Study of Dielectric Loss and Conductor Loss among Microstrip, covered Microstrip and inverted Microstrip Gap Waveguide utilizing variational Method in Millimeter Waves

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***Abstract*—In this paper, the classic variational method is applied for newly introduced inverted microstrip gap waveguide. Then, the dielectric losses and the conductor losses among the microstrip, covered microstrip and inverted microstrip gap waveguide are analytically calculated based on the variational method in millimeter waves. According to our theory, the dielectric losses of microstrip and covered microstrip gap waveguide are at least 7 times higher than that of inverted microstrip gap waveguide. Therefore, inverted microstrip gap waveguide has huge advantage of low loss in millimeter waves.**

***Index Terms*—variational method, Green's function in spectral domain, loss comparison of microstrip, covered microstrip and inverted microstrip gap waveguide.**

I. Introduction

Recently, lots of attention has been paid to millimeter waves (mmWs) because of their wide band property and the current saturation of spectrum at microwave frequencies. Traditional hardware technologies such as microstrip, covered microstrip and standard hollow waveguide have technological difficulties to satisfy with mmWs application. The main reason is that the dielectric loss of microstrip and covered microstrip rapidly increases versus the frequency in mmWs. Newly introduced inverted microstrip gap waveguide (IMGW) [1] is a new type of wave guiding structure to overcome the disadvantage of high dielectric loss in mmWs, as shown in Fig.1. From the theory of soft- and hard-surfaces [2], the metallic textured pins surface is able to realize an approximate Perfect Magnetic Conductor (PMC) boundary condition since PMC does not exist in nature. The feature of the IMGW is that the metallic pin surface forces the electromagnetic wave propagates within the air gap between the microstrip and the top PEC plate so that high dielectric loss can be avoided in mmWs. Thereby, the IMGW has a much lower dielectric loss compared with traditional covered microstrip, microstrip line and stripline. In this work, the variational method is applied to analytically calculate the dielectric losses and conductor losses of microstrip, covered microstrip line and IMGW. Then their comparisons of dielectric losses and conductor losses are summarized.

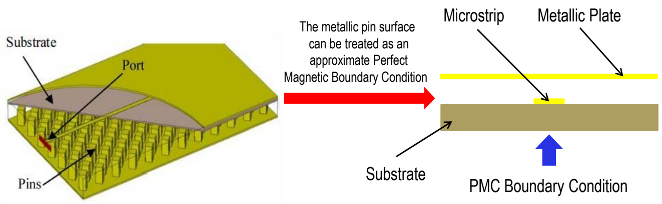

Fig. 1. 3-D geometry for inverted microstrip gap waveguide and in the right the metallic pins have been replaced by Perfect Magnetic Conductor boundary condition.

II. Variational Method and Green's Function

The cross-sectional view of the IMGW, covered microstrip and microstrip are illustrated in Fig.2. According to [3], the TEM mode in a transmission line can be described by a model of electrostatic fields as the dominant mode. Therefore, the TEM mode problem can be treated as an electrostatic model, namely solving a Poissons equation or a Laplaces equation. The corresponding electric potential distribution $\psi(x, y)$ is related to the charge density $\rho(x, y)$ by the Poisson's equation,

$$\nabla^2\psi(x,y) = \frac{\partial^2\psi(x,y)}{\partial x^2} + \frac{\partial^2\psi(x,y)}{\partial y^2} = -\frac{\rho(x,y)}{\varepsilon} \tag{1}$$

where ε is the permittivity of the substrate in the structure. In reality, the thickness of microstrip is much smaller than the width w so that the microstrip can be considered as infinite thin and $\rho(x, y)$ can be described by

$$\rho(x,y) = f(x)\delta(y - h_s) \tag{2}$$

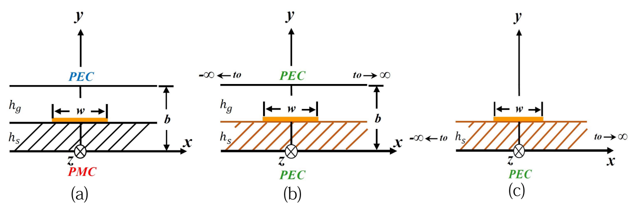

Fig. 2. Cross-sectional view for (a) IMGW, (b) Covered Microstrip, (c) Microstrip.

where $\delta(y-h_s)$ is the Dirac's function and $f(x)$ the charge density distribution on the microstrip.

The Green's function G, regarded as the potential due to a unit charge in an infinitely small volume at (x', y'), is the solution to the equation of

$$\nabla^2 G(x, x'; y, y') = -\frac{1}{\varepsilon}\delta(x-x')\delta(y-y') \tag{3}$$

where $\delta(x-x')\delta(y-y')$ is the Dirac's function which expresses a unit charge. Once the Green's function G is obtained, the electric potential $\psi(x, y)$ due to the charge distribution $\rho(x', y')$ can be determined by the superposition principle expressed as:

$$\psi(x, y) = \int_{l'} G(x, x'; y, y')\rho(x', y')dl' \tag{4}$$

where the integral is defined over the conductor contour l' in 2-D cross sectional structure. Now we apply the Fourier transform to convert the 2-D problem to a spatial 1-D problem in spectrum,

$$\widetilde{\psi}(k, y) = \int_{-\infty}^{\infty} \psi(x, y)e^{-jkx}dx. \tag{5}$$

According to the differential property of the Fourier transform, namely, $\frac{\partial^2\psi(x,y)}{\partial x^2} \Leftrightarrow (jk)^2\widetilde{\psi}(k, y)$, eq.(1) can be written in spectral domain as:

$$-k^2\widetilde{\psi}(k, y) + \frac{\partial^2\widetilde{\psi}(k, y)}{\partial y^2} = 0 \qquad (y \neq h_s). \tag{6}$$

In spectral domain the solution of the potential distribution on the microstrip can be expressed as:

$$\widetilde{\psi}(k, y) = \widetilde{f}(k)\widetilde{G}(k, y), \tag{7}$$

where $\widetilde{f}(k)$ and $\widetilde{G}(k, y)$ are the charge density and the Green's function in spectral domain. The corresponding Green's functions of microstrip, covered microstrip and IMGW are given by (8), (9) and (10), respectively,

$$\widetilde{G}_m(k, h_s) = \frac{sinh(kh_g)}{k[\varepsilon_0 cosh(kh_g) + \varepsilon_s sinh(kh_s)]}. \tag{8}$$

$$\widetilde{G}_c(k, h_s) = \frac{sinh(kh_g)sinh(kh_s)}{k[\varepsilon_0 sinh(kh_g)cosh(kh_s) + \varepsilon_s cosh(kh_g)sinh(kh_s)]}. \tag{9}$$

$$\widetilde{G}_i(k, h_s) = \frac{sinh(kh_g)cosh(kh_s)}{k[\varepsilon_0 cosh(kh_s)cosh(kh_g) + \varepsilon_s sinh(kh_s)sinh(kh_g)]}. \tag{10}$$

The trial charge density is given by:

$$f_{narrow}(x) = \left|\frac{x}{w}\right|, \qquad |x| \leq \frac{w}{2} \quad and \quad w \leq 0.3\ mm. \tag{11}$$

The corresponding Fourier Transform expressions $\widetilde{f}_{wide}(k)$ are as follows:

$$\widetilde{f}_{wide}(k) = \frac{1}{k}sin(kw/2) + \frac{2}{k^2 w}\left[cos(kw/2) - \frac{2sin(kw/2)}{kw/2} + \frac{sin^2(kw/4)}{(kw/4)^2}\right] \tag{12}$$

Theoretically, the loss components of a transmission line include dielectric loss and conductor loss. The attenuation constant of a transmission line due to the conductor loss can be obtained by the following:

$$\alpha_c = \frac{R_s \int_l i_s^2 dl}{2\int_S v\varepsilon(\nabla\psi)^2 dS} \quad [Neper/Unit\ Length] \tag{13}$$

where $R_s = \sqrt{0.5\omega\mu_0/\sigma_c}$ is the surface resistance, σ_c the conductivity of the microstrip, $i_s = v\rho(x, h_s)$ the current density on the microstrip, and $v = c\sqrt{C_0/C}$ the propagation velocity. Similarly, the attenuation constant due to the dielectric loss can be calculated by :

$$\alpha_d = \frac{\sigma_d \int_S(\nabla\psi)^2 dS}{2\int_S v\varepsilon(\nabla\psi)^2 dS} \quad [Neper/Unit\ Length] \tag{14}$$

III. Comparison of Losses

The table indicates the dielectric losses and conductor losses of IMGW, covered microstrip line and microstrip with 1 mm wide microstrip and 0.3 mm thick Rogers Ro4003 substrate. The table indicates that the dielectric loss is the major loss in traditional microstrip and covered microstrip in mmWs. The dielectric losses of microstrip and covered microstrip are around as 7 times higher as that of the IMGW so that IMGW has very strong competitive strength for Monolithic Microwave Integrated Circuit (MMIC) in mmWs.

Loss Types	Dielectric Loss	Conductor Loss
IMGW	0.15 dB/cm	0.1 dB/cm
Covered Microstrip	1.2 dB/cm	0.1 dB/cm
Microstrip	1.1 dB/cm	0.09 dB/cm

IV. Conclusion

In this work, variational method has been applied for calculating dielectric losses and conductor losses among newly IMGW, covered microstrip and microstrip in mmWs and IMGW has much lower dielectric loss than that of the other two types.

References

[1] P.-S. Kildal, "Three metamaterial-based gap waveguides between parallel metal plates for mm/submm waves, " in *3rd European Conference on Antennas and Propagation, EuCAP 2009*, pp. 28-32.

[2] P.-S. Kildal, "Artificially soft and hard surfaces in electromagnetics, " *IEEE Trans. Antennas Propag.*, vol. 28, no. 10, pp. 1537-1544, 1990.

[3] R. E. Collin, *Field Theory of Guided Waves,* Wiley-IEEE Press, New York, Dec. 1990.