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CROSS-POLARIZATION REDUCTION OF E-SHAPED MICROSTRIP ARRAY USING SPIRAL-RING RESONATOR

Chandan K. Ghosh[1, *] and Susanta K. Parui[2]

[1]Department of Electronics & Communication Engineering, Dr. B. C. Roy Engineering College, Durgapur, India

[2]Department of Electronics & Communication Engineering, BESU, Howrah, India

Abstract—Design of (2 × 2) E-shaped microstrip patch antenna array integrated with spiral ring resonators (SRRs) is introduced for the reduction of cross-polar (XP) radiation. The addition of SRRs in the array structure does not affect other characteristics of the array antenna. The array is designed to function in the 5.25 GHz which corresponds to IEEE 802.11a wireless LAN application. The characteristic analysis such as return loss (RL), bandwidth (BW), and radiation patterns of the antenna with and without SRRs have been investigated. The array offers a bandwidth of 405 MHz (For RL < -10 dB) covering frequencies ranges from 5.175 to 5.580 GHz and gain of 12.60 dBi has been achieved. The array has been studied both numerically and experimentally by introducing SRRs. The XP radiation has been reduced by 10.5 dB with two sets of SSRs of similar geometry placed in between the patch elements of the array structure. Prototype antennas with and without SRRs have been fabricated tested and a remarkable agreement is obtained between the measured and the simulated results.

1. INTRODUCTION

Over the last two decades the wireless communication system has experienced a significant growth from first generation (1G) analogue voice signal to forthcoming fourth generation (4G) mobile technology. The motto of 4G communication system is to provide Wi-Fi (Wireless-Fidelity) communication network, high quality audio and video

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* Corresponding author: Chandan Kunar Ghosh (mcet_ckg@yahoo.com).

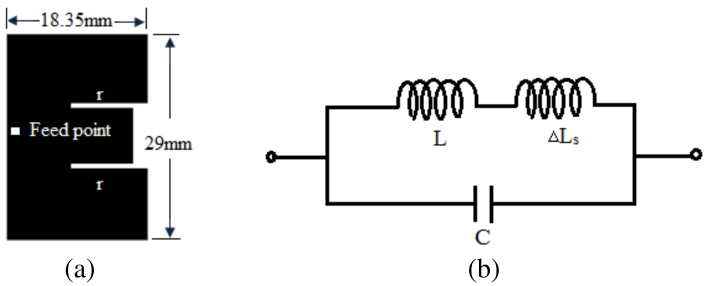
services. Today's technology requires high data rate and longer range to provide quality services to the users. For current mobile communication, the diversity scheme has already been implemented to mitigate the fading effects of multipath scenario [1, 2]. In this study, initially an antenna array with E-shaped antenna element has been design to improve the gain, BW and directivity. This is achieved as a result of the use of multiple antenna elements, exited through single feed point via the transmission line networks. Secondly, the SRR has been introduced in the array system in order to reduce the XP radiation. The reduction of XP radiation of the array system has been achieved as a result of the combination of array antenna and SRRs.

Recently many new technologies have been proposed for reducing XP level of multi-element antenna systems. For example, some degree of orthogonally polarized fields is always associated with the radiating energy, resulting in XP radiation [3–5]. Experimental studies indicate considerable XP level in H-plane particularly, which typically appears around 15–20 dB below the peak gain. Considerable XP radiation appears to be a major limitation to frequency reuse in a microstrip radiator using polarization diversity. Different techniques to reduce the XP radiation from a microstrip patch array (MSA) have been explored earlier, showing their individual merits in open literature [6–12]. Some investigations in [6] and [7] used dual feed with 180° differential phases between them. Modified feed geometry [8, 9] and shaped ground plane [10, 11] have also been explored to achieve reduced XP level, but all of them involve high cost and complexity in fabrication. In an investigation [13] by the same group, they noticed that orthogonal resonance may cause considerably high XP radiation from a circular patch and also successfully employed defected ground structure (DGS) for the first time to suppress the same. The use of DGS offers back radiation which is not desirable for antenna design as the DGS is supposed to perturb and suppress the occurrence of any orthogonal resonance.

In our investigation a new SRR geometry has been explored and XP radiation has been reduced significantly without any back radiation. The SRRs have been placed in the same plane between the antenna elements of the array and its effects have been studied. To validate the concept initially a single element E-shaped antenna has been designed and then an array of four elements have been built and tested with and without SRRs. The primary design based on the input impedance of the antenna is done by the simulation studies using commercially available IE3D electromagnetic simulator which works on the principle of method of moment (MoM). The experimental results with a set of prototypes using Agilent make N5230A, network analyzer and a fully automated anechoic chamber are presented. As to the best of our knowledge, the resonator of any shape has not yet been addressed in the same plane of the patch array for reduced XP studies. Compared to other available E-shaped MSA designs, for reducing XP level, the proposed design avoid back radiation using SRR in the same plane of the array elements.

2. DESIGN OF E-SHAPED SINGLE ELEMENT ANTENNA

E-shaped microstrip patch antenna has been realized at centre frequency of 5.25 GHz and accordingly the characteristic parameters of length (L) = 18.35 mm, width (W) = 29.0 mm are obtained from standard formulae [14]. The E-shaped patch element and its equivalent circuit are given in the Figures 1(a) & 1(b). RT/Duroid substrate of thickness of 1.580 mm, loss tangent of 0.001 and dielectric constant of 2.2 has been considered for this design. To meet the actual design requirements, i.e., operating frequency, band width and the radiation efficiency, some approximations have been taken. The single element has been taken as a base element of the four element array.



(a) (b)

Figure 1. (a) Geometry of the single element, (b) equivalent circuit [L = inductance, C = capacitance and ΔL_s = additional series inductance due to slot (r)].

The length of the slot 'r' of the patch element (Figure 1) has been numerically studied and it is found that the width and length are the important parameters for achieving wide BW of the patch element. The best performance achieved in our design for slot length $r = 10.0$ mm and width = 1.0 mm. As we go on increasing or decreasing the width and length of the slot 'r' it has been found that BW of the patch element decreases. The RL of the optimized E-shaped antenna element and its radiation pattern (E-plane & H-plane) are shown in the Figures 2(a) & 2(b).

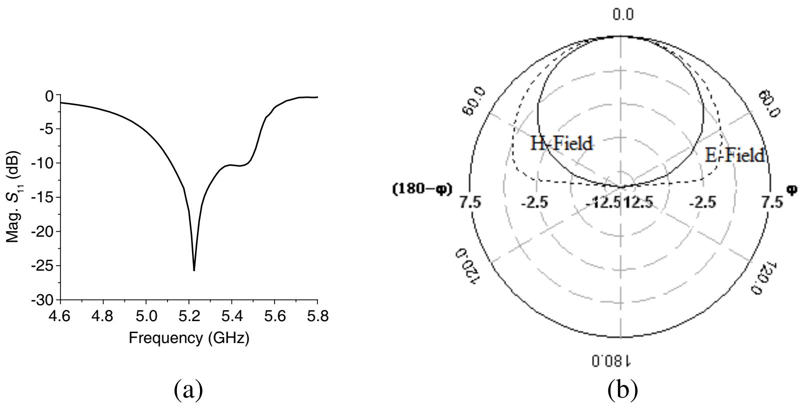


Figure 2. (a) Return loss, (b) radiation pattern of the single element.

3. MICROSTRIP LINE FEED ANTENNA ARRAY DESIGN

Using E-shaped single element, an array of four identical elements has been designed. High-low transmission line concept has been used in case of feed network in order to match the impedance of the array. The array is fed by a probe of diameter 1.2 mm in the middle of the thicker transmission line of width 2.0 mm by using SMA connector of impedance 50 Ohms. The distance (edge to edge) between the antenna elements has been optimized for better performances and fixed at 29.5 cm ($0.517\,\lambda$). The E-shaped MSA has been chosen in this design due to its simple construction, high BW, conformability to mounting in system and expected characteristics satisfying the short distance communication requirements. The mutual coupling including radiation pattern coupling between closely arrayed antenna elements cause the decrease of an array performance. From the antenna system point of view, some structures like defected ground structure (DGS), different meta-structures or resonators integrated with microstrip antenna, perturb or suppress some of the properties/RF functions of the antenna system. In this work, we have used SRR in the array structure in such a way that suppresses the XP radiation by around 10.5 dB. The schematic diagram of the four element array integrated with SRRs is illustrated in the Figure 3. The detail dimensions of the feed network

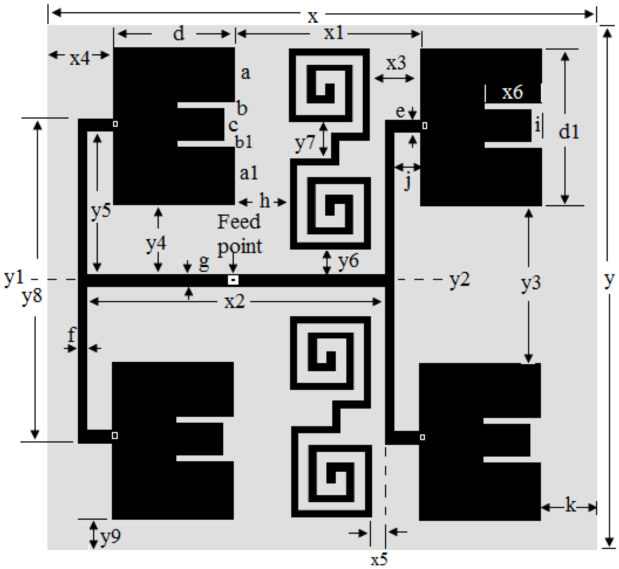


Figure 3. Schematic diagram of the array with two SRRs [Lower part is the mirror image of the upper one in the $y1y2$ plane].

Table 1. Dimension of the patch array.

Parameters	mm	Parameter	mm	Parameters	mm
x	75.5	$y3$	12.0	$b = b1 = f$	1.0
$x1$	29.5	$y4$	5	c	8.0
$x2$	42.5	$y5$	18.0	d	18.0
$x3 = h$	8.0	$y6$	1.0	$d1$	28.0
$x4 = k$	5.0	$y7$	5.0	e	2.0
$x5$	4.0	$y8$	42.0	g	2.0
$x6$	10	$y9$	3.0	i	2.0
y	74.0	$a = a1$	9.5	j	3.0

and array geometry are shown in the Table 1. The feed network by means of transmission line, is connected at the middle of the patch edges for better impedance matching.

SRRs are placed in the same plane of the radiating elements to avoid back radiation. SSR geometry and its detail dimension are shown in the Figure 4.

The line width and gap between them of SRR is maintained

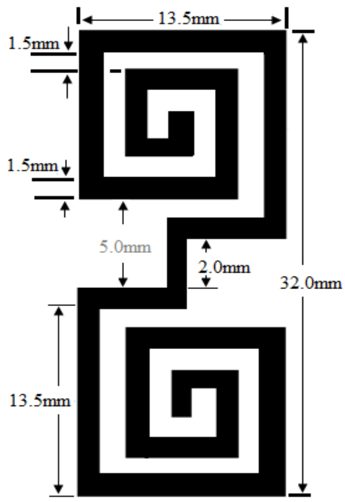


Figure 4. Schematic diagram of SRR geometry.

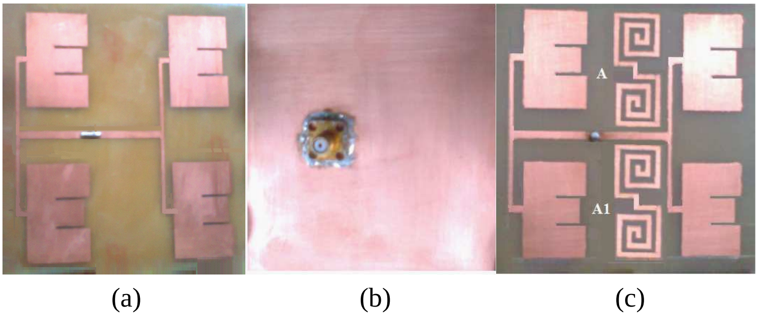


Figure 5. Prototype antenna, (a) front view of four element array, (b) back view, (c) with SRR ($A + A_1$).

1.5 mm. In this paper, the impact of SRRs on the array performance has been investigated step by step. The SRR structure created on the substrate between array elements effectively disturbs the current distribution in the elements and thus, introduces high line inductance and capacitance of the microstrip line [15, 16]. Thus, it obtains wide stop band and compact size, which meet emerging application challenges in wireless communication. Recent advances of this technology have proven that, this type structure is simple solutions to the problems of surface and leaky waves [17] and also to improve antenna performances in terms of radiation, isolation between the patch elements. The prototype antennas are shown in the Figures 5(a)–5(c).

4. RESULTS AND DISCUSSION

Simulated RL of the array with SRRs is shown in the Figure 6. From Figure 6 it is observed that there is no significant change in the RL curve when array is integrated with SRRs. From RL curve the band width of the patch antenna of 400 MHz is observed. The simulated antenna gain of 7.5 dBi for single element and of 12.60 dBi for array has been achieved. Simulated impedance characteristics of the array are shown in the Figure 7. This graph proves the impedance matching of the array.

Measured S-parameters with and without SRRs are shown in the

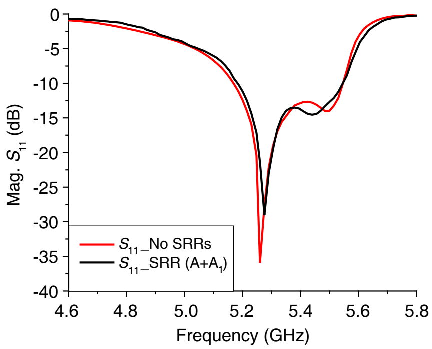


Figure 6. Simulated RL of the array with and without SRR.

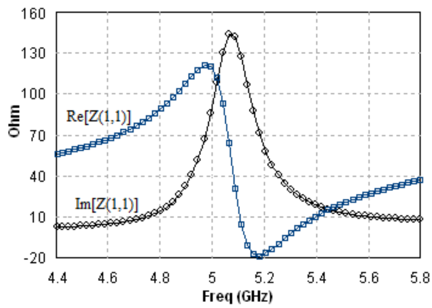


Figure 7. Impedance graph of the array without four SRRs.

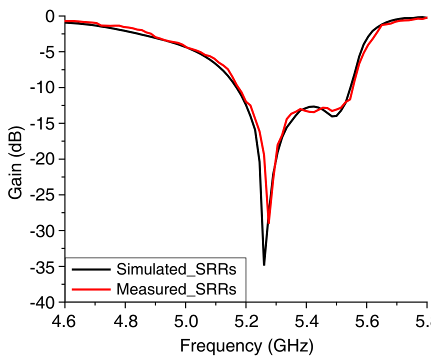


Figure 8. Measured S-parameters with and without SRRs of the proposed array.

Figure 8. One can observe a small difference between measured and simulated data of RL curve at resonant frequency. This might be due to other unknown parasitic effects which are not considered in the simulation. Since the soldering is not done with a machine on the PCB, positional errors might give rise to the discrepancy.

The surface current distribution of the array with and without SRRs is illustrated in the Figure 9. From this figure, it is observed that surface current in the patch element of the array is uniformly distributed. This current distribution proves that the proposed antenna is a good radiator.

From 3D simulated radiation pattern view shown in the Figure 9(c) it is seen that the gain of the array is 12.97 dBi. The Simulated co-polar and XP radiation pattern at 5.25 GHz with and

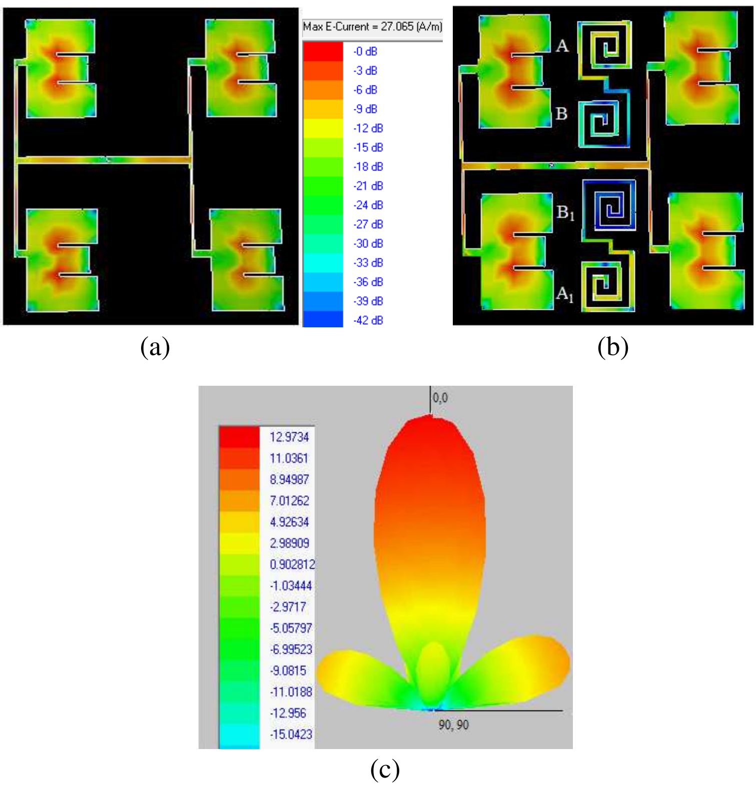


Figure 9. Simulated surface current distribution of the proposed antenna, (a) without SRR, (b) with SRR ($A + A_1$), (c) 3D view of radiation pattern with SRR.

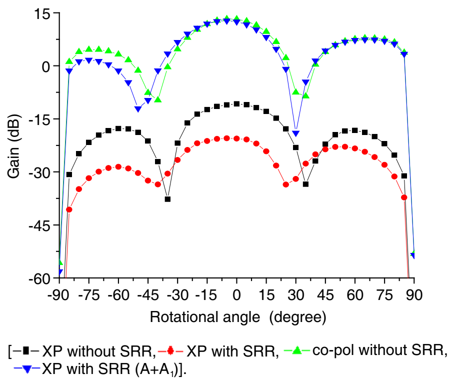


Figure 10. Simulated co-polar and XP radiation pattern at 5.25 GHz.

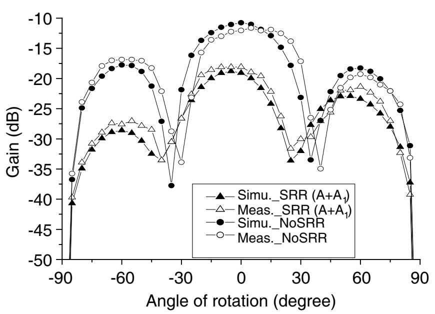


Figure 11. Simulated and measured XP radiation pattern at 5.25 GHz.

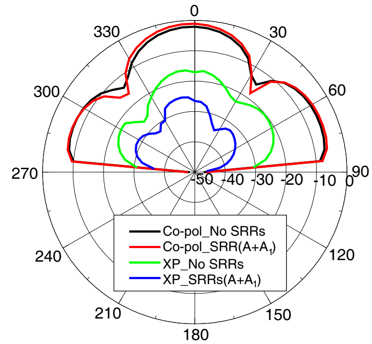


Figure 12. Measured co-polar and XP radiation pattern at 5.25 GHz.

without SRR is illustrated in the Figure 10.

From simulated radiation curves it is observed that the co-polar radiation patterns for different configurations are almost similar but the XP radiation has been reduced by around 10.5 dB in presence of SRRs. Measured XP and co-polar radiation pattern for different configurations are illustrated in the Figure 11.

From Figure 11 it is observed that there is good agreement between simulated and measured radiation pattern. The measured XP radiation with SRR $(\mathrm{A} + \mathrm{A}_1)$ is 10.5 dB less than that of without SRR. The measured polar plot of co-polar and XP radiation pattern with and without SRRs is shown in Figure 12. From Figure 12, the suppression of XP radiation is clearly observed by the introduction of SRRs and it is also observed that there is no significant variation in the co-polar pattern.

5. CONCLUSION

SRR is proposed as a technique of suppressing XP radiation of a microstrip antenna array. An E-shaped patch array with and without SRR are examined using simulation and experimental results and the idea is verified. The proposed antenna array integrated with SRRs is electrically small, high gain and directivity and suitable to handle easily. From the simulated results it is observed that the maximum gain obtained in the broadside direction and the peak gain at the design frequency for the array without SRR of 12.60 dBi and with SRR of 12.975 dBi has been achieved. The BW with and without SRRs of 400 MHz is reported. Furthermore, the SRR causing suppression in XP does not affect any other characteristics like the co-polarized radiation over the principal planes, backward radiation, gain, and input impedance compared to those with conventional microstrip patch. Thus, the proposed concept can be employed for achieving improved XP values where high XP becomes a major limitation in some antennas having some attractive features. In this article, we have mainly focused on XP radiation of SRRs integrated array. The reduction of XP radiation has been reduced by 10.5 dB in presence of SRRs in the array structure.

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