Direct Ink Write Processing Of Signal Crossovers Using Aerosol Jet Printing Method

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Presentation Outline

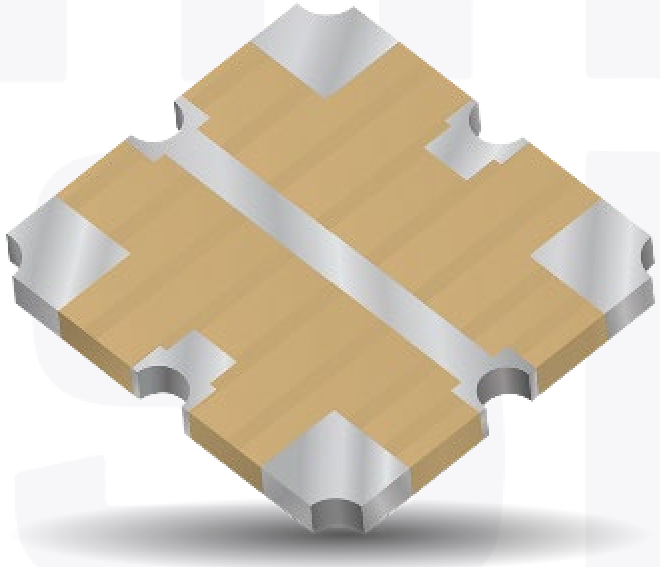
- Introduction
- Outline
- Crossover Structure Designs
- Results
- Conclusions

Crossovers: Introduction

- Efficient Electronic Integration Requires Signals To Crossover One Another
- RF-DC, RF-RF, DC-DC Signal Crossovers

Current Strategies:

- Multilayered PCBs
  - High Performance (Low Insertion Loss and High Isolation)
  - High Cost
- Surface Mount Technology (SMT) Devices
  - Large Physical Space (5.08 x 5.08 x 1.8 mm^3)
  - Rigid Design

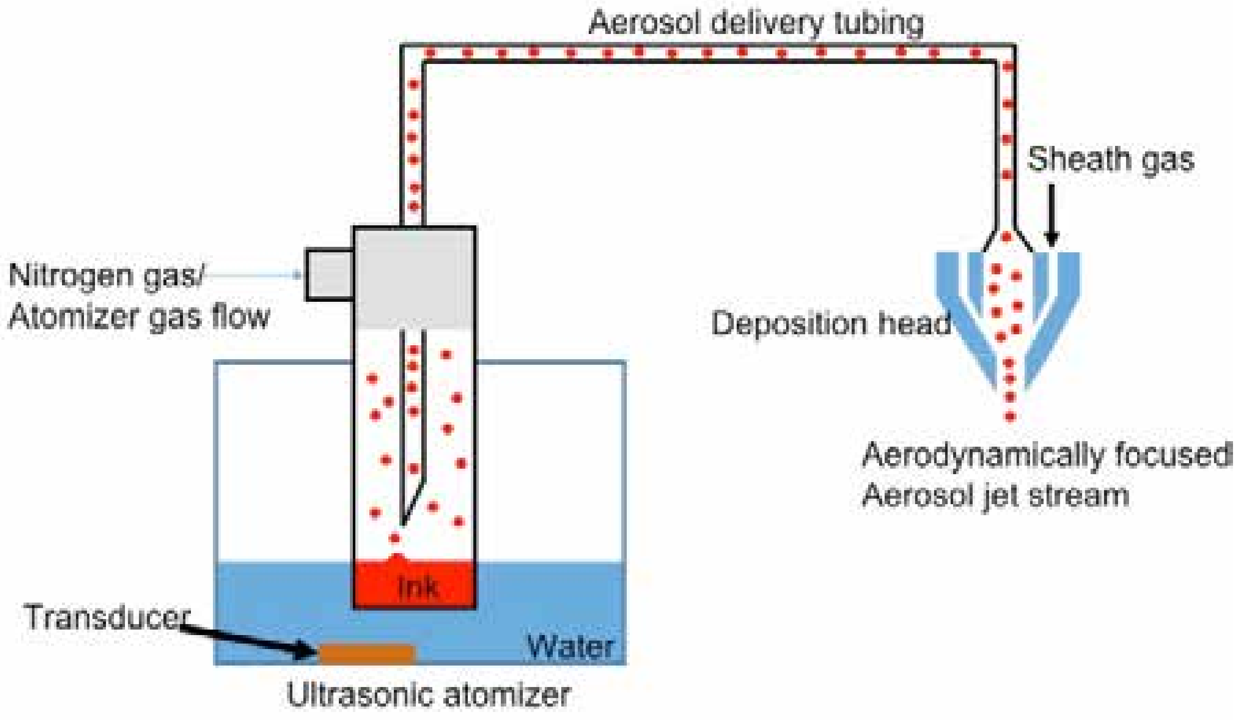


Aerosol Jet Printing: Introduction

- Direct Write Technology – Create Microscale and Nanoscale 2D or 3D Functional Structures on Flat or Conformal Surfaces
- Materials Include Variety of Aerosolization Capable Materials
  - Colloidal Inks
  - Nanoparticle-filled Inks
  - Diluted Thick-film Pastes
  - Thermosetting and UV Curable Polymer Solutions

Aerosol Jet Printing: Process

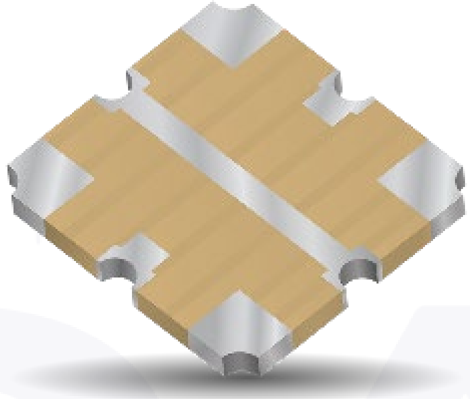
- Ultrasonic or pneumatic atomization of the ink
- Mist of droplets dense in metal, dielectric, or organic material
- Delivered to the deposition head by a carrier gas (dry nitrogen)
- Focused into a tight stream by coaxial sheath gas
- Deposition onto a substrate 2 to 5 mm below the nozzle



Aerosol Jet Printing: Advantages

- Creation of Features With Dimensions As Small As 5 µm And Up To Several mm
- Wide Range Of Materials
- Ultrasonic Atomization For Ink Viscosities Up to 7 cP
- Pneumatic Atomization For Ink Viscosities Up To 1000 cP

Pros and Cons



COTS SMT

Pros:

- Flip Chip Soldering

Cons:

- Limited Frequency Range
- Limited Power Handling
- Design Revolves Around The Chip

Direct Write Technology

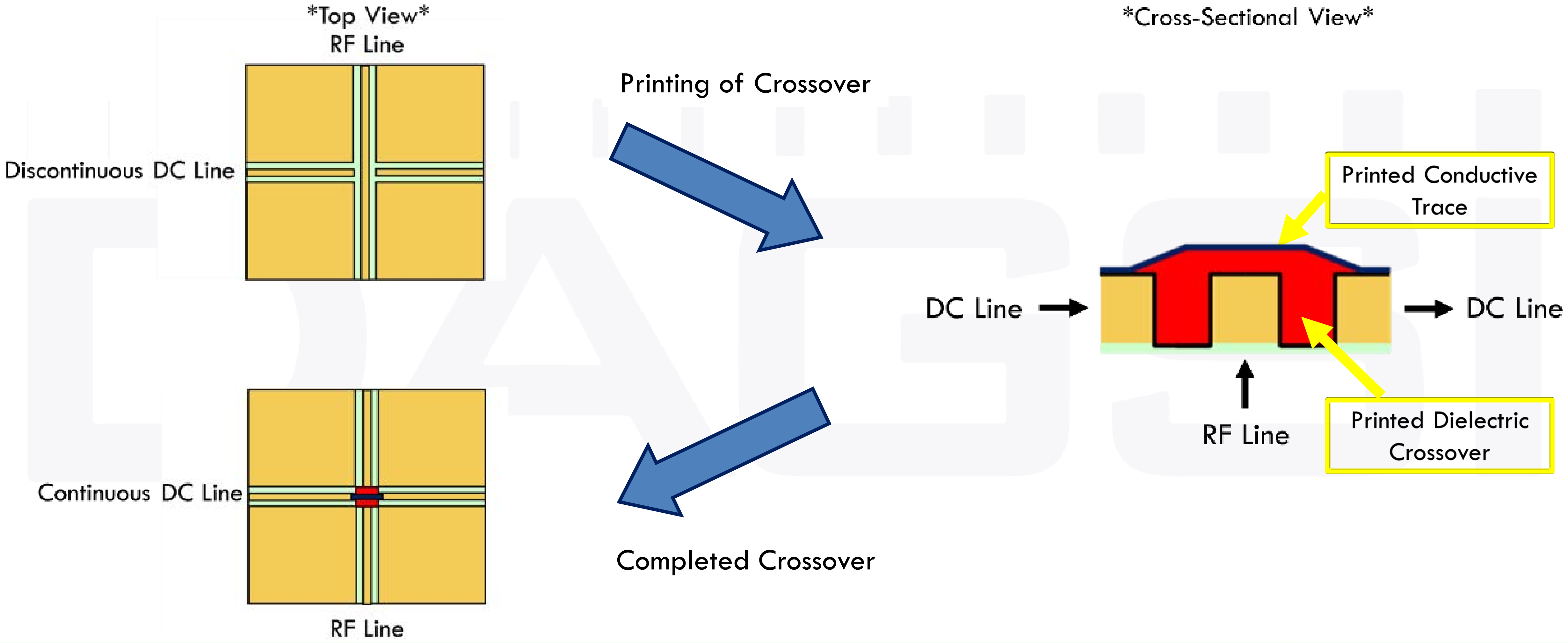
Pros:

- Printing at specific locations
- Features as small as 5 µm
- Wide range of materials
- Design Freedom

Cons:

- Ink availability

Outline



Top View
RF Line
Discontinuous DC Line
Printing of Crossover
Cross-Sectional View
Printed Conductive Trace
DC Line
DC Line
RF Line
Printed Dielectric Crossover
Continuous DC Line
Completed Crossover
RF Line

Outline

Objective:

Reliably Print Crossover Structures

Structures Under Study:

- Dielectric Pad Design
- Dielectric Ramp Design

Materials Under Study:

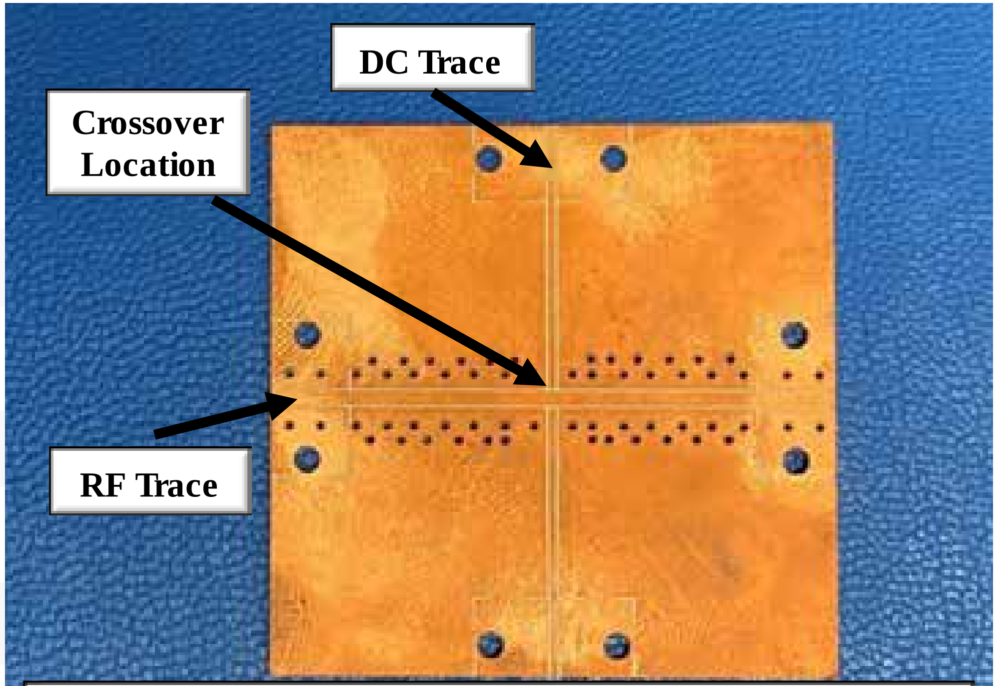
- Benzocyclobutene (BCB, dielectric [ε_r=2.65 (1 GHz)], thermally curable)
- Norland Electronic Adhesive 121(NEA, dielectric [ε_r=4.04 (1 MHz)], UV curable)
- Electroninks 615 (EI-615, conductor, thermally curable)

Equipment

- Optomec's AJ 200
- Agilent 8720ES S-parameter Network Analyzer
- BK Precision 1743b DC Power Supply
- FLIR ETS320 Thermal Camera
- Keyence, DekTak, and Multimeter

Outline

- 2 Crossover Structures Were Designed (Pad And Ramp)
- 5 NEA and 5 BCB Crossover Structures Were Printed
- EI-615 Was Printed Over The Crossover And Connected The DC Circuit Traces
- Samples Were Connected To A Network Analyzer And DC Power Supply
- DC Carrying Capability And Changes In The S21 Parameter Were Recorded
- Recorded Heat Spread Via A Thermal Camera



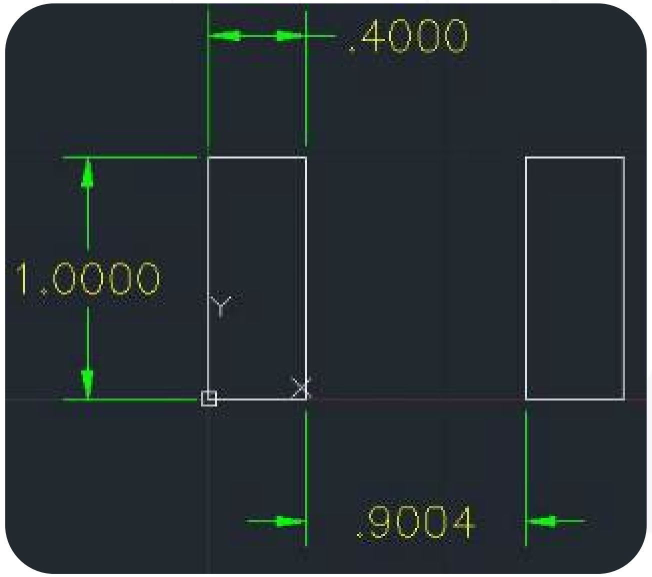
Prefabricated boards were used as the substrate for testing the crossovers

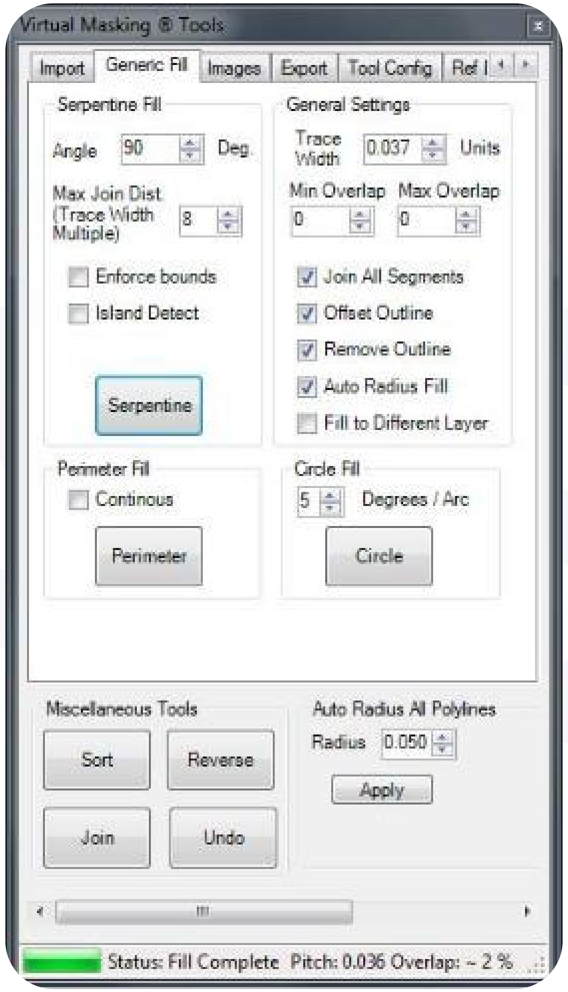
Ink Settings

Ink	Nozzle Size (µm)	Sheath Gas Flow (ccm)	Ultrasonic Atomizer Gas Flow (ccm)	Ultrasonic Atomizer Power (mA)	Pneumatic Atomizer Gas Flow (ccm)	Pneumatic Exhaust Gas Flow (ccm)	Curing Type
BCB	300	30	35	0.5	X	X	Thermal
NEA 121	300	40	X	X	910	850	UV
EI-615	150 or 200	50	7	0.3	X	X	Thermal

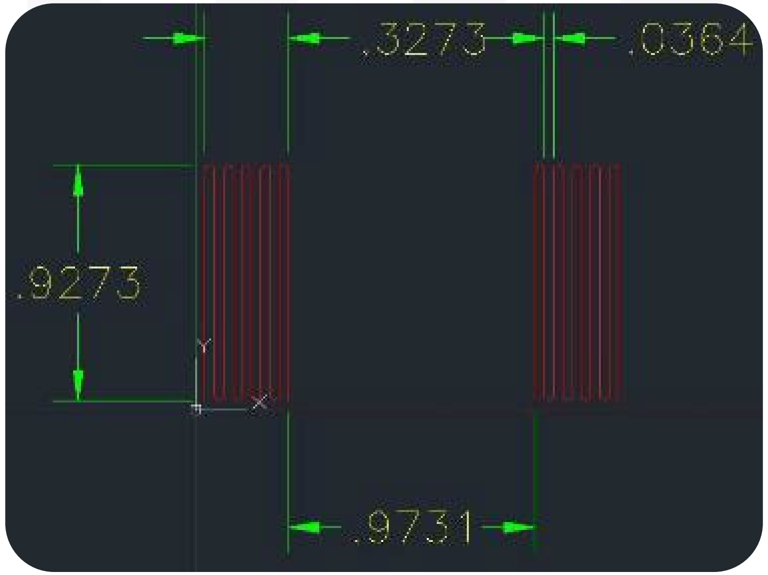
Creation Of Tool Paths

AutoCAD

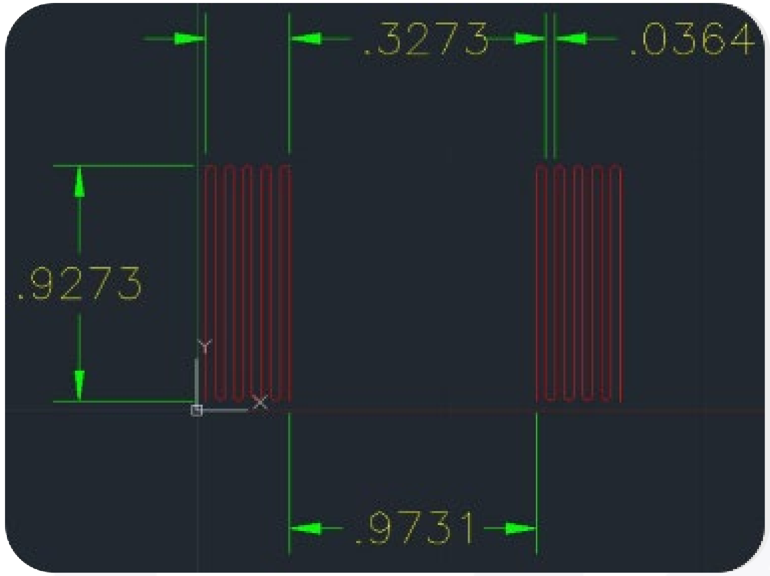




VMTools Add-On

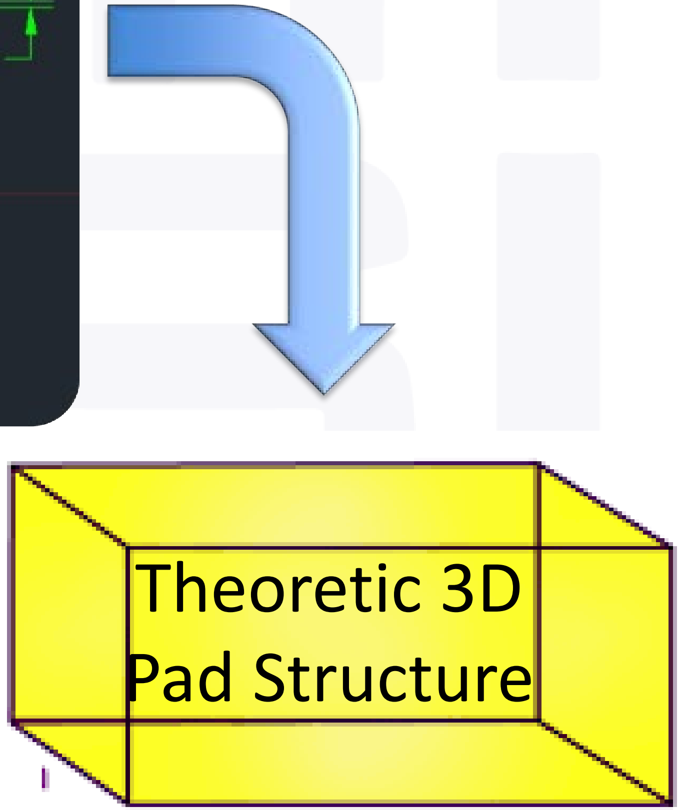


Pad Design

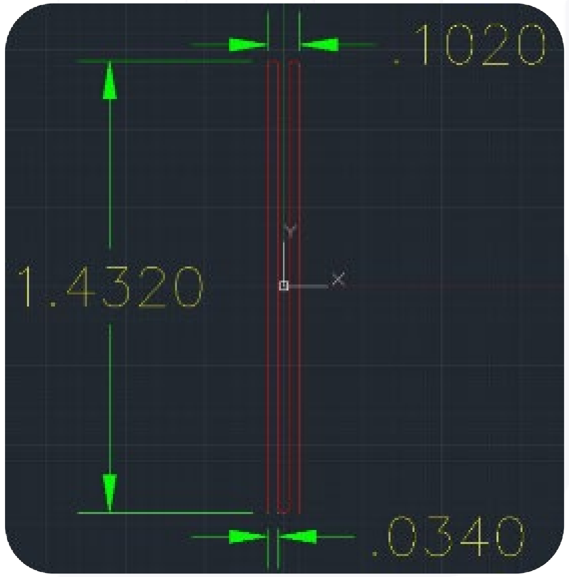


NEA Trench
Filling Design

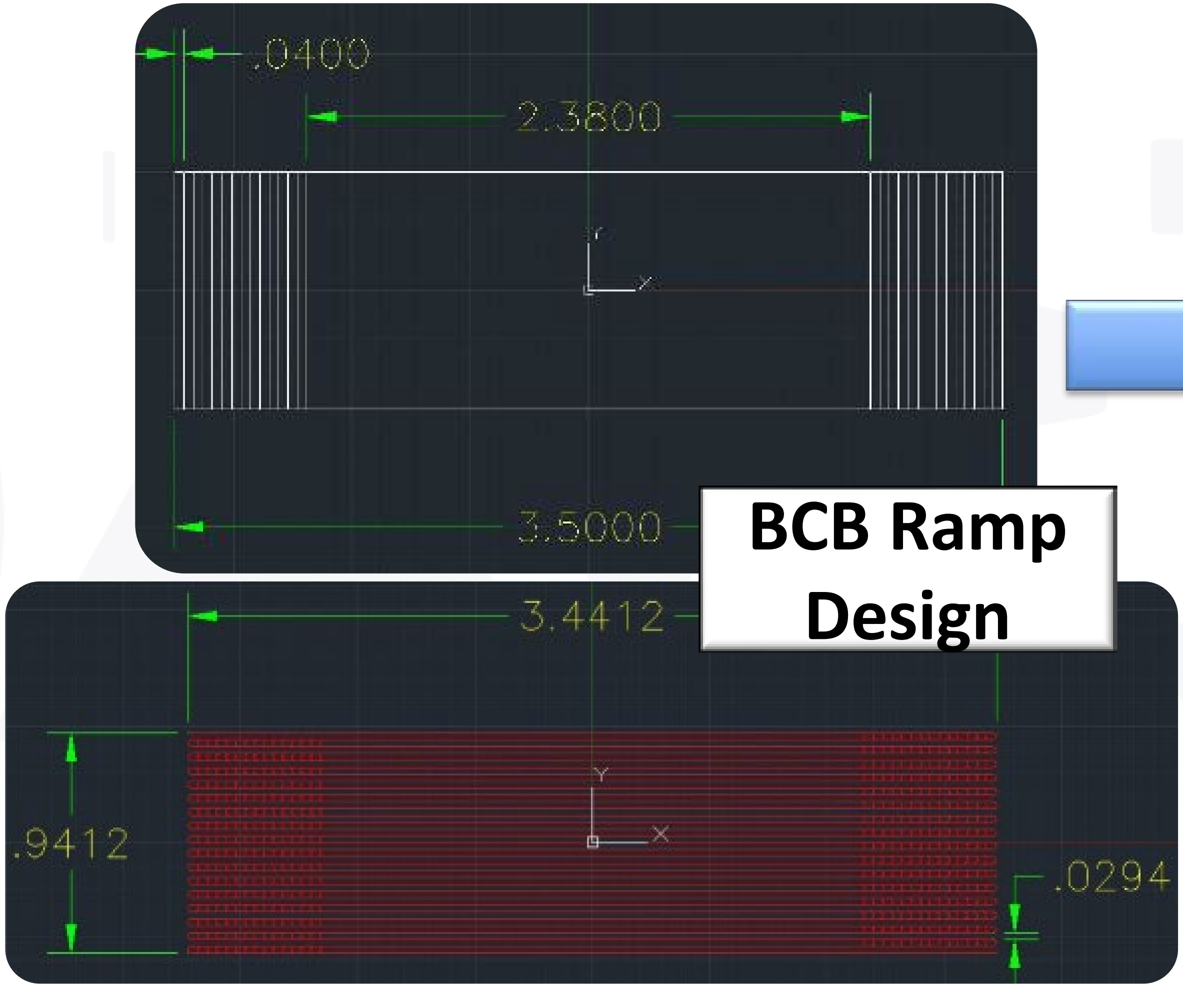
NEA Pad
Design



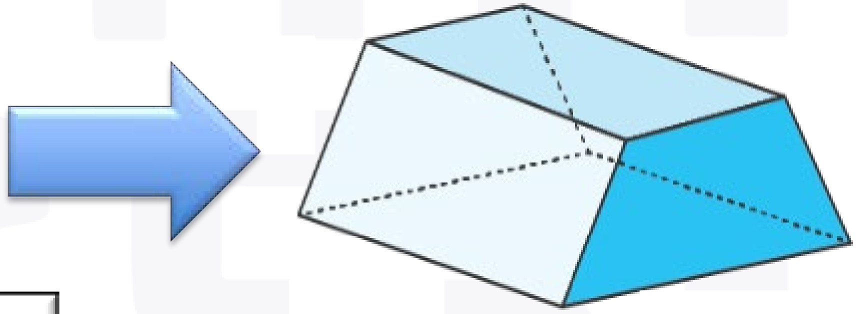
Ramp Design



BCB Trench Filling Design

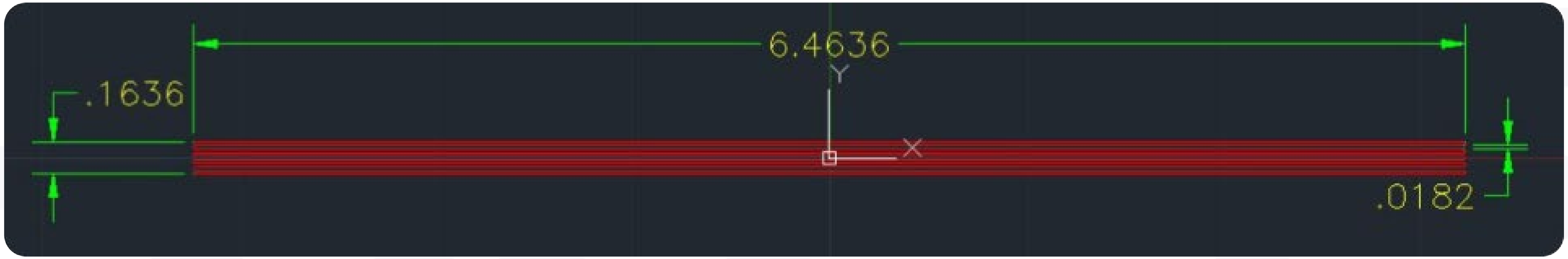


BCB Ramp Design

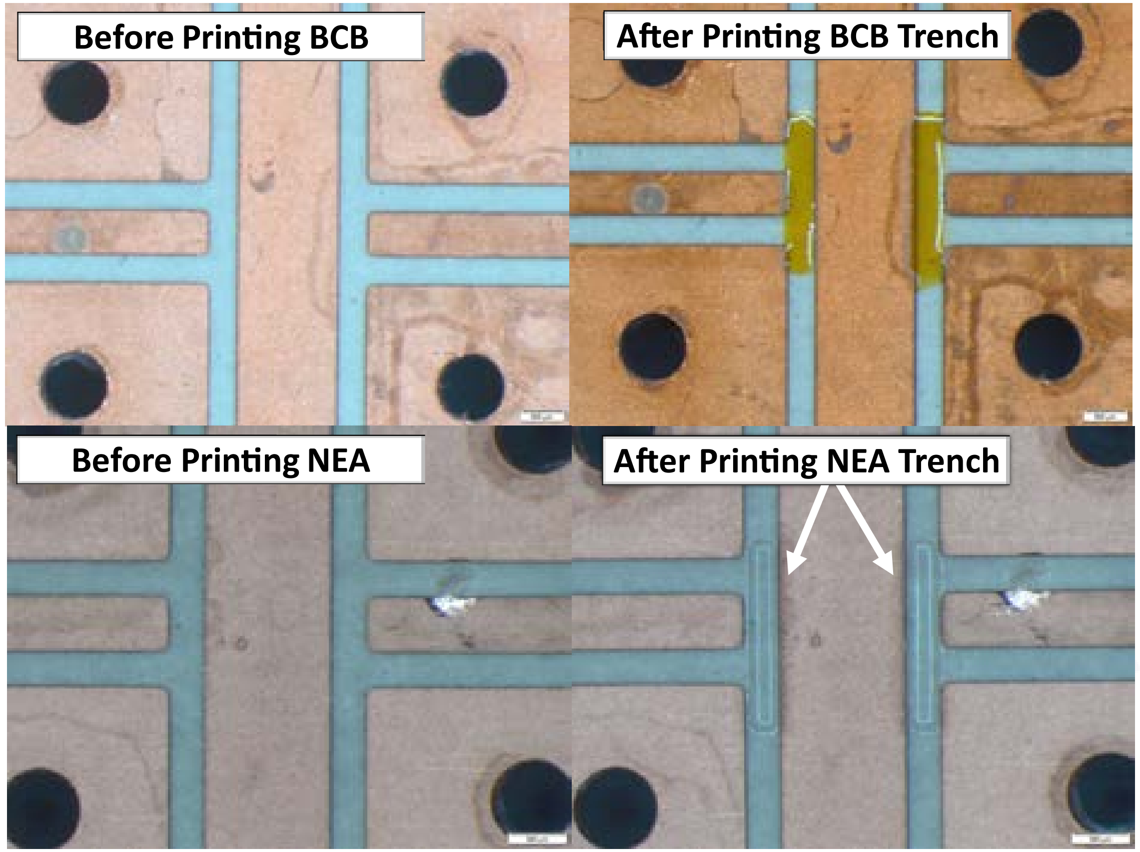


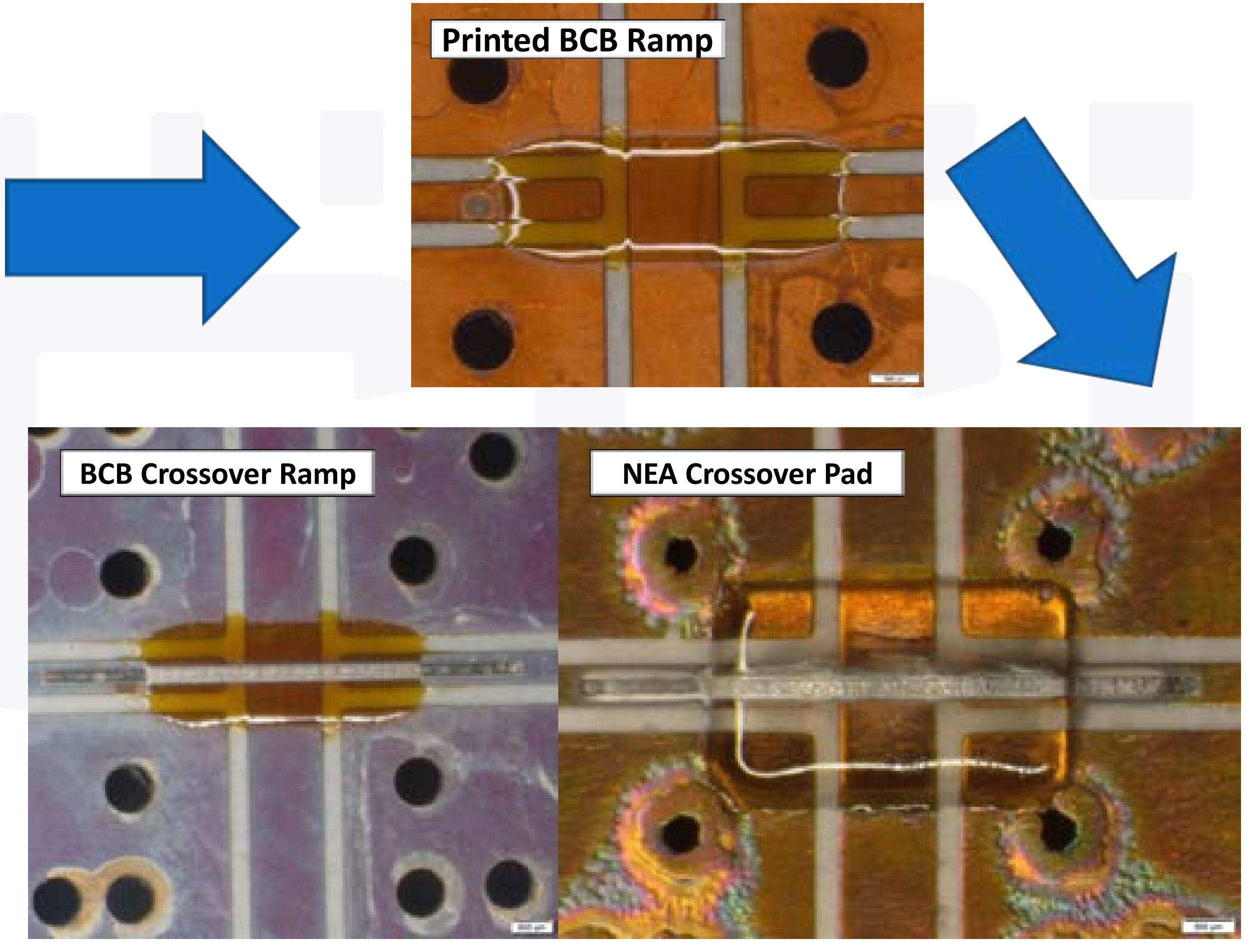
Theoretic 3D Ramp Structure

Conductive Trace Designs

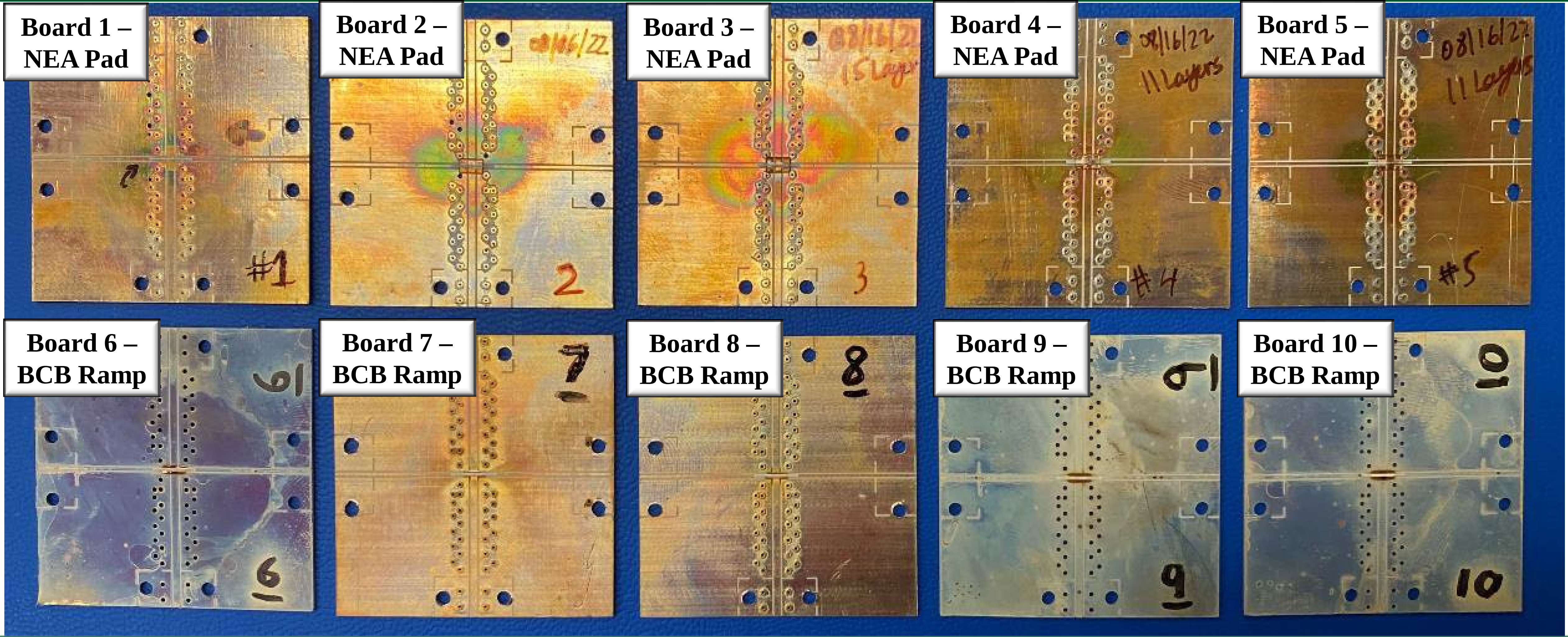


Printing Of Crossover Structures



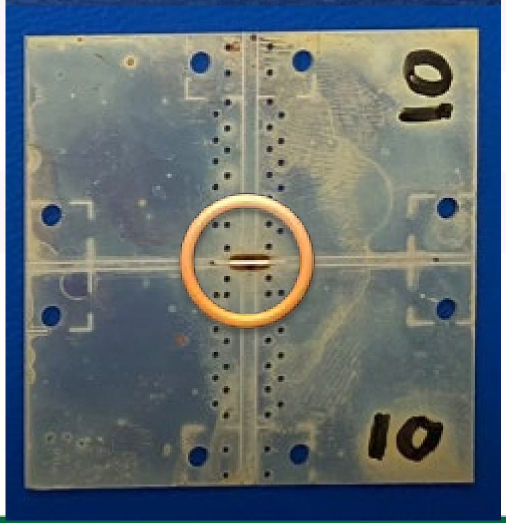


Completed Crossovers



Completed Crossovers

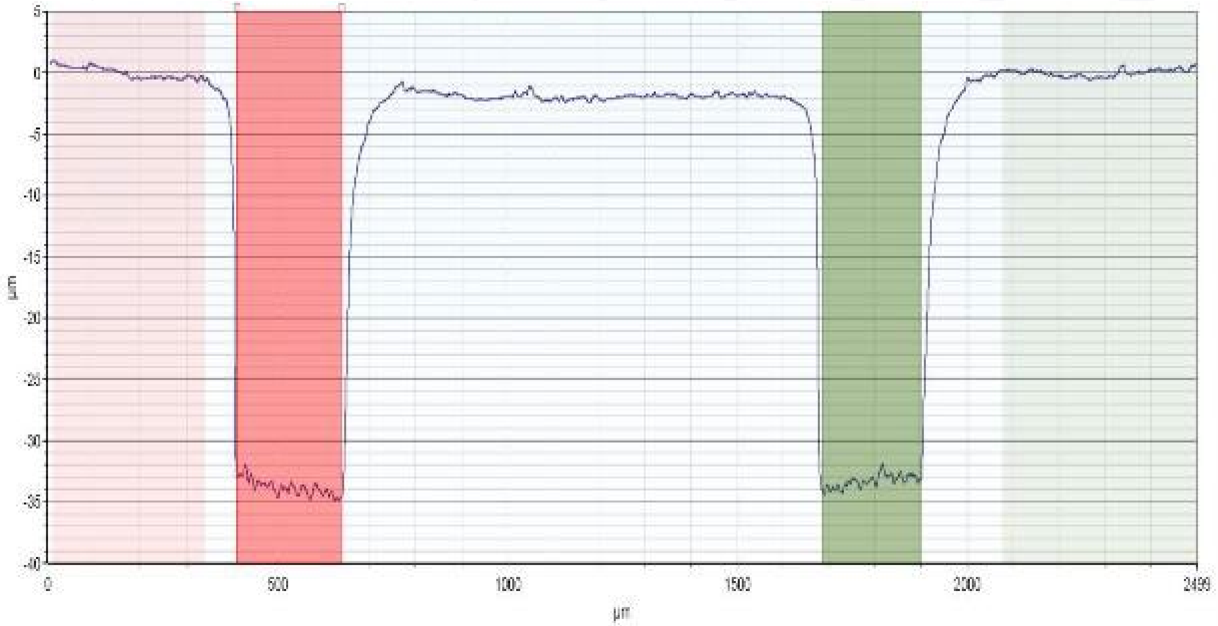
Board 2 –
NEA Pad



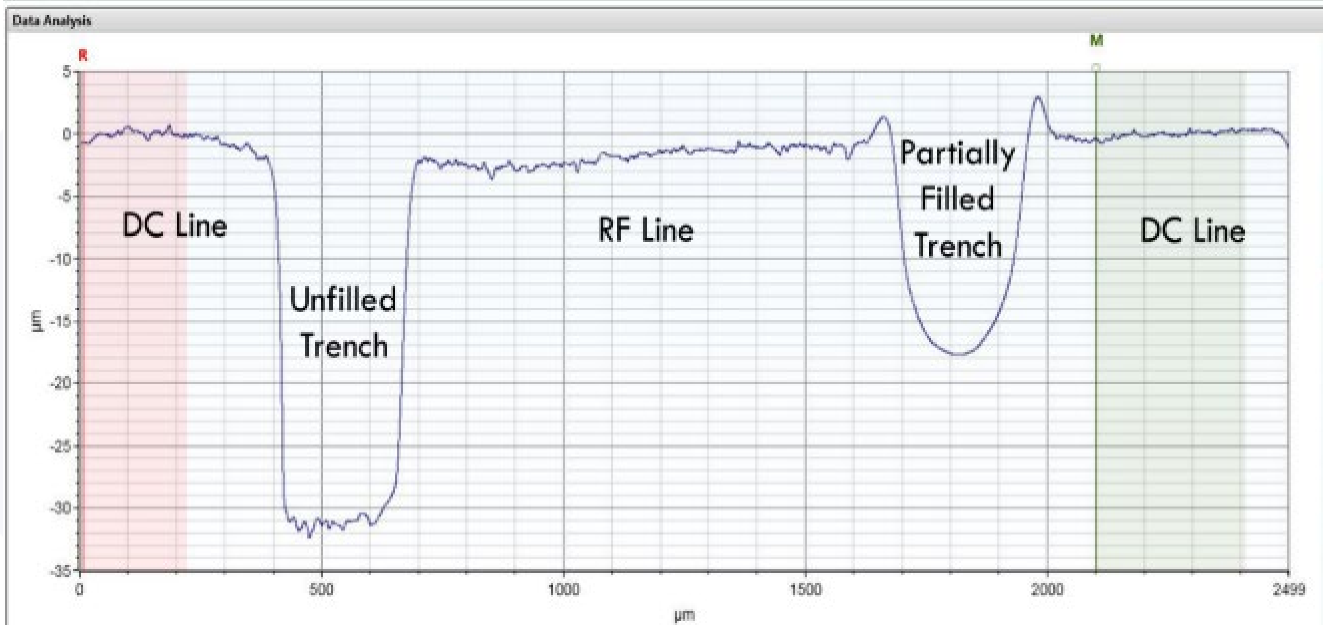
Board 10 –
BCB Ramp

Results: BCB Trench Filling

Before BCB Trench Filling

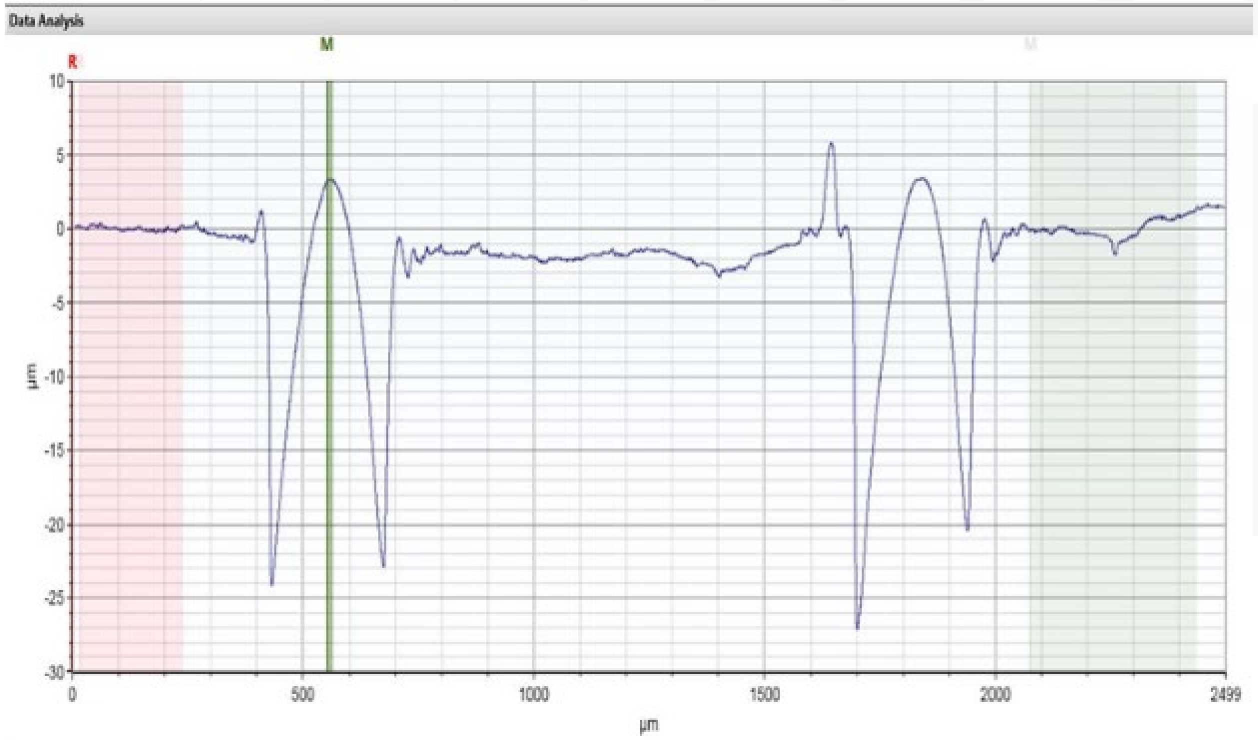


Partial BCB Trench Filling

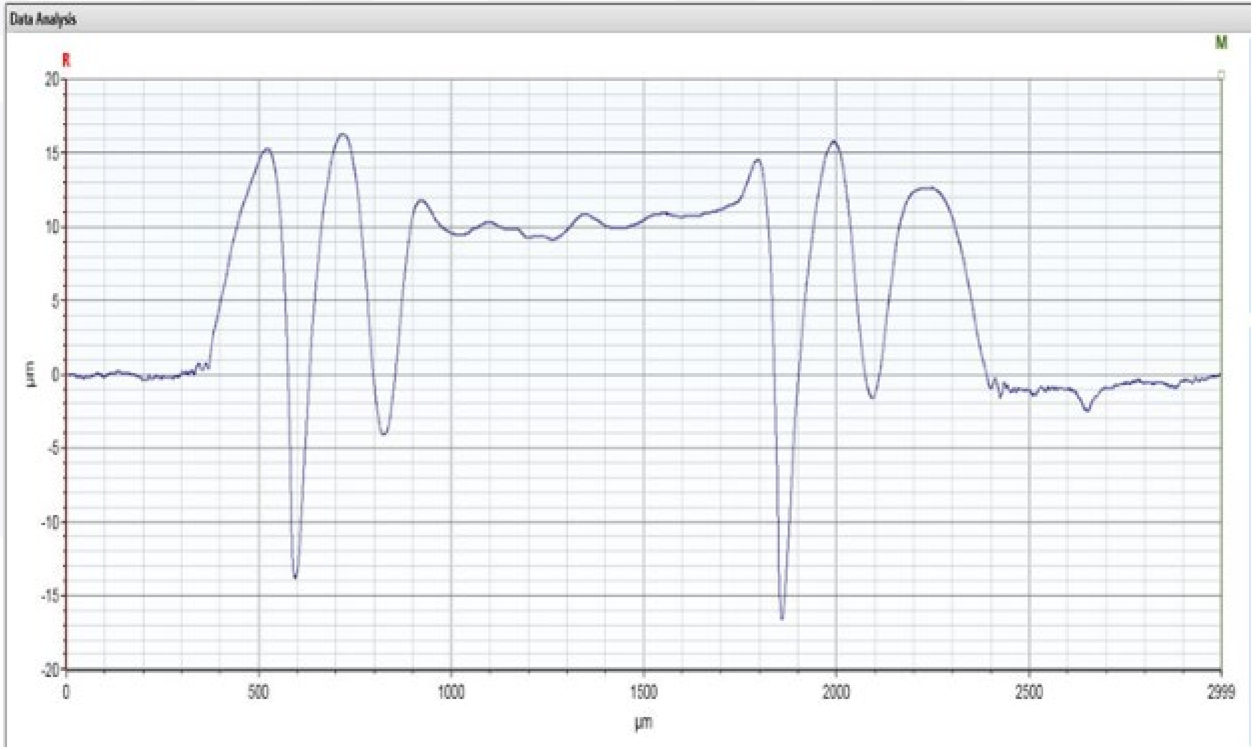


Results: NEA Trench Filling

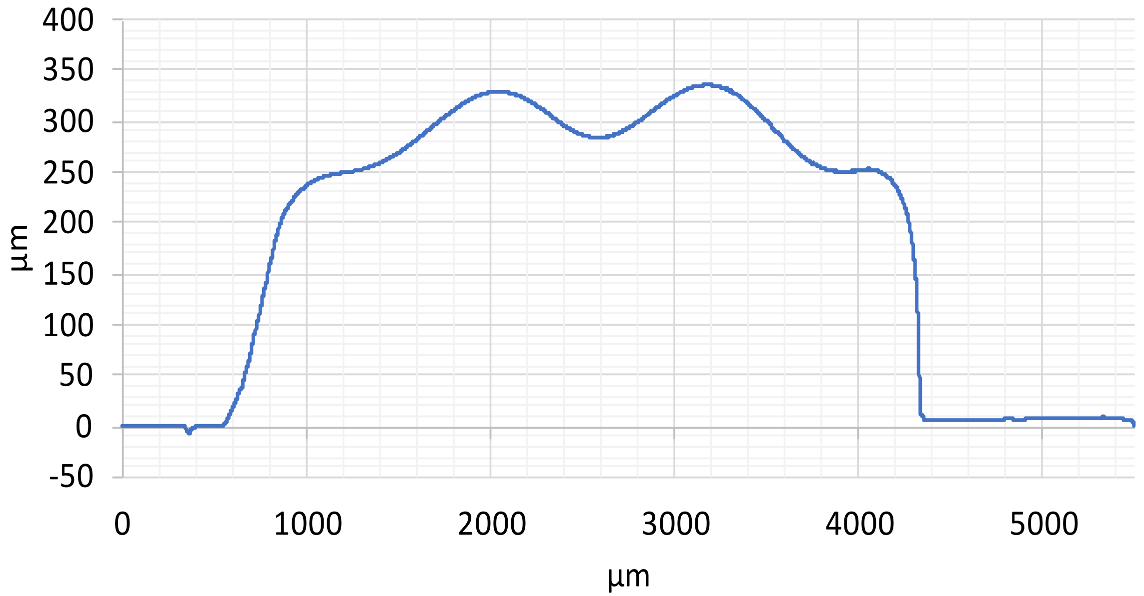
After NEA Trench Filling



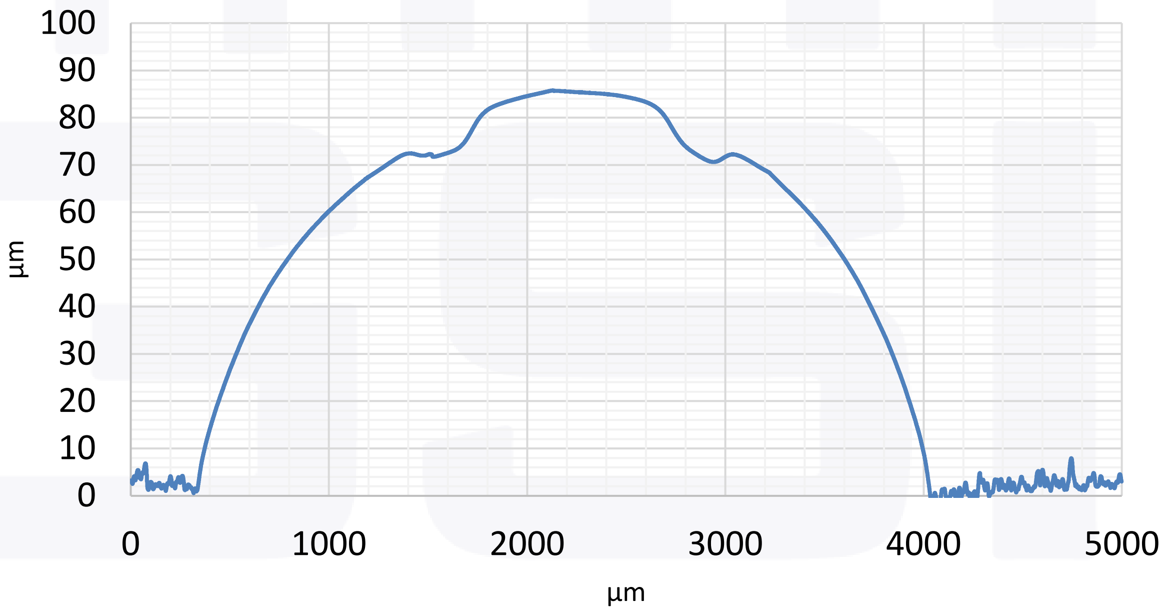
After NEA Pad



Results: Pads Vs Ramps

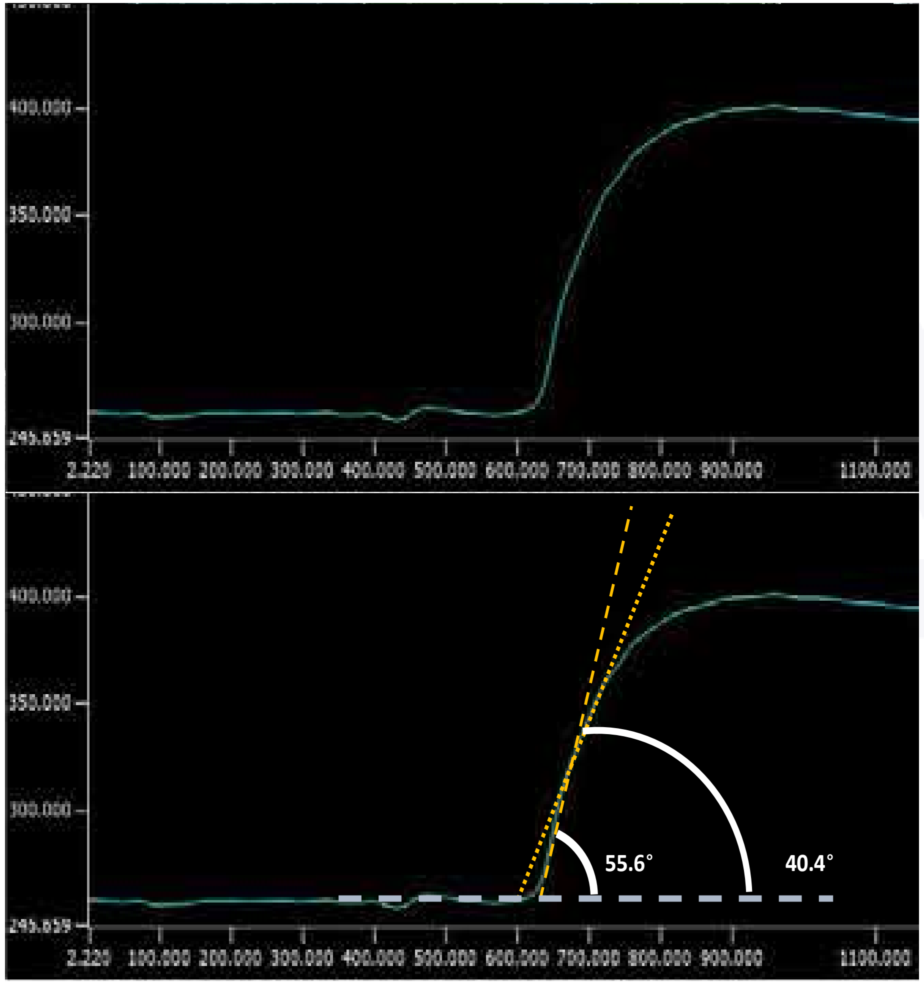


NEA Pad Profile



BCB Ramp Profile

Results: Pads Vs Ramps

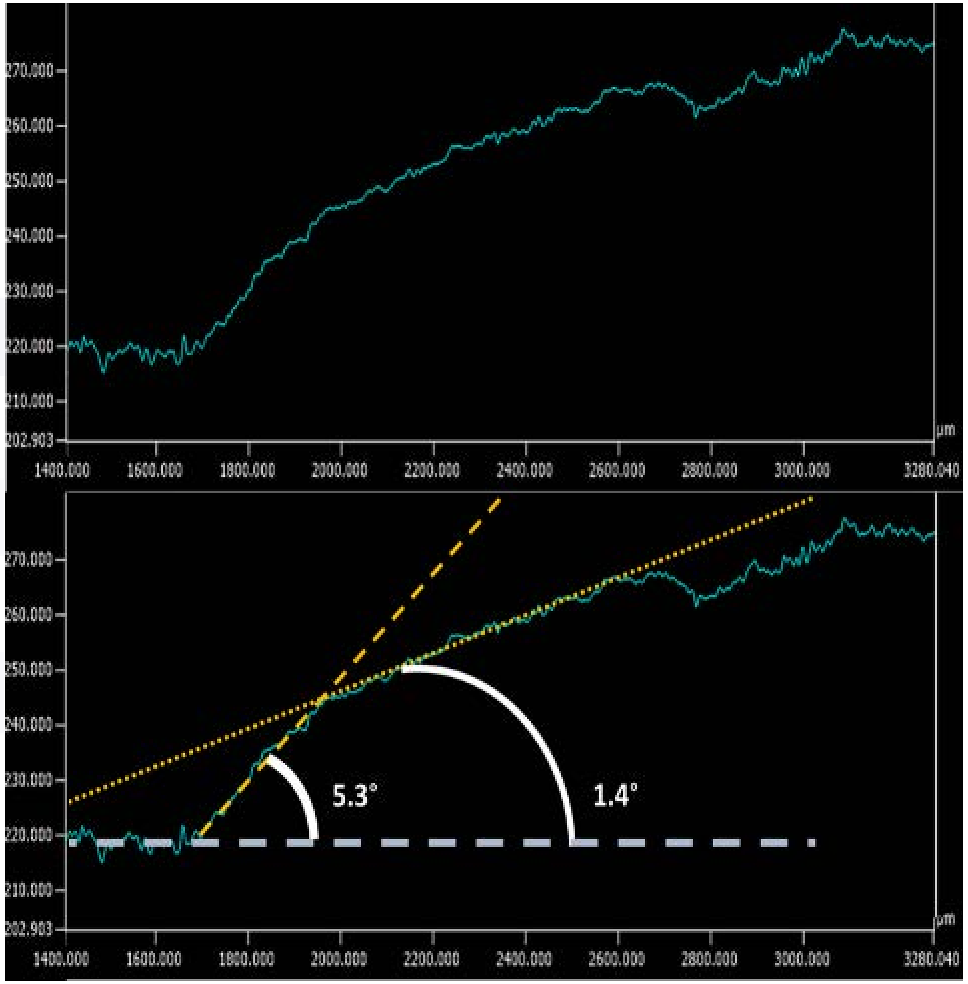


← NEA Pad
Average Slope Angle: 48°

- Required Multiple Print Sessions and Tilting

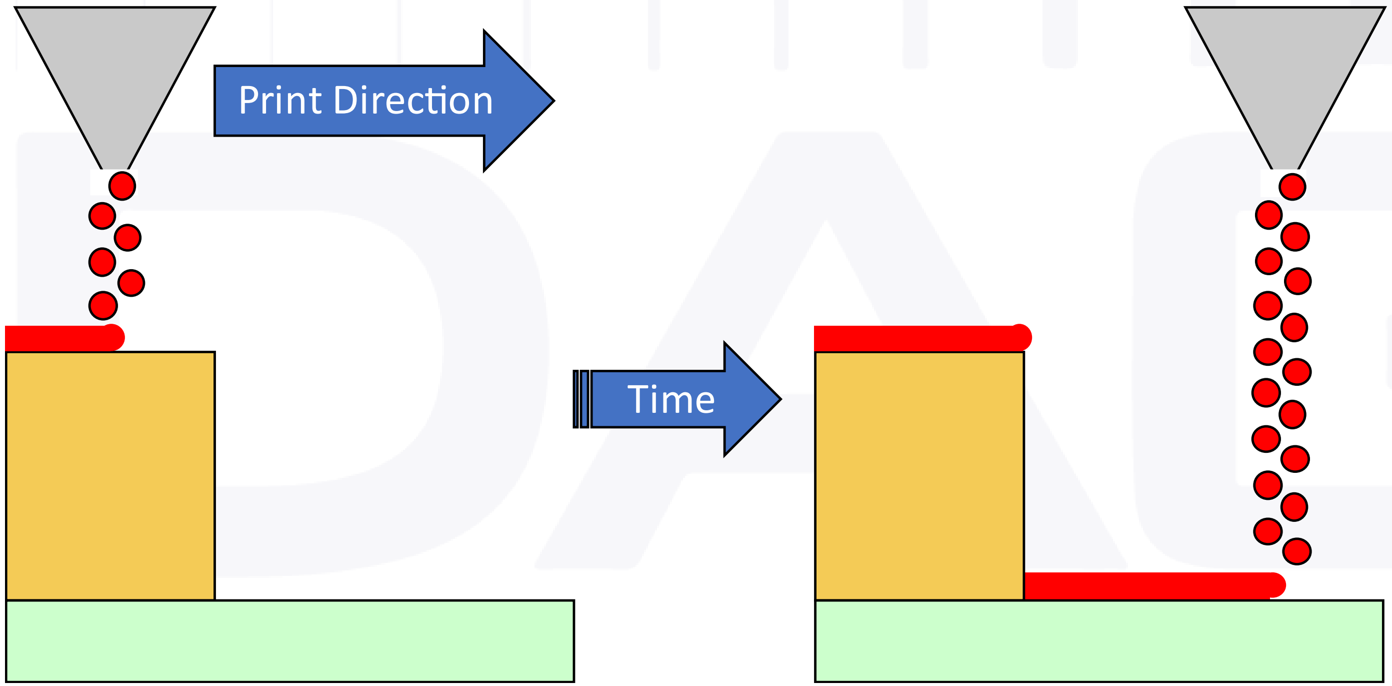
BCB Ramp →
Average Slope Angle: 16°

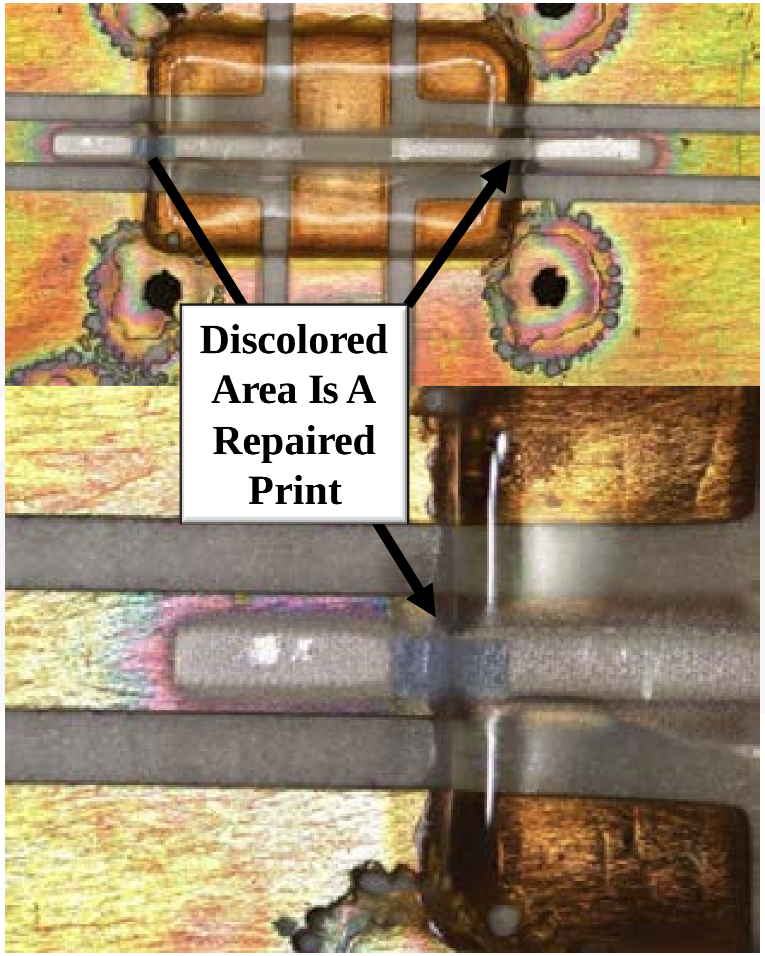
- One Print Session With No Tilting



NEA Pad Tilting

Conformal Printing

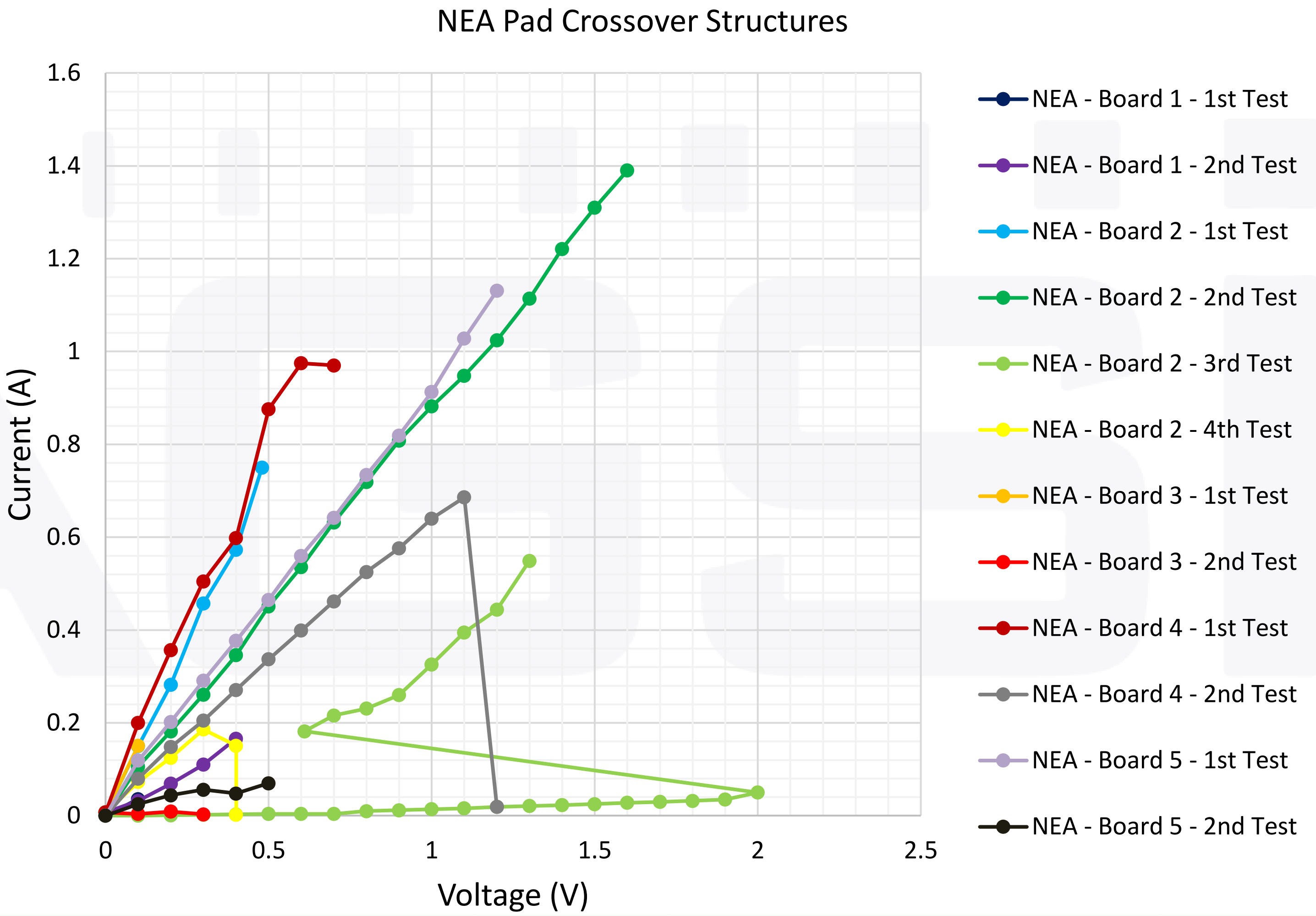




Results: NEA Pad I-V Curves

NEA Pad Structures

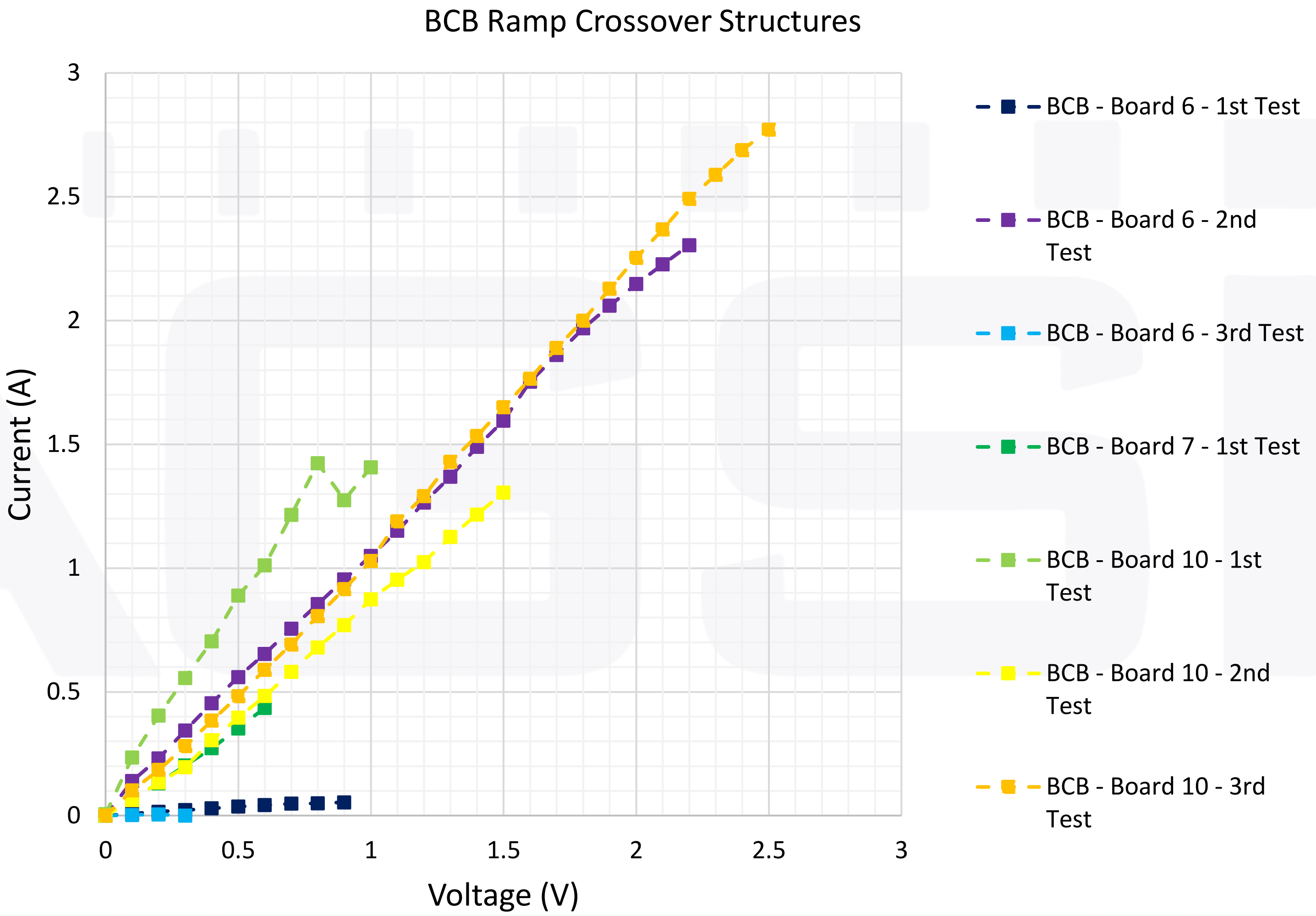
- Average Survival Current Up To 0.5 A
- Max Survival Current Up To 1.39 A



Results: BCB Ramp I-V Curves

BCB Ramp Structures

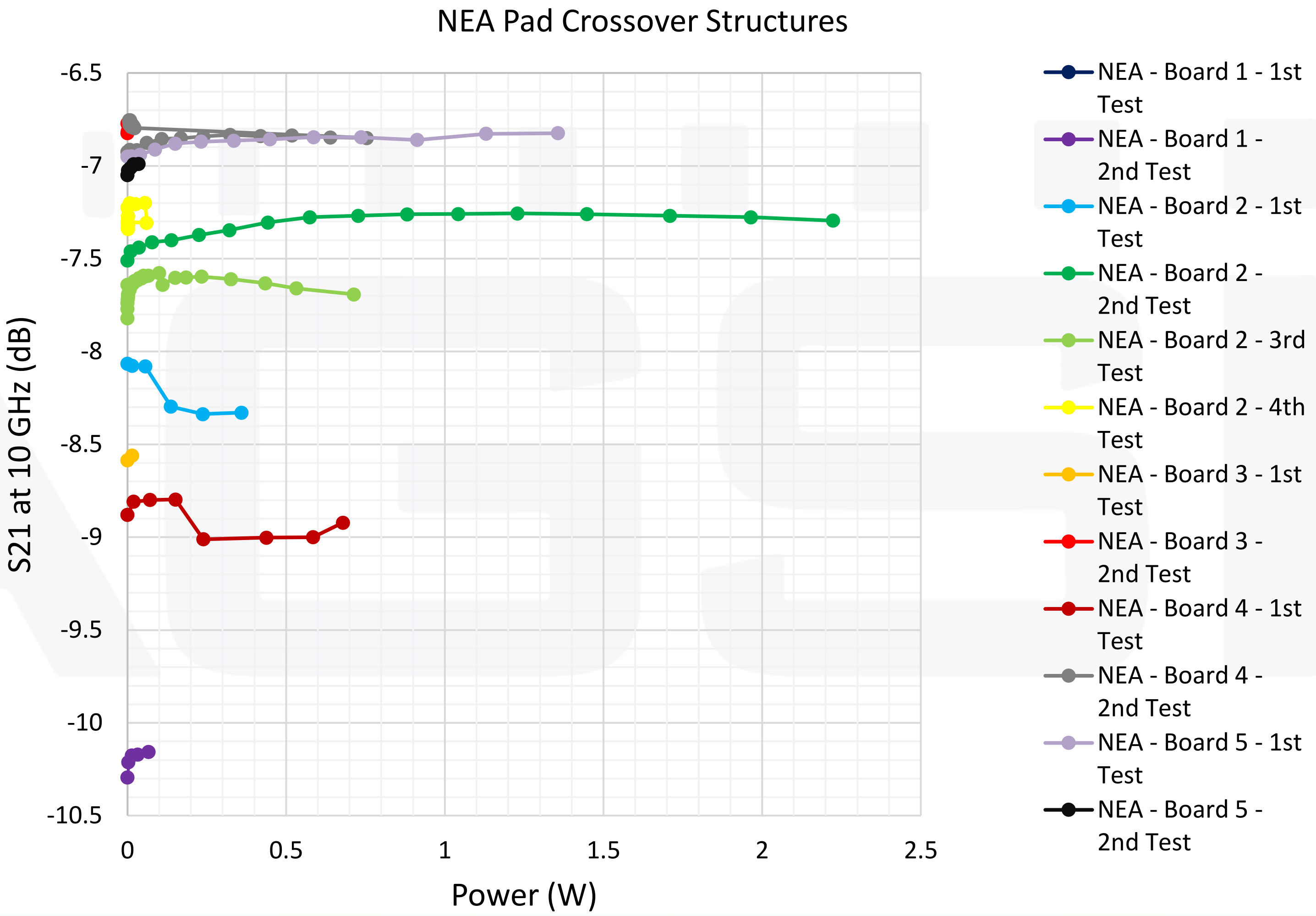
- Average Survival Current Up To 1.3 A
- Max Survival Current Up To 2.772 A



Results: NEA Pad Power Handling

NEA Pad Structures

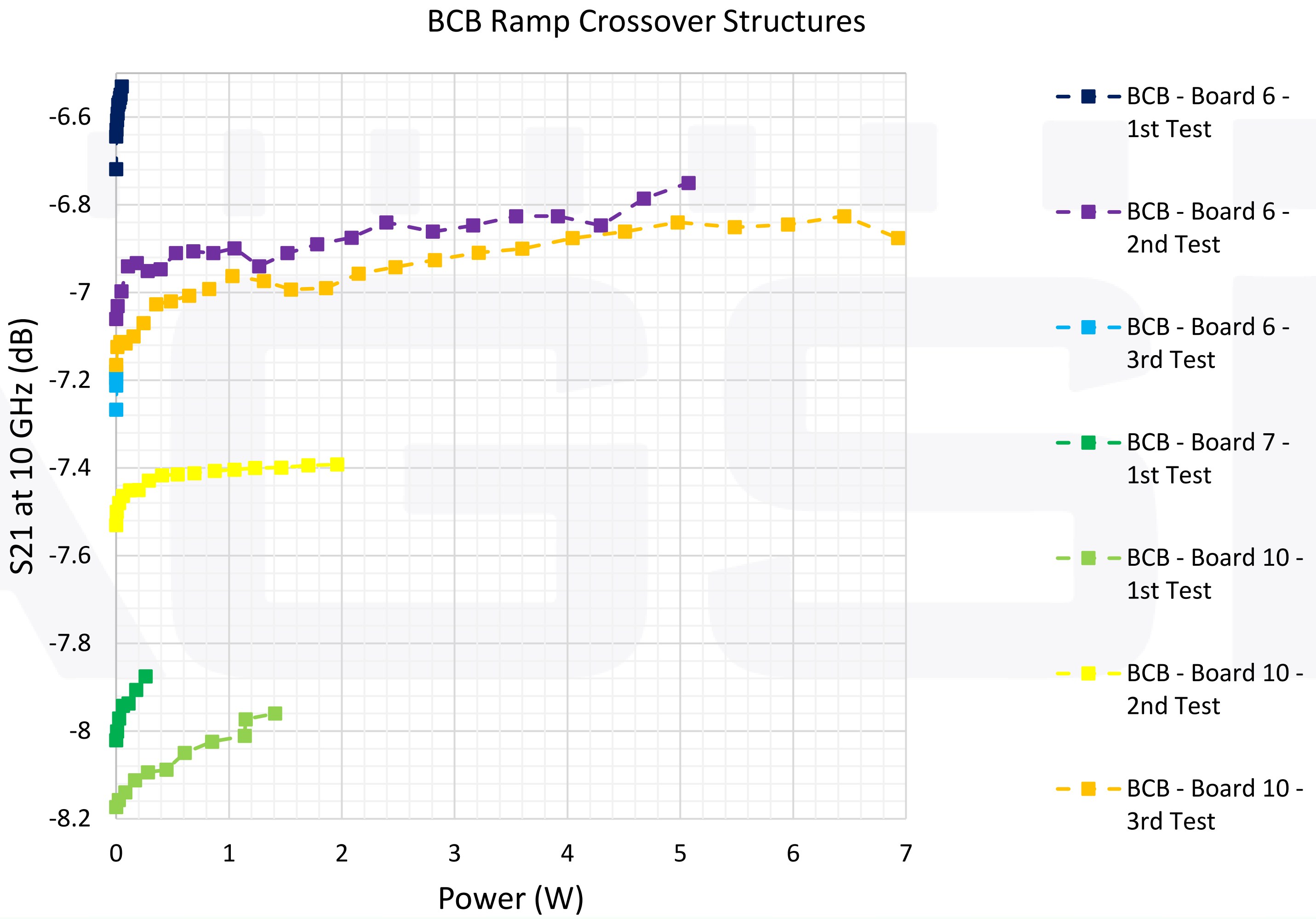
- Average Survival Power Up To 0.36 W
- Max Survival Power Up To 2.224 W
- Largest ΔS21: 0.271 dB



Results: BCB Ramp Power Handling

BCB Ramp Structures

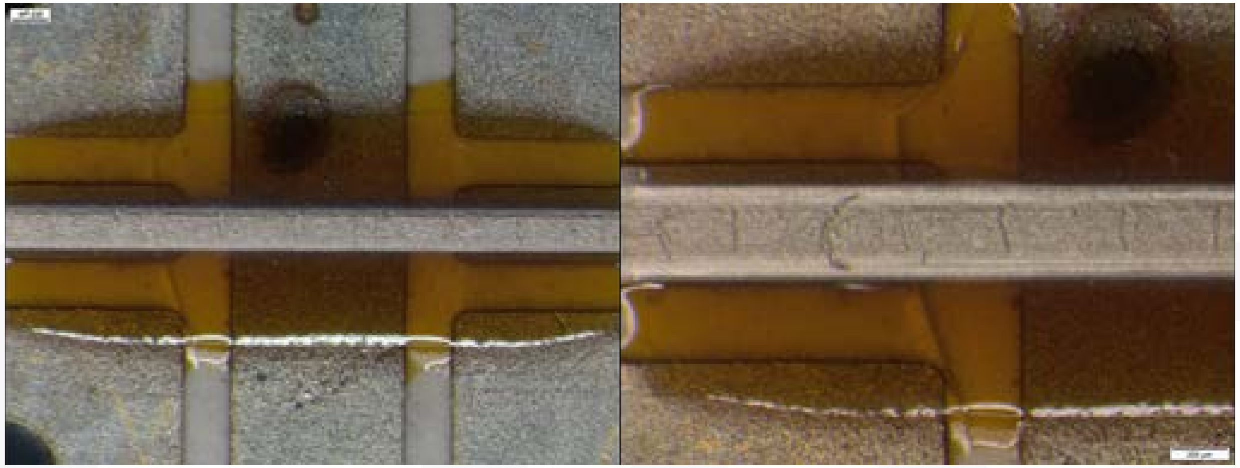
- Average Survival Power Up To 1.4 W
- Max Survival Power Up To 6.93 W
- Largest ΔS21: 0.339 dB



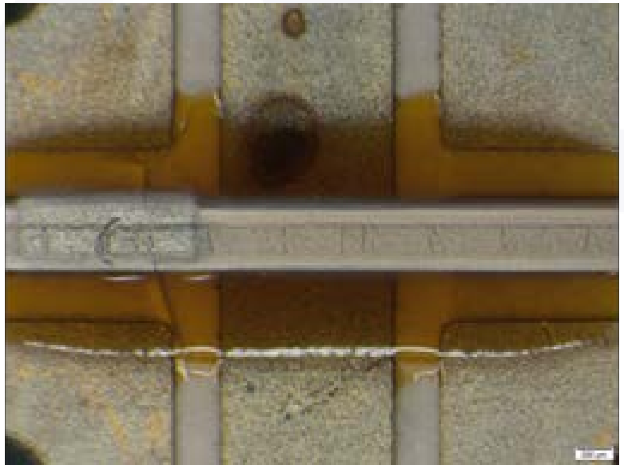
Failure Analysis: BCB Ramp

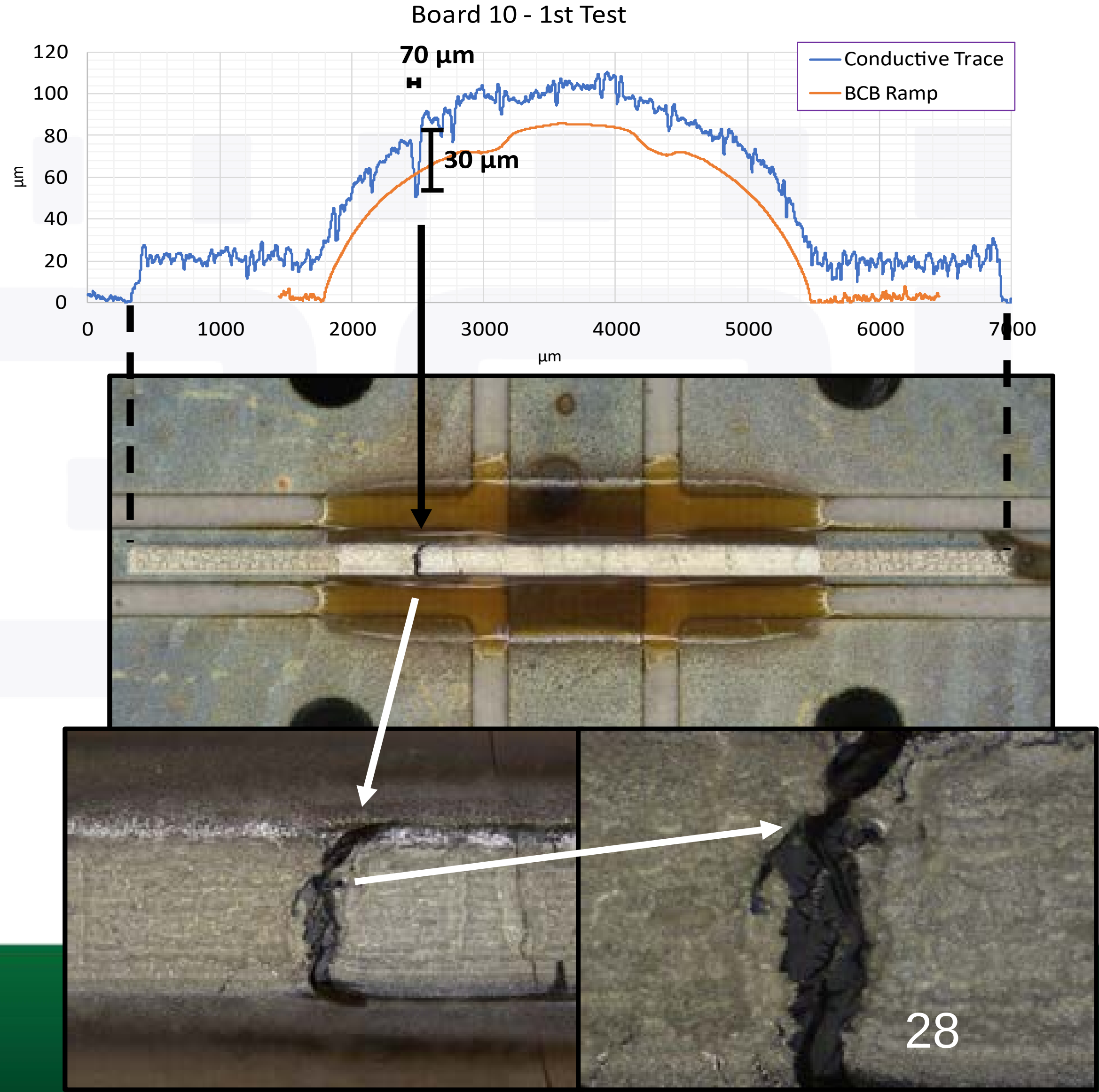
1st Test: Before/After

2nd Test



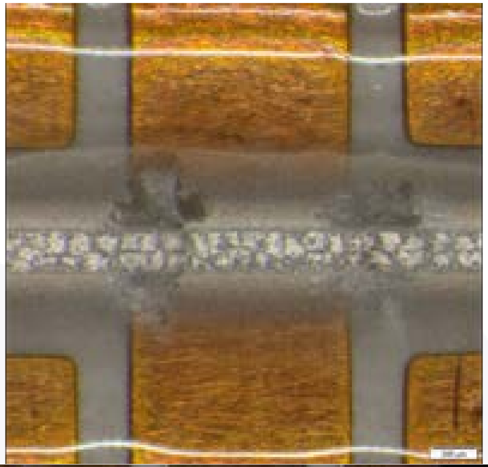
3rd Test →





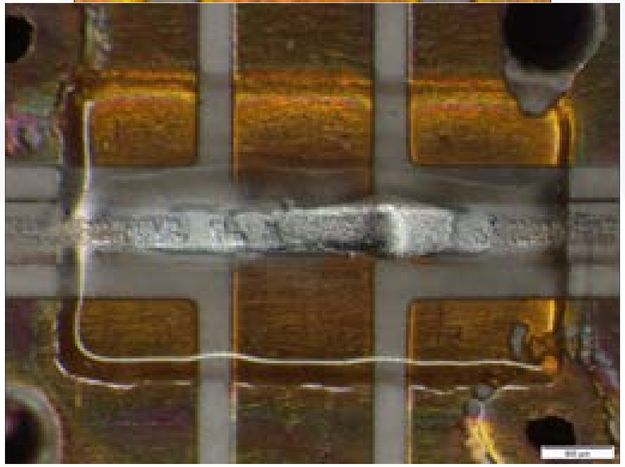
Failure Analysis

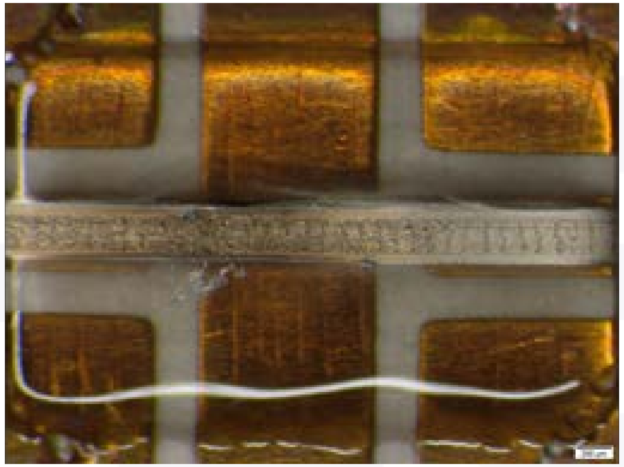
NEA Pad



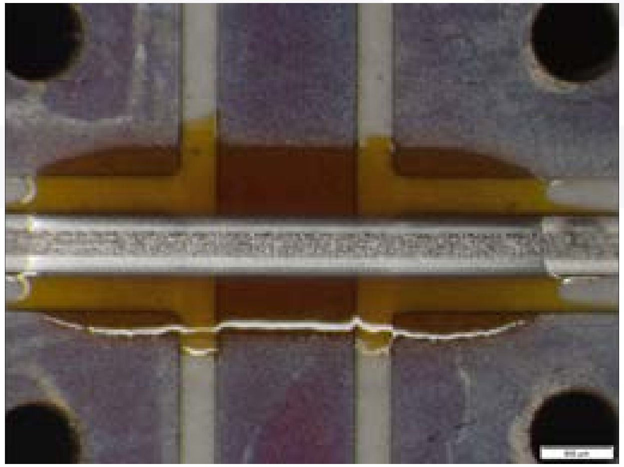
Repair

NEA Pad





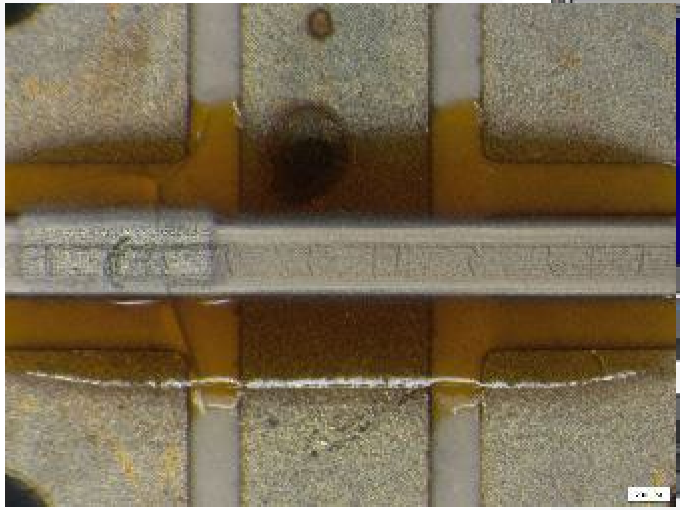
NEA Pad

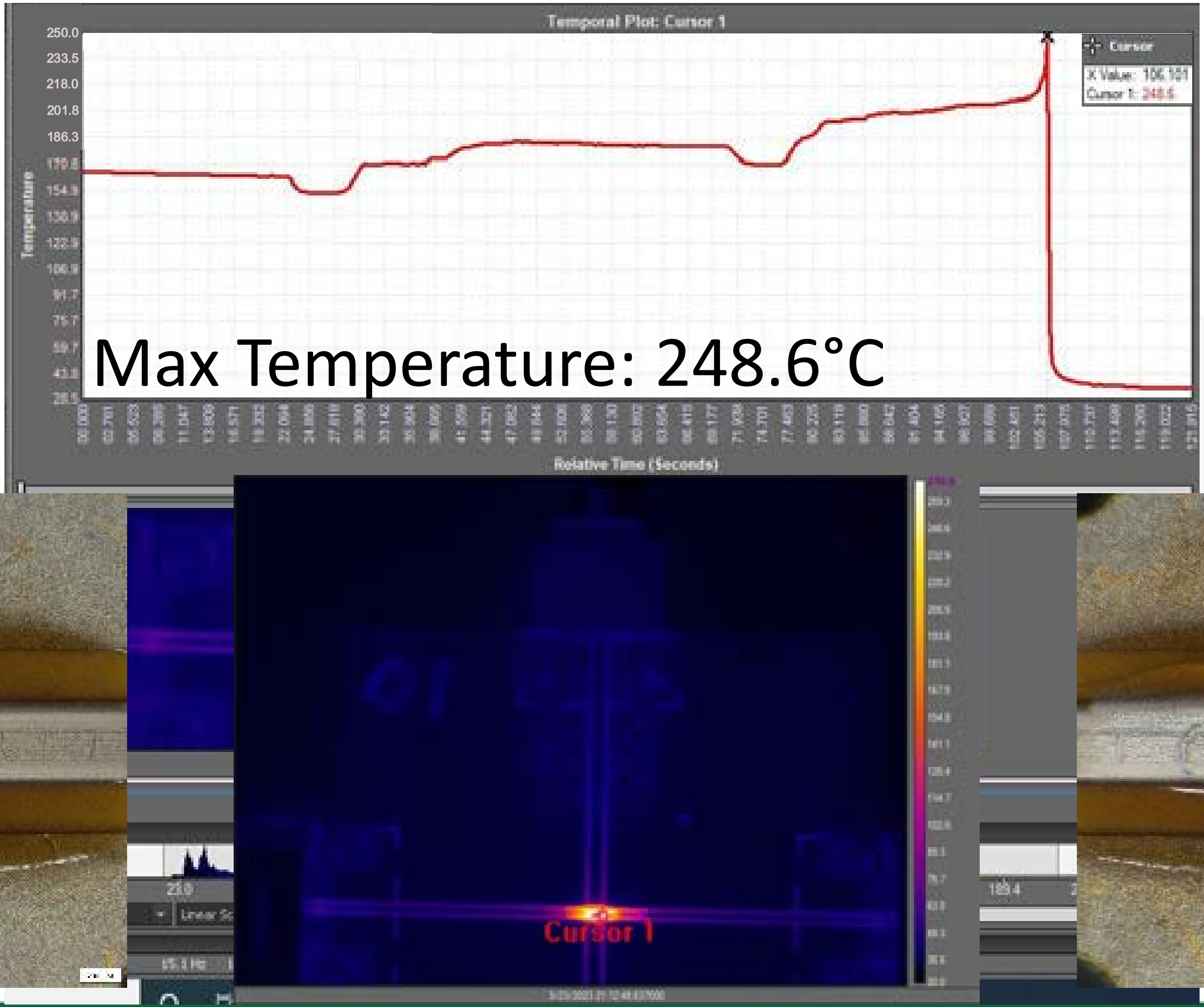


BCB Ramp

Thermal Analysis: BCB Ramp

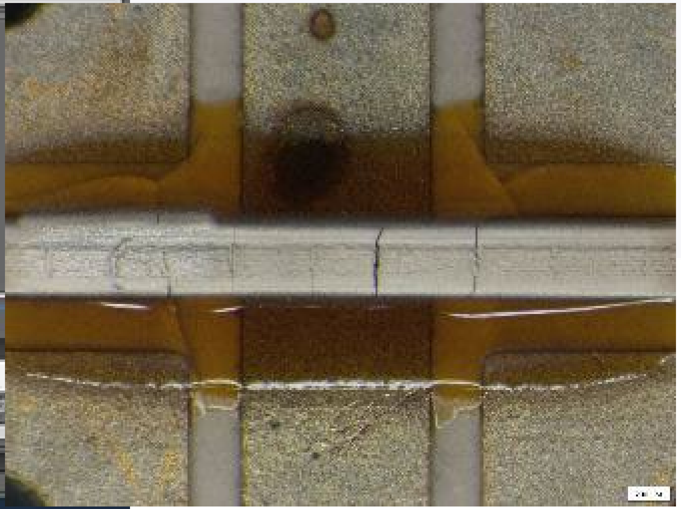
Before Testing



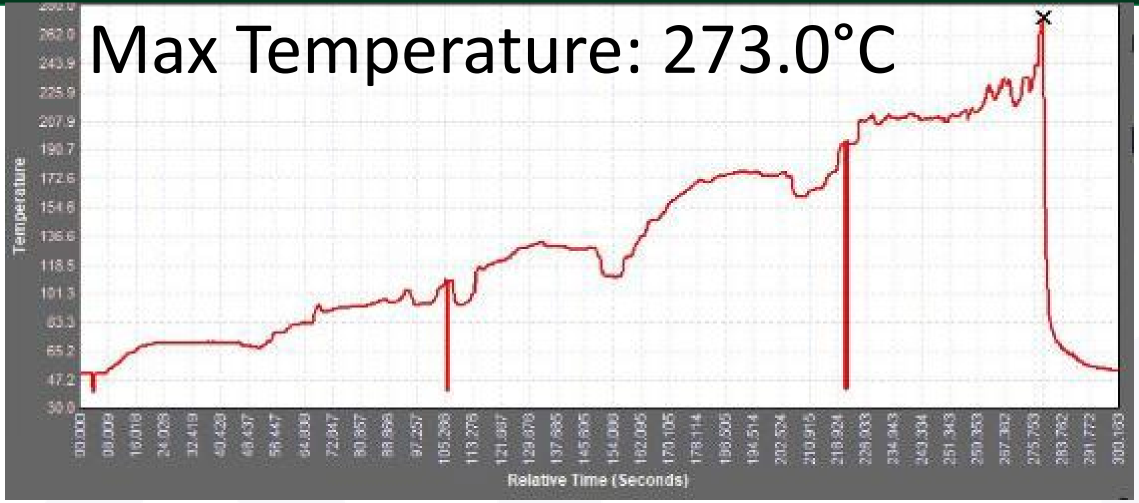


Max Temperature: 248.6°C

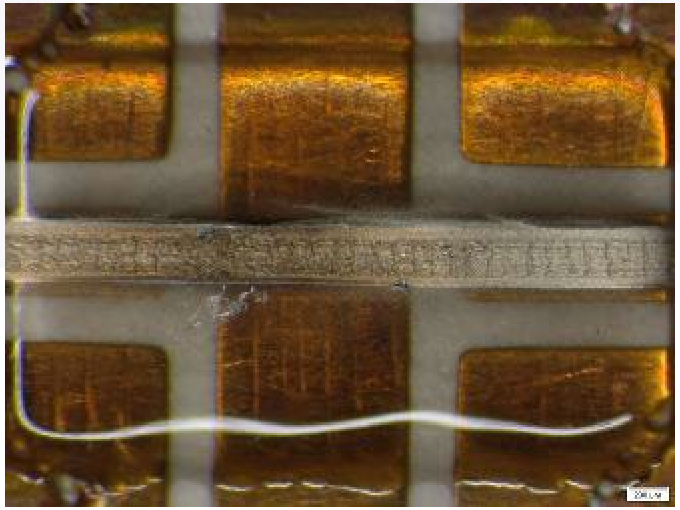
After Testing



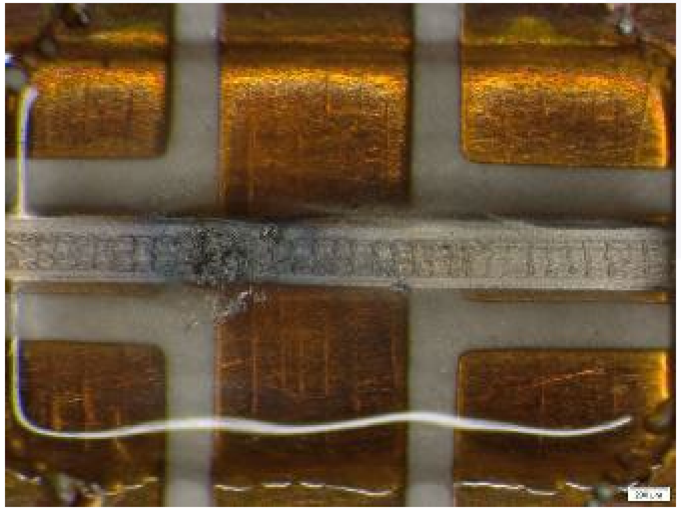
Thermal Analysis: NEA Pad



Before Testing



After Testing



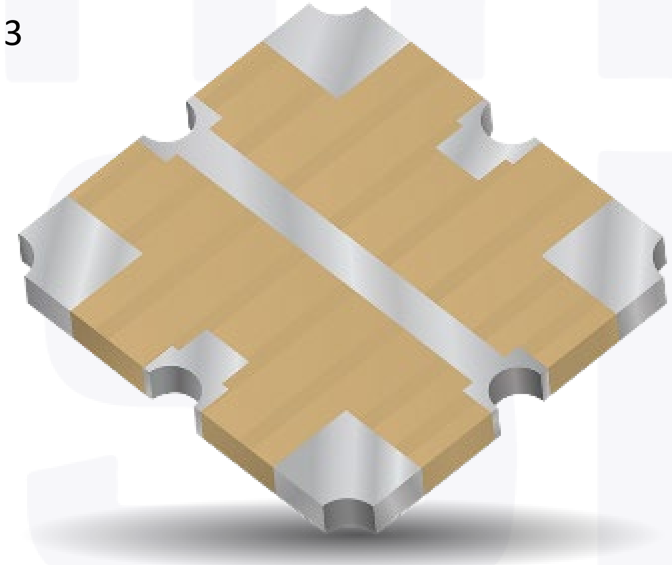
Comparison To COTS SMT Devices

COTS SMT Devices:

- MLO® SMT RF-DC Crossover Footprint: 4.98 x 4.98 x 0.46 mm^3
  - Specifications: 9 W at 6 GHz
- X2BS Crossover Footprint: 5.08 x 5.08 x 1.8 mm^3
  - Specifications: 10 W at 6 GHz

Printed Crossovers:

- Pad Design: 3.8 x 2.3 x 0.365 mm^3, 2.224 W at 10 GHz
  - 3.6x vol. reduction and 2.8x area reduction to MLO®
  - 15.7x vol. reduction and 3.0x area reduction to X2BS
- Ramp Design: 3.65 x 1.15 x 0.141 mm^3, 6.93 W at 10 GHz
  - 19.3x vol. reduction and 5.9x area reduction to MLO®
  - 78.7x vol reduction and 6.1x area reduction to X2BS



Conclusions

- 5 NEA Pad and 5 BCB Ramp Crossover Structures Were Printed

	Maximum Power (W)	Maximum ΔS21 at 10 GHz (dB)	Maximum Temperature (°C)
NEA Pads	2.224	0.271	273.0
BCB Ramps	6.93	0.339	248.6

- Comparable to COTS SMT Components:
  - Slightly Less Power Handling
  - 6.1x reduction in physical board space
  - **Extremely Tailorable: Materials, Shape, Specifications**

Acknowledgements

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- Packaging Lab
- Funding: AFRL SFFP, DAGSI (SOCHIE Control# RY11-WSU-22-3 - FE 2) , WSU (Grant #671512)
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