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RESEARCH PAPER

Four element triangular dielectric resonator antenna for wireless application

RAVI KUMAR GANGWAR, PINKU RANJAN AND ABHISHEK AIGAL

A wideband four element triangular dielectric resonator antenna (TDRA) has been designed and fabricated by using 50 Ω coaxial probe feed. The input and radiation characteristics of the proposed antenna have been extracted through Ansoft HFSS and CST Microwave Studio simulation software and compared with the experimental results. The simulated results have been in good agreement with the experimental results. The proposed antenna characteristics have also been compared with the same dimensions of the single element TDRA, and found enhancement in bandwidth with lower resonant frequency. Its performance has also been compared with same area (equal to proposed antenna) of single element TDRA. The proposed antenna provides nearly 37% bandwidth ($|S_{11}| < -10$ dB) at a resonant frequency of 5.45 GHz with 4.76 dBi peak gain. The symmetry and uniformity in the radiation patterns is obtained consistently for the entire operating bandwidth. The proposed antenna shows consistently symmetric monopole type radiation pattern with low cross polarization for WLAN (IEEE 802.16) and WiMAX applications. The performance of the proposed antenna has been compared with some similar type of dielectric resonator antenna (DRA) shapes and it has been observed that TDRA is taking very less radiation area for giving better performance than other DRA shapes.

Keywords: Triangular dielectric resonator antenna (TDRA), Wideband, WLAN and WiMAX, Probe feed, Monopole

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INTRODUCTION

Dielectric resonators (DRs) are nonmetallic object which functions similar to metallic cavities [1]. The DR can be used as radiating element and act as a DR antenna with different excitation methods such as microstrip line, coaxial probe, and aperture coupling and co-planer waveguide feed. Dielectric resonator antennas (DRAs) are available in many basic shapes such as cylindrical, rectangular, spherical, hemispherical, and triangular geometry etc. [2, 3]. It has several attractive features such as small size, low profile, high radiation efficiency, flexible feed arrangement, simple geometry structure, light weight, low cost, a wide range of material dielectric constant which gives more flexibility to the antenna designer [2–5]. Triangular dielectric resonator antennas (TDRA) is more compact in size compared with rectangular and circular disc DRAs [6].

For DRAs, bandwidth enhancement is a major design consideration for practical application. To enhance the bandwidth of DRAs, there are several techniques such as changing the aspect ratio of DRA [3], varying the dielectric constant of the material [7], sectoring and splitting of the basic structure [8] by using stacked DRAs and multi-segments [8, 9], multi-element [7], introducing air-gap between ground and the DRA element [10]. Inserting low dielectric material below the high dielectric material also leads to improvement in bandwidth [11].

For monopole type radiation pattern, some studies on DRAs are reported in the literature. The dielectric ring resonator antenna is used for constructing small and compact monopole like radiation pattern and has been studied [12]. Multi-element cylindrical DRA and half split hemispherical DRAs have been investigated for monopole like radiation pattern with wide bandwidth by Guha and Antar [13, 14], which shows an enhancement in bandwidth by introducing multi-element and splitting basic structure. Similarly, four elements rectangular DRA excited with coaxial probe gives 35.25% bandwidth with monopole radiation pattern investigated for bandwidth enhancement [15]. Further, for X-Band application three element dual segments TDRA with monopole like radiation pattern has been investigated through simulation and experimentally [16]. Segmentation of hemispherical DRA was investigated in multi-element composite forms with monopole type radiation for wideband application [17]. Half hemispherical DRA with array of slot has been introduced with 29% bandwidth for wideband application, by increasing the probe length a shift in resonance frequency has been observed and it behaves like monopole DRA [18].

This paper presents the simulation and experimental studies of a four element TDRA, which is fed by a 50 Ω coaxial probe feed. The simulation study of the proposed antenna array is carried out using commercially available Ansoft HFSS and CST Microwave Studio simulation software. The simulation and measured results are in good agreement for the proposed antenna. The proposed antenna input characteristics has been

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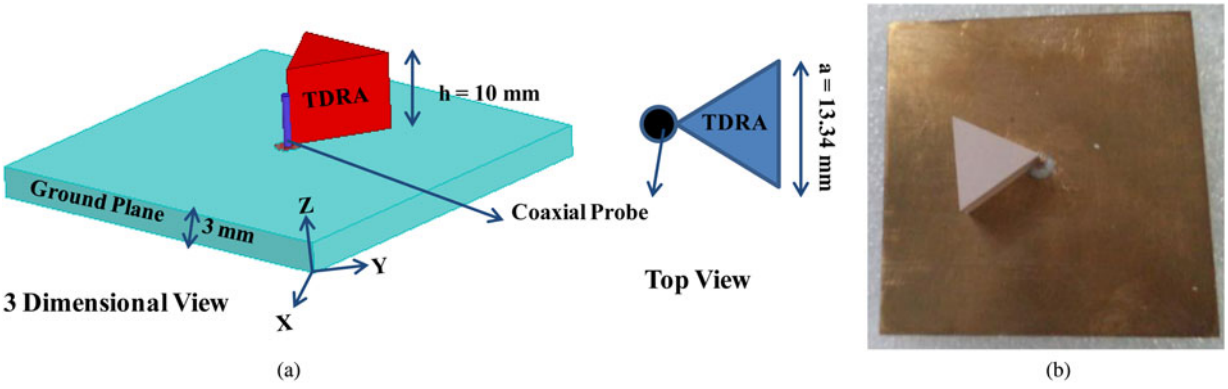


Fig. 1. (a) Geometry, (b) fabricated prototype of single element TDRA.

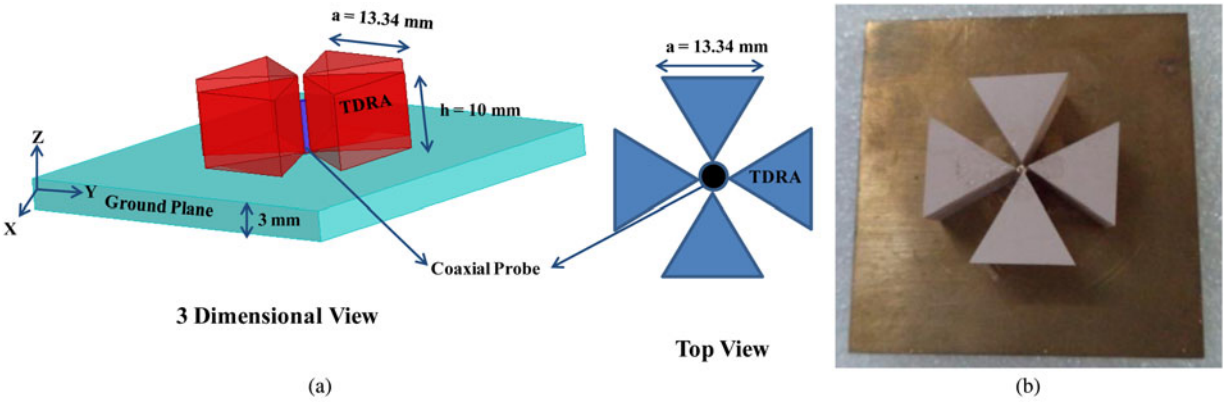


Fig. 2. (a) Geometry, (b) fabricated prototype of proposed four elements TDRA.

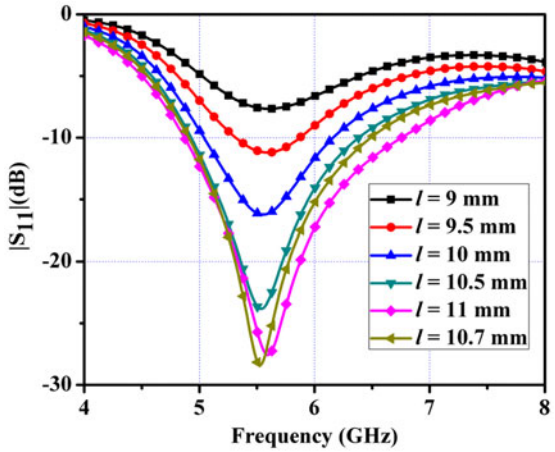


Fig. 3. Effect of variable probe length l for the $|S_{11}|$ characteristics of proposed antenna.

compared with single element TDRA and found enormous enhancement in bandwidth. The proposed antenna produces a monopole like radiation pattern over entire bandwidth having a resonant frequency of 5.45 GHz.

CONFIGURATION OF ANTENNA DESIGN

The geometry of the single element TDRA and the proposed four elements TDRA is shown in Figs 1 and 2. The dimension of each DR of the structure is $a = 13.34$ mm and height $h = 10$ mm. The dielectric constant of the material is $\varepsilon_r = 12$ (TCI ceramics Inc, USA, K-12, tan $\delta = 2.0 \times 10^{-4}$) used for each element of the proposed antenna. The DR elements of the composite structure are packed together in a compact way on a metallic ground plane of dimensions 50 mm × 50 mm × 3 mm. The proposed antenna has been excited by a 50 Ω coaxial probe, which touches the corner edge of all the four elements of the TDRA as shown in Fig. 2. The main reason for taking TDRA is that for a given height and resonant frequency, it offers a smaller area than either a cylindrical or rectangular DRA [19]. Thus, it is beneficial for an antenna array application. For a larger range of space available between TDRA elements gives enhancement in bandwidth.

RESULTS AND DISCUSSION

A) Return loss and Input Impedance versus frequency curve

The simulated $|S_{11}|$ versus frequency curve has been optimized for different probe height (l) shown in Fig. 3. The height of the probe is found to be 10.7 mm above the ground plane, through extensive simulation for minimum return loss of the proposed antenna. Similarly for single element TDRA probe height is obtained 10.8 mm above the ground plane. The simulation study of $|S_{11}|$ versus frequency curve of the proposed antenna and single element TDRA has

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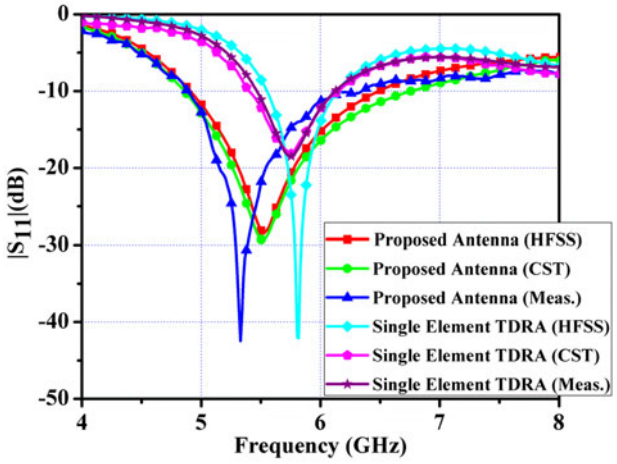


Fig. 4. Comparison of simulated and measured $|S_{11}|$ parameter of the proposed four elements and single element TDRA (same dimension).

been carried out using Ansoft HFSS and CST Microwave Studio simulation software. The $|S_{11}|$ versus frequency curves has been experimentally measured using Vector Network Analyzer (VNA; ROHDE & SCHWARZ- 10 MHz–20 GHz. ZVM). The simulated and experimental return loss versus frequency curves of the proposed four elements and the single element TDRA are presented in Fig. 4. From Fig. 4, simulated and measured resonant frequency, operating frequency range, and the percentage bandwidth of the proposed antenna as well as single element TDRA are extracted and shown in Table 1. From Fig. 4 and Table 1, it can be observed that there is good agreement with simulation and measured results. The bandwidth of the proposed antenna is found higher than the single element TDRA this is due to reduction in the effective dielectric constant of the proposed DRA and also due to higher surface volume area for radiation.

The performance of proposed antenna has been compared with single element TDRA (same area as proposed antenna) shown in Fig. 5. It is apparent from Fig. 5, that the single element TDRA ($a = 26.68$ mm) of same area has less operating bandwidth and higher resonant frequency similar to single element TDRA ($a = 13.34$ mm) of same dimension compared with proposed antenna.

The input impedance versus frequency characteristic of the proposed antenna has been investigated using Ansoft HFSS and CST Microwave Studio simulation software. The input impedance of the proposed antenna is also measured experimentally with the help of VNA (ROHDE & SCHWARZ-10 MHz—20 GHz. ZVM). The simulated and measured input impedance versus frequency curve of the proposed antenna is shown in Fig. 6. Simulated and measured value of input resistance is extracted and given in Table 2. From Fig. 6 and Table 2, it can be observed that there is good agreement with simulated and measured results and also their values are very close to 50 Ω impedance of coaxial probe feed.

The comparison between other shapes of DRA (previous published article) and proposed antenna has been shown in Table 3. From Table 3 it can be observed that the proposed antenna has better operating bandwidth and percentage bandwidth compared with Cylindrical DRA and Rectangular DRA. It can also be observed from Table 3, TDRA is taking very less radiation area for same performance or even better than other shapes.

Table 1. Resonant frequency and return loss performance of proposed four element and single element TDRA.

	Antenna geometry					
	Single element TDRA			**Proposed four element TDRA**		
Parameter	**Ansoft HFSS**	**CST-MWS**	**Measured**	**Ansoft HFSS**	**CST-MWS**	**Measured**
Operating frequency range ($\|S_{11}\| \leq -10$ dB)	5.5–6.2 GHz	5.5–6.2 GHz	5.6–6.2 GHz	4.8–6.8 GHz	4.8–7.0 GHz	4.7–6.8 GHz
Resonant frequency (f_r)	5.8 GHz	5.8 GHz	5.8 GHz	5.5 GHz	5.5 GHz	5.45 GHz
% Bandwidth ($f_h - f_l/f_r$)	12.06%	10.34%	10.34%	36.36%	40%	37.61%

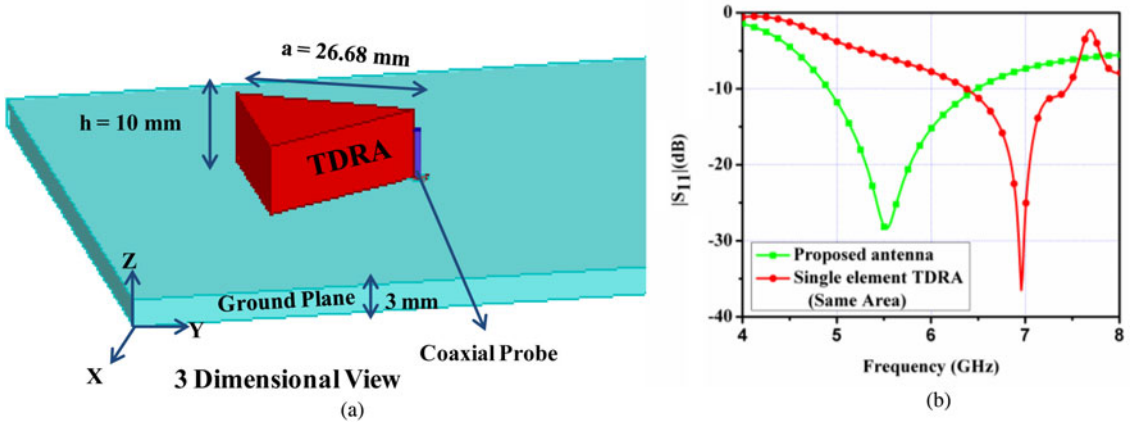


Fig. 5. (a) Geometry of single element TDRA (same area of proposed antenna), (b) comparison of $|S_{11}|$ parameter of the proposed antenna and single element TDRA (same area).

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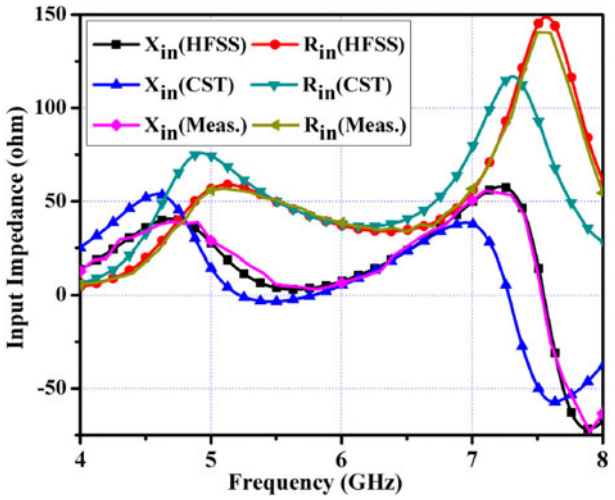


Fig. 6. Variation of input impedance versus frequency of proposed four elements TDRA.

B) Near field distribution

The simulation study of the near field distribution of the proposed TDRA has been carried out at resonant frequency 5.5 GHz using the Ansoft HFSS simulation software. The composite electric and magnetic field distributions of the proposed TDRA are 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. For TDRA the summation of indices of dominant mode should be zero, which is satisfying for TM_{10-1} mode. Also it can be observed that the electric field component face their counter vectors and thus cause no radiation along the broadside direction. 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. Since the elements of the antenna composite TDRA structure effectively produces identical radiation fields at resonant frequency 5.5 GHz. The uniform and consistently symmetric monopole-type pattern has been achieved over the full matching bandwidth for the proposed antenna.

Table 2. Input resistance of proposed four elements TDRA for simulated and measured results at resonant frequency.

	Technique		
Parameter	**Ansoft HFSS**	**CST microwave studio**	**Measured**
Input resistance	50.5 Ω	50.7 Ω	50.25 Ω

C) Far field distribution

The far field patterns of the proposed antenna at resonant frequency and at 5.8 GHz are studied through Ansoft HFSS simulation software and also measured in anechoic chamber. The simulated and measured radiation pattern of the proposed antenna in *E* - and *H*-Plane at resonant frequency are shown in Figs 8(a) and 8(b) and at 5.8 GHz is

Table 3. Comparison of proposed antenna with other shapes of similar published structures.

DRA Shape	Radiation area of DRA (mm^2)	Volume of DRA (mm^3)	Feed type	Radiation pattern	Dominant mode	% Bandwidth	Resonant frequency (GHz)	Reference
CDRA	1570	3140	Coaxial probe	Monopole	$HEM_{11\delta}$	29	3.5	[13]
RDRA	1904	3120	Coaxial probe	Monopole	TE^{Y}_{211}	35.25	5.7	[15]
TDRA	924	3080	Coaxial probe	Monopole	TM_{10-1}	37.61	5.45	Proposed antenna

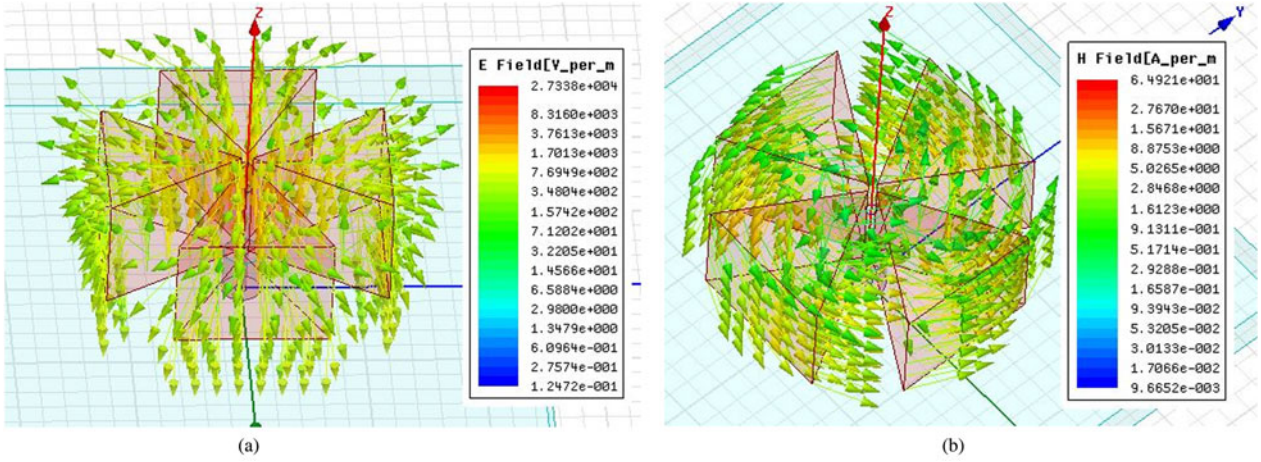


Fig. 7. Near field distribution in proposed four elements TDRA (a) *E*-field, (b) *H*-field.

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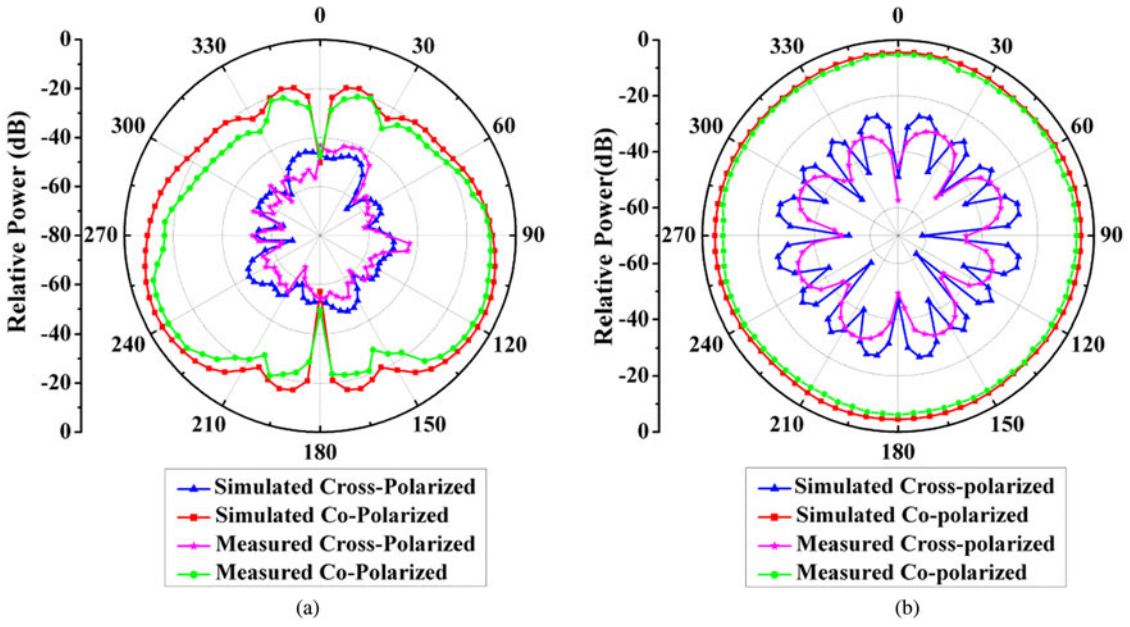


Fig. 8. Radiation pattern of proposed four elements TDRA (a) in *E*-plane, (b) in *H*-plane at resonant frequency 5.45 GHz.

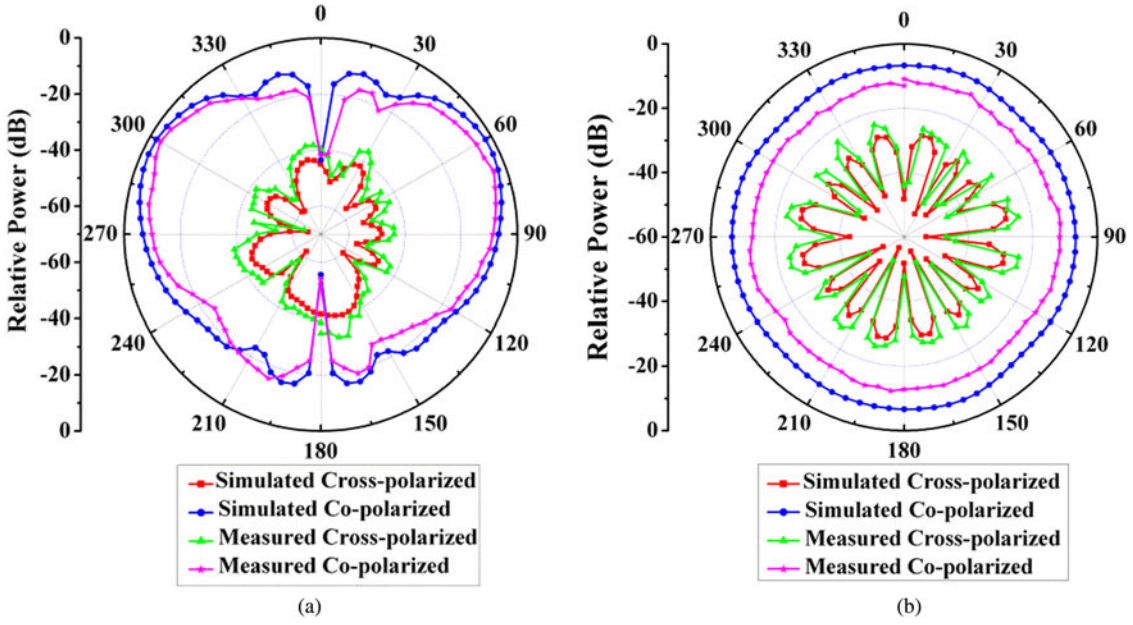


Fig. 9. Radiation pattern of proposed four elements TDRA (a) in *E*-plane, (b) in *H*-plane at 5.8 GHz frequency.

shown in Figs 9(a) and 9(b), respectively. For the measurement and simulation *E*-plane has been chosen for $\phi = 0^\circ$ and *H*-plane for $\theta = 90^\circ$. It is also apperant from the radiation pattern for both frequency that the co-polarization and cross-polarization level difference is more than 30 dB, which is appriciable for DRA. From Figs 8 and 9 it can be observed that the radiation pattern of the proposed antenna is omni-directional in *H*-plane. No radiation along broadside direction of the proposed DRA is in conformity with the counteracting *E*-field distributions within the elements of the proposed TDRA. Simulated radiation pattern are in good agreement with the measured radiation pattern. It is also observed that the simulated radiation efficiency and peak directivity of the proposed antenna is found 99% and 4.95 dBi, respectively. Three-dimensional (3D) radiation pattern of the proposed antenna is shown in Fig. 10. From Fig. 10, it is found that the peak gain of antenna is found 4.76 dBi. Figure 11 shows gain versus frequency curve, and from which it can be observed that the simulated and measured gain are in close agreement. For the antenna gain measurement, three antenna method has been used. The proposed antenna has been used as recevier antenna and 2–18 GHz horn antenna is used for transmission.

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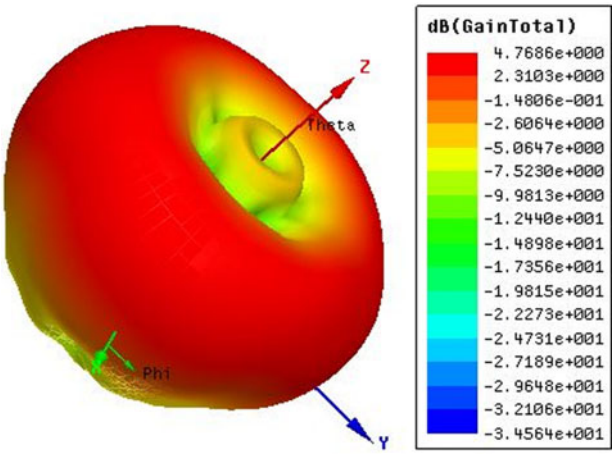


Fig. 10. 3D radiation pattern of proposed four elements TDRA at resonant frequency.

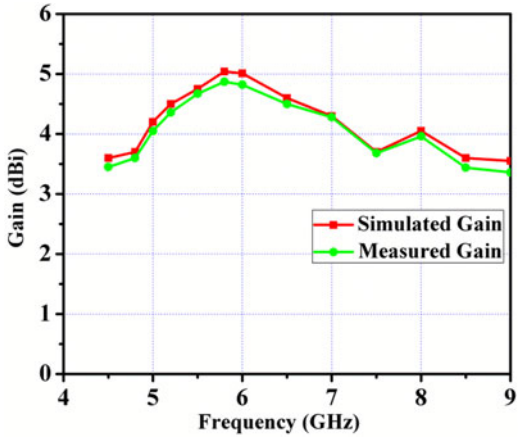


Fig. 11. Gain versus frequency curve of proposed four elements TDRA.

CONCLUSION

A wideband four element TDRA has been designed and fabricated. The simulation of the proposed antenna has been performed using Ansoft HFSS and CST Microwave Studio software. Measured results are in good agreement with simulated one. The proposed antenna has also been compared with single element TDRA and found enhancement in bandwidth. From the study it is inferred that the bandwidth of the proposed antenna has been found nearly 37% and provide a consistently symmetric monopole type of radiation pattern with 4.76 dBi peak gain at resonant frequency. The proposed antenna has been compared with other similar DRA shapes and found superior in performance. The designed antenna has wide application in 5.0 GHz WLAN (IEEE 802.16) and WiMAX band of communication.

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