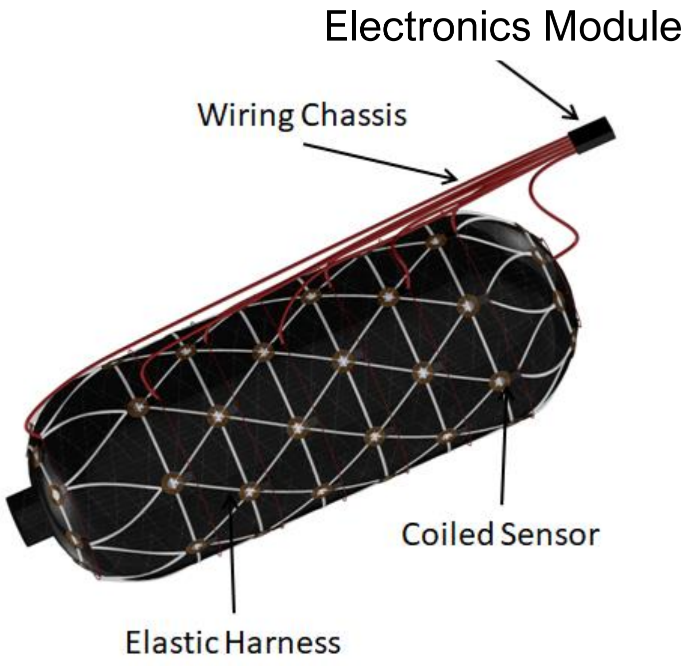
Onboard Damage Detection in Carbon Fiber Composites in Hydrogen Storage Tanks

Dr. Joshua R. Biller
Principal Scientist, TDA Research, Inc.



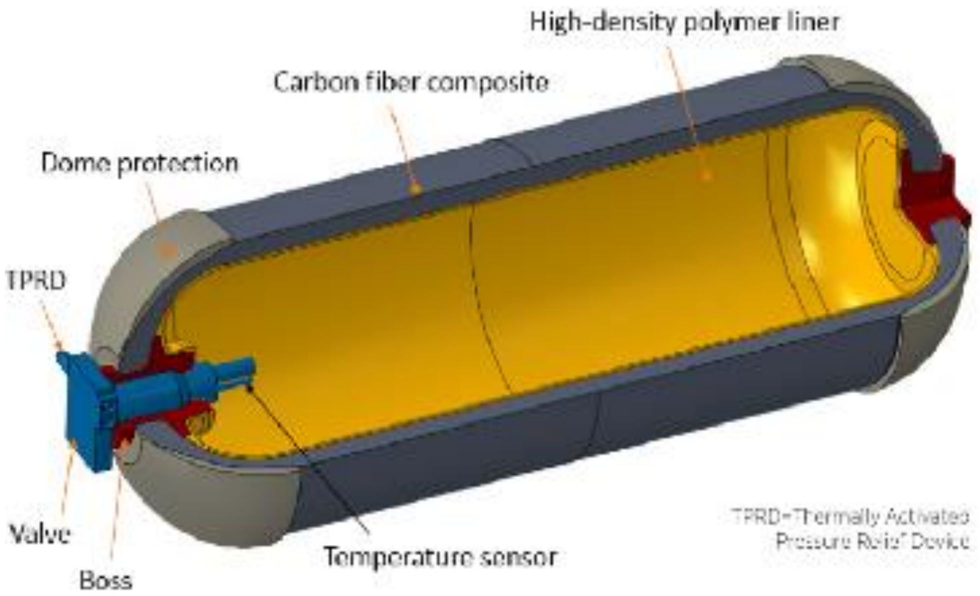
May 2024
Long Beach, CA

sampe
Conference & Exhibition

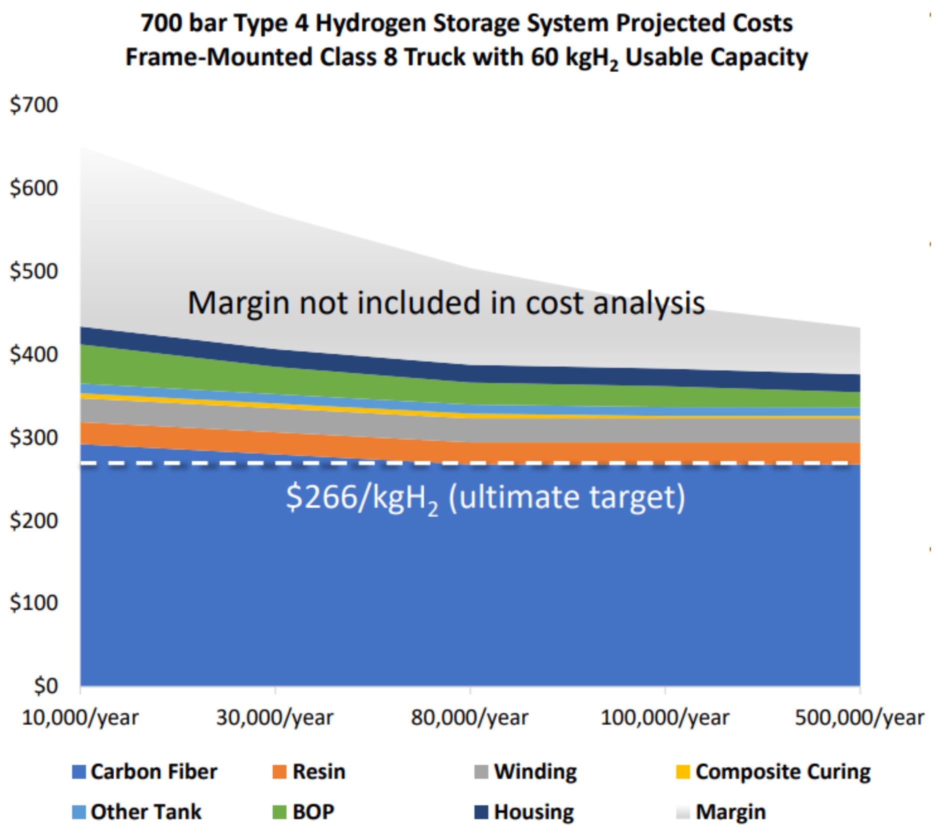
Who is Talking to You?

- **Dr. Josh Biller**
  - TDA Research
  - Principal Scientist
- Physical Chemist, Physicist, and a passable impersonation of an electrical engineer.
- If it involves electromagnetic frequencies (DC to 18 GHz), magnetism or magnetic resonance, I’m likely developing a sensor around it.
- U. Denver (2009 – 2015), NIST-Boulder (2015-2018), TDA (2018-

Composite Overwrap Pressure Vessels (COPV)



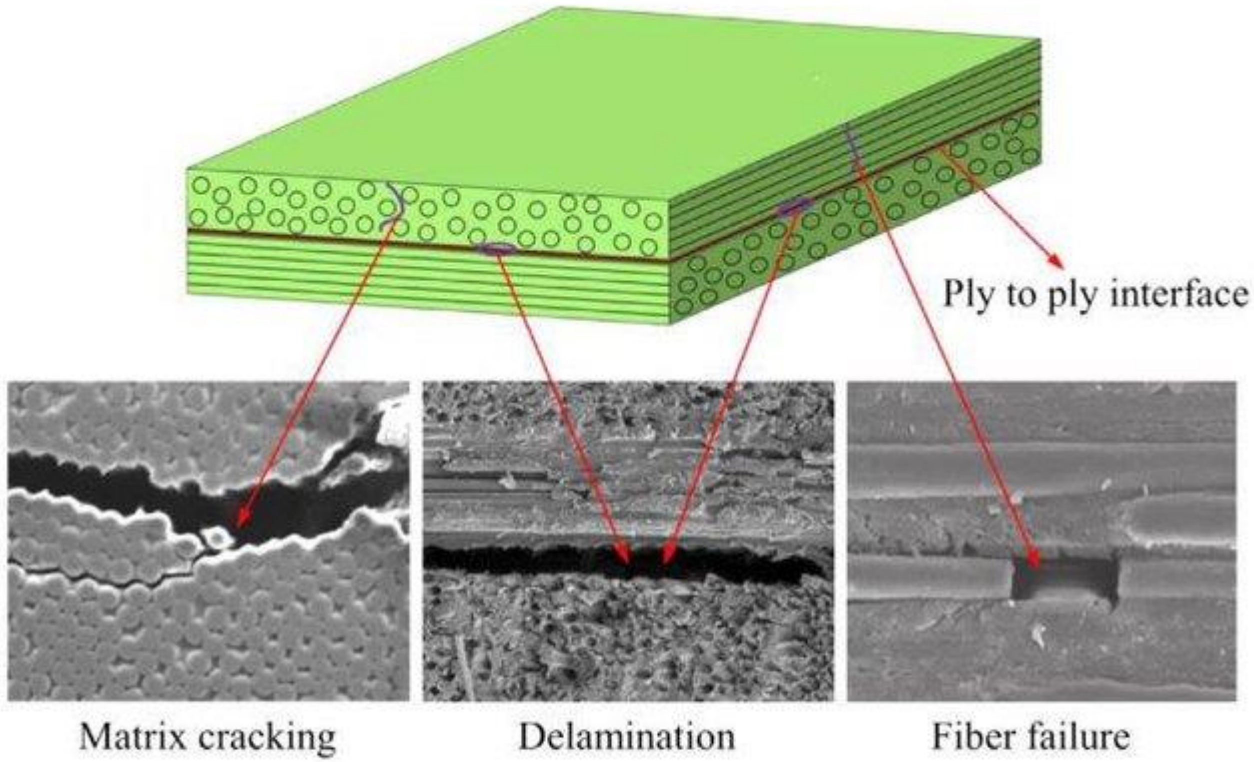
Process Modeling Group, Nuclear Engineering Division, ANL



Reducing thick carbon fiber overwrap (25 – 40 mm) directly supports $266/kgH_2$ target

Credit: (2022) Cassidy Houchins, Strategic Analysis Inc.

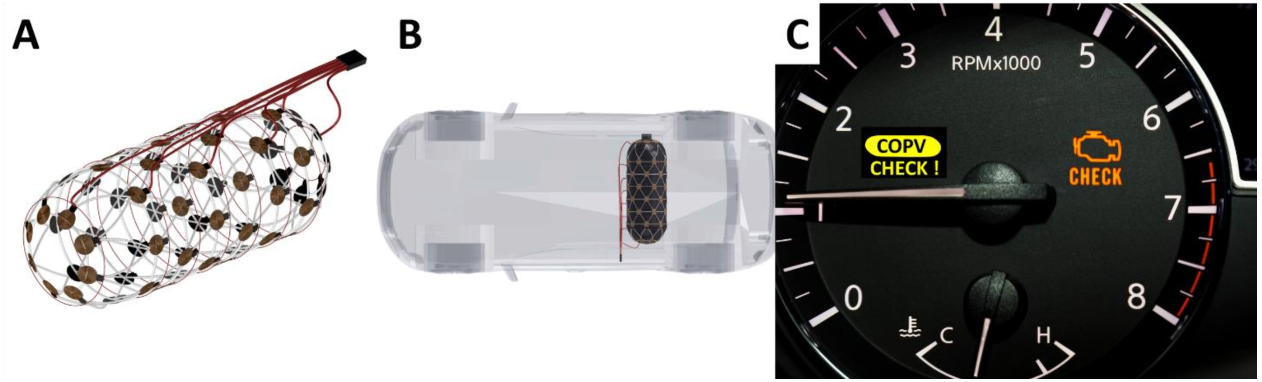
Carbon Fiber Failure Mode



Bui, T. & Hu, X. *Engineering Fracture Mechanics* 248(8):107705

- Carbon fiber failure modes are not yet as well characterized as metals
- There is a fear that failure under pressure could be catastrophic
- Safety margins of 2.5x are recommended

Structural Health Monitoring



If a real-time monitoring system existed – could you relax carbon fiber thickness requirements?

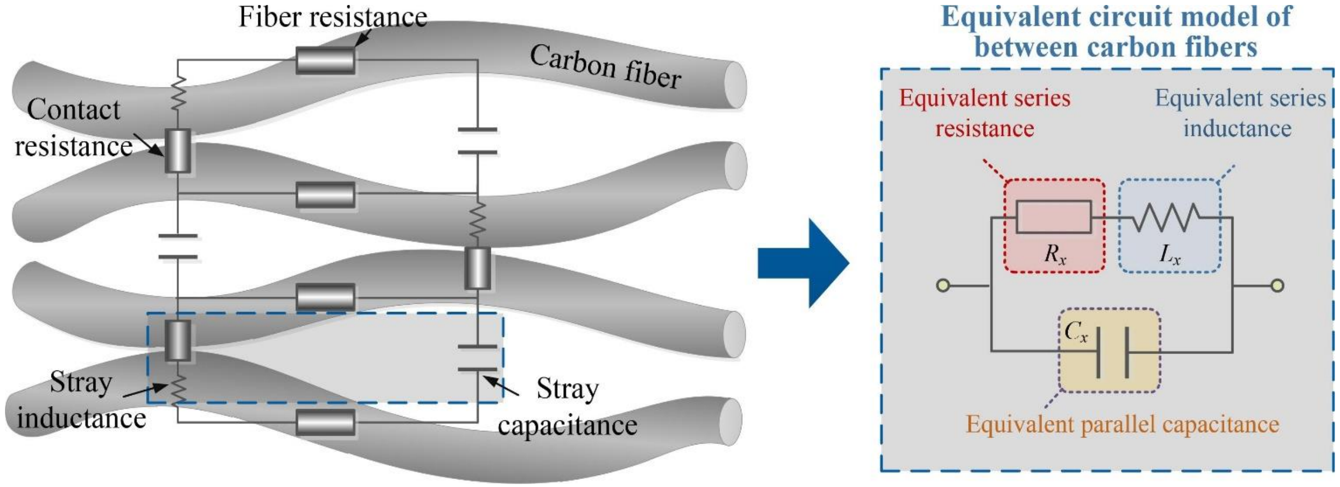
Practical Considerations –

- Low profile
- Can't require change to manufacturing "recipe" (i.e. embedded sensors)
- Can't take much power
- Needs to interface with vehicle computer
- Needs to convince DOT …

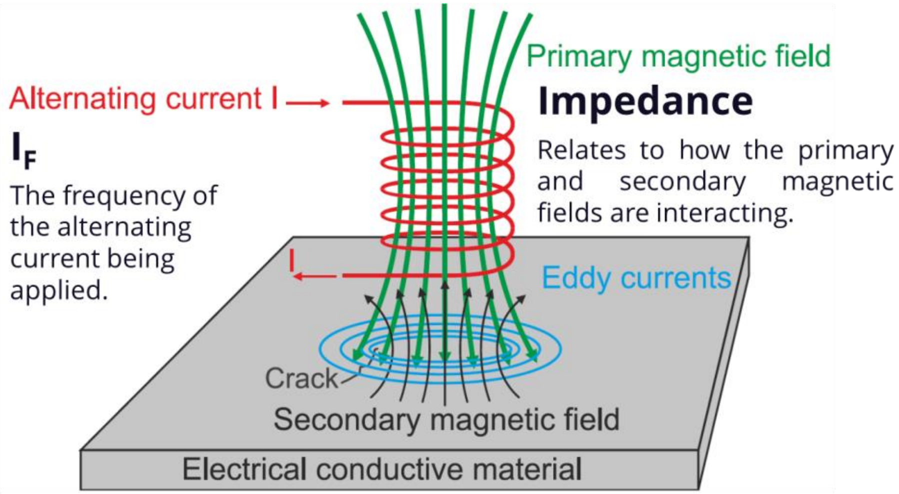
sampe Conference & Exhibition

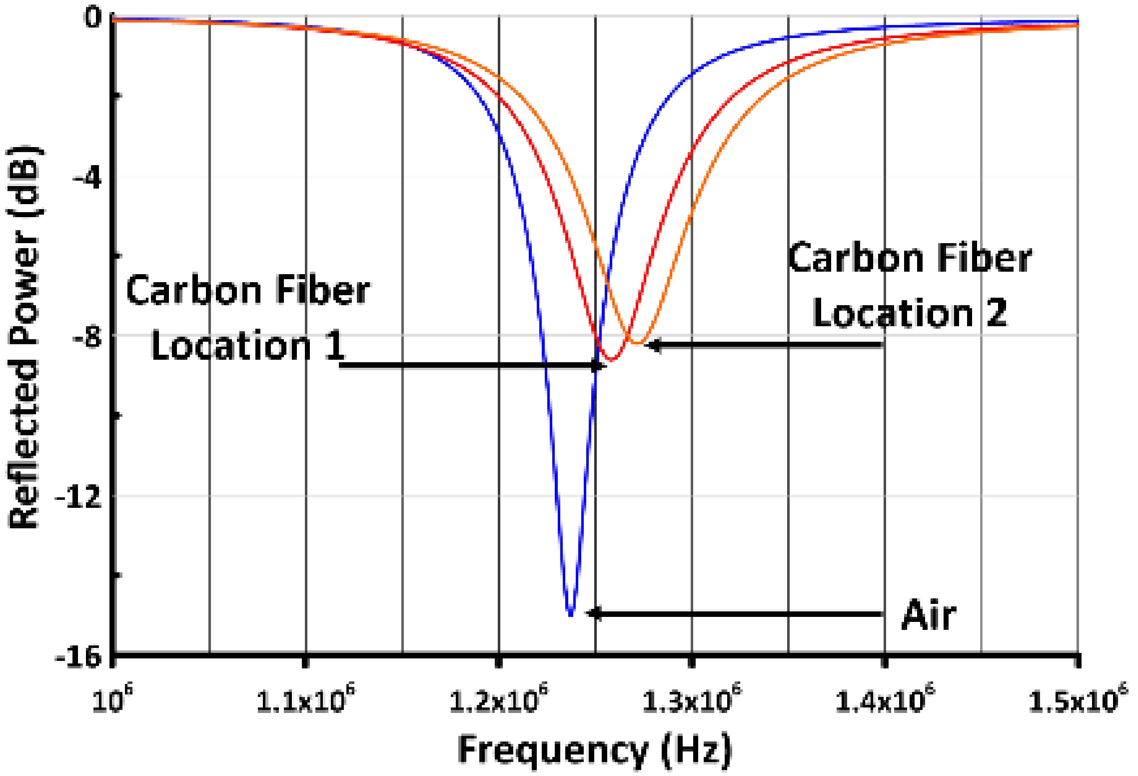
USPTO # 18/222,249, filing date 07/14/2023

Structural Health Monitoring



Wang, T., Wu, D. (2023) Composite Structures, 116948

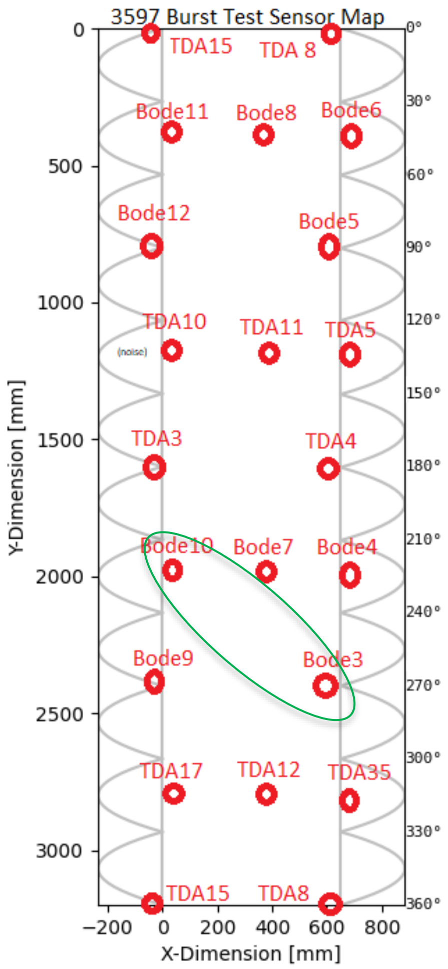


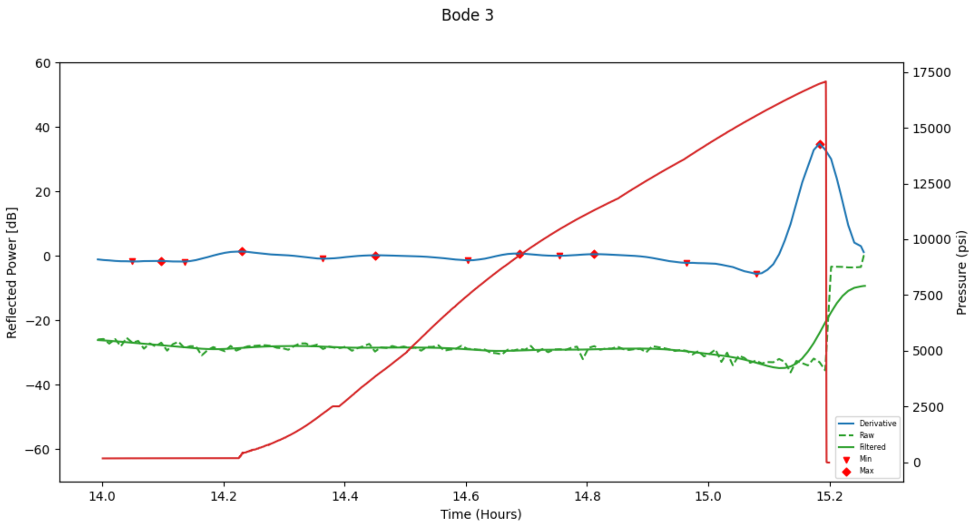


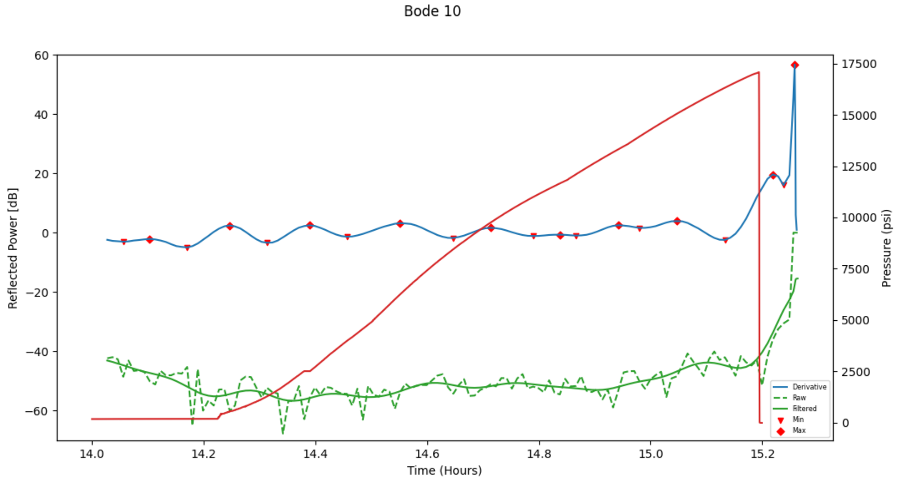
“Electromagnetic Inductive Coupling Analysis (EM

USPTO # 18/222,249, filing date 07/14/2023

Structural Health Monitoring





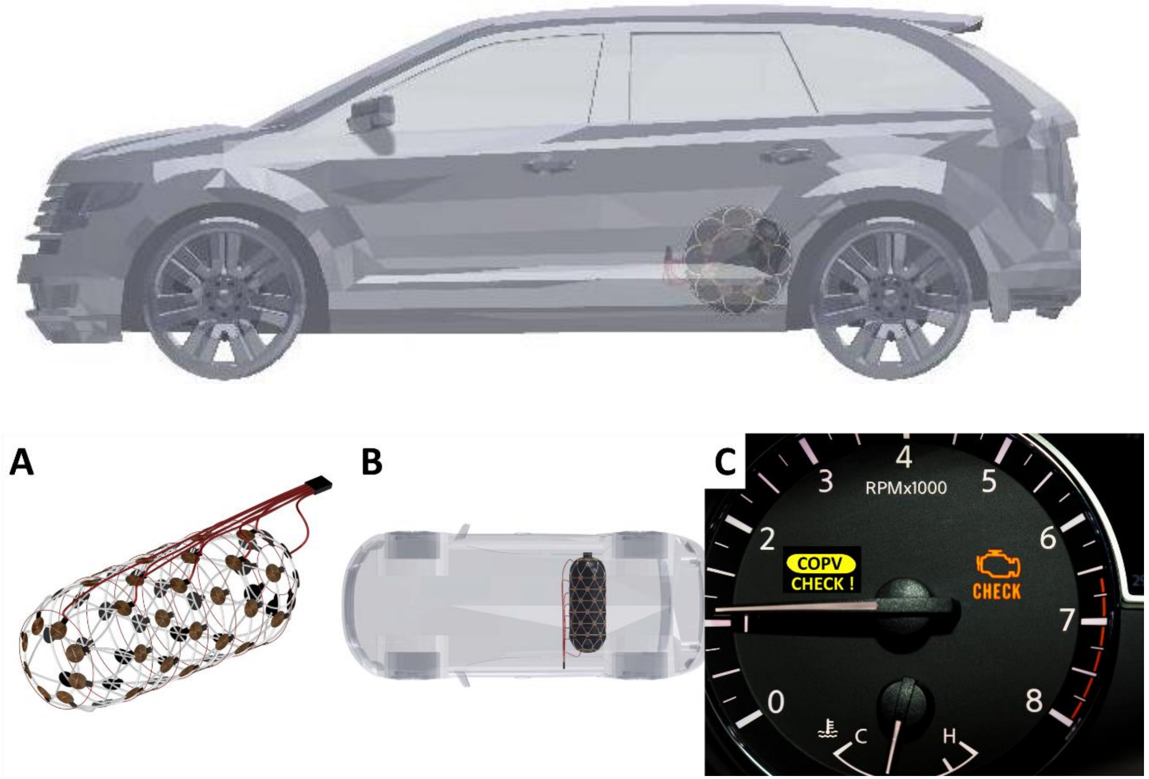


EMICA - SHM

sampe
Conference & Exhibition

USPTO # 18/222,249, filing date 07/14/2023

Mission Accomplished?

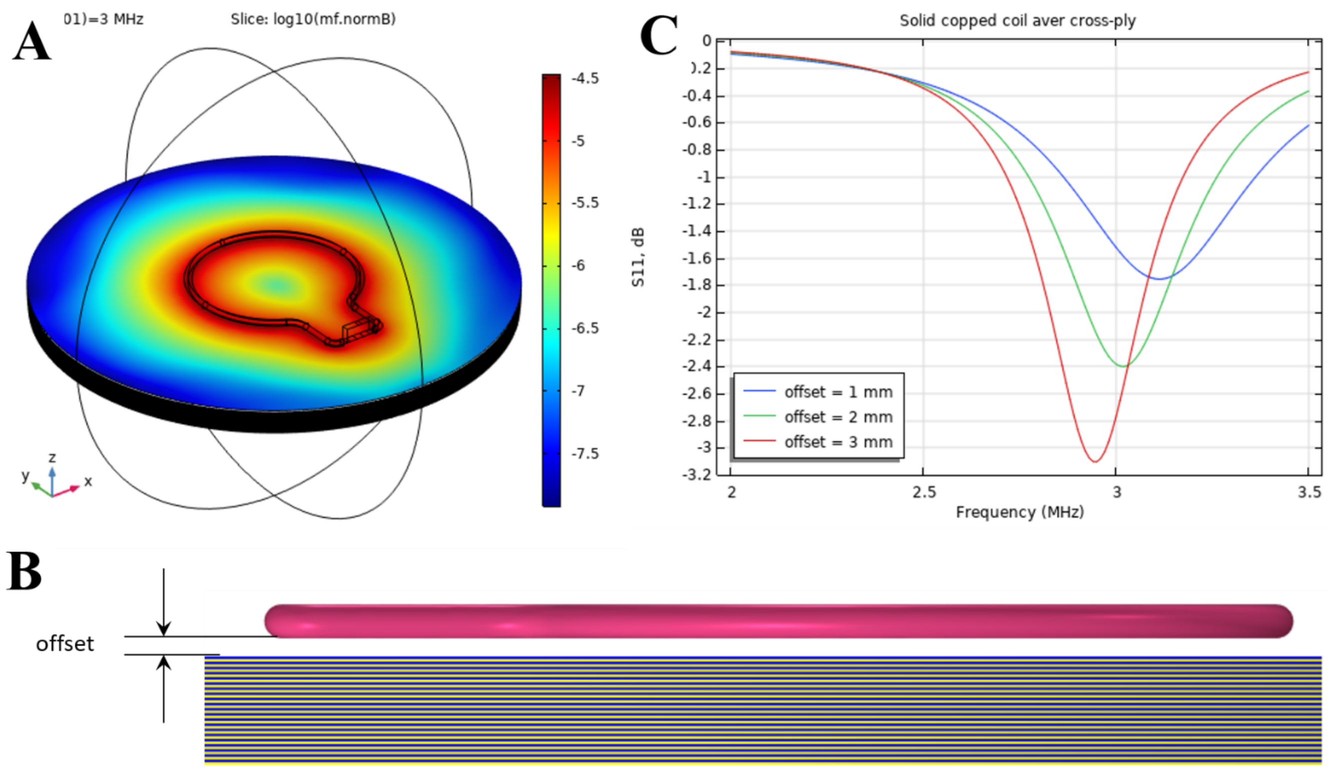


- No …
- Totally unproven new approach
  - Unlike ultrasound, eddy current testing or Xray CT
- There’s no safety data or context for this new technique
- “If I put something on, I have to take something off”
- Without DOT blessing, there is no thinning the carbon fiber on COPV

How Do You Build the Convincing Dataset?

- Understand the nature of electromagnetic field in carbon fiber laminate (It’s extremely complicated. Run away!)
- Make “standard” laminate samples with known defects at specific locations and calibrate (Works pretty well, metrology for the win)
- Make “standard” COPV with known defects (thank you Steelhead) and calibrate.
- Compare standard samples with a “gold standard” NDE (thanks to LM)

Electromagnetic Field in Carbon Fiber

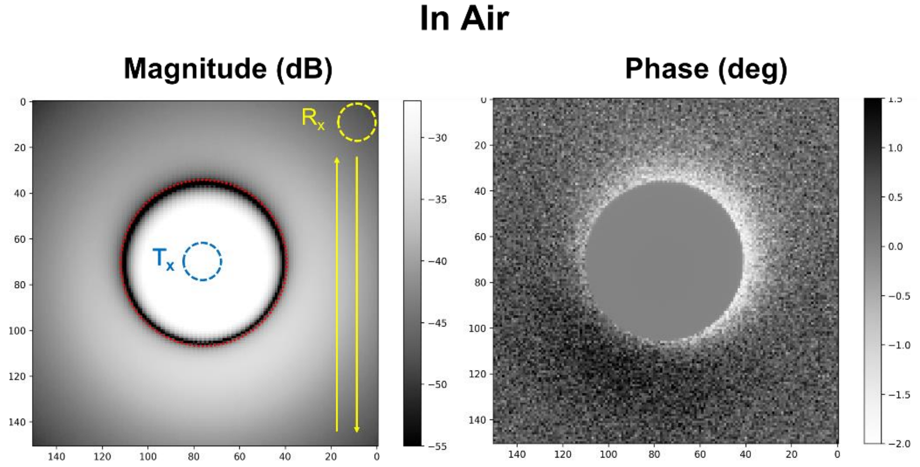


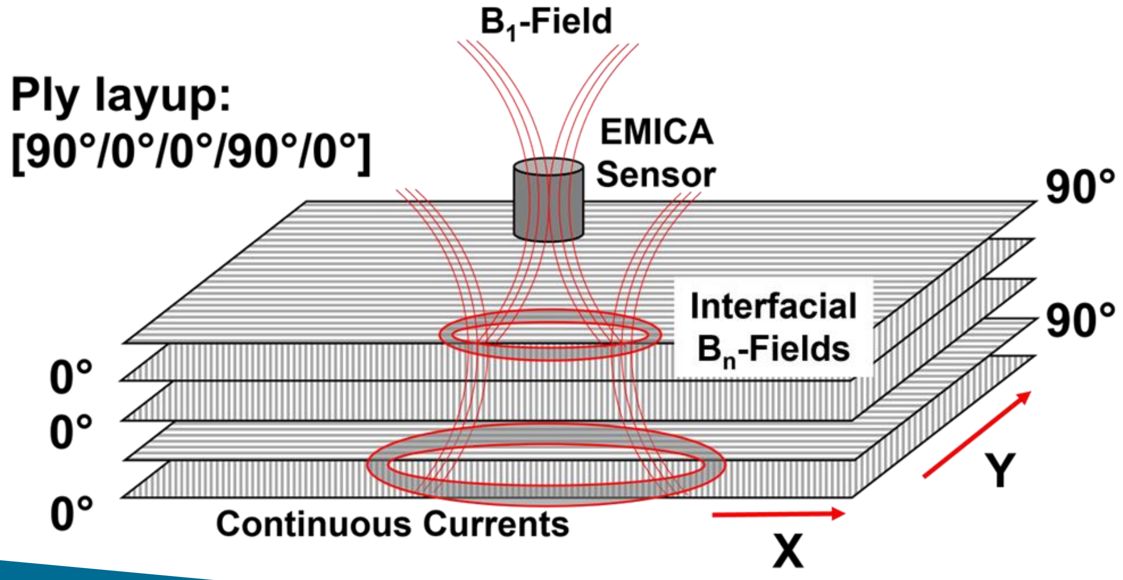
TDA & Alta Sim Technologies

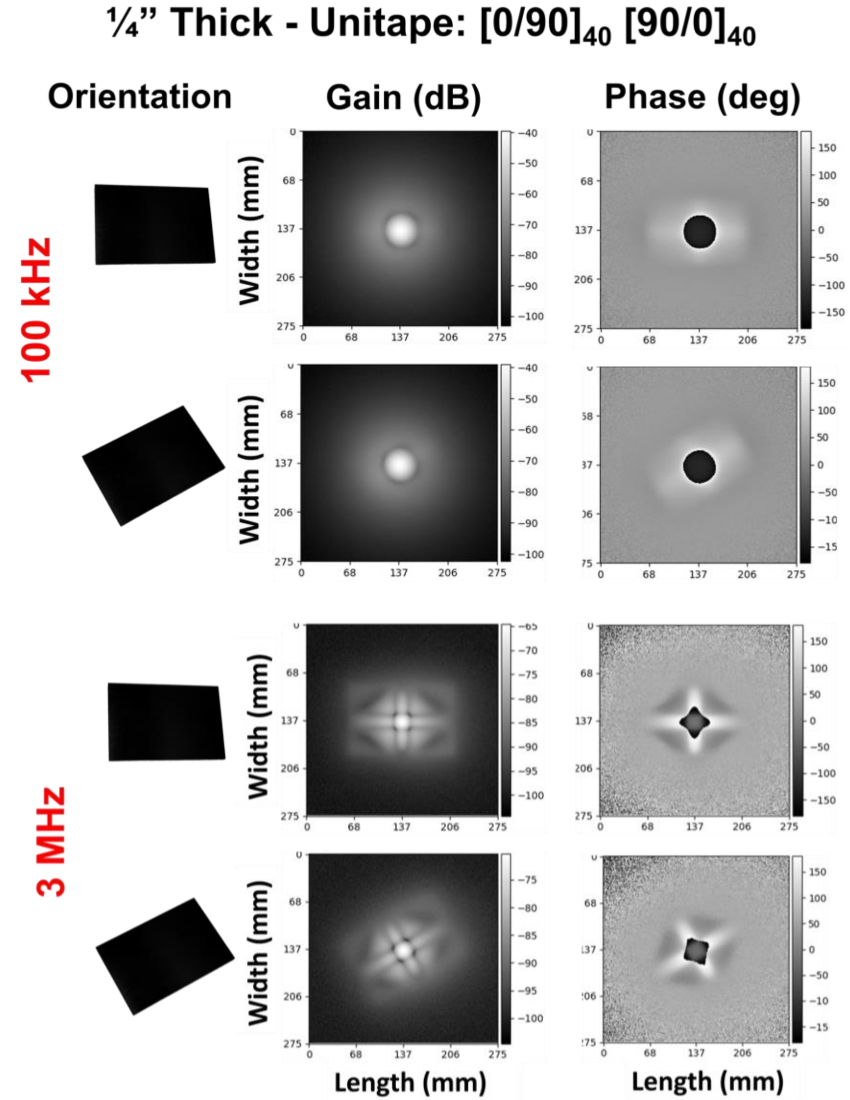
- You can force a simulation, but our best determined operating conditions site between two modules in COMSOL
- Your CF can't be very thick, or complicated
- **You can't simulate the spread of EMF along and through the carbon fiber laminate**

USPTO # 18/222,249, filing date 07/14/2023

Electromagnetic Fields in Carbon Fiber



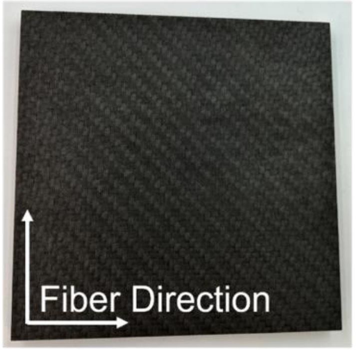




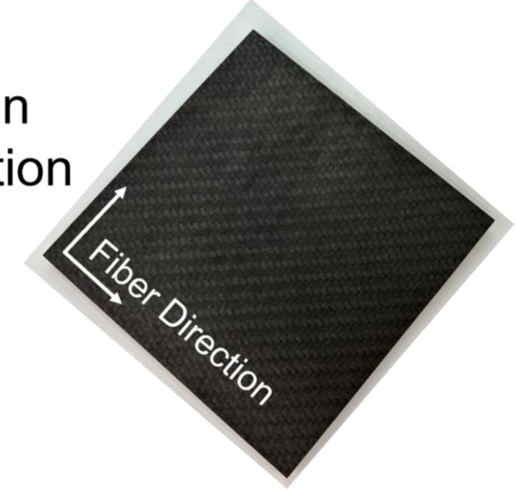
USPTO # 18/222,249, filing date 07/14/2023

Electromagnetic Fields in Carbon Fiber

Scan Direction

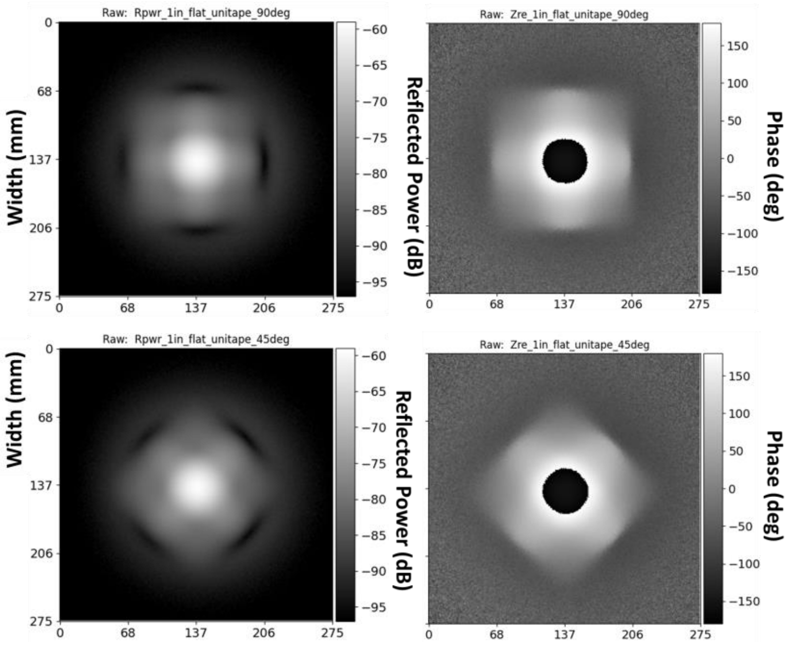


Scan Direction



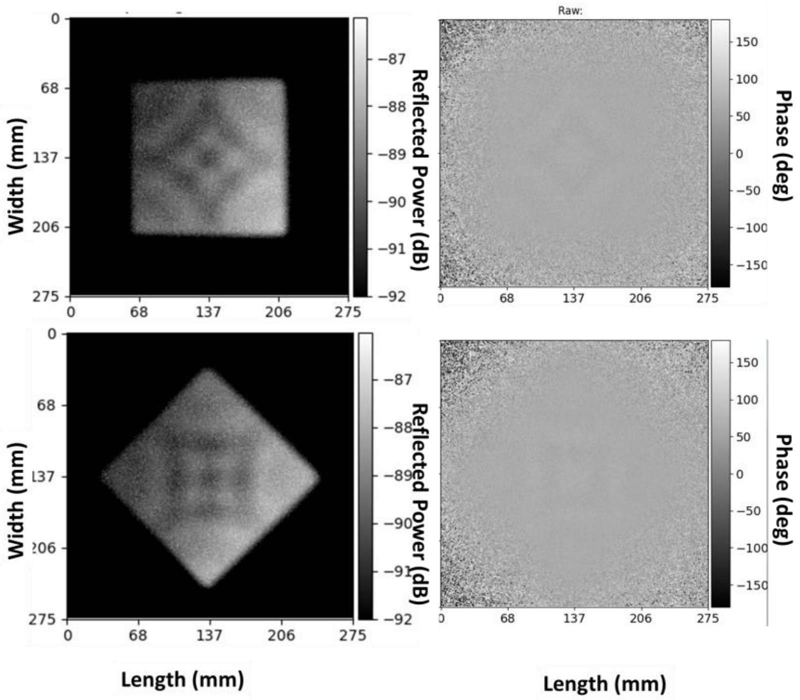
100 kHz

Gain (dB) | Phase (dB)



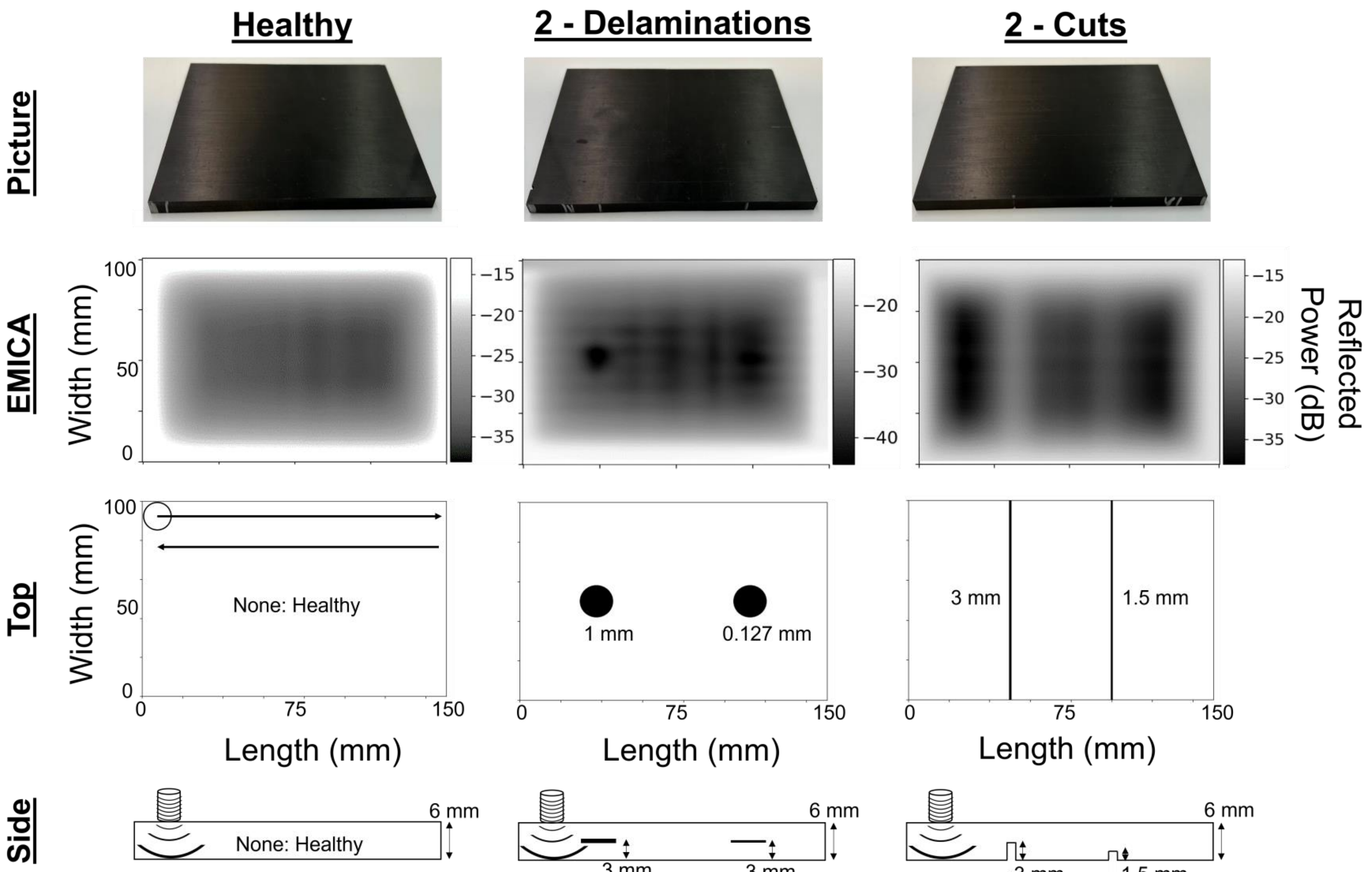
3 MHz

Gain (dB) | Phase (dB)



1" thick
Unitape [0/90]
6" x 6"

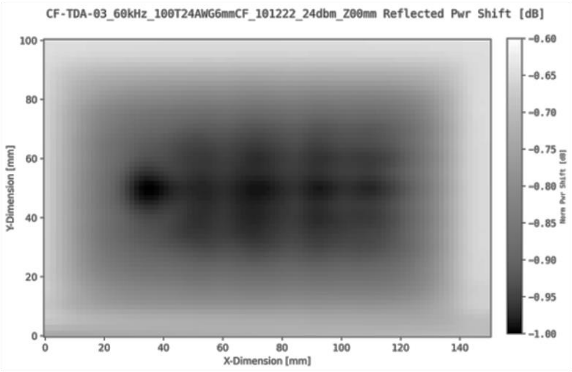
Standard Laminate Panels



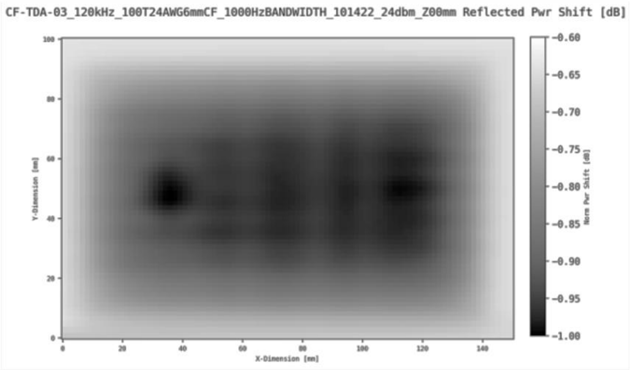
USPTO # 18/222,249, filing date 07/14/2023

Standard Laminate Panels – Penetration Depth

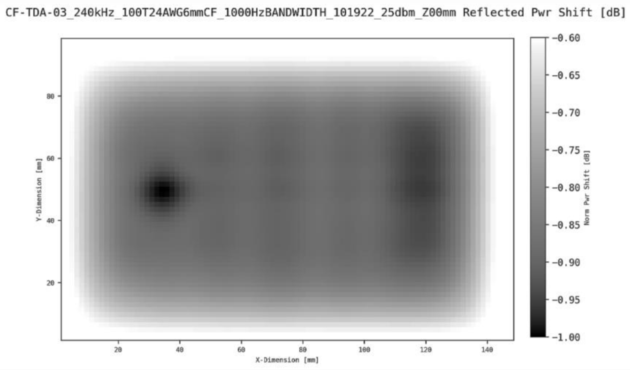
60 kHz



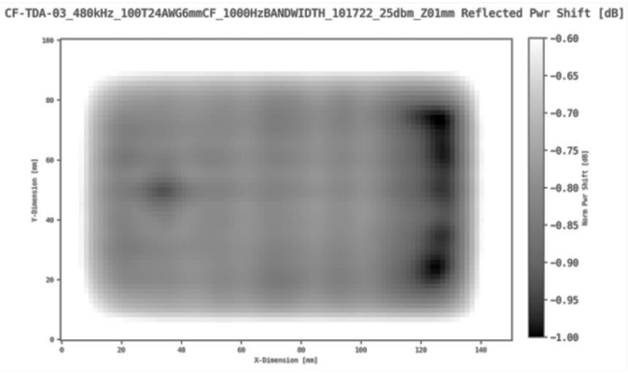
120 kHz



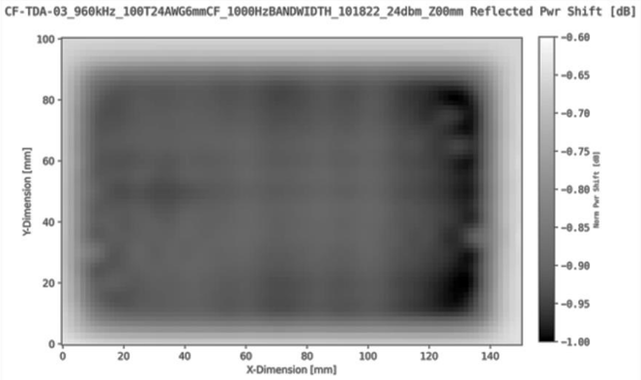
240 kHz



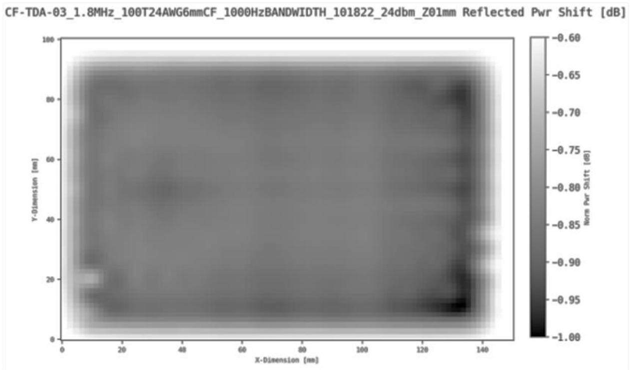
480 kHz



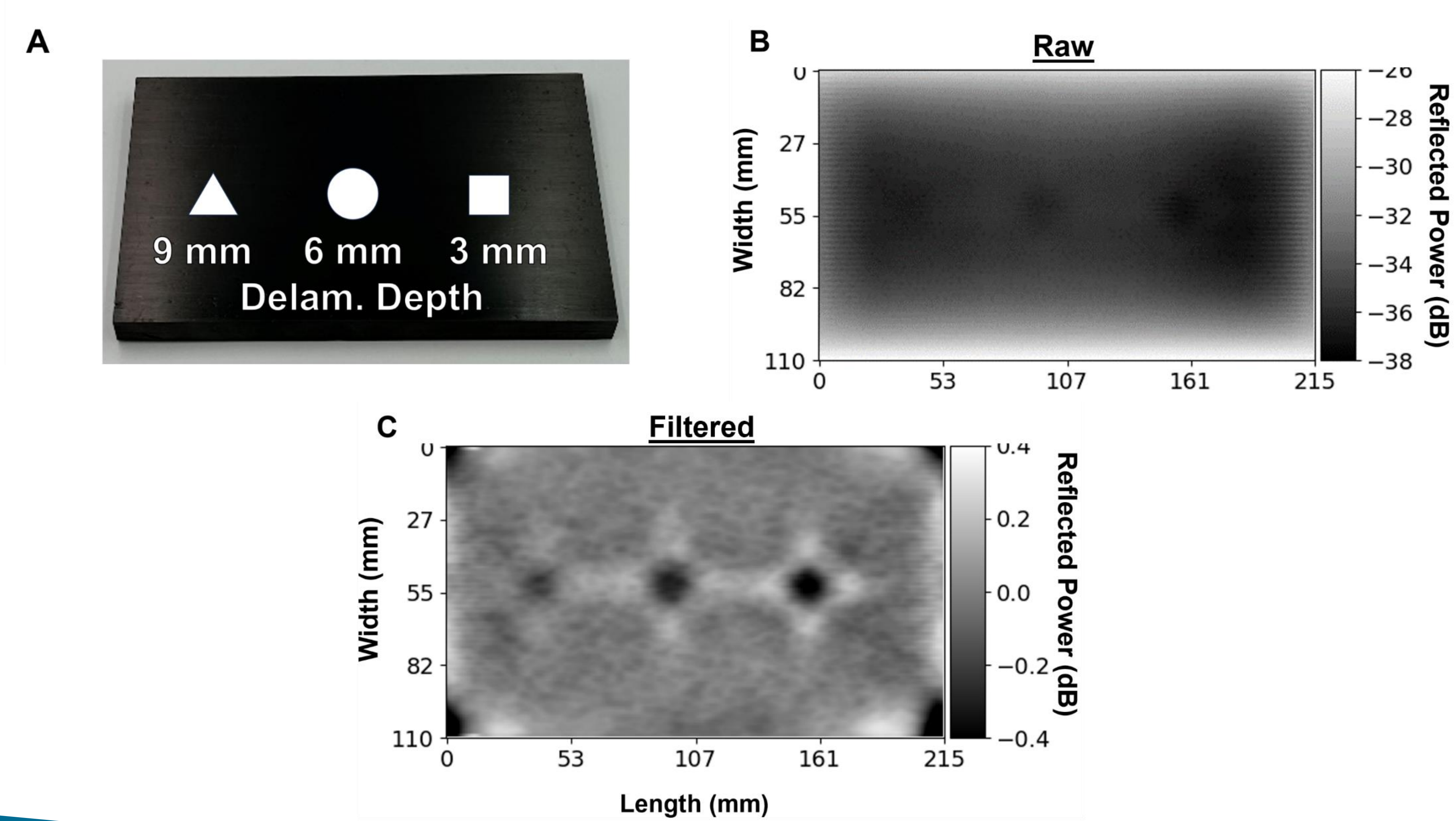
960 kHz



1.8 MHz

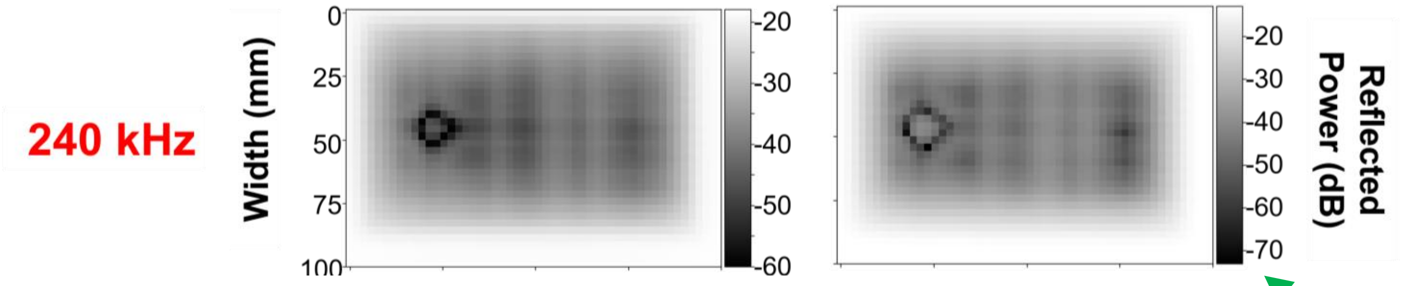


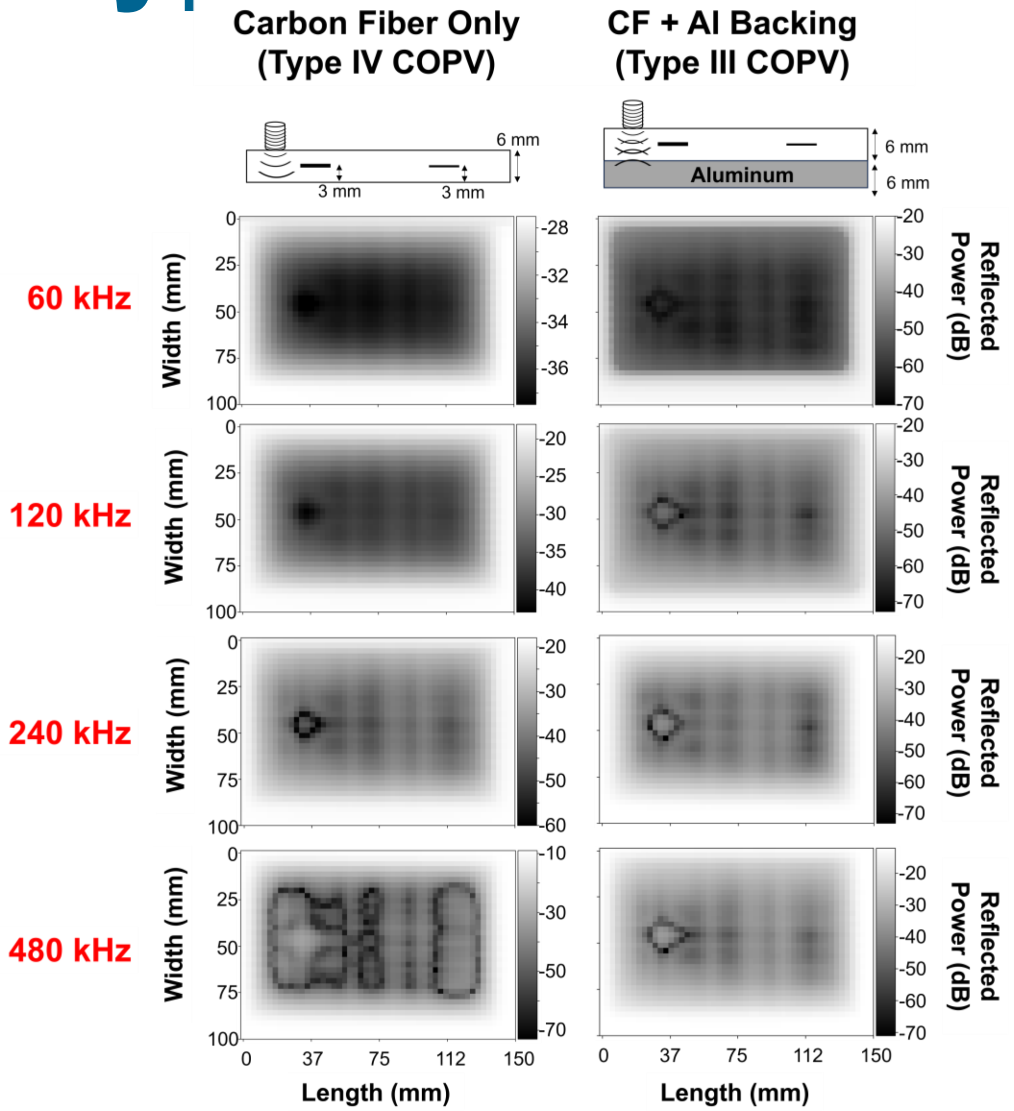
Penetration Depth at a Single Frequency



USPTO # 18/222,249, filing date 07/14/2023

"Simulating" Type III vs Type IV COPV



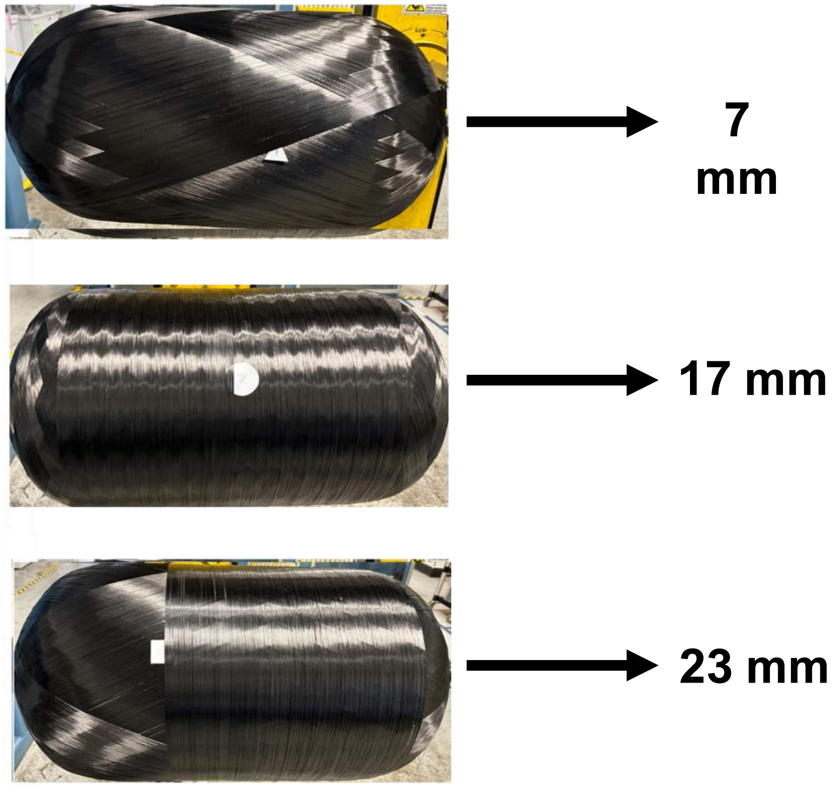


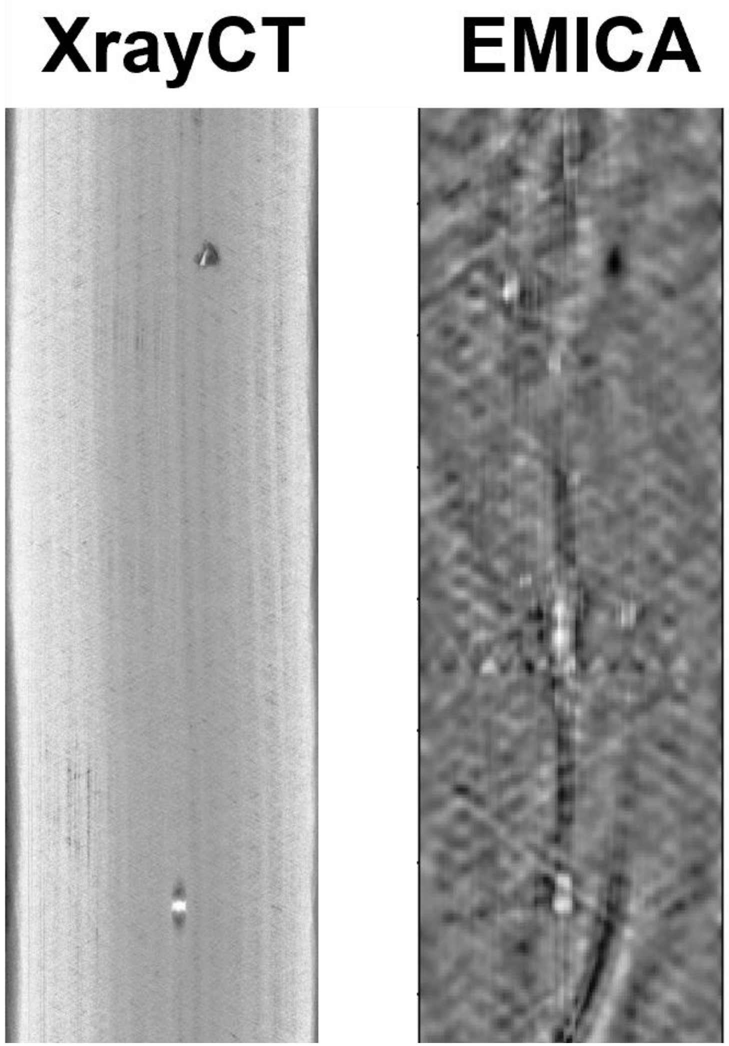
Aluminum in "Type III" reinforces the EMF.
Q: Does this mean you can look at the carbon fiber and the liner?
A: It does. Don't worry, we'll get there in a few slides ☺

USPTO # 18/222,249, filing date 07/14/2023

Standard COPV

Tank Winding





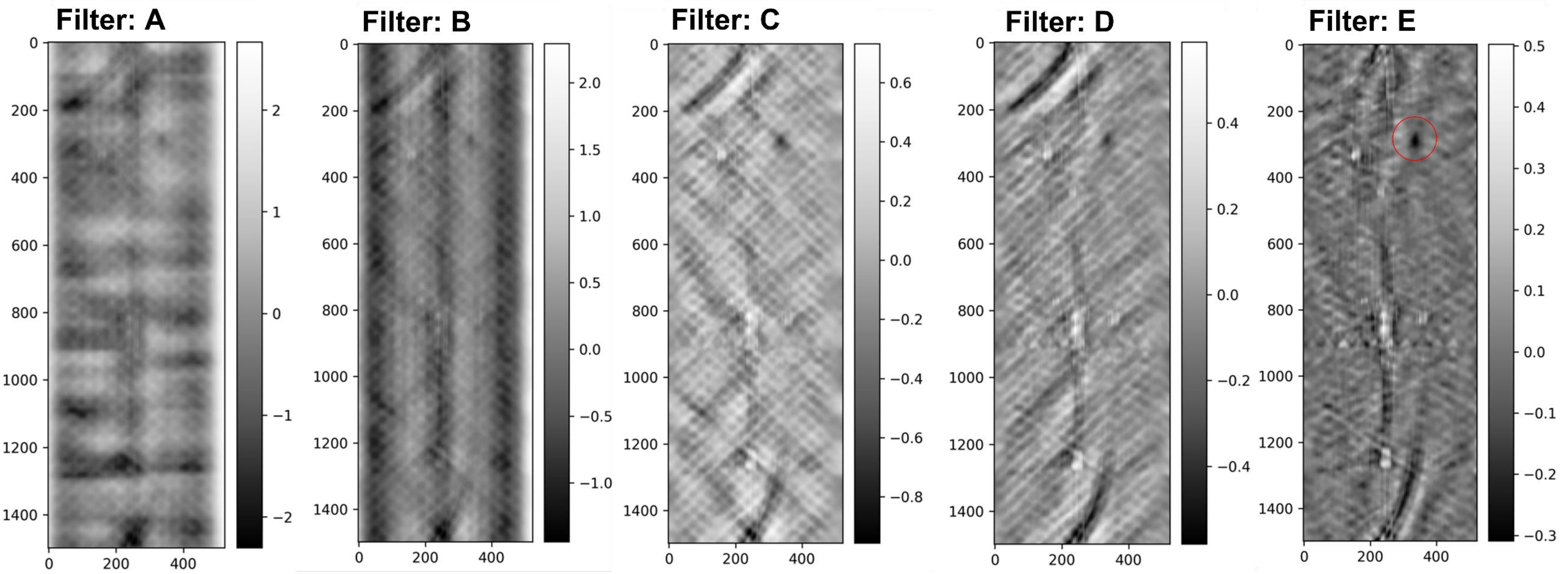
LOCKHEED MARTIN

TDA RESEARCH

sampe Conference & Exhibition

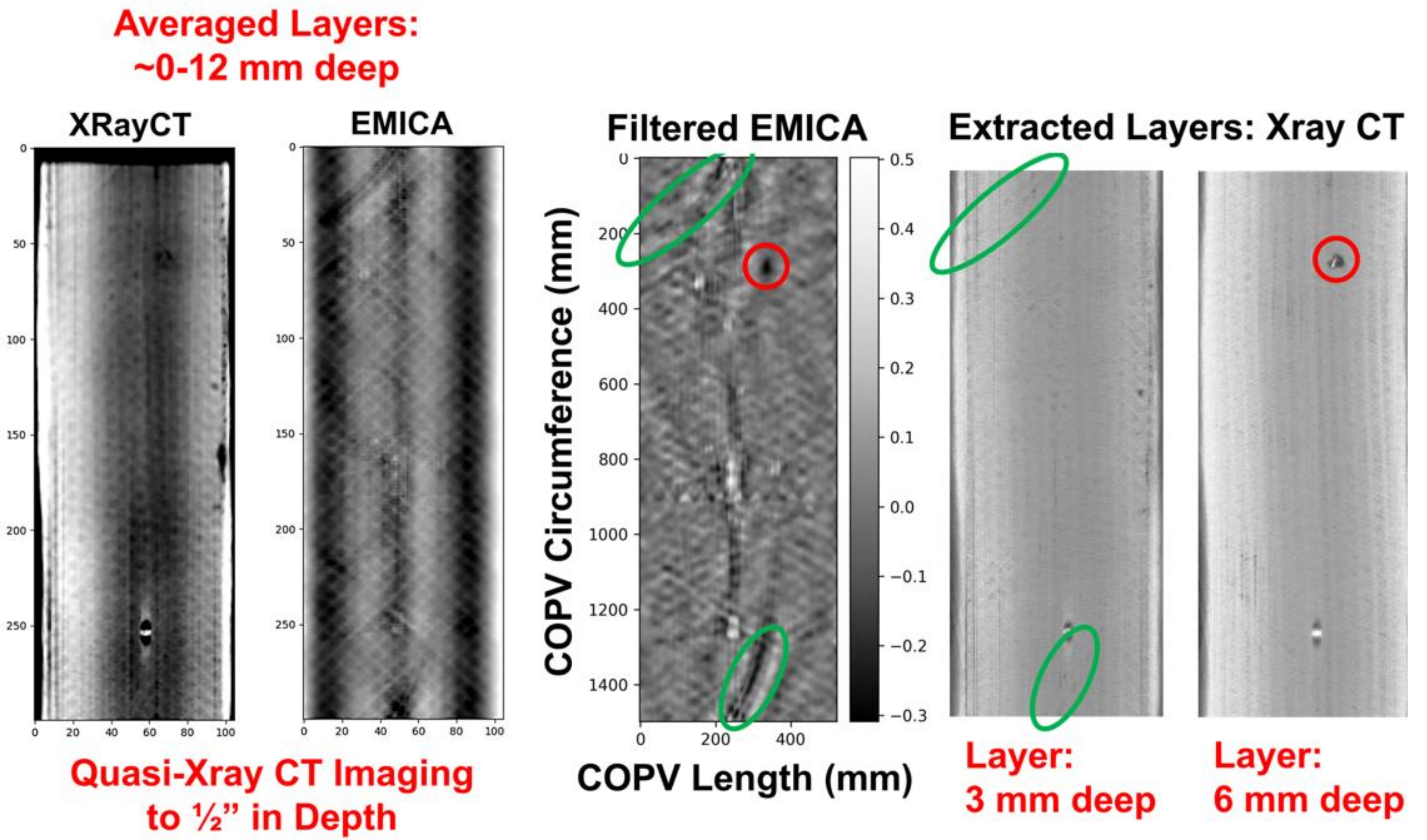
USPTO # 18/222,249, filing date 07/14/2023

Standard COPV



Can’t show the wrap angle date we can extract – send us your tank and we’ll tell you all about it …

EMICA vs. XrayCT



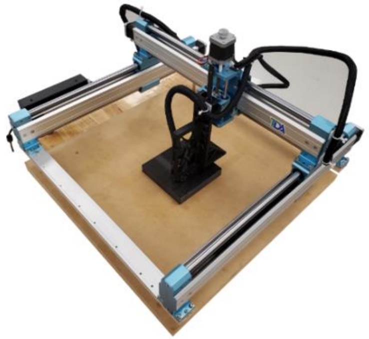
With current state-of-the art, can see down 12-15 mm into carbon fiber laminate on COPV (due to spread of EMF along COPV)

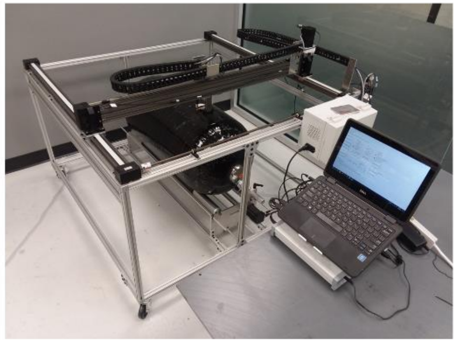
Can see deeper in laminate samples (especially with aluminum backing)

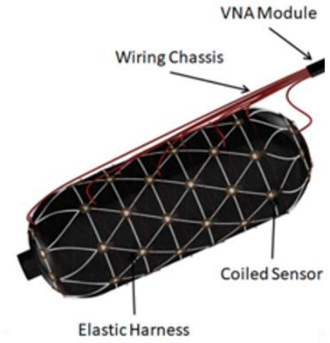
Imaging through 12-15 mm CF thickness is a useful milestone (even though we're working towards 30-40 mm)

USPTO # 18/222,249, filing date 07/14/2023

EMICA Imaging Form Factors







TDA RESEARCH

EM Vision Currently In Use by Industry Partner

320 L COPV

86 L COPV

15 L COPV

Summary

- Electromagnetic Inductive Coupling Analysis (EMICA) is a new imaging technique for defect detection in carbon fiber
  - Works on pressurized or unpressurized tanks
  - No gels or coupling liquids
  - Imaging of full 86 L COPV in ~2 hrs (currently working to drive that down)
  - Detection of defects
  - Identification of wrap angles
  - Interrogation of CF + aluminum liner, or aluminum liner only depending on frequency selection

Outlook

- EMICA 2024 V1 is ready for sales
  - Build and calibrate scanner
  - Designed and built custom GUI for data collection and processing
- The EMICA technique has so many different directions to go
  - Driving towards 30 – 40 mm to complete original DOE goal
  - $\leq$ 15 mm thickness is applicable to lots of carbon fiber applications
  - Regulatory work to provide confidence that with EMICA SHM installed, DOT could drop safety factor of COPV and help get to 266 kgH_2 target

Thank You!

jbiller@tda.com

DOE DE-SC0019981
The HFTO
Mr. Zeric Hulvey & Ms. Asha Dee Celestine
Jesse Adams (prior)
Bahman Habibzadeh (prior)

Brad Spatafore, MS
Mechanical Engineering
In-Field Device Design

Kevin Finch, PhD
(Analytical Chemistry)
Integrate data collection and software design

David Long, EE, ME
Circuit board design and construction
Precision machining
Support with data collection and software design

sampe
Conference & Exhibition