Parasitic Striplines for Mutual Coupling Reduction between Dual Polarized Phased Array Antenna Elements

Mukundan A[a]*, Steffy Benny[b], Dr. Swaroop Sahoo[c]

*[a*bc]IIT Palakkad, Kerala, 678557, India*

Abstract

In this paper, a simulation-based method has been used to demonstrate reduction in mutual coupling between phased array elements of a dual-polarization phased array antenna. The antenna element used in this phased array has been designed as dual layer antenna to operate at 2.8 GHz and has been simulated in high-frequency structure simulator (HFSS). The two layers have two microstrip square patches and the top patch acts as a parasitic microstrip antenna. The mutual coupling reduction is achieved by two microstrip lines printed on a substrate over the antenna elements. For the design analysis of mutual coupling and its reduction two of the antenna elements are placed adjacent to each other. The simulated results indicate that the mutual coupling is suppressed by 4-6 dB without affecting the cross-polarization levels.

Keywords: Mutual Coupling reduction; Dual-polarized antenna;

Nomenclature

EBG	Electromagnetic Band Gap
DGS	Defected Ground Structures
λ	Wavelength of operating frequency
ϕ	Azimuth angle
θ	Elevation angle

1. Introduction

Dual polarization phased array radars operating in S-band are widely used in retrieving weather information accurately. However, these radars are constrained in the scan angle range. This limit is because of the scan blindness at wide scan angles from broadside direction [1]. The scan blindness is affected by mutual coupling between antenna which is characterized by scattering parameter between various ports. This in turn is related to active reflection coefficient of mth element, (Γ_m) that is a function of scan angle and mutual coupling between elements as in equation (1)

$$\Gamma_m(\theta_0) = \sum_{n=1}^{N} S_{mn} e^{-j(n-m)u} \tag{1}$$

Where S_{mn} is the scattering parameter between m and n ports (represents coupling), $u = kd\ sin\ sin$ □ $,\ d$ is the inter-element spacing. This results in degradation of performance including impedance mismatch, limited scan range, scan angle misalignment, etc. Mutual coupling is because of surface waves, near field and space wave coupling between elements of an antenna array. Depending on various factors, one of these causes of coupling will dominate the others. These factors include but are not limited to, ground plane size, thickness and type of substrate material and the types of modes excited by the patch antenna and the grounded dielectric slab [2]. If a very thick dielectric slab with high permittivity has the antenna printed on it, the main cause of coupling becomes surface waves when substrate thickness, h/λ_0 satisfies equation (2)

$$\frac{h}{\lambda_0} \geq \frac{3}{2\pi\sqrt{\varepsilon_r}}, \tag{2}$$

where h is the thickness of substrate, λ_0 is the wavelength and ε_r is the relative permittivity [3]. These waves propagate through the grounded dielectric slab and once reaching the edge of the slab they diffract. When an antenna is placed in the near field of another antenna near field coupling becomes the major cause. This effect is particularly dominant when a substrate of very low permittivity is used to print the antenna on. The radiation characteristics of the antenna can be severely degraded under such

* Mukundan A
E-mail address: 121701013@smail.iitpkd.ac.in

conditions. In very thin grounded substrates although the surface wave phenomenon is only weakly excited, space wave coupling can dominate especially when antennas are in close proximity. Space wave coupling has a dominant electric field component that is normal to the grounded slab.

Many solutions have been proposed to reduce mutual coupling between antenna elements that are fed by coaxial cables at microwave frequencies. These include electromagnetic band gap structures (EBG) which acts as band gap for the surface wave propagation [4] [5]. EBG structures are difficult to implement and make the antennas very expensive and are not cost effective. In addition, defected ground structures (DGS) that are special structures in the ground plane which help in reducing mutual coupling between elements [6] [7]. On the other hand, DGS structures tend to impact cross-polarization level (which is unacceptable) in dual-polarization antennas that are aperture fed antennas. Different metamaterial structures are being proposed to obtain reduction in mutual coupling. These metamaterial structures are complicated to implement and are difficult to characterize. As a result of the above-mentioned limitations aperture fed dual polarization antenna mutual coupling reduction has not been studied in detail. This paper explores the reduction in mutual coupling between antenna elements that are impacted by surface wave coupling by using parasitic microstrips. These microstrips are placed on top of the substrate above the antenna element and the position of the parasitic element with respect to the antenna element is optimized to reduce mutual coupling, achieve the required reflection coefficient and not impact the cross-polarization between dual-polarizations. Section 2 describes the proposed antenna structure in detail with the details of the proposed structure to reduce mutual coupling. Section 3 has the simulation results comparing mutual coupling in antenna arrays with and without micro-striplines. Conclusions are discussed in Section 4.

2. Proposed Antenna Structure

2.1 Design of a single element

A dual polarized antenna is designed and simulated that operates in the frequency range of 2.66 to 3.1 GHz and uses aperture coupled feeding technique. This antenna has 3 substrates of which two have radiating square patches (top patch length = 28.5 mm and bottom patch length = 25.5 mm) with their substrates (dielectric constant = 2.55) stacked one over another as shown in Figure 1(a). There is a ground plane beneath the middle substrate with two dumbbell shaped slots. The slots correspond to horizontal and vertical polarizations are arranged perpendicular to each other to ensure required isolation between them. Below this, there is the feed substrate (dielectric constant=4.1) with microstrip feedlines at the bottom as in Figure 1(b).

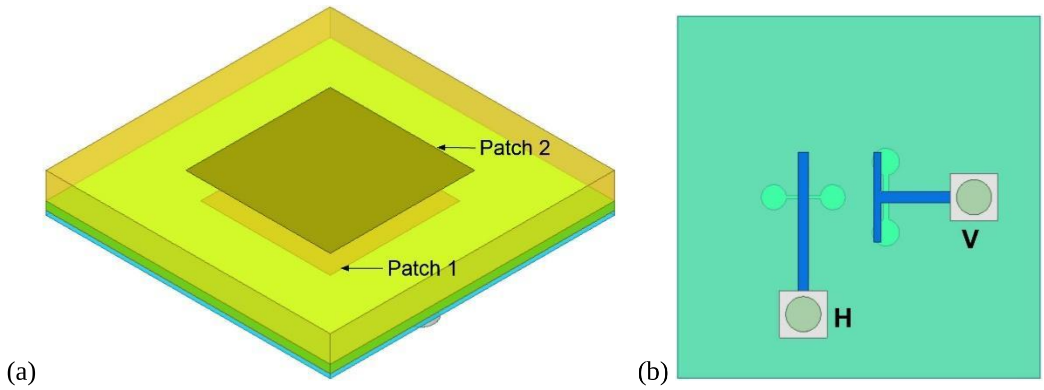

Fig. 1. Antenna Structure for (a) Isometric view and (b) Bottom view.

The two layer antenna element achieves bandwidth of 400 MHz. The dumbbell shaped aperture coupled feeding technique is used here to obtain lower cross-polarization level [8] [9] [10]. The S-parameter plot of the single element is shown in Figure 2 showing that the reflection coefficients, S(HH) and S(VV), for both the ports are below -14 dB in the required frequency range. Isolation between two ports, S(HV), is below -48 dB in the desired frequency range. Radiation patterns for the two polarizations of the single antenna element is shown in Figure 3. Cross-polarization level at broad side direction is 53 dB and 50 dB below main lobe for H and V polarizations, respectively.

	H-Pol	V-Pol
Gain	4.67 dB	4.68 dB
Cross-Pol level at θ=0º	53.80 dB	50.44 dB
Bandwidth	2.66 to 3.08 GHz	

Table. 1. Specifications of the antenna element.

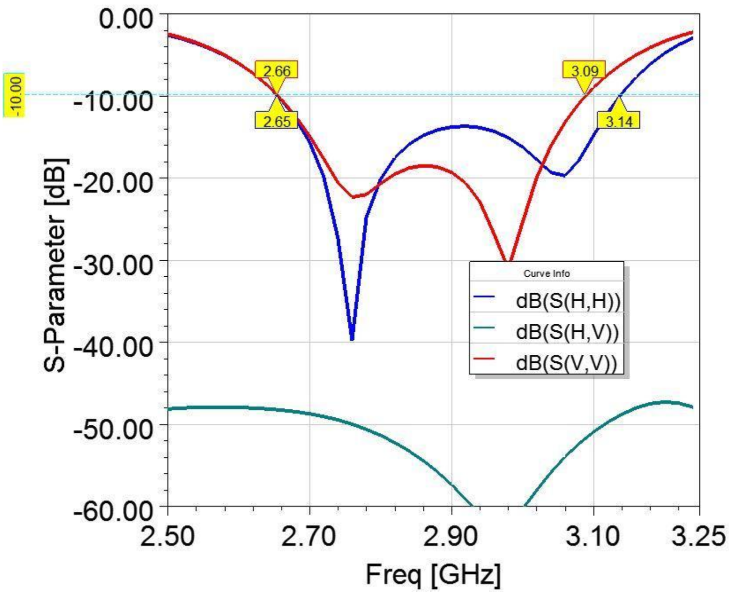

Fig. 2. S-Parameter plot for single antenna

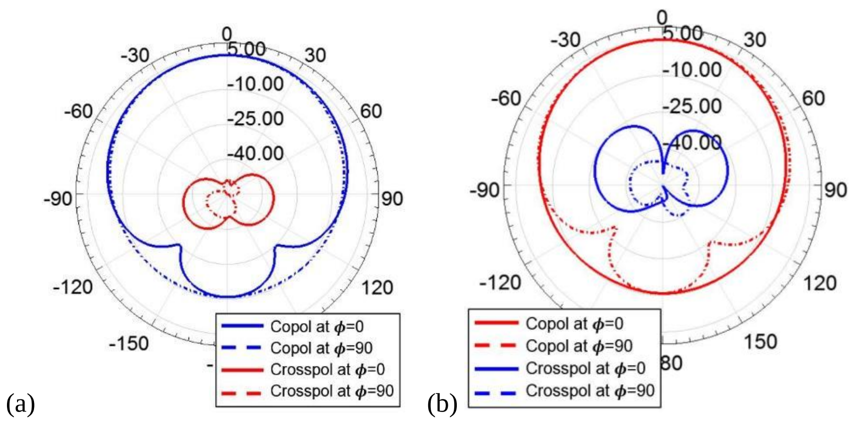

Fig. 3. Radiation Pattern for (a) H-Polarization and (b) V-Polarization.

A 1X2 array of the elements is designed with an inter-element spacing of 0.5λ and is shown in Figure 4 (a). The simulations results in Figure 4 (b) show that mutual coupling between the elements is -19 to -24 dB for H and V polarizations. This mutual coupling is due to surface wave as is already proven by the theory and equations in Section 1.

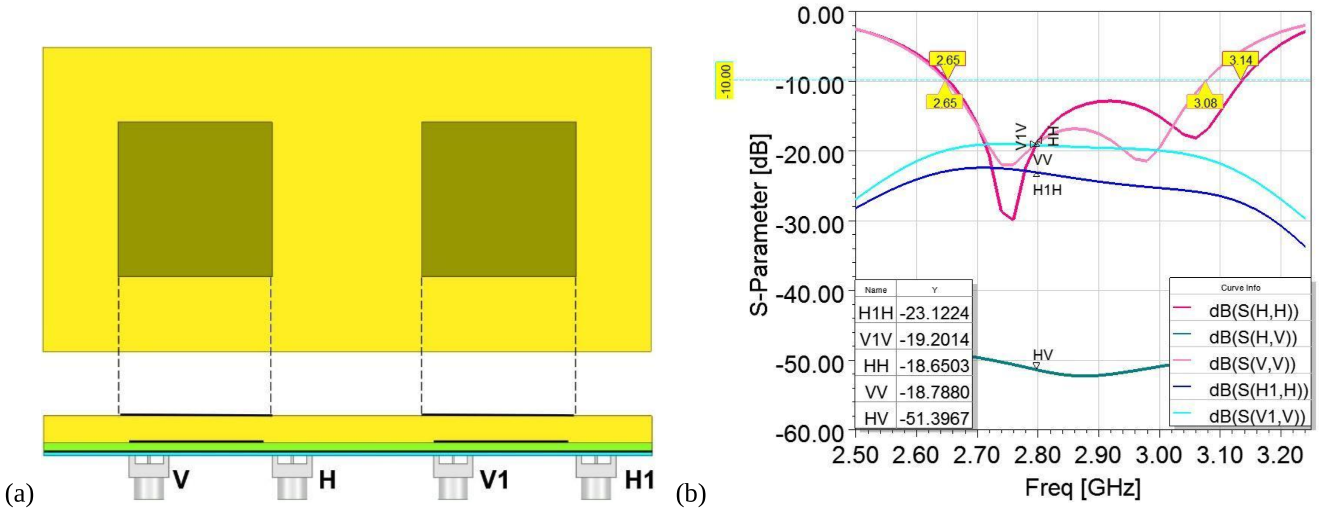

Fig. 4. (a) Top and side view of normal 2X1 array and (b) its S-Parameter plot.

2.2 Mutual Coupling Reduction

The mutual coupling reduction technique uses another substrate of dielectric constant 2.55 at the top of the antenna array. Above the substrate two microstrip lines are etched on the top of this substrate. Top and side view of the antenna structure is shown in Figure 5a. This extra microstrip and substrate combination acts as a band stop filter and reduces the level of mutual coupling between elements due to surface wave in the frequency range of 2.6 to 3.1 GHz. The optimized values for thickness of the top layer are 0.5mm and length and width of the microstrip lines are 52.8 mm and 3.8mm respectively. Distance between the parasitic lines is taken to be 7.48mm.

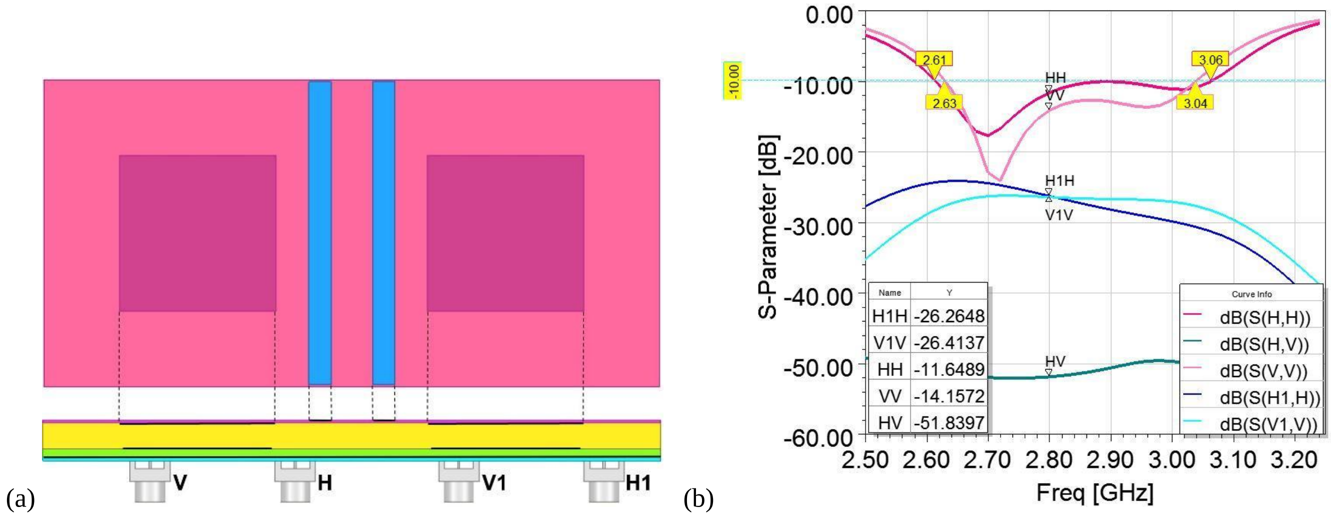

Fig. 5. (a) Top and side view of 2X1 array with striplines and (b) its S-Parameter plot.

3. Simulation Results

The simulated S-parameter values for 2X1 antenna array with strip lines above are shown in Figure 5 (b). Total bandwidth remained 430 MHz before and after adding micro-striplines. The mutual coupling is suppressed by adding two microstrips to -26.2 dB and -26.4 dB for H and V ports. Thus, mutual coupling suppression of 3-7 dB is achieved. The two micro-striplines above dielectric does the function of a band reject filter in the working frequency region [11]. Thus, it stops the surface waves and other near field radiations causing mutual coupling. Mutual coupling reduction is also analyzed using surface current at various layers of the antenna element. Figure 6a and 6b show that the current on the adjacent patch when first H-port is excited for antenna array with and without striplines, respectively. The surface current induced in the adjacent element (without suppression) is approximately 1-2 A/m which reduces to almost 0 A/m (with suppression). Similarly, Figure 6c and 6d show the mutual coupling reduction when V-port of single element is excited. The surface current induced is 3-5 A/m (without coupling suppression) which is again reduced to approximately 1 A/m (after coupling reduction). It is clear that current in the unexcited element due to mutual coupling has been reduced with the use of parasitic striplines for both polarizations.

Table 2. Comparison of the properties of 2X1 array without and with parasitic striplines.

	Without parasitic striplines		**With parasitic striplines**	
	H-Pol	*V-Pol*	*H-Pol*	*V-Pol*
Gain	7.81 dB	7.67 dB	7.74 dB	7.33 dB
Cross-Pol level at θ=0º	54.28 dB	49.62 dB	60.10 dB	48.56 dB
Bandwidth	2.65 – 3.08 GHz		2.63 – 3.05 GHz	

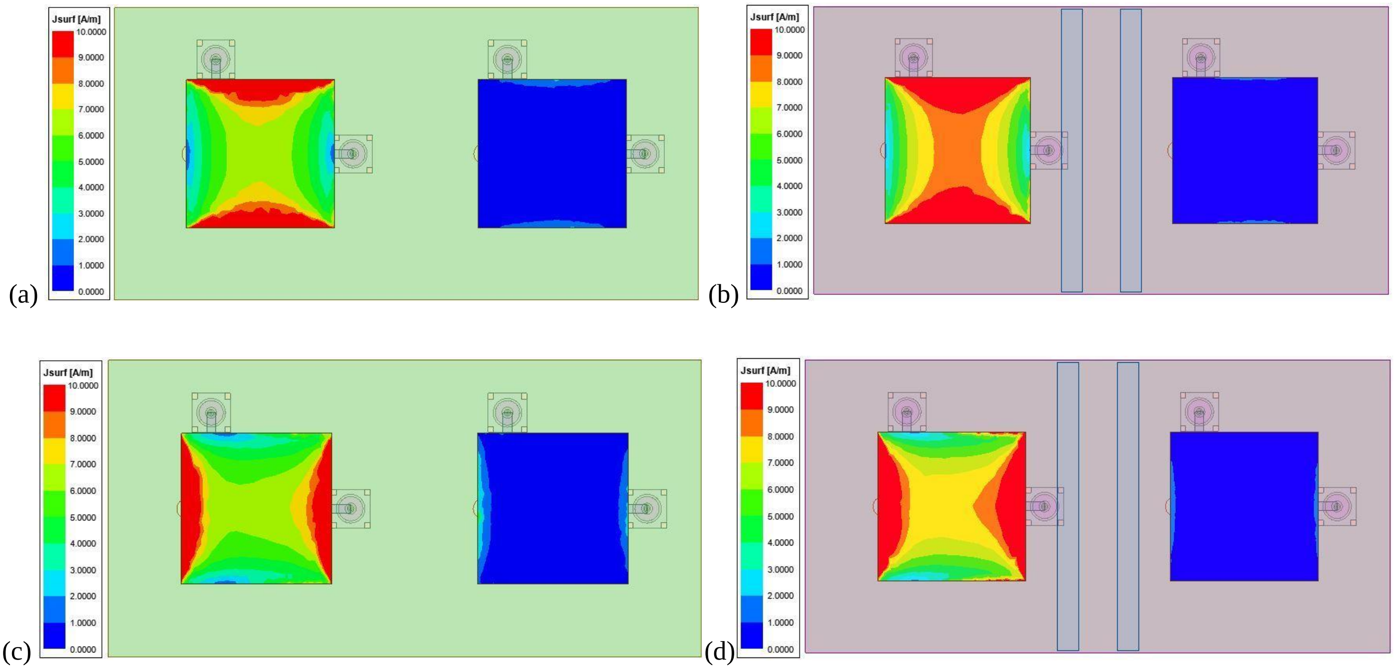

Fig. 6. Surface current plots (a) Normal 1X2 array and (b) 1X2 array with micro-striplines when H-port is excited (c) Normal 1X2 array and (d) 1X2 array with micro-striplines when V-port is excited.

Radiation patterns for the array with and without the striplines are shown in Figure 7. It can be seen that the cross-polarization level remains same for both H and V polarization before and after placing the parasitic micro-striplines. Cross-polarization levels are 54 dB and 49 dB below the main lobe for H and V polarizations, respectively. Similarly, the beamwidth and pattern does not change with the introduction of the striplines.

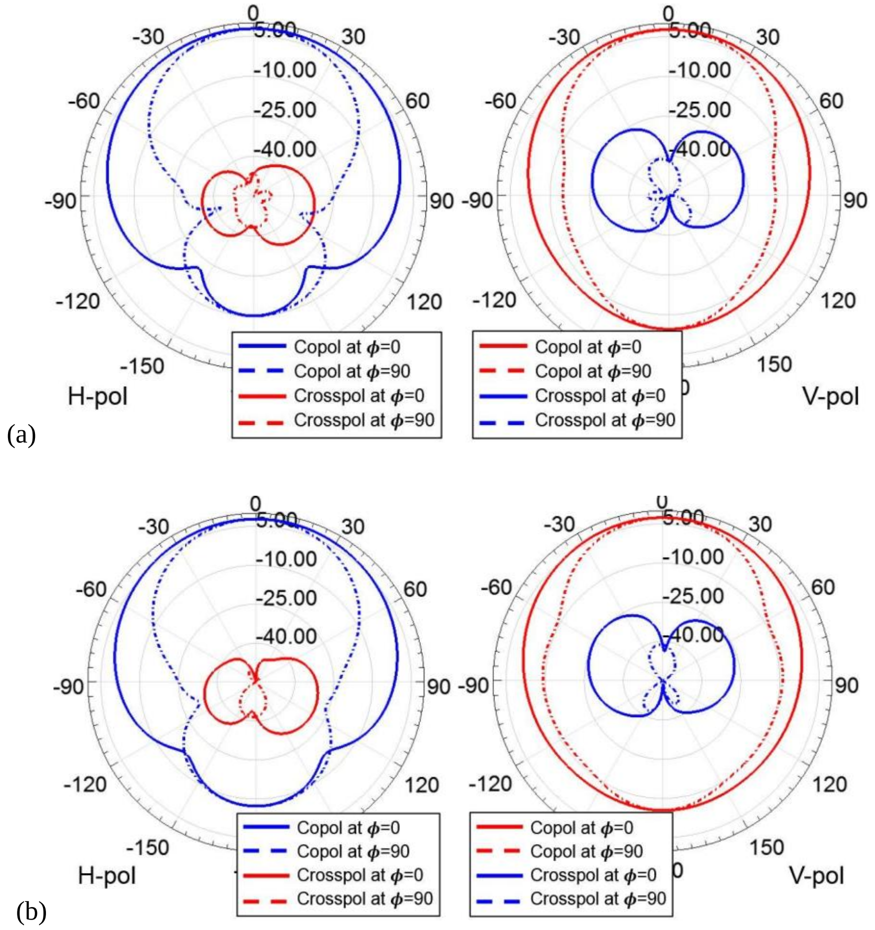

Fig. 7. Radiation patterns for 1X2 array (a) without striplines and (b) with striplines.

4. Conclusion

The paper proposes a technique to reduce mutual coupling for a dual polarization antenna array at an operating frequency of 2.6 to 3.04 GHz. The two micro-striplines inserted between the adjacent elements above a dielectric suppresses coupling in the operating frequency range. The designed structure resulted in increased isolation between adjacent elements from -19 dB to -26 dB for V-port and -23 dB to -26 dB for H-port. Other parameters like bandwidth and cross-polarization level remained same.

References

1. Pozar, D.M., 2003. A relation between the active input impedance and the active element pattern of a phased array. IEEE Transactions on Antennas and Propagation, 51(9), pp.2486-2489.
2. Ahmed, M.I., Sebak, A., Abdallah, E.A. and Elhennawy, H., 2012, June. Mutual coupling reduction using defected ground structure (DGS) for array applications. In 2012 15 International Symposium on Antenna Technology and Applied Electromagnetics (pp. 1-5). IEEE.
3. Li, Q., Ding, C., Yang, R., Tan, M., Wu, G., Lei, X., Jiang, X., Fang, S., Huang, M., Gong, Y. and Wei, Y., 2018. Mutual coupling reduction between patch antennas using meander line. International Journal of Antennas and Propagation, 2018.
4. Farahani, H.S., Veysi, M., Kamyab, M., Tadjalli, A., 2010. Mutual coupling reduction in patch antenna arrays using a UC-EBG superstrate. IEEE antennas and wireless propagation letters, 9, pp.57-59.
5. Assimonis, S.D., Yioultsis, T.V. and Antonopoulos, C.S., 2012. Design and optimization of uniplanar EBG structures for low profile antenna applications and mutual coupling reduction. IEEE Transactions on Antennas and Propagation, 60(10), pp.4944-4949.
6. Acharjee, J., Mandal, K., Mandal, S.K. and Sarkar, P.P., 2016, January. Mutual coupling reduction between microstrip patch antennas by using a string of H-shaped DGS. In 2016 International Conference on Microelectronics, Computing and Communications (MicroCom) (pp. 1-3). IEEE.
7. Nadeem, I. and Choi, D.Y., 2018. Study on mutual coupling reduction technique for MIMO antennas. IEEE Access, 7, pp.563-586.

8. Balanis, C.A., 2015. Antenna theory: analysis and design. John wiley & sons.
9. Saeidi‐Manesh, H., Karimkashi, S., Zhang, G. and Doviak, R.J., 2017. High‐isolation low cross‐polarization phased‐array antenna for MPAR application. Radio Science, 52(12), pp.1544-1557.
10. Benny, S. and Sahoo, S., 2020, December. Enhancement in Dual Polarization Phased Array Antenna Performance an Calibration Techniques for Weather Radar Applications. In 2020 International Symposium on Antennas & Propagation (APSYM) (pp. 25-28). IEEE.
11. Sun, X.B. and Cao, M.Y., 2017. Mutual coupling reduction in an antenna array by using two parasitic microstrips. AEU International Journal of Electronics and Communications, 74, pp.1-4.

Acknowledgement

This work is done at IIT Palakkad and we extend our heartfelt thanks to all the staff and faculty for all the resources provided and the excellent and encouraging working conditions.