

PAPER • OPEN ACCESS

De-embedding technique for accurate modeling of compact 3D MMIC CPW transmission lines

To cite this article: U H Pohan *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **309** 012069

View the [article online](#) for updates and enhancements.

You may also like

- [Fabrication and characterization of thin film Ni–Cr resistors on MMICs](#)
Mohammad A Alim, Ali A Rezazadeh, Peter B K Kyabaggu et al.
- [Effect of feeders in 3D modeling of low impedance multilayer CPW transmission line](#)
R I Zaini, P B K Kyabaggu and E P Sinulingga
- [GaN HEMTs and MMICs for space applications](#)
P Waltereit, W Bronner, R Quay et al.



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

De-embedding technique for accurate modeling of compact 3D MMIC CPW transmission lines

U H Pohan¹, P B K Kyabaggu² and E P Sinulingga^{*1}

¹ Electrical Engineering, Universitas Sumatera Utara, Medan, Indonesia

² Bukoola General Enterprises, Kampala, Uganda

*E-mail: emerson.sinulingga@usu.ac.id

Abstract. Requirement for high-density and high-functionality microwave and millimeter-wave circuits have led to the innovative circuit architectures such as three-dimensional multilayer MMICs. The major advantage of the multilayer techniques is that one can employ passive and active components based on CPW technology. In this work, MMIC Coplanar Waveguide (CPW) components such as Transmission Line (TL) are modeled in their 3D layouts. Main characteristics of CPWTL suffered from the probe pads' parasitic and resonant frequency effects have been studied. By understanding the parasitic effects, then the novel de-embedding technique are developed accurately in order to predict high frequency characteristics of the designed MMICs. The novel de-embedding technique has shown to be critical in reducing the probe pad parasitic significantly from the model. As results, high frequency characteristics of the designed MMICs have been presented with minimum parasitic effects of the probe pads. The de-embedding process optimises the determination of main characteristics of Compact 3D MMIC CPW transmission lines.

1. Introduction

Improved characteristics of Monolithic Microwave Integrated Circuit (MMIC) components are highly desirable at high frequency. The solution would be to utilize a three-dimensional (3D) Multilayer Coplanar Waveguide (CPW) technique. By employing 3D CPW technique that has features such as design flexibility and highly integration between passive and active components in MMIC technology, optimization of the current and novel components with much improved performance can be realized. [1–7]. As precise and reliable models are of significant importance in RF/microwave circuit design, with the increasing of operation frequency, the influence of probing pads and interconnect parasitic on MMIC components performance has become more and more important [8–11]. This research concerns with the understanding of the parasitic effects i.e. probe pads parasitic occur in the characteristics of MMIC components. The parasitic effect of pads had been gradually visible as frequency increases.

Novel de-embedding technique for high frequency characterization of MMIC components is developed and has been proposed in this work to support accurate on-wafer measurements. The effect of frequency resonance and its relation with the pads parasitic effect in CPW transmission line are analyzed. Then the pads effects are reduced by applying the new simplified de-embedding technique to produce more evidence of relation between the pads parasitic with the frequency resonance phenomena in the transmission line. Two types of transmission lines, the conventional planar and the planar with polyimide (3D) CPW transmission line are modeled and tested. These two common CPW



transmission lines are chosen to give the fully understanding on the de-embedding technique and the phenomena of resonance frequency for particular transmission lines in microwave circuits.

2. COST De-embedding Technique

In this work, de-embedding technique has been developed from the Cascade Open Short Thru (COST) Method [9] with simplified pad parasitic matrices for Microwave On-Wafer Measurement. This technique utilizes the open, short and thru dummy structures to de-embed the probe pad parasitic of a Device Under Test (DUT). The suggested parasitic model of DUT is shown in figure 1.

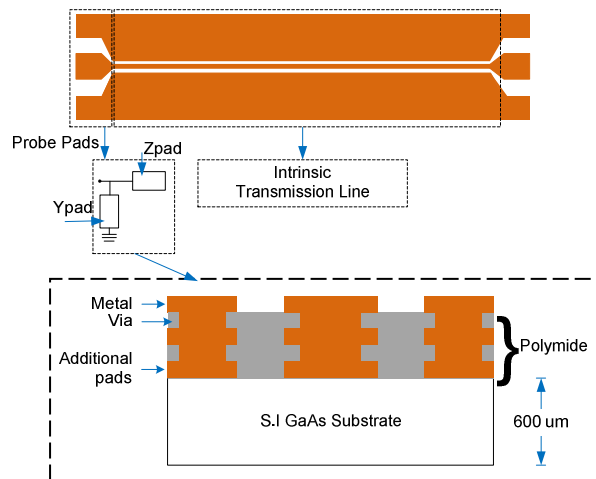


Figure 1. (a) Top view of M3 PI 1,2 CPW 3D Transmission Line and
(b) The cross-sectional view of the left probe pad of M3 PI 1,2 CPW Transmission Line.

In the COST Method, the resistive and inductive effects which originated from the probe pads are taken into account [9]. The ABCD-matrix representations of the probe pads' parasitic in Port-1 and Port-2 are simplified and defined as

It should be noted that the Y and Z-parameters of open and short dummies can be converted from S-parameters measurements and simulations. In this work, the tested dummy structures to acquire the pads parasitic matrices values for open, short and thru conditions are shown in Figure 2.

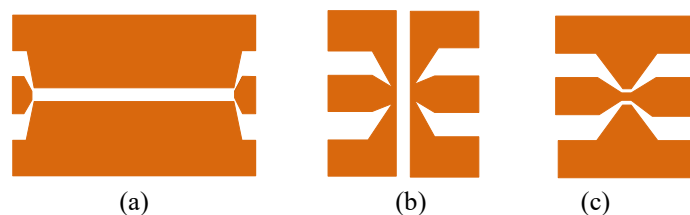


Figure 2. Dummies test for the new de-embedding technique
(a) 0.5 mm Open, (b) Short and (c) Thru structures

As the operation frequency becomes higher, the influence of resonance frequency, probe pads and interconnect parasitic on transmission line performance become more important for the transmission line characterization in the circuits. By understanding the parasitic effects, then the de-embedding technique can be developed accurately in order to predict high frequency characteristics of the designed MMICs.

3. Results and analysis

In this work, planar CPW transmission line with length 2.4 mm is designed and tested first before the de-embedding technique applied to the planar on Polyimide CPW transmission line. Problem will occur when the length of the chosen transmission line is greater than $\lambda/2$ as the structure suffered a resonant effect and the electrical behavior will change after the resonance frequency [8]. This is shown in the simulation in figure 3 and 4 before applied de-embedding. To understand more of the relation, one should analyze the comparison of characteristic impedance and relative effective permittivity data of the planar CPW transmission line before and after applying the simplified COST de-embedding process as shown in figures 3 and 4.

One can see that the half-wavelength resonances' phenomena ($\lambda/2$ effect) prevent or limit the determination of characteristic impedance of the transmission line starting at resonant frequency of 24 GHz as shown in figure 3. It becomes more apparent in terms of its relative effective permittivity shown in figure 4. This is due to the length dependencies of the propagation constants. The measured and simulated data after the de-embedding process for planar CPW transmission lines are compared and shown in figures 3 and 4.

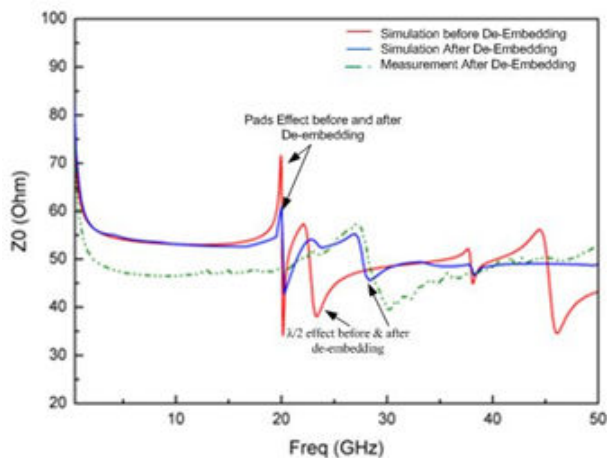


Figure 3. Comparison of characteristic impedance before and after de-embedding process for a planar CPW transmission line.

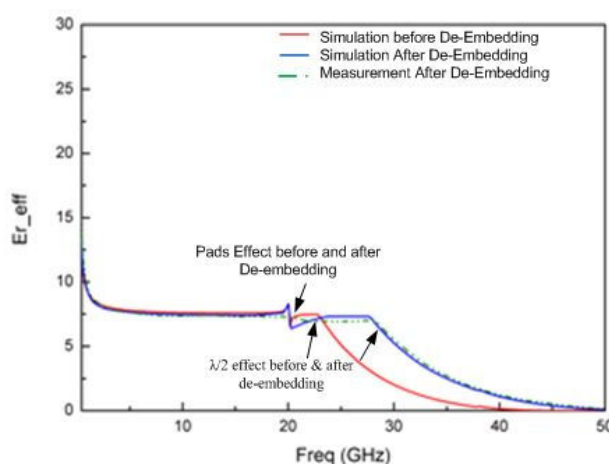


Figure 4. Comparison of relative effective permittivity before and after de-embedding process for a planar CPW transmission line.

As the purpose of the de-embedding process is to maximize the determination of characteristic impedance and relative effective permittivity of the transmission line, the proposed method has de-embedded the parasitic effect. By applying the new technique one can understand better and observe the influence of the parasitic pads in the measurement and take it into consideration for further improvement in designing the microwave circuits.

De-embedding process shows that the influence of pads parasitic has been reduced. As a result, resonance frequency effect on transmission line has been reduced as well. Thus one can conclude that the parasitic pads increase the resonance effect on transmission line. Another important finding from this work that the resonance frequency has been shifted from 23.5 GHz to 28.5 GHz and these findings are consistence for both measurement and simulation cases. One can states that length and size of the pads in the designed transmission line need to be considered carefully in order to reduce the effect of resonance frequency that can disturb the determination of line's characteristics.

Results in figure 5 and 6 show the characteristic impedance and relative effective permittivity of a planar on Polyimide (M3 PI 1,2) CPW (3D) transmission line respectively. Due to the de-embedding technique, resonance frequency in the de-embedded simulation and measurement has shifted and only occurred at around 38 GHz. Thus one can say that the new technique has yielded the expected improvement characteristics. Again, the electrical behavior will change for transmission line with length greater than $\lambda/2$ [8] as confirmed by data in figure 5. For planar with polyimide, this electrical behavior takes place after 38 GHz.

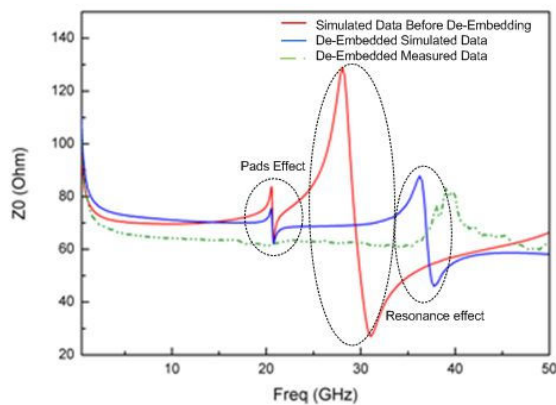


Figure 5. Comparison of characteristic impedance before and after de-embedding process for simulated and measured planar with polyimide (3D) CPW transmission line.

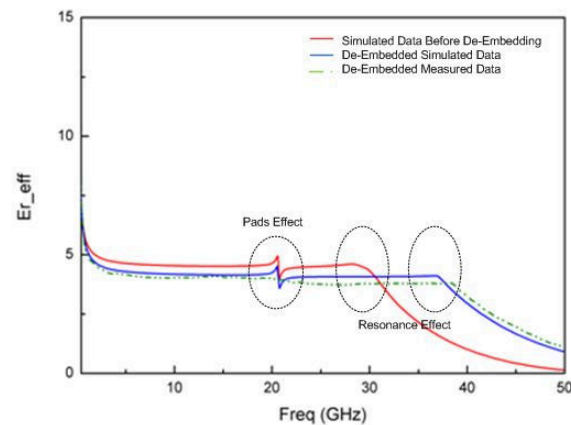


Figure 6. Comparison of relative effective permittivity before and after de-embedding process for simulated and measured planar with polyimide (3D) CPW transmission line.

The novel de-embedding technique has produced the expected improvement by reducing the pads effect significantly. As results, the resonance effect also reduced and this finding confirms the aforementioned statement about the relation of parasitic pads and the resonance effect. The measured data after applying the de-embedding technique have been produced and consistence with the simulated one.

4. Conclusions

It has been confirmed from this work that if one intends to insert transmission line between two parts of a circuit without changing the electrical behavior at particular frequency then one should choose transmission line with length equal to $\lambda/2$. The de-embedding technique is an analytical method therefore the purpose of the de-embedding process is to reduce the parasitic effect and to maximize the determination of characteristic impedance and relative effective permittivity of the Compact 3D CPW MMIC components. The novel de-embedding technique has shown to be critical in reducing the probe pad parasitic significantly from the model. As results, high frequency characteristics of the designed MMICs have been presented with minimum effects of probe pads' parasitic.

5. References

- [1] Vo T V, Krishnamurthy L, Sun Q and Rezazadeh A A 2006 3-D low loss coplanar waveguide transmission lines in multilayer MMICs *Microwave Theory and Techniques IEEE Transactions On* **54** 2864-71
- [2] Marsh S 2006 *Practical MMIC Guide* Norwood: Artech House, Inc
- [3] Ezzedine A K 2007 Advances in microwave and millimeter-wave integrated circuits *Radio Sci. Conf* 1-8
- [4] Mukherjee M 2010 Advanced microwave and millimeter wave technologies semiconductor devices circuits and systems *InTech* 1-14
- [5] Diebold S, Weber R, Seelmann-Eggebert M, Massler H, Tessmann A, Leuther A, Kallfass I 2011 A fully-scalable coplanar waveguide passive library for millimeter-wave monolithic integrated circuit design *The 41st European Microwave Conf* 293-6
- [6] Hong W et al 2012 Research advances in microwave and millimeter wave circuits and systems in the SKLMMW *19th Int. Conf. on Microwave Radar and Wireless Communications* 807-9
- [7] Sinulingga E P, Rezazadeh A A, Kyabaggu P B K, Alim M A and Zhang Y 2015 3D momentum modeling technique and measurements of CPW compact gas multilayer MMICS *Asia-Pacific Microwave Conf* 1-3
- [8] Heymann P, Prinzler H and Schnieder F 1994 De-embedding of MMIC transmission-line measurements *IEEE MTT-S Digest* 1045-8
- [9] Cho M-H and Huang G-W 2006 A cascade open-short-thru (cost) de-embedding method for microwave on-wafer characterization and automatic measurement *IEEE Trans.* **E88-C(5)** 845-9
- [10] Issaoun A and Xiong Y Z 2007 On the deembedding issue of cmos multigigahertz measurements *IEEE Transactions on Microwave and Techniques* **55(9)**
- [11] Xi-Sung L 2013 THRU-based cascade de-embedding technique for on-wafer characterization of RF CMOS devices *IEEE Transactions on Electron Devices* **60(9)**