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Research paper

Metamaterial loaded circular ring micro strip antenna with CSRR as ground plane for 5g applications

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Abstract

This paper presents a miniaturized UWB antenna with metamaterial for WLAN and Ku band applications. Miniaturization is obtained using metamaterial loaded ground structure (CSRR) and surface wave losses improved using EBG structures. The physical dimension of the antenna is 20 mm x 20 mm. In unloaded condition the antenna resonates at single band. When the same antenna is loaded with CSRR in the ground plane, it resonates at different frequencies which are used to achieve 5G applications which is the demand of current technology. The Metamaterial based antenna is designed for some improvement in the performance of directivity gain, return loss and size of circuit area. A patch antenna has been designed and fabricated to operate between 9GHz-16GHz.

Keywords:*Complimentary Split Ring Resonator;EBG, FR4; Multiband; Negative Permeability; Rogers RT Duroid.*

1. Introduction

There is growing demand for compact as well as multi-band microstrip patch antennas in the rapidly changing scenario of wireless and mobile communication. Secondly these antennas need the features such as high gain, high directivity and large bandwidth.
Microstrip patch antennas have greater potential due to their low profile, light weight and low cost. Moreover, the performance of these antennas can be reinforced by using techniques such as making the slots inside the patch, curving, stacking, use of high permittivity substrates etc. The above mentioned techniques have certain limitations [1-10]. Up to a great extent metamaterial i.e Defected Ground Structure has appreciably eliminated these limitations. In addition some applications of microstrip patch antenna required small size to meet the miniaturization in communication systems.
In 1968, Veselago theoretically predicted the basic properties of the artificial material simultaneously possessing the negative values of magnetic permeability (μ) and electric permittivity (ε) termed as metamaterial [14]. The structure consists of split ring resonators (SRRs) to produce negative permeability and thin wire elements to generate negative permittivity. The negative permittivity was proved and theorized with an array of metallic wires in 1996 by Pendry. The metamaterial characteristics of different split ring resonators like square, rectangular, omega, split squared ring resonator etc. have been reported in [11-13].These resonators are widely used in different microwave applications such as antennas, waveguides, filters etc. [1-2]. The authors have reportedelectrically small microstrip patch antenna loaded with metamaterial square SRR and MSRR respectively [5-6].Han Xiong et al. proposed metamaterial rectangular patch antenna operating at 13.5GHz for UWB application with the dimension of 27.6×31.8 mminF4BM-2 substrate [15].
Miniaturized multiband microstrip patch antenna loaded with double circular slot ring resonator has been proposed [15]. Dual resonant microstrip patch antenna can also be achieved by using circular geometry metamaterial in the ground plane which works at 2.7 GHz and 7.5 GHz[16]. It was also reported that miniaturization can be done by using negative permittivity metamaterial based on CSRR[17]. Patch antenna miniaturization for Electromagnetic Compatibility (EMC) applications is reported in [18] using CSRR.
This defect which is introduced on a ground plane called Complementary Split Ring Resonator (CSRR) which is the dual of Split Ring Resonator (SRR) will disturb the distribution of current by influencing the input impedance and the flow of current to the antenna. It can also restrict the excitation and electromagnetic waves propagating through the substrate layer. Electro-Magnetic band gap (EBG) is also inserted to suppress the surface wave losses.
In this work, metamaterial CSRR is used to reduce the mutual coupling .The objective of this paper is to propose a circular ring microstrip patch antenna loaded with metamaterial at the ground plane. This paper focuses on comparison of metamaterial loaded circular ring patch antenna on different substrate materials. The simulation tool used is Ansoft HFSS version 13 which is an industrial standard for simulating 3D full wave electromagnetic behaviour of a structure.It offers multiple solver technologies based on finite element, integral equation or advanced hybrid methods to solve a wide range of applications. To calculate the 3D electromagnetic field inside the structure and the corresponding S-parameters, HFSS employs Finite Element Method (FEM) which delivers the most accurate result.
This paper is organized into following section. In section II, the detailed geometrical structure of the circular ring microstrip antenna and the CSRR unit cell with their designs are presented. In section III, the results ofmetamaterial loaded circular ring microstrip patch antenna is presented and compared using different substrate materials.

2. Antenna geometry

In this paper, circular ring microstrip antennas loaded with metamaterial have been designed using High Frequency Structure Simulator(HFSS). The substrate materials are FR4 and RT Duroid.The sketch and geometries of the circular ring microstrip patch antenna are shown in fig.1. In this structure, initially a circular ring patch antenna with inner radius=4 mm and outer radius = 8 mm is designed.

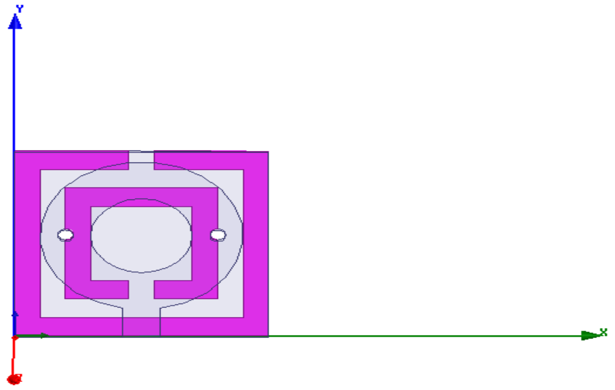


Fig. 1: Geometrical Structure of Metamaterial Loaded Circular Ring Antenna.

The proposed square CSRR is etched on the ground plane. The geometrical dimensions of a square CSSR are; length of the outer split ring is L_s=20 mm, gap at the split of both rings (g), width of the rings (w) , and the separation between the inner and outer splitrings (s) are set to; g=w=s=2 mm. The dimensions of the split ring structure are shown in the Fig.2.

Here two air cavities (cylindrical holes) of same radius=0.6 mm are drilled to make EBG structure. This antenna is designed and simulated on FR4 and RT Duroid substrate of thickness h=1.6 mm and ε_r=4.4and 2.33.The antenna is fed at x=3 mm and z= 1.6 mm using microstrip feed line which is easy to fabricate, simple to match and model.

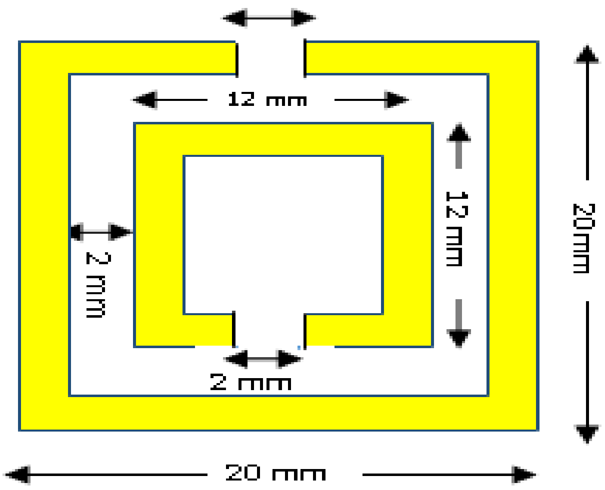
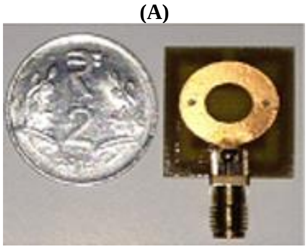


Fig. 2: Geometrical Structure of CSRR Etched on the Ground Plane.

(A)



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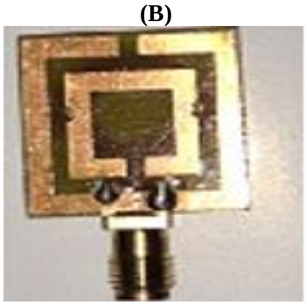
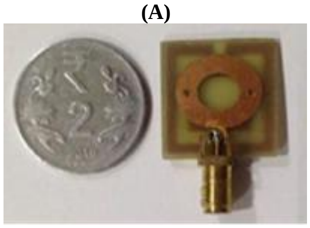


Fig. 3: Photographs of Fabricated Metamate-Rial Loaded Circular Ring Microstrip Patch An-Tenna on FR4 Substrate A) Radiating Patch B) Ground Plane.

(A)



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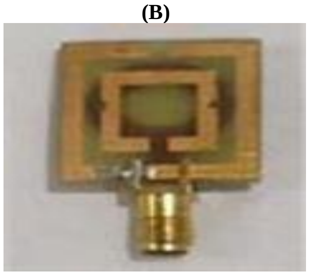


Fig. 4: Photographs of Fabricated Metamate-Rial Loaded Circular Ring Micro Strip Patch Antenna on RT Duroid Substrate A) Radiat-Ing Patch B) Ground Plane.

Fig. 3(a), 3(b), 4(a) and 4(b) depicts the photographs of the radiating patch and the ground plane of the fabricated antenna respectively. The purpose to select the circular ring shape is to increase the resonant length and to reduce the volume of the antenna.

The proposed antenna is entirely handmade and high degree of accuracy is maintained in the entire fabrication processes. HFSS simulator is used to simulate the antenna. The performance of different dielectric material for design of a circular ring microstrip patch antenna loaded with metamaterial is analysed in terms of bandwidth, gain and directivity. A circular ring microstrip patch antenna was designed not only to improve the antenna bandwidth but also to reduce the size of the conventional microstrip patch antenna. Analysis of the design of microstrip patch antenna at X and Ku band frequency range (8-18GHz) has been carried out using commercial available computer model of HFSS and results are obtained for return loss, VSWR , Gain, Directivity and radiation pattern.

A comparative study is performed to know the dielectric properties of two different substrates affecting antenna performance. The different substrate materials used in the proposed antenna are Rogers RT/ Duroid 5880(tm), and FR4 substrate. The table1 shows the different substrate materials used with their relative permeability and relative permittivity and the design specification of the proposed antenna.

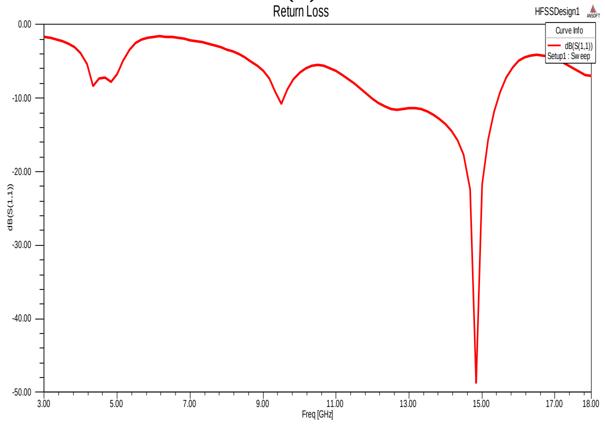
Table 1: Design Specification

Sl.No	Description	Unit	
1	Substrate Material	FR4 EPOXY	RT Duroid
2	Ground Plane	CSRR	
3	Resonant Frequency	9 GHz	
4	Relative Permittivity	4.4	2.33
5	Outer circle	8 mm	
6	Inner circle	4 mm	
7	Radiation Box	Air	
8	Cylindrical Holes	0.6 mm	

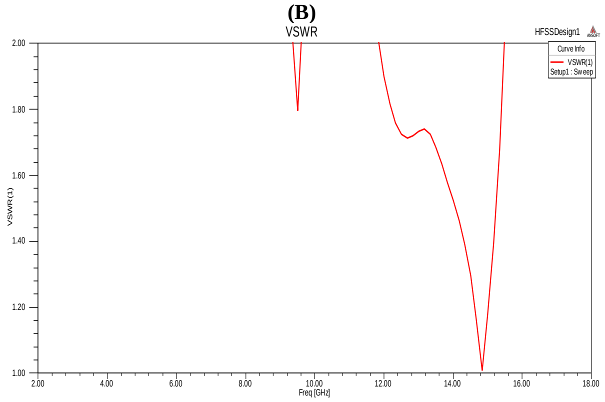
3. Results and discussion

The functional parameters such as return loss, VSWR, gain, directivity, radiation efficiency and radiation patterns using 3D polar plot are analyzed for different substrate materials using simulation. The simulated characteristics of various antenna parameters of CSRR microstrip ring antenna on FR4 substrate are shown in fig.5.

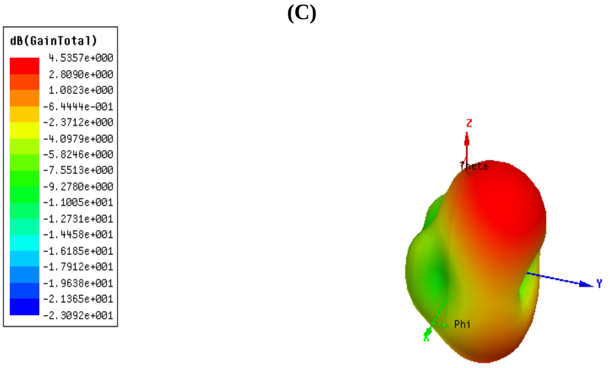
(A)



(B)



(C)



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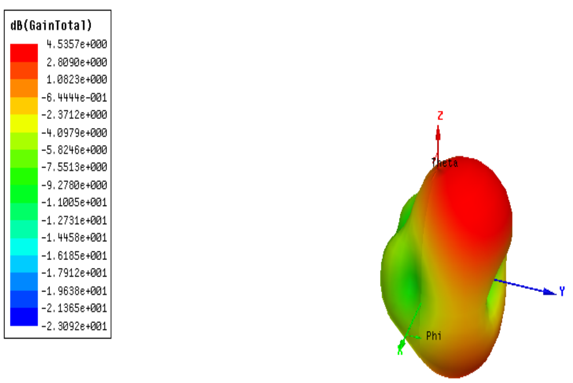

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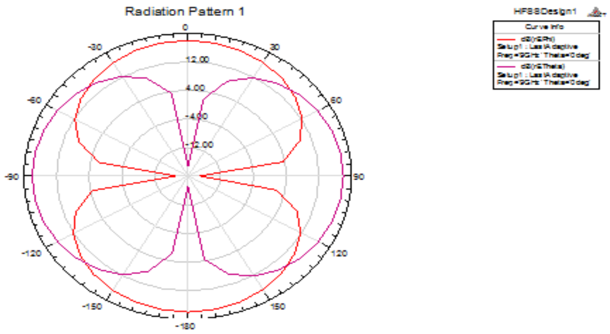
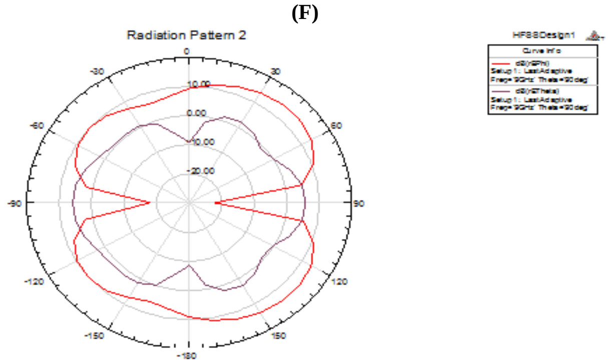


(F)



(G)

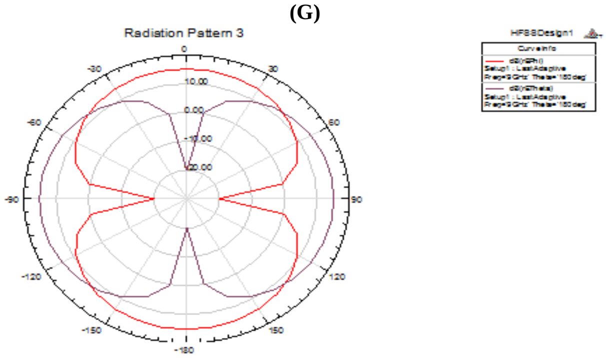


Fig. 5: Simulated A) Return Loss B) VSWR C) Gain D) Directivity E) Radiation Pattern at 0o F) Radiation Pattern at 90o G) Radiation Pattern at 180oon FR4 Substrate.

Fig.5(a) shows the return loss (S_{11}) characteristics of metamaterial loaded circular ring microstrip antenna on FR4 substrate.The antenna resonates at 9.5 GHz and 14.8 GHz with a gain of 4.5 dB and bandwidth of175 MHz and 3.5 GHz respectively[20-22].

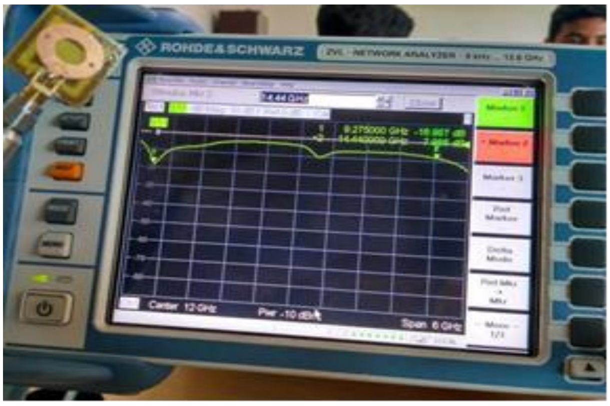


Fig. 6: Photograph of Experimental Set Up to Test Metamaterial Loaded FR4 Based Circular Ring Micro strip Antenna.

Fig.6 shows the photograph of the experimental set up of return loss and SWR measurement of the fabricated antenna using Rohde and Schwarz network analyzer (Frequency range9 kHz-13.6 GHz)

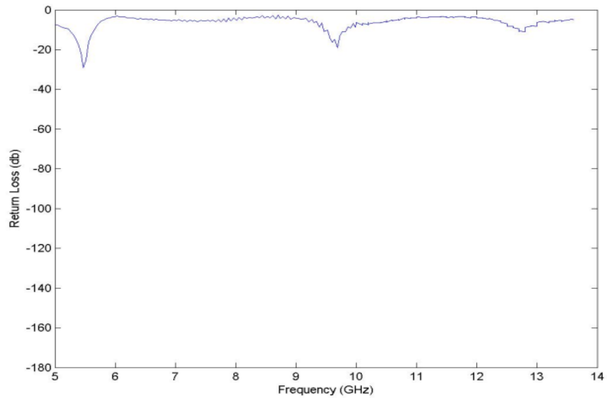
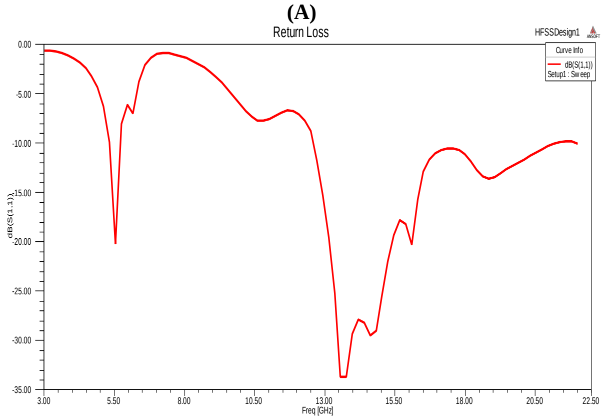


Fig. 7:.Measured Return Loss (S11) Characteristics on FR4 Substrate.

The measured return loss (S11) characteristics of the metamaterial loaded circular ring microstrip antenna on FR4 substrate which is plotted in MATLAB is illustrated in fig.7.This antenna find its applications in S band marine radar applications and X band communications

Fig.8 depicts the simulated characteristics ofvarious antenna parameters of CSRR microstrip antenna on RT duroid substrate

(A)



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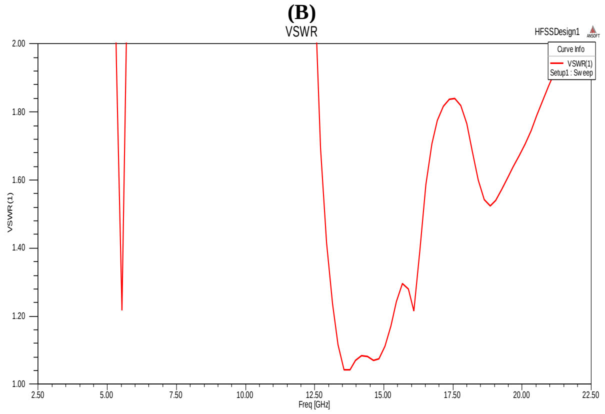

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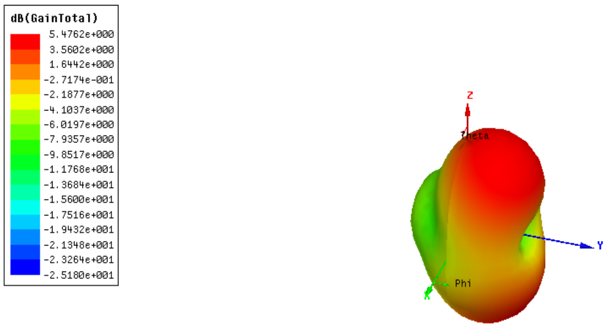

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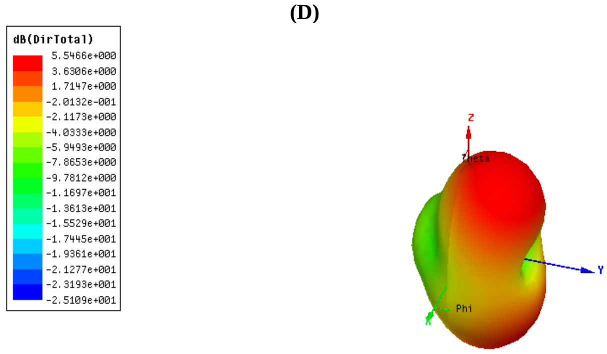

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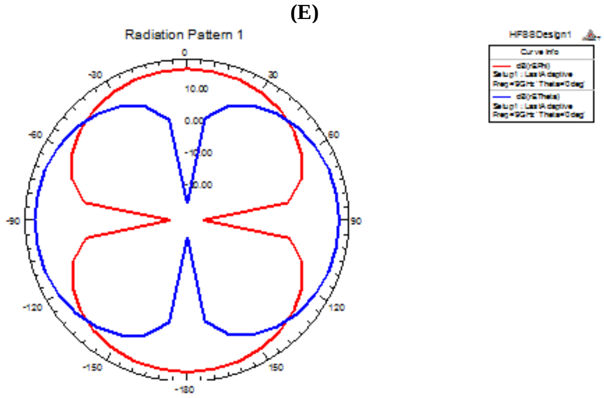
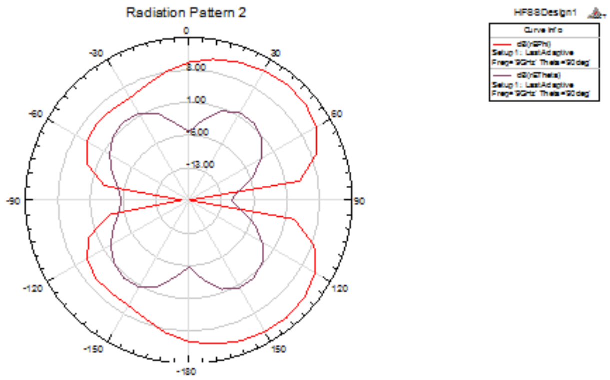


(F)



(G)

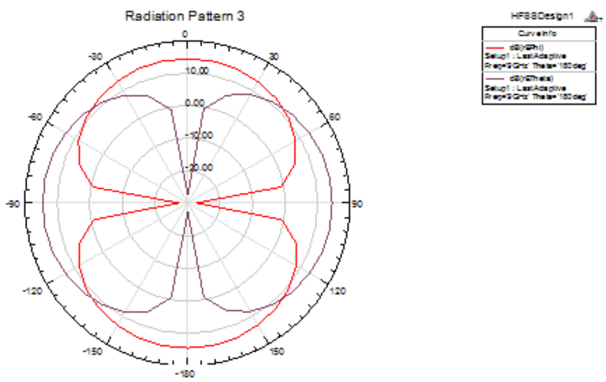


Fig. 8: Simulated A) Return Loss B) VSWR C) Gain D) Directivity E) Radiation Pattern At 0o F) Radiation Pattern at 90o G) Radiation Pattern at 180oon RT Duroid Substrate.

Fig.8(a) represents the return loss (S_{11}) characteristics of metamaterial loaded circular ring microstrip antenna on RT Duroid substrate.The antenna resonates at 5.5 GHz ,13.7 GHz and 16.1 GHz with a gain of 5.47 dB and bandwidth of400 MHz and 8.5 GHz respectively[20-22].

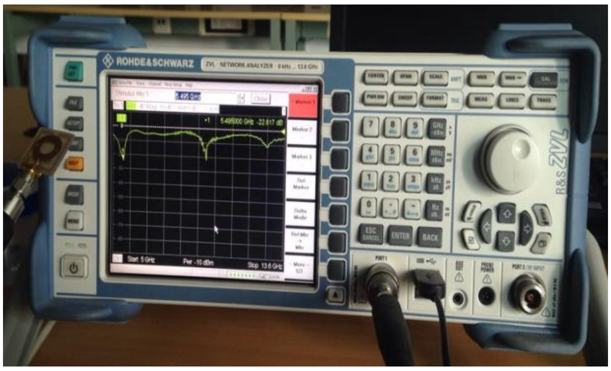


Fig. 9: Photograph of Experimental Set Up to Test Metamaterial Loaded RT Duroid Based Circular Ring Microstrip Antenna

Fig.9 shows the photograph of the experimental set up of return loss and SWR measurement of the fabricated antenna using Rohde and Schwarz network analyzer
(Frequency range9 kHz-13.6 GHz)

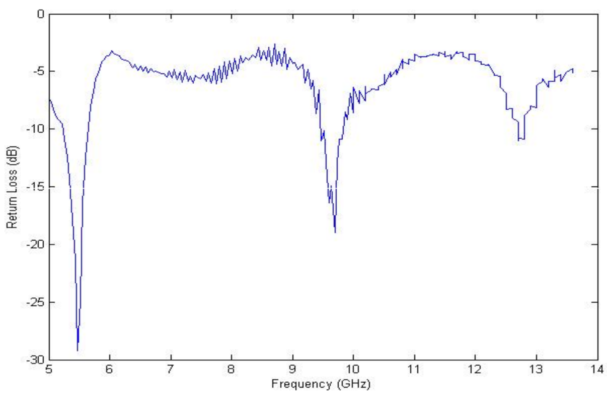


Fig. 10:.Measured Return Loss (S11) Characteristics on RT Duroid Substrate.

The measured return loss (S_{11}) characteristics of the metamaterial loaded circular ring microstrip antenna on RT Duroid substrate plotted in MATLAB is illustrated in fig.10.This antenna find its applications in WLAN and X band communications.
The table 2 shows the antenna parameters for Metamaterial loaded Circular Ring MPA using FR4 and RT Duroid substrate.

Table 2: Comparative Analysis of Various Antenna Parameters

Substrate Material	FR4 Substrate		RTDuroid Substrate	
Return Loss	9.5 GHz	-10.65 dB	5.5 GHz	-20.2 dB
	14.8 GHz	-48.62 dB	13.7 GHz	-33.23 dB
			16.1 GHz	-20.93 dB
VSWR	9.5 GHz	1.7	5.5 GHz	1.08
	14.8 GHz	1	13.7 GHz	1.07
			16.1 GHz	1.19
Bandwidth	9.5 GHz	175 MHz	5.5 GHz	400 MHz
	14.8 GHz	3.5 GHz	13.7 GHz	8.5 GHz
			16.1 GHz	
Application	9.5 GHz	S band marine radar applications	5.5 GHz	WLAN
	14.8 GHz	X band	13.7 GHz	X band
		communications	16.1 GHz	communications
Gain	4.5 dB		5.47 dB	
Directivity	5.6 dB		5.47	
Efficiency	80.35%		100%	

4. Conclusion

A CSRR loaded circular ring microstrip patch antenna is studied, designed and simulated and antenna parameters such as return loss, VSWR, Gain, directivity, efficiency & radiation patterns with different substrate materials are compared. Metamaterial loaded Circular Ring MPA using Rogers RT/Duroid5880 (tm) substrate gives the best results with 100 % efficiency and more bandwidth which is suitable for WLAN, X and Ku band applications.

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