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Design of SRR Array Embedded PIFA for LTE-Hi Applications

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Abstract: This study presents an indigenous SRR array embedded PIFA using FR4 substrate for LTE-Hi applications. Five different SRR array configurations are used and the SRR arrays are placed in inner side of the radiating plate of the PIFA for gain enhancement and high bandwith. The proposed antenna resonates in the frequency band of 2.6-3.9 GHz covering 2600, 3500, 3700 MHz which is suitable for various applications. An antenna has been fabricated and the measured results are found to be in good agreement with simulated results.

Key words: Long term evolution, PIFA, split ring resonator, gain, frequency, India

INTRODUCTION

The demand of mobile broadband system arises due to increase in mobile internet traffic and high data rate (Chen *et al*., 2014). Now a days, most of the mobile internet traffic is produced in hotspots and indoor environments. Wi-Fi is commonly accepted solution for these type of environments. Although, the seamless switching is a problem between cellular cells and hotspots deployed so far. Watching over the user as well as the market inclinations with improved hotspot solutions, major efforts are put in 3 GPP on heterogeneous networks along with small cells. Therefore, Long Term Evolution (LTE) based hotspots with indoor solutions to deal with the challenges of mobile broadband systems are initiated. The 3.4-3.8 GHz frequency band fulfills this rising traffic needs (Wang *et al*., 2014). The compact size and good performance of a Planar Inverted-F Antenna (PIFA) makes it the attractive prospect for handsets, especially for WLAN application (Azremi *et al*., 2008).

PIFA is a $\lambda/4$ resonant structure realized by short-circuiting the radiating patch to the ground plane of the antenna. The structure is similar to a shorted microstrip patch antenna considering air as dielectric. As compared to the conventional microstrip patch antenna, the PIFA with miniaturized patch size is able to resonate at specified operating frequency (Zhu *et al*., 2009; Ahmad *et al*., 2014; Shin *et al*., 2004). However, the disadvantage of narrow bandwidth restricts the basic PIFA to be used for diverse applications. Therefore, it is necessary to increase the bandwidth so that, the same can be used for wireless communication and other applications (Zhu *et al*., 2009). The research on the reduction in size of PIFA is going on but the considerable effect taking place on gain is ignored (Zelenchuk and Fusco, 2009). With the aim of achieving required quality of service, high gain and wide bandwidth; planar antenna arrays have previously been offered. To attain high gain, arrays of several patch elements are used. But there is a slight increase of 2-5% in bandwidth (Pozar, 1992). Another scheme to have moderate gain along with good bandwidth in planar fashion is the grid array antenna (Kraus, 1964; Palmer and Cloete, 1997; Nakano *et al*., 1995).

Metamaterial such as square Split Ring Resonator (SRR), circular SRR, labyrinth, etc., are also meant for size minituarization, mutual coupling reduction, improvement in bandwidth and gain, etc. (Arora *et al*., 2015). For the enhancement of the antenna gain, many researchers reported the use of a superstrate layer above microstrip patch antenna. Highly-reflective surface, artificial magnetic superstrate, dielectric slabs and electromagnetic bandgap structures are most commonly used configurations of superstrates (Foroozesh and Shafai, 2010; Attia *et al*., 2009; Vettikalladi *et al*., 2009; Attia and Ramahi, 2008). Attia *et al*. (2010) presented a planar 12×12 array of SRRs printed on the dielectric layer including 3 layers of the superstrate each separated with 2 mm of air layers to improve the gain with single resonant band but the antenna profile has increased considerably. However, the loading of different SRR array configurations in the inner side of top radiating plate has not been presented so far. This study deals with the placement of different configurations of SRR array on the inner side of radiating top plate of PIFA for gain enhancement. For this, the circular SRR array is considered and it was observed as one of the possible solution.

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MATERIALS AND METHODS

Antenna design: Upcoming mobile systems are needed to look for higher frequency band like 3.4-3.8 GHz to distinguish new spectrum intended for mobile broadband. For this, a PIFA has been designed with different SRR array configurations. The empirical equation for finding the resonant frequency of PIFA is:

$$f_0 = v/4(L_2+W_2) \quad (1)$$

Where:

L_2 and W_2	= The length and width of the radiating plate of the PIFA
v	= The speed of light
f_0	= The resonant frequency

The design of an antenna comprises of basisc PIFA structure having different combinations of 2×1, 1×2 or 2×2 SRR array configurations in the inner side of the top radiating plate. Low cost FR4 substrate with relative permittivity of 4.4 and thickness of 1.6 mm is used. The ground plane dimensions are 30× 30 mm and radiating top plate dimensions are 10×16 mm. The width and height of the shorting plate is 5 and 6 mm, respectively. Coaxial feed is used for the excitation of the antenna. The antenna performance is observed without SRR and with different SRR array configurations. Without any SRR array, the antenna resonates at the frequency of 3.5 GHz. The geometrical structure of antenna without SRR is shown in Fig. 1 and its return loss is shown in Fig. 2. Figure 3 depicts five SRR array configurations placement which are used to measure the performance of PIFA. The geometrical structure of SRR is shown in Fig. 4. The separation between inner and outer split rings 'c' and the gap at the splits of rings 'w' are set to be 0.5 mm. The radius of outer split ring r_1 = 2 mm and radius of the inner split ring r_2 = 1 mm. The designed antenna is simulated using HFSS electromagnetic simulator.

Initially, the antenna is simulated without any SRR array to optimise the height of the shorting plate. The

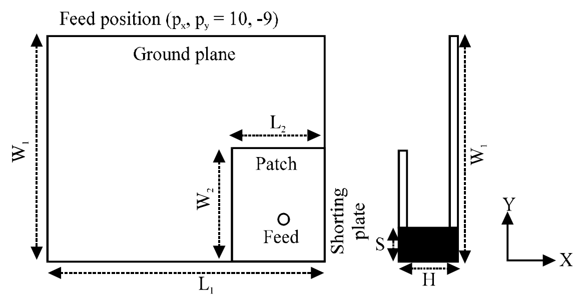

Fig. 1: Top and side view of PIFA

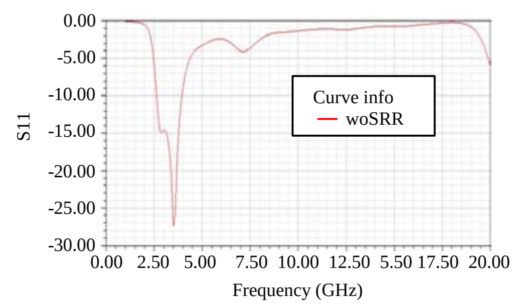

Fig. 2: Return loss of PIFA without SRR

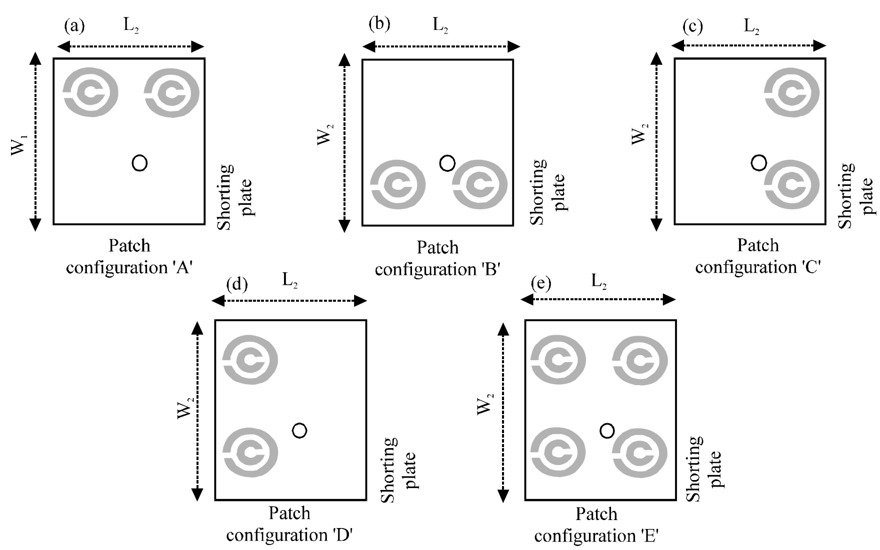

Fig. 3: Geometrical structure of SRR configurations 'A-E': a and b) 2×1 SRR array; c and d) 1×2 SRR array; e) 2×2 SRR array

Table 1: Resonating frequency, return loss, bndwidth and gain of PIFA with and without SRR array

Parameters	Resonating frequency (GHz)	Bandwidth (MHz)	Return loss (dB)	Gain
Without SRR	3.5	1320	-27.4	7.1
With SRR array				
A	3.39	1290	-31.9	8.1
B	3.4, 14.6	1280, 230	-44.2, -16.6	7.18, 4.67
C	3.3	1230	-25.5	13.2
D	2.9, 3.4	1290	-24.8, -35.5	14.9, 11.5
E	3.2, 3.8, 14.5	1140, 250	-22, -26.6, -16.9	8.84, 17.1, 4.5

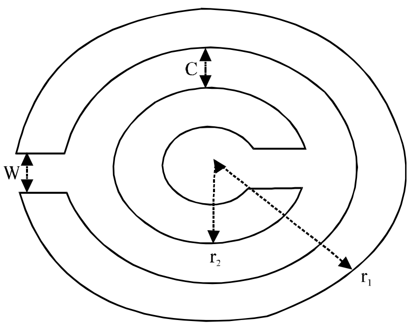

Fig. 4: SRR unit cell

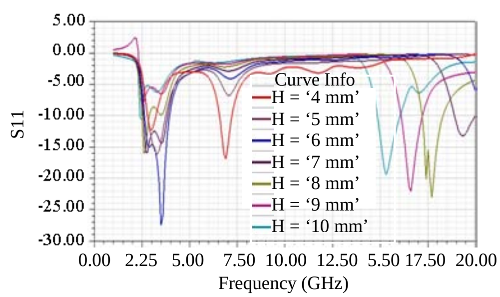

Fig. 5: Return loss of PIFA (without any SRR array) with variation in height of shorting plate

height H is varied in steps of 1 mm from 4-10 mm. The variation of PIFA without SRR. The size of the antenna at resonance frequency 3.5 GHz is 0.11×0.18λ. As per the optimized height for the antenna is observed as 6 mm. Figure 5 depicts the return loss with shorting plate height desired dimension of antenna given in Fig. 1, the different configurations of SRR array 'A-E' is embedded on the inner side of the radiating plate. The simulation result shows a slight shift in resonating frequency after placing the SRR array. The SRR causes a perpendicular magnetic field due to magnetically resonant structure. The split gap in the inner and outer ring behaves like a capacitor which is capable of controlling the resonant characteristics of the structure. Table 1 shows the resonating frequency, return loss, bandwidth and gain of PIFA without SRR and with different SRR array configurations.

In configuration A and B, 2×1 SRR array is placed along X axis whereas in configuration C and D, 1×2 SRR array is placed along Y axis. The configuration E has 2×2 SRR array. Figure 6 shows the frequency characteristics for different PIFA configurations.

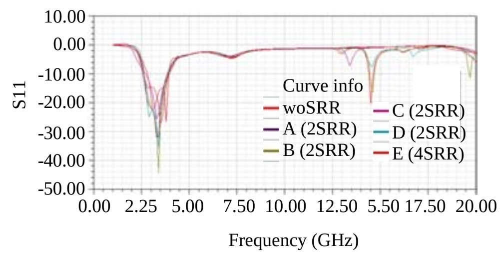

Fig. 6: Return loss of PIFA with and without SRR array

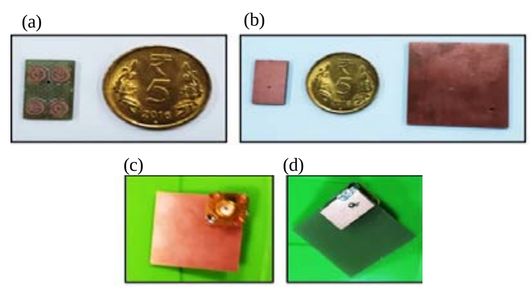

Fig. 7: Photogarph of fabricated PIFA with configuration 'E': a) Inner side of radiating plate; b) Outer side of radiating plate and ground plane; c) Ground plane and d) Radiating plate

As compared to without SRR case, the resonant frequency is shifted towards lower side from 3.5-3.4 GHz with decrease in bandwidth from 1.32-1.29 Ghz and 1.28 Ghz in SRR array configuration A and B, resepectively. However, the gain of configuration A and B is more than the antenna without any SRR. The configuration C resonates at 3.3 Ghz having frequency band of 2.72-3.95 GHz with gain 13.2 dB while the configuration D shows two resonating frequency of 2.9 and 3.4 GHz having frequency band of 2.64-3.93 GHz. The 6.1 and 7.8 dB improvement in gain is observed in configuration C and D, respectively. The configuration E resonates at three frequencies of 3.2, 3.8 and 14.5 GHz with small decrease in bandwidth. However, the gain for configuration E is more than all other configurations. The simulation results shows enhancement in gain when SRR array is used. To validate the simulation results, the antenna has been fabricated with 2×2 array as shown in Fig. 7. The radiating plate with SMA connecter is also shown in Fig. 7.

RESULTS AND DISCUSSION

Anritsu MS 46322A vector network analyzer is used and the return loss S_{11} is measured. The measured and simulated return loss are shown in Fig. 8. It is observed that measured S_{11} is in agreement with simulated one. A good impedance matching is achieved in the frequency range from 2.60-3.9 GHz but a shift in higher resonant frequency is also observed. However, the measured bandwidth is more than the simulated bandwith. The small error in simulated and measured resonating freuency may be due to fabrication process. The comparison of simulated and measured results of PIFA with configuration E is depicted in Table 2.

Figure 9 illustartes the elevation and azimuth radiation patterns of the proposed antenna. The gain of the PIFA antenna is enhanced in the maximum radiation direction using the 2×2 SRR array. The gain of PIFA with configuration E is 8.84, 17.1 and 4.5 dB at 3.2, 3.8 and 14.5 GHz, respectively.

The 3D gain plot of PIAF with SRR array configuration 'E' at three different resonant frequencies are shown in Fig. 10.

Hossain *et al*. (2014) have examined four different unit cells with varying design parameters to assess the minor shift in the resonance frequencies of the metamaterial. The same behavior is also observed with the use of SRR arrays in this antenna.

The antenna using metamaterial array is presented by Attia *et al*. (2010) for the enhancement of antenna gain but the large size of the antenna is not compatible with modern handsets. Similarly, a study reported by Islam *et al*. (2014) an H-shaped metamaterial is designed for multiband microwave applications having bandwiths of 500 and 300 MHz in C and S bands, respectively. However, the antenna designed in this manuscript has not effects of the unit-cell size on the resonant frequencies of the metamaterial. The two array configurations cause a

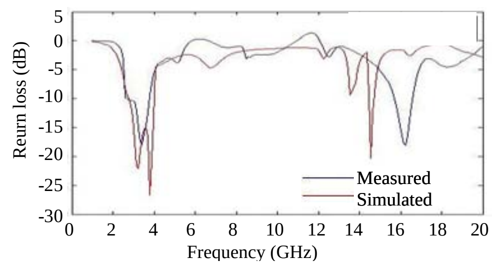

Fig. 8: Simulated and measured Return loss of PIFA with SRR array configuration 'E'

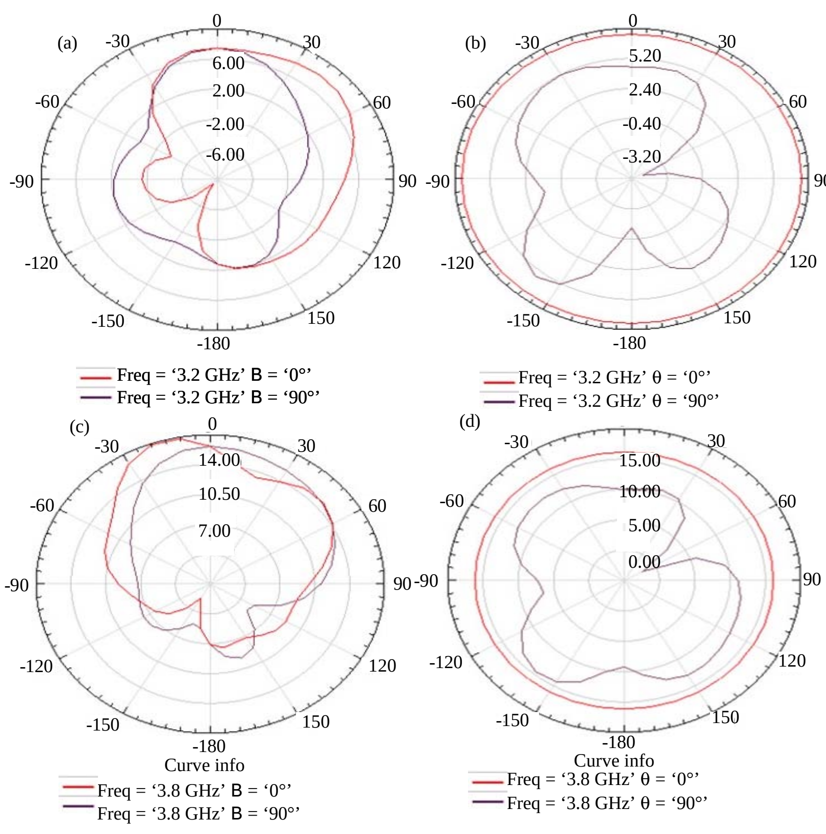

Fig. 9: Continue

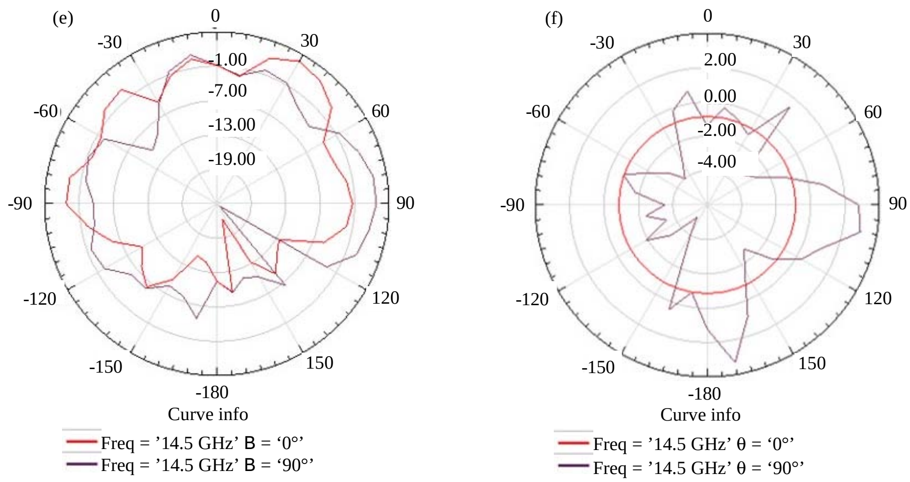

Fig. 9: Radiation patterns of PIFA embedded with confiuration 'E' at three resonating frequencies; a and b) 3.2 GHz; c and d) 3.8 GHz; e and f) 14.5 GHz

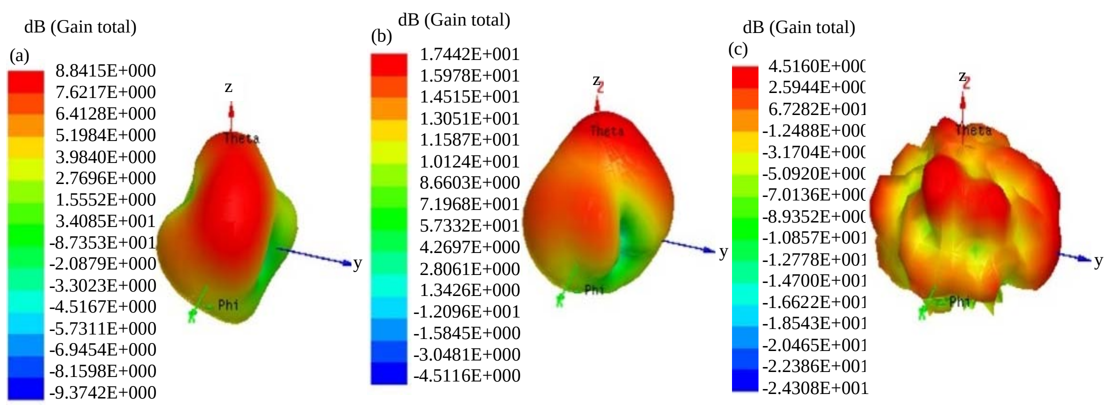

Fig. 10: 3D gain of PIFA embedded with SRR array confiuration 'E' at three resonating frequencies; a) 3.2 GHz; b) 3.8 GHz and c) 14.5 GHz

Table 2: Simualted and measured results of PIFA with SRR array configuration 'E'

Simulated Results			Measured results			
Resonating frequency (Ghz)	Frequency band (GHz)	Bandwidth (MHz)	Resonating frequency (GHz)	Frequency band (GHz)	Bandwidth (MHz)	Error (%)
3.2	2.8-3.95	1150	3.43	2.6-3.79	1190	6.0
3.8			3.4			11.0
14.5	14.4-14.65	250	16.2	15.7-16.5	800	11.0

only provides good gain and small size but also having a bandwidth of 1.19 GHz which is suitable for advanced wireless devices.

CONCLUSION

This study presents a PIFA with five different SRR array configurations having high gain and large bandwidth for LTE-Hi application. A novel method of SRR array placement in the inner side of the radiating plate is used. A comparison of PIFA without SRR and with five different SRR array configurations is carried out to observe the antenna performance parameters. An antenna with 2×2 SRR array (configuration 'E') has been fabricated and found that the simulated results are in good agreement with the measured results. The proposed antenna is of small size suitable for personal wireless applications with a large bandwidth of 1.19 GHZ and high gain of 17.1 dB.

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