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Losses in Waveguide and Substrate Integrated Waveguide (SIW) For Ku Band: A Comparison

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ABSTRACT*- In this paper equivalent Substrate Integrated Waveguide (SIW) for a waveguide is designed. Different types of losses in the waveguide and the optimized SIW are calculated theoretically and a comparison is done between the two. The comparison proves that at millimeter wave frequencies the choice of dielectric becomes crucial for a waveguide design and SIW is preferable to be used at these frequencies because the leakage losses decrease significantly.*

Keywords*- waveguide; SIW; dielectric loss; conduction loss; leakage loss*

I. INTRODUCTION

Conventional waveguides, the first generation of microwave guiding structures had the advantages of having high power carrying capacity and high Q-factor, but also had the disadvantages of being bulky and voluminous. The next generation of microwave guiding elements was the strip-like or slot-like planar printed transmission lines used in Microwave Integrated Circuits (MICs).These were planar low profile structures but lacked the high power carrying capacity and high Q-factor of the conventional waveguides. To bridge the gap between MIC structures and conventional waveguides, Substrate Integrated Circuits (SICs) were developed which are planar low profile structures like MIC structures, also having high power carrying capacity and high Q-factor similar to waveguides[1].

Principle of operation of SIC was to build artificial channels within the substrate to guide the waves. Two techniques are used to build these channels (which are embedded in the substrate).One is to use metallic vias which act as sidewalls. Other technique uses contrast in values of ε_r so that phenomenon of total internal reflection can take place and the wave gets confined within the artificial channel [2]. A Substrate Integrated Waveguide (SIW) is one of the topologies of SIC. The SIW technology has been successfully applied to several microwave and millimeter-wave components, including active circuits, passive components and antennas [3].

II. THEORETICAL DETAILS

SIW consists of substrate with metalized vias acting as two side walls and two metallic walls (upper and lower) as shown in Fig.1b. Its design parameters are the distance between the two rows of vias(a), pitch(p), diameter of each via(d), height of the substrate (w) and dielectric constant ε_r.

For a waveguide with width $\boldsymbol{\ell}$ and height **h** its equivalent SIW [4] parameters can be found using equation (1) which relates different dimensional parameters of waveguide and its equivalent SIW.

$$\ell = a - 1.08\frac{d^2}{p} + 0.1\frac{d^2}{a} \qquad (1)$$

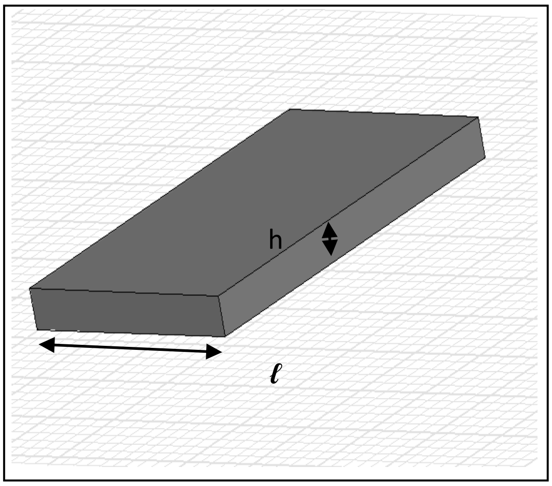

Figure 1a. Topology of Waveguide

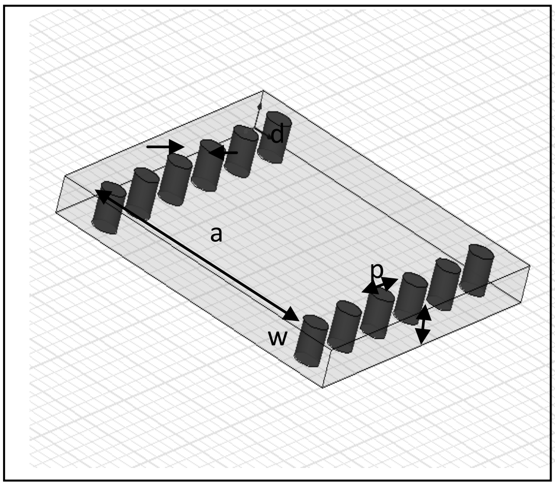

Figure1b.Topology of SIW

Waveguides have two types of major losses, the dielectric loss (α_d) and the conductor loss (α_c).

$$\alpha_d = (k^2 \tan\delta)/2\beta \qquad (2)$$

$$\alpha_c = R_s \frac{(2h\pi^2 + \ell^3 k^2)}{\ell^3 h\beta k\eta} \qquad (3)$$

where k is free space wave number
β is phase constant
tanδ is the dielectric loss tangent
η is the intrinsic impedance of the medium

$$\eta = \sqrt{\frac{\mu_0}{\varepsilon_0 \varepsilon_r}} \qquad R_s = \sqrt{\frac{\omega\mu_0}{2\sigma}}$$

σ is conductivity of metal

R_s is surface resistivity of the conductors

$$\alpha_{\text{waveguide}} = \alpha_d + \alpha_c$$

In Substrate Integrated Waveguides, along with dielectric loss (α_d) and conductor loss (α_c) leakage loss (α_l) also exists which has a significant effect on the performance. Equations for α_d and α_c for SIW is rewritten as,

$$\alpha_d = (k^2 \tan\delta)/2k_z \qquad (4)$$

$$\alpha_c = \frac{Rs}{a_e\, \eta \sqrt{1 - \frac{k_c^2}{k^2}}} \left[\frac{a_e}{w} + \frac{2k_c^2}{k^2}\right] \qquad (5)$$

a_e is the equivalent width of the SIW[3]

$$k_c^2 = k^2 - k_z^2$$

$$\alpha_l = |k_{zi}| \qquad (6)$$

$$k_z(f) = \sqrt{\left\{k^2 - \left[\frac{2}{a_e} cot^{-1}\left(\frac{f_c}{f}\, r_s(1-j)\right)\right]^2\right\}} \qquad (7)$$

r_s is real part of the surface wave impedance [5], a_e is the effective value of a and k is the free space wave number, f_c is cut off frequency and f is operating frequency.

III. SIMULATION AND RESULTS

The waveguide is designed for Ku band (f_c=14 GHz) with dimensions ℓ=6.86mm. , h=0.5mm. and ε_r=2.33, the parameters of its equivalent SIW are calculated using equation(1) to be a=7.2mm., p=2mm., d=0.8mm., w=0.5mm., ε_r=2.33.The different parameters of the SIW are varied to find the dimensions of the optimal SIW [6]. The dimensions for the optimal SIW obtained after several iterations are a=7.2mm. p=3mm. d=0.8mm. w=0.5mm. Er=2.33.

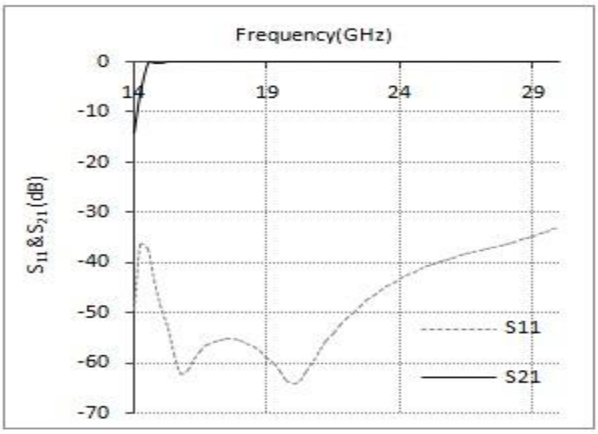

Figure 4a. S_{11} and S_{21} for the waveguide

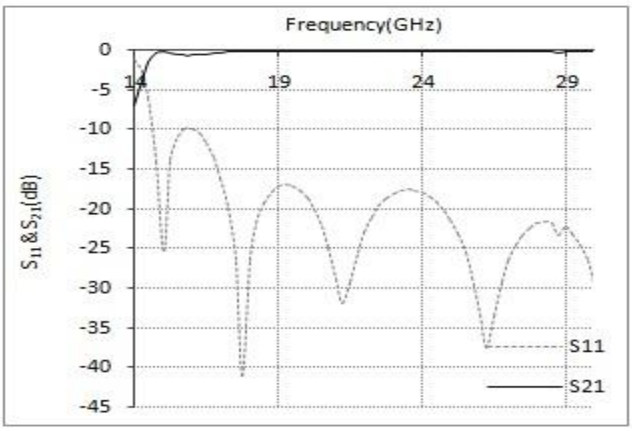

Figure 4b. S_{11} and S_{21} for the optimized SIW

Fig. 4 shows the variation of S_{11} and S_{21} for the waveguide and the equivalent SIW which is showing similar performance as the waveguide. Performance of S_{11} for SIW is a bit deteriorated from waveguide but still it is under acceptable limits (<-10 dB) throughout the frequency range.

Dielectric loss (α_d) and conductor loss (α_c) for the waveguide are calculated using equations (2) and (3) and their variation with frequency is shown in Fig. 5. Both the factors are decreasing with frequency up to 19 GHz and become constant after that. As frequency increases beyond 23GHz α_d starts increasing slowly, but α_c remains constant. The value of α_d goes higher than $\alpha_{c\ at}$ higher frequency range (>16 GHz).

Values of α_d , α_c and α_l for the optimized SIW are found using equations (4) through (7) and their variation with frequency is shown in Fig. 6. The factor α_l is decreasing; α_d is increasing slowly and α_c first decreases in the lower side of the frequency band and remains constant with the increase in frequency in the higher band.

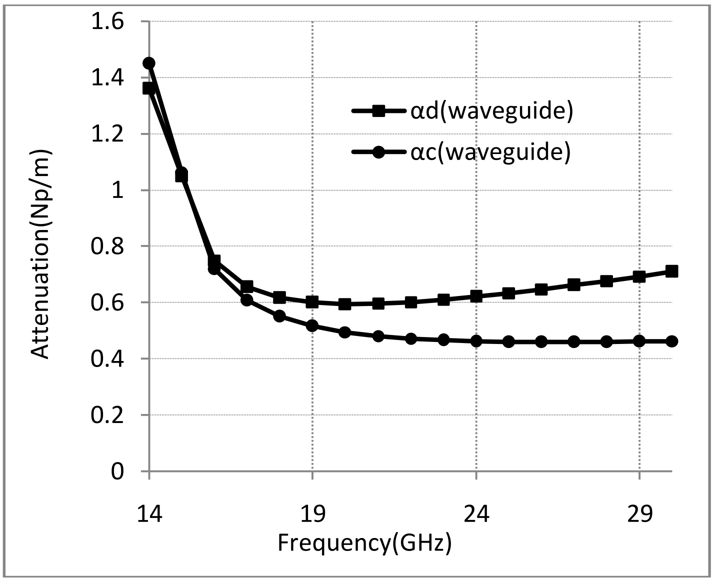

Figure 5. α_d and α_c for the waveguide

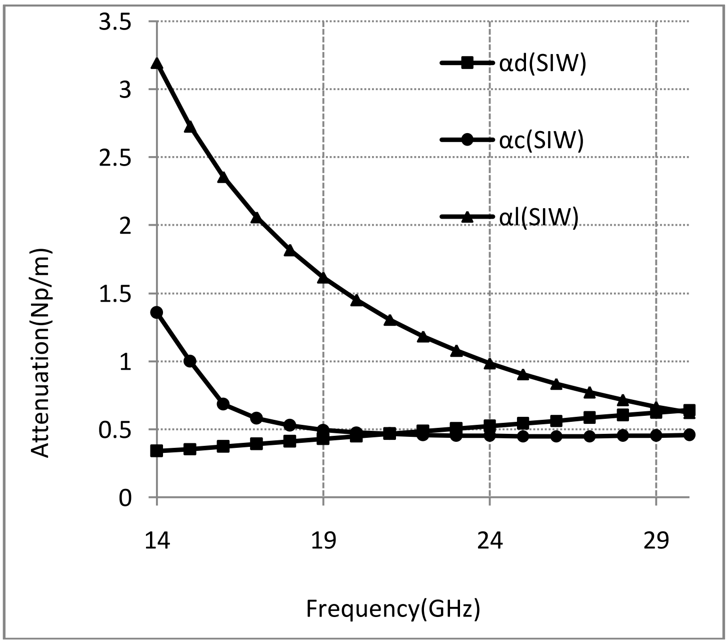

Figure 6. α_d, α_c and α_l for the SIW

Fig. 7 shows the variation of different attenuations occurring in a waveguide as well as in a SIW with respect to frequency. The comparative graph shows all the values are lying in the same range except for a very high value of leakage loss in case of a SIW in lower side of frequency range. This results in a very high value of total attenuation α_t for SIW as compared to the waveguide in lower side of the frequency range. But as we go on increasing the frequency the discrepancy reduces giving comparable values of total attenuations α_t(waveguide) , α_t (SIW) for waveguide and the optimized equivalent SIW respectively. As frequency increases beyond 28GHz dielectric loss becomes the most significant loss. This proves that the SIW structures are more useful at millimeter wave frequencies and their losses become comparable to the waveguides.

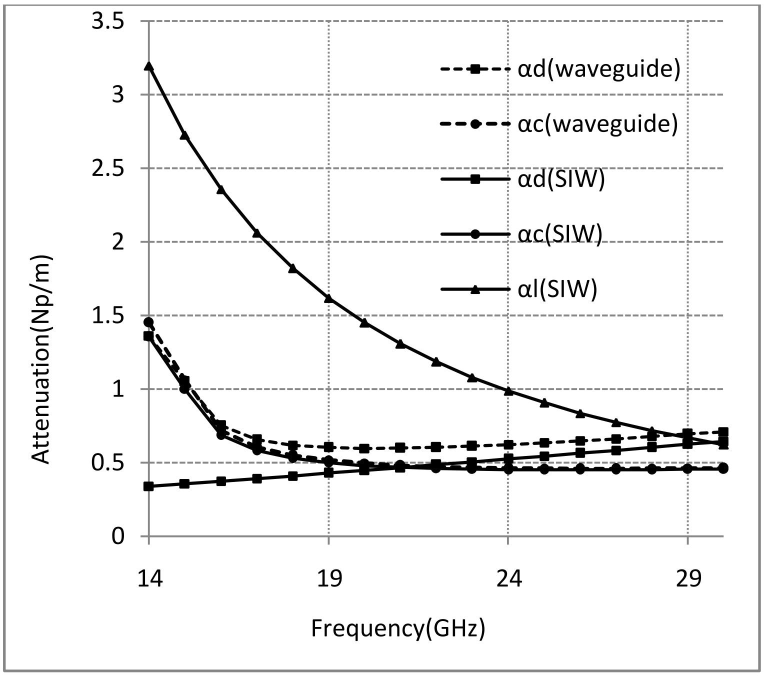

Figure 7. α_d and α_c for the waveguide and α_d, α_c and α_l for the SIW

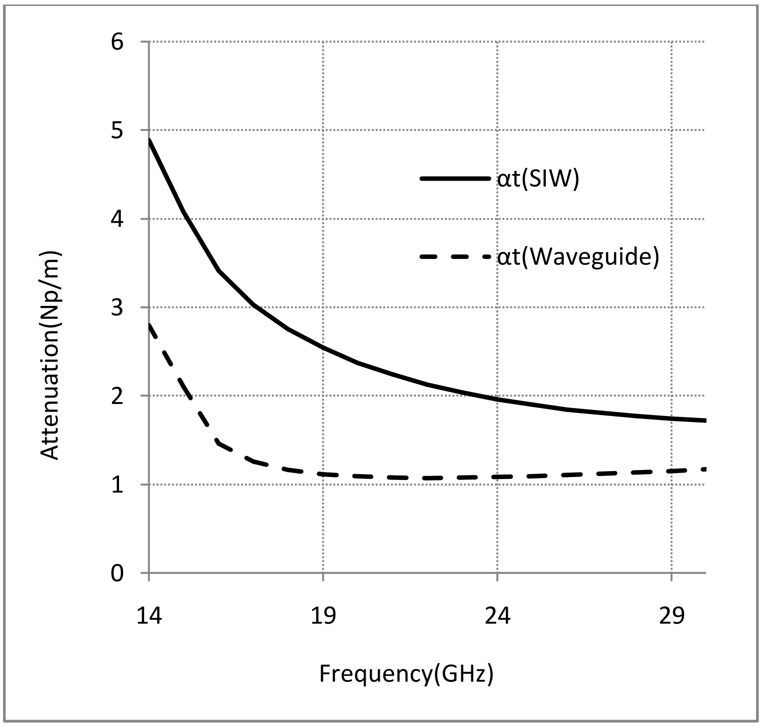

Figure 8. α_t for the waveguide , α_t for the SIW

As the frequency increases total attenuation in SIW α_t(SIW) approaches the total attenuation in waveguide α_t(waveguide). In lower side of the frequency range the value of α_t (SIW) is higher than that of a waveguide which can be attributed to the leakage losses occurring due to gaps between the cylinders of SIW. But as we go on increasing the frequency the discrepancy reduces due to the fall in leakage loss and both the total losses α_t(waveguide), α_t (SIW) become almost equal.

IV. CONCLUSION

A SIW equivalent has been designed for a Ku band (f_c=14 GHz) waveguide. For a waveguide of width 6.86mm. Height 0.5mm and ε_r=2.33. parameters for the equivalent SIW are calculated to be a=7.2mm., d=0.8mm., p=2mm., h=0.5mm.The optimized equivalent SIW is considered for further analysis. The parameters for the optimized SIW are a=7.2mm., d=0.8mm., p=3mm., h=0.5mm.

Attenuation constant is theoretically calculated which are occurring due to dielectric and conductor for the waveguide and due to dielectric, conductor and leakage for the SIW. Total attenuation is compared between the two. It has been concluded that at lower side of the frequency band leakage loss in SIW plays the most significant role. In this range of the frequency band leakage loss in SIW is very high but as frequency increases it falls down to the order of other losses i,e of the order of dielectric and conductor losses and attenuation in SIW approaches to that of waveguide.

It is also concluded that dielectric loss slowly increases with frequency and plays the most significant role at upper frequency bands. For a wave guiding structure to work with lower attenuations at higher frequency ranges the choice of dielectric substrate plays the most significant role. We can also conclude that SIW performance comes closer to the waveguide performance at millimeter wave frequencies and so considering all their advantages, it is feasible to use SIWs for higher frequencies.

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