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Design of Multiband PIFA loaded with Split Ring Resonator

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Abstract : *In this paper, a multiband planar inverted-F antenna (PIFA) with high gain and appreciable bandwidth at the resonant frequencies is designed using metamaterial concept. The proposed PIFA without metamaterial is designed to resonate at 7.46 GHz with return loss of -23.71 dB and gain value 5.41 dBi. The designed antenna is having maximum possible bandwidth of 361.8 MHz. The proposed PIFA with split ring resonator (SRR) loading resonates at multiple frequencies i.e. 5.60 GHz, 6.68 GHz, 7.98 GHz, 8.44 GHz and 9.42 GHz. Return loss at 5.60 GHz is -22.48 dB and gain is 7.10 dBi. At 6.68 GHz return loss is -34.55 dB and gain is 7.68 dBi. Return loss is -30.4 dB at 7.98 GHz and gain is 4.21 dBi. At 8.44 GHz return loss is -15.23 dB and gain is 4.04 dBi. Return loss and gain values at 9.42 GHz is -16.88 dB and 4.77 dBi respectively. After loading with metamaterial maximum bandwidth observed is of 736 MHz. Metamaterial loading has shown to increase the number of resonant frequencies of reference antenna with bandwidth and gain enhancement. It also had an impact on the antenna performance in terms of the return loss improvement and size reduction. Nicolson-Ross-Weir (NRW) method has been employed for verifying metamaterial characteristics of SRR. Design is simulated using HFSS Software.*
Keywords: *Multiband, Nicolson-Ross-Weir (NRW), PIFA, return loss, Split Ring Resonator (SRR).*

I. Introduction

PIFA is widely used in mobile and portable applications because of its various merits such as low cost, low profile and attractive radiation patterns etc. However, it has limitation of narrow bandwidth and low gain. Over the years, several techniques have been proposed by researchers for bandwidth and gain enhancement of PIFA. The rapid development of electronics and wireless communications led to great demand for wireless devices that can operate at different standards such as universal mobile telecommunications system (UMTS), Bluetooth, wireless local-area network (WLAN) and also satellite communications[1].Therefore, it is required to design small size, high gain, and low cost antennas with appreciable bandwidth for multiband applications. There are a number of PIFA designs with different configurations to achieve single and multiple operations by using slots of different shapes. Truncated corner technique, meandered strips and meandered shapes have been used to create multiple band operations [2]. However, these techniques usually have a tradeoff with antenna bandwidth or gain while achieving multiband characteristics. Metamaterial loading has proved to be an advantageous approach for improving basic antenna features such as impedance matching, bandwidth, gain and efficiency along with miniaturization.

Metamaterials are the artificial materials having properties which may not be found in nature. These materials possess negative permeability (μ) and negative permittivity (ε) that support the backward wave propagation of electromagnetic waves [3]. The invention of metamaterial started in the late 1960s. In 1967, Russian physicist Victor Georgievich Veselago studied the electrodynamics of substances with simultaneously negative values of dielectric permittivity (ε) and magnetic permeability (μ) [3]. Later on J.B. Pendry and his colleagues, proved that the array of metallic wires can be used to obtain negative permittivity and split ring resonators for negative permeability [4]. Next a structure was fabricated, which was a composition of split ring resonator and thin wire and was named as LHM (left handed material) because the electric field (**E**), magnetic intensity (**H**) and propagation vector (**k**) were related by a left-hand rule. Apart from exhibiting negative refractive index, metamaterials also presents some interesting properties such as the reversal of the Snell Law, Doppler Effects, and Cherenkov radiation etc.

A compact SRR loaded antenna was presented in [5]. It was seen that the gap between patch and SRR plays an important role in determining the resonant frequency of antenna. In [6], gain of the antenna was improved by placing metamaterial slab over the patch. Power radiated by antenna can be improved by employing DNG material [7]. In [8], miniaturized annular patch resonator was designed by partially loading it with metamaterial. In [2], slots are made on the patch to obtain multiband PIFA for WLAN and WiMAX application. But the gain achieved from the structure could reach upto maximum of 5dbi. In [9] multiband patch antenna filled with metamaterial structure over a metamaterial substrate is investigated and designed. Designed antenna however has lower gain and efficiency compared to a patch antenna with a metamaterial substrate or patch antenna filled with metamaterial structures and placed over FR4 substrate. A printed monopole antenna is proposed [10], in which broadband dual mode feature is obtained using metamaterial loading. Split Ring

Resonator (SRR) is a novel design consisting of two concentric metallic rings with a split on opposite sides. SRR can result in an effective negative permeability over a particular frequency region. They exhibit magnetic resonance at certain frequencies and hence are called as resonator. Basically, SRR is a LC tank circuit having equivalent inductance "L" and the capacitance "C" between two concentric rings resonating at particular frequency [11]. 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].

In this work the multiband PIFA with high gain, reduced size and wider bandwidth is proposed using split ring resonator (SRR). SRR is printed on the substrate of reference antenna. The characteristics of PIFA are studied without SRR and with SRR loading. This paper is structured into five sections. The detailed geometrical structure and design of the proposed PIFA without SRR and with SRR loading is presented in Section 2 and 3 respectively. In Section 4, the metamaterial properties of SRR are verified using effective medium theory. The simulation results of unloaded and loaded PIFA are also presented in this section. Finally, the paper is concluded in Section 5.

II. Proposed PIFA Antenna

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

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

Where λ is the wave length, 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, to make it resonate at 7.46 GHz. The patch is having dimensions of 44 X 50 mm2 and shorting plate is having a width of 5mm. 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 of width 5mm.

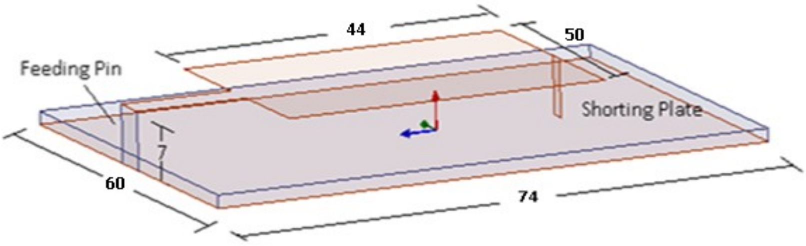


Fig. 1: The 3D view and detailed dimensions of the proposed antenna without metamaterial

III. Proposed PIFA with SRR

Proposed structure consists of a short circuited patch at a distance of 3mm from ground and circular SRR's printed over the substrate. SRR structure is used to exhibit negative permeability. Fig. 2 shows the geometrical structure of SRR unit cell. The radius of outer ring (r2) = 4 mm and the radius of inner ring (r1) = 2 mm. The separation between inner and outer ring (d) = 1mm, gap in the ring (g) = 1mm and width of the circular ring (c) = 1 mm. Fig. 3 shows the detailed dimensions of PIFA with SRR loading. 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.

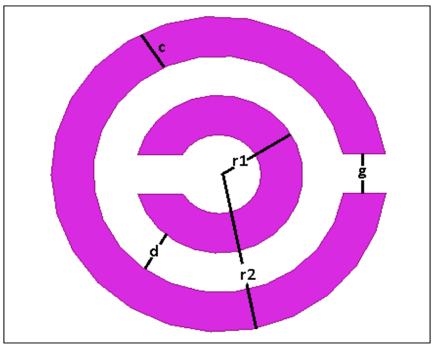


Fig. 2 Geometrical structure of metamaterial SSR unit cell.

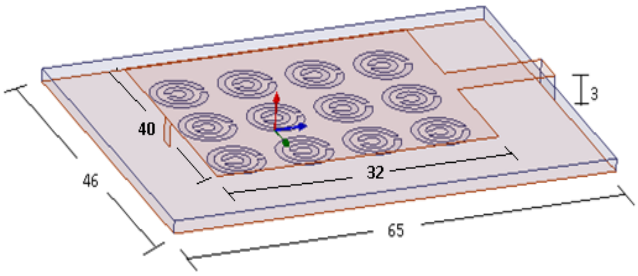


Fig. 3: The 3D view and detailed dimensions of the proposed antenna with SRR

IV. Simulation results and metamaterial verification

In this section, the metamaterial properties of SRR are verified 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 shows that the SRR resonate at 10.9 GHz.

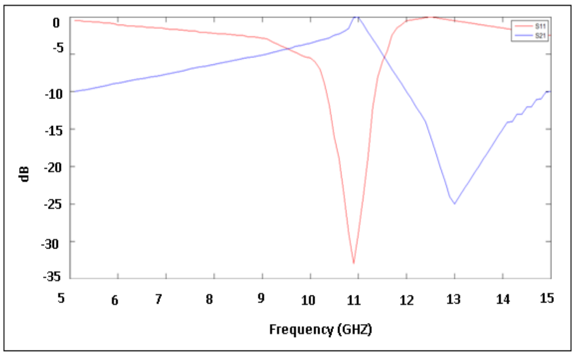


Fig. 4: S-parameters (S_{11}) and (S_{21}) of the SRR structure

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 [13].

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

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

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) [13].

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

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

Fig. 5 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.

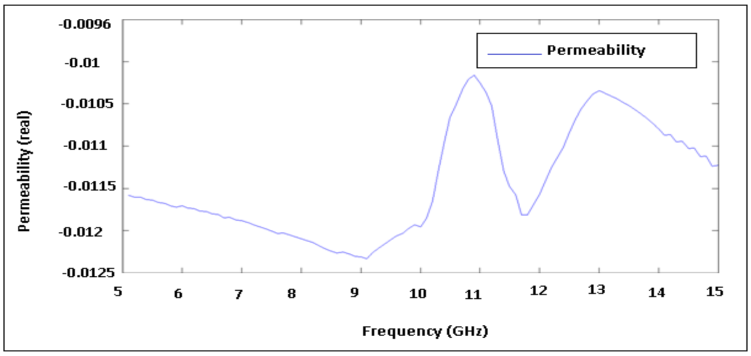


Fig.5: Permeability (μ_r) characteristics of SRR.

The return loss ($S11$) characteristic of an unloaded PIFA is shown in Fig. 6. PIFA without loading resonates at f_r = 7.46 GHz with return loss of -23.71dB. The bandwidth achieved for this structure is 361.8 MHz. Fig.7 depicts the gain plot for reference antenna which is having a value of 5.41dBi

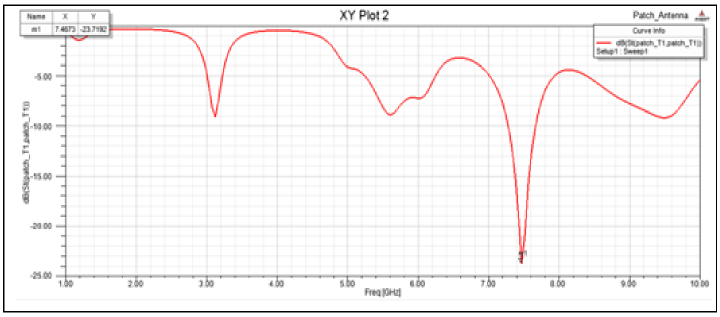


Fig. 6: Simulated return loss results for proposed PIFA without metamaterial

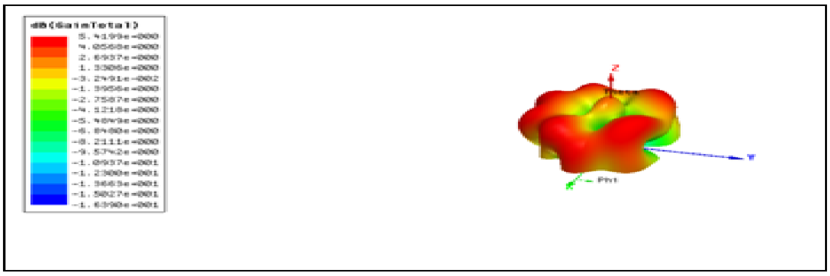


Fig. 7: Total gain of reference antenna

Fig. 8 shows simulated return loss versus frequency results for PIFA with SRR loading. It is seen that the proposed antenna structure resonates at multiple frequencies. Also after loading, the antenna shows reduction in its resonant frequency and thus miniaturization is accomplished in proposed structure. Fig. 9 shows the gain values at resonant frequencies. Maximum gain value achieved for the structure is 7.68 dBi at 6.68 GHz**.** The proposed antenna shows 32.65 % reduction in the size compared to the reference antenna. Table I shows the values of antenna parameters such as return loss, gain and bandwidth values at different resonant frequencies.

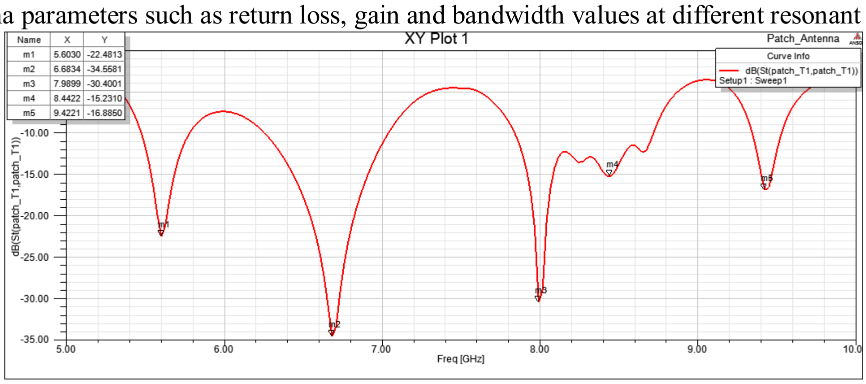
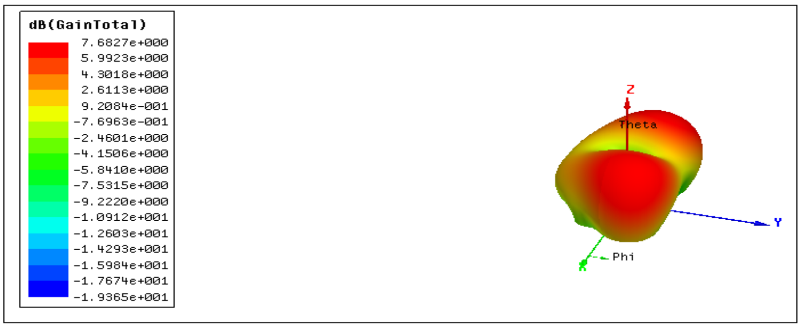


Fig. 8: Simulated return loss results for proposed PIFA with SRR

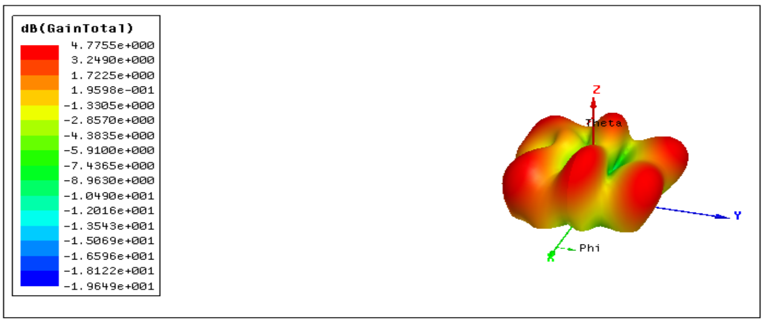
(a)



(b)

(c)

(d)



(e)

Fig.9: Total gain of PIFA with metamaterial (a) at 5.60 Ghz (b) 6.68 Ghz (c) 7.98 Ghz (d) 8.44 Ghz (e) 9.42 Ghz

TABLE I: Antenna parameters with SRR loading

BAND	FREQUENCY IN (GHz)	MIN. RETURN LOSS (S11) IN dB	GAIN IN (dBi)	BANDWIDTH IN (MHz)
I	5.60	-22.48	7.10	251
II	6.68	-34.55	7.68	678
III	7.98	-30.40	4.21	736
IV	8.44	-15.23	4.04	736
V	9.42	-16.88	4.77	201

V. Conclusion

From the simulated results it is found that the parameters of the proposed antenna with SRR loading increases significantly in comparison to PIFA alone. The main advantages are basically related to the multiband behavior achieved, high gain and wider bandwidth. The resonant frequency of proposed antenna is also reduced to lower value after loading with SRR and hence provided miniaturization effect. The proposed structure finds its usability in mobile application and satellite communication.

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