A Monopole Antenna with SIR Ground for Harmonic Suppression and Bandwidth Enhancement

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Abstract **─** A novel approach of adding a step impedance resonator (SIR) ground on the coplanar waveguide (CPW) monopole antenna has been proposed in this paper. The purpose of using the SIR ground is to suppress the harmonic radiation generated by rectifying diodes in a rectenna system and to enhance the impedance bandwidth. The measured results of the proposed antenna show that a 10-dB return loss bandwidth could reach 53% (2.32-4.05GHz) with respect to the center frequency of 3.23GHz, and all the second and third harmonics have been completely suppressed.

Index Terms **─** Harmonic suppression, monopole antenna, rectenna.

I. INTRODUCTION

Wireless power transmission (WPT) delivers energy to load through free space without using physical transmission line, which has received significant attention in many fields, such as wireless sensors, telemetry, radio frequency identification (RFID), and recycling ambient microwave energy [1-2], etc. The rectenna is one of the most important components for WPT. A typical rectenna consists of a microwave antenna, a matching circuit, a lowpass filter (LPF), rectifying diodes, a LPF for DC path, and a resistive load [3].

The rectifier diode is a nonlinear element, which generates harmonics of the fundamental frequency. These unwanted harmonics cause problems in systems, which decrease the efficiency of the rectifier antenna system. In order to suppress the harmonic radiation, several effective techniques have been studied, such as using cascaded filter [4], short pin [5], electromagnetic bandgap (EBG) structure [6]. However, the cascaded filter increases the circuit size and cost, and yield an additional insertion loss. The short pin technique increases both complexity and process; the EBG structure needs a larger circuit area so that the periodic structure can be formed. A SIR structure is usually used on the feed line to suppress the harmonics [7-9], but which may decrease the bandwidth of the antenna.

In this paper, the monopole antenna with SIR structure etched on the ground is designed to suppress the harmonics. To choose the proper dimension of the slot, the relationship between the high-order resonance frequency and the impedance ratio K is analyzed. Compared with other antenna [10], the proposed one is simpler and easier to fabricate. As a result, the second and the third harmonics are suppressed and the bandwidth does not decrease.

II. ANTENNA DESIGN

Figure 1 shows the schematic diagrams of the proposed monopole antenna, which is fabricated on a 1.6-mm-thick FR4 substrate with dielectric constant ε_r=4.4 and loss tangent tan δ =0.02. This antenna is fed by a 50-Ω coplanar waveguide (CPW) transmission line with a width of 6mm (Wf) and a length of 15mm (Lf).The dimensions of the ground are 13(Lg) $\times$16.5(Wg) mm^2 and the overall dimensions of the antenna are 40(W) $\times$ 53(L) mm^2. In general, the length of monopole antenna is usually about a quarter-guided-wavelength. The approximate value for the length L1 of the radiating strip is given by

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$$L \approx \frac{\lambda_g}{4} = \frac{c}{4\sqrt{\frac{\varepsilon_r + 1}{2}} f_r}, \quad (1)$$

where c is the speed of light, f_r is the monopole resonant frequency. The dimensions of the rectangular radiator of the antenna (L1×W1) are 23.5×12 mm^2.

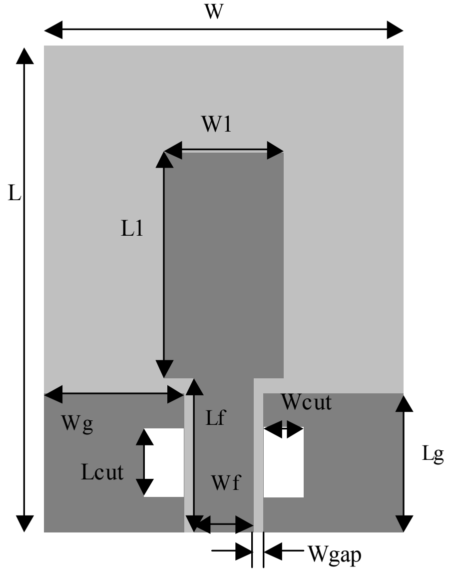


Fig. 1. The proposed monopole antenna.

In order to suppress the harmonics, we used the stepped-impedance resonator (SIR) [11-12] structure on the ground. Equation 2 is used to investigate the fundamental and high-order resonance condition of the SIR shown in Fig. 2.

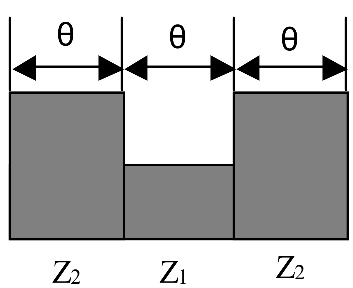


Fig. 2. SIR structure.

$$Z_{in} = jZ_2 \frac{Z_1\left(-Z_2 + Z_1 \tan^2\theta\right) + Z_2\left(Z_1 + Z_2\right)\tan^2\theta}{\tan\theta\left(2Z_1Z_2 + Z_2^2 - Z_1^2\tan^2\theta\right)}, \quad (2)$$

where Z_1, Z_2 are the characteristic impedances of SIR and θ is the electrical length.

To obtain the fundamental resonant frequency f_0, we can substitute (2) into the resonant condition

$$Z_{in} \to \infty, \quad (3)$$

and then find the solutions as

$$2K + K^2 = \tan^2\theta_0, \quad (4)$$

where K is the impedance ratio of SIR in the form of $K=Z_1/Z_2$. The high-order resonance frequency f_{hn} (n=1,2,3, …) can be obtained by the similar process.

$$2K + K^2 = \tan^2\theta_{h1}. \quad (5)$$

$$\tan\theta_{h2} = 0, \quad (6)$$

then

$$\begin{aligned} \frac{f_{h1}}{f_0} &= \frac{\theta_{h1}}{\theta_0} = \frac{\pi}{\tan^{-1}\sqrt{2K+K^2}} - 1 \\ \frac{f_{h2}}{f_0} &= \frac{\theta_{h2}}{\theta_0} = \frac{\pi}{\tan^{-1}\sqrt{2K+K^2}} = \frac{f_{h1}}{f_0} + 1 \end{aligned} . \quad (7)$$

To make an intuitive understanding of (7), the relationship between the high-order resonance frequency and the impedance ratio K is plotted in Fig. 3. Then, we can clearly see from Fig. 3 that the high-order resonance frequencies will move far away from the fundamental one if K is decreased. Therefore, if using the SIR structure, the harmonics will be suppressed. So, we cut a slot 4.5(Lcut) × 2.6(Wcut) mm^2 on the ground and optimized by Ansoft HFSS 11.

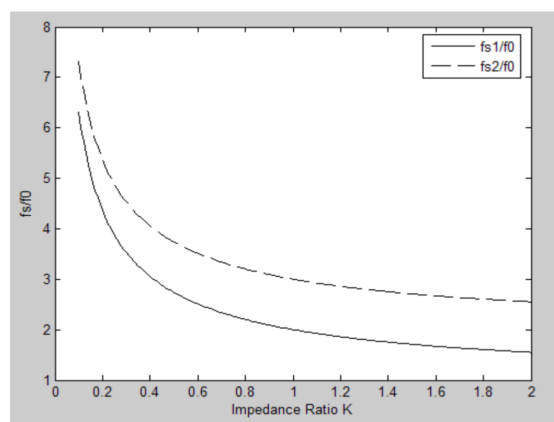


Fig. 3. High-order resonance frequency of the SIR.

III. RESULTS AND DISCUSSION

A fabricated prototype for the proposed monopole antenna was constructed and implemented. The measured results were performed by using a vector network analyzer. Figure 4 describes the simulated and experimental reflection coefficient against the frequency for the antennas, where good agreements have been achieved. As observed, the measured impedance bandwidth with -10dB reflection coefficient for the conventional antenna is from 2.33GHz to 3.21GHz at the fundamental frequency and for the second and the third harmonics are at 5.8GHz and 9.3GHz, respectively. For the proposed antenna, the corresponding measured impedance bandwidth is from 2.32GHz to 4.05GHz at the fundamental frequency and is suppressed completely at the second and the third harmonics. In this experiment, attaching a SIR structure on the ground plane does not result in deterioration of bandwidth but on the contrary enhancing the bandwidth.

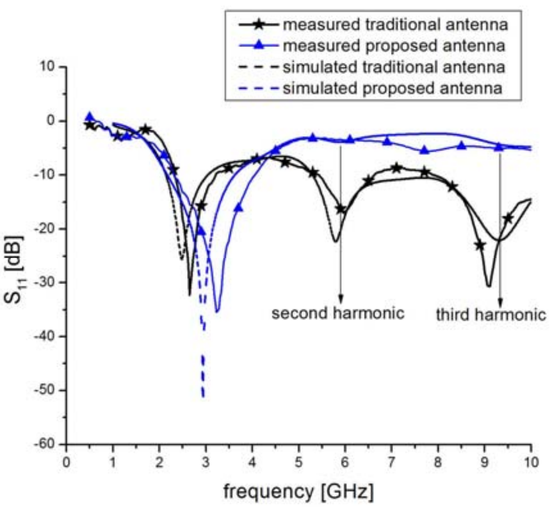
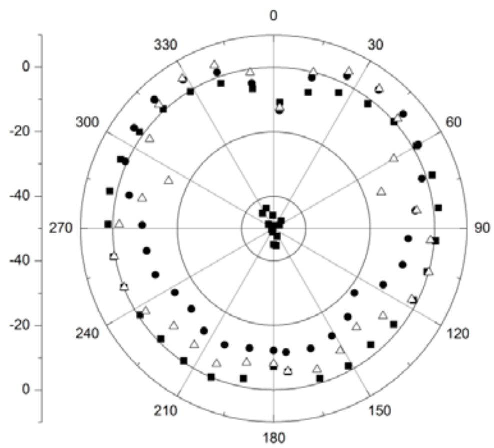


Fig. 4. Simulated and measured reflection coefficient of the conventional and proposed antennas.

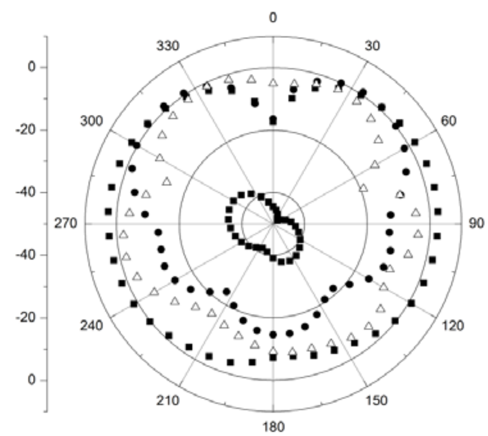
The radiation patterns at these frequencies were also measured for both antennas. The E- and H-plane copolarization patterns for the proposed antenna and the conventional monopole antenna are presented in Figs. 5 and 6, respectively. At the fundamental frequency, the copolarization patterns for the proposed antenna are similar to those of the conventional monopole antenna. At the second and third harmonic frequencies, the gains of the proposed antenna are lower than the conventional antenna. This means that the harmonics of the proposed antenna are diminished.

IV. CONCLUSIONS

A CPW-fed monopole antenna with the SIR ground is presented for achieving harmonic suppression. Since the proposed antenna could be made by just cutting a slot on the ground plane, it is easy to fabricate. Simulated and experimental results show that the proposed antenna is perfect for suppressing the second and third harmonics and also good for enhancing the bandwidth simultaneously.



(a)



(b)

Fig. 5. Measured E-plane copolarization patterns (solid square: 2600MHz(both co- and X- pol); solid circle: 5800MHz; open uptriangle: 9300MHz). (a) Conventional monopole antenna, (b) proposed antenna.

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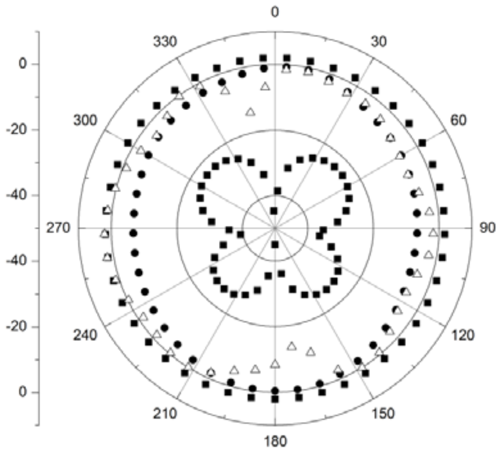
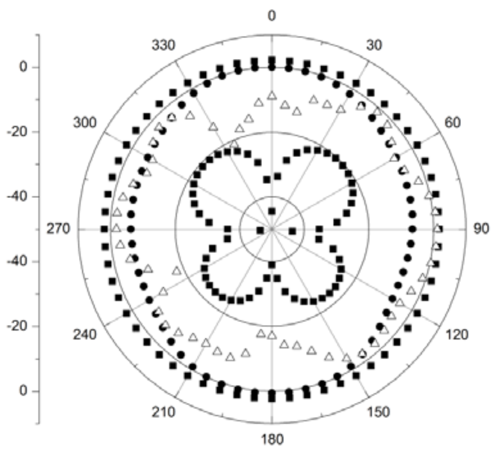


(a)



(b)

Fig. 6. Measured H-plane copolarization patterns (solid square: 2600MHz(both co- and X- pol); solid circle: 5800MHz; open uptriangle: 9300MHz). (a) Conventional monopole antenna, (b) proposed antenna.

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