Electromagnetic Modelling of MMIC CPWs for High Frequency Applications

E P Sinulingga[*1], P B K Kyabaggu[2], A A Rezazadeh [3]

[1]Electrical Engineering Department, Universitas Sumatera Utara, Indonesia
[2]Bukoola General Enterprises, Kampala, Uganda
[3]Elecrical and Electronic Engineering, The University of Manchester, United Kingdom

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

Abstract. Realising the theoretical electrical characteristics of components through modelling can be carried out using computer-aided design (CAD) simulation tools. If the simulation model provides the expected characteristics, the fabrication process of Monolithic Microwave Integrated Circuit (MMIC) can be performed for experimental verification purposes. Therefore improvements can be suggested before mass fabrication takes place. This research concentrates on development of MMIC technology by providing accurate predictions of the characteristics of MMIC components using an improved Electromagnetic (EM) modelling technique. The knowledge acquired from the modelling and characterisation process in this work can be adopted by circuit designers for various high frequency applications.

1. Introduction
The multilayer technique in MMIC technology provides the flexibility needed for microwave designers and engineers to be able to realise various low loss characteristic impedance CPW transmission lines [1]. Several multilayer transmission lines have been fabricated using photolithography to realise 3D CPWs which yield wide range characteristic impedances. This is achieved by utilising either overlap metal designs (denoted by OV) or elevation signal conductor designs (denoted by ELEV). CPW lines with an impedance between 65 and 70 ohms and dissipation loss ranging between 0.2 and 0.5 dB/mm, as well as CPW lines with characteristic impedance as low as 13 ohms with dissipation loss of 0.4 dB/mm, have been reported [1]. However the frequency observed was limited to between 16 GHz and 21 GHz. Currently there is no available data and analysis indicating that fabricated multilayer CPW configurations with relatively low attenuation characteristics (below 1 dB/mm) can be used at frequencies beyond 21 GHz. Furthermore, data presented in [1] shows a tendency towards higher dissipation loss as frequency increases beyond 16 GHz for all the fabricated structures.

In many applications (such as wireless applications up to 70 GHz) or in the integration of MMIC with nano scale devices, it is essential to utilise low-loss multilayer CPW transmission lines as interconnects or a feed lines. These narrow bandwidth observations make the wideband characteristic investigations of various multilayer CPW transmission lines presented in [1] become essential. In addition, MMIC components which have been modelled and fabricated need to be tested through on-wafer measurements in order to validate the desired components characteristics. As in some designs, CPW MMIC transmission lines may have a very narrow signal conductor track (S) or gap (W) between their grounds and their signal conductor track. Therefore, these CPW transmission lines require bonding pads and feeders (also known as probe pads) to accommodate the size of the probes

used in the on-wafer measurement. Often the probe pads provide unwanted parasitic effects which influence the characteristics of the intrinsic components.
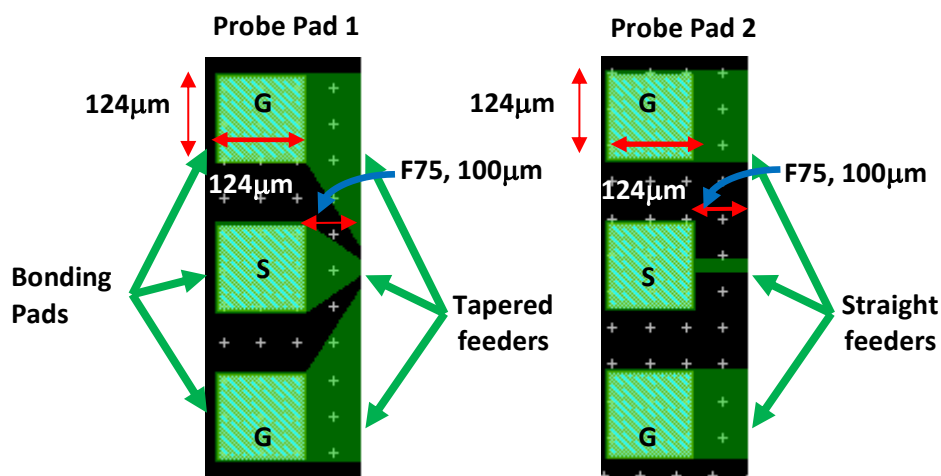
2. Probe Pads Design

Several investigations have been reported to de-embed the effect of these pads [2, 3]. Although these indicate some improvements, the utilised methods do not completely remove the distortions caused by the probe pads. In addition, in some cases the de-embedding technique may alter the intrinsic characteristic of the components. One therefore needs to analyse the actual effect of the probe pads in multilayer CPW structures based on their designs. Furthermore, one may suspect there to be a relationship between probe positions and the magnitude of the unwanted distortions (either in the simulation or on-wafer measurement). This has never before been reported in any literature. It is thus essential to begin investigations by analysing the effect of the shape of the probe pads, followed by the probe positions in multilayer CPW MMIC transmission lines.
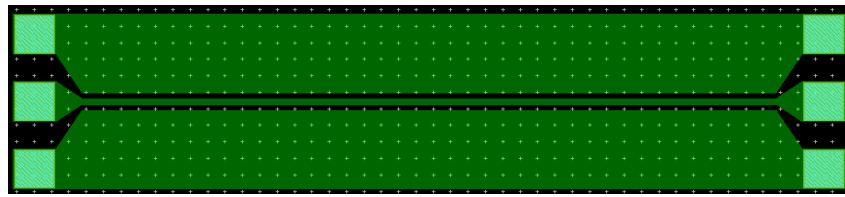
In this work, two designs of probe pads (each consists of bonding pad and feeder) have been considered. The cross-sectional view of the bonding pads and the top views of both probe pads are shown in Figures 1 and 2 respectively. Each design in Figure 2 has two different lengths of feeder, i.e. 75 μm and 100 μm. These are investigated to establish the effect of the feeder to the magnitude of the unwanted distortion. Both probe pads are embedded into a multilayer transmission line with a signal conductor width of 20 μm, a gap width of 15 μm and an intrinsic length of 2000 μm. The thickness of semi-insulating GaAs (h_1) is 600 μm. The thickness of polyimide (h_2) and metal (t) are 5 μm and 0.7 μm respectively. The top view of the transmission line with probe pad 1 is shown in Figure 3. The simulated S-parameters for both probe pad designs are shown in Figures 4 and 5.
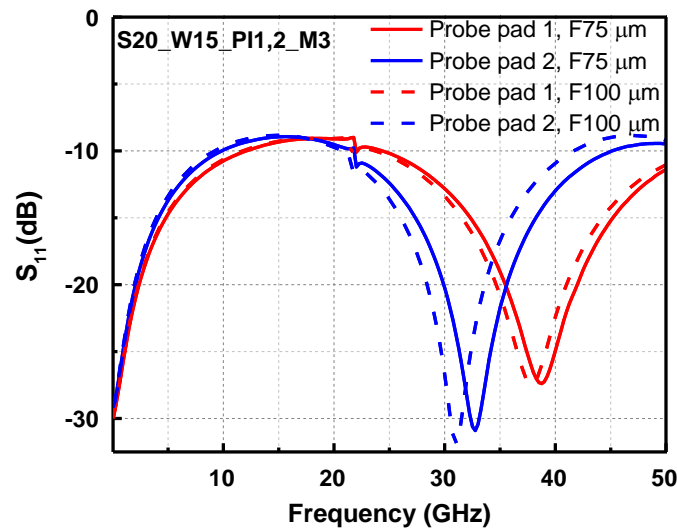

Figure 1. Cross-sectional view of a bonding pad for a multilayer CPW transmission line.

Figure 2. Top views of two different shapes of probe pads, each consisting of bonding pads and feeders with different shape.

Figure 3. Top view of the layout of a multilayer CPW transmission line embedded with probe pad 1.

Figure 4. Simulated S_{11} parameter of multilayer CPW transmission lines with various probe pads.
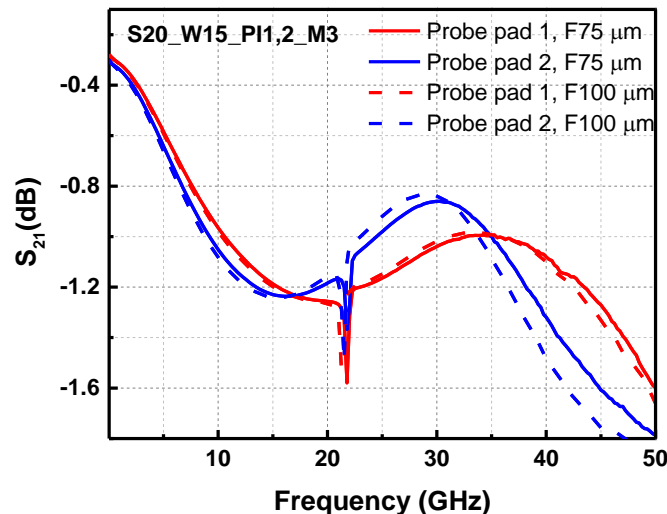
The data simulation shows that probe pad 1 with a tapered feeder have higher resonance frequency than probe pad 2 with a straight feeder. This is due to the shape of the feeders which allows the signal to have a smooth transition between probes and the intrinsic transmission lines. There is no significant effect of having a longer feeder length, except that the resonance frequency shifts slightly to a lower frequency. Based on this finding, probe pad 1 with feeder length 75 μm is chosen as the default probe pads in this work.
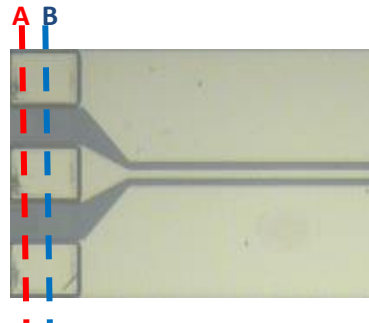
3. Optimum Electromagnetic Modelling
Observations of data presented in figures 4 and 5 also demonstrate a probe pad effect which may disturb the intrinsic characteristics of the transmission lines. These are shown in both S_{11} and S_{21} parameters at 22 GHz. Two reference probe positions (A and B, in the on-wafer measurement and layout simulation) as illustrated in figure 6 have therefore been investigated. The horizontal distances of position A and B from the end of the pads are 30 μm and 62 μm respectively. The fabricated CPW transmission line in figure 3 has been measured with these two probe positions. The results are presented in figure 7. One can demonstrate using the on-wafer measurement that by shifting the probe from position A to B, the distortions which occur at 22 GHz and 44 GHz can be slightly reduced. This is due to the optimum distance available for the CPW mode to settle as the signal incident to the probe pads.

In order to gain more understanding of this distortion, a similar approach has been employed in the simulation. This investigation involves EM modelling using port reference offset positions A and B, with some setup modifications. The simulation with reference position A utilises the edge mesh, while the simulation with reference position B utilises the edge and transmission line meshes. The motivation driving these modifications is to understand the effect of complex current computation within the transmission line, including the multilayer bonding pads which may yield some uncertain characteristics. This can provide a clear understanding of the source of distortions at 22 GHz and 44

GHz. The results are presented in figure 8. One may observe the improvement achieved by using port reference B and utilising both edge and transmission line meshes. The simulation data show good agreement at a lower frequency before the unwanted distortions occur at 22 GHz and 44 GHz. The utilisation of edge and transmission line meshes together with the reference offset position B reduces these distortions. This finding demonstrates that simulator and measurement software faces complex transverse current distribution [4,5] at the edge of the structure as well as at its port discontinuity, i.e. the multilayer bonding pads.

Figure 5. Simulated S_{21} parameter of multilayer CPW transmission lines with various probe pads.
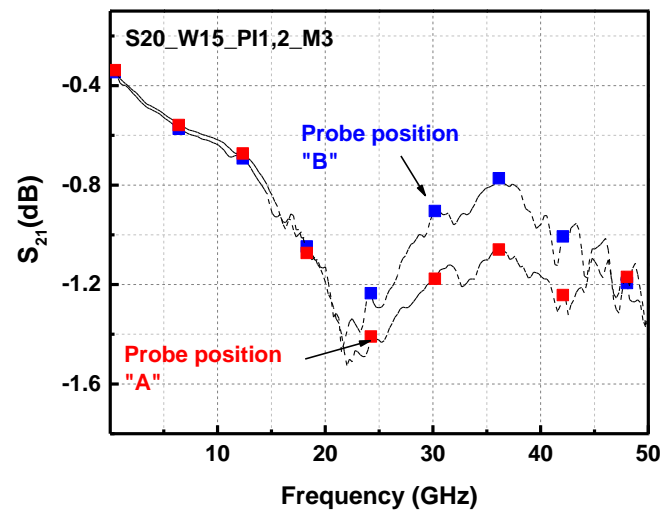

Figure 6. Micrograph of a multilayer CPW transmission line with illustration of different probe positions.
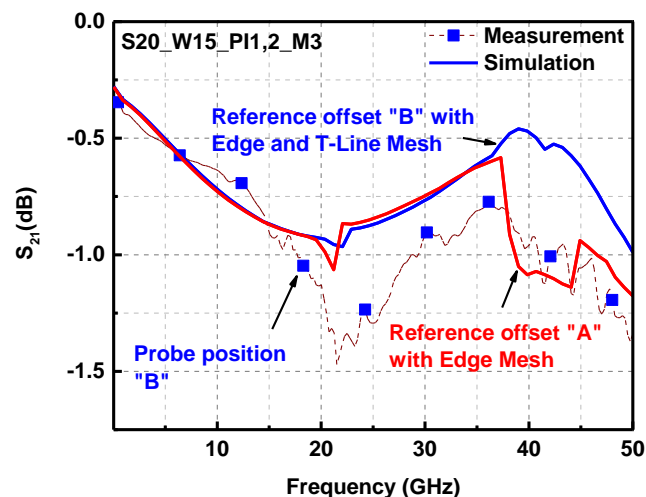
Furthermore, the Agilent ADS Momentum 2011 simulator is powered with an adaptive frequency sampling (AFS) algorithm. This feature compares sampled S-parameters data points to a rational fitting model in order to accurately represent the spectral response of the modelled components or circuits [4,5]. The simulation therefore yields less uncertainty characteristics for large frequency ranges than the measurement.

4. Conclusions
The results confirmed that the S-parameters characterisation is valid for use with the multilayer CPW structure. The results presented also confirm that the new simulation setup with additional edge and transmission line mesh (Ref B, EDGE) yields very good agreement with the measured data. It reduces distortions at 22 GHz and 44 GHz which resulted from uncertainties arising as a consequence of complex transverse current distribution on the edge of the multilayer CPW transmission line as well as at its discontinuity, i.e. the multilayer bonding pads.

Figure 7. Measured S_{21} parameter of a multilayer CPW transmission line with different probe positions.

Figure 8. Simulated and measured S_{21} parameter of a multilayer CPW transmission line with different reference offset ports or probe position.

References

[1]   Vo T V, L. Krishnamurthy, Sun Q and Rezazadeh A A 2006 3-D Low Loss Coplanar
        Waveguide   Transmission Lines in Multilayer MMICs *Microwave Theory and
        Techniques, IEEE Transactions* **54** pp 2864 – 2871
[2]   Chen C H and Deen M J 2001 A General Noise and S-parameter Deembedding Procedure for
        On-Wafer High Frequency Noise Measurements of MOSFETs *Microwave Theory and
        Techniques IEEE Transactions* **49** pp 1004 – 1005
[3]   Heymann P, Prinzler H and Scnieder F 1994 De-Embedding Of MMIC Transmission-Line
        Measurements *International Microwave Symposium Digest, IEEE MTT-S* pp 1045 – 1048
[4]   Agilent Technologies 2011 *Advanced Design System 2011 User's Guide*
[5]   Agilent Technologies 2011 *Agilent AN154 -S-Parameter Design; Agilent Application Note*