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RESEARCH PAPER

A miniaturized dual-band ZOR antenna using epsilon negative transmission line loading

ASHISH GUPTA AND RAGHVENDRA KUMAR CHAUDHARY

A miniaturized dual-band CPW-fed metamaterial antenna is presented and developed in this paper. Zeroth-order mode is originated by realizing open-ended composite right/left-handed transmission line. A dual split ring resonator is introduced to obtain another mode. The antenna is operated in the frequency region 1.60–1.64 and 2.76–2.79 GHz. Shunt inductance is offered by means of thin stripline connecting ground planes. It is demonstrated that by applying metamaterial loading (thin stripline) proposed antenna is capable to achieve 51.9% miniaturization with respect to the antenna without metamaterial loading. The presented antenna has an electrical size of 0.162 $\lambda_o \times 0.108\ \lambda_o \times 0.008\ \lambda_o$ at $f_o = 1.62$ GHz. The antenna exhibits simulated gain of 1.05 and 2.59 dB in the broadside directions at 1.62 and 2.78 GHz, respectively. Beside that this antenna offers dipolar-type pattern and omnidirectional pattern in the xz-and yz-planes respectively at both bands, which is beneficial to be used in modern wireless applications. The design methodology of the proposed antenna is described with the help of current distributions and parametric analysis.

Keywords: Split ring resonator (SRR), Zeroth-order resonance (ZOR), Epsilon negative transmission line (ENG-TL)

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I. INTRODUCTION

Multiband metamaterial antennas are more beneficial than wideband antennas as they can be used for multiple modern wireless applications with the lower interference level at undesired bands [1–3]. Unusual characteristics of metamaterials such as negative permittivity–permeability, antiparallel group and phase velocity, and zeroth-order (ZOR) mode propagation make the antenna outstanding to serve particular applications [4]. Multiple bands can be achieved by introducing different elements such as complimentary split ring resonator (CSRR) [1]. Dual-band antennas are very popular in terms of metamaterial antennas [2, 3] using epsilon negative transmission line (ENG-TL) approach. ZOR is one of the favorable phenomenon in metamaterial antenna, which enable one to make ZOR frequency independent from the physical size of the antenna. Enormous work has been reported on ZOR-based antennas either using unit-cell approach [5–7] or composite right/left-handed (CRLH) resonant approach [8–10].

It is more accessible to realize resonating/radiating elements into coplanar-waveguide (CPW)-fed antenna structures and thereby facilitate great design freedom to antenna engineers. Typically ground planes are on the same plane as of patch for CPW-fed structures, which offers expedite analysis of metamaterial (MTM) antennas [5–7]. It is studied that asymmetric structures provides more miniaturization as compared to symmetric structures [5]. Pioneering work by Niu et al. [6, 7] used three MTM unit cells in which bandwidth enhancement is achieved by merging multiple modes in a single pass band and manipulating *Q* factor. It is already established that number of modes are evaluated by number of unit cells. In this connection, backed ground CPW-fed antennas came into picture. Sharma *et al.* [8] qualitatively analyze two different structures for miniaturization and band broadening, respectively. It is studied that backed ground plane offers additional shunt inductance which is helpful to reduce the electrical size of the antenna. Lumped components are realized in order to obtain CRLH transmission line in CRLH antennas [9, 10]. A single-cell antenna is proposed using T-type discontinuity and achieved three expected modes ($n = 0$, $n = \pm 1$) [9]. It is also studied that compact elements such as meandered line inductors degraded the gain performance due to high level of miniaturization. Therefore electromagnetic bandgap structures are added in CPW-fed MTM antennas to enhance the gain by the same authors recently [11, 12]. Proposed structure gain is independent from such gain degradation ambiguity.

This paper presents a compact dual-band MTM antenna based on ENG-TL approach. In the proposed antenna lower band (ZOR mode) is provided by the ENG-TL. In order to originate the second mode dual SRR are loaded on other side. It is studied that this mode is contributed by coupling between inner and outer SRRs. The novelty of proposed work corresponds to originate two different modes which are independent to each

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other thereby resonant frequency can be configured easily by varying the dimensions of relative elements.

II. ANTENNA MODELING AND GEOMETRY

ENG-TL is the modified form of CRLH transmission line in which series capacitance is not present [8]. In the proposed antenna, signal patch characterizes L_R, while shunt capacitance is provided by the gap between signal patch and ground plane. Shunt inductance is associated with the thin stripline join ground planes and is individually responsible to originate ZOR mode. Proposed antenna shows an asymmetric structure, which is provided by a ground plane at one side, while other side is loaded with dual SRR. Figure 1 shows the configuration of proposed antenna with pertinent design dimensions in captions. Thin stripline is used to connect the ground planes and provide shunt inductance. Whole structure is fabricated on a 1.57 mm thick RT Duroid substrate 5880 tm ($\varepsilon_r = 2.2$, $\tan\delta = 0.0009$).

III. ANTENNA DESIGN AND ANALYSIS

Proposed antenna is designed in such a way that ENG-TL can be realized. An asymmetric ground plane CPW-fed structure is first conceived. It is essential to incorporate shunt inductance in order to behave as an MTM antenna. Consequently, a thin stripline is introduced between ground planes at other side. Figure 2 shows the input reflection coefficients with respect to three configuration, e.g. configuration-1 (without stripline and dual SRR), configuration-2 (with stripline without dual SRR), and configuration-3 (proposed antenna). One can quickly conclude by observing Fig. 2 that thin strip line is responsible for originating the ZOR mode (at 1.62 GHz) and miniaturization. It is observed that 51.9% miniaturization (shifted from 3.37 to 1.62 GHz) is achieved with respect to configuration-1 by introducing thin stripline. It also indicates that second mode is due to coupling between inner and outer SRRs.

Parametric analyses have been performed on electromagnetic software HFSS 14.0 to obtain optimized dimensions.

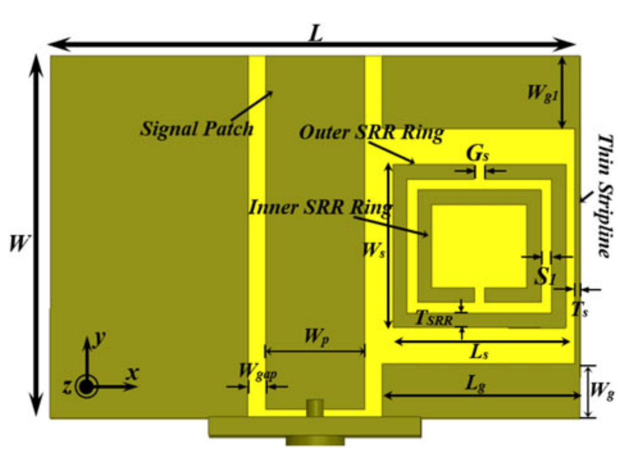

Fig. 1. Geometry of the proposed antenna. (All dimensions are in mm: $L = 30$, $W = 20$, $W_p = 5.6$, $W_s = 9$, $L_s = 9.8$, $L_g = 11.2$, $W_{g1} = 4$, $W_{gap} = 1$, $T_{SRR} = 0.8$, $T_S = 0.3$, $S_1 = 0.6$, $G_s = 0.6$).

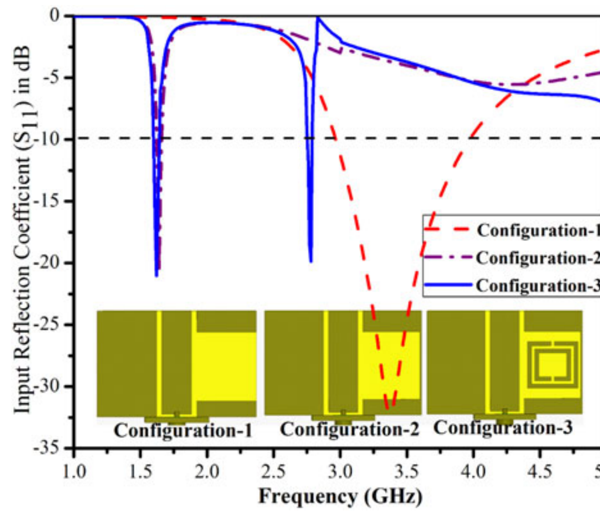

Fig. 2. Input reflection coefficients of the proposed antenna with different configurations.

The effect of stripline thickness (T_s) on ZOR frequency can be illustrated by Fig. 3. It is studied that more current concentration within certain area leads to more inductance. For the open-ended case ZOR frequency is given by $\omega_{sh} = 1/\sqrt{L_L C_R}$. Figure 3 supports above statement as thickness is increased, ZOR frequency also increases. Figure 4 is shown, in order to demonstrate the variation of input reflection coefficient with respect to dimension W_s. Significant effect can be observed on second resonance (at 2.78 GHz) and is decreased as W_s is increased, while ZOR mode is in steady state. The dimension of the SRR are chosen such that $W_s = 0.08\ \lambda_o$, where λ_o is the free space wavelength at $f_o = 2.78$ GHz. It is also noted that $L_s = 1.08\ W_s$ selected during optimization.

In order to describe the performance of thin strip line and dual SRR, current density at both modes are plotted in Fig. 5. It is observed that currents are centralized on thin stripline at the ZOR mode in the specified region. It can be also concluded that the second mode is originated by the contribution of inner and outer SRR. In order to validate the ZOR mode E-field distributions of the proposed antenna at ZOR frequency is presented in Fig. 6. It can be recognized that all

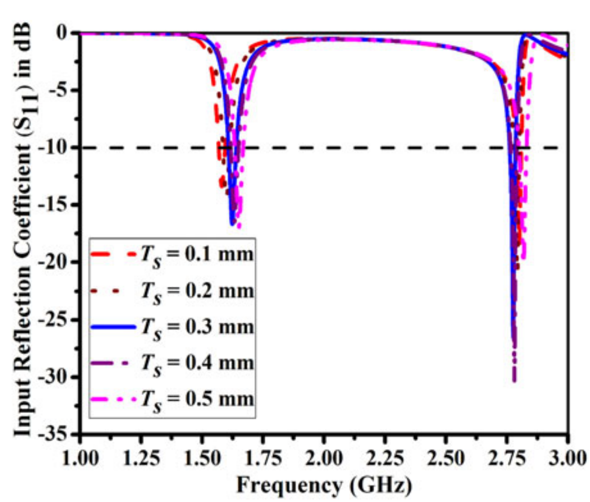

Fig. 3. Input reflection coefficients of the proposed antenna by varying stripline thickness T_s.

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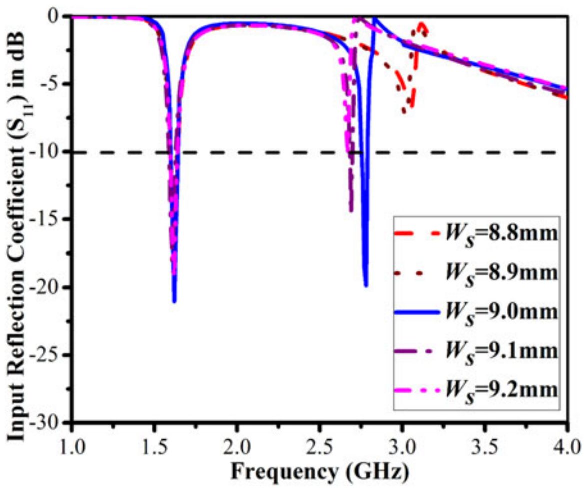

Fig. 4. Input reflection coefficients of the proposed antenna by varying SRR width W_s.

field lines are in phase except some slight discontinuity at the edges which demonstrates the existence of ZOR mode.

IV. EXPERIMENTAL RESULTS

Prototype is fabricated on RT Duroid 5880 (tm) substrate using a chemical etching process and is presented in Fig. 7. Input reflection coefficient measurements are carried out on Agilent N5221A PNA network analyzer. Figure 8 demonstrates the simulated and measured input reflection coefficients, which show well agreement among simulated and experimental results have been observed. Measured results show the first and second bands at 1.6 and 2.93 GHz, respectively. Minor shift in the second band (found at 2.93 GHz) is observed and is subjected to the fabrication tolerance in SRR.

Far-field measurements are carried out in free space by taking log-periodic antenna as reference antenna. As depicted by Fig. 9, proposed antenna shows perfect dipolar-type radiation pattern and omnidirectional pattern in the *xz*-plane and *yz*–planes, respectively. Cross-polarization level is not measured due to high radiation losses and large interference level in free space. Simulated gain of 1.05 and 2.59 dB is achieved at 1.62 and 2.78 GHz, respectively. Measured peak antenna gain is also calculated among two planes (*xz*- and *yz*-planes) as −0.54 and 1.70 dBi at 1.62 and 2.78 GHz, respectively. It has been observed that losses due to impedance

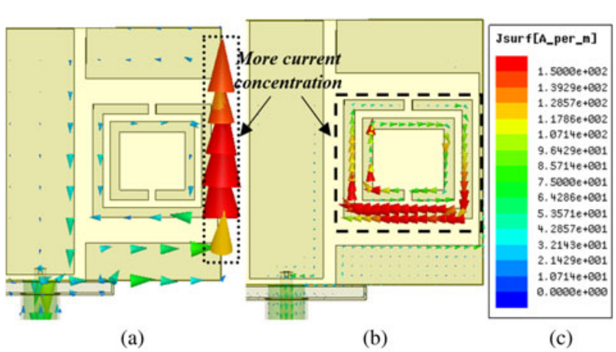

Fig. 5. Surface current density of the proposed antenna, (a) at 1.62 GHz. (b) At 2.78 GHz. (c) magnitude scale.

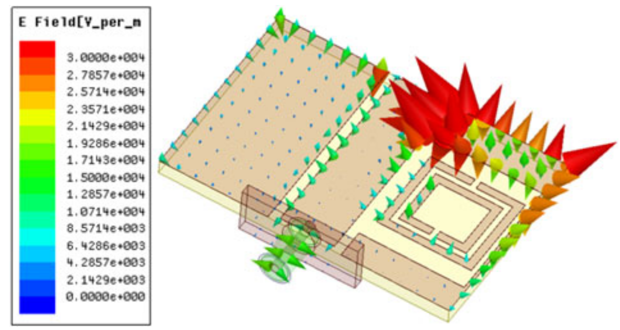

Fig. 6. *E*-field distributions of the proposed antenna at the ZOR mode.

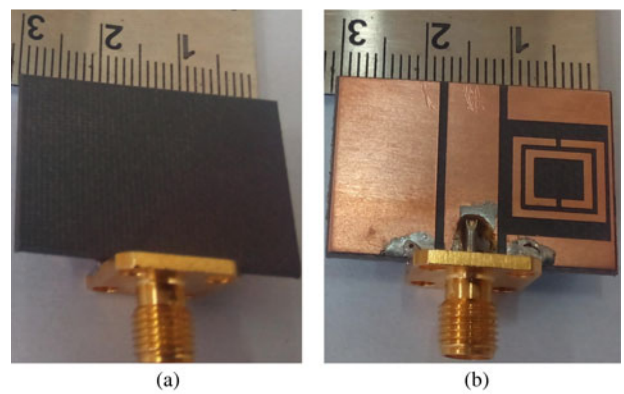

Fig. 7. Photographs of the fabricated prototype. (a) Top view. (b) bottom view.

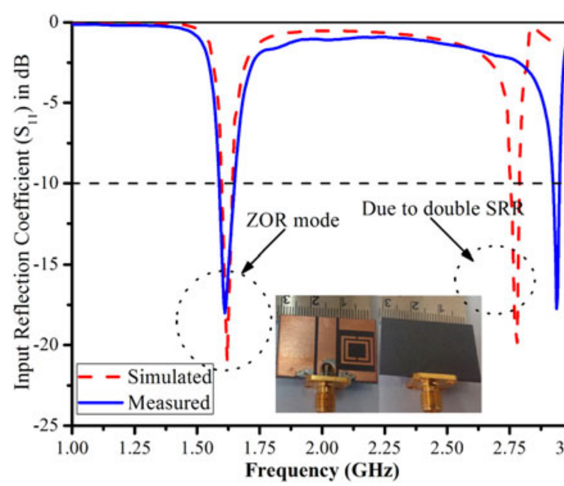

Fig. 8. Simulated and measured input reflection coefficients of the proposed antenna.

matching, i.e. subminiature version A connector losses are significant as the antenna size is very small, which is the reason for getting such smaller gain with that of the simulated one.

The setup for measuring gain consists of log-periodic antenna as a transmitting antenna, which is connected to the radio frequency (RF) source. The gain of the log-periodic antenna is already known by using two identical log-periodic antennas. In addition to that, spectrum analyzer is connected to the antenna under test to observe the received power. The antennas are separated by a distance *R*, and it must satisfy the far-field criterion of each antenna. In this paper, gain of

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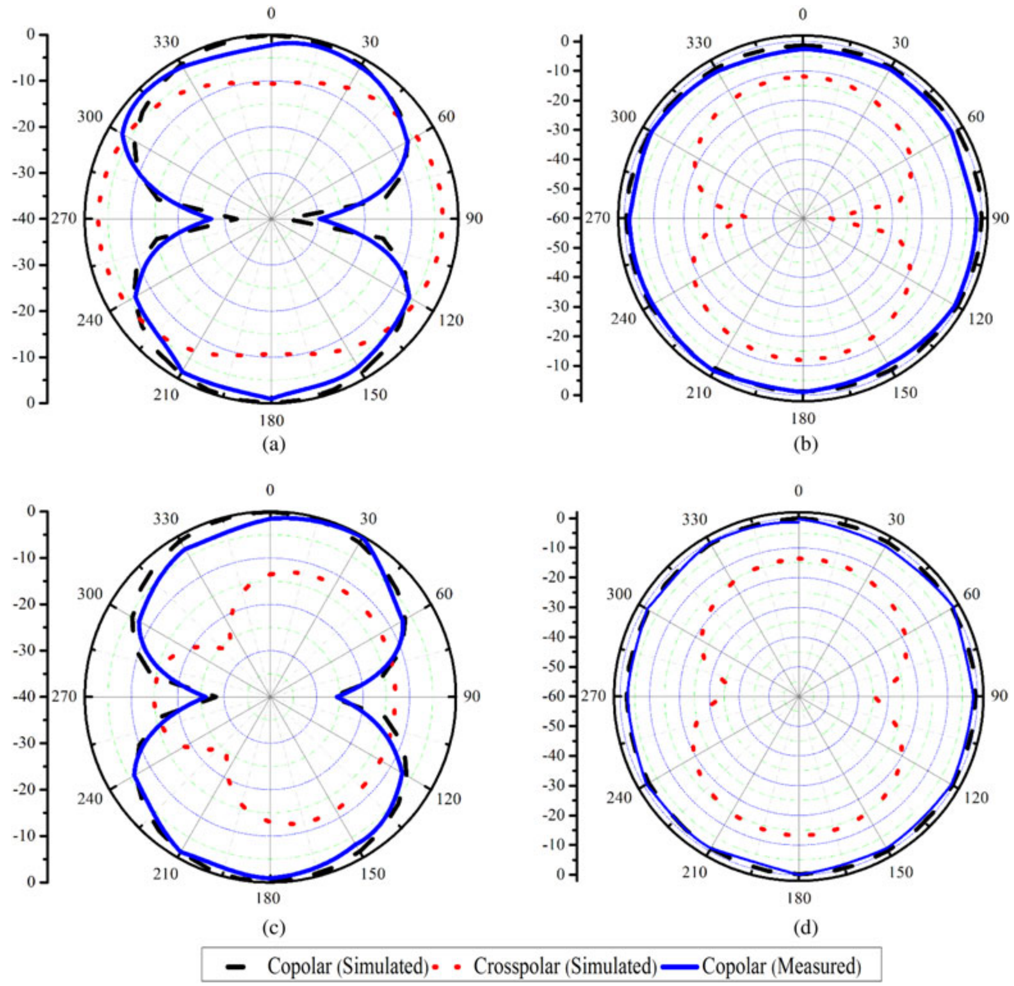

Fig. 9. Simulated and measured radiation patterns of the proposed antenna. (a) *xz*-plane at 1.62 GHz. (b) *yz*-plane at 1.62 GHz. (c) *xz*-plane at 2.78 GHz. (d) *yz*-plane at 2.78 GHz.

the antenna is calculated by two antenna method using Friis transmission formula, which is given as hereunder:

$$G_{ot}G_{or} = \left(\frac{4\pi R}{\lambda}\right)^2\left(\frac{P_r}{P_t}\right). \quad (1)$$

The above equation can be written as in the logarithmic decibel form as

$$G_{ot(dB)} + G_{or(dB)} = 20\log_{10}\left(\frac{4\pi R}{\lambda}\right) + 10\log_{10}\left(\frac{P_r}{P_t}\right), \quad (2)$$

G_{ot} = gain of transmitting antenna (known), G_{or} = gain of receiving antenna (unknown), R = distance between transmitting and receiving antenna (in meter), λ = free space wavelength corresponding to frequency on which gain to be measured, P_t = transmitted power, and P_r = received power.

Proposed antenna shows simulated radiation efficiency of 98.5 and 97.2% at ZOR mode and second band, respectively. Table 1 compares the present work with the earlier published work on MTM ZOR antennas. It indicates significant amount of miniaturization with the improved radiation efficiency. However in [3], the gain at the ZOR mode is extreme high and is due to large aperture size. Furthermore, the proposed

Table 1. Comparison of the proposed antenna with recently published work.

Parameters	This work	[1]	[3]	[5]	[13]	[14]
f_{ZOR} (GHz)	1.62	2	2.52	1.5	2.3	2.46
Overall electrical size (λ_o)	0.162 × 0.108	–	0.42 × 0.42	0.107 × 0.127	0.20 × 0.14	0.26 × 0.196
Fractional B.W. (%)	2.46	5.9	4.3	4.8	4.34	3.25
Peak gain (dBi)	1.05	−4.6	4.04	−2.15	2.3	0.71
Radiation efficiency (%)	98.5	34	–	42.5	79	61.2
Via process	No	Yes	Yes	No	Yes	No
Dielectric constant (ϵ_r), loss tangent (tanδ)	2.2, 0.0009	2.2, 0.0009	3.5, 0.0018	2.2, –	4.4, 0.02	4.4, 0.02
Thickness (mm)	1.57	1.57	1.524	1.6	0.8	1.59

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antenna does not require any via process tends to ease of fabrication.

V. CONCLUSION

This paper presents a miniaturized CPW-fed dual-band ZOR-based metamaterial antenna. ZOR mode is originated by realizing an ENG-TL while another mode is obtained by coupling between inner and outer SRRs. Both modes can be configured and independent to each other. By applying metamaterial loading 51.9% miniaturization is achieved with respect to structure without metamaterial loading. The antenna is operating over 1.6–1.64 and 2.76–2.79 GHz with peak gain of 1.05 dB and 2.59 dBi, respectively at ZOR mode and second mode. Proposed antenna shows compact feature offering electrical size of 0.162 $\lambda_o \times$ 0.108 $\lambda_o \times$ 0.008 λ_o at the ZOR mode. Fabricated prototype demonstrates excellent dipolar and omnidirectional pattern in the *xz*- and *yz*- planes, respectively. Simulated radiation efficiency are 98.5 and 97.2% at the first and second modes, respectively.

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