

Leaky Wave Antenna Design based on SIW Technology for Millimeter Wave Applications

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Abstract: - Actually, substrate integrated waveguide (SIW) technology offers a promising advance for the implementation of compact, low-loss and cost effective components at microwave and millimeter-wave frequency. In this paper a new type of leaky-wave antenna (LWA) using substrate integrated waveguide (SIW) as the base structure is proposed and numerically designed. The proposed antenna is therefore a good candidate for millimeter-wave applications. This antenna is accurately simulated by using CST the antenna radiates one main beam that can be steered from the backward to the forward direction by changing frequency. The simulations were conducted using the simulator CST Microwave studio.

Key words: -Leaky wave antenna, substrate integrated waveguide, CST.

1 INTRODUCTION:

In recent years, a new waveguide technology called the substrate integrated waveguide (SIW) has been introduced in many microwave communication systems [1-7]. SIW (substrate integrated waveguide,) is a synthetic rectangular electromagnetic waveguide formed in a dielectric substrate by densely arraying metalized via-holes which connect the upper and lower metal plates of the substrate, SIW is used to design all passive components and assemble all active components on a same support. Substrate integrated waveguide (SIW) has been applied to the design of leaky-wave antenna [8-10]. As a post wall waveguide, SIW is a planar structure and is suitable for millimeter-wave applications due to its advantages of low cost, low profile, and easy integration with planar circuits.

Leaky-wave antennas (LWAs) possess certain advantages over conventional antenna arrays. A high-gain LWA can be achieved by simply extending its physical length, which can result in a compact size especially in millimeter-wave applications. Furthermore, LWAs can be designed to exhibit both forward and backward beam steering by incorporating metamaterials into their unit cells. Nevertheless, the frequency-scanning capability of metamaterial-based LWAs is not suitable for more common fixed-frequency applications.

In this paper, a novel leaky-wave antenna based on the SIW technique in the millimeter-wave is presented, first we design a SIW component operating in millimeter-wave for TE_{10} mode with CST Microwave Studio® commercial software's. The design procedures begin by extracting the equivalent width guide and then calculate the width

of SIW, by the following formulas design. After that, and for transit SIW to microstrip we use the ADS (advanced design system) Software.

Finally, we design a leaky-wave antenna based on substrate integrated waveguide (SIW) with transverse slots; the antenna radiates one main beam that can be steered from the backward to the forward direction by changing frequency

2 Siw design

SIW constructed by metal filled via-hole arrays in substrate and grounded planes which can be easily interconnected with other elements of the system on a single substrate plat form without tuning, this system can be miniaturised into small package called the system in package SIP which has a small size and a low cost. A schematic view of an integrated waveguide is shown in Fig. 1. A substrate-integrated waveguide (SIW) is made of metallic via arrays in the substrate between top and bottom metal layer replacing the two metal sidewalls. The propagation properties of the mode in the SIW are very similar to the electromagnetic field distribution of TE_{10} like mode in a conventional metallic rectangular waveguide (RWG).

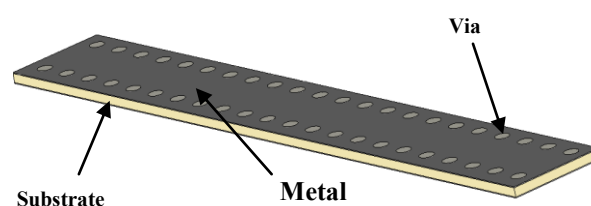


Fig.1 SIW structure.

Fig. 2 shows the cross-sectional view field distribution of dielectric waveguide and SIW without transitions at 5.5 GHz.

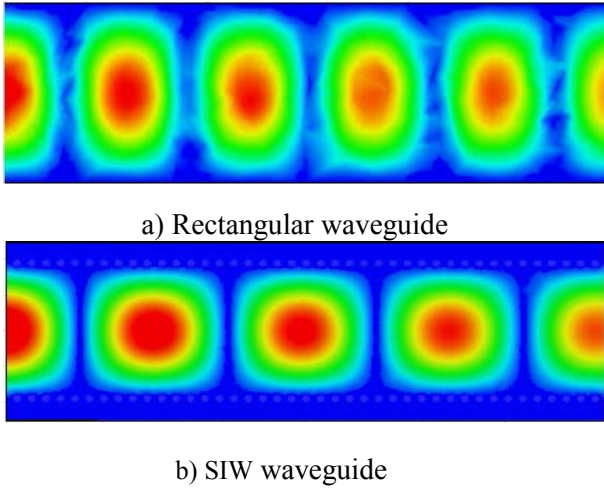


Fig.2 Electric fields distributions in rectangular waveguide and SIW waveguide.

In this section we calculate the parameters of SIW by the following equations.

Since SIW design generally works in TE₁₀ mode, so here $m=1, n=0$. Therefore the equation for cutoff frequency reduces to:

$$f_c = \frac{c}{2a} \tag{1}$$

For DFW with same cut off frequency, dimension "ad" is found by:

$$a_d = \frac{a}{\sqrt{\epsilon_r}} \tag{2}$$

Having determined the dimension ad for the DFW, we can now pass to the design equations for SIW [1-2],[9].

$$a_s = a_d + \left(\frac{d^2}{0.95s}\right) \tag{3}$$

Where, a is the total broad side dimension of the rectangular waveguide, as is the separation between via rows (centre to centre), a is the width of DFW, d is the diameter (as shown in Fig. 2) and c is the velocity of light in free space.

For SIW design, the following two conditions are required [1-2],[9]:

$$d \leq \frac{\lambda_g}{5} \tag{4}$$

$$s \leq 2d \tag{5}$$

Where : λ_g (guided wavelength) is it given by:

$$\lambda_g = \frac{2\pi}{\sqrt{\frac{(2\pi f)^2 \epsilon_r}{c^2} - \left(\frac{\pi}{a}\right)^2}} \tag{6}$$

We use these equations to build a SIW with CST (Fig. 1) by the following specification ; cutoff frequency of TE₁₀ mode in SIW is selected about 31 GHz with the following parameters on Arlon Cu 2331x (lossy), with dielectric constant of $\epsilon_r=2.33$ and $\text{tang } \delta=0.0013$.

The result of the simulation for the cut off frequency 31 GHz is given by the Fig. 3.

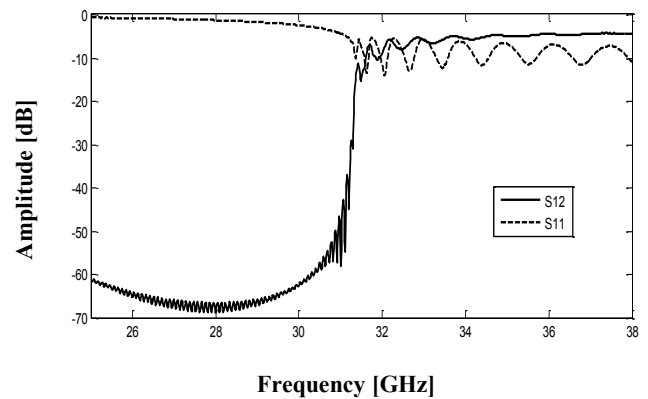


Fig. 3 The reflected power and the transmission coefficient of the SIW waveguide. The SIW waveguide parameters are set to: $a_s=3.2 \text{ mm}, d=0.4 \text{ mm}, s=1.8 \text{ mm}, b=0.508 \text{ mm}$.

In order to combine SIW and microstrip technologies, SIW-microstrip transitions are very required .

This kind of transition consists of a tapered microstrip line section that connects a 50 microstrip line and the integrated waveguide. The taper is used to transform the quasi-TEM mode of the microstrip line into the TE₁₀ mode in the waveguide.

This transition contains two main parameters, the original width W_0 , the final width W of the profile line. It is necessary to calculate the impedance of SIW guide, which is given by the following formula :

$$Z_{pi} = Z_{TE} \frac{b\pi^2}{8a_s} \tag{7}$$

For the calculation of the guide impedance, it is also necessary to calculate the wave impedance of TE mode, which is given by [1-2],[9]:

$$Z_{TE} = j\omega \frac{\mu}{\gamma} = j\omega \frac{\mu'}{\beta} = \sqrt{\frac{\mu}{\epsilon}} \times \frac{\lambda_g}{\lambda} \tag{8}$$

The calculated parameters are used to construct a taper by using ADS (advanced design system) software, the physical transition structure of microstrip line with the guide HMSIW is shown in Fig. 4.

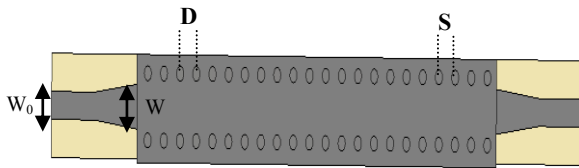


Fig. 4 Topology of transition with SIW guide.

This line is simulated by using CST. The simulated result is shown in Fig. 4.

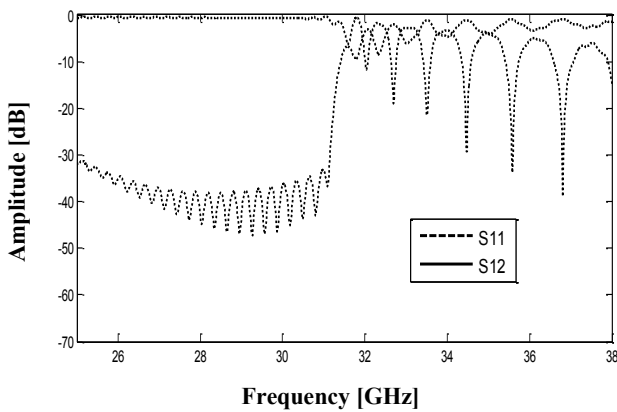


Fig. 5. Reflected power and the transmission coefficient of SIW guide.

We observe from Fig. 5 a good matching and the apparition of various resonant frequencies. Let us notice that there not is any transmission for the frequencies below the cut off frequency 31.5 GHz.

3 Leaky wave antenna using SIW

Fig. 6 shows the structure of a SIW LWA .The substrate Arlon Cu 233lx (lossy) with its thickness = 0.508 mm, $\epsilon_r= 2.33$ and loss tangent equal to 0.0013 with slots in the surface situated in both side of SIW.

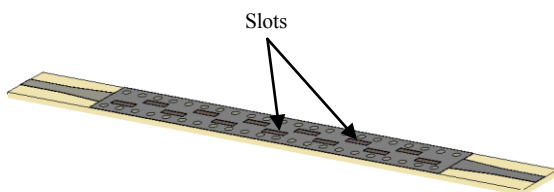


Fig. 6 Configurations of the proposed SIW leaky-wave antenna structures.

The simulated results of S-parameters for leaky wave antenna based on SIW are shown in Fig. 7. It can be observed that simulated S_{11} is below -10 dB from 30 to 36 GHz and S_{21} is bigger than -10 dB from 30 to 36 GHz.

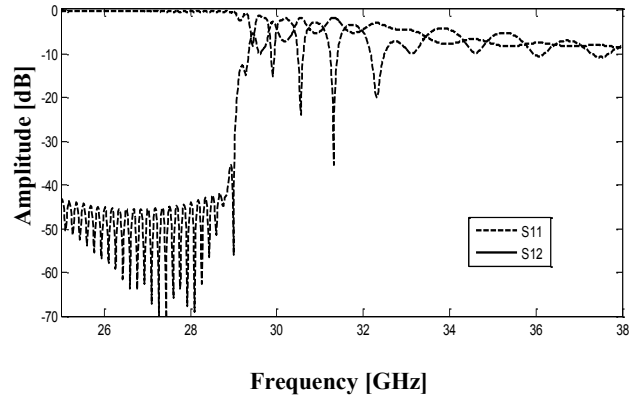


Fig. 7. simulated S-parameters of LWA based on SIW .

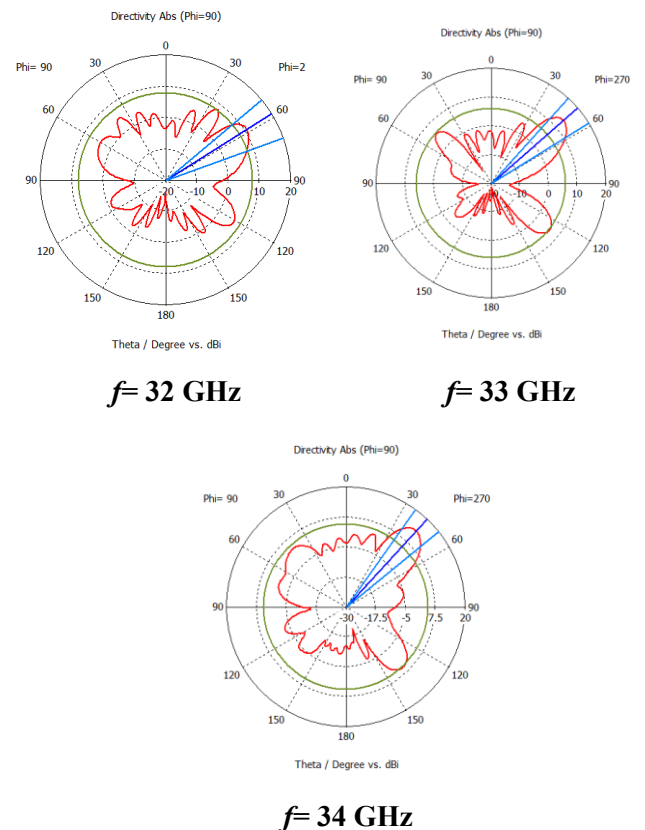


Fig. 8. The simulated radiation patterns in polar coordinates.

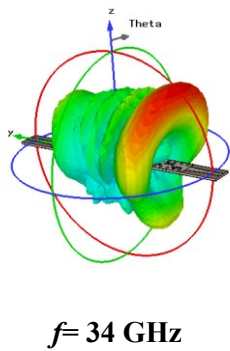
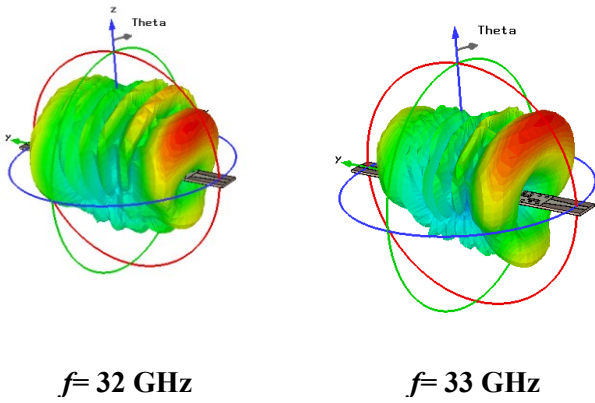


Fig. 9. The simulated radiation patterns in 3-D

Fig. 8 and 9 shows respectively the simulated radiation patterns in polar and 3-D. It is seen that, when the frequency is increased, the main beam moves from the backfire towards the end fire direction. At the transition frequency, the radiation goes exactly to the broadside.

In this part position of slots is changed, the figure below shows the final structure.

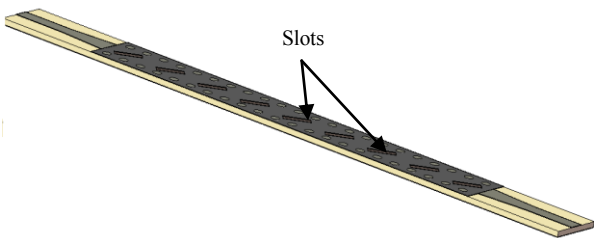


Fig. 10 SIW leaky-wave antenna structure.

The simulated results of S-parameters are shown in Fig. 11.

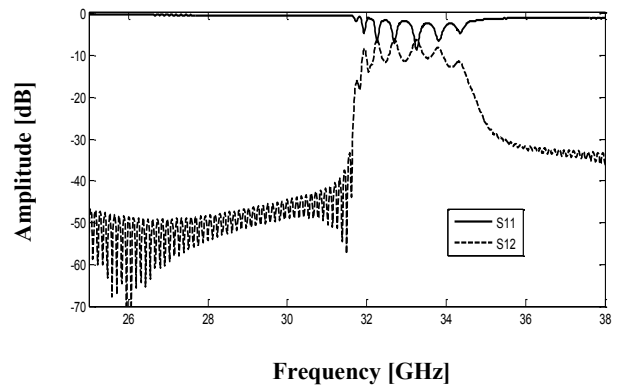
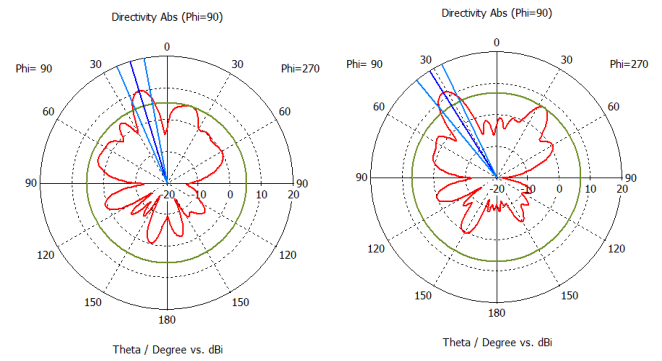
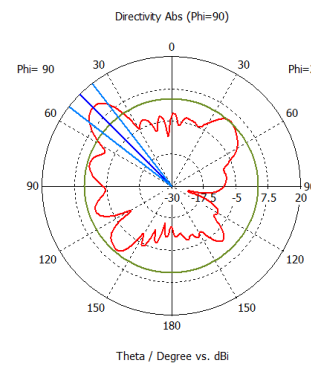


Fig. 11 simulated S-parameters of LWA based on SIW .



$f = 32 \text{ GHz}$

$f = 33 \text{ GHz}$



$f = 34 \text{ GHz}$

Fig. 12 The simulated radiation patterns in polar coordinates.

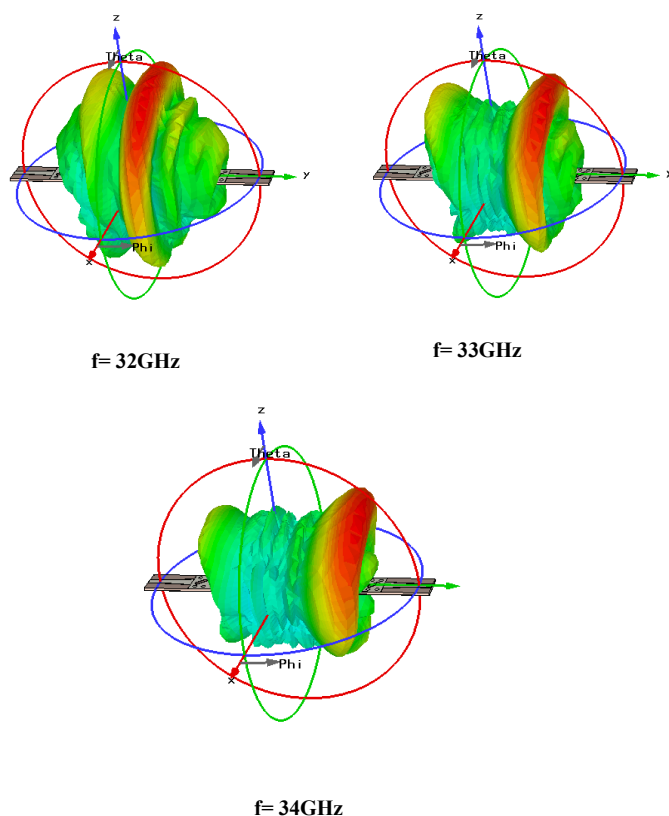


Fig. 13. The simulated radiation patterns in 3-D.

Fig. 12 and 13 shows respectively the simulated radiation patterns in polar and 3-D. It is seen that by changing the position of slots in the center, the radiation pattern diagram becomes more directive.

4 Conclusion

A leaky-wave antenna based on the SIW technique is proposed. Results show that the proposed antenna has the advantages of wide band width, high gain, low fabrication cost, low weight in addition to its common features like high directivity and beam steering capability which make it suitable for millimeter-wave applications. The design is first passed by calculating the parameters of SIW, then we optimize the taper to make the transition between supply and input guide to ensure a perfect adaptation, after that we designed a leaky wave antenna based on a substrate integrated waveguide (SIW), the direction of radiation in this antenna change according to the variation of frequency, it is concluded also that the position of slots influences the directivity.

References

- [1] B. Mansouri, M. Abri, H. Abri, M. A. Rabah, J. Tao, and T.-H. Vuong, *SIW Bandpass Filter Screens S-Band Signals*, pp. 62-66, Mars, 2015.
- [2] M. A. Rabah, M. Abri, J. Tao, and T. H. Vuong, *Substrate Integrated Waveguide Design Using The Two Dimensional Finite Element Method*, Progress In Electromagnetics Research M, Vol. 35, pp. 21-30, 2014.
- [3] J. E. Rayas-Sanchez and V. Gutierrez-Ayala, *A General EM-Based Design Procedure for Single-Layer Substrate Integrated Waveguide Interconnects with Microstrip Transitions*, IEEE MTT-S Int. Microwave Symp. Dig., Atlanta, GA, Jun. 2008, pp. 983-986.
- [4] S. Lim, C. Caloz, and T. Itoh, *Electronically-controlled metamaterial based transmission line as a continuous-scanning leaky-wave antenna*, in IEEE MTT-S Int. Microwave Symp. Dig., Fort Worth, TX, Jun. 6-11, 2004, pp. 313-316.
- [5] K. Okubo, M. Kishihara, A. Yamamoto, J. Yamakita, and I. Ohta, *New composite right/left-handed transmission line using substrate integrated waveguide and metal-patches in IEEE MTT-S Int. Microwave Symp. Dig.*, Boston, MA, Jun. 7-12, 2009, pp. 41-44.
- [6] L. Yan, W. Hong, K. Wu and T.J. Cui, *Investigations on the propagation characteristics of the substrate integrated waveguide based on the method of lines IEE Proc.-Microw. Antennas Propag*, Vol. 152, No. 1, February 2005.
- [7] X. Chen, W. Hong, T. Cui, J. Chen and K. Wu, *Substrate Integrated Waveguide (SIW) Linear Phase Filter*, *IEEE Microwave and Wireless Components Letters*, Vol. 15, No. 11, 2005.
- [8] J. Xu, W. Hong, H. Tang, Z. Kuai, and K. Wu, *Half-Mode Substrate Integrated Waveguide (HMSIW) Leaky-Wave Antenna for Millimeter-Wave Applications*, *Antennas and Wireless Propagation Letters*, Vol. 7, pp. 85 - 88, 2008.
- [9] S. Doucha and M. Abri, *New Design of Leaky Wave Antenna Based on SIW Technology for Beam Steering*, *International Journal of Computer Networks & Communications (IJCNC)*, Vol.5, No.5, September 2013.
- [10] Y. Weitsch and T. Eibert, *A left-handed/right-handed leaky-wave antenna derived from slotted rectangular hollow waveguide in European Microwave Conf*, Munich, Germany, Oct. 9-12, 2007, pp. 917-920.