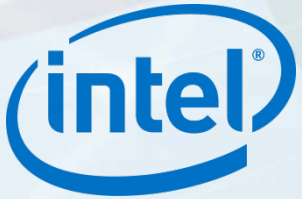
High-speed PCB electrical characterization with good stability and repeatability



Jimmy Hsu

Adolph Cheng Alex Wei Fred Chou

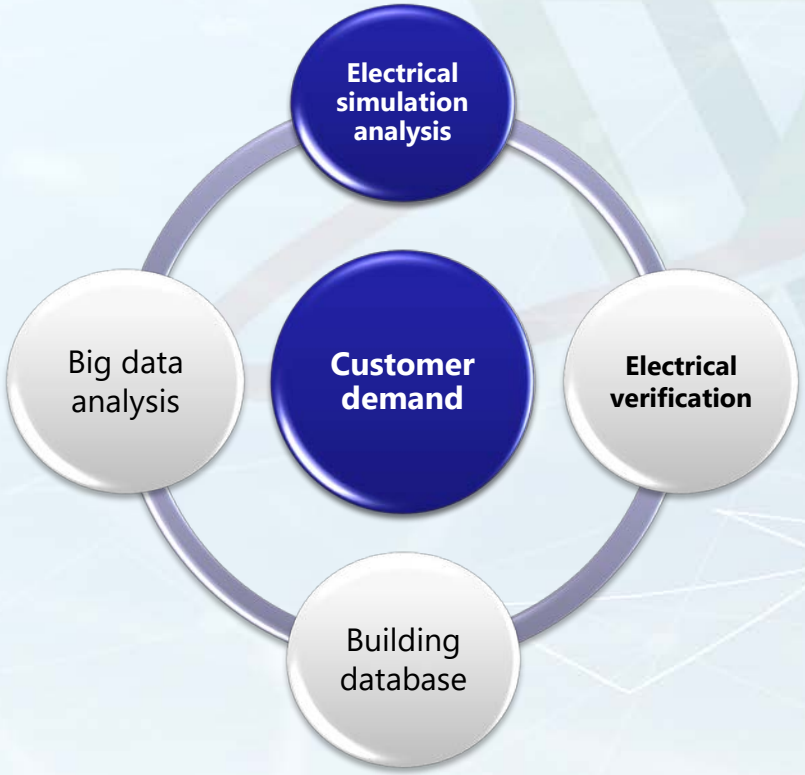
PROBE TODAY, FOR TOMORROW

Overview

- Background
  - Quality assurance of Probe Card
  - Industry Mega-Trends
  - Intel Delta-L for PCB Electrical Characterization
- Intel's Delta-L Algorithm
- Bottleneck of Handheld Probing Setup
- Solution for Stability, Repeatability and Less Time Consuming
- Summary & Future Work

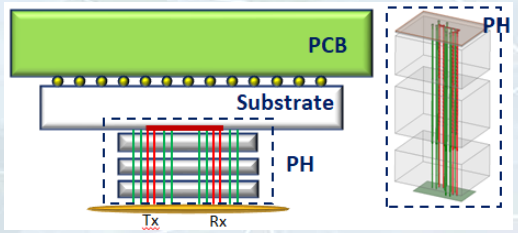
Quality Assurance of Probe Card

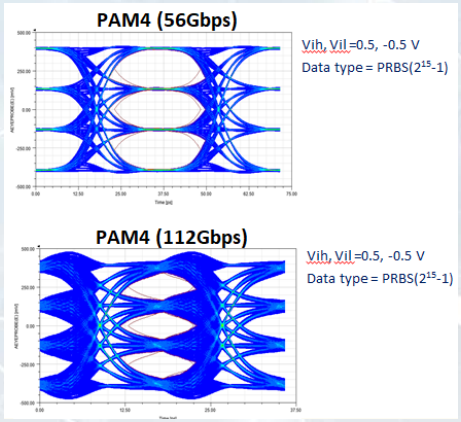
Quality Assurance is a cornerstone to MPI's Probe Card business. This includes verification methodologies (e.g. Automated TDR test process equipment) to meet customer demand and support our quality improvement processes.



Early stage:

1. Establish 2.5D / 3D model for electrical analysis
2. Confirm compliance with customer requirements





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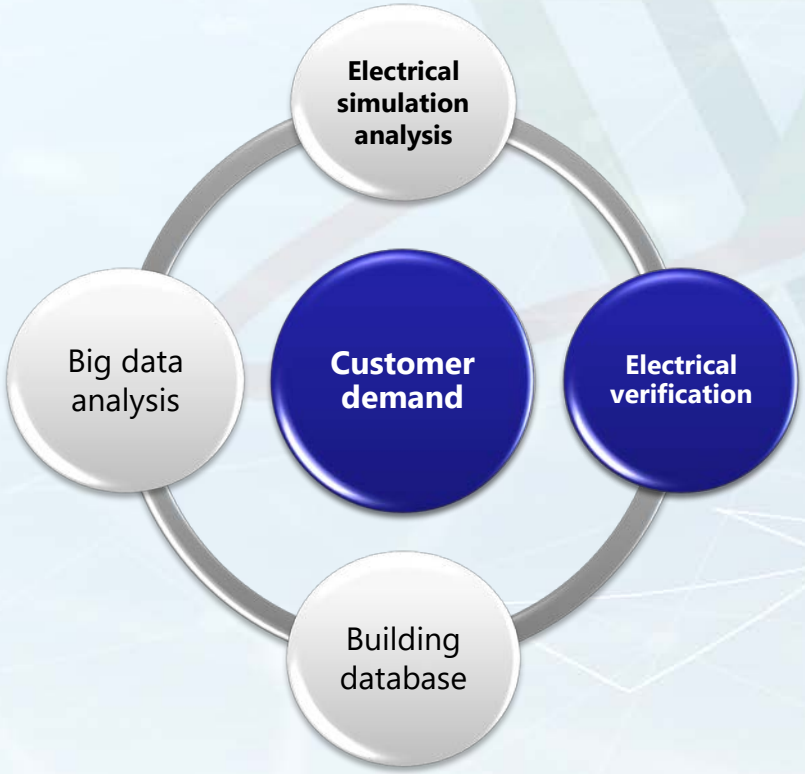
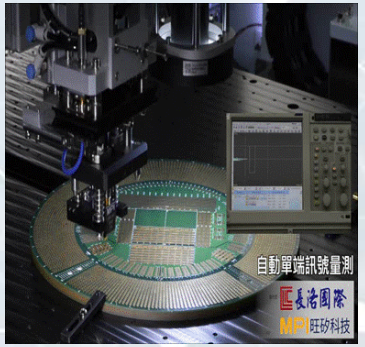


Mid-term:
1. **(PCB / Substrate) Electrical Inspection Process**
2. **ISO/TAF certification of Testing laboratory**



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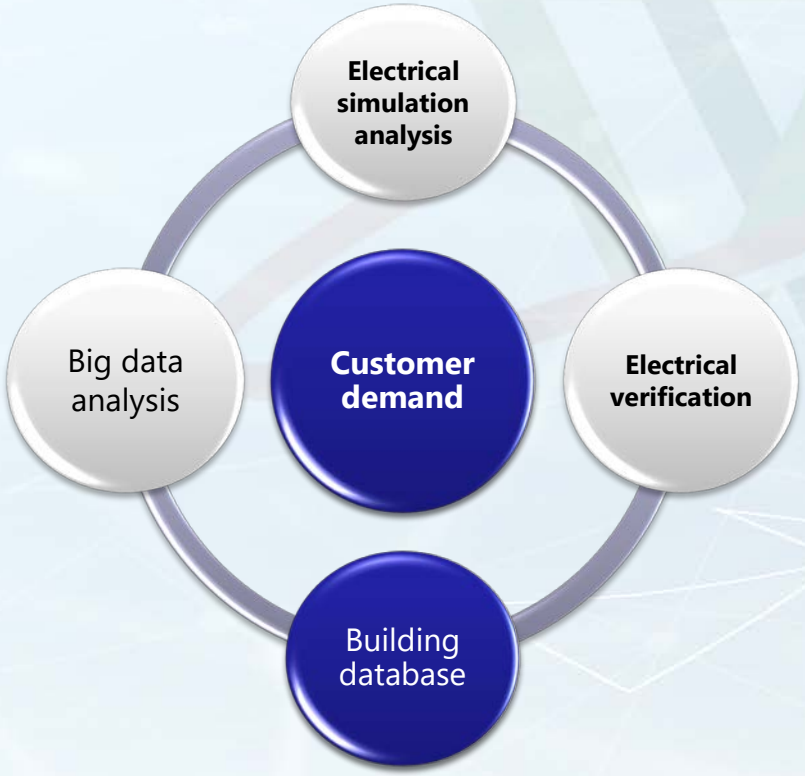

P/O	xxxxxxxxx	Supplier	xxx	File No.	xxxxxxxxx
Board Name	xxxxxxxxx	Single End Spec. xxΩ±xx%;		Single End Measurement Result	xxx~xxx
PCB Series No.	xxx	Differential Pair Spec. xxxΩ±xx%;		Differential Pair Measurement Result	xxx~xxx
MFG Date Code	xxxx	Timing DelaySpec.		Timing Delay Measurement Result	
Inspector	Adolph	Judgement	■PASS □Fail □Wait MRB-A-_____	Approval	Alex
Testing Date	2020/11/11				
Remark					

Symbol pin information							Impedance			Time Delay (ps)
NO.	REFDES	PIN_NUMBER	NET NAME	Layer	Nature	SPEC.	Mean(Ω)	Max(Ω)	Min(Ω)	
195	J1	3S1,5S1	3S1,5S1		Differential pair	xxxΩ±xx%	xxx	xxx	xxx	xxxx
196	J1	9S1,11S1	9S1,11S1		Differential pair	xxxΩ±xx%	xxx	xxx	xxx	xxxx
197	J1	21S1,23S1	21S1,23S1		Differential pair	xxxΩ±xx%	xxx	xxx	xxx	xxxx
198	J1	30S1,32S1	30S1,32S1		Differential pair	xxxΩ±xx%	xxx	xxx	xxx	xxxx
199	J1	36S1,38S1	36S1,38S1		Differential pair	xxxΩ±xx%	xxx	xxx	xxx	xxxx
200	J1	42S1,44S1	42S1,44S1		Differential pair	xxxΩ±xx%	xxx	xxx	xxx	xxxx
201	J1	6S1,8S1	6S1,8S1		Differential pair	xxxΩ±xx%	xxx	xxx	xxx	xxxx
202	J1	12S1,14S1	12S1,14S1		Differential pair	xxxΩ±xx%	xxx	xxx	xxx	xxxx
203	J1	18S1,20S1	18S1,20S1		Differential pair	xxxΩ±xx%	xxx	xxx	xxx	xxxx
204	J1	24S1,26S1	24S1,26S1		Differential pair	xxxΩ±xx%	xxx	xxx	xxx	xxxx
205	J1	33S1,35S1	33S1,35S1		Differential pair	xxxΩ±xx%	xxx	xxx	xxx	xxxx
206	J1	39S1,41S1	39S1,41S1		Differential pair	xxxΩ±xx%	xxx	xxx	xxx	xxxx
207	J1	45S1,47S1	45S1,47S1		Differential pair	xxxΩ±xx%	xxx	xxx	xxx	xxxx
208	J1	3S5,5S5	3S5,5S5		Differential pair	xxxΩ±xx%	xxx	xxx	xxx	xxxx

Quality Assurance of Probe Card

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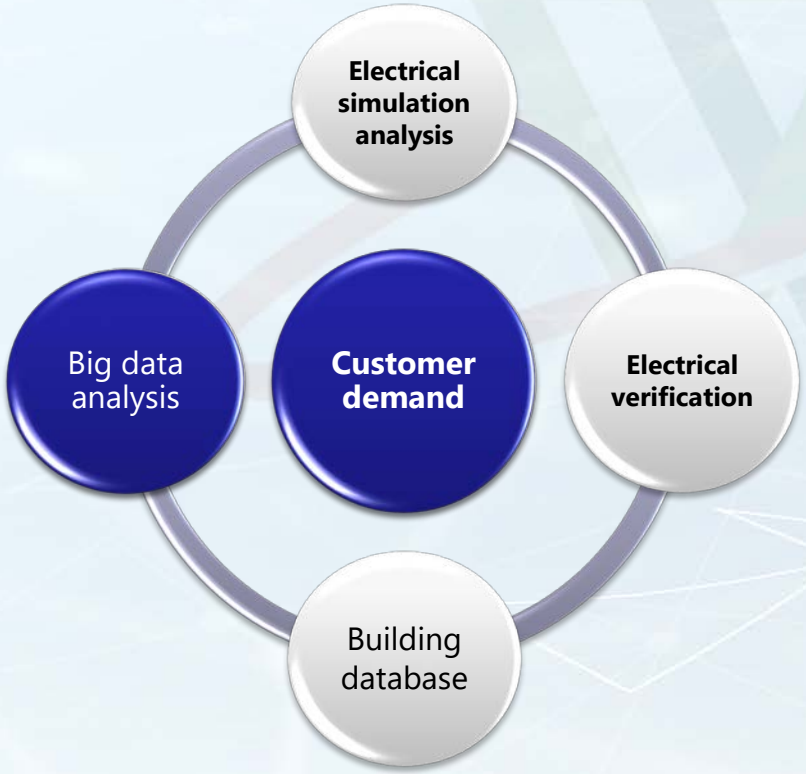
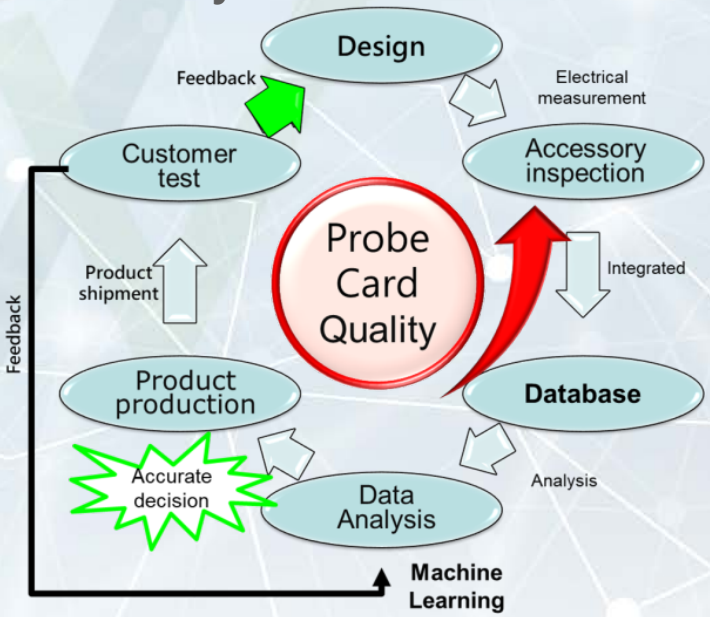


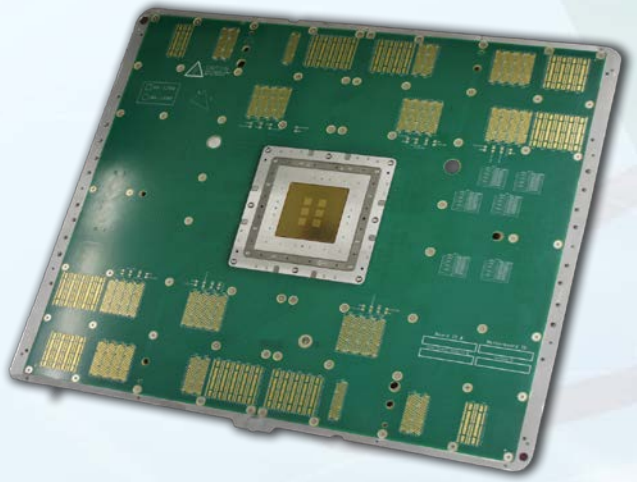
Late:

1. **Key Objective Quality control**
2. **Object Hierarchical Filtering**
3. **Process Adjustments**



Quality Assurance of Probe Card

MPI work together with Intel to solve PCB loss characterization in HVM by MPI's experience measuring probe card.



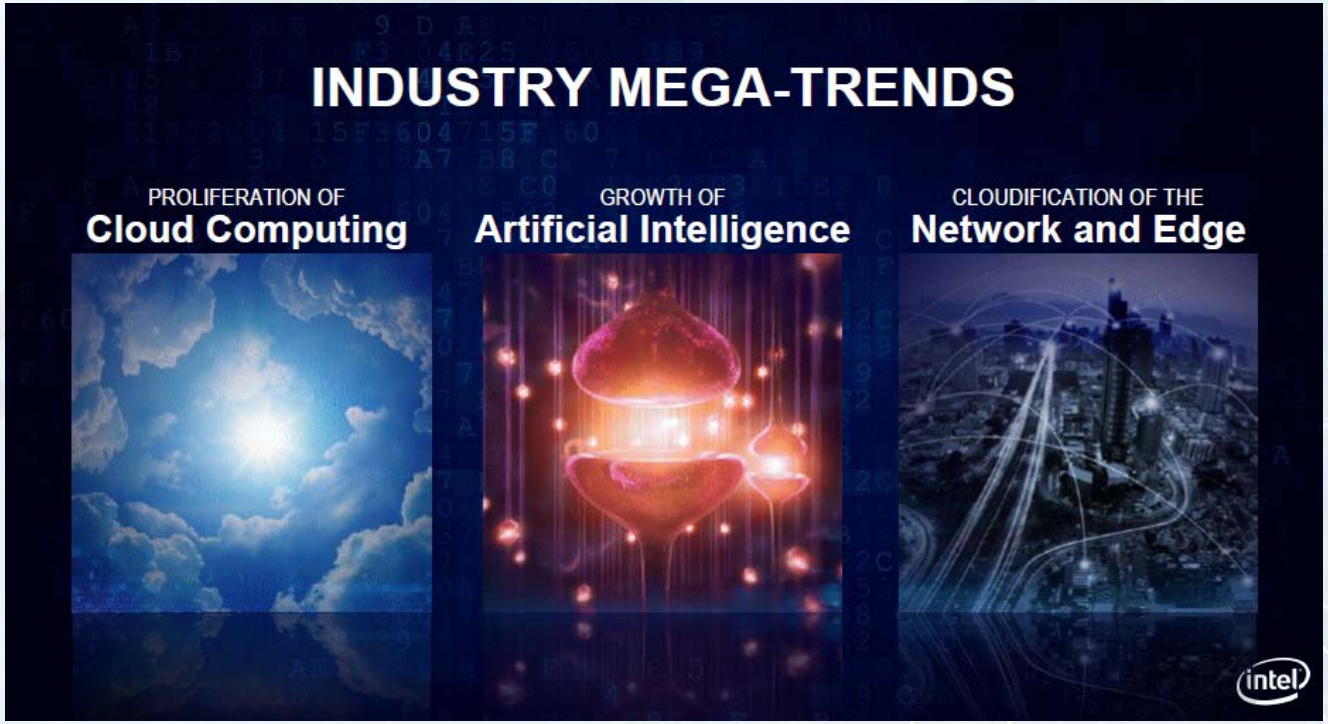
MPI Technology Transfer

Quality Inspection:
TDR Impedance, Loss, Crosstalk, PDN and so on.
Data Rate:
NRZ: 32+GT/s, PAM4: 56GT/s, 112GT/s

Quality Inspection:
PCB Loss characterization in HVM
Data Rate:
NRZ: <32+GT/s

Industry Mega-Trends

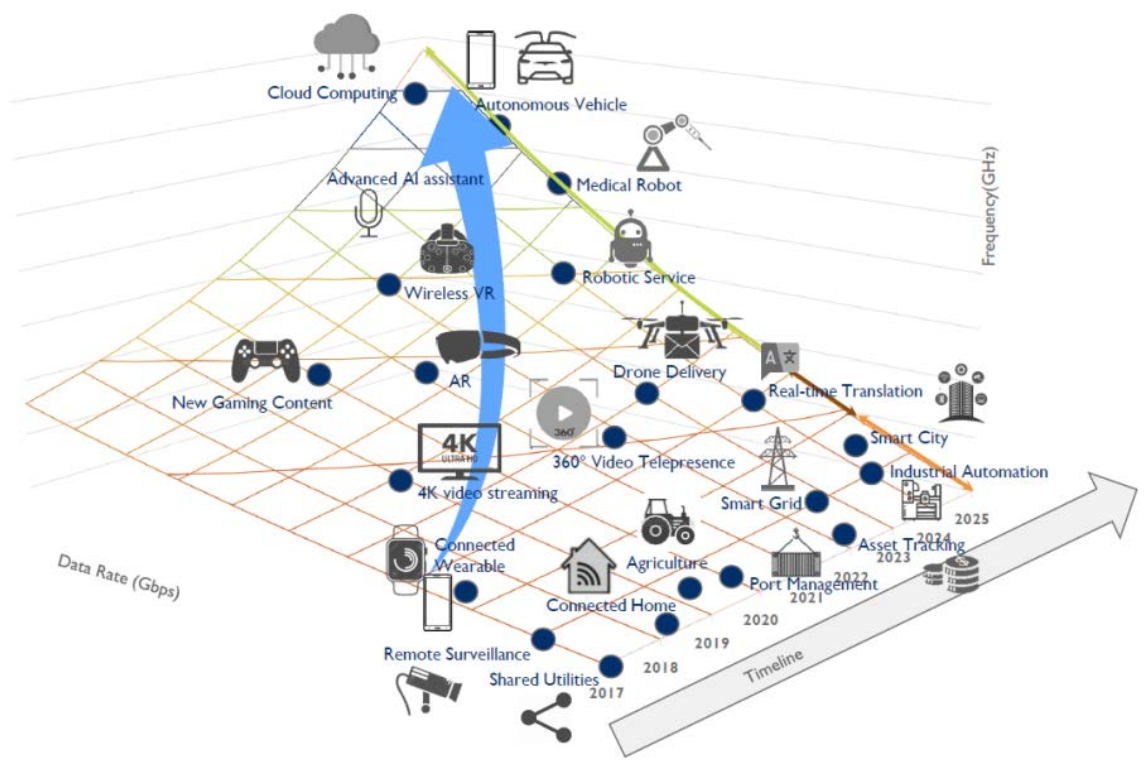
Future IT trends proposed by Intel require industry focus on product development, design and business through cloud services.



Source: Intel Corporation presentation material released on Nov.21,2019.

Intel Delta-L for PCB Electrical Characterization

As market demand for cloud computing is increases, channel loss on printed-circuit board (PCB) will continue to increase in importance in order to meet requirements of signaling integrity for high-speed I/Os .



Intel Delta-L Algorithm Benefit

- **Efficiently characterize PCB loss**
- **PCB material selection Guide for Designe**
- **PCB material quality monitoring**

Source: Intel Corporation presentation material released on Nov.21,2019.

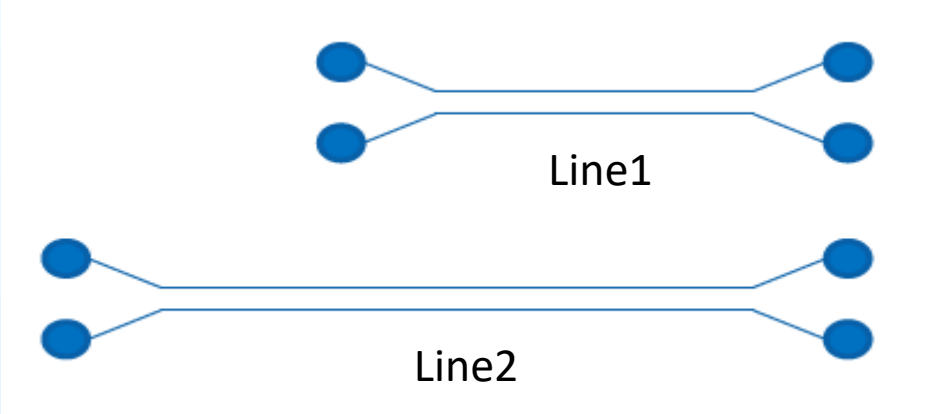
Overview

- Background
- Intel's Delta-L Algorithm
  - Delta-L Algorithm
  - Probing Quality Characterization
  - Measurement Quality Check
  - Repeatability Check
- Bottleneck of Handheld Probing Setup
- Solution for Stability, Repeatability and Less Time Consuming
- Summary & Future Work

Delta-L Algorithm

- **Intel's PCB Loss Methodology: Delta-L Algorithm**
- **Loss can be extracted by measuring two different length transmission lines**

Measurement



PCB Loss

Delta-L

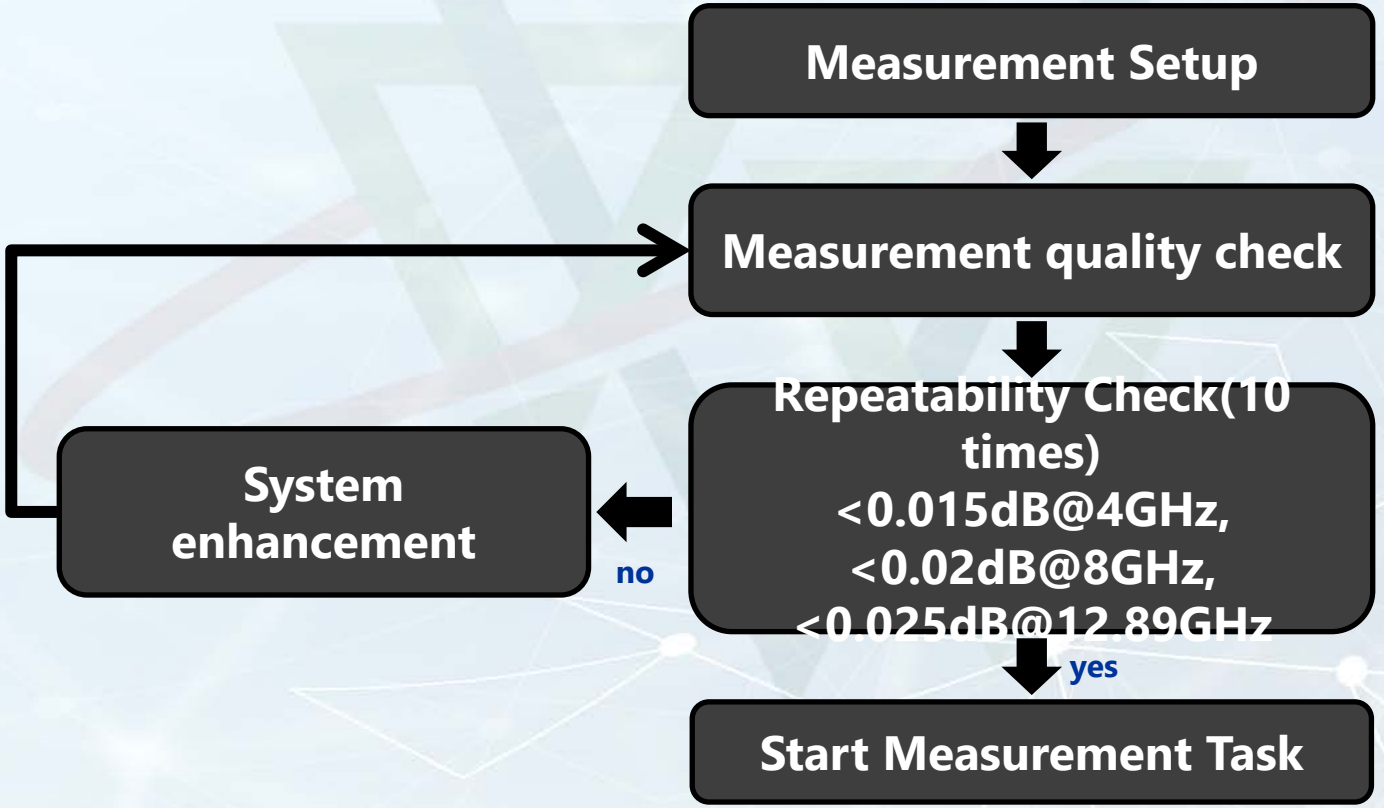
$$T_{L1} = T_A \times T_B$$
$$T_{L2} = T_A \times T_{DUT} \times T_B$$
$$T_{L2} \times {T_{L1}}^{-1} = T_A \times T_{DUT} \times T_B \times {T_B}^{-1} \times {T_A}^{-1}$$
$$T_{L2} \times {T_{L1}}^{-1} = T_{DUT}$$

$$T_{DUT} = \begin{bmatrix} e^{\gamma*(L_2-L_1)} & 0 \\ 0 & e^{-\gamma*(L_2-L_1)} \end{bmatrix}$$
$$\gamma = \alpha + j\beta$$
$$S21_{DUT} = e^{-\gamma*(L_2-L_1)} = e^{-\alpha*(L_2-L_1)}$$
$$Loss\ per\ inch = |S21_{DUT}|/\Delta Length$$

Source: Delta-L+ for Electrical Characterization, http://www.intel.com/content/www/us/en/processors/xeon/delta-l-plus-methodology-for-electrical-characterization-guide.html
MULTILINE TRL REVEALED, https://www.researchgate.net/publication/4027015_Multiline_TRL_revealed

Probing Quality Characterization

In order to validate measurement stability and repeatability, Intel proposed the probing quality characterization process below.

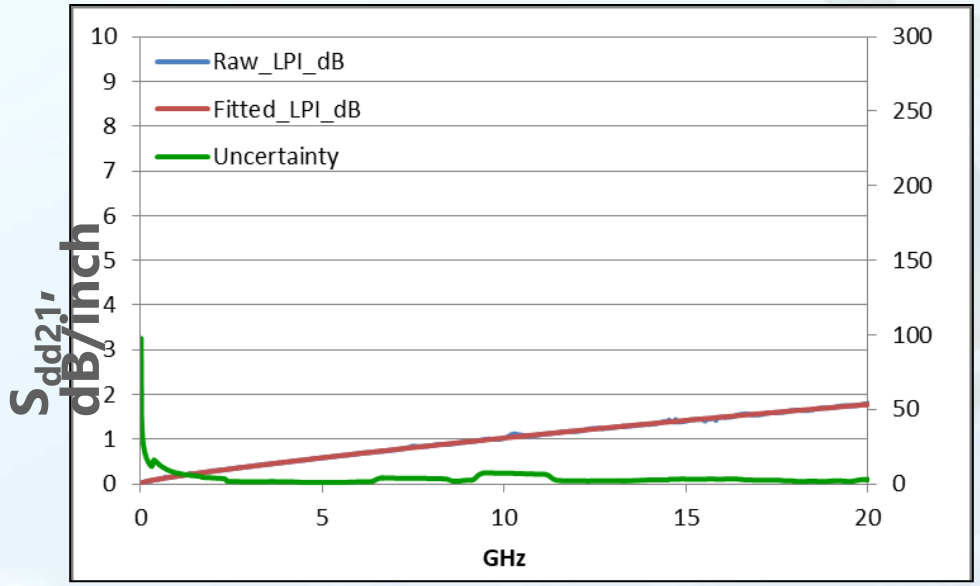


Source: Test Method 2.5.5.14, Measuring High Frequency Signal Loss and Propagation on Printed Boards with Frequency Domain Methods, IPC-D24D

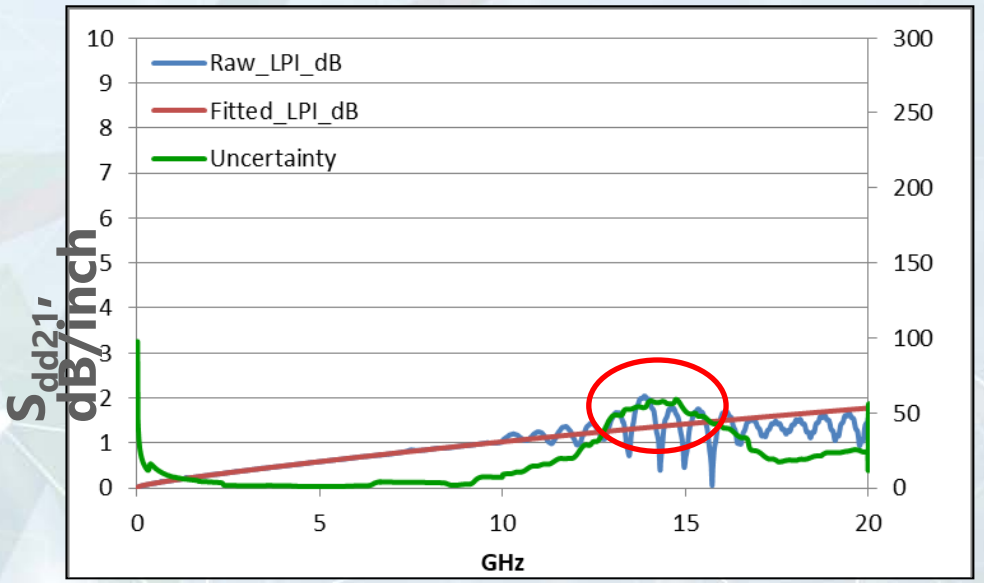
Measurement Quality Check

Uncertainty Check<20%

Uncertainty Check<20%



Uncertainty Check>20%



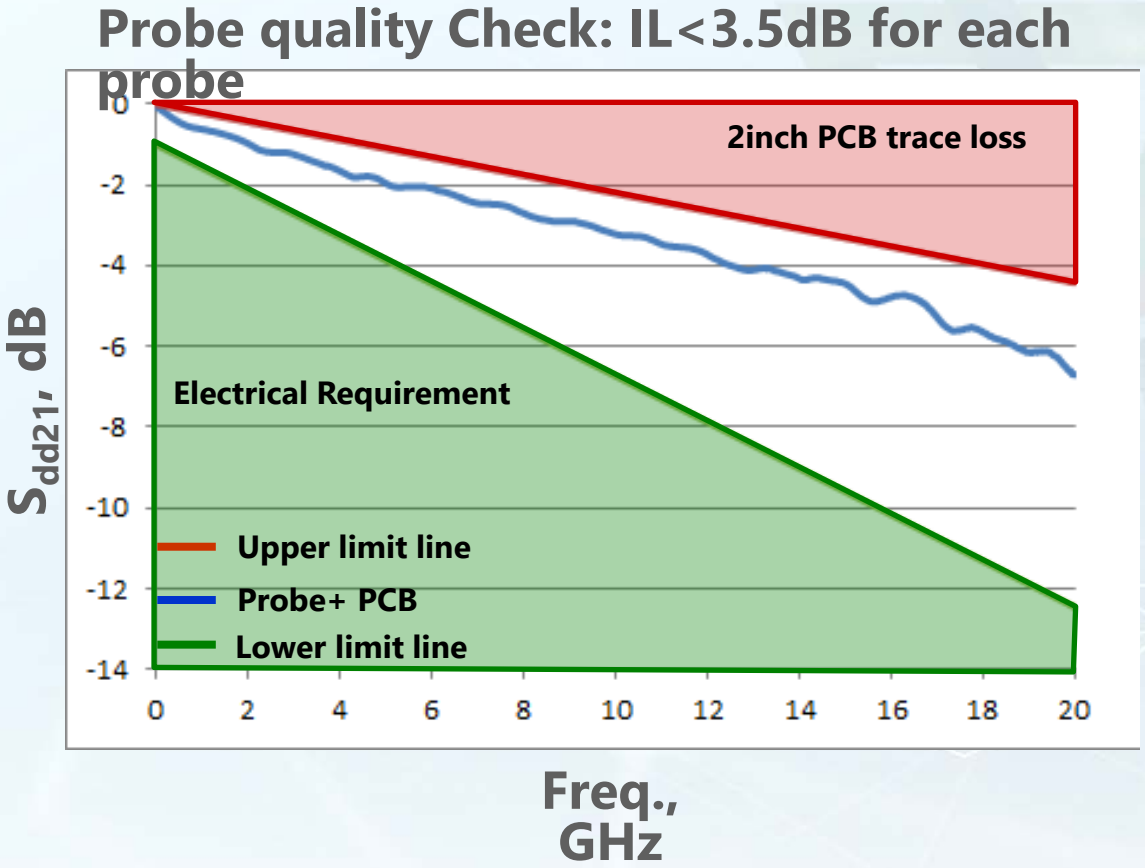
Sources of "Glitches" in Measured Data

1. Manufacturing variation
2. Quality of probes & fixture
3. De-embedding algorithm

Source: Test Method 2.5.5.14, Measuring High Frequency Signal Loss and Propagation on Printed Boards with Frequency Domain Methods, IPC-D24D

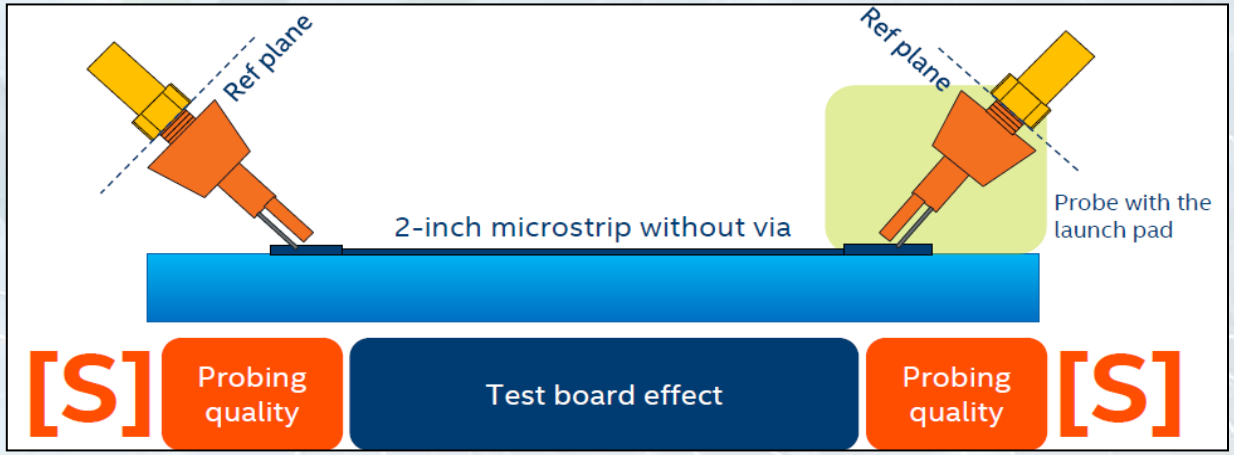
Measurement Quality Check

Probe quality check: IL<3.5dB for each probe @20GHz



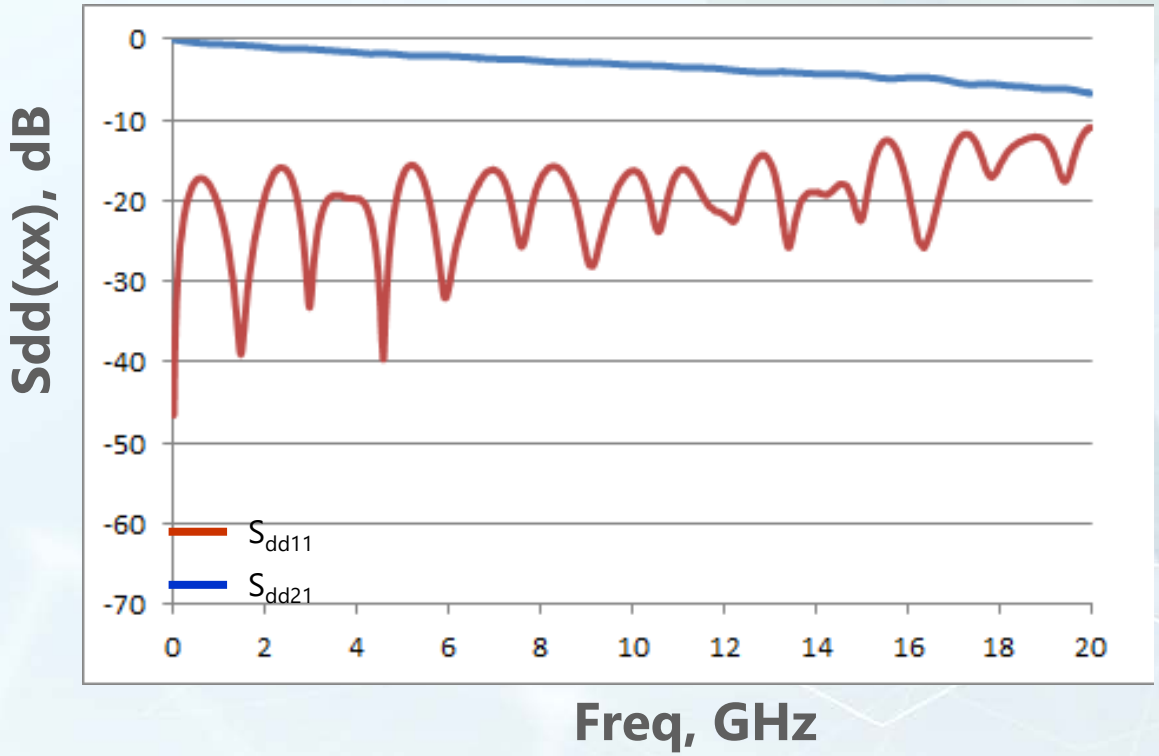
Electrical Requirement

3.5dB at 20GHz X 2 probes + 2inch x 2.5dB/ inch at 20GHz

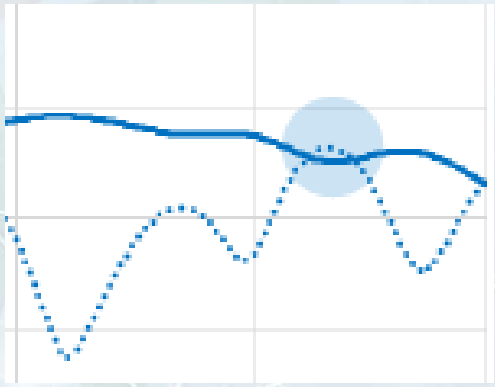


Measurement Quality Check

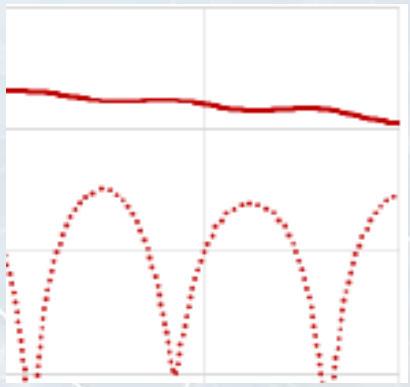
- **Cross over check: IL and RL don't cross over**



Cross over



Non-Cross over



Source: Test Method 2.5.5.14, Measuring High Frequency Signal Loss and Propagation on Printed Boards with Frequency Domain Methods, IPC-D24D

Repeatability Check

L1	4GHz	8GHz	12.89GHz
T1	0.491	0.858	1.261
T2	0.492	0.858	1.260
T3	0.492	0.860	1.263
T4	0.492	0.858	1.261
T5	0.491	0.858	1.261
T6	0.492	0.859	1.262
T7	0.490	0.858	1.261
T8	0.489	0.856	1.259
T9	0.490	0.858	1.261
T10	0.491	0.858	1.261
σ	0.001	0.001	0.001
pass/fail	pass	pass	pass

- **At least 10 measurements conducted to ensure repeatability (probing setup quality)**

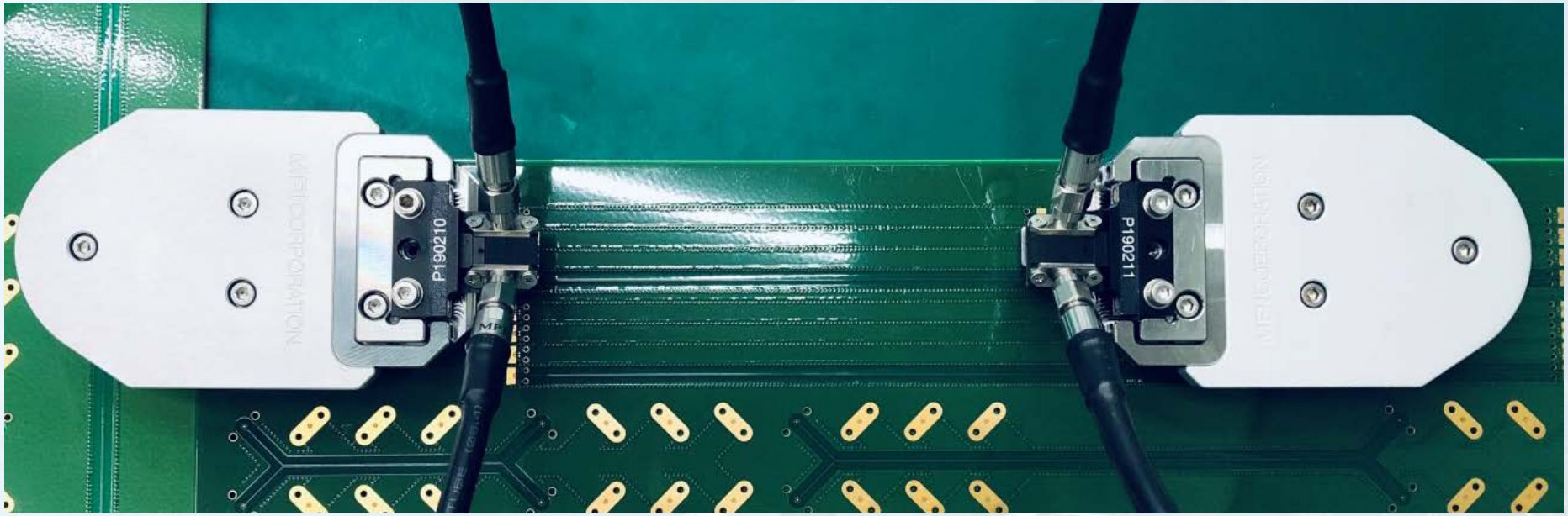
- **Standard deviation specification:**
  - **<0.015dB@4GHz**
  - **<0.02dB@8GHz**
  - **<0.025dB@12.89GHz**

Overview

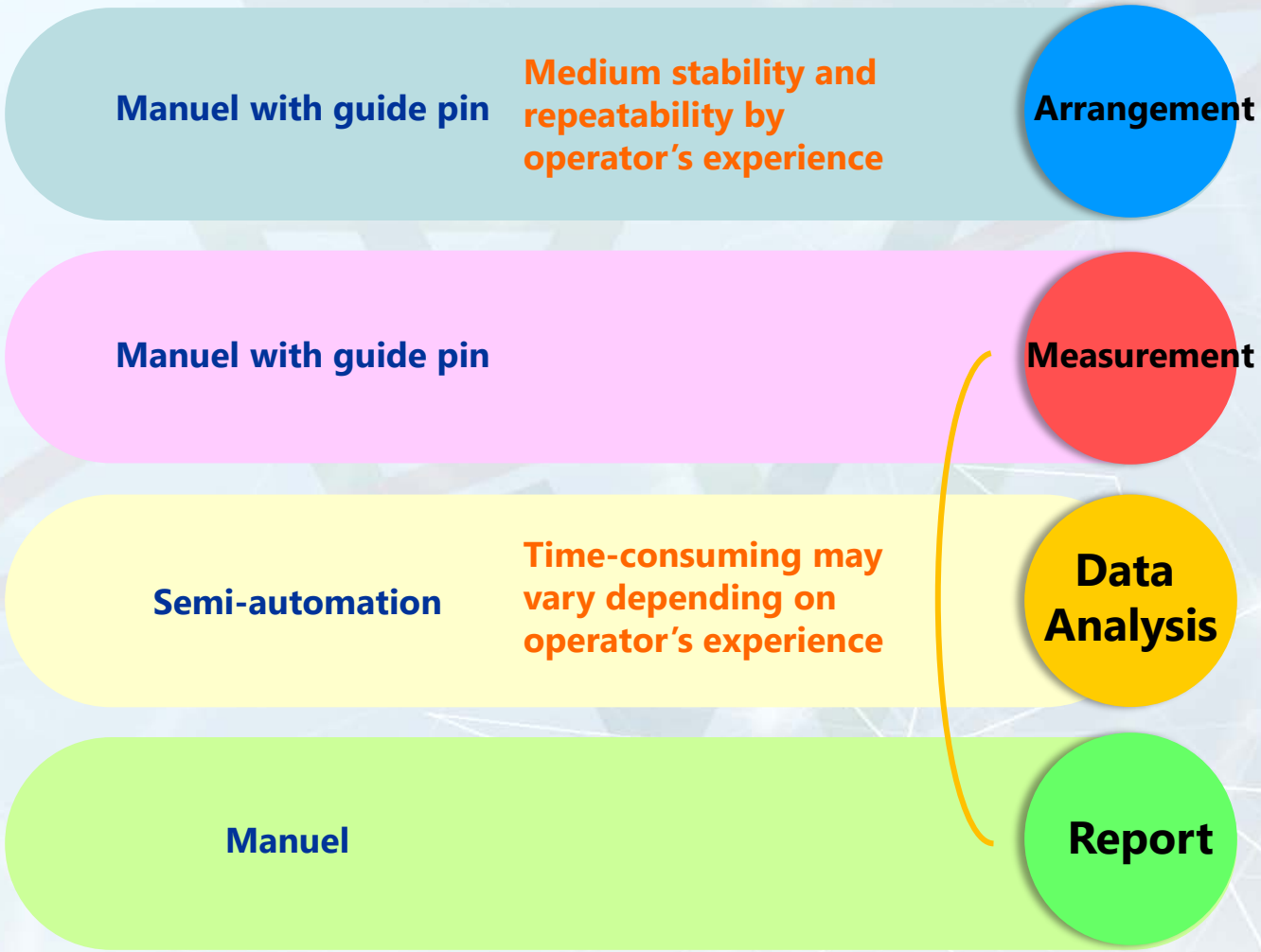
- Background
- Intel's Delta-L Algorithm
- Bottleneck of Handheld Probing Setup
  - Measurement Method
  - Handheld Probing Process
  - Bottleneck of Handheld Probing Setup
- Solution for Stability, Repeatability and Less Time Consuming
- Summary & Future Work

Measurement Method

Handheld probing is the commonest way for insertion loss of PCB.

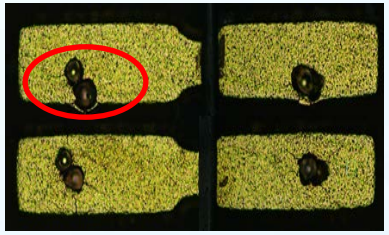


Handheld Probing Process

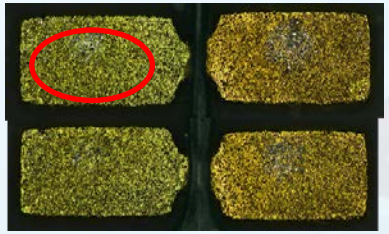


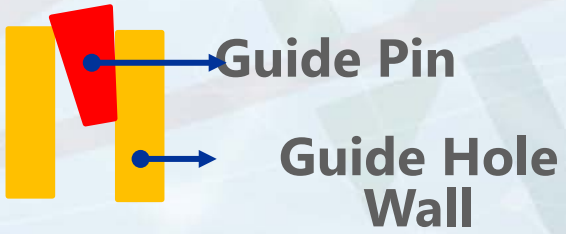
Bottleneck of Handheld Probing Setup

1. Touching offset

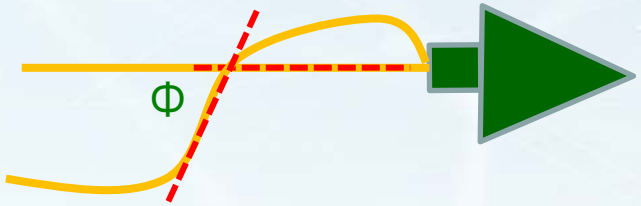


2. Bad contact condition (e.g. no probe marks)



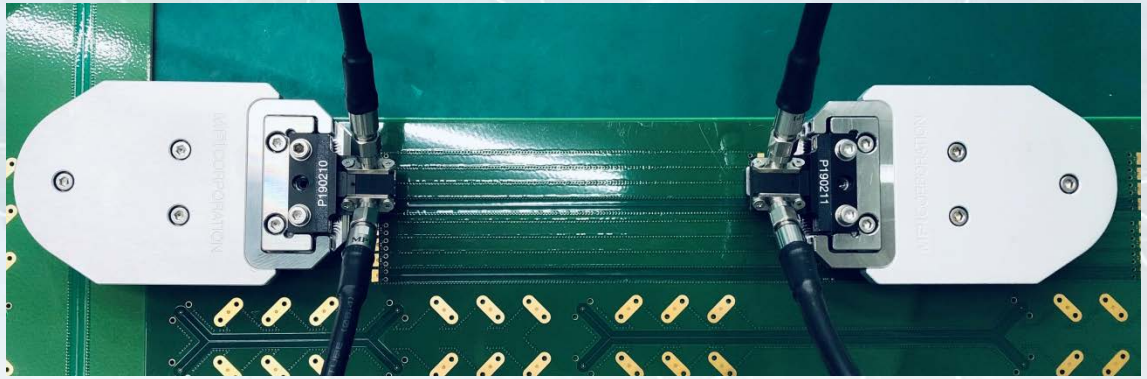


3. RF test cable repeatability



4. Time consuming

- Pad Arrangement Setting
- Measurement Data Saving
- Data Analysis
- Report



Overview

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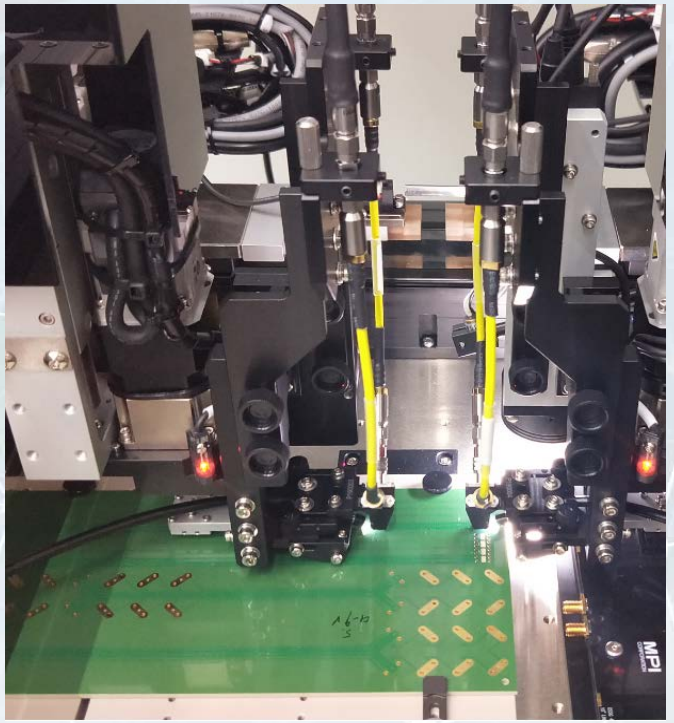
- Intel's Delta-L Algorithm
- Bottleneck of Handheld Probing Setup
- Solution for Stability, Repeatability and Less Time Consuming
  - Semi-automation Delta-L measurement system
  - Comparison between Handheld and Semi-automation
  - Result - Measurement Time
  - Result - Repeatability
- Summary & Future Work

Semi-automation Delta-L measurement system

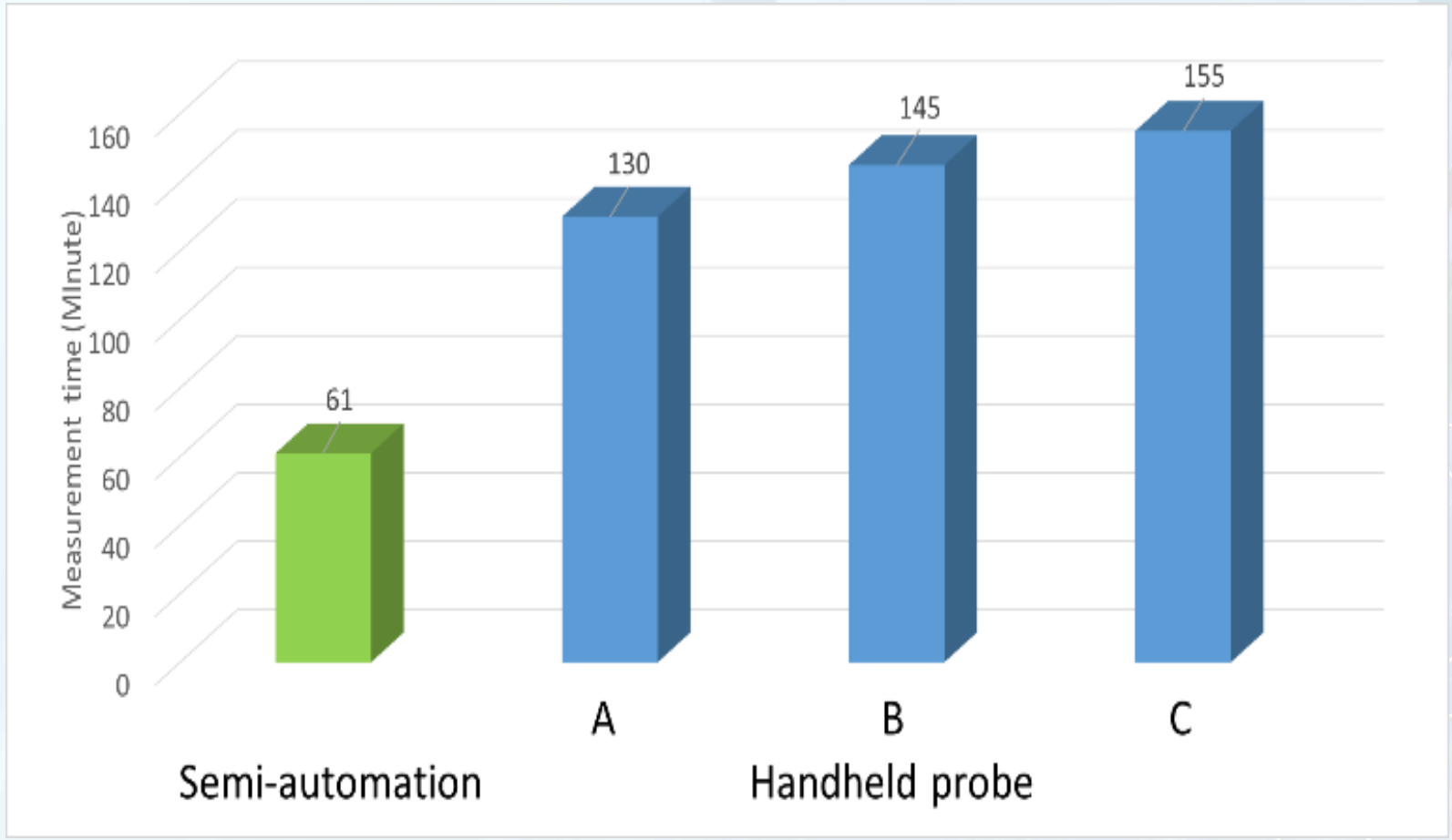
Automation can significantly improve stability, repeatability and time consumption over handheld operations

- **Enter, MPI's Semi-automatic Delta-L Solution:**



Handheld		Semi-automation	
Manuel with guide pin	Arrangement	Image Setting Gerber import coordinate input	User friendly and efficient setup process
Manuel with guide pin	Measurement	Optical system X, Y, Z, θ precision systems Cable fixture	Good stability Repeatability
Semi-automation	Data Analysis	Auto-saving raw data Auto-executing Delta L	Time Saving
Manuel	Report	Auto-generator	Customized Report

Result - Measurement Time



A **130 minutes**
Most experienced

B **145 minutes**

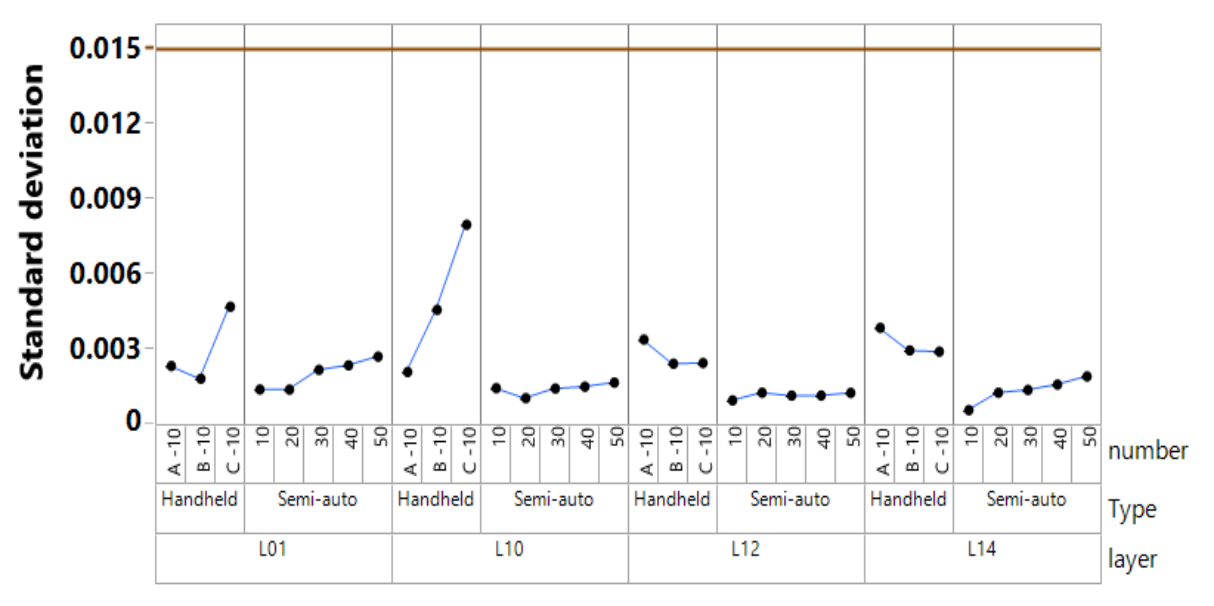
C **155 minutes**
Beginner

The Semi-Automation Delta-L solution took half the time to complete the same measurements when compared to handheld operation.

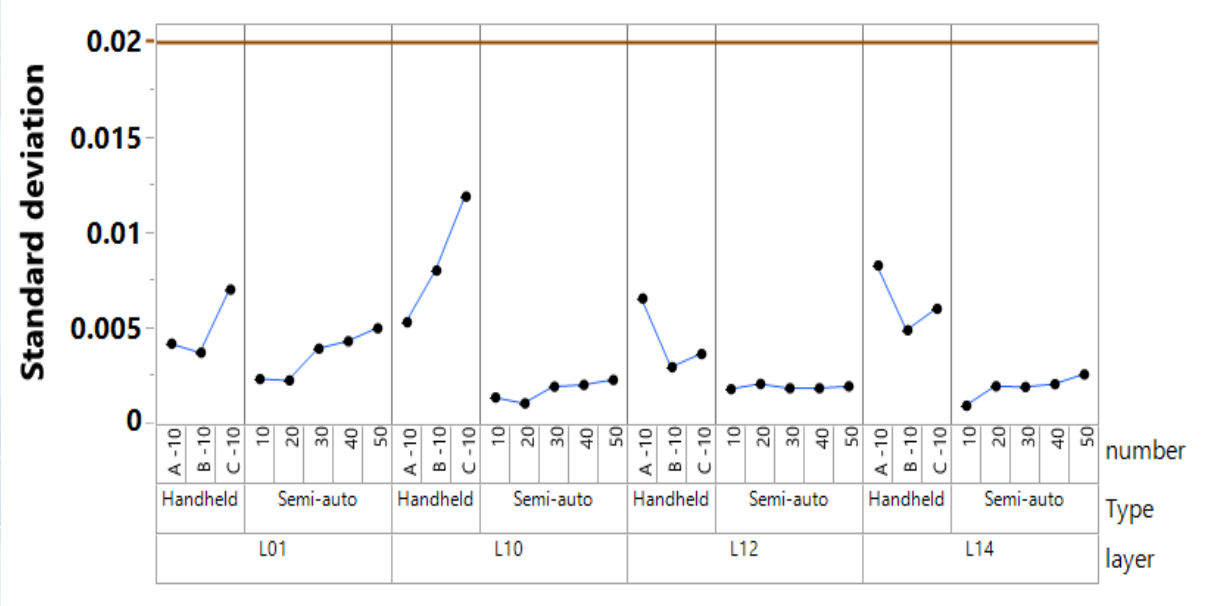
Result - Repeatability

The repeatability of semi-automated Delta-L is greater than handheld results with improved standard deviation from different operators.

4GHz



8GHz



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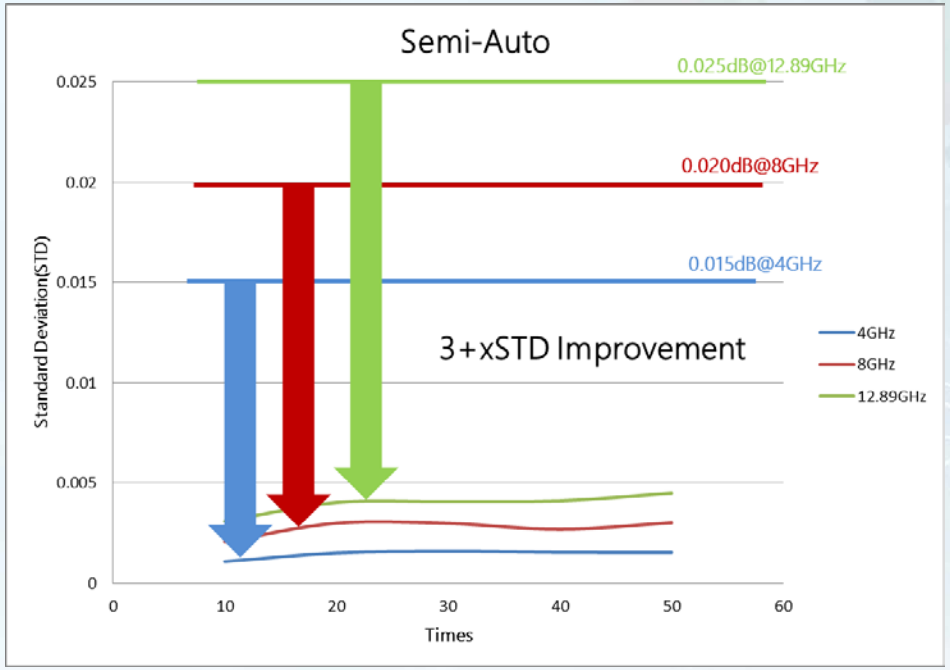
  - Summary
  - Future Work

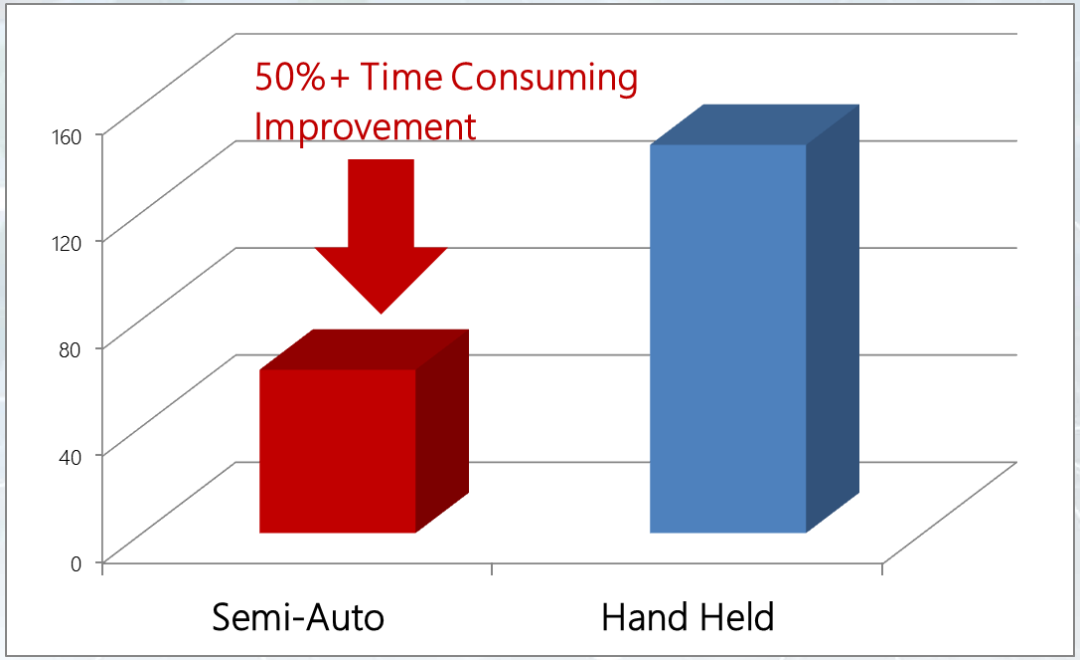
Summary

Semi-automation Delta-L Solution

To have more accurate and robust PCB loss characterization.

- ✓ **Enhances the measurement repeatability(3+x STD Improvement).**
- ✓ **High frequency characterization(20+GHz)**
- ✓ **Reduces more than half of measurement resource(>50% +Time Consuming Improvement).**





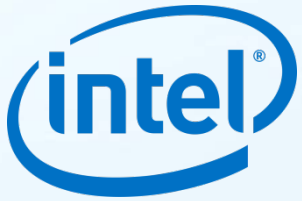
Future Work

To develop an advanced metrology for PCB loss characterization at higher frequency since computing market always needs more throughput.

Years	2020		202X	
Inspection Item	Application	Data Rate	Application	Data Rate
Insertion Loss	PCIe 3.0	8GT/s	PCIe 5.0	32GT/s
	PCIe 4.0	16GT/s	PCIe 6.0	XXGT/s
	Ethernet	25GT/s		
Others	NA		SI/PI study	

Acknowledgements

Special Thanks to:



Jimmy Hsu

Raymond Chuang Steven Wu Christine Liu
Mark Sun Samson Tang Jason Ho Gary Tsai Derrick

Monica Liu William Lin Wayne Lin Ed Chang
Alex Yang Kenny Huang Johnny Hsieh

Any Questions?