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A WIDEBAND TRAPEZOIDAL DIELECTRIC RESONATOR ANTENNA WITH CIRCULAR POLARIZATION

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Abstract—A new design of a circularly-polarized (CP) trapezoidal dielectric resonator antenna (DRA) for wideband wireless application is presented. A single-layered feed is used to excite the trapezoidal shaped dielectric resonator to increase resonant frequency and axial ratio. Besides its structure simplicity, ease of fabrication and low-cost, the proposed antenna features good measured impedance bandwidth, 87.3% at 4.21 GHz to 10.72 GHz frequency bands. Moreover, the antenna also produces 3-dB axial ratio bandwidth of about 710 MHz from 5.17 GHz to 5.88 GHz. The overall size of DRA is 21 mm × 35 mm, which is suitable for mobile devices. Parametric study and measurement results are presented and discussed. Very good agreement is demonstrated between simulated and measured results.

1. INTRODUCTION

In the last two decades, Dielectric Resonator Antennas (DRA) have received lots of attention due to the attractive characteristics such as high radiation efficiency, considerable bandwidth, low temperature coefficient and low profile. Since dielectric resonators (DRs) have very low loss, higher efficiency without any conductor loss is ensued. Thus, DRAs own much lower loss and also are a very good candidate to design the antenna for microwave bands [1].

Several techniques have been reported to enhance the bandwidth of DRAs [2, 3]. These effective techniques use some special composite dielectric resonator configuration, such as stacked DR [4] and

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embedded DRs [5]. Moreover, various types of feeding techniques were utilized to excite DRAs such as using a coaxial probe [6], a rectangular waveguide [7] and a microstrip feed-line [8, 9]. An Isosceles Trapezoidal Dielectric Resonator Antenna with the impedance bandwidth of 21.5% was introduced in [10]. In this design, the bandwidth was increased by creating a slot and optimizing its position.

Circular polarization antennas have been used in some mobile satellite communications and large number of communication systems [6]. Advanced designs have been reported to obtain circular polarization (CP) and dual-polarized operations for DR antennas [11]. Two feed points are normally used to produce circular polarization antenna, where the feed points are spatially 90° apart, and feed with equal amplitude signals in 90° phase differences [12, 13]. Generally, the complexity of designing DRAs can be avoided by utilizing a single-point feed system [12].

Although the single feed is simpler, it produces a narrower axial-ratio (AR) bandwidth. In [14], an elliptical DR antenna using single-slot feed square patch was designed to obtain CP, which typically results in narrow axial-ratio bandwidths, 3.5%. In [15, 16], a parasitic patch antenna using hemispherical DRA and rectangular shaped dielectric resonator were reported. Unfortunately, these structure produced axial ratio bandwidth of 2.4% and 2.7% respectively. A considerably higher axial-ratio (AR) bandwidth of 10.6% has been reported in [17], for a stair-shaped rectangular DRA. In [18], a Wideband CP Trapezoidal DRA antenna was excited by a single 45° inclined slot fed by a microstrip feed line. It produced the impedance bandwidth of 33.5% and AR of 21.5% respectively.

In this paper, a new configuration of Ultra Wideband DRA using trapezoidal-shaped resonator to achieve circular polarization is presented. Unlike previous designs, the proposed structure uses a simple microstrip feed to excite the trapezoidal-shaped resonator to enable wideband resonance on a single layered structure. Moreover, the antenna is optimized to resonate in widebands, i.e., from 4.21 GHz to 10.72 GHz with simultaneous circular polarization of 15% from 5.13 GHz to 6 GHz. Its low-cost and compactness makes it especially easy to be embedded into portable devices such as WiMAX routers and Wi-Fi band. It may also be integrated into larger handheld devices such as smart phones and portable WiMAX video/TV receivers.

2. ANTENNA CONFIGURATION AND DESIGN

The geometry of proposed design is shown in Figure 1. The structure is realized by using the equations developed for the magnetic wall

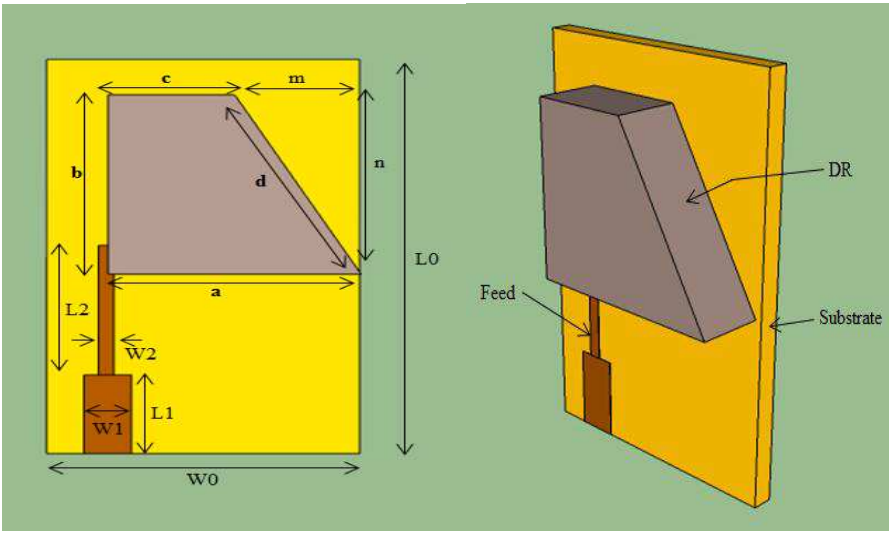

Figure 1. Schematic diagram of the proposed dielectric resonator antenna: top and 3D views.

waveguide model with the dielectric slab in the transverse plane of the waveguide [19]. Enforcing the magnetic wall boundary condition at the side wall surfaces of the resonator, the following equations are used for the wave-numbers:

$$k_x = \frac{m\pi}{a} \tag{1}$$

$$k_y = \frac{n\pi}{h} \tag{2}$$

$$k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_0^2 \tag{3}$$

where k_x, k_y, and k_z denote the wave-numbers along the x, y, and z directions, respectively, inside the Dielectric Resonator and k_z also should satisfy:

$$k_z \tan\left(\frac{k_z d}{2}\right) = \sqrt{(\varepsilon_r - 1)\, k_0^2 - k_z^2} \tag{4}$$

In this design, firstly the rectangular DR is considered and its dimensions are obtained by using magnetic wall waveguide model.

The trapezoidal-shaped DR is placed on a FR4 substrate with a dielectric constant 4.6 and loss tangent of 0.0019 and size of 21 mm × 35 mm. The proposed DR is fabricated on Rogers-R03010 microwave dielectric material with a dielectric constant of $\varepsilon_r = 10.2$, loss tangent of 0.0013 and with a thickness of $h = 5.1$ mm. The proposed DR parameters are depicted by a, b, c and d as shown in Figure 1. The microstrip feed line is attached to one side of the DR and connected to the SMA connector on top side of the substrate whereas the ground plane is printed on the bottom side of the substrate. In order to have an input impedance of 50 ohm, the width of the microstrip-fed line is 3.2 mm.

3. PARAMETRIC STUDIES AND DISCUSSIONS

For a better realization of the proposed trapezoidal-shaped DRA impedance bandwidth, a parametric study is performed to see the effect on the reflection coefficients, which is usually helpful for practical antenna design. The simulation of CST Microwave Studio [20], based on the finite integral technique, is used for the parametric analysis. For further improvement of the bandwidth, a triangular-shaped area is removed from the rectangular part. In fact, by deducing this volume, the Q-factor is decreased. As the bandwidth is related to the $1/Q$ so the bandwidth is enhanced. Figure 2 shows that by removing a triangular area from the rectangular DR the impedance matching is improved especially at high frequencies which is about 1.6 GHz. It is noteworthy that not only this removing improved the impedance bandwidth; it also causes to achieve the circular polarization. Cutting triangular area creates the asymmetric shape, which is the main reason to achieve circular polarization. From simulation and measurement radiation patterns results in Figure 7, it is found that the Right hand circularly polarized (RHCP) is achieved at broadside ($\theta = 0$ deg). It can also be understood by the current distributions, the current vectors rotate counter-clockwise with time that dominated by Right hand circularly polarized (RHCP).

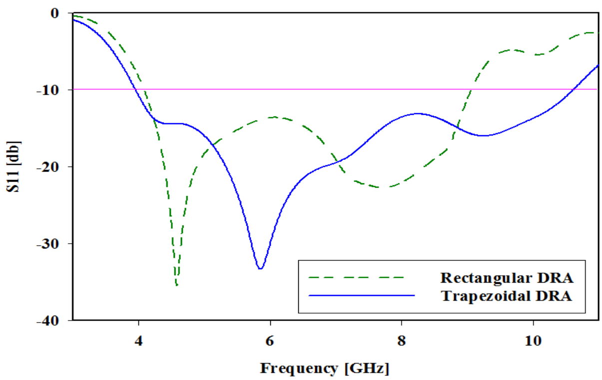

Figure 2. Comparison between simulated S_{11} of the rectangular and trapezoidal DR antenna.

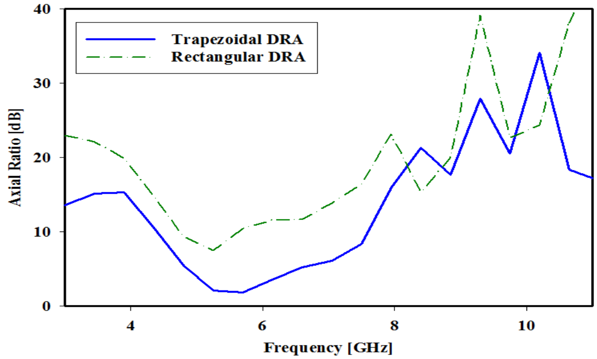

Figure 3. Comparison between simulated AR of the rectangular and trapezoidal DR antenna.

Figure 3 represent the comparison between rectangular DRA and proposed design. It is clearly shown that with the initial shaped which is rectangular, the polarization of the antenna is not circular polarized. A good CP bandwidth is enabled by the proposed antenna. The simulation illustrates that AR goes under 3 dB which indicates the circular polarization.

For the purpose of broadening the matching band and improve the coupling between the DR and the strip, by reducing the width of the microstrip-fed line (from W_1 to W_2), the impedance of the line is increased therefore, coupling between DR and the feed can be improved. So by finding the optimum values of W_1, W_2, L_1 and L_2, finest coupling and consequently, the maximum bandwidth are achieved.

4. EXPERIMENTAL RESULTS AND DISCUSSION

The dimensions $(a \times b \times c \times d)$ of the proposed DR are $16\,\text{mm} \times 15\,\text{mm} \times 8\,\text{mm} \times 17\,\text{mm}$ that are equivalent to $0.309\lambda \times 0.29\lambda \times 0.154\lambda \times 0.33\lambda$ and λ is the free space wavelength at the resonant frequency of 5.8 GHz $(\lambda = 0.0517\,\text{m})$.

There is a Triangular-Shaped removed from RDR with m, n and d dimensions to improve the impedance bandwidth of DRA. The best result was achieved when $m = 8\,\text{mm}$, $n = 15\,\text{mm}$ and $d = 17\,\text{mm}$. Table 1 shows the dimension of the proposed antenna.

The prototype circularly polarized DR antenna is shown in Figure 4. Simulated and measured return losses of the proposed DRA as a function of frequency are plotted in Figure 5. Good agreement

Table 1. Antenna dimension.

Parameters	Volume (mm)	Parameters	Volume (mm)
L_0	35	a	16
L_1	7	b	15
L_2	11.5	c	8
W_0	21	d	17
W_1	3.2	h	5.1
W_2	1	m	8
		n	15

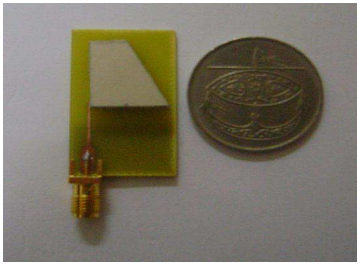

Figure 4. Photograph of the fabricated DR antennas.

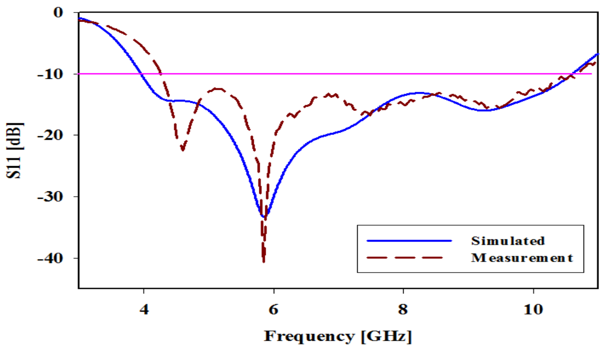

Figure 5. Simulated and measured S_{11} of the realized antenna.

between simulated and measured results indicates the high tolerance of the antennas in terms of dimensions and materials. The simulated and measured reflection coefficients demonstrate a bandwidth (reflection coefficient < -10 dB) of 91.5% (3.95–10.60 GHz) and 87.3% (4.21–10.72 GHz), respectively.

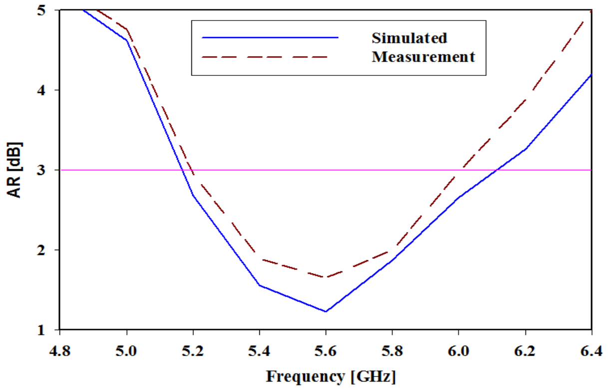

Figure 6. Simulated and measurement AR.

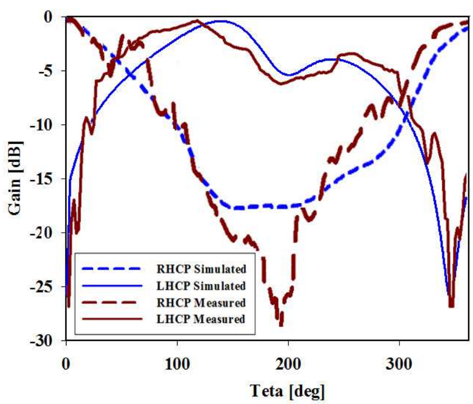

Figure 7. Simulated and measured radiation patterns at 5.8 GHz.

Non-symmetrical DR shape which has been produced by deducing a Triangular-Shaped area from the RDR, not only influences to improve the impedance bandwidth, but also it causes to excite CP waves. The Right hand circularly polarized (RHCP) is achieved at the center frequency of 5.55 GHz. The simulated and measured Axial Ratio (AR) is shown in Figure 6. The simulated AR shows 850 MHz bandwidth ($AR < 3$ dB), which is from 5.13 GHz to 6 GHz. However, the measurement results indicate a 710 MHz bandwidth that is between 5.17 GHz and 5.88 GHz.

The simulation and measurement radiation patterns at 5.8 GHz is shown in Figure 7. The antenna is designed to create a right-hand circular polarization (RHCP) at broadside ($\theta = 0$ deg) and a left-hand circular polarization (LHCP) is considered to be the cross-polarization.

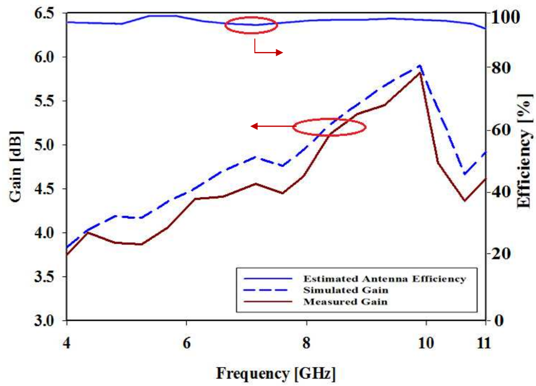

Figure 8. Estimated antenna efficiency, simulated and measured gain of the antenna versus frequency.

The figure represents that the measured cross polarization at 5.8 GHz is −28 dB. The 3 dB beamwidth of proposed DRA is around 70° at this resonant frequency. The oscillatory measured pattern is due to the combined effects of the antenna mounting, edge connector losses, and the current on the cable.

In addition, the measured gain of the proposed antenna and estimated efficiency versus frequency are demonstrated in Figure 8. The overall gain varies between 3.7 and 5.8 dB. It is indicated that this prototype of antenna produces high gain around 5.8 dB at 9.6 GHz. As evident from the Figure 8, the proposed RDR antenna has high radiation efficiency more than 94%.

5. CONCLUSION

In this paper, a trapezoidal dielectric resonator antenna for supporting the wideband operation has been presented. By removing a triangular-shaped area from the rectangular dielectric resonator, wideband antenna was achieved. The measurement result shows that the impedance bandwidth is approximately 6.51 GHz (87.3%). It is also discovered that the CP radiation waves are achieved at the center frequency of 5.55 GHz. The measurement AR bandwidth is around 710 MHz. By using this design, several wireless systems operating within 4.5 GHz to 10.70 GHz such as WiMax, Wi-Fi, L-band and C-band are supported, simultaneously. Good agreement between the measured and simulated results was achieved. In addition, suitable radiation pattern and gain characteristics over the whole covered frequency range were obtained. As a result, this antenna is attractive and can be of practical use for several wireless communication systems.

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