

# Bandwidth Enhancement and Radiation Characteristics Improvement of Triangular Dielectric Resonator Antenna

Mehdi Ghorbani<sup>1</sup>, Mohsen Khalily<sup>2</sup>, Habib Ghorbaninejad<sup>1</sup>, Pei Xiao<sup>2</sup>, Rahim Tafazolli<sup>2</sup>

<sup>1</sup>Department of electrical engineering, University of Guilan, Rasht, Iran

<sup>2</sup>Institute for Communication Systems (ICS), Home of the 5G innovation center (5GIC), University of Surrey, U.K.  
ghorbani.me@gmail.com

**Abstract**— In this paper, an ultra-wideband, Dielectric Resonator Antenna (DRA) has been proposed. The proposed antenna is based on isosceles triangular DRA (TDRA), which is fed from the base side using a  $50\Omega$  probe. For bandwidth enhancement and radiation characteristics improvement, a partially cylindrical-shape hole is etched from its base side which approached probe feed to the center of TDRA. The dielectric resonator (DR) is located over an extended conducting ground plane. This technique has significantly enhanced antennas bandwidth from 48.8% to 80% (5.29-12.35 GHz), while the biggest problem was radiation characteristics. The basis antenna possesses negative gain in a wide range of bandwidth from 7.5 GHz to 10.5 GHz down to -13.8 dBi. Using this technique improve antenna gain over 1.6 dBi for whole bandwidth, while peak gain is 7.2 dBi.

**Keywords**— Dielectric resonator Antenna (DRA), Triangular DRA, Wideband, probe feed

## I. INTRODUCTION

DRA antennas features include low cost, low loss, small size, and high radiation efficiency. Therefore, they are favorable subject for antenna designers. On the other hand, UWB antennas have been widely used in radars, navigation, GPS, biomedical systems, mobile satellite communications, the direct broadcast systems, telemetry etc. Variety shapes of DRAs like rectangular and cylindrical DRA antennas have been studied, and various techniques have been used to improve the antenna parameters.

One of the most important features of the antenna is impedance bandwidth. Antenna bandwidth can be widened through feed or resonator. Tapered strip excitation from a side of the dielectric resonator [1] and extended microstrip feed in the proximity of DR [2] significantly improved antenna bandwidth. In [3], DRA feed was modified base on the concept of hybrid antenna. Trapezoidal DRA [4] is proved as a potential structure for wideband applications. Changing the structure of Square or rectangular DRA also can improve the antenna impedance bandwidth. Loading inclined slits on diagonal of square DRA [5], and several printed rectangular loops on Ring Rectangular DRA [6] are clear illustrations of this importance.

The TDRA is another research topics which have been taken into consideration in recent years, due to offering a wide

impedance bandwidth. A  $30^\circ$ - $75^\circ$ - $75^\circ$  TDRA which was fed by a probe has a wideband feature [7]-[8]. It also was discovered that excitation of TDRA from the center of the base side result to wider bandwidth. In [9], equilateral TDRA with a specific shape of CPW loop feed had been designed.

Another useful techniques, which has widely been used, are multiple shapes next to or in front of each other and stacked configuration. Three TDRA [10] and four TDRA with same [11] and different permittivity [12] were investigated in which all TDRAs were fed from the apex. Stacked form of TDRAs [13] and different scales of up and down sections [14] were also reported for wideband applications. In [15] arrays of a circular-shape slots are drilled uniformly, it improved bandwidth by letting down the quality factor.

In this paper, an ultra-wideband TDRA has been designed, which includes worthwhile results in comparison with relevant recent works. The proposed antenna is a isosceles TDRA antenna, which is located on the extended conducting ground plane and is fed by a coaxial probe from base of triangle. The basis TDRA suffer from inappropriate return loss as well as negative gain on approximately 3GHz. A partially cylindrical-shape hole is etched from the base side of the TDRA, The proposed structure realized wideband and good radiation characteristics in the whole antenna bandwidth.

## II. DESIGN AND SIMULATION

### A. The Proposed Antenna Structure

Fig. 1(A) and 1(B) show the 3D view and top view of the proposed antenna, respectively. The proposed antenna composed of a triangular dielectric that is mounted on a square-shaped conductive ground plane, and small circle is removed from the base side of the TDRA. The proposed antenna is fed by a  $50\Omega$  coaxial probe which it is placed inside of the circle so that it touches the lateral wall of hole. Conducting ground plane dimensions are assumed  $140 \times 140$  mm<sup>2</sup>, and the dielectric material with permittivity of 10 is used. The proposed antenna dimensions includes triangle median ( $a=19$  mm), and the small side ( $b=9$  mm) and height of  $h=19$  mm. The center of a 3.0 mm circle has been closed to the center of TDRA in the distance of 1.5 mm. The TDRA is fed with a  $50\Omega$  coaxial probe which is placed inside, and touches the innermost surface of the circle. Probe height is considered  $h_p=7$  mm.

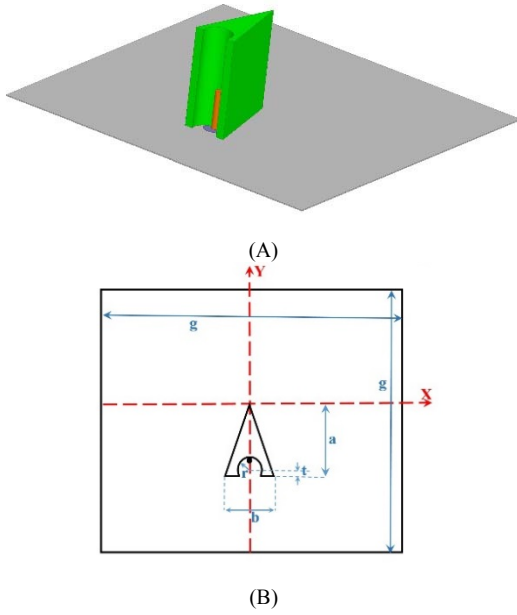


Fig. 1. A. 3D view and B. top view of the proposed antenna configuration

### B. Design Steps

**Isosceles base size:** Figure 2 (A) and (B) respectively show the gain and the return loss of the proposed antenna in the term of triangle base. The figures show that decreasing the base size improves the antenna bandwidth. The antenna bandwidths are respectively 50.5%, 48.8%, and 44.5 % for the base size of 8, 9, and 10 mm. The purpose is bandwidth improvement in higher frequencies, but the gain in the frequency range of 7.5 GHz to 10.5 GHz is less than 0 dBi. Therefore, gain improvement is much more critical than bandwidth. On the whole,  $b=9$  mm is chosen.

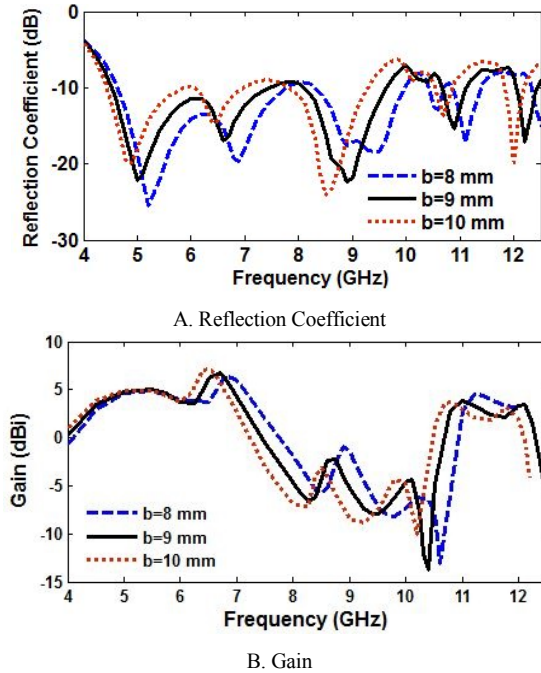


Fig. 2. A. Return loss and B. Gain of the proposed antenna in accordance with base triangle

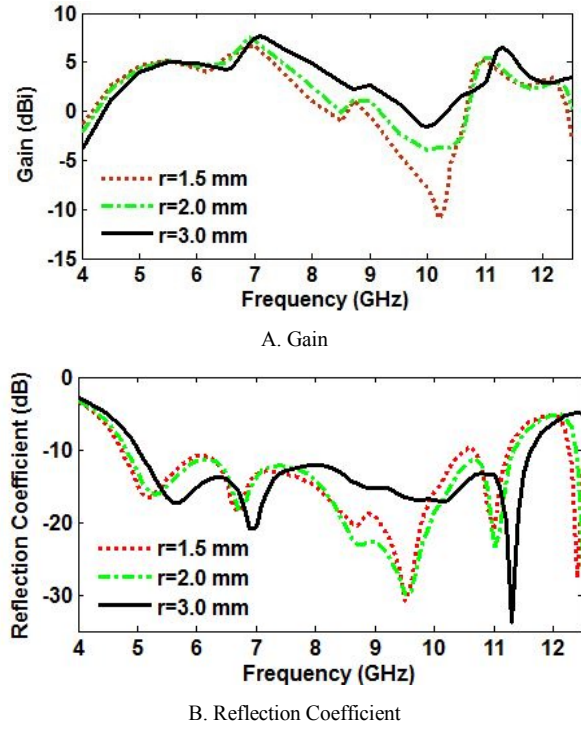


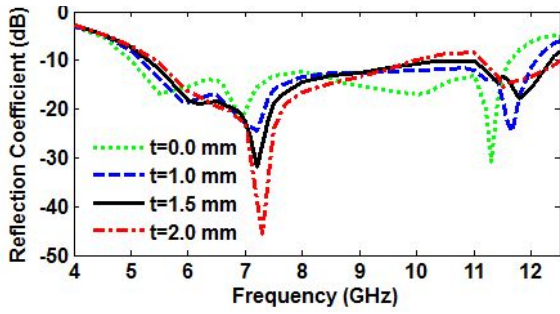
Fig. 3. A. Gain and B. Return loss of the proposed antenna in accordance with circle diameter

**Removed circle diameter ( $r$ ):** At the next step of design procedure, a circle is removed from triangle cross-section. At this step, the center of the circle is assumed to locate on the base side of the triangle. Figures 3A, 3B show the gain and the return loss in accordance with the circle radius.

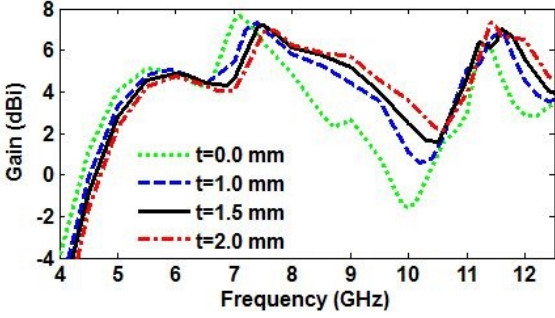
These figures depict that increasing of the circle diameter improves the gain chart significantly, particularly around 10 GHz. It also improves the return loss. Figure 3 (A), and (B) shows that increasing of the circle diameter improves the gain chart significantly, and return loss chart slightly, therefore  $r=3.0$  mm is chosen as the best value. This technique improves the bandwidth of the proposed antenna from 48.8% to 80.0%, and minimum gain is improved from -13.8 dBi to -1.6 dBi, but still 700 MHz of the bandwidth has the gain of less than 0 dBi. It should be mentioned that the higher values of  $r$  decreases the distance between inside wall of the hole and triangle sides and attenuate the side thickness of the hole. Consequently, it prevents next step.

**Movement of circle center to inside the triangle ( $t$ ):** At this step, the circle center that at previous step was assumed on the base side, is closed to the inside of the triangle ( $t$ ). The parameter of  $t$  is the distance between the center of circle and the base side of triangle (see figure 1 (B)).

Figures 3 (A) and (B) show the return loss and the gain of the proposed antenna in term of the parameter of  $t$ . Figure 3 (B) depicts that increasing of the parameter of  $t$  improve the gain chart, but figure 3 (A) illustrates that increasing of this parameter improve the return loss in lower frequencies and deteriorates it in higher frequencies. For the case of  $t=2.0$  mm, the return loss chart in the range of 10.0 GHz to 11.1 GHz suffer from inappropriate return loss, therefore  $t=1.5$  mm is chosen as the best value for this step of parametric study.



A. Return loss



B. Gain

Fig. 4. A. Return loss and B. Gain of the proposed antenna in the term of distance between the circle center and the base side of triangle

The final dimensions of the proposed antenna are shown in table 1.

TABLE I. FINAL DIMENSIONS OF PROPOSED ANTENNA

Parameter	g	a	b	h	r	t
Value	140	19	9	19	3	1.5

(all dimension in mm)

### C. Results

The proposed antenna has been simulated and optimized using HFSS, and good characteristic is achieved. The impedance bandwidth of 80.0 % from 5.29 GHz to 12.35 GHz is achieved with a suitable return loss ( $S_{11}$ ). The gain variation is from 1.6 dBi to 7.2 dBi, and the mean gain is 4.5 dB. Figure 5 shows the E-plane and H-plane of the proposed antenna at 6.0, 9.0 and 12.0 GHz. These figures show that the proposed antenna has a stable radiation pattern at all of the bandwidth. Side lobe and back lobe level at 6.0 GHz are -18 dB, at 9.0 GHz are -17 dB and -18 dB, and at 12.0 GHz are -14 dB and -18 dB, respectively.

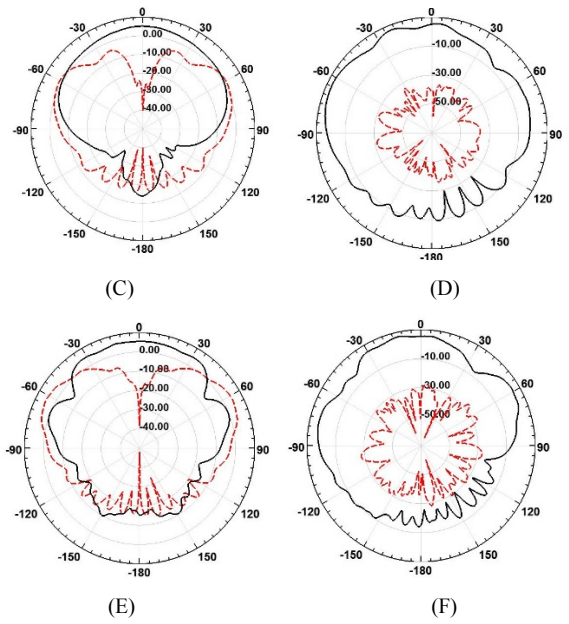
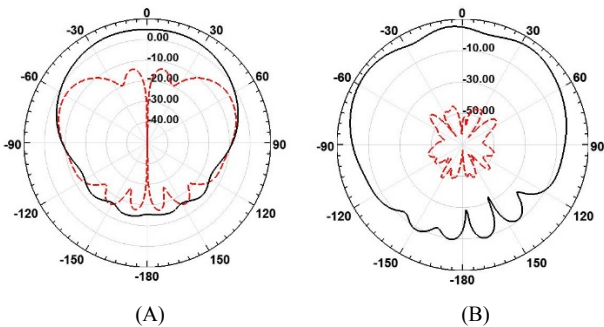


Fig. 5. A, C, and E: E-plane; B, D, and F: H-plane of the proposed antenna respectively at 6, 9, and 12 GHz

It was reported that for a specified resonant frequency and Dielectric resonator height, TDRAs offers the smaller area in comparison with cylindrical and rectangular antenna. Also, it was proved that just TMz modes are excited in TDRA antennas. This resonant frequency for equilateral TDRA can be written as follows [10]:

$$f_{mn} = \frac{c}{2\sqrt{\epsilon_r}} \left[ \left( \frac{4}{3a} \right)^2 (m^2 + mn + n^2) + \left( \frac{k}{2h} \right)^2 \right]^{\frac{1}{2}} \quad (1)$$

Where  $c$  is light speed in free space,  $\epsilon_r$  is relative permittivity,  $a$  is side length, and  $h$  is DRA height.

Figures 6 (A), (B), (C), and (D) show the internal electric field of TDRA at respectively 6.2 GHz, 7.2 GHz, 11.4 GHz, and 11.8 GHz. From the figures, it can be founded that these resonant frequencies are related to TM101, TM103, TM105, and TM115.

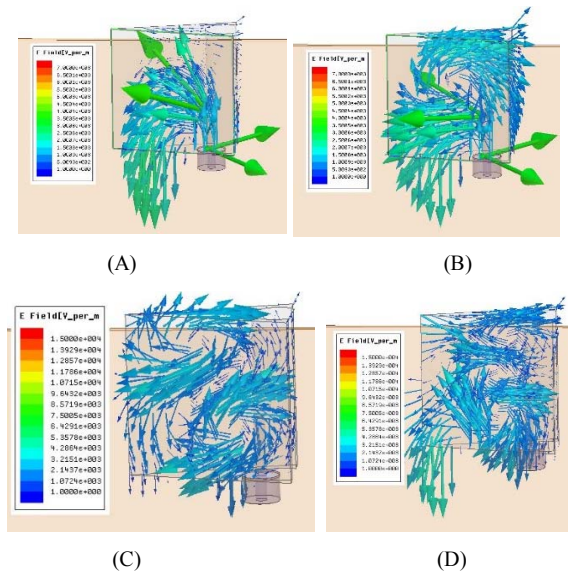


Fig. 6. Electric field patterns at A. 6.2 GHz, B. 7.2 GHz, C. 11.4 GHz, and D. 11.8 GHz

In many papers such as [15] and [16], the effect of hole or arrays of holes in DRA antennas was investigated. Using the hole can improve impedance bandwidth by reducing the quality factor of the antenna. In this paper, an embedded semi-cylindrical hole has been optimized to overcome the inappropriate values of the gain in the middle of the bandwidth (7.5 – 10.7 GHz). Figures 3A, and 4A show that increasing the hole diameter, as well as, movement of the hole to the center of TDRA lead to less quality factor, and better gain chart, but it disturbs the return loss at these frequencies.

In figure 2A, the reflection coefficient of the conventional TDRA has two resonances around 9 GHz. The first resonance is activated by monopole, and the second one is caused by TDRA. Decreasing of  $b$  activate two resonant frequencies which are coincided, in the frequency range that gain values are significantly inappropriate. Using hole inside DRA inherently enhances return loss, so we should find a way to improve gain chart concurrently. Figure 7A shows the E-field vectors of conventional TDRA at 10.3 GHz. This figure shows that E-field vectors are not generally in the same direction. It can be observed that many of E-field vectors are parallel to ground plane or have a significant horizontal component. The effect of such pattern for E-field vectors is canceled by the effect of conducting ground plane. Consequently, it decreases antenna gain. Figure 7B shows the E-field vectors of the proposed antenna at the same frequency. In this figure, it can be clearly seen that the E-field vectors are mostly in the vertical direction or have a significant vertical component, so they aimed to better gain value. Figure 8A, 8B show the radiation pattern of TDRA at 10.3 GHz for conventional TDRA in comparison with the proposed antenna.

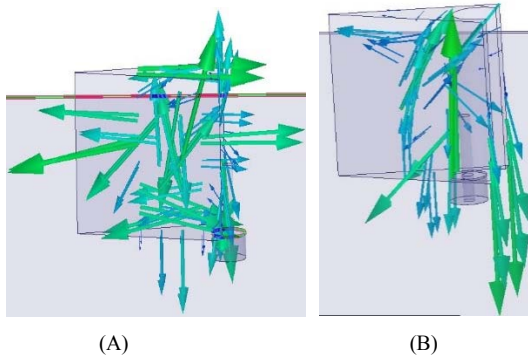


Fig. 7. Electric field patterns at 10.3GHz for A. conventional TDRA, B. the proposed antenna

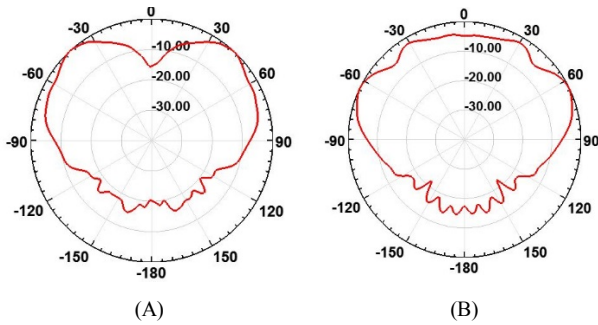


Fig. 8. Radiation patterns at 10.3GHz for A. conventional TDRA, B. the proposed antenna

TABLE II. GAIN, AND BANDWIDTH, OF REFERENCED TDRAS COMPARE WITH THE PROPOSED ANTENNA

Ref. No.	gain dBi	Frequency range GHz	BW %	Permittivity
[7]	1.2 – 7.0	4.33 – 7.02	47.4	10
[8]	-	4.21 – 6.76	46.5	10
[9]	Max: 6.12	2.34 – 2.97	23.5 7	10
[10]	-	9.27- 11.67	22.9	9.8
[11]	3.5 – 4.76	4.8 – 7.0	37	12
[12]	Max: 5.04	6.74 – 9.74	33	10, 12.4, 16
[13]	Max: 7.98	4.0 – 6.02	41	9.8
[14]	-	2.0 – 3.0	40	12
[15]	-	3.0 – 6.3	71	9.8
Proposed antenna	1.6 – 7.2	5.29 – 12.35	80	10

Table 2 shows the gain and the bandwidth of referenced antennas compare with the proposed antenna. The table shows that the proposed antenna has a good gain and excellent impedance bandwidth. The radiation pattern is also stable in the whole bandwidth.

### III. CONCLUSION

In this paper, a TDRA with a drilled cylindrical hole at the small side of the triangle is proposed. Using this hole could improve impedance bandwidth by reducing quality factor. Results of conventional TDRA show that gain chart in the middle of the bandwidth is not appropriate. Therefore, location and dimensions of the hole are optimized so that gain chart was improved and stabilized. Using this technique collimates E-field vectors in the vertical direction and improves gain chart, as well as, impedance bandwidth. In the proposed antenna, a bandwidth of 80% (5.29 GHz – 12.35 GHz) and gain variation of (1.6 dBi – 7.2 dBi) has been achieved.

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