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Wireless Temperature Sensor for Gas Turbine Engine Applications

Wireless Sensor Technologies, LLC

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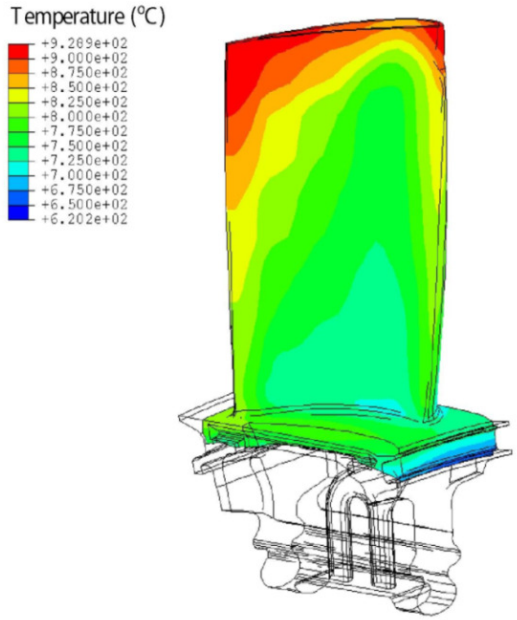
Presenter

John R. Conkle is a founder and the President of Wireless Sensor Technologies, LLC (WST). Mr. Conkle is an experienced technology leader possessing a broad range of executive, senior management, and technical skills and experience in information and wireless companies. He has an extensive background in starting and growing technology businesses. During the past twenty-five years Mr. Conkle has focused on wireless systems and products having developed manpack equipment for the military for signal intercept and geolocation, cellular distribution systems to allow wireless reception in tunnels and large buildings, and mobile communications systems for training range applications. At WST, Mr. Conkle is developing temperature and pressure sensors for harsh operational environments like the gas turbine engine, and energy harvesting-powered wireless networks for condition monitoring applications

WIRELESS SENSOR TECHNOLOGIES

Motivation: Need for Sensors in the Hot Section of Turbine Engines



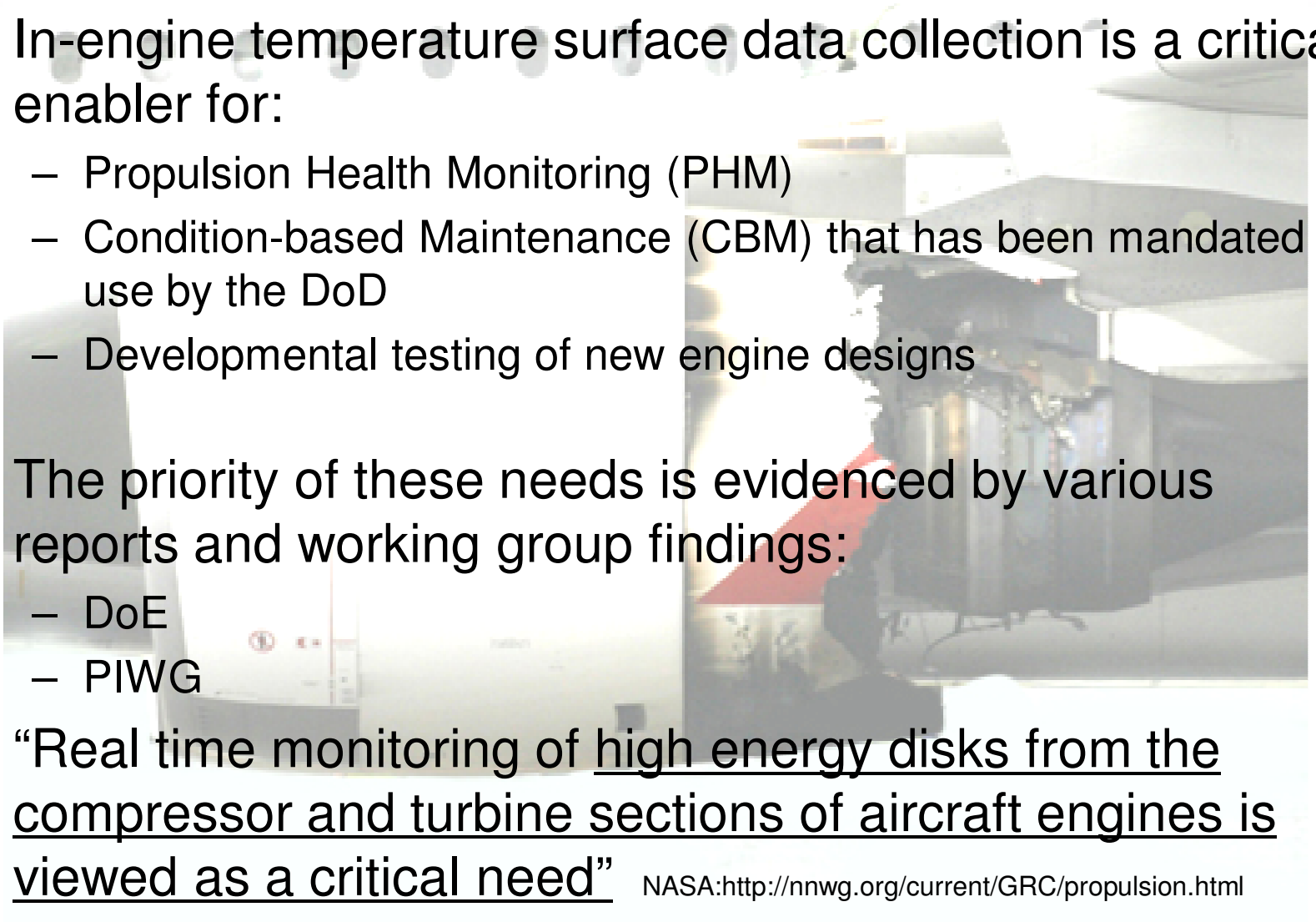
Problem:

1. **Catastrophic Failure caused by degradation and damage to hot section components**
2. **Poor characterization of degradation process affects the development of durable components.**

Demonstrated Need:

- **Difficult to model turbine blade physical parameters due to severe temperature gradients across surface of the blade**
- **A critical need for sensors for direct measurement on the surfaces of the blade.**

Critical Need for Temperature Data



- In-engine temperature surface data collection is a critical enabler for:
  - Propulsion Health Monitoring (PHM)
  - Condition-based Maintenance (CBM) that has been mandated for use by the DoD
  - Developmental testing of new engine designs
- The priority of these needs is evidenced by various reports and working group findings:
  - DoE
  - PIWG
- "Real time monitoring of high energy disks from the compressor and turbine sections of aircraft engines is viewed as a critical need" NASA:http://nnwg.org/current/GRC/propulsion.html

Organizations with Problem

- Organizations that can benefit from gas turbine engine wireless temperature sensors include:
  - Engine Developers
  - Users
  - Maintenance/re-work organizations

Approved for release by U.S. Air Force

- **Other harsh environment applications**
  - Control and CBM applications in carbon, steam, or nuclear-fueled power plants.

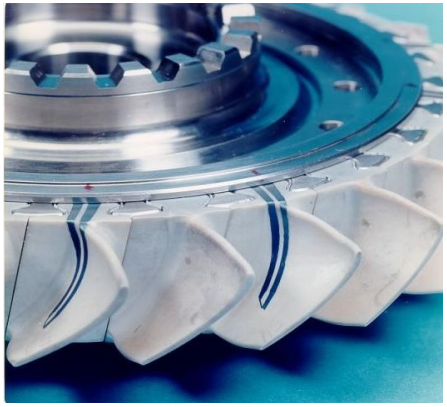
Current State-of-the-Art

A number of techniques are being used to monitor the surface temperature of blades, vanes, combustors, discs etc. in gas turbine engines including:

- Embedded wire thermocouples
- Thermal spray instrumentation
- Thin film thermocouples
- Infrared photography
- Pyrometry including 3d pyrometry
- Thermographic phosphors
- Thermal paints
- Irradiated semiconductor single crystals (SiC)

Baseline Technology

- Gas Turbine Engine Temperature Sensors – Rotating Components
  - Wired thermocouples are used for developmental testing
  - No sensors meeting all the requirements for operational monitoring are available



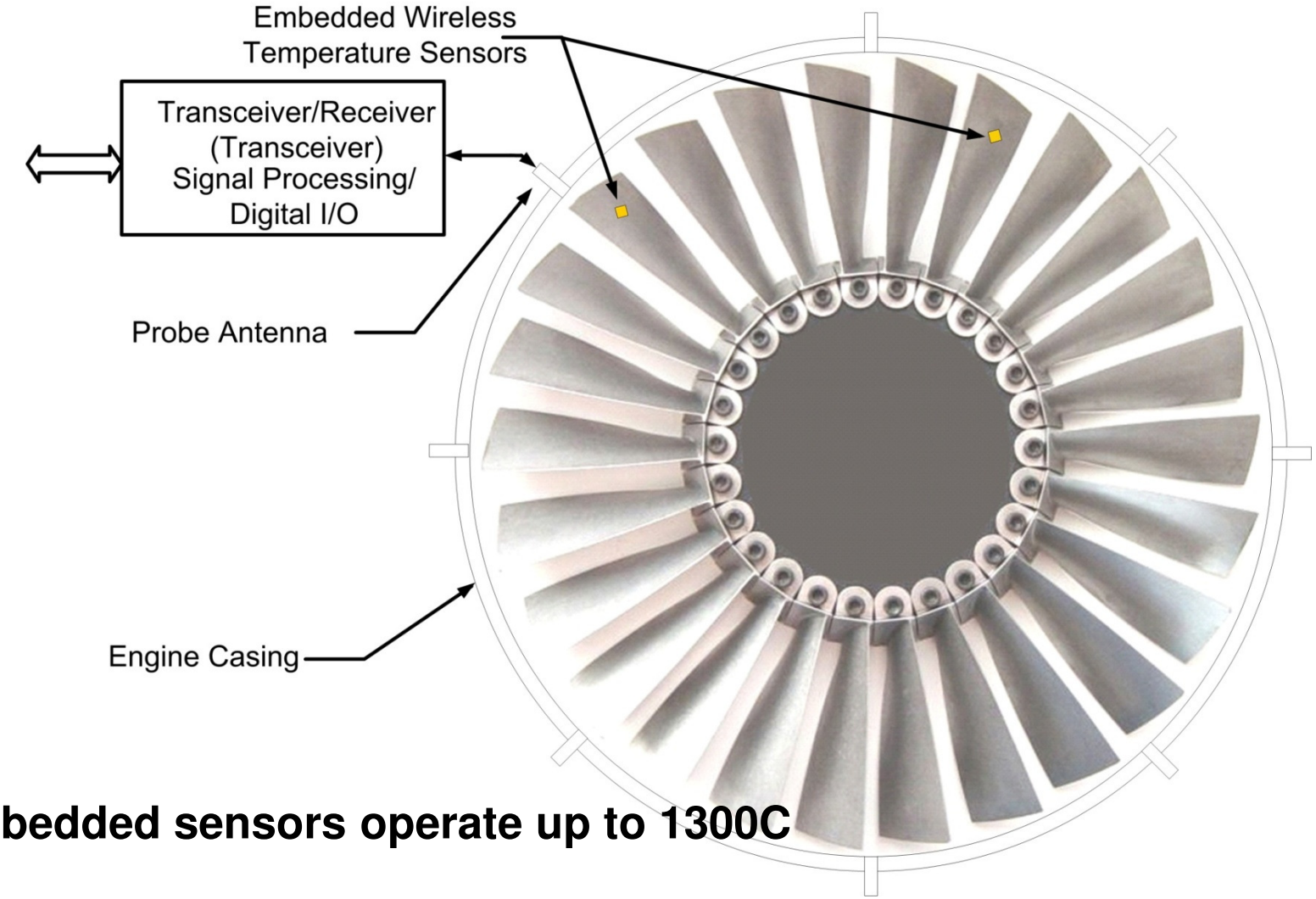
Honeywell high bypass turbofan series engine
Courtesy of Honeywell Aerospace

- Wired thermocouples are not reliable in this environment
  - Wired connections fail after only 10's of hours of operation
  - Expensive to install
  - Slip ring connection requires very high signal levels

Harsh Environment Sensor Requirement

- Accurate temperature measurement
  - 10^0 C accuracy
  - Range of -60 to 1300C
- Long-term reliability
  - ‘00’s of hours for developmental testing
  - “000’s of hours for PHM and CBM applications
- Easily mount on turbine blade or other surface to be monitored
- For Rotating Component - Cannot alter the blade dynamics (weight, gas flow)
  - “Massless”
  - “Zero” height

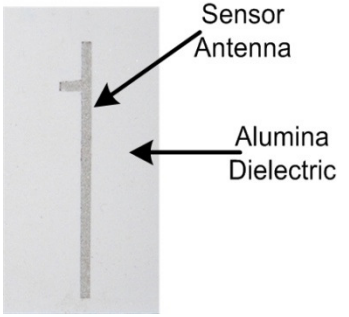
Sensor System Overview – Our Solution



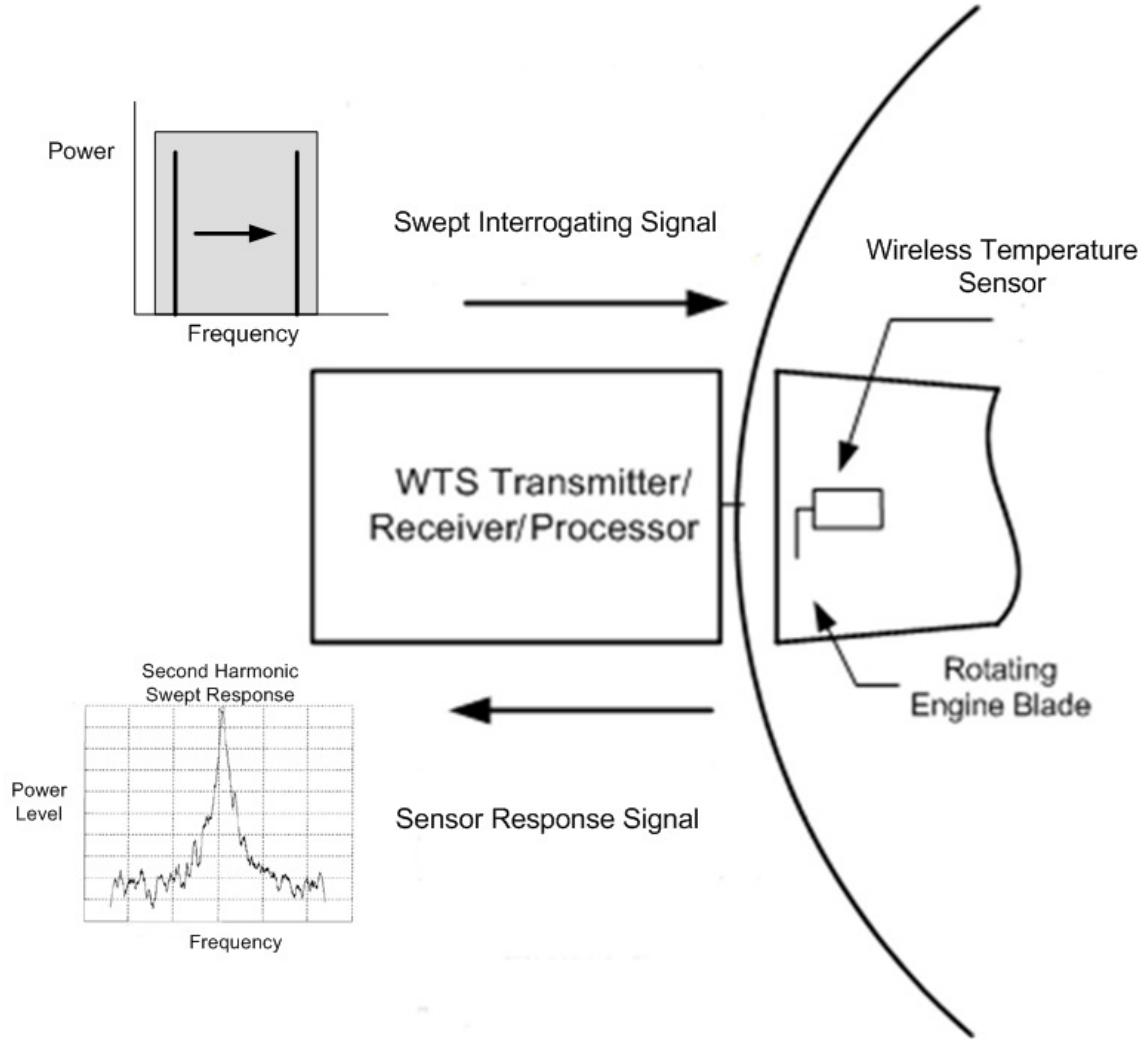
Embedded sensors operate up to 1300C

Sensor Properties

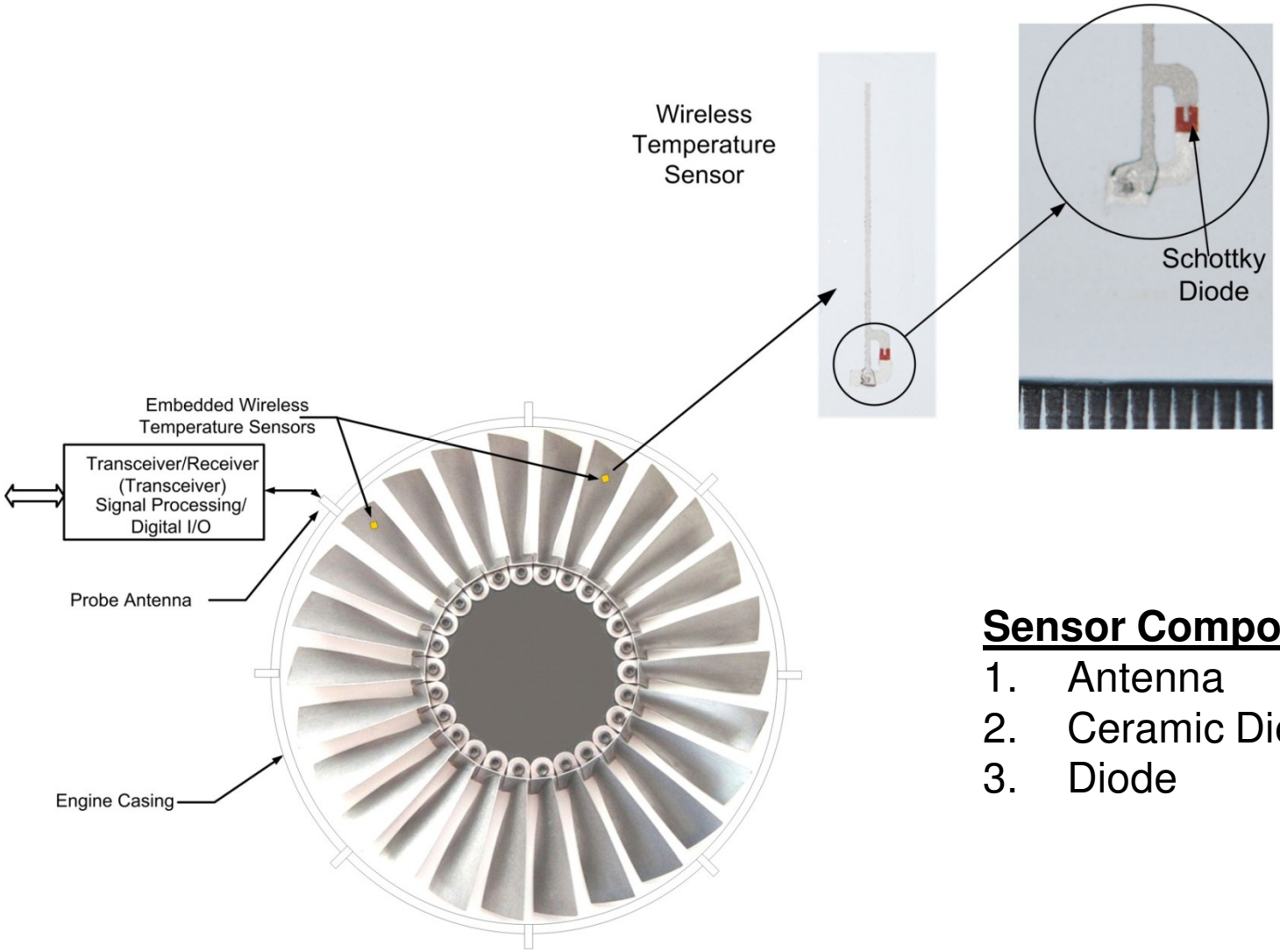
- Sensor is passive: requires no power to operate
  - Operates similar to RFID device
- Sensor is similar to a very small integrated circuit
  - It is “printed” on a blade or other surface to be monitored
- Sensor size and weight very small
  - Will not alter the dynamic characteristics of the surface or the gas flow around it



System Operational Concept



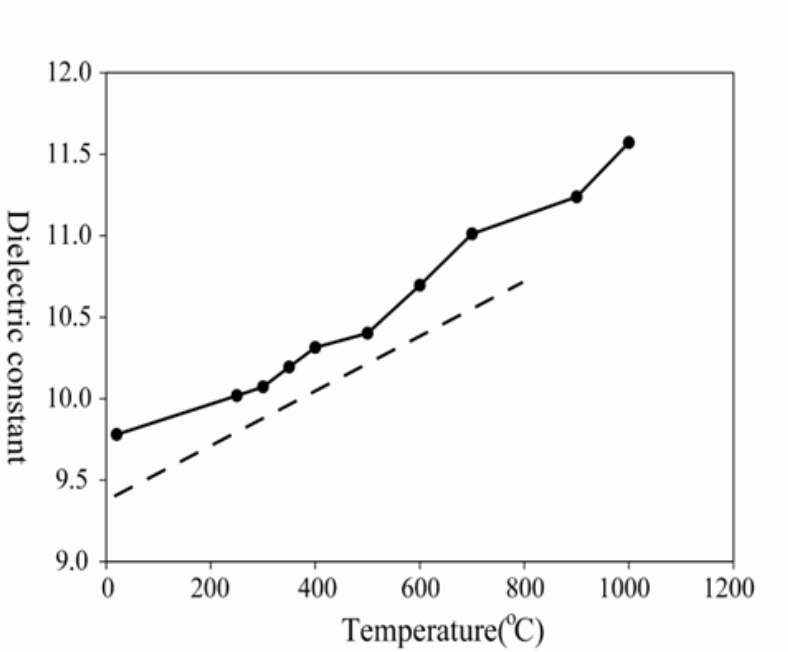
Wireless Temperature Sensor Hardware



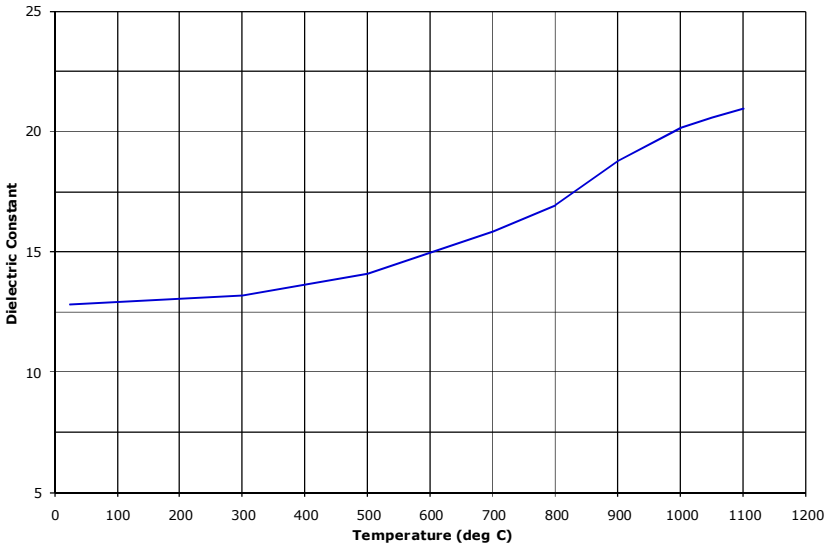
Sensor Components

1. Antenna
2. Ceramic Dielectric
3. Diode

Sensor is a Temperature Dependent Resonant Circuit



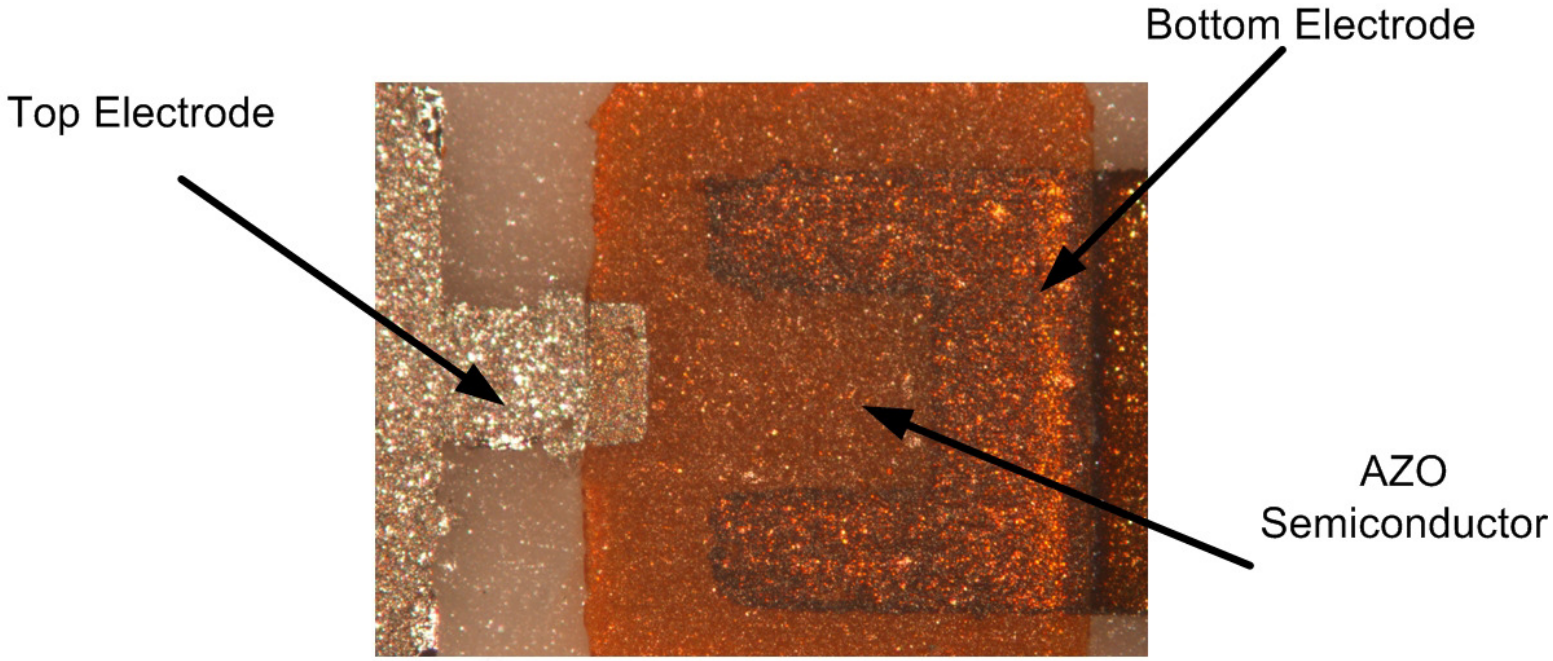
Temperature dependence of Alumina Dielectric



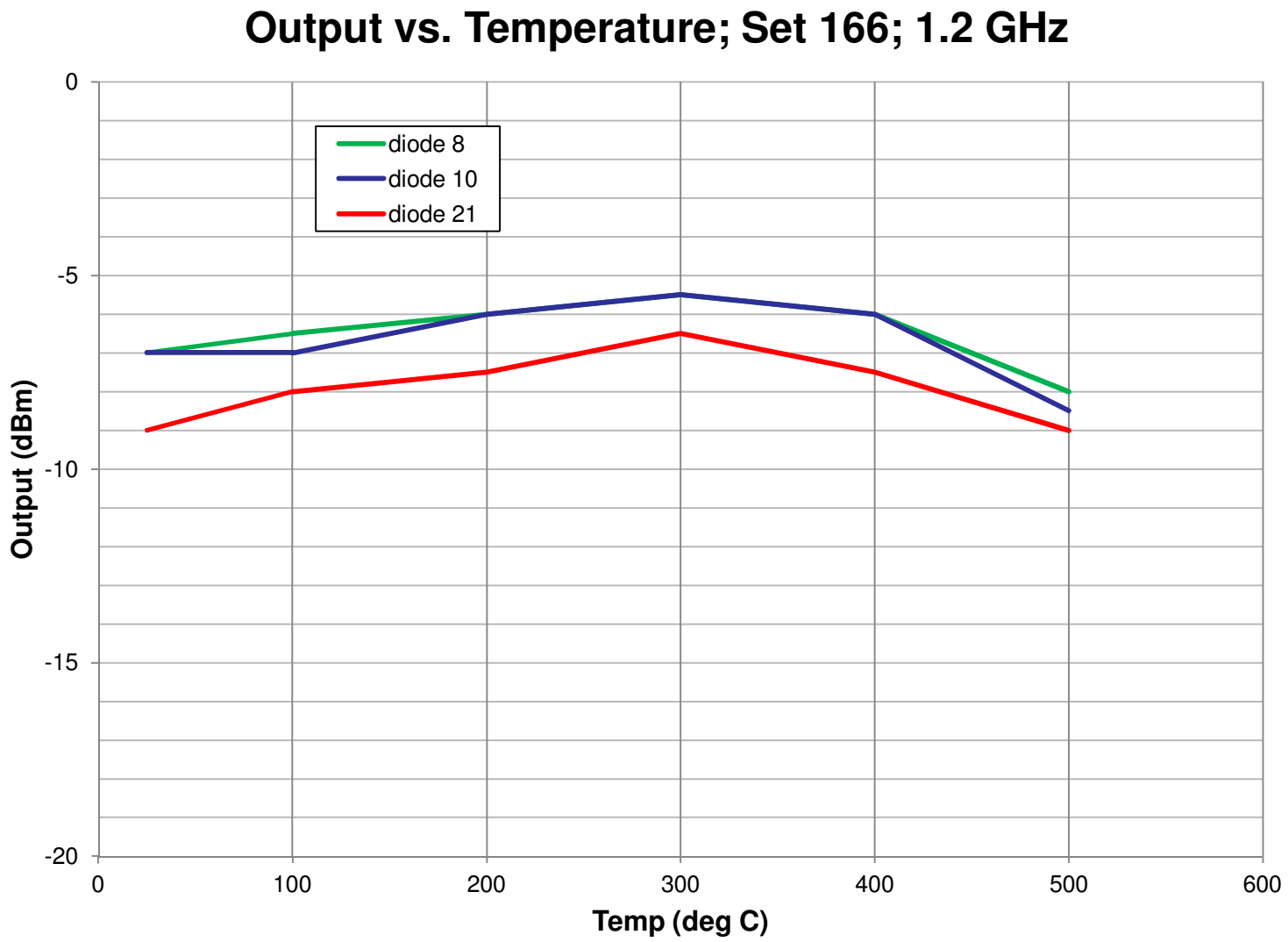
Temperature dependence of Yttria Stabilized Zirconia Thermal Barrier Coating (YSZ TBC) Dielectric

Current Generation High Temperature AZO Schottky Diode

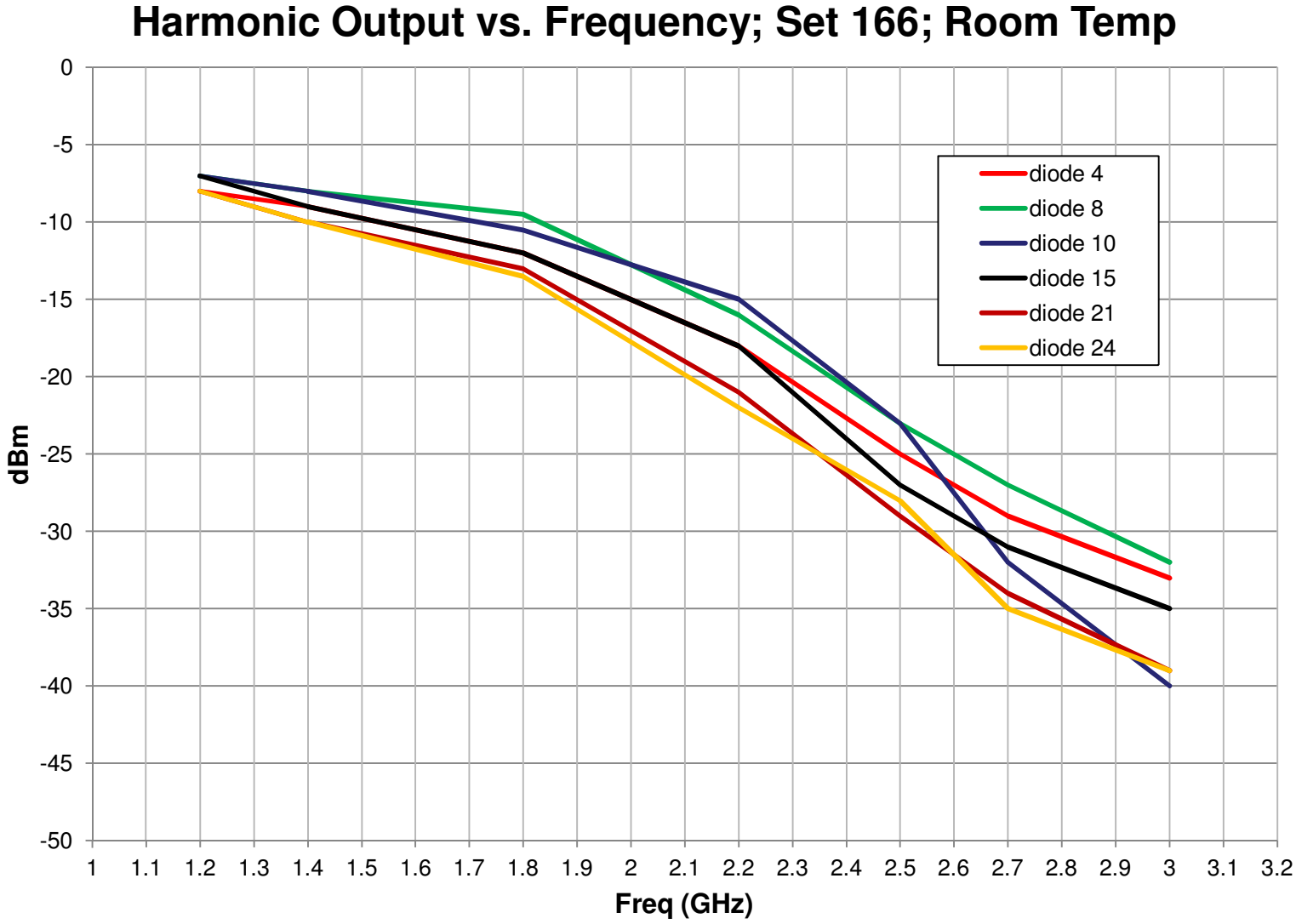
- Diode generates 2nd, 3rd, etc. harmonic of interrogating signal
- Allows straightforward discrimination of sensor output from interrogating signal



Diode - Current Generation Temperature Performance

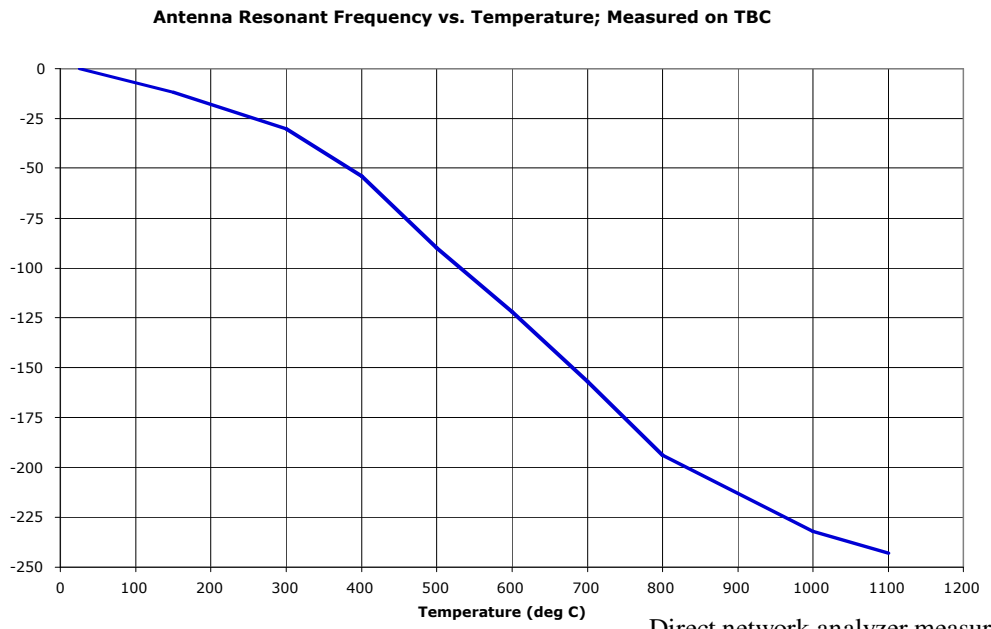


Diode – Current Generation RF Performance



Prototype Sensor Performance

The performance of a TBC-based wireless temperature sensor has been characterized from 25 to 1100 degrees C:



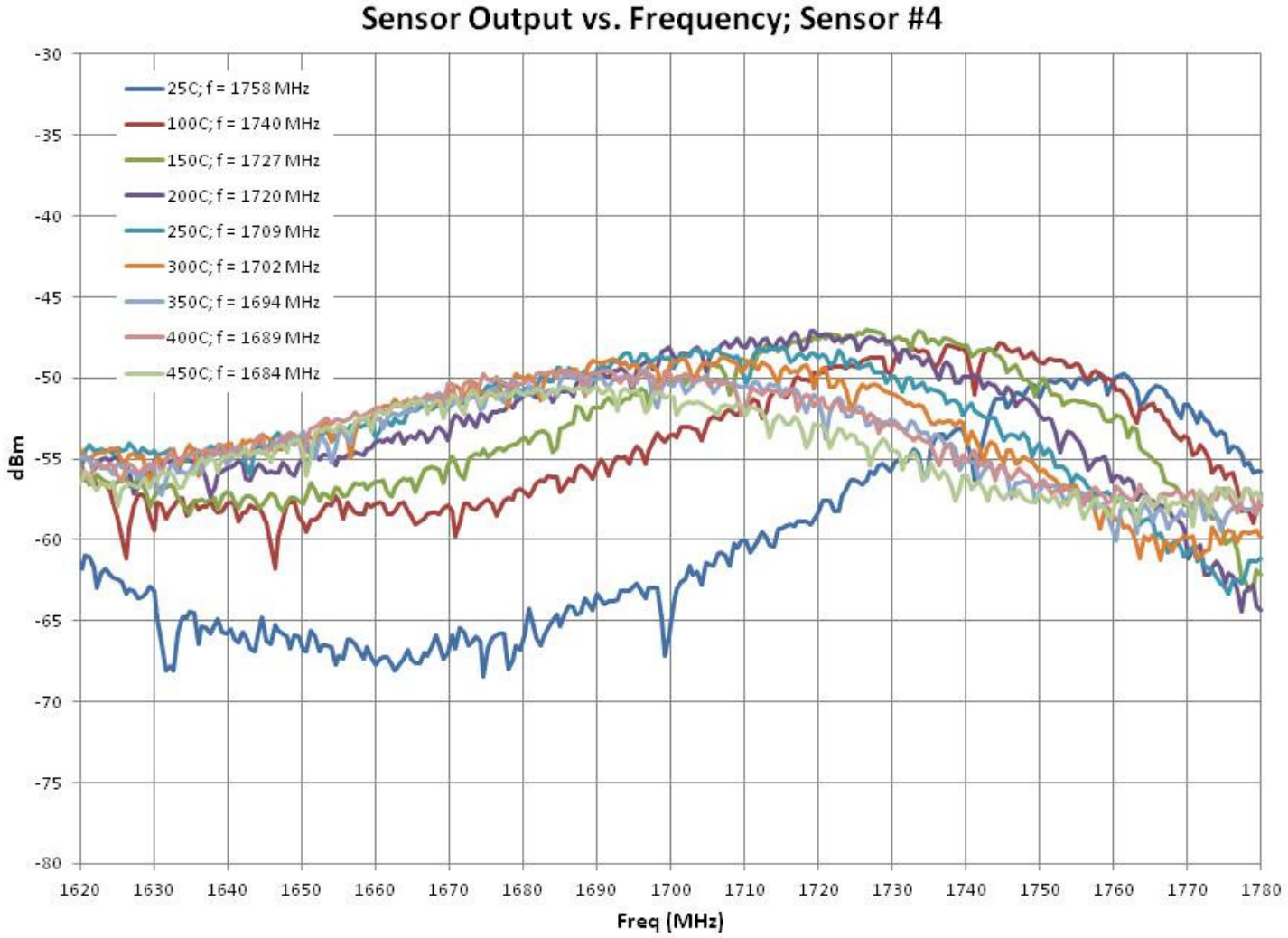
Direct network analyzer measurement

- Data is monotonic over the entire temperature range
- Sensor frequency change vs. temperature is repeatable
- Sensor frequency change vs. temperature shows no hysteresis

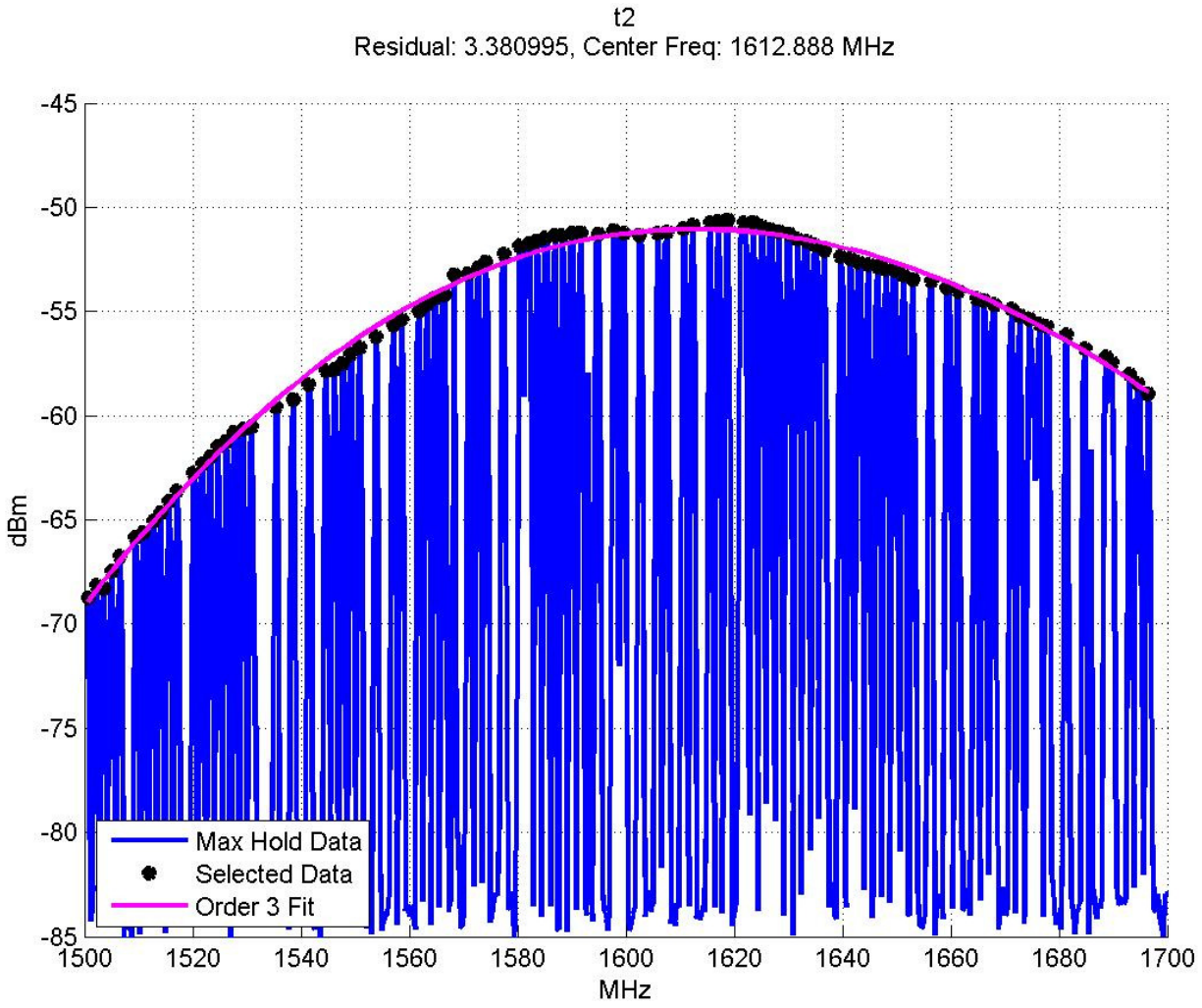
Signal Processing

- 3rd order polynomial curve fit
- Calibration Table
- Temperature estimation algorithm

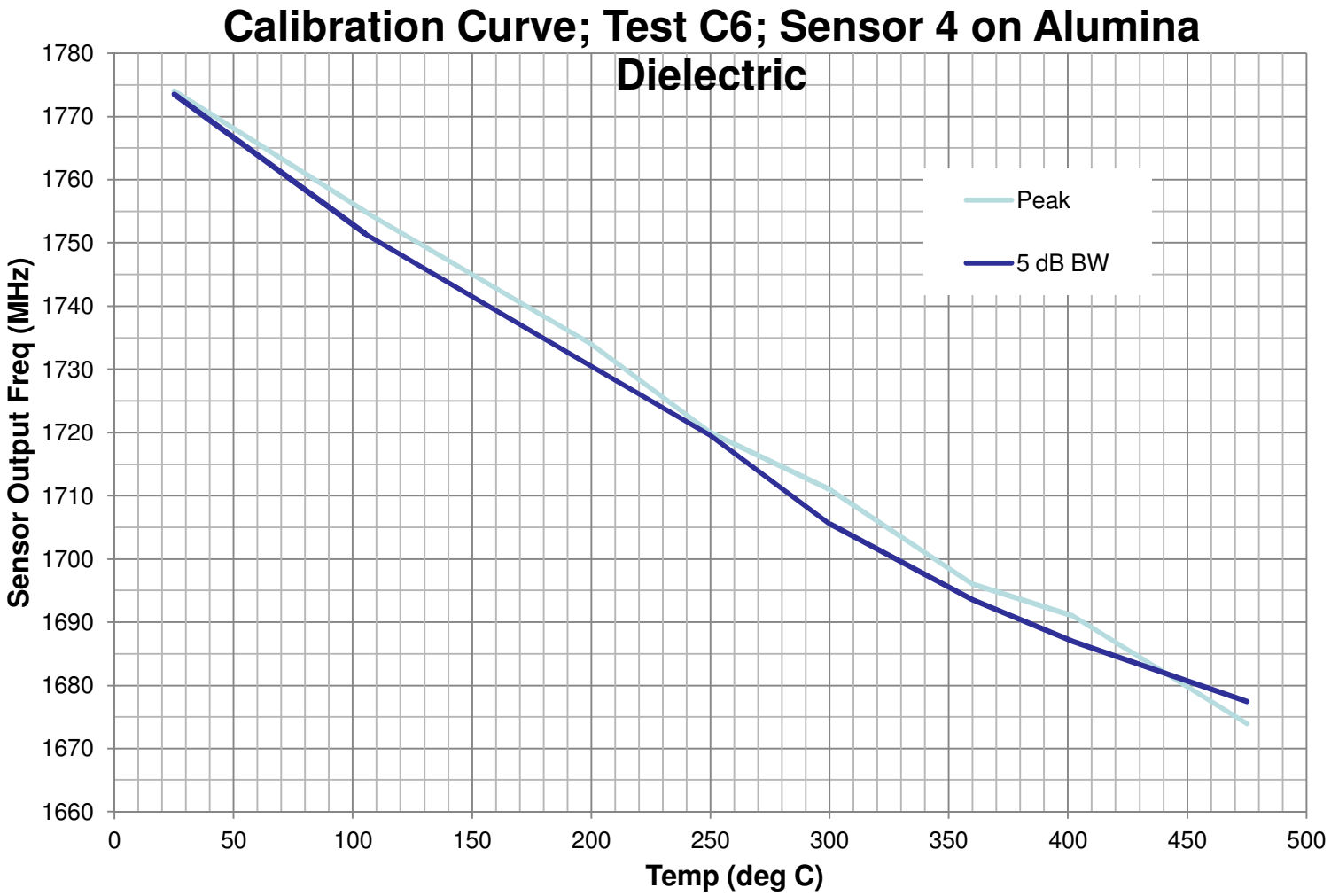
Family of Sensor Outputs vs Temperature



Curve Fit – Calculate sensor response spectral peak



Sensor Response – Calibration Curve



Sensor Accuracy

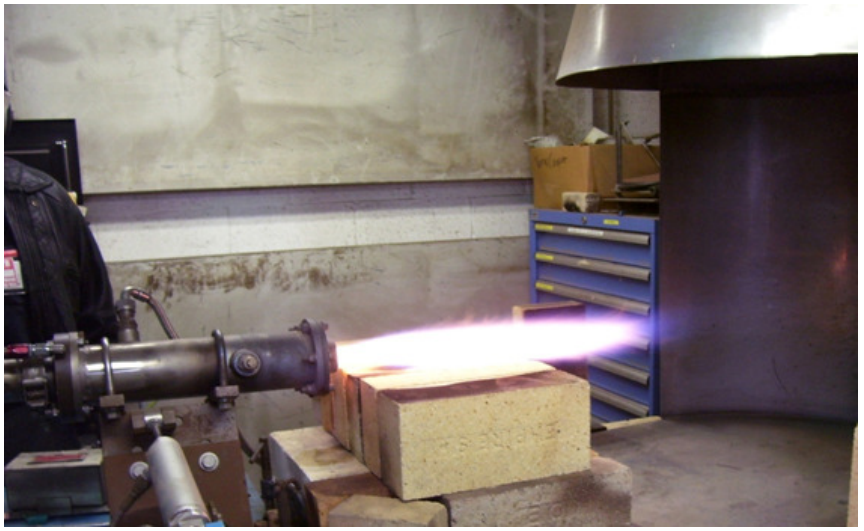
- Measured accuracy of current generation sensor is:

  4.38ºC (1σ)

- Hysteresis – 0 (less then the resolution of our test equipment)

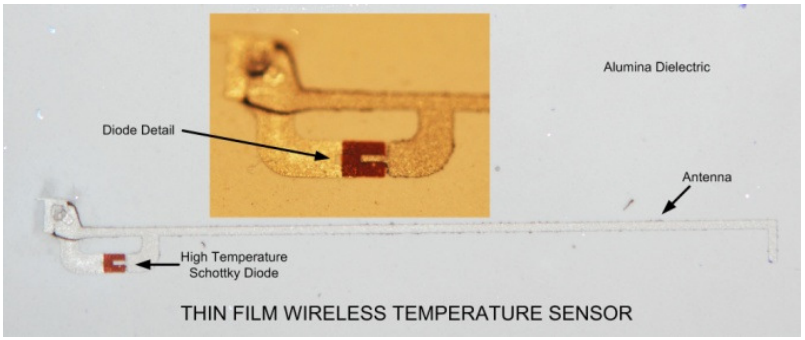
Current State of Development

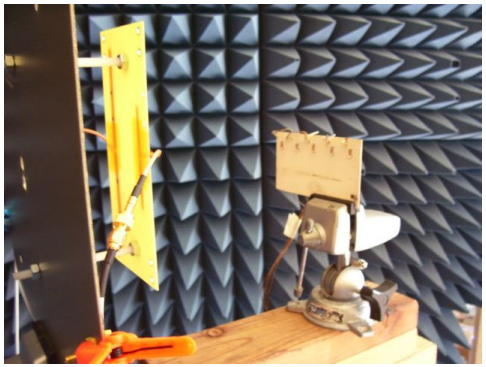
- The WTS is currently under development and being evaluated in a laboratory environment.
  - TRL 4 (Component/subsystem validation in laboratory environment)
- We are evaluating the performance of the sensor in a burner rig environment
- Anticipate TRL 5 fall 2012
  - (System/subsystem/component validation in relevant environment)



Wireless Sensor Technologies, LLC

- **Company Focus – Wireless sensors for harsh environments**
  - Proprietary technology in wireless strain, temperature and pressure sensors
  - Technical strength is the extensive experience of the principals in wireless and high temperature sensor technologies
  - Patented IP on wireless temperature sensor technology





- **WST founded in November 2007**
  - John Conkle, President
  - Dr. Otto Gregory, Principal
  - Tom Birnbaum, Principal

This Work has been Supported By:

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Thank You!

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