Department of Electrical, Computer,
Software and Systems Engineering

Additively Manufactured RFID-Based Passive Wireless Sensors

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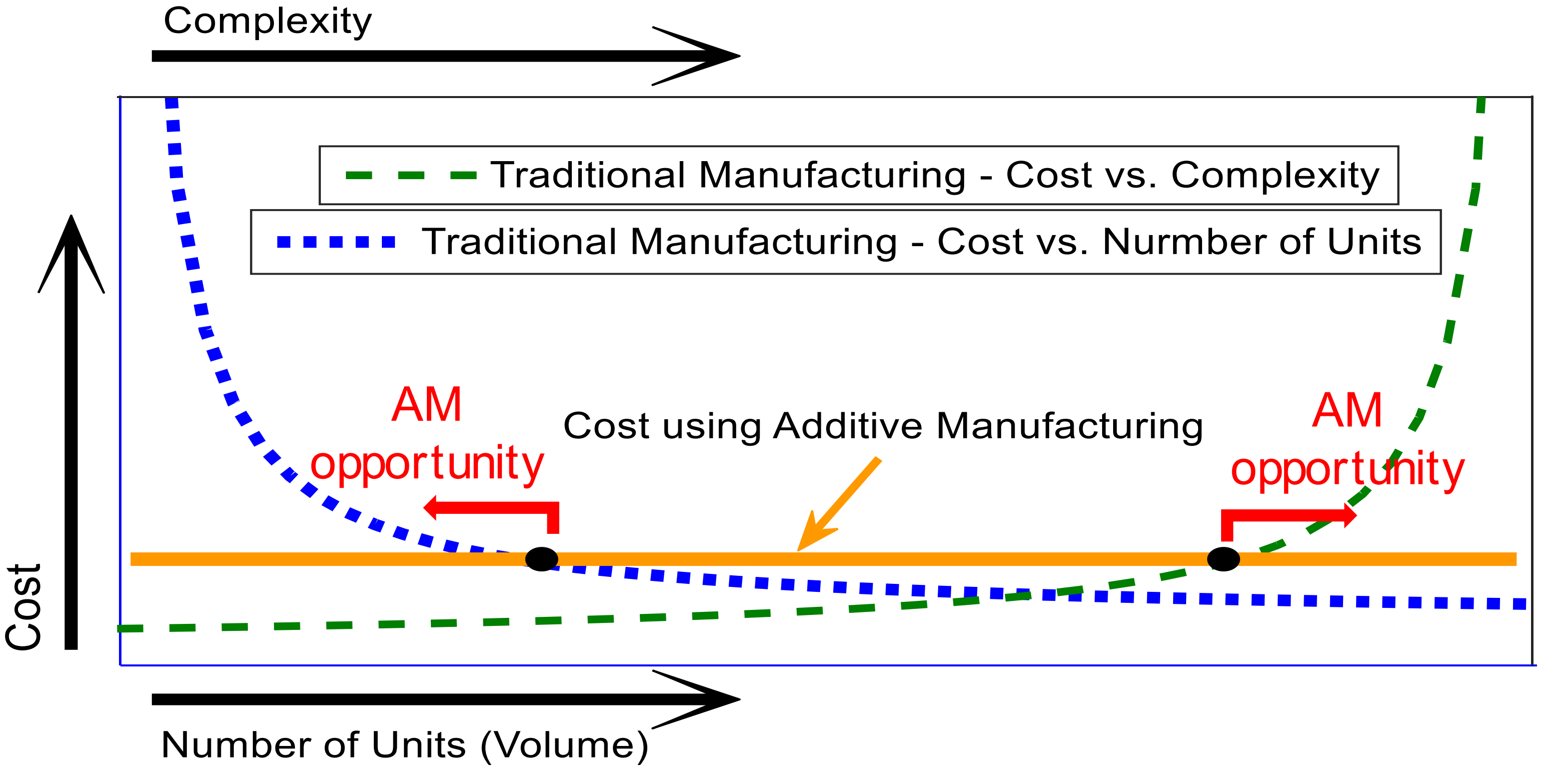
Wireless Devices and Electromagnetics Laboratory

www.wide-lab.com

Agenda:

- ✓ *Introduction*
- ✓ *DDM Process (Additive Manufacturing)*
  - *- Multilayer RF Electronics*
- ✓ *Laser Enhanced DDM*
  - *- 3D Component Packaging*
  - *- mm-Wave Multilayer Circuit*
- ✓ *Wireless Passive Sensing for Micro Meteorite Orbital Debris (MMOD) Impacts*
- ✓ *ERAU Capabilities. Micaplex. WiDE Lab*

Introduction



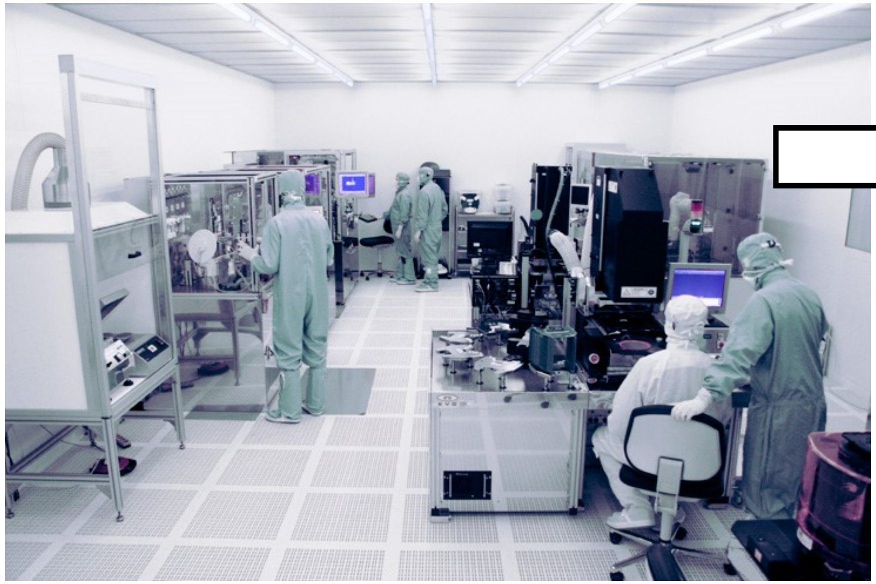
3D Printed Fuel Nozzl
(FAA Certified)
by General Electric.

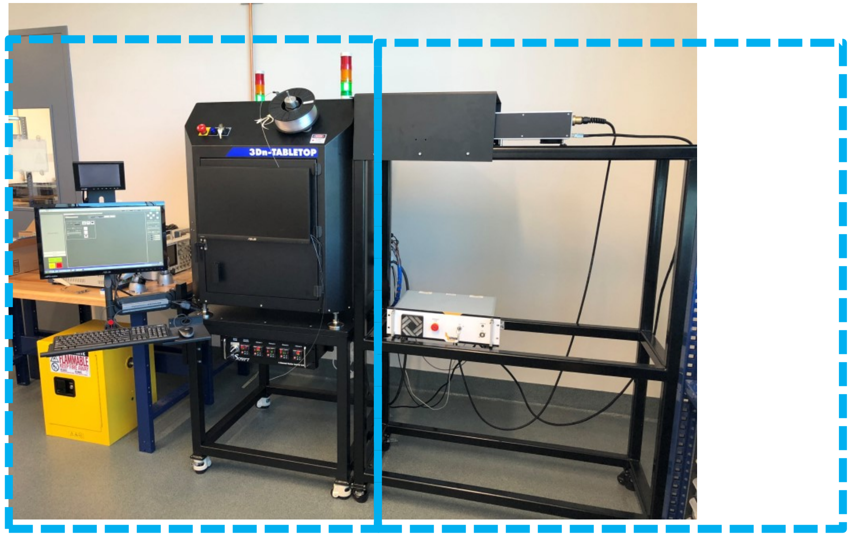
Improved Design:
25% lighter
5x stronger
Substitutes 18 parts

http://www.gereports.com/post/116402870270/the-faa-cleared-the-first-3d-printed-part-to-fly/

Simpler designs are less costly and better – **Not true with AM**

Evolution (Revolution)

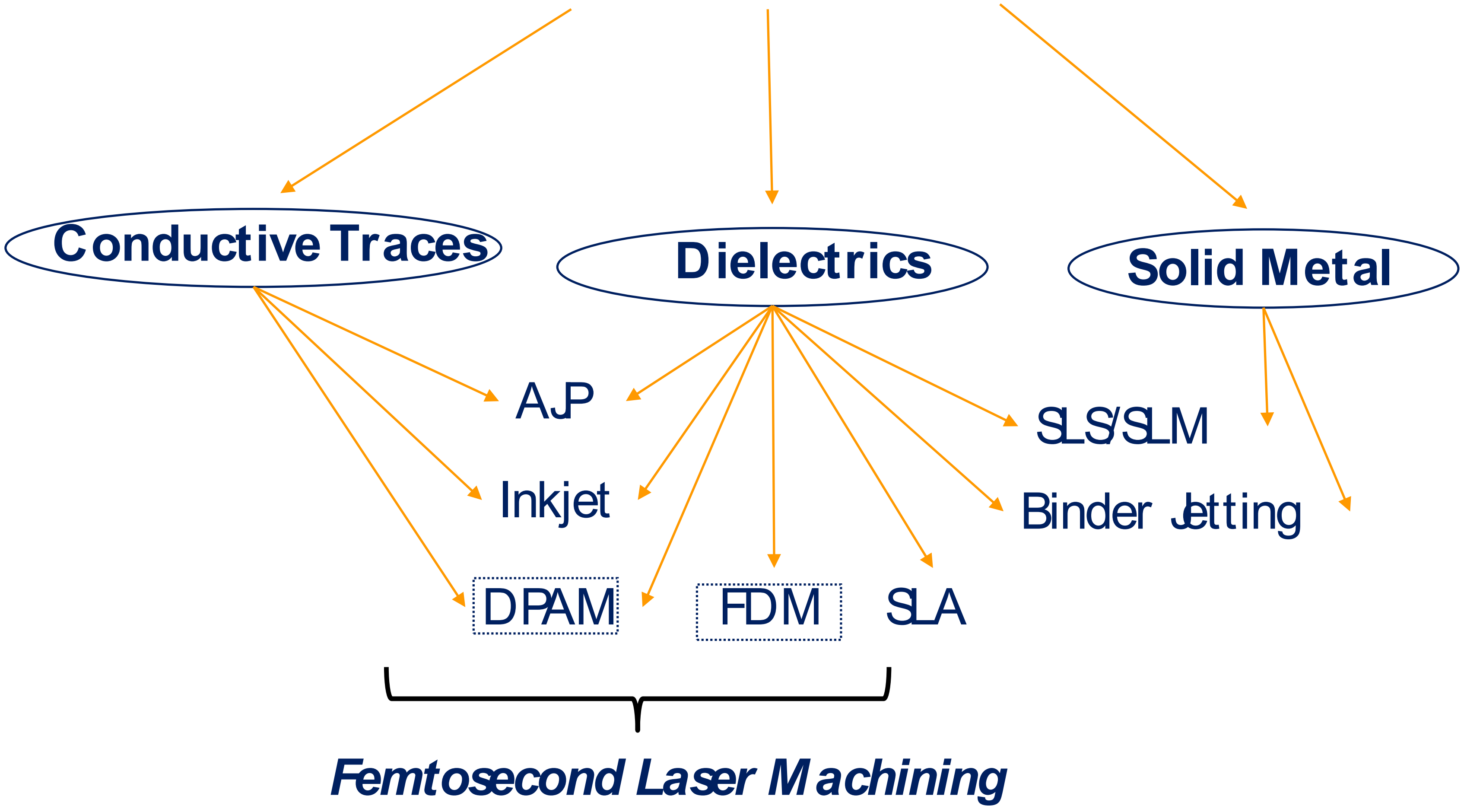




nScrypt DPAM system Femtosecond Laser (10 W)

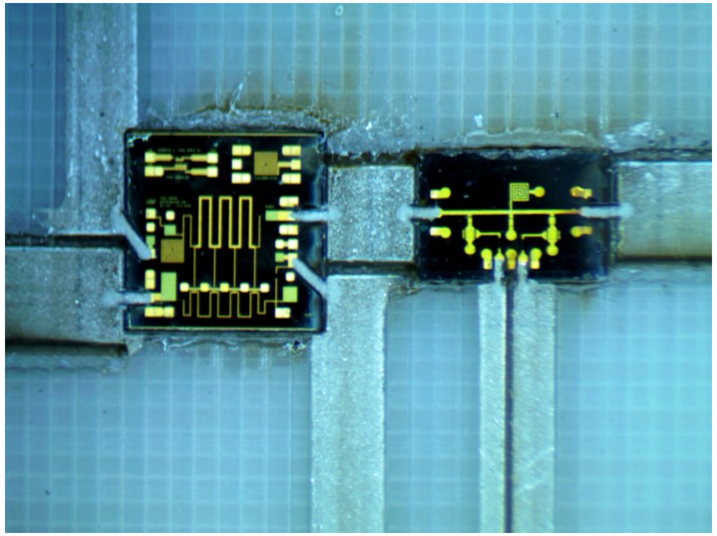
ExOne Innovent

3D Printing Technologies
RF Circuits and Antennas



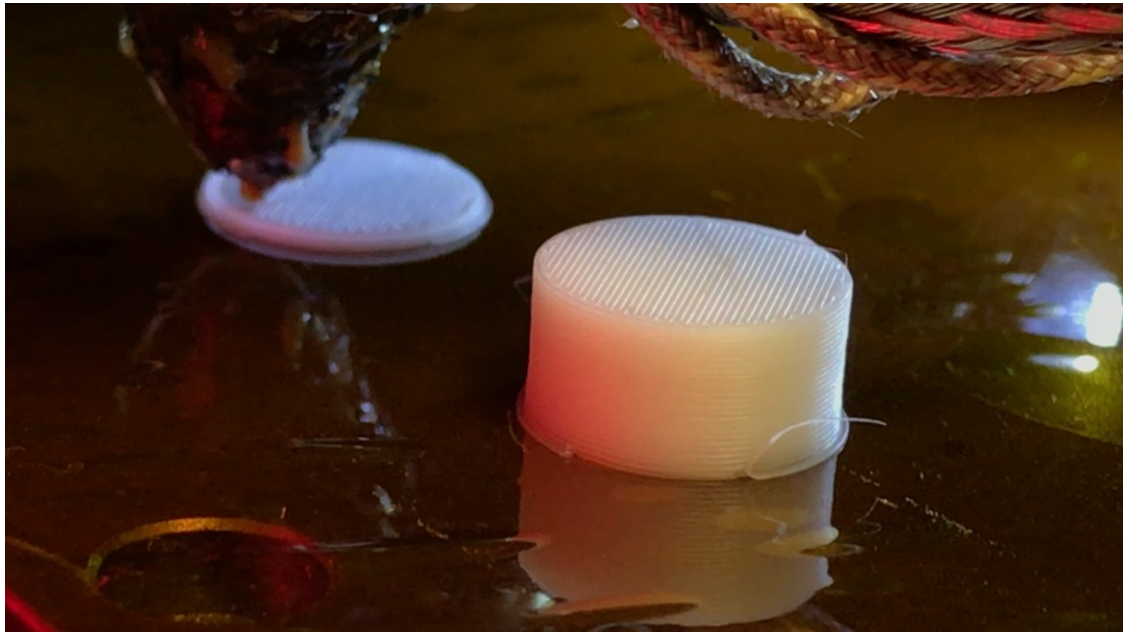
DDM - Introduction

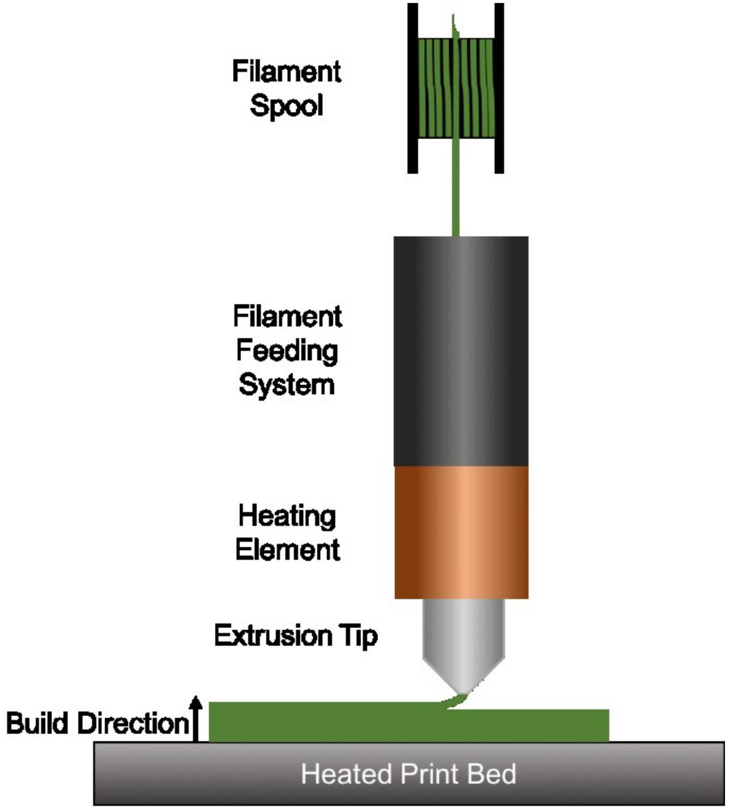
- Direct Digital Manufacturing (DDM): Combination of additive and subtractive processes, *applied directly from CAD file to part*.
- This work: combination of FDM, micro-dispensing and laser machining.
  - Multiple materials, multiple layers.
  - Low temperature.
  - Match performance of Cu-clad microwave laminates.
  - Embed/integrate/package microelectronics.
  - Volumetric control of materials.



DDM Process: *FDM*

Video:

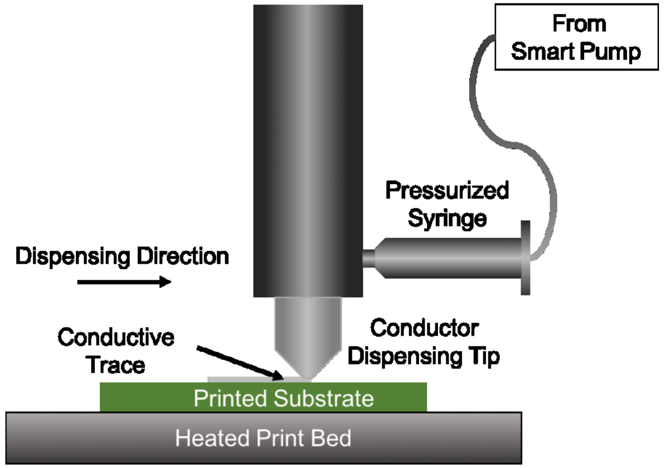




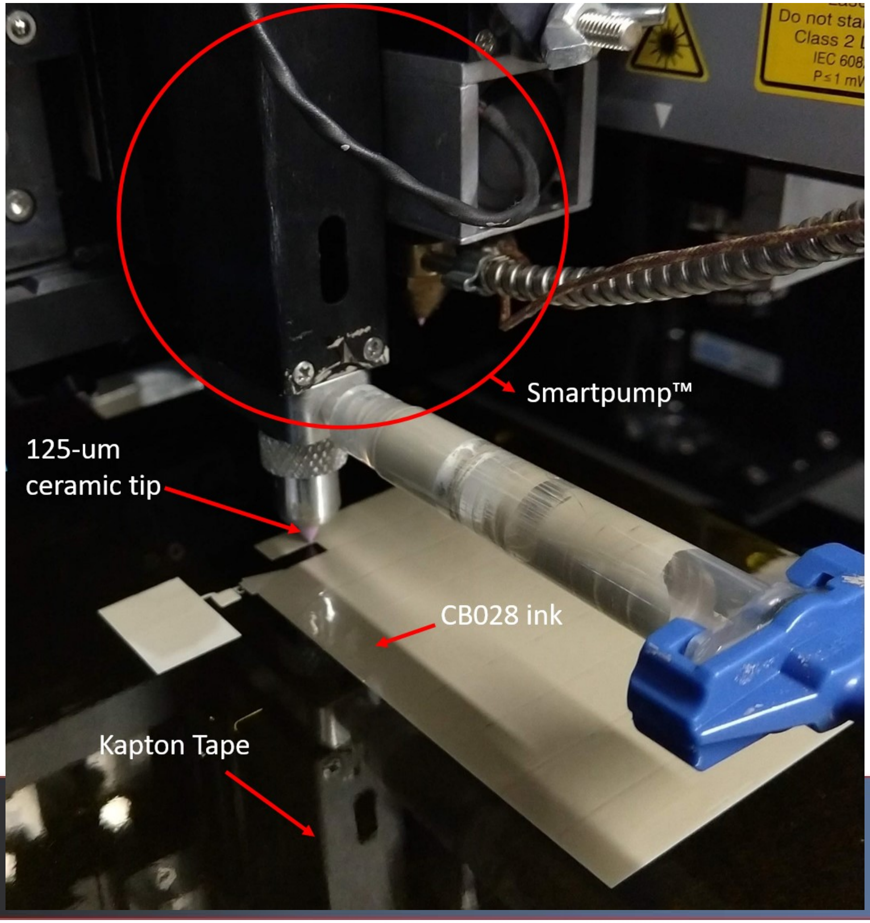
Typical nozzle temperature 200°C –350°C
Minimum layer thickness ~50 microns

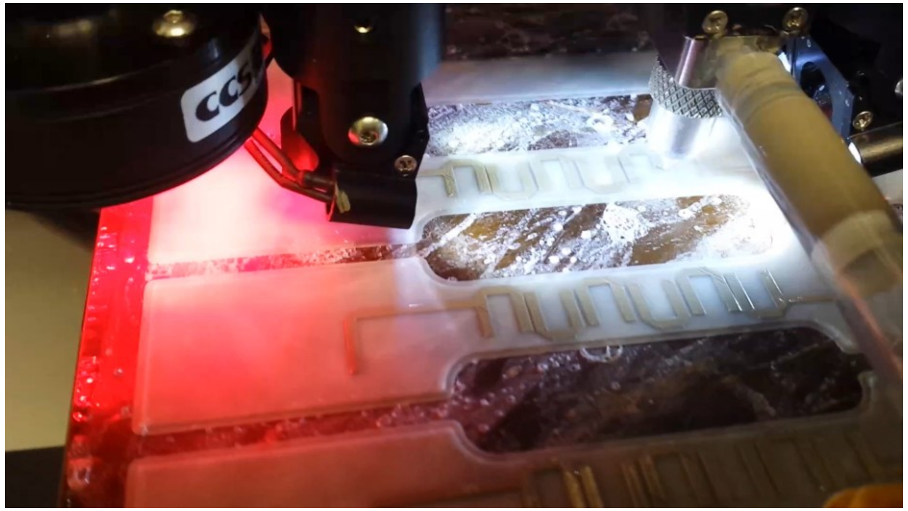
DDM Process: *Micro-Dispensing*

- Pastes such as Ag particle alloys used for conductors.
- Pressure, speed, etc. adjusted for desired feature sizes.
- Conformal printing using laser mapping.



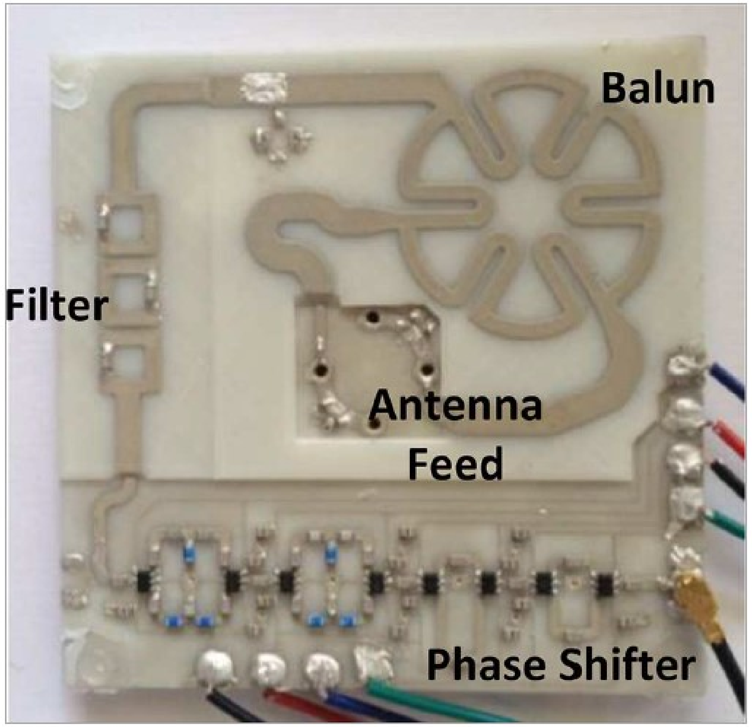
Tip inner diameters:
250µm
125µm
75µm
25µm

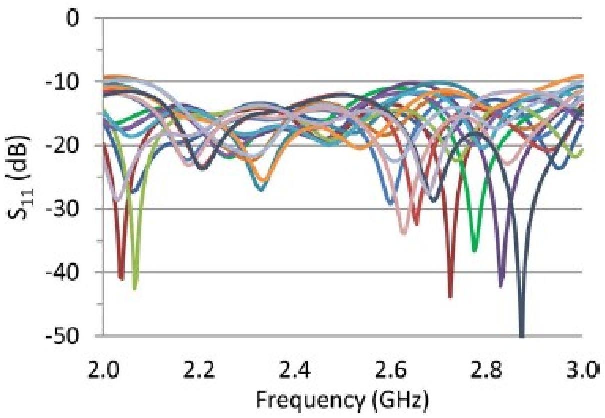




Multilayer RF Electronics

2.45 GHz phased array antenna unit cell





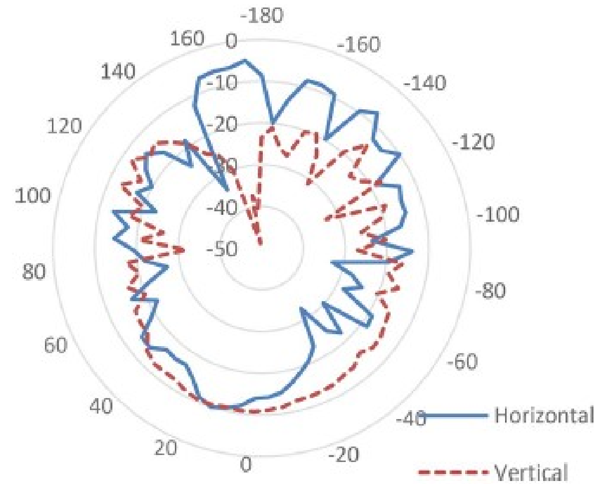
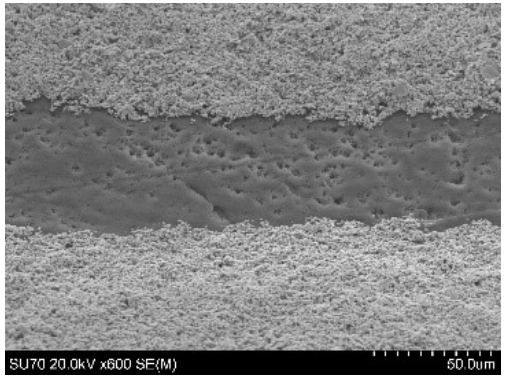


Fig. 24. Measured radiation patterns of the 2.45 GHz phased array unit cell. The vertical and horizontal gain pattern plots are shown.

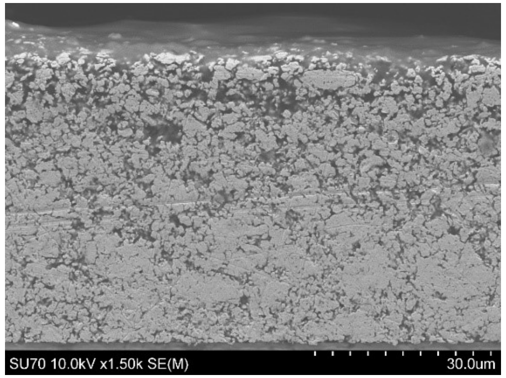
Thomas P. Ketterl, Yaniel Vega, Nicholas C. Arnal, John W. I. Stratton, **Eduardo A. Rojas-Nastrucci**, María F. Córdoba-Erazo, Mohamed M. Abdin, Casey W. Perkowski, Paul I. Deffenbaugh, Kenneth H. Church, and Thomas M. Weller, "A 2.45 GHz Phased Array Antenna Unit Cell Fabricated Using 3-D Multi-Layer Direct Digital Manufacturing," in IEEE Transactions on Microwave Theory and Techniques, vol. 63, no. 12, pp. 4382-4394, Dec. 2015.

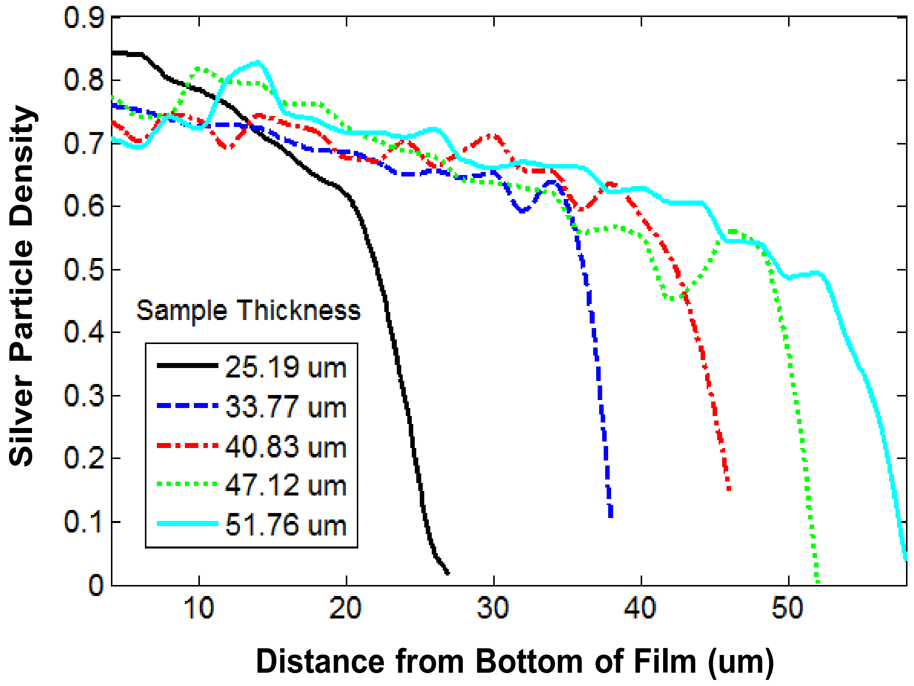
Losses & Frequency Limits

Surface roughness

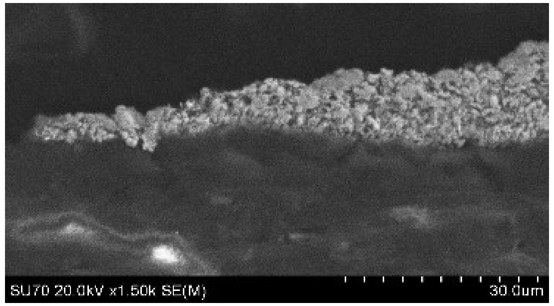


Non-uniformity

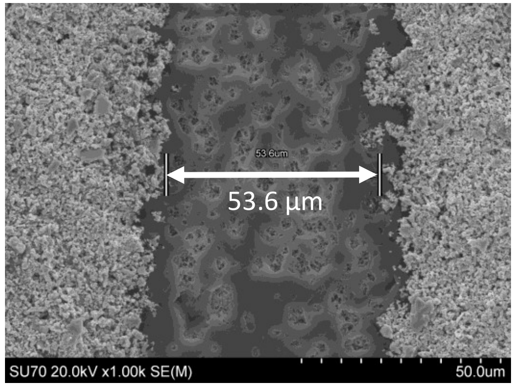




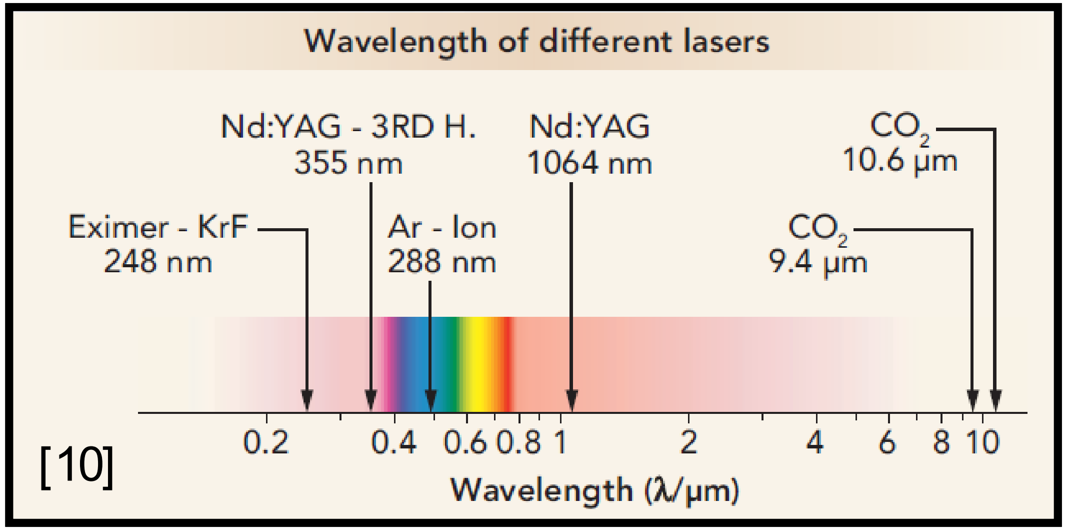
Tapered edges



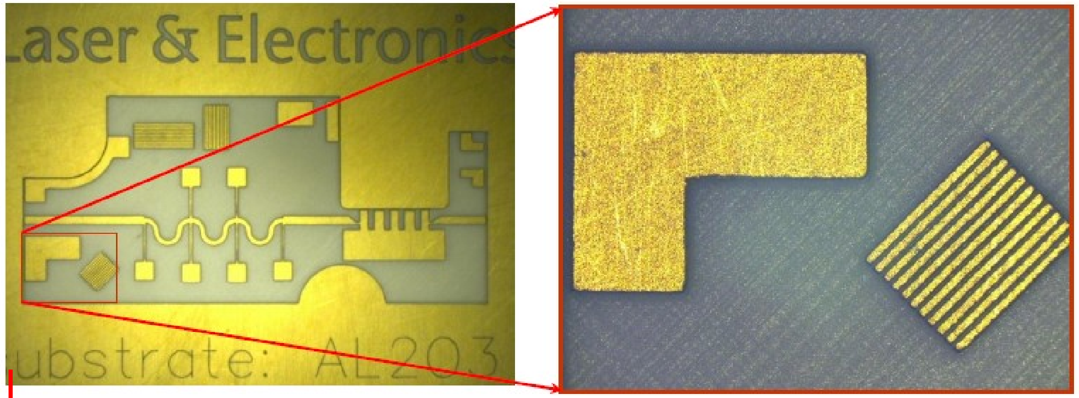
Maximum resolution of 50 μm



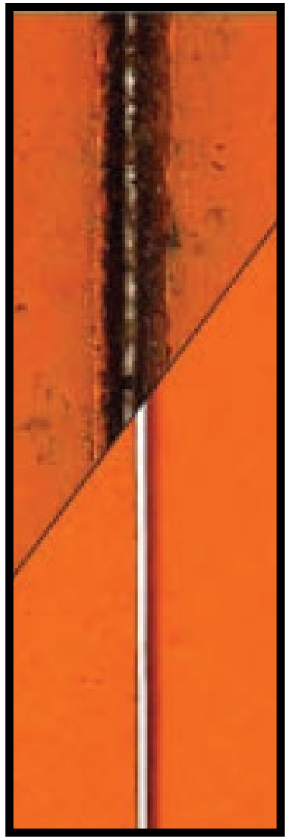
Laser Enhanced DDM



[10]



RF Applications LPKF - 25um cut



CO2 (top) vs Nd:YAG (bottom) cut on Kapton

CO2

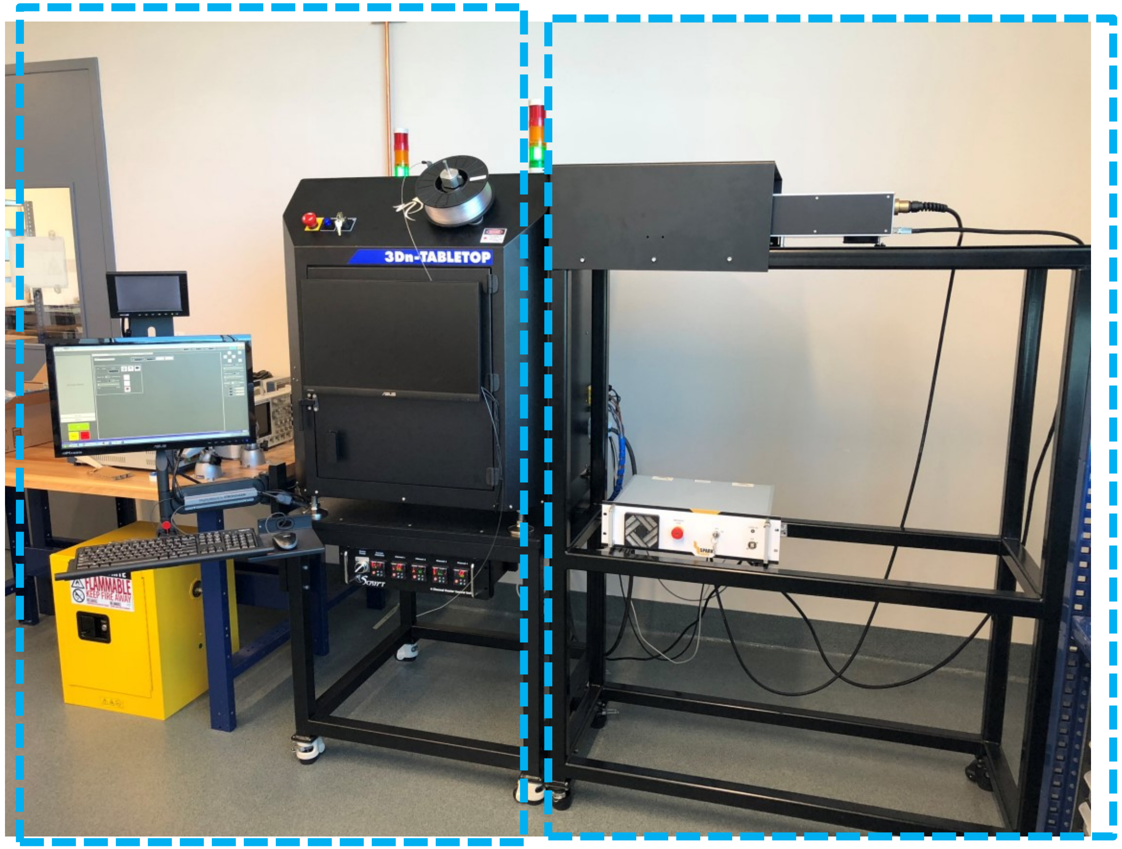
- λ : 10.6 um
- Pulse width: ms to ns
- Local Heating, melting, material vaporization
- Thermal damage

Nd :Yag

- λ : 1064 nm
- Pulse width: ps, fs
- Cold ablation
- Greatly reduced thermal damage

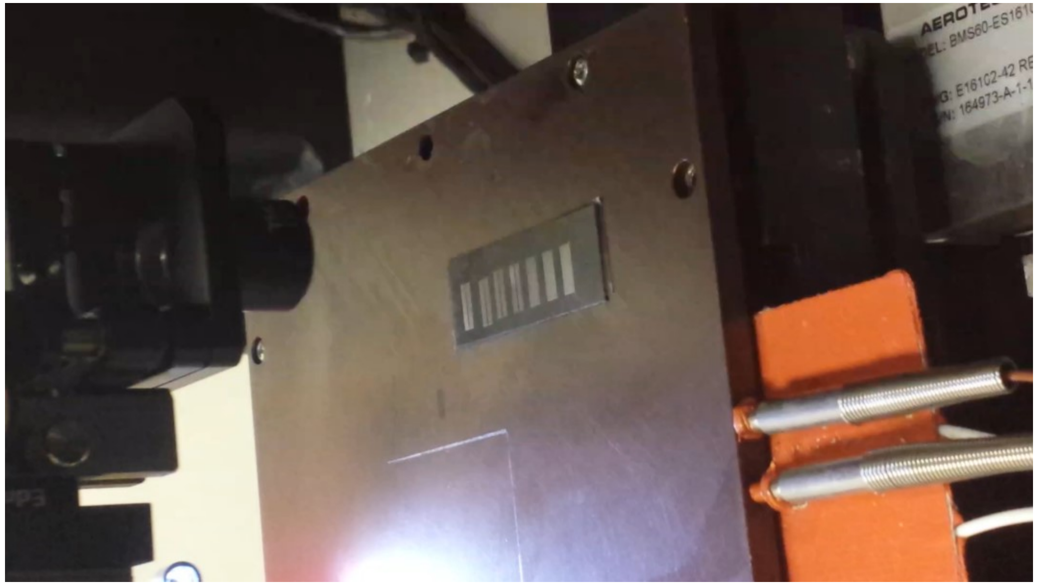
Laser Enhanced DDM

Femtosecond Laser Machining
Lumera Nd:YAG



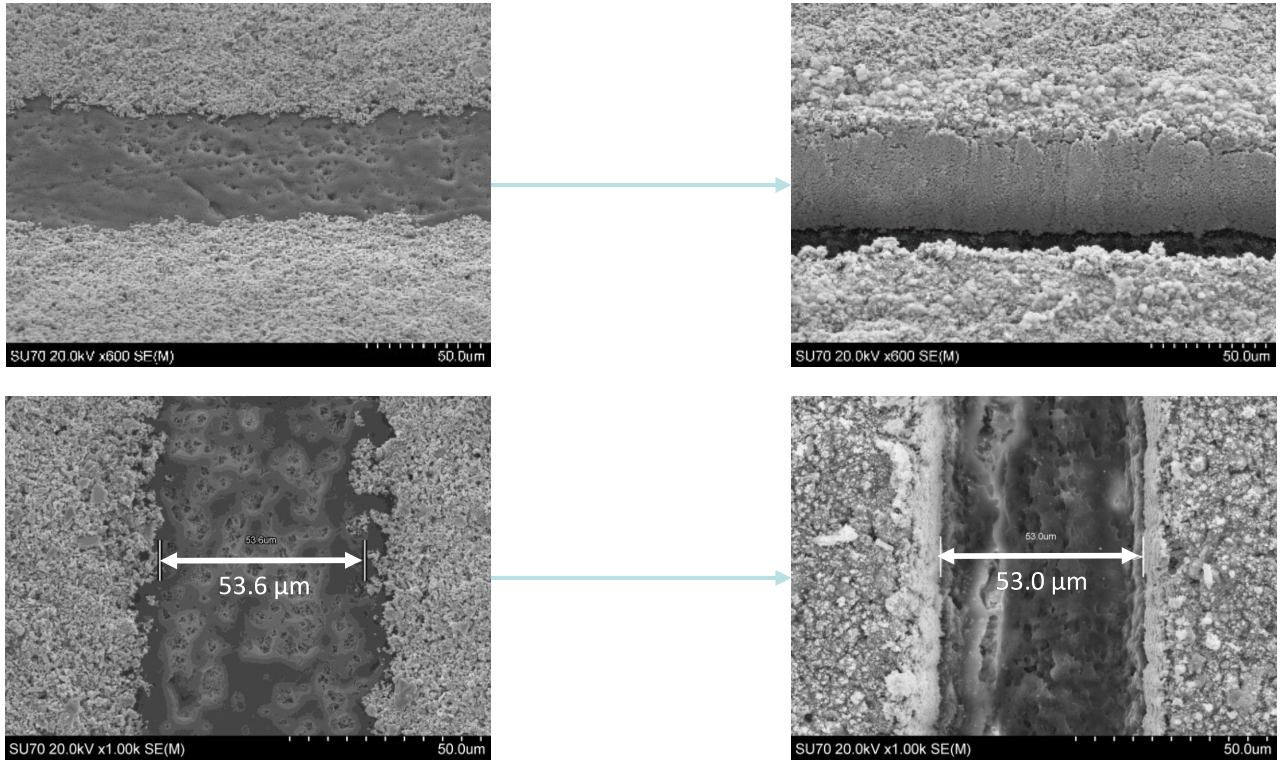
nScrypt DPAM system   Femtosecond Laser (10 W)

Laser machining process:



Laser Enhanced DDM

Micro-Dispensing | Micro-Dispensing + Laser Machining

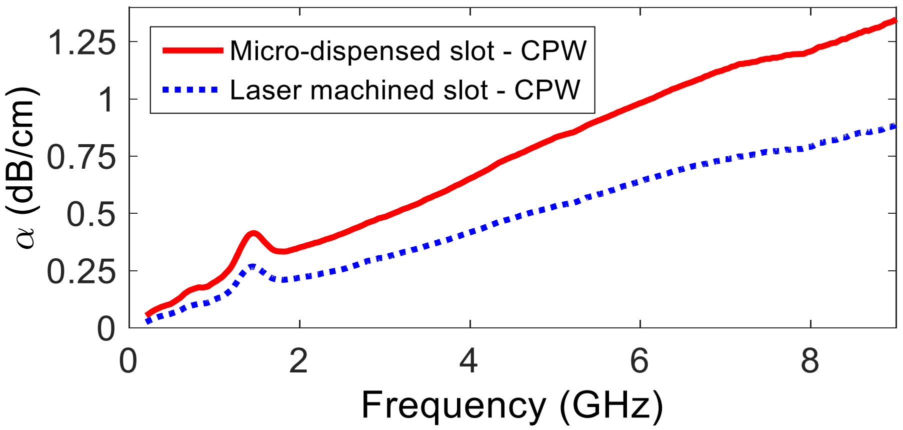


Pulsed ps Nd:YAG laser

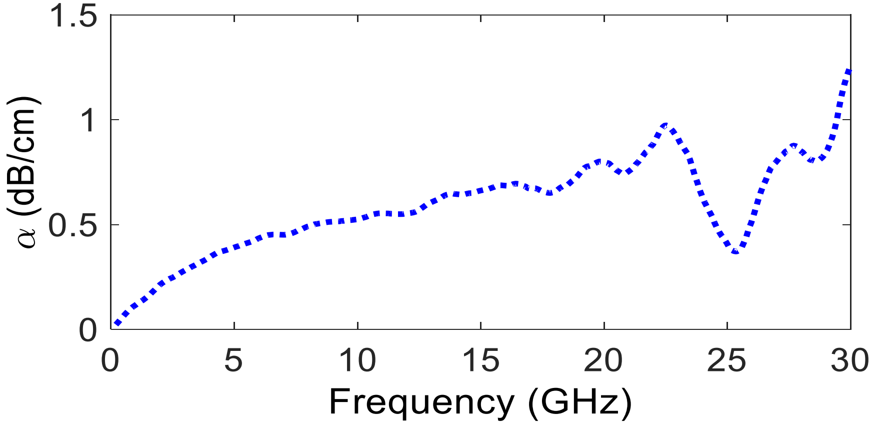
E.A. Rojas-Nastrucci, Harvey Tsang, Paul Deffenabugh, T. M. Weller, Ramiro A. Ramirez, D. Hawatmeh, and Kenneth Church, "Characterization and Modeling of K-Band Coplanar Waveguide Digitally Manufactured using Pulsed Picosecond Laser Machining of Thick-Film Conductive Paste," in IEEE Transactions on Microwave Theory and Techniques, vol. 65, no. 9, pp. 3180-3187, Sept. 2017.

Laser Enhanced DDM

Loss of CPW with slot size of 50 μm



Loss of CPW with slot size of 20 μm



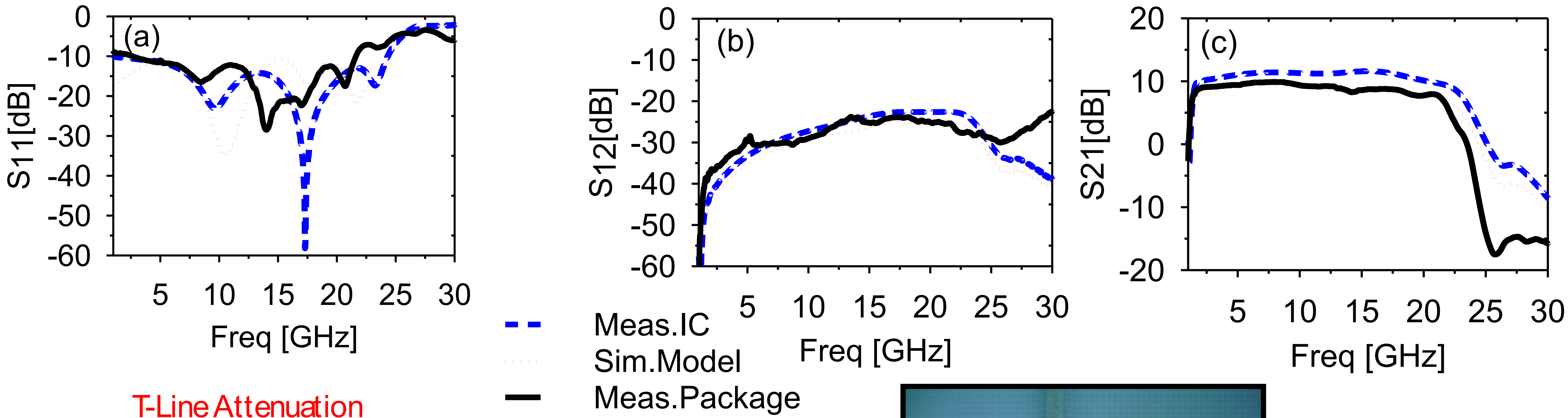
Micro-dispensed CB028: σ_{eff} < 1e6 S/m

Laser machined CB028: σ_{eff} > 1e7 S/m

Attenuation comparable to Cu cladding

E. A. Rojas-Nastrucci, Harvey Tsang, Paul Deffenabugh, T. M. Weller, Ramiro A. Ramirez, D. Hawatmeh, and Kenneth Church, "Characterization and Modeling of K-Band Coplanar Waveguide Digitally Manufactured using Pulsed Picosecond Laser Machining of Thick-Film Conductive Paste," in IEEE Transactions on Microwave Theory and Techniques, vol. 65, no. 9, pp. 3180-3187, Sept. 2017.

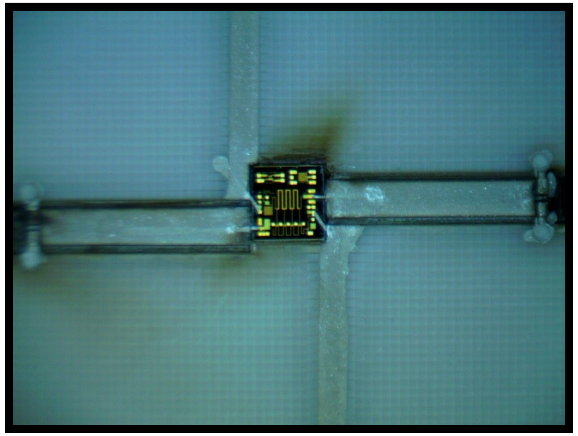
Simulated & Measured Data



T-Line Attenuation

5 GHz – 0.125 dB/mm

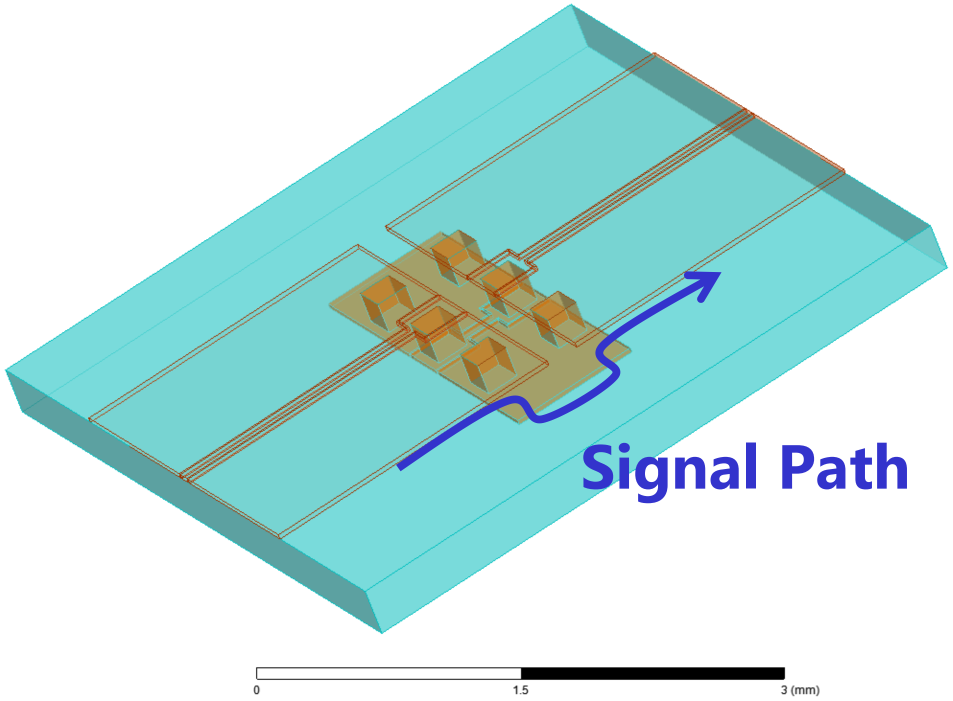
20 GHz – 0.2 dB/mm



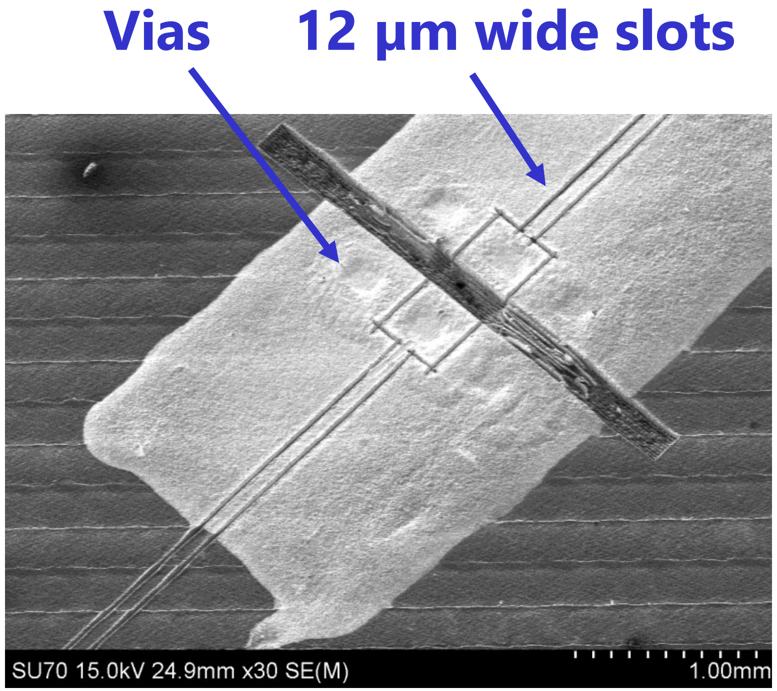
Return loss

10 dB – within frequency band of interest

DDM Multi-Layer Interconnects



Simulated Structure

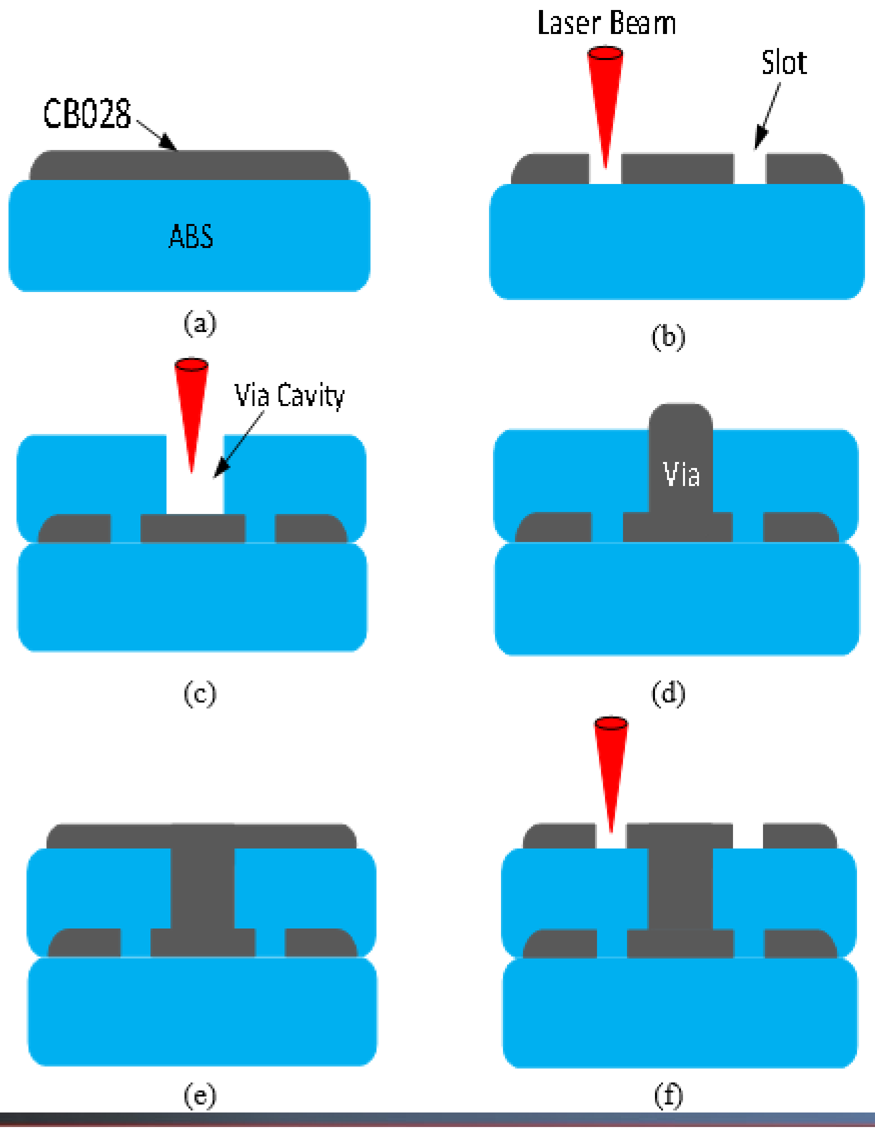


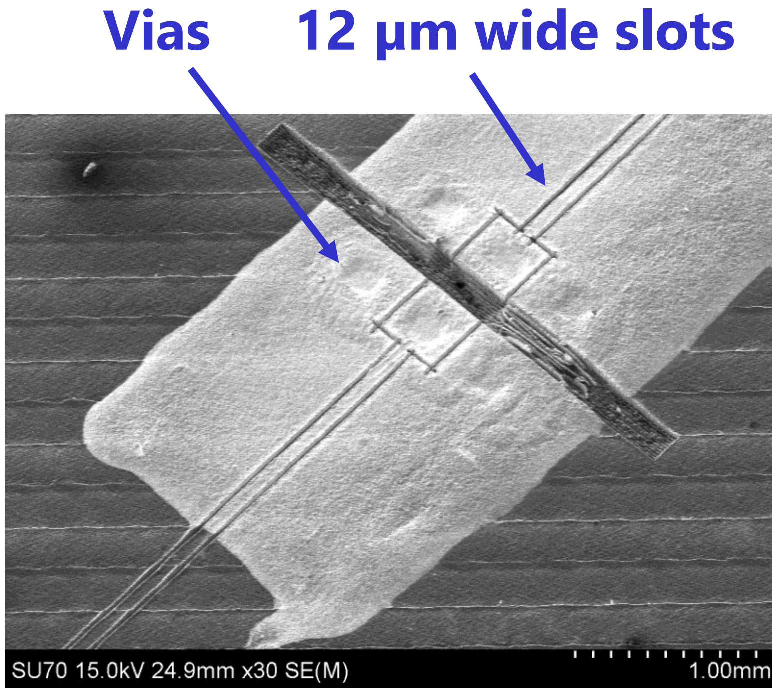
Fabricated Structure

- Dielectric layers are ABS with a thickness of 50 µm.
- CB028 micro-dispensed with a typical layer thickness of 25 µm
- Traces are machined using picosecond laser, achieving 12 µm wide slots.

DDM Multi-Layer Interconnects

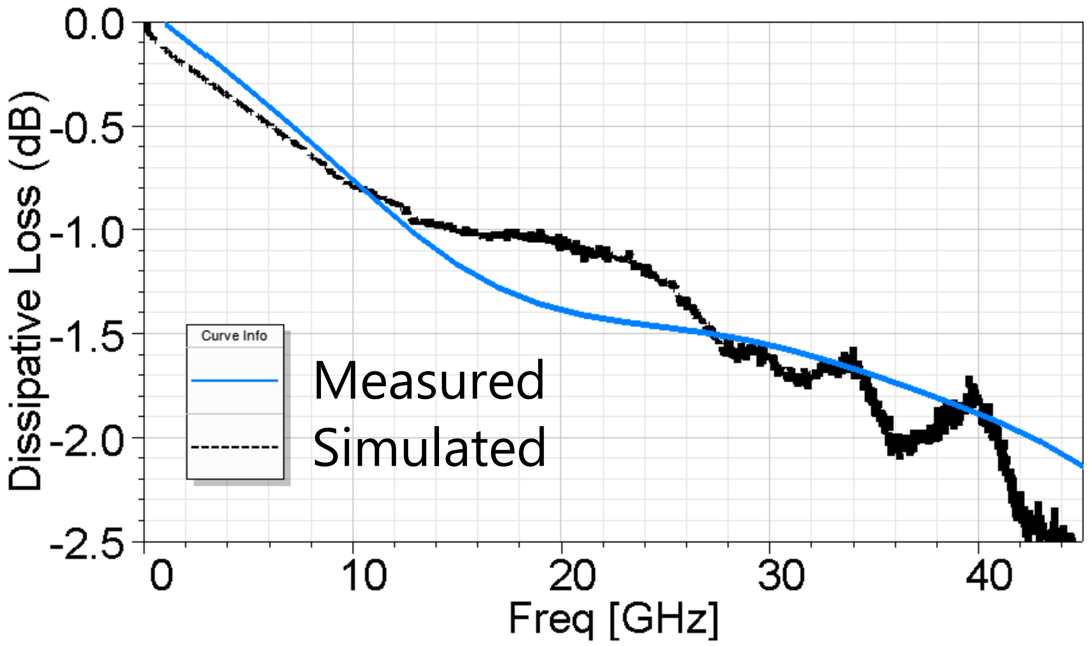
Process

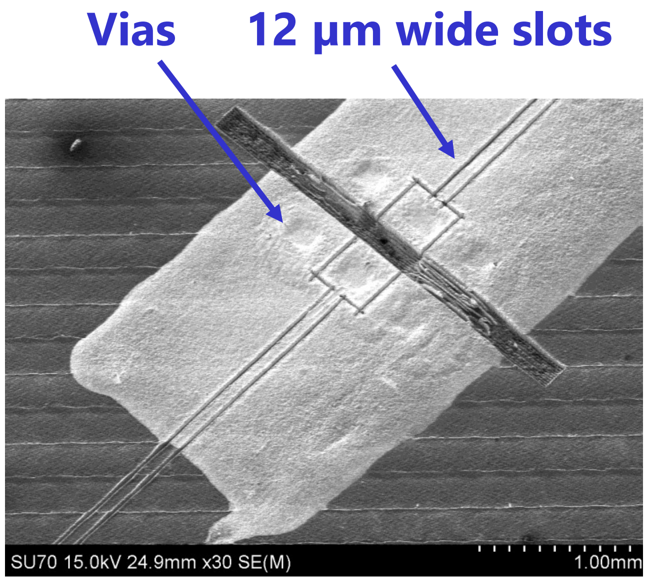




Fabricated Structure

DDM Multi-Layer Interconnects





Fabricated Structure

- Test structure that includes two CPW vertical transitions shows 4.25 dB/cm of loss at 40 GHz.

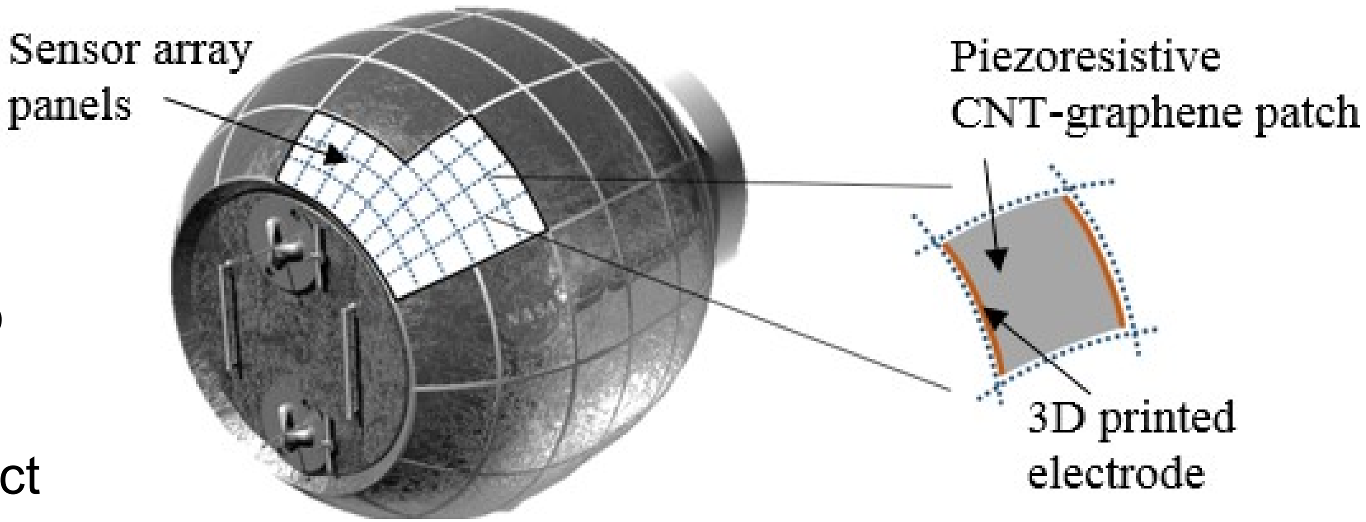
Novel Sensing Mechanisms

Sensor developed by Daewon Kim and Sirish Namilae

- **Objective**

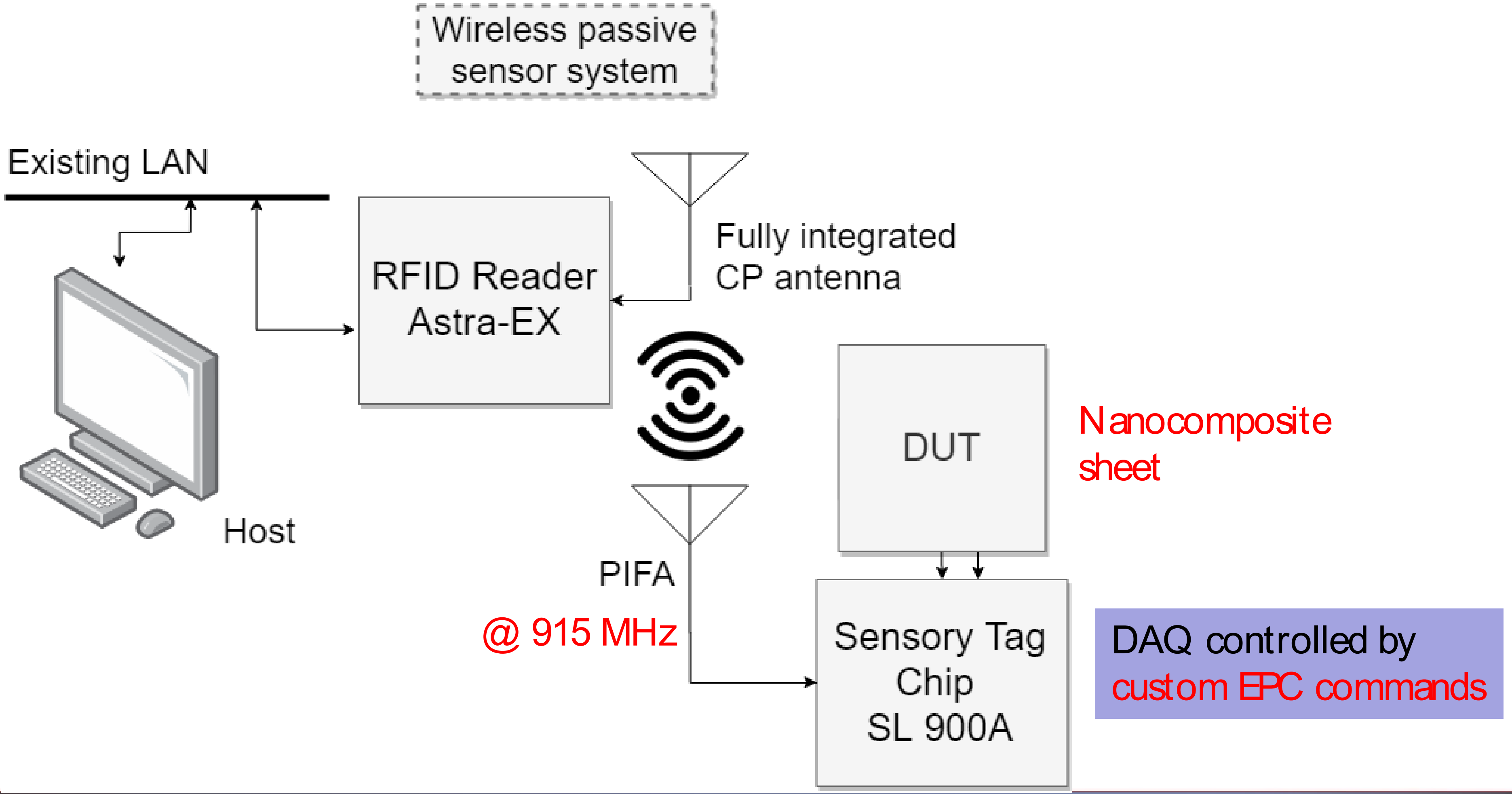
Develop an MMOD impact detection system that can be incorporated into the inflatable structure. An integrated SHM system should provide existence and location of damage, depth of penetration, and damage extent.

- **Approach**
  - Develop flexible piezoresistive sensors composed of carbon nanotubes sheet and coarse graphene platelets.
  - Perform static and dynamic impact testing to measure sensor performance.
  - Perform multi-sensors and multi-layers impact testing to prove MMOD detection capabilities.



Design of the Wireless Passive Sensor

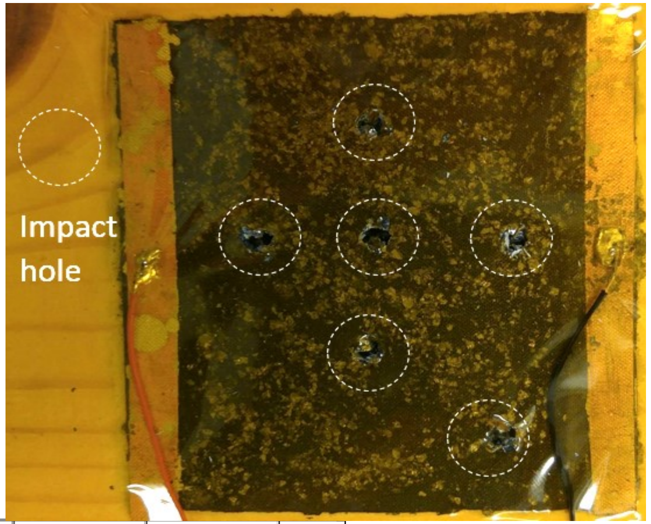
Overall system based on RFID technology

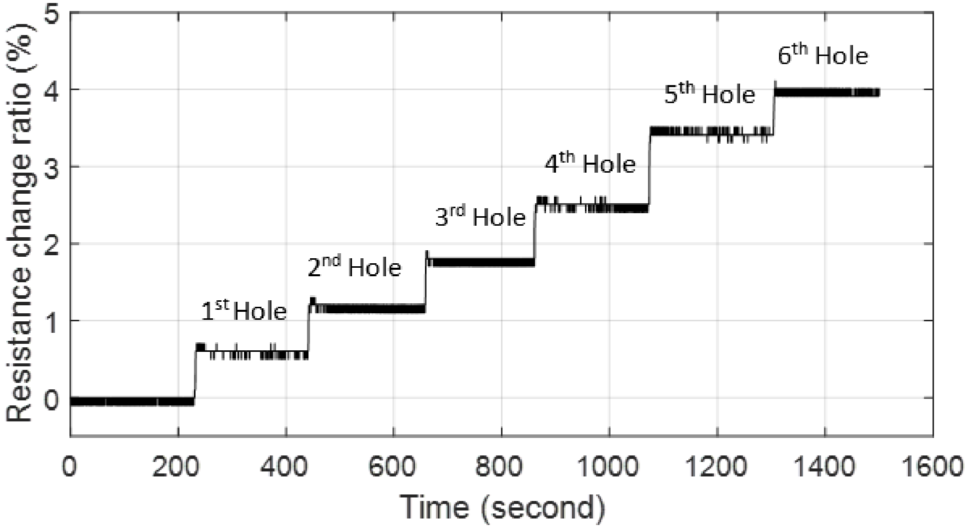


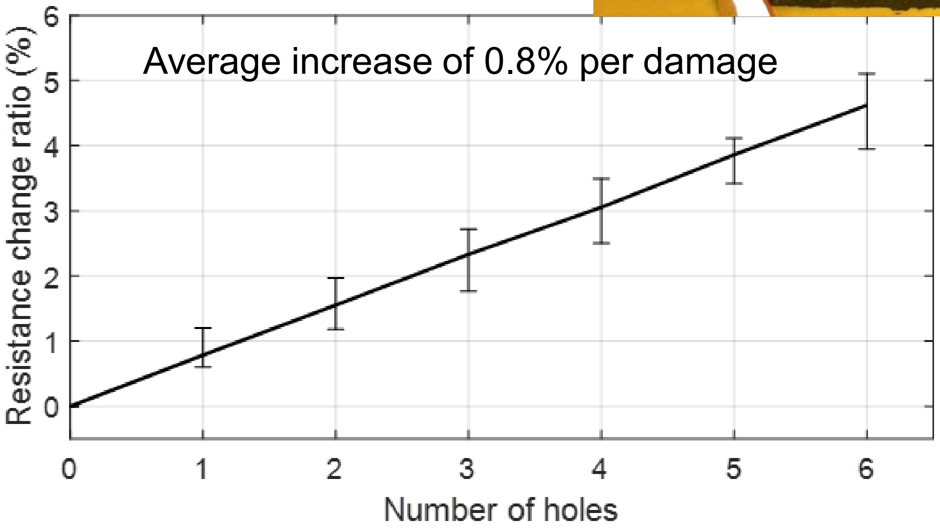
Sensor - Static Puncture Testing

Sensor developed by Daewon Kim and Sirish Namilae

- Resistivity with multiple holes
  - 2.5 in x 2.5 in nanocomposites covered with Kapton tape; six holes are successively added.
  - Change in resistance when subject to static damage induced by drilling 3 mm holes.
  - Resistance remains constant with added holes → stable

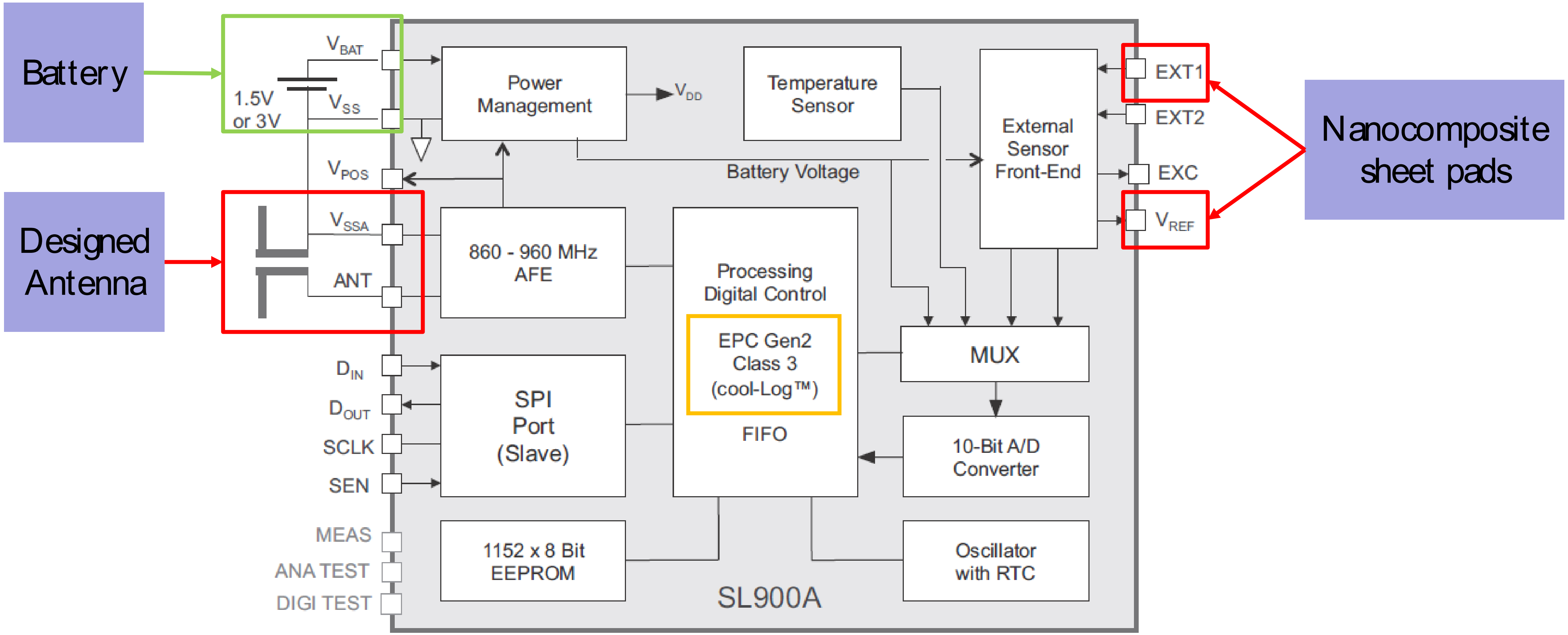






Design of the Wireless Passive Sensor

Basic block diagram of the IC sensory tag



Credits: AMS

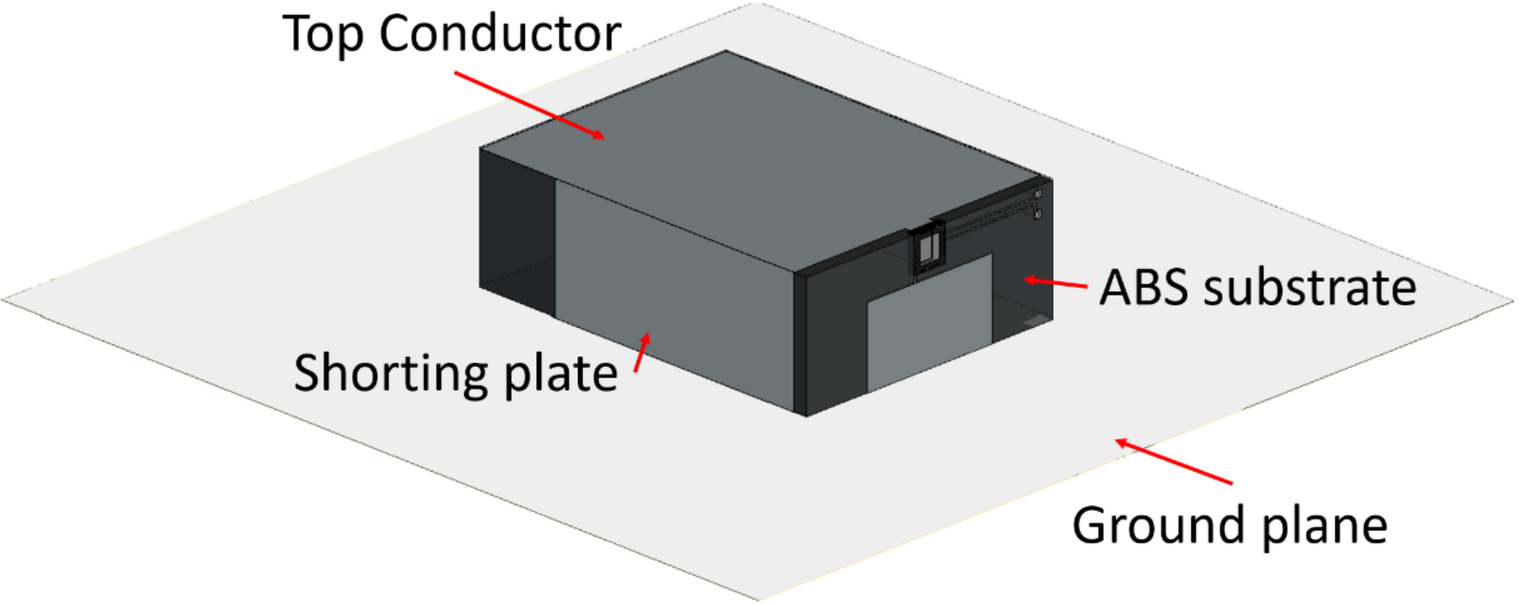
Design of the Wireless Passive Sensor

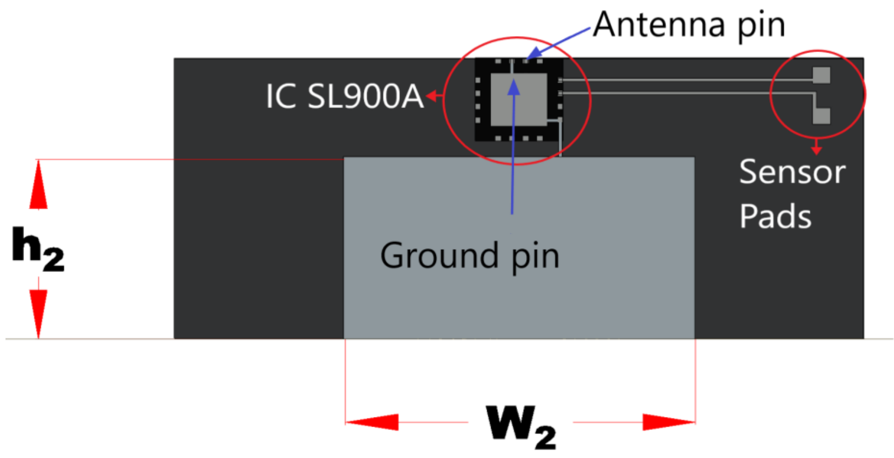
Features of the IC sensory tag

Electrical Characteristics	Value
Antenna pad impedance	**123-j303 Ω**
Antenna pad sensitivity	-6.9 dBm
Antenna pad sensitivity (Battery assisted)	-15 dBm
Carrier frequency	860 MHz to 960 MHz
External sensor interface pads resistance	200 Ω

Design of the Wireless Passive Sensor

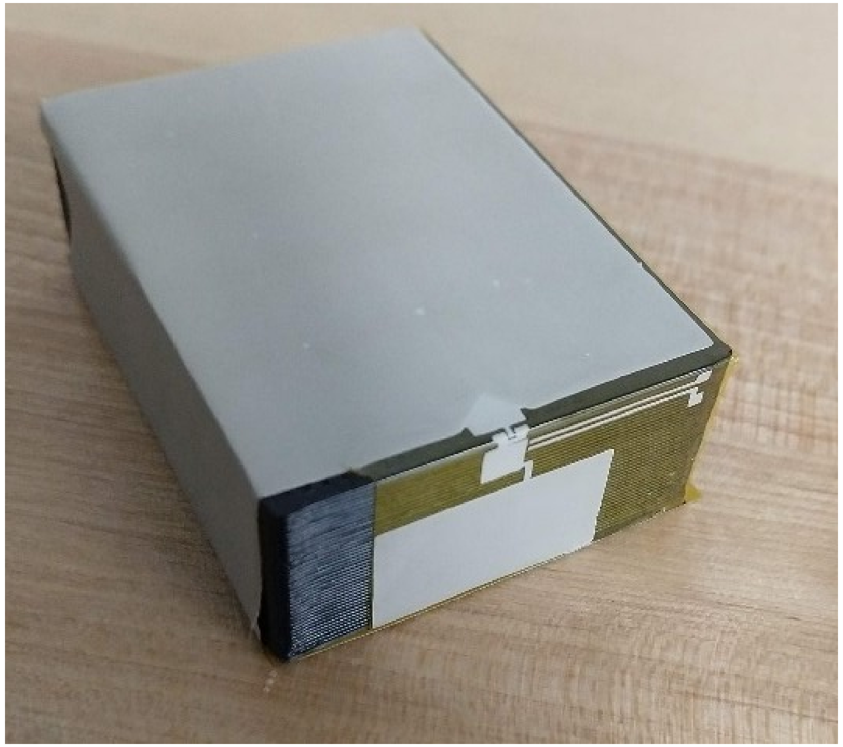
Electrically small antenna (ESA) based on a PIFA design

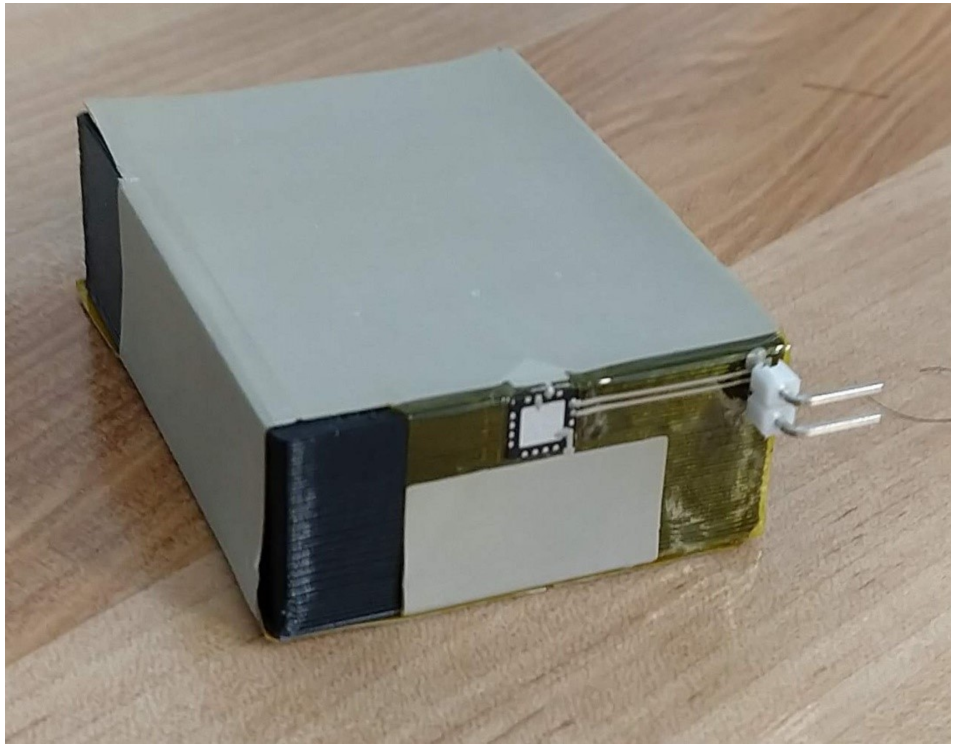




Design of the Wireless Passive Sensor

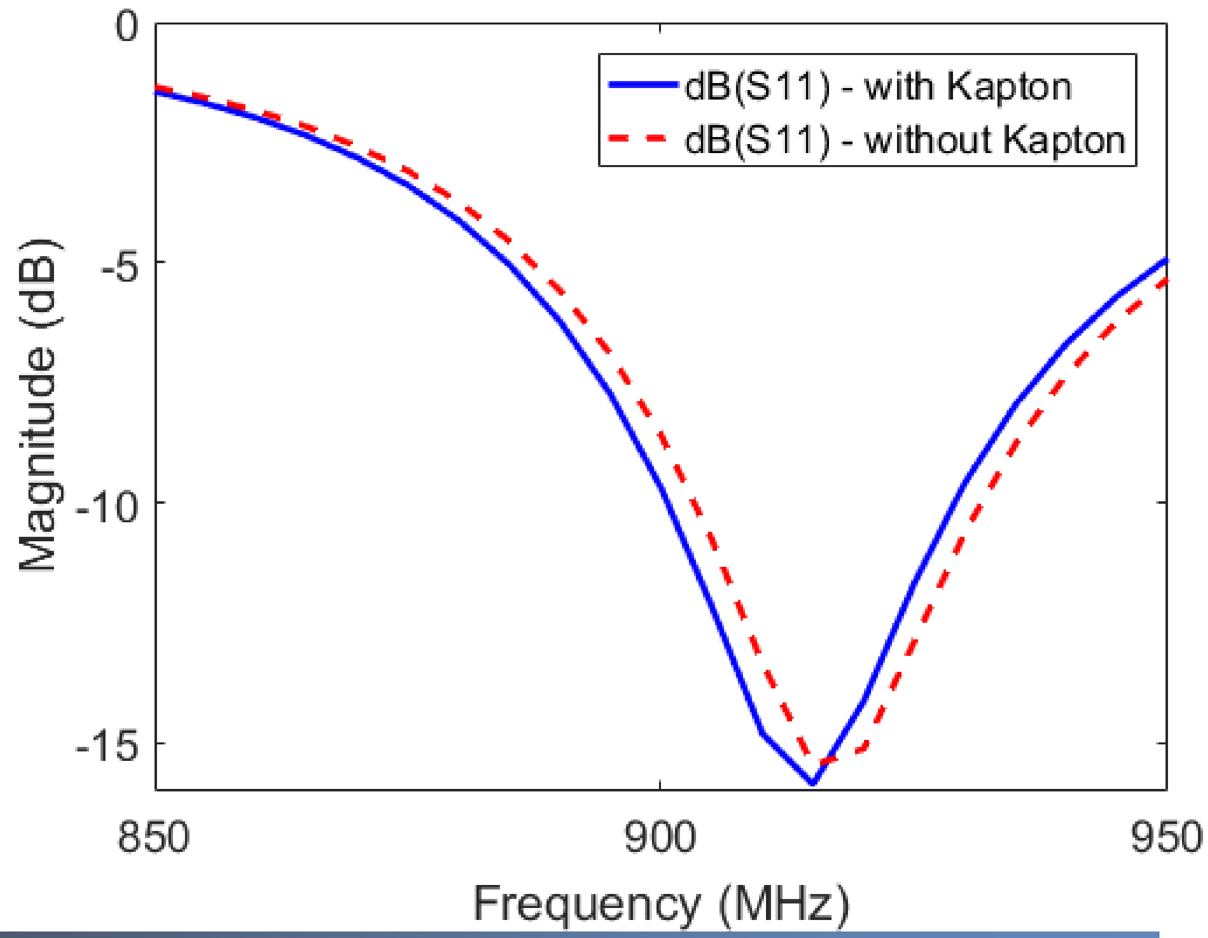
Fabricated Sensor





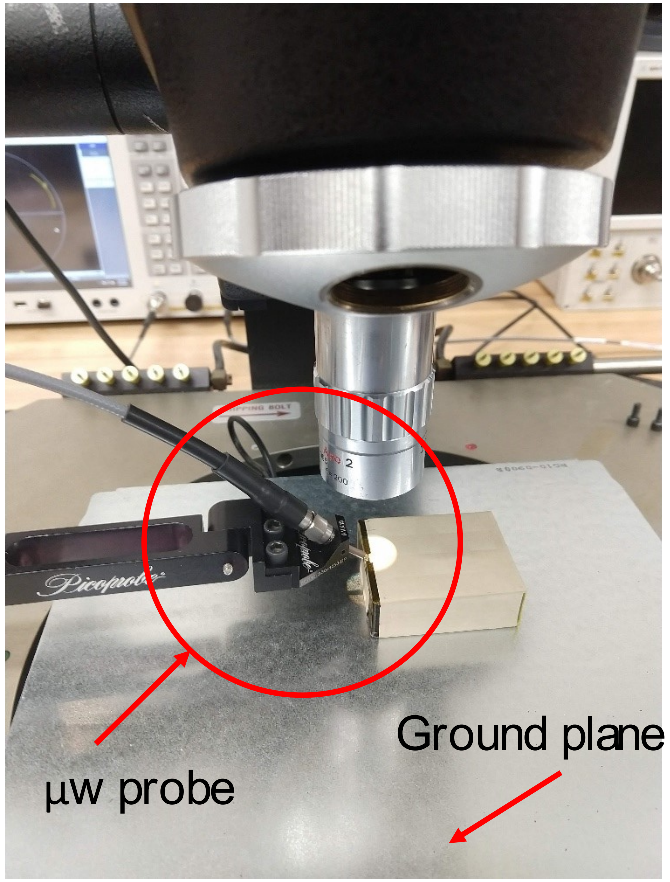
Design of the Wireless Passive Sensor

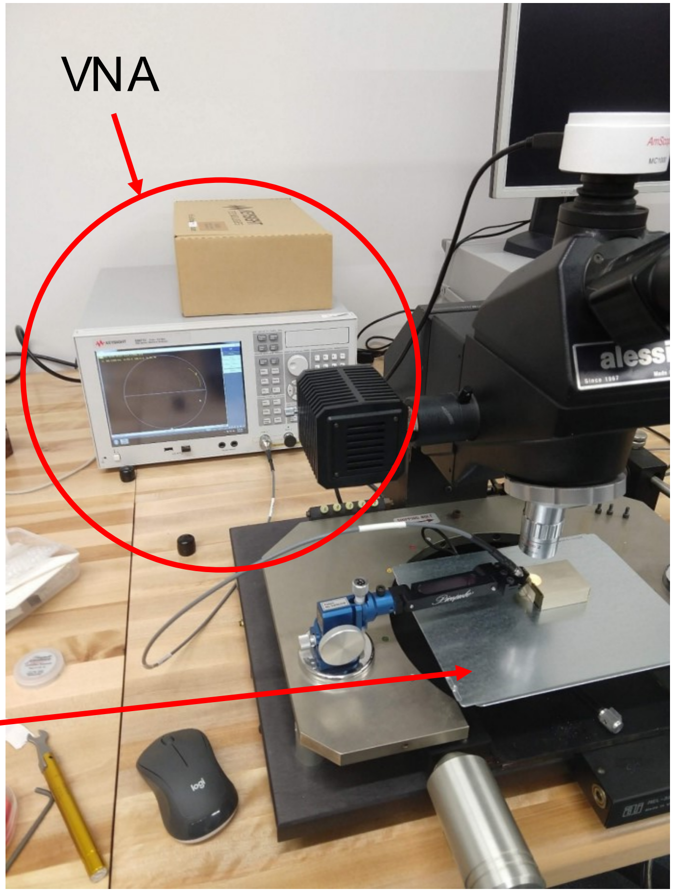
Effect of Kapton wrapping on S11



Results - Wireless Passive Sensor

S11 response measurement

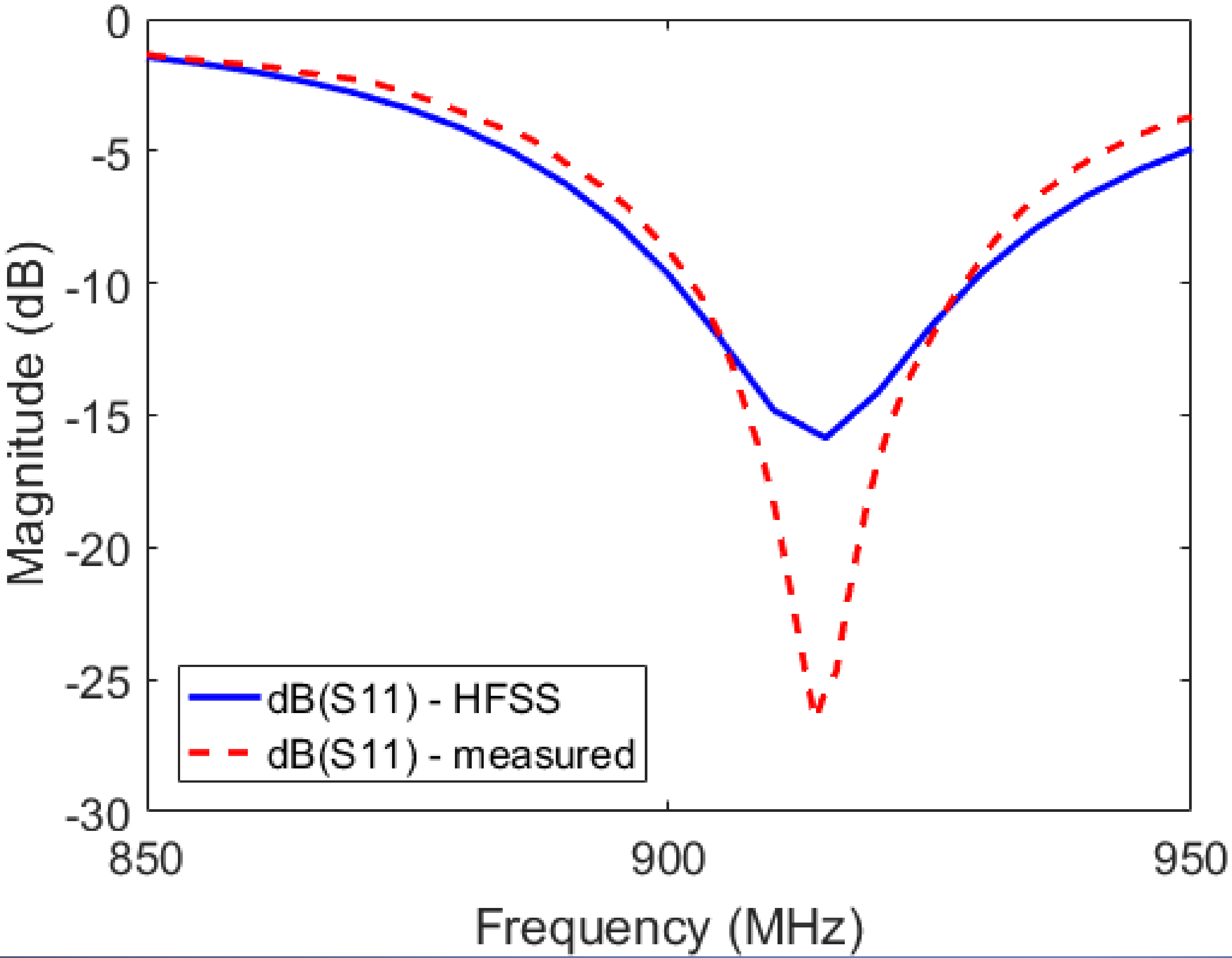




Measuring fixture:
- Gap: 0.4 mm
- Width: 0.2 mm
- Length: 0.4 mm

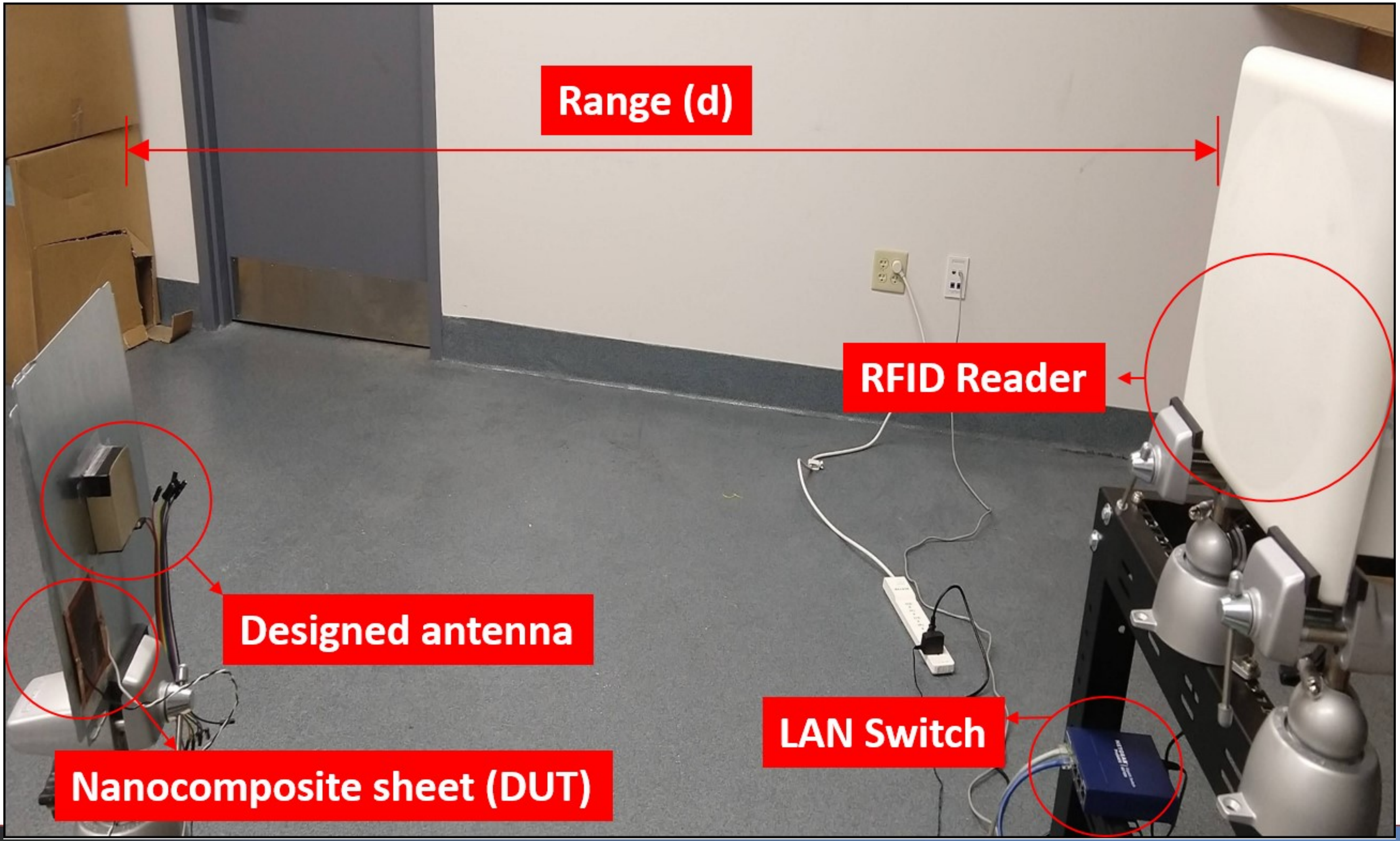
Results - Wireless Passive Sensor

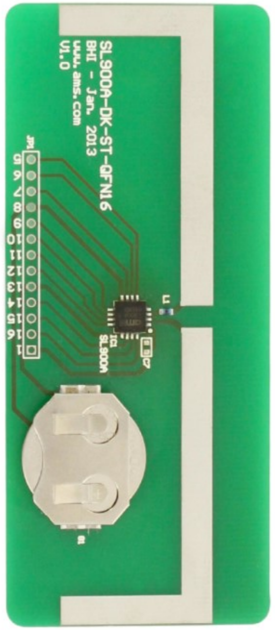
S_{11} measured



Design of the Wireless Passive Sensor

Set-up for measuring the range of the passive wireless





AMS SL900A
Demo Board

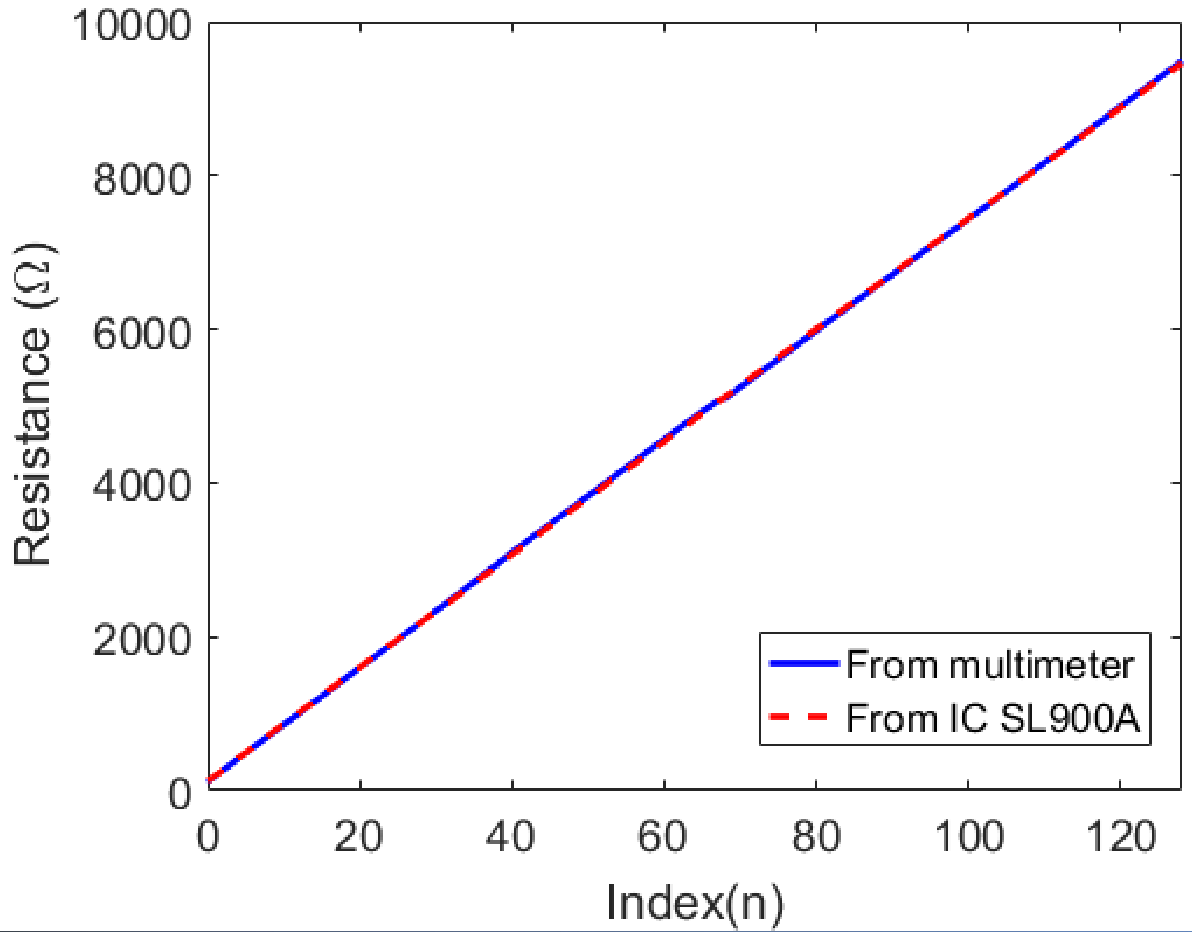
Results - Wireless Passive Sensor

Sensor range for AMS demo board and the designed antenna

	Detection (m)	Sensing (m)
AMS Demo Board	3.8	1.4
AMS Demo Board (Battery assisted)	12.4	2.6
Designed antenna	3.2	1.9

Results - Wireless Passive Sensor

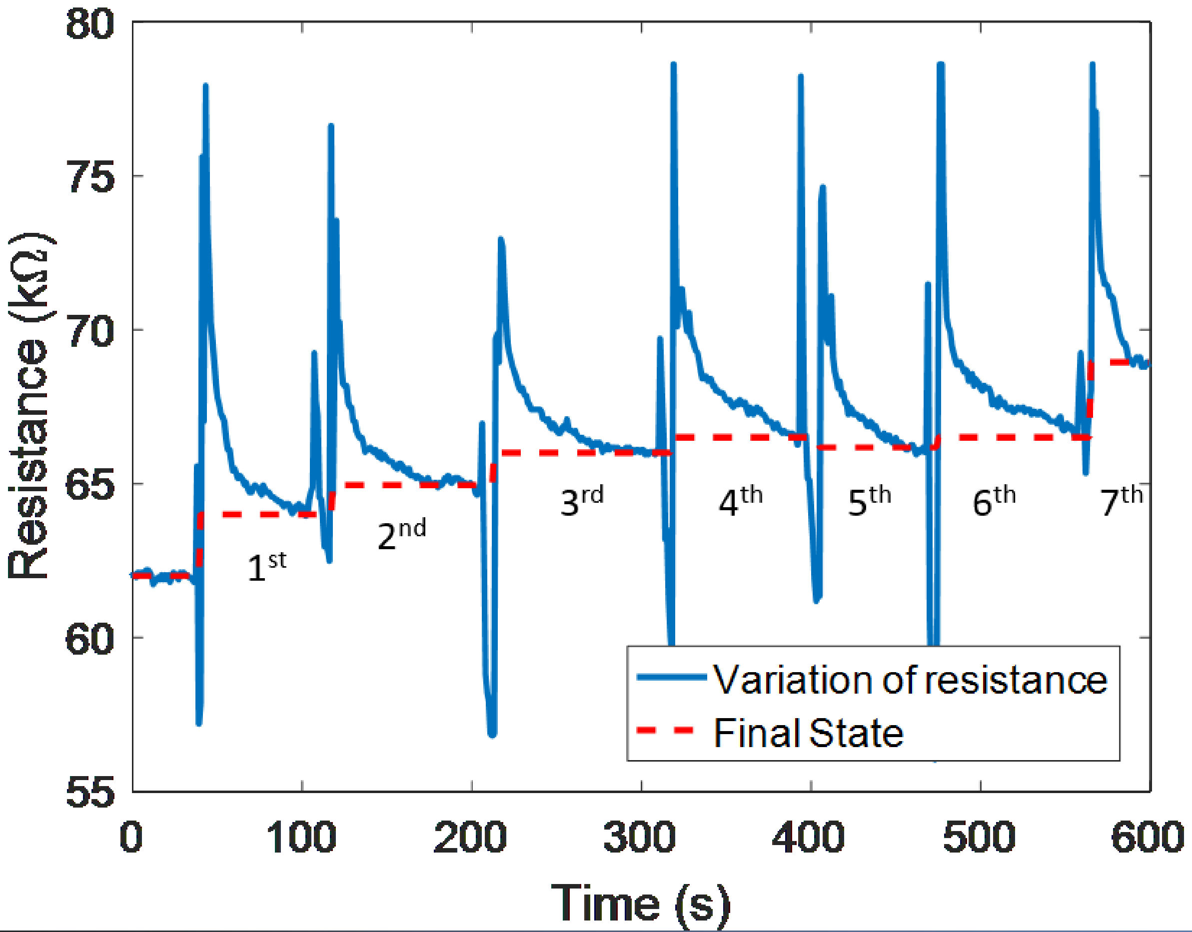
Resistance sensing using the wireless passive sensor

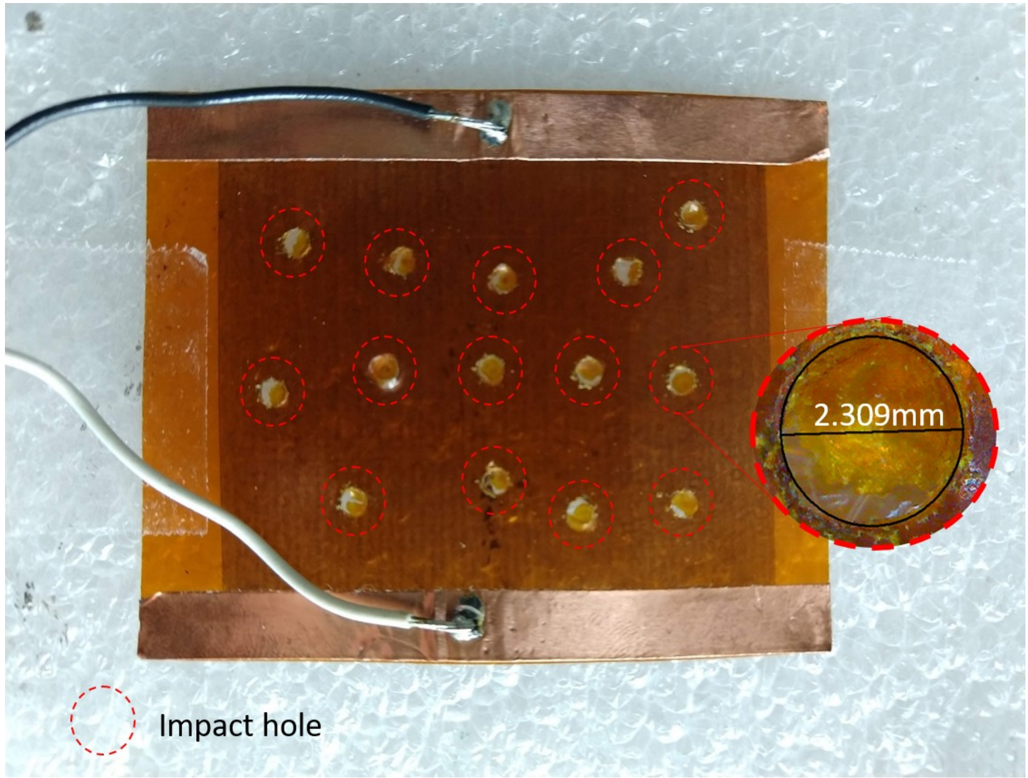


Mean error: 1%
Max error: 22%

Results - Wireless Passive Sensor

Resistance change of the nanocomposite sheet – Static damage test





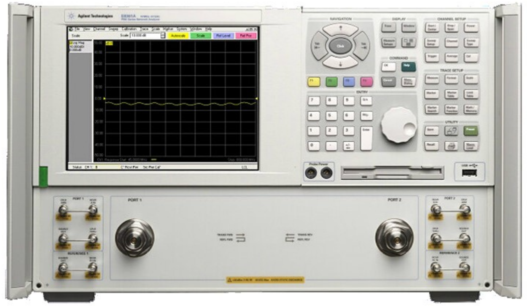
Research Park

WiDE Lab

ERAU Micaplex

4200 sq. ft of RF Labs

Capabilities - Hardware

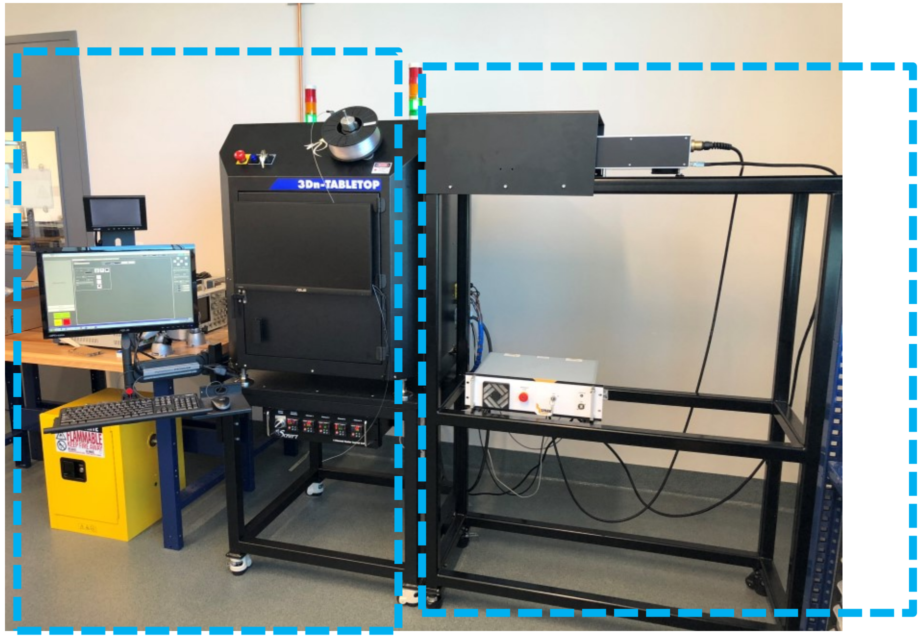


Keysight PNA (67 GHz)

ETSAMS-8500 Anechoic Chamber
(12 ft x 12 ft x 24 ft)

LPKF Laser PCB Mill

RF Probing



nScrypt DPAM system Femtosecond Laser (10 W)

Capabilities – Test Beds

Gulfstream GIII

Learjet

Turbines

[redacted]

Dr. Thomas Weller, Dr. Jing Wang, Dr. Ramiro Ramirez, Dr. Di Lan, Dr. Daewon Kim, Dr. Sirish Namilae, Dr. Ken Church, Dr. Paul Deffenbaugh

Thank you