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Negative refractive index material-inspired 90-deg electrically tilted ultra wideband resonator

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Abstract. A negative refractive index material loaded patch antenna is proposed for ultra wideband applications. The wideband operation has been achieved by creating a defected ground plane with a CNC shaped split ring resonator. The defected ground plane CNC resonator also exhibits a 90-deg electrical tilt. Two additional slots are engineered in the patch antenna for further bandwidth enhancement. A −10 dB bandwidth with an order of 57.89% has been achieved with a peak gain of 5.37 dBi at a 5.5 GHz resonant frequency. Measured results demonstrate good agreement with simulated results. [DOI: 10.1117/1.OE.53.10.107104]

Keywords: negative refraction; optical technology; photonic band gap structure; split ring resonator.

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1 Introduction

The science associated with negative refraction has immensely contributed to microwave and optical technology in the past decade. Photonic band gap structures and split ring resonators (SRR) have the abilities to tweak the properties of electromagnetic waves.[1] One such extremely popular passive device is a microstrip patch antenna, which has shown very attractive possibilities of integration with photonic band gap structures and split ring resonators.[1] Microstrip patch resonators became greatly popular in the past few years, owing to the various advantages it offers such as ease of manufacturing, efficient radiation, compact size, and being light weight.[2] The major drawback of the patch antenna is the narrow bandwidth.[2] The proposed patch antenna takes used negative refraction technology to enhance the bandwidth by tweaking the electromagnetic property of the material. The defected ground plane structures are widely utilized for bandwidth enhancements.[1,2] Left-handed materials are capable of providing subwavelength focusing as an optical lens.[3] Instead of keeping a planar ground plane at the bottom of the patch antenna, a CNC-shaped SRR, which exhibits a negative refractive index, has been proposed to work as a defected ground plane. A traditional defected ground plane antenna suffers in gain; however, the proposed resonator structure provides a fair gain for ultra wideband (UWB) applications. The geometry of the proposed resonator and its negative refraction is illustrated in Fig. 1.

Figures 1(a) and 1(b) illustrate the top view and bottom view of the resonator, whereas Figs. 1(c) and 1(d) are the relative permittivity and relative permeability of the CNC resonator, respectively. Negative refractive materials, or metamaterials, have shown enormous potential for altering antenna properties for application-specific designs.[4,5] In the presented design, a left-handed CNC unit cell was first simulated and then the negative refraction was computed using a computational technique based on effective Bloch impedance of the medium.[6] Metamaterials have offered a wide range of applications in the optical and terahertz (THz) regimes. One such potential application for the proposed negative refractive index structures is utilization in semiconductor substrates for improvement in carrier concentration.[7] Photoexcitation and electrical injections can further be employed for active modification in the resonant properties of the substrate. A magneto-electric antenna, exploiting the interference between the magnetic and electric modes in an SRR, is designed for the experimental realization of a compact and robust optical antenna, which outperforms larger, multielement antennas in both bandwidth and directionality.[8] In addition, the proposed SRR can also be utilized in the design of a thermally tunable THz composite material[9] and a strong LC response of resonator can be utilized for designing thick substrate materials for optical engineering applications.[10]

Magnetically excited magnetic resonances with negative magnetic permeability in an InP-based optical waveguide with an array of gold SRRs are experimentally observed with the effect of an incident-polarization-dependent absorption feature at 1575 nm. The magnetic resonance is a result of SRR array interaction with the magnetic field of the propagating electromagnetic wave. This leads to the utilization of the proposed resonator in all optical switching applications.[11]

2 Antenna Design, Simulation, and Measured Results

The fabricated antenna prototype is illustrated in Fig. 2. Figures 2(a) and 2(b) represent the top view and bottom view of antenna. The proposed compact antenna has been fabricated on a substrate material of FR4 Epoxy with a size of $80 \times 80\ \text{mm}^2$ and a thickness of 1.54 mm. The material has a relative permittivity, ε_r, of 4.4 and a dielectric loss tangent, δ, of 0.02. A CNC resonator of length $1.35 \times L$ and width W

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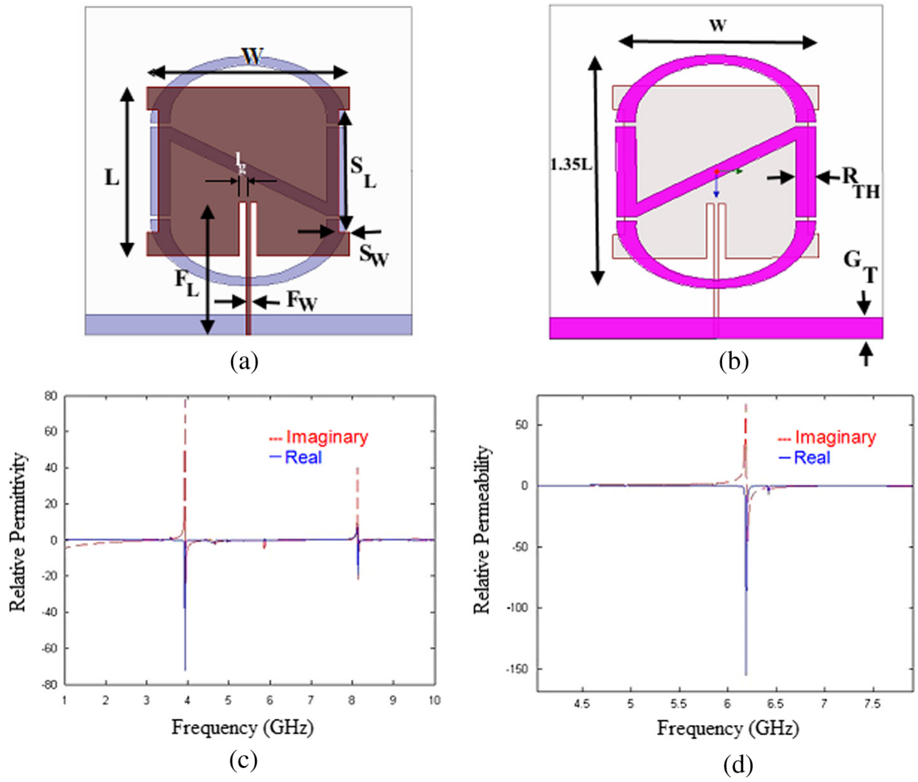

Fig. 1 Negative refractive index inspired patch resonator. (a) Top view. (b) Bottom view. (c) Relative permittivity. (d) Relative permeability.

is etched as a defected ground plane of the patch antenna. The angle of the N section in the CNC resonator is kept as 45 deg. Variation in angle of the CNC resonator provides a further shift in electrical tilt; however, this will be presented as a separate article. The slots on top of the patch antenna are utilized for fine tuning and they can be exploited for achieving the required bandwidth of the antenna coupled with a CNC resonator. The antenna parameters in millimeters are as follows: patch width $(W) = 49.41$; patch length $(L) = 41.35$, feed length $(f_L) = 32.3$, feed width $(F_W) = 1.1$, inset gap $(I_g) = 0.6$, slot length $(S_L) = 30.0$, slot width $(S_W) = 5.5$, resonator thickness $(R_{TH}) = 4.12$, length of N N section $= 26$, ground plane thickness $(G_T) = 6$.

Figure 3 illustrates the graph of the simulated and measured return losses, and Fig. 4 shows the antenna radiation characteristics. The measured return loss graph illustrates

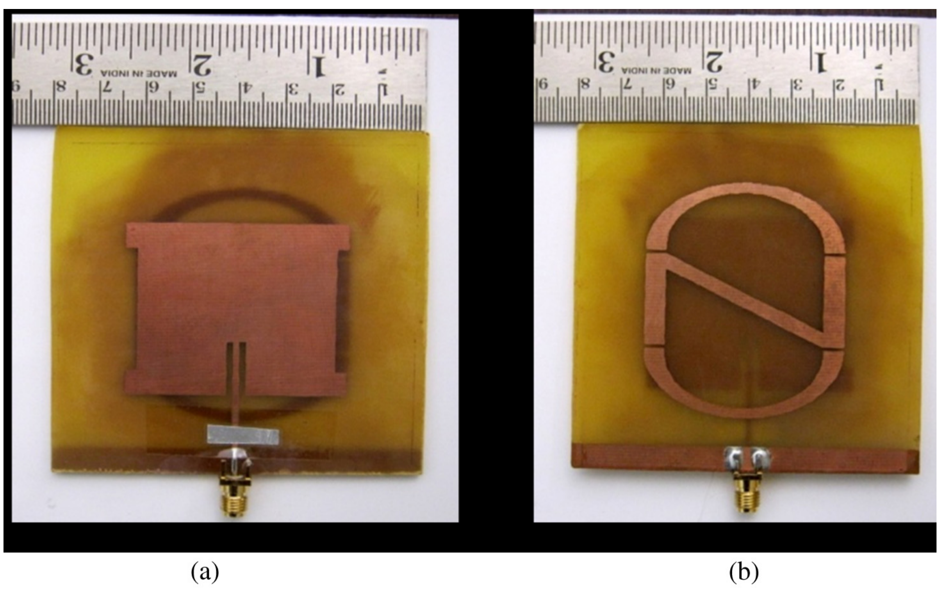

Fig. 2 Fabricated prototype of antenna. (a) Top view. (b) Bottom view.

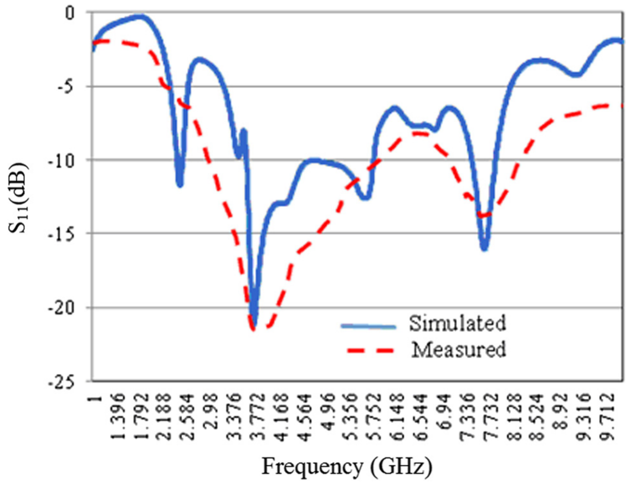

Fig. 3 Antenna return loss.

that a −10 dB bandwidth starts from 2.98 to 5.575 GHz, which is an order of 57.89%. The simulated −10 dB bandwidth of the resonator was 49.83%. After application of an impedance matching stub on the printed circuit board at the inset feed line, a higher bandwidth on the order of 57.89% was achieved. The realized bandwidth is significantly higher than that of traditional patch antennas, which typically have a bandwidth on the order of 3 to 4%. The gain achieved at 5.5 GHz is 5.37 dBi as illustrated in the polar plot of Fig. 4(a). Simulated and measured radiation patterns of the proposed antenna having a 90-deg electrical tilt are demonstrated in Fig. 4(b). Both the antenna gain and the 90-deg electrical tilt are achieved due to inception of the CNC resonator.

Figure 5 demonstrates the frequency versus gain curve, which shows that a fair gain is achieved in the frequency range of 2.98 to 5.575 GHz. An array of 2×2 or $4 - 4$ CNC resonators can be employed for high gain multiple input multiple output antennas. The proposed antenna can be tuned to an application-specific frequency range by modifying the proposed geometry parameters of the CNC resonator.

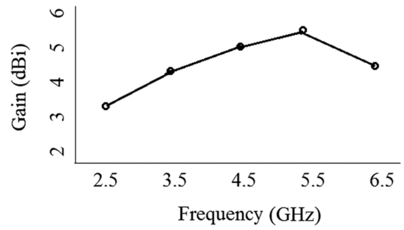

Fig. 5 Realized antenna gain.

3 Conclusion

A compact metamaterial inspired UWB slotted patch resonator is presented. Antenna bandwidth enhancement, gain, and electrical tilt are achieved by engineering the defected ground plane and the CNC-shaped resonator. Experimental results demonstrate spectrum coverage of 2.98 to 5.575 GHz; hence, the designed UWB antenna offers applications in both WiFi technology operating at 5.5 GHz and WiMAX technology operating over a wide band of 3.3 to 3.8 GHz. The geometrical dimensions of the CNC-shaped resonator can be modified in order for the antenna to be utilized in different wireless applications. The proposed CNC-shaped resonator leads active tunable electronic components, such as varactors, to be placed in the gaps for the antenna to be electrically tunable with the desired antenna pattern modification. The electrical tilt along with a wide band are also useful for wideband code division multiple access (W-CDMA) applications where the electrical up-tilt and down-tilt of antenna beam is crucial in the performance of W-CDMA communications.

Acknowledgments

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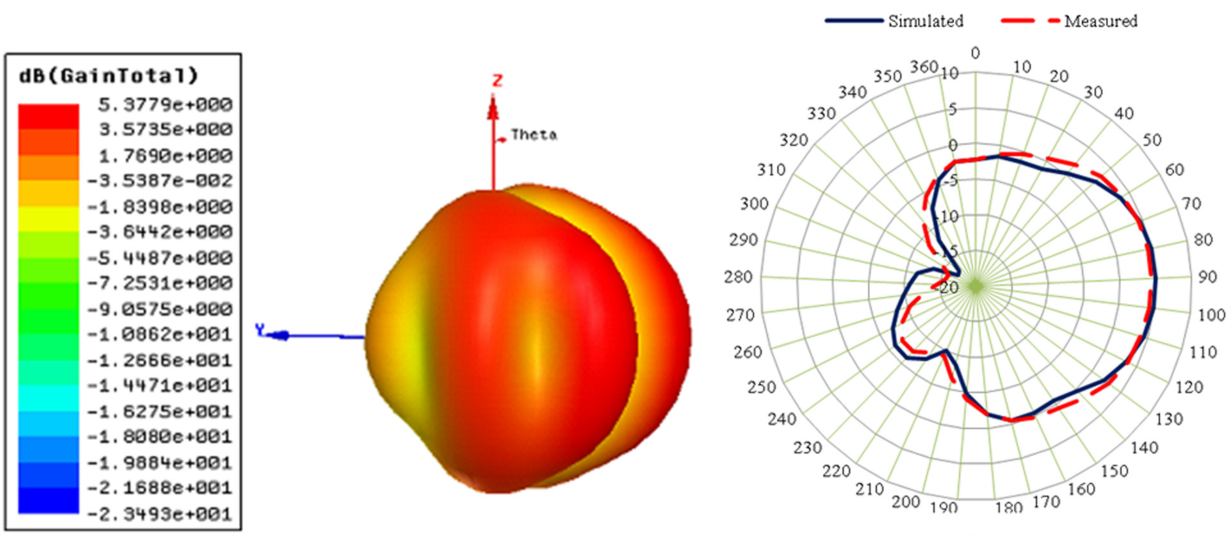

(a) (b)

Fig. 4 Antenna radiation characteristics. (a) Polar plot. (b) Radiation pattern.

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