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Frequency Switching of PIFA Using Split Ring Resonator

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Abstract:- In this paper, a PIFA loaded with split ring resonator (SRR) is presented, in which frequency switching is performed by varying the radius of split rings. The proposed Planar inverted- F antenna (PIFA) without metamaterial resonates at 7.46 GHz with return loss of -23.71 dB, gain value 5.41 dBi and bandwidth 361.8 MHz. Proposed PIFA structures with metamaterial loading resonates at multiple frequencies with gain and bandwidth enhancement in comparison to reference antenna. Size reduction is also accomplished after loading with metamaterial. Nicolson-Ross-Weir (NRW) method is employed to verify the single negative (SNG) metamaterial characteristics of split ring resonator. Design is simulated using HFSS Software.

Keywords:- Multiband, metamaterial, Nicolson-Ross-Weir (NRW), PIFA, return loss.

I. INTRODUCTION

In recent years, there is a growing demand for compact, efficient and high gain multiband antennas in wireless and mobile communication. Antennas are designed to cover one or more wireless communications bands such as the Global System for Mobile Communications (GSM900 and 800), Personal Communication System (PCS 1800 and 1900), Digital Communication Systems (DCS), Global Position System (GPS), Universal Mobile Telecommunications System (UMTS), Wireless Local Area Networks (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX), etc [1]. Apart from multiband characteristics, antennas need other features such as high gain, high directivity and large bandwidth. PIFAs are widely used in a variety of communication systems especially in mobile phone handsets due to low profile, light weight, easy integration and manufacturability [2]–[4]. There have been a number of PIFA designs with different configurations to achieve single and multiple operations by using different shapes of slots. Truncated corner technique, meandered strips and meandered shapes have been used to create multiple band operations. Branch line slit has been used to achieve dual-band operations [1]. But the above mentioned techniques have certain limitations. Metamaterial is a novel way to overcome these limitations by enhancing the overall performance of antenna.

Metamaterials are the artificial materials having some special properties which cannot be found in nature. They are synthesized by embedding specific inclusions, such as periodic structures, in the host media. In contrast to natural material, metamaterials exhibit negative values of permittivity and permeability. Due to this extraordinary behavior of metamaterials they are called as double negative (DNG) or single negative (SNG) materials. Metamaterials are referred as mu negative (MNG) if the permeability (μ) is negative and epsilon negative (ENG) incase the permittivity (ε) is negative [5]-[7]. If both the value of permittivity and permeability is negative simultaneously then the composite possesses an effective negative index of refraction for isotropic medium and is named as a left handed metamaterial. They are so named because the electric field (**E**), magnetic intensity (**H**) and propagation vector (**k**) forms a left-handed system [8]. In 1968, Veselago considered materials having negative permeability and permittivity and reported that the direction of Poynting vector is anti-parallel to the direction of phase velocity in these new engineered materials [5]. In 1990, Pendry reported that an array of metallic wires can be used to obtain negative permittivity and split ring resonators for negative permeability [6]. Further in 2000, a structure was fabricated, which was composition of split ring resonator and thin wire [7]. Metamaterials are introduced in antenna design for enhancing its performance and reducing profile. Major advantages of metamaterial antennas are miniaturization, high gain, high directivity and broad bandwidth. Metamaterial antennas are becoming functional for modern satellite, wireless and mobile communication technologies for high speed voice, data and multimedia communication [9].

Compact multiband PIFA having independent controls on the resonant bands for UMTS, m-WiMAX and 5 GHz WLAN over a wide range have been proposed in [1]. But, the maximum gain achievable with the proposed structure was 5 dBi only. A planar metamaterial antenna using offset fed diamond shaped split rings (DSSR) was presented in [9]. It was observed by authors that DSRR behaves as patch antenna in normal cut configuration whereas if the antenna structure is excited at offset cut it exhibits metamaterial characteristics. Antenna structures operating at several telecommunications standards such as GSM/WiMAX/UWB/Wi-Fi are presented in [10]. Proposed PIFA structures are having Bi-bands, tri-bands and quadric-bands antennas. In [11], a planar metamaterial MSRR loaded electrically small microstrip patch antenna with high gain and efficiency is presented. Metamaterial loading has demonstrated improvement in gain, matching, efficiency & bandwidth performance along with miniaturizaiton. The split ring resonator is an artificial structure used to achieve metamaterial properties. The SRR works as small magnetic dipole and increases the magnetic response of the material employed. SRR can be seen as a LC circuit when the radius of rings are much smaller than its wavelength. SRRs are well known in metamaterials since they can provide negative permeability that can create a stopband response at the resonant frequency and also produce new bands of operation [12]. A compact SRR loaded antenna is presented in [13]. It was seen that the gap between patch and SRR plays an important role in determining the resonant frequency of antenna.

In this work frequency switching of multiband PIFA is proposed by varying the radius of split rings employed in the design. SRRs are printed over the dielectric substrate. The characteristics of PIFA are first studied without SRR and then with SRRs having different radius values. Variations in return loss, gain and bandwidth can be seen in proposed structures by simply varying the radius of split rings. This paper is organized into five sections. The detailed geometrical structure and design of the proposed PIFA without SRR is presented in section II. Section III contains PIFA structure with varying values of SRR loading. In Section IV, the metamaterial properties of SRR are verified using effective medium theory. The simulated results of unloaded and loaded PIFA structures are also presented in this section. Finally, the paper is concluded in Section V.

II. PROPOSED PIFA ANTENNA

The design started with the conventional patch dimensions which can be calculated by using equation (1).

$$L + W = \frac{\lambda}{4} \qquad (1)$$

where λ is the wavelength, L and W are the length and width of the top patch. The final dimensions of antenna are calculated to be 74 x 60 x 7 mm3, which resonates at 7.46 GHz. The patch is having dimensions 44 X 50 mm2. Fig1.depicts the geometrical structure of proposed PIFA without metamaterial loading. The dielectric substrate used for design is FR-4, with dielectric constant 4.4 and thickness 1.5748 mm. The antenna is fed using 50 Ω microstrip transmission line having width 5mm.

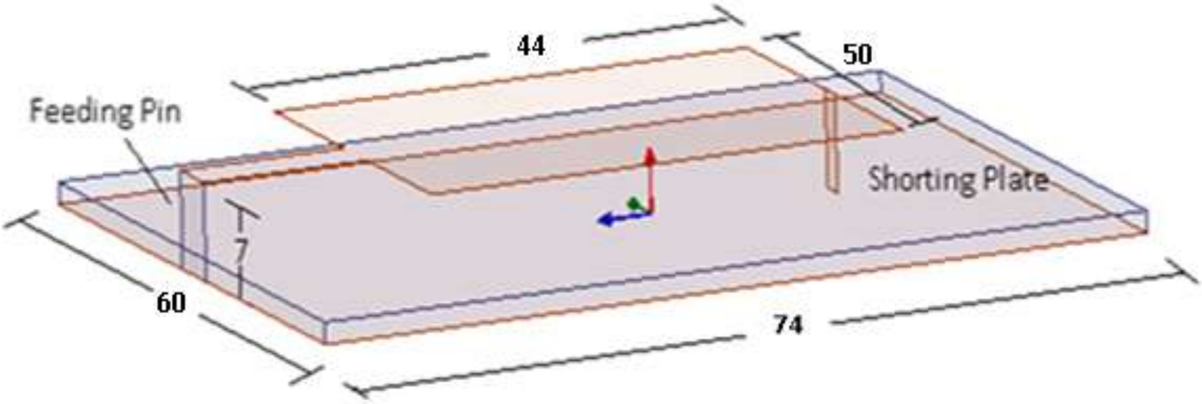


Fig. 1: The 3D view and detailed dimensions of the proposed antenna without SRR

III. PROPOSED PIFA WITH VARYING SRRS

Proposed structure consists of a short circuited patch at a distance of 3mm from ground and circular SRR’s printed over the substrate. The dimensions of the PIFA with SRR structure is 65 X 46 X 3 mm3. Patch is having dimensions of 40 X 32 mm2. Shorting and feeding pins are having the same dimensions as reference antenna. FR-4 substrate with the thickness as 1.5748 mm and dielectric constant value 4.4 is used in the design. Fig. 2 shows the geometrical structure of SRR unit cell, where r2 is the radius of outer ring and r1 is the radius of inner ring. The separation between inner and outer ring (d) = 1mm, gap in the ring (g) = 1mm and width of the circular ring (*c*) = 1 mm. The values of r1 and r2 are changed without altering the values of separation between inner and outer ring (d), gap in the ring (g) and width of the circular ring (*c*), which remain1 mm. Fig. 3 shows the structure of PIFA with SRR loading having maximum radius 6 mm. The structure is having outer ring radius r2=6 mm and inner ring radius r1=4 mm, with separation between inner and outer ring (d), gap in the ring (g) and width of the circular ring (*c*) = 1 mm. . Fig. 4 shows the structure of PIFA with SRR loading having maximum radius 8 mm. The structure is having outer ring radius r2=8 mm and inner ring radius r1=6 mm, with separation between inner and outer ring (d), gap in the ring (g) and width of the circular ring (*c*) = 1 mm. As the radius of rings is increased, the number of rings used in the design are reduced in order to maintain the same loading position. Fig. 5 shows the structure of PIFA with SRR loading having maximum radius 10 mm. The structure is having outer ring radius r2=10 mm and inner ring radius r1=8 mm.

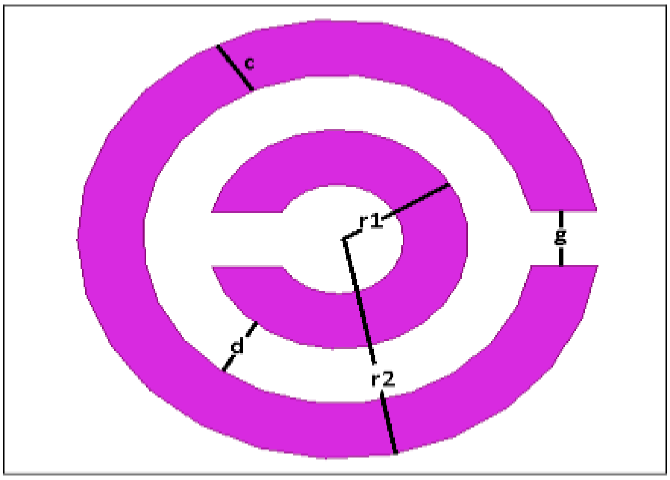


Fig. 2: Geometrical structure of metamaterial SSR unit cell.

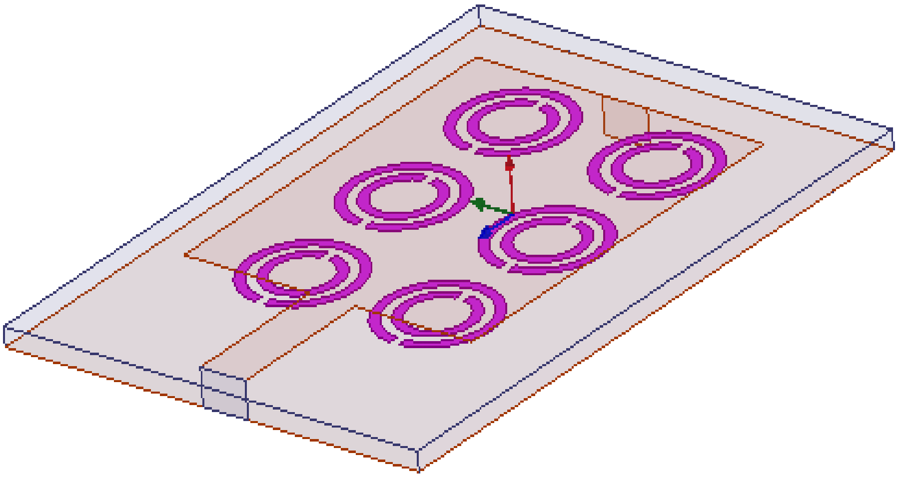


Fig. 3: Proposed antenna with SRR having maximum radius 6 mm

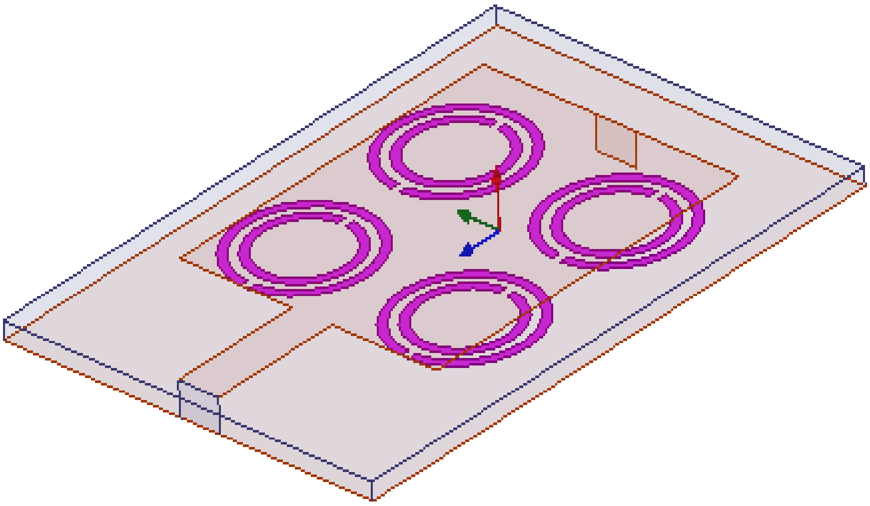


Fig. 4: Proposed antenna with SRR having maximum radius 8 mm

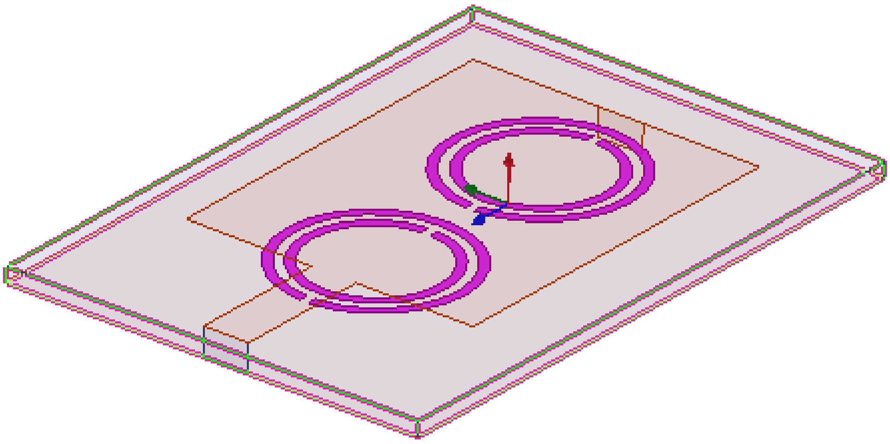


Fig. 5: Proposed antenna with SRR having maximum radius 10 mm

IV. SIMULATION RESULTS AND METAMATERIAL VERIFICATION

The metamaterial properties of SRR are verified in this section, using effective medium theory. Nicolson-Ross-Weir method (NRW) has been employed for verifying that SRR metamaterial structure possesses negative values of Permeability within the operating frequency ranges. Fig. 4 shows the reflection coefficient (S_{11}) and transmission coefficient (S_{21}) characteristics of the SRR. It depicts that the SRR unit cell resonates at 10.9 GHz.

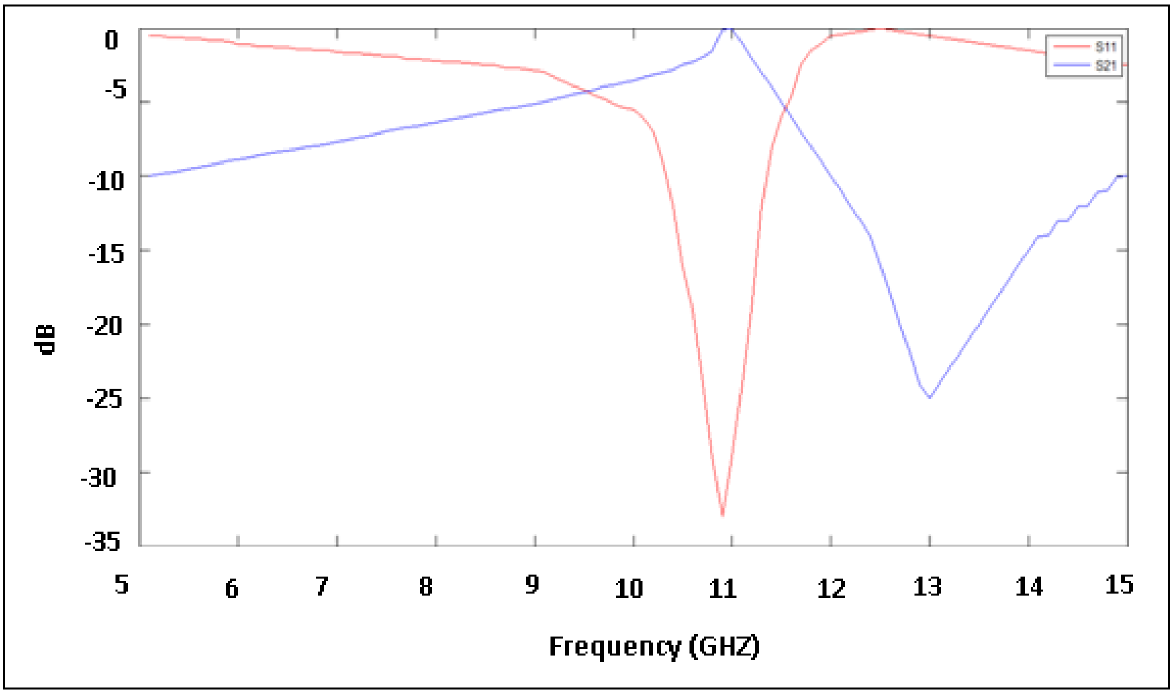


Fig. 6: S-parameters (S_{11}) and (S_{21}) of the SRR structure

The effective medium parameters are derived from the reflection and transmission coefficient parameters (S-parameters) using Nicolson-Ross-Weir (NRW) approach. The expressions of Equations (2) and (3) are used for calculating these values [14].

$$\mu_r = \frac{2}{jk_0 d}\frac{1-V_2}{1+V_2} \qquad (2)$$

$$\varepsilon_r = \frac{2}{jk_0 d}\frac{1-V_1}{1+V_1} \qquad (3)$$

where k_0 is wave number, d is the thickness of substrate, $V1$ and $V2$ are the composite terms to represent the addition and subtraction of S-parameters. The values of $V1$ and $V2$ are estimated using Equations (4) and (5) [14].

$$V_1 = S_{21} + S_{11} \qquad (4)$$

$$V_2 = S_{21} - S_{11} \qquad (5)$$

Fig. 7 indicates the permeability characteristics (μ) of SRR unit cell. This structure exhibits real negative permeability (μ_r) which indicates single negative that is mu negative (MNG) characteristics of SRR structure. By using the obtained S-parameters, above mathematical equations and MATLAB code the metamaterial characteristics of SRR are verified.

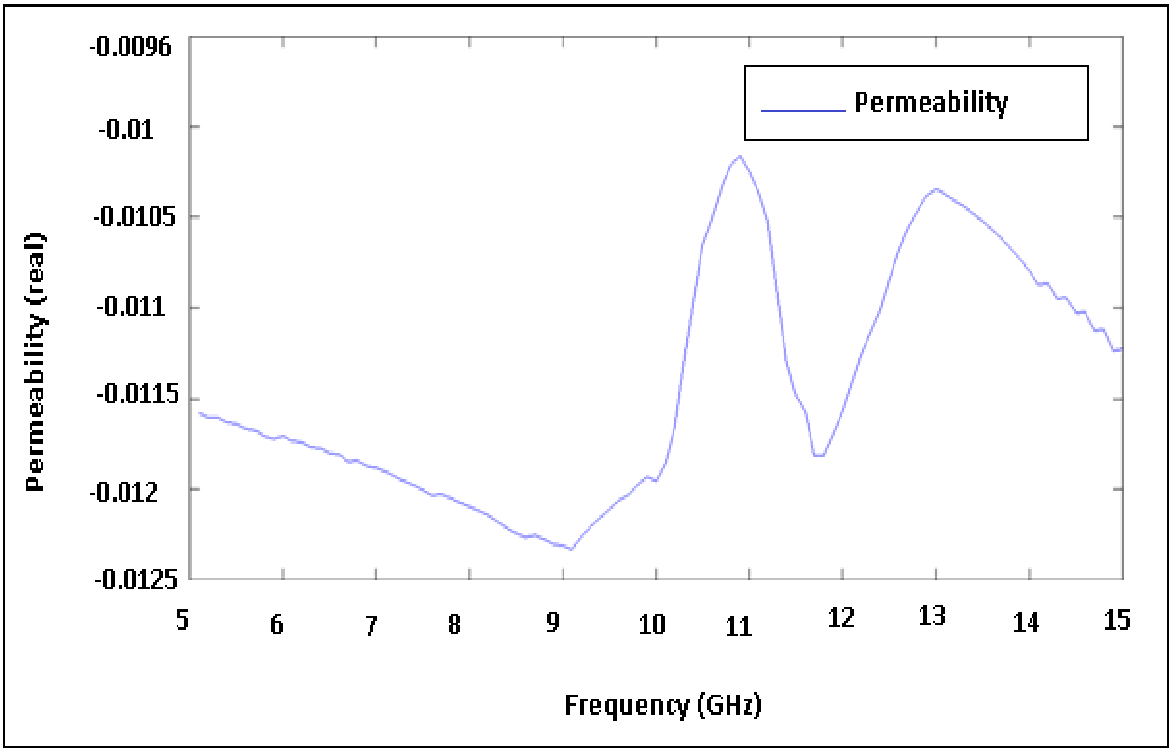


Fig.7: Permeability (μ_r) characteristics of SRR.

Fig. 8 shows the return loss ($S11$) characteristics of an unloaded PIFA. The PIFA structure without loading resonates at f_r = 7.46 GHz with return loss of -23.71 dB and gain of 5.41 dBi. The gain plot of reference PIFA at frequency 7.46 GHz is shown in fig. 9. Simulated return loss versus frequency results for PIFA loaded with SRR of varying radius are shown in fig 10. Fig 10 (a) shows return loss characteristics of PIFA loaded with SRR having r2= 6mm and r1= 4 mm. This design has obtained maximum bandwidth of 693.5 MHz. In fig. 10 (b) SRR loading is having r2= 8 mm and r1= 6 mm. Maximum achievable bandwidth under this design is 683.5 MHz. With SRR of r2=10 mm and r1= 8 mm, return loss characteristics of fig. 10 (c) are obtained. From this structure maximum bandwidth of 1.175 GHz is achieved. Table I shows the value of antenna parameters (such as gain, return loss and number of resonant frequencies) achieved with SRR structure having varying radius. The gain plots of PIFA loaded with varying SRR radius is shown in fig. 11. Fig 11(a) shows the gain plot of PIFA loaded with SRR having r2= 6 mm at 6.32 GHz. The gain plot at frequency 6.73 GHz of PIFA loaded with SRR of r2=8 mm is shown in fig. 11(b). Fig 11(c) depicts the gain plot of PIFA with SRR having r2=10 mm at 6.74 GHz.

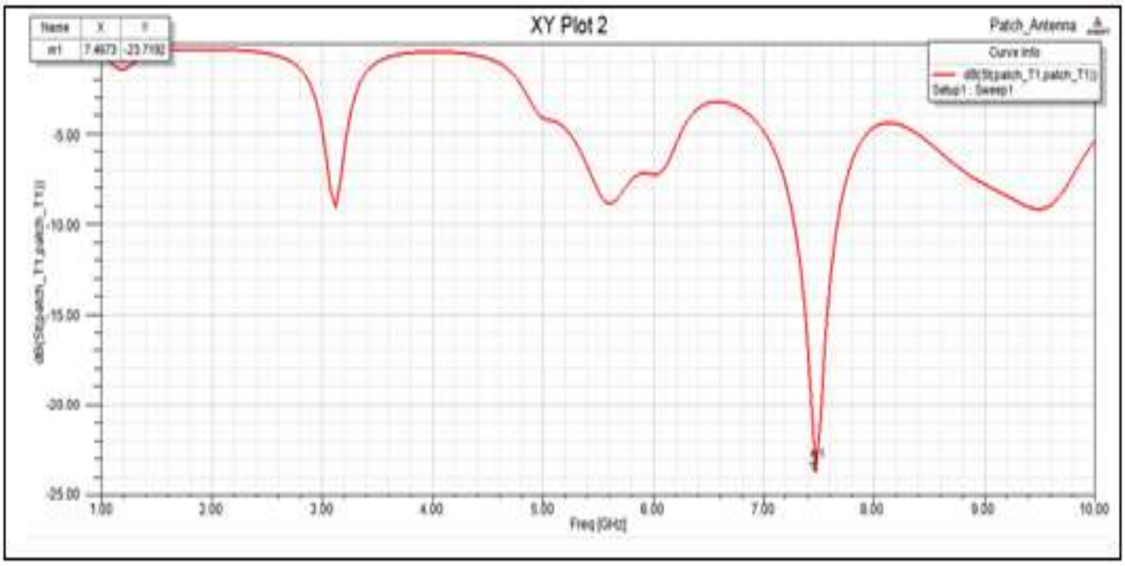


Fig. 8: Simulated return loss results for proposed PIFA without metamaterial

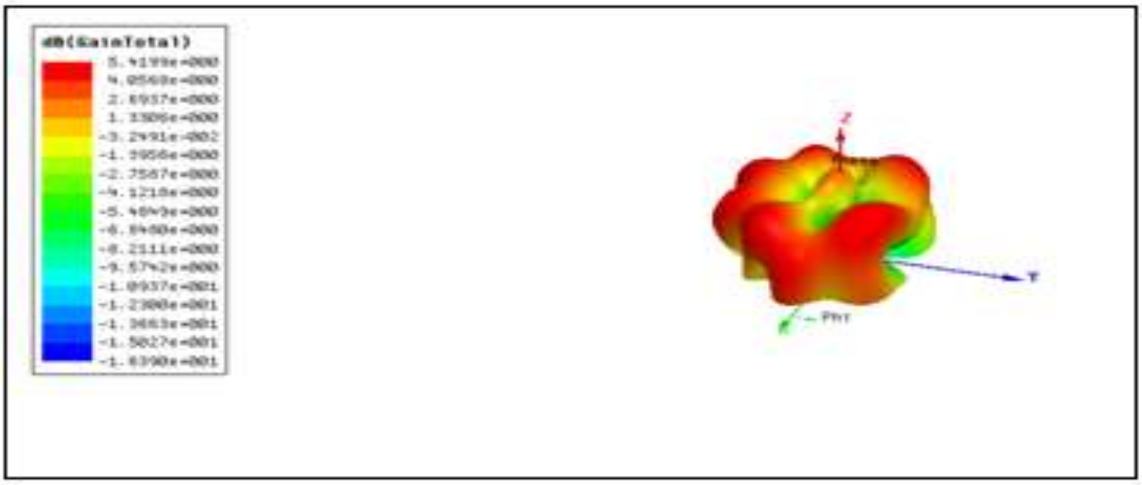
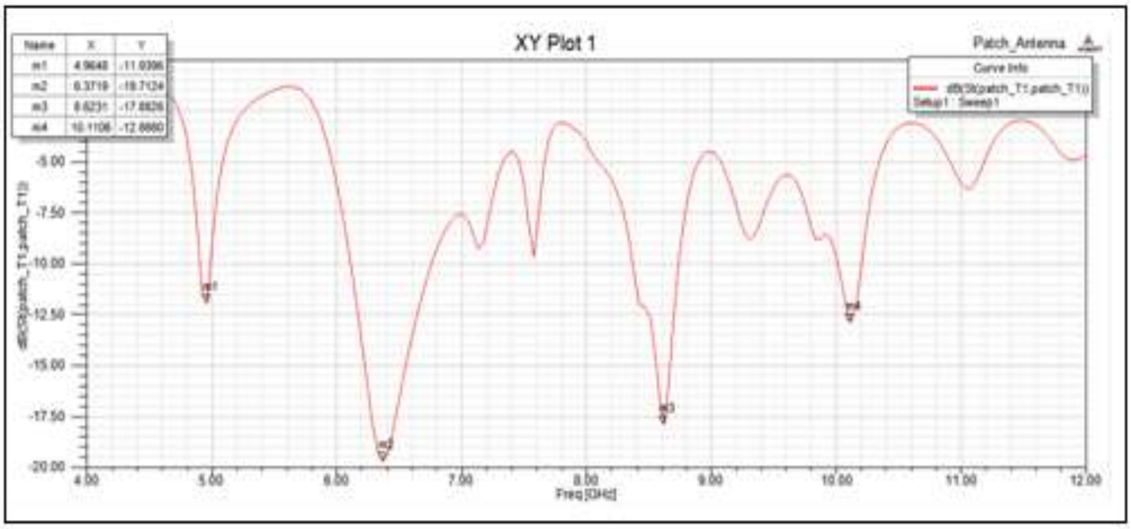
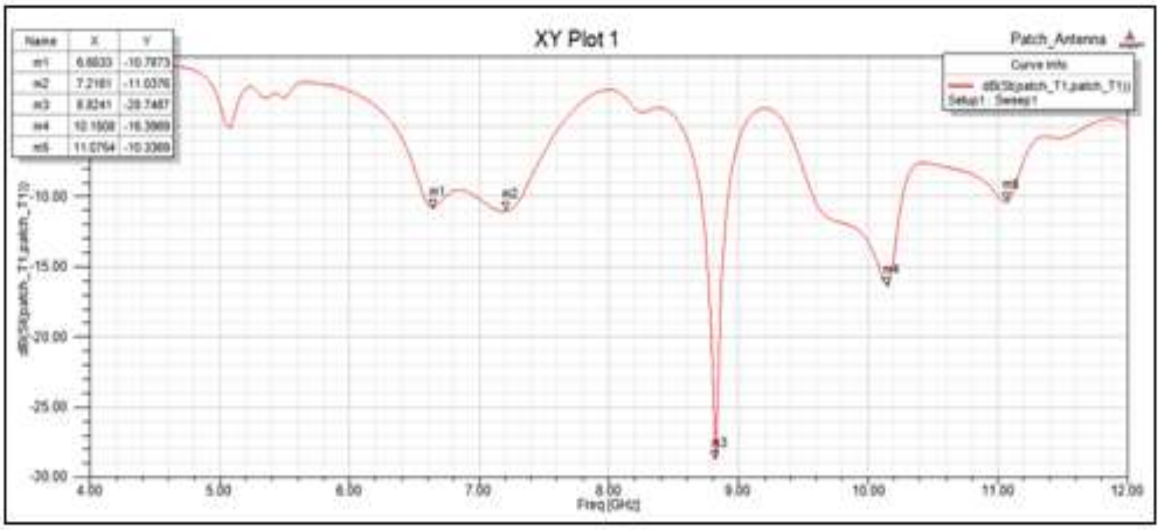


Fig. 9: Total gain of reference antenna

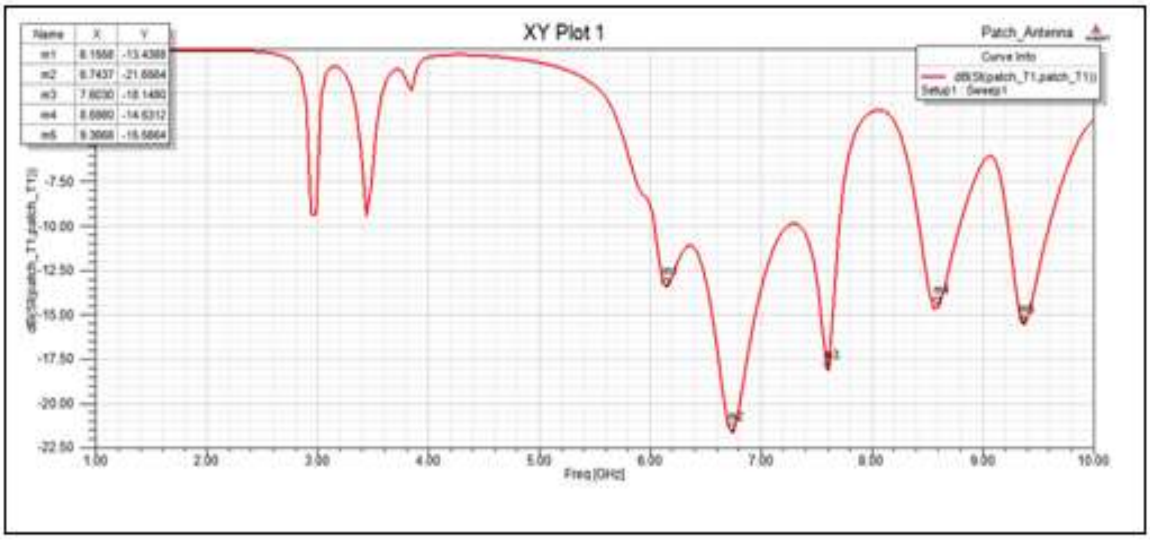


(a)



Name	X	Y
m1	6.6833	-10.7873
m2	7.2181	-11.0376
m3	8.8241	-28.7487
m4	10.1508	-16.3969
m5	11.0764	-10.3369

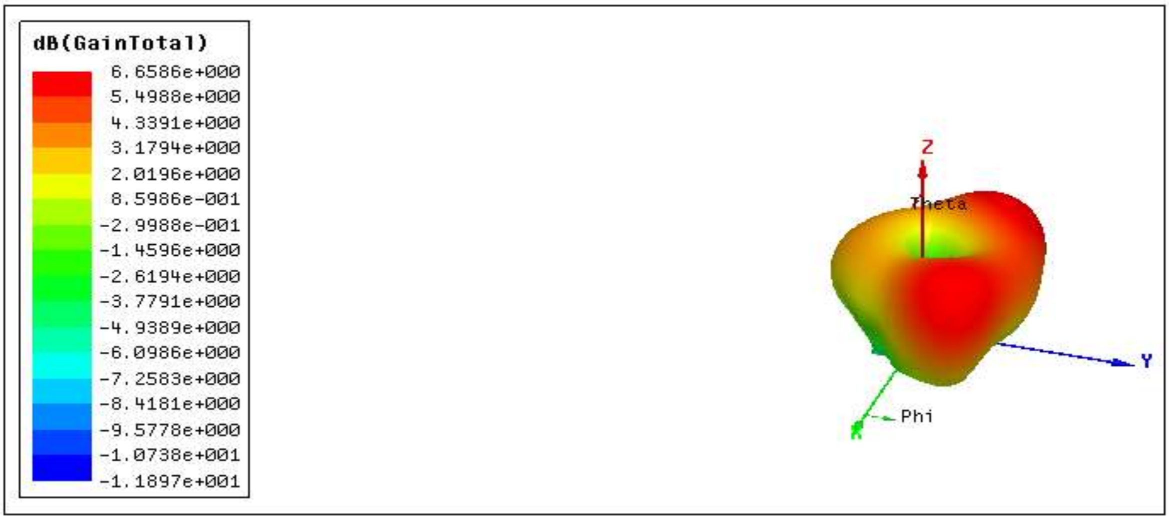
(b)



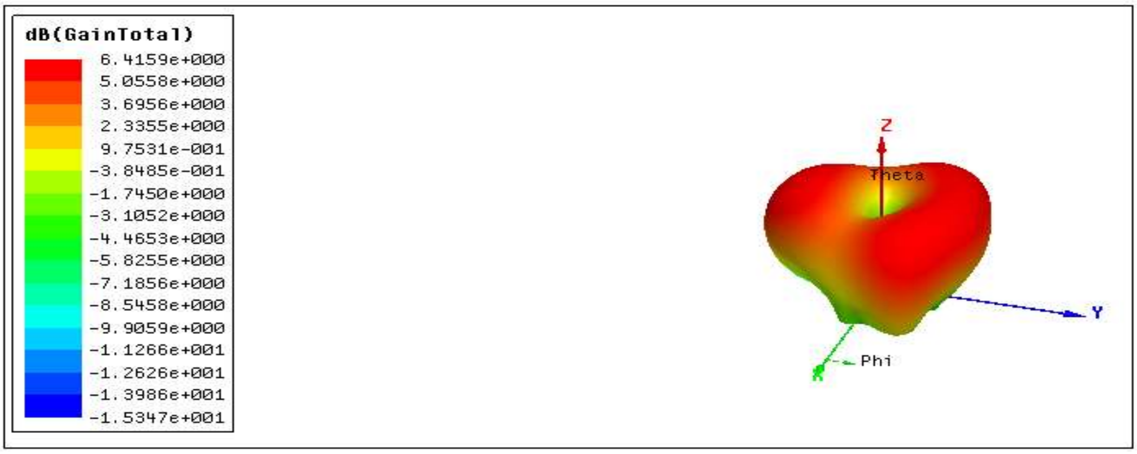
Name	X	Y
m1	6.1558	-13.4388
m2	6.7437	-21.6884
m3	7.6030	-18.1480
m4	8.6860	-14.6312
m5	9.3668	-15.5864

(c)

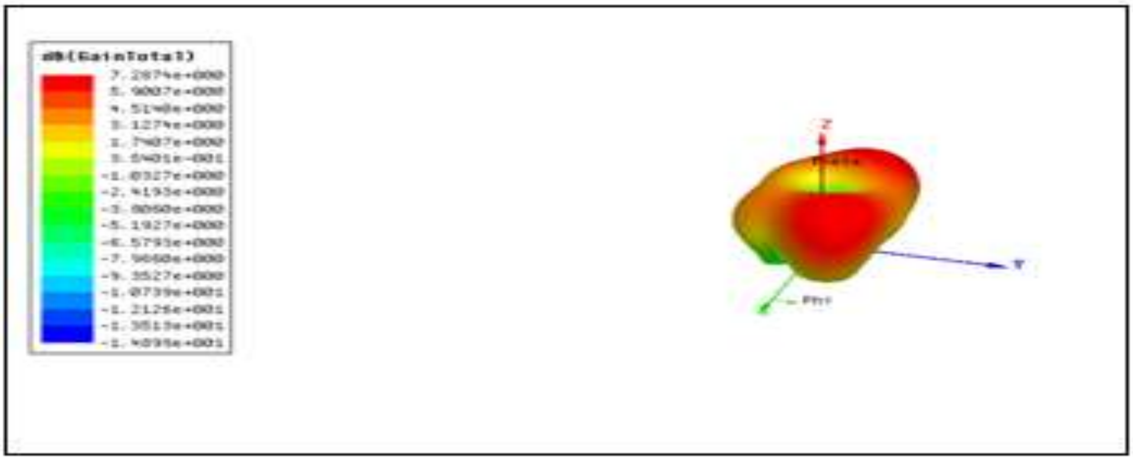
Fig. 10: Return loss (S11) characteristics with different split ring radius. (a) r2= 6 mm and r1= 4 mm , (b) r2= 8 mm and r1= 6 mm , (c) r2= 10 mm and r1= 8 mm.



(a)



(b)



(c)

Fig. 11: Total gain of proposed structure (a) for r2= 6 mm and r1= 4 mm at 6.37 GHz, (b) for r2= 8 mm and r1= 6 mm at 6.65 GHz, (c) for r2= 10 mm and r1= 8 mm at 6.74 GHz.

Table I: Antenna parameters for proposed structures with varying SRR radius

Without SRR			With SRR having r2= 6 mm and r1= 4 mm (with 6 number of SRR unit cells)			With SRR having r2= 8 mm and r1= 6 mm (with 4 number of SRR unit cells)			With SRR having r2= 10 mm and r1= 8 mm (with 2 number of SRR unit cells)		
Freq (in GHz)	Return Loss (in dB)	Gain (in dBi)	Freq (in GHz)	Return Loss (in dB)	Gain (in dBi)	Freq (in GHz)	Return Loss (in dB)	Gain (in dBi)	Freq (in GHz)	Return Loss (in dB)	Gain (in dBi)
7.46	-23.71	5.41	4.96	-11.93	4.70	6.65	-10.78	6.41	6.15	-13.43	7.48
			6.37	-19.71	6.65	7.21	-11.03	6.42	6.74	-21.65	7.28
			8.62	-17.88	7.25	8.82	-28.74	7.18	7.60	-18.14	3
			10.11	-12	7.78	10.15	-16.39	7.15	8.59	-14.53	4.14
						11.07	-10.33	7.29	9.36	-15.56	5.35

V. CONCLUSIONS

SRR loaded antenna is presented which resonates at 7.46 GHz without SRR and at multiple frequencies with SRR placed over the substrate. From simulated results it is observed that after loading, the resonant frequency of antenna reduces and helps in miniaturization. The proposed antenna structures show 32.65 % reduction in the size compared to the PIFA without metamaterial. Moreover, changing the radius of split rings has significant effect on bandwidth, gain and resonant frequencies of antenna. Maximum bandwidth was achieved with the split ring loading having radius 10 mm The proposed structure finds its usability in mobile application (WLAN) and satellite communication.

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