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MULTI-BAND RECTANGULAR MICROSTRIP ANTENNA USING A METAMATERIAL-INSPIRED TECHNIQUE

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Abstract—A new design methodology for multi-band rectangular microstrip antenna using a metamaterial-inspired technique is proposed. The methodology uses the metal disk with SRR-shaped slot placed horizontally between the patch and the ground plane. With the introduction of the split ring, sub-wavelength resonance can be achieved while the dominant mode of patch cavity remains the same, so the antenna can operate at multi resonant frequencies. Construction of the multi-band antenna requires only the sandwiching of two etched circuit boards. The antenna has the properties of low profile, easy fabrication and low cost. Dual-band and tri-band antennas are fabricated and measured, which validate the design methodology.

1. INTRODUCTION

The great success in mobile communication industry has fostered the development of antenna in wireless systems [1]. Low profile and multi-band antenna design has received great attention from both academic and commercial areas, due to the need for multi-band operation and reduced size [2]. Modern communication systems, such as GPS, WLAN, often require multi-band antenna with compactness and low cost. Printed antenna is the mostly used solution for its low profile, light weight, and easy integration [3]. However, printed antenna is difficult to miniaturize since the dominant mode of their resonant frequency is determined by path cavity. And multi-band printed antenna has many resonant structures which make the dimension of antenna large.

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To minimize the size of an antenna and operate at multi resonant frequencies, many techniques have been proposed, including high permittivity [4], shorting plates/pins [5] and fractalizing the radiate patch [6]. However, these antennas may have high cost and need larger space or special fabrication techniques [7, 8], which are not applicable for multi communication systems.

As one of the most important elements of metamaterial [9, 10], split ring resonator (SRR) was first demonstrated by Pendry et al. [11], for synthesis of μ-negative media. SRRs are placed properly where the magnetic field is polarized along the axis of the ring. This small particle may be made to resonate at a frequency determined by the capacitance and inductance of the ring structure. Many applications have been reported with SRR, such as UWB antenna [12], AMC structure [13, 14] and filter [15, 16]. Miniaturization of patch antenna with SRR is proposed by Raoul O. Ouedraogo [17]. CSRR are placed horizontally between the ground plane and radiating patch, so the electric field of the dominant mode within patch cavity is polarized normal to the CSRR, which can be excited and lower the resonant frequency of the patch.

A rectangular planar antenna using a metamaterial-inspired technique is proposed in this paper for multi-band operation. The methodology uses single or dual-mode SRR structure placed horizontally between the ground plane and the radiating patch. New sub-wavelength resonate frequency can be excited and multi-band operation occurs. Construction of the optimized antenna requires only the sandwiching of two etched circuit boards. The proposed antennas are demonstrated through simulations and experiments, with dual-band and tri-band operations, respectively.

2. BASIC ANTENNA CONFIGURATION

The geometry of the proposed multi-band patch antenna is shown in Fig. 1. The antenna has a simple configuration, consisting of

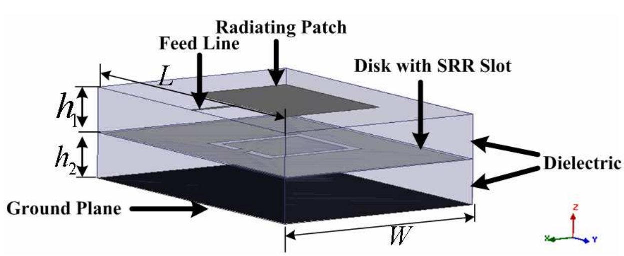

Figure 1. Geometry of the multi-band patch antenna.

two dielectric substrates (Taconic Material TLA-6) with thickness of 1.5 mm, relative permittivity of 2.65 and a substrate loss tangent of 0.0017. A radiating rectangular patch is placed above one substrate, and a microstrip feed line is used to excite the patch, while a ground plane is placed backed the other substrate. A conducting disk with SRR-shaped slot is placed horizontally between two substrates. The geometry of the radiating patch, shown in Fig. 2, remains the same for different antennas for comparison. The first resonance frequency is determined by the cavity formed by rectangular patch and ground. The sub-wavelength resonant frequency can be formed by the disk with SRR-shaped slot. The property of sub-wavelength resonant frequency is determined by SRR, so dual-band or tri-band antenna can be implemented with different SRR shape slots. The rectangular patch has a length of $L_{patch} = 30$ mm, width of $W_{patch} = 20$ mm. Microstrip feed line has different width W_{feed} for different antenna, which is used to match the antenna impendence.

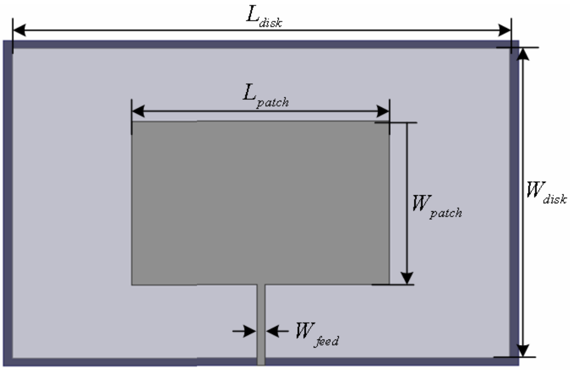

Figure 2. Geometry of the rectangular patch.

3. DESIGN OF TWO TYPE MULTI-BAND ANTENNA

With the above methodology, dual- and tri-band antennas are designed for multi-communication systems. Antennas are designed, fabricated and measured. The performance of the proposed structure is compared with tradition rectangular patch antenna.

3.1. Dual-band Antenna

The basic configuration is shown in Fig. 1. The geometry of the disk containing the SRR slot is shown in Fig. 3. The SRR has square side length 20 mm, width of slot 2 mm, and the split gap

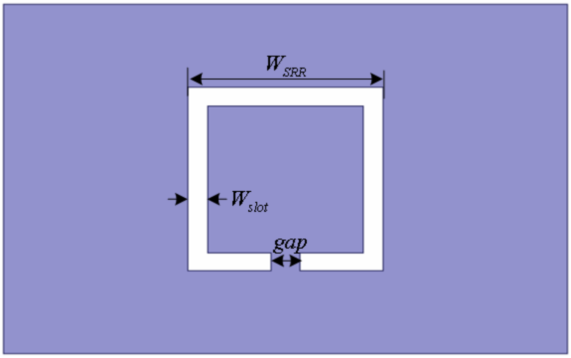

Figure 3. Geometry of the disk with SRR-shaped slot.

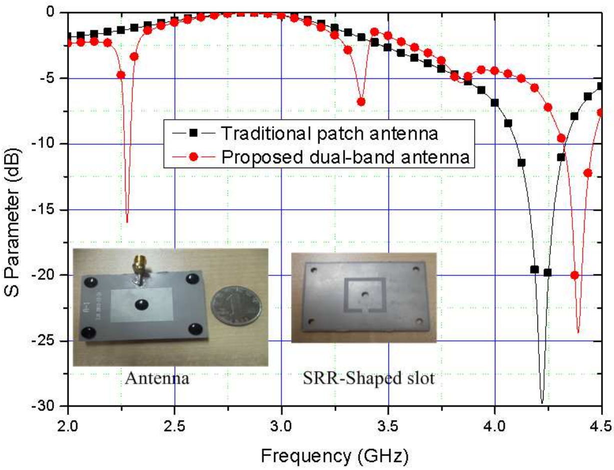

Figure 4. Photograph of proposed dual-band antenna and its measured S parameters.

3 mm. With a single-mode SRR structure, antenna can operate at two different frequencies. The fabricated antenna and the measured reflection coefficient are shown in Fig. 4. The first resonant frequency is 4.4 GHz, determined by the dominant mode of the cavity, and the other sub-wavelength frequency is 2.3 GHz. Compared with tradition patch antenna, the antenna can operate at two different frequencies. The radiation patterns are measured and shown in Fig. 5. The antenna has the similar radiation pattern with traditional patch antenna at 4.4 GHz. However, the proposed antenna has the dipole-like radiation pattern at 2.3 GHz, which means that the ground has little influence due to its relatively smaller size.

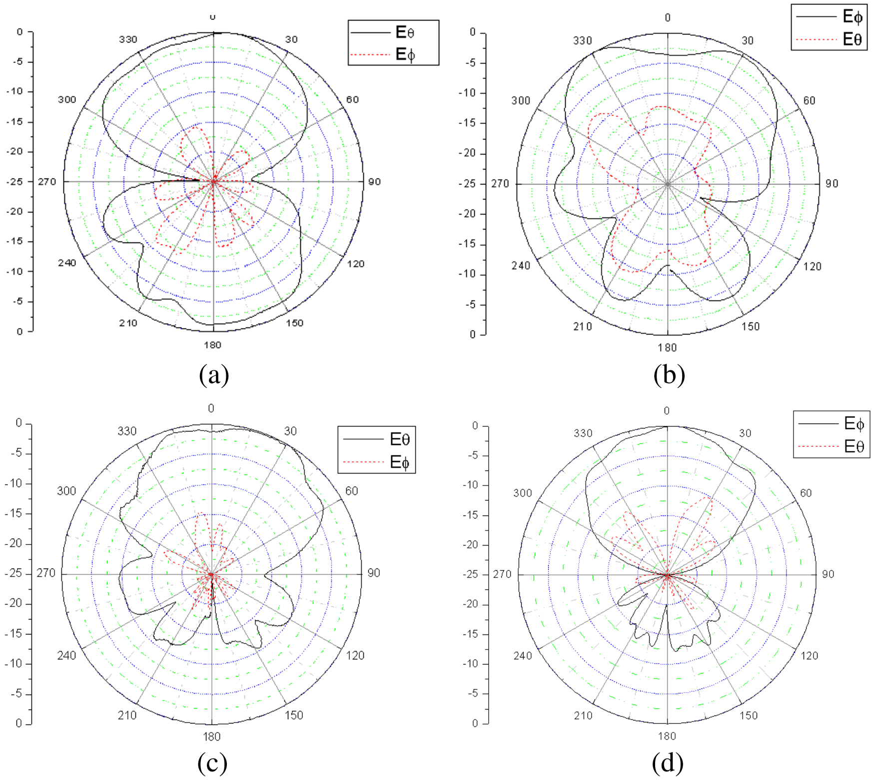

Figure 5. Measured radiation patterns of proposed dual-band antenna: (a) xz plane at 2.3 GHz, (b) yz plane at 2.3 GHz, (c) xz plane at 4.4 GHz and (d) yz plane at 4.4 GHz.

3.2. Tri-band Antenna

With the single mode SRR-shaped slot, the proposed antenna can operate at two different frequencies. One is determined by the dominate mode, and the other is sub-wavelength resonate frequency. Dual-mode SRR is removed from the conducting disk placed horizontally between two substrates, and two sub-wavelength resonant frequencies can be created. The geometry of dual mode SRR is shown in Fig. 6, and its parameters are shown in Table 1. With analysis method of odd- and even-modes, dual mode SRR has two resonant

Table 1. Parameter values of dual-mode SRR.

Parameter	W_{SRR}	W_{slot}	W_1	W_2	L_1	L_2	L_3	gap
Value (mm)	20	2	3	2	8	12	6	3

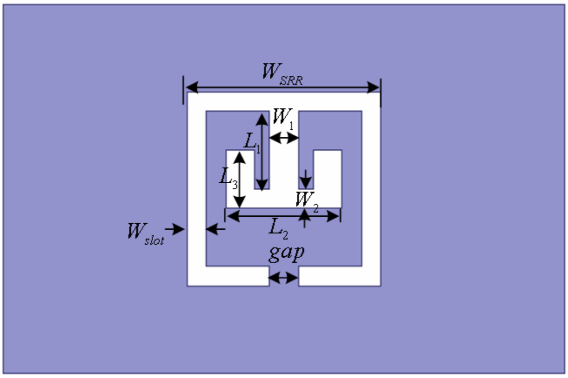

Figure 6. Geometry of dual-mode SRR in tri-band antenna.

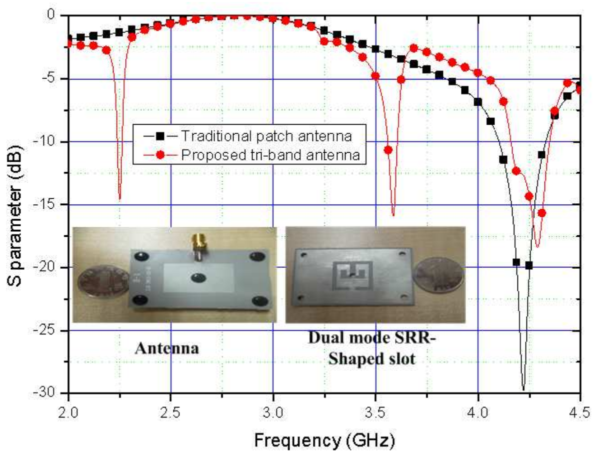

Figure 7. Photograph of proposed tri-band antenna and its measured S parameters.

frequencies. The proposed antenna is fabricated and measured. Its photographs and measured S parameter are shown in Fig. 7. It can be seen that there are three resonant frequencies, 2.25 GHz, 3.59 GHz and 4.3 GHz, respectively. Two lower resonant frequencies are generated by the introduction of dual-mode SRR, while the resonant frequency 4.3 GHz is determined by the dominant mode of the patch cavity. The radiation pattern is measured and shown in Fig. 8. At 2.25 GHz, the radiation pattern characteristic of the proposed antenna is similar to that of a dipole. At 3.59 GHz and 4.3 GHz, the radiation patterns are the radiation typical of patch antenna.

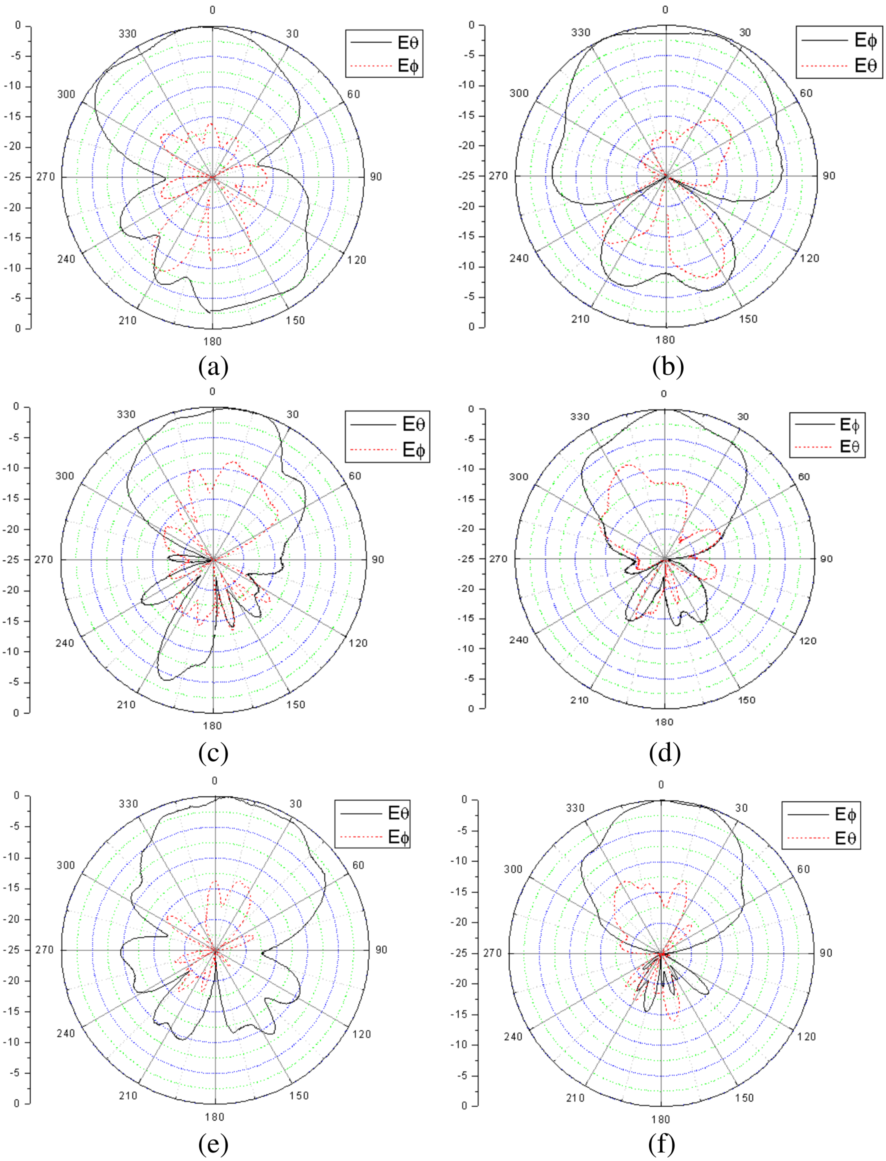

Figure 8. Measured radiation patterns of proposed tri-band antenna: (a) xz plane at 2.25 GHz, (b) yz plane at 2.25 GHz, (c) xz plane at 3.59 GHz, (d) yz plane at 3.59 GHz, (e) xz plane at 4.3 GHz and (f) yz plane at 4.3 GHz.

4. CONCLUSION

A new design methodology for multi-band rectangular microstrip antenna using metamaterial-inspired technique is proposed. By placing metamaterial structure horizontally between the ground plane and the radiating patch, new sub-wavelength resonant frequency can be excited, and multi-band operation occurs. With different SRR structures, the antenna can operate at two or three resonant frequencies. Compared with other multi-band antennas, the proposed antenna requires only the sandwiching of two etched circuit boards. The antenna can be widely applied to communication system for its easy fabrication, low cost, and low profile.

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