International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

Design of Steered Array Lens Antenna System with Isolation Enhancement

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Abstract— A new compact economical patch array antenna with beam steering ability and mutual coupling reduction between the patches is presented in this article. By incorporating modified hexagonal spilt ring resonator metamaterial structure in one of the 1 X 2 patch array enables the property of beam steering as well as mutual coupling reduction. Similarly, by incorporating modified hexagonal split ring metamaterial structure in both the patch of 1x2 patch array antenna mutual coupling reduction of around 21dB at 2.4GHz without beam steering capability is observed. The spacing of 0.25λo between the patches of an antenna array, around 24 dB lower mutual coupling at the operating frequency is obtained. Both left and right modified patch produces a beam scanning of -200 to +200 respectively. The fabricated prototype antenna results are validated with simulation results using experimental measurements.

Index terms: beam steering, metamaterial resonator, mutual coupling, patch array antenna

I. INTRODUCTION

Electronically antenna beam can be steered towards desired target by beam steering antennas that are able to produce narrow directional beams by forming low side lobes. Beam steering capability of antenna by using metamaterial structure such as transmission line with negative refractive index or left/right-handed transmission line have been reported in [1] – [4]. Many beam steering techniques such as using RF Switches to feed power for the transmitting part of antenna array with reflectors [5], by incorporating the orthogonal DGS slots at the ground plane of 1X2 microstrip patch array antenna [6], enhances gain and directivity, saves power, lowers interference of the microstrip antenna. In [7] high gain and beam steering has been achieved by sixteen elements of antennas placed at the edge of the square shape structure and every side has four Quasi-Yagi elements for vehicle applications in 5G. Beam steering with low cost planar array energized by parabolic reflector has been discussed in [8]. Beam steering required for 5G applications using a millimeter-wave sized dipole array of linear phased has been discussed in [9]. In all these works, concentration towards mutual coupling reduction between patches in an array structure is ignored. A distance of half wavelength between patches in antenna array is maintained usually to overcome the effect of mutual coupling issue. But antenna miniaturization becomes difficult with this. Also, mutual coupling effect hinders the radiation performance of an antenna array system [10]- [11]. Hence the performance of an antenna with array structure can be enhanced by treating mutual coupling effect between the patches in an array structure. Hence in this paper an attempt is made to design a beam steering antenna with reduced mutual coupling effect in an 1X2 microstrip patch antenna. For 0.25λo spacing between the patches of an antenna around 24 dB mutual coupling reduction at the operating frequency is achieved. Both left and right patch are modified by creating modified hexagonal spilt ring resonator slot structure to get beam scanning of -200 to +200 respectively. Further both patches of 1x2 microstrip patch antenna array are modified by creating modified hexagonal split ring resonator slot structure to get an around 21 dB of mutual coupling reduction.

Manuscript published on 30 September 2019
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II. ANTENNA DESIGN AND ANALYSIS

Case 1: 1x2 Microstrip Patch Antenna array with Single Patch modified.

The proposed geometry of microstrip patch antenna array with left patch modified and right patch modified is shown in Fig. 1(a) and Fig. 1(b). The microstrip patch array antenna is designed on low cost FR4 dielectric substrate with a permittivity of 4.4 and thickness h = 1.57 mm. Both antenna array patches are rectangular with co-axial feeding. The dimension of the patch is 36.5 X 27.5 X 0.1 mm and operating at 2.5 GHz frequency. The spacing of 31.25 mm (0.25λo) between the patches of an antenna array is considered.

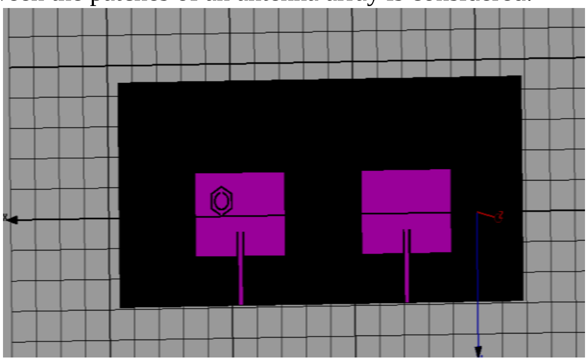

Fig. 1 (a) 3D model of 1 X 2 microstrip patch antenna array with left patch modified

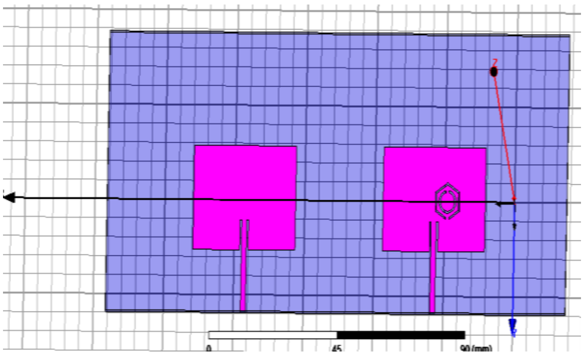

Fig. 1(b) 3D model of microstrip patch antenna array with right patch modified

The proposed modified hexagonal spilt ring resonator (MHSRR) unit cell consists of one inner circular ring encircled by an outer hexagonal ring with symmetrical splits as shown in Fig. 2. This MHSRR structure slot is done for left patch to get right shift and right patch to get left shift beam steering. To get high isolation as well as beam steering, the optimized dimensions are Lm = Wm = 11mm, g = 1 mm, h0 = 5 mm, C0 = 3 mm, t = 1 mm.

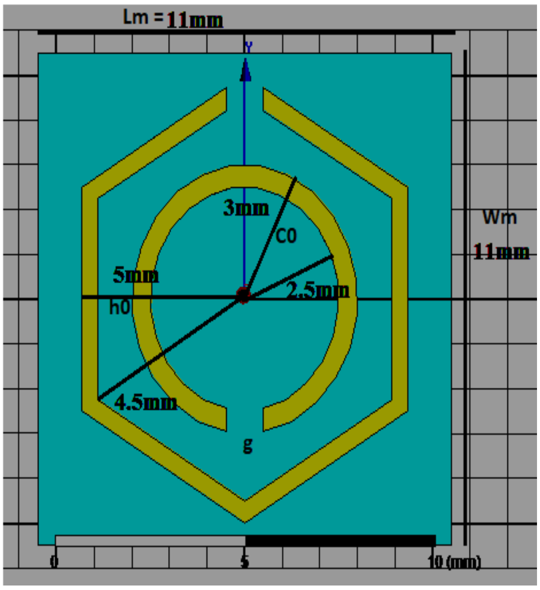

Fig.2 3D model of modified hexagonal spilt ring resonator

Numerical simulation in ANSYS HFSS is used to evaluate the performance of the designed patch modified antenna array using MHSRR structure slot. The antenna measurements are carried out using PNA Network Analyzer from Agilent Technologies (E8363C, 10MHz-40GHz). The experimental setup for the measurement of operating frequency is shown in Fig. 3(a). The simulated and measured isolation S12 and return loss S11 plot of a patch array antenna without patch modified are illustrated in Fig. 3(b). Similarly, the simulated and measured isolation S12 and return loss S11 plot of a left patch modified are illustrated in Fig. 3(c).

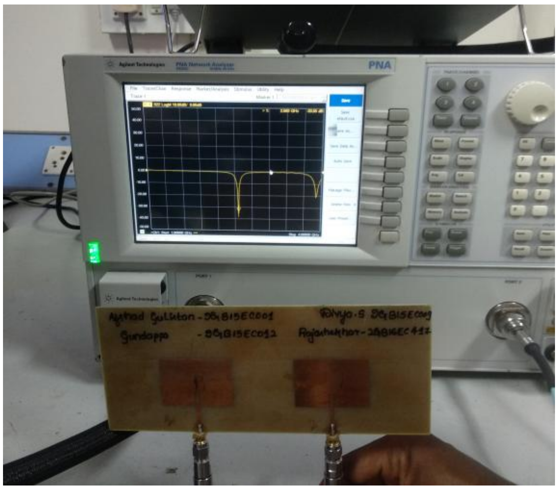

Fig. Experimental setup for the measurement of return loss and mutual coupling for 1x2 patch array.

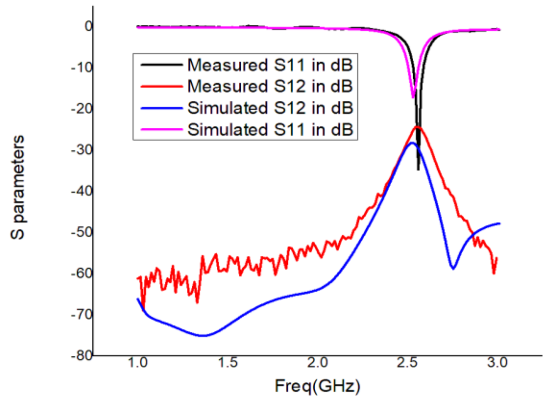

Fig. 3(b) S11 and S12 parameters of microstrip patch antenna array without patch modified

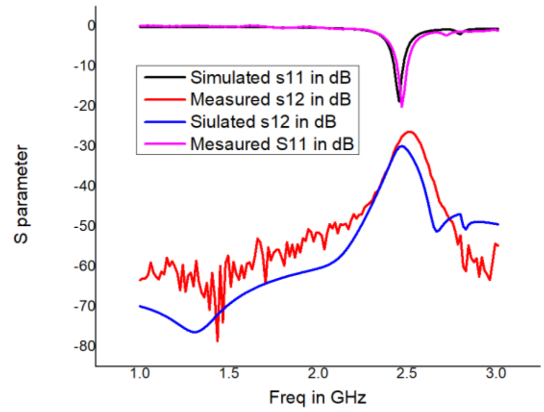

Fig. 3 (c) S11 and S12 parameters of microstrip patch antenna array with left patch modified

The working range of the suggested antenna array slightly changes to greater frequency. The coupling between the elements of antenna array at the operating frequency 2.5 GHz is dropped from -28.208 dB to -32.670 dB in simulated antenna and -25.370 to -28.480 in fabricated antenna. Respectively simulated and measured values of 4.5 dB and 3.2 dB isolation is obtained between the elements. The setup for the measurement of antenna radiation pattern and gain is shown in Fig. 4(a).

Retrieval Number C6866098319/2019©BEIESP
DOI: 10.35940/ijrte.C6866.098319
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

The simulated and measured radiation plots for modified patch antenna with and without MHSRR metamaterial slot are shown in Fig. 4(b), Fig. 4(c), Fig. 4(d). We can notice that antenna array radiation models with and without MHSRR metamaterial slot systems have a small distinction in resonance frequency, that is, the constructed MHSRR metamaterial slot system can decrease mutual coupling without influencing radiation features.

Fig. 4(a) Setup for the measurement of radiation pattern and gain

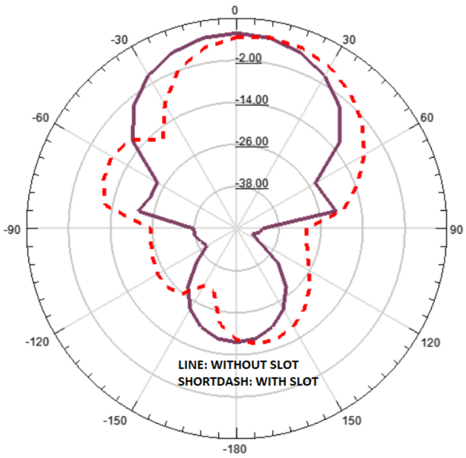

Fig.4 (b) Simulated radiation pattern of microstrip patch antenna array at 2.5 GHz without and with left patch modified

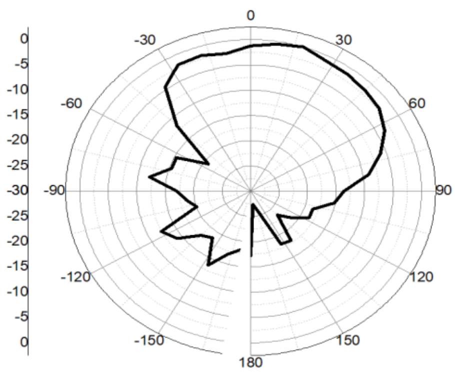

Fig.4 (c) Measured radiation pattern of microstrip patch antenna array at 2.5 GHz with left patch modified

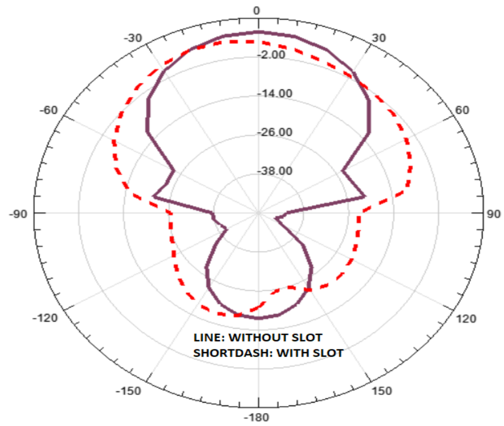

Fig.4 (d) Simulated radiation pattern of microstrip patch antenna array at 2.5 GHz without and with right patch modified

Case 2: 1x2 Microstrip Patch Antenna array with both Patch modified.

The proposed geometry of microstrip patch antenna array with both patches modified is shown in Fig. 5(a).

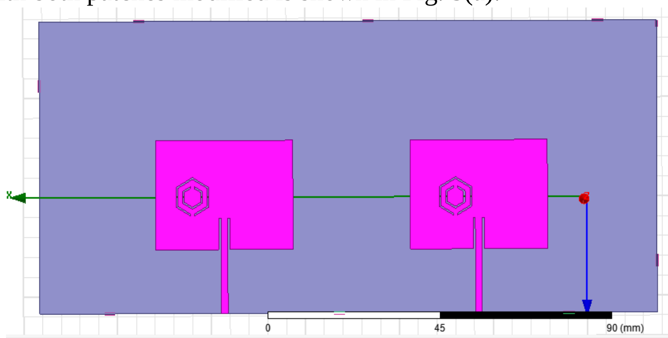

Fig. 5 (a) 3D model of microstrip patch antenna array with right patch modified

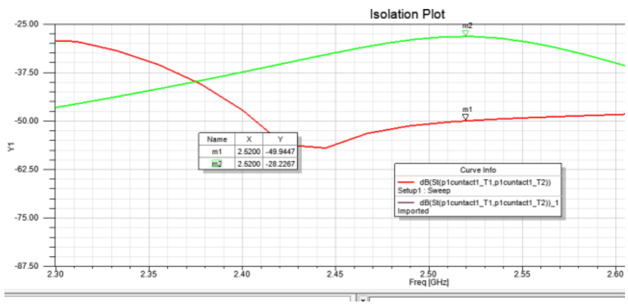

Fig. 5 (b) S12 parameters of microstrip patch antenna array with both patches modified

Fig. 5(b) shows that around 21dB of mutual coupling reduction due to incorporation of modified hexagonal slots on both patches.

The analysis of the simulated and measured results are listed in Table. I

TABLE I. ANALYSIS OF SIMULATED AND MEASURED RESULTS

SL. No	Antenna Type	S11 in dB	S12 in dB	Gain in dB	Beam tilt angle in degrees
1	1x2 patch array without patch modified (simulated)	-17.1943	-28.208	5.996	0
2	1x2 patch array without patch modified (measured)	-34.6326	-25.370	4.217	0
3	1x2 patch array with left patch modified (simulated)	-18.7349	-32.670	5.526	+ 20
4	1x2 patch array with left patch modified (measured)	-20.2314	-28.480	4.435	+20
5	1x2 patch array with right patch modified (simulated)	-15.1506	-52.054	3.86117	- 20
6	1x2 patch array with both patches modified (simulated)	-16.07	-49.17	3.1	0

CONCLUSION

In this task, a novel approach to design beam steering arrays which also reduces mutual coupling effect between microstrip patch array antenna is proposed. By modifying one of the patches in an array system it is possible to achieve both beam steering and mutual coupling reduction in an array system. A +200 and -200 of beam tilt with mutual coupling reduction of around 24 dB can be obtained respectively by modifying left and right patch in 1x2 patch array antenna. Similarly, by incorporating the same modified hexagonal structure on both the patches mutual coupling reduction of 21dB is achieved without beam steering. The proposed antenna is designed using low cost FR4 epoxy material that can be employed in 2.5GHz wireless applications.

ACKNOWLEDGMENT

The writers wish to thank the department of Electronics & Communication Engineering, NITK Suratkal, India for supporting to conduct antenna measurements using PNA Network Analyzer from Agilent Technologies (E8363C, 10MHz-40GHz).

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