International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 /doi:10.14445/22315381/IJETT-V69I6P206

Volume 69 Issue 6, 38-42, June 2021

Metamaterial Integrated Superstrate Antenna for C, X, and Ku Bands Applications

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Abstract —*This paper investigates six bands printed antenna integrated with eight shaped 8 x 7 periodic arrays as superstrate, circular ring, and Rectangular shaped Split Ring Resonator (RCSRR) as the radiating portion and half ground plane, respectively. The superstrate antenna, along with an array of patches, plays a major role in improving the gain. The antenna structure uses Roger RT Duroid 5880 substrate and FR4 as the superstrate. The proposed design has a fractional bandwidth of about 6.25% (5.32–5 GHz), 8.2% (6.1–5.62 GHz), 2.6% (7.34–7.15 GHz), 3.26% (10.3–9.97 GHz), 7.2% (11.5–10.7) and 2.5% (14.72–14.36 GHz) respectively and it is suitable for modern wireless communication applications. The effect of different substrate materials in the designed antenna structure is also compared and modeled using CST 2019 version. The superstrate antenna shows satisfactory performance across all the resonant frequencies.*

Keywords — *Circular Ring, Metamaterial, Rectangular Split Ring Resonator, RT Duroid*

I. INTRODUCTION

Microstrip antennas have been studied as the well-known choice among current wireless systems due to their inherent benefits such as low cost, robustness, ease to fabricate, operate at microwave frequencies, etc. [1]. However, the main drawbacks of these antennas are narrow bandwidth, less gain, low efficiency, and small power handling capacity, which restrict their usage to higher frequencies.

Many techniques have been highlighted in the literature over the years to overcome the limitation of low gains, such as (i) resonance gain method [2] (ii) using layers of multiple dielectric substrates [3] (iii) use of shorting pins, plates, etc. [4] (iv) feeding techniques [5].

The metamaterial proposed by Veselago in 1967 [6] exhibits properties like negative permeability and negative permittivity from the structure itself. The performance of the microstrip antenna system can be enhanced further by utilizing metamaterial due to their peculiar electromagnetic properties, which have inspired a lot of researchers in the antenna field.

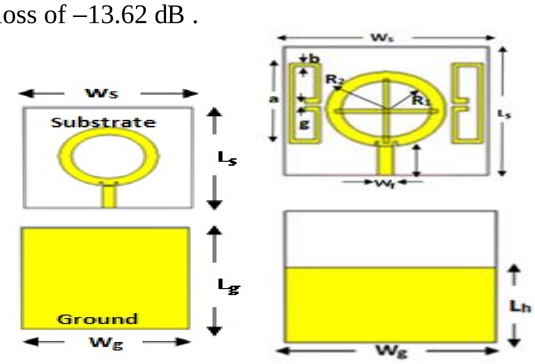
The authors have presented an enhanced metamaterial antenna array for the MIMO system [7]. Metamaterial loaded slot antenna have been employed to achieve five-band operation is presented in [8]. Size reduction of printed patch antenna through the use of high dielectric materials has been reported in [9]. A single band-slotted metamaterial superstrate antenna has been reported in [10].

The purpose of this paper is to propose a compact metamaterial superstrate multiple-band antenna with improved and reasonable gain at all operating frequencies by incorporating a metamaterial split ring resonator with a plus shape at the center of the circular ring patch and eight shaped 8x7 periodic array as a superstrate. The proposed metamaterial superstrate antenna is also compared with different substrate materials.

This manuscript is arranged as follows: In section II, the specification of the proposed metamaterial-inspired superstrate antenna structure is illustrated. Results and experimental validation are presented in section III. The conclusion is given in section IV.

II. ANTENNA GEOMETRY

A conventional circular ring microstrip antenna of size 40 x 40 x1.6 mm^3 is designed on commercially available Roger RT/Duroid 5880 dielectric material with dielectric constant ε_r=2.2 and loss tangent δ=0.0013 respectively as shown in Figure .1a. This conventional structure with full ground configuration resonates at 13.7 GHz with a return loss of −13.62 dB .

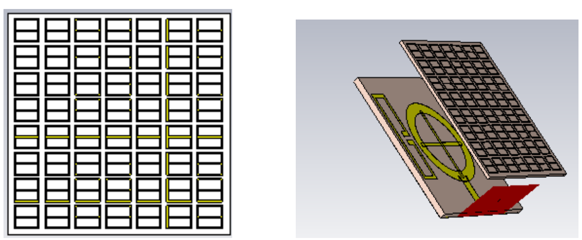


(a) **(b)**

Fig 1: Layout of (a) Conventional antenna (b) SRR with half ground configuration

In order to make the antenna operate in multiband, the designed antenna geometry consists of a new circular ring patch with a plus symbol printed structure incorporated at the center and two rectangular split-ring resonators (SRR) etched at the sides are shown in Figure.1b. The geometric dimensions of the rectangular split-ring resonator are a= 25 mm and b=g=1mm, respectively. The plus-shaped structure is formed by combining two rectangular-shaped planar printed patches. This structure makes the antenna operate at 5, 5.85,7.2,11 and 14.5 GHz, respectively. This antenna structure has a greater number of operating bands so that a single antenna design can cover a greater number of wireless standards and reasonable gain.

The gain of the proposed antenna structure can be enhanced further by using a flat superstrate which is kept at the height of 14 mm over the printed antenna, as shown in figure.2. It is patterned using FR4 with height h=1.6 mm and ε_r= 4.4, respectively. An array of 8 x 7 eight shaped structures are made on the top of the superstrate, and its performance is analyzed. This superstrate antenna exhibits resonance at about 5.1 (C-band), 5.8 (upper WiMAX), 7.2(medical BAN),10 (X-band), 11 (X-band) and 14.49 GHz (Ku-band). This superstrate antenna structure enhances the antenna gain that is mainly used for various wireless standards.



(a) (b)

Fig 2: Superstrate structure a) Top view (b) Side view

The designed antenna structure is modeled using a CST simulator. For a given resonance frequency (f_r) and relative dielectric constant (ε_r), the radius dimension of the circular ring patch element can be evaluated by the equation as below [11]

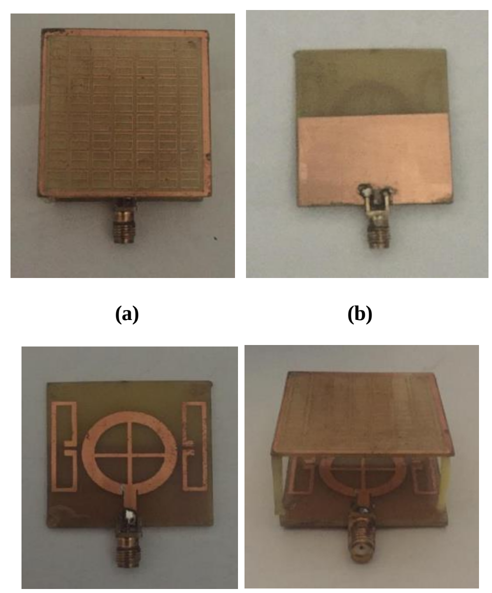
$$f_r = \frac{c}{\pi R_2}\sqrt{\frac{1+\varepsilon_r}{2\varepsilon_r}} \quad (1)$$

Using Eq. (1), the evaluated inner radius (R_1) of the patch element is 8.74 mm. An inset feed planar microstrip line (L_f x W_f) is used in the designed model to obtain 50 Ω impedance matching. The design values of the superstrate antenna structure to obtain good results are mentioned in Table I.

Table I. Descriptions of Antenna

Description	**Size(mm)**
The inner radius of the patch (R_1)	8.74
The outer radius of the patch (R_2)	11.74
Length of the substrate (L_s)	40
Width of the substrate (W_s)	40
Height of the substrate (h)	1.6
Length of inset feed line (L_f)	7
Width of inset feed line (W_f)	3
Length of the ground plane (L_g)	40
Half ground plane length (L_h)	20
Half ground plane width (W_g)	40
Length of plus shape	8.74
Width of the plus shape	1

The prototype of a metamaterial-loaded superstrate patch antenna is fabricated using a photolithographic process. Figure .3 a and b shows fabricated model of superstrate structure and half ground plane configuration. The photographs of the RSRR printed antenna and cross-sectional view of the fabricated model are shown in Figure.3c and d.



(a) (b) (c) (d)

Fig 3: Photographs of fabricated model a) 8 x 7 periodic array b) Half ground plane c) RSRR Patch antenna d) Cross-sectional view

III. RESULTS AND DISCUSSION

The fabricated prototype has been examined successfully using Vector Network Analyzer (5 kHz –15 GHz).

The simulated S_{11}-parameter of the conventional, RSRR, and superstrate configuration is depicted in the figure.4

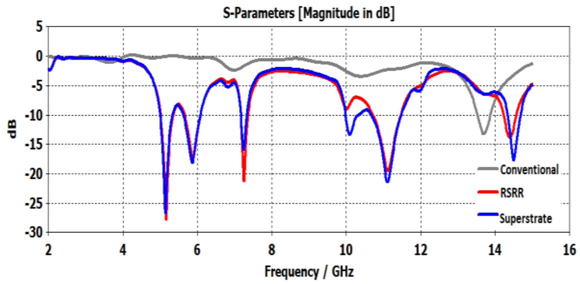


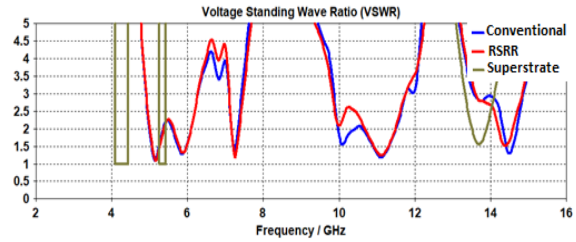
Fig. 4 S_{11} characteristics of the proposed antenna structure

The conventional structure with full ground configuration resonates at 13.7 GHz with return loss of −13.62 dB. The RSRR with modified circular ring structure makes the antenna to operate at 5, 5.85 ,7.2,11 and 14.5 GHz with return loss of −26.44 , −18.1, −15.84, −13.25, −21.4 and −17.8 dB respectively. The proposed superstrate structure resonates at six bands namely 5, 5.85 ,7.2,10,11 and 14.5 GHz with return loss of −26.44 , −18.1, −15.84, −13.25, −21.4 and −17.8 dB respectively.

The tested return loss characteristics of the superstrate structure are illustrated in Figure 5.

Fig 5: Photograph of the measured S_{11} characteristics

Figure.6 a and b depict the simulated and measured Voltage Standing Wave Ratio (VSWR) curve as a function of operating frequency. The VSWR curve compares conventional, RSRR, and proposed superstrate structures. It is observed from the simulated value that the mismatch is low in the proposed superstrate antenna model.



(a)

(b)

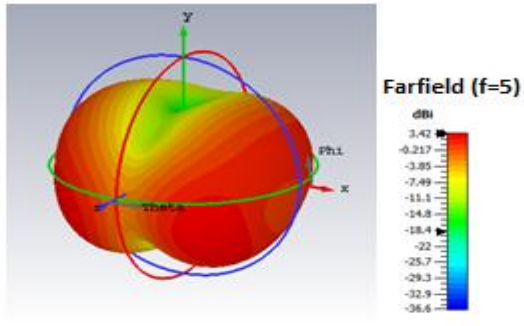
Fig 6: VSWR Characteristics (a) Simulated (b) Measured

Table II shows the simulated S_{11}, VSWR, and the fractional bandwidth of the proposed superstrate structure.

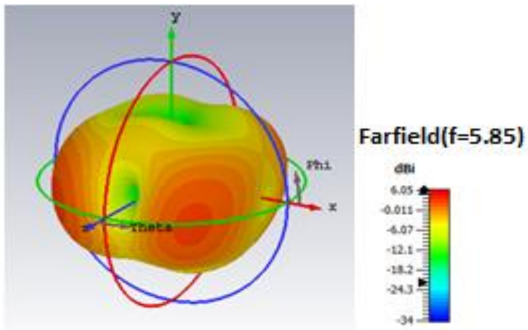
The simulated gain plot in 3D view of the antenna at 5, 5.85, 7.2, 10,11, and 14.5 GHz are depicted in Figure.7(a) – (f).

Table II Simulated characteristics of the proposed model

Band	Simulated Frequency band (GHz)	S_{11} (dB)	VSWR	Fractional Bandwidth (%)
1st	5.32-5	-26.64	1.09	6.25
2nd	6-5.62	-18.08	1.28	8.2
3rd	7.34-7.15	-15.84	1.38	2.6
4th	10.3-9.97	-13.25	1.55	3.26
5th	11.5-10.7	-21.4	1.1	7.2
6th	14.7-14.36	-17.8	1.29	2.5



(a)



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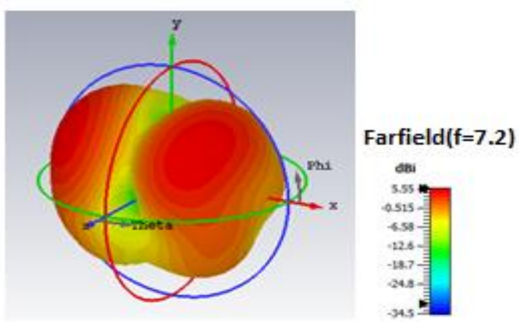
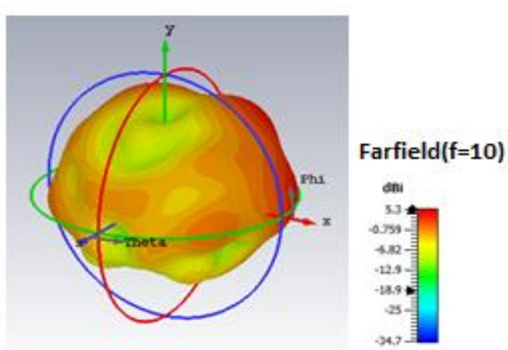
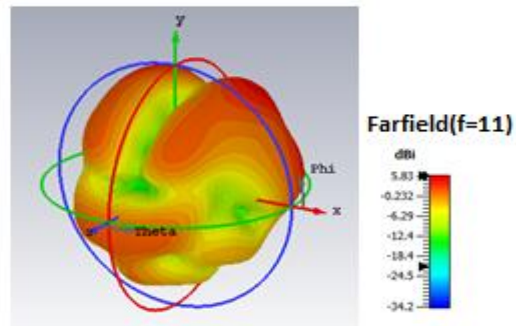


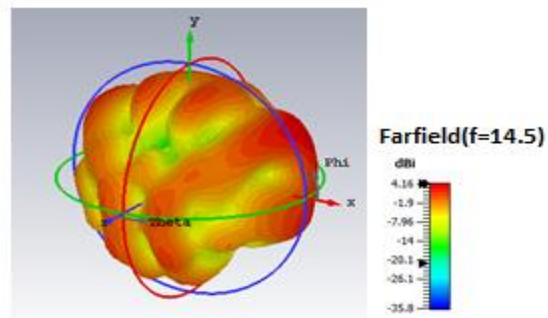
(c)



(d)



(e)



(f)

Fig 7: Simulated 3D gain characteristics at all operating bands

From Figure 7(a)-(f), it is noticed that at first resonance (i.e., 5 GHz), second resonance (i.e.,5.85 GHz), third resonance (i.e.,7.2 GHz), fourth resonance (i.e.,10 GHz), fifth resonance (11 GHz) and sixth resonance (14.5 GHz) the radiation performance are bidirectional in nature with a total gain of 3.42, 6.05, 5.5, 5.3, 5.83 and 4.16 dB respectively.

Figure. 8 compares the gain characteristics of metamaterial-inspired superstrate antenna along with RSRR antenna designed with Roger and FR4 substrate materials. The superstrate antenna provides significant improvement in gain compared to SRR structure designed using Roger and FR4 substrate materials.

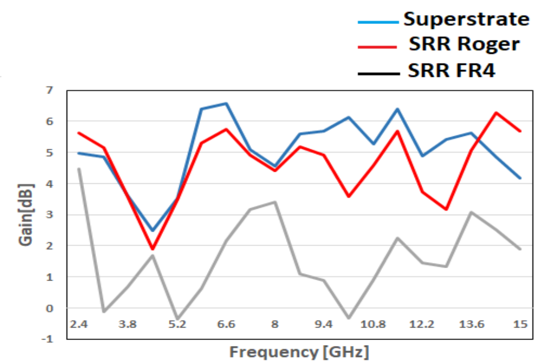


Fig 8: Gain Characteristics

It is observed from the simulated results that six band operation, improved gain performance, lesser return loss, and considerable bandwidth are the advantages of the proposed metamaterial inspired superstrate antenna structure

IV. CONCLUSIONS

A planar six band metamaterial-inspired superstrate antenna has been designed and presented in this manuscript. The proposed structure is analyzed with the simulation and measurement results. The gain of the designed structure was enhanced by using an 8 x 7 periodic array as superstrate, which uses FR4 dielectric as superstrate material and Roger RT duroid 5880 as substrate material. Therefore, the proposed design is well suited for current wireless communication applications.

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