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# A WIDEBAND LOW-PROFILE MONOPOLAR PATCH ANTENNA

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**ABSTRACT:** *A wideband low-profile monopolar patch antenna is presented in this article. The proposed antenna consists of a circular-ring patch shorted to the ground plane by four shorting posts and a coupling patch connected with a feeding probe for bandwidth improvement. This designed antenna can provide a wide operating band (68.5% for VSWR < 2) while keeping a low profile (about 7% of the free-space wavelength at the lowest operating frequency) and it also offers stable monopole-like radiation patterns over the operating band. An antenna prototype is fabricated for testing, and the measured results agree well with the simulated ones.* © 2010 Wiley Periodicals, Inc. Microwave Opt Technol Lett 53:28–32, 2011; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.25631

**Key words:** *monopolar antenna; wideband; low profile; omnidirectional*

## 1. INTRODUCTION

The extensive applications of wireless communication system stimulate the development of various antennas and those with some specific characteristics such as wide impedance bandwidth, omnidirectional radiation, and compact size (or low profile) are in demand. Monopolar wire-patch antennas are attractive candidates for omnidirectional radiation applications because they can provide stable monopole-like radiation patterns over their operating frequencies with a very low profile. However, the primary drawback of these antennas is their narrow impedance bandwidth, for example, the bandwidth of the antenna reported in Ref. 1 is only 3% for voltage standing wave ratio (VSWR) < 2. Recently, some techniques have been utilized for impedance bandwidth improvement, such as coupling feed method [2–6], planar monopoles or cylindrical monopoles in replacement of feeding probes [7–9], and ground plates(or shorting wall) in replacement of ground wires [3, 5, 7].

For example, an L-shaped probe is used in Ref. 2 to feed the upper circular patch, but the operating bandwidth is about 32% for $S_{11} < -10$ dB. Using ring patch for coupling feed is another way to improve the impedance bandwidth, the antenna proposed in Ref. 3 possesses a bandwidth of 52.6% for $S_{11} < -10$ dB, but the size of the ground plane is too large ($0.58\ \lambda_L \times 0.58\ \lambda_L$, where $\lambda_L$ is the free-space wavelength of the lowest operating frequency). Replacing the feeding probes with planar monopoles can also effectively expand the impedance bandwidth, the antenna presented in Ref. 9 can provide a very wide operating bandwidth of 138% for $S_{11} < -10$ dB. This wide bandwidth characteristic mainly benefits from the inherent characteristic of planar monopole, which indicates that the height of the planar monopole cannot be reduced too much and the profile of the monopolar patch antenna will be relatively high. Note that the overall height and the diameter of the monopolar patch antenna are $0.093\ \lambda_L$ and $0.924\ \lambda_L$, respectively.

A new design of monopolar wire-patch antenna with a circular-ring patch and coupling feed technique is proposed in this article. It possesses a low profile of $0.07\ \lambda_L$ and a small patch diameter of $0.42\ \lambda_L$. The measured results show that this

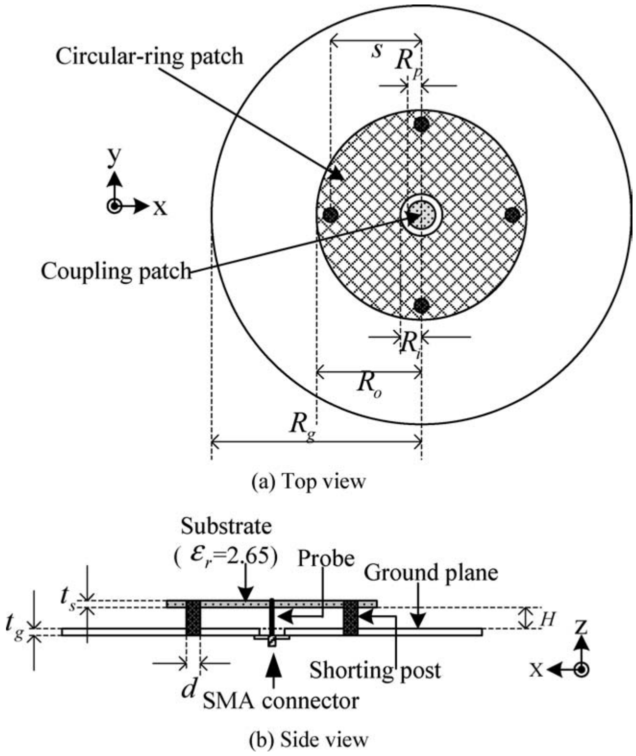


**Figure 1** Model structure of monopolar circular-ring patch antenna: (a) top view; (b) side view

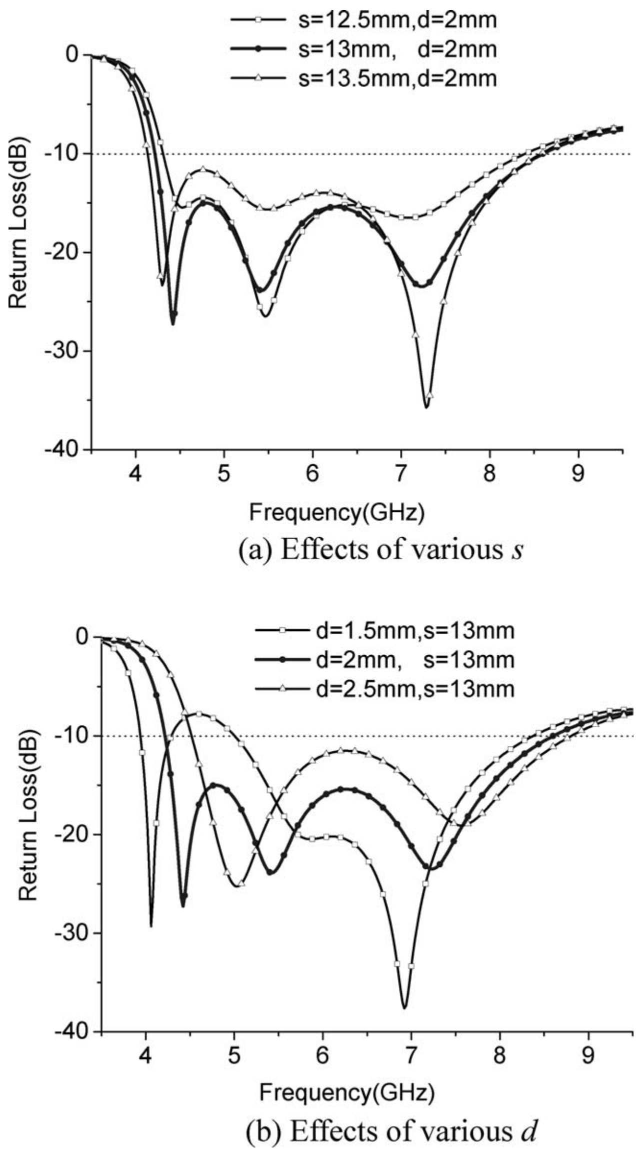


**Figure 2** Effects of various $s$ and $d$ on the return loss of the proposed antenna. Other dimensions are given as $R_o = 15$ mm, $R_i = 3$ mm, $R_p = 2$ mm, $R_g = 30$ mm, and $H = 3$ mm

presented antenna has a wide impedance bandwidth of 68.5% ranging from 4.27 to 8.72 GHz for VSWR $< 2$. On the other hand, stable monopole-like radiation patterns with omnidirectional radiation characteristic in H plane over the operating band are realized.

## 2. ANTENNA DESIGN

### *2.1. Model Structure*

The model structure of the proposed antenna is shown in Figure 1. A circular-ring patch and a circular coupling patch that are connected with a feeding probe are etched on a dielectric substrate for the ease of fabrication. Four metal posts, which are symmetrical to the center of patches, are used to shorten the circular-ring patch to the ground plane and to support the substrate. The relevant dimensional parameters of this antenna are given as: outer and inner radii of the circular-ring patch ($R_o$ and $R_i$), radius of the coupling patch ($R_p$), radius of the ground plane ($R_g$), height of the metal posts ($H$), diameter of the metal posts ($d$), separation of each metal post from the center of the patch ($s$), diameter of the feeding probe ($d_p$), thickness of the ground plane ($t_g$), thickness of the substrate ($t_s$), and relative permittivity of the substrate ($\varepsilon_r$). Some of these parameters are kept constant as $d_p = 1.3$ mm, $t_g = 1$ mm, $t_s = 1$ mm, and $\varepsilon_r = 2.65$.

### *2.2. Operating Mechanism*

A simulation study on the current distribution of the proposed antenna reveals that the electric current on the metal patches over the operating band is basically arranged in the radial direction while the electric field is perpendicular to the patches, which is indicated by the equivalent theory that the equivalent magnetic current is arranged along the perimeter of the slot formed by the circular-ring patch and coupling patch together with the ground plane. The duality theory ensures that this resultant magnetic current loop with uniform phase produces omnidirectional radiation with vertical polarization.

In fact, the proposed antenna possesses three resonant modes which share the same monopole-like radiation pattern, that is, parallel resonance, top-loaded monopole resonance, and the fundamental resonance of the circular-ring slot. The first mode of the monopolar patch antenna, which situated below the well-

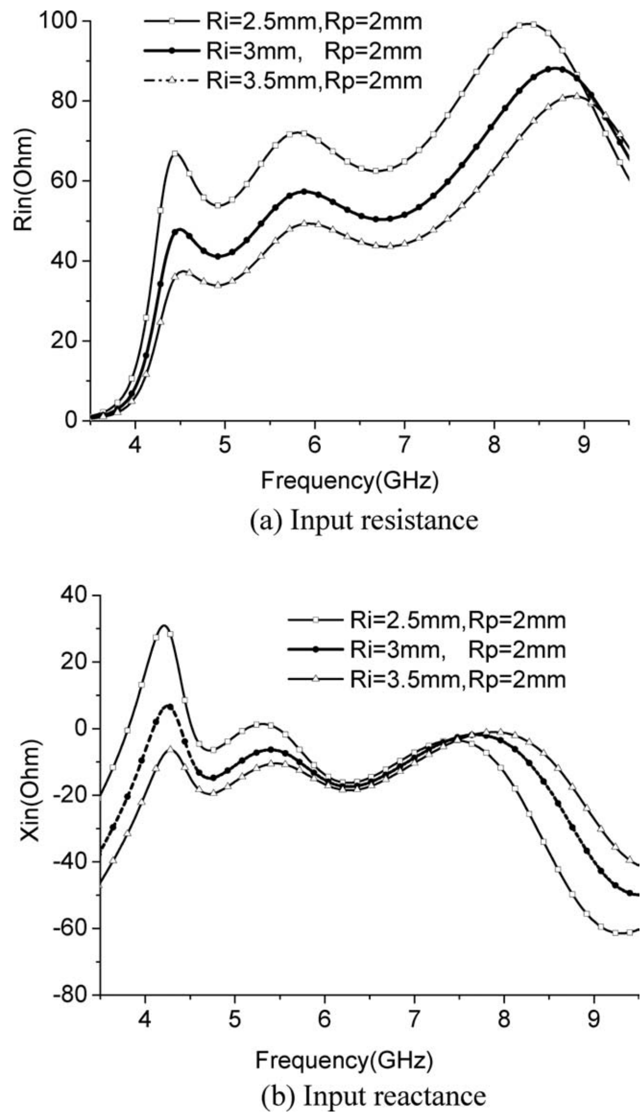


**Figure 3** Effects of various $R_i$ on the input resistance and reactance of the proposed antenna. Other dimensions are given as: $R_o = 15$ mm, $R_p = 2$ mm, $R_g = 30$ mm, $H = 3$ mm, $s = 13$ mm, and $d = 2$ mm

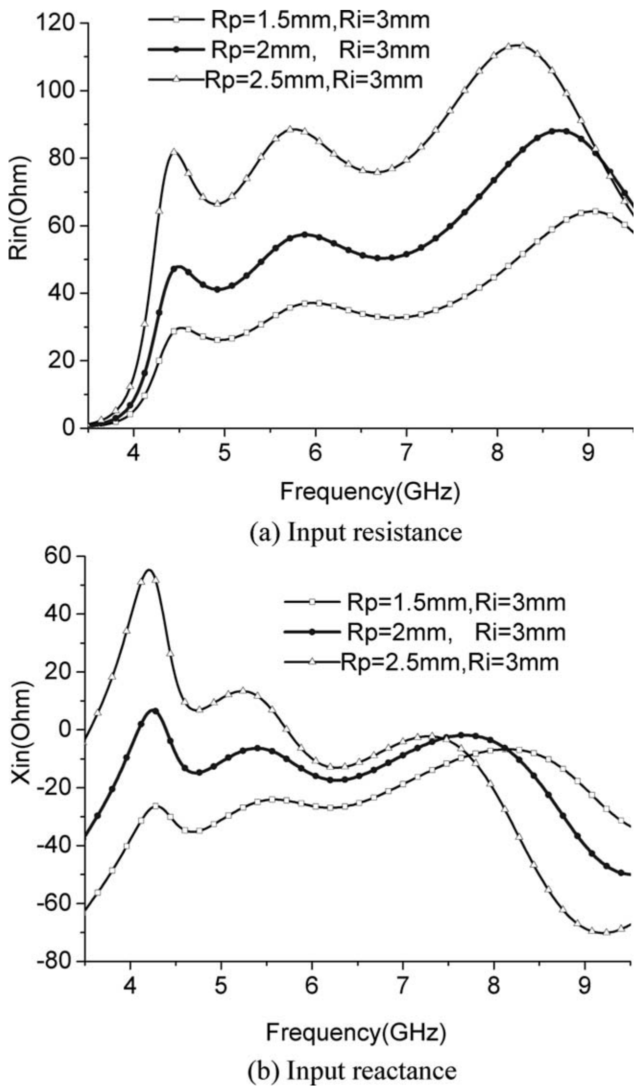


**Figure 4** Effects of various $R_p$ on the input resistance and reactance of the proposed antenna. Other dimensions are given as: $R_o = 15$ mm, $R_i = 2$ mm, $R_g = 30$ mm, $H = 3$ mm, $s = 13$ mm, and $d = 2$ mm

known classical fundamental mode of the conventional microstrip patch antenna (no shorting posts used), comes from the parallel resonance of the equivalent capacitance and inductance that results from patch, ground plane, and the shorting posts [1]. The second mode originates from the quarter-wavelength monopole. The existence of the top-loaded patches introduces an extra equivalent capacitance that can help to reduce the height of the monopole. The third mode results from the circular-ring slot formed by the circular-ring patch and the coupling patch.

### 2.3. Design Guidelines and Parametric Analysis

A parametrical study is carried out to optimize the performance of the proposed antenna, and some key parameters that strongly impact the characteristics including the lowest operating frequency and impedance bandwidth are illustrated here. There are

**TABLE 1 Dimensional Parameters of the Designed Antenna**

| Parameter | $R_o$ | $R_i$ | $R_p$ | $H$ | $s$ | $d$ |
|---|---|---|---|---|---|---|
| Value (mm) | 15 | 3 | 2 | 3 | 13 | 2 |

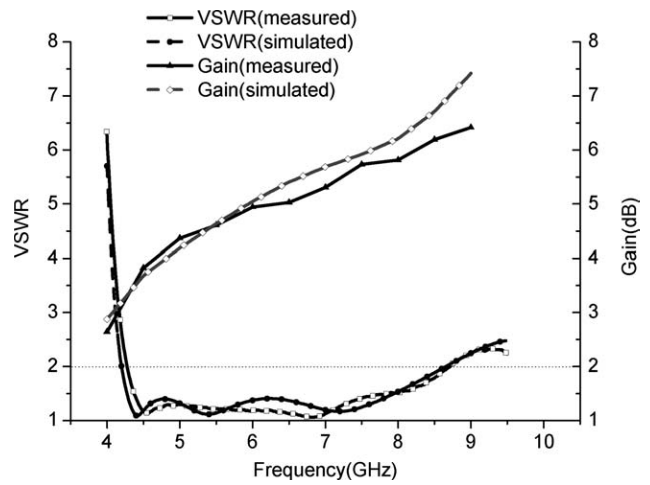


**Figure 5** VSWR and gain versus frequency of the designed antenna

three resonant modes that produce omnidirectional radiation as pointed out earlier, i.e., parallel resonance, top-loaded monopole resonance, and the fundamental resonance of the circular-ring slot, which indicates that the impedance bandwidth can be

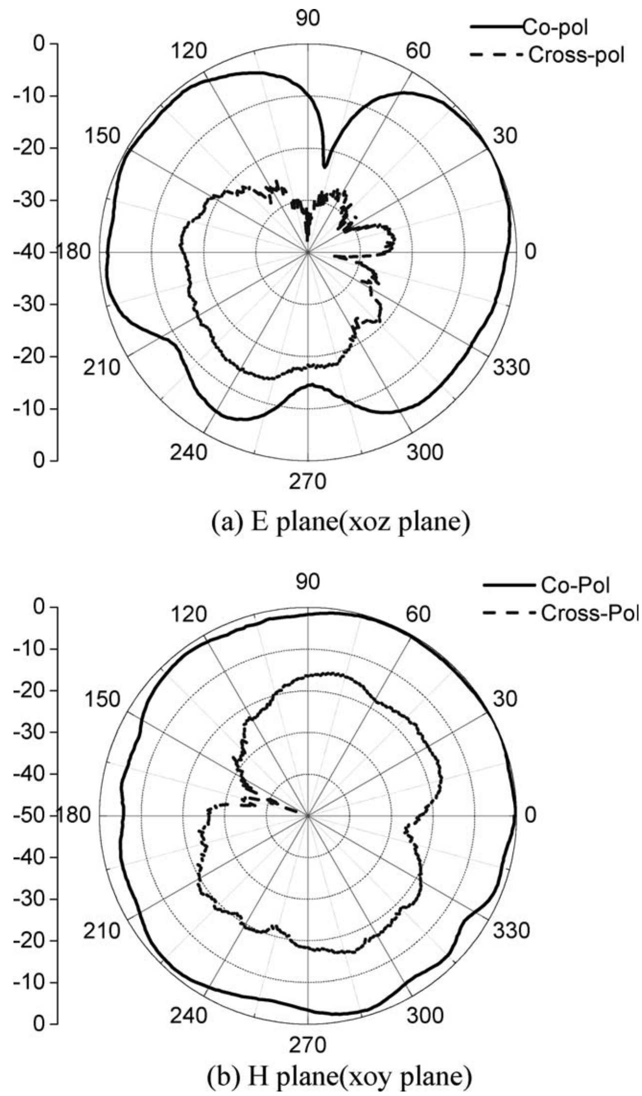


**Figure 6** Measured radiation patterns in two principal planes at 4 GHz

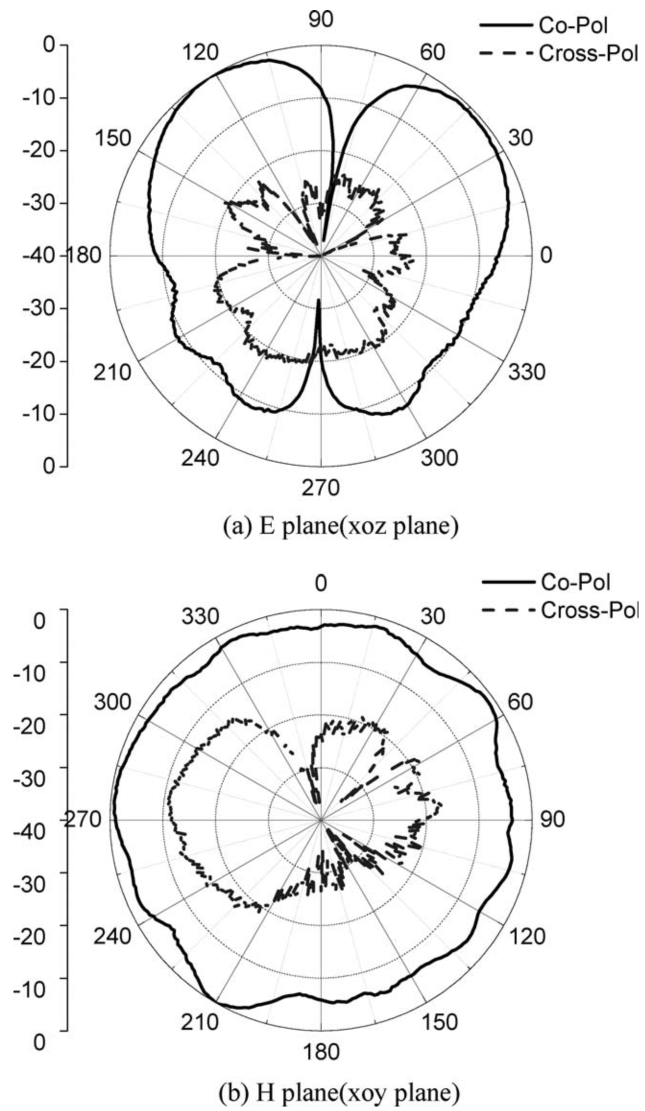


**Figure 7** Measured radiation patterns in two principal planes at 6.5 GHz

significantly broadened by reasonably positioning the resonant frequencies of these modes. On the other hand, the antenna size is basically dominated by the parallel resonance, which is situated below the other two modes in the operating band.

The resonant frequency of the parallel resonance mode is mainly controlled by the outer radius of the circular-ring patch ($R_o$), height of the shorting posts ($H$), separation of each shorting wire from the center of the patch ($s$), diameter of the metal posts ($d$), and radius of the ground plane ($R_g$).The simulation study reveals that the resonant frequency of this mode can be reduced by increasing $R_o$, $R_g$, $H$, and $s$ or decreasing $d$. It can be concluded from Figure 2 that using thinner shorting posts ($d$ becomes smaller) with farther spacing from the patch center ($s$ gets larger) can help to reduce the antenna size (patch size and profile) at given operating frequency. The existence of substrate can also decrease the resonant frequency because of dielectric loading effect.

The antenna bandwidth is mainly dependent on the inner radius of the circular-ring patch ($R_i$) and radius of the coupling patch ($R_p$), which dominates the electromagnetic coupling intensity of the two patches and hence the input impedance of the proposed antenna. It can be seen from Figures 3 and 4 that by increasing $R_p$ or decreasing $R_i$, more electric current are coupled on the circular-ring patch, so the input impedance gets larger. The diameter and height of the shorting posts ($d$ and $H$) can strongly influence the equivalent capacitance and inductance of the first mode (i.e., the parallel resonance mode), so the input impedance as well as bandwidth are consequently influenced.

Note that the patch size and profile can be reduced by increasing the spacing of shorting posts to the patch center, but the ripple level of the radiation pattern in azimuth plane is also increased.

## 3. RESULTS AND DISCUSSION

Based on upper design principles and simulation study, a prototype of the proposed antenna with its dimensions listed in Table 1 is fabricated and measured. The simulated and measured VSWR together with gain versus frequency are plotted in Figure 5. The simulated VSWR agrees well with the measured one, and the discrepancy mainly attributes to the instable property of the dielectric substrate and the fabrication error. Figure 5 also shows the simulated and measured gain over the frequencies ranging from 4 to 9 GHz, which indicates that the measured gain variation is about 3.8 dB (from 2.6 to 6.4 dB). This variation can be well explained by the augment of the electric size of the ground plane at higher frequency.

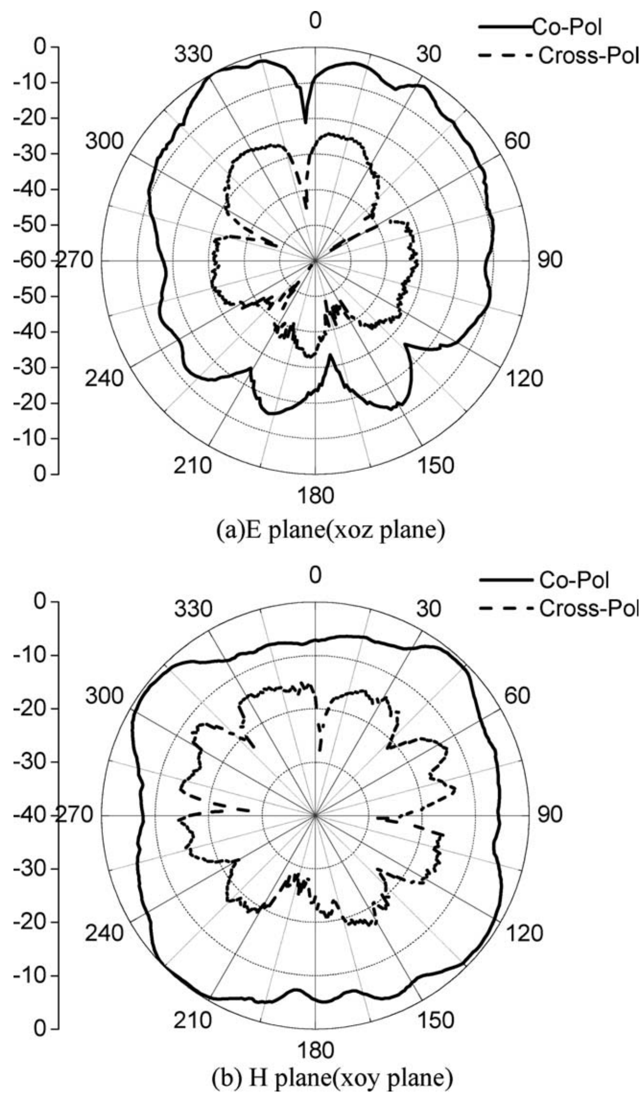


**Figure 8** Measured radiation patterns in two principal planes at 9 GHz

Measured radiation patterns in two principal planes (E plane and H plane) at 4, 6.5, and 9 GHz are plotted in Figures 6–8, respectively, which indicate that stable monopole-like radiation patterns with omnidirectional radiation characteristic in azimuth plane over the operating band are realized. The gain variation in H plane at 4 GHz, 6.5 GHz, and 9 GHz are 5.8 dB, 6.8 dB, and 7.9 dB, respectively. This relative large fluctuation partly results from the coarse immobility of antenna and testing error. The existence of four shorting posts further increases the fluctuation at higher frequencies as pointed out in Section 2, which makes the radiation pattern in H plane at 9 GHz seem like a malformed square.

## 4. CONCLUSIONS

A new design of monopolar wire-patch antenna with circular-ring patch and coupling feed technique is proposed in this article. This designed antenna can provide a wideband operation while keeping a low profile and it also provides stable monopole-like radiation patterns over the operating band. An antenna prototype is fabricated for testing, and the measured results agree well with the simulated ones.


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# ULTRAWIDEBAND MICROSTRIP INTEGRATED-ANTENNA-FILTER


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**ABSTRACT:** *A new three-port integrated-antenna-filter (IAF) module is proposed for ultrawideband applications. The IAF is designed by closely packing a slot antenna and a patch filter on a single substrate. The reflection coefficient, mutual coupling, input impedance, radiation pattern, and insertion loss of the proposed configuration are studied. Since it was found that the mutual coupling between antenna and filter parts of the IAF is very small across a very wide bandwidth, the two parts can be designed almost independently.* © 2010 Wiley Periodicals, Inc. Microwave Opt Technol Lett 53:32–34, 2011; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.25665


**Key words:** *integrated antenna; ultrawideband; slot antenna; patch filter*

## 1. INTRODUCTION

Modern wireless systems are usually required to be compact and low cost [1]. Integration of certain resonating devices, such as antennas, oscillators, and filters, is very difficult because of their relatively large sizes, as compared with other components that can be easily implemented on a silicon chip. Usually, the antennas and filters are made on different external packages. Recently, the system-in-package, system-on-chip, low-temperature-cofired-ceramic approaches have been extensively used to integrate all wireless front-end devices into a single module for reducing the footprint [2, 3]. In these cases, the antenna and filter can be fabricated separately on different metallic layers in the package, at the cost of increasing the design complexity. Recently, attempts were also made to embed the filtering element into the antenna feedline [4]. To improve the performance of the ultrawideband transceivers, the antenna and bandpass filter are preferably integrated together to perform frequency preselection in radiofrequency front-ends [5]. Thus far, however, little or no studies have been carried out to closely combine the antenna and filter into a very close distance without any isolation. In [6], it was proposed to integrate an antenna and a filter onto the same surface of a substrate, but the bandwidth is quite limited. In this letter, a three-port integrated-antenna-filter (IAF) fabricated on a single substrate is proposed for ultrawideband applications. It is constructed by closely integrating a slot antenna with a patch filter etched on both sides of the same substrate. The reflection coefficient, radiation pattern, insertion loss, and mutual coupling are simulated and measured, with good agreement. The coupling between the antenna and filter was found to be very low without the need of using any isolation layers.

## 2. ANTENNA CONFIGURATION

An ultrawideband IAF is proposed by combining a slot antenna ($w_1 = 1.99$ mm, $w_2 = 1.49$ mm, $w_3 = 0.8$ mm, $d_1 = 24$ mm, $d_2 = 31$ mm, $d_3 = 7.5$ mm, $d_4 = 4$ mm, $g_1 = 12$ mm, $g_2 = 13.5$ mm, $g_3 = 0.5$ mm, $g_4 = g_5 = 0$ mm, and $g_6 = 2.7$ mm) and a patch filter ($d_5 = 10.445$ mm, $d_6 = 16$ mm, $d_7 = 2.75$ mm, $d_8 = 0.5$ mm, $d_9 = 8$ mm, and $g_7 = 0.2$ mm), as shown in Figure 1. A Duroid substrate of $\varepsilon_r = 2.94$ and thickness $h = 0.762$ mm was used in the IAF design. The U-shaped slot resonator, which can be excited and tuned by using the fork-shaped microstrip [7], is used for the design of an ultrawideband antenna. It was found that the impedance of the antenna can be matched easily by changing the lengths of the fork-shaped microstrip ($g_1$, $g_2$). The filter resonator is capacitively-coupled to the 50-Ω microstrip lines through two narrow slots [8]. In the measurements, a ground plane of 6 cm ($x$-direction) × 5 cm ($y$-direction) in size is used.

## 3. SIMULATED AND MEASURED RESULTS

Ansoft HFSS was used to simulate the IAF configuration. The fabricated antenna was measured using the HP8510C network analyzer. In the measurements, each unused port was terminated by a 50-Ω load. First, the filter part was studied first. Figure 2