Hindawi
International Journal of Antennas and Propagation
Volume 2019, Article ID 4068572, 7 pages
https://doi.org/10.1155/2019/4068572

Research Article

A Miniaturized Periodic Microstrip Leaky Wave Antenna with Shorting Pins

Bin Xi, Yuanxin Li, and Yunliang Long

School of Electronics and Information Technology, School of Electronics and Communication Technology, Sun Yat-sen University, Guangzhou 510006, China

Correspondence should be addressed to Yuanxin Li; liyuanx@mail.sysu.edu.cn

Received 11 May 2019; Revised 3 July 2019; Accepted 30 July 2019; Published 28 August 2019

Academic Editor: Laura Corchia

A miniaturized periodic microstrip leaky wave antenna (MLWA) with shorting pins is proposed in this paper. The suggested antenna consists of a number of stubs that are periodically placed on the side of the transmission line, with the outside edges of the stubs being all integrated with shorting pins. In comparison with the whole-width stubs MLWA, the proposed antenna has an advantage of effective reduction in antenna size for the similar beam-scanning capability. A series of simple and effective equations were obtained to calculate the propagation constant and determine the operating band of the antenna. The consistency of the calculated and measured propagation constant confirms the validity of the parameter equations. As demonstrated by experimental results, the main beam scans electronically and continuously from 145° to 61° in the *y*-*z* plane as the operating frequency changes from 5.7 GHz to 11.7 GHz.

1. Introduction

The microstrip leaky wave antenna (MLWA), which was developed by Menzel in 1979, exhibits various advantages such as ease to match, low profile, and beam-scanning capability [1]. The beam-scanning capacity is considered to be the most significant characteristic of MLWA, which is a crucial reason why it can be widely applied in multiple fields [2, 3]. The conventional uniform MLWA works in the first high-order mode [4]. Nevertheless, the main beam of the conventional uniform MLWA antenna scans in the forward quadrant only instead of all quadrants of the hemispherical space [5].

Backward to forward beam-scanning capacity is easy to achieve by applying the composite right-/left-handed (CRLH) [6–8]. Unfortunately, CRLH leaky wave antenna design is highly, perhaps excessively, complex [9].

Additionally, the periodic construction can be exploited to achieve backward to forward direction beam scanning, owing to the positive or the negative phase constants [10]. This feature is characterized by the complex propagation constant [11]:

$$k_{zn} = k_z - \frac{2n\pi}{p} = \beta_{zn} - j\alpha_{zn}, \tag{1}$$

where β_{zn} represents the phase constant, α_{zn} indicates the attenuation constant, p is referred to as the spacing, and n denotes the order of space harmonics [12]. The periodic antenna working in either the leaky region ($|\beta_{zn}/k_0| < 1$) or the bound region ($|\beta_{zn}/k_0| > 1$) determines the character of the single space harmonic. The periodic antenna leaks energy by the $n = -1$ space harmonic [13].

Different types of periodic LWA have been developed so far, such as periodically loading the antenna with U-shaped slots [14], periodic structure with fifteen matched unit cells (UCs) that are cascaded [15], periodic antenna with a series of offset truncated DSPSLs [16], or periodic meandered-line-loaded LWA [17]. The main beam of these antennas can be effective on scanning from backward to forward direction.

Over the most recent years, substantial achievements have been made regarding the open stopband (OSB) suppression [18]. An infinite periodic composite right-/left-handed (CRLH) MLWA was analyzed in [19]. A novel

technique for OSB suppression in 1D periodic printed LWA was suggested in [20].

Due to the advantages of easy tuning to the desired frequency that can be optimized, stubs were extensively used in the past for impedance matching or tuning the antenna [21]. 1D periodic combline LWA with OSB suppression was proposed in [22]. In this paper, the introduction of shorting pins is effective on reducing the antenna size in similar beam-scanning capacity with the OSB suppression.

A miniaturized periodic MLWA with shorting pins is presented in this paper. The proposed antenna, as shown in Figure 1, consists of stubs that are periodically placed on the side of the transmission line. The outside edges of stubs are all integrated with shorting pins. In Section 2, the antenna design of the proposed antenna is described. In Section 3, the shorting pins are analyzed and the electric-field distributions of the proposed and whole-width antenna are investigated. A series of simple and effective equations are obtained to calculate the propagation constant, and the validity of equations makes it convenient to determine the operating band for the given structural parameters. Compared with the whole-width MLWA, the proposed miniaturized antenna displays advantage of effective reduction in antenna size for similar beam-scanning capabilities. In Section 4, the measured far-field radiation patterns in the *y-z* plane and the measured gain of the antenna prototype are presented. The *S*-parameters (S_{11}) and normalized propagation constants are also evaluated.

2. Antenna Design

A prototype of the proposed miniaturized periodic MLWA is illustrated in Figure 2. As described above, the proposed antenna is comprises a series of stubs, with the outside edges of the stubs all integrated with shorting pins. To achieve better impedance matching and ease of testing, the proposed miniaturized periodic antenna is designed with two ports, which are theoretically equivalent and interchangeable. The parameters of the proposed MLWA are listed in Table 1. The proposed antenna is fabricated on a substrate with relative permittivity of $\varepsilon_r = 2.65$, dielectric loss tangent of $\tan\delta = 0.005$, and thickness of $h = 0.8$ mm. The radius of the shorting pins is $r = 0.5$ mm.

From Figures 2 and 1(b), a quarter-wavelength matching transformer is introduced to the unit. The matching transformer consists of a microstrip line of width w_T and length l, placed at a distance d_1 from the edge of the stub. By adding a matching section into each unit cell, the impedance (Z_0) can be made almost equal to 50 Ω at the broadside frequency. Thus, the OSB around broadside frequencies can be suppressed.

3. Theoretical Analysis and Formulations

3.1. Shorting Pins. The electric-field distributions of the proposed miniaturized periodic MLWA and whole-width stubs MLWA are shown in Figure 3. From the electric-field distribution of the whole-width stubs MLWA at 9 GHz, as shown in Figure 3(a), the electric field in the middle of the stub is quite weak.

The addition of a shorting pin connects the antenna patch and the ground plane, which forces the electric field to zero, and a mirror reflection is realized. As shown in Figure 3(b), the electric field on the outside edges of stubs is zero. The electric field of each stub is basically the same, and the periodic operating mode is excited. Some periodic modulation is introduced, which suggests that the proposed miniaturized LWA with shorting pins should be the periodic structure. In addition, the main beam of the antenna scans effectively from backward to forward direction as operating frequency increases.

The comparison of the propagation constants of the proposed miniaturized periodic MLWA and the whole-width stubs MLWA, which are simulated by *Ansoft HFSS*, are shown in Figure 4. The proposed miniaturized periodic MLWA has the advantage of effectively reducing the antenna size. The antenna width is reduced by as much as 50% as compared to the whole-width MLWA in similar beam-scanning capability.

3.2. Complex Propagation Constant. The complex propagation constant k_{zn} of the proposed periodic structure could be expressed by Floquet's equation [23]:

$$k_{zn} = \beta_{zn} - j\alpha_{zn} = k_z - \frac{2\pi}{p}, \tag{2}$$

$$p = d. \tag{3}$$

The phase constant β_{zn} determines the direction of the main beam, which could be given by the following equation: [24].

$$\frac{\beta_{zn}}{k_0} = \sin\left(\frac{\pi}{2} - \theta\right), \tag{4}$$

the angle θ of the main beam is defined by the phase constant with variation of the operating frequency. The attenuation constant α_{zn} is related to the half-power beam-width θ_{HPBW} of the main beam:

$$\frac{\alpha_{zn}}{k_0} = 0.18\theta_{\mathrm{HPBW}} \cos\left(\frac{\pi}{2} - \theta\right). \tag{5}$$

The complex propagation constant k_z of the periodic unit could be calculated as follows [25, 26]:

$$k_z = \sqrt{\omega^2\mu\varepsilon_r - k_x^2}, \tag{6}$$

$$\exp\left(jk_xW'\right) = -\frac{k_x - \omega\mu y_\omega}{k_x + \omega\mu y_\omega}, \tag{7}$$

$$y_\omega = \frac{h}{120\lambda_0} + j\frac{k_0\varepsilon_{\mathrm{eff}}\Delta W}{120\pi}, \tag{8}$$

where W' in (7) represents the equivalent width of the antenna and ΔW in (8) indicates the equivalent extension. After extensive simulated analysis using *Ansoft HFSS*, W' and ΔW could be calculated as follows:

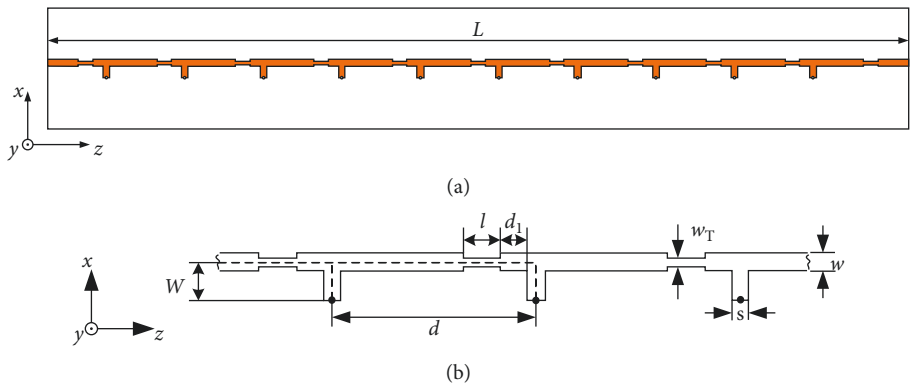

Figure 1: The proposed miniaturized periodic microstrip leaky wave antenna with shorting pins. (a) Top view; (b) detail view.

Figure 2: Prototype of the proposed miniaturized periodic MLWA with shorting pins.

Table 1: Parameters of the radiation patch.

Symbol	Parameter	Size (mm)
W	Length of the stub	5
d	Spacing of the stubs	26
s	Width of the stub	2.2
w	Width of the transmission line	2.2
w_T	Width of the transformer	1.25
l	Length of the transformer	4.8
d_1	Distance from the stub	3.4
L	Whole length of the antenna	285

$$W' = 1.497W + 22.095h\frac{\varepsilon_{\text{eff}} + 18.012}{\varepsilon_{\text{eff}} + 5.053}\frac{d/h - 6.404}{d/h + 35.603}\frac{h/s - 0.389}{h/s - 0.386}, \tag{9}$$

$$\Delta W = -0.841h\frac{\varepsilon_{\text{eff}} - 2.221}{\varepsilon_{\text{eff}} - 2.214}\frac{W'/h - 40.973}{W'/h - 40.347}\frac{d/s - 13.621}{d/s - 13.623}, \tag{10}$$

where W represents the length of the stubs, d indicates the spacing between the stubs, s denotes the width of the stubs, and h stands for the thickness of the substrate.

ε_{eff} is referred to as the effective dielectric constant:

$$\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\frac{1}{\sqrt{1 + 10h/W'}}. \tag{11}$$

There are two chief parameters which affect the propagation performance of the proposed antenna: length of the stub W and the structural spacing d. The comparison of the propagation constants, which are calculated by (2)~(11) and simulated by *Ansoft HFSS*, are presented in Figures 5 and 6. The normalized phase constants are variable from −1 to 1, and the calculated results match well with the simulated results. The attenuation constants are consistent, which indicates the validity of (2)~(11).

As revealed in Figure 5, the operating band of the miniaturized periodic MLWA shifts from 5.8 GHz~11 GHz to 5 GHz~10.8 GHz as the length of the stubs (W) increases from 4 mm to 8 mm. As a result, the operating band shifts toward the lower frequency as the length of the stub increases. The result is largely attributed to the increase in the equivalent width of the antenna.

The effect exerted by the structural spacing (d) on the propagation constant is shown in Figure 6. The propagation curve shifts upwards as d increases from 22 mm to 30 mm. This effect is manifested in the operating band that shifts toward the lower frequency.

As evidenced by the fitting of the simulated results with the calculated results, the operating band can be determined by (2)~(11). The method of using formulas is quick and easy.

4. Measurement Results

The radiation patterns and gain of the proposed miniaturized periodic MLWA in the far-field condition are measured. The propagation constants and S-parameters are also shown.

The measured y-z plane radiation patterns are illustrated in Figures 7–9. As expected, the main beam scans from backward to forward direction as the operating frequency increases. Continuous beam scanning around broadside direction is achieved in Figure 8, and the OSB is suppressed. As indicated by the experimental results, the main beam of the proposed antenna scans electronically and continuously from 145° to 61° in the y-z plane as the operating frequency increases from 5.7 GHz to 11.7 GHz.

In Figure 7, the main beam steers in the backward direction. At the operating frequencies of 5.7 GHz, 6.5 GHz, and 7.7 GHz, the main beam is directed at 145°, 120°, and 98°, respectively. In Figure 8, the operating frequencies are 7.9 GHz, 8.3 GHz, and 8.9 GHz. At these frequencies, the main beam directs at $\theta = 96°$, $\theta = 91°$, and $\theta = 84°$. The main beam steers in the broadside direction. As shown in Figure 9, the main beam points at 82°, 72°, and 61° in the forward

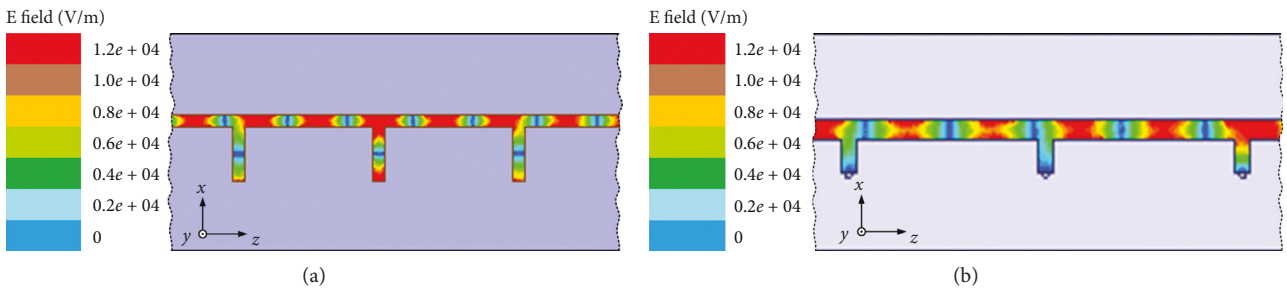

Figure 3: Electric-field distributions of the miniaturized and whole-width MLWA at 9 GHz. (a) Whole width; (b) miniaturized.

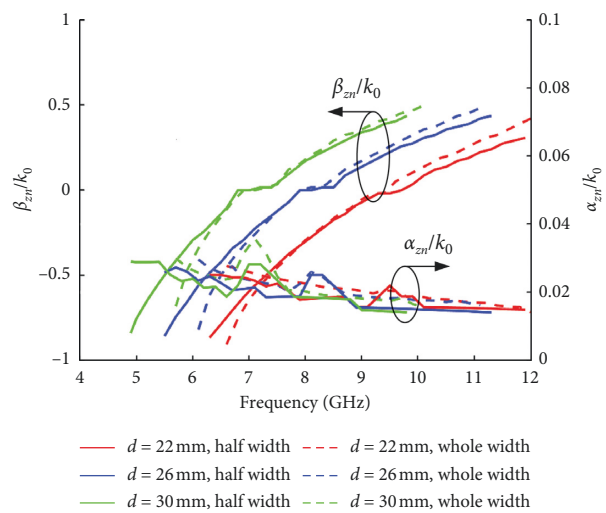

Figure 4: The propagation constants of the miniaturized and whole-width MLWA by *HFSS*.

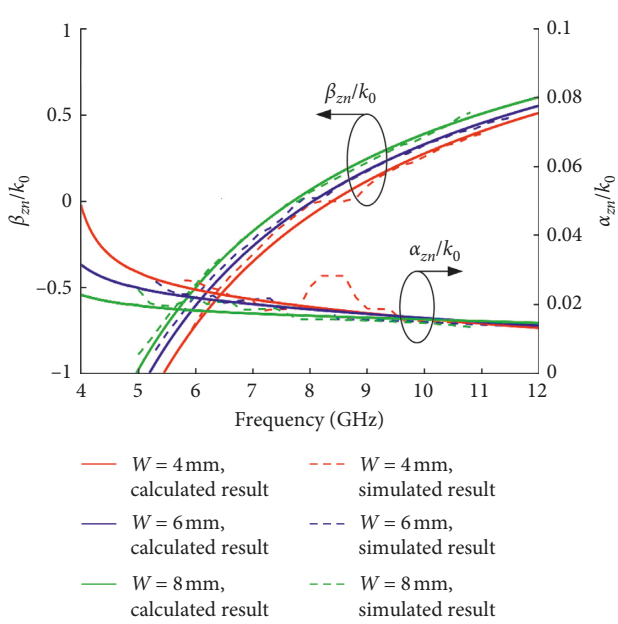

Figure 5: The propagation constants calculated by (3)~(11) and simulated by *HFSS* of the proposed antenna with different W (d = 26 mm).

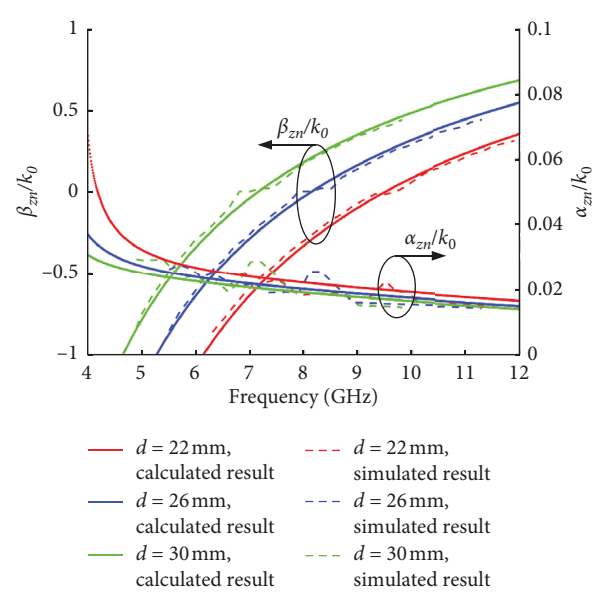

Figure 6: The propagation constants calculated by (3)~(11) and simulated by *HFSS* of the proposed antenna with different d (W = 5 mm).

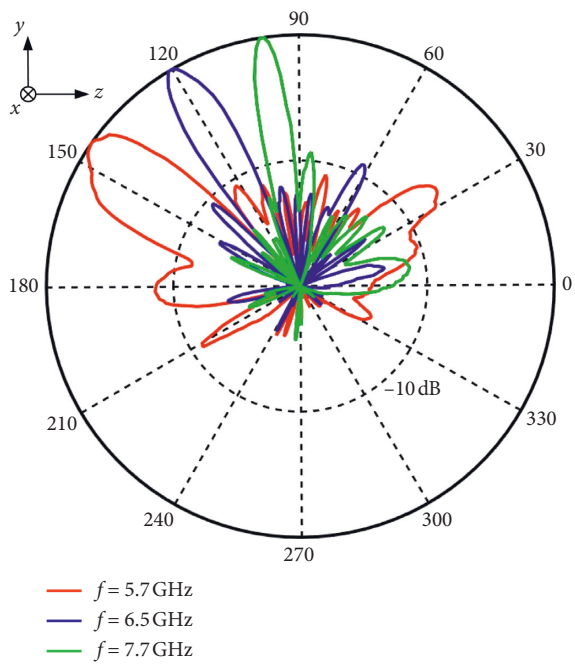

Figure 7: The measured radiation pattern of the proposed periodic antenna in the backward direction.

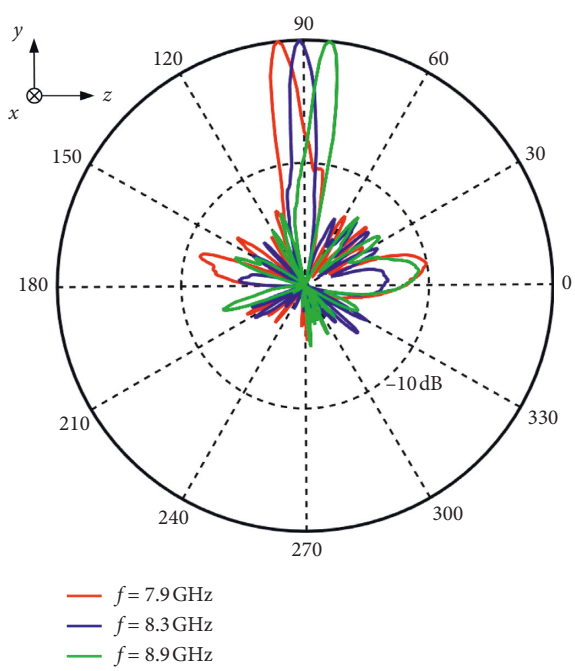

Figure 8: The measured radiation pattern of the proposed periodic antenna in the broadside direction.

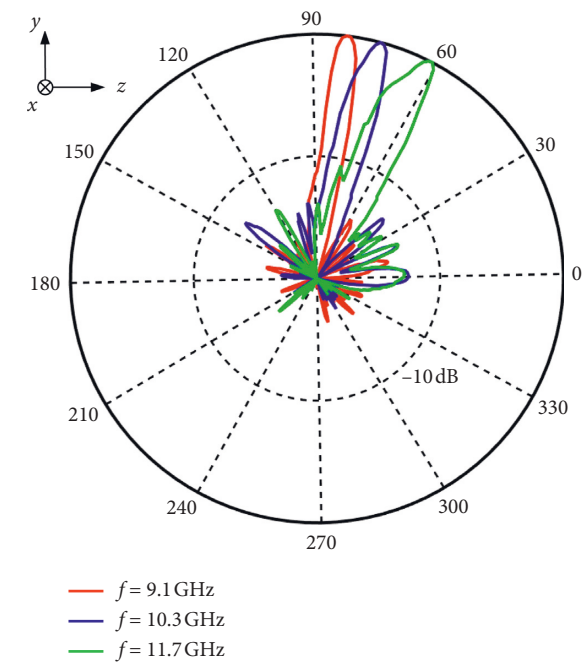

Figure 9: The measured radiation pattern of the proposed periodic antenna in the forward direction.

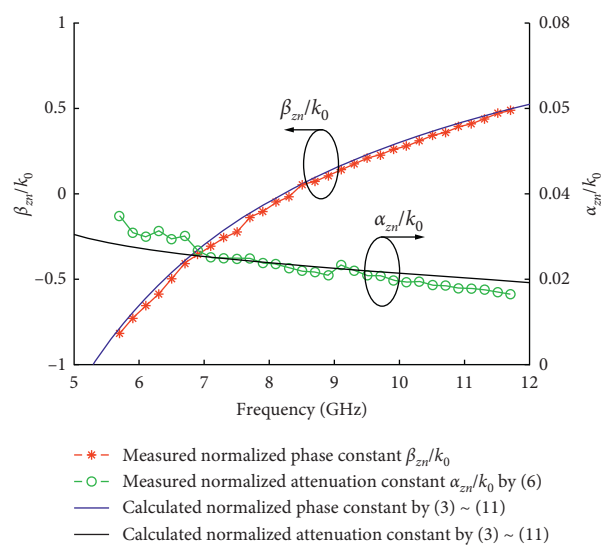

Figure 10: Comparison of the calculated by (3)~(11) and measured propagation constants of the proposed MLWA.

direction at operating frequencies of 9.1 GHz, 10.3 GHz, and 11.7 GHz.

The normalized phase constants β_{zn}/k_0 and the attenuation constants α_{zn}/k_0 ($k_0 = 2\pi/\lambda_0$ is the free space wave number) of the proposed antenna are shown in Figure 10. The measured normalized phase constants confirm well to the results calculated by (2)~(11). Besides, the trend of the measured and calculated normalized attenuation constant are consistent. The fitting result further validates the feasibility of (2)~(11), and the validity of equations makes it convenient to determine the operating band for given structural parameters.

The reflection coefficient and the measured gain of the proposed antenna are presented in Figure 11. The simulated and measured reflection coefficients (S_{11}) are mostly less than −10 dB in the operating bandwidth range of 5.7 to 11.7 GHz. As expected, the measured gain is essentially constant as the beam is scanned through the broadside

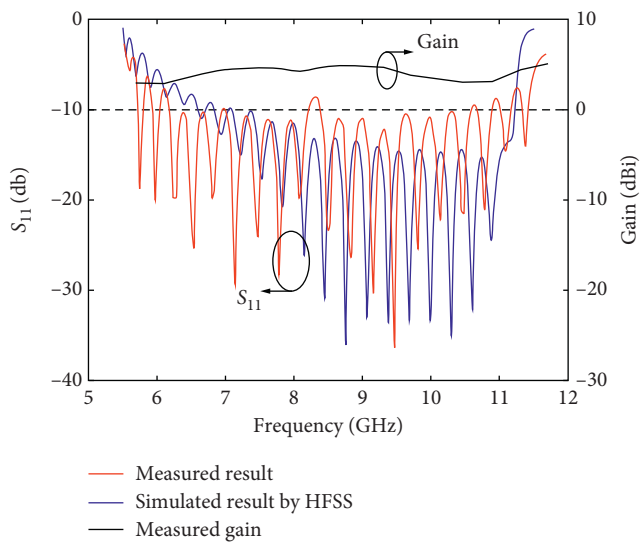

Figure 11: The reflection coefficient and measured gain against frequency of the proposed periodic MLWA.

Table 2: Comparison between parameters/characteristics.

Antenna	Patch width (mm)	Operating band (GHz)	Beam scanning range	Measured gain (dBi)
[3]	21	9.8~12	143°~67°	6~10.7
[7]	40	8~15	180°~70°	7~10.4
[13]	12	3.4~4.3	122°~75°	>6
[17]	13	10.8~16	150°~56°	8~11.5
This work	**6.1**	5.7~11.7	145°~61°	3.72~5.9

direction. From 5.7 to 11.7 GHz, the measured realized gain is consistent with only a 2.18 dBi gain variation. An excellent match is achieved, and the antenna has been successful in suppressing the OSB.

A comparison performed between parameters/characteristics of the proposed periodic antenna and previously published studies is indicated in Table 2. The advantage of effective reduction in antenna size is apparent compared with the existing periodic antenna. Due to the reduction in antenna width, the measured realized gain is reduced as compared to previously published studies. Despite this, the radiation pattern is excellent, and the measured realized gain is consistent over the scanning band.

5. Conclusion

In this paper, a miniaturized periodic MLWA with shorting pins is suggested. The proposed antenna consists of a series of stubs, which is periodically placed on the side of the transmission line. The outside edges of the stubs are all integrated with shorting pins. The proposed miniaturized periodic MLWA shows the advantage of effective reduction in antenna size. The antenna width is reduced by as much as 50% when compared to the whole-width MLWA in similar beam-scanning capability. A series of simple equations were obtained to calculate the propagation constant of the proposed periodic MLWA, and the validity of equations makes it convenient to determine the operating band for given structural parameters. An excellent consistency among the calculated, simulated, and measured results validated the effectiveness of the parameter equations. The periodic structure allows its main beam to scan from 145° to 61° as the operating frequency changes from 5.7 GHz to 11.7 GHz. The proposed antenna is simple and easy to manufacture, which will make it suitable for application in the automobile radar system or the traffic control.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

Acknowledgments

This work was supported by the Nature Science Foundation of Guangdong Province under Grant no. 2015A030312010.

References

[1] W. Menzel, "A new travelling-wave antenna in microstrip," *AEU*, vol. 33, no. 4, pp. 137–140, 1979.

[2] N. Yang, C. Caloz, and K. Wu, "Full-space scanning periodic phase-reversal leaky-wave antenna," *IEEE Transactions on*

Microwave Theory and Techniques, vol. 58, no. 10, pp. 2619–2632, 2010.

[3] K. Chen, Y. Zhang, S. He, H. Chen, and G. Zhu, "A novel frequency scanning leaky-wave antenna based on corrugated substrate integrated waveguide," *International Journal of Antennas and Propagation*, vol. 2018, Article ID 5034721, 6 pages, 2018.

[4] G. M. Zelinski, G. A. Thiele, M. L. Hastriter, M. J. Havrilla, and A. J. Terzuoli, "Half width leaky wave antennas," *IET Microwaves, Antennas & Propagation*, vol. 1, no. 2, pp. 341–348, 2007.

[5] R. D. Seager and J. C. Vardaxoglou, "Characterisation of leaky wave antennas constructed from solid rectangular waveguides with a dipole frequency selective surface sidewall," in *Proceedings of the IEE National Conference on Antennas and Propagation*, no. 461, pp. 295–298, Orlando, FL, USA, July 1999.

[6] D. Patron, Y. Liu, and K. R. Dandekar, "A miniaturized reconfigurable CRLH leaky-wave antenna using complementary split-ring resonators," *Journal of Electrical and Computer Engineering*, vol. 2018, Article ID 6839028, 12 pages, 2018.

[7] Z. Fu, T. Zhang, T. Wu, Y. Lan, W. Huang, and L. He, "Wide-angle frequency scanning leaky wave antenna loaded CSRR patch based on SSPP transmission line," *International Journal of Antennas and Propagation*, vol. 2019, Article ID 2613591, 11 pages, 2019.

[8] D. K. Karmokar, S.-L. Chen, T. S. Bird, and Y. J. Guo, "Single-layer multi-via loaded CRLH leaky-wave antennas for wide-angle beam scanning with consistent gain," *IEEE Antennas and Wireless Propagation Letters*, vol. 18, no. 2, pp. 313–317, 2019.

[9] W. N. Huang, Y. J. Cheng, and H. Deng, "Substrate integrated waveguide leaky-wave antenna conforming to conical shape surface," *International Journal of Antennas and Propagation*, vol. 2015, Article ID 359670, 7 pages, 2015.

[10] D. Sanchez-Escuderos, M. Ferrando-Bataller, J. I. Herranz, and M. Cabedo-Fabres, "Periodic leaky-wave antenna on planar Goubau line at millimeter-wave frequencies," *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 1006–1009, 2013.

[11] Y. D. Lin and J. W. Sheen, "Mode distinction and radiation-efficiency analysis of planar leaky-wave line source," *IEEE Transactions on Microwave Theory and Techniques*, vol. 45, no. 10, pp. 1672–1680, 1997.

[12] Y. X. Li, Q. Xue, E. K.-N. Yung, and Y. L. Long, "The periodic half-width microstrip leaky-wave antenna with a backward to forward scanning capability," *IEEE Transactions on Antennas and Propagation*, vol. 58, no. 3, pp. 963–966, 2010.

[13] L. Liu, C. Caloz, and T. Itoh, "Dominant mode leaky-wave antenna with backfire-to-endfire scanning capability," *Electronics Letters*, vol. 38, no. 23, pp. 1414–1416, 2002.

[14] D. K. Larmokar and K. P. Esselle, "Periodic U-slot-loaded dual-band half-width microstrip leaky-wave antennas for forward and backward beam scanning," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 12, pp. 5372–5381, 2015.

[15] M. H. Rahmani and D. Deslandes, "Backward to forward scanning periodic leaky-wave antenna with wide scanning range," *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 7, pp. 3326–3335, 2017.

[16] D. Ye, Y. Li, Z. Liang, J. Liu, S. Zheng, and Y. Long, "Periodic triangle-truncated DSPSL-based antenna with backfire to endfire beam-scanning capacity," *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 2, pp. 845–849, 2017.

[17] H. Zhang, Y.-C. Jiao, G. Zhao, and C. Zhang, "Half-mode substrate integrated waveguide-based leaky-wave antenna loaded with meandered lines," *Electronics Letters*, vol. 53, no. 17, pp. 1172–1174, 2017.

[18] S.-L. Chen, D. K. Karmokar, Z. Li, P.-Y. Qin, R. W. Ziolkowski, and Y. J. Guo, "Circular-polarized substrate-integrated-waveguide leaky-wave antenna with wide-angle and consistent-gain continuous beam scanning," *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 7, pp. 4418–4428, 2019.

[19] S. Paulotto, P. Baccarelli, F. Frezza, and D. R. Jackson, "A novel technique for open-stopband suppression in 1-D periodic printed leaky-wave antennas," *IEEE Transactions on Antennas and Propagation*, vol. 57, no. 7, pp. 1894–1906, 2009.

[20] C. Caloz, T. Itoh, and A. Rennings, "CRLH metamaterial leaky-wave and resonant antennas," *IEEE Antennas and Propagation Magazine*, vol. 50, no. 5, pp. 25–39, 2008.

[21] S.-Y. Jeon, K. Nikitin, A. Dewantari, J. Kim, and M.-H. Ka, "Low-noise amplifier protection switch using p-i-n diodes with tunable open stubs for solid-state pulsed radar," *IEEE Microwave and Wireless Components Letters*, vol. 27, no. 11, pp. 1004–1006, 2017.

[22] J. T. Williams, P. Baccarelli, S. Paulotto, and D. R. Jackson, "1-D combline leaky-wave antenna with the open-stopband suppressed: design considerations and comparisons with measurements," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 9, pp. 4484–4492, 2013.

[23] J. Liu, W. Zhou, and Y. Long, "A simple technique for open-stopband suppression in periodic leaky-wave antennas using two nonidentical elements per unit cell," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 6, pp. 2741–2751, 2018.

[24] J. Guo, Z. Li, J. Wang, M. Chen, and Z. Zhang, "Analysis and design of leaky-wave antenna with low SLL based on half-mode SIW structure," *International Journal of Antennas and Propagation*, vol. 2015, Article ID 570693, 5 pages, 2015.

[25] A. K. Bhattacharyya, "Long rectangular patch antenna with a single feed," *IEEE Transactions on Antennas and Propagation*, vol. 38, no. 7, pp. 987–993, 1990.

[26] D. M. Pozar, *Microwave Engineering*, John Wiley & Sons, Hoboken, NJ, USA, 3rd edition, 2015.