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Investigation of gain effect of multi-band patch antenna based on composite rectangular SRRs

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ABSTRACT

The paper focus on describing the important influence and physical law of the Split_Resonant_Rings (SRRs) based on Left Handed Material (LHM) on patch antennas. The FDTD method, together with FEM method is used to study the characteristics of patch antenna based on composite rectangular SRRs. A novel composite rectangular SRR system is formed by assembling the conventional patch antenna and SRRs, it is found that electromagnetic wave resonance occurs at several bands: GSM (880–960 MHz), DCS (1710–1881 MHz), and PCS (1850–1990 MHz). The electromagnetic wave's "tunnel effect" and evanescent waves' enhancing effect are formed, which can improve the localization extent of electromagnetic wave's energy apparently, such effects can improve the antenna's radiation gain and its matching condition. The phenomenon indicates that such composite rectangular patch antennas are promising in wireless communications such as mobile phone, satellite communication and aviation.

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1. Introduction

The antenna's micromation is one of the key technologies of Receiver/Transmitter System's micromation in wireless communications. As compared to conventional microwave antenna, microstrip patch antennas have advantages of light weight, low volume, low fabrication cost, low profile planar configuration, can be easily integrated with microwave integrated circuits (MICs). Its major disadvantages are narrow bandwidth and low gain, which ask for some techniques to overcome these disadvantages.

Left Handed Material which was firstly presented in 1990s is a novel periodic artificial electromagnetic structure. It has negative permittivity and negative permeability simultaneously, when the EM wave propagates through the material, the electric field, magnetic field, and wave vector of the electromagnetic wave in such a medium would form a left handed triad, so it is called Left Handed Material (LHM). This kind of material, as a novel artificial EM material, has attracted a lot of attention and interests recently. As early as 1968, Vesolago has investigated the abnormal phenomenon of LHM from the theoretic aspect [1], in 2000, Smith and his group first fabricates the negative material experimentally in the microwave band [2,3], the LHM's abnormal EM characteristics exhibit its important application value in optical and electromagnetic areas.

It has been proved that the LHM's equivalent permittivity and permeability are both negative during a frequency band. On the other hand, if the small electrically antenna are surrounded by very thin LHM, the antenna's radiation impedance can be changed from capacitance to inductance, it is the same with the Matching net added between the antenna and free space. The antenna's radiation efficiency can be improved by designing the LHM properly.

The patch antenna based on composite rectangular SRRs is studied by the method of FDTD; its concerned parameters are attained by simulation and analysis. The equivalent permittivity and permeability of the composite rectangular SRRs can be calculated by NRW method [4]. The characteristics of the antennas with and without SRRs are compared, finding that the patch antenna with SRRs has a lower return loss and a higher gain.

2. Computing model of antenna with composite rectangular SRR

The FDTD [5–7] is a method used frequently to calculate the patch antennas for its advantages among these algorithms used in patch antenna's computation, and Maxwell equations can be transformed into scalar field model by calculating, then use numerical difference coefficient in the second rank precision instead of differential quotient, discrete the differential equations in space-time using the method proposed by Yee, and make patch antenna based on composite rectangular SRRs meshed [5]. We assume Δx, Δy are space steps towards x, y direction, respectively, Δt is time

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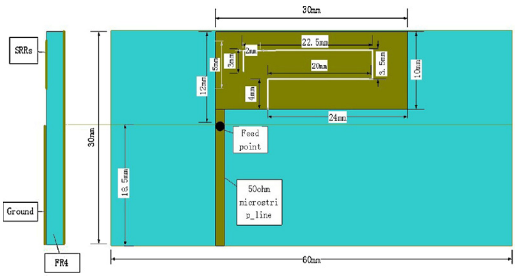

Fig. 1. Side view and top view of the patch antenna based on composite SRRs.

step, then we can get difference equations in scalar field model, and Maxwell equations can be transformed into FDTD equations in iteration formulation when it is in TE model.

$$E_x^{n+1}(i,j) = E_x^n(i,j) + \frac{H_z^{n+(1/2)}(i,j+(1/2)) - H_z^{n+(1/2)}(i,j-(1/2))}{\Delta y} \cdot \frac{\Delta t}{\varepsilon(i,j)} \quad (1)$$

$$E_y^{n+1}(i,j) = E_y^n(i,j) + \frac{H_z^{n+(1/2)}(i+(1/2),j) - H_z^{n+(1/2)}(i-(1/2),j)}{\Delta x} \cdot \frac{\Delta t}{\varepsilon(i,j)} \quad (2)$$

$$H_z^{n+(1/2)}(i,j) = H_z^{n-(1/2)}(i,j) + \frac{E_x^n(i,j+(1/2)) - E_x^n(i,j-(1/2))}{\Delta y} \cdot \frac{\Delta t}{\mu} - \frac{E_x^n(i+(1/2),j) - E_x^n(i-(1/2),j)}{\Delta x} \cdot \frac{\Delta t}{\mu} \quad (3)$$

To ensure steady results in iteration constringency Δx, Δy, Δt must satisfy these steady conditions [5]:

$$\Delta t \leq \frac{1}{c\sqrt{(\Delta x)^{-2} + (\Delta y)^{-2}}} \quad (4)$$

The calculating formulation for H_x, H_y, E_z in TM model can be attained by the same way.

We take Perfectly Matched Layer (PML) [6,7] as the boundary condition towards X, Y direction while computing [7,8], and divide a cell by 20×20 discretization, then we choose 4000 as the time step, finally the microwave PBG antenna with source is simulated by the FDTD numerical method.

We take the Gauss pulse as the excitation source for its smoothness in the time domain, and the bandwidth is easy to choose. The electric field *Ez* vector under the microstrip on the excitation plane is:

$$Ez(t) = \exp\left[-\frac{(t-t_0)^2}{T^2}\right] \quad (5)$$

The parameters are: $T = 40\Delta t$, $t_0 = 110\Delta t$. where Δt, t_0 and T are time increment step, time delay, and half-width Gauss pulse. Its frequency ranges from 0 to 14.1 GHz. 4000 time steps are chosen. The patch antenna based on composite rectangular SRRs is calculated by the FDTD numerical method.

The side view and top view of the conventional patch antenna are shown in Fig. 1, the equivalent dielectric constant of the substrate is 4.4, and its dimension is 60 mm × 30 mm × 0.8 mm, a patch with an area of $10 \times 30\,(\text{mm}^2)$ is placed in the middle of the top substrate, there are five slits in this patch, the slits are defined by slit_*i* (i = 1, 2, 3, 4, 5), the width of these slits are all 0.5 mm, and length are 4 mm, 20 mm, 3.5 mm, 22.5 mm, 3 mm respectively. Gaussian discrete excitation is chosen as the antenna's excitation. The coaxial feed is taken, the distance between the feed location and patch edge is 1.5 mm.

The top view of the phone antenna based on composite rectangular SRRs is shown in Fig. 1. On the other side of the substrate, the half is ground whose dimension is 18.5 mm × 60 mm, and the other half is periodic rectangular SRRs, whose dimension are

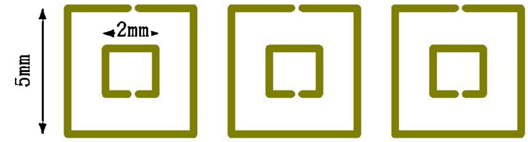

Fig. 2. Geometry structure of the SRRs.

shown in Fig. 2, where the outer is 5 mm × 5 mm, and the inner is 2 mm × 2 mm, the width are all 0.5 mm, the width of the cut in the SRR is 0.4 mm, the distance between the first two adjacent SRRs is 10 mm, the last two adjacent SRRs is 9 mm.

The antenna's frequencies have covered the GSM band (880–960MHZ), DCS band (1710–1880 MHz), PCS band (1850–1990 MHz) and the WLAN band (2400–2480 MHz).

3. Simulation results and analysis

The FDTD-based simulator is used to analyze the above two antennas whose working frequencies cover the GSM, DCS, and PCS bands. There are electromagnetic resonances in each band, and the maximum antenna gain can be attained, as shown in Fig. 3.

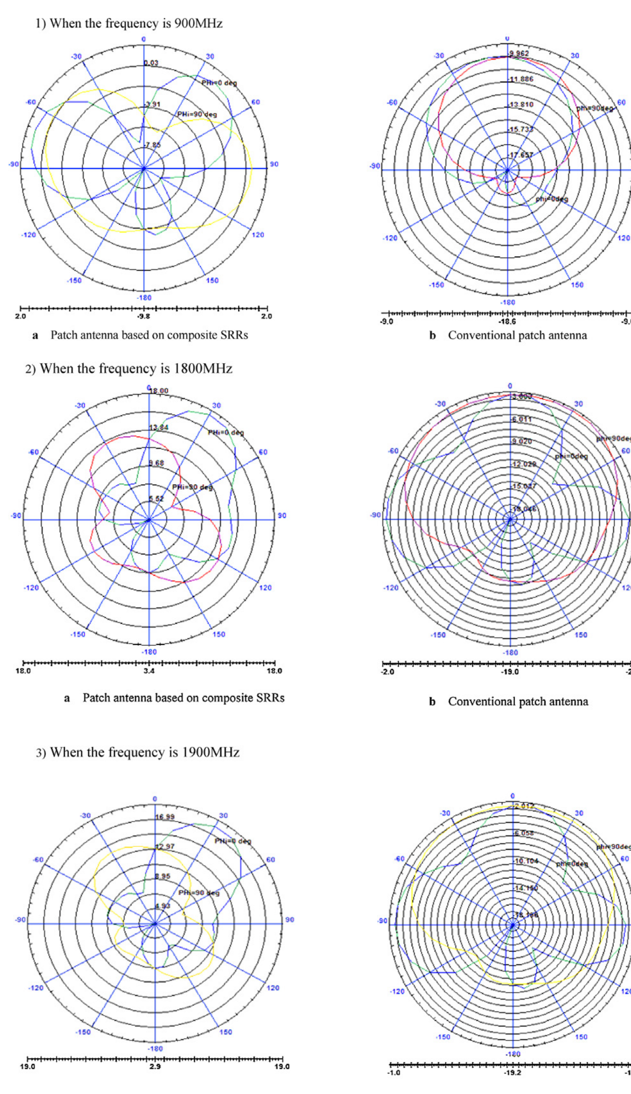

Fig. 3. Radiation patterns of the two antennas.

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