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RESEARCH PAPER

# Wideband four-element two-segment triangular dielectric resonator antenna with monopole-like radiation

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*In this paper, a wideband two-segmented four-element triangular dielectric resonator antenna (TDRA) with coaxial probe feed has been proposed. The proposed antenna has been analyzed, optimized, and studied through Ansoft HFSS simulation software. The prototype of the proposed antenna has been fabricated and its input characteristics are measured with the help of R&S Vector Network Analyzer. Good agreement has been obtained between simulated and measured results. The proposed design has been compared with two segments TDRA and found wider bandwidth with lower resonant frequency. The proposed antenna provides monopole-like radiation pattern over the entire bandwidth with nearly 33% bandwidth (return loss ≥10 dB) at a resonant frequency 6.9 GHz and 4.93 dBi peak gain. The proposed antenna is suitable for application of C-band microwave frequencies.*

**Keywords:** Triangular dielectric resonator antenna, Return loss, Monopole radiation pattern, Wireless application

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## I. INTRODUCTION

Dielectric resonators (DRs) act as an antenna element due to its radiation capabilities while placing into an open environment [1]. It offers several advantages for antenna designer such as high radiation efficiency, low profile, small size, flexible feed arrangement, simple geometry structure, etc. It gives more flexibility to antenna engineers for selecting a wide range of dielectric material for antenna design [2–4]. Triangular dielectric resonator antenna (TDRA) is more compact in size as compared with rectangular, cylindrical, and circular disc DRAs for a given height and it also covers smaller area for a given resonant frequency [5, 6]. Due to its compact construction, it allows more space among DRA elements for designing an antenna array or multi-element antenna [5–7]. Equilateral triangle has symmetry with respect to its sides as well as angles from the center of the triangle, which gives flexibility to designer for reducing mutual coupling between adjacent elements. Low-profile equilateral TDRA excited with $TM_{10-1}$ fundamental mode using very high dielectric material has been reported in [5].

For DRAs, enhancement of bandwidth has major design consideration for antenna designer. Some bandwidth enhancement techniques have been reported in literatures [8–12]. Some studies on DRAs are reported in the literature for monopole type radiation pattern with wide bandwidth [13–22]. Guha *et. al.* investigated four elements cylindrical DRA and half-split hemispherical DRAs for wide bandwidth and monopole-type radiation pattern [14, 15]. Similarly, four elements rectangular DRA excited with coaxial probe is described and shown wide bandwidth with monopole radiation pattern [16]. Further, three elements, dual segments, and four elements TDRA with the monopole-like radiation pattern have been studied through simulation and experiment [17, 18]. Segmented hemispherical DRAs have been investigated as monopole low-profile DRA, which shows bandwidth improvement as well as monopole in nature [19]. Wideband three and four elements multi-layer multi-permittivity cylindrical DRAs have also been investigated for monopole radiation pattern of wireless application [20–22]. The design of a DRA array using disk shape with high dielectric constant material has been used to get 4.6% bandwidth at resonant frequency of 2.34 GHz, which shows that high dielectric constant materials can be used to reduce the resonant frequencies [23, 24].

This paper presents the simulation and experimental studies of four elements two segment TDRA for the monopole-like radiation pattern over a wide bandwidth. Some elementary simulated results of the proposed structure have been reported by authors for the first time in [25]. Proposed antenna has extension of [18].The simulation study of the proposed antenna has been carried out using commercially available Ansoft HFSS simulation software. The simulated results have been compared with measured results, which show good agreement with each other. The proposed antenna produces a monopole-like radiation pattern over a wide bandwidth having a resonant frequency of

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6.9 GHz. The simulated and measured return loss of the proposed antenna has been compared with the two segments TDRA and found enormous enhancement in bandwidth with lower resonant frequency.

## II. ANTENNA GEOMETRY

TDRA has advantages like smaller radiation area for a given height and resonant frequency compared with other shapes like cylindrical and rectangular DRA. It provides large space between DR elements which helps antenna designers for designing antenna arrays. Thus, it helps antenna designers to introduce multi-element concept for bandwidth enhancement for efficient utilization of the radiation area.

The resonant frequency of single-element TDRA for $TM_{mnl}$ mode approximately has been given by [5, 6].

$$f_{mnl} = \frac{1}{2\sqrt{\varepsilon\mu}}\left[\left(\frac{4}{3a}\right)(m^2 + mn + n^2) + \left(\frac{\rho}{2h}\right)^2\right]^{1/2}. \quad (1)$$

This can also be written as

$$f_{mnl} = \frac{c}{2\sqrt{\varepsilon_{r,eff}}}\left[\left(\frac{4}{3a}\right)(m^2 + mn + n^2) + \left(\frac{\rho}{2h}\right)^2\right]^{1/2}, \quad (2)$$

where $c$ is the speed of light, $\varepsilon_r$ the dielectric constant of TDRA, $a$ the length of each side of the TDRA, and $h$ the height of the TDRA. The indices of resonant frequency $m$, $n$, and $l$ satisfy the condition $l + m + n = 0$, but they all cannot be zero simultaneously. Here $\rho = 1$ for the fundamental $TM_{10-1}$ mode.

The resonant frequency of the two segments TDRA has been calculated for the $TM_{10-1}$ mode by equation (2). The effective dielectric constant ($\varepsilon_{r,\ eff}$) has been calculated through combining the upper segment and lower segment of the DR element by equation (3) [26].

$$\varepsilon_{r,eff} = \frac{h_1 + h_2}{h_1/\varepsilon_1 + h_2/\varepsilon_2}, \quad (3)$$

where $h_1$, $h_2$ and $\varepsilon_1$, $\varepsilon_2$ are the heights and dielectric constants of the lower and upper segments of TDRA, respectively. Here $h_1 + h_2$ is known as the effective height of the proposed TDRA.

The proposed four elements and two segments equilateral TDRA have been designed and fabricated, which are shown in Figs 1 and 2, respectively. Equilateral TDRA has the side dimension $a = 13.34$ mm. The upper segment of the two segments TDRA has dielectric constant ($\varepsilon_2$) = 12 (TCI Ceramics, K-12, tan $\delta = 2.0 \times 10^{-4}$) with height $h_1 = 8$ mm and the lower segment is Teflon which has a dielectric constant ($\varepsilon_1$) = 2.08 with height $h_2 = 2$ mm. The proposed four elements two segments TDRA are made by combining four two-segment equilateral TDRA, which are packed together in a compact way with metallic ground plane of dimensions

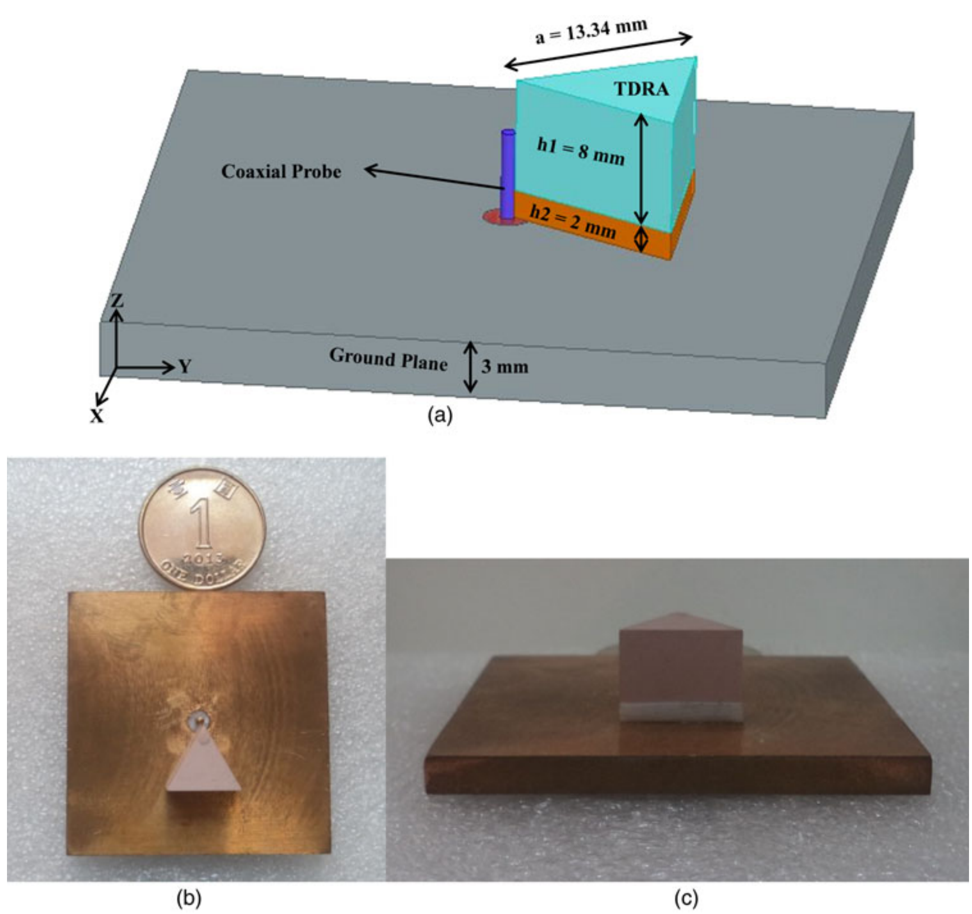


**Fig. 1.** Two segments TDRA. (a) Schematic diagram. (b) Top view of the fabricated structure. (c) Side view of the fabricated antenna.

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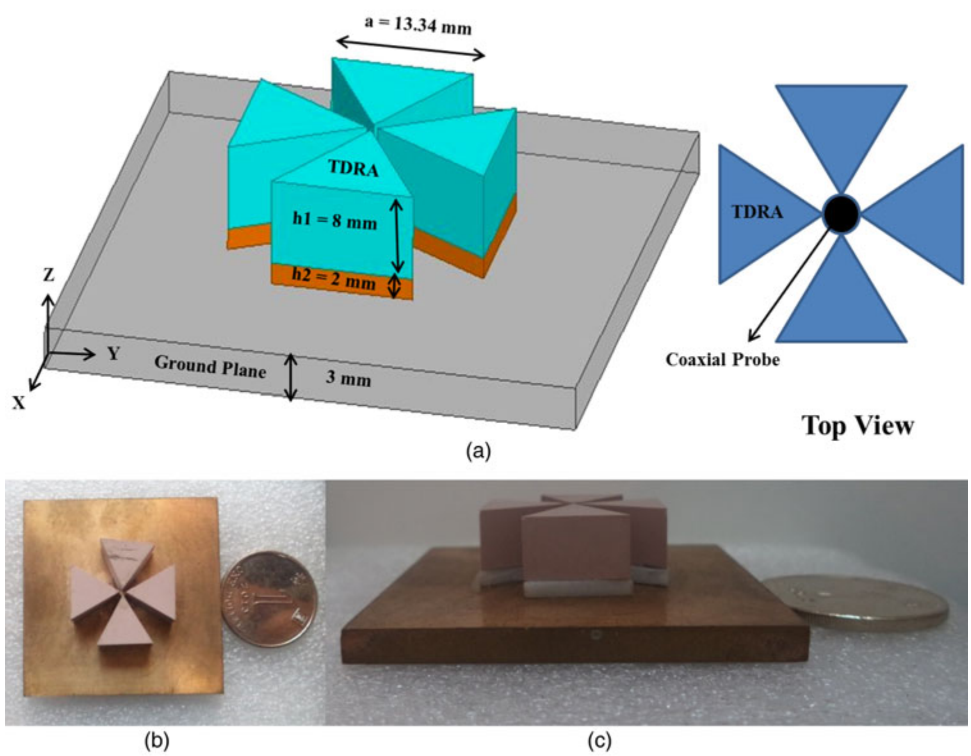


**Fig. 2.** Proposed four-element two-segment TDRA. (a) Schematic diagram. (b) Top view of the fabricated structure. (c) Side view of the fabricated antenna.

$50 \times 50 \times 3$ mm$^3$. Very small amount of adhesive material (Feviquick) has been used for combining two segments of ceramic materials, as well as the ground plane with ceramic materials. Large quantity of adhesive can create a thinner gap between two ceramic materials and between ground planes, which create small shifting in resonant frequency [23, 24]. The ground plane size has been optimized through extensive simulation for minimum return loss and maximum bandwidth. As the dimension of DRA is very less compared with the ground plane size, we can assume that optimized dimension would behave like an infinite ground plane for the DRA. The elements of the proposed four-element two-segment TDRA are centrally excited by a 50 Ω coaxial probe which touches the corner edges of all the elements. From equations (1)–(3), the resonant frequency of the two segments TDRA is found to be 6.84 GHz.

## III. RESULTS AND DISCUSSION

The simulation study of return loss versus frequency characteristics of the proposed antenna and two segments TDRA have been carried out using Ansoft HFSS simulation software. The proposed antenna has been fabricated and measured. The return loss versus frequency curves has been experimentally measured by Vector Network Analyzer (ROHDE & SCHWARZ-10 MHz–20 GHz.ZVM).The height of the probe above the ground plane for the proposed antenna is determined through extensive simulation to obtain minimum return loss at the corresponding resonant frequency. The simulated return loss versus frequency curve of the proposed antenna has been optimized for different probe height ($l$) shown in Fig. 3. From Fig. 3, it can be observed that the desired probe height of the proposed antenna is found 9 mm for minimum return loss. Similarly, the desired height of the probe is found to be 10.2 mm for the two segments TDRA. Percentage bandwidth variation with the dielectric constant of upper segment ($\varepsilon_{r1}$), by keeping the dielectric constant of lower segment (Teflon, $\varepsilon_{r2} = 2.1$) constant, has been shown in Fig. 4. As it is very clear from the below Fig. 4, that the dielectric constant of upper segment ($\varepsilon_{r1} = 12$) is providing highest percentage bandwidth as compared with other dielectric constant. From Fig. 4, it can also be observed that the percentage bandwidth of the proposed antenna is decreasing by increasing the dielectric constant of the upper segment.

The simulated and experimental return loss versus frequency curves of the proposed antenna and two segments TDRA are shown in Fig. 5. From Fig. 5, simulated and measured resonant frequency, operating frequency range and the operating bandwidth of the proposed antenna, and two segments TDRA are extracted and shown in Table 1. From

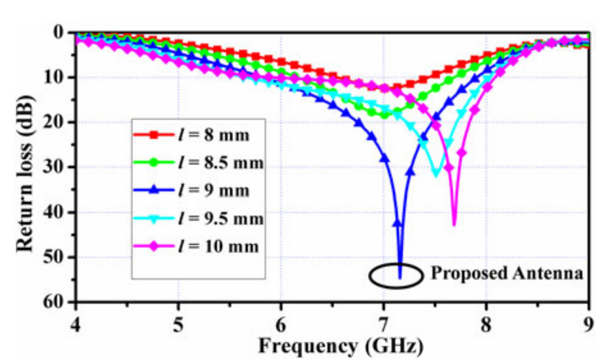


**Fig. 3.** Simulated return loss versus frequency curves of the proposed antenna for different values of probe length.

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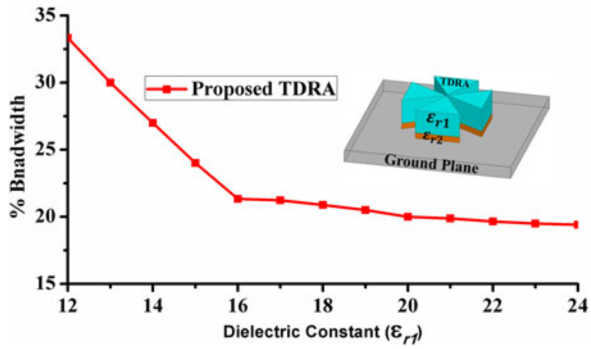


**Fig. 4.** Simulated percentage bandwidth versus dielectric constant of the upper segment of the DR ($\varepsilon_{r_1}$) curve for the proposed antenna.

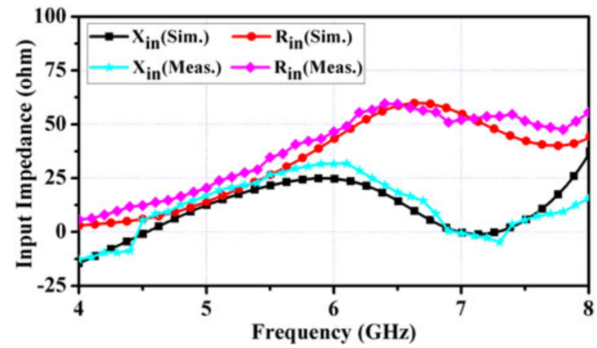


**Fig. 6.** Variation of simulated input impedance versus frequency of the proposed antenna.

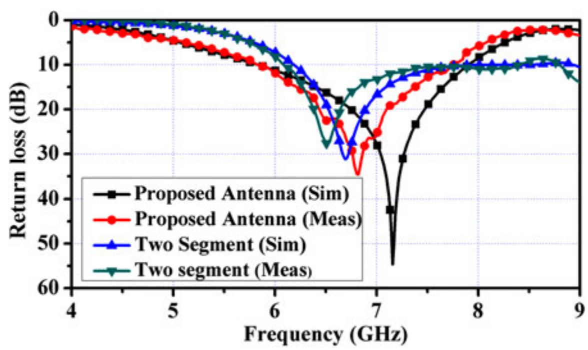


**Fig. 5.** Comparison of the simulated and measured return loss of the proposed antenna and two segments TDRA.

Fig. 5 and Table 1, it can be observed that the proposed antenna provides wider bandwidth, which shows good agreement between simulation and measurement results. The proposed four-element two-segment TDRA has higher bandwidth compared with two segments TDRA due to more radiation surface area. It can also be depicted from Fig. 5 and Table 1, that there are little differences between resonant frequencies of the proposed and two segments TDRA. The difference in results comes due to its fabrication complication like improper alignment and effect of binding reagent (adhesive material), etc. Table 2 shows comparison between other published DRAs. From Table 2, it can be observed that the proposed antenna has better performance in comparison with other published DRAs. The proposed antenna also provides wider bandwidth (2300 MHz) as compared with four elements TDRA [18], as it takes the same radiation area and gives wider bandwidth which leads to its importance. Owing to two segments, the effective dielectric constant of the two segments TDRA is being reduced and due to which improvement in bandwidth has been observed.

The input impedance versus frequency characteristic of the proposed antenna has been investigated using Ansoft HFSS simulation software. The input impedance of the proposed antenna has also been measured with the help of Vector Network Analyzer (VNA (ROHDE & SCHWARZ-10 MHz–20 GHz.ZVM)).The simulated and measured input impedance versus frequency curve for the proposed antenna is shown in Fig. 6. Its numerical values of real part of input impedance has been extracted from Fig. 6 and found to be 50.5 and 50.25 Ω, respectively, at resonant frequency. The input impedance at resonant frequency is very close to 50 Ω impedance of the coaxial probe feed, which shows good impedance match. It is also observed that simulated input impedance has good agreement with measured result.

The simulation study of the near-field distribution of the proposed TDRA has been carried out at the resonant frequency using the Ansoft HFSS software. The distinct electric and magnetic field distributions for the proposed TDRA are

**Table 1.** Resonant frequency and return loss performance of the proposed antenna and two-segment TDRA.

| Antenna geometry/parameter | Two-segment TDRA | | Proposed antenna | |
|---|---|---|---|---|
| | Ansoft HFSS | Measured | Ansoft HFSS | Measured |
| Operating frequency range (return loss\| ≥10 dB) | 6.3–7.5 GHz | 6.3–7.6 GHz | 5.6–8.0 GHz | 5.5–7.8 GHz |
| Resonant frequency ($f_r$) | 6.7 GHz | 6.5 GHz | 7.2 GHz | 6.9 GHz |
| % Bandwidth ($f_h$–$f_l$/$f_r$) | 17.91% | 20.00% | 33.33% | 33.33% |

**Table 2.** Comparison of the proposed antenna with similar structures.

| DRA shapes | No. of DR element | Radiation pattern | Operating frequency range (GHz) | Resonant frequency (GHz) | % Bandwidth | References |
|---|---|---|---|---|---|---|
| Triangular | 03 | Monopole | 9.27–11.67 | 10.8 | 22.92 | [17] |
| Cylindrical | 04 | Monopole | 3.05–4.00 | 3.4 | 29.00 | [14] |
| Triangular | **04** | **Monopole** | **5.50–7.80** | **6.9** | **33.33** | **Present paper** |

Bold signifies present paper result.

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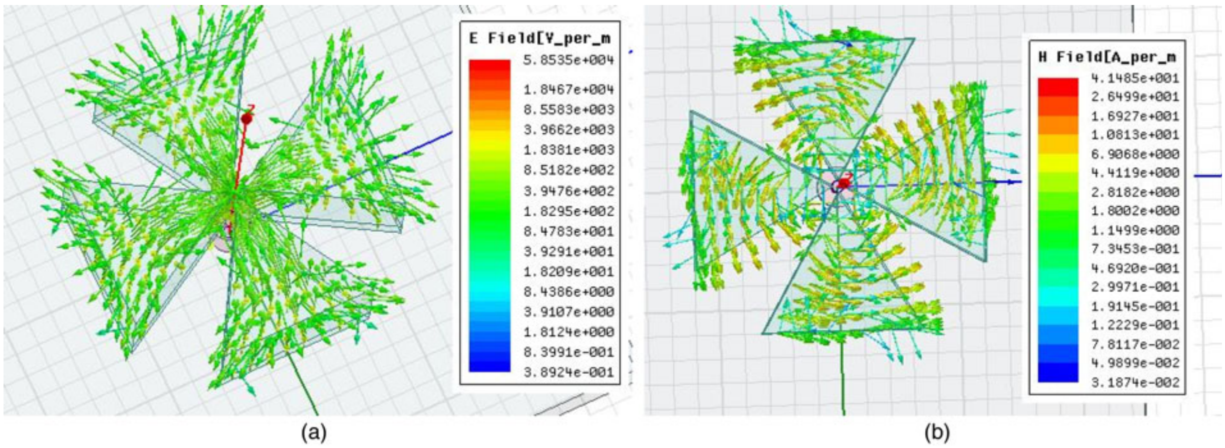


**Fig. 7.** Near-field distribution in the proposed four-element two-segment TDRA, (a) *E*-field and (b) *H*-field.

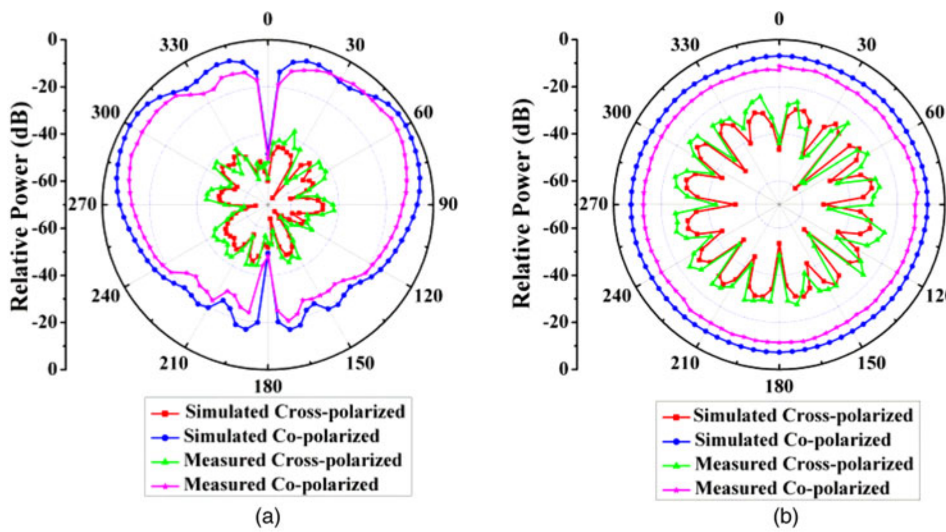


**Fig. 8.** Radiation pattern of the proposed four-element two-segment TDRA in the (a) *E*-plane and (b) *H*-plane at 6.9 GHz frequency.

shown in Fig. 7. It is apparent from Fig. 7 that the coaxial probe excites $TM_{10-1}$ dominant mode fields in the antenna elements and also the electric field components face their counter vectors, thus no radiation is emitted along the broadside direction [16]. The resultant electric field is polarized along the *z*-direction and thus it leads to a vertically polarized radiation surrounding the radiating structure like a quarter wave electric monopole [18].

The far-field patterns of the proposed antenna at resonant frequency 6.9 GHz are studied through Ansoft HFSS simulation software and compared with measured one. The far-field measurement of the proposed antenna has been taken place inside anechoic chamber. The simulated and measured radiation patterns of the proposed antenna in the *E*- and *H*-planes at resonant frequency are shown in Figs 8(a) and 8(b), respectively. The radiation patterns of the proposed antenna have also been measured at 7.2 and 5.9 GHz, which are shown in Figs 9 and 10, respectively. From the radiation patterns of the proposed antenna, it can be observed that the radiation pattern of the proposed antenna is omnidirectional in the *H*-plane and monopole-like radiation pattern in the *E*-plane. No radiation along the broadside direction of the proposed DRA is in conformity with the counteracting *E*-field distributions within the elements of the proposed TDRA [5]. The proposed antenna shows very low cross-polarization level in both the *E*- and *H*-planes. The simulated radiation efficiency and peak directivity of the proposed antenna is found 99% and 5.1 dBi, respectively. Simulated and measured gain versus frequency curves of the proposed antenna has been shown in Fig. 11. From Fig. 11, it can be observed that the gain is linear in operational bandwidth with an average value of nearly 4.93 dBi. It can also be observed that the simulated gain results are in good agreement with measured gain results. For the measured gain calculation three antenna method has been used [27].

## IV. CONCLUSION

A wideband four-element two-segmented TDRA has been designed through simulation using Ansoft HFSS simulation software. The proposed antenna has been fabricated and tested. The proposed antenna has been compared with the same dimension of two segment TDRA, and found bandwidth enhancement (≈11.00%) with lower resonant frequency. From the study, it is inferred that the bandwidth of the

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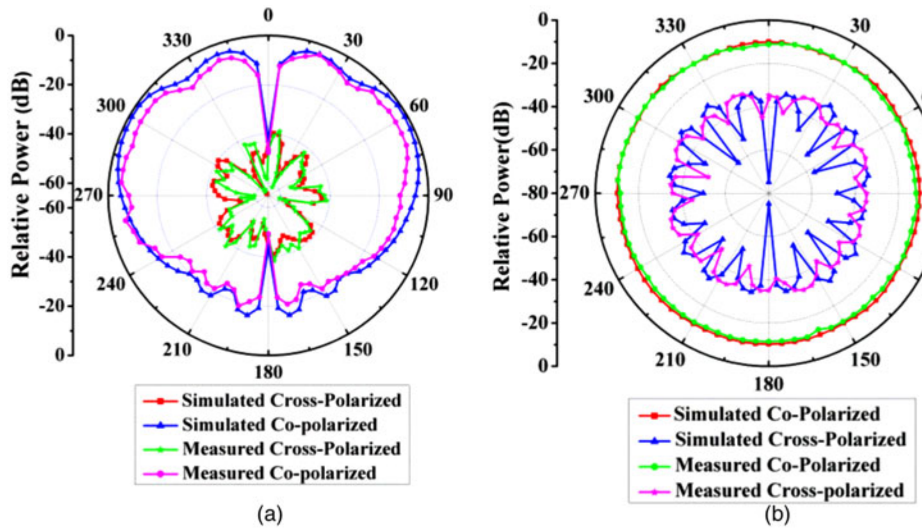


**Fig. 9.** Radiation pattern of the proposed four-element two-segment TDRA in the (a) *E*-plane and (b) *H*-plane at 7.2 GHz frequency.

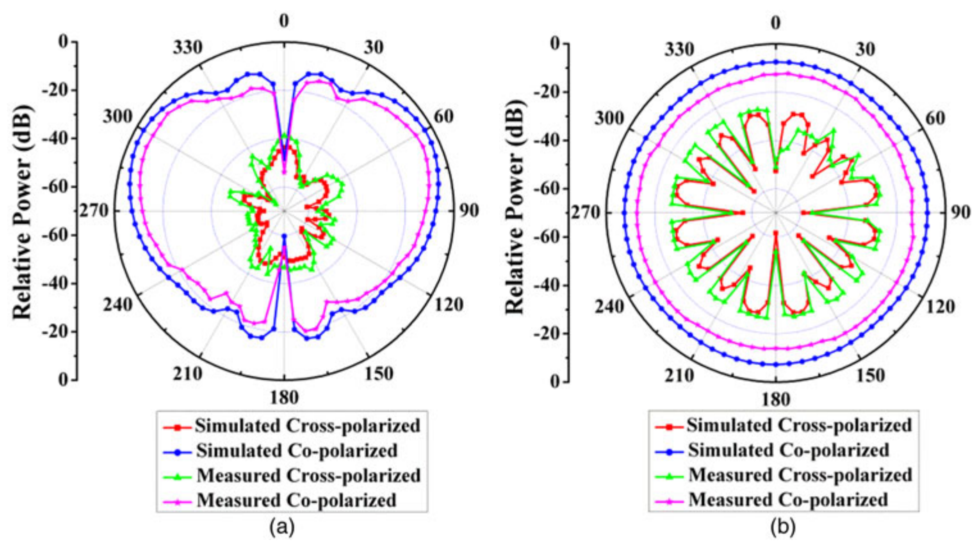


**Fig. 10.** Radiation pattern of the proposed four-element two-segment TDRA in the (a) *E*-plane and (b) *H*-plane at 5.9 GHz frequency.

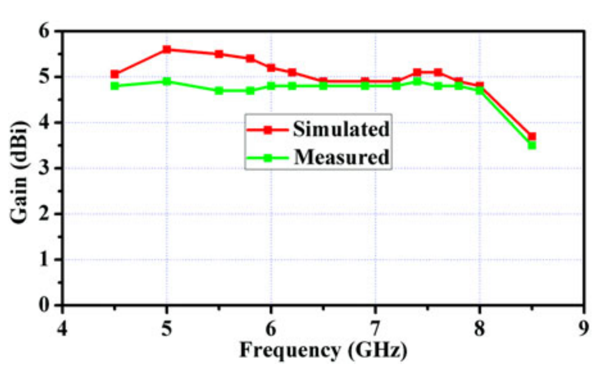


**Fig. 11.** Gain versus frequency variation of the proposed four-element two-segment TDRA.

proposed antenna has been found nearly 33% and provide a monopole type of radiation pattern with nearly 4.93 dBi gain in complete operating frequency band. The results obtained may be useful for designing and developing antennas for subsurface communication, geophysical exploration, biomedical telemetry, and for mobile terrestrial and aerospace communication systems for C-band frequency application.

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