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SIZE REDUCTION AND BANDWIDTH ENHANCEMENT OF A UWB HYBRID DIELECTRIC RESONATOR ANTENNA FOR SHORT-RANGE WIRELESS COMMUNICATIONS

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Abstract—In this paper, a novel hybrid dielectric resonator (DR) antenna for Ultrawideband (UWB) short-range wireless communications is proposed. The proposed antenna consists of a microstrip fed monopole loaded with a half cylindrical dielectric resonator antenna of Rogers RO3010 mounted on RT5880 substrate with a finite ground plane. The microstrip line fed monopole antenna is on the other side of the substrate. Compared to the conventional circular cylindrical DR mounted on a finite ground plane (reference antenna), the proposed antenna has a reduction in the antenna size by about 30% with a bandwidth increase by about 22% than the reference antenna. The proposed antenna has a good impedance bandwidth. In addition, the proposed antenna has a quite higher and more stable gain than that of reference antenna. Moreover, the antenna has a good omni-directional radiation patterns in the H-plane. The proposed antenna is considered a good candidate for UWB short-range wireless communication systems.

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1. INTRODUCTION

Since the US Federal Communications Commission (FCC) announced using the frequency band 3.1–10.6 GHz for UWB radio applications in 2002, ultrawideband (UWB) technology is considered as an attractive and promising technology for high-speed and short-range indoor wireless communications [1]. Recently, a remarkable interest in UWB system design and implementation has been shown in both academic research and industrial applications. An important part of the UWB system, the antenna, has received great attention and significant research to meet the antenna design requirements for UWB applications, such as compact size along with wide bandwidth performance. One possible solution for achieving both size reduction and bandwidth enhancement is the dielectric resonator antenna (DRA). The DRAs have shown high radiation efficiency and low dissipation loss as well as have a small size, light weight, and low profile, which are considered unique characteristics rather than conventional metallic antennas [2–12]. Moreover, DRAs are considered good candidates for high efficiency, wideband, and cost-effective applications because they offer more design flexibility than the conventional antennas.

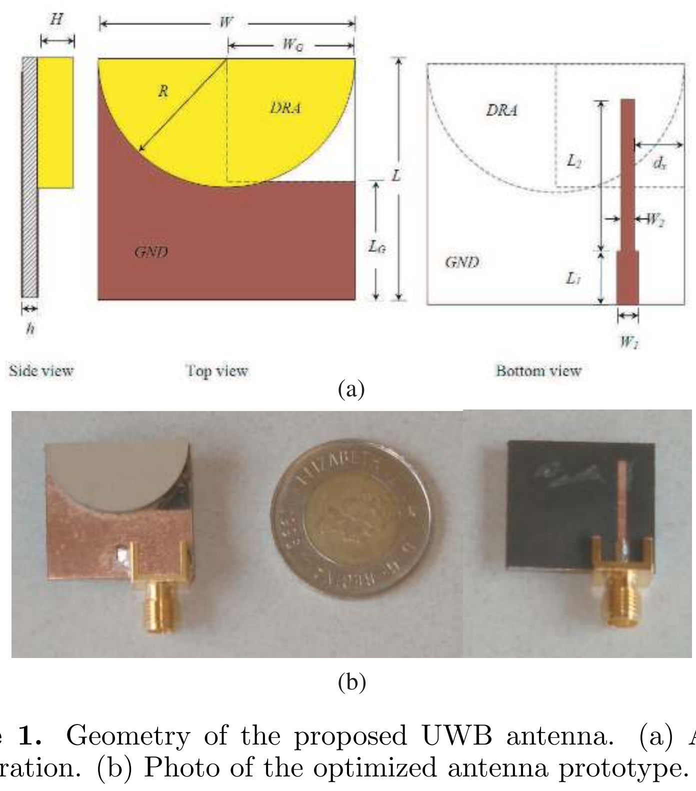
This paper presents the design of a novel and compact DR antenna for UWB short-range wireless communications. The proposed antenna is a hybrid antenna consisting of a microstrip fed monopole loaded with a half cylindrical dielectric resonator antenna of Rogers RO3010 mounted on a Rogers RT5880 substrate with a finite ground plane. The microstrip line fed monopole antenna is on the other side of the substrate. Details of the proposed antenna are described and studied. An extensive parametric study was then carried out to investigate the effect of different design parameters on the antenna performance. The numerical results show that the radiation patterns of the proposed antenna are quite stable with frequency. The proposed antenna has E-plane broadside radiation patterns, while the H-plane radiation patterns are almost omni-directional patterns. In addition, the proposed antenna exhibits stable gain across the whole operating frequency band.

2. ANTENNA DESCRIPTION AND PARAMETRIC OPTIMIZATION

The reference antenna used to design the proposed antenna is the conventional circular cylindrical DR made of Rogers RO3010 (relative permittivity $\varepsilon_r = 10.2$) with radius R and thickness H mounted on RT5880 substrate (thickness $h = 0.787$ mm, relative permittivity $\varepsilon_r = 2.2$ and loss tangent $\tan\delta = 0.0009$) with a finite ground plane as in Figure 1(a). The microstrip line fed monopole which installed in the lower side of the substrate consists of a $50\,\Omega$ transformer with width W_1 and length L_1 and a microstrip line monopole of width W_2 and length L_2. It is located at distance dx from the substrate edge. The ground plane and microstrip line together act as a monopole antenna. Further, the antenna bandwidth was increased by loading the monopole antenna with dielectric resonator antenna. It has been shown from the full-wave electromagnetic (EM) simulations that the DR has some modes which could be excited by the monopole.

Table 1. Optimized parameters dimensions for the proposed antenna (Units: mm).

W	L	R	H	W_1	L_1	W_2	L_2	W_G	L_G	dx	h
24	22.5	12	2.54	2.0	5.0	1.24	14.2	12	11	4.76	0.787



(a)

(b)

Figure 1. Geometry of the proposed UWB antenna. (a) Antenna configuration. (b) Photo of the optimized antenna prototype.

The optimized antenna parameters are introduced in Table 1. The antenna geometry and the photo of the fabricated antenna prototype are shown in Figures 1(a) & (b), respectively. The designed antenna is simulated and optimized using two commercial electromagnetic simulators: Ansoft HFSS [13], which utilizes Finite Element Method (FEM) in frequency domain, and CST Microwave Studio [14] that is based on Finite Integration Technique (FIT) in time domain. Figure 2 shows the evolution of the proposed DRA to achieve size reduction from the conventional one.

The proposed antenna has a size reduction of about 30% than the antenna in Figure 2(a) with a reduction in the operating bandwidth by 8% than the conventional antenna. The proposed antenna has a size of $24 \times 20.5\,\mathrm{mm}^2$ ($0.25\lambda \times 0.21\lambda$ at UWB lower frequency $f = 3.1\,\mathrm{GHz}$). To overcome the reduction in the operating bandwidth due to reducing the antenna size, Figure 3 presents the antenna impedance bandwidth enhancement by loading the monopole antenna having a slot in the truncated ground plane of the microstrip substrate of width W_G with dielectric resonator antenna.

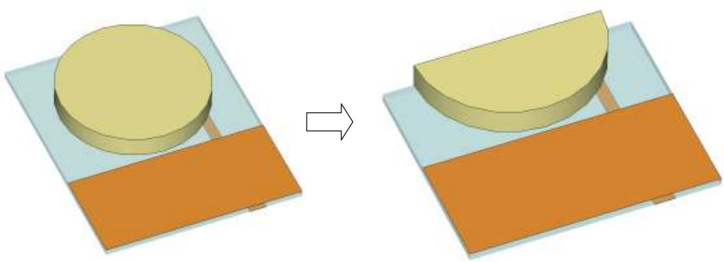

(a) (b)

Figure 2. Evolution of the proposed antenna, step 1: size reduction.

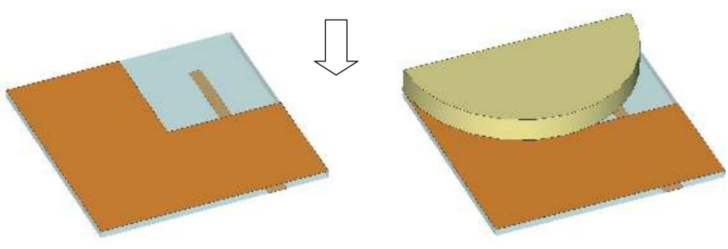

(a) (b)

Figure 3. Evolution of the proposed antenna, step 2: bandwidth enhancement.

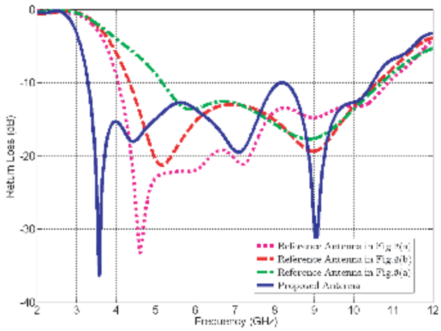
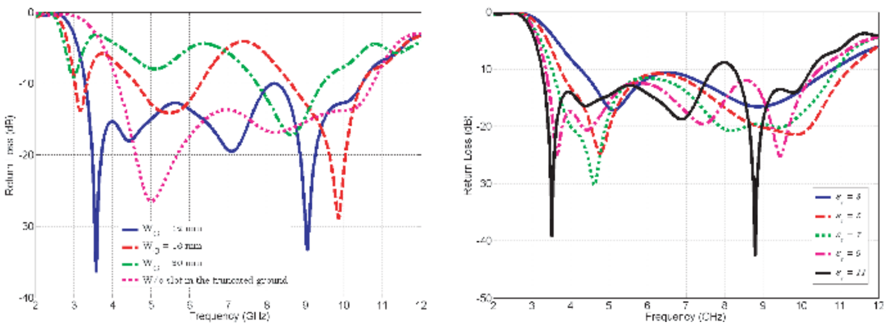


Figure 4. Return loss curves versus frequency for the proposed antenna. Reference antennas curves are shown for comparison.

Figure 4 presents the return loss curves versus frequency for the proposed antenna and the reference antennas in Figures 2(a) & (b) and Figure 3(a). It can be seen that by reducing the antenna size by 30% (from $24 \times 29.5\,\text{mm}^2$ to $24 \times 20.5\,\text{mm}^2$); the bandwidth is slightly decreased by about 8% (from 6.8 GHz to 6.25 GHz). When a slot in the truncated ground plane is used as in Figure 3(b), the bandwidth is increased by 22% (from 6.25 GHz to 7.61 GHz). The effect of using the DR on the antenna performance is shown also for comparison. It can be seen that removing the DR will reduced the bandwidth simply because the modes of the DRA are not excited by the monopole and the slot. The resonant frequencies of the DR can be extracted from Figure 4. Figure 4 shows the return loss versus frequency for the proposed antenna with and without DR. It can be noticed that the effect of using DR appears in adding two more resonances in the low frequency band, i.e., 3.57 GHz and 4.43 GHz to the existing monopole resonances, i.e., 7.1 GHz and 9.05 GHz.

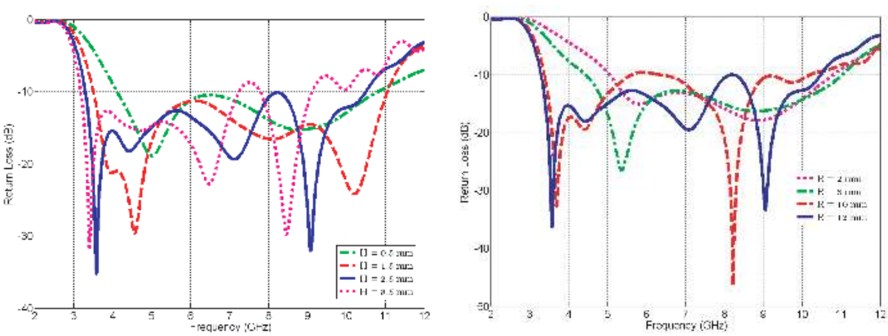
An extensive parametric study was carried out to investigate the effect of different design parameters on the antenna performance. A parametric study in Figure 5(a) shows how the slot in the truncated ground plane of the microstrip substrate width W_G strongly affects the antenna operating bandwidth. It has been found that the optimized value for the slot width in the truncated ground plane to achieve the maximum available bandwidth is $W_G = 12\,\text{mm}$. Also, the effect of varying the relative permittivity of the DR on the antenna performance has been studied and presented in Figure 5(b). The DR with relative permittivity of 10.2 gives the wider bandwidth which covers the whole UWB frequency band. For further understanding the effect of antenna parameters on its performance, parametric studies have been numerically calculated for DR height H and radius R as shown in Figures 6(a) & (b), respectively. It can be noticed that the return loss curves shift towards the lower frequency when the DR height H increases. To achieve the maximum available bandwidth, the optimum value for the DR height H should be 2.54 mm.

Figure 6(b) shows that the DR radius R is a very critical parameter on the antenna impedance bandwidth. By increasing the DR radius R, the antenna bandwidth increases as well especially at lower frequency band. It can be seen that the optimized value for the DR radius is $R = 12$ mm. Figures 7(a) & (b) present the return loss curves versus frequency for different values of monopole length L_2 for $L_1 =$



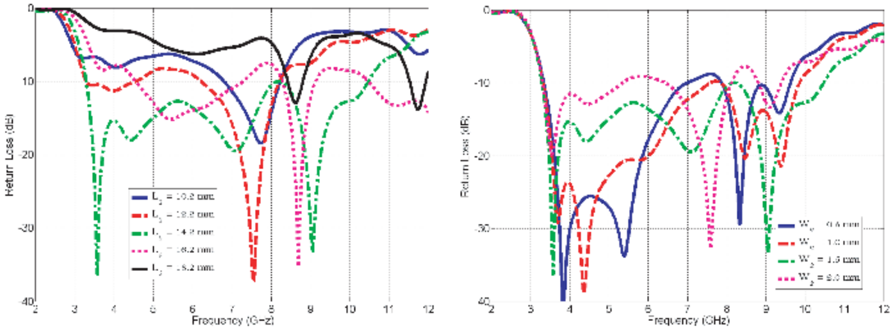
(a) (b)

Figure 5. Return loss curves for different values of (a) slot in the truncated ground plane width W_G, (b) relative permittivity of the DR ε_r.



(a) (b)

Figure 6. Return loss curves for different values of DR, (a) height H, (b) radius R.



(a) (b)

Figure 7. Return loss curves for different values of (a) monopole length L_2 for $L_1 = 5.0\,\mathrm{mm}$, (b) monopole width W_2 for $W_1 = 2.0\,\mathrm{mm}$.

5.0 mm and monopole width W_2 for $W_1 = 2.0\,\mathrm{mm}$, respectively. The length of the monopole L_2 is strongly affects the antenna return loss curve. Also, the monopole width W_2 significantly affects the antenna performance. The optimum values for L_2 and W_2 are 14.2 mm and 1.24 mm, respectively.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

The measured and calculated return loss curves of the proposed antenna are shown in Figure 8. The antenna yields a calculated impedance bandwidth of about 105% (3.2–10.4 GHz) almost covering the whole UWB frequency bandwidth while the measured impedance bandwidth is about 117% (3.3–12.7 GHz) for $S_{11} < -8.5\,\mathrm{dB}$ (VSWR $< 2:1$) or multi-band for return loss $S_{11} < -10\,\mathrm{dB}$ (VSWR $< 2.2:1$). This disagreement with the calculated results may be due to fabrication tolerance or misalignment of the DR when it is mounted on the substrate. The antenna input impedance (both real and imaginary parts) is calculated and presented in Figure 9. Also, the antenna phase linearity as a function of frequency has been studied numerically and experimentally. The results of the antenna group delay are shown in Figure 10 with maximum measured group delay of about 6 ns.

The maximum gain in the boresight direction and the total efficiency of the antenna are also calculated and presented in Figures 11(a) & (b), respectively. The other curves for reference antennas are also plotted in the same figure for comparison purposes. It can be noticed that the proposed antenna exhibits stable gain across the whole frequency band more than the reference antennas in Figures 1(a) & (b) and Figure 2(a). Also, the total efficiency of the proposed antenna is better than the reference antenna through the frequency band of interest. The radiation patterns of the proposed antenna are calculated at 4, 6 and 8 GHz and plotted in Figure 10. It can be noticed that the proposed antenna has E-plane broadside pattern and nearly omni-directional H-plane patterns. The surface current distributions of the proposed antenna at resonant frequencies are shown in Figure 13. The current distribution confirms that the first two resonances, i.e., 3.5 GHz and 4.4 GHz are for the DR while the other two resonances, i.e., 7.1 GHz and 9.05 GHz are for the microstrip-fed monopole antenna.

It is clear that the proposed antenna works as a monopole antenna loaded by a half cylindrical DRA. It is clear that the designed monopole antenna which is relatively short in length works at 9 GHz. Adding the DRA to the monopole antenna excites new resonances especially at low frequency band.

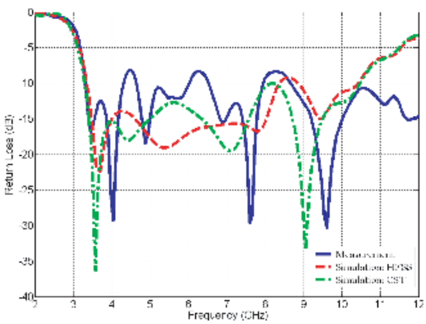


Figure 8. Comparison of simulated and measured return loss curves of the proposed antenna.

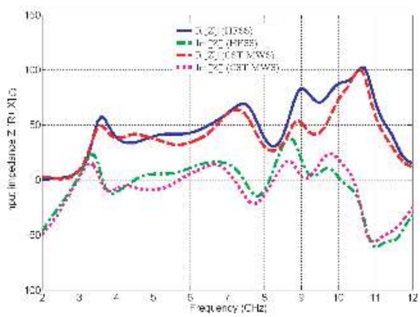


Figure 9. Antenna input impedance $Z_{in} = R_{in} + jX_{in}$.

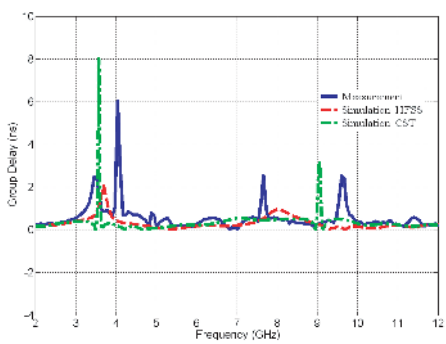
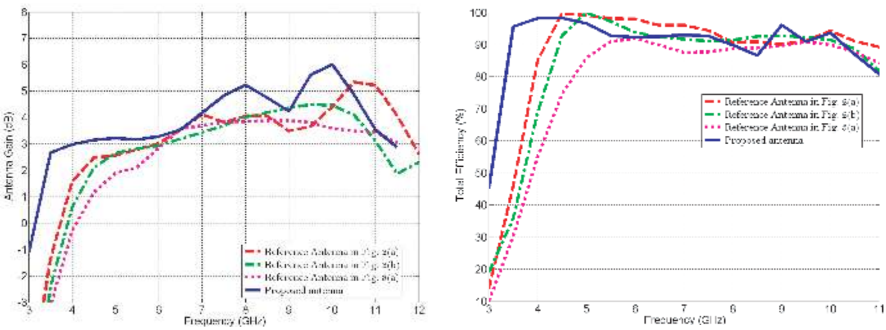
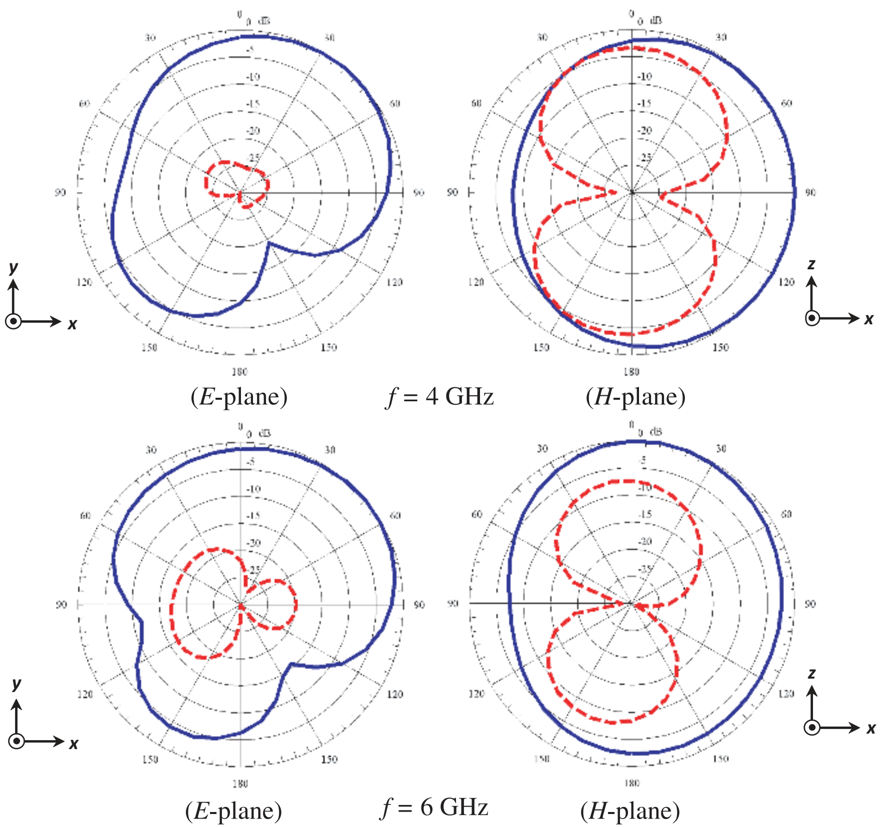


Figure 10. Measured and calculated group delay of the proposed antenna.



(a) (b)

Figure 11. (a) Gain, (b) total efficiency of the proposed antenna. Reference antennas curves are shown for comparison.



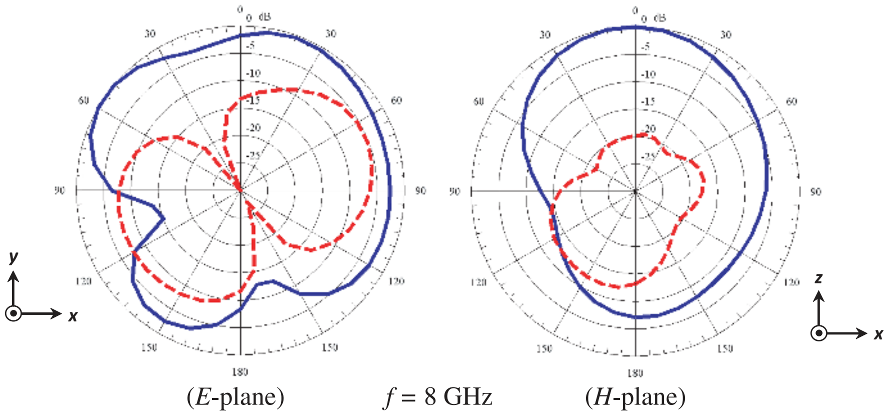


Figure 12. Calculated radiation patterns of the proposed antenna. Solid lines for co-polar and dashed lines for cross-polar.

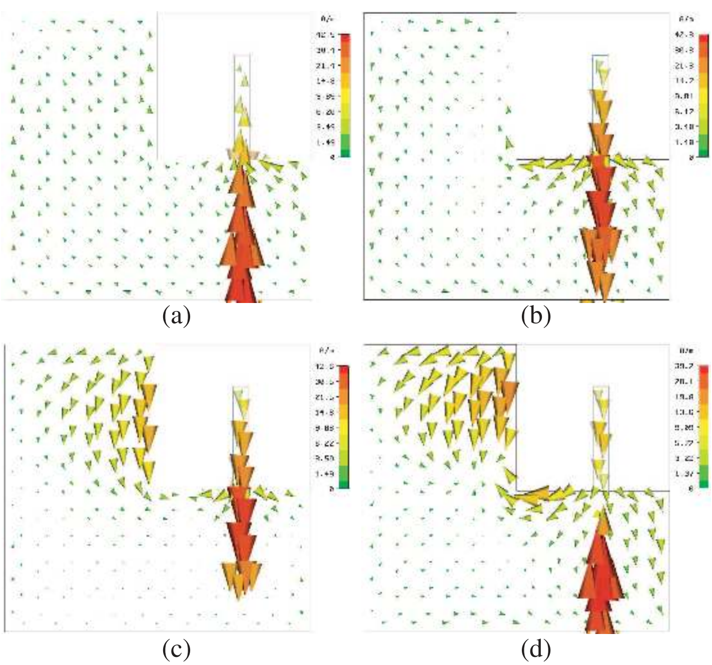


Figure 13. Surface current distribution of the proposed antenna at different frequencies (a) $f = 3.5\,\text{GHz}$ (b) $f = 4.4\,\text{GHz}$ (c) $f = 7.1\,\text{GHz}$ (d) $f = 9.05\,\text{GHz}$.

4. CONCLUSION

In this paper, a novel compact UWB DR antenna for UWB short-range wireless communication systems has been presented. The proposed antenna has a reduction in the antenna size by about 30% with a bandwidth increase by about 22% than the reference antenna. Technique for size reduction and bandwidth enhancement has been presented and discussed in detail. Also, the effect of antenna parameters on the antenna performance is addressed. The proposed antenna prototype has been simulated, fabricated and tested. Both simulated and measured results show that it has a broadband matched impedance band with almost constant gain. It also has a good E- and H-plane radiation patterns through the entire UWB frequency band. From these results, it is confirmed that the proposed antenna is a good candidate for UWB short-range wireless communication applications.

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