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On the Variations of Shunt Characterization Technique of Decoupling Transmission Line for Millimeter-Wave CMOS Applications

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Abstract Decoupling transmission line (TL) is a low characteristic impedance TL that is used for isolating DC and RF signals in millimeter-wave CMOS circuits. Low characteristic impedance makes the direct measurements difficult for characterization. A shunt characterization method is presented for the characterization. In this method, the S-parameters are calculated directly. Nevertheless, the results might change according to calculation procedure. In this work, variations on shunt characterization method are investigated and their effects on millimeter-wave CMOS amplifier simulation accuracy are introduced.

Keyword CMOS, decoupling transmission line, metal-insulator-metal, shunt characterization, mm-wave, variations

1. INTRODUCTION

60 GHz ISM band enables communications up to around 40 Gbps for a single transceiver (TRX) [1]. A simple one-stage amplifier schematic is provided in Fig. 1. The decoupling TL is mainly used for DC to RF isolation for wideband [1], [2]. Especially for millimeter-wave frequency region, lumped components like RF chokes and decoupling capacitors have parasitics. As a result simulation accuracy decreases considerably. The main characteristics of decoupling TL are the very low characteristic impedance (~2Ω). The characterization of this device is not an easy task, because of its low characteristic impedance when measured in a 50 Ω system [3]. An indirect characterization method is introduced [4]. However, this method also has some accuracy issues. This work mainly focuses on the variations of the method presented in [4], and its effect on the amplifier simulation results.

2. SHUNT CHARACTERIZATION TECHNIQUE

To achieve low characteristic impedance for decoupling TL several considerations are done; e.g. finger capacitors are introduced between signal and ground in addition to metal-insulator-metal (MIM) capacitors. For this reason, decoupling TL is also called MIM TL [4]. The shunt characterization method can be applied using two structures shown in Fig.2, assuming that pad, TLs, and tee-junction are modeled beforehand. MIM TL can be represented in terms of S-parameters as in the following Eq. (1).

$$[S_{\mathrm{MIMTL}}] = \begin{bmatrix} S_{\mathrm{MIMTL11}} & S_{\mathrm{MIMTL21}} \\ S_{\mathrm{MIMTL21}} & S_{\mathrm{MIMTL11}} \end{bmatrix} \qquad (1)$$

Eq. (2) represents the three port S-parameters of tee-junction with a 10 μm TL connected to its third port. One can calculate the reflections illustrated in Fig. 3. From these reflections one can calculate the S-parameter of MIM TL. Eq. (3) is the representation of results in terms of reflection and three-port S-parameters of Eq. (2). From this equation, Γ_{MIM} can be calculated as in Eq. (4). With a similar manner Γ_2 can be calculated from the second structures measured results as given in Eq. (5). Reflection Γ_1 can be related to Γ_{MIM} as in Eq. (6). Finally, MIM TL S-parameters can be calculated in Eq. (7) and (8).

$$[S_{\mathrm{T-TL}}] = \begin{bmatrix} S_{11} & S_{21} & S_{13} \\ S_{21} & S_{11} & S_{13} \\ S_{13} & S_{13} & S_{33} \end{bmatrix} \qquad (2)$$

$$[S_{\mathrm{Meas}}^{\Gamma_{\mathrm{MIM}}}] = \begin{bmatrix} S_{11} & S_{21} \\ S_{21} & S_{11} \end{bmatrix} + S_{13}^2/(1/\Gamma_{\mathrm{MIM}} - S_{33}) \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix} \qquad (3)$$

$$\Gamma_{\mathrm{MIM}} = 1/\left(S_{33} + S_{13}^2/\left(S_{\mathrm{Meas,11}}^{\Gamma_{\mathrm{MIM}}} - S_{11}\right)\right) \qquad (4)$$

$$\Gamma_2 = 1/\left(S_{33} + S_{13}^2/\left(S_{\mathrm{Meas,11}}^{\Gamma_2} - S_{11}\right)\right) \qquad (5)$$

$$\Gamma_1 = S_{\mathrm{TL-10\mu m,11}} + \frac{{S_{\mathrm{TL-10\mu m,21}}}^2}{(1/\Gamma_{\mathrm{MIM}} - S_{\mathrm{TL-10\mu m,11}})} \qquad (6)$$

$$S_{\mathrm{MIMTL11}} = \frac{(\Gamma_2 - \Gamma_{\mathrm{MIM}}\Gamma_1)}{1 + (\Gamma_2 - \Gamma_{\mathrm{MIM}} - 1)\Gamma_1} \qquad (7)$$

$$S_{\mathrm{MIMTL21}} = \sqrt{(\Gamma_{\mathrm{MIM}} - S_{\mathrm{MIMTL11}})(1 - S_{\mathrm{MIMTL11}})} \qquad (8)$$

As it can be observed from Eq. (4), (5), calculations uses measured return losses (e.g. $S_{\mathrm{Meas,11}}^{\Gamma_{\mathrm{MIM}}}$). Addition to that, same calculations can be done by using measured transmission S-parameters. Unfortunately, due to the very low characteristic impedance of MIM TL, measurement accuracy decreases and as a result the two calculations give different results.

3. VARIATIONS ON CHARACTERIZATION METHOD

The S-parameters of MIM TL is calculated from both the measured reflection and transmission S-parameters of the structures in Fig.2. After the calculation of MIM TL S-parameters from the measured values, the simulation of structure given in

Fig. 2(b) is done and compared with the measured results as can be observed in Fig. 5(a), and (b). The simulation of two different MIM TL case for one-stage amplifier are done and compared with the measured results. The measured amplifier has the schematic of Fig. 1. The results are provided in Fig. 6(a)-(d). It can be observed that there are differences around 60 to 70 GHz region. However, with a proper modeling approach these differences can be minimized.

4. CONCLUSION

MIM TL has very low characteristic impedance, for DC to RF isolation purposes used in millimeter-wave band. Shunt characterization method is proposed to overcome measurement difficulties. Even so there are some variations in this method. In this work, one of these variations is investigated and effects on one-stage amplifier are provided.

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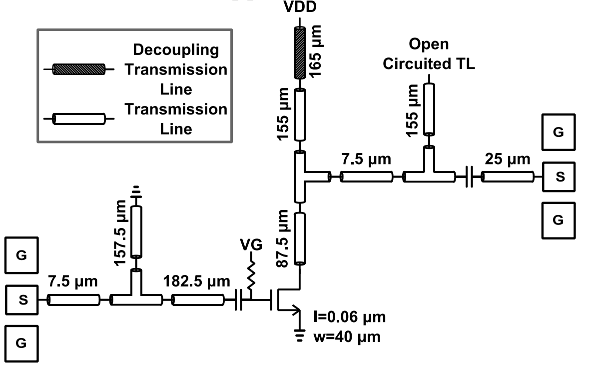
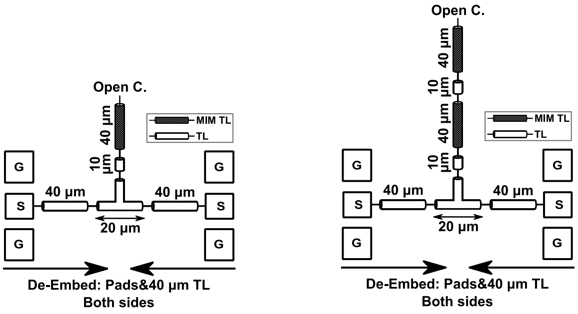
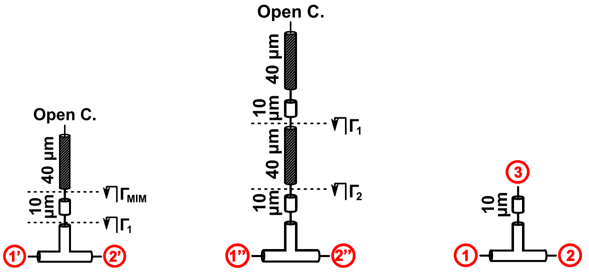


Fig.1. An example, one-stage common-source millimeter-wave amplifier schematic.



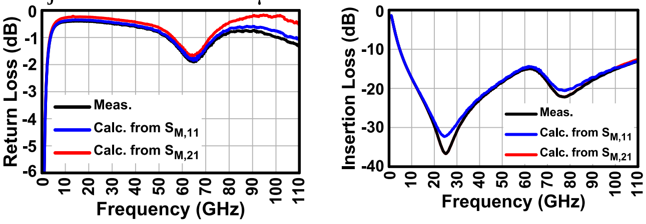
(a) (b)

Fig.2. Shunt characterization structures for MIM TL, (a) one 40 µm MIM TL shunt connected, and (b) two 40 µm MIM TL shunt connected with 10 µm normal TL interconnected.



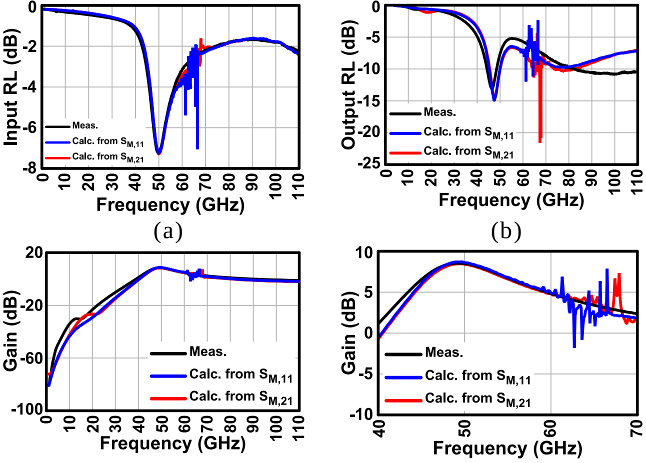
(a) (b) (c)

Fig.3. De-embedded structures for MIM TL from Fig.2(a) and (b), respectively. (c) Port definition of tee-junction with 10 µm TL connected.



(a) (b)

Fig.5. Comparison of measured and characterized from reflections ($S_{M,11}$) and transmission ($S_{M,21}$) values S-parameters for the structure provided in Fig. 2(b) in terms of S_{11} (dB) and S_{21} (dB).



(a) (b)

(a) (d)

Fig.6. Comparison of measured and model results of one-stage amplifier (Fig.1). Two different simulation results are provided based on two different MIM TL calculations.