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Performance of patch antenna through varying structure and positions

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A miniaturized 15×20×1.6 mm3 antenna has been proposed with improved impedance bandwidth and gains for wireless communication applications. The proposed antenna has been attached with three narrow rectangular stubs; in addition, the bottom plane of the antenna has been inserted with –ε, -μ structure. The antenna properties like radiation pattern, gain, field distributions have been mentioned. Moreover, the proposed metamaterial has been optimized to get better characteristics by using HFSS 2020R1. Here, we have observed the effect of the resonance frequency of the designed antenna by changing the position of the metamaterial in the ground plane. The aforesaid antenna covers the wireless, Wi-MAX, C Band, K Band, Ku Bands with significant gain, S11 < -10dB. The antenna has been fabricated and tested.

Keywords: Patch antenna, Metamaterial, Radiation pattern, Gain

1 Introduction

Today, in the universal system, we need, small, high bandwidth, multiple resonant frequencies antennas. These challenges have been somewhat achieved by researchers[1,2]. For miniaturization, various methods have been proposed like meander line[3], fractal[4], metamaterial[5-7]. The metamaterial has shown special feature like –epsilon, -Permeability[8]. By using this nature various metamaterial cells have been developed like SRR 40×40×1.6 mm^3 for WLAN, C band[9], triangular CSRR[10], Z shape[11], symmetrical circular fractal metamaterial[12]. In Singh, 0.56 λo × 0.35 λo (32 × 20 mm^2) size radiating surface has been operated at 1710 MHz to 2110 MHz bases on ZOR.

In Tadesse[13] superstrate layer has been used to enhance BW, 67% reduction in size. By using the RCSRR unit cell, a five band antenna has been obtained[14]. Meta absorber has also been used to get wideband nature in Ku band (12GHz to 18 GHz)[15]. In Mohammad[16], U-shaped strips have been used to get L, S, C, and X-bands. In Gupta[17], two CPW-fed metamaterial antennas with an impedance bandwidth of 50.1% have been achieved. In Al-Zoubi[18], 150×150mm^2 antenna got 5.7dBi Gain at 5.8GHz resonance frequency using the center-fed approach. In Mishra[19], 30 × 10 Meta array of size 4 cm × 4 cm has been used to obtain C, X, Ku bands.

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The researchers have been struggling to design small antennas with sufficient antenna properties, so we have worked on designing small antennas with innovative methods to achieve the desired results. To overcome the problems faced due to small antennas like insufficient gain, radiation efficiency, return loss, we have used metamaterial techniques. The significant contributions by using this technique have to create a miniaturized design suitable for modern communication technology.

Here five antennas with names Ant_1 to Ant_5 of size 15×20mm^2 have been proposed. The ground plane of the antenna has a rectangular in shape, and it reduces return loss of the antenna. Two circular rings with slots have been placed below the ground plane to enhance antenna performance.

Ant_1 has been miniaturized with Fr4 Epoxy with Deictic constant 4.4. It has dimensions i_1=20mm, i_2=15mm, i3=1mm, i4=4mm, i5=1mm, i6=8mm, i7=10mm, i8=10mm, i9=8mm, i10=2mm shown in Fig. 1.

The area of Ant_1 is only 100 mm^2. In history, different shape of antennas has been developed. Like triangular, elliptical, circular, but these are large in size. In order to obtain resonance in C, X bands, the size of the patch must be large but here innovatively have been designed a small antenna by using thin stubs. Generally, to get high impedance, slots have been used in the patch due to those slots current path increases, but here we have used stubs with size 1×8mm^2. To achieve better impedance matching a 6×20mm^2 size ground plane has been used. The Ant_1 has been simulated by HFSS.

The Ant_1 has been operated at 5.49GHz-8.80GHz, 11.65GHz-13.29GHz, 14.72 GHz-17.85 GHz with S11< -10dB shown in Fig. 2(a). The size of the ground plane influences the return loss of the antenna, so here, we have optimized the area of the ground plane by varying length from 3mm to 6mm, and we observed change in S11 shown in Fig. 2(b). At 6mm length for Ant_1 supports X, K, ka bands.

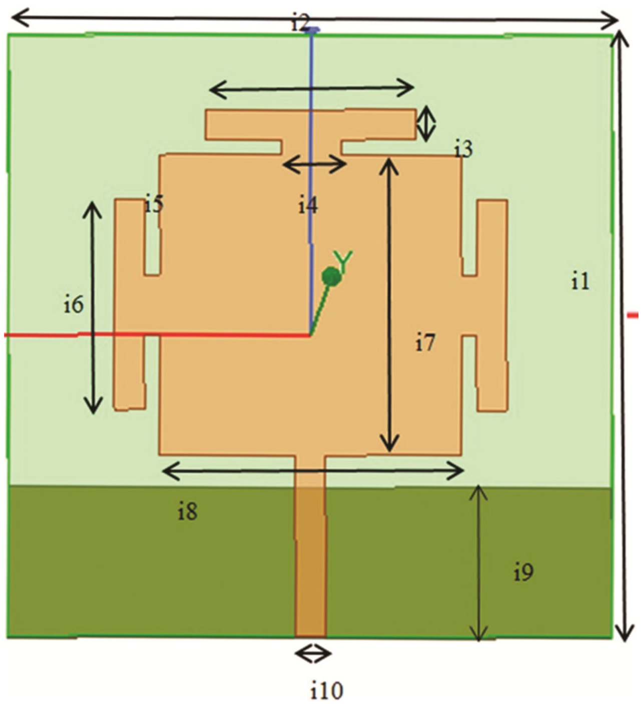

Fig. 1 — Basic structure of Ant_1[4].

The parameters of Ant_1 at resonant frequencies 6.5GHz, 12.8GHz, 16.35GHz are mentioned in Table 1.

From Fig. 2(c & d), the antenna has low return loss at 6.5 GHz, 12.8GHz, and 16.35GHz and has a peak Gain greater than 2dB. At 6.5 GHz the antenna has isotropic radiation compared to the remaining frequencies.

2 Materials and Methods

2.1 Metamaterial inspired antenna design

The metamaterial inspired antenna design is explained in this section.

By using metamaterial Ant_2, Ant_3, Ant_4 were developed shown in Fig. 3(a). Here metamaterial was initially placed near to ground patch, after that we moved metamaterial to very nearer to ground plane and observed change in S11 as shown in Fig. 3(b). After that two metamaterials were placed diagonally across ground plane and observed fluctuations in S11 showed in Fig. 3(c).

Table 1 — Properties of Ant_1

Parameter	6.5GHz	12.8GHz	16.35GHz
Peak Directivity	2.13	3.09	2.49
Peak Gain	2.03dB	2.46dB	2.48dB
Radiation Efficiency	95.2%	79.6%	88.6%

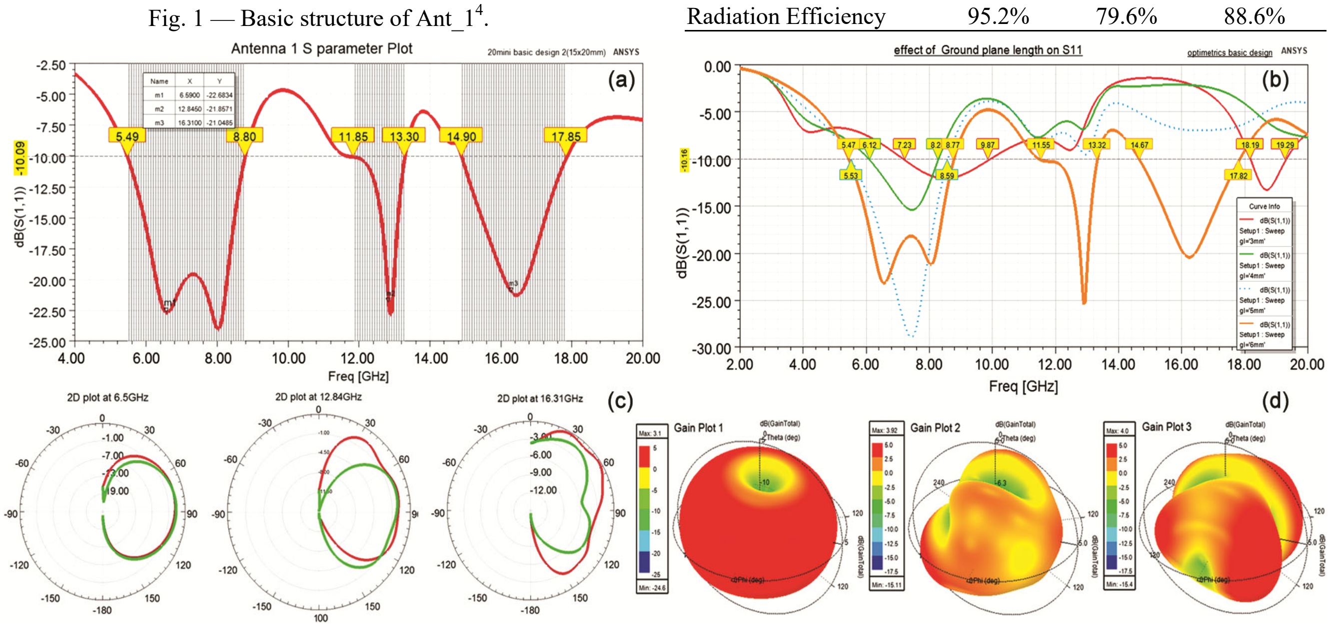

Fig. 2 — Parameters of Ant_1 (a) s11 of Ant_1, (b) variation in s_{11} by changing i9 size, (c) 2D radiation pattern of Ant_1, and (d) radiation pattern at 6.5 GHz, 12.8GHz, 16.35GHz[10].

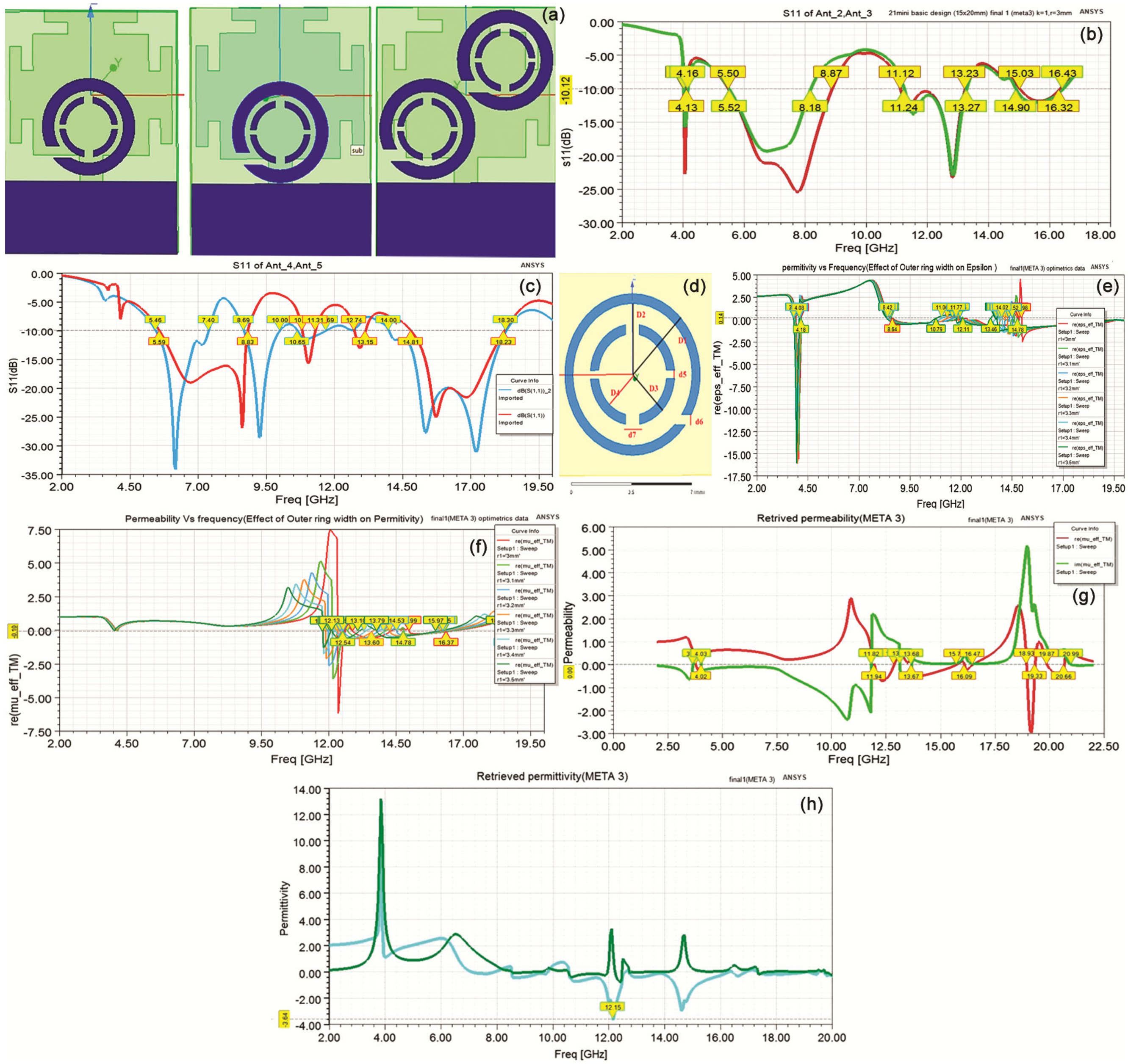

Fig. 3 — Proposed antennas and metamaterial structures (a) structures of Ant_2 to Ant_4, (b) and (c) shows S11 of Ant_2, Ant_3,Ant_4, Ant_5, (d) and (e) shows unit cell structure, (f) effect of outer ring width on epsilon, (g) Permeability Vs Frequency, and (h) Epsilon Vs Frequency[16].

The Ant_2 was operated at 5.50 GHz - 8.87 GHz, 11.12 GHz - 13.23 GHz, 15.03 GHz -16.32 GHz. The Ant_3 was operated at 5.52 GHz - 8.17 GHz, 11.24 GHz - 13.27 GHz, 14.91 GHz - 16.42 GHz. The Ant_4 was operated at 5.59 GHz - 8.83 GHz, 11.04 GHz, 12.98 GHz, and 14.81 GHz - 18.23 GHz.

Several researchers proposed different methods to analyze metamaterials, in Lu Wei-Bing[20] S Parameters were used to find negative characteristics of Cell. Lu wei-bing used Structural parameters to study metamaterials[21]. Smith *et al.*[22] analyzed in homogeneous metamaterials. From A. B. Numan[23], the parametric analysis equations of unit cell mentioned below,

$$z = \pm\sqrt{\frac{(1+S11)^2 - S21^2}{(1-S11)^2 - S21^2}} \quad \ldots (1)$$

$$n = \frac{1}{kd}\left[\{[\ln(e^{jnkd})]'' + 2m\pi\} - i[\ln(e^{jnkd})]'\right] \quad \ldots (2)$$

$$\varepsilon = \frac{n}{z} \quad \dots (3)$$

$$\mu = n \times Z \quad \dots (4)$$

D1 = 4mm, D2 = 3.5mm, D3 = 2.6mm, D4 = 2mm, D5 = 0.5mm, D6 = 0.5mm, D7 = 0.8mm

2.2 Optimization of unit cell

The proposed Unit cell had two rings. The inner ring had four gaps, outer ring had one gap (D6) shown in Fig. 3(d). To get low epsilon, permeability the D2 value was changed from 3 mm to 3.5 mm with step size 0.1 mm shown in Fig. 3(e & f).

At D6 = 1mm, D3 = 3mm, the unit cell has –ε from 4.31 GHz - 4.53GHz, 8.82GHz - 11.87GHz, 12.39 GHz to 19.90 GHz and –μ from 3.3 GHz to 16.8 Ghz. In Ant_2, Ant_3, Ant_4 , the gap D6 is 1mm and D2 is 3.5mm. In Fig. 3(h), the proposed unit cell arranged in diagonal, due to this type of arrangement low value of ε, μ is obtained from 7.12 GHz to 16.12 GHz and 8.53 GHz to 14.68 GHz.

3 Results and Discussion

3.1 Fabricated antenna design

In ant_5 two unit cells placed in ground plane in diagonal shape shown in Fig. 4(a). Here inner and outer rings width of metamaterial was 0.2 mm.

From Fig. 4(b & c), the antenna has an isotropic radiation and satisfactory gain was achieved. The Ant_5 was operated at 5.46 GHz - 7.40 GHz, 8.69 GHz to 10 GHz, 10.65 GHz to 11.69 GHz, 14 GHz to 18.30 GHz shown in Fig. 4(d).

The Fabricated Antenna worked at C, X, Ku bands with Impedance BW (5.41GHz - 8.07GHz, 9.40 GHz - 11.01 GHz, 12.93 - 18.24 GHz), the simulation results were almost equal but little bit change in X band region with average gain of 2.52 dB shown in Fig. 4(e & f).

From Table 2, it is observed that the proposed antenna has triple band nature and high efficiency and very small size of 15×20×1.6 mm^3.

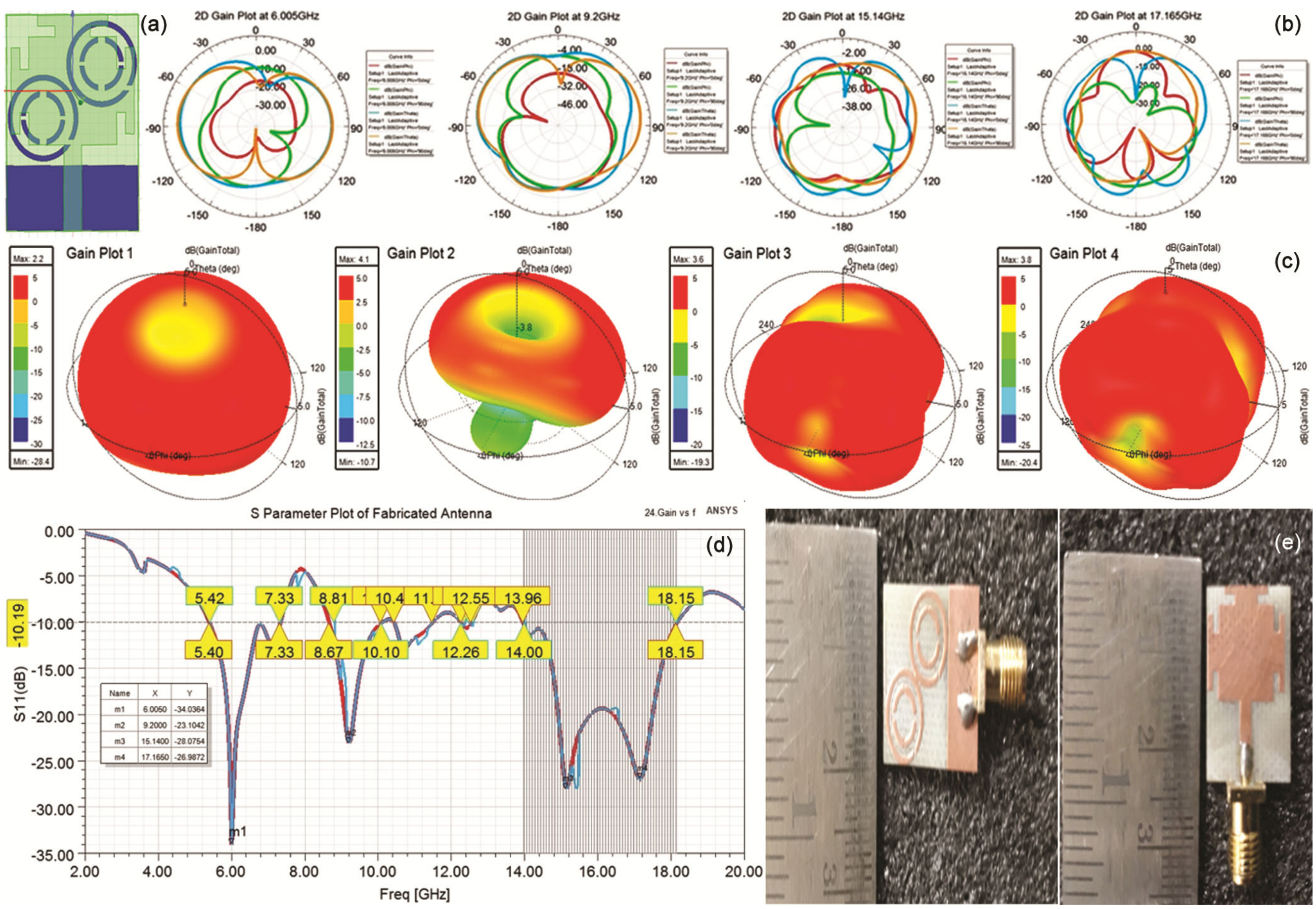

Fig. 4 — Parameters of Ant_5 and Ant_f_M3 (a) Ant_5, (b) 2D radiation pattern of Ant_5, (c) Gain of Ant_5, (d) simulation and practical results of Ant_f_M3, (e) ~~A~~ snapshot of fabricated antenna, and (f) ~~A~~ snapshot of fabricated antenna measurement[24].

Table 2 — Comparison of fabricated antenna with previous works

Paper	Dimensions	Impedance BW	Gain(dBi)	Efficiency
16	21.6×19.8×0.8 mm3	0.7-8GHz	4dBi	80%
24	30×30×1.6mm3	(13.8–4.25GHz), (16.17–16.55 GHz)	8.60, 7.37dBi	-
25	8 × 16 mm2 (Two layers)	7.96-10S,8.08-10.18 M , 13.94-18.03 S, 14-17.9 M ,18.89-20.22S, 18.75-20.32 M	8.08, 8.04dBi , 8.02, 8.03dBi , 3.12, 3.8dBi	86%, 87%, 77%
26	60 × 60 × 2 mm3	1.6 to 2.56 GHz, 4.24 to 7 GHz	1.8, 5dBi	46%, 49.11%
27	25.2×23.7×1.6 mm3	2.4/3.5/5.9 GHz	0.8dBi	-
28	78.6 × 42.5× 0.035 mm3	(0.865–1.060GHz), (2.240–2.520GHz), (3.250–4.310GHz), (4.900–6.500)GHz,	1.89dBi , 5.05dBi , 6.74dBi , 5.98dBi	62%, 71%, 95%, 83%
Proposed Antenna	(15×20×1.6mm3)	5.41GHz-8.07GHz, 9.40GHz-11.01GHz 12.93-18.24GHz	2.4dBi , 3.9dBi , 2.6dBi	93.09%, 91.23%, 88.9%

4 Conclusion

The proposed metamaterial has single negative and double negative nature at some frequencies, at that frequencies antenna parameters have been affected. The fabricated antenna has a very small size (15×20×1.6mm^3) useful for wireless communication applications. It has wide impedance BW from 12.93 GHz - 18.24 GHz and has good radiation efficiency (Greater than 85%). The fabricated and simulated results have been almost the same.

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