PHOENIX

Contract Number
DE-FE0001249

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Domain Expertise

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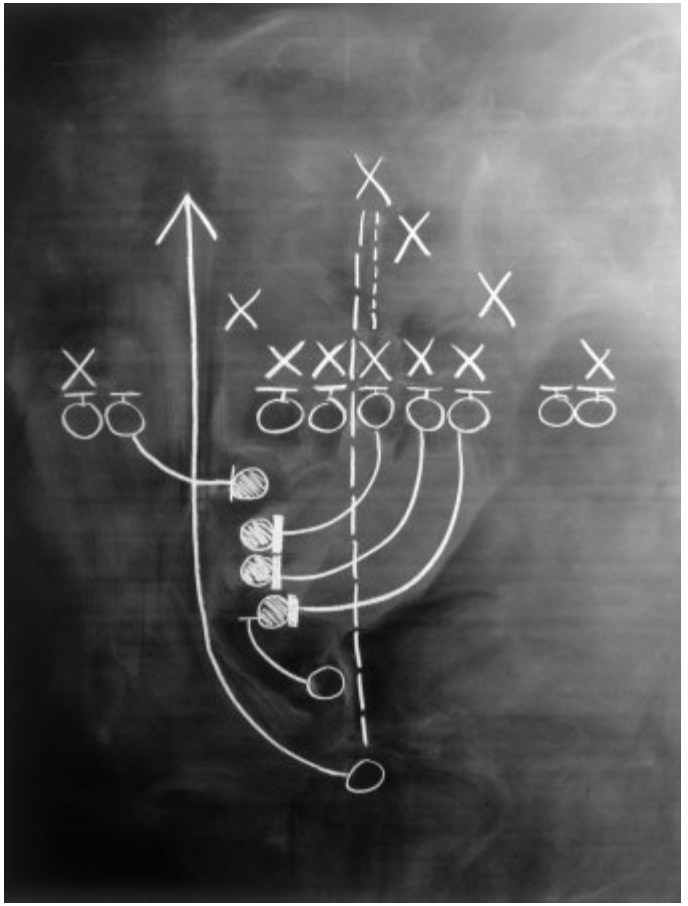
RF Testing

Presentation Outline

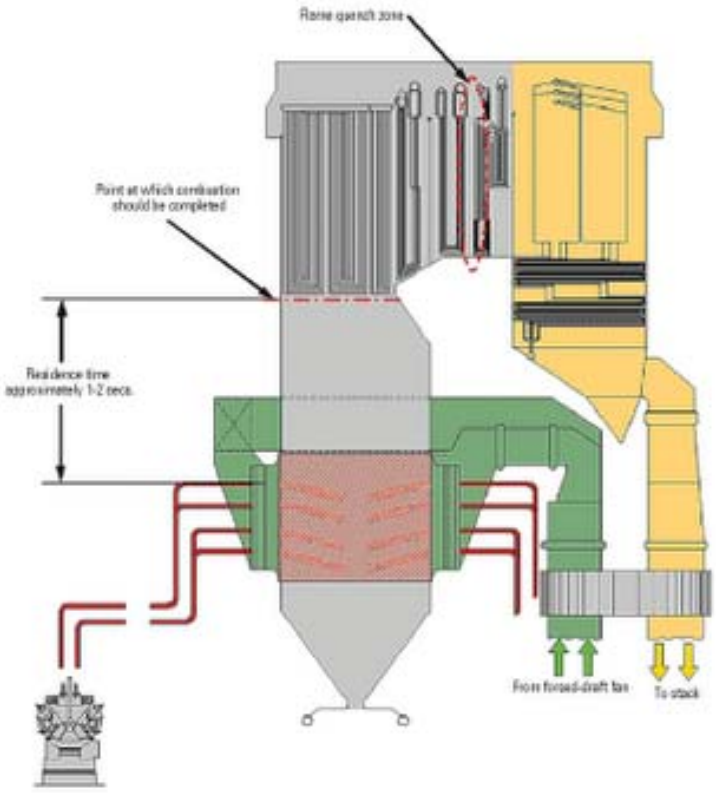
- Introduction
  - The problem
  - The solution
  - Relevance
  - The team
- Award Details
  - Contract details
  - Program objectives
  - Work breakdown structure
  - Schedule and milestones
  - Project management plan
- Conclusion



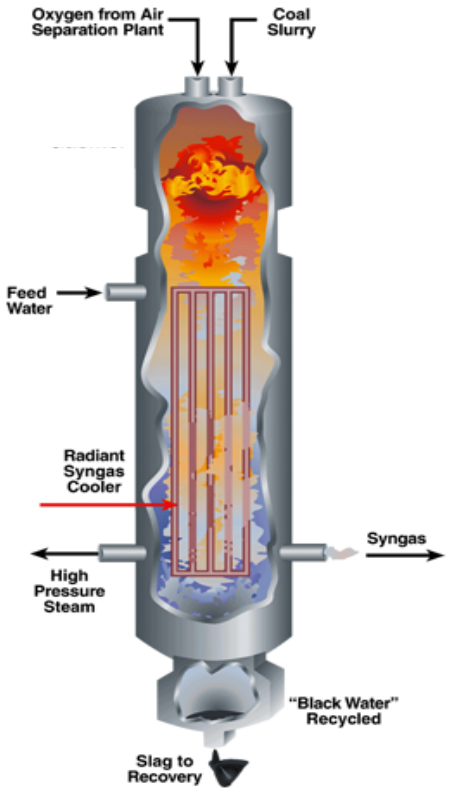
The Problem

To measure physical parameters (temperature, pressure, strain, etc.) in extreme temperature and highly corrosive environments.

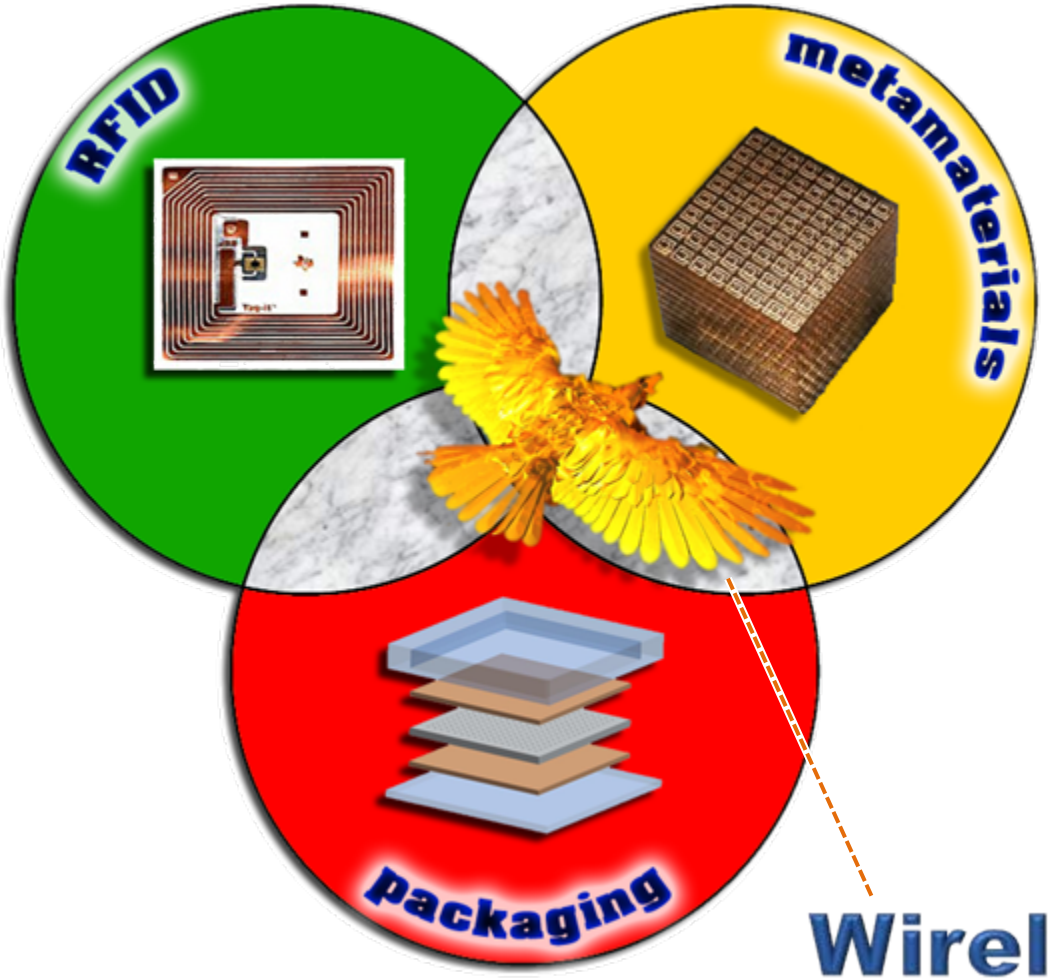
Coal-Fired Boiler Plant

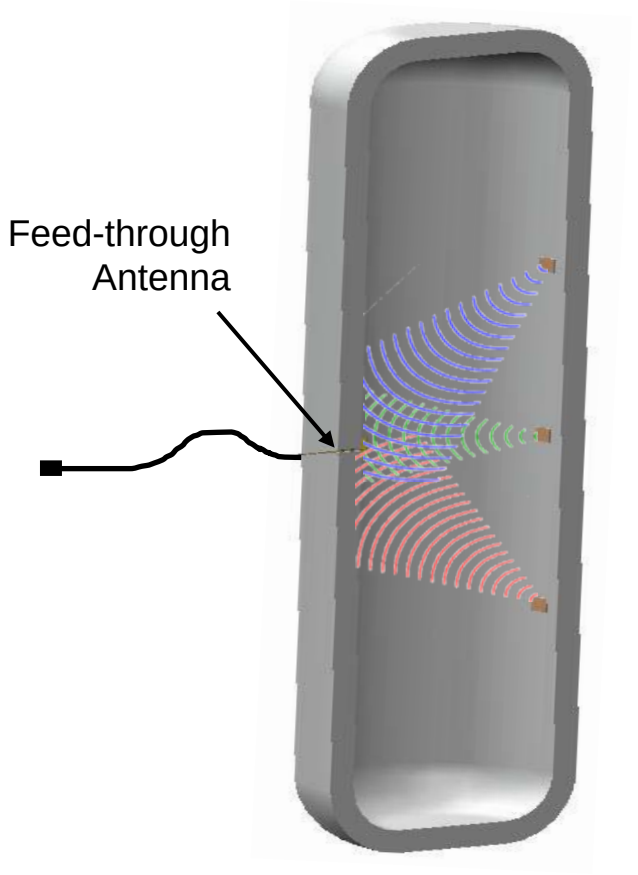


Coal-Gasification Plant



Our Solution





Wireless Sensors for Extreme Environments

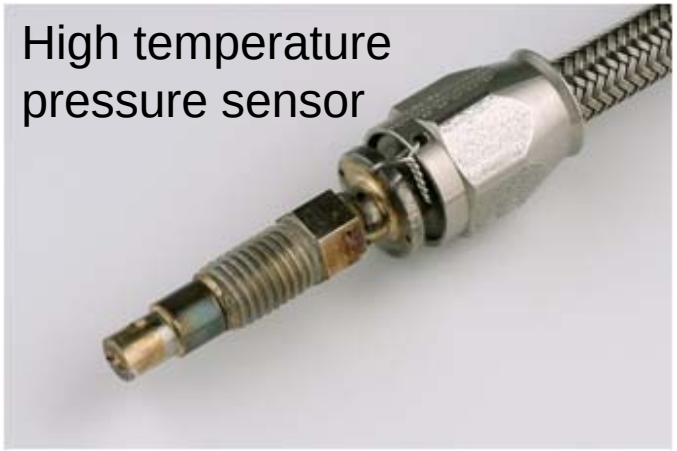
Benefits of Wireless

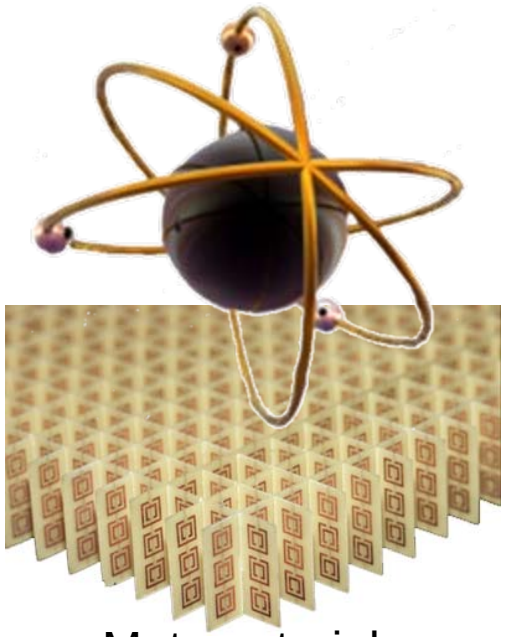
- No cables connecting to sensors
- Enhanced reliability
- Greater freedom placing sensors
- Simplified installations
- Easier multiplexing of multiple sensors
- Fully encapsulated
- Longer operational lifetime

Rationale for Solution

- Wireless mitigates many problems
- RFID is mature and proven
- Metamaterials greatly expand materials selection
- Príme has extensive experience packaging in extreme environments

RFID



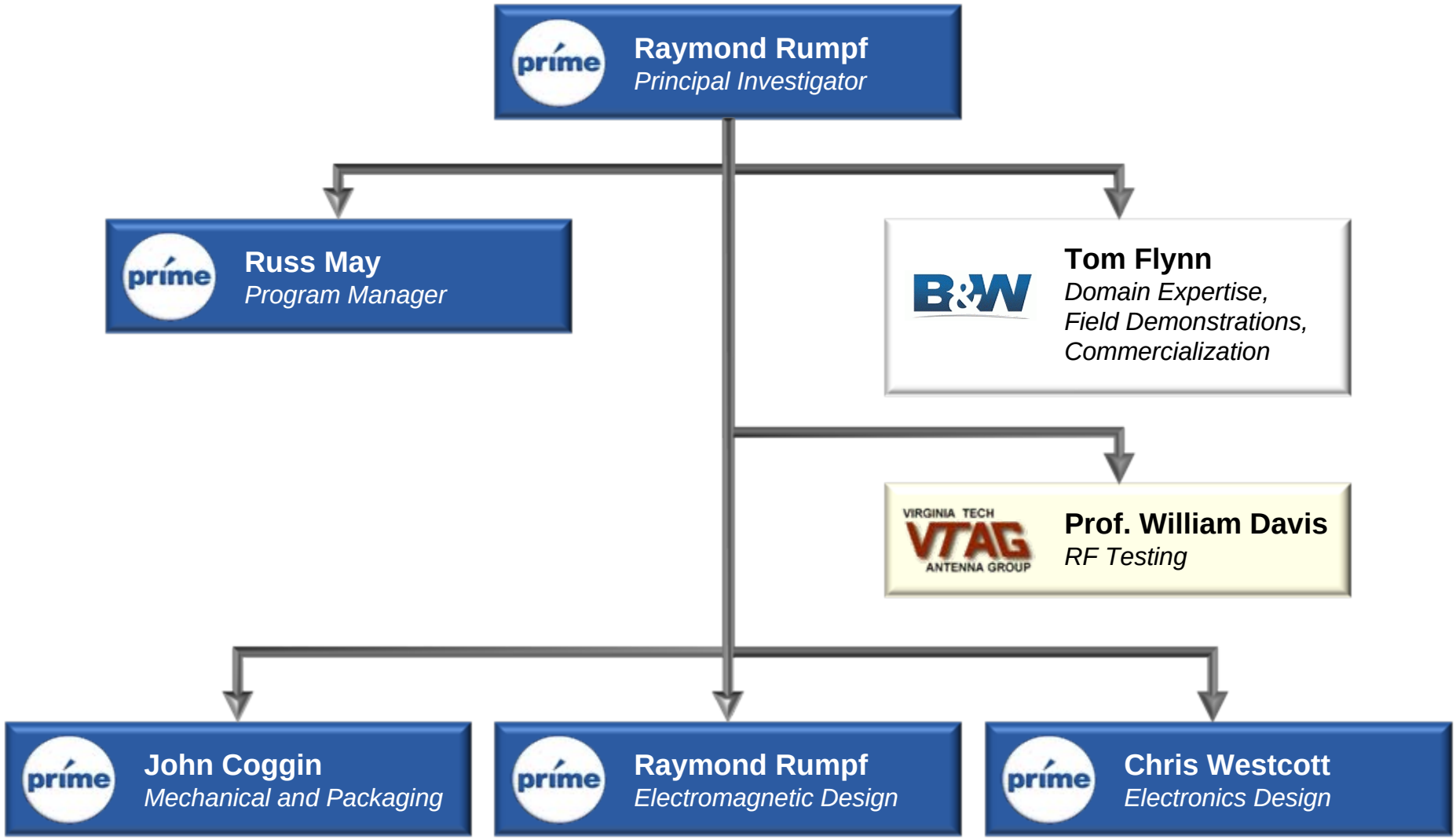


Metamaterials

Relevance

- Coal will be key to U.S. energy independence
- Process must be made cleaner and more efficient
- Closed loop control to boost efficiency
  - Sensors are critical
- Coal gasification is a promising solution
  - 1400 °F to 3200 °F
  - Reducing, corrosive, and erosive
  - Alkaline metals, H_2S, HCl, NH_3, CH_4, H_2O, CO, and H_2.
- State-of-the-Art
  - Thermocouples: limited life, sensor drift, broken cables, EMI susceptibility
  - Optical pyrometers: requires visible line-of-sight
  - Acoustic sensors: inaccurate, immature, no point measurements
  - Photonic sensors: packaging difficulties, fibers require cables, expensive

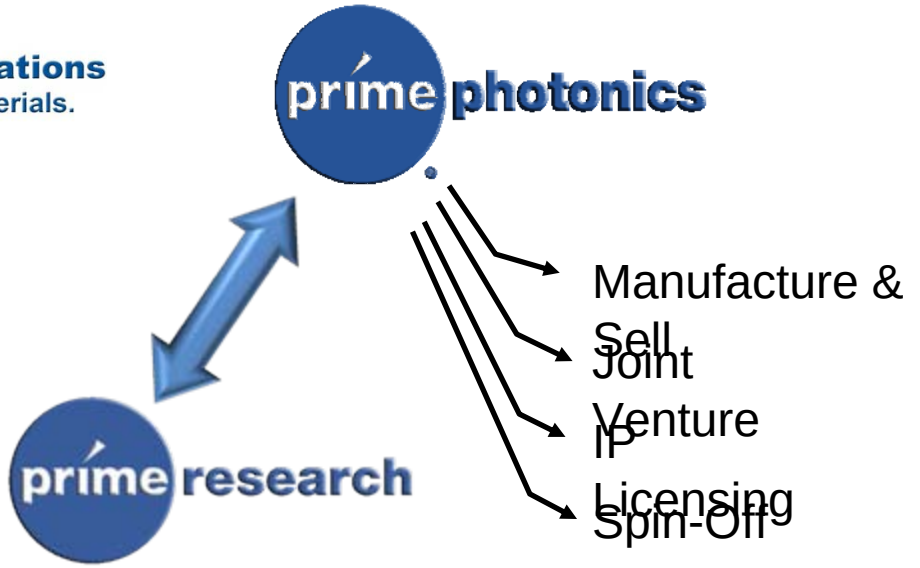
Team Organization



Prime Overview

prime Technologies for Extreme Applications
Sensors. Communications. Engineered Materials.

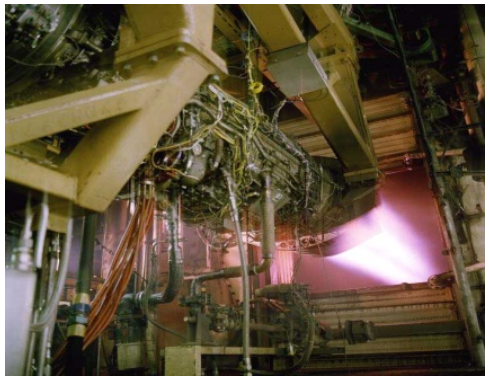
- Virginia Tech spinoff company founded in 1999
- Historically developed fiber optic sensors for harsh environments
- Expanded technologies to include sensors, communications, and engineered materials for extreme applications
- 2009 Nominee for NewVA Technology Council (NCTC) “Rising Star” Award
- Federal R&D customer base includes USAF, NSF, DARPA, Navy, Army, DOE



Contract R&E
- Government
- Private Sector

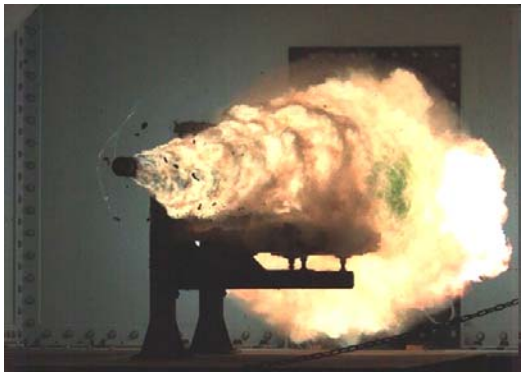
Prime Technologies (1 of 2)

High Temperature Sensors



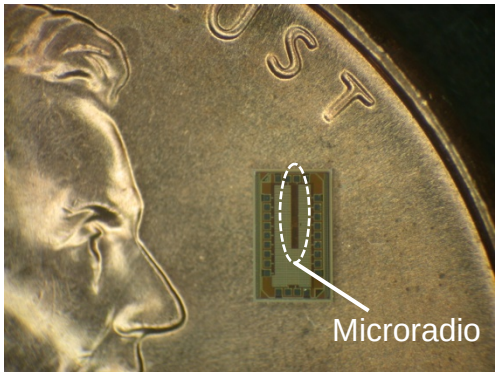
Turbines, combustion processes, process, downhole oil and gas

Ultra-Fast Sensors



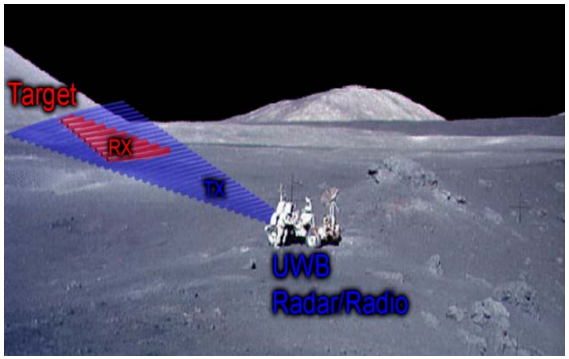
Temperature, pressure, strain, electric fields, and magnetic fields

Ultra-Low Power Micro-Radios



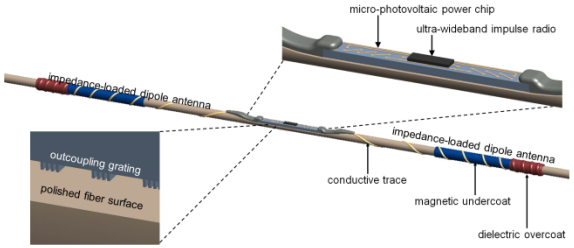
Suitable for micro-sensors. Relaxes power requirements on power harvesting.

Ultra-Low Power Radar



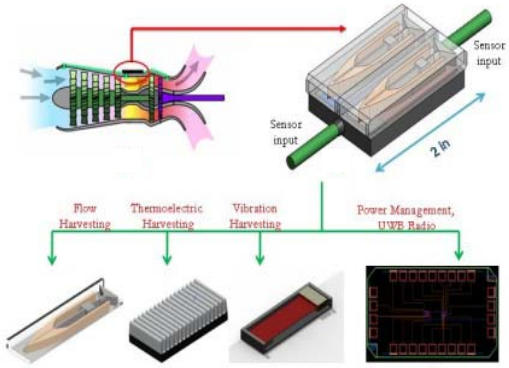
Ultra-low power, compact, high resolution, multipath immune, tracking and location.

Optowireless™



Wireless access to fiber optic backbone. Powered by light itself.

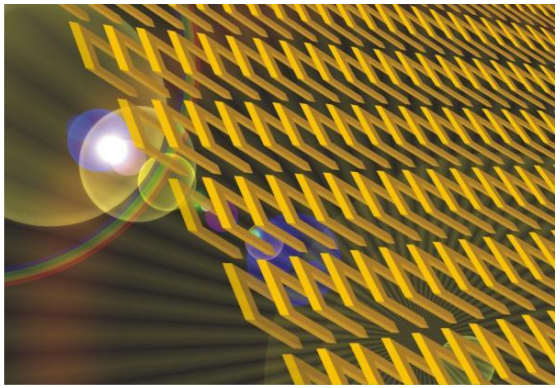
Energy Harvesting Sensors



Self-powered wireless sensors require no batteries, fuel, or associated maintenance

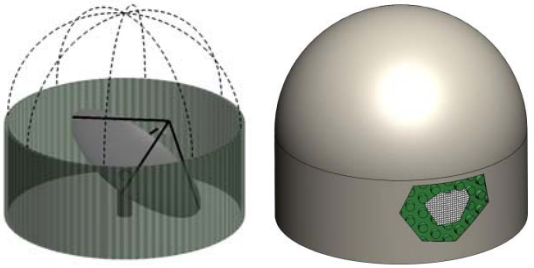
Prime Technologies (2 of 2)

Metamaterials



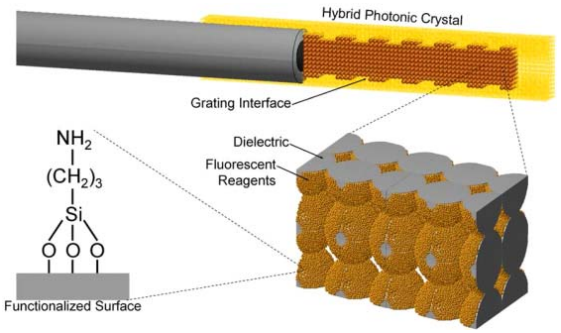
Enables more materials solutions.
Provides new and amazing properties.

Frequency Selective Surfaces



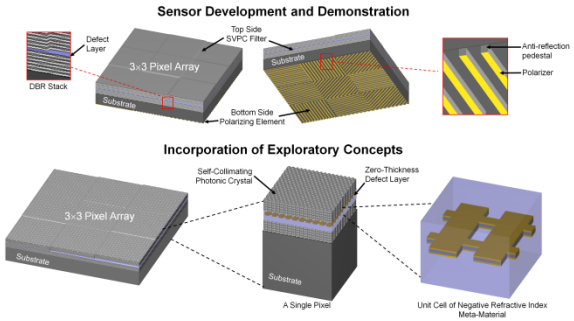
Ultra-high power capable.
Antennas, radomes, stealth, directed energy.

Chemical and Biological Sensors



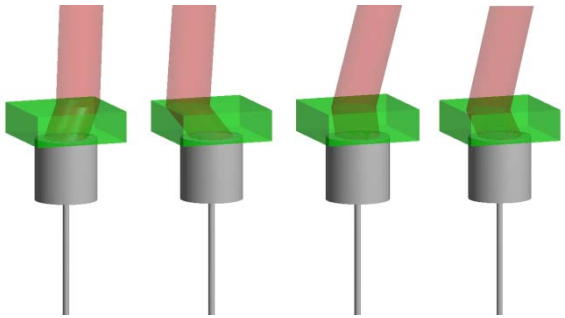
Toxic industrial chemicals, biohazards, nuclear, chemical, medicine, combustion byproducts.

Advanced Imaging



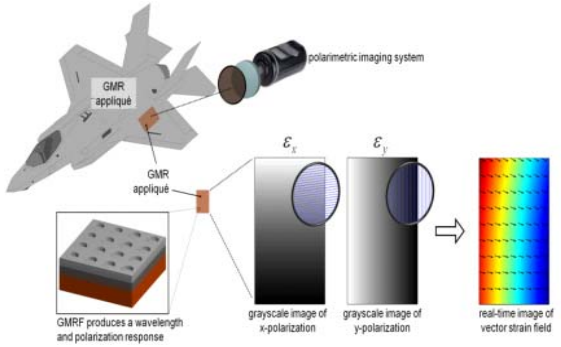
Hyper-spectral, polarization selective, passive, computational imaging, improved performance.

Passive Optical Alignment/Coupling



Completely passive, relaxes alignment tolerances.

Real-Time Full-Field Strain Sensor



Low-cost, real-time, minimal post processing, full vector field. Failure analysis. Composites.

prime
Technologies for Extreme Applications
Sensors. Communications. Engineered Materials.
®

CPT
CENTER FOR PHOTONICS TECHNOLOGY

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High Temperature Sapphire Sensors

Applications

Prime Research fiber optic-based high temperature sapphire sensors can be applied to temperature sensing applications ranging from 700°C to over 1600°C.

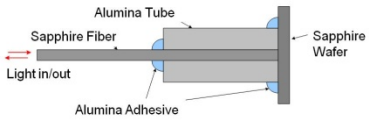
- Coal-fired combustors
- Coal and waste material gasifiers
- Boilers
- Annealing
- Glass processing
- Blast furnace
- High temperature ovens

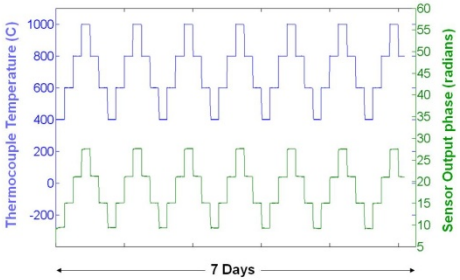
Benefits

Lightweight and small size: Standard probe is ¼" diameter, higher temperature applications do not require larger probe sizes
Immune to EMI and RFI: All optical construction
High voltage isolation: All dielectric sensor and cable materials electrically isolate the probe from the instrument
High resolution: Better than 0.1% FS resolution
Reliability and long lifetime: All sapphire/alumina transducer minimizes thermal stress
Simple construction: Solid sapphire wafer forms a Fabry-Perot etalon
Accurate: Stability of sapphire properties at high temperatures results in highly repeatable and accurate measurements

Technical Approach

- Sapphire temperature sensor reflects a unique spectral pattern that is converted to a the measurement of interest using proprietary Fourier-based processing
- Calibration maps spectral pattern frequencies into temperature
- Transducer can be packaged in high temperature metal or ceramic housings





Roadmap

Extended operation has been demonstrated in coal combustion and gasification applications.

Commercial prototypes available 2010.

Test and demonstration opportunities are welcome.

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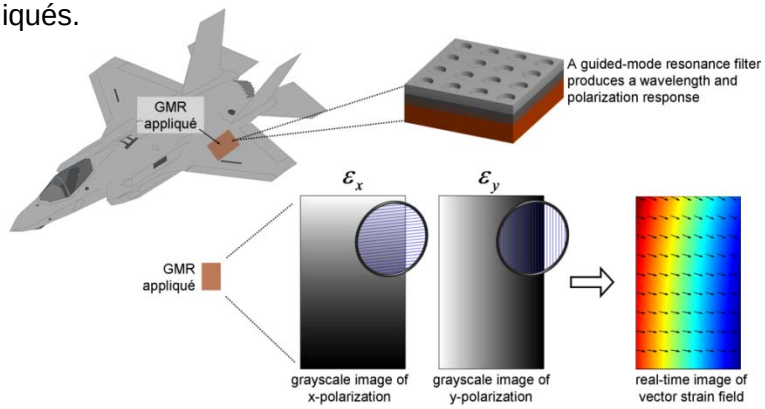
GMR Metamaterial Strain Appliqué

Application

A real-time, full-field, and full-vector strain measurement system based on polarimetric imaging of diffractive optical “stick-on” appliqués.



Benefits

Near zero post processing: Physics of sensor automatically encodes full vector nature of stress/strain into optical intensity.

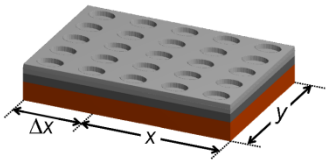
Arbitrary surfaces: Applique can be affixed to any surface of virtually any shape or profile.

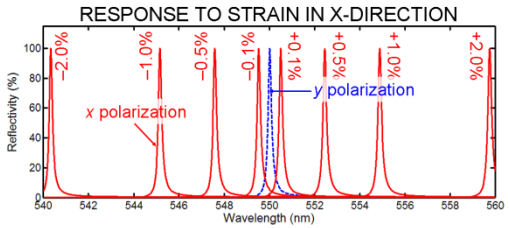
High spatial resolution: Imaging the applique enables low cost and submillimeter measurements.

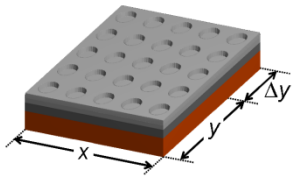
Full vector strain fields: Polarimetric imaging of applique enables intensity to be decoupled into *x* and *y* strain.

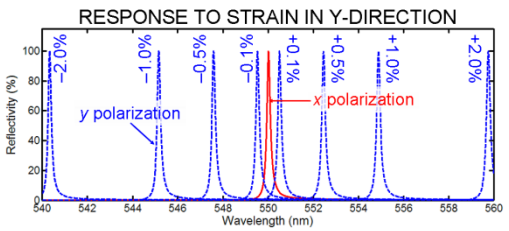
Low cost: Appliques will be inexpensive making them disposable.

Technical Approach





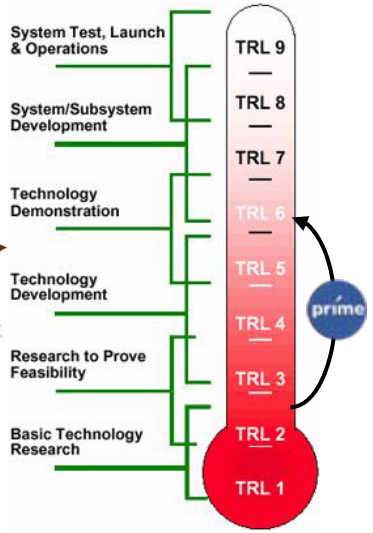




Roadmap

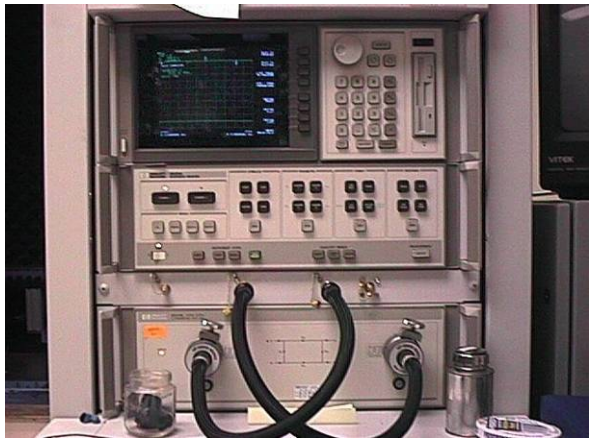
Phase I SBIR awarded Q3 2009.

Funded: Navy (NAVAIR)
Contract No.: N68335-09-C-0345

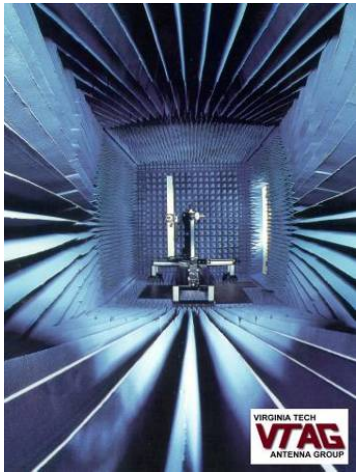


Virginia Tech Antenna Group

- Test and Measurement
  - Indoor anechoic chamber
    - 800 MHz – 40 GHz
    - Robotic positioners
  - Outdoor antenna range
    - 200 MHz – 40 GHz
    - Robotic positioners
  - Narrow and wideband propagation measurement systems
- Numerical Modeling Tools
  - NEC, HFSS, IE3D, FEKO, and Patch



HP 8510/8530 Dual-Mode Network Analyzer



Anechoic Chamber

Babcock & Wilcox

- Research Center in Barberton, Ohio
- $14 million, 55,000 ft^2 facility
- Carbon capture and pollution control

Research Center

- Small Boiler Simulator (SBS) II
- Hydraulic Model
- Clean Environment Development Facility (CEDF)
- CO_2 Capture Lab
- High-Resolution Scanning Electron Microscope
- Entrained Flow Reactor
- Fireside Corrosion Facility
- Catalysis Lab
- Plasma Transferred Arc Facility
- Bench-Scale Mercury Testing Lab

Scaled Boiler

Contract Details

- Funded by DOE NETL
  - Contract number DE-FE0001249
- Technical Contact
  - Robie Lewis, Fuels Division
- Three-Year, Two-Phase Project
  - Phase I: 1 Oct 2009 – 31 Mar 2011
  - Phase II: 1 Apr 2011 – 30 Sept 2012
- Total Contract Cost: $810,954
  - Funded Amount: $648,763
  - Cost Share: $162,191

Budget Period	Period Start Date	Gov't Share: 80%	Prime Share: 20%	Total Est. Cost
1	10/01/2009	$369,462	$92,366	$461,828
2	04/01/2001	$279,301	$69,825	$349,126
Total Project		$648,763	$162,191	$810,954

Program Objectives

- Phase I:
  - Study the RF environment inside boilers and gasifiers
  - Study electromagnetic properties of candidate materials.
  - Perform detailed design of wireless sensors.

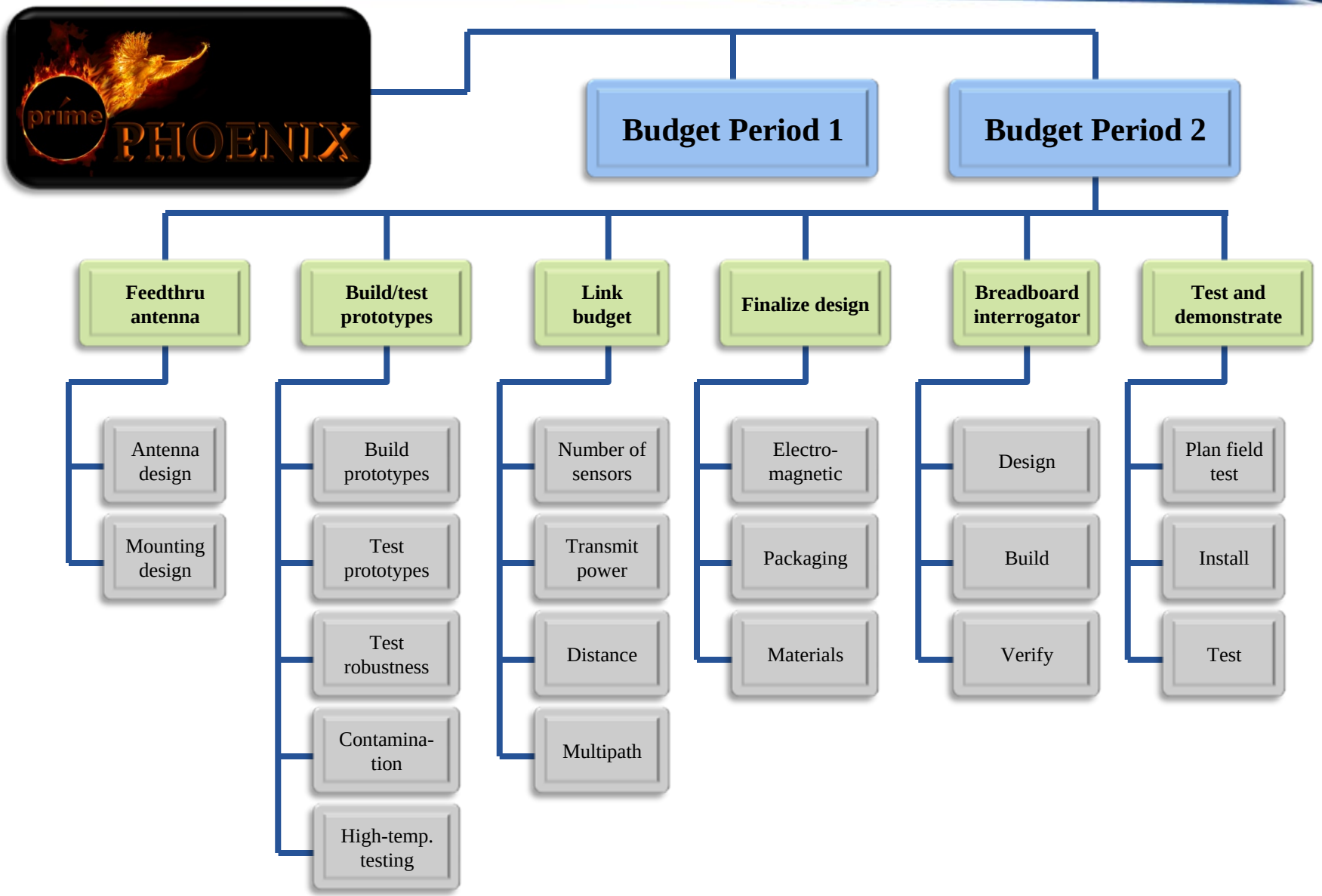
Go/No-Go Decision Metrics
1. Identify suitable frequency band with attenuation < 5 dB/m.
2. Show sensor material with sufficient response to temperature (σ > 1%/°C).

- Phase II:
  - Build and test prototype sensors.
  - Finalize design
  - Demonstrate technology in a realistic environment.

Work Breakdown Structure

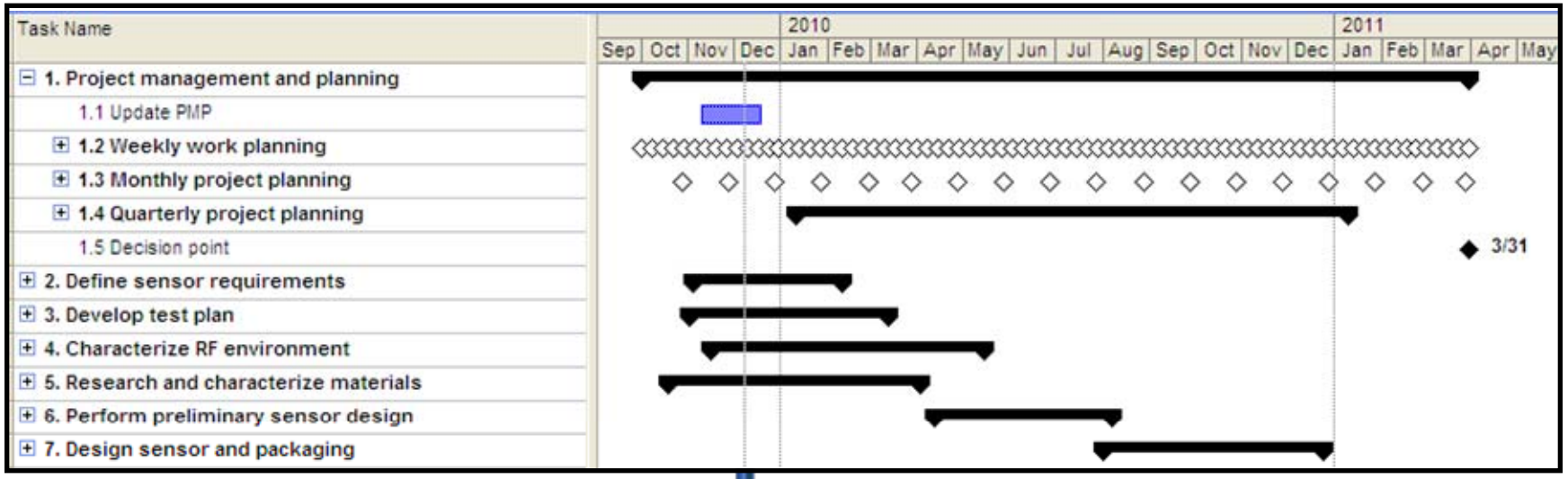
- **Budget Period 1**
  - **Project Management**
    - PMP
    - Weekly planning
    - Monthly planning
    - Quarterly planning
    - Decision point
  - **Define Requirements**
    - Program sponsor
    - Industry partners
    - Performance goals
    - Gasifier corrosion
  - **Test Plan**
    - Gather information
    - Plan tests
    - Test plan
    - Required results
  - **RF Environment**
    - EMI
    - Channel attenuation
    - Multipath interference
  - **Research Materials**
    - Electrical
    - Mechanical
    - Chemical
  - **Preliminary Design**
    - CTE
    - Diffusion
    - Creep
  - **Final Design**
    - Optimize design
    - Thin films
    - Packaging
    - Simulations
- **Budget Period 2**

Work Breakdown Structure



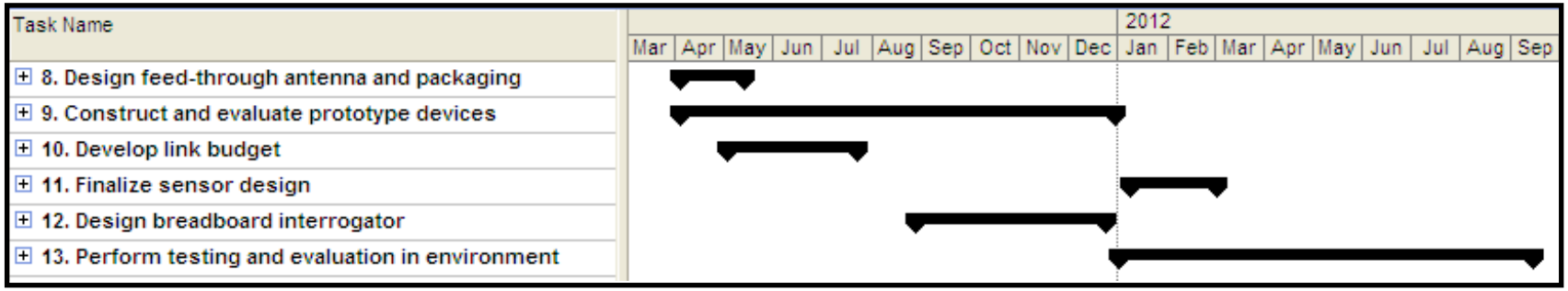
Project Schedule

Budget Period 1



- Inspected test facility
- Iterating preliminary designs to guide testing
- Experimenting installation and testing methods

Budget Period 2



Project Milestones

Budget Period 1

MS 1	Test plan complete	26 Mar 2010
MS 2	RF environment & materials characterized	24 Sept 2010
MS 3	Preliminary sensor design complete	25 Mar 2011

Budget Period 2

MS 4	Experimentation complete	30 Sept 2011
MS 5	Final sensor design complete	30 Mar 2012
MS 6	Technology Demo	30 Sept 2012

Project Management Plan

- Weekly Work Planning Process
  - Monday: review weekly plan with staff
  - Thursday: PI allocates resources for next week.
- Monthly Planning Process
  - Update project budget based on accounting data
  - Monthly reviews with CEO
    - Finances, technical status, schedule.
- Quarterly Planning and Reporting
  - PM updates schedule and financial status in PMP
  - PM submits tech report and updated PMP to DOE