A Novel Wideband End-Fire Conformal Antenna Array Mounted on a Dielectric Cone

Zengrui Li [1], Longdan Tan [2], Xiaole Kang [1], Jianxun Su [1], Qingxin Guo [1], Yaoqing (Lamar) Yang [3], and Junhong Wang [4]

[1] School of Information Engineering
Communication University of China, Beijing, 100024, China
zrli@cuc.edu.cn, darever1988@126.com, sujianxun_jlgx@163.com, qxguo@cuc.edu.cn

[2] Network Operation Center
Startimes Media Group, Beijing, 100024, China
tanld@startimes.com.cn

[3] Department of Electrical and Computer Engineering
University of Nebraska-Lincoln, Nebraska, 68182, USA
yyang3@unl.edu

[4] Institute of Lightwave Technology
Beijing Jiaotong University, Beijing, 100044, China
wangjunh@bjtu.edu.cn

Abstract ─ In this paper, a novel log-periodic antenna named quasi-second order Koch fractal log-periodic dipole array (QLPK^{2}DA) is presented for the conformal applications. The proposed antenna array shows wider operating bandwidth and small physical profile. In addition, the radiation characteristics of the proposed antenna array mounted on a dielectric cone are investigated. Results show that the cone curvature has an influence on the performance of the conformal antenna, both in terms of its bandwidth and radiation patterns. The thickness and permittivity of the dielectric cone have an effect on the bandwidth of the conformal antenna. The measured results show that the antenna has a wide band ranging from 2 GHz to 10 GHz and shows a typical end-fire radiation beam. Measurement results of both single antenna and conformal antenna array show a good agreement with simulated values.

Index Terms ─ Conformal, Koch fractal, log-periodic antenna, wideband.

I. INTRODUCTION

Wideband antennas are required for many electromagnetic applications, such as radio astronomy and UWB technology. The printed log-periodic array antenna (LPDA) has attracted great attention in wideband wireless communication systems due to many advantages, such as simple in fabrication, low cross-polarization, wide frequency band and the end-fire beam [1]. It is a challenge to reduce the antenna size while maintaining its main performance characteristics. For the purpose of antenna miniaturization, different kinds of fractal geometries have been investigated in antenna design [2-10]. Among the previous research, Koch fractal is an important geometry studied by many antenna researchers [6-10]. In [7] and [8], two kinds of the printed Koch fractal log-periodic dipole arrays are proposed. However, these two antennas only use the first order Koch fractal technique to reduce the antenna size and the bandwidth is just from 2 GHz to 3 GHz. To reduce cross-polarization and further miniaturize the antenna, quasi-second order Koch fractal dipoles are proposed for antenna design in this paper.

On the other hand, conformal antennas are mainly used in aviation, radars and military systems. For these applications, conformal antennas need to cover a wide bandwidth and have end-fire radiation beam. A variety of conformal antennas have been investigated during the past two decades, including monopole antennas [11-12], slot antennas [13-14], leaky-wave antennas [15-16], microstrip antenna arrays [17-18], log-periodic antennas [19-20] and substrate integrated waveguide (SIW) antennas [21-22], etc. However, most of these antennas are mounted on metallic surfaces and have broadside radiation beam. There are few studies about end-fire conformal antennas in literatures [20-21].

Submitted On: September 22, 2015
Accepted On: February 26, 2016

In this paper, a quasi-second order Koch-fractal log-periodic antenna dipole array is proposed for conformal applications for the first time as far as we know. The contributions of our work are as follows:

1) The quasi-second order Koch fractal element is proposed for antenna design. Compared with LPDA, the proposed QLPK^{2}DA has smaller size and operates with a wider frequency band.

2) The proposed antenna can be easily mounted on a dielectric cone. The influences of cone curvature, cone thickness and cone permittivity on the conformal antenna's bandwidth and radiation performance are investigated. The curvature of cone has an influence on bandwidth and radiation patterns of conformal antenna. The thickness and dielectric constant of cone only affect the bandwidth of conformal antenna.

3) A prototype of the conformal antenna array with four antenna elements is fabricated. Measurement results are compared with simulated values to validate our proposed design.

II. ANTENNA DESIGN

In this section, a quasi-second order Koch fractal log-periodic antenna is proposed, as shown in Fig. 1. This antenna includes ten quasi-second Koch fractal dipoles, which are cross-fed by a parallel-strip transmission line and printed on both layers of a Teflon-F4B substrate with a dielectric constant of 3.5 and loss tangent of 0.003. The thickness of the substrate is 0.5 mm.

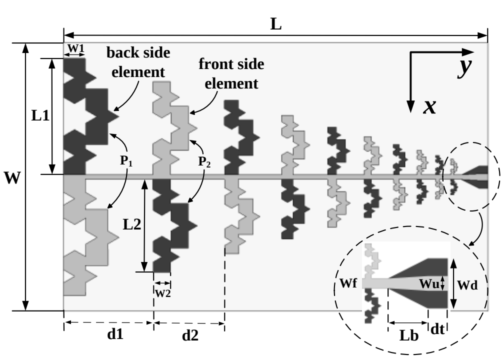


Fig. 1. Configuration of the proposed QLPK^{2}DA.

A. Design of the LPDA

A conventional printed log-periodic dipole array (LPDA) with Euclidean dipoles is designed, as shown in Fig. 2. To achieve a higher gain, the scaling factor τ and spacing factors σ of LPDA is set to be 0.84 and 0.14 respectively, based on the method described in [23-24]. The antenna's half-angle is $\alpha=30^{\circ}$. The number of the radiation dipoles are calculated to be $N=14$ to cover the desired bandwidth from 2 GHz to 10 GHz. In this design, $\tau=L_{i+1}/L_i=W_{i+1}/W_i=d_{i+1}/d_i$, where L_i and W_i are the length and width of the dipole P_i, d_i is the distance between dipole P_{i+1} and P_i.

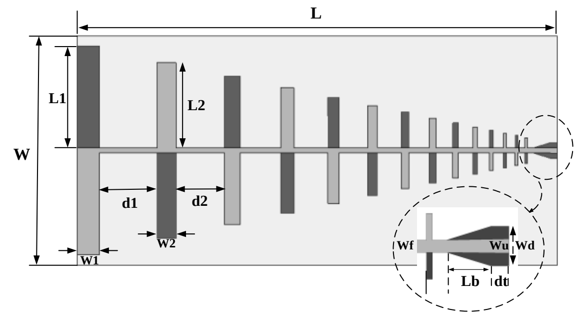


Fig. 2. Configuration of the LPDA.

B. Design of the QLPK^{2}DA

To realize the miniaturization of LPDA, Koch iteration is applied in this design. Generally, Euclidean elements are defined as Koch curves of 0th iteration (K0) while other order iterations are based on lower order Koch curves [9-10]. The Koch fractal monopoles, designed from K0 to K2, are depicted in Fig. 3. The characteristics of the antenna such as the primary resonant frequency, is directly related to the fractal dimension. For a given order, Koch elements with different indentation angles will also have different input impedances and resonant frequencies [10]. A typical indentation angle of $\theta=60^{\circ}$ is set to Koch fractal elements in this research.

However, it will bring complexity in design if Koch fractal element's width increases, especially on the higher order elements. Therefore, we propose a modified second order Koch fractal element named quasi-second order Koch fractal element. The middle part of each quasi-second order Koch fractal element is replaced by two rectangle patches "S1" and "S2", as shown in Fig. 4. This structure can also reduce the reverse current on each fractal element and reduce the cross-polarization, compared with second order Koch fractal antenna. Based on the above proposed LPDA, the QLPK^{2}DA can be realized by replacing Euclidean elements with quasi-second order Koch fractal elements, as shown in Fig. 1. A gradient microstrip balun at the end of the feeding line is designed to transform an unbalanced input signal to a balanced signal at the quasi-second order Koch fractal elements.

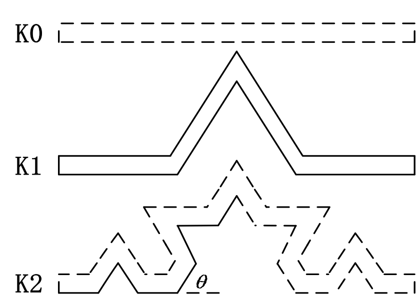


Fig. 3. Koch fractal monopoles, K0 to K2.

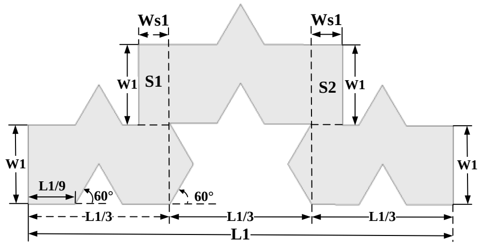


Fig. 4. Structure of quasi-second order Koch fractal element with W_{s1}=1.9 mm.

To cover the desired bandwidth (2 GHz-10 GHz), the LPDA and QLPK^{2}DA were simulated and optimized with the assistance of ANSYS High Frequency Structure Simulator (HFSS) Version 12. Figure 5 shows the simulated return loss of the two antennas. The efficiency of QLPK2DA is also simulated and achieves at least 76.7% over the entire band shown in Fig. 6. The dimensions of the designed LPDA and QLPK^{2}DA are listed in Table 1. The overall dimension of the LPDA is 66×137 mm^2, while the physical size of the QLPK^{2}DA is only 60×94.9 mm^2, which is 37% smaller than the LPDA. Apparently, the physical size of the antenna can be greatly reduced due to the quasi-second order Koch fractal structure.

The prototypes of the LPDA and QLPK^{2}DA are fabricated and shown in Fig. 7 and Fig. 8, respectively. The prototype antennas are measured by an Agilent E5071C Vector Network Analyzer in an anechoic chamber in Communication University of China (CUC).

Figure 9 and Fig. 10 show the comparisons between the simulated and measured return losses of the LPDA and QLPK^{2}DA, respectively. It is found that the measured results and simulated values of these two antennas agree with each other over the frequency band (return loss > 10 dB) ranging from 2 GHz to 10 GHz with a ratio about 5:1. In Fig. 10, the small deviation of the results in the higher frequency band may be caused by the imperfection of hand-soldering the SMA connector.

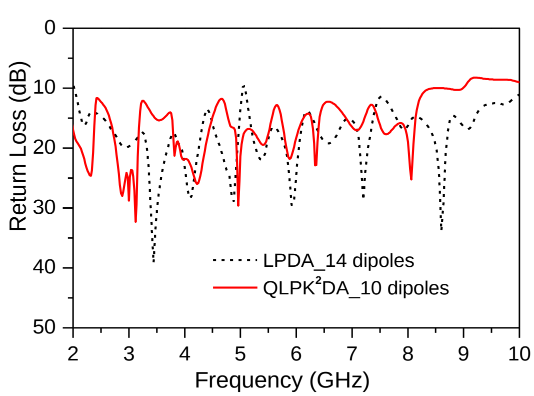


Fig. 5. Comparison of simulated return loss between LPDA and QLPK^{2}DA.

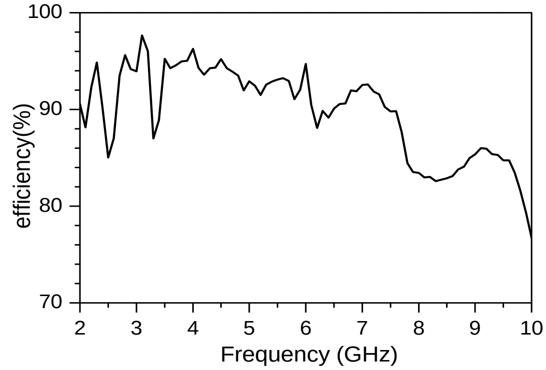


Fig. 6. Efficiency of QLPK2DA by simulation.

Table 1: Optimized parameters of LPDA and QLPK^{2}DA (In millimeters)

Parameters	L_1	W_1	d_1	W	L
LPDA	29.3	6.4	16.4	66	137
QLPK^{2}DA	26	4.9	20	60	94.9
Parameters	W_f	W_u	W_d	L_b	d_t
LPDA	1.4	1.6	5	5	2
QLPK^{2}DA	1	1.5	5	4	2

(a) (b)

Fig. 7. Prototype of LPDA: (a) front view and (b) back view.

(a) (b)

Fig. 8. Prototype of QLPK^{2}DA: (a) front view and (b) back view.

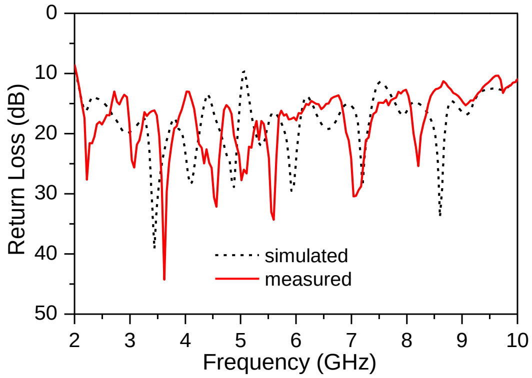


Fig. 9. Measured and simulated return loss of LPDA.

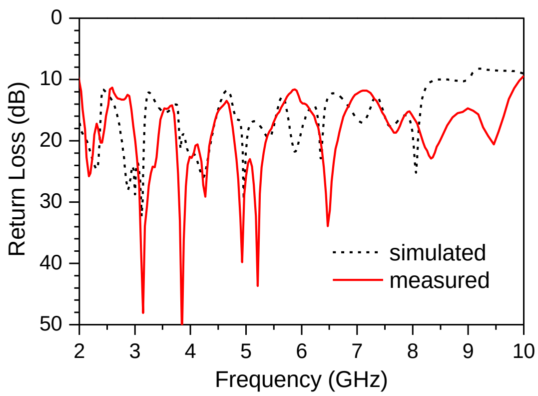


Fig. 10. Measured and simulated return loss of QLPK²DA.

The far field radiation patterns in the E-plane (xoy plane) and H-plane (yoz plane) at different frequencies were measured and plotted in Fig. 11. The measured co-polarization radiation patterns and the simulated results show good agreement in both planes. However, the measured cross-polarization radiation patterns are wider than the simulated results. It may be caused by the deviation of the relative position between test antenna and reference antenna. The proposed antenna has end-fire radiation beams in both planes and the maximum radiation is in the direction of +y axis.

The measured half power beam-width and front-to-back ratios of the QLPK²DA are listed in Table 2 and Table 3. Table 2 shows the beam-width in E-plane and H-plane vary from 42° to 72° and 54° to 94°. According to Table 3, the front-to-back ratios of the QLPK²DA achieve more than 12 dB except few frequencies, which confirmed the end-fire characteristic of the antenna. Figure 12 shows the comparisons of the measured gains between LPDA and QLPK²DA. It is observed that the gain of LPDA is higher than that of QLPK²DA except a few frequency points. Within the operating frequency band, the measured gain of the QLPK²DA in end-fire direction varies between 2.6 dBi and 8.7 dBi.

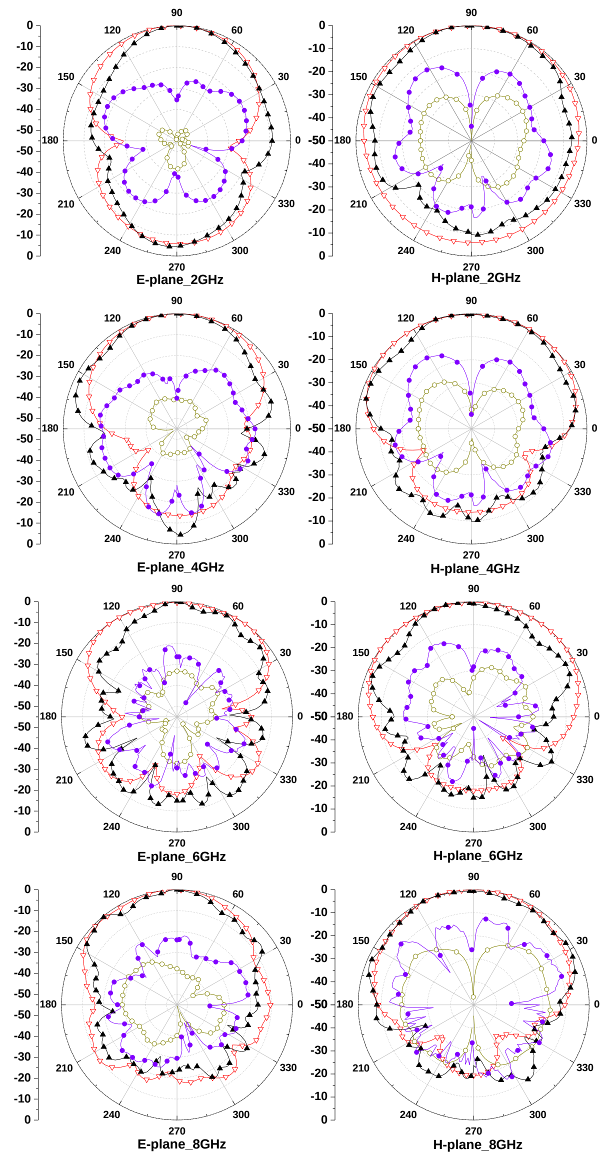


Fig. 11. Measured and simulated radiation patterns of QLPK²DA. -▲- measured co-polarization, -●- measured cross-polarization, -▽- simulated co-polarization, -○- simulated cross-polarization.

Table 2: Measured half power beam-width of QLPK²DA

Frequency (GHz)	2	4	6	8	10
E-plane (deg)	46	64	42	72	47
H-plane (deg)	86	68	54	94	50

Table 3: Measured front-to-back ratio of QLPK2DA

Frequency (GHz)	2	4	6	8	10
E-plane (dB)	8	8	17	23	20
H-plane (dB)	12	13	16	24	21

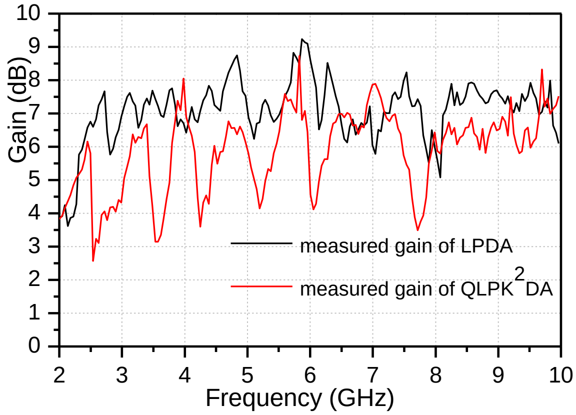


Fig. 12. Measured gain of LPDA and QLPK^{2}DA.

Since the linear phase response of the antenna in the time domain is one of the most important parameters in wideband systems, the group delay of two QLPK^{2}DA with a distance of 30 cm has also been measured. Figure 13 shows that the variation of the group delay is within 5ns across the entire frequency band, which indicates that the phase of the antenna shifts little within the operating frequency band. Thus, the proposed antenna has a desirable time domain characteristic.

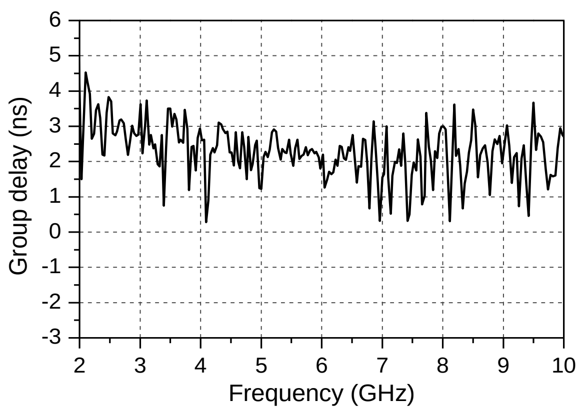


Fig. 13. Measured group delay of the proposed antenna.

III. CONFORMAL ANTENNA RESEARCH

A. Effects of cone curvature

The proposed QLPK^{2}DA is mounted on a dielectric cone to investigate the conformal antenna characteristics. The antenna is on dielectric cones with different curvatures, as shown in Fig. 14. The exterior diameters of the three cones' top/bottom surfaces are 300/360 mm, 190/210 mm, 130/150 mm, respectively. The height, thickness and dielectric constant of three cones are 350 mm, 0.5 mm and 2.1, respectively.

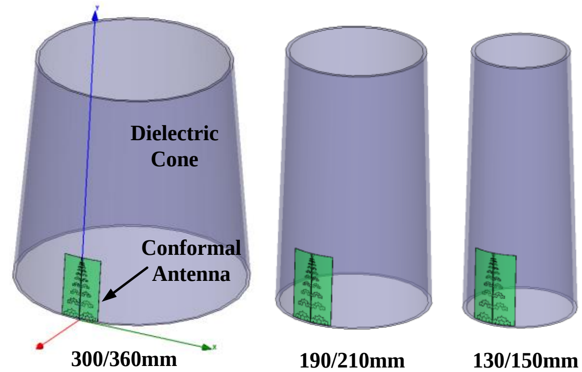


Fig. 14. Configuration of QLPK^{2}DA mounted on cones with different curvatures.

The simulated voltage standing wave ratio (VSWR) of the conformal antenna with different cone curvatures is shown in Fig. 15. It is observed that, with the increasing of cone curvature, the VSWR deteriorates especially in the middle and high frequency bands. The simulated radiation patterns of the conformal antenna with different cones curvatures at 2 GHz, 4 GHz, 6 GHz, and 8 GHz are plotted in Fig. 16. It can be seen that the variation of cone curvature has little effects on the co-polarization radiation patterns of the conformal antenna. Since the antenna is bent on the cone, there exists an extra electric current component in -*Z* direction. Therefore, the cross-polarization radiation patterns of the conformal antenna become larger with the increasing of cone curvature. The simulated half power beam-width of the conformal antenna is all less than 100 degree, as shown in Table 4.

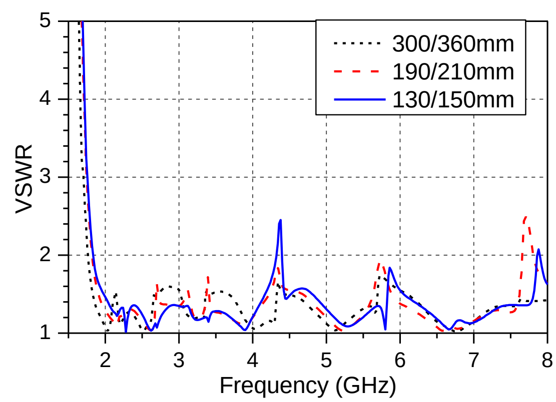


Fig. 15. Simulated VSWR of conformal antenna with different cone curvatures.

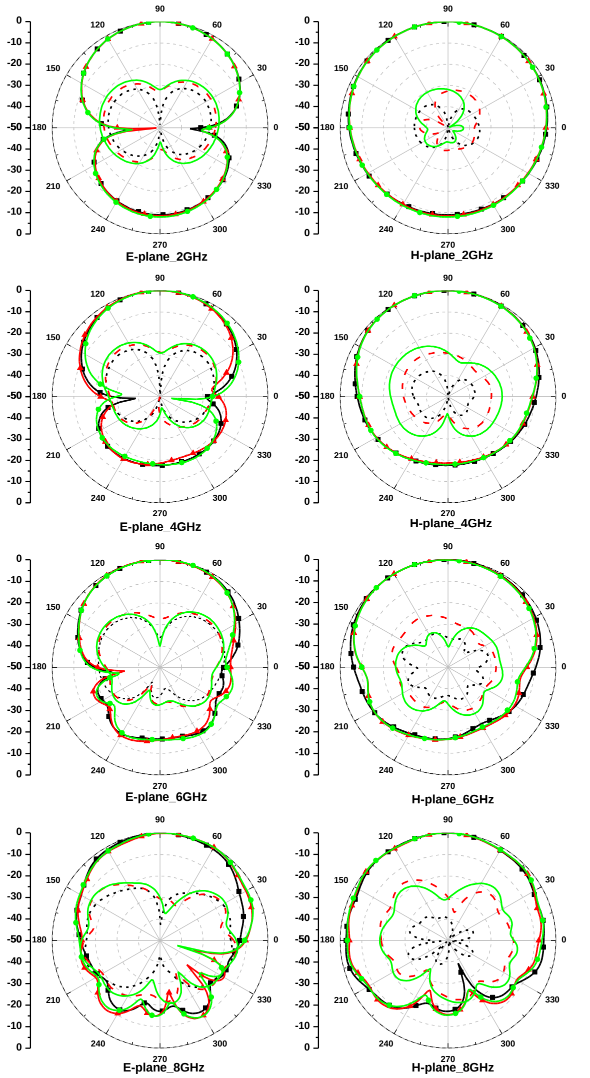


Fig. 16. Simulated radiation patterns of conformal antenna. -■- co-polarization (300/360 mm), --- cross-polarization (300/360 mm), -▲- co-polarization (190/210 mm), – – – cross-polarization (190/210 mm), -●- co-polarization (130/150 mm), — cross-polarization (130/150 mm).

Table 4: Simulated half power beam-width of QLPK^{2}DA mounted on different cones

Frequency (GHz)	2	3	4	5	6	7	8
E-plane (deg)	78	91	61	66	54	63	59
H-plane (deg)	97	79	85	92	79	83	74

B. Effects of cone thickness

In this subsection, the QLPK^{2}DA is mounted on cones with different thickness (5 mm, 7 mm, 10 mm) so as to examine the effect of the cone thickness on the characteristics of the conformal antenna. The outer diameter of cones' top and bottom surfaces is 190/210 mm. The height and dielectric constant of cones are 350 mm and 2.1, respectively.

The simulated VSWR of conformal antenna with different cone thickness is shown in Fig. 17. It is found that as the thickness increases, the VSWR becomes larger in the lower frequency band. The VSWR value varies between 1 and 3 in the whole operating band. The study on radiation performance indicates that the changes of cone thickness have little effect on far-field radiation patterns of conformal antenna.

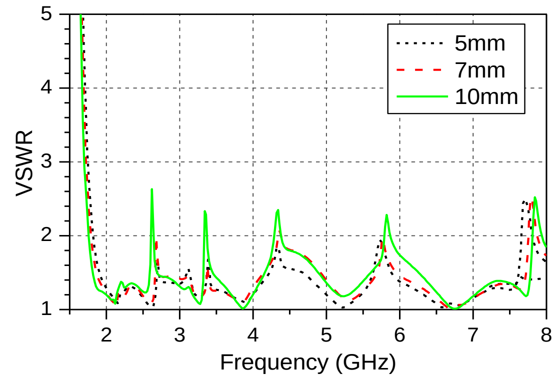


Fig. 17. Simulated VSWR of conformal antenna with different cone thickness.

C. Effects of cone dielectric constant

We also studied the performance of the antenna mounted on cones with different dielectric constants (2.1, 2.5, 3 and 3.5). The outer diameter of cones' top and bottom surfaces is 190/210 mm. The height and thickness of cones are 350 mm and 5 mm.

From Fig. 18, we can readily observe that cone dielectric constant has a significant effect on VSWR of conformal antenna. When the dielectric constant increases, the VSWR of conformal antenna deteriorates rapidly. It is found that when the dielectric constant is larger than 3, the VSWR will increase to be larger than 3, which is unacceptable for application. Studies show that the changes of cone dielectric constant have little effect on radiation performance of conformal antenna.

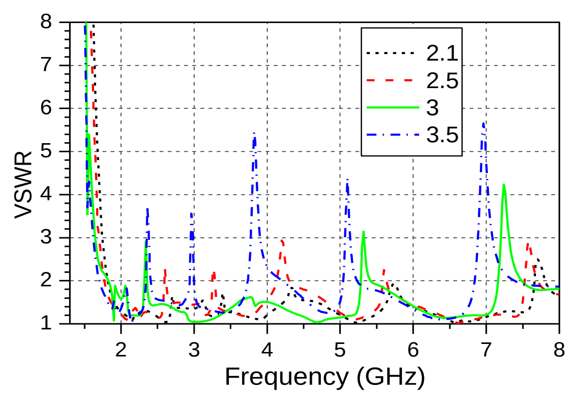
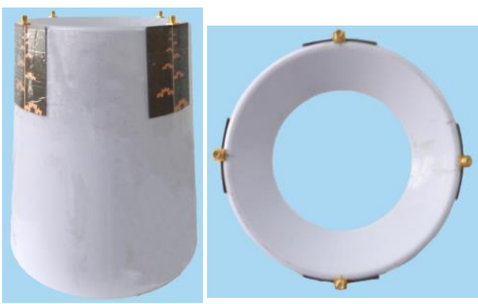


Fig. 18. Simulated VSWR of conformal antenna with different dielectric constants.

IV. EXPERIMENTAL RESULTS

A prototype of conformal antenna array is constructed by mounting four proposed QLPK^{2}DA on the surface of a polypropylene cone with a dielectric constant of 2.3, as shown in Fig. 19. The height, thickness, top and bottom surfaces' outer diameter of the cone are 274 mm, 3 mm, 188/204 mm, respectively. The prototype was measured by an Agilent E5071C Vector Network Analyzer in an anechoic chamber in CUC.

The measured and simulated return losses of the conformal antenna are shown in Fig. 20. It can be seen that the measured and simulated results are in good agreement. Because of the imperfection during building the antenna, the measured results shift a little bit towards the lower frequency band.



(a) **(b)**

Fig. 19. Prototype of four QLPK^{2}DA mounted on a dielectric cone: (a) side view and (b) top view.

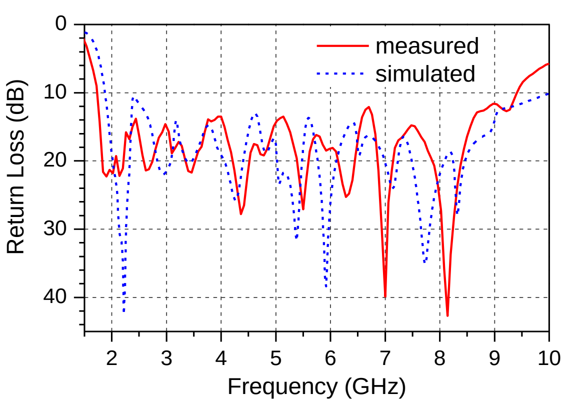


Fig. 20. Measured and simulated return loss of the conformal antenna.

Figure 21 shows the measured and simulated radiation patterns of the conformal antenna in both E-plane (xoy plane) and H-plane (yoz plane) at 2 GHz, 4 GHz, 6 GHz and 8 GHz. It is found that the conformal antenna has end-fire radiation beams in both planes. The measured radiation patterns have good agreement with simulated curves. The coupling between four ports of the conformal antenna is also investigated. Because the four QLPK^{2}DA are mounted evenly on the cone, $|S_{41}|$ is equal to $|S_{21}|$ and $|S_{42}|$ is equal to $|S_{31}|$. So we just consider $|S_{21}|$ and $|S_{31}|$ here. Figure 22 shows the measured $|S_{21}|$ and $|S_{31}|$ of the conformal antenna. It can be observed that the measured results are both less than -28 dB in the operating frequency band, which is good enough for the port coupling of the conformal antenna.

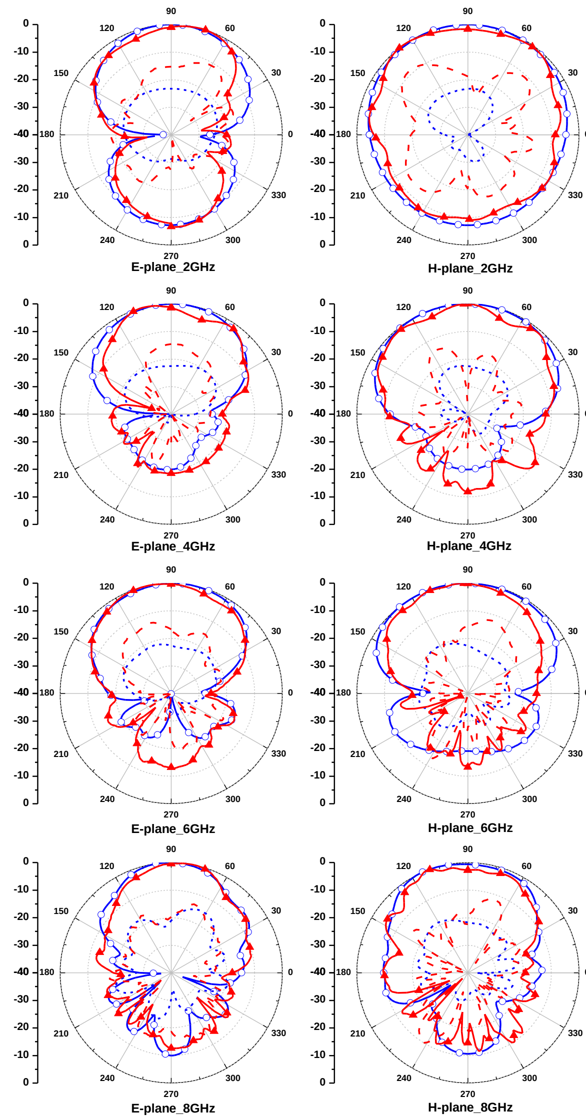


Fig. 21. Measured and simulated radiation patterns of conformal antenna. -○- simulated co-polarization, --- simulated cross-polarization, -▲- measured co-polarization, — — —measured cross-polarization.

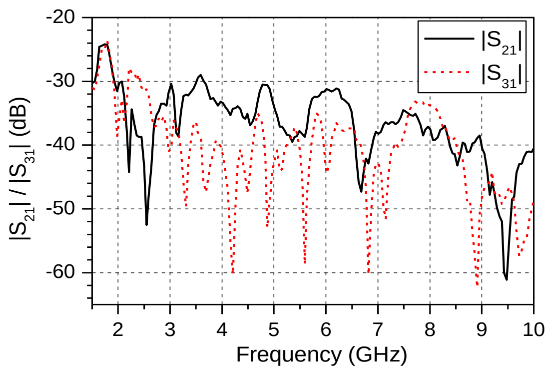


Fig. 22. Measured coupling of the conformal antenna.

V. CONCLUSION

This paper presented a novel wideband end-fire conformal antenna array mounted on a dielectric cone. A quasi-second order Koch fractal element is applied in conformal antenna research for the first time. The effects of cone curvature, thickness, dielectric constant on the performance of conformal antenna are investigated and some inspiring results for end-fire conformal antenna design have been obtained. Measured and simulated results of the prototype show the conformal antenna has wide frequency band, end-fire radiation patterns and wide half power beam-width. The proposed antenna array has a great potential to be used in conformal systems such as missiles, radars, aircrafts.

ACKNOWLEDGMENT

The work was supported in part by the National Science Foundation of China (NSFC) under grant No. 61331002, No. 61102011, No. 61201082, and in part by Excellent Innovation Team of CUC under grant No. yxtd201303.

REFERENCES

[1] C. A. Balanis, *Antenna Theory: Analysis and Design*. John Wiley and Sons. Inc., 2005.

[2] W. Chen, G. Wang, and C. Zhang, "Bandwidth enhancement of a microstrip-line-fed printed wide-slot antenna with a fractal-shaped slot," *IEEE Transactions on Antennas and Propagation*, vol. 57, no. 7, pp. 2176-2179, Jul. 2009.

[3] C. Puente-Baliarda, J. Romeu, R. Pous, and A. Cardama, "On the behavior of the Sierpinski multiband fractal antenna," *IEEE Transactions on Antennas and Propagation*, vol. 46, no. 4, pp. 517-524, Apr. 1998.

[4] A. Gorai, A. Karmakar, M. Pal, and R. Ghatak, "Multiple fractal-shaped slots-based UWB antenna with triple-band notch functionality," *Journal of Electromagnetic Waves and Applications*, vol. 27, no. 18, pp. 2407-2415, 2013.

[5] A. Azari, "A new ultra wideband fractal monopole antenna," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 26, no. 4, 2011.

[6] A. Sundaram, M. Maddela, and R. Ramadoss, "Koch-fractal folded-slot antenna characteristics," *IEEE Antennas and Wireless Propagation Letters*, vol. 6, pp. 219-222, 2007.

[7] 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. 4852-4856, 2009.

[8] H.-T. Hsu and T.-J. Huang, "A Koch-shaped log-periodic dipole array (LPDA) antenna for universal ultra-high-frequency (UHF) radiao frequency identification (RFID) handheld reader," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 9, pp. 2176-2179, Sep. 2013.

[9] S. R. Best, "On the resonant properties of the Koch fractal and other wire monopole antennas," *IEEE Antennas and Wireless Propagation Letters*, vol. 1, pp. 74-76, 2002.

[10] K. J. Vinoy, J. K. Abraham, and V. K. Varadan, "On the relationship between fractal dimension and the performance of multi-resonant dipole antennas using Koch curves," *IEEE Transactions on Antennas and Propagation*, vol. 51, no. 9, pp. 2296-2303, Sep. 2003.

[11] H.-Y. Liang, H.-C. Yang, and J. Zhang, "A cylindrical conformal directional monopole antenna for borehole radar application," *IEEE Antennas and Wireless Propagation Letters*, vol. 11, pp. 1525-1528, 2012.

[12] Z.-Q. Liu, Y.-S. Zhang, Z. Qian, Z. P. Han, and W. Ni, "A novel broad beamwidth conformal antenna on unmanned aerial vehicle," *IEEE Antennas and Wireless Propagation Letters*, vol. 11, pp. 196-199, 2012.

[13] S. Nikolaou, G. E. Ponchak, J. Papapolymerou, and M. M. Tentzeris, "Conformal double exponentially tapered slot antenna (DETSA) on LCP for UWB applications," *IEEE Transactions on Antennas and Propagation*, vol. 54, no. 6, pp. 1663-1669, Jun. 2006.

[14] G. E. Ponchak, J. L. Jordan, and C. T. Chevalier, "Characteristics of double exponentially tapered slot antenna (DETSA) conformed in the Longitudinal direction around a cylinder," *IEEE Antennas and Wireless Propagation Letters*, vol. 6, pp. 60-63, 2007.

[15] J. L. Gomez-Tornero, "Analysis and design of conformal tapered leaky-wave antennas," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 1068-1071, 2010.

[16] A. J. Martinez-Ros, J. L. Gomez-Tornero, and G. Goussetis, "Conformal tapered substrate integrated waveguide leaky-wave antenna," *IEEE Transactions*

on Antennas and Propagation, vol. 62, no. 12, pp. 5983-5991, Dec. 2014.

[17] B. D. Braaten, S. Roy, S. Nariyal, M. Al Aziz, N. F. Chamberlain, I. Irfanullah, M. T. Reich, and D. E. Anagnostou, "A self-adapting flexible (SELFLEX) antenna array for changing conformal surface applications," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 2, pp. 655-665, Feb. 2013.

[18] K. Wincza, S. Gruszczynski, and K. Sachse, "Conformal four-beam antenna arrays with reduced sidelobes," *Electronics Letters*, vol. 44, no. 3, pp. 174-175, Jan. 2008.

[19] N. A. Bishop, J. Miller, D. Zeppettella, W. Baron, J. Tuss, and M. Ali, "A broadband high-gain bi-layer LPDA for UHF conformal load-bearing antenna structures (CLASs) applications," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 5, pp. 2359-2364, May 2015.

[20] X. Gao, Z. Shen, and C. Hua, "Conformal VHF log-periodic ballon antenna," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 6, pp. 2756-2761, Jun. 2015.

[21] Y. Zhao, Z. Shen, and W. Wu, "Conformal SIW H-plane horn antenna on a conducting cylinder," *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 1271-1274, 2015.

[22] Y. J. Cheng, H. Xu, D. Ma, J. Wu, L. Wang, and Y. Fan, "Millimeter-wave shaped-beam substrate integrated conformal array antenna," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 9, pp. 4558-4566, Sep. 2013.

[23] R. Carrel, "The design of log-periodic dipole antennas," *IRE International Convention Record*, vol. 9, no. 1, pp. 61-75, 1961.

[24] C. K. Campbell, I. Traboulay, M. S. Suthers, and H. Kneve, "Design of a stripline log-periodic dipole antenna," *IEEE Transactions on Antennas and Propagation*, vol. 25, no. 15, pp. 718-721, Sep. 1977.

Zengrui Li received the B.S. degree in Communication and Information System from Beijing Jiaotong University, Beijing, China, in 1984; the M.S. degree in Electrical Engineering from the Communication University of China, Beijing, China, in 1987; and the Ph.D. degree in Electrical Engineering from Beijing Jiaotong University, Beijing, China, in 2009. He is currently a Professor with the Communication University of China, Beijing, China. His research interests include the areas of computational electromagnetics, the Finite-Difference Time-Domain (FDTD) methods, electromagnetic modeling and simulation of antennas, and communication antennas. Li is a Senior Member of the Chinese Institute of Electronics.

Longdan Tan received the B.S. and M.S. degree in Electromagnetic Field and Microwave Technology from the Communication University of China, Beijing, China, in 2012 and 2015, respectively. He is currently working at Network Operation Center, Startimes Media Group, Beijing, China as a Communication Engineer. His research interests include conformal antennas, wideband antennas for wireless communications and RF circuits.

Xiaole Kang received the B.S. and M.S. degree in Electromagnetic Field and Microwave Technology from the Communication University of China, Beijing, China, in 2010 and 2013, respectively. From 2013 to 2014, she was an Assistant Engineer of Shandong Academy of Sciences, Jinan, China, where she was responsible for the design of UWB antenna for through-wall radar system. She is currently pursuing the Ph.D. degree in Electromagnetic Field and Microwave Technology at the Communication University of China. Her research interests include conformal antennas, wideband antennas for wireless communications and RF circuits.

Jianxun Su received the M.S. and the Ph.D. degree in Electromagnetic Field and Microwave Technology from the Communication University of China and Beijing Institute of Technology, Beijing, China, in 2008 and 2011, respectively. From 2011 to 2013, he was with East China Research Institute of Electronic Engineering (ECRIEE), where he engaged in phased-array research. He is currently working as Postdoctoral Fellow at Electromagnetic Laboratory, Communication University of China. His special research interests include integral equation methods for electromagnetic problems and periodic structure analysis.

Qingxin Guo received the B.S., M.S. and Ph.D. degrees in Electromagnetic Field and Microwave Technology from the Communication University of China, Beijing, China, in 1997, 2006 and 2013, respectively. From 1997 to 2002, he was an Engineer and Project Manager of the Xiamen Overseas Chinese Electronics Co., Ltd., Xiamen, China, where he was involved with the repeaters and the mobile phone for the GSM system. From 2002 to 2004, he was a Project Manager of the Beijing Gigamega Electronics Co., Ltd., Beijing, China, where he was responsible for the design of a high-power amplifier for UHF TV transmitter and FM transmitter. From 2004 to 2008, he was a Project Manager of the Beijing Filcom Technology Co. Ltd., Beijing, China, where he was responsible for the design of a high-power combiner and multiplexer. He joined the Communication University of China in 2006. From 2011 to 2012, he was a Visiting Researcher with the Electromagnetic Communication Laboratory (EMC Lab), which is affiliated with the Electrical Engineering Department, Pennsylvania State University, University Park. His research interests include antennas, microwave passive components, and RF circuits.

Yaoqing Yang received his B.S. degree from the Beijing Jiaotong University, China, in 1983, and his M.S. degree from the Communication University of China, China, in 1986, both in Electrical Engineering. He received his Ph.D. degree in the area of Wireless Communications and Networks from the University of Texas (UT) at Austin in 2006. He is now an Associate Professor in the Department of Electrical and Computer Engineering, University of Nebraska-Lincoln (UNL). His current research interests lie in wireless communications and networks with emphasis on radio channel characterizations, cognitive radio networks, and statistical signal processing. Yang is a Senior Member of IEEE.

Junhong Wang received the B.S. and M.S. degrees in Electrical Engineering from the University of Electronic Science and Technology of China, Chengdu, China, in 1988 and 1991 respectively, and the Ph.D. degree in Electrical Engineering from Southwest Jiaotong University, Chengdu, China, in 1994. In 1995, he joined the faculty of the Department of Electrical Engineering, Beijing Jiaotong University, Beijing, China, where he became a Professor in 1999. From January 1999 to June 2000, he was a Research Associate with the Department of Electric Engineering, City University of Hong Kong, Hong Kong, China. From July 2002 to July 2003, he was a Research Scientist with Temasek Laboratories, National University of Singapore, Singapore. He is currently with the Key Laboratory of ALL Optical Network and Advanced Telecommunication Network, Ministry of Education of China, Beijing Jiaotong University, and also with the Institute of Lightwave Technology, Beijing Jiaotong University. His research interests include numerical methods, antennas, scattering, and leaky wave structures.