

A Miniaturized Microstrip Antenna Based on the Backward Waves Property of LTCC Left-handed Metamaterial Substrate

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1. Introduction

Modern wireless communication devices are required to be miniaturized, while antenna is an important part of communication system. Many scientists and engineers focus on how to achieve better performance at lower frequency on microstrip antennas in a small area. Conventional miniaturization technology includes high permittivity substrates, meandered patch, capacitive loading and so on [1]. Because of the interaction among antenna performances, the miniaturization leads to contractible bandwidth, lowered radiation efficiency and pattern degradation, and difficulties in impedance matching of the antenna. Consequently, new methods to miniaturize antenna by using metamaterial technology are proposed and theoretically discussed.

Left-handed material is a kind of novel synthetic metamaterial, whose permittivity and permeability are simultaneously negative. It is different from the traditional right-handed material, whose electric field, magnetic field and wave vector satisfy the left-hand rule, which means the phase velocity and group velocity are in the opposite directions, so they have many unusual properties, such as reversed Doppler shift, reversed Cherenkov radiation, reversed negative refraction, perfect lens and etc [2].

In literature, Enghata has shown that a pair of right-handed medium and left-handed medium blocks could be used to build small resonators, which is verified as a phase compensator [3]. One of the most important applications of this phase compensator is the miniaturization of microstrip antennas, for the phase shift gained by waves propagating in the right-handed medium block could be compensated by waves in the left-handed medium block. By theoretical analysis, the size of microstrip antennas can be reduced by multi-pair dielectric blocks and the dimensions of the antennas would no longer be proportional to the working wavelength but approximately to the ratio of the dimensions of the dielectric blocks [4].

However, the inherent severe dispersion of the practical right-handed material is different from that set in the theoretical models. Meanwhile, it's difficult in achieving metamaterials architecture in conventional PCB technology. LTCC manufacturing techniques are well suited for the small pattern sizes required by metamaterials for microwave applications. Additionally, it is easy to make

multilayer designs of complex microstructures. In this paper, a miniaturized microstrip antenna is proposed on LTCC metamaterial substrate, which is utilized to prove that the miniaturization indeed realized by the backward wave property. Furthermore, the performance of the miniaturized antenna is investigated and compared with conventional one.

2. Design of left-handed material on LTCC substrate

The configuration of the left-handed material unit cell is shown in Fig. 1. It consists of two split ring resonators (SRRs) and one strip embedded in the dielectric host medium. The strip supplies negative permittivity. The SRR is a ring with a gap, and the axis of the ring should be parallel with the magnetic field. At the resonant frequency band of the SRR, the permeability is negative [5]. Frequency characteristics are important for microwave applications. The geometric parameter of the structure determines the resonance frequency. The patterns of the metamaterial are composed in the multilayer structure and connected through microvias between layers at LTCC fabrication.

Fig. 1 is the designed left-handed material unit cell for LTCC fabrication. The substrate is composed of Ferro ULF140 ceramic films, where the permittivity is 14, the dielectric loss tangent is 0.002 and the permeability is 1. The microstructure is composed of two SRRs and one strip. The SRR has a loop, which is composed of two metal lines and two microvias. Metal lines are connected by microvias filled with metal. The width of the metal lines (W_d) is 0.2 mm, and the size of the gap (G) is 0.1 mm. The radius of the microvia (R) is 0.1 mm. The length of the ring (L) is 2 mm, and the width of it (W) is 1.2 mm. The two rings have the same physical sizes, and the other ring is obtained by rotating the front ring 180° . The strip is between these two rings, which connects two PEC planes, and the distance (S) is 0.5 mm.

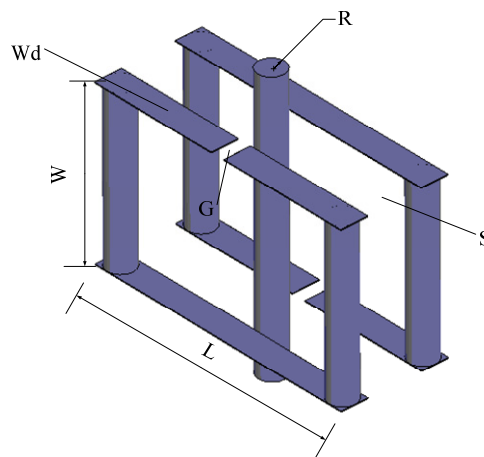


Fig. 1: The three-dimensional geometry of left-handed material unit cell

To extract the effective electromagnetic parameters, the reflection and transmission coefficients are simulated for the incident plane wave using Ansoft HFSS full-wave simulator. The effective permittivity and permeability can be extracted from these parameters [6]. The effective permittivity and permeability of the substrate with the unit cell are shown in Fig. 2. The real part of permittivity is negative in a large region. Meanwhile, the real part of permeability is negative from 4.6 GHz to 5.5 GHz. The middle layer, which needs microvia, is punched using a mechanical punching system

and filled with silver conductor pastes. Metal lines are printed on the top and bottom layers. After aligning all layers, samples are formed by the lamination process.

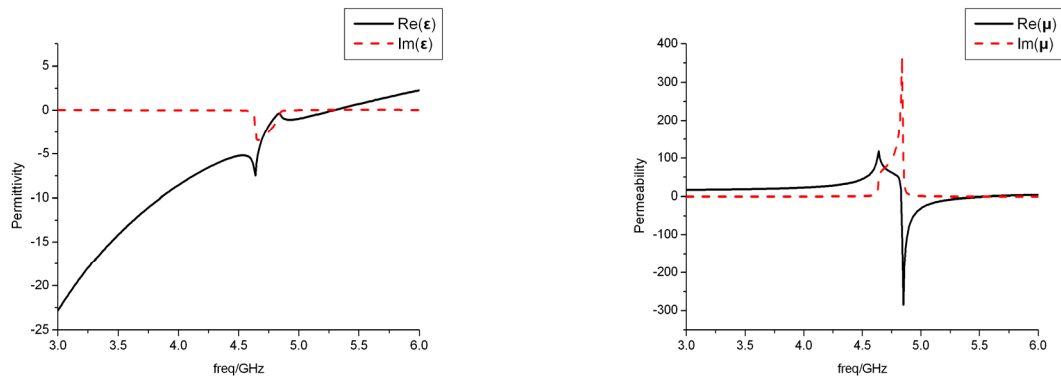


Fig. 2: Retrieved effective permittivity and permeability of designed metamaterial unit cell

3. Modeling and design of the miniaturized microstrip antennas

After the verification of the backward waves [7], a novel stage is arisen to break the fundamental dilemma, because it can be promising to reduce the physical dimensions of the patch by the unusual performance of the left-handed material fillings. A C-band rectangular microstrip patch antenna was designed using the metamaterial substrate discussed in the previous sections. Fig. 3 shows the geometry of the unit cells with the microstrip patch antenna. The size of the patch antenna is 5 mm x 12 mm. The thickness of the patch antenna is 0.006 mm, which is same as that of the metal line in the unit cell structure. The distance between the centers of the unit cells is 2 mm.

Nevertheless, when the metamaterial fillings, embedded into the substrate, are closed to the two radiative ends of the patch, the radiation conductance will be greatly influenced. In order to reduce the interference, the unit cells will be put at the center of patch, leaving the two ends free. Fig. 4 shows the reflection coefficients of the designed microstrip antenna. The antenna on the dielectric substrate has the resonance frequency at 4.6 GHz. Results show that the length of the microstrip antenna has been significantly reduced to 0.28λ .

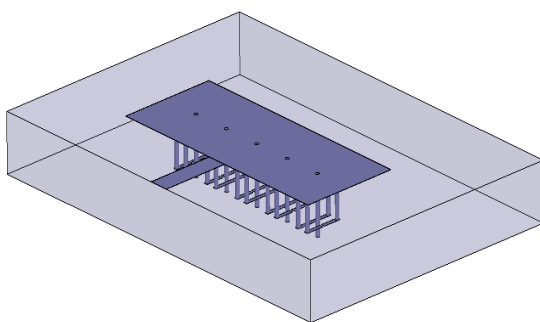


Fig. 3: Schematic illustration of the antenna geometry

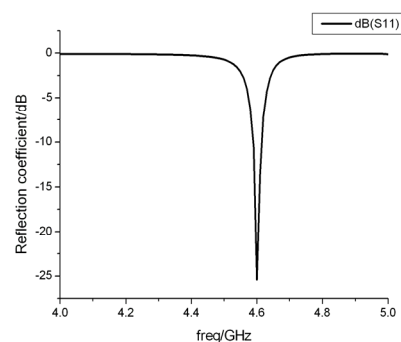


Fig. 4: Calculated reflection coefficient (S11) of antenna with left-handed material unit cells

Besides the reflection coefficient, the farfield pattern is another important issue we concerned. The 3D patterns, produced by both conventional half-wave-length microstrip antenna and the

miniaturized microstrip antenna with left-handed metamaterial fillings, are respectively demonstrated in Fig. 5 and Fig. 6. The conventional microstrip antenna is a directive antenna with a main lobe perpendicular to the antenna patch. Hence the miniaturized microstrip antenna is omnidirectional. According to the explanation of M.F.Wu [8], the E-field of conventional half-wave-length microstrip antenna is equivalent to a dipole on the horizontal plane, while the miniaturized microstrip antenna can be approximately regarded as a monopole on the vertical plane. However, the gain of proposed antenna is lower than conventional half-wave-length microstrip antenna, because the resonance of left-handed until sell will lose energy ineluctability.

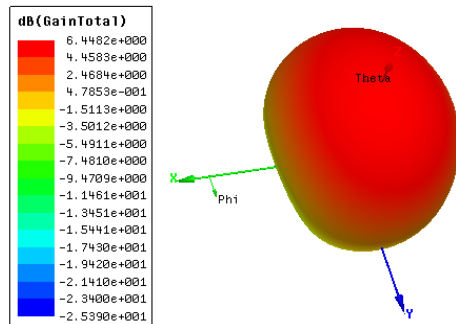


Fig. 5: 3D pattern of conventional half-wave-length microstrip antenna

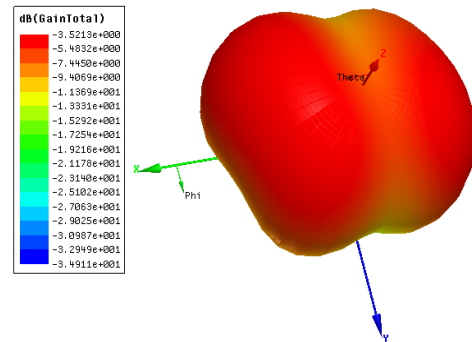


Fig.6: 3D pattern of the miniaturized microstrip antenna with left-handed material unit cells

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