Setting the Standard for Automation™

Wireless Temperature Sensor for Gas Turbine Engine Applications

John Conkle, Otto Gregory, Thomas Birnbaum

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John R. Conkle is a founder and the President of Wireless Sensor Technologies, Inc. He has an extensive background in starting and growing technology businesses. During the past twenty-five years he has focused on wireless systems and products having developed manpack signal intercept and geo-location equipment for the military, cellular distribution systems to enable wireless reception in tunnels and large buildings, and mobile communications systems for training range applications. Currently, Mr. Conkle is developing passive wireless temperature sensors and pressure sensors for the gas turbine engine environment, and energy harvesting powered wireless networks for condition monitoring applications.

jconkle@wisen-tech.com
(408) 234-3741

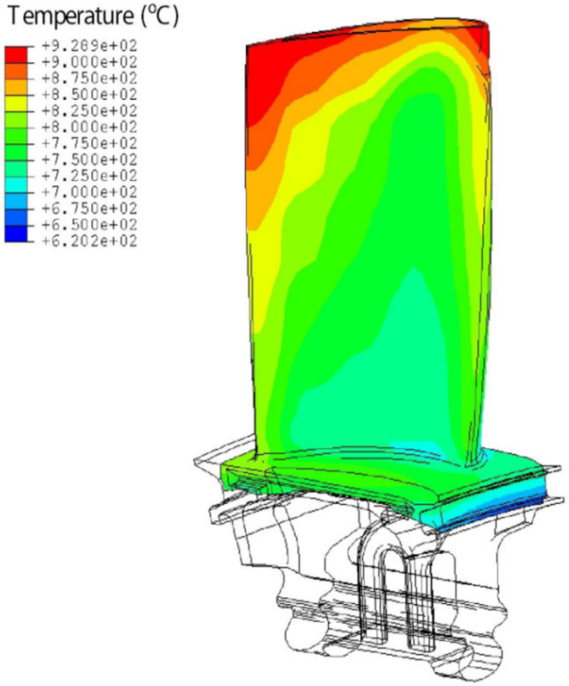
WIRELESS SENSOR TECHNOLOGIES

Agenda

- Introduction
- Current state-of-the-art:
  - Wired sensor technology
  - Wireless technology
- WST temperature sensor technology
  - System
  - Sensor
  - Transmitter/receiver/processor
- Wireless Temperature Sensor Performance
- Gas Turbine Engine Applications
  - Surface temperature and heat flux measurements

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

Quantas Airbus 380 Engine Failure



Problem:

- Degradation and damage that develops over time in hot section components can lead to catastrophic failure.
- Poor characterization of degradation process in harsh environments can affect the development of durable components.

Demonstrated Need:

- Difficult to model turbine blade temperature, strain, and heat flux due to severe temperature gradients across surface of the blade.
- Thus, there is a great need for sensors for direct measurement on the surfaces of the blade.
- Sensors must be able to survive with very low drift rates for extended periods of time.

Wireless Sensor Technology

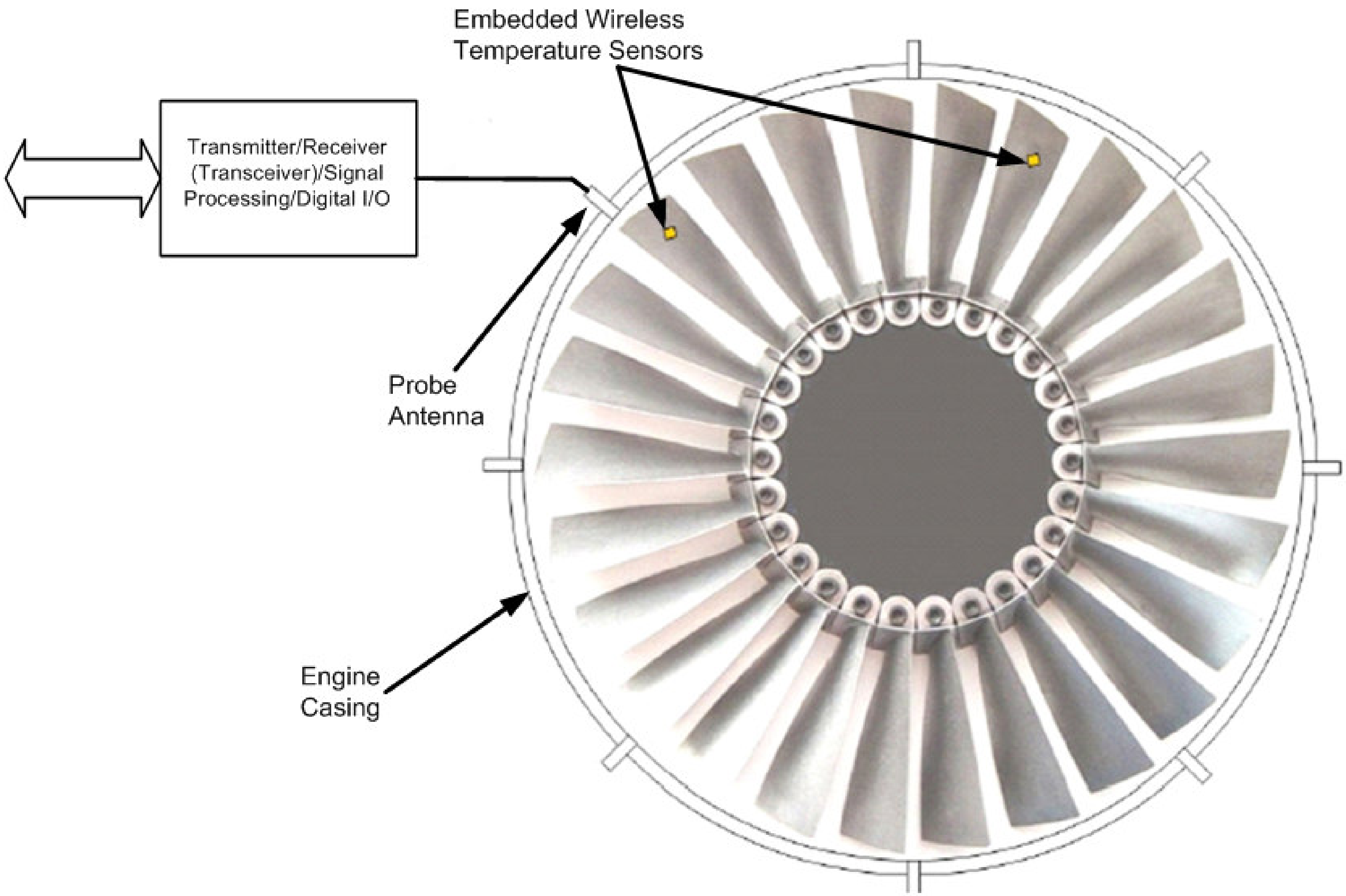
- Recent advances in materials and signal processing have enabled a new class of sensors
- Application in sensors for harsh environments, including engine hot section
- Prototype technologies
  - Temperature sensors
  - Pressure transducers
  - Strain sensors
- Orders of magnitude improvement in reliability and capacity over current wired sensor technology

Current State-of-the-Art

Monitoring the surface temperature of rotating and non-rotating components in the gas turbine is a critical enabling technology. 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)

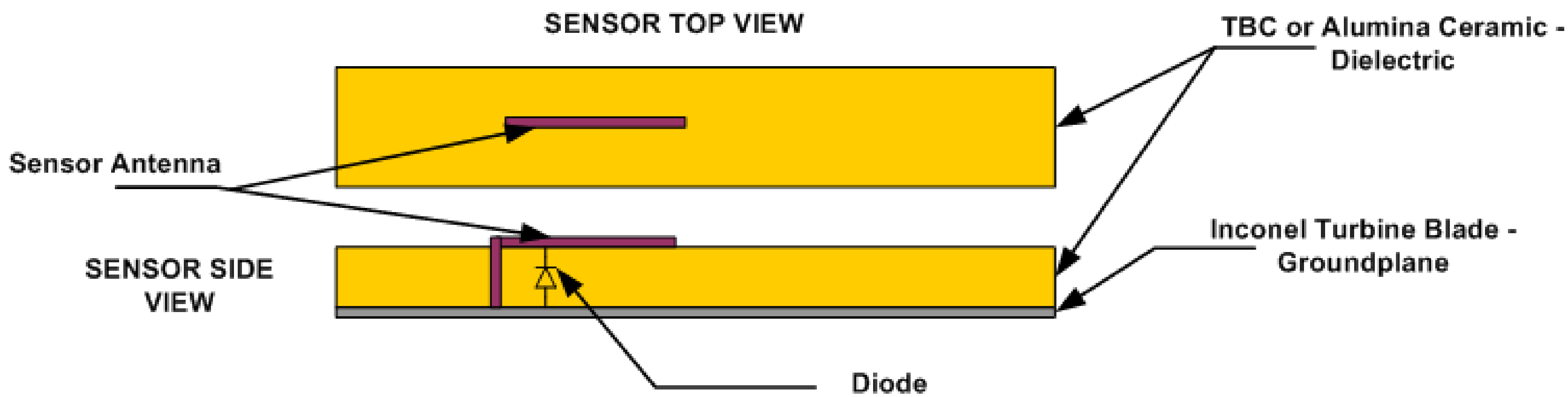
Wireless Temperature Sensor Concept



Temperature Sensor Properties

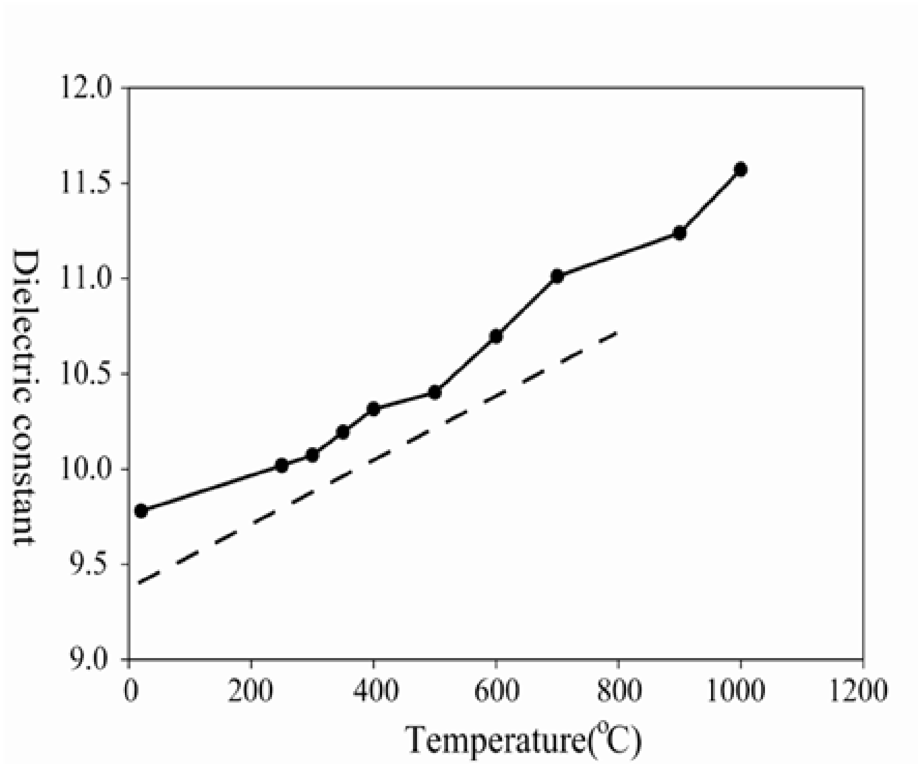
- Sensor is passive: requires no power to operate
- Sensor is designed to operate in hot section of gas turbine engines
- Sensor is similar to an integrated circuit; i.e. can be "printed" on a blade or other surface
- Small sensor footprint and thermal mass: does not affect vibrational characteristics of the blade, exhibits a rapid response and measures true surface temperature

Components of Wireless Temperature Sensor



1. Antenna
   a. Enables the interrogating signal to be received
   b. Sets the frequency of operation of the sensor
   c. Enables the return signal to be transmitted back the the Tx/Rx/Signal Processing
2. Diode
   a. Causes the generation of RF harmonics of the interrogating signal (as filtered by the antenna) which allow the return signal to be easily separated from the interrogating signal by the Tx/Rx/Signal Processing
3. Alumina or TBC Dielectric – possesses temperature-dependent electrical properties (DK, dielectric constant) which alters the antenna center frequency as the temperature changes

Alumina DK Temperature Dependence

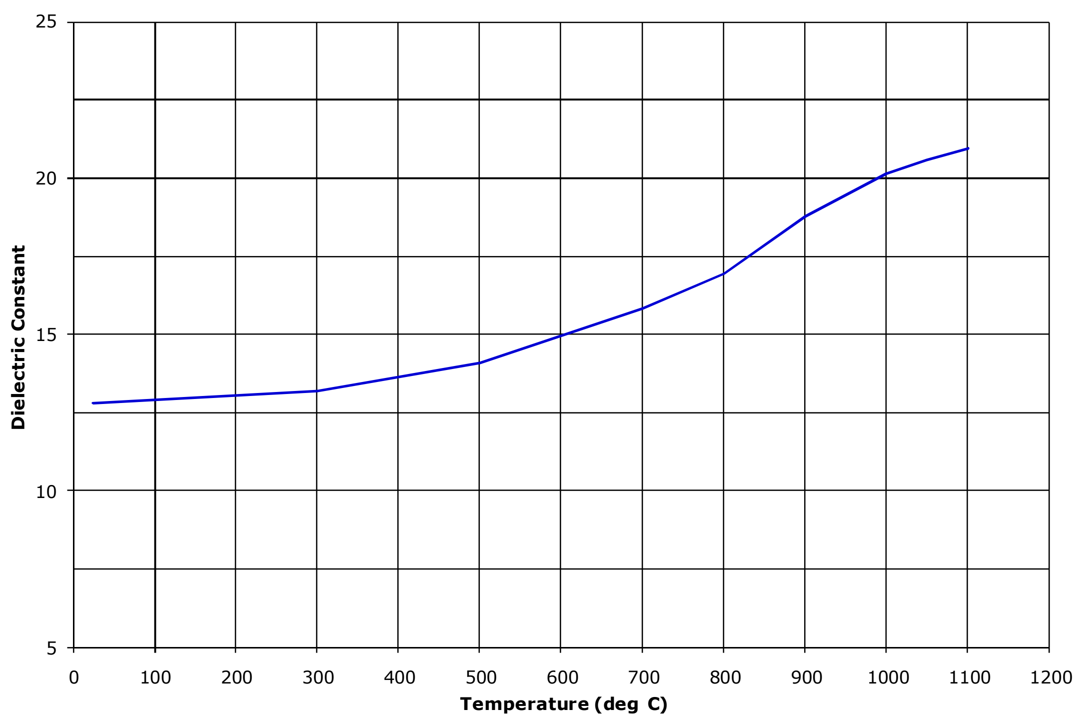


- Measured dielectric constant temperature dependence for alumina

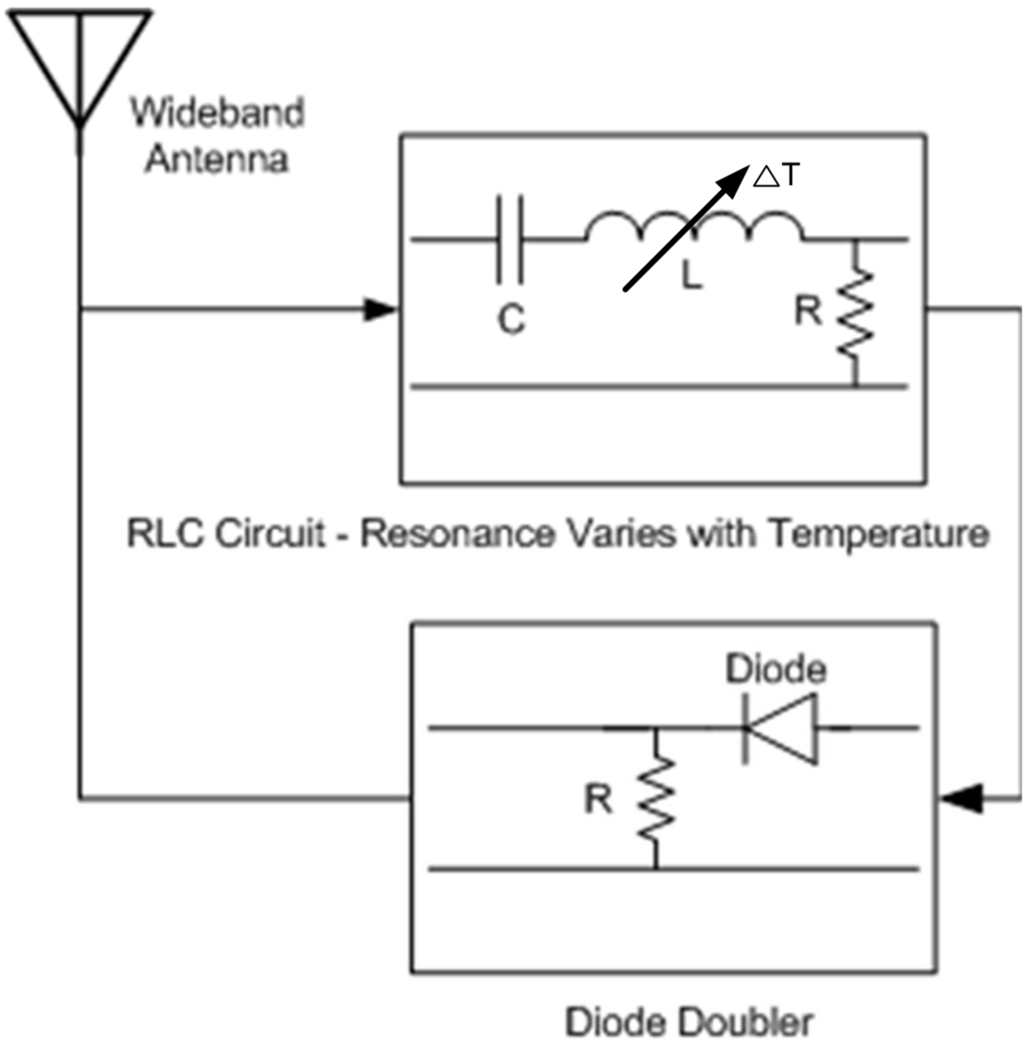
- From "Dielectric properties of alumina ceramics in the microwave frequency at high temperature", Kim. et.al., *Solid State Phenomena Vols. 124-126 (2007) pp. 743-746*

Yttria Stabilized Zirconia DK Characterization

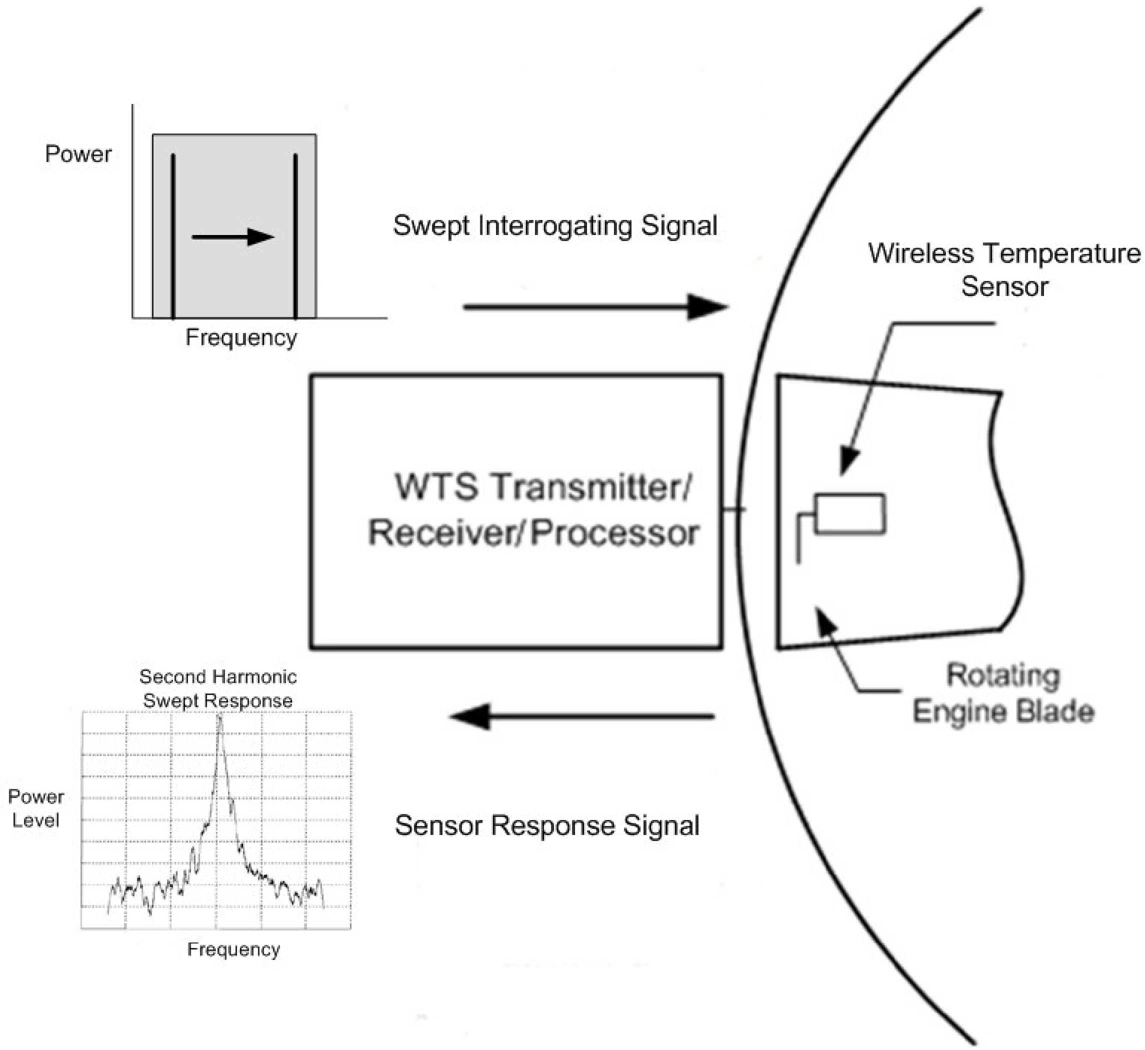
- Would TBC possess similar DK temperature dependence?
- Experiments proved that yttria stabilized zirconia (TBC) is acceptable for wireless temperature sensor operation



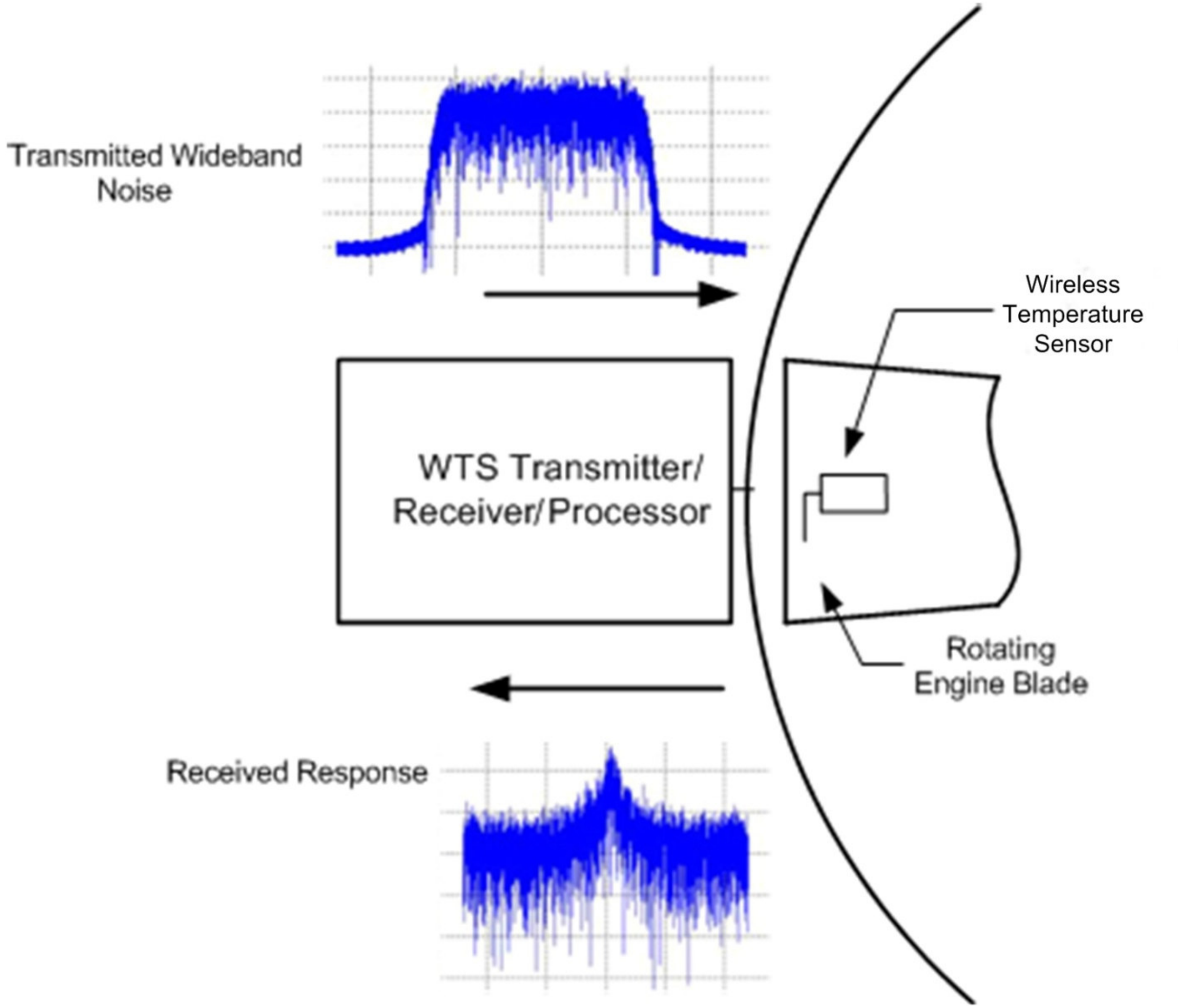
Wireless Sensor Equivalent Circuit



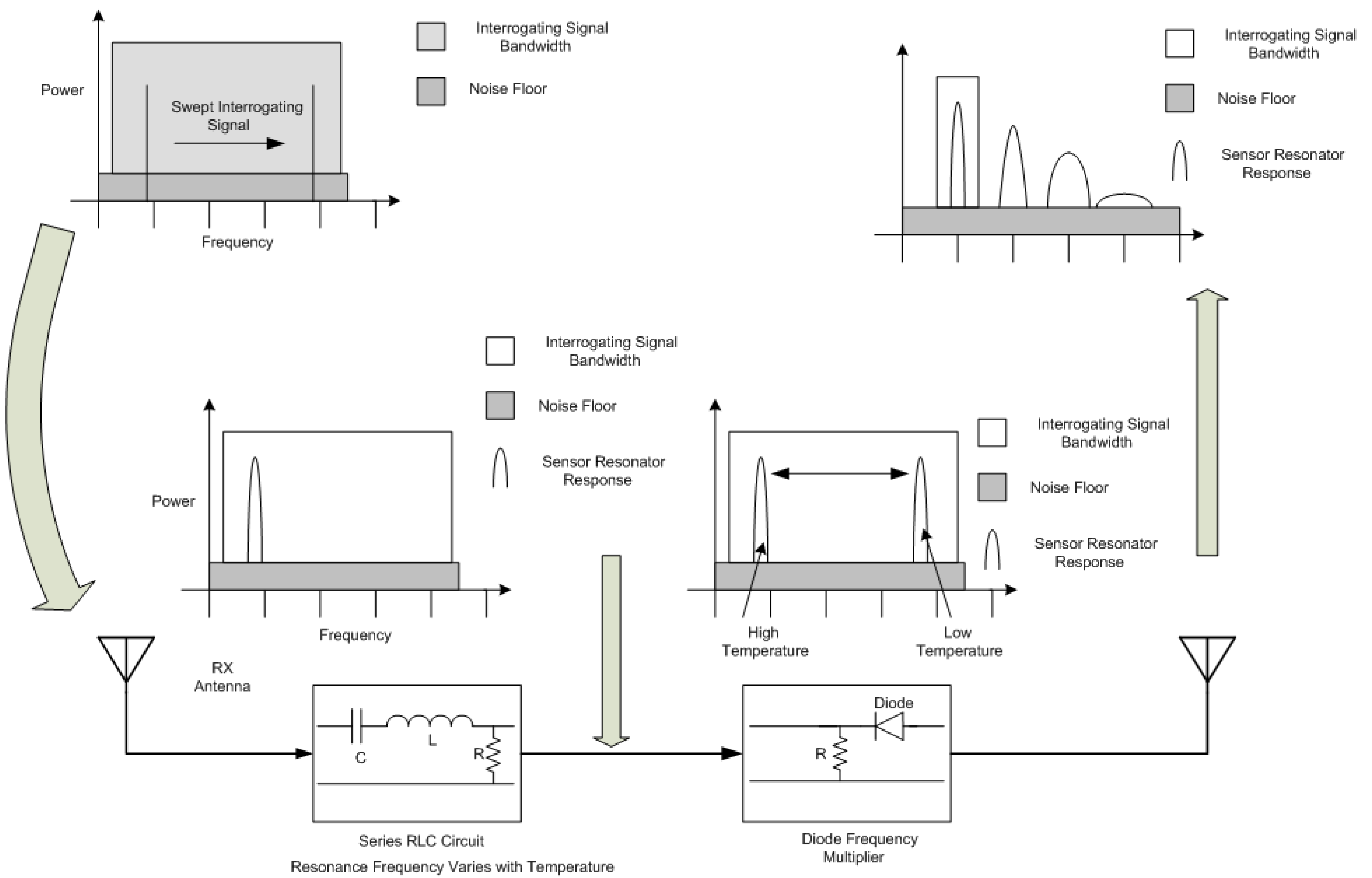
System Interrogation Concept



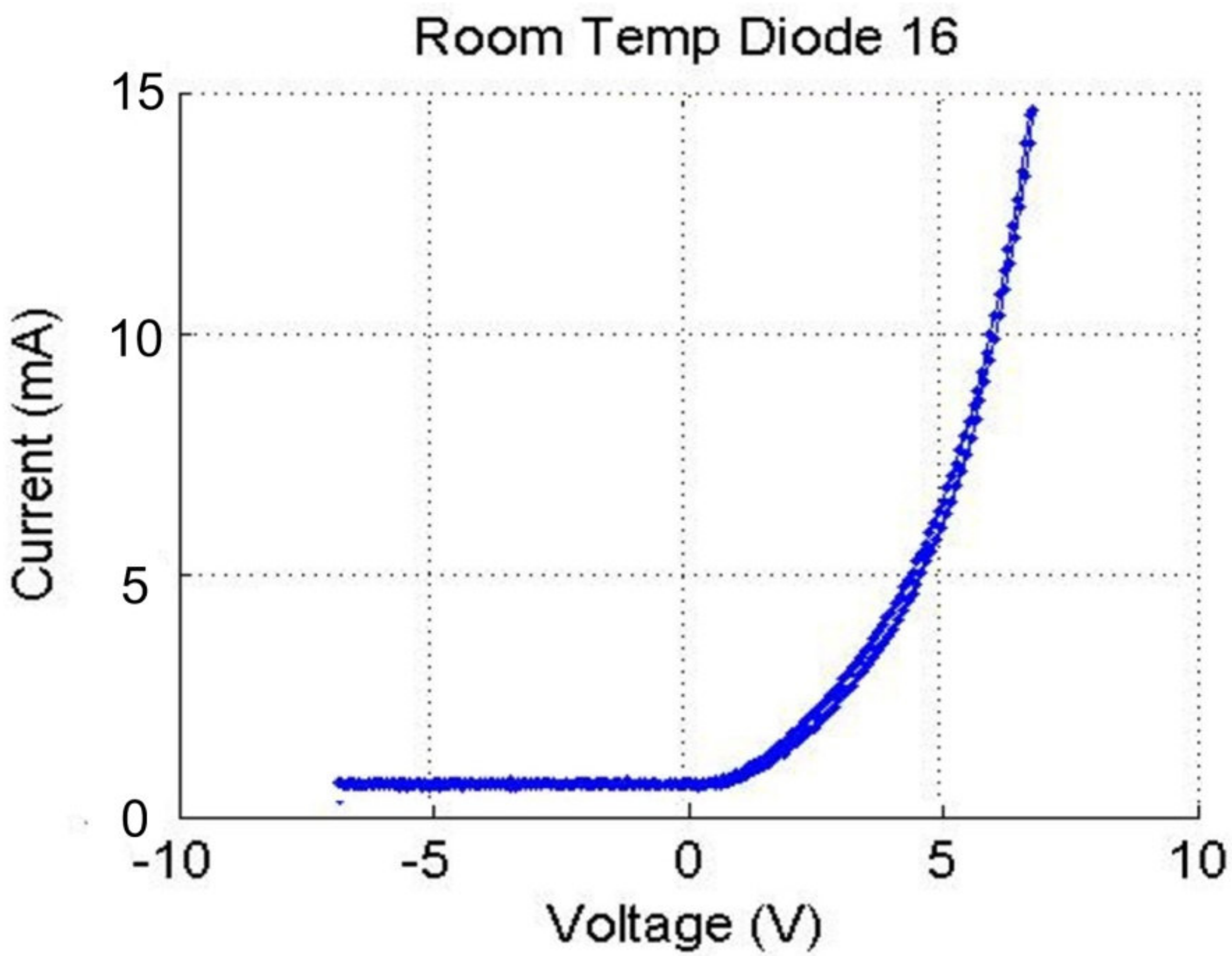
Alternate Interrogation Concept



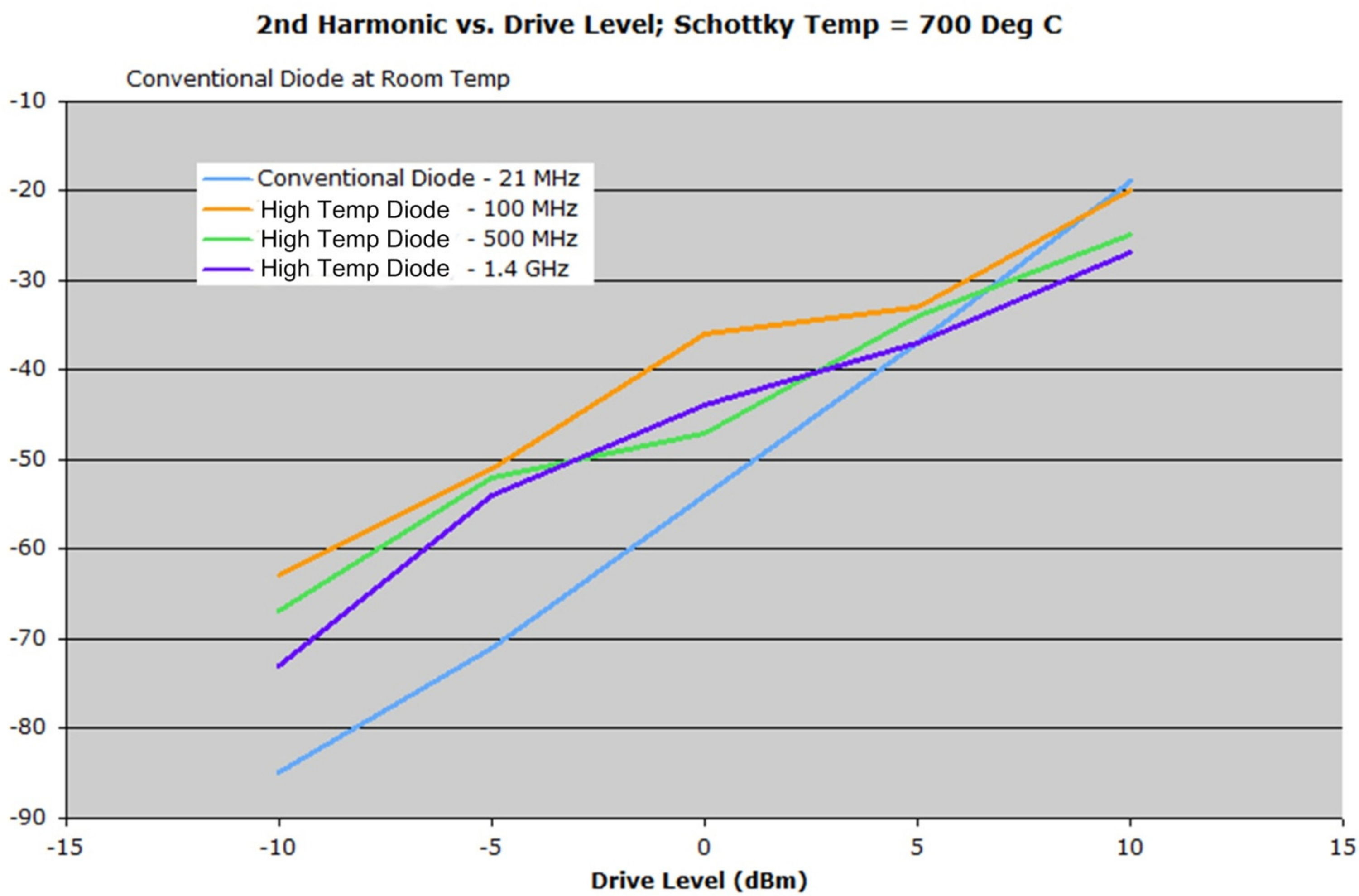
How does the wireless sensor work?



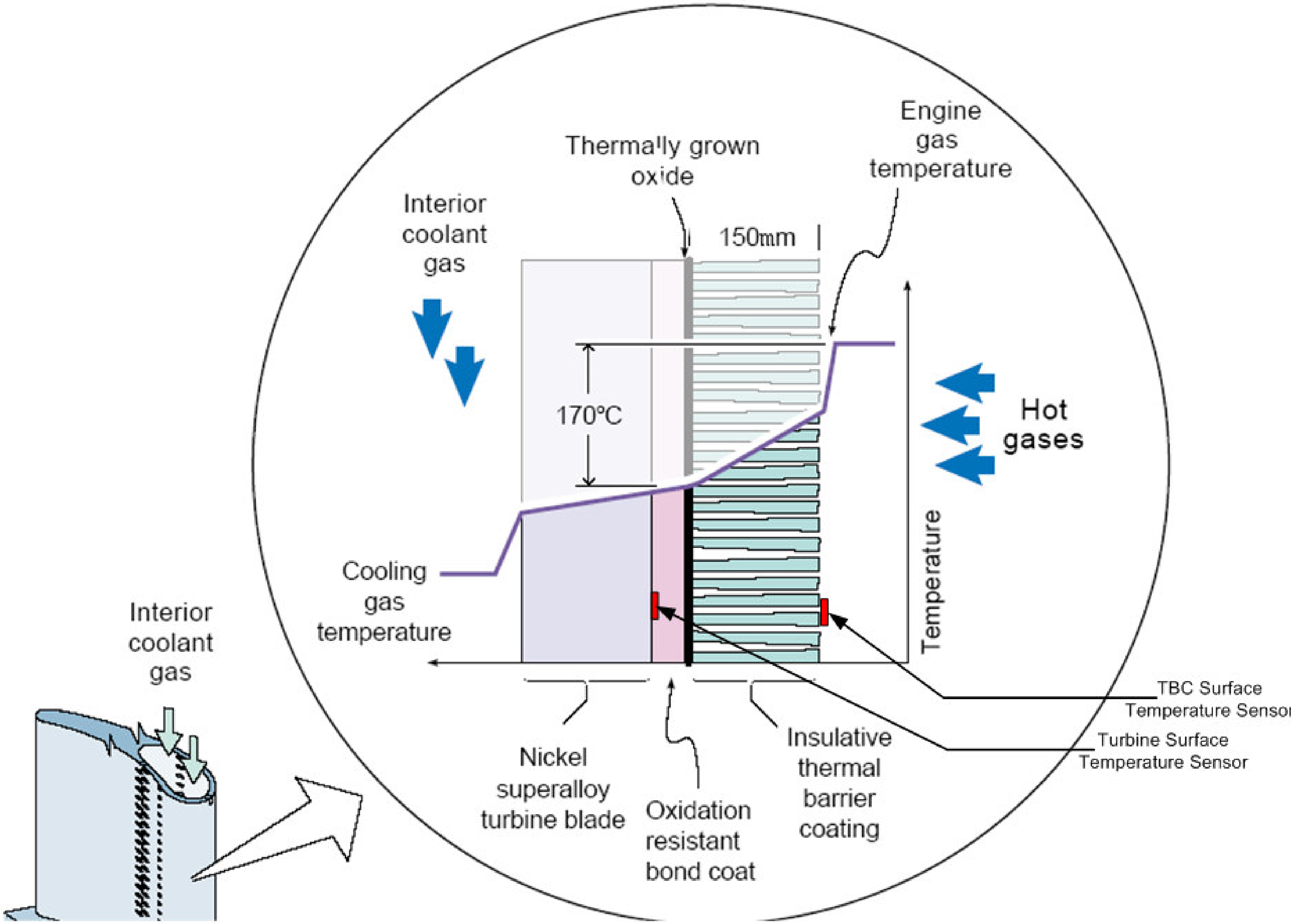
High Temperature Diode I-V Characteristics



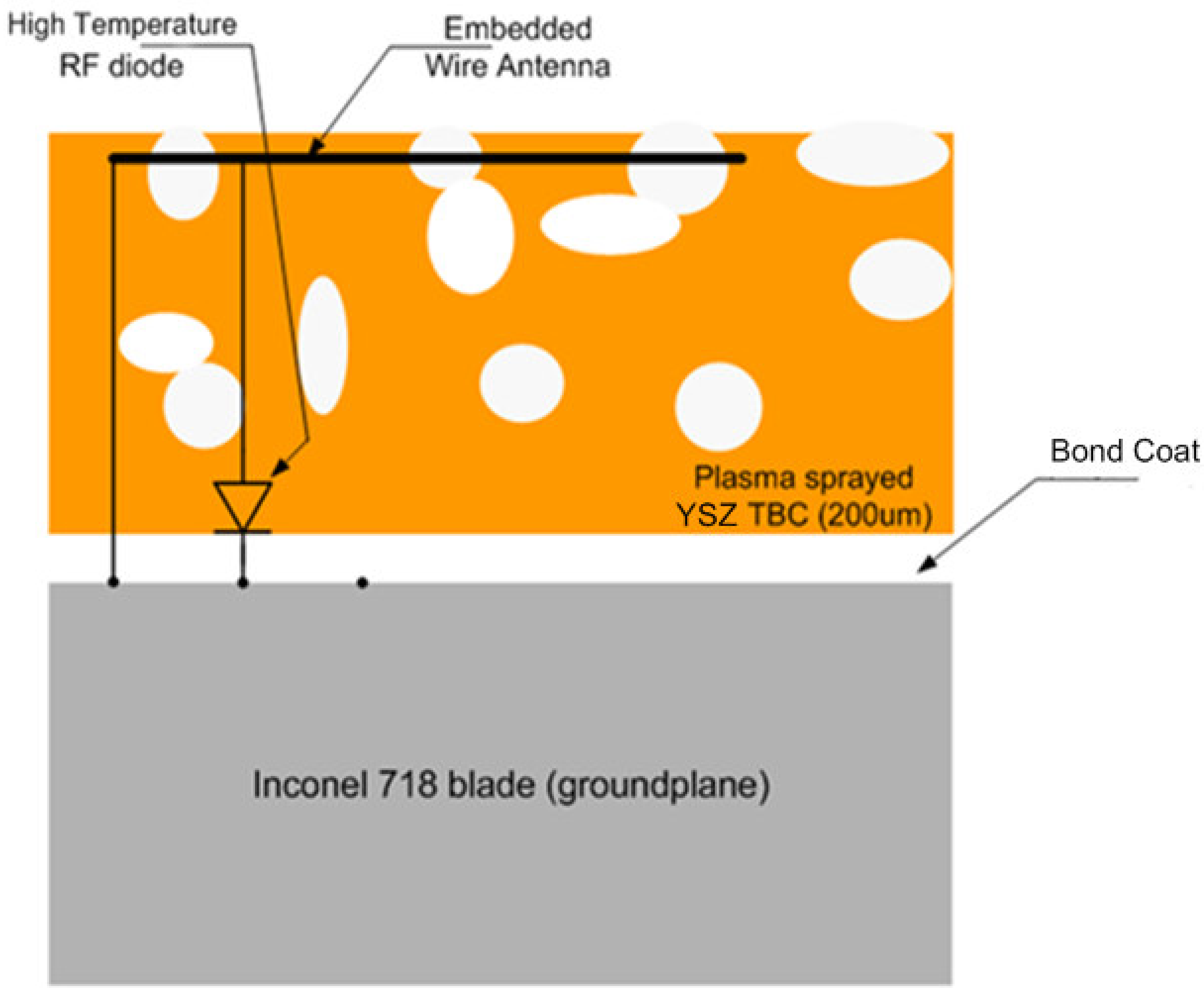
Harmonic Generation Performance at 700C



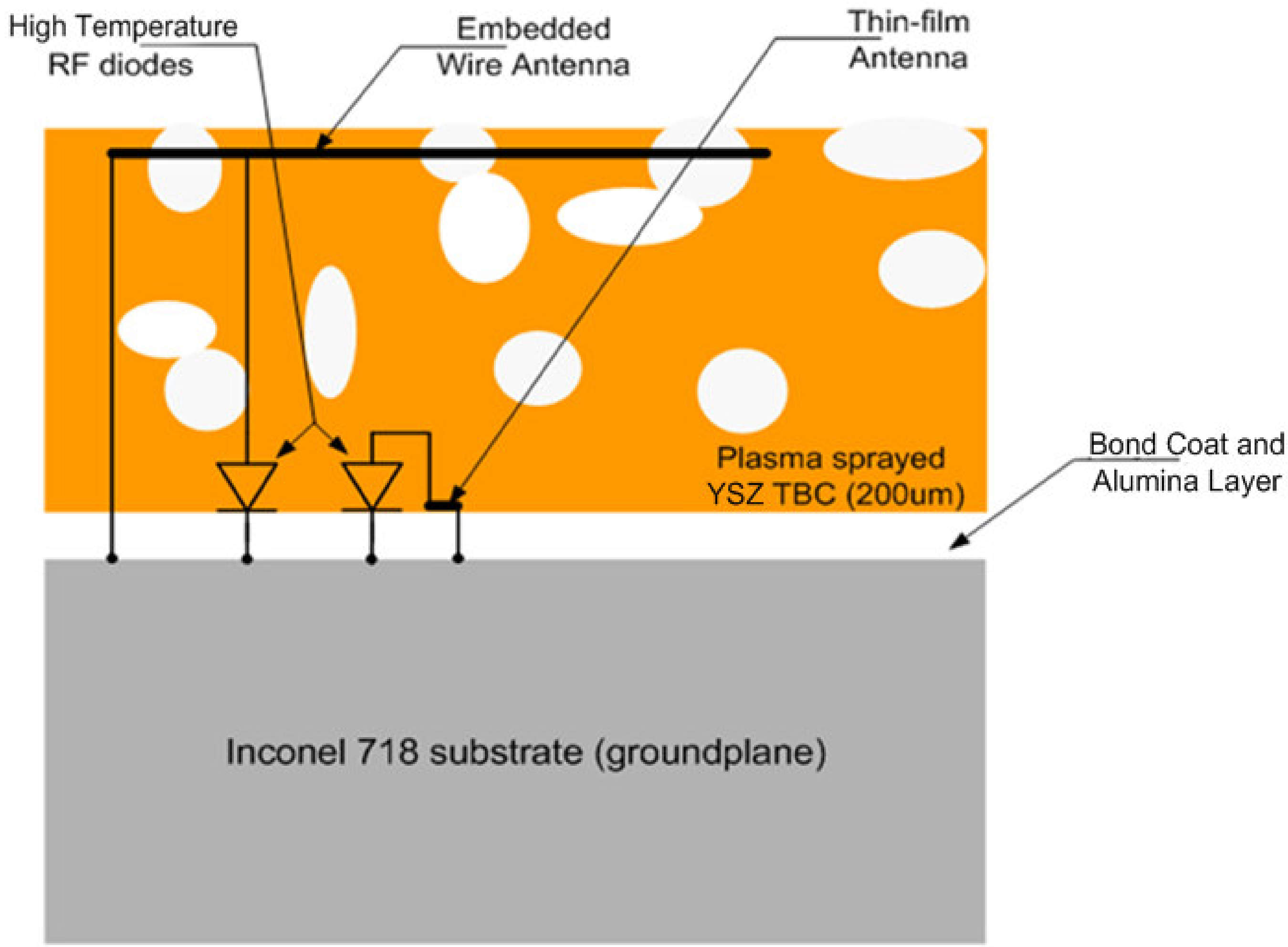
Wireless Heat Flux Sensor Requirement



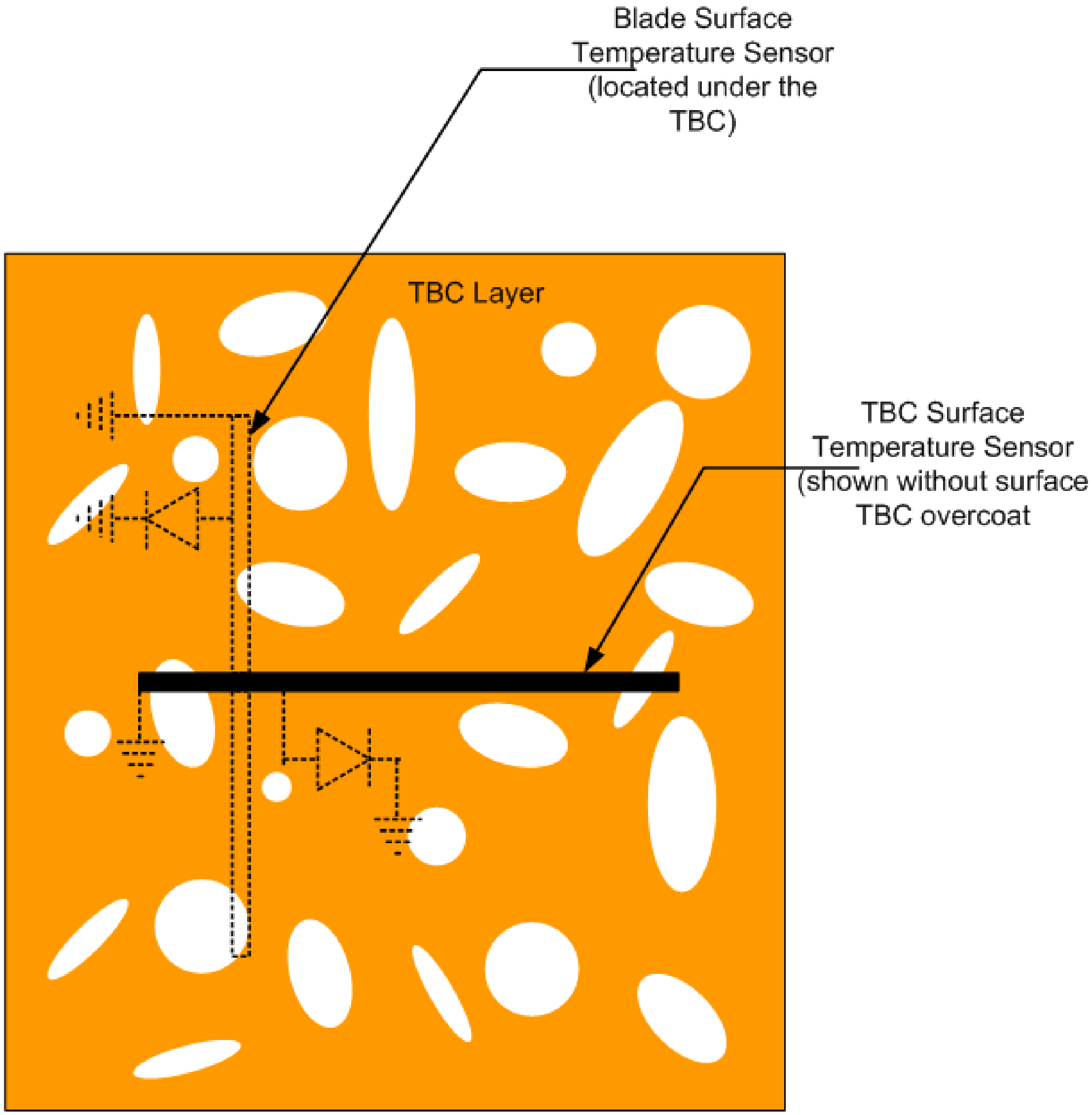
TBC Wireless Temperature Sensor



Wireless Heat Flux Sensor – Side View

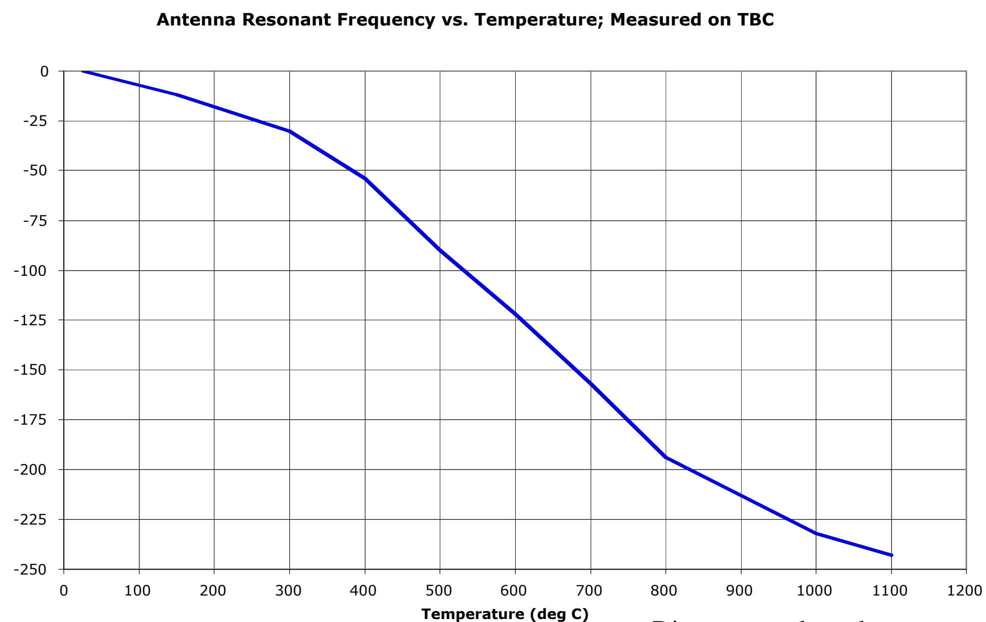


Wireless Heat Flux Sensor – Top View



Prototype Sensor Performance

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

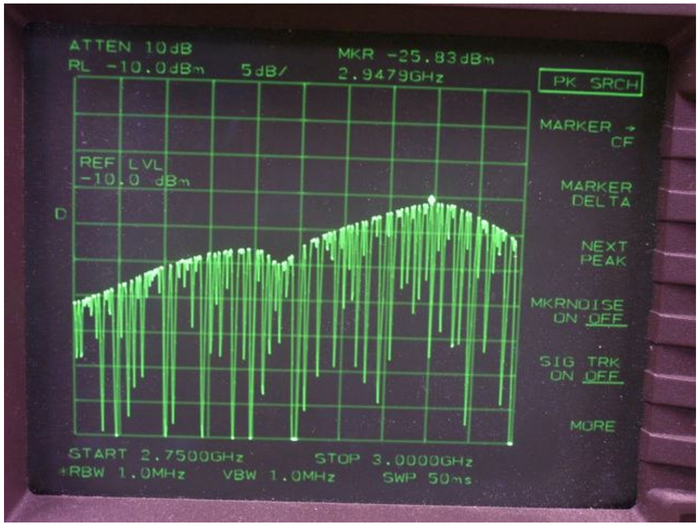


Direct network analyzer measurement

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

Prototype Sensor Performance Cont'd

- Wireless Accuracy (preliminary assessment)
  - Straightforward centroiding algorithm used to calculate temperature from harmonic output center frequency
  - Furnace temperature control resolution an error term not included in accuracy calculation
  - Test over a limited temperature range using off-the-shelf diode in the sensor circuit

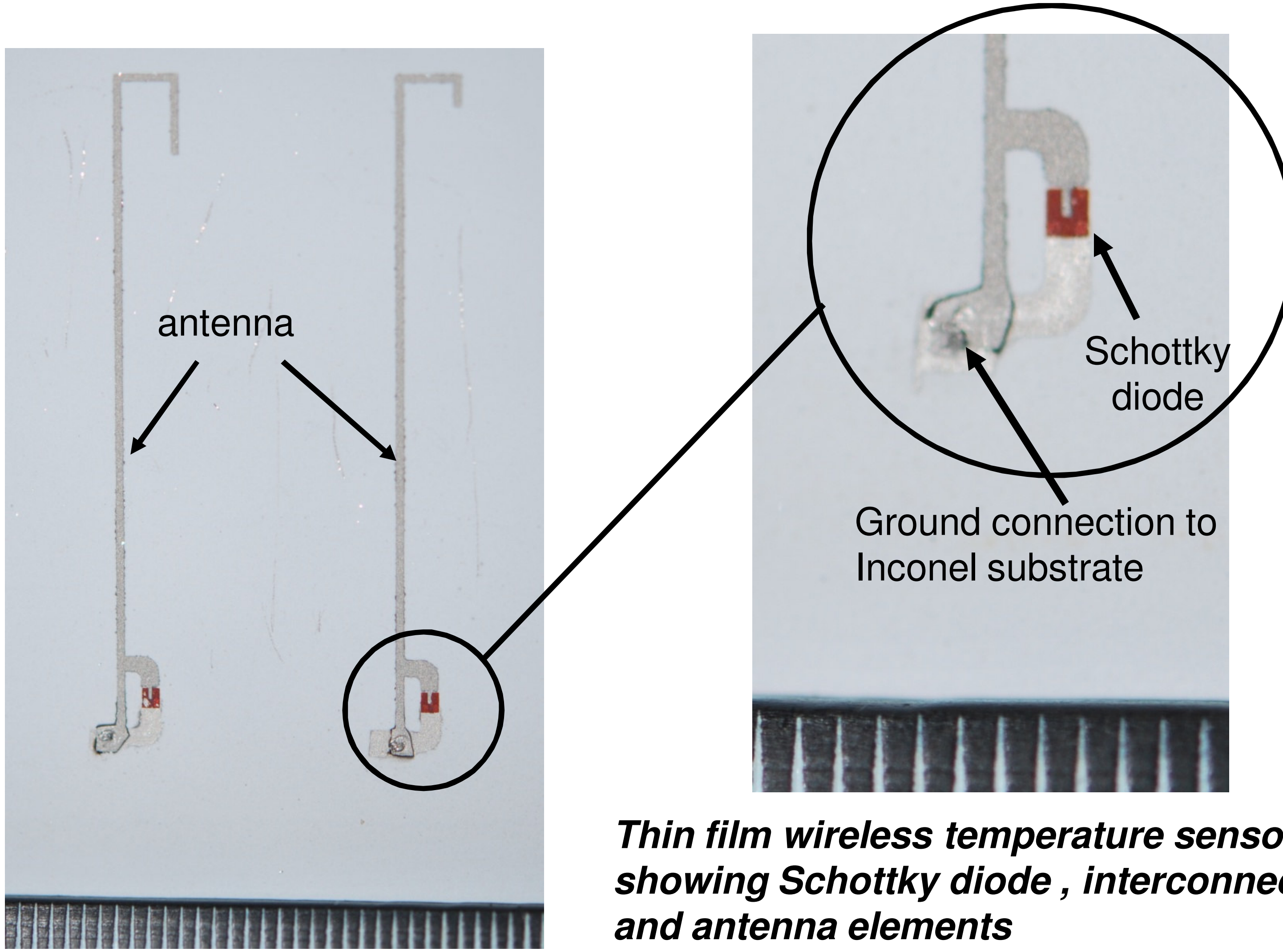


Temp (deg C)	Measured Temp (deg C); 10 dB Window
25	25
150	145
200	208
250	231

Wireless accuracy test results suggest production sensor will meet our goals - ultimate accuracy is dependent on signal processing gain and channel effects mitigation

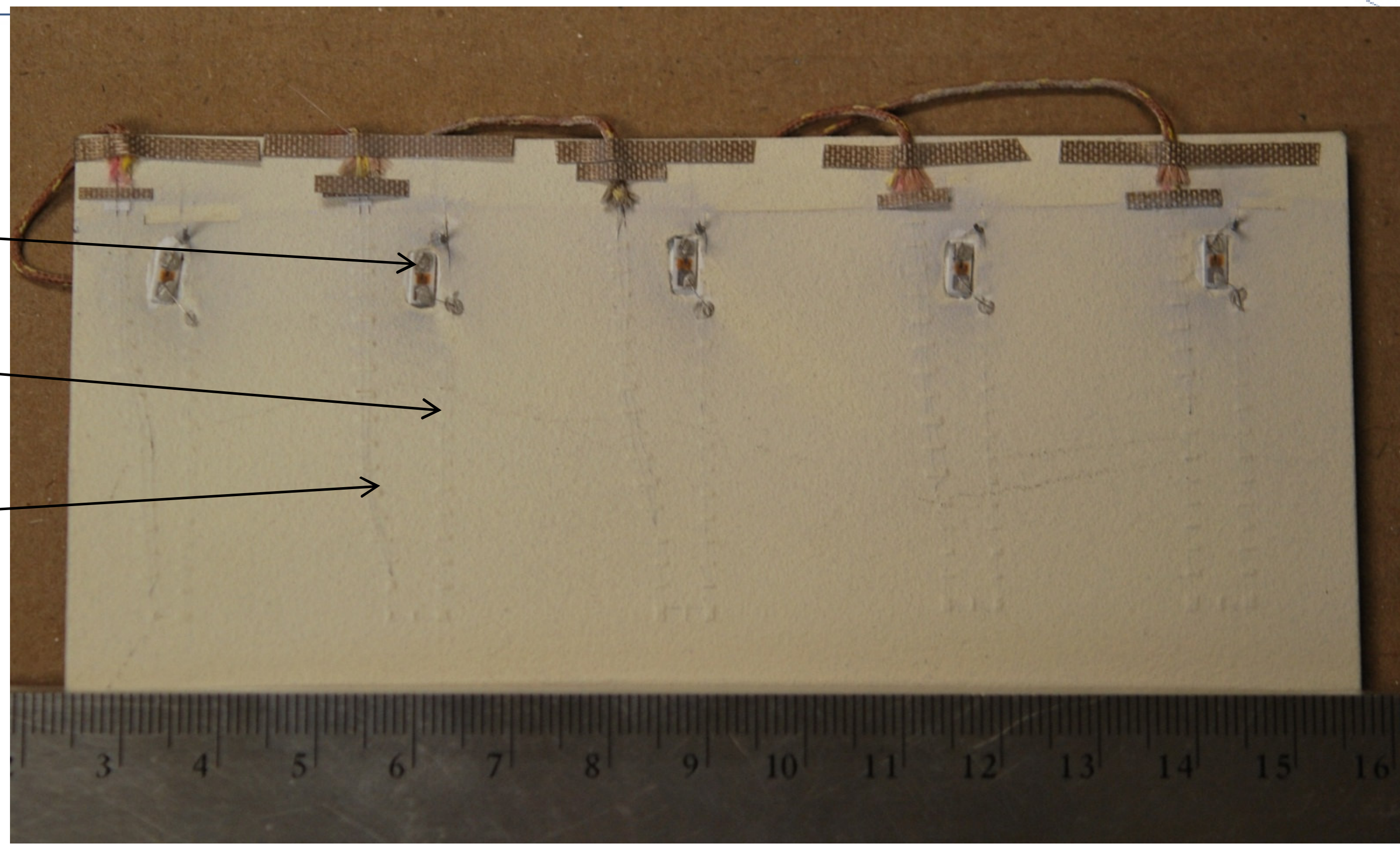
Initial Fab of Thin Film Wireless Temperature Sensors

Thin Film Sensor Detail



Thin film wireless temperature sensor showing Schottky diode , interconnects and antenna elements

Initial Discrete Sensor Fab



- Five identical discrete wireless temperature sensors with Type K thermocouple for independent temperature measurement

Applications for Wireless Temperature Sensors

- Gas turbine engines for propulsion and power generation
  - Engine developmental testing
  - Engine control
  - Propulsion health monitoring
- Power plants including nuclear power plants
  - Coal gasification stack
  - Steam turbines

This Work has been Supported By:

- Navy SBIR N08-004, N68335-08-C-0267, “Thin-film High Temperature Sensors

Core R&D supported by:

- Air Force, SBIR AF112-175, FA8650-11-M-5146, “Passive Wireless Sensors for Extreme Turbine Conditions”

- DOE SBIR, "Self Powered Wireless Sensor System for Power Generation Applications

Thank You!