International Journal of Microwave and Wireless Technologies, 2016, 8(2), 335–340.
doi:10.1017/S1759078715000021

RESEARCH PAPER

A new simple compact ultra-wideband dielectric resonator antenna with enhanced bandwidth and improved radiation pattern

SEYYED HADI SEYYEDHATAMI[1] AND RAMAZAN ALI SADEGHZADEH[2]

A new simple compact ultra-wideband (UWB) dielectric resonator antenna is presented. The antenna consists of a modified stepped microstrip-fed monopole printed antenna loaded with a rectangular dielectric resonator, truncated ground plane, and a parasitic strip underneath the dielectric resonator (DR). Using an optimized truncated ground plane and a combination of stepped feed line with DR an ultra-wide impedance bandwidth of 153% for ($|S_{11}| \leq -10$ dB), covering the frequency range of (3.7–28 GHz) is achieved. The added parasitic strip can improve the radiation pattern, especially at high frequencies. The proposed antenna covers almost the entire UWB (3.1–10.6 GHz), Ku (12.4–18 GHz), and K (18–26.6 GHz) frequency bands. Also this antenna has an omnidirectional and stable radiation pattern over the whole operating frequency range and a compact size of ($15 \times 20 \times 5.8$ mm^3) that make it suitable for wideband wireless system applications. This structure is light weight and can be easily fabricated. A prototype is built and measured. The simulated and measured results are in good agreement.

Keywords: Dielectric resonator antenna, Ultra-wideband antenna, Rectangular dielectric resonator

Received 25 August 2014; Revised 24 November 2014; Accepted 22 December 2014; first published online 26 January 2015

I. INTRODUCTION

Recently, the demand for ultra-wideband (UWB) communication systems has rapidly increased due to their many advantages including the high data rate, high speed, low cost, high accuracy in localization systems, or high resolution in radar applications. Hence, in most of the applications it is necessary that these systems have a wideband antenna with low profile, omnidirectional and stable radiation pattern, constant gain, and constant group delay. The dielectric resonator antenna (DRA) has been recently proposed to be one of the attractive candidate antennas for UWB applications due to striking characteristics, such as high radiation efficiency, light weight, small size, different feeding mechanisms, wide bandwidth, absence of ohmic losses, and no excitation of surface waves. In the last two decades many techniques have been reported to broaden the impedance bandwidth of DRAs, such as stacked DRs [1–3], special feeding mechanisms [4, 5], and conformal patch feeding [6, 7]. Although these techniques have enhanced the DRA's bandwidth, however, most of these antennas have a large size and common deficiencies, such as asymmetric and unstable radiation pattern and complicated structure.

[1]Department of Electrical Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran
[2]Faculty of Electrical and Computer Engineering, K. N. Toosi University of Technology, Tehran, Iran
Corresponding author:
S. H. Seyyedhatami
Email: h.seyyedhatami@srbiau.ac.ir

In this article, a new compact UWB DRA with enhanced bandwidth and improved radiation pattern is proposed. The proposed antenna covers UWB frequency band, and entire Ku and K-band (12.4–26.5 GHz). Lately this frequency range receives some particular research interest due to the development of high frequency communication systems. Using the combination of a stepped monopole antenna with truncated ground plane and a rectangular dielectric resonator (DR) with proper position respect to the feeding structure, the considerable electromagnetic coupling between the feeding patch and DR can be obtained. As a result the proposed DRA can provide an ultra-wide impendence bandwidth with symmetrical and stable radiation patterns. The rectangular dielectric resonator (RDR) is chosen because it provides some more advantages compared to cylindrical and hemispherical ones. The three dimensions of a RDR provide one degree of freedom more than cylindrical dielectric resonator, which can be used to control the impedance bandwidth of the antenna [8]. Moreover, a RDR gives more flexibility to the manufacturer making it more versatile in achieving a wide impedance bandwidth. In order to improve the radiation pattern at high frequencies, a parasitic strip underneath the DR is utilized. This strip eliminates some of the higher order modes that would cause a consistent omnidirectional pattern in *H*-plane across the whole operating frequency band (3.7–28 GHz). This DRA is simulated using a High Frequency Structure Simulator (HFSS) [9]. Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for UWB applications.

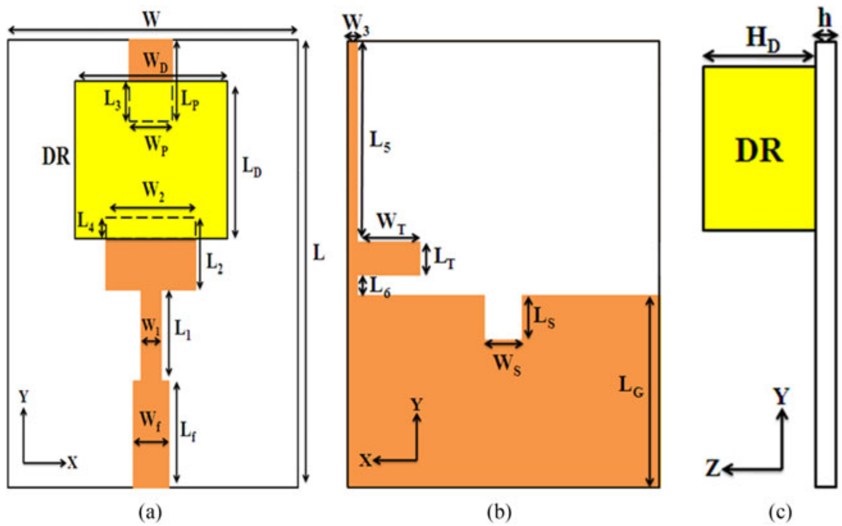

Fig. 1. Configuration of the proposed DRA (a) top view, (b) bottom view, and (c) side view.

II. ANTENNA DESGIN

Figure 1 shows the configuration of the proposed antenna, which consists of a RDR and a stepped microstrip-fed monopole antenna printed on an FR4 microwave substrate with size of 15×20 mm^2, thickness of 0.8 mm, and dielectric constant of 4.4.

In theory, a DRA with a dielectric constant of one for the DR would have the lowest *Q*-factor and therefore the widest bandwidth. In practice, however, there is a lower limit on the value of the dielectric constant required to contain the fields within the DRA in order to resonate. As a result, a relative permittivity around 10, which is normally used in related designs, is chosen for our DRA design [8]. The size of the DR has 7.5 mm length, 6 mm width, and 5 mm thickness, which is fabricated on Rogers RT/Duroid 6010 microwave dielectric material with a dielectric constant of 10.2. The feeding structure comprised of a 50 Ω microstrip transformer with $W_f =$ 1.6 mm width and $L_f =$ 5.3 mm length and a stepped monopole antenna with lengths of $L_1 = 4.3$ mm, $L_2 = 2.5$ mm and widths of $W_1 = 1$ mm, $W_2 = 4.3$ mm. By applying this step-shaped feeding and adjusting its position underneath the DR (L_4), a significant coupling and a good impedance matching can be achieved. The truncated ground plane is printed on the bottom side of the substrate with size of 8.5×15 mm^2.

Figure 2 shows the design procedure of the proposed DRA. Also the simulated reflection coefficients for the various antenna structures shown in Fig. 2 are compared in Fig. 3. The basic monopole antenna structure is shown in Fig. 2(a). From Fig. 3, it can be seen that this monopole has two resonant frequencies and a wide impedance bandwidth from 11 to 22 GHz. In order to increase the bandwidth and shift the lower band toward lower frequencies, the DR is loaded on the monopole structure as shown in Fig. 2(b). The initial dimensions of these structures are chosen in a manner that the resonant modes of the monopole and the DR can be excited with adjacent resonant frequencies to achieve a

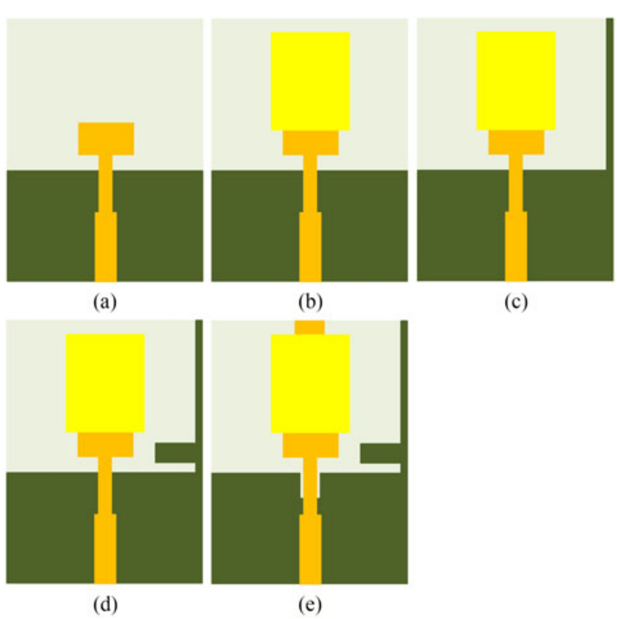

Fig. 2. Design procedure of the proposed DRA; (a) monopole antenna, (b) monopole antenna loaded with the DR, (c) monopole antenna loaded with the DR and the added tuning stub, (d) monopole antenna loaded with the DR and two added tuning stubs, and (e) proposed DRA.

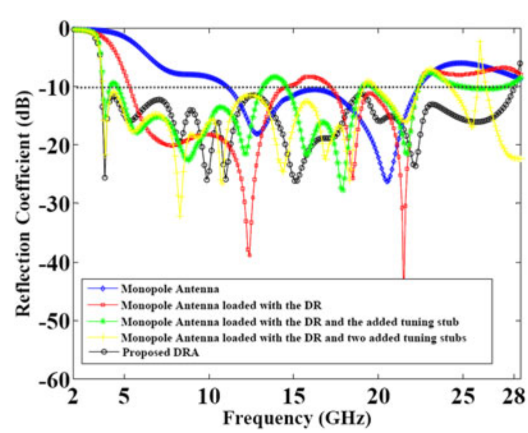

Fig. 3. Simulated reflection coefficients for the various antenna structures shown in Fig. 2.

https://doi.org/10.1017/S1759078715000021 Published online by Cambridge University Press

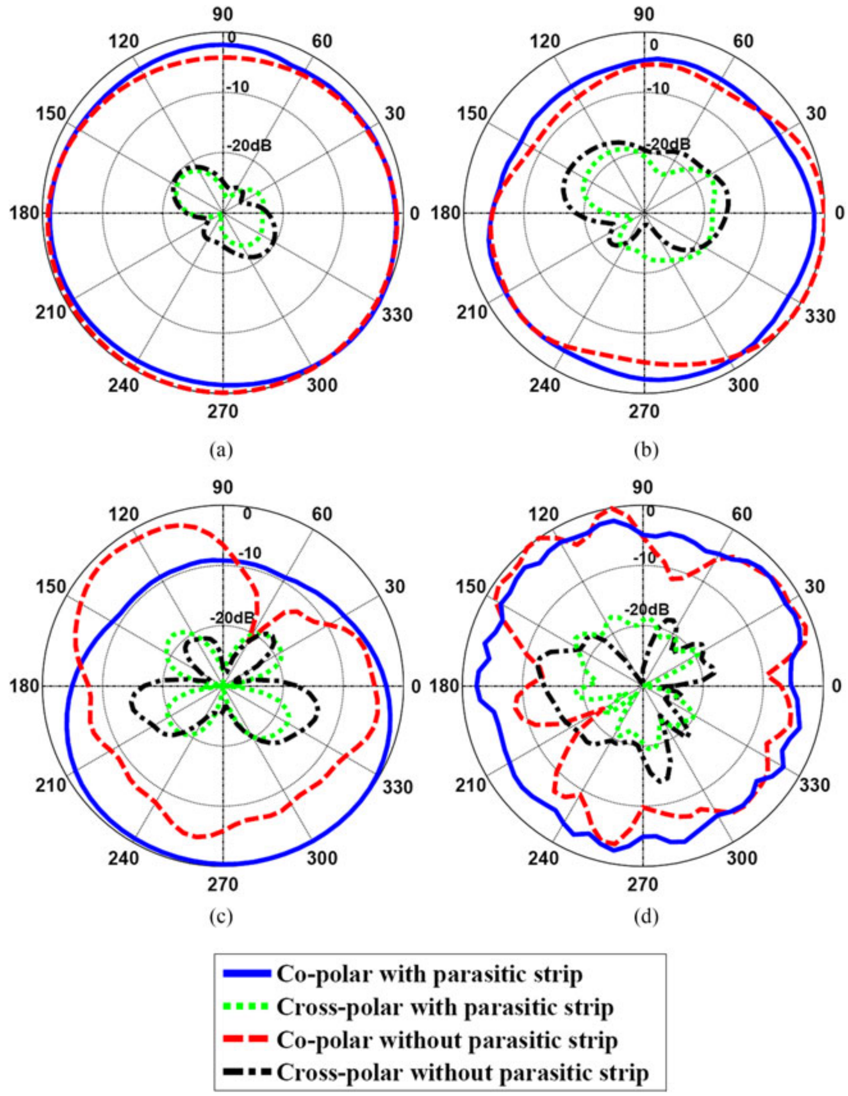

Fig. 4. Simulated *H*-plane radiation patterns of the proposed DRA with and without the parasitic strip at frequencies (a) 8, (b) 11, (c) 16, and (d) 22 GHz.

wideband operation. The dielectric waveguide model [10] can be used to predict the resonant frequencies of the DRA. However, since the truncated ground plane of the monopole feeding structure is different from the conventional ground plane, to further investigate the properties of DRA, simulations and optimization of the structures are performed using HFSS software. As illustrated in Fig. 3, the monopole antenna loaded with the DR, achieves better impedance

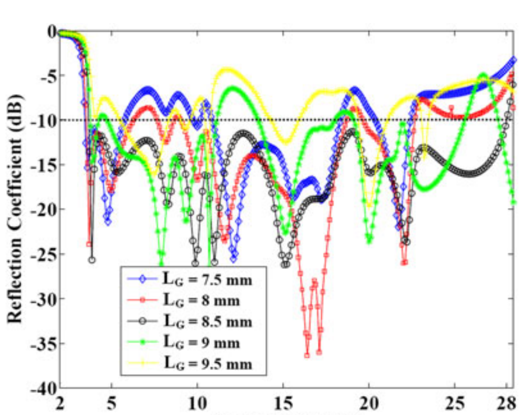

Fig. 5. Simulated reflection coefficient for various length of L_G.

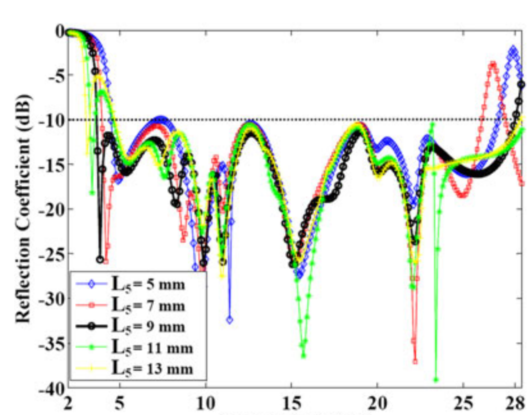

Fig. 6. Simulated reflection coefficient for various length of L_5.

https://doi.org/10.1017/S1759078715000021 Published online by Cambridge University Press

matching than the basic monopole antenna structure. However, there are some mismatches at the low frequency band (less than 5 GHz), the middle frequency band (around 16 GHz), and the high frequency band (more than 22 GHz). As shown in Fig. 2(c), in order to obtain a better impedance matching at the low frequency band, a tuning stub is added to the truncated ground plane [11]. As it is observed from Fig. 3, although the added tuning stub can improve the impedance matching, however, there is still a little mismatch at the low frequency band and the frequency band around 14 GHz. Therefore, to further improve these mismatches, an another tuning stub is added to the modified truncated ground plane, as shown in Fig. 2(d). It can be seen from Fig. 3 that the monopole antenna loaded with the DR and two added tuning stubs can achieve better impedance matching than the previous structures, but there are still some mismatches at the high frequency bands. Thus, to improve these mismatches, a rectangular slot is etched on the modified truncated ground plane below the feed line, as illustrated in Fig. 2(e). It is clearly observed from Fig. 3 that the proposed DRA with the etched slot on the ground plane can achieve a wide impedance matching, even at the high frequency bands, because the rectangular slot creates a capacitive load that neutralizes the inductive nature of the feeding patch, especially at high frequency bands.

It can be seen in Fig. 2(e) that a parasitic strip is added underneath the DR. This strip can eliminate some of the higher order modes and change the field distribution inside the DR, to achieve a stable omnidirectional radiation pattern in *H*-plane, especially at high frequency bands. As shown in Fig. 4, the simulated *H*-plane radiation patterns do not change significantly with and without the parasitic strip at 8 and 11 GHz. However, it is observed that the parasitic strip can improve the radiation patterns and achieve the almost omnidirectional patterns at 16 and 22 GHz.

Design, simulation, and optimization of the proposed DRA are carried out using HFSS, leading to the following optimal dimensions: $L = 20$ mm, $W = 15$ mm, $L_f = 5.3$ mm, $W_f = 1.6$ mm, $L_1 = 4.3$ mm, $W_1 = 1$ mm, $L_2 = 2.5$ mm, $L_D = 7.5$ mm, $W_D = 6$ mm, $H_D = 5$ mm, $L_P = 3$ mm, $W_P = 2$ mm, $L_3 = 2$ mm, $L_4 = 0.6$ mm, $L_T = 1.5$ mm, $W_T = 3$ mm, $L_S = 1.9$ mm, $W_S = 1.4$ mm, $L_G = 8.5$ mm, $W_3 = 0.5$ mm, and $h = 0.8$ mm.

In order to further investigate the characteristics of the proposed DRA and achieve the optimum antenna performance, a parametric study was carried out. The Ansoft HFSS software, which is based on the finite element method, is used for the parametric analysis of reflection coefficient. The key parameters of the proposed antenna are studied by changing one parameter at a time and fixing the others. The radiation pattern is almost unchanged for the various parameters.

Figure 5 shows the effect of the truncated ground plane length (L_G) on the reflection coefficient of the proposed DRA. It can be seen that the best matching and impedance bandwidth is achieved at $L_G = 8.5$ mm. The effect of the first tuning stub length (L_5) is shown in Fig. 6. It is observed that the impedance matching is degraded by increasing the length of L_5, at the low frequency band. Therefore, the optimized value of L_5 is equal to 9 mm. Another parametric study is done on various values of L_6, which it indicates the distance between the second tuning stub and the truncated ground plane, as shown in Fig. 7. It is observed that the impedance matching is degraded by increasing the length of L_6, at

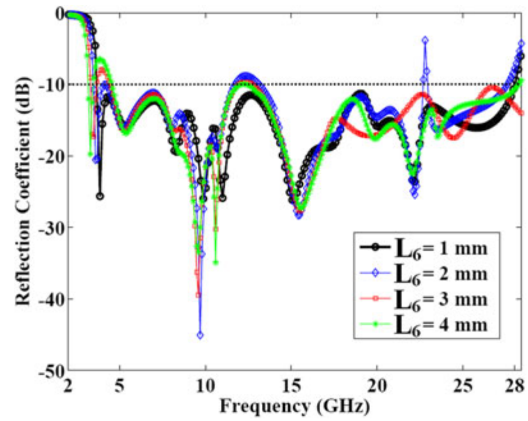

Fig. 7. Simulated reflection coefficient for various length of L_6.

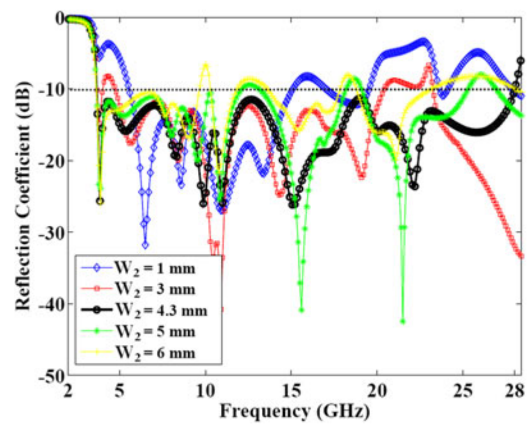

Fig. 8. Simulated reflection coefficient for various length of W_2.

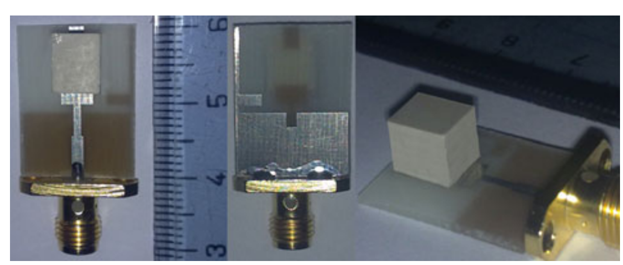

Fig. 9. Photograph of the fabricated DRA.

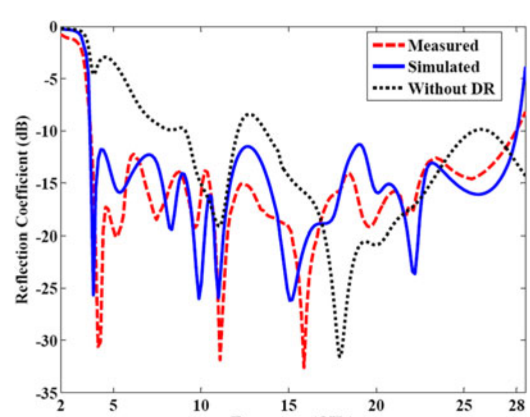

Fig. 10. Measured and simulated reflection coefficients of the proposed DRA.

https://doi.org/10.1017/S1759078715000021 Published online by Cambridge University Press

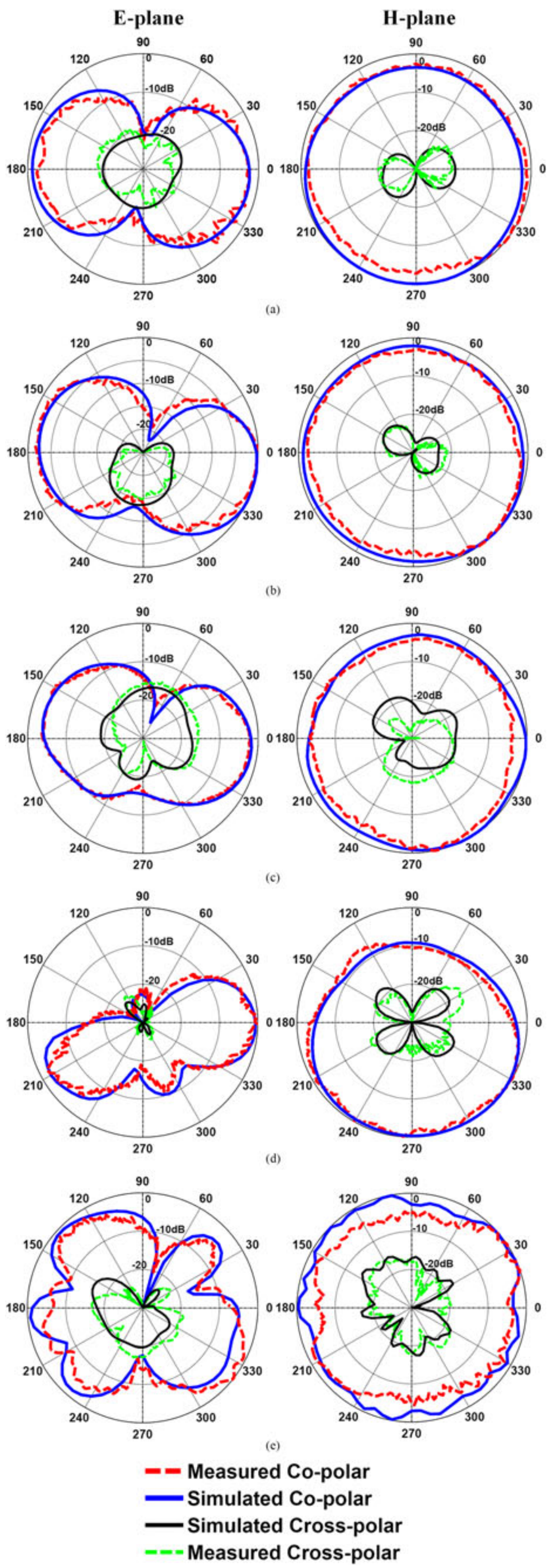

Fig. 11. Measured and simulated radiation patterns at frequencies (a) 4, (b) 8, (c) 11, (d) 16, and (e) 22 GHz.

the low frequency band. So the best impedance matching is achieved at $L_6 = 1$ mm. Figure 8 shows the effect of the W_2 parameter. It can be seen that for the lower value of W_2, the impedance matching is poor, because of the weak coupling between the feeding structure and the DR. On the other hand, for the higher value, there are some mismatches. Therefore, the best impedance matching is achieved at $W_2 = 4.3$ mm.

III. RESULTS AND DISCUSSION

To validate the proposed design, an optimized DRA was fabricated and measured, which is shown in Fig. 9. The optimized DRA parameters are as follows: $L = 20$ mm, $W = 15$ mm, $L_f = 5.3$ mm, $W_f = 1.6$ mm, $L_1 = 4.3$ mm, $W_1 = 1$ mm, $L_2 = 2.5$ mm, $W_2 = 4.3$ mm, $L_D = 7.5$ mm, $W_D = 6$ mm, $H_D = 5$ mm, $L_P = 3$ mm, $W_P = 2$ mm, $L_3 = 2$ mm, $L_4 = 0.6$ mm, $L_T = 1.5$ mm, $W_T = 3$ mm, $L_S = 1.9$ mm, $W_S = 1.4$ mm, $L_G = 8.5$ mm, $L_5 = 9$ mm, $W_3 = 0.5$ mm, $L_6 = 1$ mm, and $h = 0.8$ mm. The impedance bandwidth was measured using an Agilent 8722ES vector network analyzer. Figure 10 shows the measured and simulated reflection coefficients of the proposed antenna. A good agreement between the simulated and measured results is observed. The measured impedance bandwidth covers the frequency range (3.7–28 GHz), which is equivalent to 153% for ($|S_{11}| \leq -10$ dB). The discrepancy between the simulated and measured results can be due to the tolerance in manufacturing, imperfect soldering effect of the SMA connector, and also the accuracy of the simulation due to the wide range of simulation frequencies. Moreover, the simulated reflection coefficient of the proposed antenna without the DR is also shown in Fig. 10. It is observed from these results, when the antenna is with the DR a better impedance matching due to the loading effect, with some excited resonant modes in the DR can be achieved. As a result, an ultra-wide bandwidth is obtained using a DR.

The proposed DRA is also measured in far field anechoic chamber. Figure 11 shows the measured and simulated radiation patterns in the $H(xz)$-plane and $E(yz)$-plane at five different frequencies (4, 8, 11, 16, and 22 GHz). In the H-plane, it can be seen that the radiation patterns are almost symmetrical and stably omnidirectional across the operating frequency range. However, the radiation patterns in the E-plane are not as symmetrical as in the H-plane and

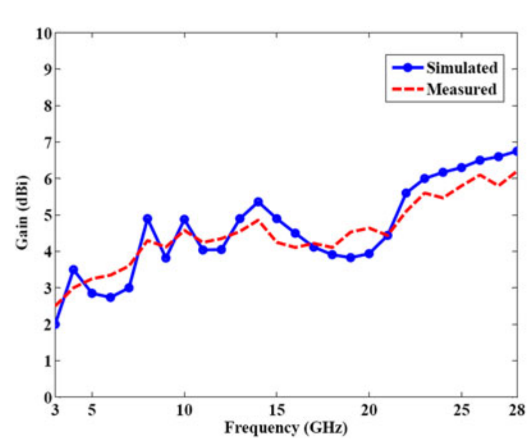

Fig. 12. Measured and simulated peak gain of the proposed DRA.

https://doi.org/10.1017/S1759078715000021 Published online by Cambridge University Press

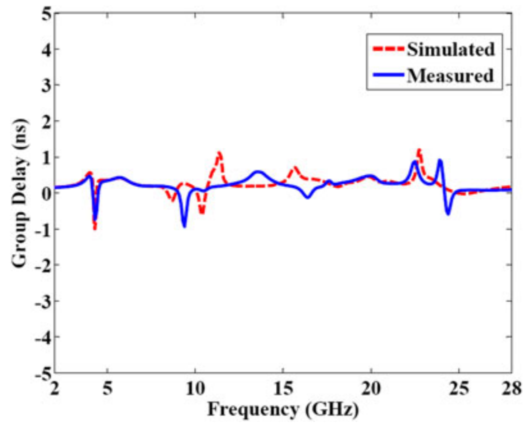

Fig. 13. Measured and simulated group delay of the proposed DRA.

have some deformations at higher frequencies due to the effects of higher order modes. Figure 12 plots the measured and simulated peak gain of the proposed antenna. It is seen that the peak gain is almost stable in the entire operating frequency range.

Group delay is an important parameter in UWB antenna design because it represents the degree of distortion of the transmitted pulses in the UWB communication. The group delay should be almost constant for a good pulse transmission. The measured and simulated group delay of the proposed antenna is shown in Fig. 13. As it can be seen, the group delay variation is less than 2 ns in the whole frequency band. This confirms that the proposed DRA is suitable for UWB communication.

IV. CONCLUSION

A new simple compact UWB DRA with enhanced bandwidth and improved radiation pattern has been proposed. Using a stepped monopole antenna loaded with a RDR and an optimized truncated ground plane, an UWB DRA with increased bandwidth is achieved and the parasitic strip is added underneath the DR to improve the radiation pattern at high frequencies. The measured results demonstrate that the proposed DRA achieves an ultra-wide impedance bandwidth about 153%, covering the frequency range of (3.7–28 GHz). Also this antenna provides almost stable omnidirectional radiation patterns, stable gain, and nearly constant group delay over the entire operating frequency range. In addition to the above characteristics this DRA has a simple structure, compact size, and easy fabrication that make it a good candidate for UWB applications and systems.

REFERENCES

[1] Shum, S.M.; Luk, K.M.: Stacked annular-ring dielectric resonator antenna excited by axi-symmetric coaxial probe. IEEE Trans. Antennas Propag., **43** (1995), 889–892.

[2] Wlash, A.G.; Young, S.D.; Long, S.A.: An investigation of stacked and embedded cylindrical dielectric resonator antenna. IEEE Antennas Wirel. Propag. Lett., **5** (2006), 130–133.

[3] Denidni, T.A.; Rao, Q.J.; Sebak, A.R.: Broadband L-shaped dielectric resonator antenna. IEEE Antennas Wirel. Propag. Lett., **4** (2005), 453–454.

[4] Chang, W.; Feng, Z.: Investigation of a novel wideband feeding technique for dielectric ring resonator antennas. IEEE Antennas Wirel. Propag. Lett., **8** (2009), 348–351.

[5] Denidni, T.; Weng, Z.: Hybrid ultra-wideband dielectric resonator antenna and band-notched designs. IET Microw. Antennas Propag., **5** (2011), 450–458.

[6] Zhang, L.N.; Zhong, S.S.; Liang, X.L.: Wideband U-shaped dielectric resonator antenna fed by triangle patch. Microw. Opt. Technol. Lett., **52** (2010), 2435–2438.

[7] Gao, Y.; Feng, Z.; Zhang, L.: Compact asymmetrical T-shaped dielectric resonator antenna for broadband applications. IEEE Trans. Antennas Propag., **60** (2012), 1611–1615.

[8] Luk, K.M.; Leung, K.W.: Dielectric Resonator Antennas, Research Studies Press, Hertfordshire, 2003.

[9] Ansoft Corporation: Ansoft High Frequency Structure Simulation (HFSS), Version 11, Ansoft Corporation, Pittsburg, PA, 2007.

[10] Mongia, R.K.; Ittipiboon, A.: Theoretical and experimental investigations on rectangular dielectric resonator antennas. IEEE Trans. Antennas Propag., **45** (1997), 1348–1356.

[11] Ahmed, O.M.H.; Sebak, A.R.; Denidni, T.A.: Compact UWB printed monopole loaded with dielectric resonator antenna. Electron. Lett., **47** (2011), 7–8.

Seyyed Hadi Seyyedhatami was born in Ardabil, Iran in 1986. He received his B.Sc. degree from Iran University of Science and Technology (IUST), Tehran, in 2008 and M.Sc. degree from Tabriz University, Tabriz, in 2010, both in Communication Engineering. He is currently working toward Ph.D. degree at Science and Research Branch, Islamic Azad University, Tehran. His research interests include microstrip antenna, dielectric resonator antenna, microwave passive components, and RF circuit design.

Ramazan Ali Sadeghzadeh received his B.Sc. degree in Telecommunication Engineering from K.N. Toosi University of Technology, Tehran, Iran, in 1984, and M.Sc. degree in Digital Communication Engineering from the University of Bradford, Bradford, UK, and the University of Manchester Institute of Science and Technology (UMIST), Manchester, UK, as a joint program in 1987, and Ph.D. degree in Electromagnetic and Antenna from the University of Bradford in 1991. From 1992 to 1997, he worked as a Postdoctoral Research Assistant in the field of propagation, electromagnetic, antenna, biomedical, and wireless communication with the University of Bradford. From 1984 to 1985, he was with Iran Telecommunication Company, Tehran, Iran, working on networking. Since 1997, he has been with the Faculty of Electrical and Computer Engineering, K. N. Toosi University of Technology. He has published more than 60 referable papers in international journals and conferences. His research interests include numerical techniques in electromagnetics, antenna, propagation, radio networks, wireless communications, nano antennas, and radar systems.