

Research Article

Study the Effect of Using Low-Cost Dielectric Lenses with Printed Log-Periodic Dipole Antennas for Millimeter-Wave Applications

Osama M. Haraz,^{1,2} Abdel Razik Sebak,^{1,3} and Saleh Alshebeili^{1,4}

¹KACST Technology Innovation Center in Radiofrequency and Photonics for the e-Society (RFTONICS), King Saud University, Riyadh 11451, Saudi Arabia

²Electrical Engineering Department, Faculty of Engineering, Assiut University, Assiut 71515, Egypt

³Department of Electrical and Computer Engineering, Concordia University, Montreal, QC, Canada H3G 1M8

⁴Electrical Engineering Department, King Saud University, P.O. Box 800, Riyadh 11421, Saudi Arabia

Correspondence should be addressed to Osama M. Haraz; osama_m_h@yahoo.com

Received 1 July 2014; Revised 19 August 2014; Accepted 19 August 2014

Academic Editor: Dau-Chyrh Chang

Copyright © 2015 Osama M. Haraz et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Design of V-band high-gain printed log periodic dipole array (PLPDA) antenna loaded with a low-cost spherical dielectric lens is introduced. The proposed antenna consists of microstrip-line-fed log-periodic dipole antenna designed to operate in the V-band with a peak gain of 12.64 dBi at 60 GHz. To enhance the antenna gain, a dielectric lens is installed. The antenna prototype is fabricated and then tested experimentally using Agilent E8364B PNA Network Analyzer. Experimental results agree well with the simulated ones. The simulated results show that the proposed antenna can work from 42 GHz up to 82 GHz with a fractional impedance bandwidth of 64.5% covering the whole V-band (50–75 GHz). At 60 GHz, the proposed antenna has peak gain of 26.79 dBi with a gain variation of 3.5 dBi across the whole V-band with stable radiation patterns over the operating band. The proposed PLPDA antenna achieves good side-lobe suppression, excellent front-to-back ratio in both *E*- and *H*-planes, and low cross-polarization levels over the entire frequency range. These unique features will make this antenna suitable for different interesting applications such as millimeter-wave radar and imaging applications.

1. Introduction

Recently, the need for wideband and high-gain antennas becomes very essential for modern wireless communication systems to achieve high speed and high data rates with maximum possible coverage. Therefore, antennas having wide bandwidth, high-gain, and stable radiation patterns across the frequency band of interest are highly demanded. Moreover, those candidate antennas should exhibit compact size and low profile with ease of integration with other components on the same printed circuit board (PCB). Printed log-periodic dipole array (PLPDA) antennas are good candidates for wireless communication applications due to their huge bandwidth with good gain stability across the entire frequency range and simple geometrical architecture for ease of fabrication [1].

The design of a suitable feeding network of PLPDA is very crucial in order to have the dipole elements correctly driven with the proper desired magnitude and phase. A PLPDA antenna can be fed by different feeding techniques such as coaxial cable, microstrip line, coplanar waveguide (CPW), conductor-backed coplanar waveguide (CBCPW), and substrate integrated waveguide (SIW). The problem with coaxial cable feeding technique is the possibility of having a severe fabrication error and misalignment problem, which come from soldering coaxial cables at microwave frequencies especially at millimeter-waves frequency bands [2, 3]. Several PLPDA antenna designs fed by coplanar waveguide (CPW) were proposed [4]. It has been reported that the CPW-fed PLPDA antenna designs suffer from the higher losses, serious crosstalk, and the disadvantage of lower power handling capability. Substrate integrated waveguide (SIW) has been

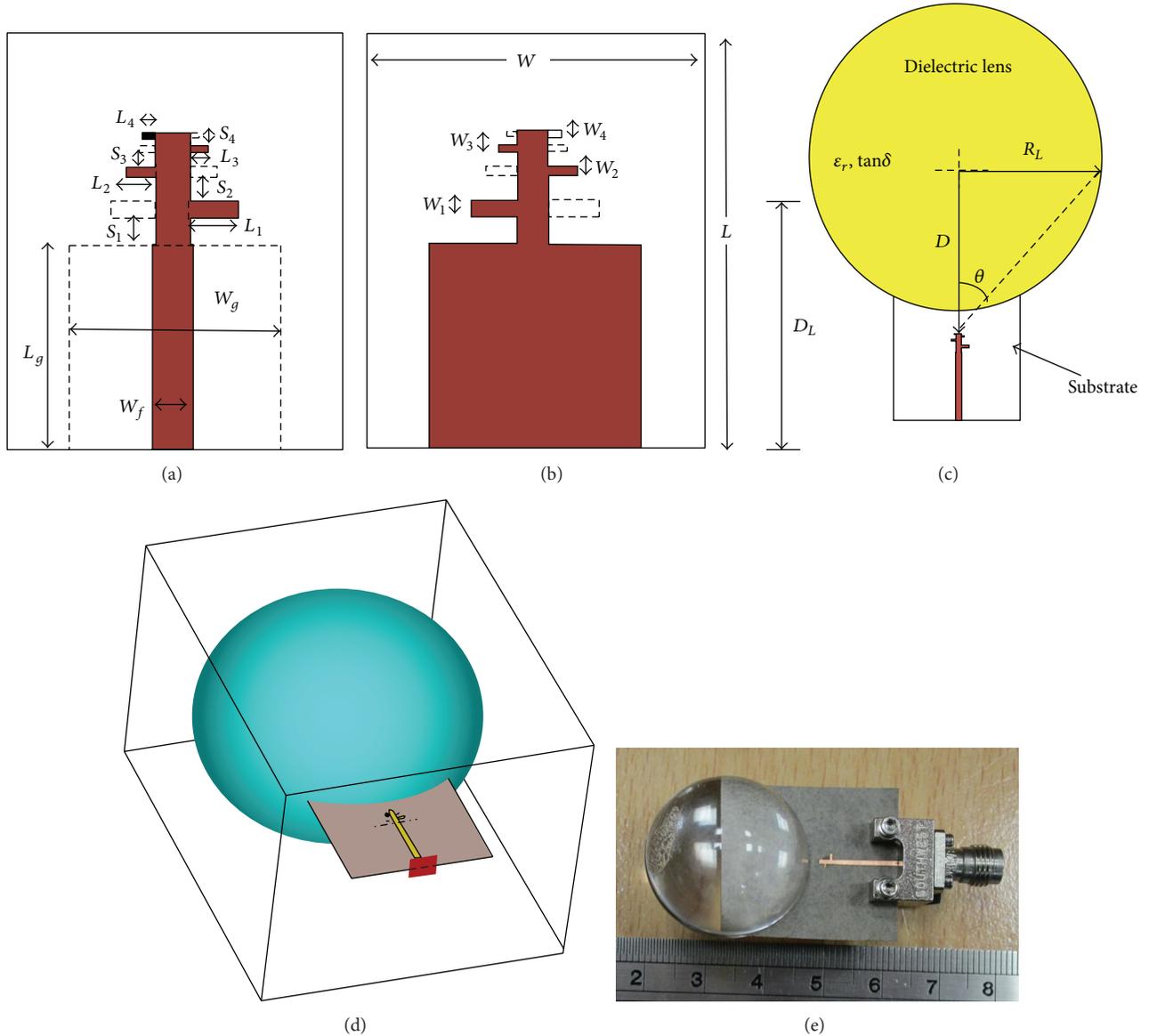


FIGURE 1: Schematic diagram, (a) top view, (b) side view, and (c) 3D view in CST (d) photograph of the fabricated PLPDA antenna prototype with a full spherical dielectric lens.

used as a feeding network for the PLPDA antenna [5–7]. According to the proposed designs, the SIW feeding network has a large size compared to the traditional printed transmission lines such as microstrip, strip lines, and CPW.

Lenses have been used by many researchers in different applications. The most typical spherical lens is Luneburg lens [8]. Because of the difficulty of manufacturing such lens, it is usually replaced by spherical shells. Lenses can be classified into two main categories depending on their applications. Lenses can be used either for shaping the beam or for beam scanning. Lenses of canonical shapes, such as hyperbolic, elliptical, and hemispherical, are used for collimating the radiated energy. Parameters of these canonical lenses can be derived analytically. However, it has been shown that Luneburg lenses do not provide optimal performance in terms of complexity of construction [9].

In this paper, antenna prototype based on printed log-periodic dipole array (PLPDA) antenna at V-band millimeter-wave frequencies has been designed, simulated, and optimized using a full-wave industry-standard simulation software program. In the proposed design, the PLPDA antenna, which is called reference antenna, is designed on a single-layer substrate and fed by a simple microstrip feeding network. It has the advantage of simple structure, compact-size, low-cost, wideband and easy of integration with other circuits on the same PCB. Proposed high-gain antenna consists of the reference antenna loaded with low-cost spherical dielectric lens. In Section 2, the geometrical configuration of the proposed antenna is presented. In Section 3, both simulated and measured results are investigated and discussed. Finally, conclusions are given in Section 4.

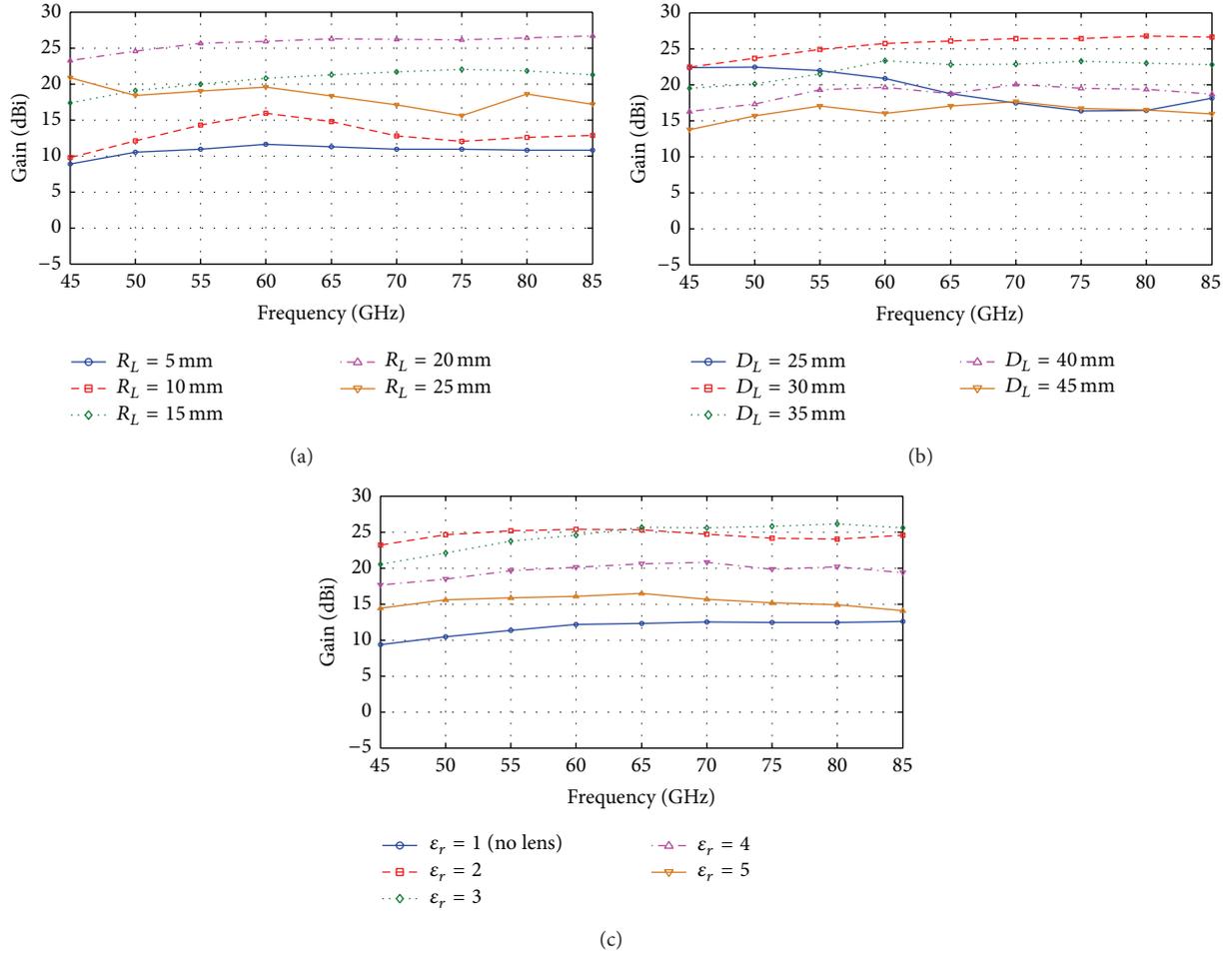


FIGURE 2: Parametric studies to investigate the effect of varying the geometrical parameters of the proposed PLPDA antenna loaded with a full spherical dielectric lens on antenna gain (a) R_L , (b) D_L , and (c) ϵ_r .

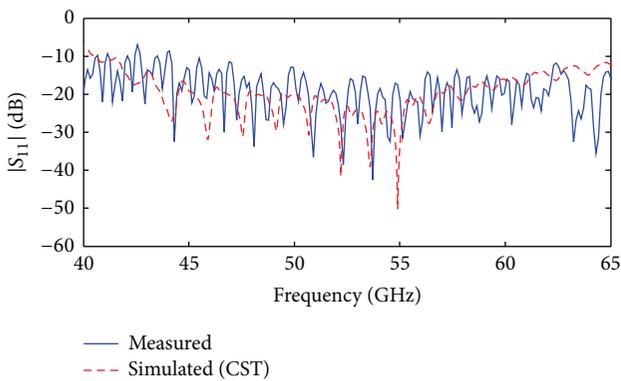


FIGURE 3: Measured and simulated return losses $|S_{11}|$ of proposed PLPDA antenna prototype with a full spherical dielectric lens.

2. Antenna Geometry and Design

The dielectric lens is used here because it focuses the incident divergent energy in the desired direction. Spherical lenses are mostly used for beam scanning with single or multiple feeding possibilities [10]. Dielectric lenses, same as the metallic

reflectors, are used for enhancing the directivity of radiation. In our case, the radiation comes from the proposed PLPDA antenna. From [11], the paraxial focus, normalized to lens radius, is given by

$$f = \frac{\eta}{2(\eta - 1)}, \quad (1)$$

where the refractive index $\eta = \sqrt{\epsilon_r}$.

It can be noticed from the above equation that the lens focus depends on the lens dielectric constant ϵ_r . So, it is very important to study the effect of lens dielectric constant on the antenna performance especially the antenna gain. For lens dielectric constant $\epsilon_r = 2.2$, the refractive index $\eta = 1.483$ and hence the paraxial rays arrive at the paraxial focus of 1.53 radii.

The top view and bottom view of the reference PLPDA antenna are shown in Figures 1(a) and 1(b), respectively. The proposed antenna prototype with a spherical dielectric lens is shown in Figure 1(c). The 3D view of the proposed antenna in CST [13] is presented in Figure 1(d). All antenna optimized parameters are listed in Table 1. The sphere has a radius R_L and its center is located at a distance D_L from the edge of substrate. The center of the sphere is located at a distance D

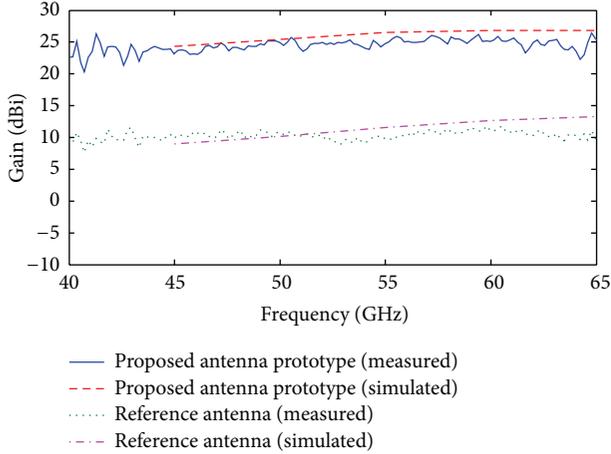


FIGURE 4: Measured and simulated gain of the proposed PLPDA antenna prototype. The gain curves for the proposed antenna are shown for comparison purposes.

TABLE 1: Parameters of the proposed PLPDA with spherical dielectric lens.

Parameter	Value (mm)
L	39
L_1	1.0
L_2	0.61
L_3	0.372
L_4	0.227
L_G	10.23
W	10
W_G	7.39
W_F	0.8
W_1	0.4
$W_2 (=W_3)$	0.244
W_4	0.091
S_1	0.5
S_2	0.62
S_3	0.378
S_4	0.23

from the end of the PLPDA antenna. For better mounting of the spherical lens to the antenna practically, a hole can be made inside the sphere to enter the substrate inside it. In our case, we stick two identical half spheres together with a special glue to form a full sphere. In that case we have the opportunity to install the substrate inside the sphere and then we can hold them together as one object as shown in Figure 1(e).

3. Parametric Studies

For understanding the role of spherical dielectric lens in increasing the antenna gain, intensive parametric studies have been carried out. This is to investigate the effect of spherical lens parameters such as the lens dielectric constant ϵ_r , radius R_L , and location from the edge of substrate D_L on

the antenna gain. Figure 2(a) shows the effect of varying the spherical dielectric lens radius R_L from 5 mm to 25 mm. It can be seen that the lens radius strongly affects the antenna gain and by increasing the lens radius, the antenna gain increases by a big value. However, after increasing the lens radius to more than 20 mm, the antenna gain starts decreasing. For example, the antenna gain increases from 11.5 dBi for $R_L = 5$ mm to 25.9 dBi for $R_L = 20$ mm at 60 GHz. The gain starts decreasing to 19.5 dBi for $R_L = 25$ mm at 60 GHz.

The effect of varying the spherical dielectric lens location from the substrate edge D_L on the antenna gain has been studied and presented in Figure 2(b). From results, it can be noticed that the parameter D_L also has a great effect on the antenna gain. By increasing parameter D_L from 25 mm to 30 mm, the antenna gain increases from 20.8 dBi to 25.7 dBi at 60 GHz. However, by increasing the parameter D_L to more than 30 mm, the antenna gain starts decreasing.

Finally, the parametric study on the lens dielectric constant ϵ_r is carried out and introduced in Figure 2(c). In case of $\epsilon_r = 1$, which means there is no lens, the antenna gain was 12.1 dBi at 60 GHz. By increasing the dielectric constant of the spherical lens from $\epsilon_r = 1$ to $\epsilon_r = 2$, the gain of the antenna starts increasing too much. However, by increasing the dielectric constant to more than $\epsilon_r = 3$, the antenna gain decreases.

After performing the above parametric studies, optimized lens parameters can be determined based on achieving the best antenna gain. The optimized lens parameters are found: $R_L = 20$ mm, $D_L = 28$ mm, and $\epsilon_r = 2.2$.

4. Results

The measured and simulated return losses of the proposed PLPDA antenna prototype with a full spherical dielectric lens are presented in Figure 3. The antenna exhibits good impedance matching characteristics across the measured range.

The gain comparison between the proposed antenna prototype and the reference antenna is shown in Figure 4. The antenna with a full spherical lens achieves higher gain compared to the reference antenna (prototype without lens). The gain of the proposed antenna prototype is about 14.5 dBi larger than that of the reference antenna. A good agreement between the measured and simulated curves is achieved.

The measured and simulated copolarization and cross-polarization radiation patterns in H -plane at different frequencies are shown in Figure 5. It can be seen from results that the directive behavior of proposed antenna prototype after adding a full spherical dielectric lens is clearly noticed. It is worthy to mention that installing the spherical lens not only improves the antenna gain but also enhances greatly the other radiation characteristics such as side lobe level (SLL), front-to-back (FTB) ratio, half power beam width (HPBW), and cross-polarization level (XPL).

A performance comparison among the proposed antenna prototypes with reference antenna at 60 GHz in terms of gain, total efficiency, FTB ratio, side lobe suppressions, HPBW, and XPL in both E - and H -planes is presented in Table 2.

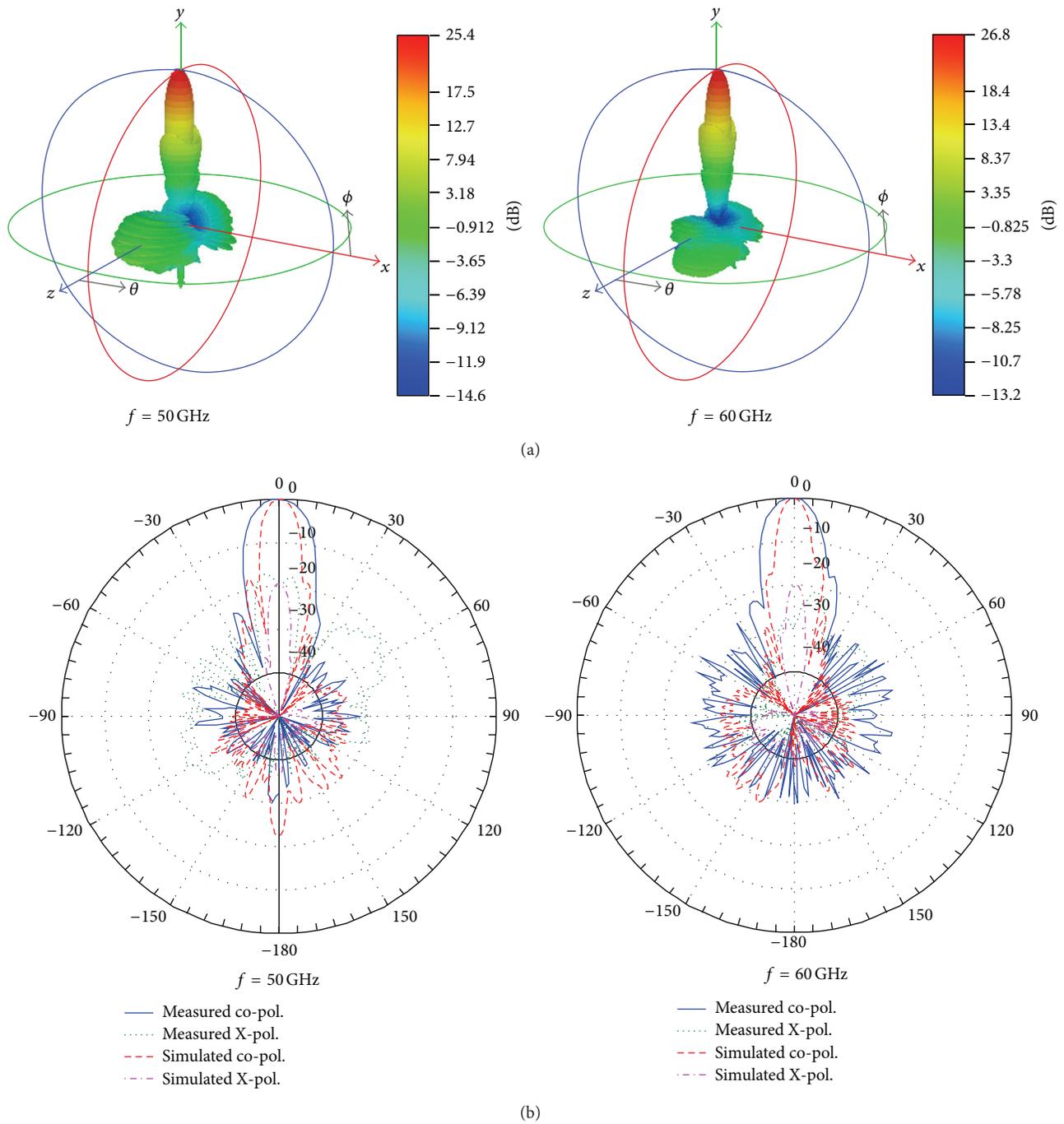


FIGURE 5: (a) Simulated radiation patterns in three-dimensional view, (b) measured and simulated co- and cross-polarization radiation patterns in the H -plane at different frequencies of the proposed PLPDA with a spherical lens.

TABLE 2: Performances of the proposed PLPDA antenna prototypes at 60 GHz.

	Gain [dBi]	Total efficiency [%]	FTB ratio [dB]	E -plane			H -plane		
				SLL [dB]	HPBW [°]	XPL [dB]	SLL [dB]	HPBW [°]	XPL [dB]
Proposed antenna prototype	26.79	93.98	35.56	-23.65	6.2°	-20.40	-28.98	6.7°	-19.86
Reference antenna	12.77	99.06	24.13	-7.96	29.8°	-19.00	-19.85	27.4°	-18.82

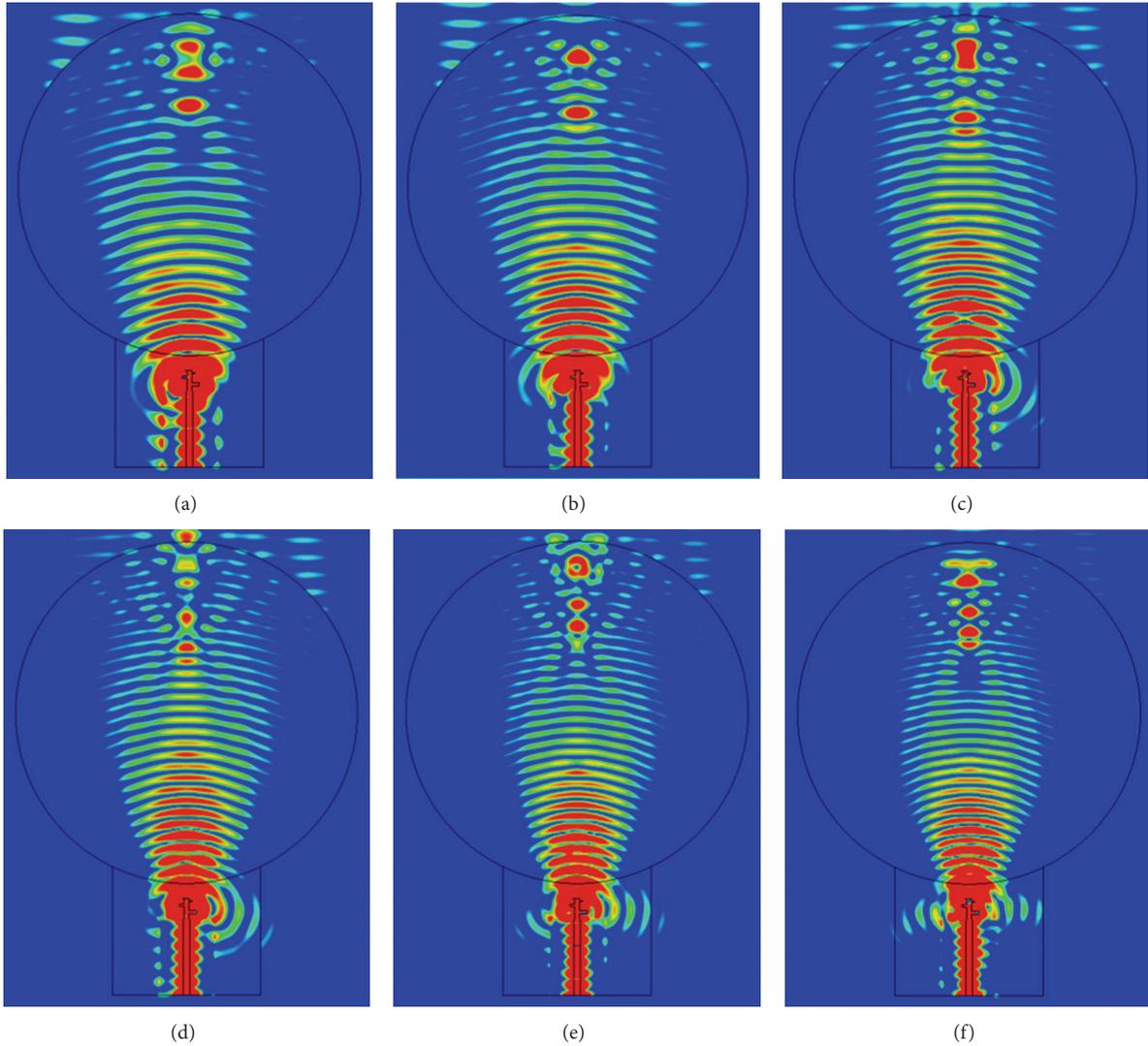


FIGURE 6: Simulated electric field distributions inside the spherical lens at (a) 50 GHz, (b) 55 GHz, (c) 60 GHz, (d) 65 GHz, (e) 70 GHz, and (f) 75 GHz.

TABLE 3: Performances of the printed log-periodic dipole array (PLPDA) antennas.

Reference	f [GHz]	BW %	Fabrication technology	Substrate type	Gain [dBi]	FTB ratio [dB]	X-pol level [dB]
[4]	34	35.3%	PCB with metallic vias	FR4	4.3	15	—
[6]	30	38.8%	SIW, PCB with vias	Rogers 5880	8.0	16	18
[7]	94	143%	Surface micromachining	Silicon	7.5	25	15
[12]	30	66.6%	PCB	Rogers 5880	8.0	15	12.5
Reference antenna	60	>45%	PCB	Rogers 5880	12.7	24.1	18.8
Proposed antenna prototype	60	>46%	PCB	Rogers 5880	26.8	35.5	19.8

For further understanding of the role of dielectric lens in increasing the antenna gain, the near-field distributions are calculated at different frequencies. The electric field distributions inside the spherical lens are shown in Figure 6. As shown, electric fields pass through the lens and thus the circular waves are flattened. In this case, the cylindrical waves

are converted into quasiplane waves on the opposite side of the lens with a noticeable increase in the antenna gain in terms of highly directive radiation.

A comparison of performance among the reported millimeter-wave works in the literature has been done in detail and summarized in Table 3. It can be noticed that the

proposed PLPDA antenna with spherical dielectric lenses is the best candidate to be used in many applications at millimeter-waves especially at V-band frequency range.

5. Conclusion

The design of high-gain printed log-periodic dipole array (PLPDA) antenna prototype operating at V-band millimeter-wave frequency range has been presented. The proposed antenna is fabricated using cheap PCB technology which makes it easy for integration with other circuits. For achieving high-gain, a low-cost spherical dielectric lens was installed. Radiation patterns and antenna gains of the proposed antenna prototype were studied and presented. Both measured and simulated results verify several advantages such as high-gain, stable radiation pattern, good SLLs in both E - and H -planes, high FTB ratio, and excellent cross-polarization levels. A detailed comparison of performance with previously reported work has been presented. The proposed antenna can be among the best candidates to be used in many V-band applications.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

- [1] H.-T. Hsu and T.-J. Huang, "A koch-shaped log-periodic dipole array (LPDA) antenna for universal ultra-high-frequency (UHF) radio frequency identification (RFID) handheld reader," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 9, pp. 4852–4856, 2013.
- [2] F. Merli, J. F. Zurcher, A. Freni, and A. K. Skrivervik, "Analysis, design and realization of a novel directive ultrawideband antenna," *IEEE Transactions on Antennas and Propagation*, vol. 57, no. 11, pp. 3458–3466, 2009.
- [3] D. E. Anagnostou, J. Papapolymerou, M. M. Tentzeris, and C. G. Christodoulou, "A printed log-periodic Koch-dipole array (LPKDA)," *IEEE Antennas and Wireless Propagation Letters*, vol. 7, pp. 456–460, 2008.
- [4] G. Zhai, Y. Cheng, Q. Yin, S. Zhu, and J. Gao, "Simplified printed log-periodic dipole array antenna fed by CBCPW," *International Journal of Antennas and Propagation*, vol. 2013, Article ID 548610, 5 pages, 2013.
- [5] C. Yu, W. Hong, L. Chiu, G. Zhai, W. Qin, and Z. Kuai, "Ultrawideband printed log-periodic dipole antenna with multiple notched bands," *IEEE Transactions on Antennas and Propagation*, vol. 59, no. 3, pp. 725–732, 2011.
- [6] G. Zhai, Y. Cheng, Q. Yin, L. Chiu, S. Zhu, and J. Gao, "Super high gain substrate integrated clamped-mode printed log-periodic dipole array antenna," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 6, pp. 3009–3016, 2013.
- [7] H. Zhou, N. A. Sutton, and D. S. Filipovic, "Surface micro-machined millimeter-wave log-periodic dipole array antennas," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 10, pp. 4573–4581, 2012.
- [8] P. Piksa, S. Zvanovec, and P. Cerny, "Elliptic and hyperbolic dielectric lens antennas in mm-waves," *Radioengineering*, vol. 20, no. 1, pp. 270–275, 2011.
- [9] C. Run-nan, Y. Ming-chuan, Z. Xing-qi, L. Ming, and L. Xiao-feng, "A novel multi-beam lens antenna for high altitude platform communications," in *Proceedings of the IEEE 75th Vehicular Technology Conference (VTC '12)*, pp. 1–5, Yokohama, Japan, June 2012.
- [10] A. Dhoubi, S. N. Burokur, A. De Lustrac, and A. Priou, "Low-profile substrate-integrated lens antenna using metamaterials," *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 43–46, 2013.
- [11] J. Thornton and K. Huang, *Modern Lens Antennas for Communications Engineering*, Wiley-IEEE Press, 2012.
- [12] G. H. Zhai, Y. Cheng, D. Min, S. Z. Zhu, and J. J. Gao, "Wideband simplified feed for printed logperiodic dipole array antenna," *Electronics Letters*, vol. 49, no. 23, pp. 1430–1432, 2013.
- [13] CST Microwave Studio, *Computer Simulation Technology*, Framingham, Mass, USA, 2012.



Hindawi

Submit your manuscripts at
<http://www.hindawi.com>

