URSI AP-RASC 2019, New Delhi, India, 09 - 15 March 2019

Reducing the RCS of MIMO Antenna using Angularly Stable FSS

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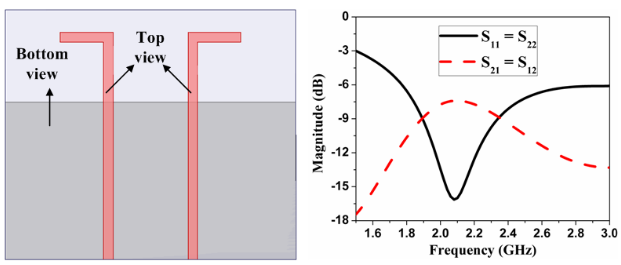
1. Abstract

A systematic design procedure for reducing the MIMO antenna RCS has been presented in this paper. The RCS reduction has been achieved at 11.3 GHz, which is out-of-band as compared to antenna working frequency of 2.18 GHz. The design flow starts with developing an isolation enhancement network for MIMO antenna which is not going to disturb the RCS reduction process. Next, an incident- and polarization-angle insensitive frequency selective surface (FSS) is designed and its array is introduced in the place of a conventional ground plane of MIMO antenna. Designed FSS is introduced in such a way that the antenna characteristics and isolation among the antenna ports are preserved by achieving the RCS reduction of an antenna at the bandpass frequency of FSS. The proposed FSS is angularly stable, hence, almost constant RCS reduction has been found for most of the incident angles. The final proposed low RCS MIMO antenna has been fabricated and measured to validate the simulation results.

2. Introduction

To meet the ever-growing demands of high data rates and excellent data transmission in wireless communication, Multiple Input Multiple Output (MIMO) technology has been introduced. The defense advanced research projects agency (DARPA) has recognized the importance of using MIMO technology in defense applications for the sake of increasing warfighter's capabilities [1]. Wireless networking and communications group (WNCG) talks over the usefulness of MIMO technology in military applications [2]. In defense and military environment, RCS of any material is a very important parameter which needs to maintain as low as possible. But, by incorporating antennas in defense applications, RCS will be increased drastically because antennas are backed by the PEC ground plane. To shrug off this problem, researchers have proposed so many antenna RCS reduction techniques. These include using of radar absorbing materials (RAM's) [3], frequency selective surface- (FSS) [4], artificial magnetic conductor- (AMC) [5] based RCS reduction techniques. For applications where size matters, an FSS- and metasurface-based RCS reduction techniques seem to be the most efficient ones. Because these techniques do not involve any extra circuitry like others. However, if one needs to apply the FSS-based RCS reduction technique for MIMO antennas, first they should take care of the isolation among the antenna ports. Because the involvement of FSS in MIMO antenna disturbs the surface current distribution which in turn affects the antenna port isolation. So, a compatible isolation enhancement network is needed for MIMO antennas before stepping into the RCS reduction process.

In literature, there are various isolation enhancement techniques for MIMO antennas. They are divided into five major categories. They are the use of defected ground structures (DGS) [6], parasitic elements [7], decoupling networks [8], metamaterials [9]. Among them, DGS, neutralization lines and parasitic elements based isolation techniques disturb the surface current distribution between antenna elements to enhance isolation between them. As the involvement of FSS in the ground plane of MIMO antenna for RCS reduction also disturbs the surface current, those three isolation techniques are not suitable in RCS reduction process. Decoupling network in MIMO antenna provides isolation between the antenna ports by not letting the surface waves to propagate from antenna element to other. Metamaterials utilize their bandgap nature to provide isolation among the antenna elements of MIMO antenna. Both these isolation techniques are compatible to use in RCS reduction process of MIMO antenna systems.

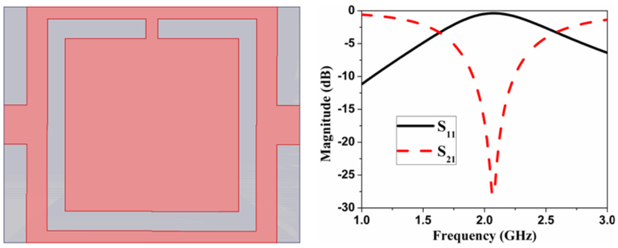


(a) (b)

Figure 1. Simple two-port antenna (a) design and it's (b) *S*-parameters (simulated)

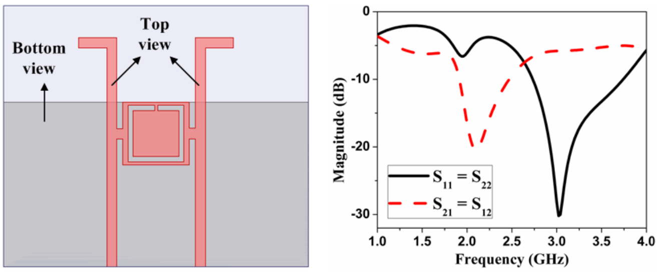
In this work, we developed a filter based decoupling network to enhance the isolation in MIMO antennas and making it suitable in the RCS reduction process. The novelty of this paper is that the proposed isolation enhancement circuit and RCS reduction circuit are independent to each other. Controlling one circuit will not affect the other. Even though in literature, an FSS-based

RCS reduction techniques are proposed, they are not incident angle insensitive. So, to provide constant RCS reduction for all the incident angles, an angularly stable FSS has been developed.



(a) (b)

Figure 2. Decoupling network (band stop filter) (a) design and its (b) *S*-parameters (simulated)

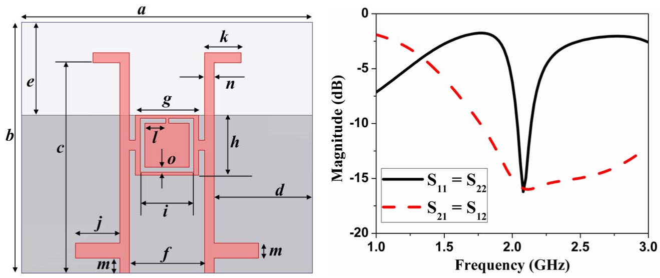


(a) (b)

Figure 3. Two-port antenna with decoupling network (a) design and its (b) *S*-parameters (simulated)

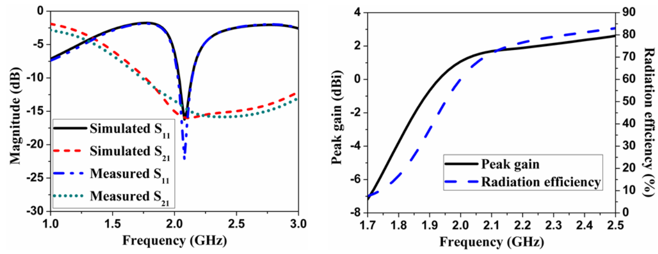
3. MIMO Antenna Design having Filter based Decoupling Network

For all the designs present in this paper, the base substrate is FR4, having 1.6 mm thickness. The design process starts with the two-element antenna, shown in Fig. 1(a). The two monopole antennas shown in Fig. 1(a) are closely spaced without any decoupling network. Hence, isolation is very poor in between them at the antenna resonant frequency of 2.08 GHz, shown in Fig. 1(b). To enhance isolation between the antenna elements, a decoupling network is designed at 2.08 GHz, shown in Fig. 2(a). From its S-parameters as shown in Fig. 2(b), band stop property can be identified at 2.08 GHz. In the next step, this band stop filter is inserted in between the antenna elements of two-port MIMO antenna, shown in Fig. 3(a). By directly inserting the decoupling network, isolation is achieved, but with the resonant frequency of antenna shifting away from 2.08 GHz, shown in Fig. 3(b). So, to achieve both resonance and isolation at the same frequency, i.e., at 2.08 GHz, a matching network in the form of stubs is used. The final proposed MIMO antenna along with matching and decoupling networks is shown in Fig. 4(a). Dimensions shown in Fig. 4(a) are $a = 58$, $b = 50$, $c = 41.9$, $d = 19.5$, $e = 18.5$, $f = 15$, $g = 12.7$, $h = 12$, $i = 10.6$, $j = 8.85$, $k = 7.25$, $l = 4.1$, $m = 3$, $n = 1.9$, $o = 1$ (all in mm). From its S-parameter plot, shown in Fig. 4(b), one can observe that more than 16 dB isolation has been achieved in the antenna working band. The designed antenna has been fabricated and its simulated S-parameters have been validated by measuring them, as shown in Fig. 5(a). Good agreement has been found between measured and simulated results. Proposed MIMO antenna exhibits around 2 dBi peak gain and more than 70 % radiation efficiency in the antenna working frequency as shown in Fig. 5(b).



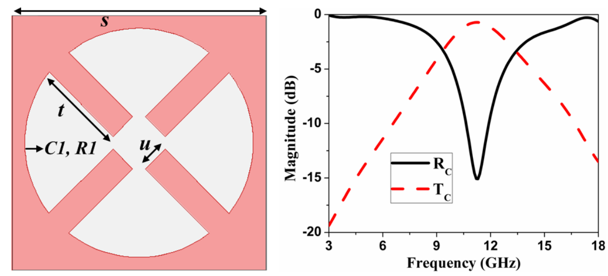
(a) (b)

Figure 4. Proposed two-port MIMO antenna (a) design and its (b) S-parameters (simulated)



(a) (b)

Figure 5. (a) Comparing simulated and measured S-parameters and (b) peak gain (measured) and simulated radiation efficiency (simulated) of antenna

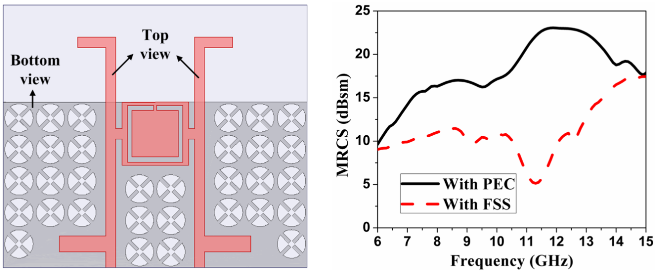


(a) (b)

Figure 6. Proposed FSS (a) unit cell and its (b) simulated reflection and transmission (s = 6 mm, t = 2.136 mm, u = 0.659 mm, $C1$ = (3 mm, 3 mm), $R1$ = 2.7 mm)

4. Reducing the RCS of MIMO Antenna

In the previous section, MIMO antenna using filter-based decoupling network has been designed. In this section, the procedure for reducing the RCS of the designed antenna has been presented. The first step in an RCS reduction process is designing an FSS at a frequency where reduction in MIMO antenna RCS is needed. The proposed FSS is shown in Fig. 6(a) and its properties are shown in Fig. 6(b). The proposed FSS allows the transmission at 11.3 GHz while reflecting the other frequencies. FSS is arranged in a ground plane of MIMO antenna in such a way that the upper conductive microstrip line part is backed by PEC [4], shown in Fig. 7(a). With this arrangement, not only antenna radiating part, but decoupling network also will not get disturbed. Hence, reducing the RCS is possible without disturbing both the antenna characteristics and isolation between the antenna elements. If different isolation enhancement network other than decoupling network is used, then it is not easy to maintain high isolation between the antennas by arranging FSS array in a ground plane.



(a) (b)

Figure 7. Final proposed low RCS MIMO antenna (a) design and (b) simulated monostatic RCS

As FSS acts like a transmitter of EM wave at 11.3 GHz, RCS reduction of more than 15 dB has been achieved at the same frequency by MIMO antenna backed by FSS as compared to MIMO antenna backed by PEC, shown in Fig. 7(b). Since FSS is having four-fold symmetry, it remains polarization angle insensitive. However, it is also important to maintain FSS reflections constant at different incident angles, so that constant RCS reduction can be found at oblique incidence. To understand this theoretically, an explanation using ray theory has been given. FSS reflection coefficient under normal incidence can be written as in (1)

$$\Gamma_{FSS} = \frac{\eta_{FSS}-\eta_0}{\eta_{FSS}+\eta_0}, \quad \eta_{FSS} = \eta_0\sqrt{\frac{\mu_{FSS}}{\varepsilon_{FSS}}} \qquad (1)$$

where μ_{FSS}, ε_{FSS} and η_{FSS} are permeability, permittivity and intrinsic impedance of FSS respectively. Γ_{FSS} is FSS reflection coefficient under normal incidence. η_0 is free space intrinsic impedance. When permittivity and permeability of FSS in (1) gets equal, then FSS intrinsic impedance gets equal to the free space intrinsic impedance. By this, reflections from FSS become very less and so, the RCS reduction is possible for MIMO antenna with FSS as compared to MIMO antenna with PEC. However, it is not that simple to analyze the RCS reduction when the antenna is under oblique incidence. Reflection coefficient at oblique incidence for TE polarization can be written as in (2)

$$\Gamma_{OTE} = \frac{\eta_{FSS}\cos\theta_i - \eta_0\cos\theta_t}{\eta_{FSS}\cos\theta_i + \eta_0\cos\theta_t} \qquad (2)$$

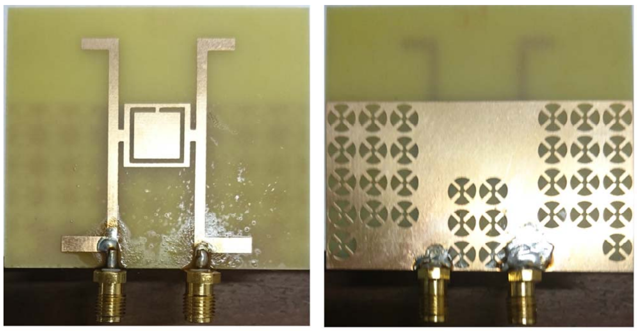
where Γ_O is oblique incidence reflection coefficient, θ_i and θ_t are incident and transmission angles. By using Snell's law, the relation between the intrinsic impedance of free space and FSS can be written as in (3)

$$\frac{\eta_0}{\eta_{FSS}} = \frac{\sin\theta_t}{\sin\theta_i} \qquad (3)$$

By solving (3) and (2), the minimum reflection condition can be obtained as shown in (4)

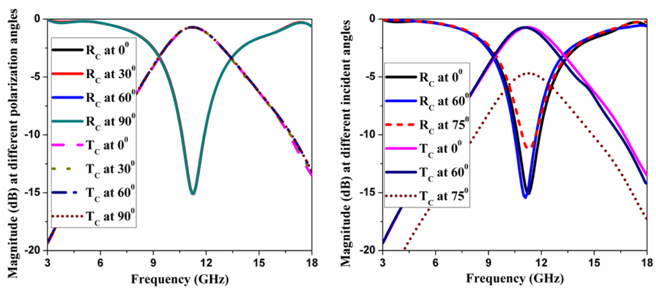
$$MR_{cri\_TE} = \mu_{FSS}\varepsilon_{FSS} - {\varepsilon_{FSS}}^2\sin^2\theta_i - {\mu_{FSS}}^2\cos^2\theta_i = 0 \quad (4)$$

Similarly, minimum reflection condition for TM polarization can be derived. It can be observed from the equations (4) that, when incident angle changes, reflections from FSS also varies drastically for both TE polarizations. Since FSS reflections are increasing with the increment in incident angle, RCS of MIMO antenna backed by FSS also increases. So, to make RCS of MIMO antenna as incidence angle insensitive for both the polarizations, an angularly stable FSS needs to be designed. The proposed FSS shown in Fig. 6(a) shows good angular stability because of four circular sectors present in its design. With FSS, reduction in RCS has been achieved from 6 to 15 GHz with a maximum value of more than 15 dB at 11.3 GHz. The top and bottom views of the final fabricated low RCS MIMO antenna (i.e., MIMO antenna with FSS) have been shown in Figs. 8(a) and 8(b) respectively. In Figs. 9(a) and 9(b), reflection and transmission properties of FSS have been shown, when it is under different polarization and incident angles. For all the polarization angles, FSS is providing the stable response, shown in Fig. 9(a). Hence, FSS will give stable response for both TM and TE polarizations. Based on this reason, the proposed FSS is analyzed at different incident angles only under TM polarization as shown in Fig. 9(b). Similar response can be found for TE polarization. Up to 60^0 incident angles, the reflection and transmission properties of FSS remain stable for TM polarization, as shown in Fig. 9(b).



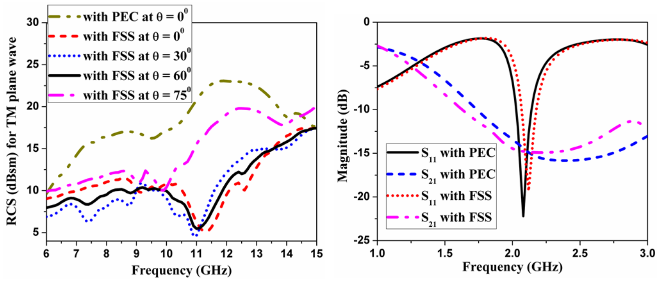
(a) (b)

Figure 8. Fabricated (a) top and (b) bottom portions of the proposed low RCS MIMO antenna



(a) (b)

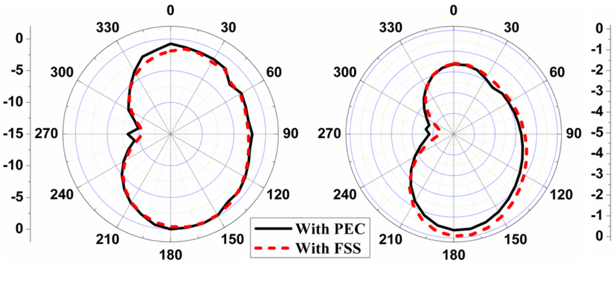
Figure 9. Simulated T_C and R_C of FSS at different (a) polarization and (b) incident angles for TM plane wave



(a) (b)

Figure 10. (a) Measured RCS at various oblique incidence under TM polarization and (b) measured S-parameters of final proposed MIMO antenna

Since RCS of a MIMO antenna completely depends on FSS transmission properties, RCS of MIMO antenna with FSS at various oblique incidence also remain unchanged with the change in polarization from TM to TE. Based on this reason, we measured the RCS of proposed antenna only for TM polarization. Measured RCS results are shown in Fig. 10(a). Same results are also valid for TE polarization except for small variations which are due to the upper conductive microstrip part. Up to 60^0 incident angles, almost constant RCS reduction is achieved by the proposed antenna as compared to the reference antenna as shown in Fig. 10(a). The simulated S-parameters have been validated by measuring them, shown in Fig. 10(b). The S-parameters of MIMO antenna remains unchanged when its ground plane is replaced by the FSS arrangement shown in Fig. 8(b). With the proposed technique, reduction in RCS is achieved by preserving the antenna characteristics. This statement is proved from Fig. 10(b). It can also be verified using Fig. 11, in which measured radiation patterns of both MIMO antenna backed by PEC and FSS are shown. In both *xz*- and *yz*-planes, radiation patterns of final low RCS MIMO antenna perfectly match with MIMO antenna backed by PEC. By just replacing the PEC with the angularly stable FSS, the proposed MIMO antenna with filter-based decoupling network has achieved a great practical usefulness when it used in defense applications. ECC and capacity loss are the important parameters to estimate MIMO performance. In this paper, both these parameters have been measured and these values are within the allowable limits. Hence, it can be said that the proposed two-port antenna is a suitable candidate for MIMO applications.



(a) (b)

Figure 11. Comparing radiation patterns of MIMO antenna when backed by PEC and FSS in (a) *xz*-plane (b) *yz*-plane (measured results)

5. Conclusion

In this paper, the technique of achieving RCS reduction for two-port MIMO antenna has been presented. Before directly moving into RCS reduction process, a filter based decoupled network has been designed to improve the isolation among the antenna ports in the MIMO system. Since the presented decoupling technique in this paper is a generalized one, it can be easily applied to multiband multi-port MIMO antennas, if one can be able to design the multi-frequency band-stop filter. By accommodating FSS in a ground plane of MIMO antenna, reduction in RCS is achieved from 6 to 15 GHz. Unlike the previously published RCS reduction techniques, this paper achieves the constant RCS reduction for up to 60^0 incident angles.

6. References

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