# A Comparative Study on Substrate Integrated Waveguide Periodic Leaky Wave Antennas with Differently Shaped Periodic Slots

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***Abstract*—In this paper, effects of different shapes of periodic slots etched on the broad wall of a via-less substrate integrated waveguide leaky wave antennas are presented. Different shapes of the slots namely circular, elliptical, rectangular and triangular are considered. A comparative performance study based on gain, radiation efficiency and scan range of the antenna for the different shapes is studied over X-band frequency range. Several structures are fabricated. 50 Ω microstrip lines are used to excite the antennas. It is observed that the rectangular shaped slot is the best choice if higher gain, radiation efficiency and wide scan range including the stopband is considered. Measured results match well with simulated results.**

***Index Terms*—Leaky wave, leaky-wave antenna, periodic structure, substrate integrated waveguide.**

## I. Introduction

Leaky wave antenna (LWA) has the advantage of beam angle scanning with frequency, high gain, and low side lobe level. There are two types of LWA's. A uniform LWA radiates throughout the length for which the main beam, usually, steers from near broadside to forward end-fire direction with the increasing frequency. And in a periodic LWA, periodic perturbations are introduced for radiation and beam scanning with increasing frequency is from backward to forward direction with a stopband near the broadside direction. Therefore, a periodic LWA has the advantage that it can scan across the broadside direction [1]. The stopband is characteristic of any periodic structure.

All LWAs use a long wave-guiding section, sometimes longer than ten wavelengths at the operating frequency. Therefore, to improve the overall gain of the antenna, the losses other than radiation loss from hosting guiding section should be as small as possible. A substrate integrated waveguide (SIW), realized in printed circuit board (PCB) technology, provides much lower loss compared to other popular PCB based guiding structures like microstrip, CPW and CPS lines etc. [2], [3]. In addition to higher gain, LWAs in SIW technology has the advantage of robustness, simple feeding and low cost. Although several uniform LWAs are reported in literature [4], only a few periodic LWA based on SIW are available. In [5], the periodic LWA utilizes gap from the vias for leakage. In this work the periodicity is introduced in the broad wall by etching periodic slots for leakage. In this work, slots of different shapes are studied. In all the designs the $TE_{10}$ mode has been used.

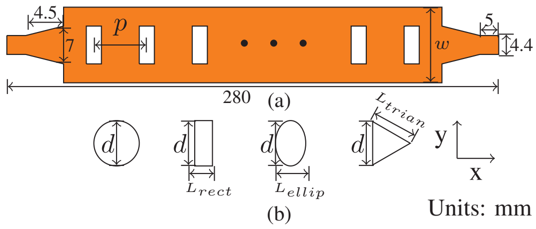


Fig. 1: (a) Top view of the periodic LWA showing different dimensions. The LWA has $w$ = 19 mm, $p$ = 17 mm (b) Different shapes of the slots where $d$ = 5.6 mm.

## II. Design and Analysis

The proposed structure is shown in Fig. 1a. Microstrip to via-less SIW transitions are used for excitation and measurement purpose. The other end of the antenna is terminated with a matched load of 50 Ω. As shown in the figure, periodic slots of different shapes are etched symmetrically with respect to the central line of the SIW in one of its broad walls. In all the present designs, because of the periodicity, Floquet Modes are generated. The propagation constant $\beta_n$ of the $n^{th}$ harmonic is given by

$$\beta_n p = \beta_0 p + 2n\pi, \tag{1}$$

where $p$ is the period, $\beta_0$ is the fundamental space harmonic and it represents propagation constant of the periodic guided wave structure. In the present design, the first harmonic, $\beta_{-1}$, which is a fast wave, is used for the radiation. Except a narrow region near the cutoff frequency, the fundamental mode in a periodically loaded SIW is a slow wave. Since $\beta_0/k_0 > 1$, it does not radiate. The, main beam direction for the LWA is given by

$$\sin\theta_m \approx \frac{\beta_{-1}}{k_0}, \tag{2}$$

where, $\theta_m$ is the main beam angle measured from the broadside direction. As the frequency increases, the main beam steers from backward direction to the forward quadrant with a stop band centered at $\theta_m = 0°$. The maximum scan angle in forward direction is limited by the emergence of a second

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beam in the backward direction, as the second harmonic $\beta_{-2}$ also starts to radiate.

Fig. 2: Photograph of the fabricated rectangular slot LWA.

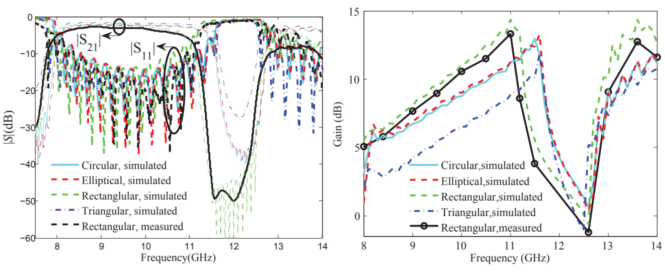
TABLE I: Different Slots Dimensions, Scan, and Gain Range (8-14 GHz)

| Type of Slot | Dimension of slot (mm) | Scan Range | Min. and max. gain (dB) |
|---|---|---|---|
| Circular | Diameter = 5.6 | 90° | 0.65 - 12.9 |
| Elliptical | $L_{ellip} = 6$ | 90° | 0.4 - 13.3 |
| Rectangular | $L_{rect} = 3.5$ | 90° | -0.69 - 14.5 |
| Triangular | $L_{triang} = 6.8$ | 90° | -1 - 11.8 |

Different shapes considered here are shown in Fig 1b. The nature of the stopband for all the structures is almost same since the period $p$ is kept the same in each case. It is observed that as the SIW width $w$ increases, the separation between two consecutive stopband increases. So the width $w$ was increased from 14.45 mm (standard width for X-band waveguide for the chosen $\epsilon_r = 2.5$) to 19 mm so as to include the X band in the passband. The period $p$ is chosen such that $p \approx \lambda_g$ where ($\lambda_g = \lambda_0/\sqrt{\epsilon_r}$) at the stopband center frequency $f_s \approx$ 12 GHz. Also as $p$ increases the passband starts from lower frequencies. So, accordingly periodicity $p$ was tuned to start the passband from 8 GHz. The slot dimension of 5.6 mm transverse to the wave propagation direction is obtained by starting from a non-resonant length at the center frequency of 10 GHz and tuning it so as to obtain return loss below -10 dB in the X-band. Once this transverse dimension is fixed for the circular slot case, it is kept the same for all the other slots as well.

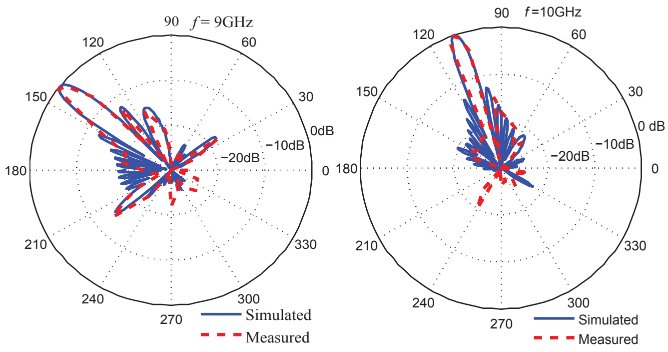
The dimensions $L_{ellip}$, $L_{rect}$, $L_{triang}$ were varied in the case of elliptical, rectangular and triangular slots to obtain good input matching in the X-band. All studies are performed in the CST Microwave Studio. A 1.58 mm thick 3M substrate with $\epsilon_r = 2.5$ and $\tan\delta = 0.0019$ is considered for all simulations. The radiation efficiency of the circular, elliptical, triangular and rectangular slot antenna varies between 55%–80%, 50%–80%, 52%–76% and 60%–87% respectively.

The sidewalls of the LWA are realized by electroplating on dielectric technique instead of periodic vias. The effects of different slot shapes on antenna performance along with their dimensions are listed in Table I. In all the cases, a stopband is obtained centred at about 12 GHz. The stopband position can be tuned by changing the periodicity $p$.




(a) (b)

Fig. 3: (a) Simulated and measured S parameters of different shaped slots (b) Simulated and measured gain plot of different shaped slots




(a) (b)

Fig. 4: (a) Simulated and measured radiation pattern at 9 GHz. (b) Simulated and measured radiation pattern at 10 GHz.

## III. Fabrication and Measurement

A photograph of the fabricated rectangular slot LWA is shown in Fig. 2. The simulated and measured return loss characteristics and gain are shown in Fig. 3a and Fig. 3b respectively. The simulated and measured radiation pattern at 9 GHz and 10 GHz are shown in Fig. 4a and Fig. 4b respectively. As the frequency increases the main beam sweeps from backward to forward direction. The measured and simulated results match closely.

## IV. Conclusion

The effect of different periodic regular shaped slots is studied for via-less SIW LWA. It is observed that the rectangular shaped slot has the highest gain and the triangular shaped slot has minimum gain. Whereas, elliptical and circular slots have almost similar gain. The scan range being dependent on the periodicity $p$ from equation 1 and 2, so the scan range in all cases is same. Also rectangular shaped slot has the highest radiation efficiency. So, it can be concluded that the rectangular shaped slot is the best choice among the options considered here.

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