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Circular Split Ring Resonator Loaded Circular Patch Microstrip Antenna for 5.2 GHz ISM Band

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Abstract: In this paper, a miniature improved gain Circular Patch Antenna (CPA) is reported. An array of Circular Split Ring Resonators (CSRRs) is loaded into a circular patch to transfigure the surface current distributions leading to miniaturization and significant gain enhancement. To obtain a bi-conical beam, the antenna is operated at Higher Order Mode (HOM). The HOM is excited by suitably selecting the feeding location. The unit cell of the CSRR is analyzed and the permittivity of the CSRRs loaded antenna structure is extracted using Scattering Parameter Inversion (SPI) method. The proposed antenna operates in 5.2 GHz band and built on a thin (0.254 mm) RT/Duroid 5880 substrate thus, flexible in nature. The bending analysis is performed showing a natural frequency shift. To validate the proposed design, the prototype is fabricated showing good agreement amongst simulated and measured results is found.

Keywords: Circular patch antenna, Circular split ring resonator, Conformal antenna, Gain enhancement, High-gain antenna, Antenna miniaturization.

1. Introduction

Microstrip patch antennas have several advantages such as small in size, less weight, low manufacturing cost, easy fabrication and can be mount on different shape of surface. However, the Microstrip patch antenna suffers with low gain and narrow bandwidth. To combat with these shortcomings several techniques have been suggested such as: Planer multi resonator configuration which provides broad bandwidth but increase the size of the antenna, electromagnetically coupled MSA in which more than one patches are placed on different dielectric layers and they are coupled electromagnetically to the feeding point at the bottom of the dielectric layer but main limitation of this structure is it increases the height of the antenna and which is not suitable for conformal applications, Log periodic MSA configuration used to increase the bandwidth but the radiation pattern varies over the impedance bandwidth also it increases the length of the antenna, Broadband Thick RMSA with Various Probes this technique helps to improve the bandwidth but due to multiple probe use impedance matching is become an issue, Gap-Coupled RMSAs techniques increase the antenna size etc. [1].

Recently Metamaterials are become new trends for fabrication as substrate material used for patch antennas. Metamaterial with negative permeability and permittivity was first hypothetically dissected by Veselago in 1968 [2]. Use of Metamaterials can increase the antenna performance characteristics like antenna gain and bandwidth [3]. Metamaterials are the artificial materials not available in nature having properties like negative permittivity and permeability which natural materials don't have [4]. The metamaterial used as a substrate exhibits large bandwidth and high gain due to the material property [5-7]. In Negative Index Metamaterial (NIM) if both permittivity and permeability are negative then that is called double negative material (DNG) [8]. Ziolkowski and Kipple [9] suggested an application of double negative material (DNG) to increase power radiation from small antenna. In addition to this size of the antenna also a very important parameter for several applications like WLAN, military gadgets, personal area communications, advance digital devices etc. demands reduction of antenna size [10]. To achieve the size reduction the complementary split ring resonators (CSRRs) [11-13] are proposed on the ground plane, providing nearly 30% of size reduction is achieved with FBR (Front to back ratio) close to 1 dB. In [14], a compact monopole CSRR loaded antenna was introduced for dual band (1.9 and 2.5 GHz) operations. Here more than one layer metasurface used as a ground plane increase the antenna characteristics. For obtaining dual polarized multibeam radiation pattern a holographic multi beamforming antenna was reported in [15]. In [16] an antenna was proposed for wideband satellite communication. This antenna provides circular polarization which is suitable for long distance communication. The frequency of operations is fixed to 5.2 GHz. In [17] a small size metasurface lens is used to increase antenna gain in boresight direction which is suitable for directional antenna. In [18] three different designs like nearly square, nearly square corner trimmed and nearly square corner trimmed with slot antenna was proposed for 5.2 GHz wireless applications. Recently, an efficient and effective optimistic technique is utilized for selection of cloud service provider in a smart city by M. Sarkar et al. [19]. For parameter antenna optimization fuzzy techniques may be adopted.

In this paper, we present a circular split ring resonator loaded circular patch Microstrip antenna. This structure operates at 5.2 GHz (ISM-band) [20] and probe feed is used to feed the antenna. Use of Metamaterial as substrate and circular split ring resonator leads to improve in antenna gain and size also reduced. The antenna was simulated, prototyped, and tested for plotting various performance measurements. The measured return loss is near to -38 dB which results good impedance matching. The CSRRs loaded antenna achieves a measured peak realized gain of 6.2 dBi. Also some of the antenna characteristics improved than those presented in [14-17] listed in table 2. This paper is organized as below sections: In Sec. 2 Antenna Configuration, In Sec. 3 results and discussion and Sec. 4 presents conclusion of the work.

Table 1. Values of x_{nm} for different propagation modes

Modes(n,m)	0,1	1,1	2,1	0,2	3,1
x_{nm}	0	1.84	3.05	3.83	4.20

2. Antenna configuration

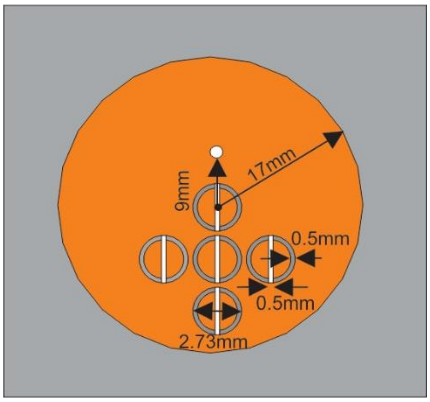
Initially, a conventional CPMA operating in TM_{02} mode is designed using the following expressions:

$$f_{nm} = \frac{X_{nm} C}{2\pi a_e \sqrt{\epsilon_r}} \tag{1}$$

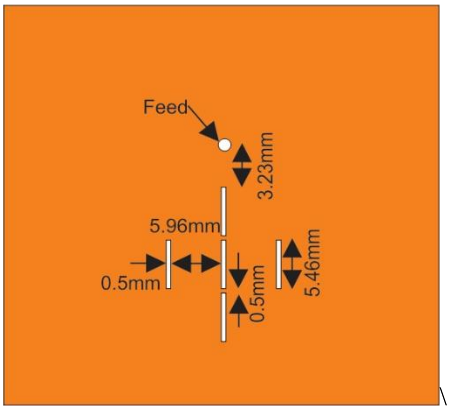
$$a_e = a[1+\frac{2h}{\pi a \epsilon r}\{ln\frac{\pi a}{2h} + 1.7726\}]^{1/2} \tag{2}$$

Where, f_{nm} is the operating frequency, X_{nm} is a constant (values for respective modes are presented in Table-1), a_e is the effective radius of the patch, a is the actual radius of the patch, h is the thickness of the substrate and ε_r is the dielectric constant of the substrate. The calculated radius of the circular patch is 23.9 mm.

The configuration of the proposed antenna is shown in Fig. 1. The proposed antenna is fabricated on a thin (0.254 mm) RT/Duroid 5880 Substrate for 50 Ω input impedance and fed through probe feed [21] SMA Connector.



(a)



(b)

Figure. 1 Configuration of the proposed antenna: (a) top view and (b) bottom view

Five CSRRs are loaded in the patch at optimized locations to alter the current distributions on the radiator (shown in Fig. 2). It can be seen in Fig. 2 that for the CSRRs loaded structure the surface current is focused on specific locations (left and right side of CSRRs) resulting in enhanced antenna gain.

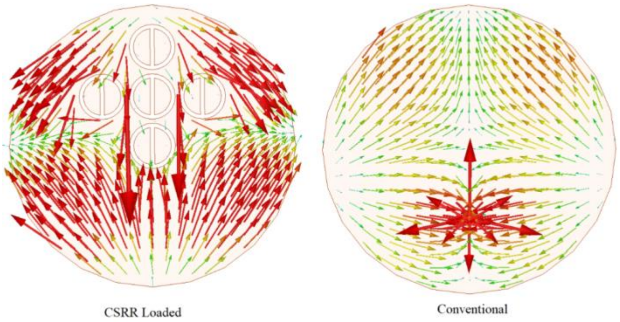


Figure. 2 Surface current distribution on the patch

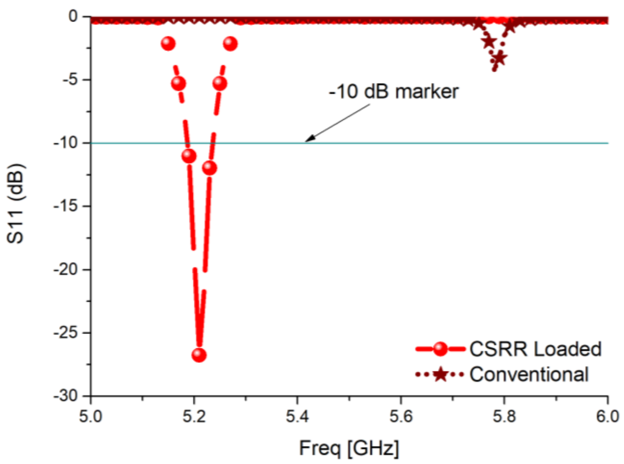
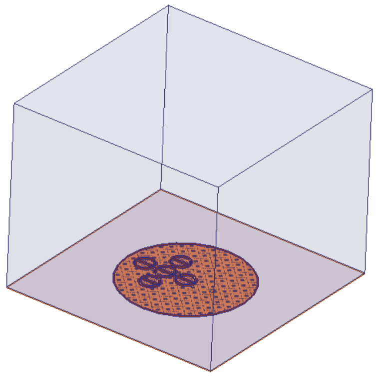


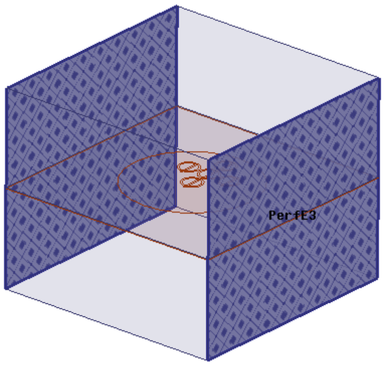
Figure. 3 Simulated S11 of the conventional and CSRR loaded antennas

It is observed in Fig. 3 that loading the CSRRs into the patch is shifting the operating frequency towards the lower side with improved impedance matching. Thus a smaller patch size is required to operate the antenna at 5.2 GHz leading to significant miniaturization. On the contrary, loading the CSRRs are resulting in overall negative effective dielectric constant which improves the radiation performance of the structure.

The effective dielectric constant of the CSRRs loaded structure is extracted using scattering parameter inversion method, as shown in Fig. 4. The CSRRs loaded antenna is placed into an air-box and master-slave boundary conditions are applied to extract the transmission magnitude and phase characteristics.



(a)



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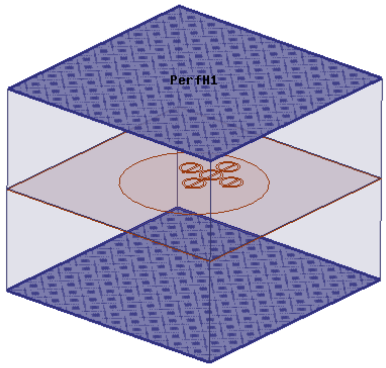
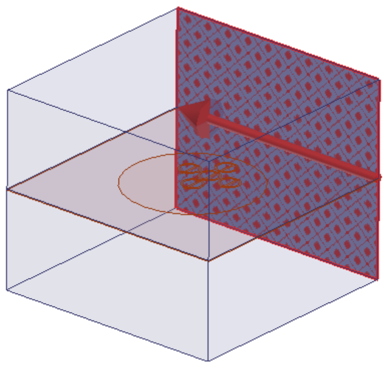
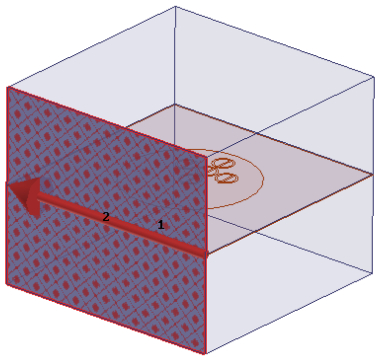


(c)



(d)



(e)

Figure. 4 Boundaries and excitation for scattering parameter inversion method: (a) antenna into the air box, (b) perfect E-field to a pair of horizontal faces, (c) perfect H-field to the pair of horizontal faces, (d) master-slave 1, and (e) master-slave 2

Thereafter, dielectric constant of the overall structure is extracted using following MATLAB program:

```
clc
clf
clear all
S11=csvread('E:\S11.csv'); %S11
parameter value
S12=csvread('E:\S12.csv'); %S12
parameter value
S11(:,2:3)=flipud(S11(:,2:3)); %freque
ncy reversal
S12(:,2:3)=flipud(S12(:,2:3)); %freque
ncy reversal
S11=S11(:,2).*(cos(S11(:,3))+i*sin(S11
(:,3)));%Complex S-parameters
S12=S12(:,2).*(cos(S12(:,3))+i*sin(S12
(:,3)));%Complex S-parameters
f=S11(:,1)*1e9;%Frequency range
c=3e8;%Speed of light
k=(2*pi/3e8)*f;%Wave Number
d=31e-3; %length/thickness
Z=((((1+S11).^2)-S12.^2)./(((1-
S11).^2)-S12.^2)).^0.5;
tmp=(Z-1)./(Z+1);
exp=S12./(1-S11.*tmp);
n=(imag(log (exp))-
i.*real(log(exp)))./(k*d);
eps=n./Z;
a=real(eps);
b=imag(eps);
```

The process for extracting dielectric constant for overall structure is given below [22-23]:

To measures wave amplitudes and phases between ports in a network, yielding a matrix such as the one given below which relates incoming and outgoing waves [24].

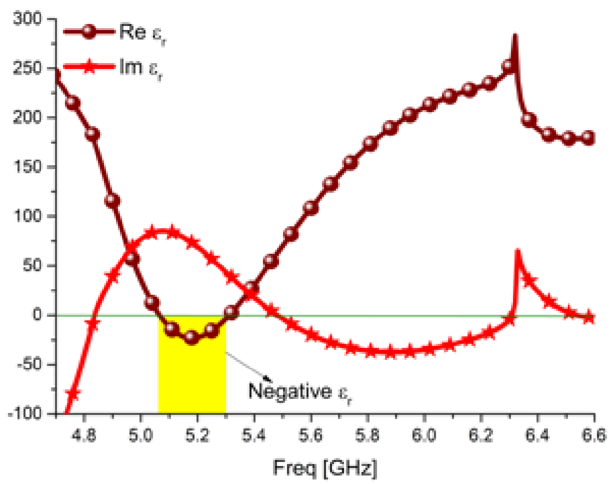


Figure. 5 Dielectric constant of CSRR loaded antenna structure

$$S=\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \tag{3}$$

$$\Gamma=\frac{Z-1}{Z+1} \tag{4}$$

Γ = relative material impedance

The approach considered here will determine Z and n then use these intermediate results to calculate permeability and permittivity.

$$Z=\pm\sqrt{\frac{(1+S_{11})^2-S^2_{12}}{(1-S_{11})^2-S^2_{12}}} \tag{5}$$

$$n=-\frac{1}{k_0 d}ln\left(\frac{S_{12}}{1-s_{11}\frac{Z-1}{Z+1}}\right) \tag{6}$$

Here,

n = refractive index

d= length/thickness

Z=Impedance

k_0= Wave Number in vacume

If the material is passive, it must have a real part of Z that is positive.

Measurement of S parameters done using vector network analyzer.

The extracted dielectric constant of the CSRRs loaded antenna structure is shown in Fig. 5. It is evident that for 5.2 GHz band, the antenna structure exhibits negative dielectric constant resulting in improved radiation performances.

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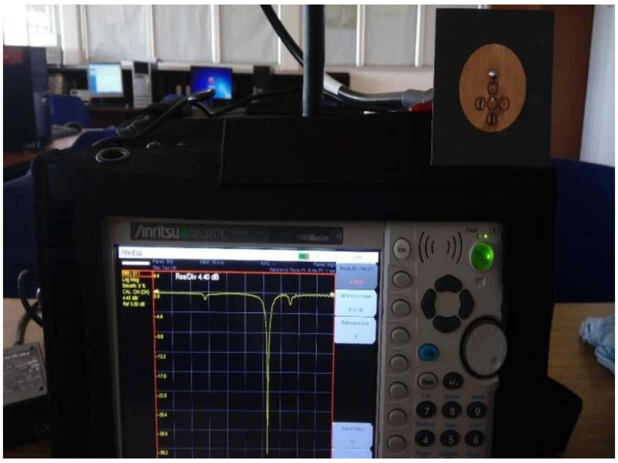
3. Results and discussion

The prototype of the antenna and S11 measurement setup is shown in Fig. 6. The S11 and gain of the antenna are measured using Vector Network Analyzer (VNA).

(a)

(b)



(c)

Figure. 6 Prototype and measurement setup: (a) top view of the prototype, (b) bottom view of the prototype, and (c) S11 measurement setup

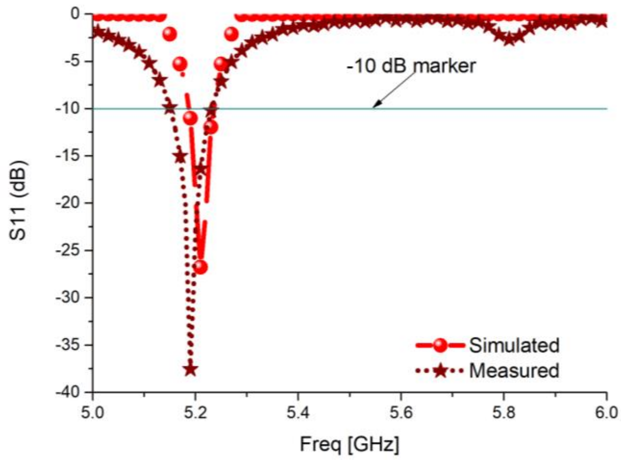


Figure. 7 Simulated and measured S11 parameter

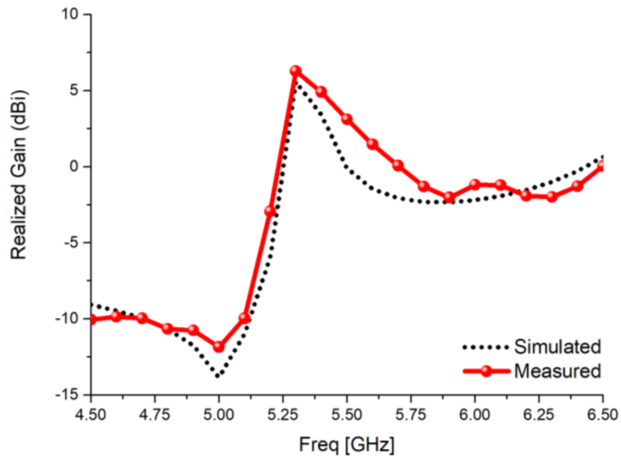


Figure. 8 Simulated and measured realized gain

The simulated and measured S11 parameter is shown in Fig. 7. The measured S11 has wider bandwidth and better impedance matching as evident in Fig. 7.

The simulated and measured frequency versus realized gain curve and simulated gain 3D-polar plot of the antenna at 5.2 GHz is shown in Figs. 8 and 9 respectively.

The CSRRs loaded antenna achieves a measured peak realized gain of 6.2 dBi. It is evident in Fig. 9 that the loading the CSRRs improves the antenna gain by 4.58 dBi.

The simulated and measured E and H-plane pattern of the antenna has very good accord, as shown in Fig. 10. Although the antenna has excellent gain and bi-conical radiation pattern, the antenna has quiet higher back radiations.

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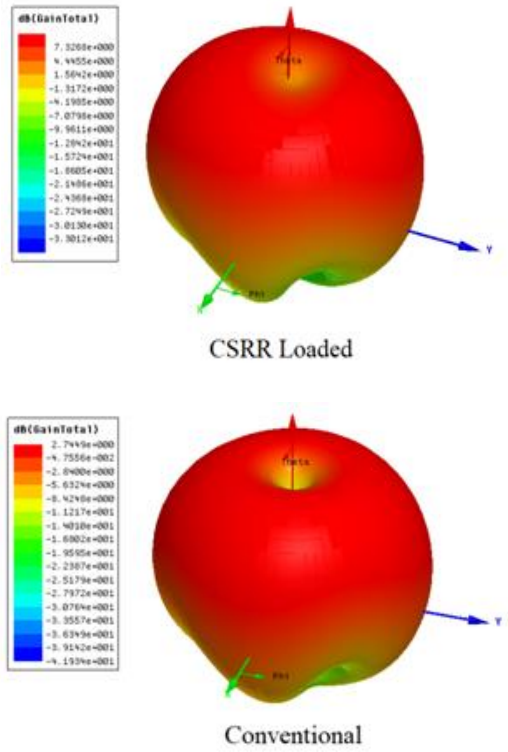
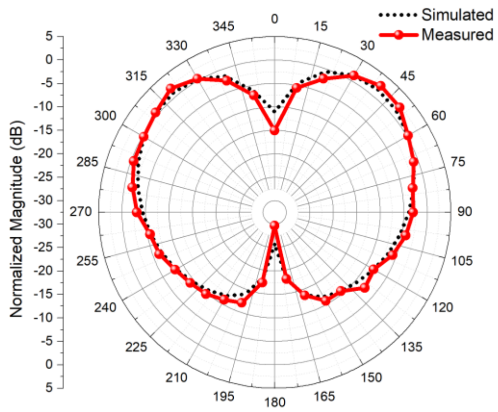
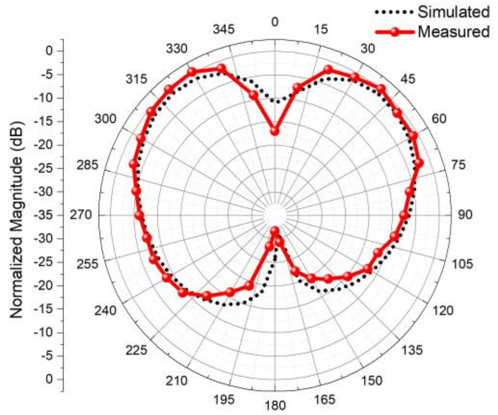


Figure. 9 Simulated gain 3D-polar plot of CSRRs loaded and conventional antenna



(a)



(b)

Figure. 10 Simulated and measured radiation pattern: (a) E-plane and (b) H-plane

Small differences between the simulated and measured results are observed which is due to the differences between the simulation model of materials and actual materials as a dielectric, connectors and metals.

Due to less thickness (0.254 mm) of the antenna it can be used as conformal antenna in future and the overall antenna footprint reduces that leads to size reduction of the antenna compare to the conventional antennas so it can be easily fit in to the anyplace. The use of split ring resonator enables rings to resonate at frequencies higher than closed rings. The structure of the resonator is simple. It has a split in its rings. The discontinuity in the ring produce capacitive effect and that increase the magnetic property of the object and good amount of radiation can be achieved. The gain achieved here is 6.2 dBi due to use of metamaterial and the five circular split ring resonator, which is far better compare to the conventional designs. The return loss S11 curve realized below -10 dB and the value is -38 dB which indicates good impedance matching and maximum power transfer takes place towards the antenna radiation side. Butterfly structure radiation pattern achieved which provides good coverage area of the device. Excellent agreement obtained between the experimental measurements and the numerical results.

4. Conclusion

A miniature circular patch antenna with improved realized gain and the bi-conical pattern is presented. The CSRRs loaded antenna is characterized by Scattering Parameter Inversion Method which is an effective method to extract material properties. Loading the CSRRs array into the patch modifies the overall dielectric properties of the structure thus, significantly affecting the antenna performances. By placing the optimized CSRR array into the antenna structure the performance of the antenna can be improved. The bi-conical pattern of the antenna is obtained by exciting the higher order mode. The return loss achieved is -38 dB at 5.2 GHz (1.2% bandwidth). The performance is better than that required to meet the demanding bandwidth specifications useful to cover the 5.2 GHz frequency band which comes under wireless C band and various applications like wireless local area network (WLAN), high speed multimedia sharing etc. At the same time, using of five circular split ring resonators improves the performance of the proposed antenna and the antenna offers high gain of about 6.2 dBi. All these

Table 2. Performance comparison of the proposed design and existing design

Ref. No.	Year	f_0(GHz)	Antenna footprint	Gain (dBi)	Minimum S11 parameter (dB)	BW (%)	Configuration
14	2017	1.9, 2.5	0.062 λ^2	4.52, 4.15	-17	5.8, 4	External Metasurface
15	2017	25	234.5 λ^2	10.2	-12	6	Integrated Metasurface
16	2016	5.2	0.07 λ	5.8	-25	33.7	External Metasurface
17	2016	4.45	1 λ^2	10.2	-23	8	External Metasurface
Proposed work	2018	5.2	0.6 λ^2	6.2	-38	1.2	Integrated

features are very useful for worldwide portability of wireless communication equipment and high speed services. Excellent agreement achieved between the experimental measurements and the numerical results.

In future a metasurface can be deployed beneath the antenna to suppress the back radiations also conformal antenna structure can be design and performance can be evaluated for various application, which can be mount on bent geometry or curved surface. Conformal types antenna provides wide coverage angle, Installation of radome not required so; eliminate the losses caused by radome, Improvement of aerodynamic profile etc.

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