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Experimental verification of Conductor loss Model for Thin Film Microstrip Line

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***Abstract*: This paper presents the improved perturbation based model of Holloway & Kuester for conductor loss computation. The model presented takes into account the frequency dependent nature of conductivity of thin film conductor. We have also shown comparison of Present model with experimental results for the frequency range 1 to 100 GHz. Deviations of the improved model from experimental are found below 9%.**

Index Terms: Conductor loss, TFMS, Perturbation method, Holloway & Kuester, Conductivity, MMIC and THz.

I. INTRODUCTION

Thin Film Microstrip Lines (TFMLs) find more and more applications, especially Si-based monolithic microwave integrated circuits (MMICs) [1] and as transmission lines in multichip modules [MCMs]. The mm-wave/THz has promising applications in the short-range wireless communication for high data rate transmission, astronomy, plasma diagnostics, medical imaging, and security etc. They are miniaturized Microstrip located on the top of the substrate. One special advantage is that the ground metallization of the TFML shields the line from the substrate effects. Therefore, e.g. low resistivity silicon substrates can be used without deteriorating microwave performance. Since high-quality polymers e.g. polyamide or Benzocyclobutene (BCB) [2] are available as dielectric layers, attenuation of such TFMLs is comparable with coplanar waveguides (CPWs) in GaAs MMICs. Since transversal dimensions can be scaled down, miniaturized TFML show excellent low dispersion.

The perturbation method is used to compute the conductor loss [3]. In these models the bulk conductivity of the strip metal is treated frequency independent. However conductivity is frequency dependent. The relaxation model shows that the bulk conductivity of metal decreases with increasing frequency. However, it is conjectured earlier that in order to show agreement of the computed conductor loss, using perturbation method, with measured conductor loss of microstrip up to 40GHz, strip conductivity should increase with frequency [4]. More recently such conductivity increase with frequency has been measured for the thin gold film (9-20nm) on 0.04mm thick Kapton substrate in the X-band [5]. In this work it is commented that deviation in nature of the dispersion in thin–film metal is due to the surface morphology of the metallic film at the interface of the substrate and strip conductor. The models to compute the conductor and dielectric losses and also the EM-simulator have been tested against the experimental results.

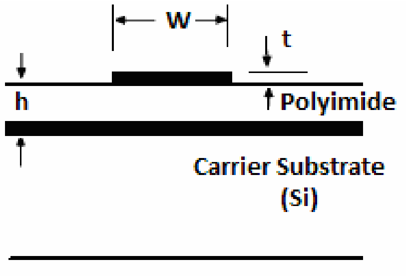

FIGURE 1: Layout of TFMS

II. CONDUCTOR LOSS

Conductor loss is computed using Perturbation method. This method is based on current density on a strip conductor. It varies as 1/√r, where r is the distance from the edge. The conductor loss at r = 0 has logarithmic divergence. This is due to the reason that the current distribution tends to infinity when it reaches edge of the strip. Such logarithmic divergence can be avoided if the integration just perturbed before the edges. This distance is known as the stopping distance. Booth and Holloway had presented a closed form expression for conductor loss computation.

$$\alpha_C = \frac{R_{SM}}{2\pi^2 Z_0 W}\ln\left(\frac{W}{\Delta}-1\right) \quad \mathrm{Np/m} \qquad (1)$$

where

$$R_{SM} = \mu_0 wt\,\mathrm{Im}\left(\frac{\cot(k_C t)+\csc(k_C t)}{(k_C t)}\right)$$

$$k_C = w\sqrt{\mu_0\varepsilon_0}\left[1 - j\frac{\sigma_C}{w\varepsilon_0}\right]^{1/2}$$

Where R_{SM} is surface impedance, k_C is wave number, σ_c is conductivity of conductor, Z_0 is characteristic impedance of Microstrip line and lastly Δ is stopping distance. Holloway and Kuester have theoretically generated a table for the normalized reciprocal stopping distance (t/Δ) for an isolated strip conductor of thickness t with 90° and 45° conductor edges [3].

Where, $\delta_s = \dfrac{1}{\sqrt{\pi f \mu_0 \sigma}}$

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In HK_sigma(0) model, we have used the curve fitted expressions of normalized stopping distance for 90° to determine conductor loss of a Microstrip line [6]. We have used only 90° strip edge curve fitted expression as in case of TFMS conductor strip is very thin hence its geometry is nearly rectangular. Perturbation method is applicable to medium and high frequency range. For low frequency range current is uniformly distributed inside the conductor giving DC conductor loss.

$$R = \frac{1}{\sigma(0)\,w\,t}$$

For ground conductor loss computation we have taken quasi closed expression of Holloway & Kuester [7].

$$\alpha_{GC} = \frac{R_{SM}}{2Z_0}\left(\frac{1}{\pi w}\right)^2 \int_{-\infty}^{\infty} \left[\tan^{-1}\left(\frac{w-2x}{2h}\right) + \tan^{-1}\left(\frac{w+2x}{2h}\right)\right]^2 \cdot dx \quad (2)$$

Here w is strip width; h is substrate height and x is the distance varying from the centre of strip to the left and right extreme up to width of the ground. In HK_sigma(f) model we have accounted the frequency dependent conductivity of the conductor [4]. We also know that the conductivity of a thin film is less than its bulk value [4] i.e. thin film conductivity of Gold (Au) is taken as 3.9e7 S/m whereas the bulk conductivity of Gold is 4.1e7 S/m.

$\sigma_{TFML} < \sigma_{BUlk}$ For conductor Strip

$$\sigma(f) = \sigma_0 \sqrt{(1 + C_0 f_{GHz})} \quad (3)$$

The loss computed from perturbation method is found more than the experimental results. Hence when conductivity of conductor increases slightly with frequency the deviations from experimental is decreasing. We have observed good agreement of HK_sigma(f) with the experimental results [8], showing deviations below 9%

III. DIELECTRIC LOSS

For dielectric loss computation we have used the standard closed form expression with a slight modification as given in (4) i.e. using frequency dependent relative permittivity instead static effective relative permittivity because this gives somewhat higher dielectric attenuation.

$$\alpha_d = \frac{\varepsilon_r}{\sqrt{\varepsilon_{reff}(w/h,t,f)}} \cdot \frac{\varepsilon_{reff}(w/h,t,f) - 1}{\varepsilon_r - 1} \cdot \frac{\pi}{\lambda_0} \cdot \tan\delta \quad \text{Np/m} \quad (4)$$

IV. RESULTS

We have shown comparison of total attenuation from our models and experimental [8] along with EM simulator results for the frequency range from 1 GHz to 100 GHz. Below is the explanation of the notations we have used in the graphs.

- **Expt** - experimental results [2]
- **CST** - 3D EM simulator
- **HK_sigma(0)** - Holloway & Kuester methodology with curve fitted stopping distance [6] and conductivity independent of frequency (model 1)
- **HK_sigma(f)** - Holloway & Kuester methodology with curve fitted stopping distance [6] and conductivity frequency dependent given by (3)

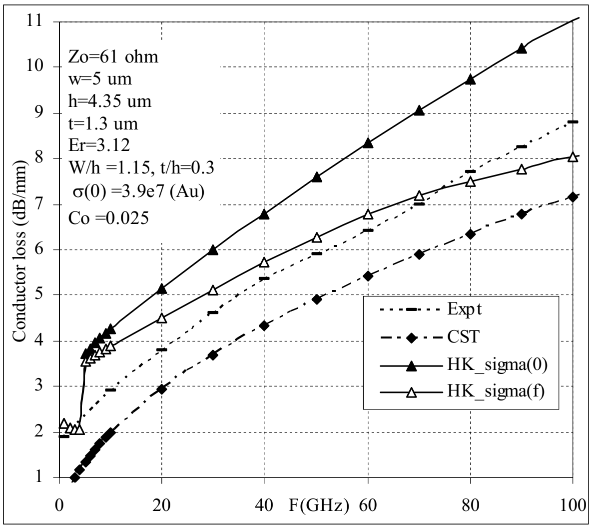

FIGURE 2: Attenuation for Thin Film Microstrip Line (61 Ω)

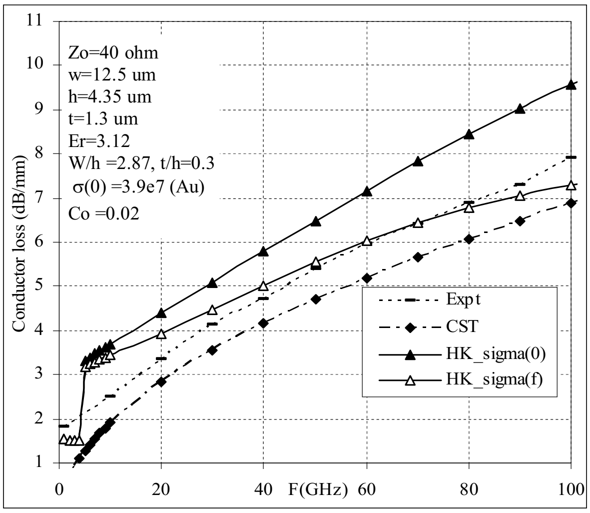

FIGURE 3: Attenuation for Thin Film Microstrip Line (40 Ω)

In Figure 2-5, we can see that HK_sigma(f) model is showing better agreement with the experimental results compared to HK_sigma(0) model, whereas EM simulator is showing much larger deviations from experimental results. We have summarized the percentage deviations in table 1 along with the empirical values of C_o we have taken.

TABLE 1: % deviation from experimental for Total loss

W um	H um	Zo	Sigma (S/m)	CST (%)	**HK_σ (0) (%)**	**HK_σ (f) (%)**	C_o for σ(f)
5	4.35	61	3.9e7	18.09	**28.79**	**7.65**	0.025
12.5	4.35	40	3.9e7	12.72	**23.03**	**5.62**	0.02
5	7.4	80	3.9e7	16.67	**28.69**	**8.93**	0.02
12.5	7.4	55	3.9e7	17.5	**12.78**	**7.64**	0.0045

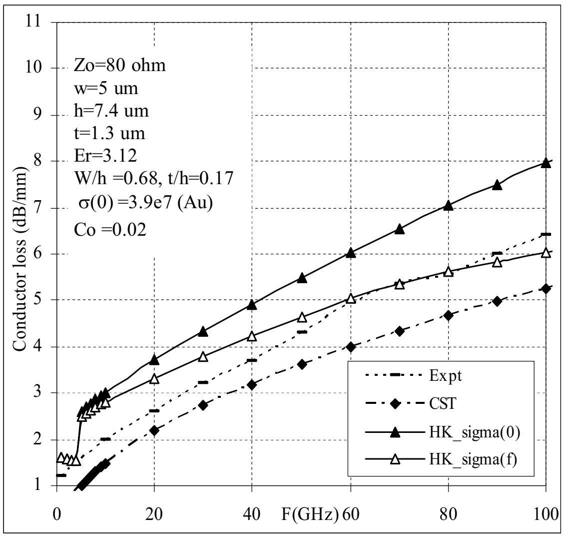

FIGURE 4: Attenuation for Thin Film Microstrip Line (80 Ω)

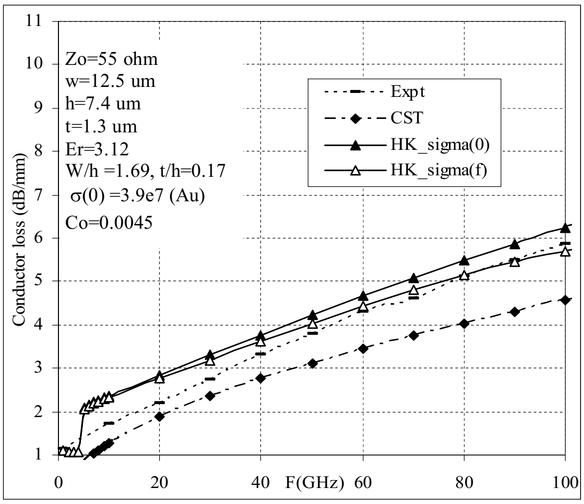

FIGURE 5: Attenuation for Thin Film Microstrip Line (55 Ω)

V. CONCLUSION

This paper has presented the experimental verification of Thin Film Microstrip Lines (TFMSs) on Polyimide substrate (Er=3.12). Presented **Model** (HK_sigma(f)) has shown deviations **below 9 %** in the frequency range from 1 GHz to 100 GHz. We have observed that conductivity of the metal increases with frequency deviating from the classical relaxation model. We could say that this deviation in nature of the dispersion in thin–film metal is due to the surface morphology of the metallic film at the interface of the substrate and strip conductor which was discussed earlier also [10]. It could be modeled by a RC circuit. This Paper concludes that model is useful, giving deviation within 9 %.

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