

# High Temperature Wireless Sensor Systems

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# Outline

## 1 Overview

- Applications
- Bearing Sensors
- Turbine Blade Sensos

## 2 Technical

- Enabling Technologies
- Bearing Sensor Design
- Blade Sensor Design

## 3 Testing Facilities

- Bearing Tests
- Spin Tests

## 4 What's Next?

- Technical Hurdles
- Generation Evolution

# *Overview*



# *Why High Temperature Wireless?*

## Data Collection from Rotating Components

Increased SNR from Sensors

Reduced Weight from Cabling

Distributed Systems

Improved Process Controls





# Applications

## Aerospace

Bearing Health Monitoring

Gearbox Health Monitoring

Distributed Engine Controls



## Power Generation

Turbine Blade Health Monitoring

Condition Based Maintenance

Smart Turbine Control



Temperature, Pressure, Flow Monitoring

Wireless Drill Head Control



Chemical Process Monitoring

Manufacturing



## Geological Exploration

## Industrial Processes

# Air Force Bearing Sensors

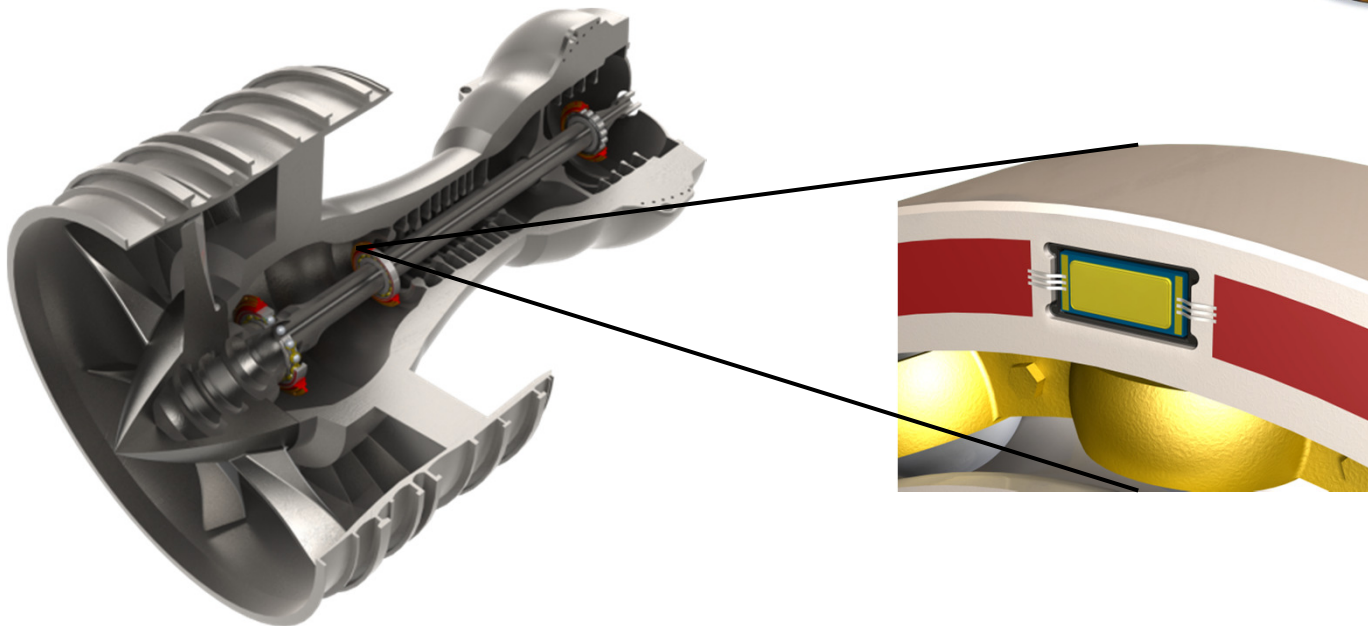
Preventative



Diagnostic



Prognostic



# *Turbine Blade Health Monitoring*

## **Schedule Based Maintenance**

**Not Real Time**

**Long Engine Down Times**

**Costly No Fault Found**

**Telemetry Only Used on New Designs**

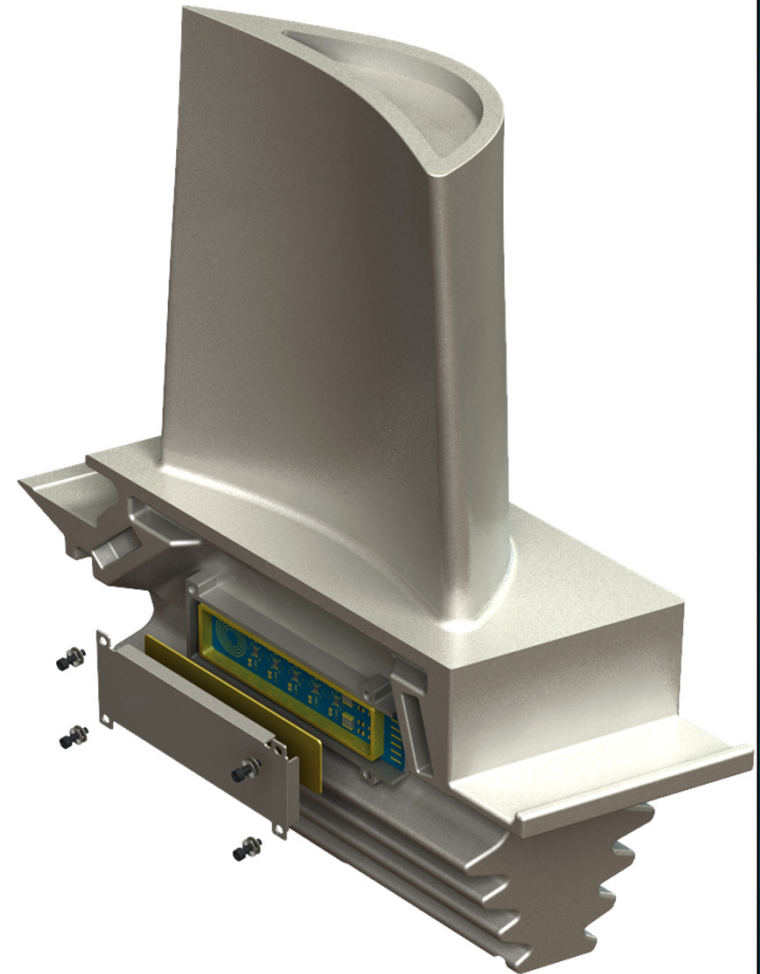
## **Condition Based Maintenance**

**Elimination of No Fault Found Conditions**

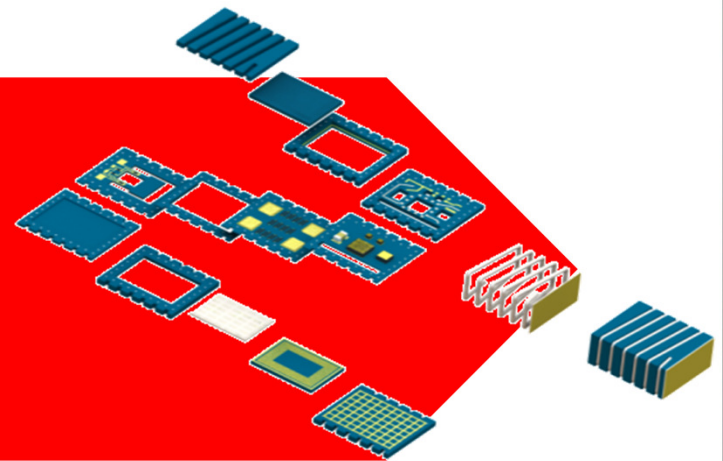
**Minimized Downtime**

**Continuous Monitoring**

**Field Data for New Engine Designs**



# 2 *Technical*





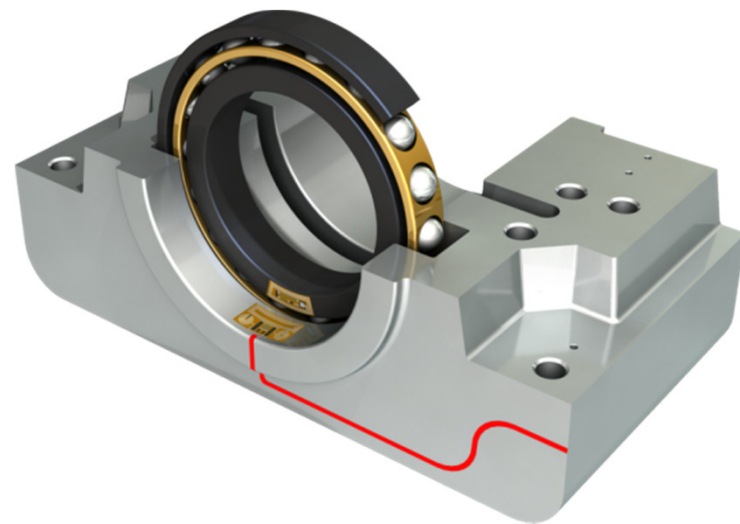
# Limitations

## Silicon Electronics

Most components rated to a maximum of 125 °C. With proper packaging, 200 °C operation is possible.

## Packaging

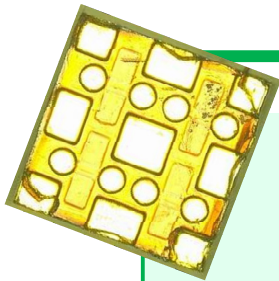
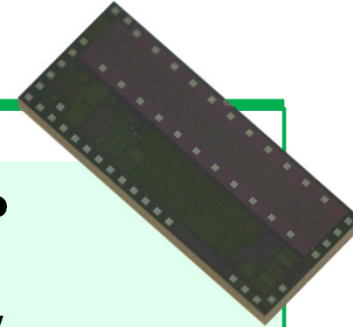
Standard electronic packaging (FR4, 63/37 solder) limits temperature operation.



# Enabling Technologies

## HTSOI

High temperature silicon on insulator devices rated to 225 °C and operable to 300 °C. Devices include 555 timers, voltage regulators, microcontrollers, op-amps, logic, ADCs, etc...

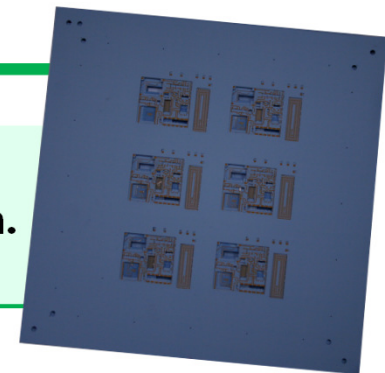


## WBG

Wide band gap semiconductors operate up to 600 °C. Only single transistor devices available such as SiC small signal JFETs and GaN HEMTs.

## LTCC

Low temperature co-fired ceramic allows for multilayer circuit boards with extreme high temperature operation.

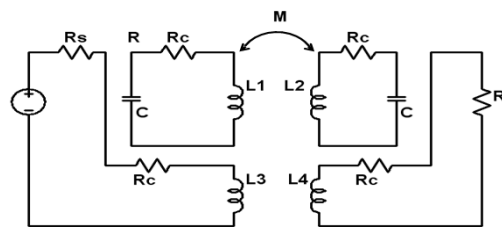


# Energy Harvesting



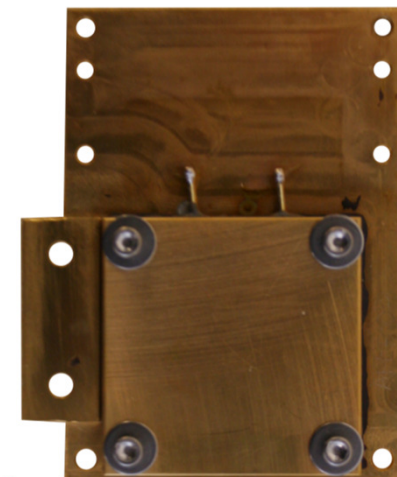
## Vibration

**Piezoelectric based vibration energy harvesting systems have been tested in literature up to 300 °C.**



## RF

**Wireless power transmission can induce greater than 50 W over short distances.**

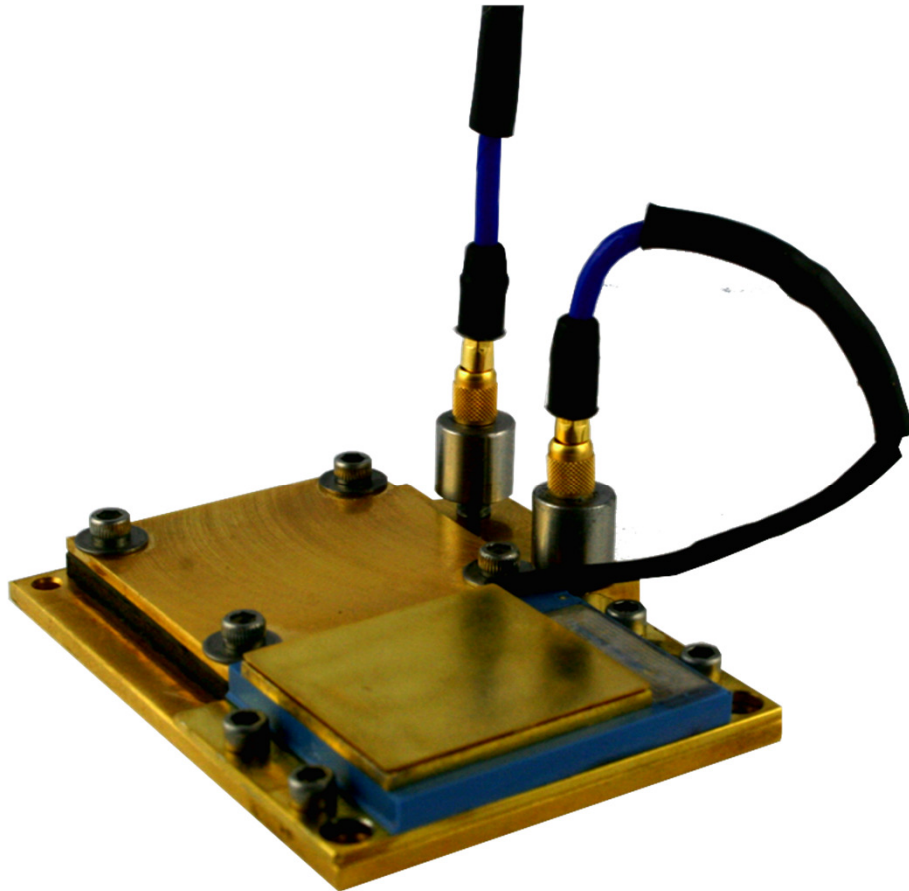


## TEG

**Thermal electric generators produce power from temperature differential.**



# Wireless Bearing Sensors



## System Requirements

225 °C Operation

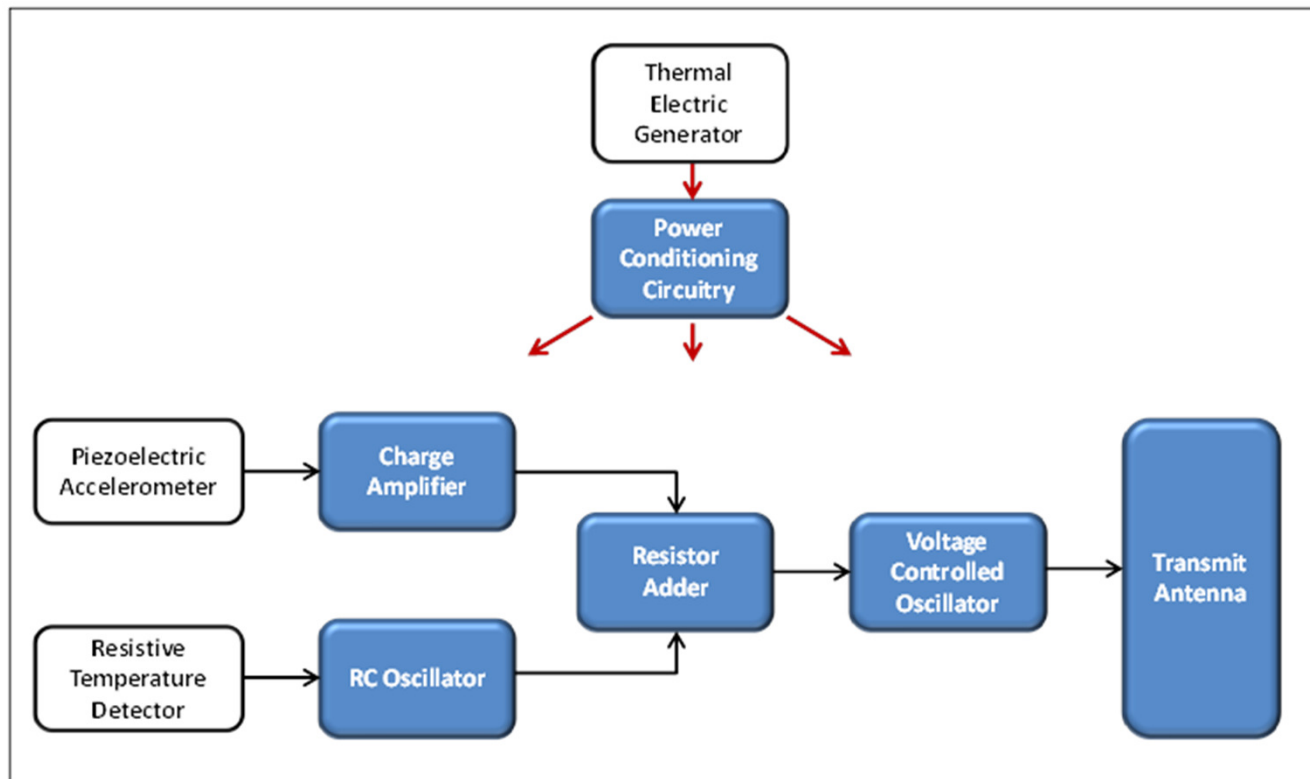
300 °C Survivability

Self-Powered

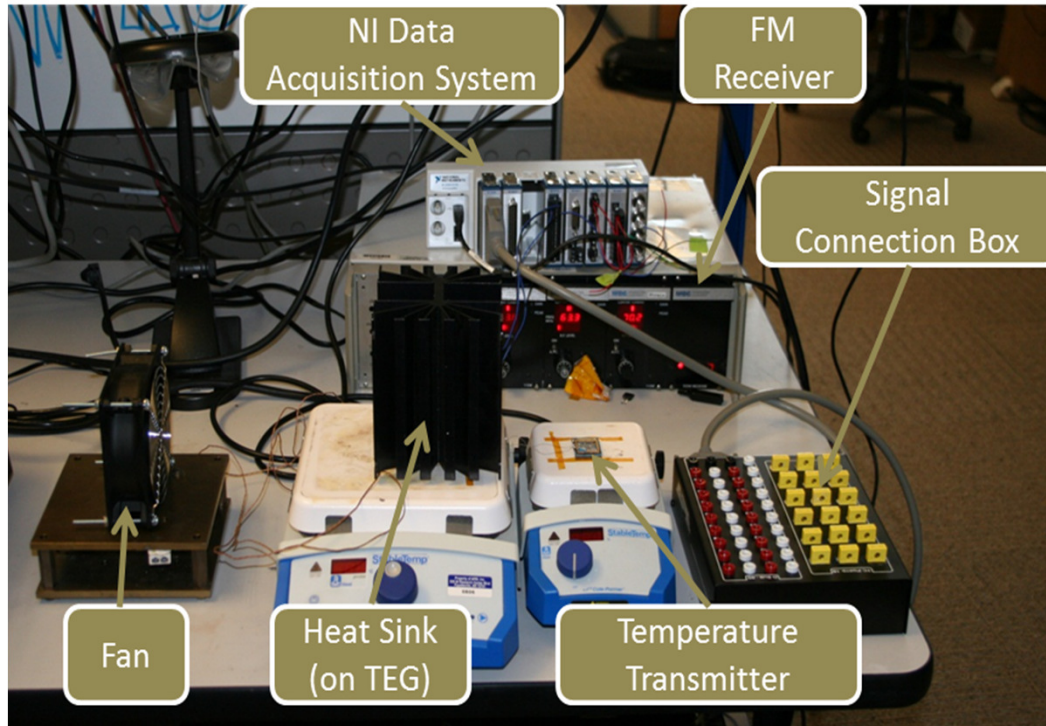
Temperature Transmission  
(+/- 2 °C)

Vibration Transmission  
(up to 20 kHz)

# System Operation



# Bearing Sensor Test Setup



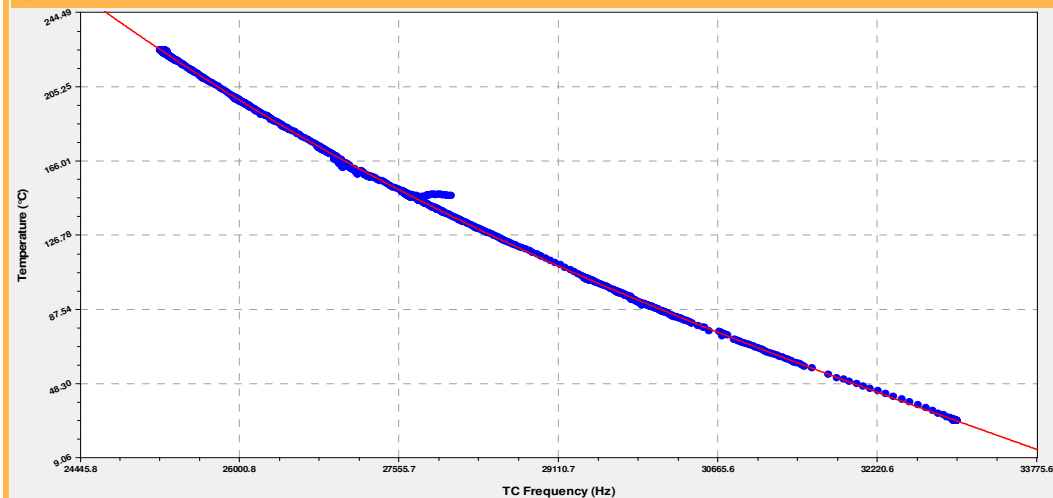
## DAQ Signal Input

- *TC on Top and Bottom of TEG*
- *TC attached to Transmitter*
- *TEG Voltage*
- *Function Generator Input*
- *Received and Demodulated Signal*

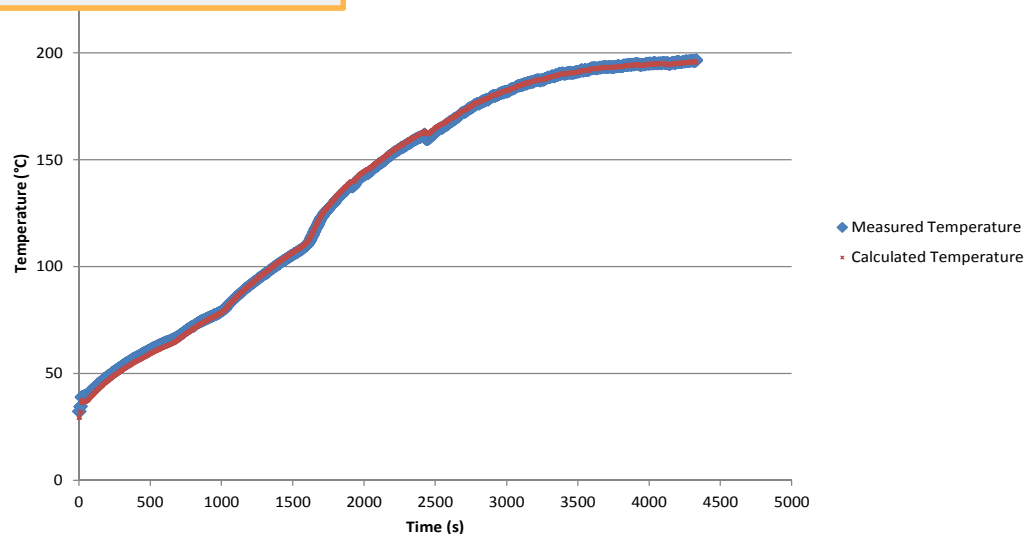


# Temperature Transmission

## Calibration

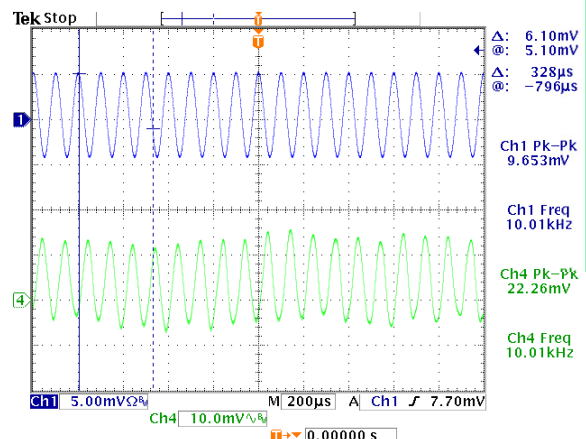
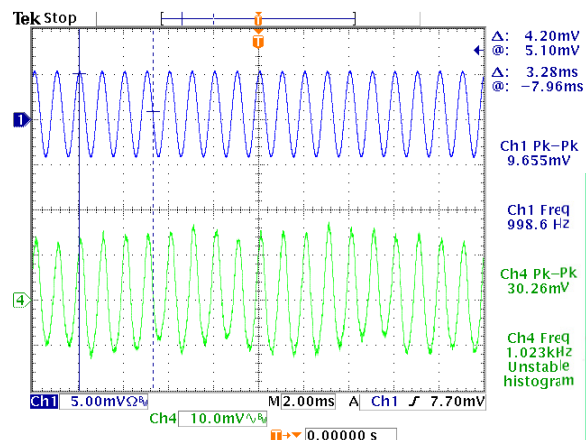


## Verification

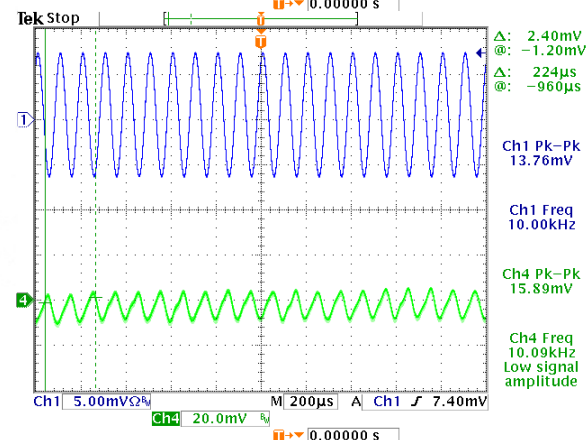
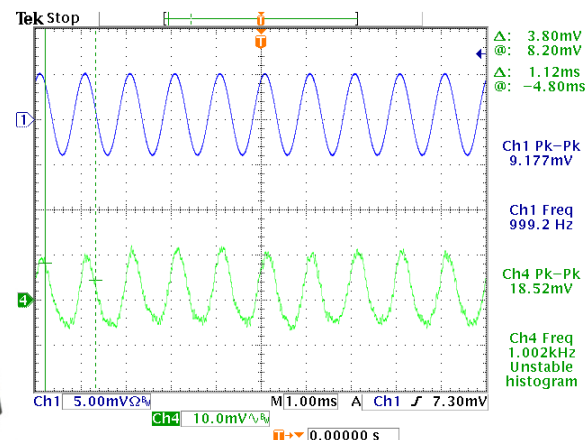
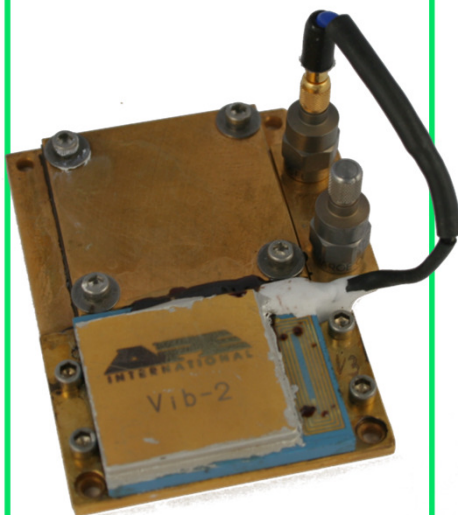


Additional  
Thermal Mass

# Vibration Transmission



175 °C

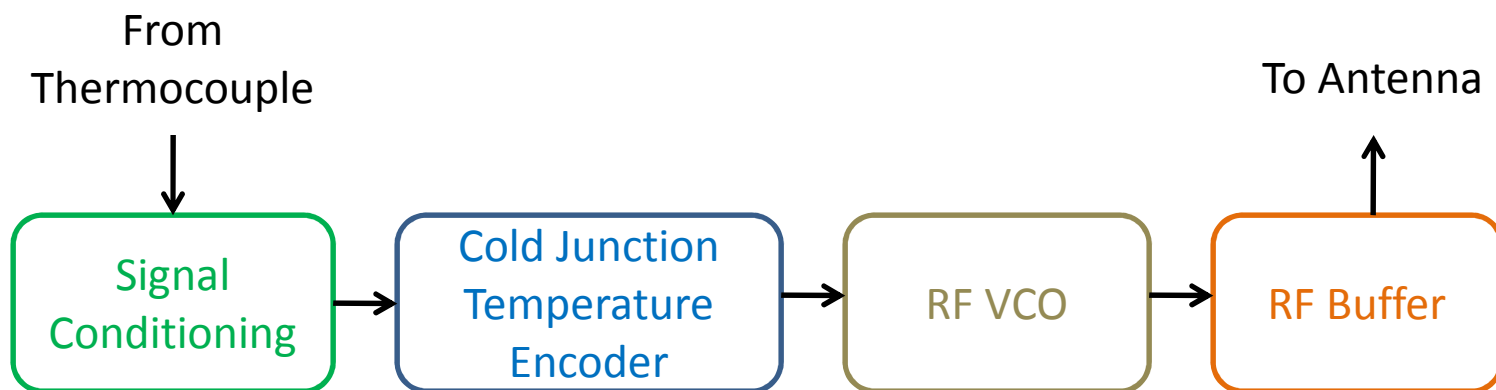


225 °C

# Turbine Blade Temperature Monitoring

## System Requirements

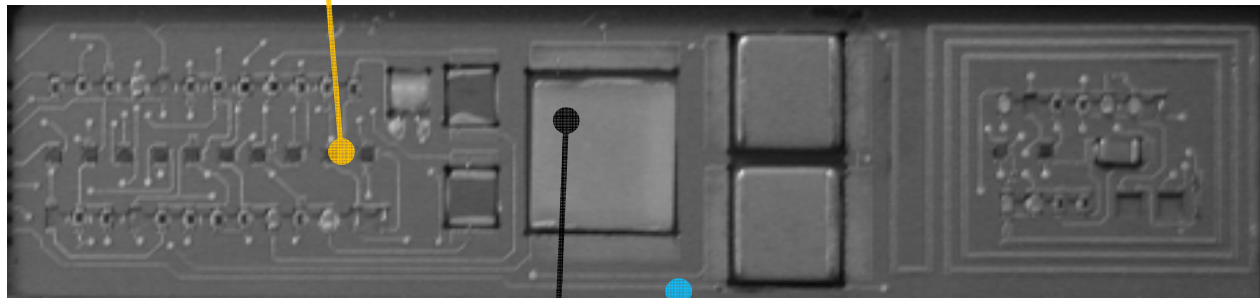
> 350 C Operation  
> 10,000 G Operation  
Wirelessly Powered  
Temperature and Strain Transmission





# *Turbine Blade Sensor Packaging*

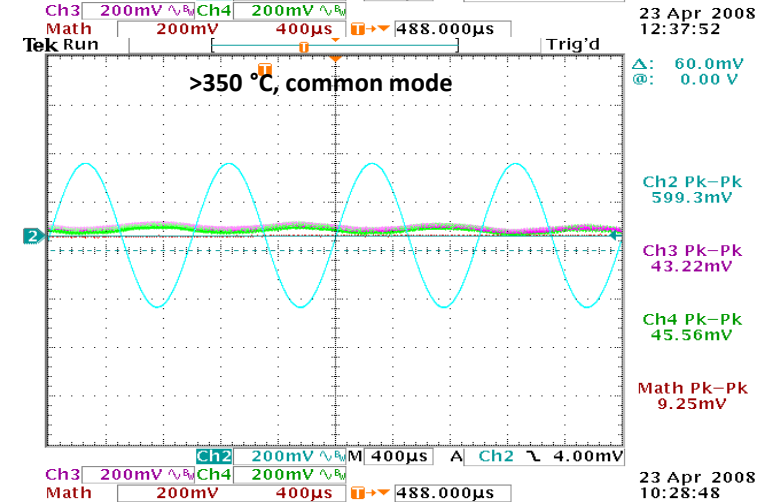
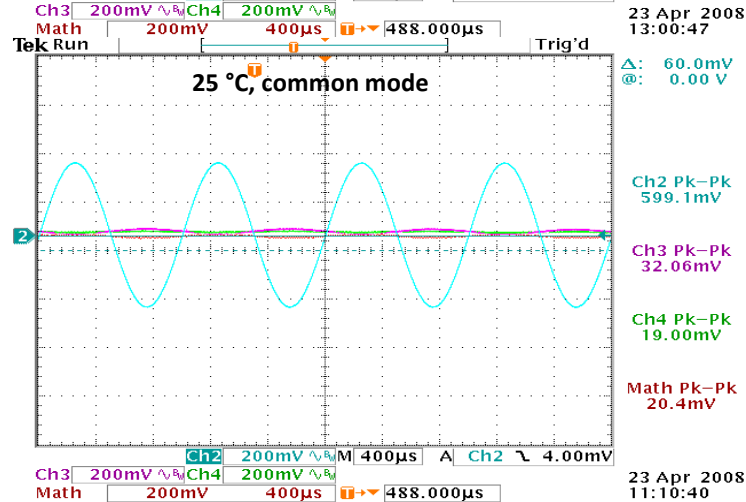
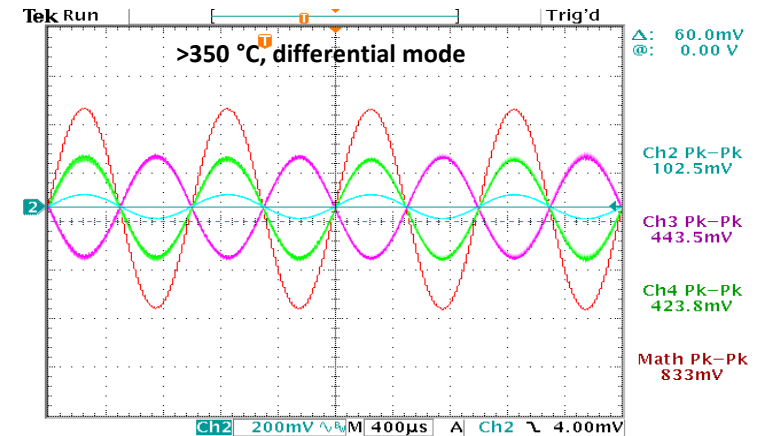
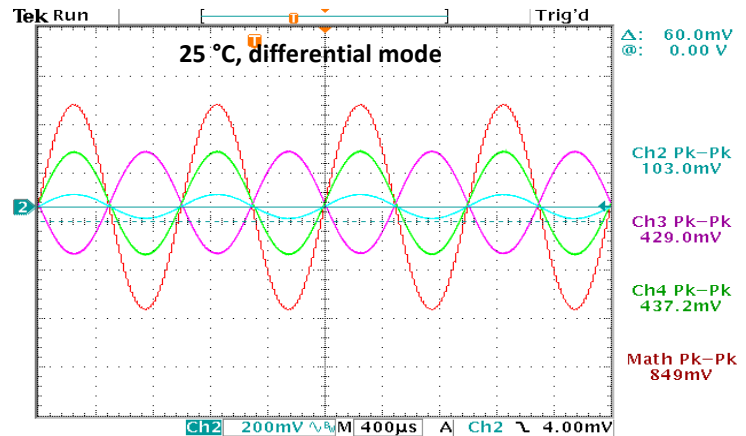
**Discrete SiC JFETs**



**Component Cavities for Vibration Stability and Minimum Wire Bond Length**

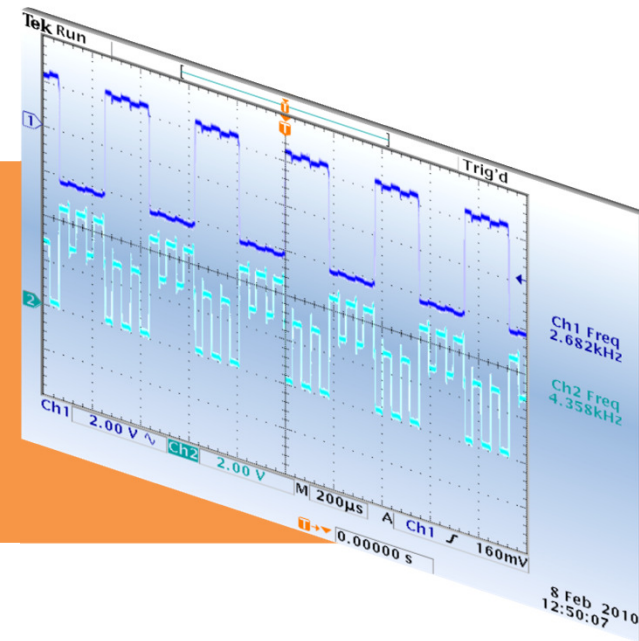
**Multilayer LTCC Circuit Board with 3d Structures**

# Temperature and Strain Transmission



# 3

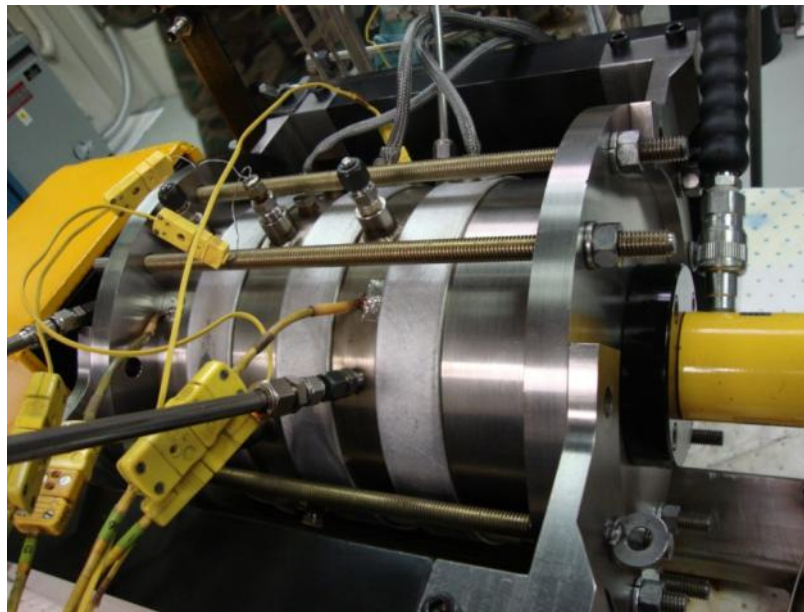
## *Testing Facilities*





# *Bearing Testing Shows System Functionality in Oily, Noisy Environment*

Bearing Test Rig Available at AFRL  
Capable of Testing Bearings to Failure  
Temperature and Vibration can be Monitored Through Wireless Sensors



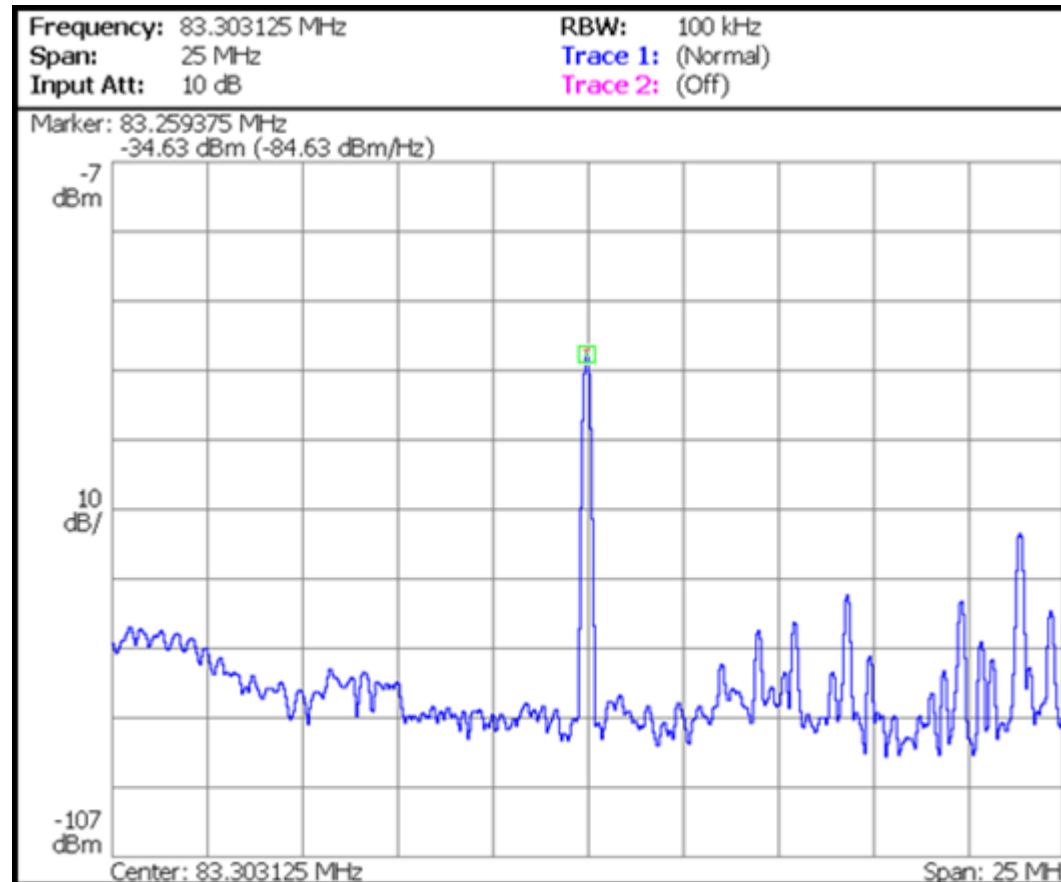
# *Spin Testing Proves System Reliability Under High-G, High Temperature Conditions*

Spin Rig Capable of 500 C and 15,000 G Loading Simultaneously  
SiC Based RF Circuitry Tested Successfully



Spin Test Rig Located at Aerodyn Engineering, Indianapolis.

# Transmission During Spin Testing



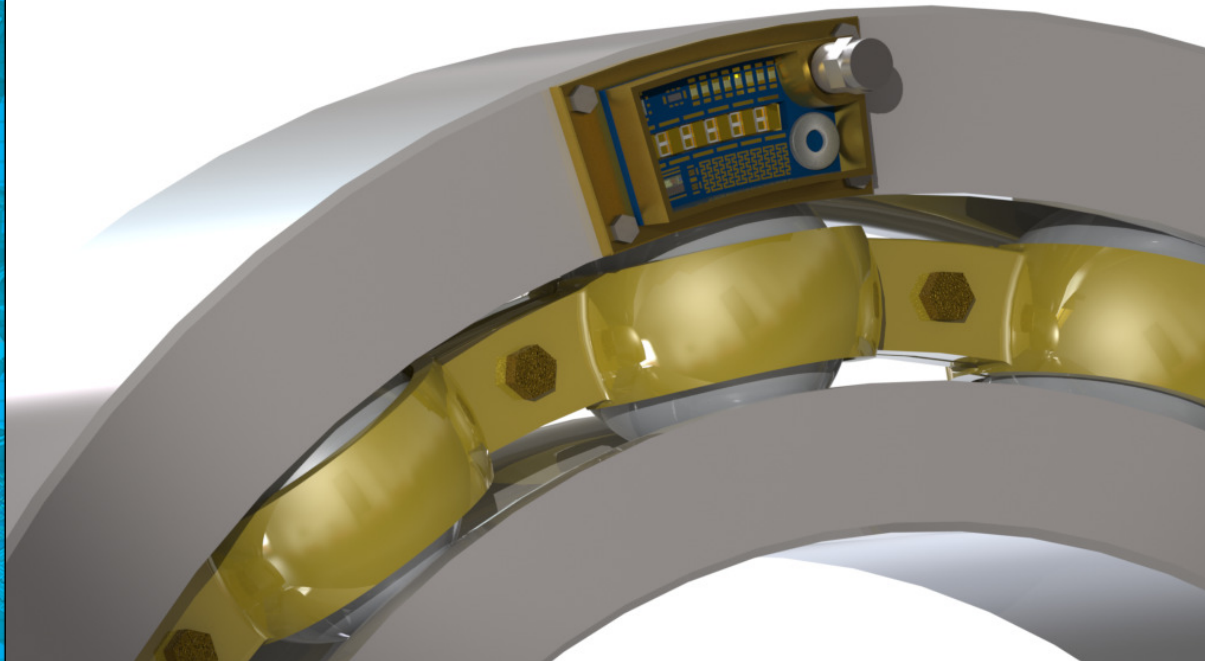
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*What's  
Next?*



## Future Work

- Integration of Energy Harvesting and Transmitter into Single Package.
- HTSOI and SiC ASICs
- Integrated Sensors
- Improved Power Conditioning



# Questions

