2022 IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications (IMWS-AMP) | 978-1-6654-7834-2/22/$31.00 ©2022 IEEE | DOI: 10.1109/IMWS-AMP54652.2022.10106795

A Center-Fed SIW-Based Leaky-Wave Antenna With Wide-Scanning Angle for mmWave Applications

Yaling Chen[1], Long Zhang[1]*, Yejun He[1], Chunxu Mao[2], Wenting Li[1]
[1]College of Electronics and Information Engineering, Shenzhen University, 518060, China
[2] Institute for Communication Systems (ICS), University of Surrey, UK

***Abstract*—This paper presents a novel center-fed leaky-wave antenna (LWA) with a broad beam-scanning range. Different from the traditional LWA with a single beam, the proposed LWA consists of a magic-T for providing an out-of-phase equal-amplitude excitation and a periodic LWA array based on substrate integrated waveguide (SIW) for radiation. A dual-beam antenna supporting a wide-scanning range through the broadside without the open stopband suppression can be realized. It should be noted that only the backward radiation beams are used in the design. A broad bandwidth of 27.7% (22.14-29.25 GHz) is achieved, according to the simulation findings. Moreover, the simulated radiation patterns illustrate that a wide range of beam scanning around ±75° including broadside direction is achieved by the proposed antenna. With its broad operating frequency band and wide-scanning angle, the proposed design shows promise for varies applications.**

Keywords*—*dual-beam antenna, leaky-wave antenna, magic-T, wide-scanning angle.

I. INTRODUCTION

Leaky wave antenna (LWA) is a frequency-controlled beam-scanning antenna without the need of additional feeding network [1]. Due to its distinctive radiation characteristics in terms of beam scanning, LWA has attracted great attention from antenna researchers. LWAs can be achieved by utilizing substrate integrated waveguide (SIW), because SIW offers the benefits of being low profile, simple to manufacture, and inexpensive [2]-[4]. SIW-based periodic LWAs support both forward and backward scanning beams including broadside one if the open stopband (OSB) is completely eliminated [5], as illustrated in Fig. 1. In general, Port 1 is designed as the excitation port, while the other port is set as a matching load, i.e., conventional feed mode. In such way, only one beam is realized to scan from backward to forward quadrant within the operating frequency range. Obviously, a broad range of beam scanning comes at the expense of wide bandwidth. Multi-beam leaky-wave antennas can achieve multiple beams to further broaden the beam-scanning range even with narrow bandwidth. However, these antennas usually utilize a large number of input ports to implement a wide-angle coverage, which undoubtedly increases the complexity and cost of antenna. For example, in [6], a multi-beam LWA with full azimuth coverage was developed. However, 28 input ports are used to design this antenna, which greatly increases the antenna complexity and cost. Therefore, it is of great interest to realize a low-cost multi-beam LWA with simple feeding network and wide-angle beam scanning characteristic within a limited operating band.

In this work, a single-layer SIW-based LWA with a wide-scanning angle is proposed. A vertical standard WR-34 rectangular waveguide is mounted under the SIW and the bottom layer of the SIW has a rectangular slot etched into it. A magic-T is obtained in this way. Using the magic-T as feeding component, a pair of out-of-phase TE waves with equal amplitudes in the SIW can be achieved. Then, by embedding the magic-T in the center of SIW-based LWA, a dual-beam antenna is implemented. On the top layer of SIW, the antenna unit cell has two identical transverse slots without the OSB suppression. Nevertheless, a wide-scanning range can be achieved since two symmetrical beams scan simultaneously from the near end-fire direction to the broadside direction with increasing frequency. Only the radiation beam scanning within the backward region is utilized without the usage of the forward one, which reduces the required bandwidth. From the simulated results, the proposed antenna supports ±75° scanning range including broadside direction.

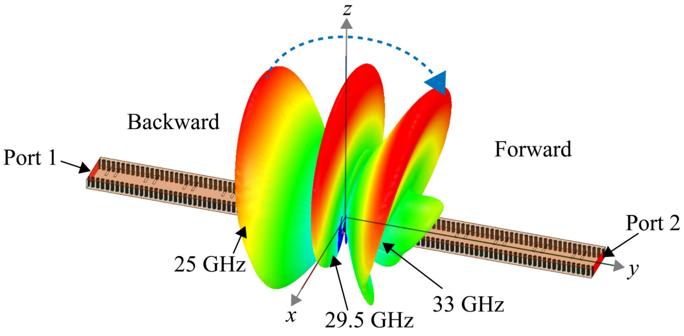

Fig. 1. Radiation characteristics of the traditional LWA.

II. ANTENNA DESIGN

A. *Antenna Geometry*

The design geometry is illustrated in Figure 2. As shown, the LWA consists of a magic-T, two symmetrical 24-cell SIW LWA, two tapered parts. The magic-T is placed in the middle of antenna to provide the excitation of antenna. Each SIW LWA array can realize a backward beam. Two tapered parts are mounted at both ends of magic-T to suppress the wave reflection, and two southwest connectors are connected to the antenna ends to absorb the residual energy.

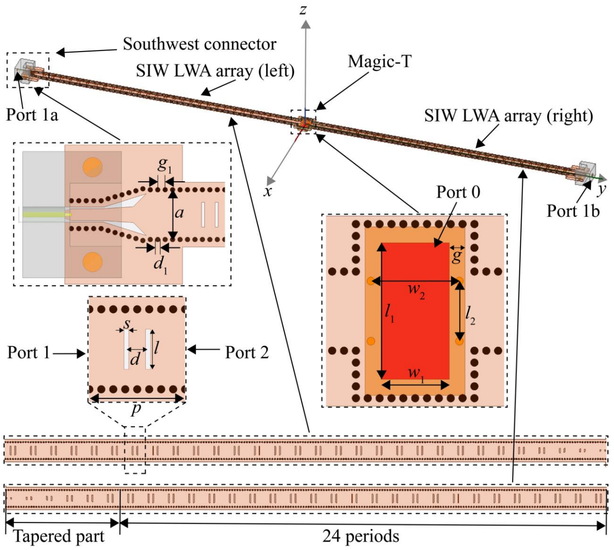

Fig. 2. Geometry of the proposed LWA. (All units are in mm: p = 6, s = 0.3, l = 2.5, d = 1.35, a = 5, g_1 =0.75, d_1 =0.5, g = 1, l_1 = 8.64, w_1 =4.32, l_2 = 3.8, w_2 =5.6)

B. *Analysis of Antenna Unit Cell*

The inset of Figure 2 shows the top view of the unit cell. As seen, the top layer of SIW has two identical transversal slots carved into each unit cell. Fig. 2 lists the optimized parameters. The following equations can be used to extract the complex propagation constants.

$$\beta_{eff} = \frac{1}{p} \bullet \mathrm{Im}\left[\cosh^{-1}\left(\frac{1 - S_{11}S_{22} + S_{12}S_{21}}{2S_{21}} \right) \right] \tag{1}$$

$$\alpha_{eff} = \frac{1}{p} \bullet \mathrm{Re}\left[\cosh^{-1}\left(\frac{1 - S_{11}S_{22} + S_{12}S_{21}}{2S_{21}} \right) \right] \tag{2}$$

Based on (1) and (2), the corresponding normalized propagation constants are depicted in Fig. 3. As shown, the OSB cannot be suppressed completely. However, these dispersion characteristics are sufficient for the antenna design since only the backward-direction region is used.

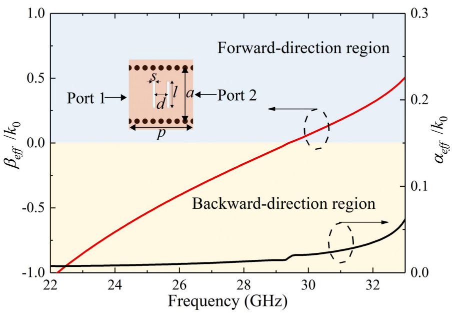

Fig. 3. Normalized propagation constants of the unit cell.

C. *Magic-T Design*

The proposed magic-T is depicted in Fig. 4. It consists of a vertical standard WR-34 rectangular waveguide, a hybrid SIW T-junction, and a rectangular slot etched on the bottom metal layer. The simulated S-parameters and phase imbalance between two output ports are also illustrated in Figure 4. Fig. 4 shows that the proposed magic-T provides a pair of out-of-phase waves with equal amplitude in two output ports.

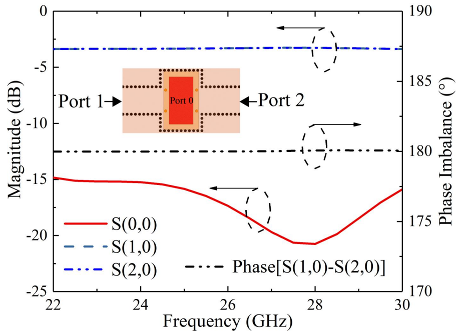

Fig. 4. Simulated S parameters and phase imbalance of the proposed magic-T.

III. SIMULATION RESULTS

By using HFSS, the simulation results can be obtained. The S-parameters and antenna gain are displayed in Figure 5. As shown, the proposed SIW LWA features a 27.7% bandwidth from 22.14 to 29.25 GHz. Moreover, the gain is up to 14.6 dBi when the proposed antenna is operating at 29.25 GHz.

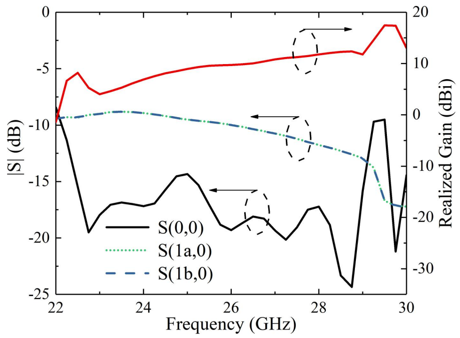

Fig. 5. S-parameters and realized gain of the proposed LWA.

Figure 6 illustrates simulated 3-D radiation characteristics of the antenna. As can been seen from Fig. 6, each beam can steer from the near end-fire to the broadside direction versus frequency. Based on this case, the proposed LWA can provide a broad scanning range in the *yoz* plane. It is worth pointing out that two backward beams can be superimposed into a broadside beam when the frequency is approaching 29.25 GHz. Since the proposed magic-T provides a pair of out-of-phase waves that propagate in the opposite directions. Therefore, a broadside beam can be realized before entering the OSB region.

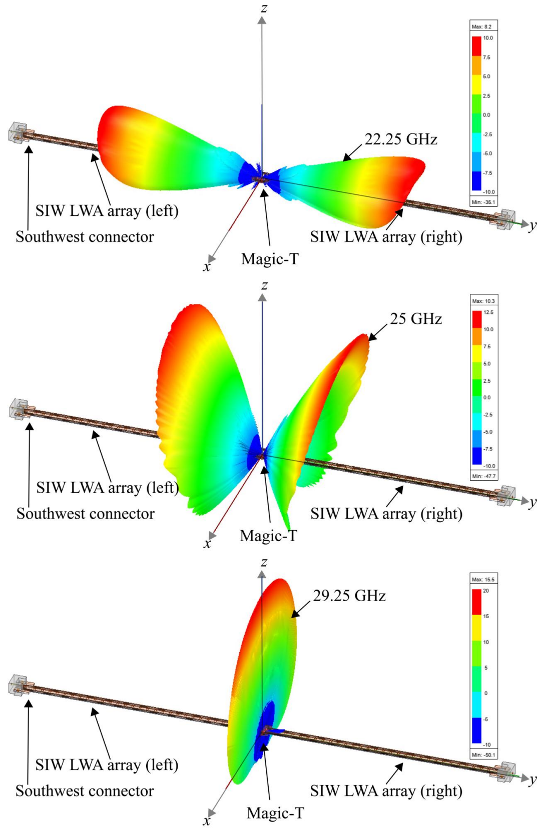

Fig. 6. Simulated 3-D radiation patterns of the proposed design.

Figure 7 depicts the antenna 2-D radiation performances. As shown, the radiation beam scans from -75° to 0° and 75° to 0° when the frequency increases between 22.25 and 29.25 GHz, resulting in a 150° broad-scanning angle. Although the antenna presented in [5] has a range of beam scanning from -49° to +69°, it is still lower than that of the proposed design. Moreover, the scanning range of that design is achieved at the cost of a wide bandwidth of 54.5%, which is much wider than the bandwidth in this work (27.7%).

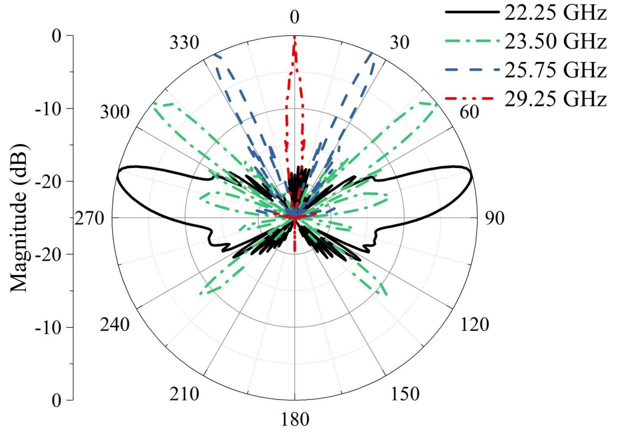

Fig. 7. 2-D radiation patterns of the LWA (*yoz* plane).

IV. CONCLUSION

This paper presents a novel center-fed SIW LWA with a broad-scanning angle. By employing the magic-T as the feeding component, a dual-beam LWA can be realized. The two symmetrical beams scan simultaneously from the near end-fire to the broadside direction versus frequency. In this manner, a 150° wide scanning range is realized. Moreover, a broad bandwidth of 27.7% is also obtained in this design.

ACKNOWLEDGMENT

This work is supported in part by the National Natural Science Foundation of China under Grants No. 61801299, 62101341, and 62071306, and in part by the Natural Science Foundation of Guangdong Province under Grant 2020A1515011037, and in part by the Shenzhen Science and Technology Program under grants JCYJ20200109113601723, 20200810131855001, and JSGG20210420091805014.

REFERENCES

[1] Y. L. Lyu et al., "Leaky-wave antennas based on noncutoff substrate integrated waveguide supporting beam scanning from backward to forward," *IEEE Trans. Antennas Propag.*, vol. 64, no. 6, pp. 2155-2164, Jun. 2016.

[2] Y. Chen, L. Zhang, Y. He, S.-W. Wong, W. Li and S. Gao, "A broadband high-gain H-plane SIW horn antenna," in *Proc. 2020 Intern. Conf. on Micro. and Millimeter Wave Techn. (ICMMT)*, 2020, pp. 1-3.

[3] Y. Chen, et al., "A pattern reconfigurable SIW horn antenna realized by PIN diode switches," in *Proc. 2021 Computing, Communications and IoT Applications(ComComAp)*, 2021, pp. 112-115.

[4] Y. Chen, L. Zhang, Y. He, C. Mao, S.-W. Wong, W. Li, P. Chu, and S. Gao, "Broadband high-gain SIW horn antenna loaded with tapered multi-strip transition and dielectric slab for mm-wave applications," *IEEE Trans. Antennas Propag.*, vol. 70, no. 7, pp. 5947-5952, July 2022.

[5] R. Ranjan, and J. Ghosh, "SIW-based leaky-wave antenna supporting wide range of beam scanning through broadside," *IEEE Antennas Wireless Propag. Lett.*, vol. 18, no. 4, pp. 606-610, Apr. 2019.

[6] Z. L. Ma and C. H. Chan, "A novel surface-wave-based high-impedance surface multibeam antenna with full azimuth coverage," *IEEE Trans. Antennas Propag.*, vol. 65, no. 4, pp. 1579-1588, Apr. 2017.