Multi-physics modelling for Flexible Hybrid Electronics

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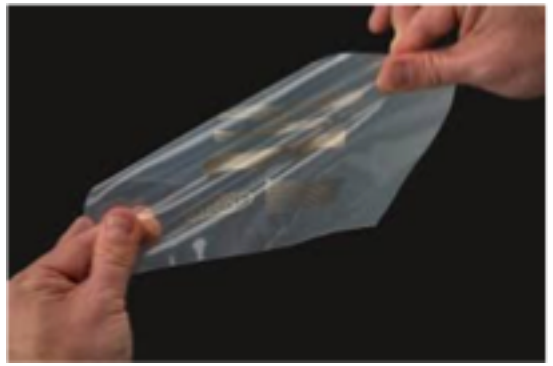
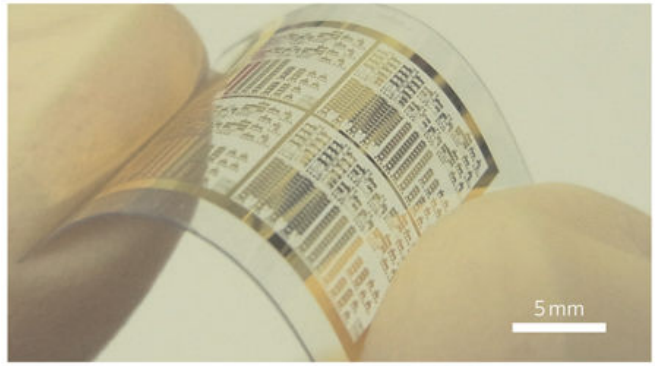
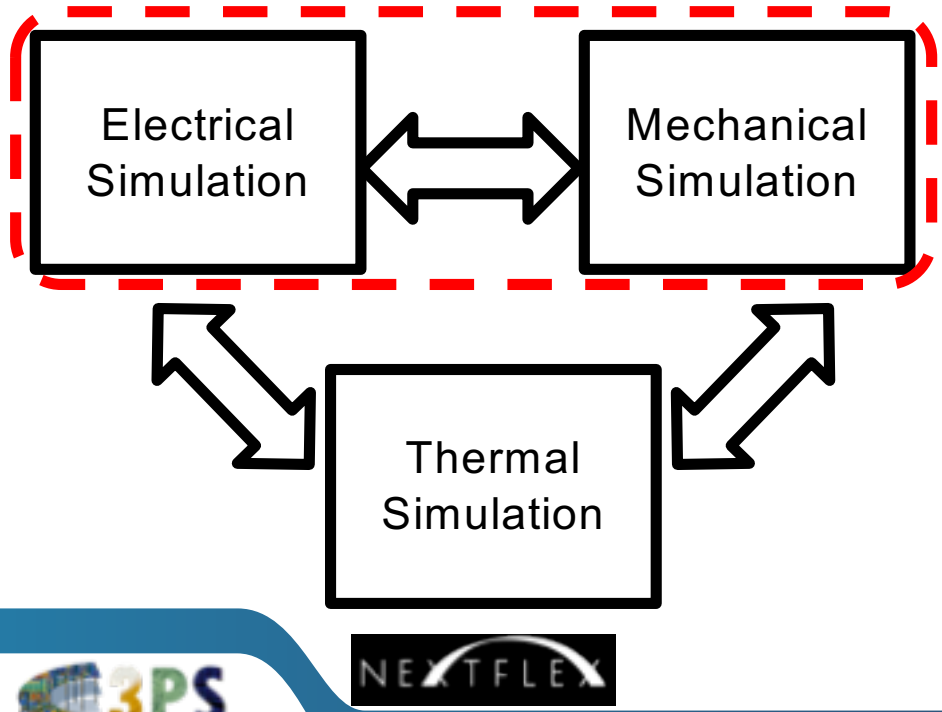
Stretching



Bending



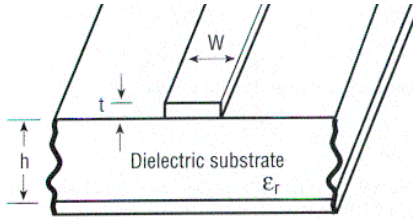
Twisting



- ❑ Modeling operating conditions important
- ❑ Possible scenarios:
  - Mechanical loading changes electrical response due to geometrical changes
  - Mechanical loading changes electrical properties

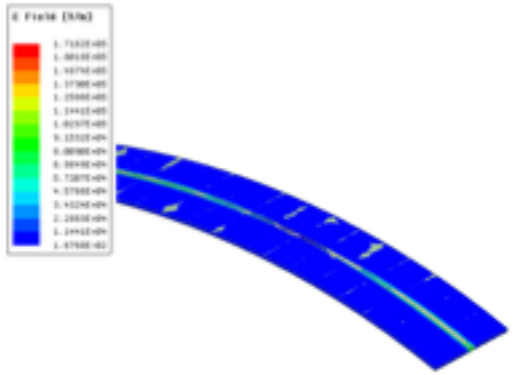
  ……
- ❑ Questions to be answered:
  - ❑ Are such effects important?
  - ❑ How do you model the electrical response in such scenarios?
  - ❑ Are the commercially available tools adequate?
  - ❑ How complex are such simulations?
  - ❑ Can you develop models that are predictive and capture behavior?

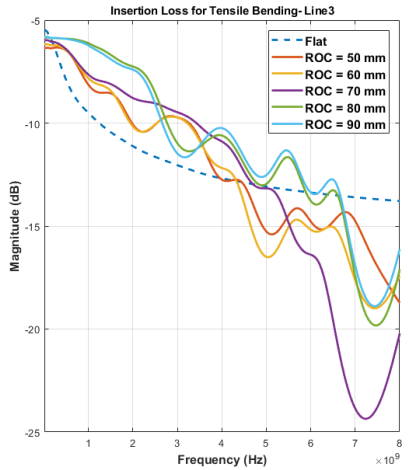
Aerosol Jet Printed Microstrip Line

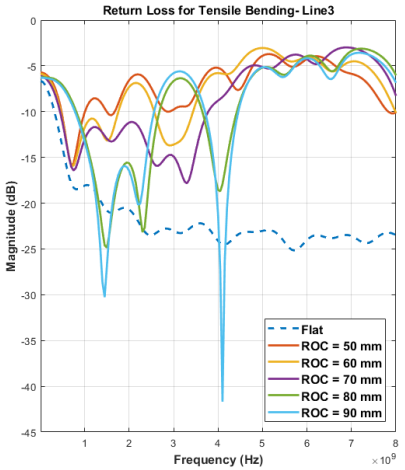


- 5 mil Kapton Polyimide with single-sided 18 µm Copper coating
- UTD silver nano-ink

Modeling

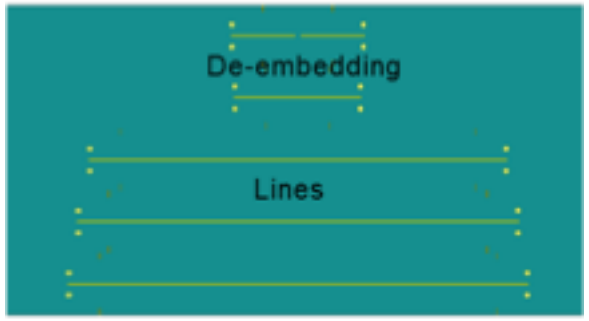






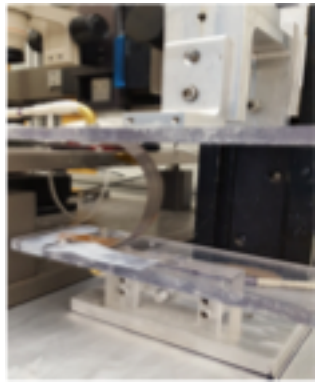
Electrical Response Changes with Bending (Modeling)

Test Structures

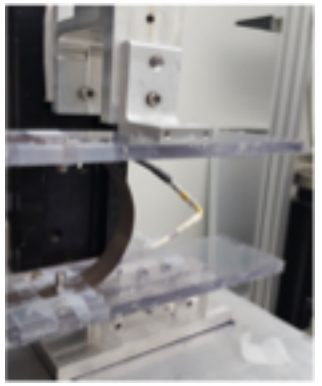


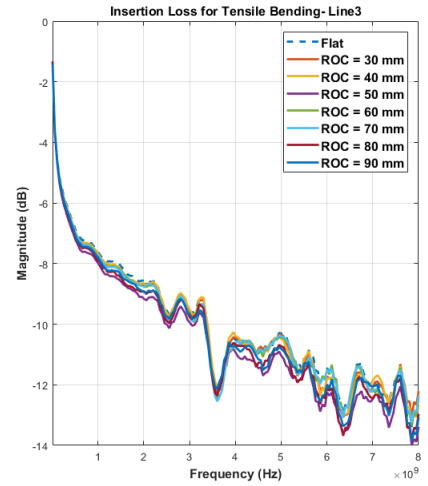
Measurement

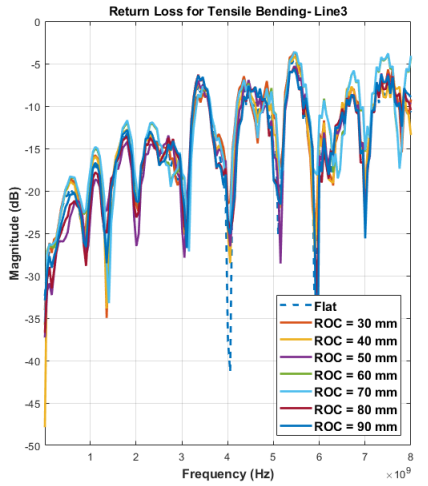
Tensile



Compressive



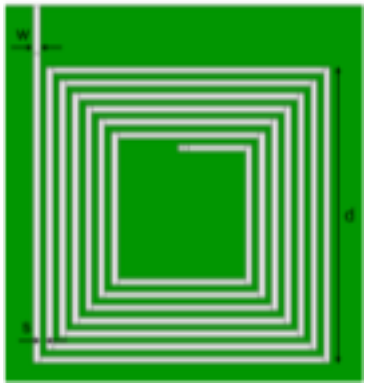


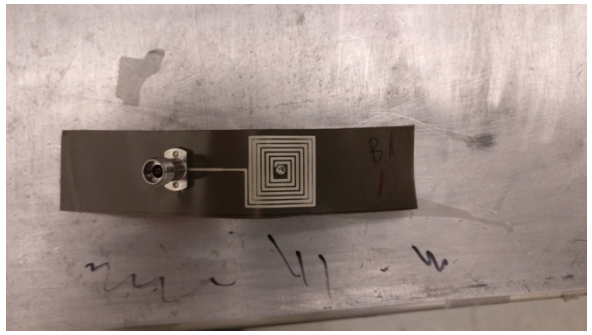


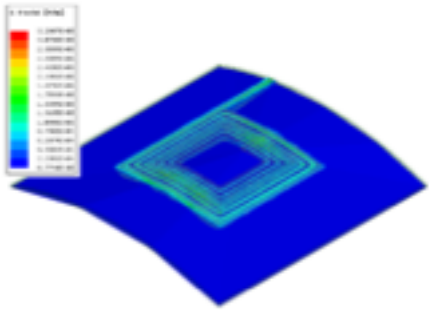
- ❑ Are Modeling Tools Incorrect?
- ❑ No (In this Case)
  - ❑ Difficulty in replicating measurement setup in the Tool is the problem!

Electrical Response Doesn't Change with Bending (Measurement)

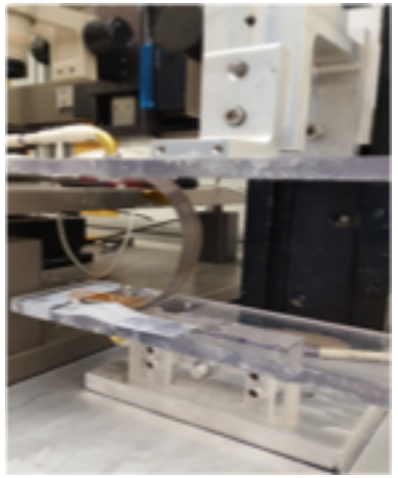
Screen Printed Power Inductor (Single Cycle)



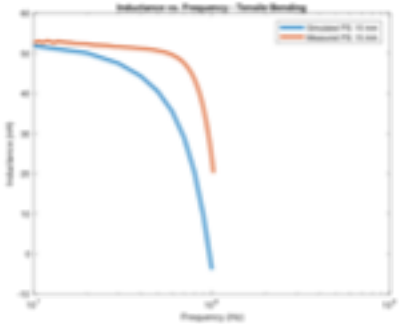
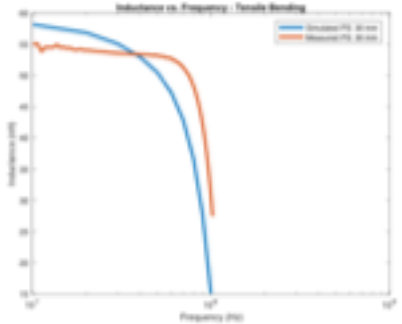
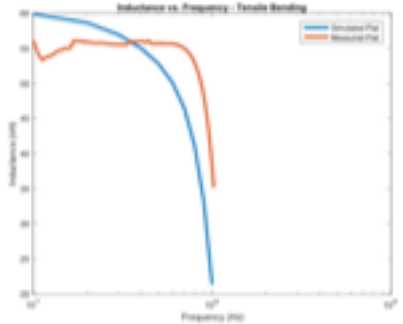
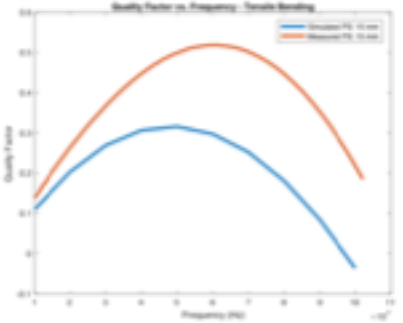
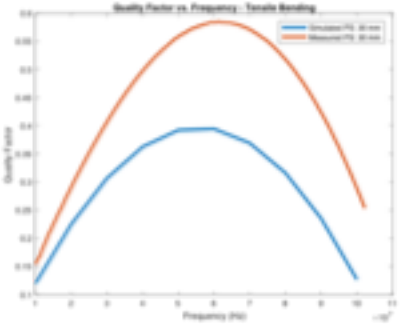
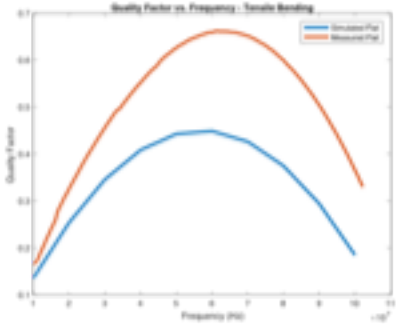




- 5 mil Kapton Polyimide with 18 µm Copper ground plane
- Silver ink 10.5 µm



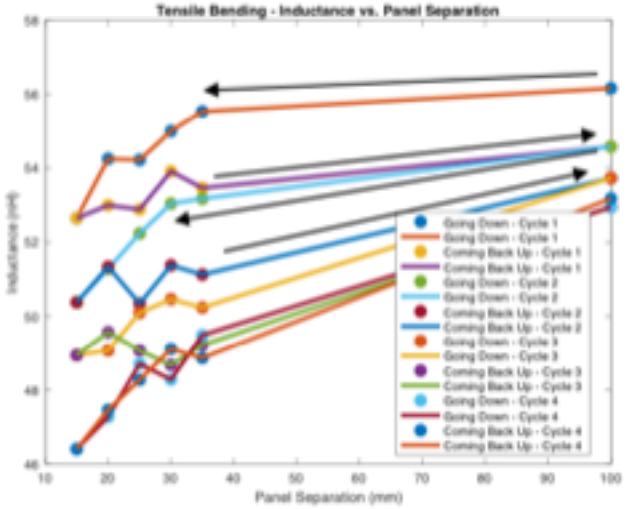
Red: Measured
Blue: Simulated
PS: Panel Separation

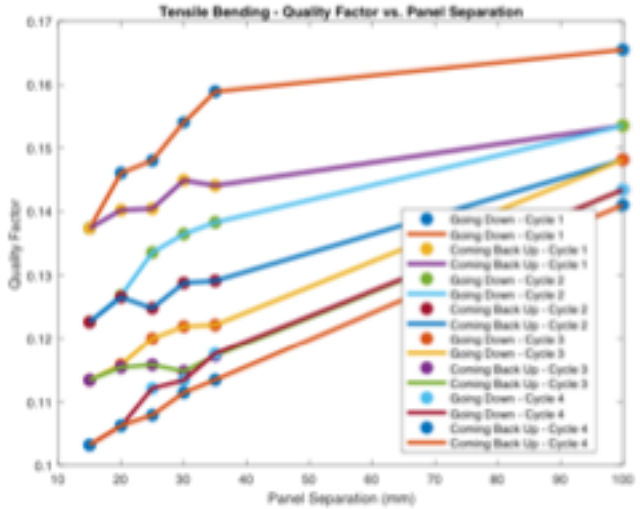







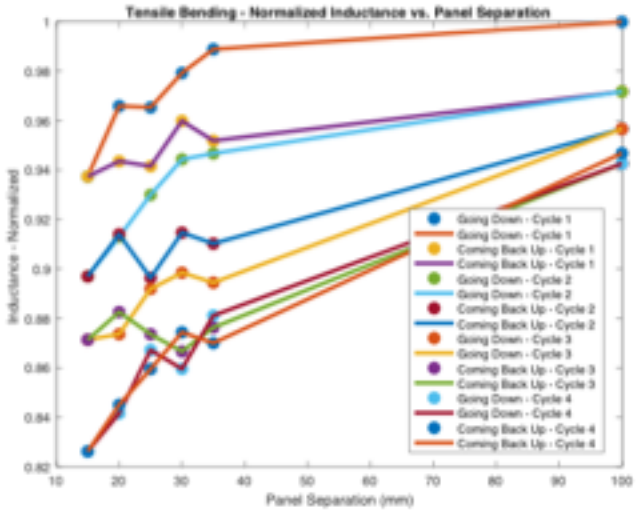
PS: 15 mm | PS: 30 mm | Flat

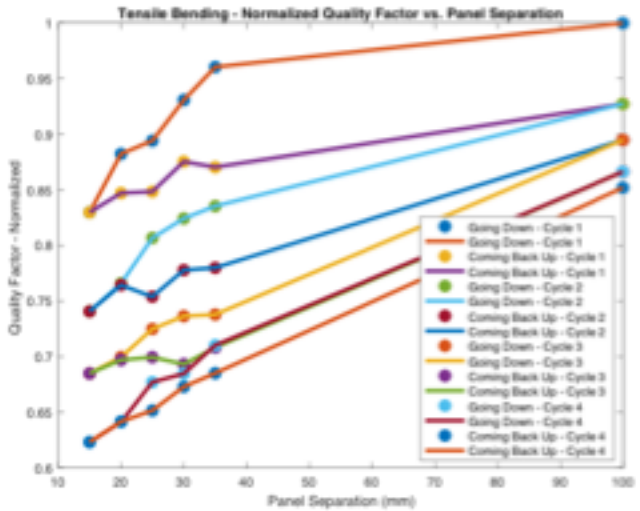
- ❑ With decreasing panel separation both the inductance and Quality Factor decrease (measurements).
- ❑ Modeling captures this effect partially!

Screen Printed Power Inductor (Multiple Cycles)









- Tensile Bending
- Four Cycles
- Flat – 15mm Panel Separation – Flat - ….
- Substantial change in Inductance & Q Factor
- Unable to capture the Memory effect in Modeling!

Multi-physics Needs, Challenges & Possible Solutions for Flexible Hybrid Electronics

- Tools have reasonable capability to share Mechanical and Electrical Geometric Models
  - Challenge
    - Unable to reproduce the exact mechanical loading conditions
- Multi-physics Modeling
  - Challenges
    - Requires significant user expertise to set-up model
    - Numerical instability a problem sometimes
    - Does not account for any electrical property change due to mechanical loading (Ex: Resistance Change)
    - Does not account for any memory effects (Ex: Multiple cycle bending)
    - CPU & Memory Intensive
- What needs to happen for FHE to succeed
  - Tools need to be well calibrated with measurements, gaps identified & solutions developed to fill gaps.
  - Predictive modeling required that is Super Fast and error free
    - Correlate Multi-physics model with Measurements
    - Rely on tools to generate data samples
    - Use Machine Learning to develop predictive model
      - Incorporate into Process Design Kits (PDK)