A Novel Miniaturized Triple band Patch Antenna with CSRR Elements

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Abstract— *In this paper, a novel miniaturized Triple-band microstrip antenna is presented in which Metamaterial loading is utilized within the patch margin to obtain significant miniaturization. The antenna is loaded with two pairs of Complementary Split Ring Resonators (CSRR's) on both sides of the symmetry axis of the patch and whose dimensions are disparate. Through an appropriate choice of CSRR parameters, the antenna is induced to resonate at three different frequencies; lower than the resonance of the unperturbed patch. The RF-simulations are carried out with Ansys HFSS®, a benchmarked commercial simulator. The proposed antenna may find application in UMTS, WLAN, Bluetooth, WiMax wireless segments.*

Keywords— Microstrip Patch Antenna (MPA), Miniaturisation, Metamaterial, Triple Resonance

I. Introduction

Microstrip patch antennas are the most preferred planar antennas for wireless and other applications because of features like planar configuration, conformability, portability, suitability for array, light weight and low cost cheap; despite having some drawbacks like narrow band and low gain [1].Researchers have employed several approaches to overcome these latter limitations like increasing dielectric constant and/or substrate thickness, stacking of patches, parasitic elements, DGS, PBG, etc. [1].

The CSRR elements utilized for miniaturization and Triple-banding fall within the larger category of metamaterials. Metamaterials may be defined as materials that exhibit negative refractive index i.e. an apparent increase in the velocity of propagation (unlike natural materials that retard the electromagnetic wave). One of their special properties is negative permeability and permittivity, although only over a certain range of frequencies. Metamaterials do not occur readily in nature and are artificially devised using structures composed of reactive elements. A key requirement is that the unit cell size of these structures should be less than a quarter of the guided wavelength in the medium. It is because of these properties that metamaterials increasingly play a key role in antenna research in the current times. The metamaterial structures may or may not be periodic and their properties are determined by their structures satisfying the homogeneous limit criteria [2]. Several varieties of Split Ring Resonators and Complementary Split Ring Resonators are reported till now.

The energy from the patch is coupled into resonators, which behave like dipoles, by means of magnetic and capacitive coupling. Literature is available with dual and triple band operation obtained through CSRR-loading on patch [3-8]. In all these, uniform loading only has been utilized over the patch i.e. the dimensions of the different CSRR's are chosen identical [3,10]. When both the sides are loaded with CSRR's of same dimensions, one achieves miniaturization. Researchers like Yuandan Dong *et al* [3] have used CSRR structures on a patch to miniaturize the dimensions and for improving its radiation performance.

The more we load the patch with CSRR's, greater will be the percentage of miniaturization; but as the number of CSRR's increases, the gain of the patch goes down with reduction in bandwidth. This, in turn, may be increased by stacking of additional patches and / or introducing reactive impedance surfaces as proposed by Yuandan Dong *et al.* In the present paper, the previously reported CSRR-loading technique has been adapted to obtain three discrete resonances from the same basic rectangular microstrip patch antenna without needing any stacked patches, multiple substrates or parasitic elements. Further, the inclusion of CSRR's reduces the resonant frequency of the patch yielding miniaturization. Since for the present work, the wireless applications are the chief concern, the principal bands kept in mind are UMTS (1920-2170MHz), BLUETOOTH (2400-2483.5MHz),Wi-Fi (2400-2480MHz), WiMax (2500-2690MHz) [9]. In our work, we have loaded the patch with two pairs of CSRR with their dimensions retained different on both the sides of the patch axis of symmetry. In other words, differential loading has been investigated leading to miniaturization and three discrete resonances. In the ensuing section, we briefly review CSRR's.

II. Complementary split ring resonators

Complementary Split Ring Resonators are the duals of the well-known split ring resonators. The latter consist of one or more rings that are split at the end i.e. the ring is not closed at one end. Starting from this, if one replaces the metallic tracks with air and vice versa, we obtain the dual i.e. the CSRR (of which a four ring version is illustrated in Fig. 1) where W,L,S,G stands for width, length of the outer ring, space between rings and gap respectively. The structure is excited by applying an electric field in the axial direction. The resonant frequency is nearly the same as compared to the corresponding SRR and hence the same equations may be used for computing its value [10]. The CSRR structures are alternately obtained when mirror image of SRR is etched on metal surface. They exhibit negative permittivity whereas Split Ring Resonators have negative permeability. Babinet's principle has been gainfully applied in deriving the electrical characteristics of the dual of SRR that is CSRR. We next outline the design methodology adopted for the proposed antenna.

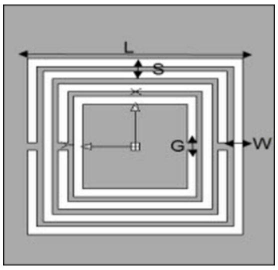

Fig. 1: CSRR (white region represents air)

III. Design Methodology

The design of the proposed differentially-resonant, CSRR-loaded rectangular microstrip patch antenna (Variant) is carried out in stages; each step supported by optimization using the FEM-based commercial electromagnetic simulator, Ansys HFSS®. Essentially, the design approach involves the following steps:

1) Design of basic Inset-fed rectangular microstrip patch.
2) Design of the basic CSRR's with different dimensions (and resonant frequency)
3) Loading the patch (from Step 1) with two pairs of CSRR with disparate dimensions. E.M. optimization of the patch & CSRR dimensions concurrently to obtain the desired Triple resonances.

A. Step 1

A MATLAB program is developed for calculating the length and width of rectangular microstrip patch antenna – implementing the design equations. The designed antenna is excited using an inset microstrip feed line with an impedance 50 ohms and optimized to resonate at 2.86 GHz. This frequency is chosen to be in S band in order to get a triple band miniaturized antenna resonating in UMTS, WLAN, Bluetooth, WiMax spectra as mentioned earlier. Also the CSRR structure's resonant frequency is chosen to resonate at a frequency lesser than this frequency. The substrate used is RT Duroid with a ε_r of 2.2, with a thickness of 60 mils. The final optimized size of the patch is 0.3244λ × 0.4485λ, while its return loss characteristics are shown in Fig. 2. Accounting for the fringing fields, the ground-plane size is retained as 60 mm X 60 mm. The initial feed location is calculated using the expression for Z_{in} [1]. The feed position is optimized further using the simulator; the exact position being 8.48 mm inside the radiating edge. The width of the microstrip line is 4mm (for 50-ohm impedance).

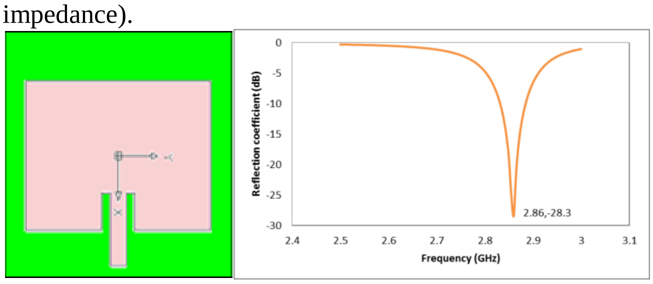

Fig. 2: Basic Inset-fed Patch; Simulated S11

B. Step 2

The homogeneity condition that must be fulfilled in order for the structure devised to behave as a metamaterial element is given in equation 1.

$$p \le \frac{\lambda}{4} \qquad \dots (1)$$

Where p stands for unit cell size and that should be less than or equal to quarter of the wavelength. From the operating wavelength, the minimum dimension of the unit cell of CSRR is determined. Unit cell dimension satisfying homogeneous condition is computed next. For practical realization of meta structures property, The unit cell size is chosen to be less than one eighth of wavelength. In our case it is λ/9.54, λ/11.92 on right and left sides of patch. The resonant frequency of CSRR is calculated from the set of equations [11-12].

$$\omega_o = \frac{1}{\sqrt{L_c C_c}} \qquad \dots (2)$$

$$L_c = \frac{4.86\mu_0}{2}(L - w - s)\left[\ln\left(\frac{0.98}{\rho} + 1.84\rho\right)\right] \qquad \dots (3)$$

$$\rho = \frac{w + s}{L - w - s} \qquad \dots (4)$$

$$C_c = [L - 1.5(2 + d)]C_{pul} \qquad \dots (5)$$

The resonant frequency (ω_o) is decided by the relative permitivity of the substrate, width of the strip and the gap between the rings. Where *w,L,s* stands for width, length of the outer ring, space between rings. *Cpul* expression is available in [11] which involves the elliptical integral of the first kind.

C. Step 3

The patch is next loaded with the two disparate CSRR's; a pair of each type on either side of the patch axis of symmetry (along the feed line – see Fig. 3). The optimized dimension of CSRR are tabulated separately in the Table 1 with the letters R, L within brackets indicates that it is placed on right and left side of the patch.

No.	CSRR Parameter	Value (mm)
1	Width	0.5
2	Gap	0.6
3	Space (R,L)	0.5,0.5
4	Length (R, L)	λ/9.54, λ/11.92

Table 1: The Optimised Dimensions of CSRR

The triple-band behavior is accounted by the two different resonances of the designed CSRR's. Apparently, the CSRR placed further away from the feed couples energy to the patch more effectively than the nearer one [3] this is because CSRR load on patch are made to face each other and hence may be more crucial in determining the resonant frequency. The HFSS® analysis of the final optimized radiator with differential CSRR-loading shows three distinct resonances is shown in Fig. 3. The various key parameters of antenna are simulated in HFSS® and are presented in Table 2.

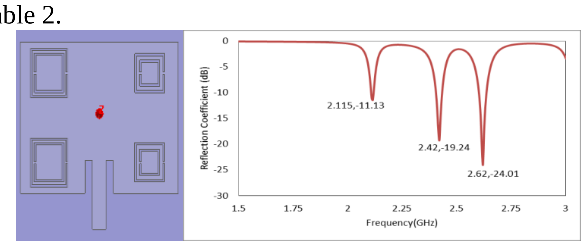

Fig. 3: Model of the Variant (Top view) & S_{11} plot

No.	Parameter	Value at 2.115 GHz	Value at 2.42 GHz	Value at 2.62 GHz
1	Peak directivity	4.64	5.02	4.066
2	Peak gain (dB)	1.85	2.89	1.37
3	Efficiency	39.89	57.55	34.37

Table 2: Simulated Parameters of Variant

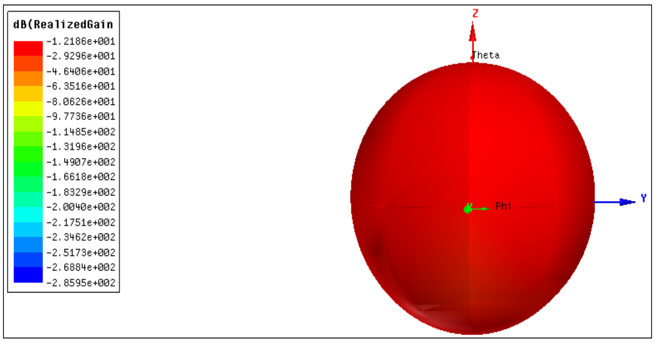

Fig. 4: Polar Plot of Variant at 2.115 GHz

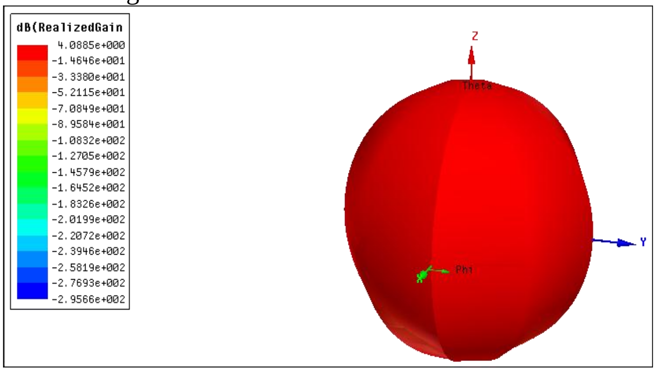

Fig. 5: Polar Plot of Variant at 2.42 GHz

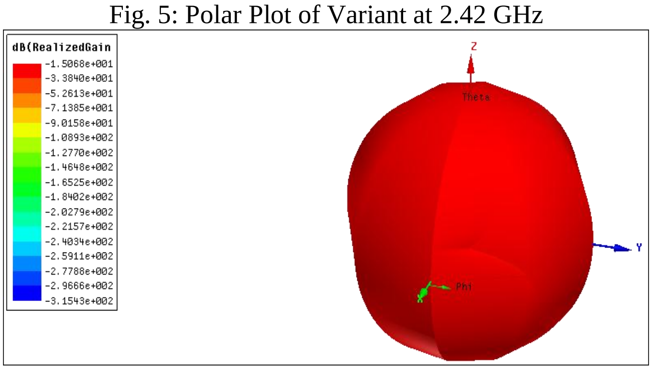

Fig. 6: Polar Plot of Variant at 2.62 GHz

IV. DISCUSSIONS

The paths travelled by current in reaching the radiating edges have increased due to CSRR etch on it. Thus three different paths are created due to differential load on patch, creating triple resonances as well as miniaturization. The pattern still remains conserved (See Figs. 4-6). To visualize this, surface current density plots on patch at 2.86, 2.115, 2.42, 2.62 GHz are shown in Figs.7-10. The proposed variant's dimensional details and miniaturization details are all summed up in Table 3, while return loss, gain, resonant frequency, applications of the proposed Variant are all presented in Table 4.

Frequency (GHz)	Patch Dimension	Patch Area (mm^2)	Patch Area Reduced (mm^2)
2.86	0.3244λ×0.4485λ	1598	----
2.115	0.5357λ×0.4499λ	2652	1054
2.42	0.4691λ×0.3908λ	2009	411
2.62	0.4314λ×0.3607λ	1712	114

Table 3: Summary of Area of MPA & Variant

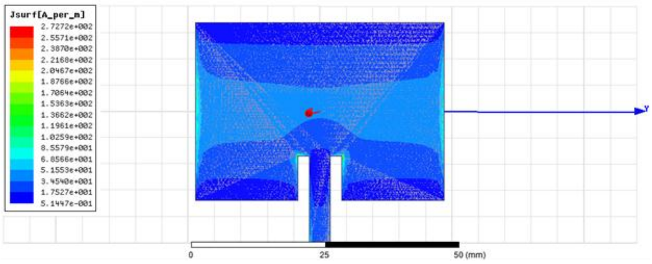

Fig. 7: Magnitude of Surface Current Density Plot on Patch Surface at 2.86 GHz

Resonant Frequency (GHz)	Reflection Coefficient (dB)	Peak Gain (dB)	Applications
2.115	-11.13	1.85	UMTS
2.42	-19.24	2.89	WLAN,BLUETOOTH
2.62	-24.01	1.37	WIMAX

Table 4: Summary of Details of the Variant

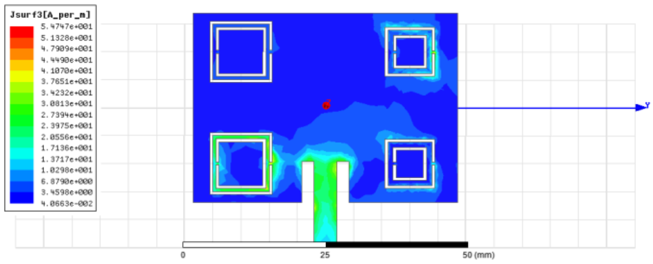

Fig. 8: Magnitude of Surface Current Density Plot on Patch Surface at 2.115 GHz

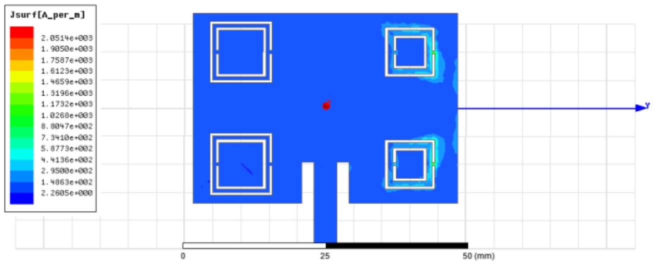

Fig. 9: Magnitude of Surface Current Density Plot on Patch Surface at 2.42 GHz

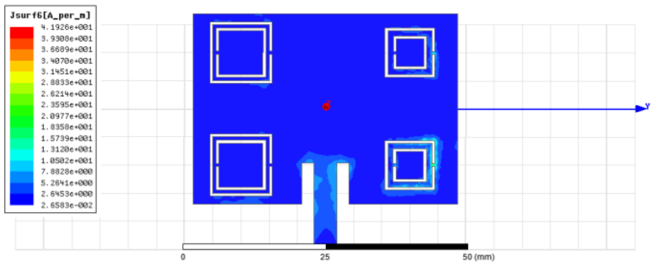

Fig. 10: Magnitude of Surface Current Density Plot on Patch Surface at 2.62 GHz

V. Conclusion

An effective method to attain triple band operation using two differentially-resonant meta-structures loaded within the patch margin is presented. The design aspects of the basic inset-fed rectangular patch and the CSRR employed for loading it are presented. The original radiation pattern of the patch is almost preserved in the CSRR-loaded version. The antenna besides being miniaturized has triple-band resonance; for which the specific wireless application is also suggested. The proposed antenna (Variant) is planar, compact and can be easily fabricated using standard PCB techniques. Further scope of improvement may be to attempt to broadband the antenna using any known technique or for circular polarization with improved gain.

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