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Wideband Gain-Enhanced Miniaturized Met Material-based Antenna for Wireless Applications

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Abstract:-Complementary Split Ring Resonators and Spiral Resonators; a category of artificially-devised metamaterial components; are loaded onto a microstrip patch and effectively utilized for obtaining wideband behaviour through staggered resonances and for radiator size reduction. A basic inset-fed patch antenna is loaded with a pair of CSRR on both the sides with a small change in dimension leading to closely overlapping resonances resulting in a wide bandwidth. Additonally, a spiral resonator is inscribed in the ground-plane under the patch metallization to suppress surface waves and to improve the radiation characteristics. The antenna is simulated and optimized using Ansys HFSS®, a benchmarked commercial software. Analyzed results of the proposed antenna are presented. Satisfactory impedance and radiation characteristics are obtained with ~ 87% radiation efficiency and 6% miniaturization.

Keywords: Metamaterials, CSRR (Complementary Ring Resonator), Spiral Resonators, Miniaturization.

I. INTRODUCTION

Met materials are a class of materials, not readily occurring in nature and are artificial man-made materials. They exhibit negative permeability and permittivity over certain frequency ranges that may be controlled through a choice of the physical parameters and exploited for a variety of applications. Such materials have been effectively ultilized by researchers for improvements in antenna features like size reduction, gain and bandwidth enhancement [1]. Microstrip antennas are well-known planar antennas that find tremendous application in many areas; and particularly in the wireless domain. Over the last two decades, significant improvements have been proposed in planar antennas by many researchers; some of the latest innovations being the use of metamaterials to achieve such improvements. Most recently Split Ring Resonators, CSRR, SR, Reactive Impedance Surfaces (RIS) are investigated [2-5]. Yuandan Dong et.al. Have reported miniaturization of patch when loading the patch with CSRR and RIS [6].Wenquan et.al used CSRR on ground for Beam Steering application [7]. The present work is related to both [6, 7] in the sense that it uses a pair of CSRR and SR for antenna miniaturization. In our work we have introduced a new method to attain wideband performance through staggered resonance by loading patch with slightly different dimension and while ground is loaded with SR for effective surface wave suppression.

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The frequency spectrum of GSM (1710-85) MHz [2] has been kept as a target specification, although the proposed technique is adaptable to any band of interest.

II. DESIGN OF PROPOSED ANTENNA

A basic microstrip rectangular patch antenna is first designed using two substrates (Rogers 3003 and Rogers 3210) and employing a direct feeding technique viz. the Inset Feed. It is relatively straight-forward to achieve a satisfactory impedance match referring the design equations from [8]. The proposed antenna has two substrate layers with thickness of 60 mils each. The microstrip line is fed at a distance of 8.065 mm inside the patch margin for good matching with a standard 50Ω impedance system. The designed patch resonates at 1.873 GHz (see Figs. 1 & 2).

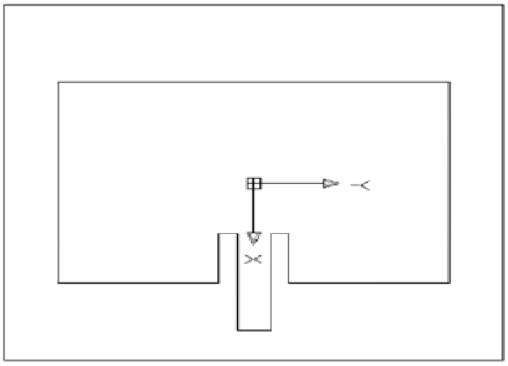

Figure 1 Inset fed Patch Antenna

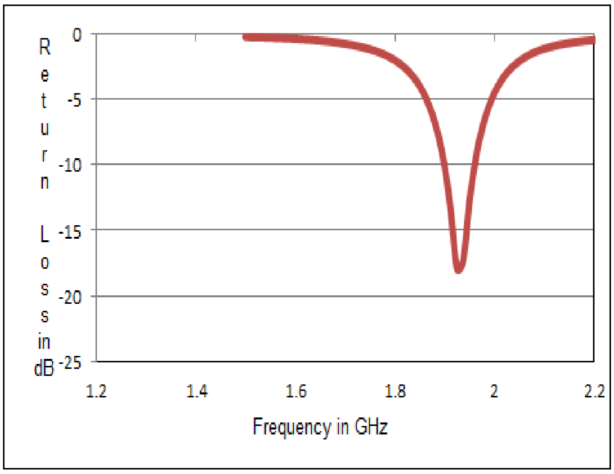

Figure 2 Return Loss Characteristic

Complementary Split Ring Resonators

These structures are duals of split ring resonators which exhibit negative permeability. CSRR exhibits negative permittivity. When loaded onto the patch, the CSRR couples the field by both magnetic and capacitive coupling mechanisms [5, 9]. As the path travelled by the current

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loops is longer across the patch metallization, this leads to miniaturization. Two different resonances were created by designing two different resonant frequencies of CSRR structures slightly off-tuned with respect to each other. The resonances being close enough; overlap each other causing a stagger-tuned response that yields a broad bandwidth. Further, surface wave suppression is achieved by etching spiral resonators on the ground-plane of the antenna substrate.

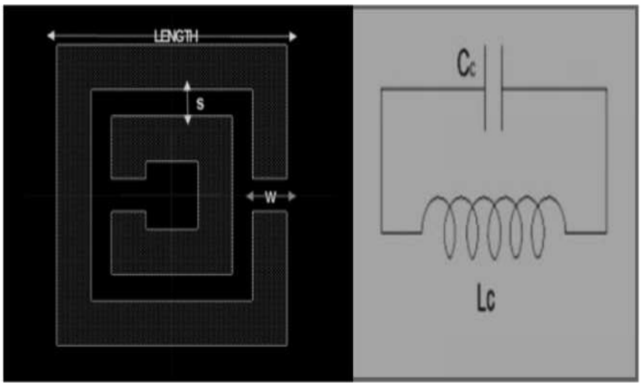

Figure 3 CSRR and its Equivalent [5]

The design equation of CSRR and SR to calculate resonant frequency are summarized below (further details may be obtained from relevant references). .

The Resonant Frequency of the CSRR is given by [5]

$$\omega_o = \frac{1}{\sqrt{L_c C_c}} \tag{1}$$

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

$$\rho = \frac{w+s}{L-w-s} \tag{3}$$

$$C_c = [L-1.5(2+d)]C_{pul} \tag{4}$$

The resonant frequency is a function of the relative permitivity of the substrate,width of the strip and the spacing between the rings. Here 'w', 'L', 's' stands for width, length of the outer ring,spacing between rings, ρ is filling factor,Cpul is per unit capacitance. The resonant frequency of a single CSRR is calculated to be 1.426 GHz. The design equations for the spiral resonators are as follows

$$L_{SR} = \frac{\mu_0}{2\pi} l_{SRavg}\left[\frac{1}{2}+In\left(\frac{l_{SRavg}}{2\omega}\right)\right] \tag{5}$$

$$C_{SR} = C_o \frac{l}{4(\omega+s)} \frac{N^2}{N^2+1} \sum_{n=1}^{N-1}\left[l-\left(n+\frac{1}{2}\right)(\omega+s)\right] \tag{6}$$

Where 'ω'stands for width,'s' for spacing ,'N' is an integer,'n' the number of turns,'l' the length, and expressions for lSRavg and Co expression is available in [5]. The equivalent of the spiral resonator is also a combination of inductance and capacitance and can be seen in [5] .

III. Analyzed Results

Using the formulae in the foregoing section, the design dimensions of both the CSRR's (loaded on the patch) and the spiral resonator (loaded on the ground layer) were obtained. The complete radiator geoemtry including the patch and the three metamaterial elements loaded into it was anlyzed using Ansys HFSS®, which is a benchmarked commercial e,m, simulator. Minor optimization of the element dimensions was also carried out on the same software platform to obtain the exact ferequency band desired. The final dimensional details for the metamaterial elements are summarized in Table 1. The HFSS® simulation model is illustrated in Fig. 4 along with the predicted impedance characteristics. The effect of stagger-tuning by CSRR-loading is clearly evident (on comparing the impedance plot of the unloaded patch – Fig. 2).
Using an absorbing boundary condition (ABC), the far-field characterstics of the propsed element are also obtained (see Fig. 5). The radiation plots resemble the expected TM01 dominant mode of the microstrip patch antenna. Minor asymmetries in the pattern are owing to the perturbation of the patch metallization as well as the ground-plane due to the met material loading.

Table 1 Details of Dimensions of CSRR and SR

Parameter	CSRR	Parameter	SR
Width (mm)	0.5	Width (mm)	0.25
Space (mm)	0.6	Thickness (micron)	35
Gap (mm)	0.5	Distance (mm)	0.5
Length (mm) Right &left side	9.5, 9.3	Turns	15

Figure 4 The Top and Ground View of the Proposed Antenna (showing CSRR loading in patch and spiral resonator in ground plane)

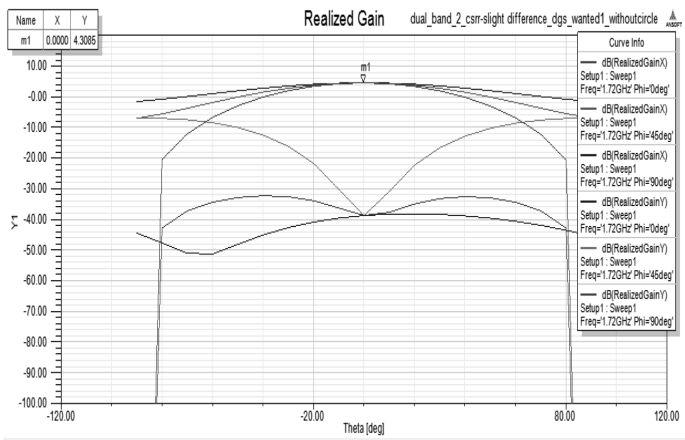

Figure 5 Realized Gain at 1.72 GHz

The key simulation results of the proposed antenna are summarized in Table 2. The GSM band is a possible application for this kind of radiator and an excellent bandwidth is obtained in the present design version.

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A miniaturization to the extent of 6% is achieved that may lead to reduction in the antenna size for a more handy personal unit. The obtained radiation efficiency also indicates that perfoprmance is not sacrificed for the sake of redcued radiator dimensions.

Linear vertical polarization is achieved in the current design. Future scope of work in this direction may be to attempt for circular polarization realization which may be done along with EM coupling techniques. The antenna may be easily fabricated using photolithographic technique; and is hence, potentially cheap while also being compact in size.

Table 2 Summary of Proposed Antenna and Suggested Application

Frequency (GHz)	Return Loss (dB)	Gain (dB)	Efficiency	Miniaturization	Suggested Application
1.72 GHz	-10.17	4.3	87 %	6 %	GSM

IV. CONCLUSION

A new method to miniaturize a microstrip patch antenna is proposed wherein metamaterial loading has been effectively utilized to reduce the antenna dimensions.The gain, bandwidth and radition efficiency are found to be adequate for the suggested wireless application. The percentage of miniaturization achieved in the present design is 6%.

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