A Novel Transition for a Half-Mode Substrate Integrated Waveguide Leaky Wave Antenna

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***Abstract*—A novel transition structure of the half mode substrate integrated leaky wave antenna has been proposed in this paper. The transition structure can efficiently convert the input power to the leaky mode to enhance the efficiency of the leaky wave antenna and avoid possible reflection at the terminal of the leaky wave antenna. Moreover, a modified method of complex propagation constants extraction for leaky wave antenna is also presented in this paper, which gives accurate prediction on the radiation performance of the leaky wave antenna. Measured and simulated results indicate that the proposed transition structure makes the side lobe of the half mode substrate integrated leaky wave antenna smaller.**

***Index Terms*—Leaky wave antennas, Half mode substrate integrated waveguide**

I. Introduction

Half-Mode substrate integrated waveguide (HMSIW) leaky wave antenna can be a good candidate when a high directive radiation pattern is required for an antenna on a low-profiled printed circuit board design [1]–[5].

Since the radiation pattern of the LWA is a narrow beam which we even have means to steer it to a require direction [6], [7]. It has been used widely in radar system and the satellite communication application .

However, the one of the challenges of the LWA design is to suppress the side lobes pattern. It occurs because of the unwanted reflections in the LWA structure. Here, a transition structure for HMSIW LWA is proposed. It efficiently converts the input power into the higher order mode significantly. In section II, the numerical results of the extraction of the complex propagation constants based on the Through-Line method and the transverse resonant technique are displayed. The structure of the transition of the HMSIW is demonstrated in section III with a fullwave simulation. The comparison between the simulation and measurement results are presented in section IV.

II. A Preliminary Analysis on the HMSIW LWA

For LWA, it can be modelled as a lossy transmission line characterized by a complex propagation constant $k_x = \beta_x - j\alpha_x$, where β_x and α_x are the phase constant and the attenuation constant, respectively. The radiation pattern of the leaky wave antenna is typically a fan beam with its peak occurs at θ_M from zenith [8], [9]

$$\theta_M \approx \arcsin \frac{\beta_x}{k_0} \tag{1}$$

where k_0 is defined to be the wave number in free space. An important application of the LWA is to adjust the frequency to vary β_x/k_0 (The normalized phase constant), and one can steer the beam to θ_M. If the effect of the aperture length of LWA is taken into account, the formulae are available [2] :

$$R(\theta) \approx \frac{1 + e^{-2k_0 L(\frac{\alpha_x}{k_0})} - 2e^{-k_0 L(\frac{\alpha_x}{k_0})} \cos(k_0 L\phi)}{(\frac{\alpha_x}{k_0})^2 + (\phi)^2} \cos^2\theta \tag{2}$$

$$\phi = \frac{\beta_x}{k_0} - \sin\theta \tag{3}$$

These formulae state that the radiation pattern for an finite leaky wave line source that is supported by a purely forward wave can be estimated to be $R(\theta)$. The possible reflections in the LWA are here being ignored. In reality, some reflections can be easily made with some incautious designs at the terminal of the LWA such as an open end termination. These reflections can induce back lobe and side lobes [2] when the LWA is being excited at the end of the terminal of the LWA. Therefore, the potential reflections have to be suppressed to prevent the back lobe and side lobes.

To analysis the LWA, the complex propagation constants are the significant parameters. Since the characteristic of the radiation pattern of LWA is highly correlated with the constants, as mentioned in Eq. (1), (2) and (3). It would be of most importance to extract the complex propagation constants in first.

Here, the numerical Through-Line method [10] with the aid of HFSS [11] and the modified transverse resonance formulation are used to extract the frequency dependence of the complex propagation constant of the HMSIW LWA. The transverse resonance formulation is based on the a rigorous Wiener-Hopf technique [2], [9], [12] and a modified waveguide model for half mode substrate integrated waveguide [13], [14]. To be much explicit, in the expression of the resonance condition mentioned in [2], the effective half width of the HMSIW is substituted by an empirical formula [13], [14]:

$$w_{eff_{HMSIW}} = w - 0.54\frac{d^2}{s} + 0.05\frac{d^2}{2w} \tag{4}$$

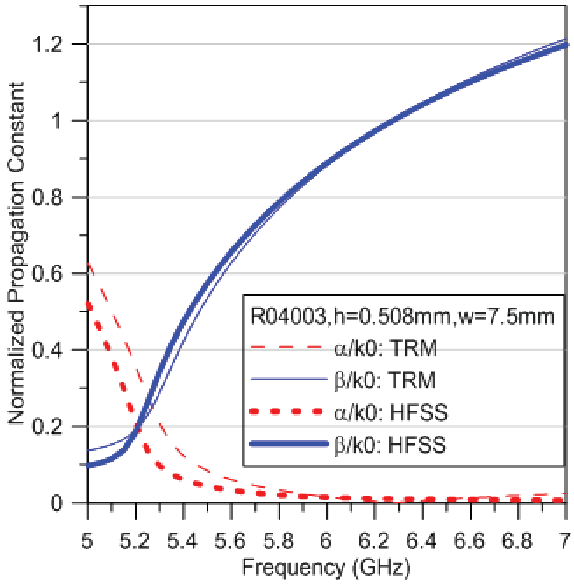


Fig. 1. The extracted propagation constant from the numerical T-L method and the transverse resonance method.

Where w is the physical waveguide width, d is the diameter of the vias and s is the spacing between adjacent vias of the HMSIW. A numerical root searching procedure is then made to find the complex propagation constant. The numerical results of the numerical Through- Line method [10] and the transverse resonance formulation [2], [9], [12] are shown in Fig. 1. It can be seen that the results are in a fair agreement. Form the results, the usable frequency range of this leaky wave antenna as the range which falls in the space wave leakage region [3] is approximately from 5.3 GHz to 6.2 GHz.

III. A Novel Transition for the HMSIW LWA

Figure 2 shows the structure of a HMSIW as the half mode LWA (HMLWA). The substrate is Rogers R04003 with its thickness = 0.508 mm, ε_r= 3.55 and loss tangent = 0.0027 to implement the HMSIW. The aperture length of the LWA is chosen to be 72 mm ($\sim$ 1.4λ). The port2 is assumed be terminated with a 50 ohm load in order to avoid back lobe problems.

Although the classical asymmetric feed can be considered as a simple and direct method to feed the LWA, the discontinuity of the feed structure may possibly be responsible for some side lobes. Therefore, the reflections at the terminal of the LWA has to be suppressed to impress the side lobes [2]. Here, a novel transition which is inspired by a SIW transition [15] is proposed to enhance the efficiency to convert the incident power from the micro-strip line to the leaky mode.

The proposed transition with a stub and a trapezoidal pad connecting the stub and the HMLWA is shown in Fig. 3. The entire HMSIW LWA structure integrated with the transition is displayed in Fig. 4. The associated parameters shown in Fig. 3 and Fig. 4 are tabulated in Table I. The parameters $W_{transtub}$ and L_{tran} play important roles on matching the incident modal field to the desired leaky modal field. They are chosen to be 3.1 mm and 6 mm respectively.

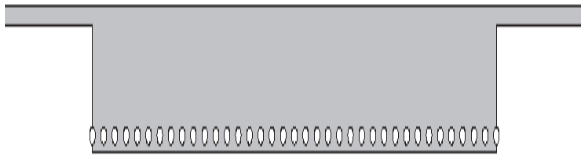


Fig. 2. A half mode substrate integrated waveguide.

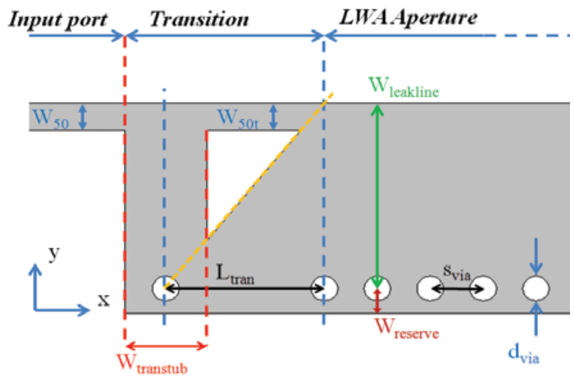


Fig. 3. The configuration of the HMSIW integrated with the proposed transition.

TABLE I
Parameters of the LWA Integrated with the Transition

W_{50}	1.1	$W_{transtub}$	3.1	L_{lwa1}	10
W_{50t}	1.1	L_{tran}	6	L_{lwa2}	10
$W_{leakline}$	7.5	s_{via}	2	L_{xsub}	107
$W_{reserve}$	1	d_{via}	2	$L_{leakline}$	72
L_{subl}	30	L_{subl}	30	unit:	mm

The simulated electric field distribution of the HMLWA is plotted in Fig. 5. Some of the incident power is used to excite the via of the stub scattering cylindrical waves. As the result, the composition of the incident field including the scattered wave and the incident TEM wave can then better matches the field distribution of the leaky mode. The effect of the transition on the 2-port S-parameters of the HMLWA is plotted in Fig. 6. A good improvement on the return loss can be observed. The forward transmission coefficient is nearly the same as the case without the transition. According to the simulation result, the transition design does not disturb the operation of the leaky mode. Furthermore , this transition can greatly improve the conversion of the of the quasi TEM mode of the microstrip to the leaky mode.

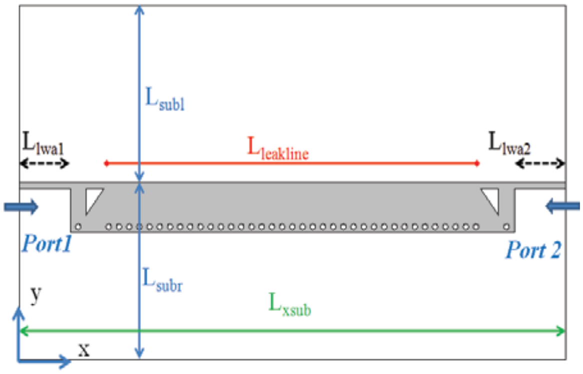
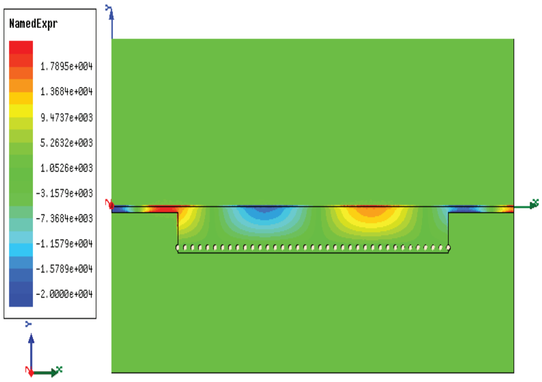
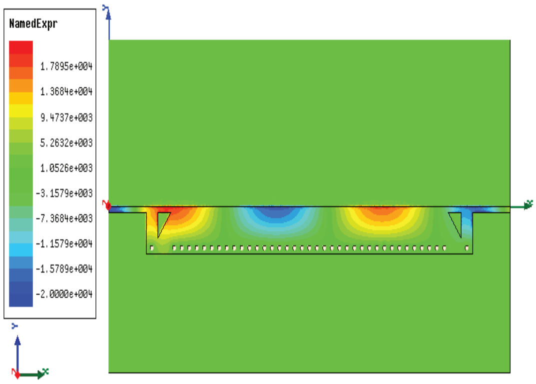


Fig. 4. Configuration of the proposed entire HMSIW LWA.



(a)



(b)

Fig. 5. Simulated electric field (a) HMSIW without the transition. (b) HMSIW with the transition.

IV. Experimental Verifications

The HMSIW LWA with the proposed transition structure is fabricated as shown in Fig. 7. The vias drilled and electroplated by using a printed circuit broad carving machine. The comparison between the measured and the simulated S-parameters of the LWA with transition is shown in Fig. 8. A fair agreement between simulated and measured results can be observed. Figure 9 shows the comparison of the simulated, measured, and the theoretical estimation of the normalized radiation pattern. The radiation pattern which is phi-polarized

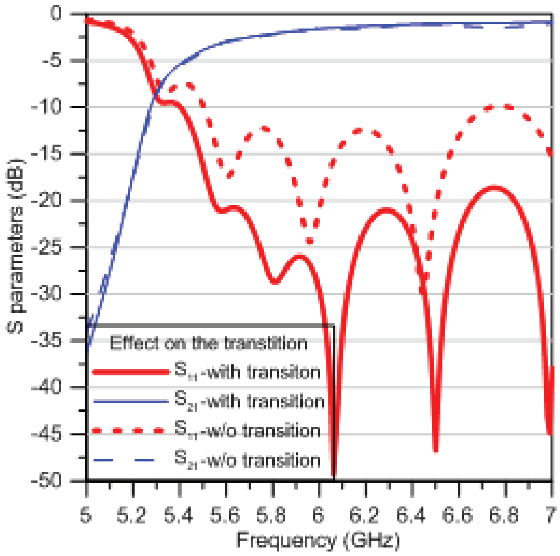


Fig. 6. The effect of the transition on the 2-port S-parameters.

Fig. 7. The fabricated HMSIW LWA integrated with the transition.

at 6.0GHz is only sampled due to the limited space. The theoretical estimation is found by utilizing Equation (2) and (3) accompany with the data acquired in the numerical T-L procedure. Since the transition is used to suppress the potential reflections at the terminal of the LWA, the LWA now is quite close to a theoretical line source that the radiation pattern fairly agrees with Equation (2) and (3).

V. Conclusion

A novel transition designed for a HMSIW operated at the space wave leakage region is proposed in this paper. The transition can better convert the input power into the HMSIW without inducing reflections. The results show that the reflection coefficient and the transmission coefficient are having a good improvement. The analysis method to extract the propagation constant of LWA accompany with the formulae can be successfully used to verify the radiation performance of

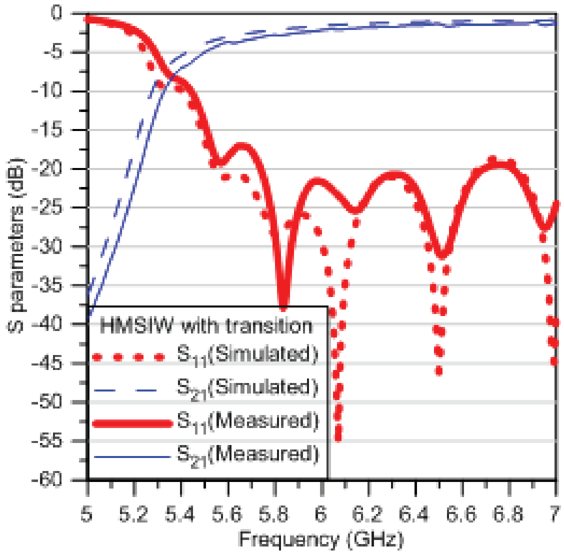


Fig. 8. Comparison between the measured and simulated 2-port S-parameters.

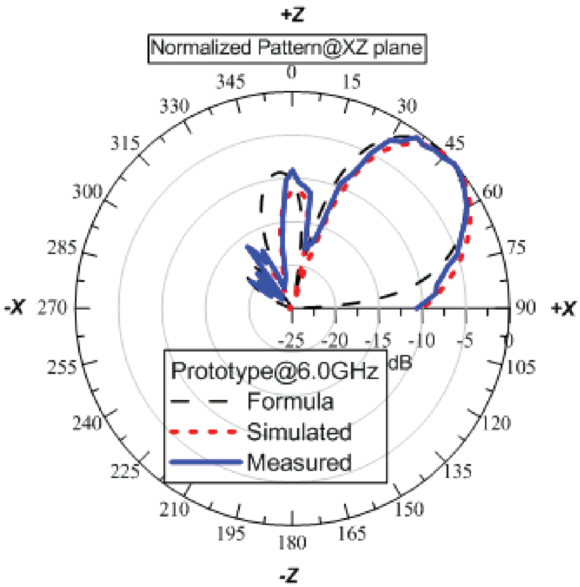


Fig. 9. Comparison of the radiation pattern in XZ plane at 6.0GHz.

the modified LWA. This transition design can greatly facilitate designs for HMSIW LWA.

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