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Size Reduction of Microstrip Patch Antenna by Using Meta-Fractal Technique

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Abstract: Size reduction of square patch antenna is proposed using meta-fractal technique. This technique implies adding fractal shape (Peano shape here) to the classical square antenna to reduce its size and then a complementary split ring resonator (CSRR) is slotted on the patch as a defect. The defect enforces the antenna to behave as meta-material in a specific frequency range. Peano fractal antenna has three resonances. The complementary split ring resonator affects the upper two x- band frequencies and makes the antenna resonates at 9.5 GHz and 10 GHz rather than 10 GHz and 10.89 GHz. Shifting the resonances of the antenna means size reduction is obtained. Calculations are carried using (HFSS) software, which is based on finite element modeling. Good convergence obtained of measurement and calculated results.

Key terms: Antenna Miniaturization; Fractal Antenna; Left handed material; Meta-material; Split Ring Resonator.

I. INTRODUCTION

Microstrip antenna has a lot of interest in litterateurs due to their low profile lightweight and low cost of fabrication [1]. Antenna size is the most important parameter in many wireless applications. Although the microstrip antenna has low profile, but it still not small enough in many wireless communication systems. Size reduction of an antenna was investigated vastly in publications [2,3]. Many techniques have been used to reduce antenna size, among these techniques is slotting the patch of antenna [4], using shorting posts [5], and using high permittivity dielectric substrate [6]. Fractal shapes are very useful technique to get size reduction. Many fractal antenna designs were published in recent years [7,8]. Left-handed materials are another technique for miniaturizing antenna size. Left-handed materials are artificial structures that have electromagnetic properties not found in nature [9]. Pendry was the first one who describe negative permeability medium [10]. Later Smith implement first left-handed materials consist of periodic SRRs and long strips [11]. Recently, CSRR structure is used to reduce microstrip antenna size [12].In this paper, size reduced in two steps. Peano shape was applied to the square patch antenna, and then the fractal patch is loaded with CSRR as a second step of miniaturization. Good results of size reduction have obtained for both simulated and fabricated models using these two techniques.

II. ANTENNA DESIGN

Fractal shape generation of the antenna can be obtained by applying the fractal generator. The starting shape of the antenna is a square of 30 mm side length. The generator is the first iteration of Peano curve. The generator is applied to each side of the square to get the final fractal shape of the antenna. The generator is a straight segment which is divided into three segments, the middle one is also divided into three segments. Keeping the middle one and removing the others, and then connecting the remaining segments with tuning length called indentation width will get the shape of the generator [13]. Fractal shape is shown in Fig. 1. Patch antenna etched on a substrate of dimensions 70 mm x 70 mm x 1.5 mm. The substrate material is FR4 with relative permittivity (ε_r = 4.4). The antenna is fed by co-axial cable. Calculations and optimization of resonant frequencies are done using HFSS software.

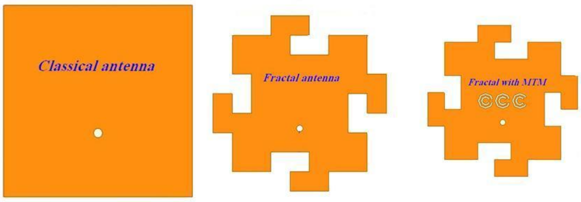


Fig.1. Fractal Peanoantenna shape

III. COMPLEMENTARY SPLIT RING DESIGN

Split ring design consists of three different capacitors. Capacity changes when the gap of the ring changes. Gaps are chosen to be 0.6 mm, 1 mm, 1.7 mm of the inner and outer rings of the first, second, and third model respectively. These gaps make the unit cells resonate at 9.5 GHz, 10 GHz, and 10.8 GHz respectively according to the relation below,

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

Shape of unit cells used in our design is shown in Fig. 2. Resonance frequencies of these unit cells can be noted through S-parameters plot versus frequency, this is shown in Fig.3. Where L=4mm, s=t=0.4mm, g1=0.6mm, g2=1mm, and g3=1.7mm.

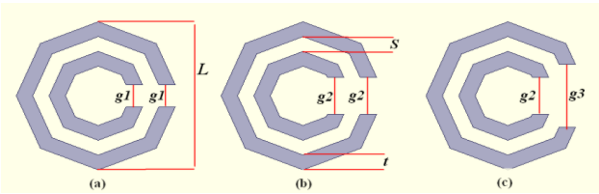


Fig.2. Split ring design

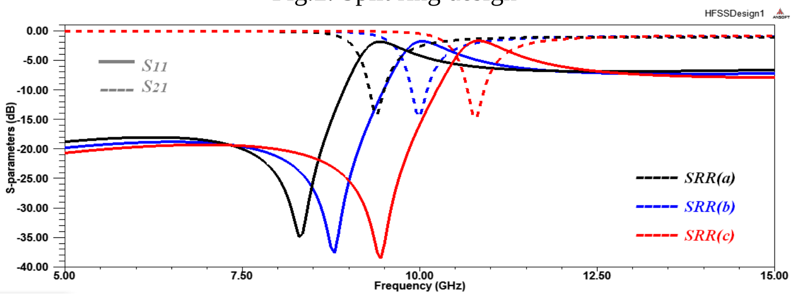


Fig.3. S- Parameters vs. frequency of SRR (a), SRR (b), and SRR(c)

IV. RESULTS AND DISCUSSION

Complementary Split Ring Resonator (CSRR) is embedded on microstrip patch antenna after adding fractal Peano shape to the patch to reduce its size. Adding (CSRR) on the antenna are used to increase the surface current. Increasing surface current cause a decrease in the resonant frequency of the antenna [14]. Complementary Split Ring Resonator models are placed in a waveguide to calculate its S- parameters. From these parameters, we can calculate relative permittivity, relative permeability, and refractive index. Relative permittivity and permeability of the unit cells are shown in Fig. 4 and Fig.5 respectively. The refractive index of these models is shown in Fig. 6. Dispersion diagram of the unit cells is shown in Fig. 7. The efficiency of antenna is shown in fig. 8.

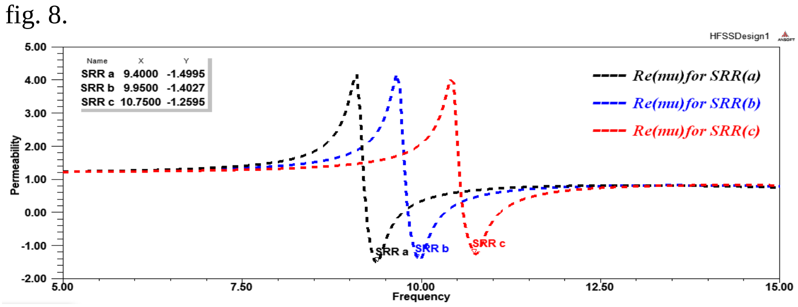


Fig.4. Relative permittivity of unit cells a, b, and c

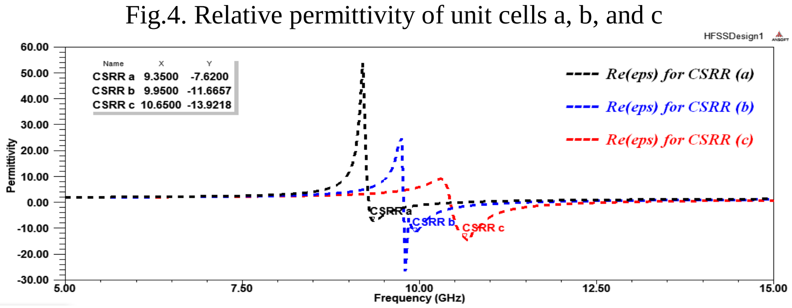


Fig.5. Relative permeability of unit cells a, b, and c

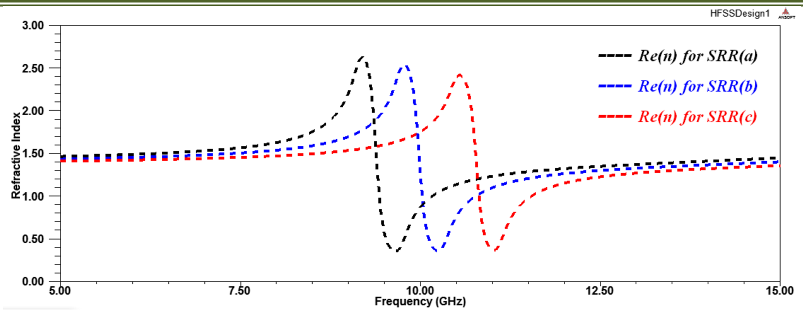


Fig.6. Refractive index of unit cells a, b, and c

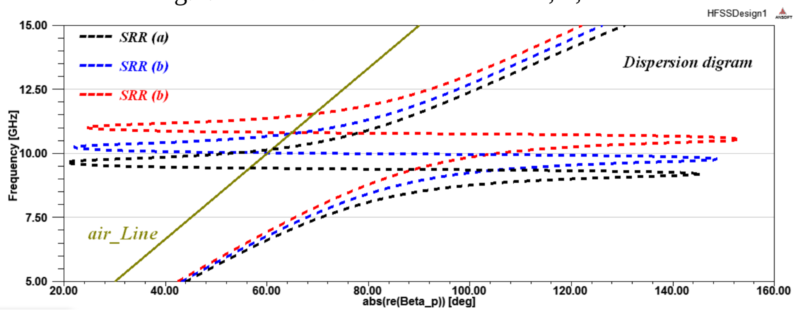


Fig.7. Dispersion diagram of unit cells a, b, and c

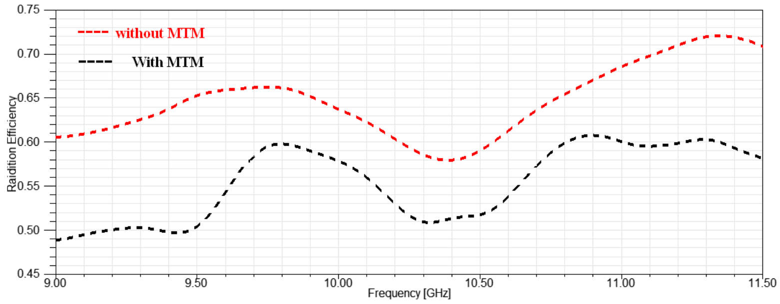


Fig.8. Antenna Efficiency

From figures above, we can see the unit cells have negative permeability and refractive index near zero located at its resonance frequencies. When split rings are used as complementary split rings, negative permittivity is obtained. According to the Babinet's principle [15], SRR has negativepermeability characteristics, while CSRR has negative permittivity characteristics as shown in Fig.9.

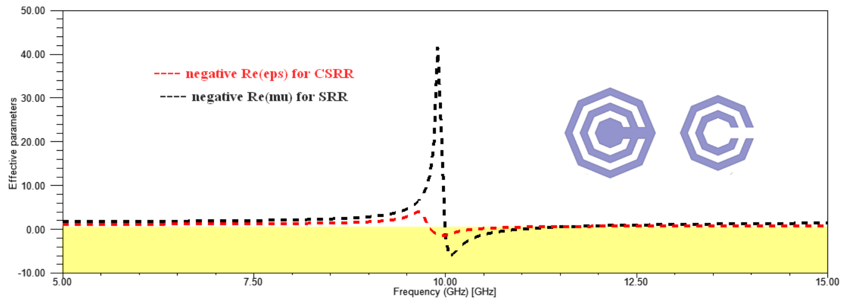


Fig.9. Relative permittivity and permeability magnitude difference of SRR and CSRR

Fractal Peano antenna has three resonance frequencies located at 1.95 GHz, 10 GHz, and 10.88 GHz. Applying CSRR to the patch, will decrease the resonance frequencies located at x- band. The fabricated shape of the patch is shown in Fig. 10. Resonance frequencies of fractal Peano antenna with and without CSRR are shown in Fig.11 and Fig.12.

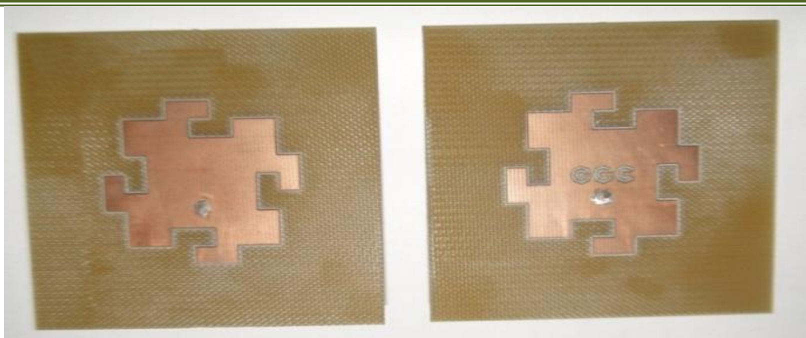
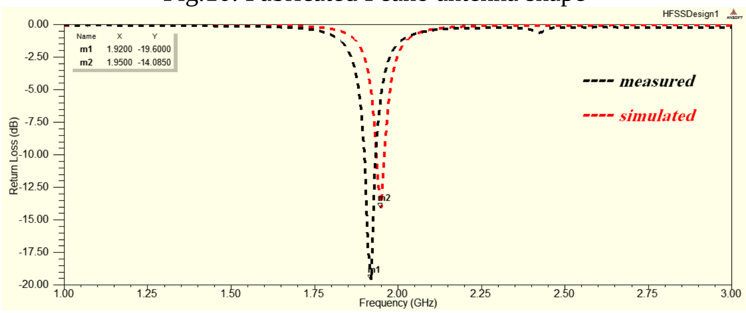
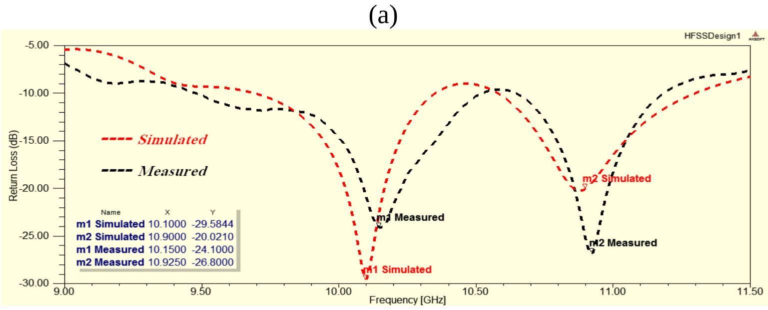


Fig.10. Fabricated Peano antenna shape

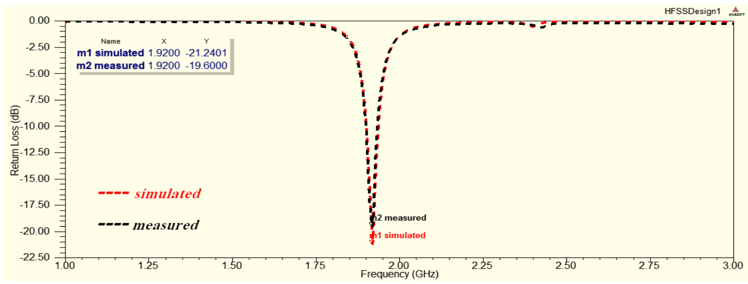


(a)

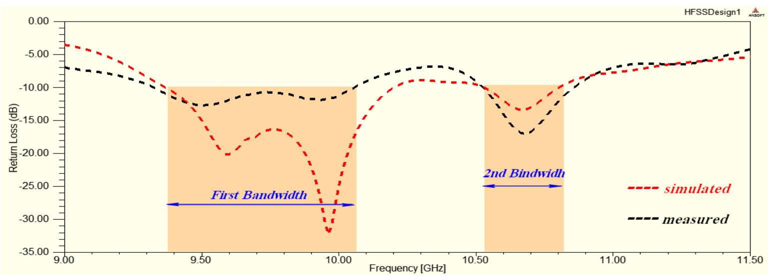


(b)

Fig.11. Resonance frequencies (a) s- band (b) x- band of Peano antenna without CSRR



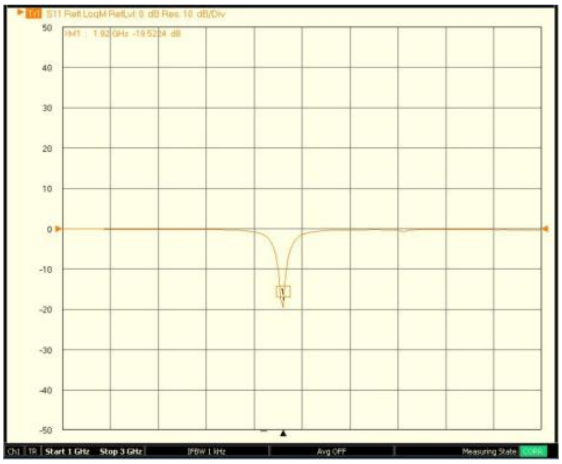
(a)



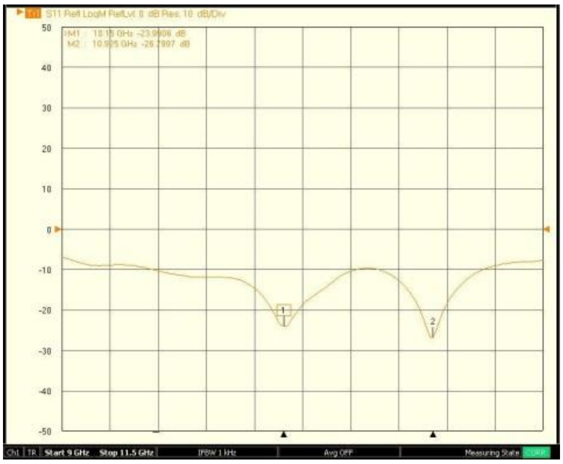
(b)

Fig.12. Resonance frequencies (a) s- band (b) x- band of Peano antenna with CSRR

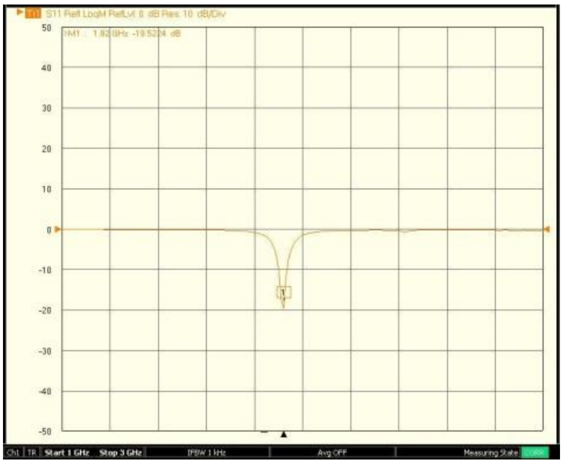
The measured results of the fabricated antenna using network analyzer are shown in Fig. 13.



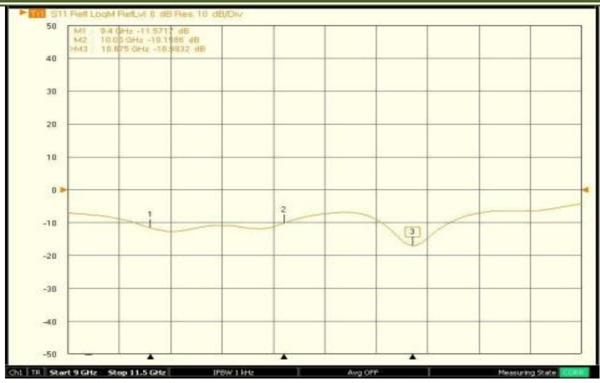
(a)



(b)



(c)

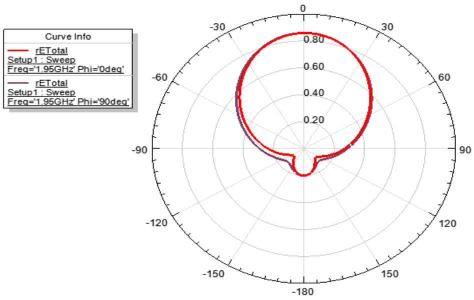


(d)

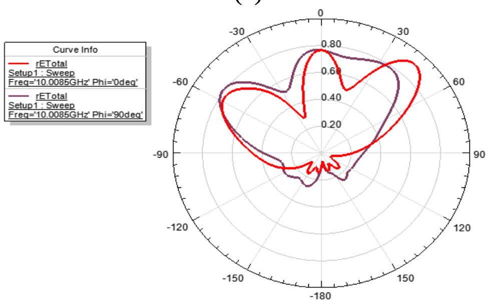
Fig.13. Measured resonances (a) s- band without CSRR (b) x- band without CSRR (c) s- band with CSRR (d) x- band with CSRR

From figures above, we can see full agreement in results between simulated and measured results for s-band frequency. The small difference in x- band results related to the edges of the fractal shape, since these edges become active at higher frequencies and cause an increase in edge effect.

The square patch antenna that operates at 1.95 GHz has a λ/4 side length equal to 39 mm. Antenna design in this paper has λ/4 side length equal to 7 mm. That means we get a reduction in size reaches to 83% according to s- band frequency. There is also a decrease in x- band frequencies after applying CSRR to the patch. Two-dimensional far field also calculated and it is shown in Fig. 14.



(a)



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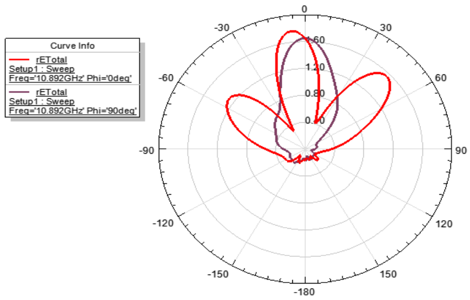

(c)

Fig.14. Far field of Peano antenna (a) 1.95 GHz (b) 10 GHz (c) 10.8 GHz

V. CONCLUSION

Size antenna reduction is of great interest in wireless communication systems. Tow techniques are used in reducing the size of a square patch antenna. Fractalizing the classical shape is a first step of reduction and adding CSRR as defect on the patch is the second step. First iteration of Peano curve is chosen to fractalize the antenna and three models of CSRR is embed on the patch. Calculations made using (HFSS) software code. Simulation results show a reduction in the size of the antenna reaches 83% relative to the s- band operating frequency. This model is fabricated and measurement done using vector network analyzer. Good agreement obtained of measured and simulated results.

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