Hybrid De-Embedding for 116Gbps Test Channels

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***Abstract*—This paper presents the de-embedding method to remove test fixture impact at 116 Gbps to predict the performance at Ball Grid Array(BGA). It describes the technique to improve the probe contact discontinuity caused by measurement probe contacts.Investigation and analysis show reduction on reflections compared to the normative way. The root caused is discussed and the efficacy of the methodology are demonstrated in Time Domain Reflectometry (TDR) and eye diagram measurements. This method is useful to those who face the same test fixture removal issue at 116 Gbps.**

***Index Terms*—De-embedding, high-speed measurement, SERDES, reflections**

I. Introduction

There are many de-embedding methods to remove test fixtures to predict the performance at BGA. The de-embedding data must accurately represent the actual channel and simulation data [1] [2]. As the data rates increases to 116 Gbps, signal quality verification at device pin is getting nontrivial and challenging. This paper presents a technique to remove the test fixture effect for better correlation with simulation data. The key concept is to improve the discontinuity resulted by non-ideal measurement probe contacts which differs from the actual system path at 116 Gbps. Proof-of-concept show the reflections are reduced by 50% at the virtual probe point. This constitute a closer correlation to the simulation data thus confirms the benefit of this technique.

Typically, replica channels are design at the same board to reduce the discrepancy between printed circuit board (PCB) materials . These channels are measured using a subMiniature version (SMA) or micro-probe contact, which causes signal reflection loss up to 10% or more. At lower data rates, the impact of passivity and causality error is still low.This is getting more challenging as speed goes beyond 100 Gbps whereby small channel variations will cause deviation to the actual system performance. Poor de-embedding can lead to inaccurate measurements.

This paper introduce hybrid de-embedding technique to remove text fixture effect at 116 Gbps. It elaborate four steps to replace probe contact measurement with probe contact simulation s parameters. Result shows 50% improvement in terms of reflections than the normative way [5] in Time Domain Reflectometry (TDR) measurements. Eye diagrams are measured to prove correlation in time domain.The organization of this paper starts with the discussion on the inaccuracy of de-embedding and the theory. Then, the paper highlights the four steps to replace the measured with simulation S parameters . The result section presents the improvement between hybrid de-embedding and simulation data to show the technique efficacy. TDR, eye diagram measurements, Eye Height(EH) and Eye Width(EW) are the key indicator to show the effectiveness. Finally, a summary of this paper.

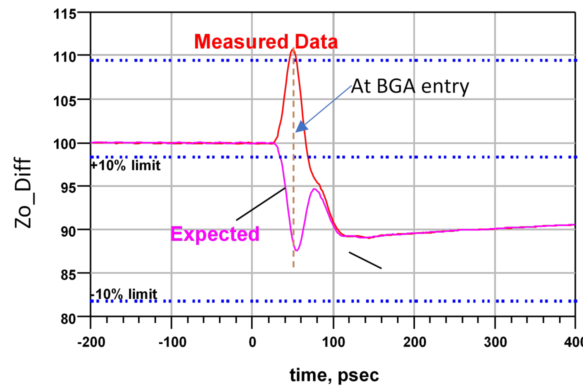

Fig. 1. TDR performance deviation between measured data and expected data

II. Inaccurate De-embedding at 116 Gbps

Conventional de-embedding at high data rates show more losses compare to the actual system.This is due to non-ideal signal current return path that cause high impedance spike as in Fig.1 (red plot) [3]. Based on TDR measurement , it resulted high impedance which is about 110 ohm or over 10% from nominal 100 ohm. It deviates the actual measurement when performing de-embedding. The expected BGA transition is shown by magenta colour curve in Fig.1 . As can be seen, the deviation is quite significant between the two plots.Next subsection explains the theory that constitute the discrepancy between the expected and measured plot.

A. Theory

In theory, high frequency current will flow on the least inductive channel paths [1]. The interconnect transitions from BGA balls to PCB are optimized during the design phase. This is to ensure minimum impedance discontinuity with reference to the channel characteristic impedance (Z_o) target. First order of Z_o approximation is given by (1). By altering the dimensions of PCB structures, the channel inductance (L_o) or

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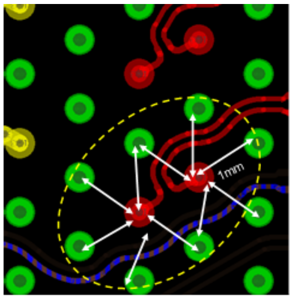

Fig. 2. Intended BGA patterns with 8 surrounding ground balls

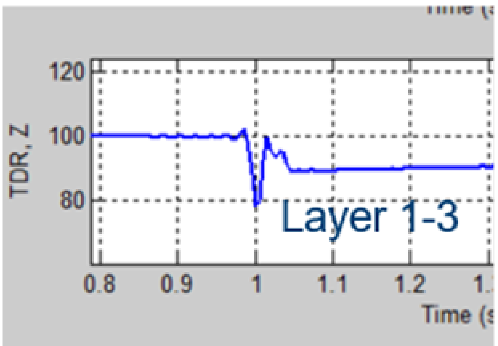

Fig. 3. Simulated 10ps TDR transition showing smooth transitions

capacitance (C_o) can be varied to yield the targeted impedance values.

$$Z_o = \sqrt{\frac{L_0}{C_0}} \tag{1}$$

From our observations, measurements using micro probes at BGA did not represent the actual measurement especially at the BGA transitions. This is due to the current flow may not represent the actual system path when measuring for S parameters. Fig. 2 shows a typical BGA balls configuration whereby return currents (yellow dotted circle) flow around the signal differential pair. However, measurement probing did not adhere to the same current path. It forces the return current to the probe ground path that differ from the design expectations. This issue can be seen clearly by the TDR plots from Fig. 3. The probe contact exhibits a higher impedance discontinuity. This is mainly due to the probe contact limitations that usually have only one or two ground pins compared to six or eight ground ball return path on actual system as depicted in Fig. 2.

Fig. 4 shows another example of a replica channel implementation on a PCB that illustrate the problem. The replica channel consists test point 3 (TP3) and test point 2 (TP2) to mimic the channel path on test point 1 (TP1) and Device Under Test (DUT). The replica channel measurements will have discrepancies due to different passive channel characteristic. At the PCB , the transition occur at the DUT BGA whereas the transition at replica channel occur at SMA connector. Therefore, the users need to verify the test fixture passive characteristics carefully. This is to ensure the de-embedding method is close to the actual system environment. At high data rates, the accuracy of de-embedding procedure is a key figure of merit to expose the true performance.

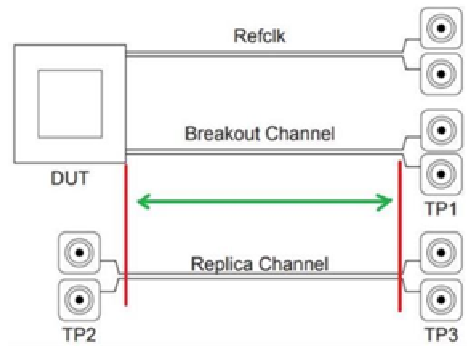

Fig. 4. Replica Channel

To ensure a good signal quality at the load, the transition impedance must be relatively equivalent to the channel characteristic impedance, Z_o. This is to minimize the signal reflections as suggested by (2) whereas, Z_o,is the reference impedance and Z_L is the load impedance. From Fig. 1, we calculated, the probe contact discontinuity caused reflection of 11% compared to 5% from simulation data. Therefore, direct de-embedding using probe contact measurement will lead to inaccuracy compare to the actual case. This inaccuracy lead for the proposal of hybrid de-embedding technique. In next section, we will discuss about the hybrid de-embedding technique to reduce the probing reflections.

$$\Gamma = \frac{Z_L - Z_o}{Z_L + Z_o} \tag{2}$$

III. Hybrid De-embedding Flow

This section elaborates the technique to remove the probe contact fixtures that causes inaccuracy. The general idea is to remove the measured S parameters and replace it with the simulated probing S parameters. In general, the hybrid de-embedding process involves four steps.

- The first step is to convert the measured S parameter to Transmission matrix or T parameter as in Fig.5 [4]. This operation can be be solved using MATLAB or circuit simulation tool such as Advance Design System (ADS) as denoted in (3). This denotation is an expression that converts S parameter to T parameter using the software tools .

$$S\ parameter = T\ paramater \tag{3}$$

- The second step is to attain the probing tool model S parameters and correlate with measured data as in Fig. 6.In this test case, return loss for simulated and measurement are compared. The purpose of this action is to ensure the S parameter waveform is comparable thus it can be replace with probing model S parameters.

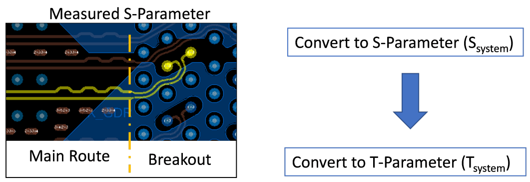

Fig. 5. Step 1:Convert S-parameter to T-parameter

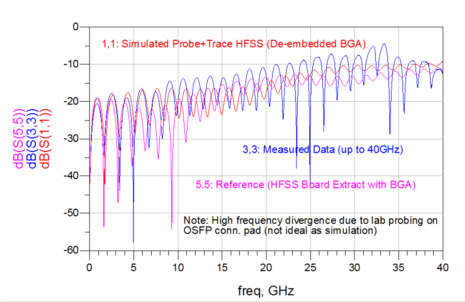

Fig. 6. Step 2 :Comparison on measured data and simulated model

- The third step is to convert the S parameters probing model and actual BGA transitions into T parameter matrix as in Fig.7. These two are the simulated S parameters model that need to be replace with measured data denoted in (4).
- Finally, remove the probe contact discontinuity from the measured data in step 1 and replace the simulation model in step 3. Then, convert the T parameters to S parameters depicted in Fig. 8. The mathematical expression is denoted in (4) and (5).

$$T_{hybrid} = [T_{BallContact}].[T_{ProbeContact}]^{-1}.[T_{System}] \tag{4}$$

$$T_{hybrid} = [S_{hybrid}] \tag{5}$$

The resultant of these steps are the new S parameters file. The file generated can be use for de-embedding and obtain the true performance at BGA . Next section discusses the results to prove the efficacy.

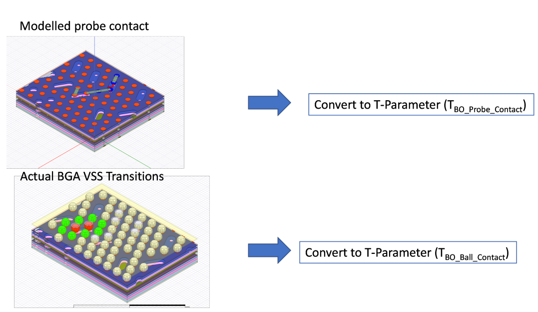

Fig. 7. Step 3: Convert the correlated model probe contact and actual BGA model transitions to T-Parameter matrices

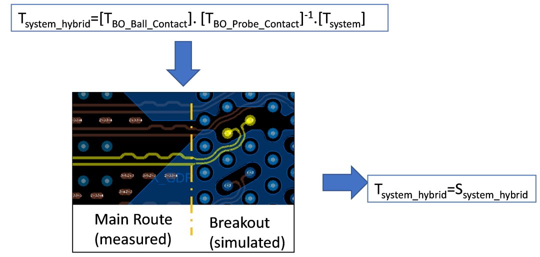

Fig. 8. Final step: T parameters to S parameters

TABLE I
EYE HEIGHT AND EYE WIDTH

Measurment	Baseline/Simulation	De-embed	Hybrid De-embed
Eye Height (mV)	615	605	614
Eye Width (ps)	29.6	26.4	27.7

IV. RESULTS

This section elaborate the results using S parameters as a de-embedding file.TDR,eye diagram,eye height and eye width are measured to quantify the effectiveness.These measurements are performed using test equipment such as Vector Network Analyzer (VNA) and real time oscilloscope.

VNA is used to measure TDR as depicted in Fig.9. Three measurements displayed differences. The hybrid- data transition impedance (blue curve) is within +/-10% tolerance limit and closer to the reference or simulated data (pink curve) in Fig. 9. As mentioned in section II, the measured data (red curve) exhibits high reflections compared to the reference data. Base on this assessment, we have improved the measurement accuracy using hybrid data (blue curve) to be close as possible to the reference or simulated data.

Next, we performed eye diagram measurements at 28 Gbps using real time oscilloscope. Transmitter(TX) is sending PRBS 23 pattern to the channel path and eye diagram is measured at the real time oscilloscope. Base on the eye diagram waveform in Fig. 10, the middle figure showed the highest jitter. The rising and falling edge of the eye diagram is thicker than the two eye diagrams. The hybrid data at the most right showed lower jitter.

Table 1 shows the results in terms of Eye Height(EH) and Eye Width (EW).Hybrid de-embed data is comparable to simulation data. The de-embed data or measured data has larger variance for EH.In a brief hybrid de-embedding data gives better correlation to the simulation data which has minor differences. Last section, summarize the paper and conclusion.

SUMMARY

This paper propose a hybrid de-embedding technique to correct the fixture probing impedance discontinuity that causes deviation to actual system performance.It explain the problem

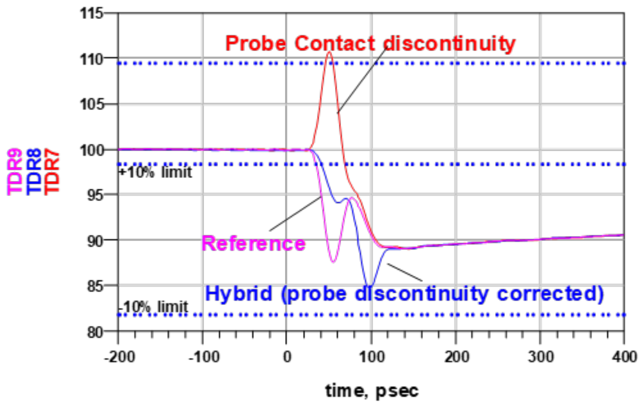

Fig. 9. TDR measurements on measured, hybrid and reference data

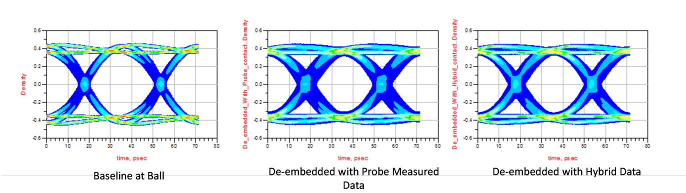

Fig. 10. Eye Diagram measurement across the baseline(simulated),measured and hybrid data

and the theory that causes the discontinuity at 116 Gbps. Section III describes the four steps to perform hybrid de-embedding. In the result section, we showed TDR,eye diagram, EH and EW measurements to prove the efficacy. The results show that there is a correlation between the simulated and the hybrid de-embedding data. Eye diagram showed positive margin of 5% and 4% on eye width and eye height data. This technique is useful for those facing the same test fixture data quality issue that may compromise their measurement quality.

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