A Comprehensive Study on Improving Probe Card Transmission Lines for Effective High-Frequency Wafer-Level Testing

POSTER #20

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Alessia Galli, Dario Villa
(Technoprobe)

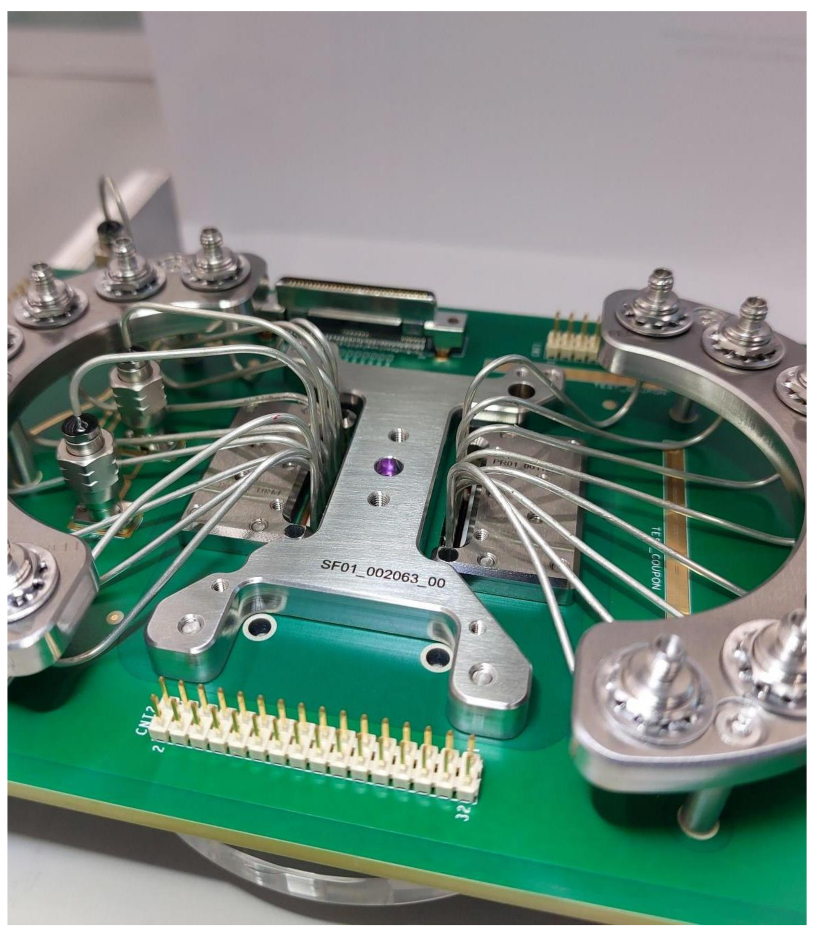
TECHNOPROBE

Introduction

- Semiconductor manufacturers are increasingly focused on researching technical solutions for testing RF electronic devices directly on silicon wafers.

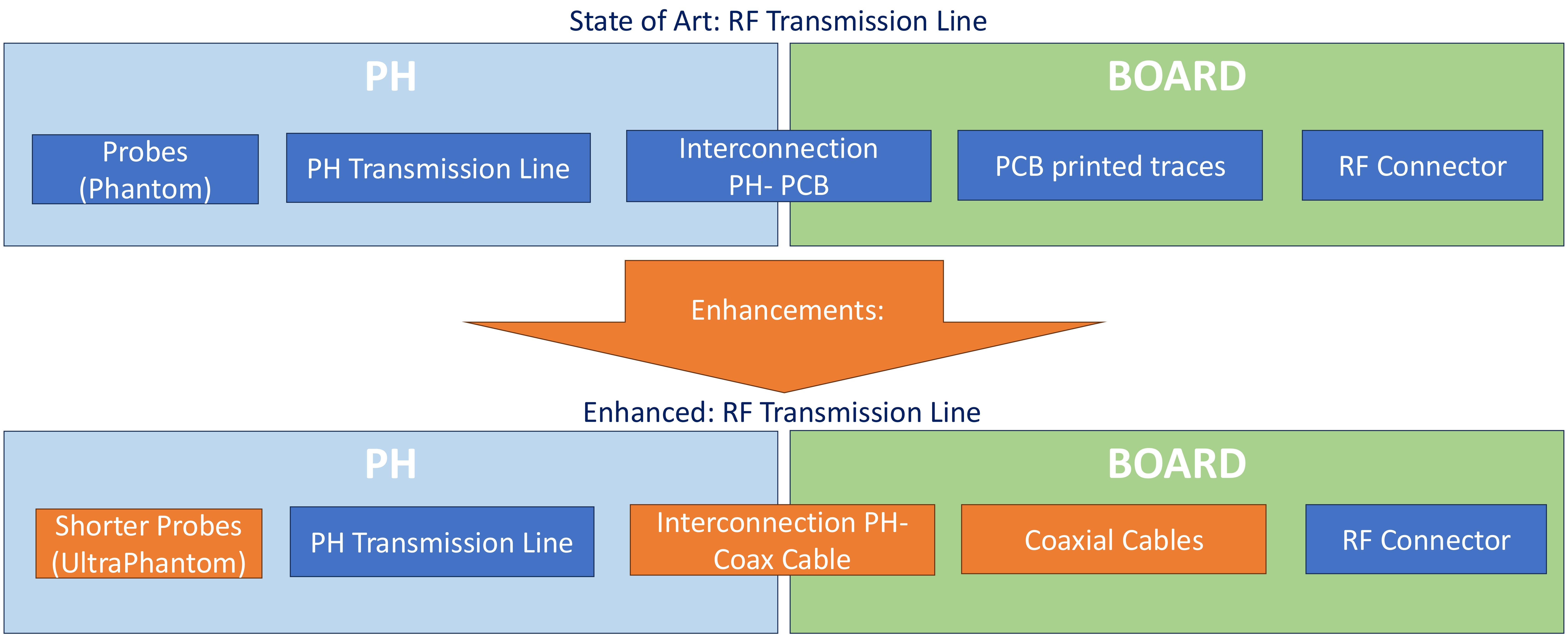
- One main challenge is about establishing an interconnection between the device and the tester through a controlled impedance transmission line with minimal losses.

- This study presents an innovative approach to the problem: by surpassing the typical design of Probe Cards, it proposes alternative solutions which are validated through simulations and following experimental tests.

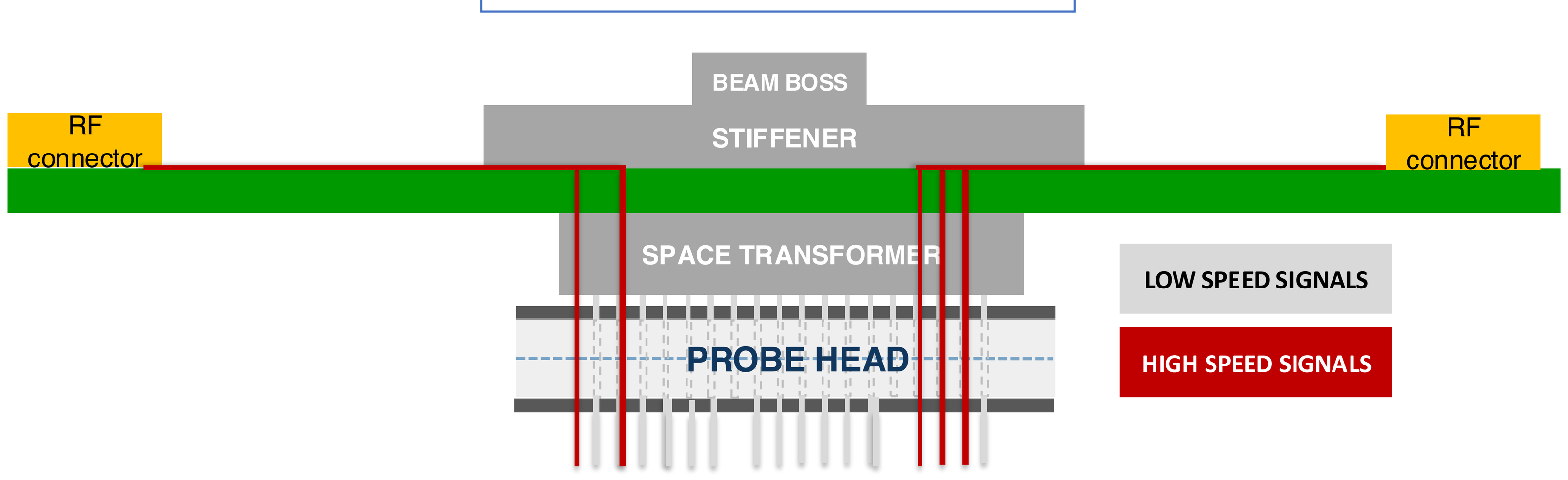


RF challenges and Probe Cards

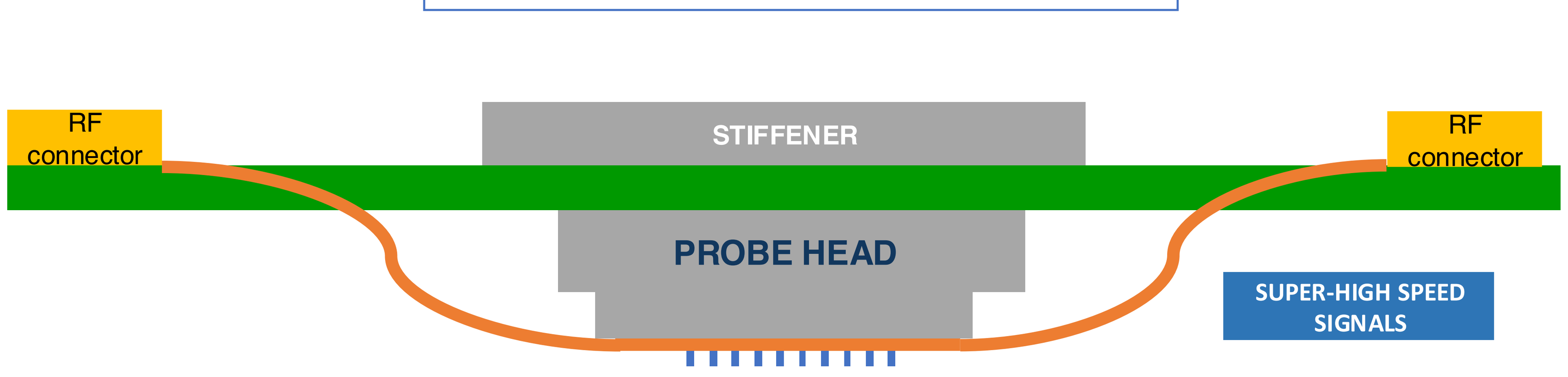
- For frequencies exceeding 70 GHz, the transmission of RF signals is even more challenging. Consequently, each element of the RF transmission line must be deeply studied and improved.



Phantom Probe Card



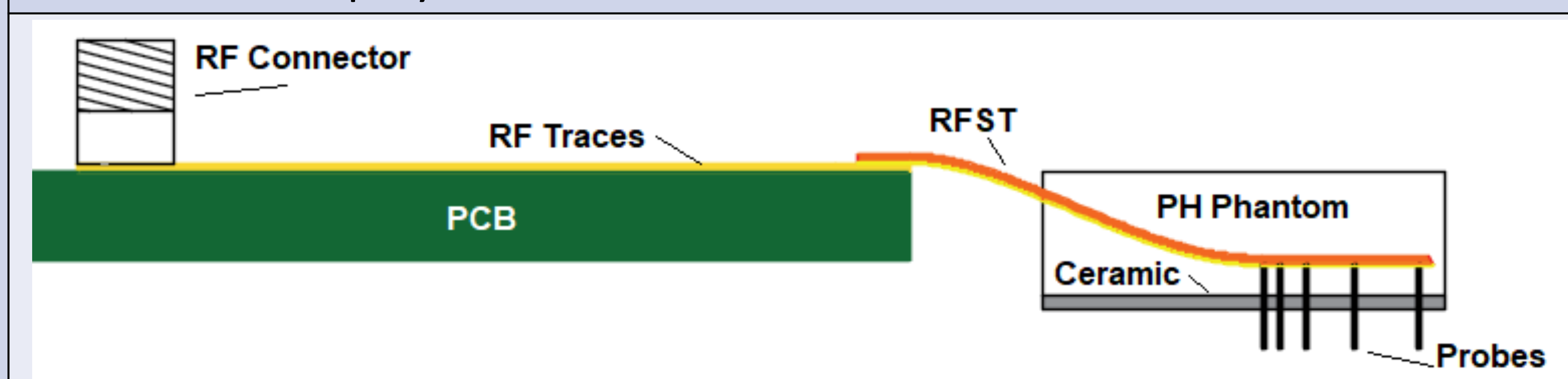
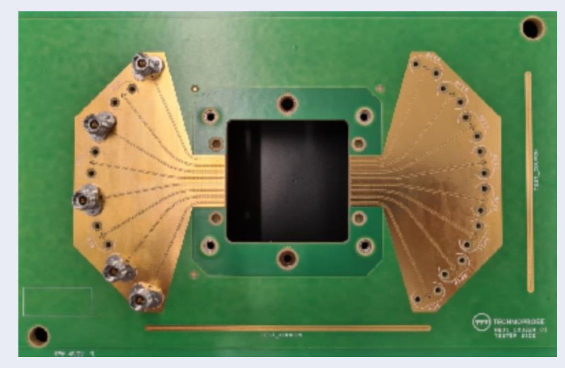
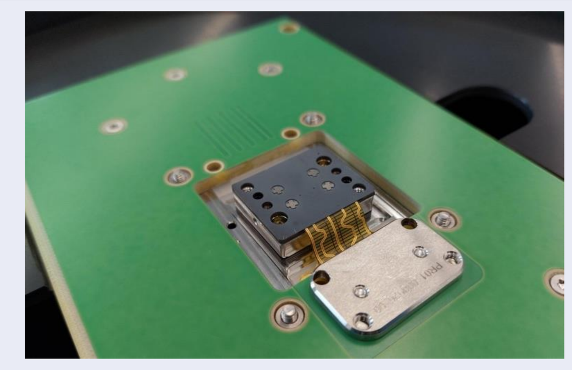
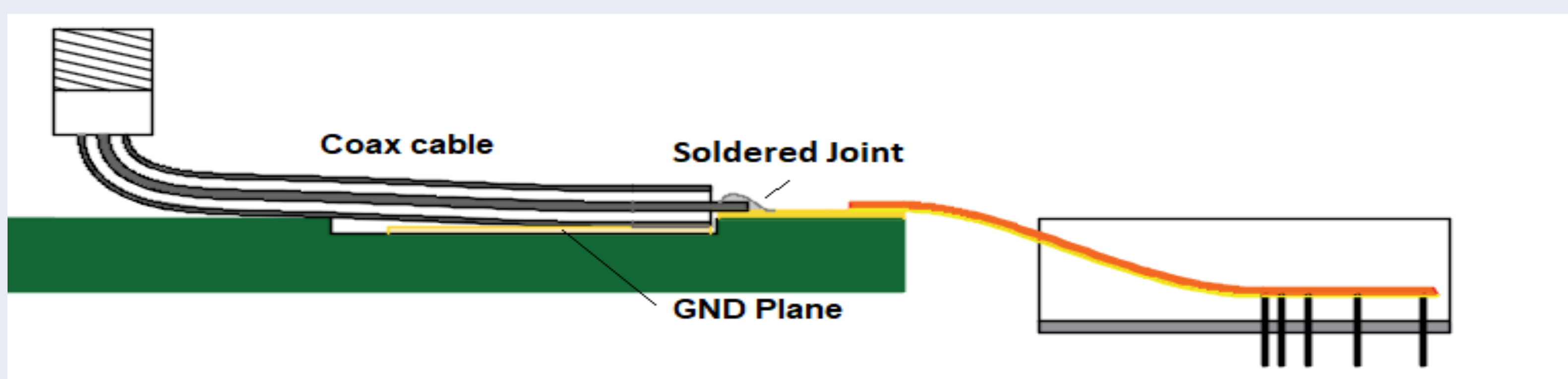
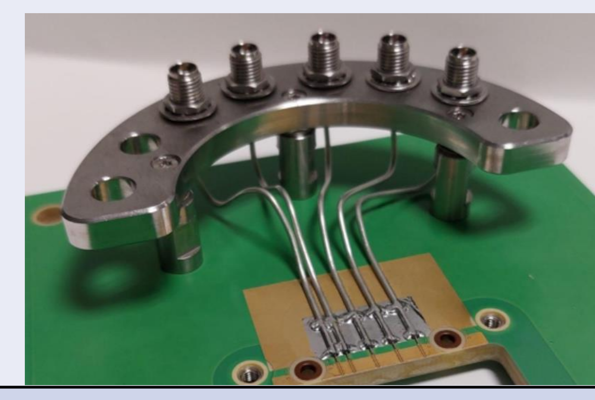
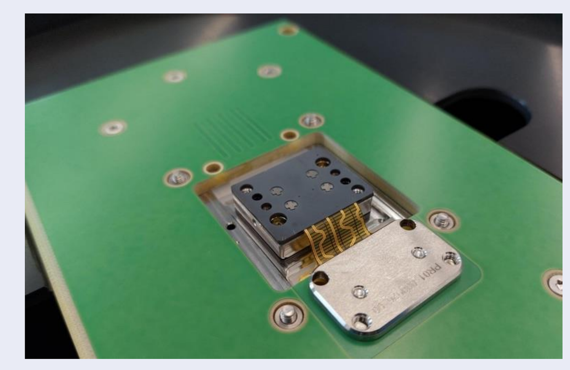
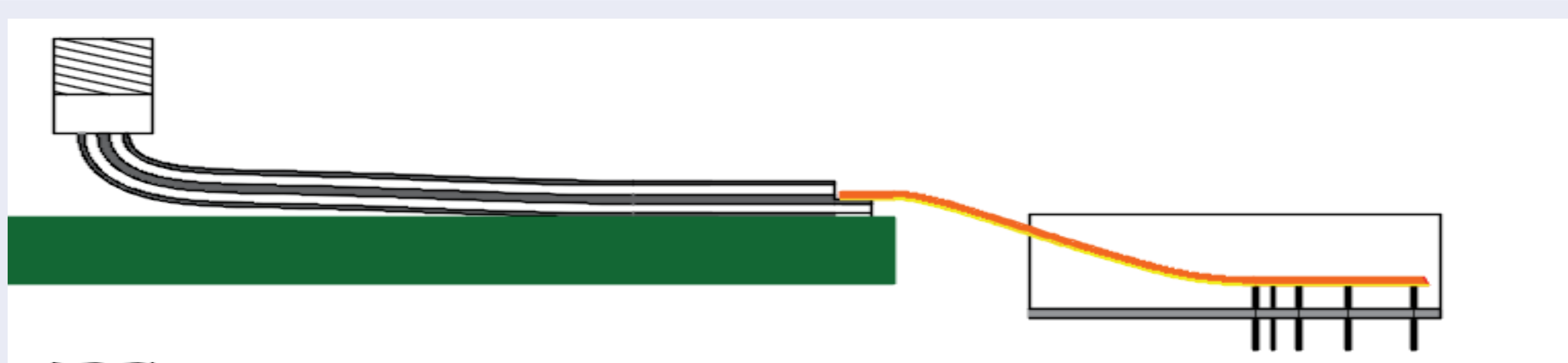
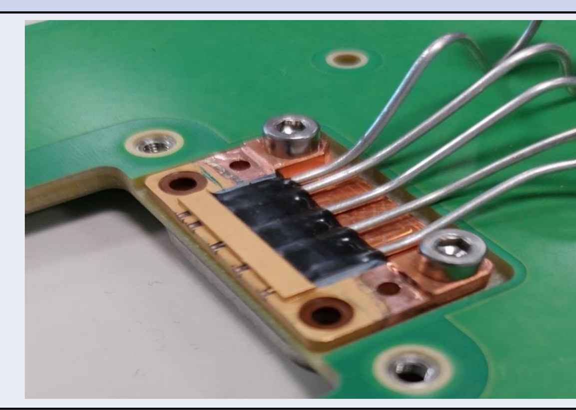
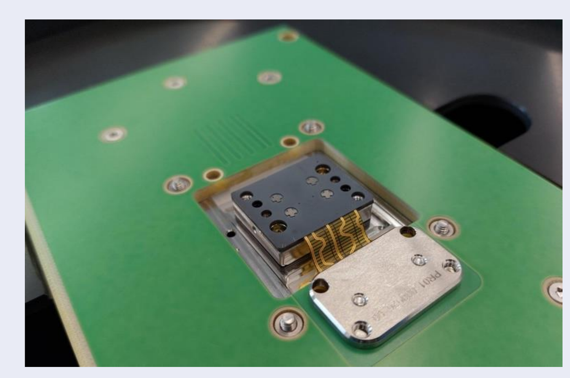
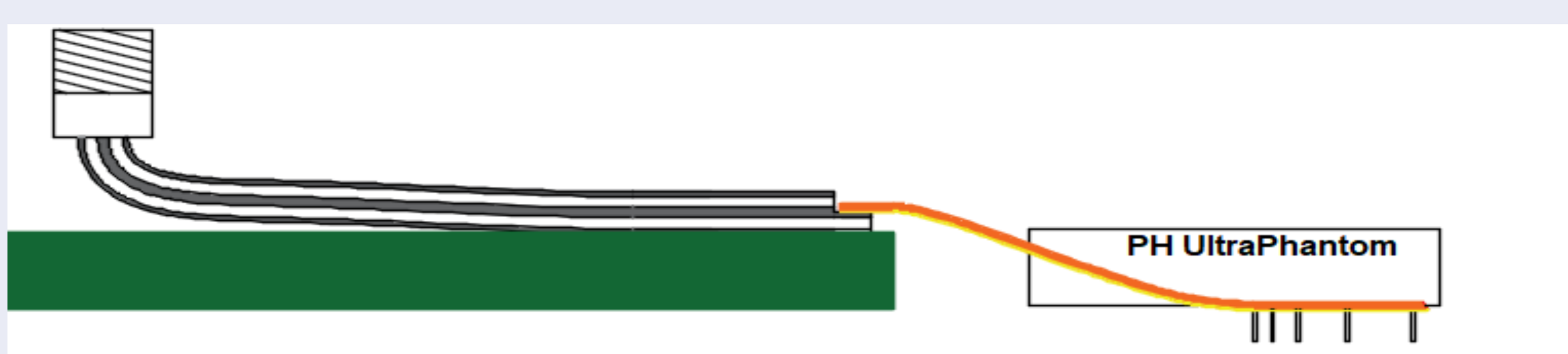
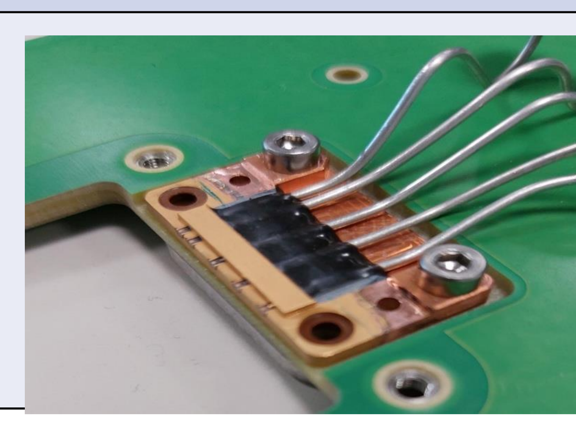
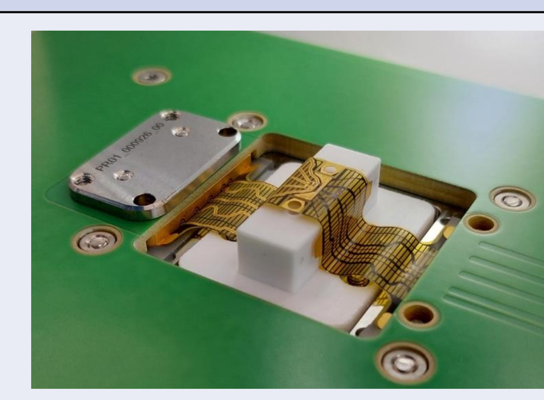
UltraPhantom Probe Card



Case Studies

- To compare the State of Art of the board and the correlated interconnection solutions with two enhanced options, a PH with RF Phantom probes was fabricated and sequentially mounted on each test sample.

- The most effective solution has been also evaluated using UltraPhantom probes. This innovative technology eliminates the need for ceramics and utilizes shorter probes compared to traditional phantom designs, aiming to reduce probe's inductance and CrossTalk.

<table>
<tr><th>#</th><th>Probe Card Structure</th><th>Board</th><th>PH</th></tr>
<tr><td rowspan="2">A</td><td>• Dominant solution in the PC market.
• Dielectric employed: PTFE</td><td>Standard Board</td><td>Phantom PH</td></tr>
<tr><td>
</td><td></td><td></td></tr>
<tr><td rowspan="2">B</td><td>• Extremely short PCB traces
• RFST is connected via an electromechanical contact at the opposite end.</td><td>Soldered Board</td><td>Phantom PH</td></tr>
<tr><td>
</td><td></td><td></td></tr>
<tr><td rowspan="2">C</td><td>• Traces on the PCB are entirely removed
• One coax cable's end is milled to provide a flat surface for the RFST pads within the interconnection area.</td><td>Milled Board</td><td>Phantom PH</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="2">D</td><td>• Traces on the PCB are entirely removed
• UltraPhantom PH</td><td>Milled Board</td><td>UltraPhantom PH</td></tr>
<tr><td>
</td><td></td><td></td></tr>
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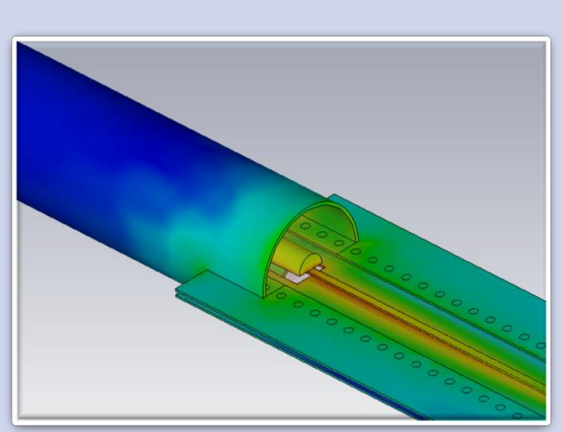
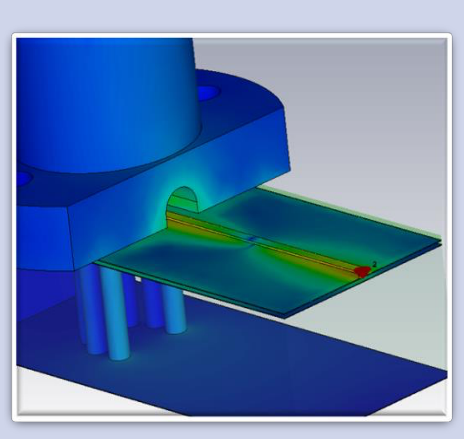
3D EM simulations Vs Experimental Setup

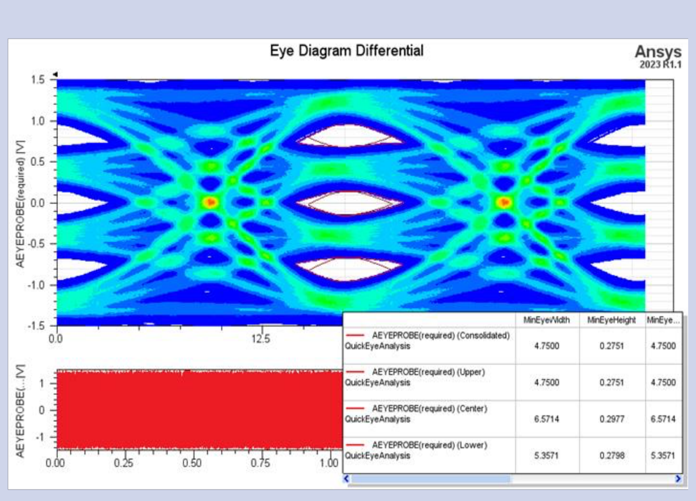
- To identify the most effective design for the three boards and the two PH, extensive 3D EM simulations of performance have been conducted.
- EM simulations are consequently compared to experimental test data, to validate the theoretical model together with the test setup.

3D EM simulation

- Ansys HFSS, CST Microwave Studio (Full 3D FEM EM software);







Experimental Data Collection

STEP 1: **Calibration**

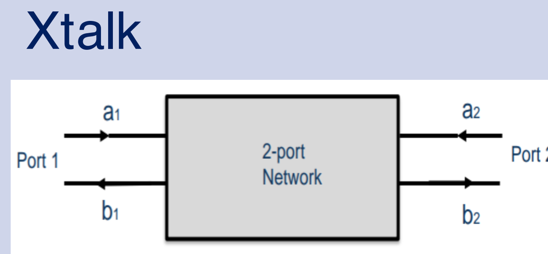
- Two calibration sets with SOL-SOLT (Short, Open, Load, Thru) technique were collected on two distinct reference planes
  - at the end of VNA's cable;
  - after the calibration substrate;

STEP 2: **Data Collection**

- VectorStar™ Vector Network Analyzer (VNA) was employed

STEP 3: **S-parameters Extraction**

- Insertion loss
- Return loss
- Xtalk



$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

Comparison

Data Type	Board Type	PH Type	Colour
Measure	STD	Phantom	
Simulation	STD	Phantom	

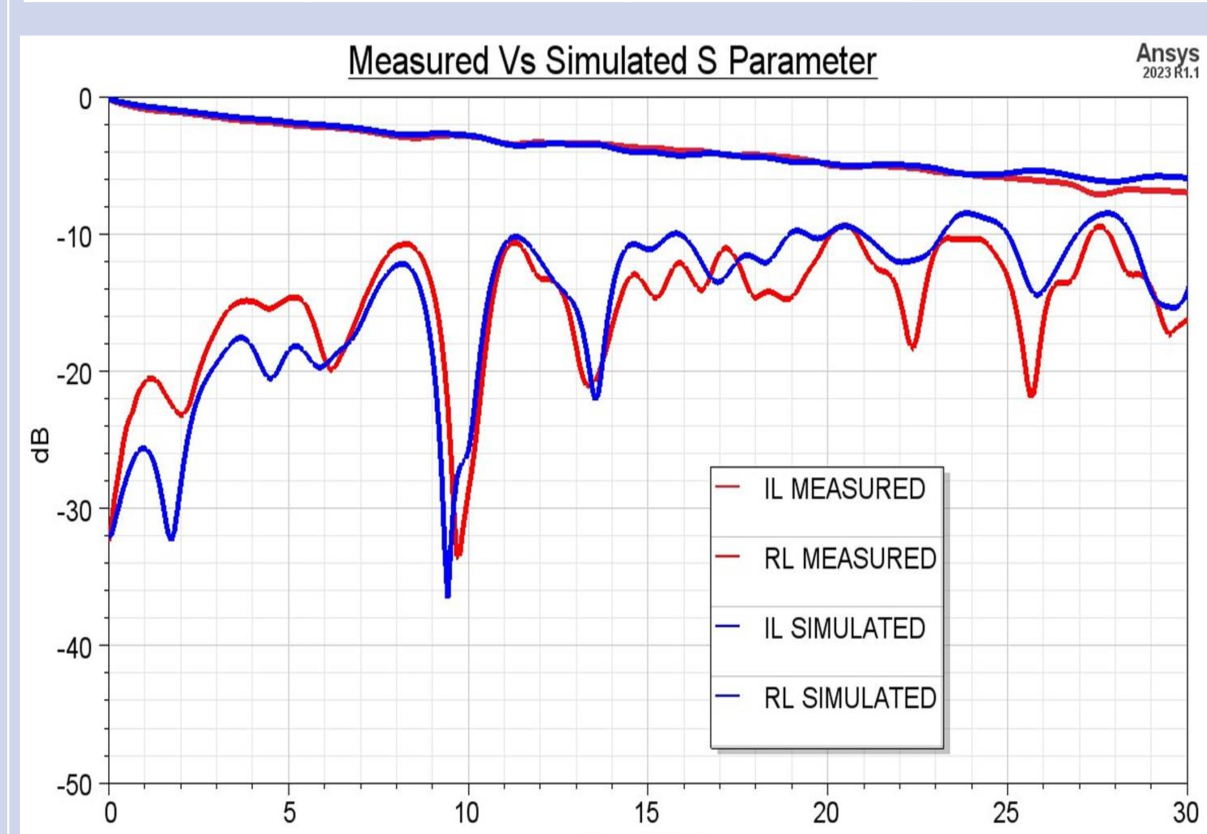


Fig 1: Match between measured (red line) and simulated (blue line) data of IL and RL for #A: STD BOARD and Phantom PH

Results up to 30 GHz

- The results of the initial test , presented in Fig. 2, involved a comparison of Insertion Loss (IL) and Return Loss (RL) measurements at probe points for the three Probe Cards: Standard board, Soldered and Milled Coax board, all utilizing the same Phantom Probe Head:
  - 2 dB range between STD and Coax Board solutions along the entire bandwidth.
  - 8 dB range between STD and Milled Coax Board solution in the <10GHz band.

Fig 2: Insertion Loss, Return Loss at Connector and Needle side's measures of Phantom Probe Head on Standard Board (red line), Soldered Coax Board (blue line) and Milled Coax Board (green line).

- The comparison between Phantom and UltraPhantom Probe Heads was conducted, as it is shown in Fig 3. Results in terms of IL and RL at probes are presented, showing similar outcomes, as anticipated by internal simulations.
  - Probe length difference: 300µm
  - Probe inductance difference: 0.5 nH.

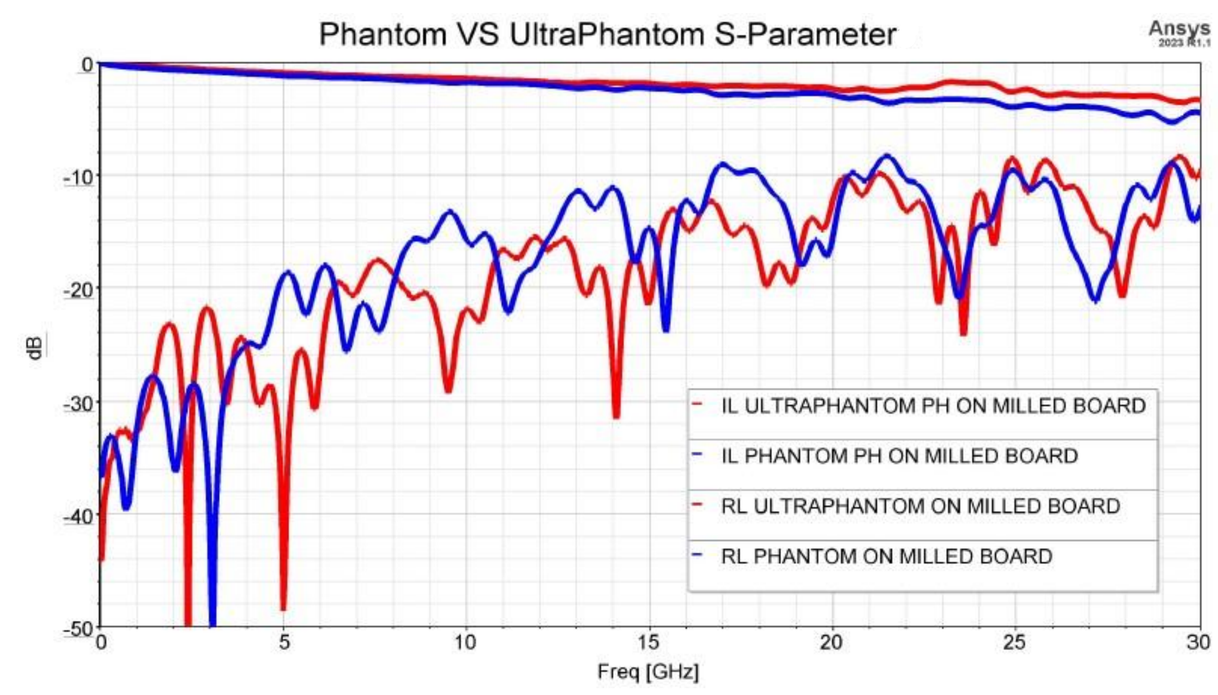


Fig 3: Comparison of Measured data of Insertion Loss and Return Loss between Phantom PC (blue lines) and UltraPhantom one (red lines).

- The comparison of CrossTalk data between Phantom PC and UltraPhantom one is particularly relevant, presented in Fig 4.
- UltraPhantom technology demonstrates better performances compared to Phantom Probe cards by approximately 10 dB across the entire bandwidth.
  - Meticulous attention given to factors contributing to self-inductance during the development of UltraPhantom technology.
  - UltraPhantom Technology is ideal for applications requiring minimal CrossTalk, low self-inductance, and controlled impedance, such as filters, antenna tuners, switches, and similar DUTs.

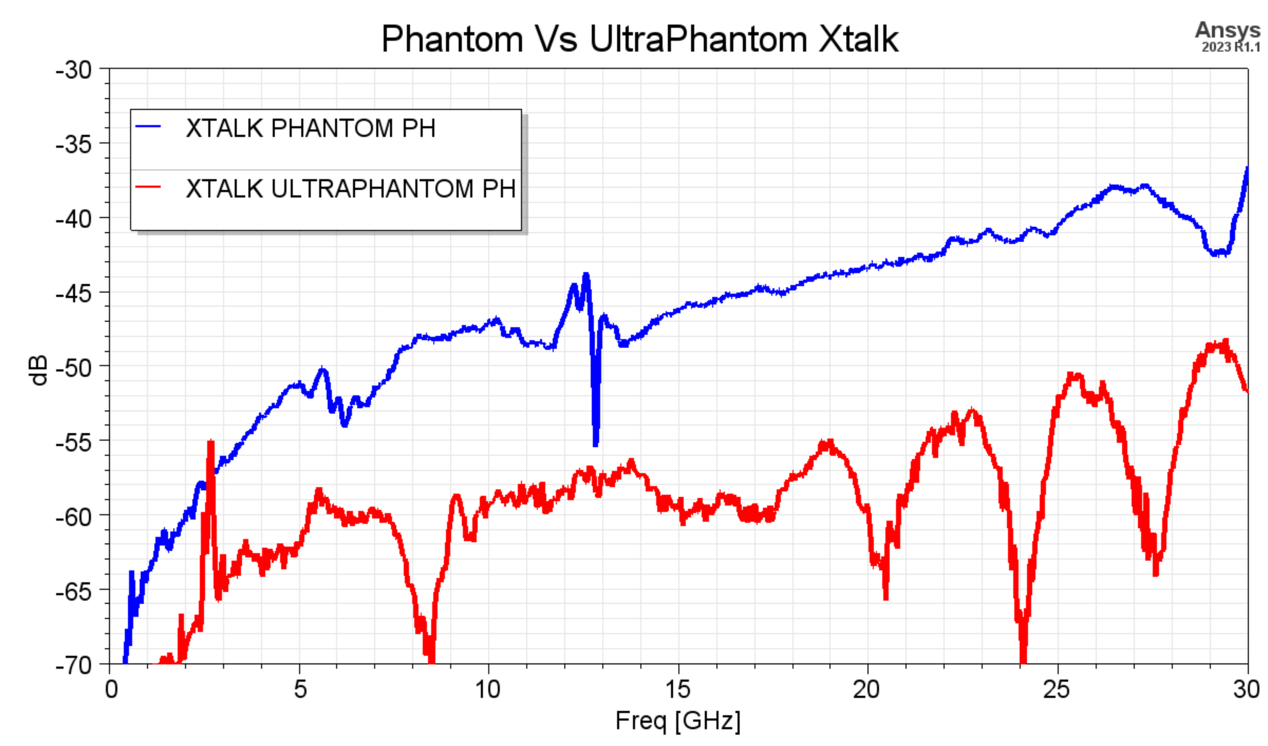
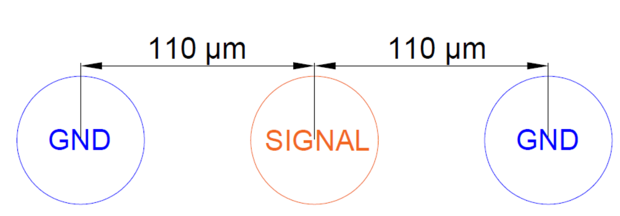


Fig 4: Comparison of Measured data of CrossTalk between Phantom ProbeCard (blue lines) and UltraPhantom one (red lines).

Results up to 150 GHz

- Additional simulations were conducted to analyse the actual RF performance across the entire bandwidth up to 150 GHz in GSG configuration at 100 μm pitch, presented in Fig 5.
- The performance bandwidth of UltraPhantom is significantly shifted towards higher frequencies compared to Phantom technology, making UltraPhantom ideal for application at very high frequencies (> 80 GHz).



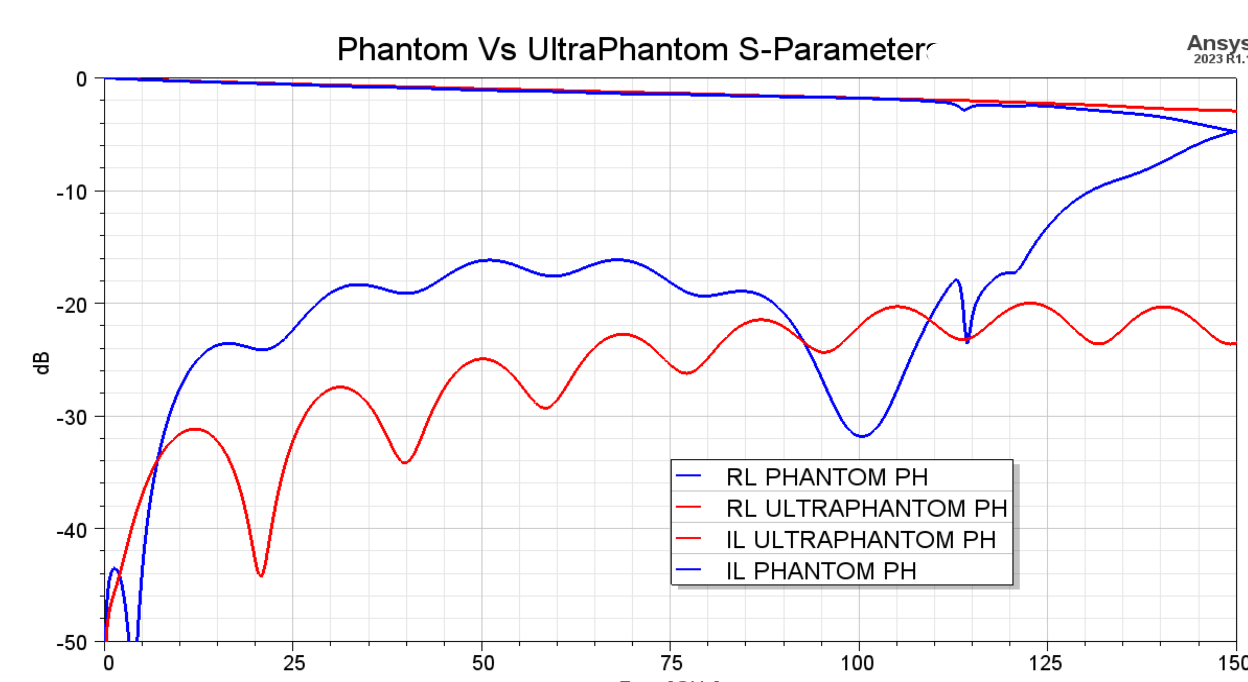


Fig 5: Comparison of Phantom and UltraPhantom simulated data of RL and IL up to 150 GHz.

Conclusions

- This study has explored solutions aimed at enhancing the RF performances of probe cards for effective High-Frequency and Low Inductance wafer level testing.
- The results illustrate that employing coaxial cables (especially when they are directly connected to the RFST), remarkable improvements in terms of insertion loss (IL) and return loss (RL) can be observed.
- The integration of UltraPhantom technology has demonstrated significant progress in addressing challenges related to needle self-inductance and CrossTalk, providing superior performance compared to traditional Phantom probes.
- The promising S-parameter simulations at very high frequencies (up to 150GHz) for UltraPhantom technology will have to be validated through experimental tests, to address the future RF challenges.

Contact information

Alessia Galli:

alessia.galli@technoprobe.com

Dario Villa

dario.villa@technoprobe.com

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