Custom Test Fixture Design and Measurement Correlation of Differential Pairs in a Flip-Chip Organic Buildup Package Using Measurement Based De-embedding

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Abstract— **The design of a custom test fixture to measure the 4-port S-Parameters of a flip-chip substrate using 4-port network analyzer and fixture de-embedding is presented. Fixture effects for probes and SMA to microstrip launches are removed using measurement based de-embedding through adapter characterization removal. Residual error of de-embedding is presented along with correlation of the model to measurement.**

I. INTRODUCTION

The increased integration of high-speed SerDes in standard organic buildup package technology requires accurate modeling to ensure compliance with aggressive return-loss requirements. In this paper, the measurement correlation process of a 45mm x 45mm, 10-Layer (4-2-4) High Density Buildup (HDBU) organic substrate which is modeled using Agilent Momentum is described. Due to fixture and calibration limitations of having microprobe for die side measurement and coaxial for PCB side measurement at the BGA ball, a custom test fixture is designed and fabricated. The fixture design process is described including planning, SMA transition optimization, feedline design, and DUT mounting. Raw measured data as well as fixture de-embedding results to remove both the probe and coax-to-microstrip feedlines are presented. Errors from the de-embedding process are presented as well as model correlation and considerations for crosstalk measurement correlation for the present version of the test fixture.

Using standard probe equipment it is not possible to directly measure differential insertion-loss for a package substrate where signal traces originate on the top layer and terminate on the bottom layer at a BGA ball. The many challenges include different pitch for probes on the bump side, traditionally 180um-225um minimum, and the BGA ball side (typically 0.8mm-1.27mm), making for a non-ideal thru connection for calibration [1]. There are also mechanical challenges with fixturing in that one set of probes must be inverted and either additional optics, or the ability to reposition them, is required to allow for simultaneous probe placement on both the bottom side of the device under test (DUT) and the top side. There are few probe solutions available today that can support two sided probing, however a relatively low cost fixture if carefully designed can yield good results. Where the authors in reference [1] used model based de-embedding, this approach uses measurement based de-embedding to fully characterize the feedlines using TRL calibration and the probes through adapter characterization removal to fully de-embed the probes and PCB fixtures from the DUT.

II. FIXTURE DESIGN

The dielectric material selected for the fixture (Figure 2) was Rogers 4350B for it superior loss characteristics. The fixture stackup is routed on a single top layer with ground plane on layer #2, however a four layer stackup was selected in order to maintain thickness for mechanical stability and prevent warping during assembly.

The SMA connector was modeled in a 3D full-wave field solver and optimized to launch from coax to coplanar waveguide with ground plane (CPWG). Care was taken to maintain matched impedance and tapered transition to the SMA connector to reduce reflections ensuring maximum performance of the fixture. It is critical that the fixture be significantly better performance than the device under test for this application. It is important to select an SMA connector for the specific application which will ensure tapered transition from 3.5mm coax to the fine PCB trace (10mil) which provides sufficient ground transition as well to ensure matched impedance.

A set of TRL calibration standards were fabricated on the same panel adjacent to the site where the device under test would be soldered. Due to the bandlimited nature of Thru-Reflect-Line (TRL) calibration where the bandwidth is established by the insertion-phase of the line standard relative to the thru (20degrees to 160degrees typically, or 8:1 bandwidth), a set of four lines were fabricated to cover the bandwidth from 100MHz to 20GHz.

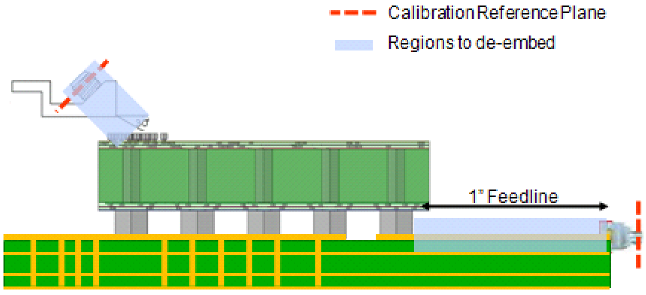

Figure 1 Measurement reference planes and de-embedding region

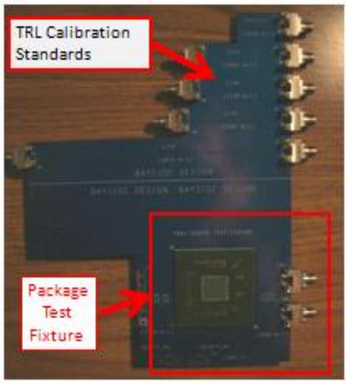

Figure 2 Test fixture

The zero-length thru standard was designed to be two inches so as to establish the reference plane in the center of the thru line. The thru standard represents two feedlines back to back which will be used to probe the BGA side of the device. After de-embedding the feedline, the reference plane will be established at this point. The feedlines to the BGA balls of the DUT are one-inch SMA to microstrip transitions, exactly half of the thru standard.

There were also many mechanical considerations such as weight of the cables on the SMA connectors and their force on the delicate probes, PCB height and size to obtain level seating on the probe station chuck as well as SMA connector height which had to be filed down due to the way it restricted the motion of the micromanipulator arm.

III. RESULTS

The raw performance of the TRL standards were measured (**Error! Reference source not found.** and Figure 4) using 2-port SOLT calibration. The TRL standard return-loss performance is considered excellent with less than -25dB to approximately 11GHz, and less than -15dB to 20GHz.

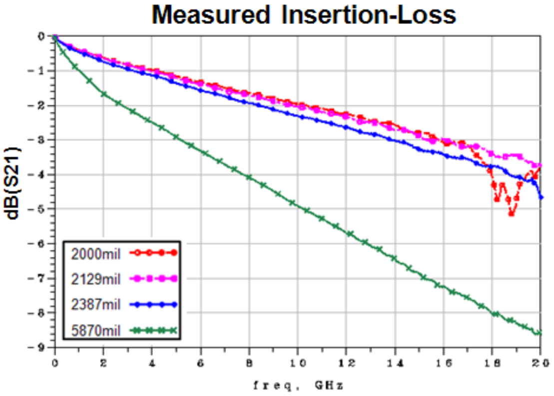

Figure 3 Measured TRL Standard Insertion-Loss

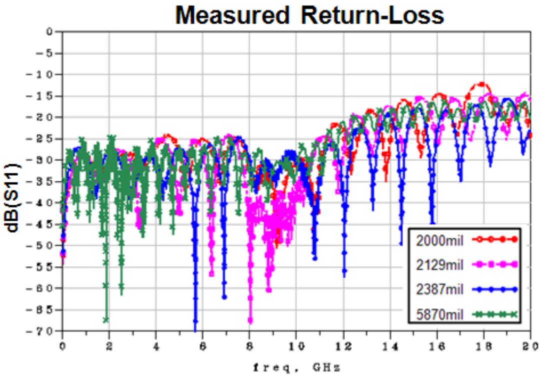

Figure 4 Measured TRL standard Return-Loss

Using a N5230A Agilent 4-Port Vector Network Analyzer calibrated with 4-port ECal module in 3.5mm coaxial waveguide, the fixture and DUT 4-Port S-parameters were measured using GGB Industries microprobes and coaxial cables. Characterization of the probes and microstrip feedlines were performed using adapter characterization where a 1-Port SOL (Short-Open-Load) calibration is performed in coaxial waveguide, followed by a second SOL calibration using characterized wafer standards. From these two calibration sets for each probe the 2-port S-parameters of the probes are determined and applied as part of the fixture de-embedding. Similarly, a 2-port calibration is performed in 3.5mm coaxial waveguide, followed by TRL calibration, from which the s-parameters for the feedline are determined. A simple way to test the quality of de-embedding of the 1" feedline is to try and de-embed the zero-length thru standard to see the residual error left over. Both the resulting phase and scalar error after de-embedding are shown in Figure 5 and Figure 6, respectively. The phase error is less than 5-degrees across the band of 1GHz-7GHz. The residual scalar error after de-embedding is less than 0.3dB.

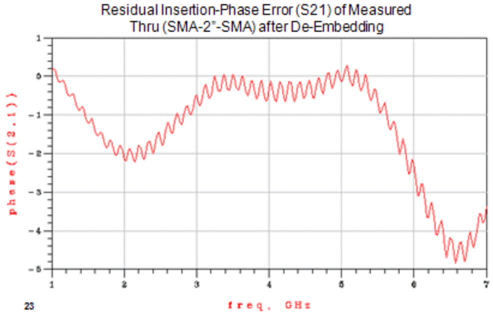

Figure 5 Residual error of insertion-phase after de-embedding to zero length thru

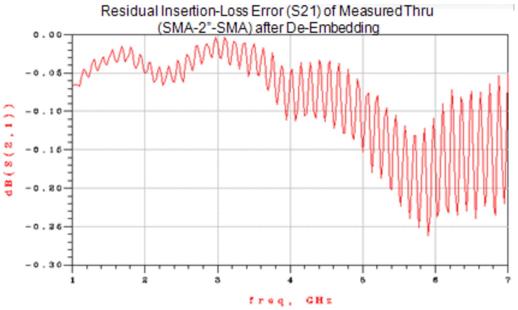

Figure 6 Residual error of insertion-loss after de-embedding to zero length thru

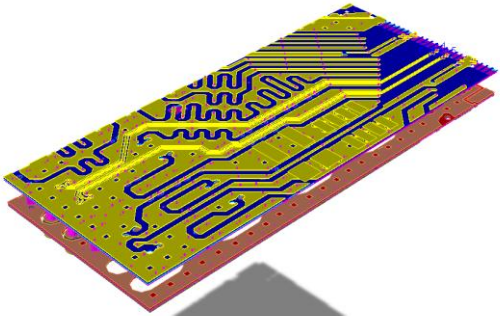

Figure 7 Package Model

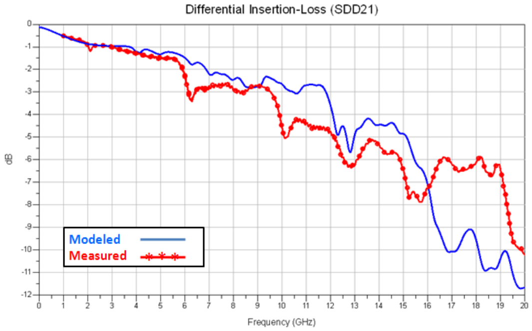

Figure 8 Measured vs. Modeled Differential Insertion-Loss

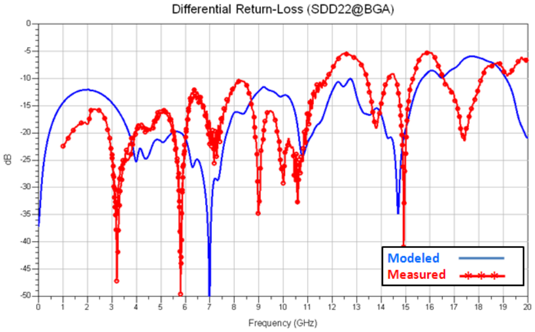

Figure 9 Measured vs. Modeled Differential Return-Loss

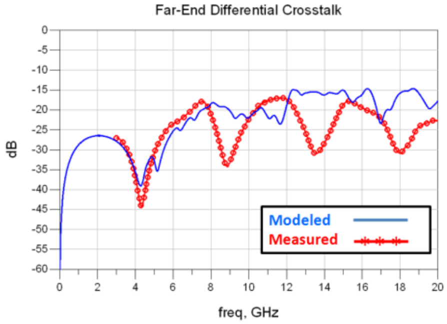

Figure 10 Measured vs. Modeled Differential Far-End Crosstalk

IV. CONCLUSIONS

The test fixture and measurement-based de-embedding showed that the customer performance requirements for return-loss were met. Even without de-embedding of the probes and feedlines, one can still gather useful data. Through the use of adapter-characterization it was shown that probe and feedline effects could be minimized in the overall measurement, however the residual error for TRL measurement based de-embedding was noticeably higher.

The missing resonances in the modeled return-loss data is attributed to modeling inaccuracies. Because of the size of the problem and many fine features and the computational limitations of the hardware at the time of this work, the trace modeling was partitioned in to two regions, and the continuity of the return path was favorably modified in the process. The measured insertion-loss, Figure 8, is higher than modeled result. The BGA pad on the PCB is not de-embedded from the measurement and it is also absent from the model.

The required differential crosstalk was desired to be -30dB, however when measured this result was much higher at -20dB. The reason for the increased crosstalk was due to the fact that in the fixture design the aggressor was short-circuited to ground on the board and the victim was open-circuited on the die side. This resulted in increased internal reflections and crosstalk between the aggressor and victim. The extracted modeled S-parameters were recalculated with the appropriate boundary conditions to match the DUT, and the result showed that under these conditions the model correctly predicted -20dB crosstalk. It was determined that the device, when appropriately terminated, would yield -30dB isolation between adjacent pairs. It is noted that the crosstalk primarily comes from the package core plated thru-hole vias and BGA balls as the traces are well shielded and isolated in the package.

With the confidence of how the model agrees with measured data it is possible to use the model to further optimize the BGA transitions from the package to the board. Additional work is in progress on the measurement based de-embedding technique presented to increase the accuracy at higher frequencies and reduce de-embedding error.

REFERENCES

[1] H. Shi, G. Liu, A. Liu, "Accurate Calibration and Measurement of Non-Insertable Fixtures in FPGA and ASIC Device Characterization", DesignCon, February 2006