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Research Article

Uniplanar Millimeter-Wave Log-Periodic Dipole Array Antenna Fed by Coplanar Waveguide

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A uniplanar millimeter-wave broadband printed log-periodic dipole array (PLPDA) antenna fed by coplanar waveguide (CPW) is introduced. This proposed structure consists of several active dipole elements, feeding lines, parallel coupled line, and the CPW, which are etched on a single metallic layer of the substrate. The parallel coupled line can be optimized to act as a transformer between the CPW and the PLPDA antenna. Meanwhile, this transform performs the task of a balun to achieve a wideband, low cost, low loss, simple directional antenna. The uniplanar nature makes the antenna suitable to be integrated into modern printed communication circuits, especially the monolithic millimeter-wave integrated circuits (MMIC). The antenna has been carefully examined and measured to present the return loss, far-field patterns, and antenna gain.

1. Introduction

With the development of the modern wireless communication systems with low transmitted power and high data rate demand, the wideband and high-directivity antenna becomes an essential component in the front-end system. The traditional log-periodic dipole array (LPDA) antenna in a free space environment is first introduced by Isbell [1]. Because of its end-fire characteristics, such as the fixed peak radiation and the stable radiation pattern, and broad bandwidth, the LPDA antenna has been widely studied and applied in many communication systems, such as TV, radar, satellite, and indoor commutations [2–7]. However, the traditional LPDA antenna is a dimensional structure, so it is difficult to design, debug, and achieve mass productivity at high frequency band, especially at millimeter-wave band. More seriously, it cannot be integrated with modern planar commutation system.

In order to overcome the drawbacks of the LPDA antenna, the dipole elements and the feeding lines can be achieved by using the modern printed circuit board (PCB) technology; this antenna can be called printed log-periodic dipole arrays (PLPDA) antenna [8–13]. Therefore, the PLPDA antenna takes the advantages of low profile, low cost, high stability, and ease to be massively produced and deeply integrated into modern planar integrated wireless communication systems.

Similar to the printed quasi-Yagi [14], the performances and design complexity are mainly challenged by the selection of an appropriate feeding network. The PLPDA antenna was initially introduced by Camlbell et al. [8]. The antenna is designed on a double-layer substrate, and its dipole elements, fed by the stripline in the middle metallic layer, are cross-symmetrically distributed on the top and the bottom metallic layer, respectively. But double-layer substrate configuration increases the cost of the antenna [8–11]. In order to reduce the fabrication cost, the single layer PLPDA antennas fed by coaxial cables have been proposed [12, 13]. Unfortunately, the coaxial cables should be wielded with the top and bottom feeding lines of the PLPDA antenna, which will bring significant fabrication error at high frequency band. Substrate integrated waveguide (SIW) [15–18], also named laminated waveguide [19] or postwall waveguide [20], has been deeply studied on the operation principle and widely applied in the design of the microwave and millimeter-wave antenna, filter, coupler, and systems [21–26]. Because of the intrinsic balun characteristics between the top and bottom metallic layer, the SIW can be applied to the feeding network design of the PLPDA antenna [27]. However, the size of the SIW is larger than that of the traditional printed transmission lines, such as the slot line, microstrip, and CPW. More seriously, the dipole elements of the PLPDA antenna mentioned above are totally cross-symmetrically spaced along the parallel feeding line on respective sides of the dielectric substrate, which increases the PCB fabrication cost compared to the single metallic layer design.

It is well known that, for millimeter-wave integrated circuits, CPW has several distinct advantages over microstrip, which includes the surface-mount integration, lower phase velocity variation, and good characteristic impedance control [28]. Specifically, the CPW features a wideband, low loss and fabrication cost, and simple uniplanar structure without the need for the vias and bottom metallic ground compared to the conductor-backed CPW structure [14, 29–32]. The slot PLPDA antenna can be fed by CPW [33], but the slot antenna suffers from high insertion loss and lower power handling capability.

In this paper, a new broadband CPW feed for the uniplanar PLPDA antenna is proposed. The advantage of the novel proposed antenna is that it avoids bond wires or air-bridge lines, and all the printed dipoles and the feeding lines as well as the CPW are printed on only one side of the substrate without the vias. Therefore, this novel uniplanar millimeter-wave PLPDA antenna alleviates the design complexity, reduce the cost, and can be easy to integrate with MMIC.

2. Antenna Design Principle

2.1. Geometrical Layout. The proposed PLPDA antenna with four dipole elements fed by CPW is shown in Figure 1. In the antenna design, the dipole elements are symmetrically distributed along the two feeding lines on the top metallic layer of the substrate. A gap W_g is to lead the opposite current direction between the two feeding lines. L_n, W_n, and S_n are the length, width, and spacing of the dipole elements for the PLPDA antenna. W_{sef} is the width of both the feed line and the central line of the CPW. The 50 Ω CPW is transited to the two feed lines by the two parallel uniplanar couple lines. One parallel line is connected to the central line of the CPW, and the other one is connected to one side of the ground of the CPW. The array is fed from the longest element. The proposed antenna is printed on a single layer dielectric substrate, and h depresses its height. The dipole elements, the feeding lines, the parallel uniplanar couple lines; and the CPW are totally etched on the top side of the substrate.

2.2. Current Distribution. The magnetic distribution of the CPW at dominant mode, including the side view and the top view, is shown in Figure 2. It can be seen that a 180° phase difference is presented between the central line and the ground of the CPW. The CPW can perform a good balun line to feed the PLPDA antenna over wide operating frequency band because of the wide bandwidth of its dominant mode.

Sometimes the CPW should be balanced between the left and the right ground with air-bridge line, which greatly

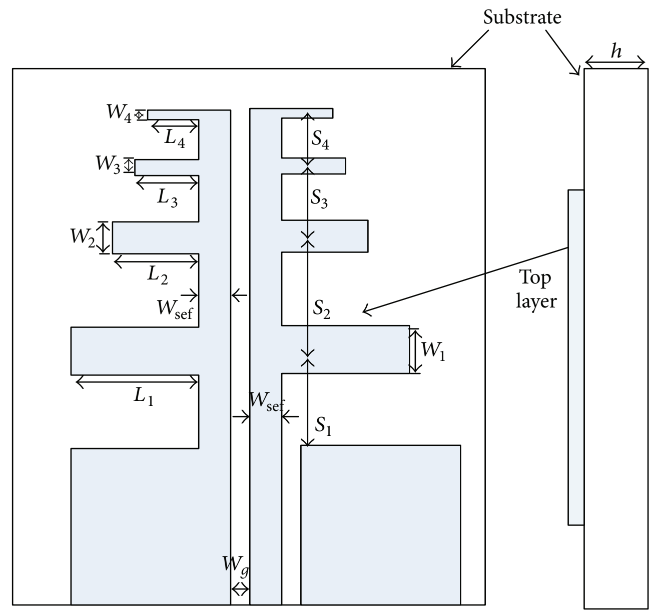

Figure 1: Geometry of the proposed CPW PLPDA antenna.

complexes the circuits design and increases the fabrication cost. In this design, the CPW is connected to the PLPDA antenna by the parallel uniplanar couple lines, which can be carefully designed to take the task of a balun to avoid the air-bridge line. Therefore, the length of the parallel uniplanar couple lines is the key factor for the proposed CPW PLPDA antenna.

Figure 3 shows the simulated current distribution of the dipole element at 35 GHz. The current is mainly concentrated in the region between the second and third dipole elements at 35 GHz. It can be seen that the currents of the second and third dipole elements on the left side are in phase with that printed in the opposite direction on the right side of the substrate, and the currents of other dipole elements on the left side are out of phase with that printed in the opposite direction on the right side of the substrate. Therefore, it is demonstrated that the proposed CPW PLPDA antenna can be radiated in the monodirection towards the shorter elements.

2.3. Parameters Determination. The proposed CPW PLPDA antenna is composed of three parts: dipole elements spaced with the feeding lines, parallel couple lines, and the CPW. At first, the parameters of the dipole elements spaced with the feeding lines can be primarily determined by the modified Carrel's method [2], including the consideration of the effective relative dielectric permittivity in computations to dipole lengths and spacing.

The length of each half wavelength dipole is depressed by L_{en}, which can be given by

$$L_{en} = 2 * \left(L_{(n+1)} + W_{sef}\right) + W_g, \tag{1}$$

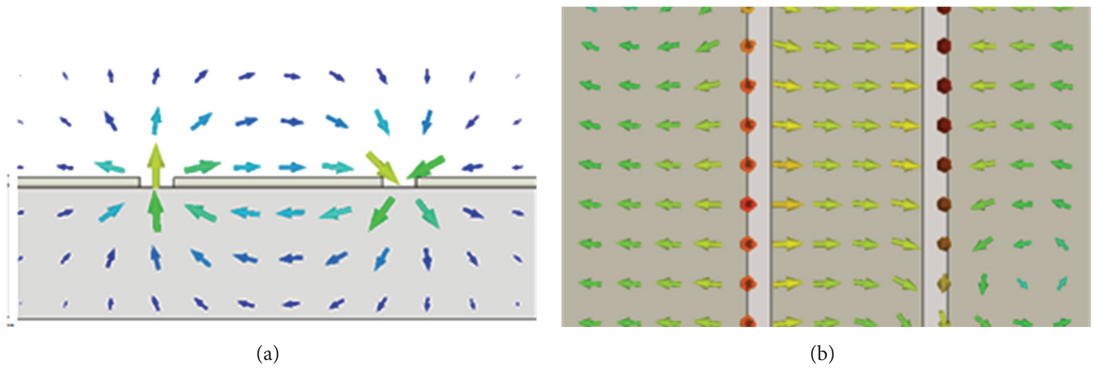

FIGURE 2: Simulated magnetic field distribution of the dominant mode in the cross view (a) and the top view (b) of the CPW.

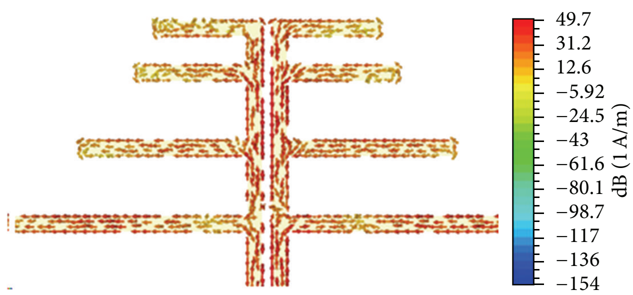

FIGURE 3: Simulated current distribution of the CPW PLPDA antenna at 35 GHz.

and according to the PLPDA antenna design principle, the parameters L_n, S_n, and W_n can be determined by the scale factor τ and spacing factor σ as given by [7]

$$\tau = \frac{L_{e(n+1)}}{L_{en}} = \frac{W_{n+1}}{W_n}, \tag{2}$$

$$\sigma = \frac{1-\tau}{4 * \tan\alpha} = \frac{S_n}{2 * L_{en}}, \tag{3}$$

where L_1 can be calculated by

$$\begin{gathered} L_1 + W_{\text{sef}} + \frac{W_g}{2} = \frac{\lambda_{\text{eff}\min}}{4} = \frac{c}{4 f_{\max}\sqrt{\varepsilon_{\text{eff}}}}, \\ \varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r + 1}{2}\frac{1}{\sqrt{1 + 12h/W_1}}, \end{gathered} \tag{4}$$

where $\lambda_{\text{eff}\min}$ is the shortest effective working wavelength, ε_{eff} is the effective dielectric permittivity, ε_r is the dielectric constant, h is the substrate thickness, and W_1 is the width of the first dipole element.

The proposed CPW PLPDA antenna is fabricated on Fr-4 with a thickness of 0.5 mm, $\varepsilon_r = 4.3$, $\tan\delta = 0.025$, and then the parameters of the 5 Ω CPW W_g and W_{sef} can be determined according to the transmission line theory.

The parallel couple line can take the tasks of the balun. It performs as a transformer between the CPW and PLPDA antenna. So the determination of S_1 is one of the key factors for the antenna design, which can be primarily chosen as quarter operating wavelength.

The length of the longest dipole L_1 can be calculated from (4) according to the lowest operating frequency. Then the length of the other elements can be calculated from (2); meanwhile, the parameters W_1 and W_{sef} can be optimized by the full-wave simulation software HFSS. The width of the other elements W_n and the spacing between the elements S_n can be obtained from (2) and (3). After optimization, the detailed dimensions of the proposed antenna are W_1 = 0.9 mm, W_2 = 0.7 mm, W_3 = 0.5 mm, W_4 = 0.4 mm, L_1 = 2.63 mm, L_2 = 1.63 mm, L_3 = 0.88 mm, L_4 = 0.63 mm, S_1 = 1.7 m, S_2 = 1 mm, S_3 = 1 mm, S_4 = 0.6 mm, W_{sef} = 0.8 mm, and W_g = 0.13 mm.

3. Experimental Results

The CPW PLPDA antenna at 25 GHz–40 GHz is designed, fabricated, and tested. The measured and simulated input return losses of the proposed antenna are presented by Figure 4. The $|S_{11}|$ is better than 10 dB from 28 GHz to 38.5 GHz. Note that over a narrow band (around 35 GHz), return loss values in excess of 15 dB can be obtained. However, compared with the simulated result, the measured center frequency of the proposed antenna is shifted toward the lower frequency about 1.5 GHz, which is mainly introduced by the relationship between the frequency and the dielectric permittivity without consideration in the simulation.

The radiation patterns and gain are examined in the microwave chamber. The measured and simulated antenna gain of the proposed antenna is shown in Figure 5. It can be seen that the CPW PLPDA antenna can achieve the maximum gain of 4 dBi at 39 GHz. The low gain, varying from 1.5 dBi to 4 dBi over the entire operating frequency band, is resulted from the large substrate losses of the Fr-4. The measured antenna gain of the CPW PLPDA antenna is less than that of the simulated results, which is mainly provided by the losses of the connectors and the increasing substrate loss of the antenna at millimeter-waves.

The radiation patterns of the 28 GHz–40 GHz CPW PLPDA antenna are measured over the entire band, which present the similar characteristics. So for brevity, only

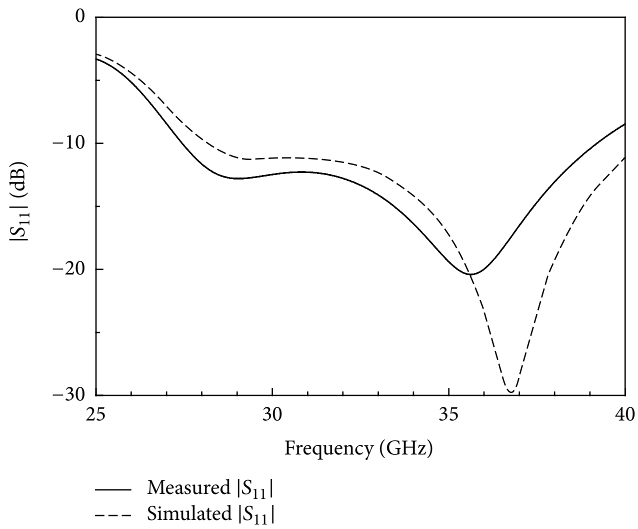

Figure 4: Simulated and measured return loss of the proposed antenna.

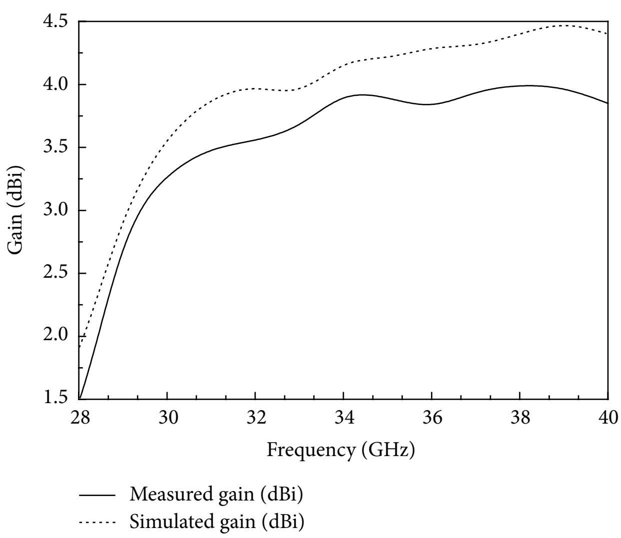

Figure 5: Simulated and measured gain of the proposed antenna.

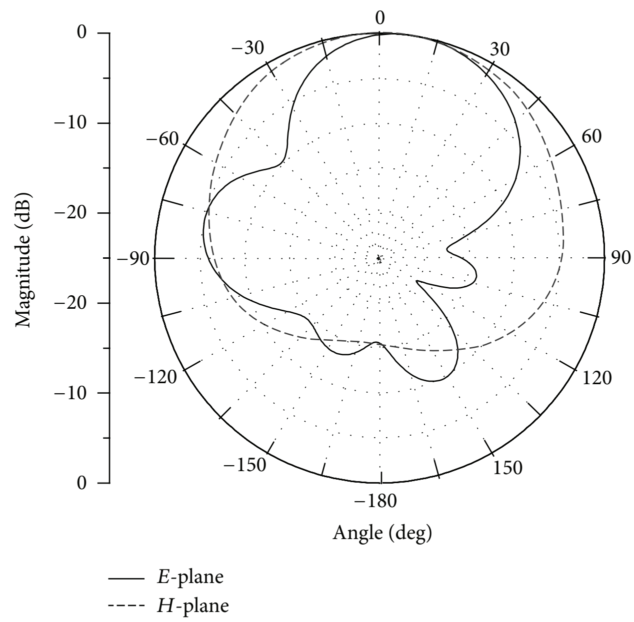

Figure 6: Measured far-field of the proposed PLPDA antenna at 30 GHz.

the 35 GHz radiation patterns are shown in Figure 6, which shows that the front-to-back ratio is larger than 15 dB. However, the main beam is shifted from the bore sight, which is caused by the nature asymmetrical feature between the central line and the ground of the CPW.

4. Conclusion

The proposed PLPDA antenna fed by CPW provides a viable choice for millimeter-wave broadband printed antennas in modern wireless communication system. The new CPW feed is more appropriate than that introduced before at millimeter-wave frequency, as it avoids the requirement for air-bridge line, vias, and any additional balun design in direct CPW-to-PLPDA connections. Therefore, the proposed antenna can be achieved on only one metallic layer of a single layer substrate, which can reduce the loss, cost, and complexity for the fabrication. The prototype for the proposed uniplanar CPW PLPDA antenna has been fabricated and measured. Radiation pattern and gain of the CPW PLPDA antenna are studied and presented. The advantages such as low cost, broadband, compactness, and simplicity are verified by the experiment. The design concept can easily be scaled for applications with different bandwidth and directivity requirements by adjusting the parameters of τ, σ, W_1, S_1, and W_{sef}, which can also improve the VSWR. So the proposed antenna can be used for wideband integrated multimode radio communication such as a digital cordless system (DCS), personal communication system (PCS), WLAN, UWB systems, and some systems required to work at Ka band.

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References

[1] D. Isbell, "Log periodic dipole arrays," *IRE Transactions on Antennas and Propagation*, vol. 8, no. 3, pp. 260–267, 1960.

[2] R. Carrel, "The design of the log-periodic dipole antenna," in *Proceedings of the IRE International Conventional Record*, vol. 9, pp. 61–75, March 1961.

[3] J. Carr, "Some variations in log-periodic antenna structures," *IRE Transactions on Antennas and Propagation*, vol. 9, no. 2, pp. 229–230, 1961.

[4] R. Mittra and K. E. Jones, "Theoretical brillouin (k-β) diagrams for monopole and dipole arrays and their applications to log-periodic antennas," *IEEE Transactions on Antennas and Propagation*, vol. 51, no. 3, pp. 533–540, 1964.

[5] N. Barbano, "Waveguide-fed log periodic antennas," *IRE Transactions on Antennas and Propagation*, vol. 16, no. 3, pp. 357–358, 1968.

[6] J. Wolter, "Solution of Maxwell's equations for log-periodic dipole antennas," *IEEE Transactions on Antennas and Propagation*, vol. 18, no. 6, pp. 734–741, 1970.

[7] A. B. Constantine, *Antenna Theory: Analysis and Design*, Wiley-Interscience, New York, NY, USA, 2005.

[8] C. K. Campbell, I. Traboulay, M. S. Suuthers, and H. Kneve, "Design of a stripline log-periodic dipole antenna," *IEEE Transactions on Antennas and Propagation*, vol. 25, no. 5, pp. 718–721, 1977.

[9] P. Alakananda and G. Inderjeet, "An analysis of log periodic antenna with printed dipoles," *IEEE Transactions on Antennas and Propagation*, vol. 29, no. 2, pp. 114–119, 1981.

[10] R. R. Pantoja, A. R. Sapienza, and F. M. Filho, "A microwave printed planar log-periodic dipole array antenna," *IEEE Transactions on Antennas and Propagation*, vol. 35, no. 10, pp. 1176–1178, 1987.

[11] 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.

[12] X. Liang and Y. W. M. Chia, "New precision wideband direction finding antenna," *IEE Proceedings: Microwaves, Antennas and Propagation*, vol. 148, no. 6, pp. 363–364, 2001.

[13] 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.

[14] H. K. Kan, R. B. Waterhouse, A. M. Abbosh, and M. E. Bialkowski, "Simple broadband planar CPW-fed quasi-Yagi antenna," *IEEE Antennas and Wireless Propagation Letters*, vol. 6, pp. 18–20, 2007.

[15] D. Deslandes and K. Wu, "Integrated microstrip and rectangular waveguide in planar form," *IEEE Microwave and Wireless Components Letters*, vol. 11, no. 2, pp. 68–70, 2001.

[16] D. Deslandes and K. Wu, "Design consideration and performance analysis of substrate integrated waveguide components," in *Proceedings of the 32nd European Microwave Conference*, pp. 1–4, Milan, Italy, September 2002.

[17] F. Xu, Y. Zhang, W. Hong, K. Wu, and T. J. Cui, "Finite-difference frequency-domain algorithm for modeling guided-wave properties of substrate integrated waveguide," *IEEE Transactions on Microwave Theory and Techniques*, vol. 51, no. 11, pp. 2221–2227, 2003.

[18] L. Yan, W. Hong, K. Wu, and T. J. Cui, "Investigations on the propagation characteristics of the substrate integrated waveguide based on the method of lines," *IEE Proceedings: Microwaves, Antennas and Propagation*, vol. 152, no. 1, pp. 35–42, 2005.

[19] H. Uchimura, T. Takenoshita, and M. Fujii, "Development of a 'laminated waveguide'," *IEEE Transactions on Microwave Theory and Techniques*, vol. 46, no. 12, pp. 2438–2443, 1998.

[20] J. Hirokawa and M. Ando, "45° linearly polarized post-wall waveguide- fed parallel-plate slot arrays," *IEE Proceedings on Microwave, Antennas and Propagation*, vol. 147, no. 6, pp. 515–519, 2000.

[21] G. Q. Luo, Z. F. Hu, W. J. Li, X. H. Zhang, L. L. Sun, and J. F. Zheng, "Bandwidth-enhanced low-profile cavity-backed slot antenna by using hybrid SIW cavity modes," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 4, pp. 1698–1704, 2012.

[22] G. Q. Luo, Z. F. Hu, Y. Liang, L. Y. Yu, and L. L. Sun, "Development of low profile cavity backed crossed slot antennas for planar integration," *IEEE Transactions on Antennas and Propagation*, vol. 57, no. 10, pp. 2972–2979, 2009.

[23] G. Q. Luo, Z. F. Hu, L. X. Dong, and L. L. Sun, "Planar slot antenna backed by substrate integrated waveguide cavity," *IEEE Antennas and Wireless Propagation Letters*, vol. 7, pp. 236–239, 2008.

[24] G. Q. Luo, L. L. Sun, and L. X. Dong, "Single probe fed cavity backed circularly polarized antenna," *Microwave and Optical Technology Letters*, vol. 50, no. 11, pp. 2996–2998, 2008.

[25] X.-P. Chen and K. Wu, "Substrate integrated waveguide cross-coupled filter with negative coupling structure," *IEEE Transactions on Microwave Theory and Techniques*, vol. 56, no. 1, pp. 142–149, 2008.

[26] G. H. Zhai, W. Hong, K. Wu et al., "Folded half mode substrate integrated waveguide 3 dB coupler," *IEEE Microwave and Wireless Components Letters*, vol. 18, no. 8, pp. 512–514, 2008.

[27] G. H. Zhai, W. Hong, K. Wu, and Z. Q. Kuai, "Wideband substrate integrated printed log-periodic dipole array antenna," *IET Microwaves, Antennas and Propagation*, vol. 4, no. 7, pp. 899–905, 2010.

[28] I. Wolff, "Design rules and realization of coplanar circuits for communication applications," in *Proceedings of the 23rd European Microwave Conference*, pp. 36–41, Madrid, Spain, September 1993.

[29] F. Taringou, D. Dousset, J. Bornemann, and K. Wu, "Broadband CPW feed for millimetre-wave SIW-based antipodal linearly slot antenna," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 4, pp. 1756–1762, 2013.

[30] A. Grbic and G. V. Eleftheriades, "Leaky CPW-based slot antenna arrays for millimeter-wave applications," *IEEE Transactions on Antennas and Propagation*, vol. 50, no. 11, pp. 1494–1504, 2002.

[31] M. A. P. Lazaro and R. Judaschke, "A 150-GHz CPW-Fed Tapered-Slot Antenna," *IEEE Microwave and Wireless Components Letters*, vol. 14, no. 2, pp. 62–64, 2004.

[32] S. Mestdagh, W. de Raedt, and G. A. E. Vandenbosch, "CPW-fed stacked microstrip antennas," *IEEE Transactions on Antennas and Propagation*, vol. 52, no. 1, pp. 74–83, 2004.

[33] S. H. Kim, J. H. Choi, J. W. Baik, and Y. S. Kim, "CPW-fed log-periodic dumb-bell slot antenna array," *Electronics Letters*, vol. 42, no. 8, pp. 436–438, 2006.