECC evolved to be expressed with S-parameters for two-antenna MIMO systems with Equation 3:

$$\rho = \frac{|S_{11}{}^{*}S_{12} + S_{21}{}^{*}S_{22}|}{(1-|S_{11}|^2-|S_{21}|^2)(1-|S_{22}|^2-|S_{12}|^2)} \quad (3)$$

Thanks to this representation, it is not necessary to know the radiation patterns of the antennas, and besides it is also easier to understand how parameters such as the common interactions of the antennas (S_{21}) and input impedance matching (S_{11}) effect the ECC. In this study, ECCs of the antennas with and without FSS wall are calculated using Eq.3 and then the ECC curves are plotted against frequency to verify the effect of the proposed FSS wall on isolation as shown in Figure 6.

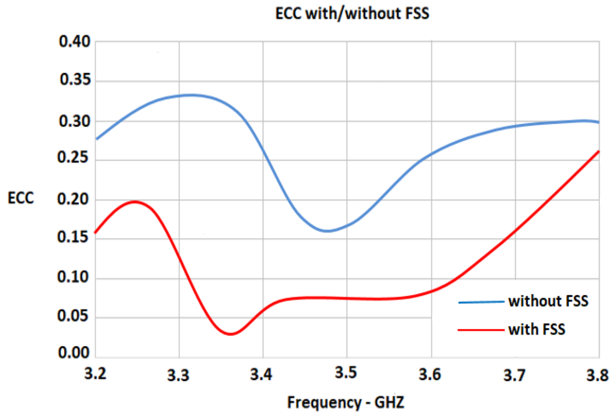

Figure 6. ECC curves of the array with/without proposed FSS wall

The ECC of the antenna without FSS wall is 0.16 at 3.49 GHz while it is 0.07 across the operating frequency band with FSS wall which supports the success of the proposed approach in mutual coupling reduction.

4. CONCLUSION

In this study, a newly designed FSS unit cell is used to reduce the near field mutual coupling effect which is the most critical problem for array antennas. Initially, a 2x1 array antenna is designed with a 3.49 GHz operating frequency and then transmission and reflection curves are plotted. Then, an FSS unit cell is designed to show band stop filter feature in the transmission band of this reference array antenna. Finally this FSS unit cells are placed between the patches with a 1x5 periodic array. According to the simulation results, mutual coupling reduced by 26.6 dB without any shift at the bandwidth. In addition, the ECC of the antenna array is computed and the curve is plotted against the frequency. It is observed that ECC has been reduced from 0.16 to 0.07 at center frequency using FSS implementation.

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