Critical parameters affecting the design of high frequency transmission lines in standard CMOS technology

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Abstract— **Different structures of transmission lines were designed and fabricated in standard CMOS technology to estimate some critical parameters including the RMS value of the surface roughness and the loss tangent. The input impedances for frequencies up to 50 GHz were modeled and compared with measurements. The results demonstrated a strong correlation between the used model with the proposed coefficients and the measured results, attesting the robustness of the model and the reliability of the incorporated coefficients values.**

Keywords—component; surface roughness; high frequency; tangent loss; coplanar waveguide; transmission line; skin depth.

I. Introduction

There is high demand for designing high frequency on-chip connectors, antennas and transmission lines that operate in the tens of GHz range. Such components are essential for many applications like monolithic millimeter-wave circuits, and SerDes design. In order to predict the behavior of the transmission line, we use one of the available commercial EM field solvers. However and in many cases; theses solvers don't provide or include parameters such as the loss tangent and surface roughness, especially at high frequencies.

When the desired operating frequency is high, the skin depth significantly affects the signal propagation especially when the conductor's surface is rough [1]. With the wavelength (λ) less than or equal to the height of the surface roughness, the attenuation becomes more critical and increases as a function of the frequency [2]. Once fabricated and measured, the roughness of the conductor's surface should be considered in the models [2] for its impact on the degradation of the propagation velocity and on the increase of the conduction and dielectric losses [3].

In the last decade, multiple researchers were investigating the properties of the transmission lines and the losses caused by the surface roughness [4-7]. Hammerstad and Jensen presented a simple equation for single and couple microstrip line parameters including the losses posed by the surface roughness. But, their equation is valid only for rectangular profile [8]. Scogna and Schaure enhanced the equation of Hammerstad and Jensen by including the triangular and cylindrical profiles [2].

In this study, we are recommending some values for the critical parameters extracted from analyzing the existing models [4-7]. The adaptability of these factors enhances the accuracy of the used models [8] for the different fabricated samples. They mainly impact the RMS value of the surface roughness and the loss tangent and extracted from microstrip transmission lines (TRL) and Coplanar Waveguide transmission lines (CPW) fabricated in standard CMOS technology.

II. Proposed Coefficients

In general, the total losses are a combination of the dielectric and conduction losses ($\alpha_{dielectric} + \alpha_{condution\ total}$). Equation (1) presents the conduction losses including the surface roughness (Δ), proposed by Hammerstad and Jensen [8].

$$\alpha_{\text{condution total}} = \alpha_c \left[1 + \frac{2}{\pi}\tan^{-1}\left(1.4\left(\frac{\Delta}{\delta}\right)^2\right)\right] \qquad (1)$$

where δ is the skin depth. After testing multiple samples with widths ranging from 2 µm up to 100 µm with a fixed length of roughly 1mm, two main findings for accurate modeling of the total losses were proposed. First, the RMS value of the surface roughness (Δ) has a frequency dependent component, described by:

$$\Delta = A \times f \qquad (2)$$

where A is a correction factor found to be varying depending on the dimensions of the transmission line and f is the frequency. Also, the measurements revealed the fact that A increases almost linearly when reducing the width of the transmission line. Moreover, the CPW has experienced twice the A value compared to a TRL having the same dimensions.

Second, for $\alpha_{dielectric}$ there is a frequency dependent component for the loss tangent, and it is modeled as follows:

$$\tan(\delta) = B + C \times f \qquad (3)$$

where B and C are correction factors found to be varying with the structure and the width of the TRL. The models consistently revealed the use of 0.006 as the value of the B factor for the TRL. This B value is about thirty times smaller for the CPW case. In addition, the C factor increases almost linearly by reducing the width of the TRL, while it vanishes completely for CPW.

III. RESULTS AND DISCUSSION

Multiple transmission lines with different structures (Microstrip and CPW) and dimensions were designed and fabricated in five metal layers standard CMOS technology in order to extract the previously mentioned critical parameters. Fig. 1 demonstrates one microstrip transmission line (Fig. 1A) and one CPW (Fig. 1B). Fig. 2 shows a compression for the real and imaginary parts of the input impedance between the existing model shown in equation (1) including the correction factors and the measured results up to 50 GHz. The strong correlation between the proposed coefficient and the measured results proves the robustness of the model and the reliability of the used coefficients.

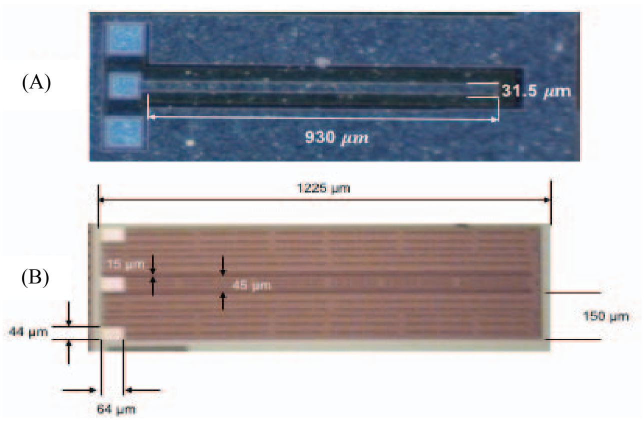
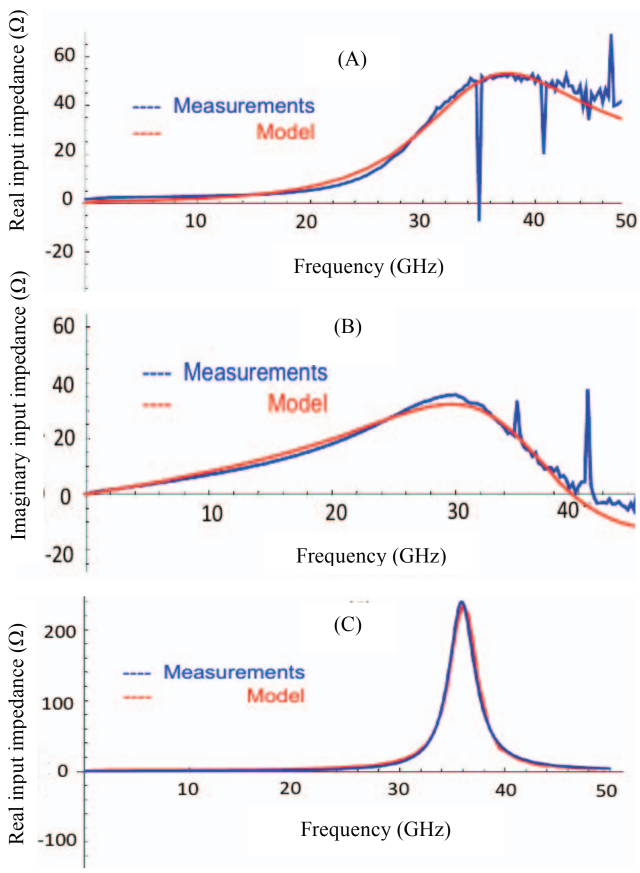


Fig. 1. (A) the microstrip line (TRL) and (B) Coplanar waveguide (CPW).



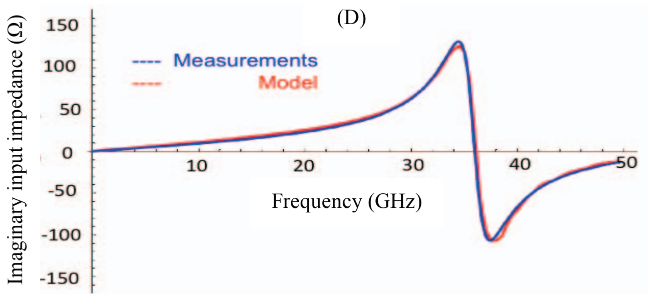


Fig. 2. (A) and (B) are the modeled and measured input impedance of TRL for real and imaginary parts, (C) and (D) are the modeled and measured input impedance of CPW for the real and imaginary parts

IV. CONCLUSION

This paper provided a guideline for the designers to include some critical values that affect the surface roughness and the loss tangent when it was difficult to find them in many of the references. Different structures of transmission lines were designed and fabricated in standard CMOS technology to estimate and extract the RMS value of the surface roughness and the loss tangent. We confirmed the dependency of the RMS value of the surface roughness on the frequency and revealed the relationship between the surface roughness and the width of the transmission line. Furthermore, we discussed the coefficients of the loss tangent including the constant factor and the frequency dependent factor and presented its relationship with the width of the transmission line as well.

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