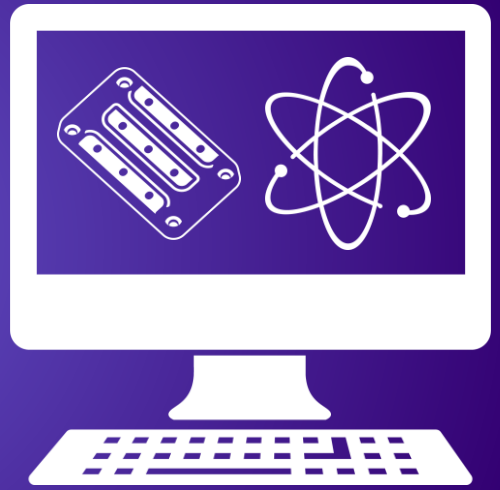
Wolfspeed™

Additive Manufacturing Approaches For Harsh Environment Telemetry



John R. Fraley

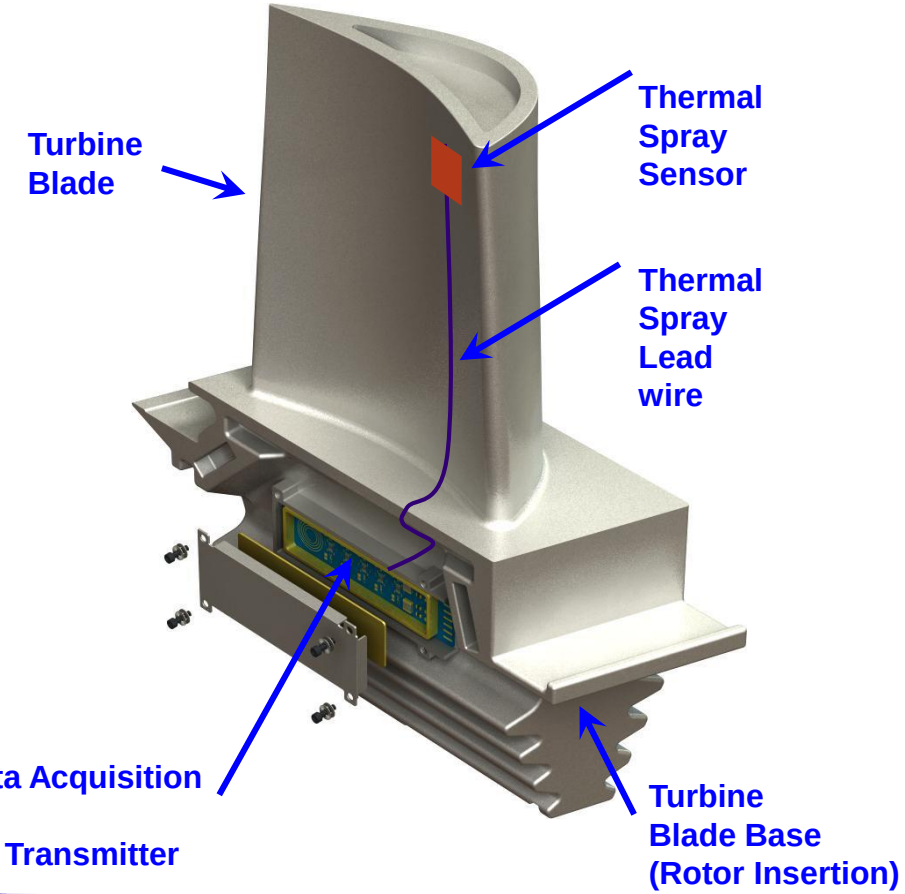
WiSEE 2018

A CREE COMPANY

THE PROBLEM: INSTRUMENTING F AND G CLASS TURBINES

Harsh Environment Wireless Telemetry

- SiC and GaN Based
- High temperature (>500 °C)
- High g-load (>15,000g)
- Real time, Continuous Condition based maintenance
- Minimize engine downtime
- Prevent catastrophic failures
- Improve future designs



THE TEAM

Wolfspeed™

A CREE COMPANY

U.S. DEPARTMENT OF ENERGY

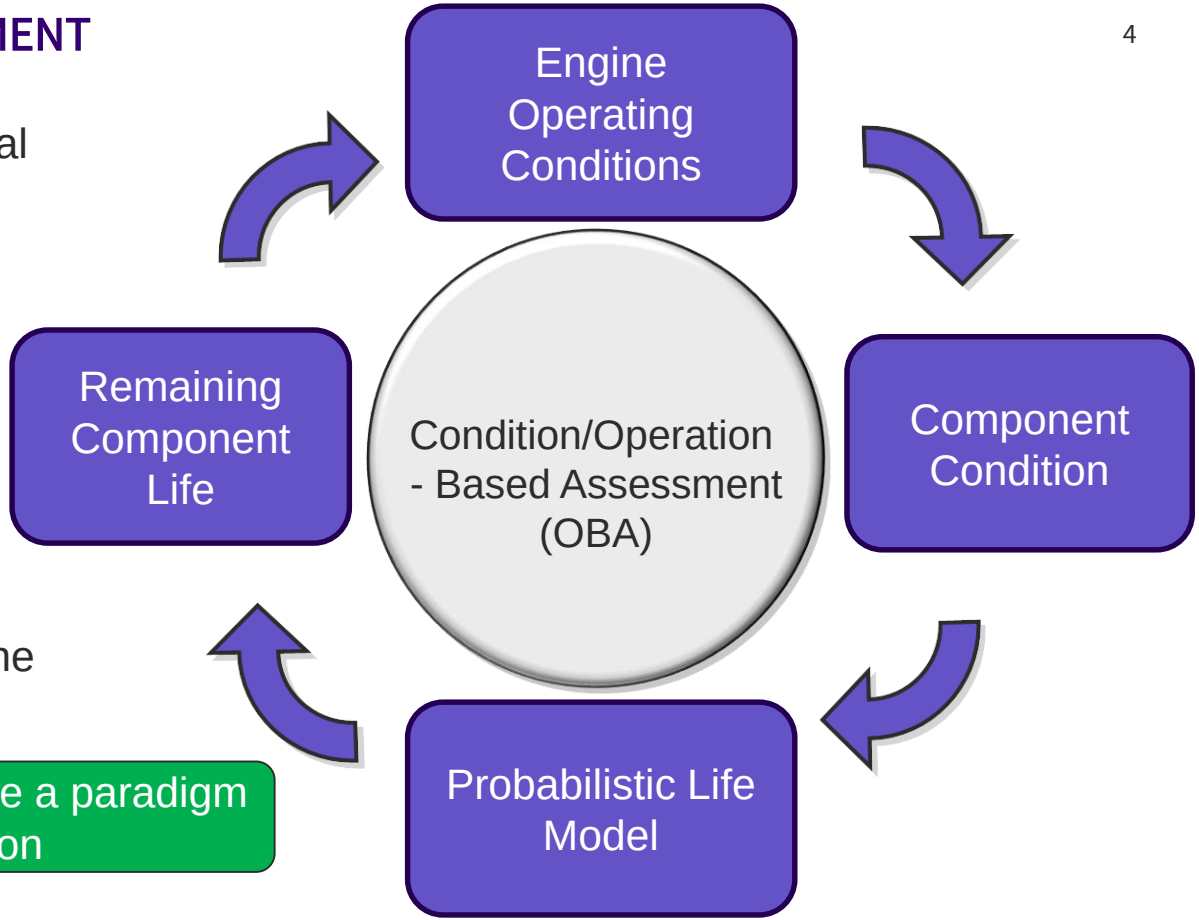
UNIVERSITY OF ARKANSAS

SIEMENS

OPERATIONAL BASED ASSESSMENT

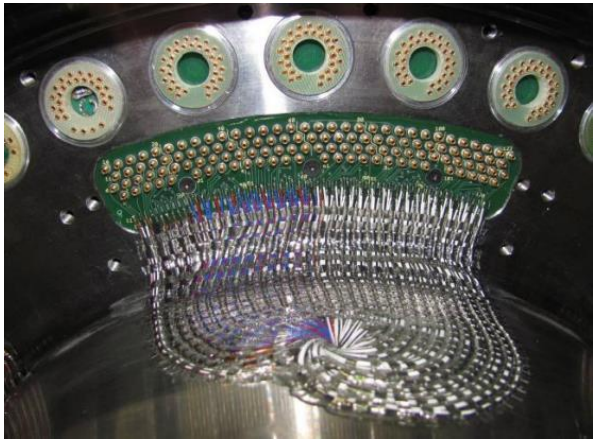
- Instrumentation provides critical information for:
  - Test Engine Evaluation
  - Design Model Validation
  - Engine Performance and Diagnostics
  - Condition Based Assessment
- Improvements over existing instrumentation is required to obtain long life data from engine fleets

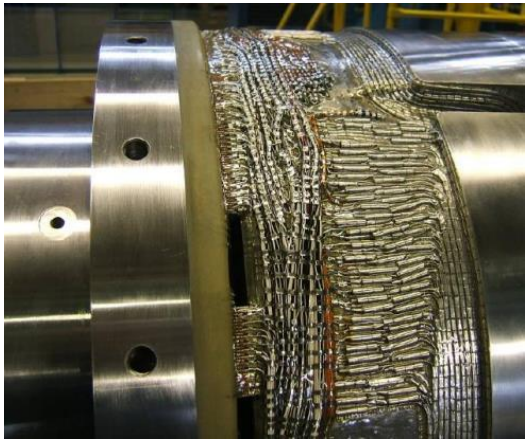
Advanced sensor systems enable a paradigm shift in engine operation



CURRENT INSTRUMENTATION

- Wires from blade rings down entire length of rotor
- Time consuming – 3-6 months per validation
- Expensive - $2-3 Million per validation
- Damages rotor; costly replacement



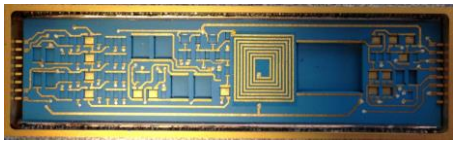


ANATOMY OF A SMART COMPONENT

Data acquisition enables real-time input to life models

Thermal spray processes enable cost-effective, integrated sensors

High temperature wireless telemetry enables real-time data transmission from rotating components



OUTCOMES

Online Condition Based Monitoring

- Reduce component-life based shutdowns results in $1-2 Million savings and 1-2% increase in machine on time
- Online engine operation for efficiency gains

Feedback for Design Optimization

- No-wires leads to higher accuracy
- Strain amplitude error ± 30% → ± 5%

Summary

- Higher engine on-time
- More design feedback
- Online feedback leads to increase in operating efficiency
- Pushing forward high temperature electronics

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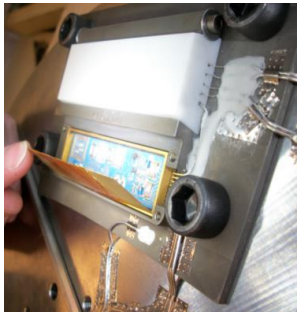
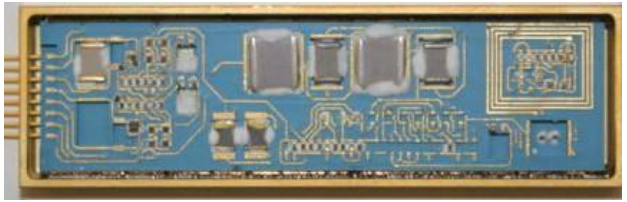
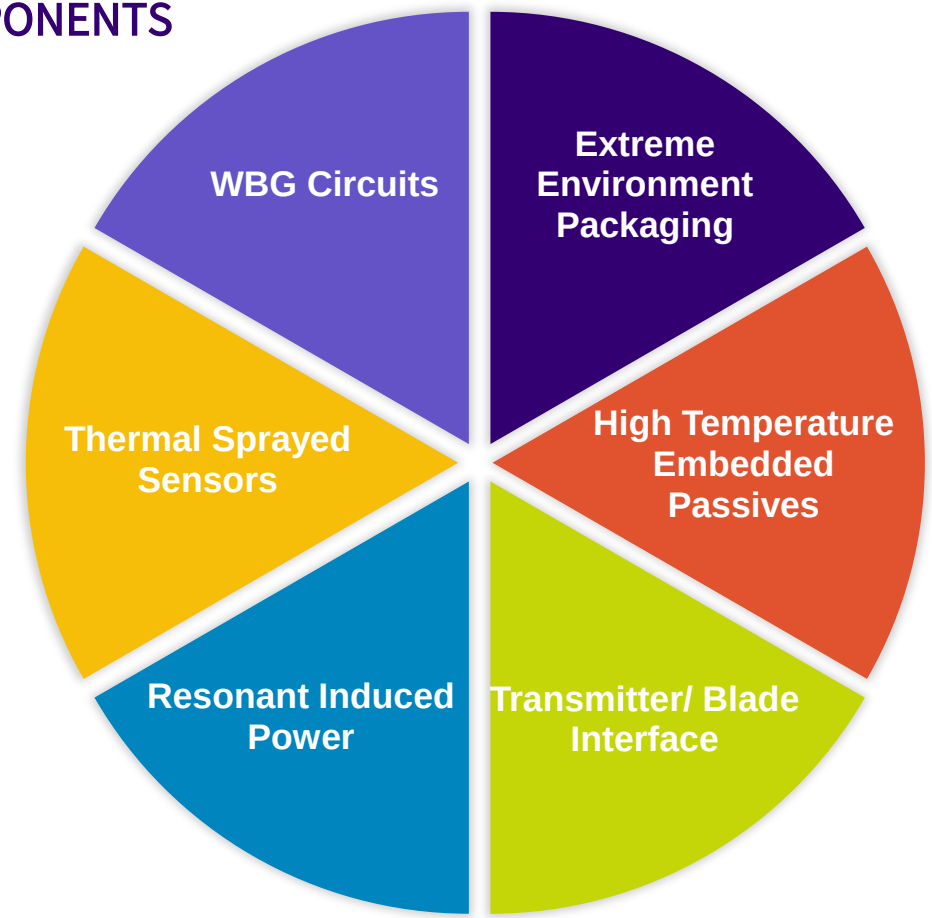
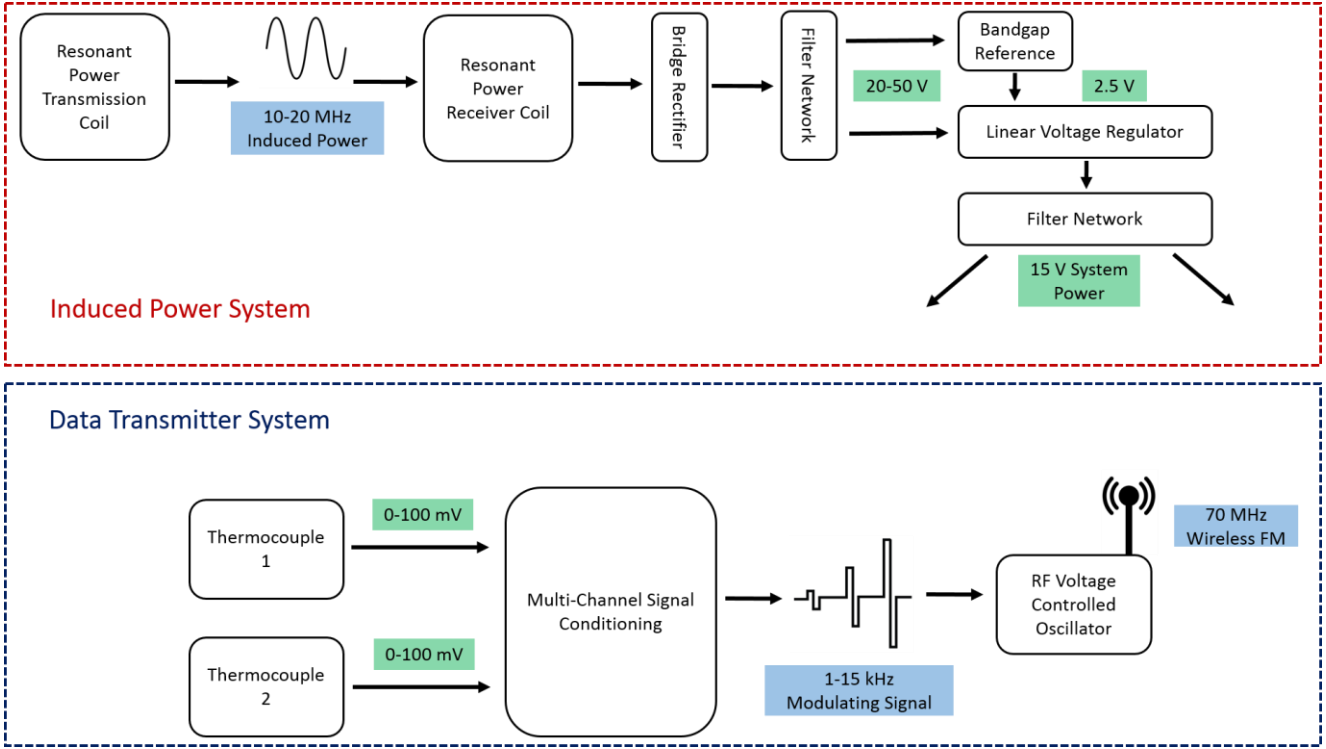




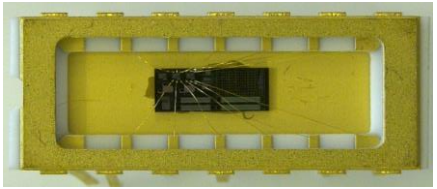
TELEMETRY COMPONENTS

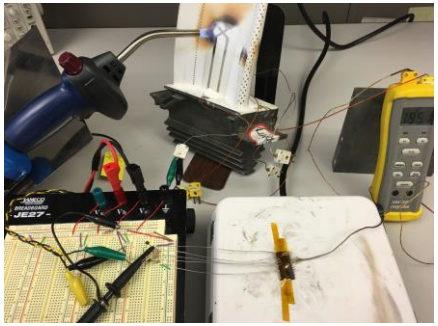


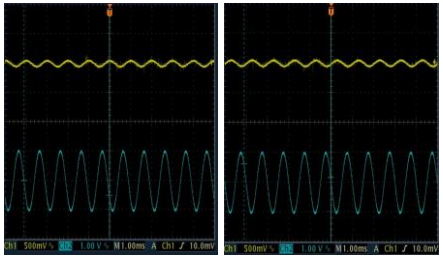
FULL SYSTEM BLOCK LEVEL DESIGN

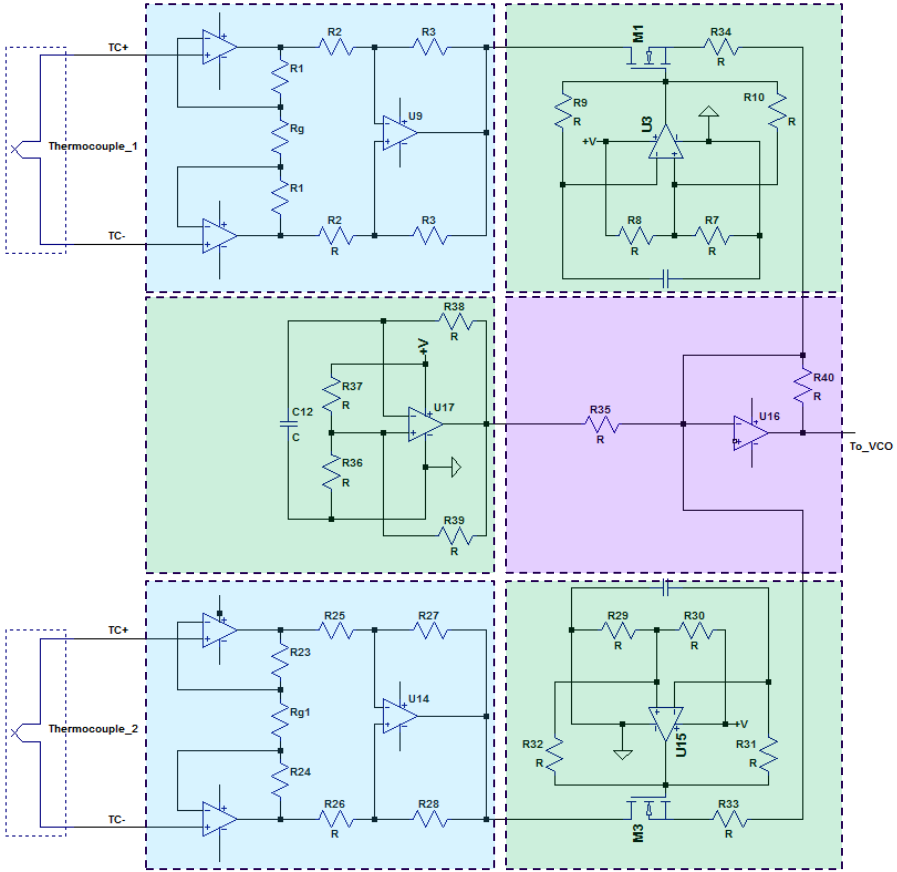


SIC SIGNAL CONDITIONING



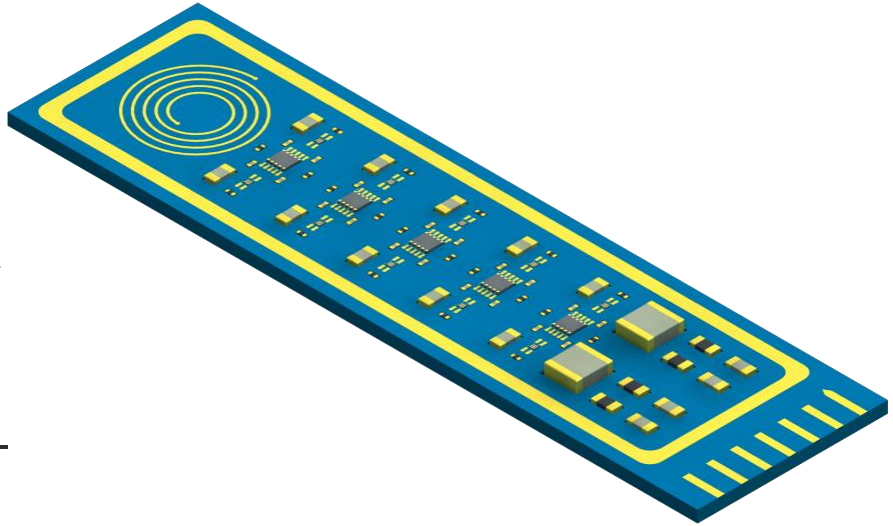






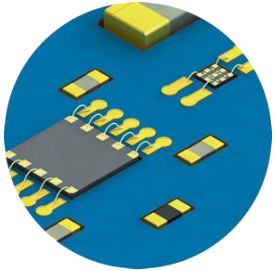
ADDITIVE MFG SUBSTRATES

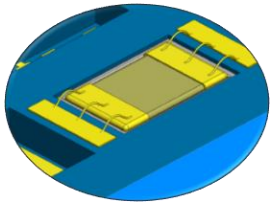
- For extreme environment wireless systems, an LTCC or HTCC substrate is used
- These substrates provide support to the wireless electronics both for high temperature operation, as well as high vibration or high g-load operation

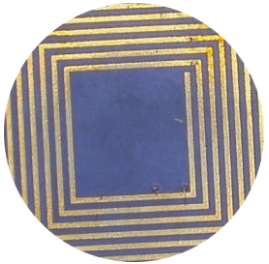


HYBRID INTEGRATION

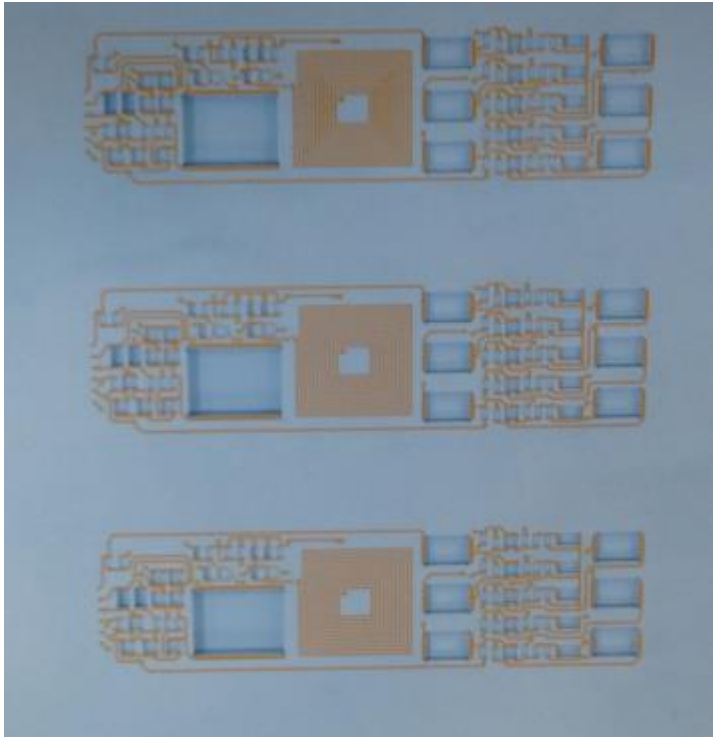
- The LTCC or HTCC substrate can provide high density multilayer electrical interconnection, and is suitable for high temperature and high frequency operation
- The substrate provides the foundation of a MCM approach, which increases reliability of the overall system
- Cavities can be placed in the substrate allowing for low profile die attachment, minimized wire bond length, and physical support for die
- Integrated passives can also be embedded into the substrate

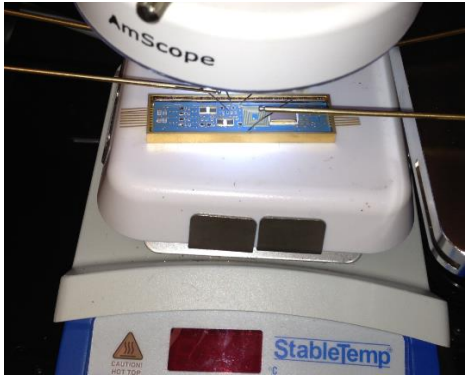


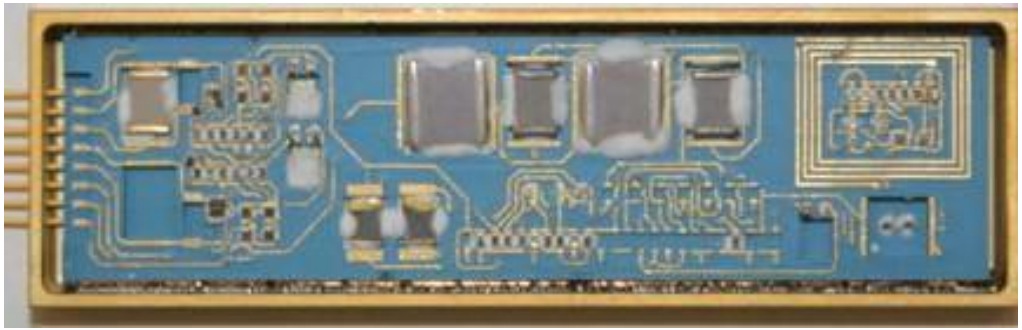




LTCC SUBSTRATES

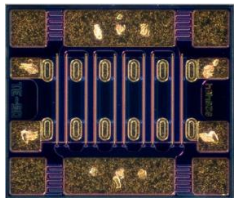


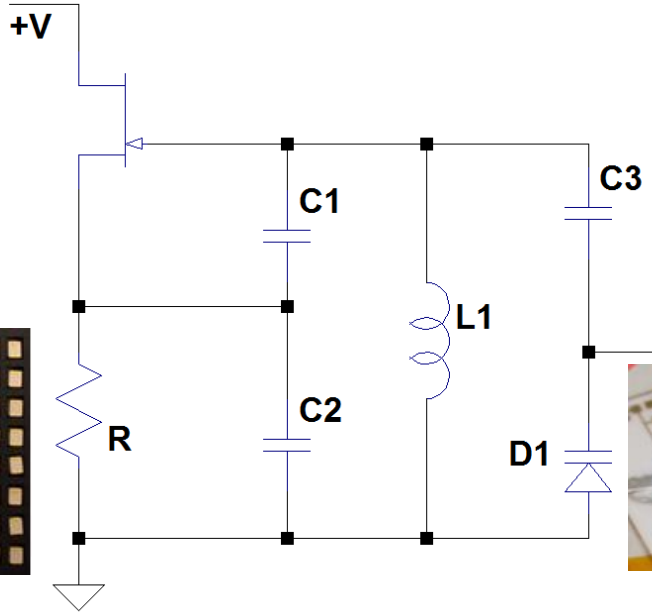




THE MAGIC OF HIGH TEMPERATURE FM

$$y(t) = A_c cos(2\pi f_c t + \frac{A_m f_\Delta}{f_m} sin(2\pi f_m t))$$

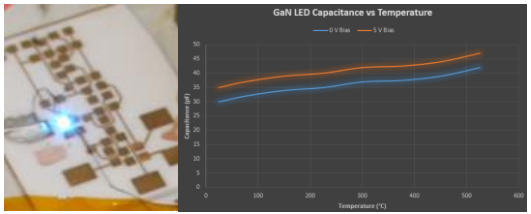




Baseband Signal

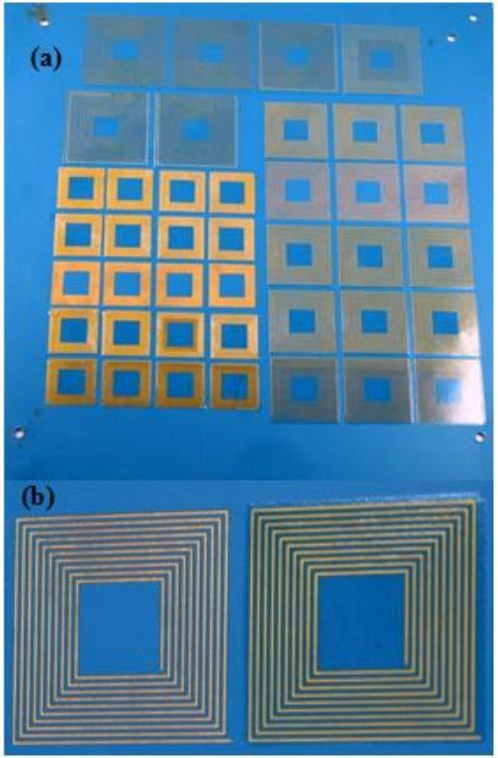
$$f_c = \frac{1}{2\pi\sqrt{L}}$$

$$f_\Delta \propto \frac{1}{2\pi\sqrt{\Delta C}}$$

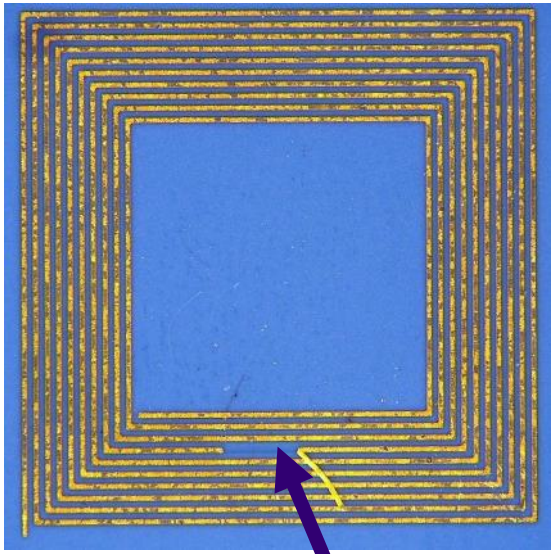


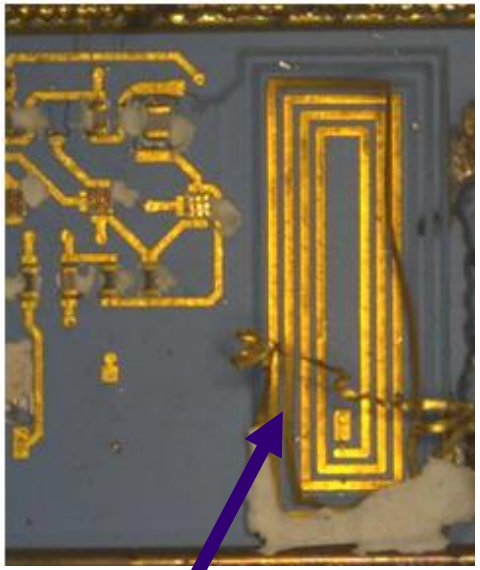
GOLD ELECTROPLATE FOR HIGH Q

$$Q = \frac{energy.stored}{average.power.dissipated} = \frac{R}{\sqrt{\frac{L}{C}}}$$



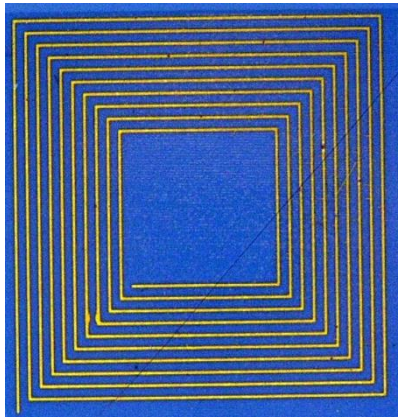
PROBLEM WITH PLATING

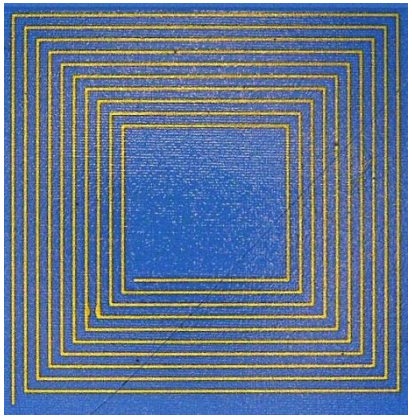


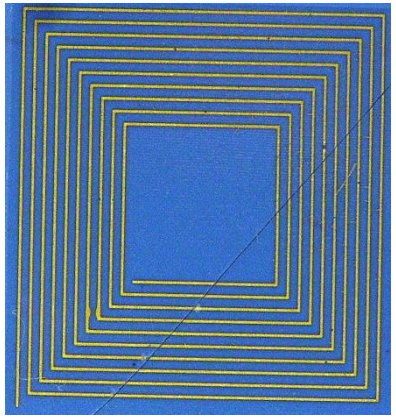


CTE Based Delamination

GLASS ENCAPSULATE

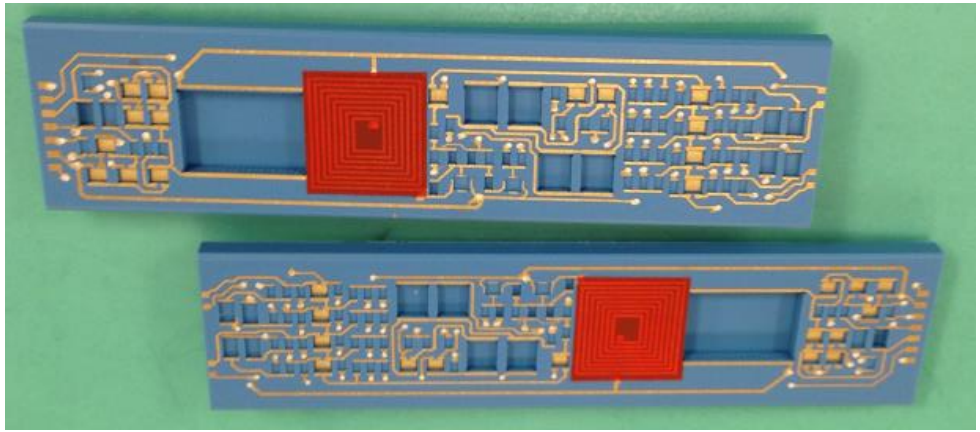


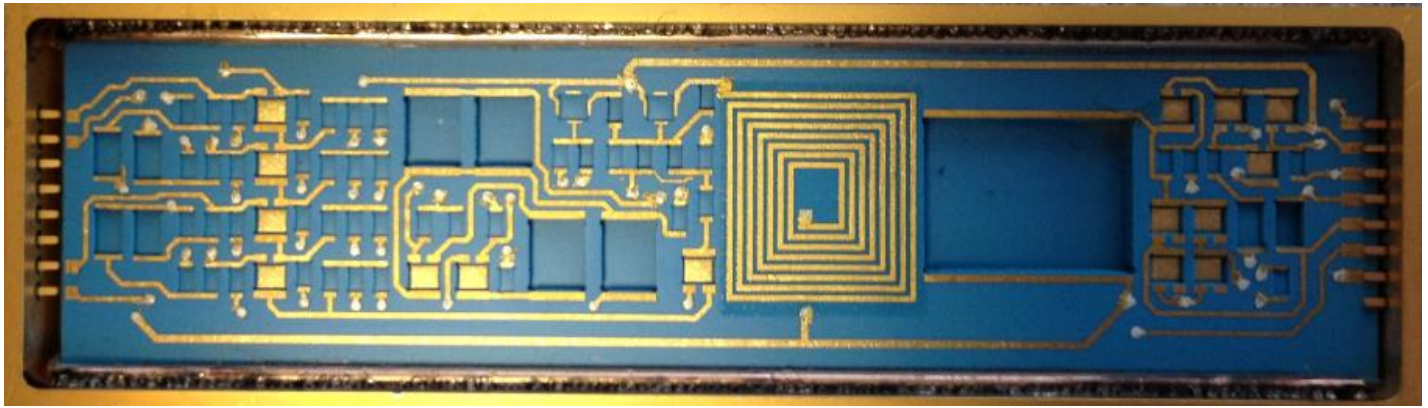




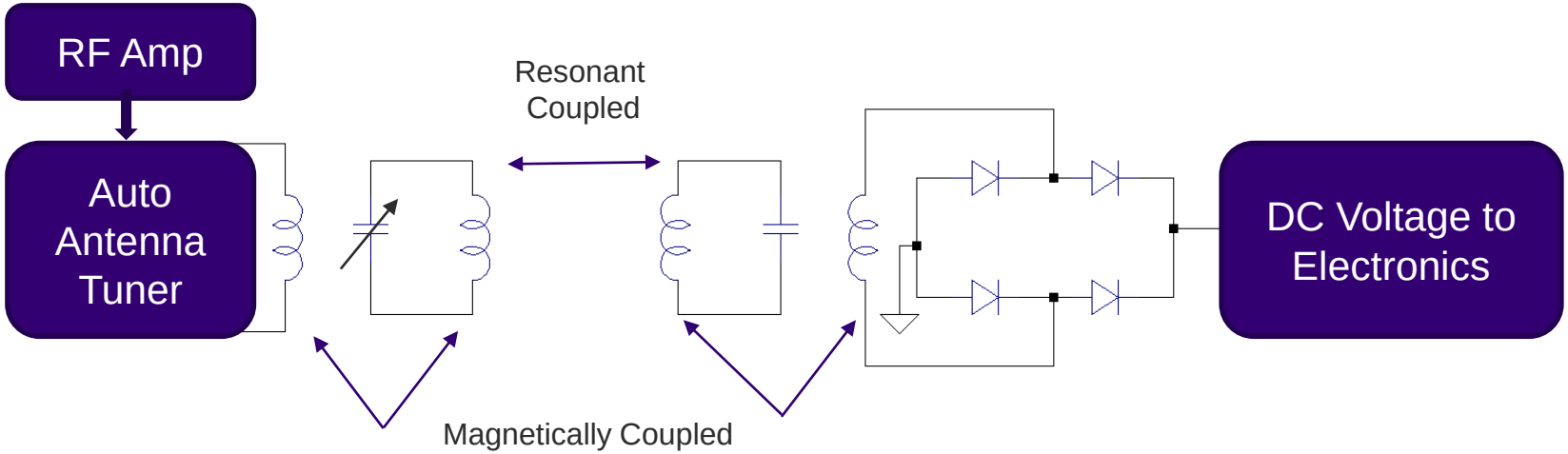
After thermal cycles (500 times from RT to 500 C), no delamination

WORKING SUBSTRATES





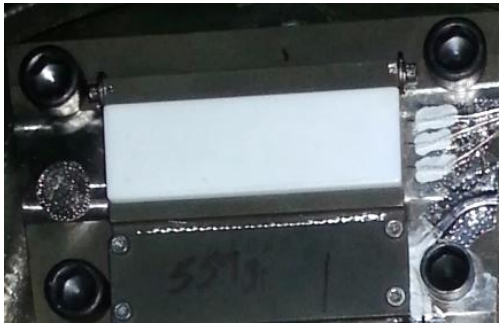
HOW TO POWER IT?

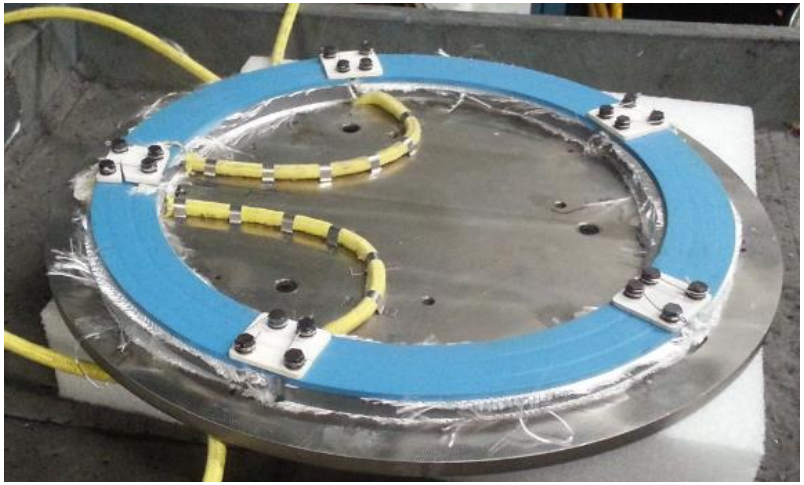


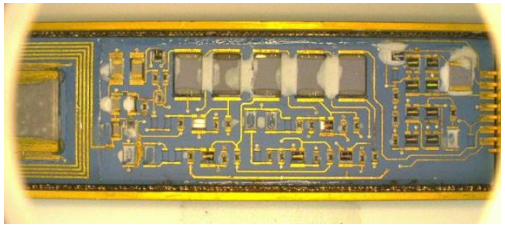
THE OLD WAY

Hand wound coil on magnetic (nanoperm) core

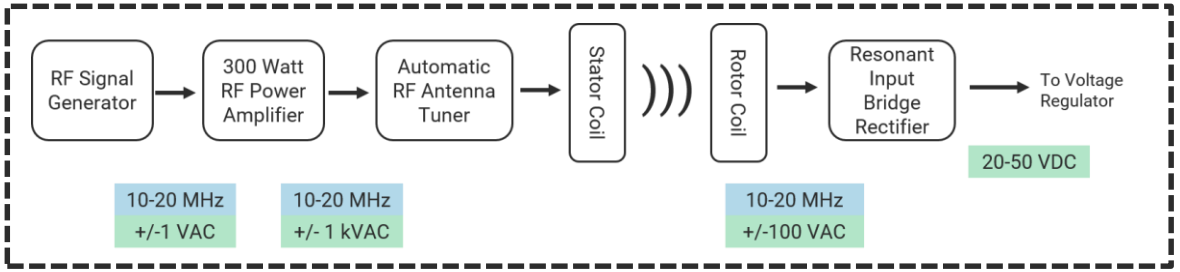
INDUCED POWER SYSTEM

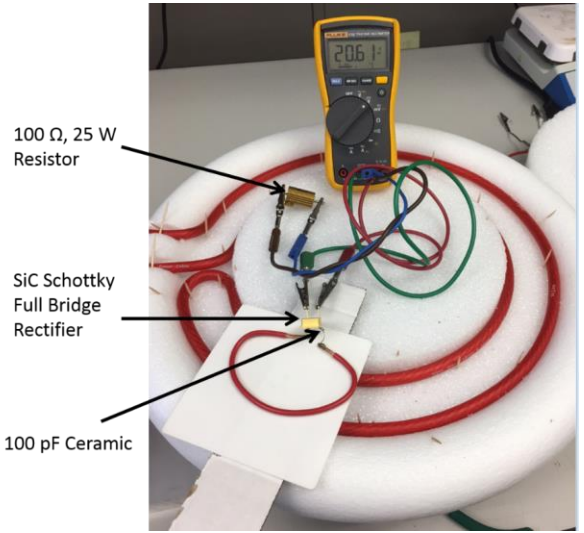




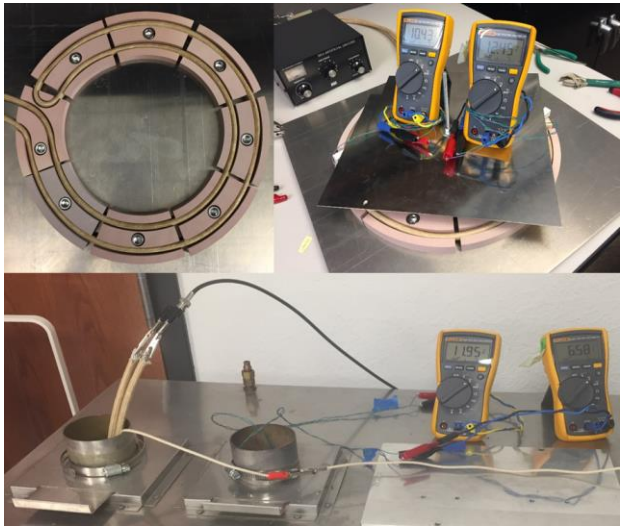


REVISED POWER SYSTEM



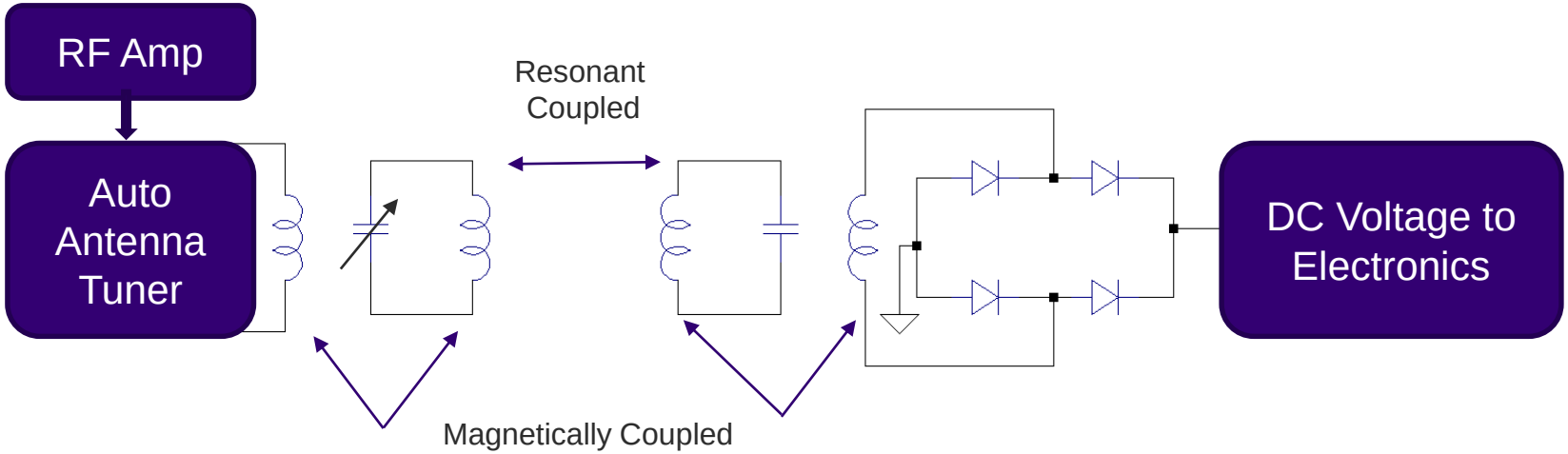


Room Temp Prototype



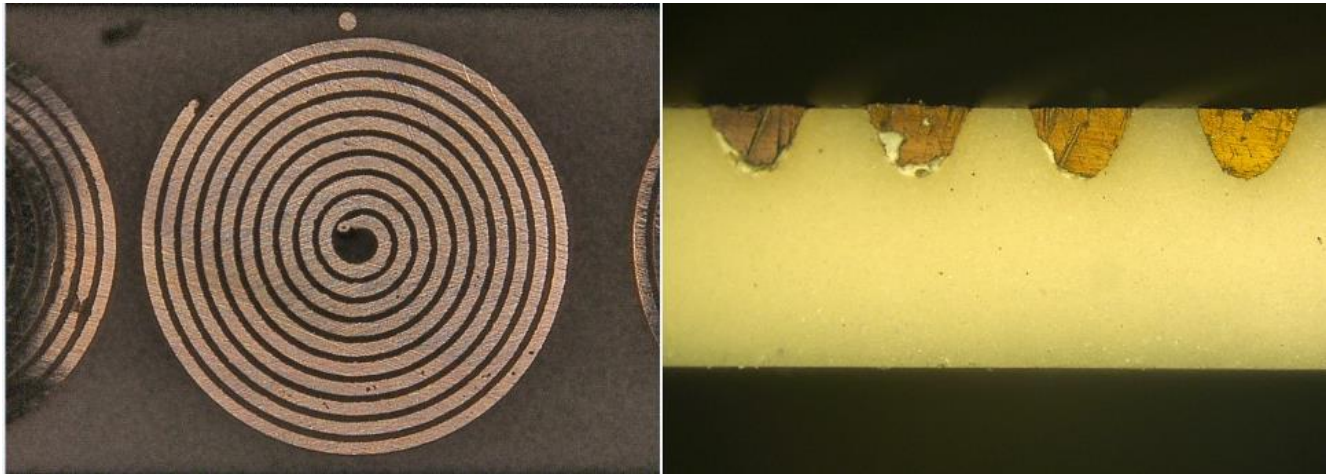
> 550 °C Prototype

POWER UP

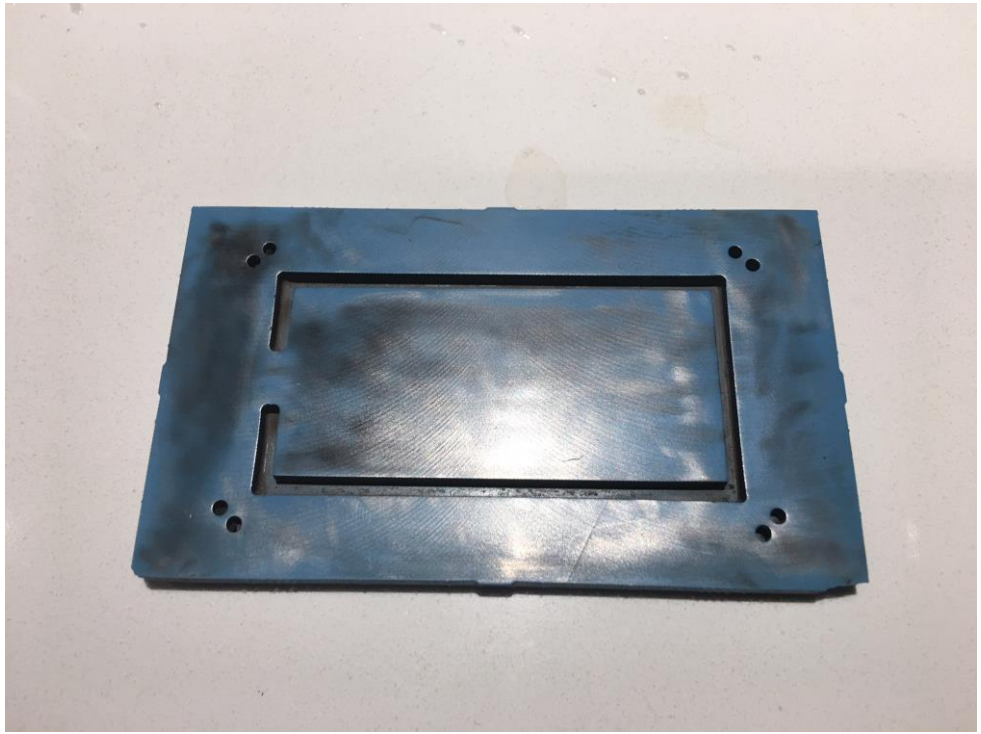


THE NEW WAY – SILVER FILLED TRENCH

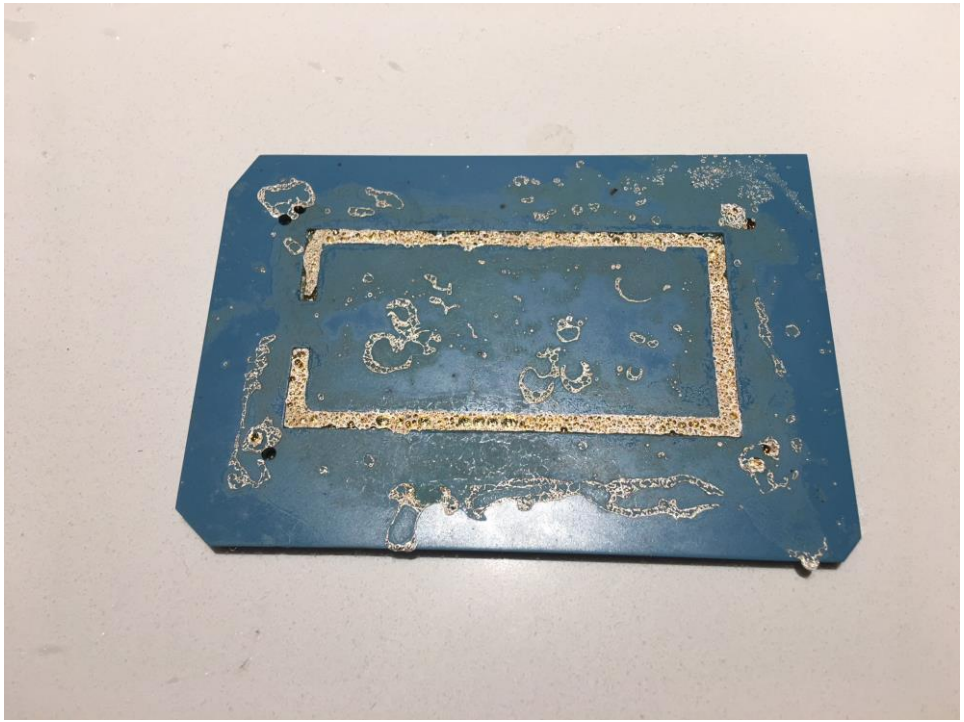
$$\eta = k\sqrt{Q_T Q_R}$$



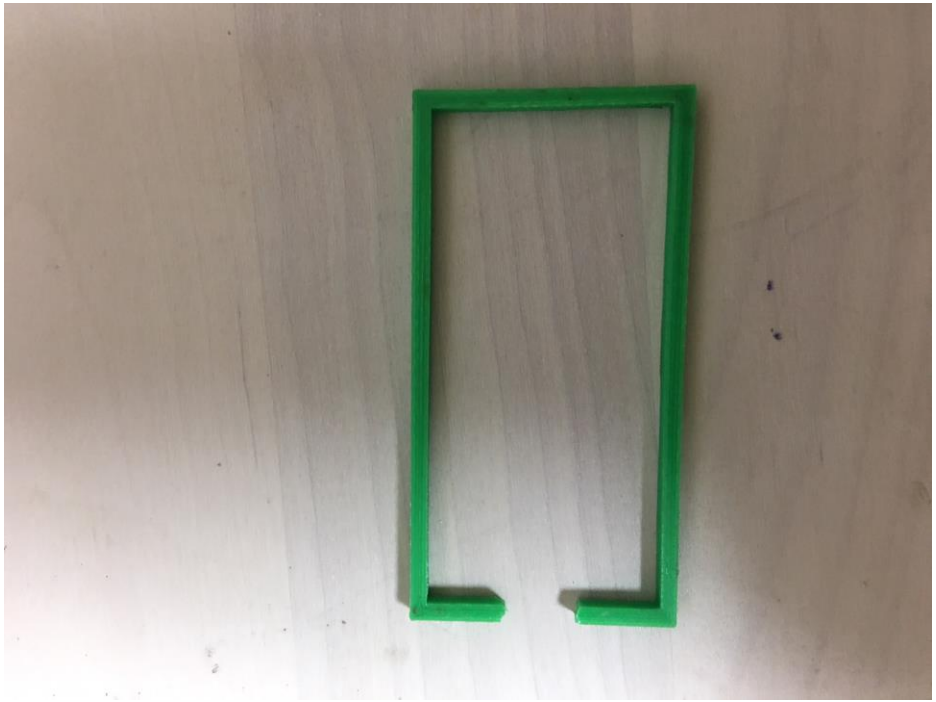
HTCC TRENCH



MANUAL SILVER POWDER FILLING



3D PRINT WITH PLA



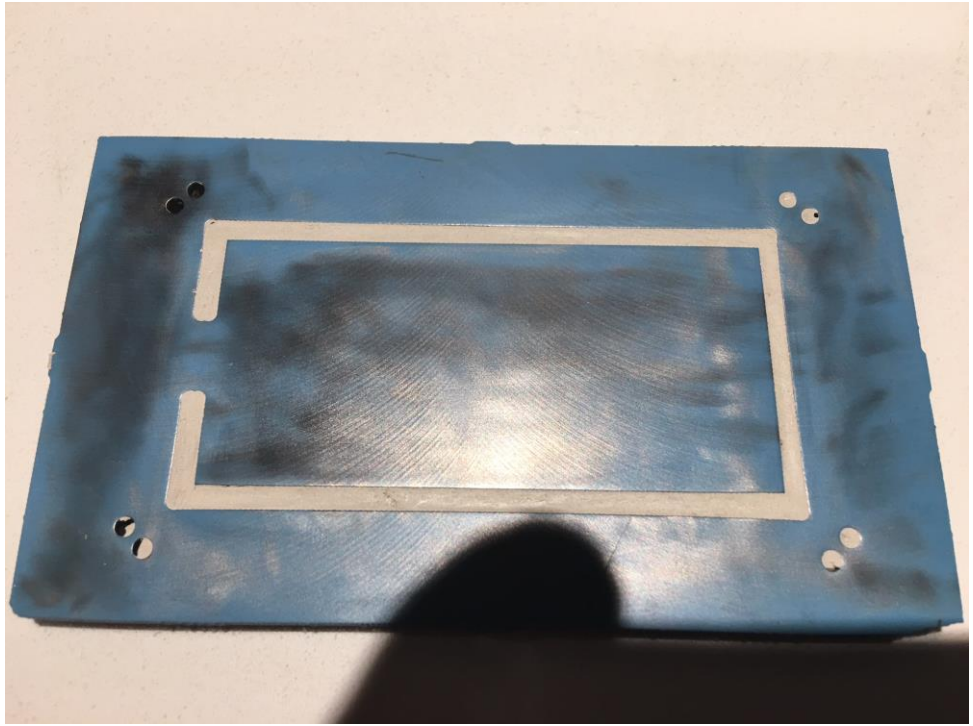
CREATING A SPRUE

INVESTING THE PLASTIC PRINT

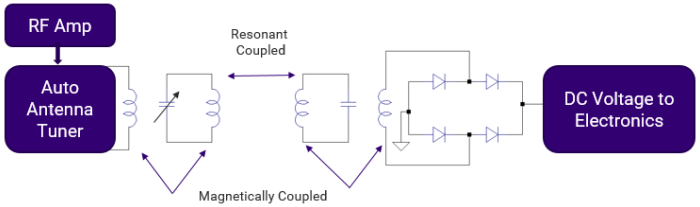
THE NEW WAY – SILVER FILLED TRENCH

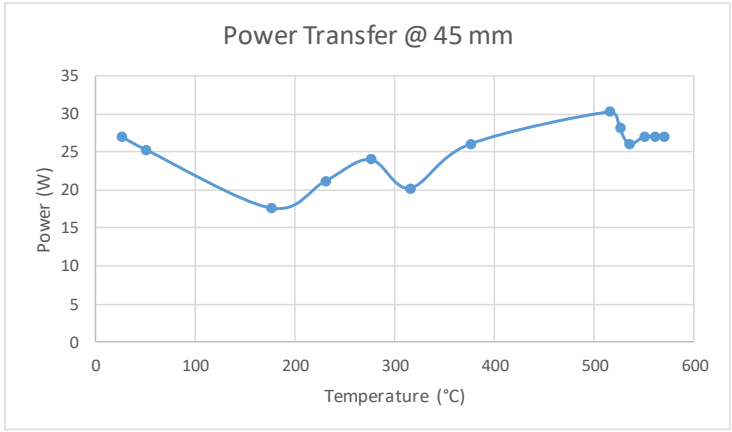
PURE SILVER CAST

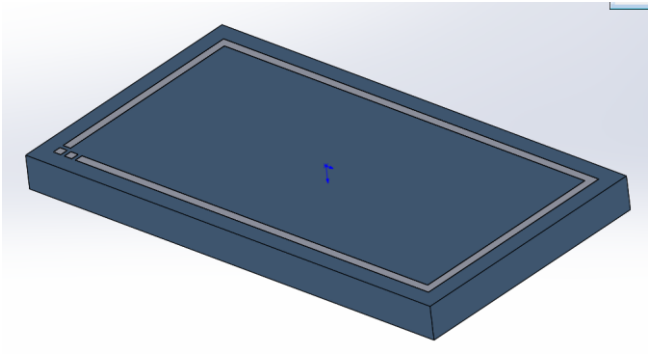
SILVER FIRED INTO HTCC

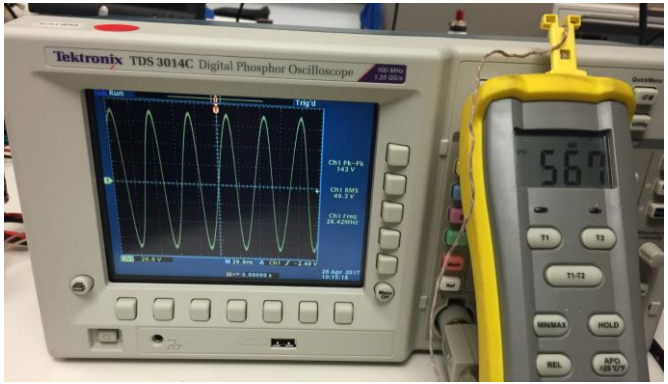


POWER TRANSFER









RECAP

- To achieve extreme environment telemetry, 3D packaging is a necessity
- Embedding passives enables high reliability functional systems
- High Q resonant inductors can be achieved with a combination of electroplating and glass encapsulation
- Even higher Q resonant power transfer systems can be achieved with AM silver filled trench technology
- 3D additive manufacturing allows realizable systems

Questions?