

## A WIDEBAND AND DUAL FREQUENCY THREE-DIMENSIONAL TRANSITION-FED CIRCULAR PATCH ANTENNA FOR INDOOR BASE STATION APPLICATION

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**Abstract**—The design and performance of a stacked patch antenna for wideband and dual-frequency operation are presented in this paper. The proposed antenna consists of a three dimensional (3D) circular transition-fed patch that is excited by a coaxial probe. By introducing a regular patch and a ring patch above the 3D circular transition-fed patch, good input impedance matching has been achieved over two frequency bands. The lower band possesses an impedance bandwidth ( $VSWR < 2$ ) of 22.8% (0.775 to 0.975 GHz) and a peak gain of 5.2 dBi, while the upper band has an impedance bandwidth ( $VSWR < 2$ ) of 65.8% (1.425 to 2.825 GHz) and a peak gain of 7.4 dBi. Other than the wideband and dual-band operation features, this antenna also has a beam tilted downward with a broadside beam pattern on the horizontal plane. Therefore, this antenna is very suitable for the indoor base station that is required to service several wireless communication systems, included CDMA800, GSM900, 3G, PCS, UMTS, BLUETOOTH and WLAN, by a single antenna.

### 1. INTRODUCTION

Patch antennas are receiving increasing interest in various mobile communication systems since they can provide advantages over traditional whip and helix antennas in terms of high efficiency, low profile and increased mechanical reliability [1]. In indoor base station applications, the requirement on bandwidth is quite stringent. Typically, the antenna is required to have a bandwidth exceeding

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17% (806–960 MHz) and 37% (1710–2500 MHz). During the last two decades, many investigators have dedicated their efforts to creating new design or variations to the original antenna that produce either wider bandwidths or multiple frequency operation in a single element [2–14]. Regarding the bandwidth enhancement of patch antennas, several techniques have been proposed, the use of multiple resonators [2], and the use of thick substrates [3]. For an electrically thick substrate patch antenna, coaxial feed is typically used. However, the increased inductance introduced by the longer probe will limit the achievable bandwidth to less than 10% of the resonant frequency. For this reason, several other methods [4, 5] have been proposed to solve this problem, including cutting a U-slot [4] on a patch, and the use of an L-probe feed [5]. Both the U-slot patch and the L-probe feed patch can attain over 30% bandwidth. Meanwhile, many solutions to achieve multiple-frequency operation were carried out [6–9], such as the multilayer stacked-patch antenna [6], the reactive-loading patch antennas by adding shorting pins and/or etching slots on a patch [7–9]. However, previous investigations either addressed the problem of widening the bandwidth or forming multiple-frequency operation, but seldom both simultaneously. In addition, when the antennas are installed in the upper area of the wall or near the ceiling vertically, as is usually the case, the radio waves radiated toward most mobile terminals are off the maximum radiation angle. Therefore, it is desirable for the base station antenna to have a beam tilted downward with a broadside beam pattern on the horizontal plane [15].

## 2. ANTENNA DESIGN AND GEOMETRY STRUCTURE

In this paper, a novel three dimensional circular patch transition-fed antenna with a regular stacked patch and a ring stacked patch is proposed to achieve broadband and dual frequency operation. The design achieves 22.8% bandwidth in the lower bands and 65.8% bandwidth in the upper bands. The fed circular element can be very high above the ground plane (so that the electrical volume can be significantly increased) and be matched using the 3-D transition structure feed which avoids the long probe or extremely wide coplanar feeding microstrip line. A regular patch and a ring patch are stacked above the fed circular patch, which operate at higher-frequency band and at lower-frequency band, respectively. A reflected section and a directional section are introduced to have a beam tilted downward with a fan beam pattern on the horizontal plane. All the metal sections are made of aluminium with the thickness of 0.5 mm.

The geometry of the antenna, which operates at both 0.775 to

0.975 GHz (lower band) and 1.425 to 2.825 GHz MHz (upper band), is shown in Fig. 1. For the proposed radiator structure, there are three sections within it (see Figs. 1(a), (b) and Fig. 2): the upper ring patch with a inner radius of  $r_1$ , a outer radius of  $r_2$  and two patch stub for support with one side length  $l_s$  and the other side length  $w_s$ . The upper ring patch is suspended over the middle regular patch by two plastic sticks. The middle regular patch has a side length of  $l_1$ , which is suspended over the lower section by two plastic sticks too. The lower section consists of a folded circular patch with a radius of  $r_3$ , which is suspended over the ground plane and supported by a nonconductive pin. It is fed by a three dimensional (3-D) transition connecting the circular patch to a horizontal connector. In order to enhance the matching of the antenna, a small 7 mm length metallic cylinder with a 1 mm diameter has been added under this three dimensional (3-D) transition. A metal strip with a width of 6 mm and a length 15 mm located at the feed position is utilized to tune reactance of the dual frequency. The left hand side of the antenna consists of two directional metal plates with high  $h_1$  &  $h_2$ , and width  $w_1$  &  $w_2$ , respectively. The right hand side of the antenna consists of a quadrate

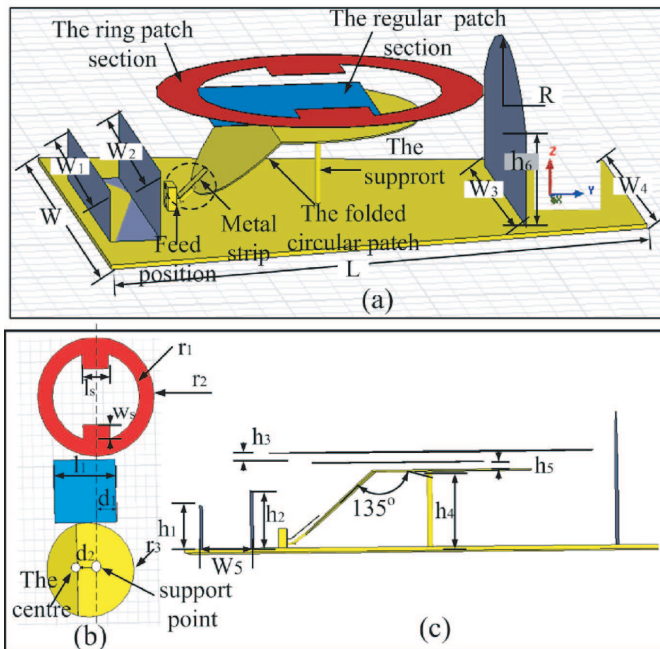
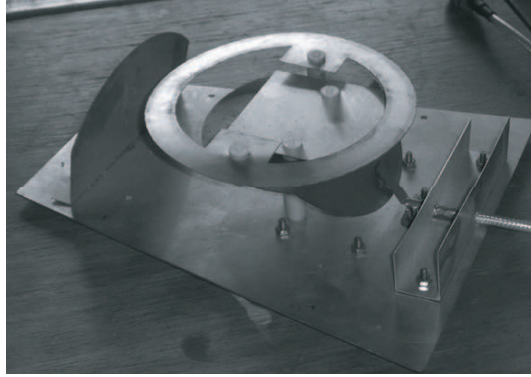
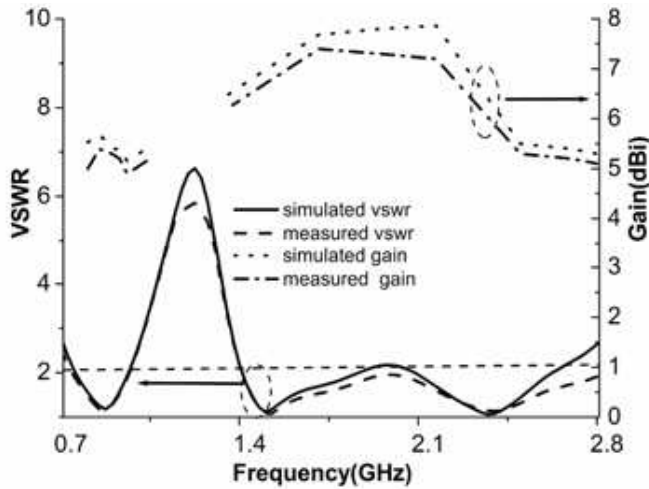


Figure 1. The geometry of the proposed antenna.



**Figure 2.** The photo of the constructed antenna.

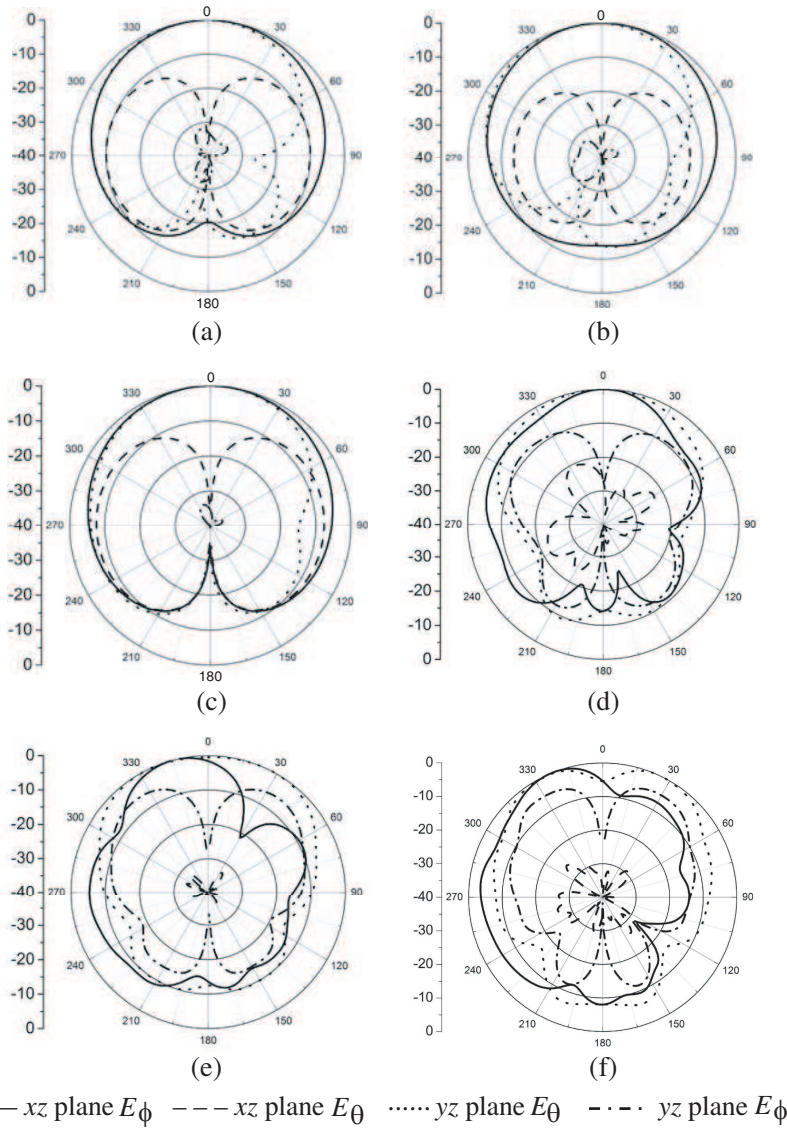


**Figure 3.** The VSWR and gain of the proposed antenna.

plate and a circular segment plate which is utilized to increase reflected area, but has no effect on the size of an ornamental and disguised radome (not shown in this paper). The proposed antenna has the following detailed parameters:  $W = 170$  mm,  $W_1 = 98$  mm,  $W_2 = 98$  mm,  $W_3 = 98$  mm,  $W_4 = 100$  mm,  $W_5 = 17.8$  mm,  $L = 196$  mm,  $h_1 = 17$  mm,  $h_2 = 22.5$  mm,  $h_3 = 4$  mm,  $h_4 = 30$  mm,  $h_5 = 3.2$  mm,  $h_6 = 30$  mm,  $R = 65.6$  mm,  $R_2 = 52$  mm.  $l_s = 26$  mm,  $w_s = 13.6$  mm,  $r_1 = 42.5$  mm,  $r_2 = 57$  mm,  $l_1 = 60$  mm,  $d_1 = 19$  mm,  $d_2 = 19.5$  mm,  $r_3 = 45$  mm.

### 3. EXPERIMENT RESULTS

As we have mentioned above, the proposed antenna can operate at both 806–960 MHz and 1710–2500 MHz. The antenna performance is



**Figure 4.** (a) 0.806 GHz, (b) 0.90 GHz, (c) 0.96 GHz, (d) 1.71 GHz, (e) 2.17 GHz, (f) 2.5 GHz.

calculated with the aid of a commercial software HFSS Ver. 10. Also, it is measured by the HP 8510C Network Analyzer and a 128 Multi-probes Spherical Near Field Measure System. Fig. 2 is the photograph of the proposed antenna. Fig. 3 shows the voltage standing wave ratio and gain against frequency curves at the operation bands, respectively. From the VSWR curves, it is clearly seen that this antenna has one resonance in the lower band and two resonances in upper band. Wide simulated and measured impedance bandwidths (VSWR < 2) of 18.5% (0.80 to 0.963 GHz) and 22.8% (0.775 to 0.975 GHz), 63.7% (1.41 to 2.73 GHz) and 65.8% (1.425 to 2.825 GHz) are obtained in the lower and the upper bands, respectively. In the same figure, it can also be observed that the simulated and measured peak gains are 5.9 dBi and 5.6 dBi, 7.9 dBi and 7.4 dBi for the lower and the upper bands, respectively. From Fig. 3, good agreements between the measured and simulated VSWR and gain are obtained. The  $xz$ -plane radiation patterns at several frequencies across the lower and the upper bands, included 0.806 GHz, 0.90 GHz, 0.96 GHz, 1.71 GHz, 2.017 GHz and 2.5 GHz, are shown in Fig. 4. For the measured radiation patterns, the main beams are tilted about at  $-4^\circ$  at 0.806 GHz,  $-6^\circ$  at 0.9 GHz,  $-7^\circ$  at 0.96 GHz,  $-5^\circ$  at 1.71 GHz,  $-15^\circ$  at 2.17 GHz,  $-25^\circ$  at 2.5 GHz, respectively. Therefore, the tilt angles are increased with the frequency in the lower and the upper bands. The  $yz$ -plane radiation patterns at these frequency are also shown in Fig. 4. It is clearly seen that the simulated and measured patterns in this plane are broadside beam.

#### 4. CONCLUSION

A wideband dual-band three-dimensional circular patch transition fed antenna is designed and implemented successfully. The experimental results reveal that it has wide impedance bandwidths (VSWR < 2) of 22.8% (0.775 to 0.975 GHz) and 65.8% (1.425 to 2.825 GHz) in the lower and the upper frequency bands, respectively. Therefore, it is capable to cover the operating bandwidths of several wireless communication systems included CDMA800, GSM900, PCS, UMTS, 3G, BLUETOOTH and WLAN. Other than the wideband and dual-band features, it also has peak gains of 5.6 dBi and 7.4 dBi in the two frequency bands. Furthermore, it has a beam tilted downward with a broadside beam pattern on the horizontal plane. Consequently, this antenna should find applications in the modern multi-band indoor wireless communication systems.

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