

## **HARMONIC SUPPRESSION CHARACTERISTIC OF A CPW-FED CIRCULAR SLOT ANTENNA USING SINGLE SLOT ON A GROUND CONDUCTOR**

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**Abstract**—A CPW-fed circular slot antenna with a slot on a ground conductor is presented for harmonic suppression. The antenna has a multi-band rejection characteristic where the second and higher rejection bands are integer-multiple of the first band, and this is generated by inserting single slot on a ground conductor of the antenna. Good agreement between the simulated and measured results is reported and the integer-multiple notch bands can be adjustable by changing the length of the slot on the ground plane.

### **1. INTRODUCTION**

With rapid development and improvement in wireless communication technology, there has been a great deal of demand for wideband antennas for various communication applications because many communication systems are operating in multiple frequency bands, and higher data rate and wide bandwidth are required to support multimedia data. However, there are several existing communication systems such as GPS, wireless local area network (WLAN) and satellite communication, and these may cause interference with a wideband communication system, for instance, UWB system [1]. Hence, a wideband antenna with a multi-band rejection characteristic

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is desirable. Many researchers have been extensively studied for the multi-band notched wideband antennas, especially for UWB applications. Wideband planar monopole antennas with dual band-notched characteristics have been proposed by using multiple  $\cup$ -,  $\cap$ -, and inverted L-shaped slots [2]. A compact printed ultra-wideband antenna etched with multiple sets of Split Ring Resonators (SRRs) inside an inner patch of the antenna [3]. A compact printed UWB monopole antenna etched with complementary split-ring resonator (CSRR) for achieving dual band-notched characteristics has been demonstrated for stop-bands of 3.40–3.48 GHz and 5.40–5.98 GHz [4]. Three types of UWB antennas with triple notched bands have been presented using etched slots on the patch or/and SRRs coupled to feed line [5]. A compact ultra-wideband (UWB) monopole antenna with four-band-notched characteristics at 3.4, 5.7, 8 and 11 GHz has been proposed by using nested complementary split-ring resonator (CSRR) which is etched inside the ground plane [6]. However, these antennas need to have multiple slots to create multi-band rejection function and, therefore, the antenna structure becomes complex in shape. Active integrated antennas where active devices (e.g., amplifier, mixer, oscillator, and etc.) are directly integrated into the antenna structure have been widely used in modern wireless communication systems because of their advantages of no-feed line losses at high frequency, low-power consumption, size and weight reduction, and reliability enhancement [7]. However, the active nonlinear devices used in active integrated antennas can create high level of harmonic radiations and electromagnetic interference (EMI) caused by the harmonic radiations degrades the performance of the communication systems. These harmonic signals can be suppressed by using a harmonic suppression band-stop filter between the active devices and the antenna, but this technique increases total size, insertion loss, and fabrication cost. To overcome these problems, harmonic suppression antennas, which can suppress harmonic radiations, using photonic bandgap (PBG), defected ground structure (DGS), circulator sector, shorting pin, tuning stub, split ground plane, and T-shaped wide slot have been reported [8–11].

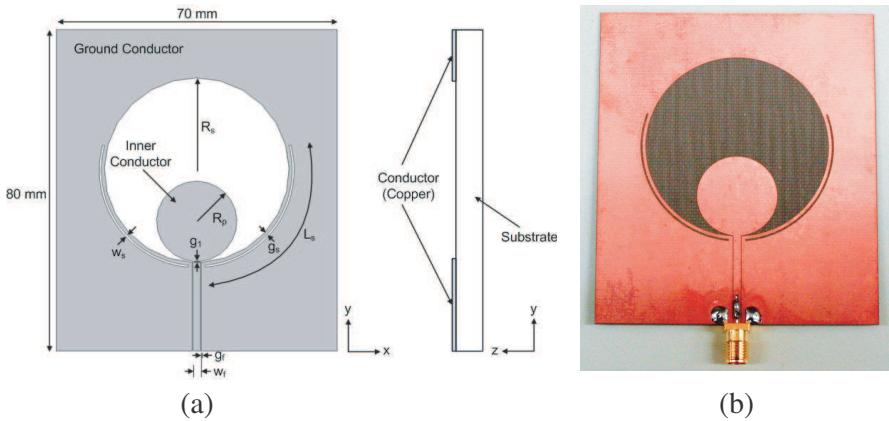
In this paper, a coplanar waveguide (CPW)-fed circular slot antenna with single arc-shaped slot on a ground conductor having an integer multiple band rejection characteristic, which can be used for harmonic suppression for desired frequency bands, is presented. The integer-multiple notched bands can be adjustable by changing the length of slot on the ground conductor of the antenna.

## 2. ANTENNA DESIGN AND RESULTS

The geometry of the CPW-fed circular slot antenna with integer-multiple notched frequency bands is shown in Fig. 1(a). The antenna is comprised of a ground conductor with dimensions of  $70 \text{ mm} \times 80 \text{ mm}$ , a circular slot, an inner circular patch, an arch-shaped slot on the ground conductor, and a CPW feed. The patch and ground conductor are etched on  $0.508 \text{ mm}$  thick Taconic RF-35 board of relative permittivity  $\epsilon_r = 3.5$  and loss tangent  $\tan \delta_c \approx 0.0018$  measured at  $10 \text{ GHz}$ . The copper cladding of the patch and the ground conductor are  $0.035 \text{ mm}$  in thickness. The radii of the circular slot ( $R_s$ ) and the circular patch ( $R_p$ ) are  $23 \text{ mm}$  and  $10 \text{ mm}$ , respectively. An offset between the lowest border of the circular slot and the lowest border of the circular patch ( $g_1$ ) is chosen to be  $0.25 \text{ mm}$ . A  $50 \text{ Ohm}$  CPW feed line has an inner conductor width ( $w_f$ ) of  $1.88 \text{ mm}$  and a slot width ( $g_f$ ) of  $0.15 \text{ mm}$ .

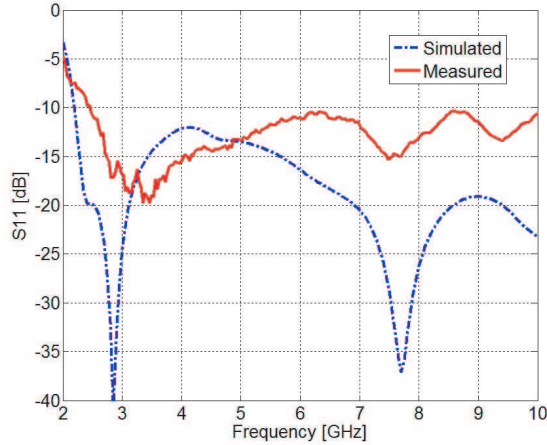
An arc-shaped slot with a length ( $L_s$ ) of  $41.9 \text{ mm}$  and a width ( $g_s$ ) of  $0.5 \text{ mm}$  is inserted on a ground conductor with an offset ( $w_s$ ) of  $1 \text{ mm}$  to create integer-multiple rejection frequency bands. The length of the slot is found to be approximately a half of the guided wavelength of the first notch frequency and this frequency is chosen to be  $2.45 \text{ GHz}$ . We note that the slot on the ground conductor should be located near feed area of the ground conductor to have integer-multiple notch frequency bands.

The proposed antenna is simulated by using commercial EM simulation software Ansoft HFSS and a prototype of the antenna is fabricated to validate the design as shown in Fig. 1(b). The CPW-fed

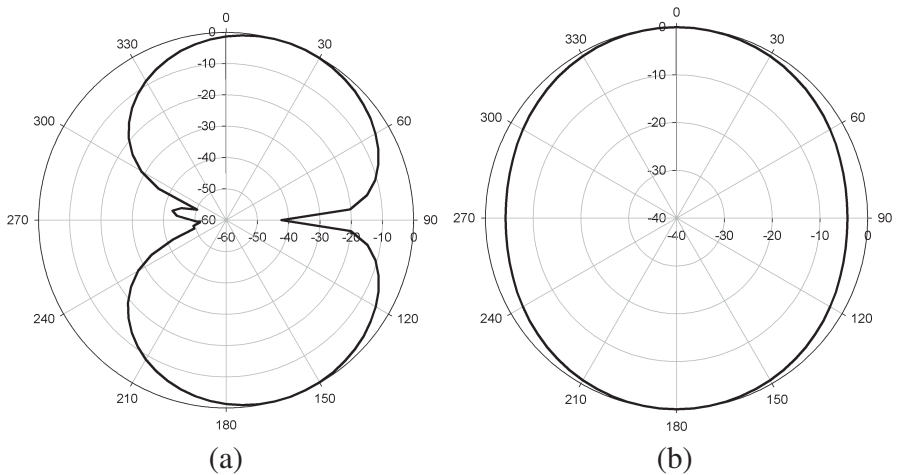


**Figure 1.** CPW-fed circular slot antenna with an arc-shaped slot on a ground conductor: (a) geometry and (b) fabricated antenna.

circular slot antenna has a very wide bandwidth ranging from 2.3 GHz over 10 GHz as shown in Fig. 2. The simulated radiation patterns of the antenna at 2.5 GHz in  $E$ - and  $H$ -planes are presented in Fig. 3, and we see that it has a bidirectional pattern in the  $E$ -plane and an omni-directional pattern in the  $H$ -plane.

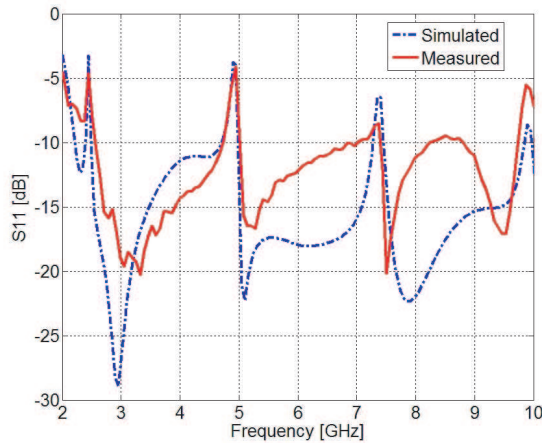


**Figure 2.** Input return loss characteristic of the CPW-fed circular slot antenna without the slot on the ground conductor.

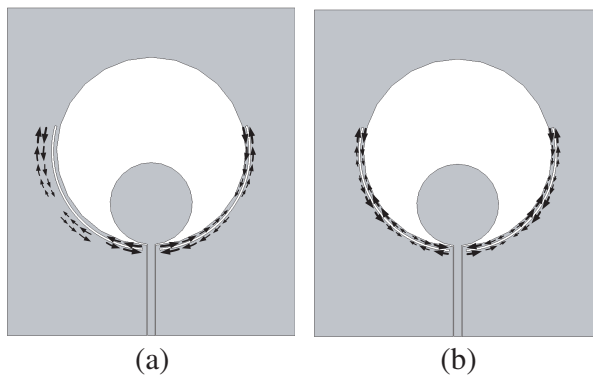


**Figure 3.** Radiation patterns of the CPW-fed circular slot antenna at 2.5 GHz: (a)  $E$ -plane and (b)  $H$ -plane.

Figure 4 shows the simulated and measured input return loss of the proposed antenna. It is observed that the first rejection band is at 2.45 GHz, and the rest three rejection bands at 4.9, 7.35, and 9.8 GHz are integer multiples of the first notch frequency of 2.45 GHz. The gradual and smooth transition from the CPW feed line to the circular slot provides an almost constant input impedance over very wide bandwidth and this creates integer-multiple rejection bands. The comparison of the simulated and measured results shows good agreement.



**Figure 4.** Input return loss characteristic of the CPW-fed circular slot antenna with the arc-shaped slot on the ground conductor.



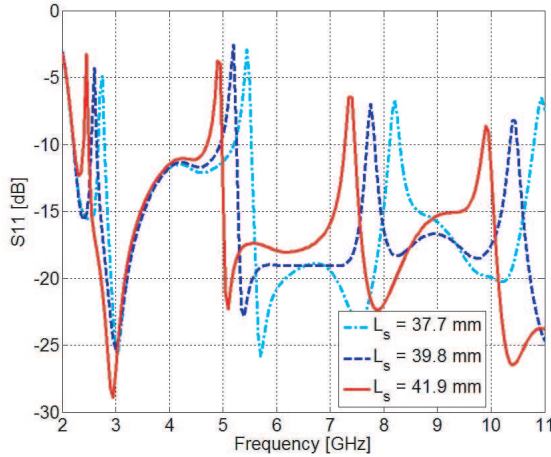
**Figure 5.** Current distribution on the arc-shaped slot at the notch bands: (a) 1st band (2.45 GHz) and (b) 2nd band (4.9 GHz).

The current distributions on the arc-shaped slot at the first two notch bands are presented in Fig. 5. For the first notch band at 2.45 GHz, stronger current distributions near the two edges of the arc-shaped slot is observed and this confirms that a half of the guided wavelength of the first notch frequency corresponds to the slot length of the slot. However, stronger current distributions are seen near the two edges and the center of the slot for the second notch band at 4.9 GHz. This implies that a half of the slot length is the half of the guided wavelength of the second notch frequency, which is twice of the first notch band. Therefore, the resonant frequency of the integer-multiple notch bands can be expressed in terms of the arc-shaped slot length  $L_s$  as

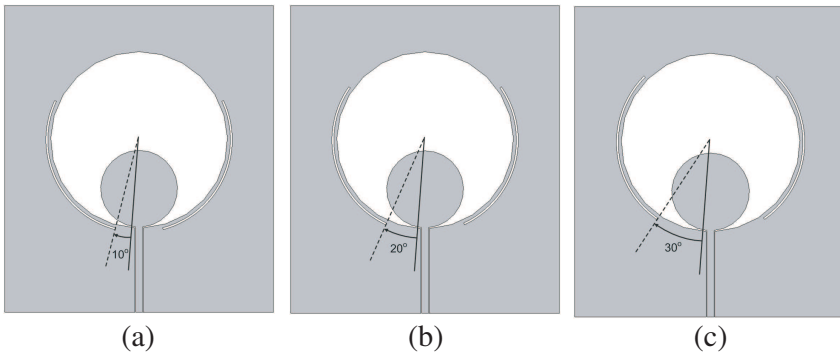
$$f_{notch.i} = \frac{c}{2iL_s\sqrt{\epsilon_{re}}}, \quad i = 1, 2, 3, L \quad (1)$$

where  $f_{notch.i}$  is  $i$ th notch frequency of the integer-multiple notch bands,  $c$  is the speed of light, and  $\epsilon_{re}$  is the effective dielectric constant.

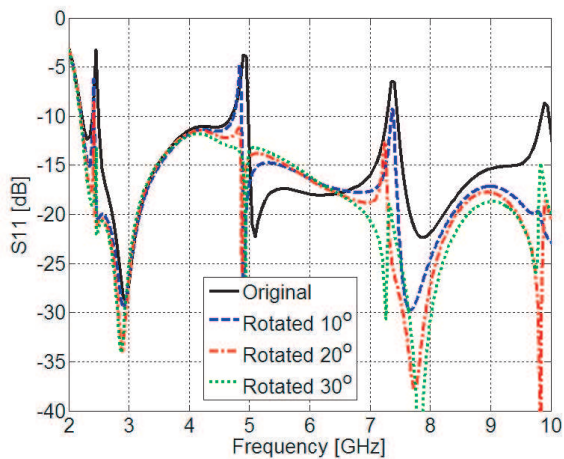
Figure 6 presents the effect of varying the length of the arc-shaped slot on the notch frequency bands. It is found that the first notch frequency moves toward higher frequency as the slot length  $L_s$  decreases from 41.9 mm to 37.7 mm, and the three other notch bands also shift accordingly. Therefore, the notch bands are adjustable by changing the length of the arc-shaped slot.



**Figure 6.** Variation of notch frequency bands by changing the length of the arc-shaped slot.



**Figure 7.** Geometry of the antenna with the arc-shaped slot away from the feeding part: (a) rotated  $10^\circ$ , (b) rotated  $20^\circ$ , and (c) rotated  $30^\circ$ .



**Figure 8.** Effect of rotating the arc-shaped slot away from the feeding part on notch bands.

Finally, the arc-shaped slot on the ground plane is rotated away from the feeding part to investigate the effect of the location of the slot, as shown in Fig. 7. It is observed from Fig. 8 that the bandwidth of notch frequencies becomes narrower and the rejection at all notch frequencies disappears as the slot is away from the feeding part. In fact, the arc-slot can be considered as a load of the input port of the antenna and it can be represented by a short-circuited stub in an equivalent circuit model of the antenna when its length becomes a

half of the guided wavelength, as explained in [2]. This means that the coupling between the slot and the input port reduces significantly when the arc-shaped slot is rotated and is away from the feeding part. We see from this that the arc-shaped slot should be placed near the feeding part to have integer-multiple notch bands.

### 3. CONCLUSION

A CPW-fed circular slot antenna with a multi-frequency band notch characteristic is presented and an arc-shaped slot is inserted on the ground conductor of the antenna. It is demonstrated from the simulated and measured results that integer-multiple notch frequency bands at 2.45, 4.9, 7.35, and 9.8 GHz in the range of 2 to 10 GHz can be created by using single slot on the ground conductor. Furthermore, these notched frequency bands can be modified by adjusting the length of the arc-shaped slot. The proposed notch antenna can be used for the applications where integer-multiple band rejections are required such as harmonic suppression for active integrated antenna systems.

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