Half-mode substrate integrated waveguide-based leaky-wave antenna loaded with meandered lines

Huan Zhang, Yong-Chang Jiao✉, Gang Zhao and Chi Zhang

A novel meandered-line-loaded leaky-wave antenna (LWA) is proposed. Two half-mode substrate integrated waveguide-based LWAs are placed face to face for obtaining high peak gains, and the meandered lines are introduced to acquire larger ratio of the beam scanning range to the operating frequency bandwidth. It is demonstrated that the operating frequency band can be narrowed by almost 1 GHz due to the meandered-line structure under the condition that the scanning range keeps unchanged. The proposed LWA is fabricated and measured. Both simulated and measured results indicate that the designed antenna is a balanced LWA operating in frequency band 10.8–16 GHz (5.2 GHz centred at 13.4 GHz). Continuous beam scanning characteristic is observed from −60° to +34°, and comparisons are given out to validate the proposed design.

Introduction: In the past few years, more and more attentions have been put on the composite right/left-handed leaky-wave antennas (LWAs) because of their continuous frequency-related beam-scanning capability [1]. Substrate integrated waveguide (SIW)/half-mode SIW (HMSIW) has been widely used due to its characteristics such as low profile and light weight while keeping the desirable features of conventional rectangular waveguides. Recently, there has been an increasing interest in the composite right/left-handed (CRLH) SIW/HMSIW-based LWAs which allow continuous beam scanning from backward to forward directions. A family of CRLH-SIW/HMSIW LWAs were proposed in [2] with the help of interdigital slots. Multi-band LWAs [3], including dual-band LWA [4] and tri-band LWA, were also designed. Usually, larger ratio of the beam scanning range to the frequency bandwidth is desirable in modern radar systems. In [5], a novel CRLH SIW with designed transmission line cell structure was applied to achieve wide continuous beam scanning range within a narrow fractional bandwidth.

In this Letter, a novel CRLH HMSIW-based LWA with improved antenna performance is proposed based on our previous work [6]. Mushroom-like structures are utilised to obtain desirable dispersion features and power leakage. Two HMSIW-based LWAs derived from [6] are arranged face to face, and then the peak gains are expected to be improved due to the antenna array effect. Moreover, the frequency bandwidth is narrowed by nearly 1 GHz when the meandered lines are loaded under the condition that the scanning range keeps unchanged. Comparisons of the proposed LWA with the reference antenna without the meandered lines are made to validate the proposed design.

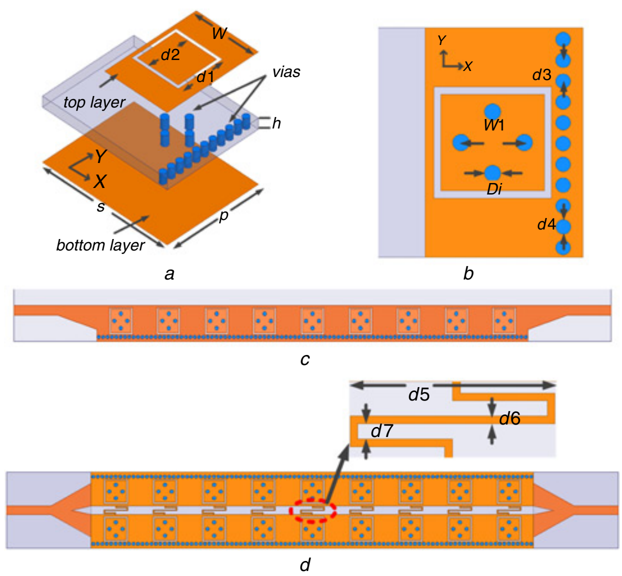

Fig. 1 *Structures of the unit cell and different LWAs*

a 3D view of the unit cell
b Top view of the unit cell
c Top view of the reference antenna
d Top view of the proposed LWA

Antenna design and analysis: Geometries of the LWAs and the proposed unit cell are shown in Fig. 1. The unit cell consists of three layers, the top layer, the bottom layer and the substrate layer made of inexpensive FR4 with relative permittivity $\varepsilon_r = 4.4$ and thickness $h = 1$ mm. The transverse dimension is $s = 8.5$ mm and the periodicity of the unit cell is $p = 11$ mm. The mushroom-like radiator is composed of two parts, a square patch and four grounded vias. Series capacitors are introduced due to the square-ring-slot between the patch of the mushroom-like structure and the broad face of the HMSIW, while metallic vias contribute shunt inductors. The conventional HMSIW-based LWA is given out in Fig. 1*c* as a reference, and the proposed face-to-face LWA is presented in Fig. 1*d*. The meandered lines are loaded to obtain large ratio of the beam scanning range to the frequency operating band, and the tapered sections are introduced for better impedance matching in the working band. Antenna parameter values are listed in Table 1.

Table 1: Antenna parameters (units: millimetre)

*d*1	*d*2	*d*3	*d*4	*d*5
5.3	4.6	1	0.7	5.3
*d*6	*d*7	*Di*	*W*	*W*1
0.2	0.4	0.8	6.5	3

Simulated dispersion features of the proposed unit cell are plotted in Fig. 2. The transition point from backward radiation to forward radiation occurs at ∼13 GHz where $\beta = 0$ (β is the phase constant) and the broadside radiation is expected to occur. The low boundary of the radiation region is at about 9.7 GHz. Stable leaky performance (characterised by the leaky constant α) is observed over the whole interested frequency band, and good transition is obtained as seen in the figure.

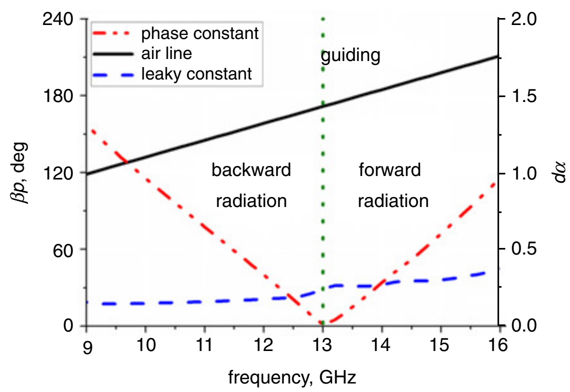

Fig. 2 *Dispersion features of the unit cell*

Comparisons on antenna peak gains and the beam scanning range among three different LWAs (i.e. the reference antenna, the proposed LWA without the meandered lines and the proposed LWA) are made, and the results are given in Fig. 3. Compared with the reference antenna, the proposed LWA without the meandered lines has higher peak gains due to the antenna array effect. However, its scanning feature is almost the same as that of the reference antenna. To obtain larger ratio of the beam scanning range to the operating frequency bandwidth, the meandered lines are loaded as shown in Fig. 1*d*. It can be clearly seen that, with the same beam scanning range of −60° to +34°, the operating frequency bandwidth is narrowed by about 1 GHz for the proposed antenna. In conclusion, compared with the reference antenna, the proposed LWA with the face-to-face arrangement and the meandered-line loading has a better radiation characteristic in both antenna gains and ratio of the beam scanning range to the frequency bandwidth.

Simulated and measured results: The final design of the proposed LWA is successfully fabricated and tested. The simulated and measured S-parameters are plotted in Fig. 4 together with the antenna prototype, and acceptable agreement is observed. Good impedance matching is achieved within the whole operating frequency band ranging from 10.8 GH to more than 16 GHz, and sufficient energy leakage is obtained in the interested leaky region. The measured radiation patterns at different frequencies are presented in Fig. 5 to make the frequency-scanning feature clear. Obvious beam scanning characteristic versus frequency is observed. The frequency point at which the broadside radiation appears shifts upwards slightly, which is mainly due to the introduction of the meandered lines and the coupling between the two array elements. The measured maximum antenna gain in the whole frequency band is 11.5 dBi, and the variation of the gains within the operating band is within 3 dBi.

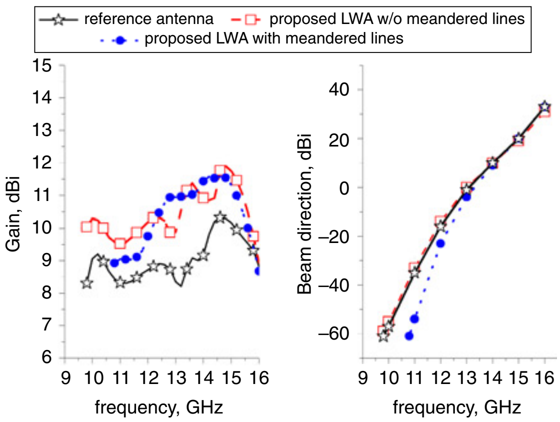

Fig. 3 *Comparisons on simulated performances among three different LWAs*

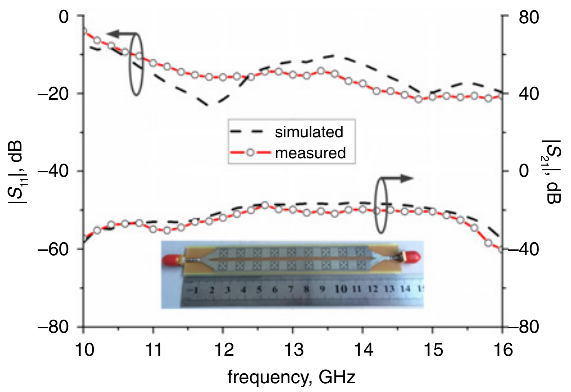

Fig. 4 *Simulated and measured S-parameters of the proposed LWA*

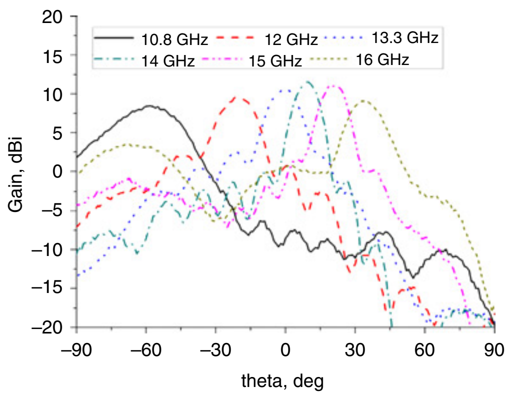

Fig. 5 *Radiation patterns in beam scanning plane at different frequencies*

Conclusion: A novel balanced CRLH-HMSIW-based LWA array loaded with the meandered lines is proposed in this Letter. Two HMSIW-based LWA elements are placed face-to-face for the antenna peak gain enhancement while the meandered lines are loaded between the elements to obtain large ratio of the beam scanning range to the operating frequency band. Measured results show that the frequency band is narrowed by about 1 GHz for the presence of the loaded components while the beam scanning range keeps unchanged. The proposed antenna is demonstrated experimentally to be a balanced LWA with the transition point at about 13.3 GHz.

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One or more of the Figures in this Letter are available in colour online.

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