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A Study on Losses in Substrate Integrated Waveguide

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Abstract – This paper presents different losses associated with Substrate integrated waveguide. As embryonic 5G technology use frequency spectrum from 28 GHz to 100 GHz, which can be achieved using mm-Wave in which frequency ranging from 30 GHz to 300 GHz. But limitations of this mm-Wave include attenuation due to metal waveguide, atmospheric attenuation and Rain fade etc. A improved waveguide method is adapted known as Substrate Integrated Waveguide. SIW is transition between micro-strip antenna and Dielectric filled Waveguide antenna. SIWs are planar structures so they can be fabricated over PCBs and can be easily integrated with supplementary transmission lines.

Keywords — Substate Integrated Waveguide; Vias; mmW; EHF or VHF; Design SIW

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I. INTRODUCTION

In Era of Faster data transfer with better reliability, 5G is under test which make use of millimeter wave also known as mmW or mm Wave which consents higher data rates upto 10 Gbps.. mmW are the waves having wavelength ranges from 30 GHz to 300 Ghz which id wedged in between microwave and infrared waves. These waves are also called as Extremely High Frequency (EHF) or Very High Frequency (VHF) waves. Millimeter wave communication are currently used for fixed links between cell towers which are generally known as Blackhaul. But on limitations side, due to shorter wavelength the mmW suffers from various attenuations like atmospheric attenuation and absorption by gases in environment. These are also affected by rain and humidity, which reduces its signal strength and range [12]. For Transmission of high frequency waves, metal or micro-strip devices are not efficient as their manufacturing requires very tight tolerance [1-2].The transmission lines if used for higher frequencies results in copper loss, skin effect, and radiation loss. For mmW or high frequencies a waveguide is preferred [4].

Substrate Integrated Waveguide (SIW) has a planar structure and the two metallic rows are used to contrive the structure. These metallic rows are linked with upper and lower metallic ground material used is the dielectric substrate. This as a whole acts as High Pass Filter. SIW has an advantage of low profile as compared to the traditional waveguide cavity. Other advantages include easy integration of SIW with microstrip, fabrication tolerance is much smaller and low profile as compared to waveguide cavity. SIW has also some advantages over microstrip resonators which include easy integration of SIW with the heat sink, self-packaging and the radiation loss is very less for mm waves. SIW resonators has its own benefits including compact size and low cost of production. The compatibility of SIW resonator with PCB and LTCC (Low Temperature Co-fired Ceramic) is another great advantage.

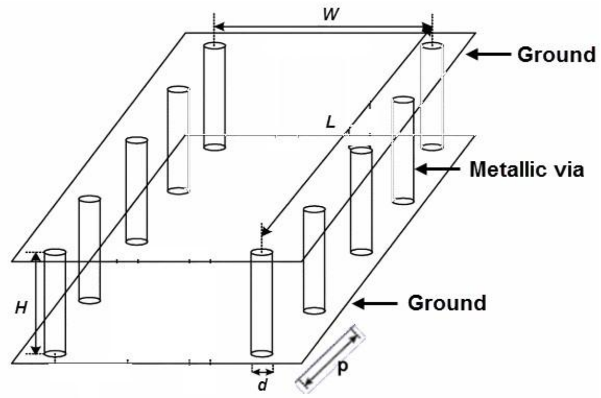

Fig 1. Structure of Substrate Integrated Waveguide

II. DESIGN PARAMETERS

a. *Design Parameters*

Firstly, the formation of Vertical Perfect conductor walls is made inside the dielectric substrate with metallic Vias. No tuning is required to combine this conductor wall with the other elements present in the system of the platform having single substrate. The length of the cavity is given by L, width by W and the height is given by H. d is denoted as the diameter of the vias and p by the vias spacing. The spacing in between the vias should not be more than half the guided wavelength in the high frequency equation [4]. In this only the TE mode is considered and is dominant. There is no existence of TM mode. This is because of vias at the sidewalls [3]. Cut off frequency can be equated as

$$\mathrm{fc}=\frac{c}{2\pi}\sqrt{\left(\frac{m\pi}{a}\right)^2+\left(\frac{n\pi}{b}\right)^2} \qquad (1)$$

B. Dielectric losses

The dielectric loss α_d in a waveguide is given by

$$\alpha_d=\frac{k^2\tan\delta}{2\beta} \qquad (2)$$

$\tan\delta$ is dielectric loss tangent

C. Conductor losses

Conductor losses are given by

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

k-free space wave number

β represents phase constant

η is medium's intrinsic impedance and is given by

$$\eta=\sqrt{\frac{\mu_0}{\varepsilon_0\varepsilon_r}} \qquad (4)$$

Conductivity of material is given by σ

R_s is surface resistivity of the conductors

$$R_s=\sqrt{\frac{\omega\mu_0}{2\sigma}}$$

$$\alpha_{wav}=\alpha_d+\alpha_c$$

D. Waveguide losses

leakage losses α_l also effects losses, including this loss the dielectric losses can be rewritten as

$$\alpha_d=\frac{k^2\tan\delta}{2k_z}$$

and conductor losses can be rewritten as

$$\alpha_c=\frac{R_s}{a_e\eta\sqrt{1-\frac{k_c^2}{k^2}}}\left[\frac{a_e}{w}+\frac{2k_c^2}{k^2}\right]$$

where a_e is equivalent width of SIW[9]

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

$$k_2(f)=\sqrt{\left\{k^2-\left[\frac{2}{a_e}cot^{-1}\left(\frac{f_c}{f}r_s(1-j)\right)\right]^2\right\}}$$

where r_s is real part of wave impedance of surface[10], f is operating frequency and f_c is cutoff frequency.

E. Radiation losses

these losses are due to gaps between metal vias. these are mostly negligible however if gap is large between the vias, the losses can be more.[11] it is given by

$$\alpha_R=\frac{\frac{1}{w}\left(\frac{d}{w}\right)^{2.84}\left(\frac{s}{d}-1\right)^{6.28}}{4.85\sqrt{\left(\frac{2w}{\lambda}\right)^2-1}}$$

these losses are measured in dB/m.

III. RESONANCE AND QUALITY FACTOR

A. Resonance

According to the design equations the resonance of the TE mode can be calculated as [5]

$$f_{res}=\frac{c}{2\pi\sqrt{\mu_r\varepsilon_r}}\sqrt{\left(\frac{m\pi}{L}\right)^2+\left(\frac{n\pi}{H}\right)^2+\left(\frac{l\pi}{W}\right)^2} \qquad \ldots.\ (5)$$

In the equation f_{res} is resonant frequency, ε_r is dielectric constant of the substrate and c is speed of light in vaccum.

B. Quality Factor

The unloaded quality factor of the waveguide which includes three types of losses is given by equation [6]

$$Q_u=\frac{Q_c.Q_d.Q_r}{Q_c..Q_d+Q_d.Q_r+Q_r.Q_c} \qquad \ldots\ldots.\ (5)$$

Where Q_c is the conductor losses by upper and lower ground plane, $Q_d$is the dielectric loss conveyed by dielectric substrate and Q_r is the radiation losses between the adjacent vias.

Conversely as discussed, the radiation losses can be controlled by spacing the via distance *p* smaller than half guided wavelength of highest operation frequency.

C. Quality Factor

The conductor loss can be calculated as [7]

$$Q_{cond} = \frac{(kWL)^3 H\eta}{2\pi^2 R_m (2W^3 H + 2L^3 H + W^3 L + L^3 W)} \quad ..(6)$$

Where k is the wave number inside the resonator and equals to

$$k = \frac{(2\pi\ f_{res}(\varepsilon_r)^{1/2}}{C} \ldots..(7)$$

R_m is Surface resistance corresponding to upper and lower ground plane and is equal to

$$R_m = (\pi\ f_{res}\mu/\sigma)^{1/2} \ldots..(8)$$

η is the wave impedance of the substrate.

IV. CONCLUSION

Numerous pros over the micro-strip and DFW, SIW is low loss waveguide for the transmission of higher frequency ranges. However the leakage loss can be substantial. The radiation loss can also be controlled by selecting the via distance half of the operating frequency for dedicated application. Applications for SIW includes communication over 5G, Ultra-Wide band Antenna. This paper discussed various losses dedicated to SIW structure so which a designer can be able to select required parameters for design.

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