Frequency beam-scanning substrate integrated waveguide cavity-backed wide slot antenna with wide-scanning angle and bandwidth

Yufan Cao ✉, *Zuping Qian, Lei Zhu*

College of Communication Engineering, Army Engineering University of PLA, Haifu Alley No. 1 Qinhuai District, Nanjing, People's Republic of China

✉ *E-mail: caoyufan135@sina.com*

Published in Micro & Nano Letters; Received on 17th August 2018; Revised on 31st October 2018; Accepted on 13th November 2018

A novel frequency beam-scanning substrate integrated waveguide cavity-backed wide slot antenna with a wide-scanning angle and bandwidth is investigated. The wide slot etched on the metal substrate is not only the radiating element but also part of the feeding network, which makes the whole structure very compact. The experiment indicates that the design principle is correct. The measured results show that the antenna achieves an enhanced operating bandwidth of about 27% with the gain from 10.12 to 16.25 dBi and the corresponding scanning angle is from 12° to 62° across the band. Good accordance is obtained between the simulated and the measured results.

1. Introduction: Frequency beam-scanning leaky wave antennas (LWAs) possess a compact structure since the radiating portion is also the feeding portion. At the same time, the beam radiates toward different directions at various operating frequencies. Since the substrate integrated waveguide (SIW) has the advantages of low profile, easy integration, simple fabrication etc. [1, 2], SIW LWAs are widely used in mobile communications, target acquisition and early warning radar.

Therefore, the planar frequency scanning SIW antenna has got a lot of attention in recent years. A modified composite right/left-handed transmission line structure was introduced in the planar beam-scanning SIW slot LWA for enhancing the scanning range and achieving the gain flatness [3]. Gain enhancement planar beam-scanning SIW slot LWA was proposed using a metallic phase correction grating cover [4]. A narrow transverse SIW periodical slot LWA fed by an half-mode substrate integrated waveguide (HMSIW) was investigated with a more compact size [5]. These types of antennas radiate through narrow slots. A wide slot antenna backed by an SIW cavity was presented and investigated for the enhancement of operating bandwidth. Its dual-resonance operation mechanism was verified by a parametric study and the surface currents analysis [6, 7]. Although the SIW cavity-backed wide slot antenna has wide bandwidth performance, the extra feeding network must be chosen to avoid destructing the single element.

In this Letter, a compact beam-scanning SIW cavity-backed wide slot LWA with a wide-scanning angle and bandwidth is investigated. The proposed SIW LWA possesses the advantages of compact size, low profile, easy fabrication, broad bandwidth and beam-scanning capability, which are good for millimetre-wave communication systems.

2. Antenna configuration: The geometry of the proposed beam-scanning SIW cavity-backed wide slot antenna is shown in Fig. 1. The antenna is fabricated on an ARLON AD600 substrate with a thickness of 1.575 mm and a relative permittivity of 6.15. Due to the fact that the radiating energy of a single element comes from the coupling wide slot, a transition with a tapered width is adopted to get the desirable bandwidth. To ensure that the energy is efficiently coupled to the next slot from the previous one, the width w_o of the output window should be wider than w_i of the input one. In this design, the coplanar waveguide feeding method is used. The total antenna structure occupies an area of $30 \times 90\ \text{mm}^2$. The parameters of the antenna are listed in Table 1.

3. Design principle: As shown in Fig. 1, the width-to-length ratio (WLR) of the rectangular slot cutting from the SIW cavity is about 0.5. The impedance bandwidth of this antenna for $|S_{11}| < -10\,\text{dB}$ increases with consistent radiation performance as WLR increases from 0.12 to 0.71. Its dual-resonance operation mechanism and the surface currents analysis are verified by a parametric study [4]. The distance between the adjacent radiating wide slot centres is about $\lambda_0/2$. While the final cavity is shortened, a travelling wave is still maintained in the antenna. To verify this conclusion, a two-port model with only one cavity-backed wide slot element is simulated. The simulation model is shown in Fig. 2. The *S*-parameters of the two-port network are described in Fig. 3. The impedance bandwidth of a single element for $|S_{11}| < -10\,\text{dB}$ is about 5.6 GHz from 17.6 to 23.2 GHz. Simultaneously, in this

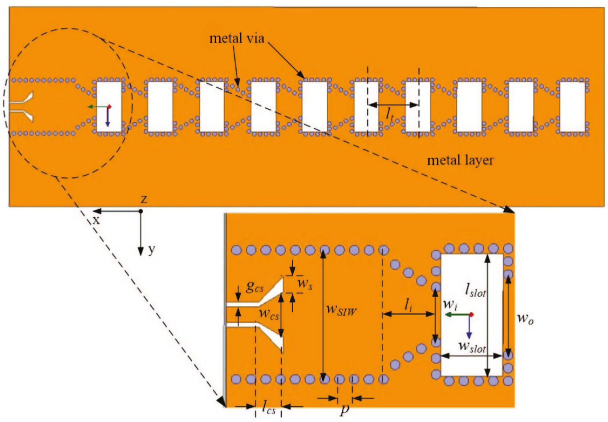

Fig. 1 *Geometry of the frequency beam-scanning antenna array*

Table 1 Parameters of the fabricated antenna (units: millimetres)

P	l_i	w_{SIW}	l_t
1	1.5	7.6	7.8
w_o	w_{cs}	l_{slot}	w_{slot}
4.4	2.9	7.6	7.6
g_{cs}	l_{cs}	w_i	w_s
0.3	1.5	3.2	1

doi: 10.1049/mnl.2018.5480

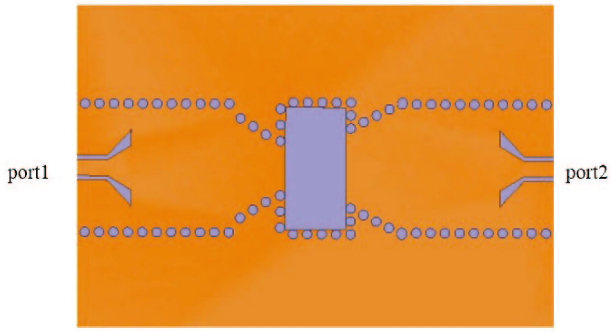

Fig. 2 *Two-port model of a single element*

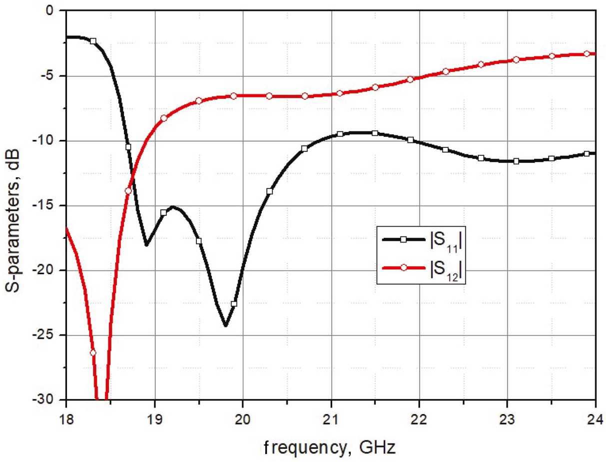

Fig. 3 *S-parameters of the single element*

bandwidth, the transmission coefficient $|S_{21}|$ is about -5 dB. If the losses resulted by the substrate and the metal are not considered, a part of the energy will be radiated out from the wide slot element, leading to 5 dB gain loss. Followed by this result, when ten SIW cavity-backed wide slots are connected in series, the transmission coefficient must be < -50 dB. Thus, the open-ended or shortened circuit have no effect toward the reflection coefficient of the antenna.

4. Results and discussion: The proposed frequency beam-scanning SIW cavity-backed wide slot LWA is optimised by using the HFSS software and fabricated for verification. The simulated radiation efficiency is depicted in Fig. 4. It is clearly observed that the radiation efficiency is more than 90% across the entire operating bandwidth. Fig. 5 gives the photograph of the proposed antenna. The measurement was carried out in the anechoic chamber. Fig. 6 depicts the comparison of the reflection coefficients between the simulated and the measured results. It can be obviously seen that the operating bandwidth ranges from 17.6 to 23.2 GHz, which achieves a wide bandwidth of about 27%. The reflection coefficients of the measurement agree well with the simulated results, saving the insertion loss caused by the dielectric loss and the slight frequency offset caused by fabrication error.

The far-field radiation patterns of the frequency beam-scanning SIW cavity-backed wide slot LWA are illustrated in Fig. 7. It indicates that the measured results are acceptable and show good accordance with the simulated ones. The main direction of the *E*-plane scans from 62° to 12° with the frequency increasing from 19 to 22 GHz. Moreover, the gain varies from 10.1 to 16.2 dBi across the band. At low frequency the side-lobe level is high. The higher the frequency, the narrower the main lobe is.

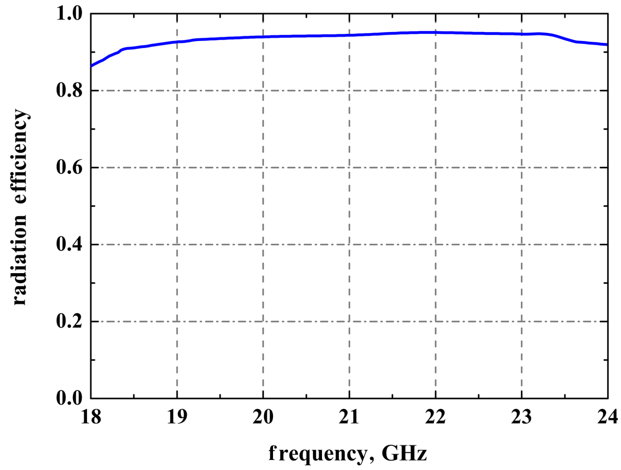

Fig. 4 *Simulated radiation efficiency of the proposed antenna*

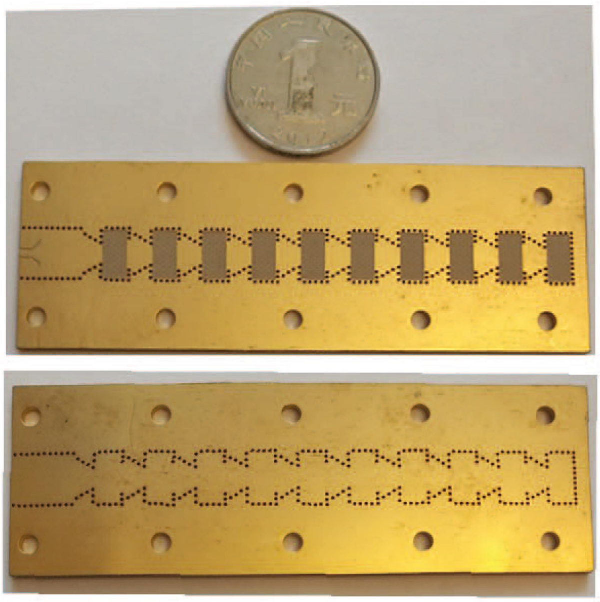

Fig. 5 *Photograph of the proposed beam-scanning antenna array*

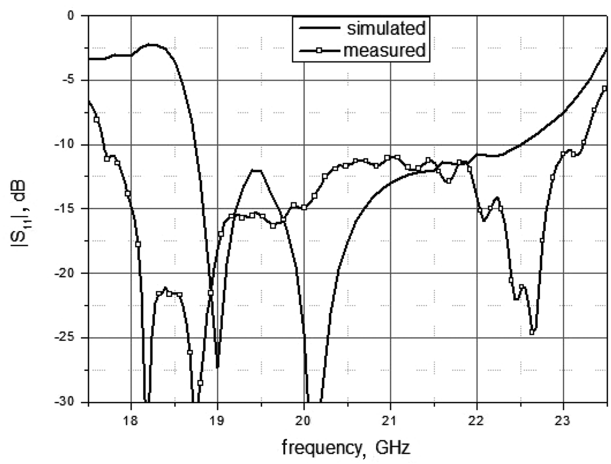

Fig. 6 *Simulated and measured $|S_{11}|$ of the proposed antenna*

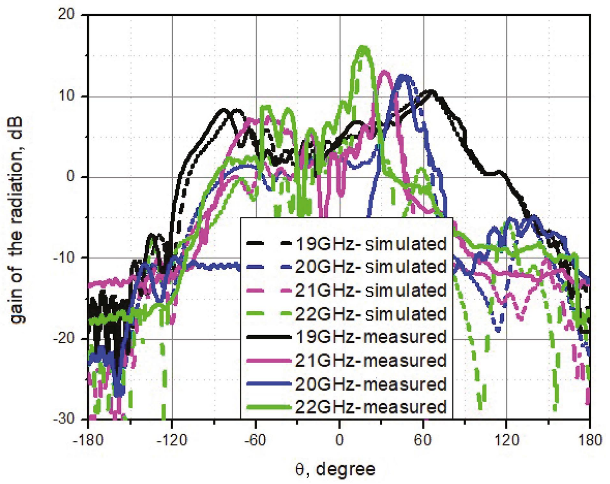

Fig. 7 *Comparison of the radiation patterns between the simulated and measured results*

5. Conclusion: In this Letter, a compact beam-scanning SIW cavity-backed wide slot LWA with a wide scanning angle and bandwidth is investigated. The measured results show that the antenna achieves the enhanced operating bandwidth of about 27% with a gain of 10.1 to 16.2 dBi and the corresponding scanning angle is from 12° to 62°. Measured results show good accordance with the simulated ones which verifies the correctness of the design method. The proposed SIW LWAs possess the advantages of compact size, low profile, easy fabrication, broad bandwidth, beam-scanning capability and good for millimetre-wave radar applications.

6. Acknowledgments: This work was supported in part by the National Natural Science Foundation of China under grant no. 61271103 and in part by the Open Project of State Key Laboratory of Millimeter Waves, Southeast University China under grant no. K201515.

7 References

[1] Cai Y., Qian Z., Zhang Y., *et al.*: 'Bandwidth enhancement of SIW horn antenna loaded with air-via perforated dielectric slab', *IEEE Antennas Wirel. Propag. Lett.*, 2014, **13**, pp. 571–574

[2] Cai Y., Zhang Y., Qian Z., *et al.*: 'Design of compact air-vias-perforated SIW horn antenna with partially detached broad walls', *IEEE Trans. Antennas Propag.*, 2016, **64**, (6), pp. 2100–2107

[3] Cao W.Q., Chen Z.N., Hong W., *et al.*: 'A beam scanning leaky-wave slot antenna with enhanced scanning angle range and flat gain characteristic using composite phase-shifting transmission line', *IEEE Trans. Antennas Propag.*, 2014, **62**, (11), pp. 5871–5875

[4] Cao W.Q., Hong W., Chen Z.N., *et al.*: 'Gain enhancement of beam scanning substrate integrated waveguide slot array antennas using a phase-correcting grating cover', *IEEE Trans. Antennas Propag.*, 2014, **62**, (9), pp. 4584–4591

[5] Lai Q.H., Hong W., Kuai Z.Q., *et al.*: 'Half-mode substrate integrated waveguide transverse slot array antennas', *IEEE Trans. Antennas Propag.*, 2009, **57**, (4), pp. 1064–1072

[6] Gong K., Chen Z.N., Qing X.M., *et al.*: 'Substrate integrated waveguide cavity-backed wide slot antenna for 60 GHz bands', *IEEE Trans. Antennas Propag.*, 2012, **60**, (12), pp. 6023–6026

[7] Gong K., Chen Z.N., Qing X.M., *et al.*: 'Empirical formula of cavity dominant mode frequency for 60 GHz cavity-backed wide slot antenna', *IEEE Trans. Antennas Propag.*, 2013, **61**, (2), pp. 969–972

doi: 10.1049/mnl.2018.5480