Slotted SIW Leaky-Wave Antenna with Improved Backward Scanning Bandwidth and Consistent Gain

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***Abstract*— A dumbbell-shaped slotted leaky-wave antenna based on composite right/left-handed metamaterial structure is proposed to improve the backward scanning bandwidth and achieve consistent gain. The antenna consists of substrate integrated waveguide (SIW) unit cells array, which is configured by a dumbbell-shaped slot, cut on the upper layer of the SIW, and an embedded patch underneath the dumbbell-shaped slot. The antenna improves the backward scanning bandwidth compared with the planar-slotted SIW leaky-wave antenna. A measured beam scanning range of -66° to 78° with consistent gain of > 10 dBi is achieved across a frequency range from 7.5 GHz to 13.0 GHz.**

***Index Terms*— Beam scanning, composite right/left-handed structure, gain, leaky-wave antenna, metamaterials, slotted-waveguide, substrate integrated waveguide.**

I. INTRODUCTION

Leaky-wave antennas (LWAs) are travelling wave antennas with electrically large radiating aperture (couple of wavelengths), they are able to provide high gain (directive beam) without a complex feeding network. The advantage of a LWA over a conventional array antenna is the simple feeding structure with low loss. Generally, first higher order mode has used to radiate in the forward direction only of the planar conventional LWAs [1]. However, the periodic structure based LWA can radiate in backward direction. Over the last decade, the composite right/left-handed (CRLH) configurations were used in the metamaterial LWA design to achieve a continuous main beam scanning from the backward to the forward with frequency [2].

Various designs of the metamaterial-based LWAs were considered. An LWA with a CRLH folded SIW structure can scan the beam from of -58° to 65° with a gain of 1.0 dBi [3]. An interdigital-shaped slotted-SIW based LWA was reported to achieve a scanning angle of -60° to 70° with gain of around 8 dBi [4]. A CRLH LWA based on rectangular waveguide structure has been demonstrated for continuous main beam scanning range from -70° to 70° with gain of 8.64 dBi [5]. In [6], a planar slotted SIW LWA was investigated for a scanning range of -66° to 78° with consistent gain.

In this paper, an LWA with dumbbell-shaped slotted SIW CRLH structure is proposed to improve the scanning angle in the backward direction with the consistent gain. The proposed slotted unit cell consists of a dumbbell-shaped slotted upper layer of the SIW and a rectangular patch between upper and lower layers of the SIW. The slotted LWA was optimized to enhance the beam scanning in the backward direction with the consistent gain.

II. PROPOSED LEAKY-WAVE ANTENNA

Fig. 1 displays the slotted SIW LWA configuration. The SIW based CRLH unit cell consists of a dumbbell-shaped slot and an inserted rectangular microstrip patch. The dumbbell-shaped slots are cut on the upper layer of the SIW and the inserted rectangular patches are right underneath of the dumbbell-shaped slot. Metallic through vias walls are utilized to configure the SIW. The structure and SIW CRLH unit cell details are displayed in Fig. 2. The RT Duroid 5880 substrate (ε_r = 2.2, tanδ = 0.0009) is used to design of unit cell with length of u_l. Total height of SIW structure is h_1+h_2 = 0.914 mm and an inserted rectangular patch is located in between the SIW structure with a height of h_1 = 0.66 mm. The width of SIW ground-plane and the SIW width are g and W_{eff}, respectively. The embedded patch and dumbbell-shaped slot dimensions are l, w, S_{l1}, S_{l2}, S_{w1}, and S_{w2}. Fifteen unit cells are used for designing of the LWA.

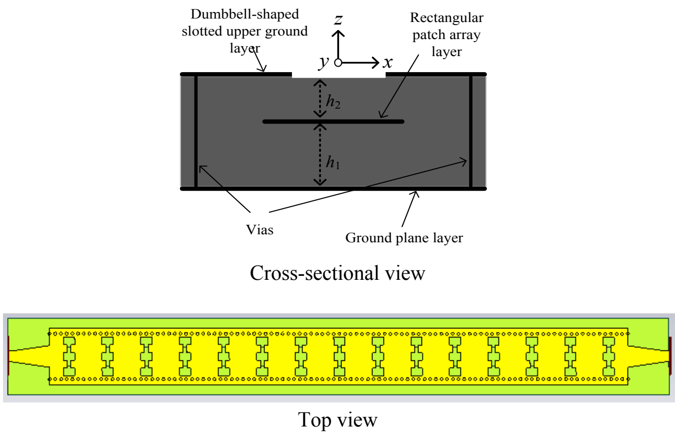


Fig. 1. Proposed slotted LWA structure.

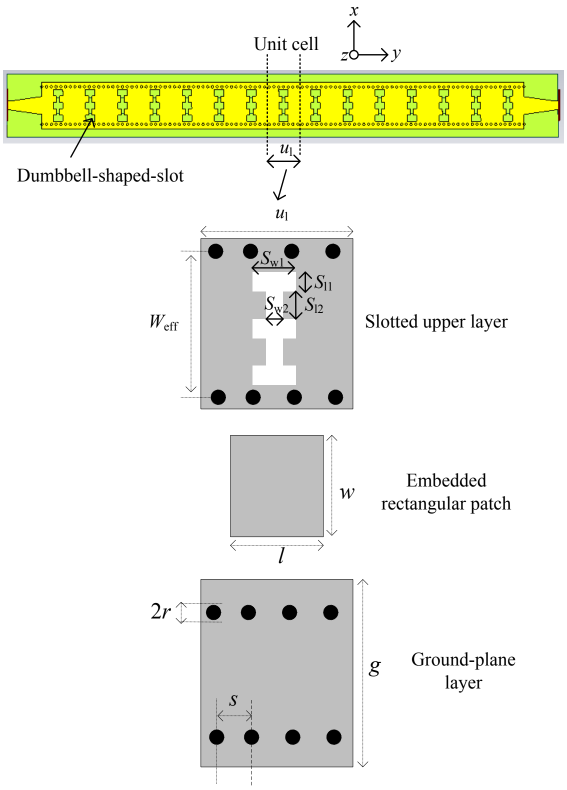


Fig. 2. Proposed LWA structure and the CRLH slotted SIW unit cell structure.

A. Dispersion diagram of the unit cell

The CST EM Eigen-mode solver [7] was used to study the dispersion diagram. As shown in Fig. 3, the balanced condition is satisfied at around of 8.7 GHz. The dotted line is the air line ($k_o = \omega\sqrt{\varepsilon_o \mu_o}$) and it crosses the highest frequency of around 13.0 GHz and the lowest frequency of around 7.5 GHz. It indicates that the frequency for left-handed region ranges from 7.5 to 8.7 GHz, while for the right-handed region from 8.7 to 13.0 GHz. The design parameters of a unit cell are: SIW ground layer width, g = 20.0 mm, u_l = 10.2 mm, w = 4.75 mm, l =3.8 mm, W_{eff} = 11.8 mm, mm, S_{l1}= 2 mm, S_{l2}= 2 mm, S_{w1}= 3 mm, and S_{w2} = 1 mm. Radius of metallic SIW via is r = 0.38 mm with via pitch of s = 1.52 mm.

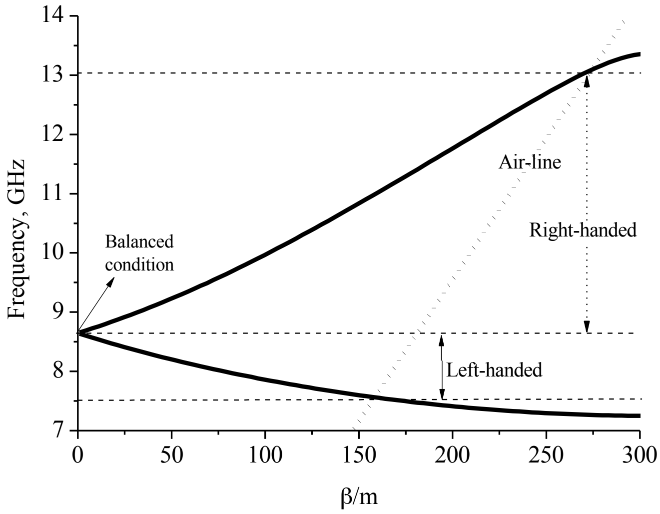


Fig. 3. Simulated dispersion diagram for the slotted CRLH SIW unit cell.

B. Comparison of the proposed and planar slotted-SIW based LWAs

In this section, the scanning angle with frequency of the planar slotted LWA [6] and the proposed dumbbell-shaped slotted LWA are compared in Fig. 4. Both LWAs (same size and same number of unit cells) are optimized for consistent gain. The proposed LWA exhibits smaller beam scanning slope with frequency, namely, the backward rdaiation frequency range is widened compared with that of the the planar slotted-LWA [6].

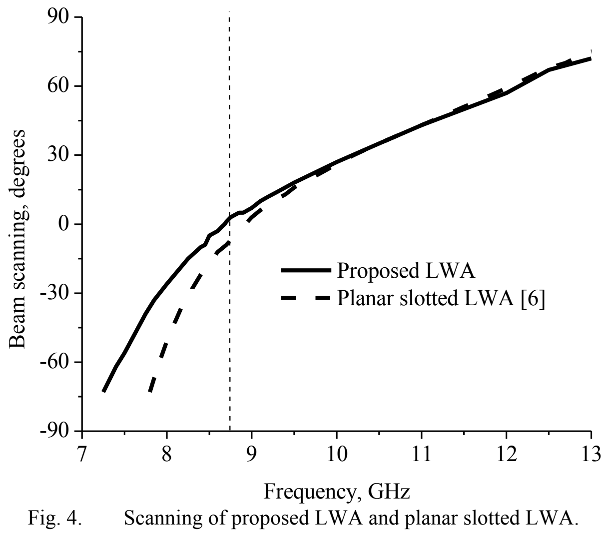


Fig. 4. Scanning of proposed LWA and planar slotted LWA.

III. Measured Results and Discussions

A dumbbell-shaped slotted SIW LWA was prototyped as shown in Fig. 5 and tested.

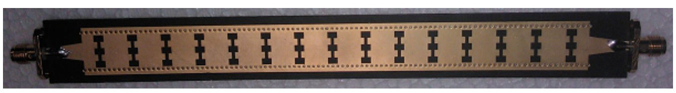


Fig. 5. Proposed LWA prototype.

The simulated and measured S-parameters ($|S_{11}|$ and $|S_{21}|$) are shown in Fig. 6, a good agreement is observed. The frequency range from 7.2 GHz to 8.8 GHz indicates the left-handed region and the balanced condition or transition frequency is 8.8 GHz. The frequency range from transition frequency, 8.8 GHz to 13.0 GHz shows the right-handed region.

Fig. 7 shows the simulated and measured main beam-scanning angle of the proposed slotted LWA. The beam-scanning angle from -66° to 78° is achieved from measurement and follows simulated beam scanning angle curve. The measured beam scanning angle (backward) from -66° to 0° is achieved across a frequency band of 7.5 GHz – 8.8 GHz and the forward scanning range from 0° to 78° can be achieved across a frequency range from 8.8 GHz to 13.0 GHz.

The simulated and measured 3-dB gain beamwidth with frequency are plotted in Fig. 8 and the measured data's follow the simulations well. The measured 3-dB gain beamwidth is consistent of 12° across a frequency range from 8.3 GHz to 11.5 GHz.

The simulated and measured main beam gain with frequency is compared in Fig. 9. The main beam measured gain is larger than 10.0 dBi across the frequency band of 7.5 GHz – 13 GHz. The main beam gain is consistent with a variation of ≤ 3.0 dB across the desired frequency band.

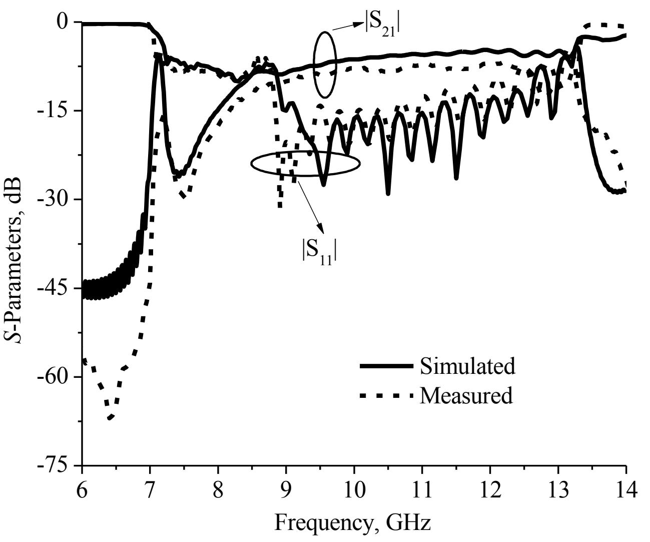


Fig. 6. S-parameters against frequency.

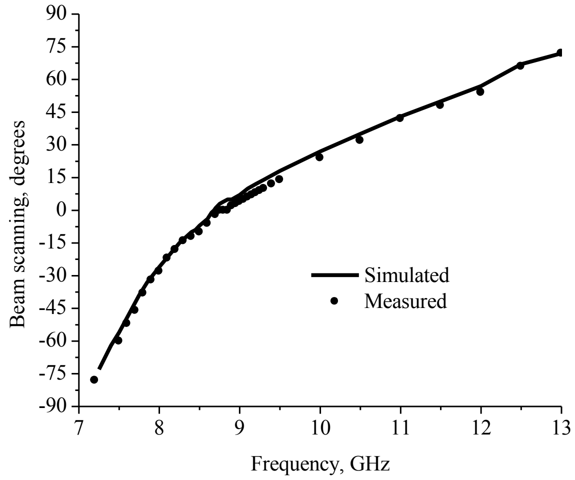


Fig. 7. Simulated and measured beam scanning against frequency.

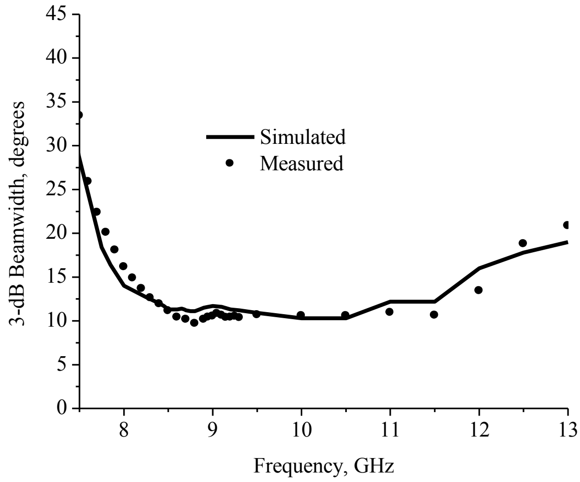


Fig. 8. Simulated and measured 3-dB beamwidth against frequency.

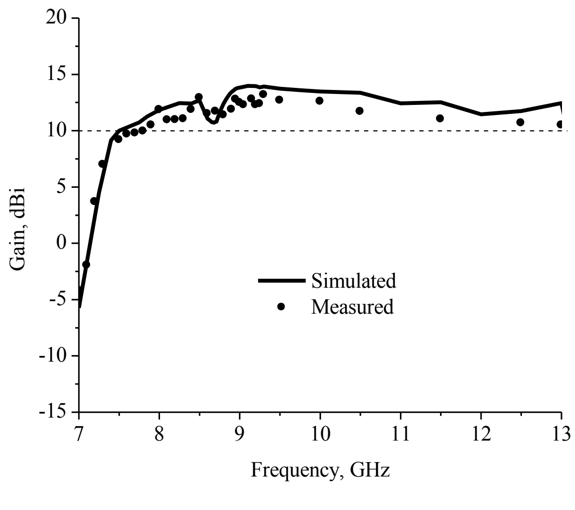
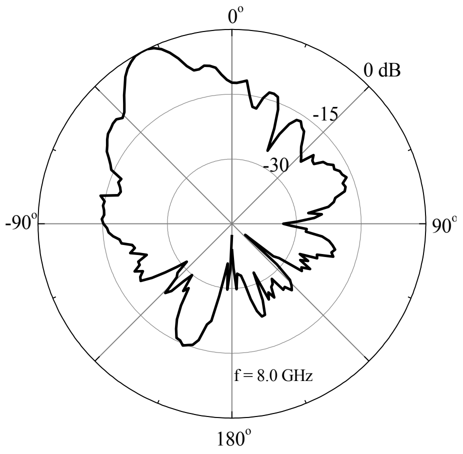
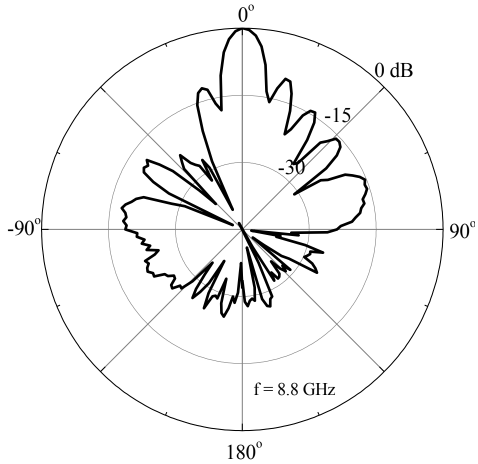


Fig. 9. Simulated and measured gain against frequency.

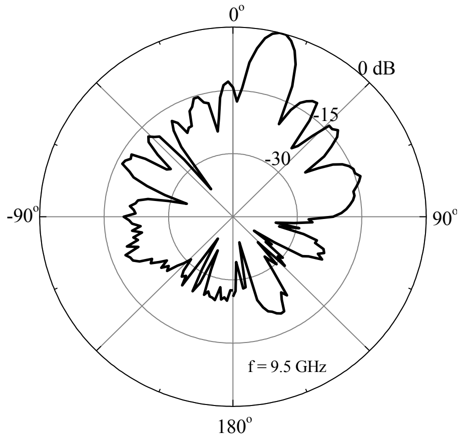
The measured normalized radiation patterns (*yz*-plane) at 8.0 GHz (at the backward direction), 8.8 GHz (at the boresight), and 9.5 GHz (at the forward direction) are shown in Figs. 10(a), 10(b) and 10(c), respectively.



(a)



(b)



(c)

Fig. 10. Measured radiation patterns: (a) at the backward direction, (b) at the boresight, and (c) at the forward direction.

IV. Conclusion

A dumbbell-shaped slotted LWA based on CRLH SIW has been demonstrated for improving the backward scanning bandwidth with consistent gain. The beam-scanning slope with frequency has been slow down in the backward direction compared with the LWA [6]. The proposed LWA is useful to get consistent gain beam scanning across the desired frequency band.

References

[1] Y. Qian, B.C.C. Chang, T. Itoh, K. C. Chen, and C. K. C. Tzuang, “High efficiency and broadband excitation of leaky mode in microstrip structures,” *International Microwave Symposium Digest*, MTT-S, vol. 4, pp. 1419–1422, 1999.

[2] C. Caloz and T. Itoh, ‘Electromagnetic Metamaterials: Transmission Line Theory and Microwave Applications,’ New York, John Wiley & Sons, 2004.

[3] T. Yang, P.-L. Chi, and R. Xu, “Novel composite right/left-handed leaky-wave antennas based on the folded substrate-integrated-waveguide structures,” *Progress In Electromagnetics Research C*, vol. 29, pp. 235–248, 2012.

[4] Y. D. Dong and T. Itoh, “Composite right/left-handed substrate integrated waveguide and half mode substrate integrated waveguide leaky-wave structures,” *IEEE Trans. Antennas and Propagation*, vol. 59, no. 3, pp. 767–775, March 2011.

[5] Y. Weitsch and T. F. Eibert, “Analysis and design of a composite left/right-handed leaky wave antenna based on the H10 rectangular waveguide mode,” *Advances in Radio Science*, 6, pp. 49–54, 2008.

[6] Nasimuddin, Z. N. Chen, and X. Qing, “Multilayered composite right/left-handed leaky-wave antenna with consistent gain,” *IEEE Trans. Antennas and Propagation*, vol. 60, no. 11, pp. 5056–5062, Nov. 2012.

[7] CST Microwave Studio, Version 2016.05, Aug. 19 2016.