TWENTY-SEVENTH ANNUAL

TestConX™

Archive

DoubleTree by Hilton
Mesa, Arizona
March 1-4, 2026

Effects of copper roughness on high-speed transmission lines.

A reality check – Yay or Nay?

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Mesa, Arizona • March 1–4, 2026

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Contents

- High-speed designs and Simulation/Correlation Importance
- Skin Effect and Copper Roughness
- PCB Fabrication and Affects on Copper Roughness
- Modelling, Simulation, Capturing Roughness profiles
- Summary & Conclusion

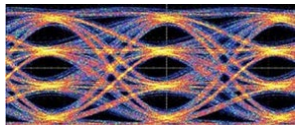
Evolution of Signal Integrity in HS Designs

"Transparent Era"

Mostly under 10 MHz
No SI considerations

Digital to Analog

- SI Becoming Critical
- Back-drills
- Discontinuities
- Modulation

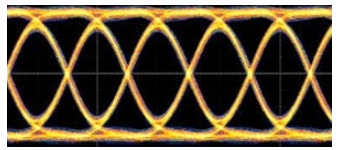


Extremely High Speed

- Full 3DFS Models
- 200Gb+ Bandwidth/CH
- PAM4/6 Modulations
- Cross talk, Phase becomes Critical

SI Emergence

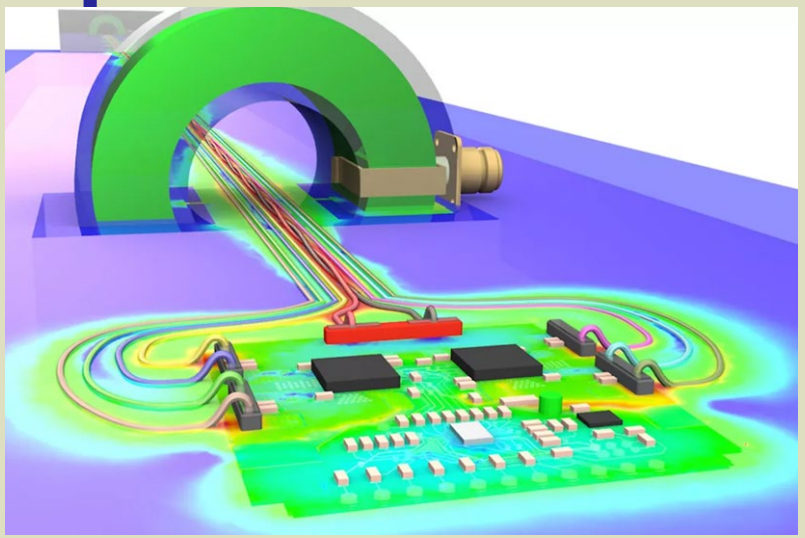
- Clocks reaching 50MHz
- Impedance Control
- Rule of thumb



Modern Transmission

- 2D and 3D Modeling
- Widespread Modulation
- Critical Cross talk and isolation requirements

Simulation And Correlation Importance

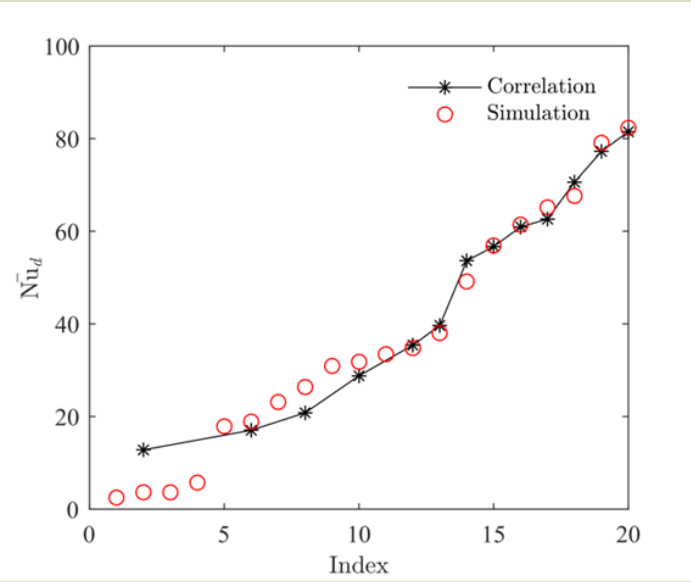


Use of EM simulations

- Capture parasitics
- Predict behavior (S-parameters, impedance, resonance, etc.)
- Optimize/tune design to a target spec

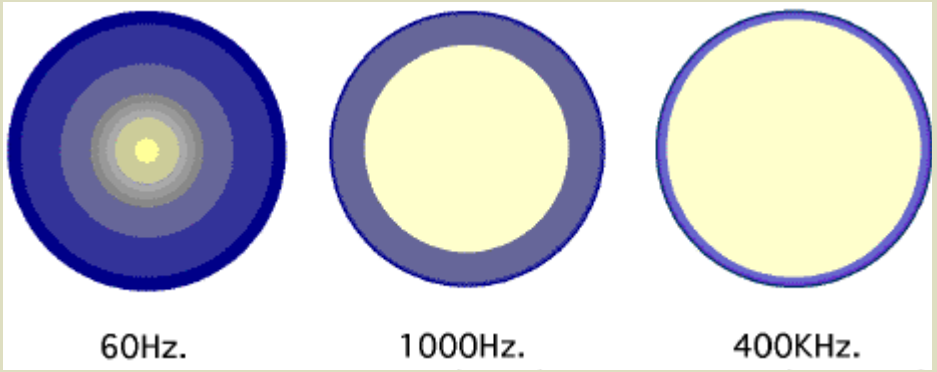
Why is Correlation important?

- Validate simulation
- Debug anomalies and re-calibrate assumptions (printed/manufactured features, Dk, component performance, etc.)
- Future design proofing

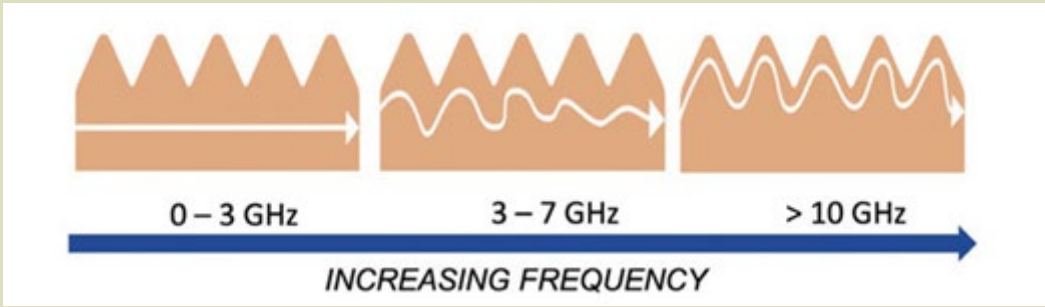


Introduction To Skin Effect And Copper Roughness

- Skin Effect
  - Current density distribution
  - Increased losses
  - Impacts on impedance & phase



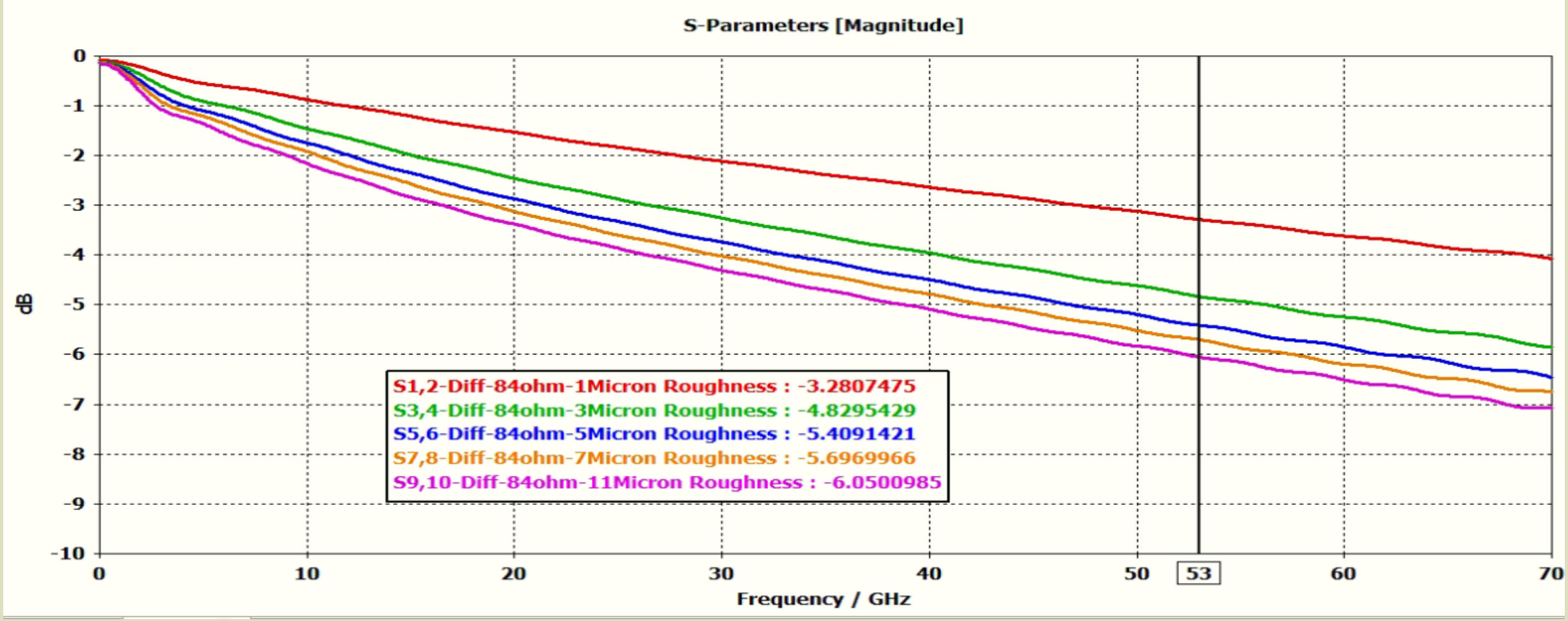
- PCB copper roughness profiles
  - Microscopic peaks & valleys
  - Conductor loss



Copper Roughness Specifications

Foil Type	Ra (um)	Rz (um)	Typical Application
STD / HTE	0.3 –1.5	5.0 – 10.0	Low cost, high peel strength
RTF	0.6 – 0.8	2.0 – 6.0	General high-speed (up to 25 Gbps)
VLP	≤ 0.55	1.5 – 3.0	25–56 Gbps signal integrity
HVLP	≤ 0.4	1.0 – 2.0	Ultra-high speed (56G/112G+), 5G
Rolled-Annealed (RA)	0.15 – 0.40	0.25 – 0.5	Flexible PCBs, microwave circuits

Actual Roughness Model Vs. Input Value Correlation



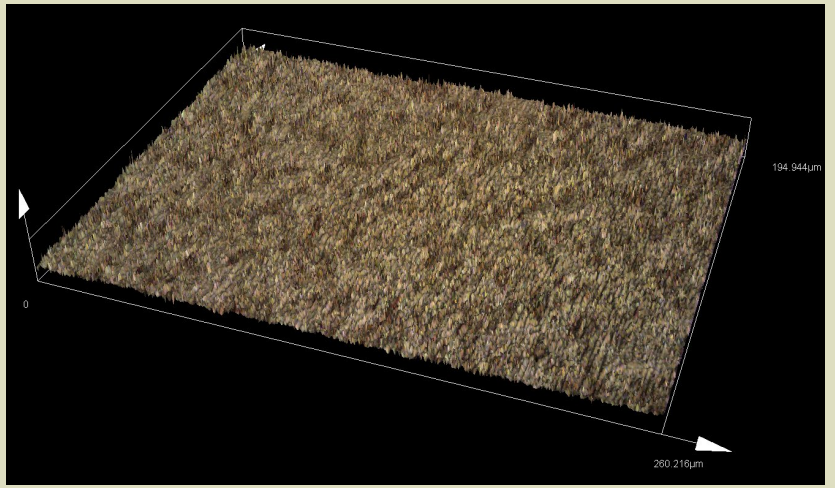
Roughness Analysis on Copper clads

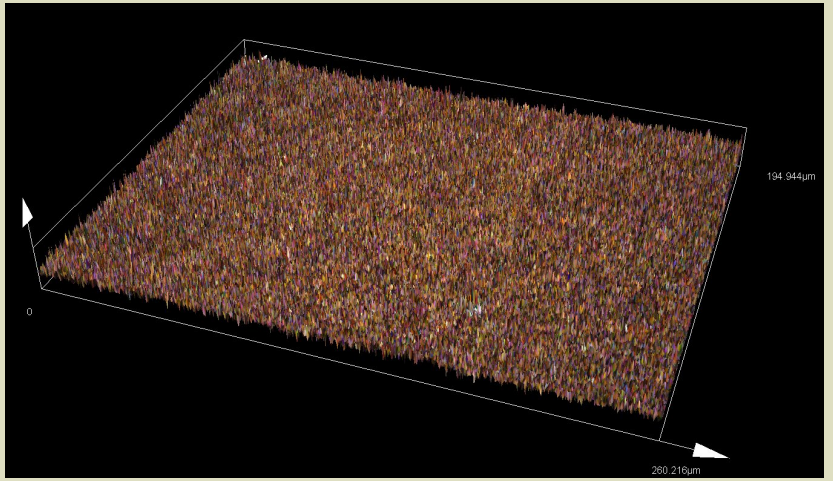
Measurement Techniques

- **Contact (Stylus) Profilometry**
  - Low-cost
  - Long Linear Scans
  - Limited Resolution
- **Non-Contact Optical Profilometry**
  - Non-destructive
  - Highly accurate
  - Resolution in nanometers
  - Limited area coverage per scan

R-Parameters vs S-Parameters

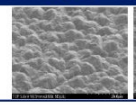
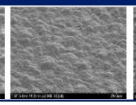
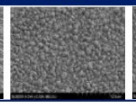
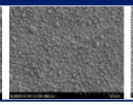
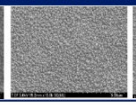
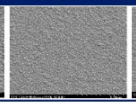
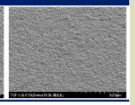
- 2D profile vs 3D surface area measurements





Copper Treatment and Copper Roughness

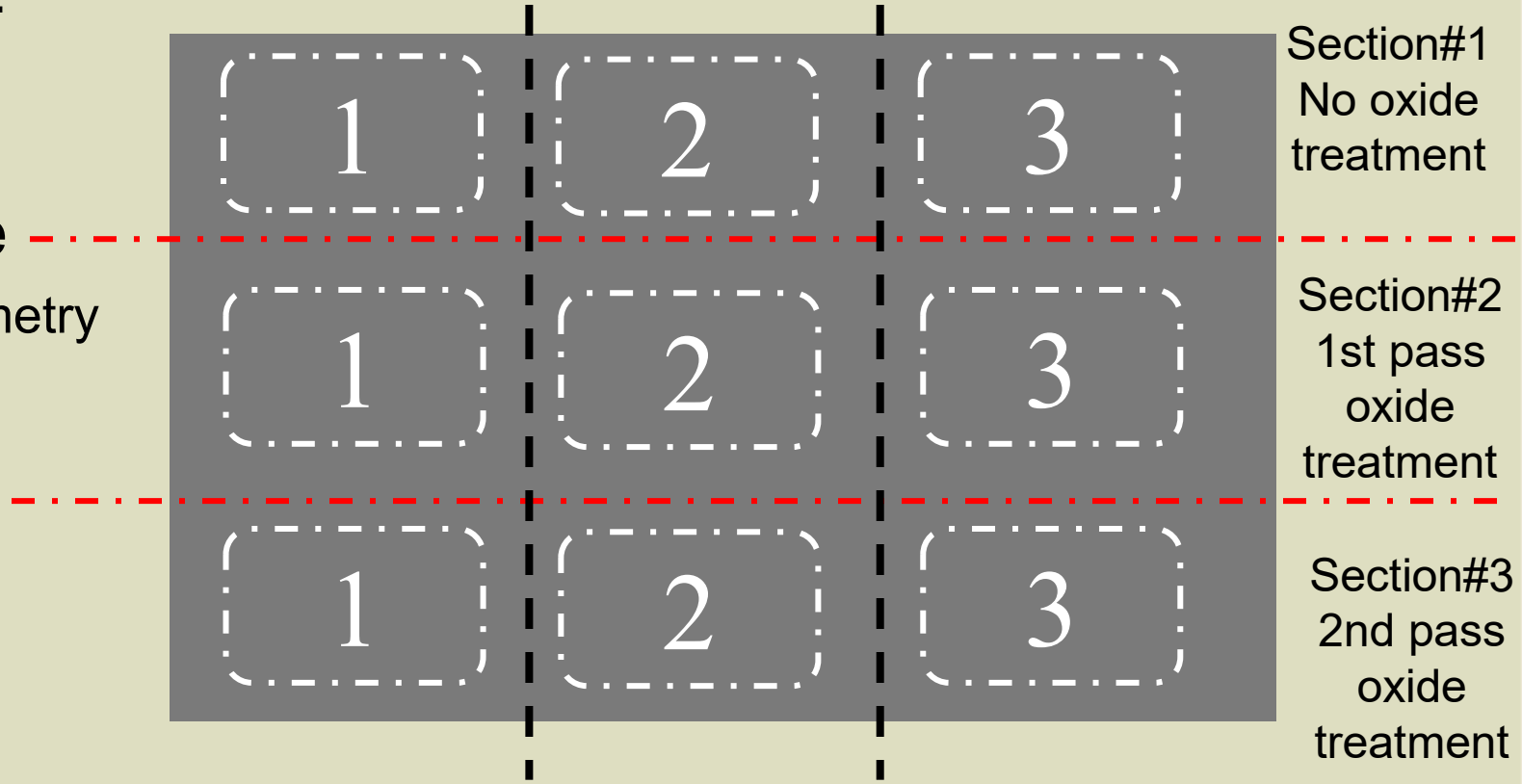
Copper Clad cores comes in many roughness specifications

	RTF2	RTF4*	HVLP	HVLP2	HVLP3	HVLP4	HVLP5*
							
Thickness (oz)	H / 1 / 2	H / 1 / 2	H / 1 / 2	H / 1 / 2	H / 1	H / 1	H / 1
Roughness, Sa (µm)	0.3	TBD	0.22	0.15	0.10	0.09	0.07

- For best signal integrity, theoretically the roughness of materials should be as small as possible
- However; all PCB layers when etched needs to go through a process called as “oxide treatment”
- Ensures best copper to resin adhesion
- This process does change the roughness specification. Oxide treatment should have minimal to negligible impact on roughness, but the actual effect mainly depends the oxide chemistry, flow rate, pressure and other factors

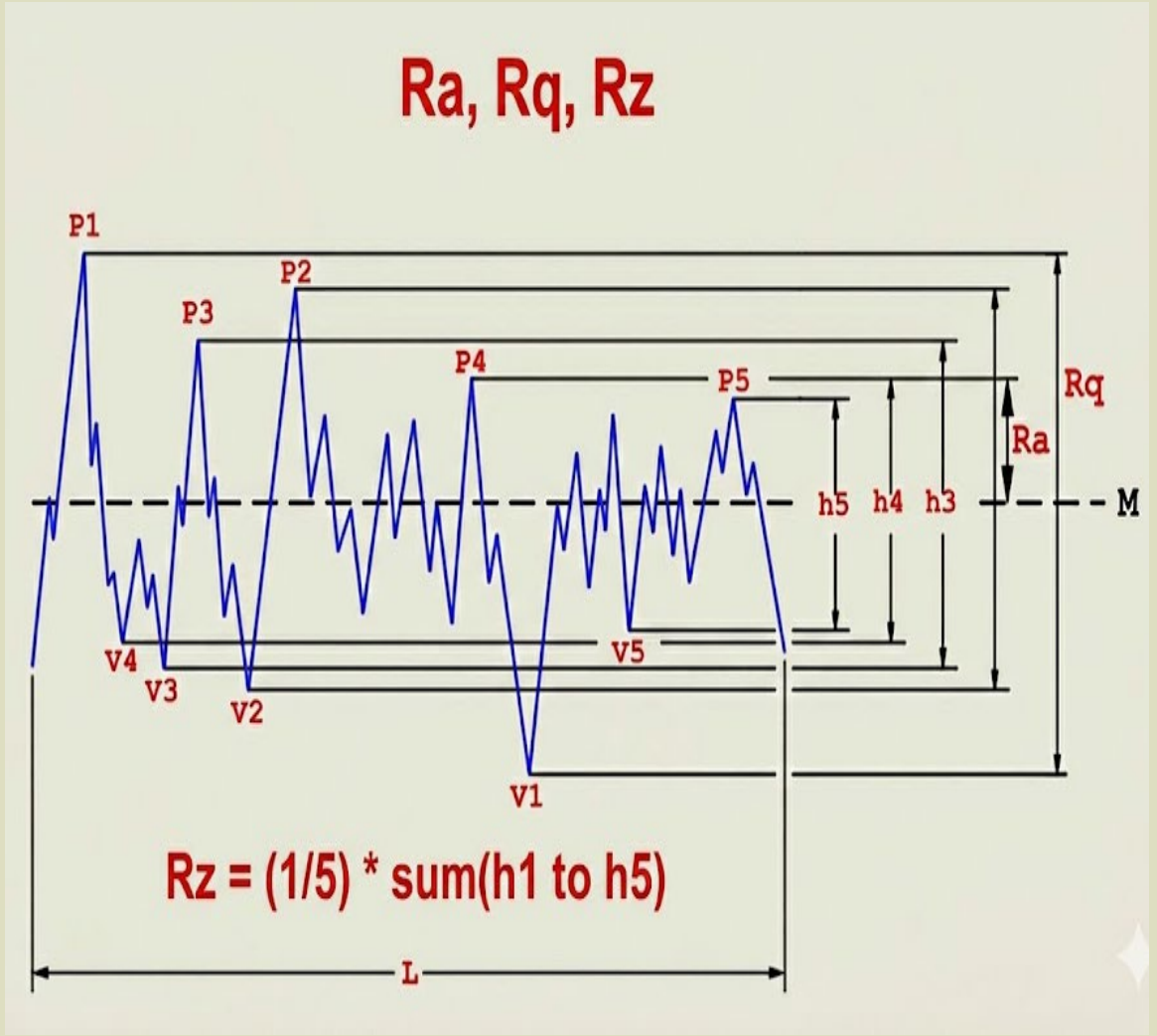
PCB Roughness measurements Study

- Copper roughness profiles:
  - RTF
  - HVLP
- Measurement Technique
  - Non-Contact Optical Profilometry
  - 500x mag
- Linear measurements:
  - 2mils square [~1000 steps]
  - 5 measurement [X & Y]
- Areal measurements:
  - 1 scan
  - 10mils x 8 mils[~1000 steps]

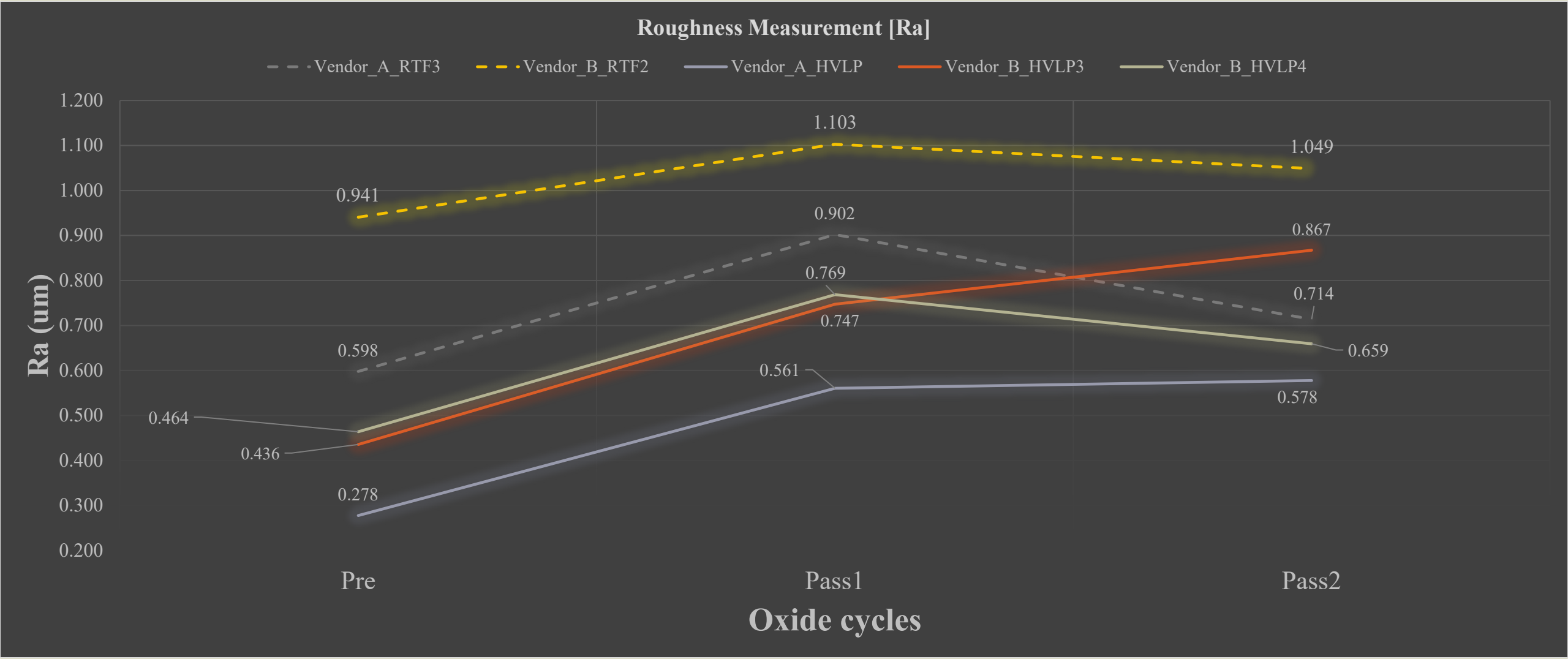


PCB Roughness measurements Study

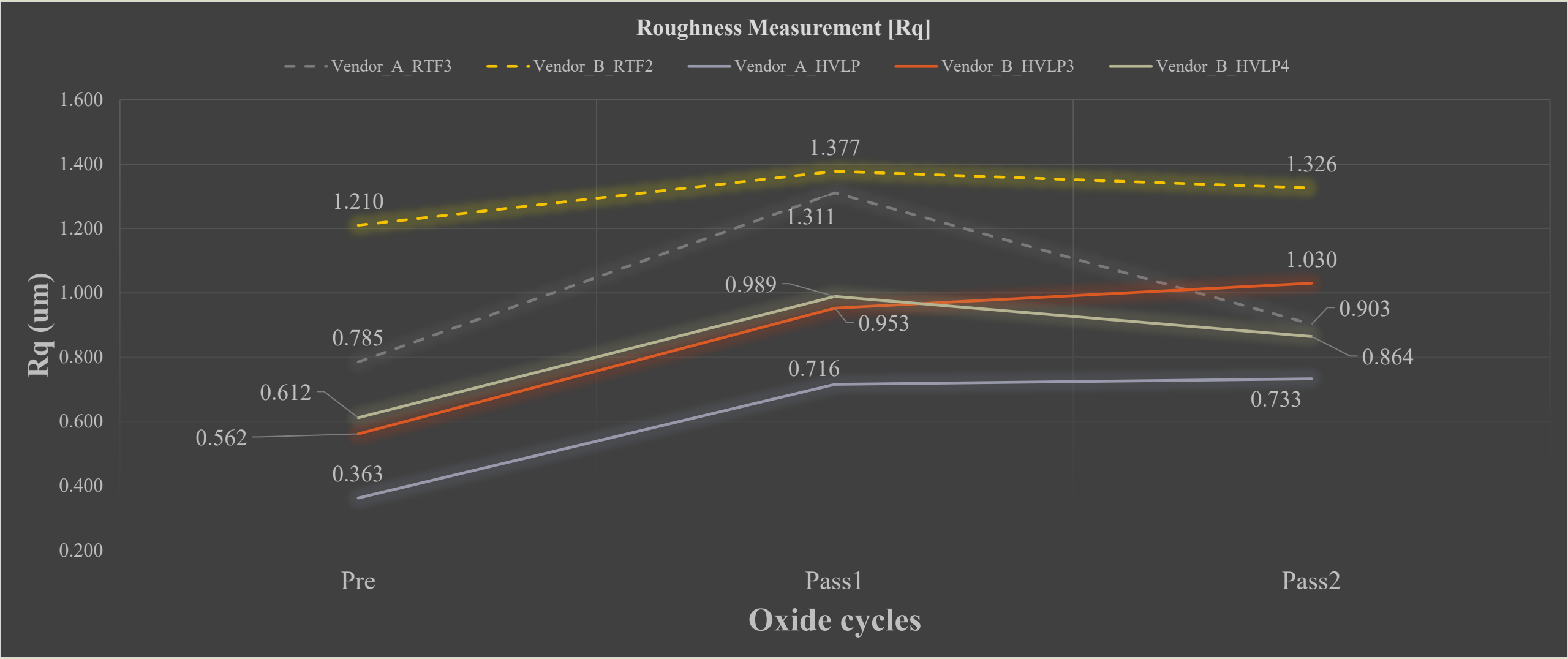
- Ra (Roughness Average): The arithmetical average of the absolute values
- Rq (Root Mean Square Roughness): The square root of the arithmetic mean of the squares
- Rz (Mean Roughness Depth): The average of the vertical distance between the highest peak and the lowest valley within five consecutive sampling lengths



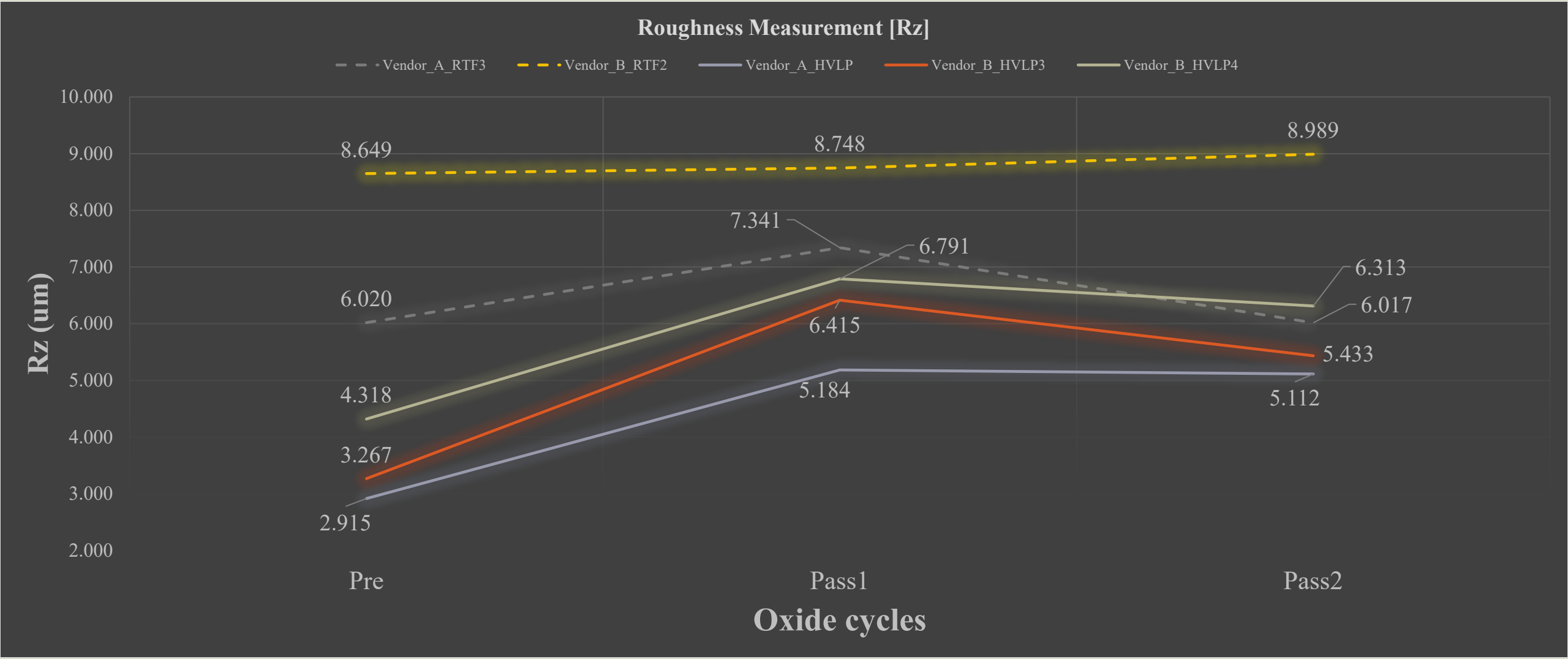
Roughness Measurements [Ra]



Roughness Measurements [Rq]

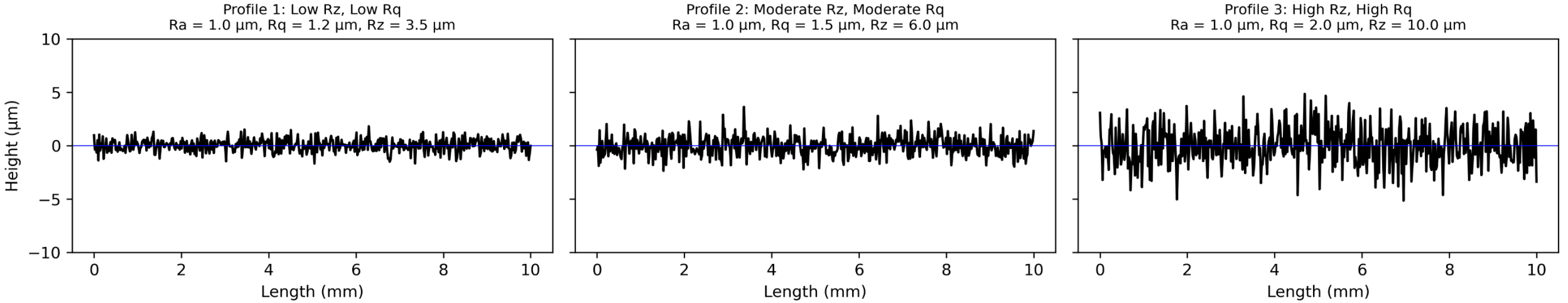


Roughness Measurements [Rz]



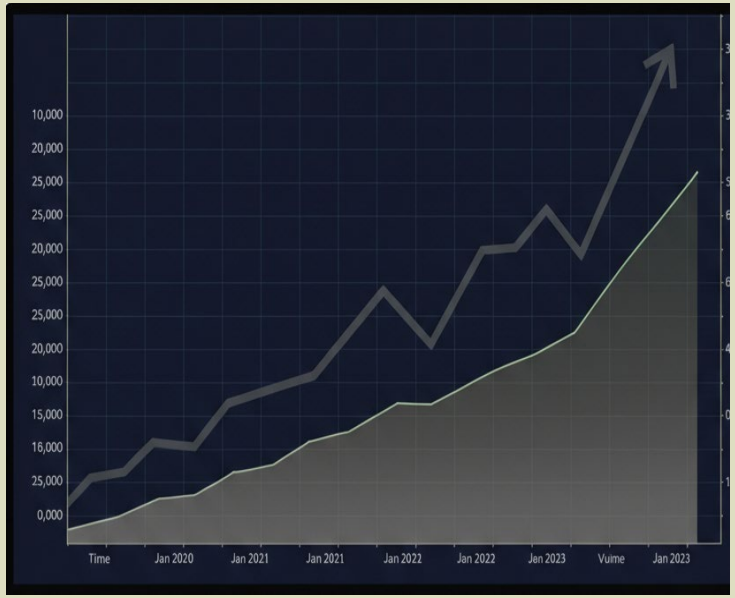
Roughness Parameters And Using Peak/Valleys Vs. Averaging

- Ra values doesn’t reflect true variation/nature of the copper profile
- Rz reflects worse case scenario of the profile
- Rq values are more sensitive to large/peaks and alleys



Roughness Measurements Summary

- The roughness measurements show increase in roughness post oxide treatment for all copper profiles
- FABs treat to one oxide treatment pass
  - However, second oxide pass data shows improve in Rz and ultimately Ra/Rq
- Roughness increase varies from FAB to FAB
- RTF vs HVLP



Roughness Measurements In Simulations

- Roughness plays important role to fully understand the losses involved.
- According to a study by Horn et al. (2015), conductor loss can increase by up to 30% when comparing a very smooth copper surface (Rz = 0.3µm) to a standard rough surface (Rz = 3.0µm) at frequencies around 20 GHz.
- Roughness values from material datasheets are not sufficient
- Roughness measurements post FAB may differ significantly
- Understanding EM simulation tools and their roughness models
  - EM tools models have limitations <5GHz considering RTF copper
  - EM tools may require measure values to be fed back to the simulation to improve correlation
  - EM tools may require to emulate roughness profile through modeling

Summary And Conclusion

- Roughness model for average (Ra), okay?
  - Provides insufficient data, Rq provides better resolution
- RTF and HVLP have similar Ra/Rq, how to decide? Difference between peak / valleys on different foils etc.
  - Average can be misleading
  - Rq values more sensitive to change in Rz
  - Check FAB oxide/micro-etch processes
- Foil vs. core difference?
  - HDI builds require further investigation
  - Outer-layer foils have additional variables with plating

Contributors

- We thank these other contributors for their valuable input:
  - Biao “Jerry” Leng
  - Syed Raza Rizvi
  - Gerard O'Brien [S T and S Group]
  - John Obrien [S T and S Group]

- Reference:
  - Effect of conductor profile structure on propagation in transmission lines (2015)
    AF Horn, PA LaFrance, CJ Caisse, JP Coonrod… - Proc. DesignCon, 2016

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