Compact Dual-Band Linearly Polarized Patch Antenna using Metamaterials for Wireless Applications

Gayathri Rajaraman[#1], M. Anitha*, Alok K. Singhal**, Khagindra Sood***& Rajeev Jyoti****

#1 Asst .Professor of ECE, Department of Electrical Engg., Annamalai University, INDIA
* Associate Professor, Department of Electrical Engg., Annamalai University, INDIA
** Scientist / Engineer-SF, Space Applications Centre (ISRO), Ahmedabad, INDIA
*** Division Head, Satellite Communication Antennas Division, SAC (ISRO), Ahmedabad, INDIA
**** Group Director, Antenna Systems Group, SAC (ISRO), Ahmedabad, INDIA
Email:gayathri_rajaraman@yahoo.co.in

Abstract – In this paper we present a novel miniaturized dual-band patch antenna based on the metamaterial concept. Complementary split ring resonators, which are excellent structures for miniaturization; along with spiral resonators are used in the proposed design for obtaining a compact dual-band patch antenna. The original patch which is designed to resonate at 2.86 GHz is found to resonate at 1.92 GHz & 2.44 GHz when loaded with three pairs of square complementary ring resonators. Further its ground is also loaded with a spiral resonator yielding a relatively compact antenna structure. The present design has been tuned to the above two bands which finds application in PCS and WLAN applications. The percentage of miniaturization obtained is 51.4 % & 17.6 % respectively. The proposed antenna achieves an efficiency of 80% & 37% in the two bands of resonance.

Keywords: Complementary split ring resonators (CSRR), Metamaterials, Spiral resonators (SR), Miniaturization

I Introduction

Microstrip patch antennas find extensive application in the wireless domain due to features like compactness, ease of fabrication & integration and relatively low cost. These antennas, however, inherently suffer from drawbacks like narrow bandwidth and poor efficiency [1]. These drawbacks need to be rectified or compensated to obtain suitable antenna characteristics for wireless applications. This can be achieved through a variety of methods; but a recent technique is to use a comparatively new class of materials called metamaterials. Metamaterials may be defined as materials exhibiting negative permeability and or permittivity over a certain range of frequencies satisfying the homogeneous condition of the unit cell size being less than or equal to one-quarter of the guided wavelength[2]. Vessalago predicted the existence of such materials in 1967 and it was later in 1996 that Pendry *et. al.* proposed man-made artificial Metamaterials structures[3]. Caloz *et. al.* proposed an analytical treatment by means of the transmission-line equivalent of Metamaterials [4]. Filbertto *et. al.* analyzed both split-ring and spiral resonators and derived expressions for computing the resonant frequency of these structures[5]. Falcon *et. al.* introduced complementary split ring resonators, applying the reciprocity theorem for their analysis[6]. Yuandan Dong *et.al.* miniaturized a patch antenna by loading it with a pair of CSRR structures; using stacked patches and a reactive impedance surface [7]. Wenquan Cao *et. al.* used CSRR on the ground plane to obtain a radiator suitable for beam steering applications [8]. In the present paper, we present a novel design where the basic microstrip patch is loaded with three pairs of CSRRs while the ground is also loaded with a spiral resonator. This has allowed two discrete resonances to be obtained while retaining acceptable radiation patterns across both, rendering the antenna effective for two popular wireless applications: WLAN (2400-2450MHz) and PCS (1850-1990 MHz) [9]. We present the paper in the following order i.e. The design approach, electromagnetic modeling and simulated results for the proposed radiator configuration.

II Design Methodology of the Proposed Antenna

Microstrip patch antennas generally may be directly fed or indirectly fed. In this work, we have chosen an inset-fed patch as the basic radiator; as in this configuration, it is relatively simple to adjust the feed position and obtain an impedance match. The design equation from [1] provides an initial estimate of the feed-point location. A suitable E.M simulator (e.g. the HFSS software) is further employed to optimize the feed position. For the present design, the basic inset-fed patch antenna is designed to resonate at 2.86 GHz (see Figs. 1 & 2). The substrate used is RT/duroid 5880 (with a dielectric constant of 2.2, loss tangent of 0.0009). The patch size is obtained as 34 mm X 47 mm using the design equations from [1]. The inset is provided at a distance of 7mm inside the patch margin while the ground size is 60 X 60 mm. The patch is excited using a microstrip line of width 4 mm (with Z_o = 50 ohms).

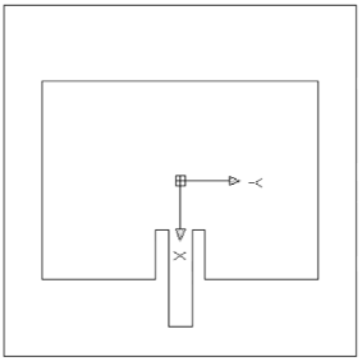

Fig.1 Basic Microstrip Patch Antenna

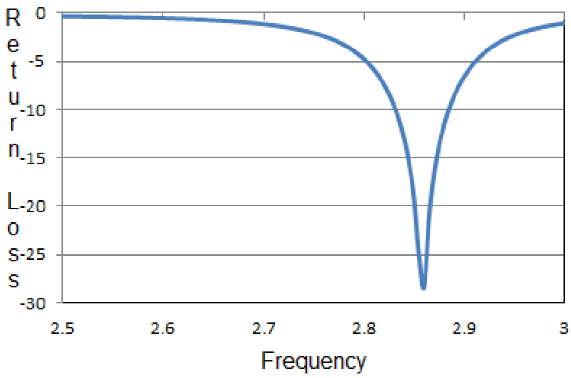

Fig. 2 Analyzed Return Loss

Next step ahead is loading the patch with the CSRR. The CSRR design is independently performed with its resonant frequency chosen such that its resonance is less than the patch resonance. Spiral resonators are reported to yield more miniaturization and this feature is exploited in our design. The patch is duly loaded with three pairs of Complementary split ring resonators and a spiral resonator on the ground. Design aspects of these two types of resonators are briefly discussed.

Complementary split ring resonators are duals of split ring resonators exhibiting negative permittivity when excited by an axial electric field [6]. They resonate at the same frequency as their equivalent split ring resonators [5]. The CSRRs behave like dipoles and they serve to couple energy to the patch for effective radiation by means of magnetic and capacitive coupling. Spiral resonators are considered to be the dual of circular resonators [5]. They have been reported to play a vital role in miniaturization yielding miniaturization to the order of λ/30 [6]. In the proposed radiator configuration, spiral resonators control the flow of surface waves and induce a phase shift in EM waves, hence improving the radiating features of patch. The phase angle depends upon factors like wavelength, refractive index and unit cell dimension. The unit cell size of the CSRR is designed as 9.5 mm X 9.5 mm which is very small relative to one-quarter of the guided wavelength satisfying the homogeneity condition for being a metamaterial. Next the patch is successively loaded with single, double and triple pairs of CSRRs. Subsequently, the radiator geometry is optimized with the E.M. simulator which provides an estimate of the frequency change due to loading. Finally, the dimension of the antenna is re-optimized for a specific requirement; in our case, the particular band of operation for an application of the wireless domain.

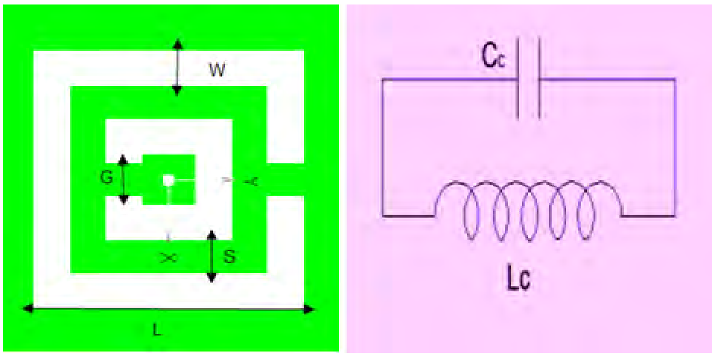

Fig. 3 CSRR and its Equivalent Circuit [5]

The various design equation of CSRR and SR are given below[5].

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

$$\omega_0 = \frac{1}{\sqrt{L_c C_c}} \qquad \ldots (1)$$

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

$$\rho = \frac{w+s}{L-w-s} \qquad \ldots (3)$$

$$C_C = [L - 1.5(2+d)]C_{pul} \qquad \ldots (4)$$

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’ stand for width, length of the outer ring& spacing between rings respectively; ρ is filling factor and C_{pul} 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

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

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

Where ‘ω’stands for width,’s’ for spacing ,’N’ is an integer,’n’ the number of turns,’l’ the length, and expressions for l_{SRavg} and C_o are available in [5]. The equivalent of the spiral resonator is also a combination of inductance and capacitance as can be seen in [5].

III Analyzed Results

The optimised dimension and the results obtained are discussed in this section.

Table 1 Details of Dimensions of CSRR and SR

Parameter	CSRR	Parameter	SR
Width (mm)	0.5	Width (mm)	0.5
Space (mm)	0.6	Thickness (mm)	0.0254
Gap (mm)	0.5	Distance (mm)	1
Length (mm)	9.5	Turns	15

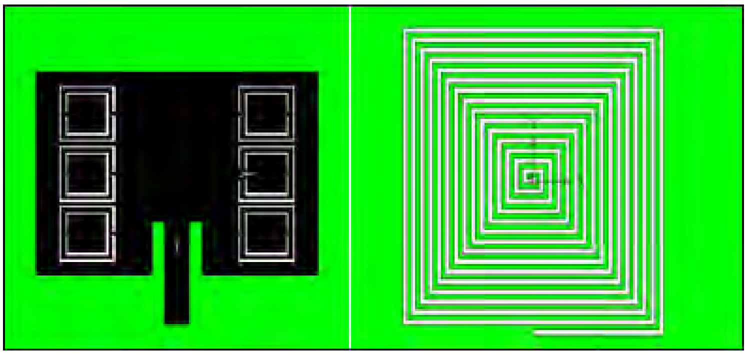

Fig. 4 The Top and Ground Views of the Proposed Antenna (showing CSRR loading in patch and the spiral resonator inscribed in the ground plane)

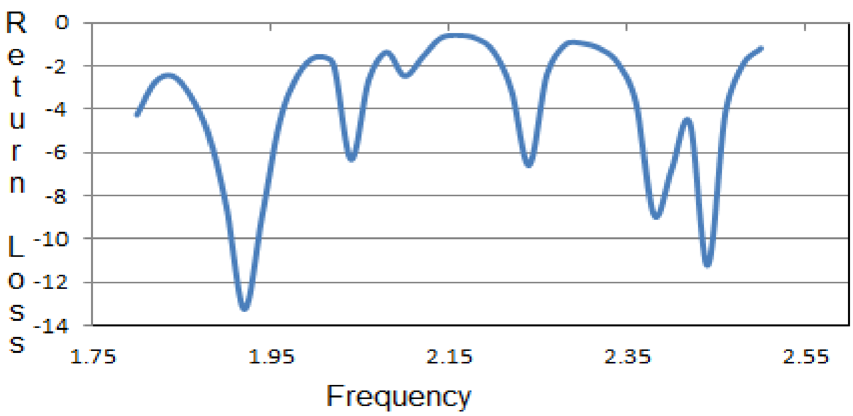

Fig. 5 Analyzed Return Loss of the Proposed Antenna (Resonant Freq’s: 1.92 GHz & 2.44 GHz)

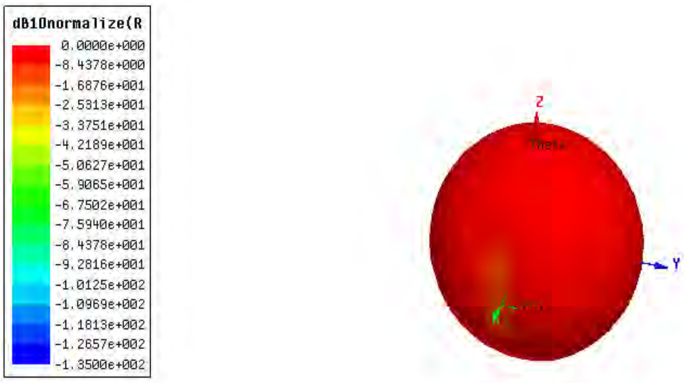

Fig. 6 Normalized Gain Plot of Proposed Antenna at 1.92 GHz (first resonance)

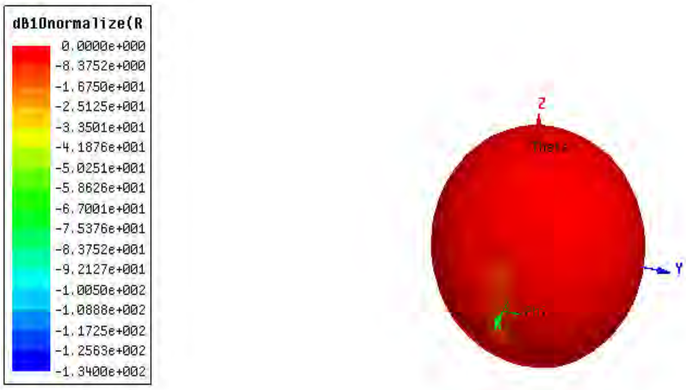

Fig. 7 Normalized Gain Plot of Proposed Antenna at 2.44 GHz (second resonance)

Table 2 Summary of Original, Proposed Antenna Variants and Suggested Applications

Antenna Frequency	Return Loss(dB)	Gain (dB)	Efficiency	Miniaturization	Suggested Application
1.92 GHz	-13.2	1.42	80 %	51.4 %	PCS
2.44 GHz	-11.2	3.07	37 %	17.6%	WLAN
2.86 GHz	-28.3	7.6	89.7 %	-------------	-----------

The analyzed return loss and gain patterns at both the resonant frequencies are presented. An examination of the return loss plot (Fig. 5) indicates that the antenna shows a triple band response in its reflection coefficient characteristic but the gain is found to be negative for that particular band. This may find application in implantable antennas i.e. medical applications. However, since in the present work, our goal is for not for such applications, the position of the feed is changed and the antenna is optimized and finalized for the required WLAN, PCS spectrum. The type of polarization obtained from the final radiators is linear vertical polarization. Owing to its planar construction, the antenna proposed may be fabricated conveniently in a single layer, using photolithographic techniques, with the alignment of the CSRR's within the patch margin and the SR under it.

Conclusion

This paper has presented the design of a patch radiator; an inset-fed variant with three pairs of CSRR's loaded into the metallization part and a single spiral resonator in its ground plane. We have successfully used the negative permittivity material (CSRR) & spiral resonators for miniaturization and improvement of antenna parameters. Two discrete resonances are obtained in the antenna impedance characteristics and these are optimized for two popular wireless application bands, the PCS & WLAN spectra. The proposed antenna maintains acceptable far-field responses at both bands and is compact, with a miniaturization of 51.4 %, 17.6 % respectively. The proposed antenna achieves a good return loss, gain and the desired efficiency. These features make it a good candidate for the suggested applications. Since the antenna is of a planar, single-layer construction, it may be fabricated using photolithography.

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AUTHOR PROFILE

Mrs. Gayathri Rajaraman is working in Annamalai University as Assistant Professor of ECE. Her area of interest is Microwaves particularly antennas. She is doing her Research in Metamaterial based Planar antennas. She has 11 years of teaching experience.

Dr.M.Anitha is Associate Professor of Electrical Engineering, Annamalai University. Her Area of interest are Electromagnetics, Microwaves, and Antenna. She has authored more than 15 papers in International journal and has Coauthored one book in the field of Electromagnetics. She has 17 years of teaching experience. She has authored 10 papers in National and international conference.

Mr. Alok Kumar Singhal was born in Bhusawar, Dist-Bharartpur, Rajasthan, India. He received the B. Tech in Electronics and Communication Engineering from MNIT, Jaipur (1997), M. Tech in Communication Engineering from MNIT, Jaipur in 2002. He joined as Scientist/Engr-SC in Space Applications Center, Indian Space Research organization, Ahmedabad, India (2002). He is Currently working as Sci./Engr.–SF in Satellite Communication Antenna Division, SAC, ISRO, Ahmedabad. He is working in the field of communication, Navigation satellite antennas, & ground terminal antennas. His research interests include wide band, multi frequency printed antennas, microstrip reflectarray antennas, Shared aperture Iso-flux antennas.

Dr.Khagindra Kumar Sood has been with the Antenna Systems Group at the Space Applications Centre (SAC) of the Indian Space Research Organization (ISRO) at Ahmedabad, Gujarat, India Since 1992 . Dr. Sood has also been a Guest Scientist at the German Aerospace Centre (DLR) at Oberpfaffenhofen, Bavaria, Germany over the period 1999-2000 where he worked on technologies for active terminal antennas at K_a- and V-bands. He has been Deputy Project Director, Communication Payload Antennas for important ISRO communication satellite projects. In this capacity, some of his notable contributions are segmented shaped reflector for enhanced inter-beam isolation for GSAT-4, unfurlable antenna for INSAT-4E and indigenous dual-gridded reflectors for INSAT-4G/GSAT-8. He has published some of his work in Electronics Letters and is an inventor/co-inventor in eight patent applications relating to antennas with high beam isolation, low cross-polarization and multimode tracking antennas. He is currently the Head of the Satellite Communication Antennas Division within the Antenna Systems Group at SAC. His key areas of interest are shaped reflectors, dual-gridded reflectors, multiple-beam antennas, unfurlable antennas, large Cassegrain earth-station antennas and feed horns, OMT's, etc. for these antennas.

Mr. Rajeev Jyoti received his Master of Science in Physics and M. Tech. in Microwave Electronics from Delhi University, Delhi, India in 1984 and 1986 respectively. Since 1987, he is involved in the development of antennas for satellite communication at Space Applications Centre (SAC), Indian Space Research Organization (ISRO), and Ahmedabad, India. Presently, he is Group Director of Antenna Systems Group at SAC, ISRO, India. He has more than 25 years' experience in development of space borne and ground antennas at SAC. He has contributed significantly in design, analysis and development of microwave antennas namely gridded antenna, multiple beam antennas and phased array antennas for INSAT/GSAT, RISAT, DMSAR projects.

Mr. Rajeev Jyoti is Fellow Member of IETE India, Senior Member of IEEE, USA, and Chair of Joint Chapter of IEEE AP and MTT, Ahmedabad. He has published more than 55 papers in various conferences and referred journals. He has 14 patents to his credit. He was awarded UN ESA Long term fellowship in Antenna & Propagation at ESTEC/ESA Noordwijk, Netherland.