A Calibration Procedure for W-band On-wafer Testing

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ABSTRACT

This paper describes a W-band (75~110 GHz) on-wafer probing calibration procedure based on the microstrip SOLT calibration technique. Two on-wafer offset-open microstrips are used together with SOLT standards to generate high frequency calibration kits. For microstrip-line calibration on 2-mil thick GaAs substrate, measurements of some passive elements are presented and compared with those measured by a multiline TRL calibration. Electromagnetic simulations of these calibration and test standards are also generated. Close agreement between measurements and computer simulation provides verification in high frequency range (75~110 GHz). Measurements using this calibration kit from 1 to 65 GHz are also checked against previously reported data [2]. It is found that this SOLT calibration standard set is valid from 1 to 110 GHz.

INTRODUCTION

With MMIC applications moving into W-band (75~110 GHz) and higher, accurate on-wafer testing at millimeter-waves is becoming more important in device and circuit characterization[1]. Recently, DuFault and Sharma reported a novel procedure [2] to enhance the accuracy of SOLT calibration up to 75 GHz, where an on-wafer multiline TRL calibration [3] is developed to measure the SOLT calibration standards and provide verification for SOLT measurement data. However, for microstrip-line calibartion upto W-band and higher, the accuracy of the equivalent model for the LOAD standard in SOLT calibration kit remains questionable. The calibration errors can be clearly displayed when checked against some offset-open lines. This is basically due to a limitation of the lumped-element model adopted by the SOLT calibration. Even with TRL calibration where the LOAD standard is not needed, electromagnetic coupling between the long lines and their adjacent circuitries has introduced another difficulty in W-band calibration.

In this paper we propose to use measurements of two additional microstrip offset-open lines, 255 μm and 1025 μm long, to correct the errors made in the **existing** SOLT standard models, in particular the LOAD model for high frequency (75~110 GHz) measurements. An **updated** SOLT calibration kit is then formulated. TRL results are also generated as supporting data although some coupling effects at W-band are detectable. Close agreement on the SOLT standard measurements and some radial stubs measurements are obtained. They are compared with electromagnetic simulated data throughout the whole frequency spectrum from 1 to 110 GHz. Accuracy of the calibration procedure is ducumented for microstrip lines on 2-mil thick gallium arsenide substrate.

MODIFICATION ON THE EXISTING (1~65 GHz) SOLT CALIBRATION

For S-parameter measurements, the short, open, load and through (SOLT) calibration requires precise knowledge of the s-parameter of four standards. As the equivalent circuit models adopted in SOLT are defined in a given topology, the distributive characteristics of the LOAD standard has long been a difficult element to model in terms of ideal lumped-elements. Such a discrepancy become more and more severe when measurements are done in W-band and higher. Our updated SOLT calibration procedure

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account for errors generated in such a situation.

The SOLT standards model derived by Dufault and Sharma [2] is adopted initially to measure two offset-open lines in 75~110 GHz frequency range. Given the knowledge that the reflection coefficient should be of unit amplitude in an ideally lossless case, we are able to modify the SOLT standard models such that they generate the desired, unit amplitude offset-open measurements. By only adjusting the line length of the microstrip line associated with the LOAD model, we successfully generate unit-amplitude reflection coefficients. Figure 1 shows high frequency measurements done by two different calibration kits and electromagnetic simulation for the 255 μm offset-open line. Large deviation or correction is found between the existing and the updated calibration kits. Agreement between EM-simulation and the updated calibration kit supports the accuracy of the phase value in measurements.

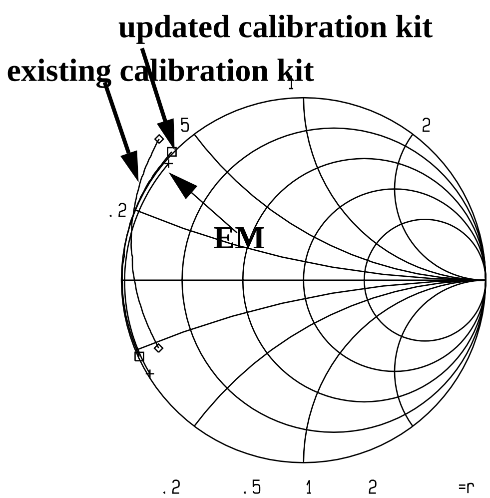

Figure 1 Measurement of a 255 μm offset-open line. The existing calibration kit measurement deviates out of the Smith chart while the updated SOLT calibration kit generates a unit-amplitude reflection coefficient. For phase values EM-simulation agrees well with the new cal-kit.

MEASUREMENTS OF PASSIVE ELEMENTS

Figure 2 and 3 shows a comparison between measurements done with SOLT and TRL calibration methods for the OPEN and the LOAD calibration standards. Sonnet [4] electromagnetic simulation results are also shown. Although electromagnetic coupling effects are detectable on TRL measurement of the OPEN standard at 94 GHz, its phase measurements matches well with EM simulation. For the LOAD standard, the SOLT calibration kit is updated such that the phase values of the measurement follow the trend predicted by TRL cal-

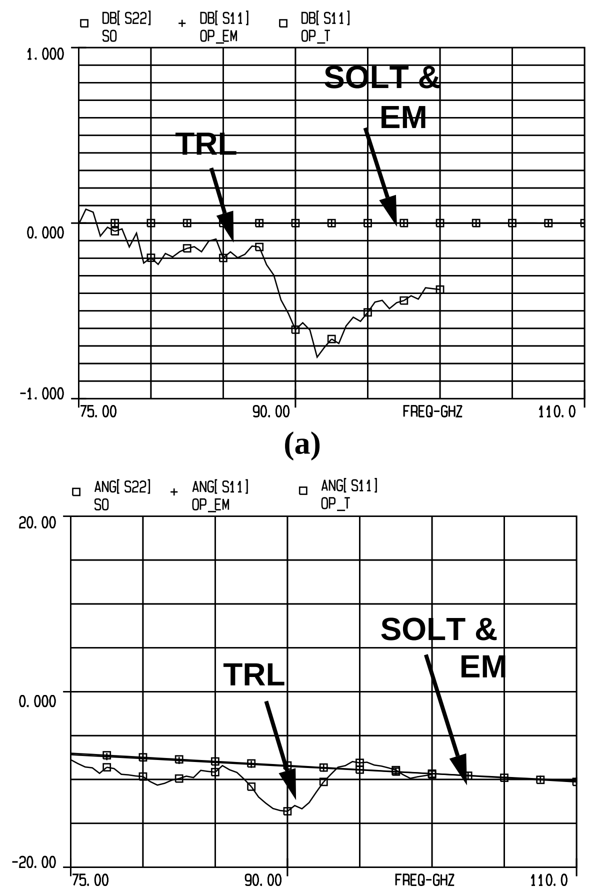

Figure 2 Measurements of the OPEN standard. Although electromagnetic coupling effects are detectable on TRL measurement of the OPEN standard at 94 GHz (a), its phase measurements (b) matches well with EM simulation.

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ibration instead of EM-simulation upon which the existing calibration kit is based. We believe that TRL data are relatively more reliable than EM-simulated data in predicting the trend in phase variation.

With the updated SOLT calibration kit we measure a 45^o radial stub designed at W-band (94 GHz). Measurements (Figure 4) with TRL and EM-simulation are also provided. As two measurements are more in agreement with each other than with EM-simulation in predicting the resonance frequency, we believe that the measurement data are more reliable. To verify the validity of the updated calibration kit in the low frequency (1~65 GHz) range, we also measure a 45^o radial stub designed at 60 GHz. Comparison of measurements done with two calibration kits are shown in Figure 5. Close agreement between two sets of data guarantees that the updated calibration kit also works well in the frequency range from 1 to 65 GHz.

CONCLUSION

Two on-wafer offset-open microstrips are used together with SOLT standards to generate

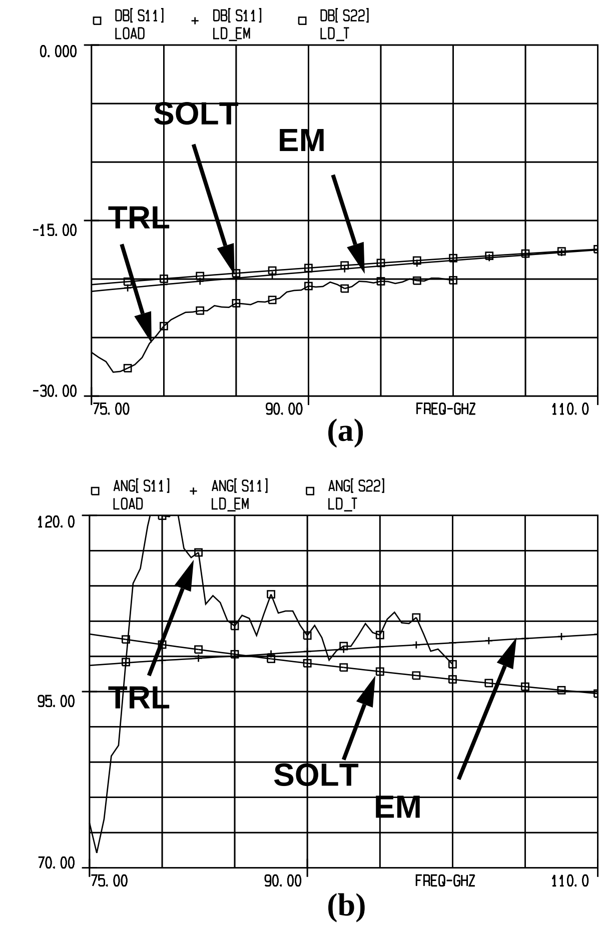


Figure 3 Measurements of the LOAD standard. The SOLT calibration kit is updated such that the magnitude of the measurement stays the same (a) but the phase values (b) follow the trend predicted by TRL calibration instead of EM-simulation upon which the existing calibration kit is based.

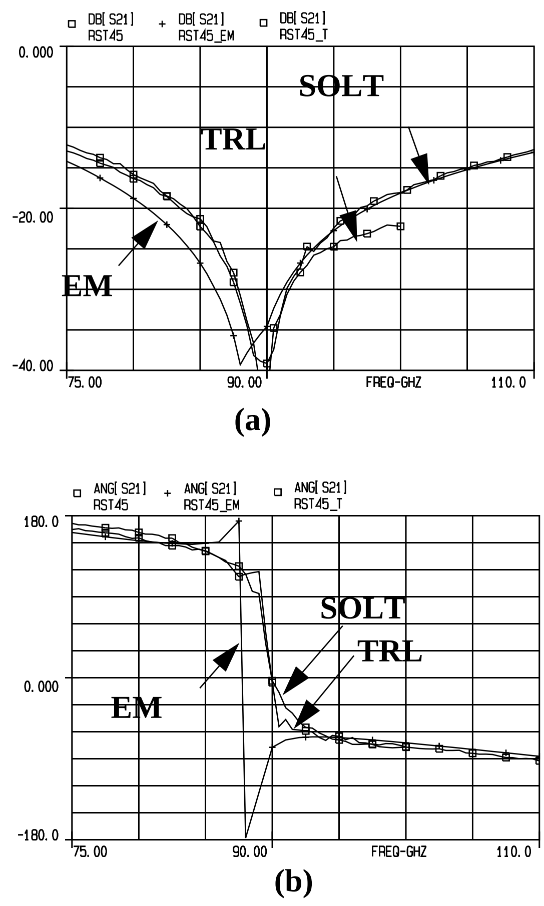
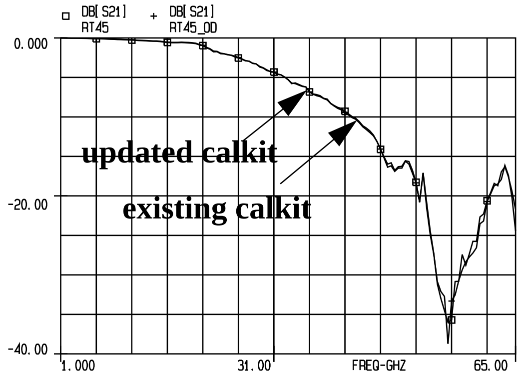
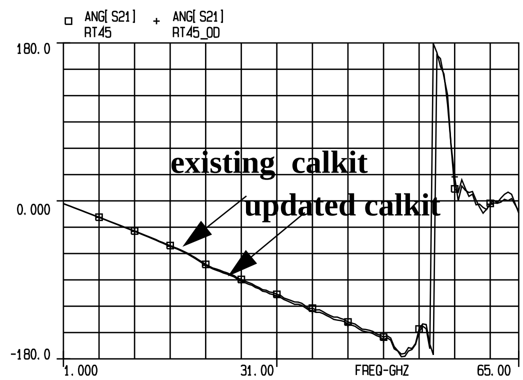


Figure 4 Measurements of the 45^o radial stub designed at 94 GHz. As indicated in magnitude (a) and phase (b) measurements, SOLT and TRL data match to each other in predicting the resonant frequency better than EM-simulation. The offset is less than 3 GHz.



(a)



(b)

Figure 5 Measurements of the 45^{o} radial stub designed at 60 GHz. As indicated in (a) magnitude and (b) phase measurements, the original and the updated SOLT calibration kits closely match to each other in predicting the resonant frequency, which supports the validity of the new calkit in low frequency (1~65 GHz).

high frequency calibration kits for microstrip-line calibration on 2-mil thick GaAs substrate. Measurements of passive elements are presented and compared with those measured by a multiline TRL calibration. Electromagnetic simulation results are also generated. Close agreement between measurements and computer simulation provides verification in high frequency range (75~110 GHz). Measurements with the updated calibration kit from 1 to 65 GHz are also checked against previously reported data [2]. It is found that the updated SOLT calibration kit is wideband. It works well throughout the whole band from 1 to 110 GHz.

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