BCRP Journal of Innovative Research in Science and Technology (BJIRST)

Volume 02, Issue 01, December, 2021, pp. 23-31

MUTUAL COUPLING AND CROSS-POLARIZATION REDUCTION IN A PATCH ANTENNA ARRAY BASED ON MICROSTRIP RESONATOR

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Abstract.:Mutual coupling arises in an antenna array because of 1. Signal leakage via conducting currents on the metallic background or surface wave along substrates 2. Leakage received from space between antenna elements. The first one can be suppressed by changing the distribution of surface currents. But in the 2nd case the radiation-leakage caused coupling can be minimized by conventional approaches using circuit manipulation. In this research work, we propose and design a decoupling module, which is planer frequency-selective surface structure. FSS structure has the ability to suppress the surface wave propagation by providing an extra coupling path which will oppose the signal goes directly from element to element. In this design it has been observed that after implementing FSS structure between antenna elements, it causes significant suppression of mutual coupling with a reduction of more than 50dB at the designed frequency of 3.7GHz.

Keywords: ***Frequency selective surface (FSS), mutual coupling, WIMAX, Microstrip patch***

1. Introduction

Because of higher data rate, superior bandwidth, larger average throughput and minimum latency [1-3] the multiple-input and multiple-output (MIMO) system is one of the most important technologies in wireless communication systems for both academia and industry. The most significant parts of MIMO systems are to restrict the scattering properties of the radiation components from the layout design of each radiation element inside arrays. As the space left for antennas are limited in the highly integrated modern communication systems which may lead to enhancement of mutual coupling, decrease of radiation efficiency and functional deterioration of the system, especially for those tri-layer patch antennas (with an extra reflection element) with double-polarization [4]. Diminution of Mutual Coupling is one of the most interesting areas for antenna designers since early days. Several techniques [5-15] were used for the diminution of

Mutual Coupling by using some structures like Electromagnetic Band Gap (EBG) structure [7-8], Defective Ground Structure (DGS) [9], different shape resonator [10-12] etc. In [13], a slot was considered on the ground plane to reduce Mutual Coupling between radiating elements. The structure used in [13] is exaggerated the radiation pattern on the rear side. This could be overcome by mushroom type EBG structure [5-6]. On the other hand, these structures suffer from an electric loss. To eliminate this electric loss a novel uni-planer compact EBG (UC-EBG) structure was proposed in [7-8]. The main disadvantages of UC-EBG structure is its design complexity. Several other techniques are also proposed to reduce the mutual coupling between the radiating elements like using slotted complementary split ring resonator (SCSRR) [14] and slot combined complementary split ring resonator (SCCSSR) [15] structure. However to reduce mutual coupling a multilayer structure has been reported in [16].

In this design we proposed a new technique for suppressing the electromagnetic coupling between the antenna elements using FSS structure as shown in Fig.1. It can be realized by a periodic allotment of metallic elements printed upon a dielectric slab. The proposed FSS structure has been simulated through the process of numerical simulation using method of moment (MOM) based IE3D electromagnetic simulator. Furthermore, the antenna performance before and after implementation of FSS have been investigated.

2. Antenna design and its configuration

When the antenna elements are kept closed to each other, they are coupled through the substrate and air. The two coupling methods arises, one is surface wave coupling through the layer of substrate and second is the direct patch to patch coupling through the air medium. Depending upon the geometrical structure and topology any one of the coupling may dominate. By providing an extra coupling path the direct patch to patch coupling can be minimized. Fig.1 shows the FSS structure along with the patch antennas.

The intention of this proposed design was to reduce the mutual coupling in an antenna array structures. This design utilizes the frequency selective surface (FSS) planer structure to diminish the mutual coupling between the adjacent patch and require a simple fabrication process. Therefore, when FSS and antenna are used in the same layer, the mutual coupling can be reduced as well as the radiation pattern is also improved. In this design we proposed a new technique, where two equal rectangular patches fed by a coaxial probe.

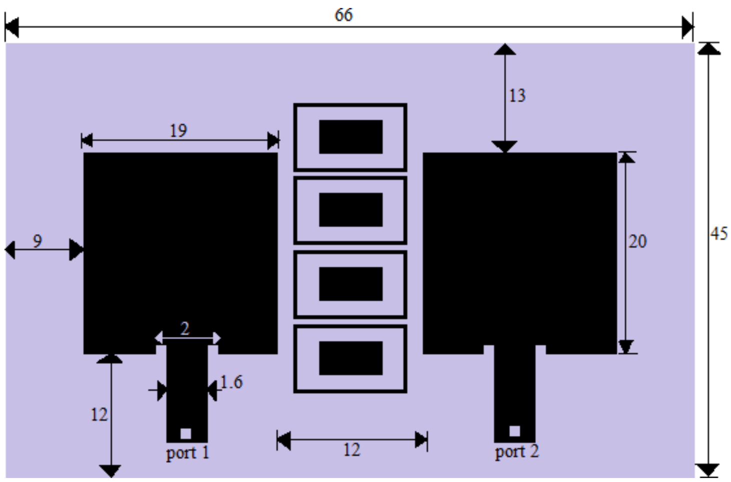


Fig.1 Schematic diagram of patch antennas with FSS (all dimensions are in mm)

3. Simulation and Measurement results

To design the proposed antenna, we have considered a $(68 \times 55)mm^2$ FR4 substrate having permittivity (ε_r) 4.4, thickness 1.6 mm and the loss tangent 0.02. Fig.3. depicts the variation of simulated S-parameters with frequency of the proposed antenna with and without resonator. Here we find a clear indication of more than 50dB mutual coupling suppression at 3.7GHz with the presence of FSS structure.

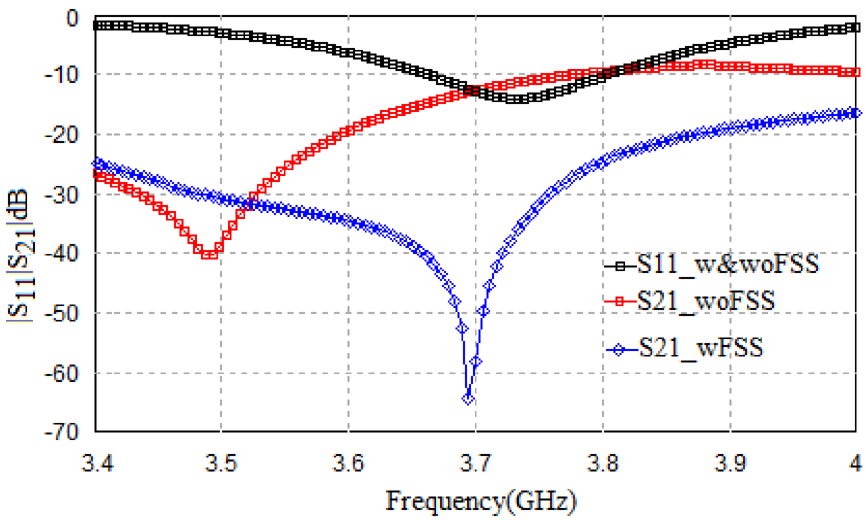


Fig.3. Simulated S-parameter variation with frequency at the presence and absence of the FSS structure.

The E-plane radiation pattern shown in Fig.4 shows that the presence of FSS structure does not degrade the pattern in broadside direction as well as it does not produce any back radiation.

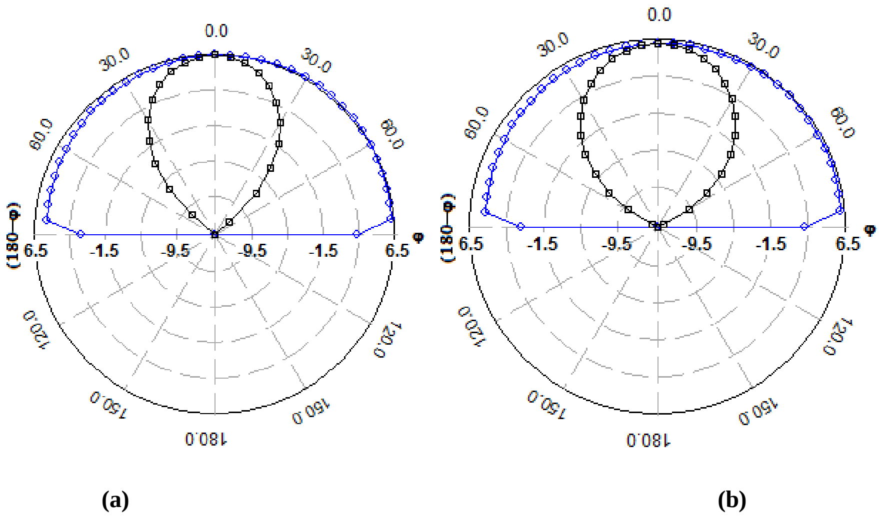
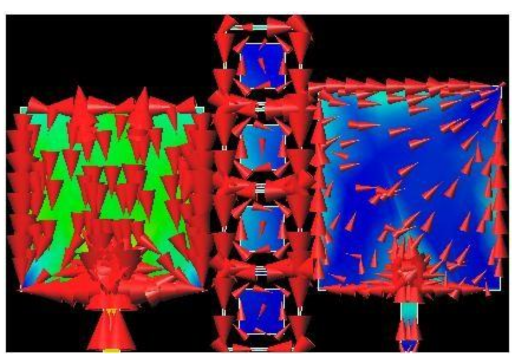


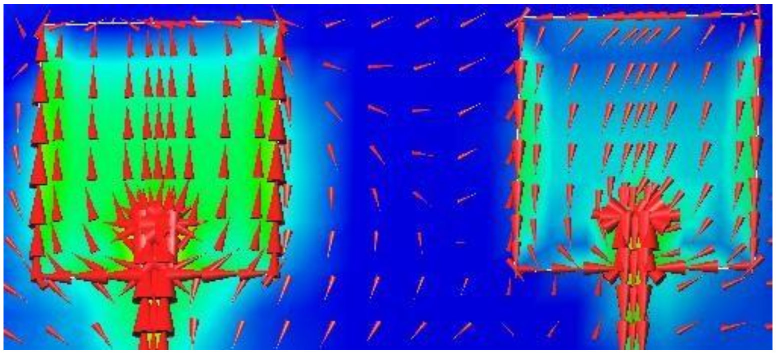
Fig.4 Elevation pattern gain (a) with (w) FSS structure (b) without (w/o) FSS structure

A suitable and optimized design methodology stimulates the meandering signal incident through the extra coupling path which prohibits the incident of direct signal coming from contiguous antenna elements. Suppression of mutual coupling can be achieved between contiguous antennas when the signals are add up destructively, due to their comparable amplitudes [26]. The proposed design reflects significant suppression of mutual coupling in the array integrated with resonator without degrading all other antenna characteristics.

It is observed from the simulated current distribution pattern shown in Fig.5 (a) that the current vectors of the excited patch is opposite to the direction of current vectors of the FSS structure at resonance frequency. Due to this, the resonator act as an electrical wall between contiguous antenna elements to prohibit the signal coming from other radiating element. On the other hand it has been observed from the given Fig.5 (b) that the presence of current vectors of non-excited patch clearly reflects the effect of mutual coupling without FSS.



(a)



(b)

Fig.5. (a) simulated current distribution in the antennas with FSS structure (b) Simulated current distribution in the antennas without FSS structure.

We have optimized the dimension of the FSS unit cell through the process of numerical simulation using MOM based IE3D simulator.

4. Antenna fabrication and measurement

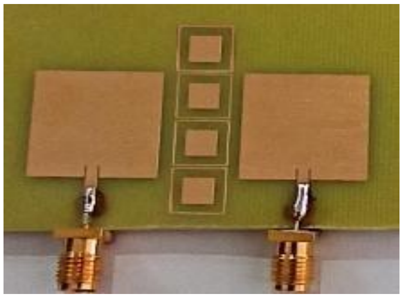


Fig.6 Front view of fabricated antenna with FSS unit

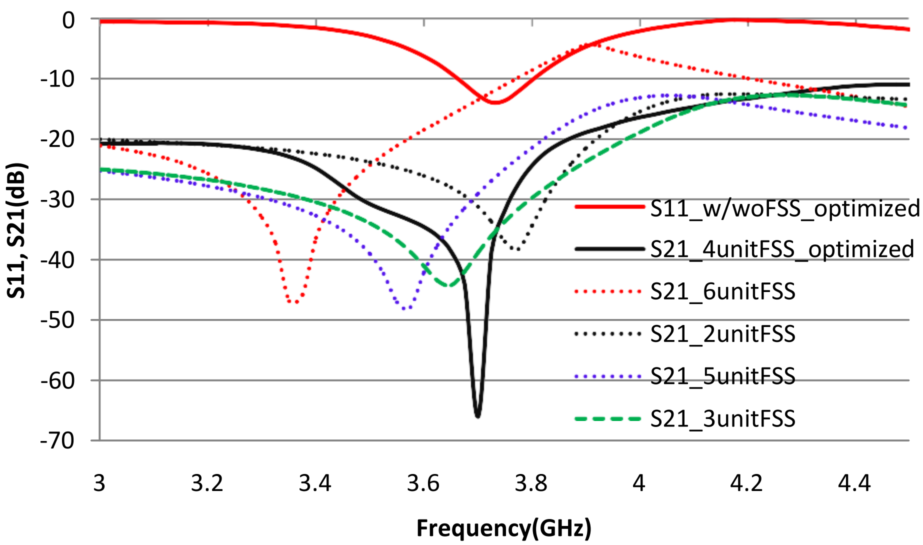


Fig.7 Parametric study of S11 & S21 parameter by varying FSS unit cell from its optimized position

From fig.7 it has been clear that after changing the position of the FSS structure from its optimized value the electromagnetic coupling between the contagious antenna elements are increasing and it will shift to the lower frequency end because of its capacitive effect.

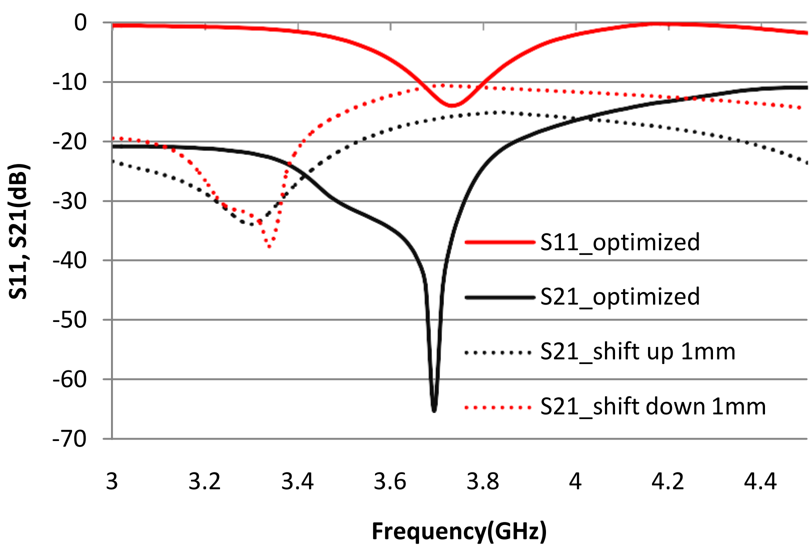


Fig.8. Parametric study by shifting up and down of the FSS structure

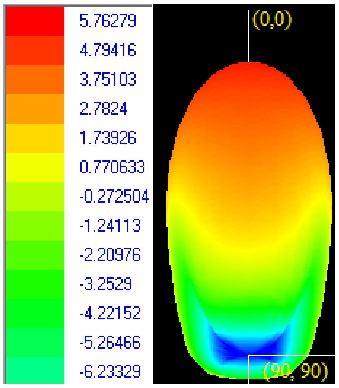


Fig.9 3D radiation pattern of the proposed antenna array with FSS.

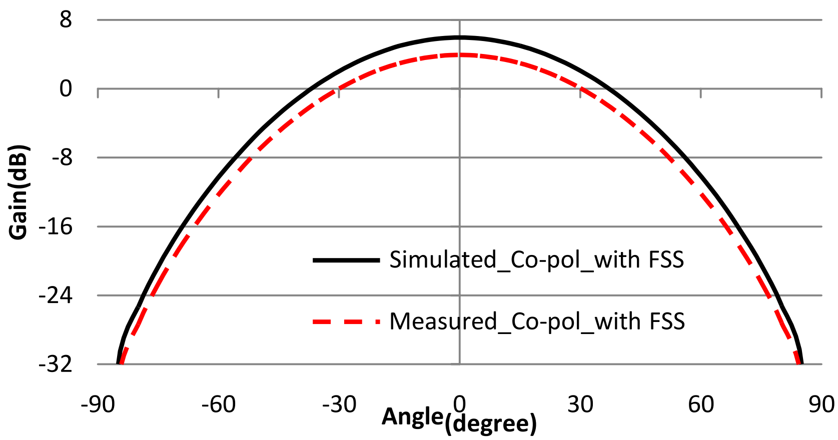


Fig.10 Measured and simulated co-polar radiation of the proposed MIMO antenna

Table 1.Comparision of the proposed work with previous reported design

Reference	Decoupling technique	Mutual coupling level without (w/o) decoupling technique FSS (w/o)	Mutual coupling level with (w) decoupling technique FSS (w)	Improvement in |S21| FSS(w) – FSS(w/o)
[19]	Neutralizatio n Line	-11dB	-33 dB	22dB
[20]	U-shape Microstrip	-22 dB	-38 dB	16dB
[21]	Double Layer EBG Structure	-10 dB	-37 dB	27 dB
[22]	Uni-planar EBG Structure	-30 dB	-55 dB	25 dB
[24]	MGS	-37 dB	-65 dB	28 dB
[25]	Mesh type resonator	-15.5 dB	-35 dB	19.5 dB
Proposed work	FSS	-12 dB	-65 dB	53 dB

5. Conclusion

Our intention of this research work was to study the prospective effect of mutual coupling arises between two adjacent antenna elements, where FSS structure was sandwiched between the elements. The proposed structure was optimized through the process of numerical simulation using MOM based IE3D simulator. As per the electrical characteristics of the proposed structure it shows a significant amount of mutual coupling suppression is achieved at resonance frequency 3.7GHz as well as it does not produce any back radiation and also it does not degrade other antenna characteristics. The radiation pattern (3dB) gain of the proposed FSS structure is

5.76dBi at resonance frequency 3.7GHz. The proposed antenna finds its application in satellite communication, mobile communication, Wi-Fi technology etc.

REFERENCES

1. Stuber, G. L. et al. Broadband MIMO-OFDM wireless communications. Proceedings of the IEEE 2004.92(2), 271–294.
2. Zhang, R. & Ho, C. K. MIMO broadcasting for simultaneous wireless information and power transfer. Wireless Communications, IEEE Transactions on 2013. 12(5), 1989–2001.
3. Liu, Y. et al. Dual-band planar mimo antenna for WLAN application. Microwave and Optical Technology Letters 2015. 57(10), 2257–2262.
4. Cheng, C., Zhang, F., Wan, Y. & Zhang, F. Miniaturized High-Isolation Dual-Frequency Orthogonally Polarized Patch Antenna Using Compact Electromagnetic Bandgap Filters. International Journal of Antennas and Propagation 2014. 230316.
5. Yu, A. and X. Zhang, A novel method to improve the performance of microstrip antenna arrays using a dumbbell EBG structure. IEEE Antennas Wireless Propagation Letters 2003. Vol. 2, No. 1,170-172.
6. Suntives, A. and R. Abhari. Miniaturization and isolation improvement of a multiple-patch antenna system using electromagnetic band gap structures," Microwave and Optical Technology Letters 2013. Vol. 55, No. 7, 1609-1612.
7. Farahani, H. S., M. Veysi, M. Kamyab, and A. Tadjalli. Mutual coupling reduction in patch antenna arrays using a UC-EBG superstate. IEEE Antennas Wireless Propagation Letters 2010. Vol. 9, 57-59.
8. Islam, M. T. and M. S. Alam. Compact EBG structure for alleviating mutual coupling between patch antenna array elements. Progress In Electromagnetics Research 2013. Vol. 137, 425-438.
9. Zhu, F. G., J. D. Xu, and Q. Xu, Reduction of mutual coupling between closely packed antenna elements using defected ground structure. Electronics Letters.2012. Vol. 45, No. 12, 601-602.
10. Farsi, S., D. Schreurs, and B. Nauwelaers. Mutual coupling reduction of planar antenna by using a simple microstrip u-section. IEEE Antennas and Wireless Propagation Letters 2012. Vol. 11, 1501-1503.
11. Alsath, M. G., M. Kanagasabai, and B. Balasubramanian, Implementation of slotted meander line resonators for isolation enhancement in microstrip patch antenna arrays. IEEE Antennas and Wireless Propagation Letters 2013. Vol. 12, 15-18.
12. Ghosh. C. K. and S. K. Parui, Reduction of mutual coupling between E-shaped microstrip antennas by using a simple microstrip I-section. Microwave and Optical Technology Letters 2013.Vol. 55, No. 11, 2544-2549.
13. OuYang, J., F. Yang, and Z. M. Wang. Reduction of mutual coupling of closely spaced microstrip MIMO antennas for WLAN application. IEEE Antennas Wireless Propagation Letters 2011.Vol. 10,310-312.

14. Suwailam, M. M. B., O. F. Siddiqui, and O. M. Ramahi. Mutual coupling reduction between microstrip patch antennas using slotted-complementary split-ring resonators. IEEE Antennas Wireless Propagation Letters 2010. Vol. 9, 876-878.
15. Shaque, M. F., Z. Qamar, L. Riaz, R. Saleem, and S. A. Khan. Coupling suppression in densely packed microstrip arrays using metamaterial structure. Microwave and Optical Technology Letters 2015. Vol. 57, No. 3, 759-763.
16. Yang, X. M., X. G. Liu, X. Y. Zhu, and T. J. Cui. Reduction of mutual coupling between closely packed patch antenna using waveguide metamaterial. IEEE Antennas and Wireless Propagation Letters 2012. Vol. 11, 389-391.
17. Balanis, C.A.: Antenna Theory. Analysis and Design, 2nd ed., John Wiley & Sons, Inc., 1997, 727–736.
18. Zheng, Q.R.; Fu, Y.Q.; Yuan, N.Ch. A novel compact spiral electromagnetic band-gap structure. IEEE Trans. Antennas Propag. 2008.56 (6), 1656–1660.
19. Zhang, S.; Pedersen, G.F. Mutual Coupling Reduction for UWB MIMO Antennas with a Wideband Neutralization Line. IEEE Antennas Wirel. Propag. Lett. 2015.15, 166–169.
20. Farsi, S., Aliakbarian, H., Schreurs, D., Nauwelaers, B., Vandenbosch, G.A.E. Mutual Coupling Reduction between Planar antennas by using a simple Microstrip U-section. IEEE Antennas Wirel. Propag. Lett. 2012, 11, 1501–1503.
21. Li, Q., Feresidis, A.P., Mavridou, M., Hall, P.S. Miniaturized double-layer EBG structures for broadband mutual coupling reduction between UWB monopoles. IEEE Trans. Antennas Propag. 2015, 63, 1168–1171.
22. Assimonis, S.D.; Yioultsis, Y.V.; Antonopoulos, C.S. Design and Optimization of Uniplanar EBG Structures for Low Profile Antenna Applications and Mutual Coupling Reduction. IEEE Trans. Antennas Propag. 2012, 60, 4944–4949.
23. Beiranvand, E., Afsahy, M., & Sharbati, V. Reduction of the mutual coupling in patch antenna arrays based on EBG by using a planar frequency-selective surface structure. International Journal of Microwave and Wireless Technologies 2017. 9(2), 349-355.
24. Sadiq, M.S., Ruan, C., Nawaz, H., Abbasi, M.A.B., Nikolaou, S. Mutual Coupling Reduction between Finite Spaced Planar Antenna Elements Using Modified Ground Structure. *Electronics* 2021, *10*, 19. https://doi.org/10.3390/electronics10010019.
25. Ghosh, C.K., pratap, M., kumar, R. et al. Mutual coupling Reduction of Microstrip MIMO Antenna Using Microstrip Resonator. Wireless Pers. Commun.2020 112, 2047-2056.
26. Nadeem, I.; Choi, D. Study on Mutual Coupling Reduction Technique for MIMO Antennas. IEEE Access 2019, 7, 563–586