Half-Mode Substrate Integrated Waveguide (HMSIW) Leaky-Wave Antenna for Millimeter-Wave Applications

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***Abstract*—A novel leaky-wave antenna is demonstrated and developed at Ka-band in this work based on the newly proposed half-mode substrate integrated waveguide (HWSIW). This antenna is accurately simulated by using a full-wave electromagnetic simulator and then fabricated through a single-layer printed circuit board (PCB) process. Wide bandwidth and a quasi-omnidirectional radiation pattern are obtained. The proposed antenna is therefore a good candidate for millimeter-wave applications. Measured results are in good agreement with simulated results.**

***Index Terms*—Half-mode substrate integrated waveguide (HMSIW), leaky-wave antenna (LWA), millimeter-wave antenna, quasi-omnidirectional radiation pattern.**

I. Introduction

PRINTED leaky-wave antennas (LWAs) have been investigated based on microstrip [1] or coplanar waveguide (CPW) [2]. The microstrip-based LWA may suffer from higher loss and surface-wave modes existing at millimeter-wave band. Recently, a substrate integrated waveguide (SIW) LWA was proposed in [3]. The SIW [4] or post wall waveguide [5] is a planar waveguide technology suitable for millimeter-wave applications due to its advantages of easy manufacture, low cost, small size, low loss, and easy integration with planar circuits.

A more compact guided wave structure called half-mode substrate integrated waveguide (HMSIW) has recently been proposed [6], [7], which preserves nearly all the advantages of SIW whereas its size is nearly reduced by half. In this letter, a novel LWA based on the HMSIW technique is presented. This antenna features wide bandwidth and a conical or quasi-omnidirectional radiation pattern suitable for millimeter-wave applications, including road-vehicle communication [8], [9] and indoor wireless communication [10]. Similar radiation characteristics can be obtained in those printed antennas [1], [2], [10]. However, the HMSIW LWA has its own advantages. It is fabricated on a single-layer PCB and no special precautions against surface-wave mode are needed compared to the antenna proposed in [1]. Also its structure is simpler and its design method is more direct compared to the antenna proposed in [2]. And its bandwidth is much wider than that of the antenna proposed in [10].

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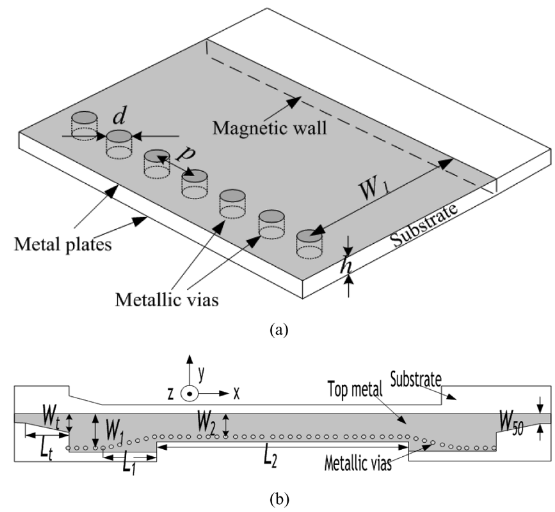


Fig. 1. Configurations of HMSIW and HMSIW LWA. (a) structure of HMSIW and (b) configuration of HMSIW LWA (top view).

II. Antenna Structure and Design

The center symmetry plane of an SIW can be equivalently regarded as a magnetic wall when it operates with its dominant mode (TE_{10}-like mode). Therefore, if the SIW is cut into two parts along the symmetry plane, each of the half SIW structures is called as the HMSIW which supports the half TE_{10}—like mode as shown in Fig. 1(a) [6], [7]. The parameters d, p, h and W_1 denote via diameter, via period, substrate thickness and HMSIW width, respectively. The proposed LWA topology is shown in Fig. 1(b), in which a transition between 50 Ω microstrip and HMSIW is used for impedance matching with a width of W_t and a length of L_t. To improve the return loss, a section of HMSIW with gradually taperd width from W_1 to W_2 is adopted. The antenna is terminated by a 50 Ω matching load.

Key parameters affecting the LWA characteristics are investigated specifically by using the EM simulation software CST. The substrate thickness has a noticeable impact on the far-field radiation pattern, depicted in Fig. 2. In H-plane there is a beam other than the main one emerging due to the small substrate thickness compared to the guided wavelength. The maximums of two beams become considerably close to each other with the thin substrate ($h = 0.5$ mm) while they become imbalanced

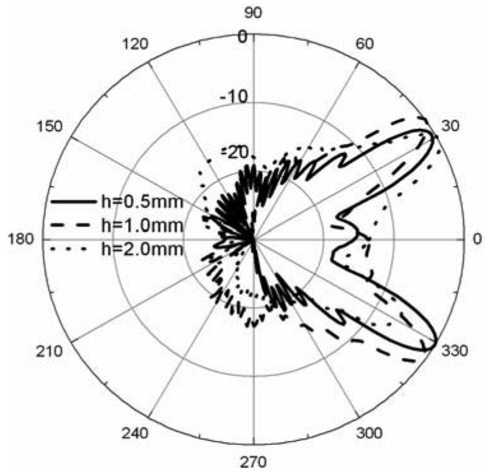
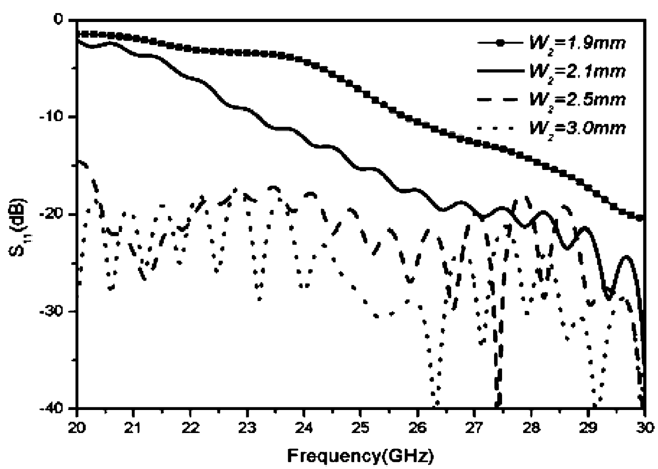
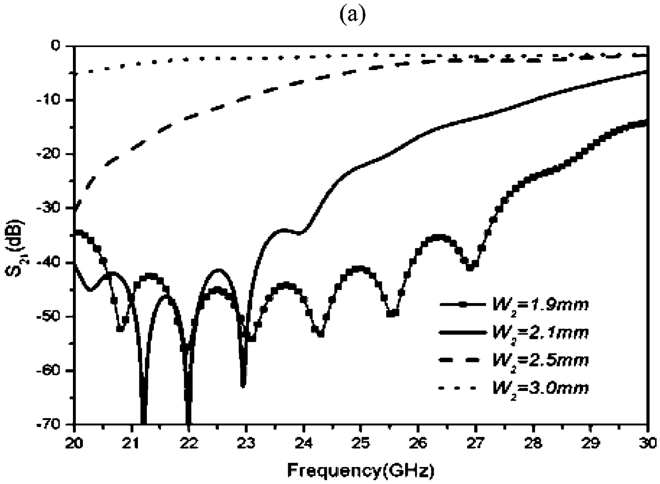


Fig. 2. Radiation pattern in H-plane versus substrate thickness ($f = 28$ GHz).



(a)



(b)

Fig. 3. S-parameters versus the width of HMSIW. (a) S11 and (b) S21.

with thick substrate ($h = 2.0$ mm). The substrate thickness is thus chosen to be 0.5 mm for achieving a quasi-omnidirectional pattern.

The leakage effect is mainly related to the width of the HMSIW. The curves in Fig. 3 compare S-parameters versus W_2 ($h = 0.5$ mm). It is noted that the width plays a remarkable role in the determination of the work frequency range for effective leakage and good return loss. There is the cut-off region below this range with deteriorated S_{11}, while above this range the radiation efficiency is too low to work as a practical LWA. The width is thus chosen to be 2.1 mm so that the work band is 25–28 GHz.

TABLE I
ANTENNA PERFORMANCES VERSUS L_2 (FREQUENCY = 26.5 GHz/28 GHz)

L_2(mm)	S21(dB)	$\Delta\theta$(degree)	SLL(dB)
50	-18.4/-4.7	16.1/17.4	-10.6/-11.8
100	-18.3/-11.2	9.6/10.1	-13.4/-12.5
150	-25.9/-14.4	7.0/7.1	-16.3/-12.3
200	-34.5/-19.1	6.2/5.5	-20.6/-12.8

TABLE II
DIMENSIONS FOR THE HMSIW LWA

d	0.4mm	L_1	6.0mm
p	0.8mm	W_1	4.2mm
W_{50}	1.54mm	W_2	2.1mm
L_t	10mm	L_2	100mm
W_t	2.5mm		

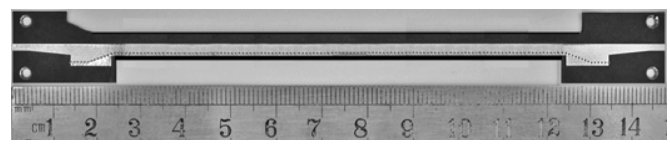


Fig. 4. Photograph of the HMSIW LWA.

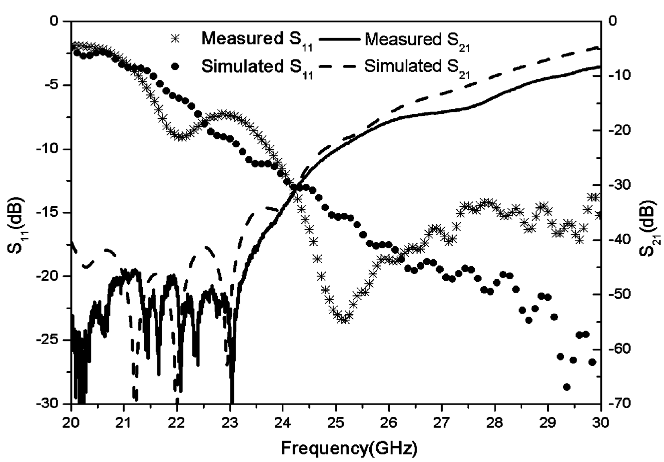


Fig. 5. Measured and simulated S-parameters.

The parameter L_2 primarily determines the half-power beamwidth $\Delta\theta$, and somewhat affects S_{21} and side lobe level (SLL). This is illustrated in Table I. It is obvious that larger L_2 leads to higher efficiency and narrower beamwidth. A tradeoff between desirable specifications and acceptable antenna size should be made. Therefore, L_2 is chosen to be 100 mm for verification, with a relatively good balance between antenna performance and structure compactness.

The parameters L_t and W_t can be designed in the way proposed in [7]. W_1 is the normal width of the HMSIW. L_1 can be tuned for improving return loss by performing simulations.

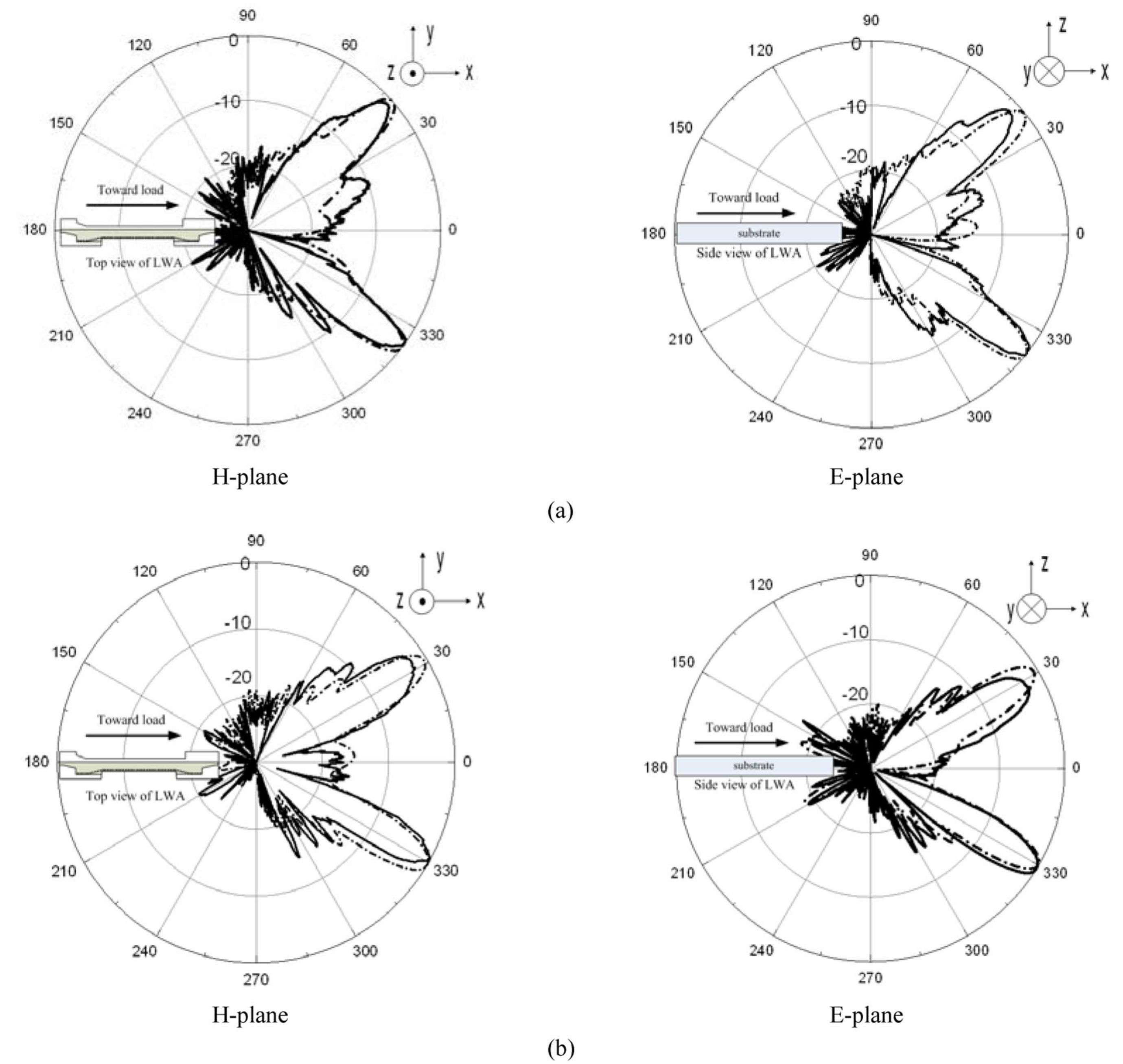


Fig. 6. Measured (solid lines) and simulated (dashed lines) radiation patterns. (a) 26.5 GHz and (b) 28 GHz.

The final dimensions of the proposed LWA are summarized in Table II.

III. Experiment Results

The proposed HMSIW LWA is designed, simulated and fabricated on a Rogers RT 5880 substrate with a thickness of 0.508 mm and a dielectric constant 2.2. The photograph is shown in Fig. 4.

Both measured and simulated results of S-parameters are shown in Fig. 5. It can be observed that the measured S_{11} is below -14 dB from 24.5 to 29.5 GHz and S_{21} is less than -14.5 dB below 28 GHz, both of which are in agreement with the simulated results. The measured S_{21} indicates that the power absorbed by a matching load is less than 3.6 percent of the input power below 28 GHz.

The far-field radiation pattern of this antenna indicates a quasi-omnidirectional characteristic, which is a hollow cone centered on the x axis. Both H-plane and E-plane radiation patterns at 26.5 GHz and 28 GHz are shown in Fig. 6, with drawn top and side views of LWA correspondingly for denotation purpose. It is shown that the beam pointing is shifted about 9° from 26.5 GHz to 28 GHz. The measured gain at 26.5 GHz is 11.1 dB in H-plane and 11.4 dB in E-plane, while the gain at 28 GHz is 11.6 dB in H-plane and 11.7 dB in E-plane. Explicitly, this quasi-omnidirectional radiation pattern of HMSIW LWA leads to the uniform-level signal reception of a vehicle or mobile terminal from a base station antenna, enabling it to be a suitable candidate for applications in millimeter-wave road-vehicle system or indoor wireless system.

IV. Conclusion

A leaky-wave antenna based on the HMSIW technique is proposed and investigated. The antenna is characterized by many attractive advantages, including compact size, easy fabrication, low cost, low loss, wide bandwidth, and direct integration with planar circuits. The proposed antenna has been fabricated on a single-layer substrate in standard PCB process. The measured results are in good agreement with the simulated ones, which validate the principle and the design of the HMSIW LWA. The proposed antenna is suitable for millimeter-wave applications with its wide bandwidth and quasi-omnidirectional features.

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