U.S. Department of Energy
Energy Efficiency and Renewable Energy

Hydrogen, Fuel Cells & Infrastructure Technologies Program

Fiber Optic Sensors for Fuel Cell Applications

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This presentation does not contain any proprietary or confidential information.

Project Objectives

- Develop small, rugged and inexpensive fiber optic temperature sensors.
- Develop a multi-point measurement capability.
- Demonstrate sensors in an operating fuel cell.
- Meet or exceed all program measurement performance requirements.
- Establish a path to a cost-competitive commercial system (i.e. <$5.00).
- Publish/patent results and attend key conferences.

Project Budget

Fiscal 2004 = $405k, all DOE funds
Fiscal 2003 = $350k, all DOE funds

Technical Barriers and Targets

Barriers - Transportation Systems B.

- Automotive sensors are required to meet performance and cost targets for measuring physical conditions and chemical species in fuel cell systems.
- Current sensors do not perform within the required ambient and process conditions, do not possess the required accuracy and range, and/or are too costly

Targets - Automotive Fuel Cell Systems, Temperature

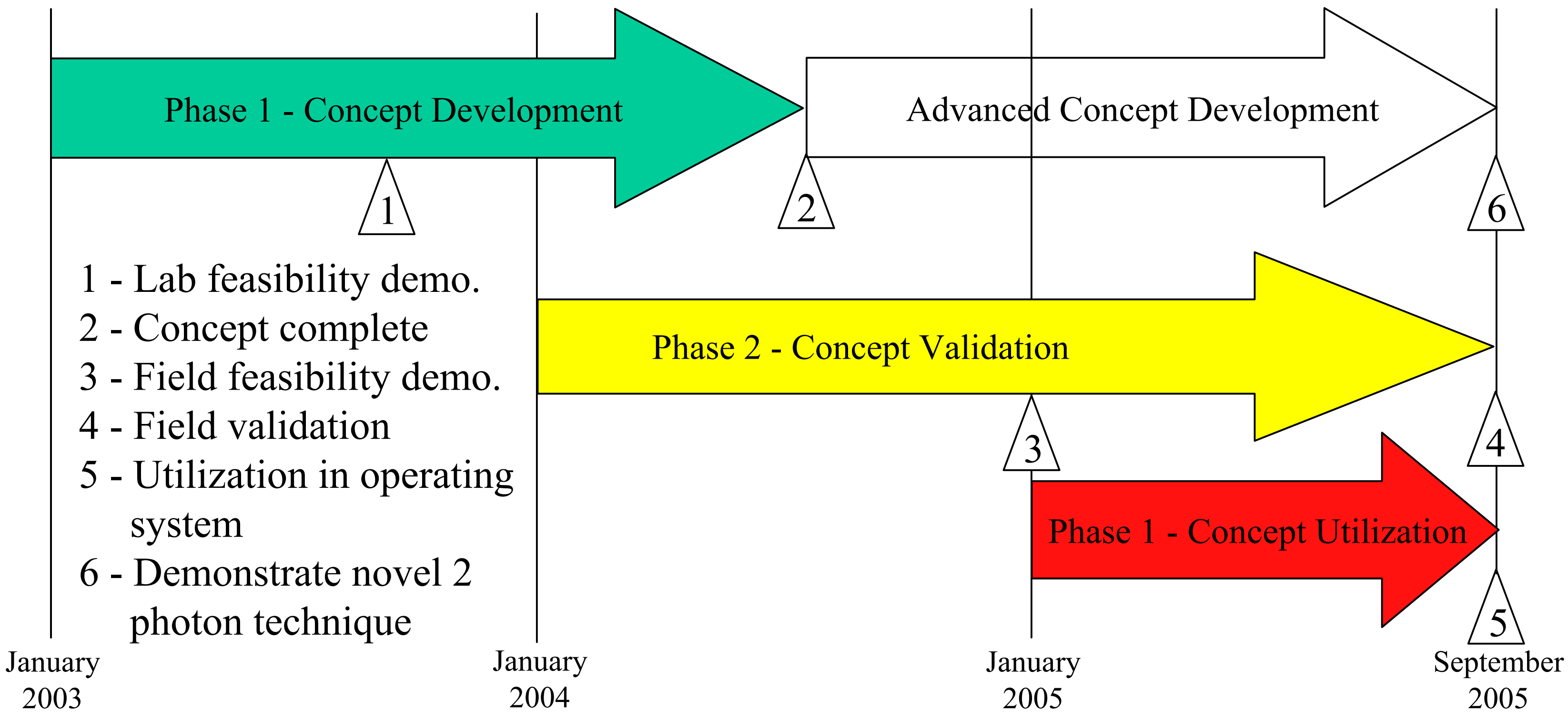
- Sensors must conform to size, weight, and cost constraints of automotive applications
- Operating range: -40 to 150°C
- Response time: -40 to 100°C range <0.5 seconds with 1.5% accuracy; 100 to 150°C range <1.0 seconds with 2% accuracy
- Gas environment: high humidity reformer/partial oxidation: H_2 30% - 75%, CO_2, N_2, H_2O, CO at 1 - 3 atm total pressure.
- Insensitive to flow velocity.

Approach

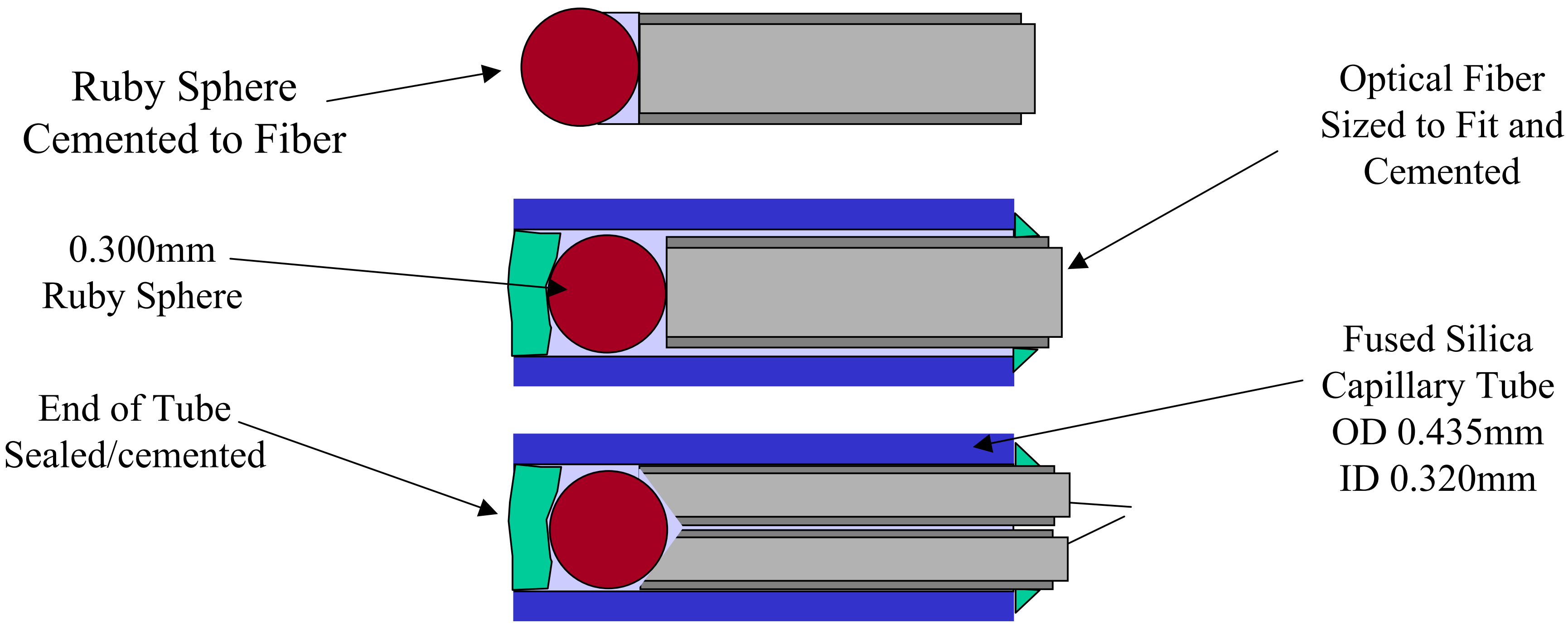
- Thermally dependent luminescence is employed for temperature measurement;
  - ➢ trade-off study was conducted to select optimum material
  - ➢ materials compatibility with FC will be tested
- Small, rugged and low cost fiber optic probes have been designed;
  - ➢ study and test various probe constructions for ruggedness
  - ➢ optimize on cost and signal-to-noise
- Low Cost Signal processing electronics are being developed;
  - ➢ Algorithm development platform → circuit board
- Prototype fuel cells are being instrumented to validate technology;
- Various concepts are being explored to provide thermal mapping.

△ Project Milestone

Project Timeline

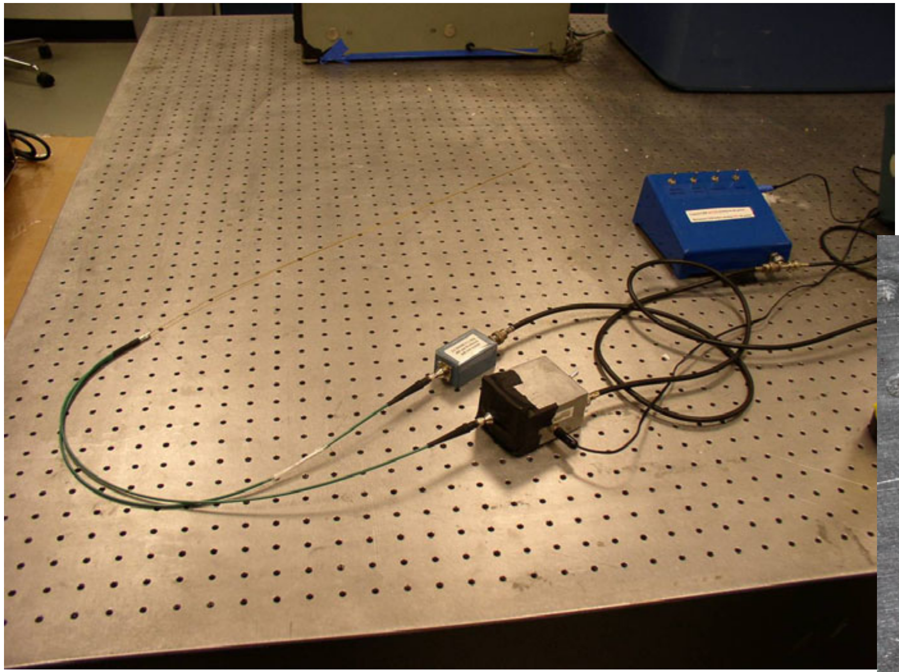


Technical Accomplishments - Fiber Optic Probe Tips



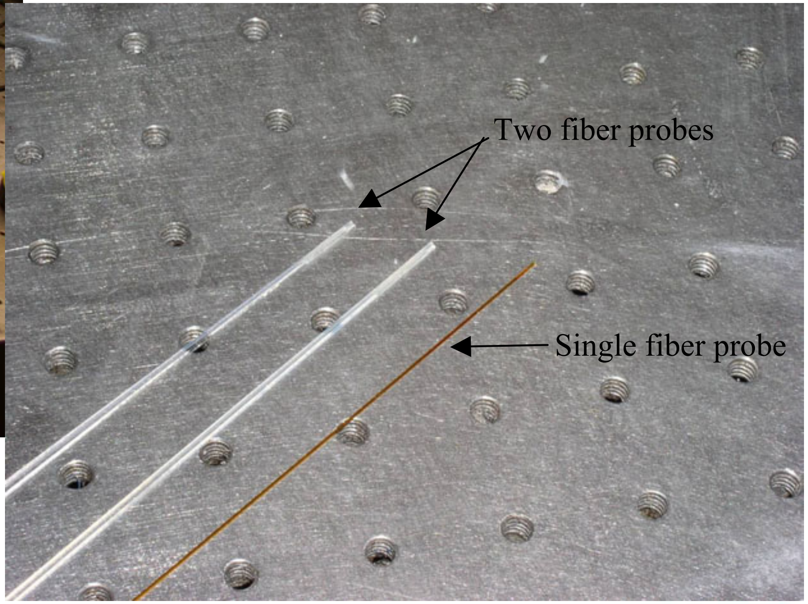
2-fiber probes do not require an optical beam splitter, significantly reducing probe cost

Technical Accomplishments - Fiber Optic Probes



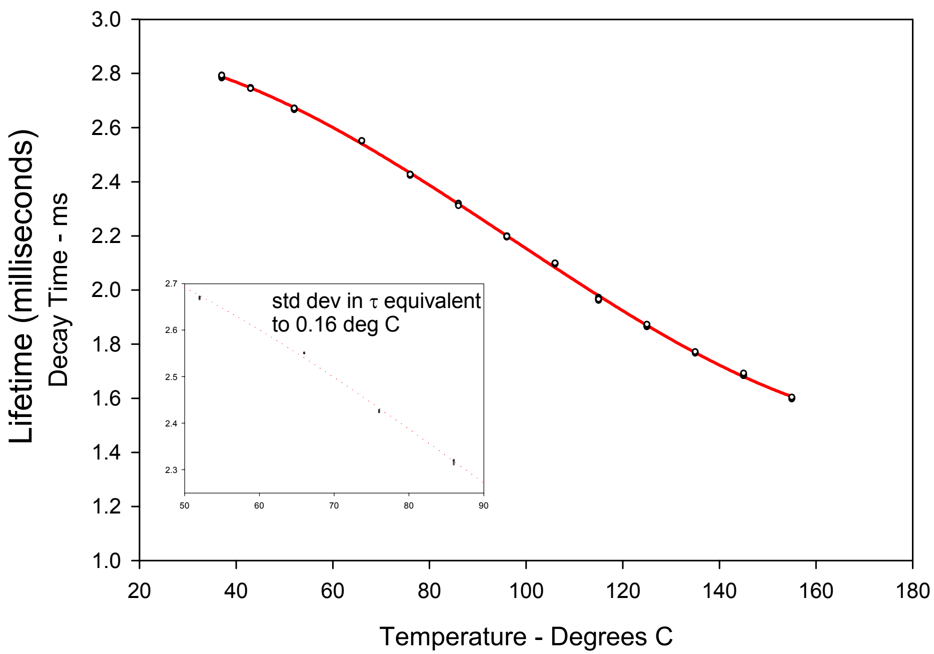
Probe designs completed to meet milestone #2

Close-up of probe tips →



Technical Accomplishments - Fiber Optic Probes

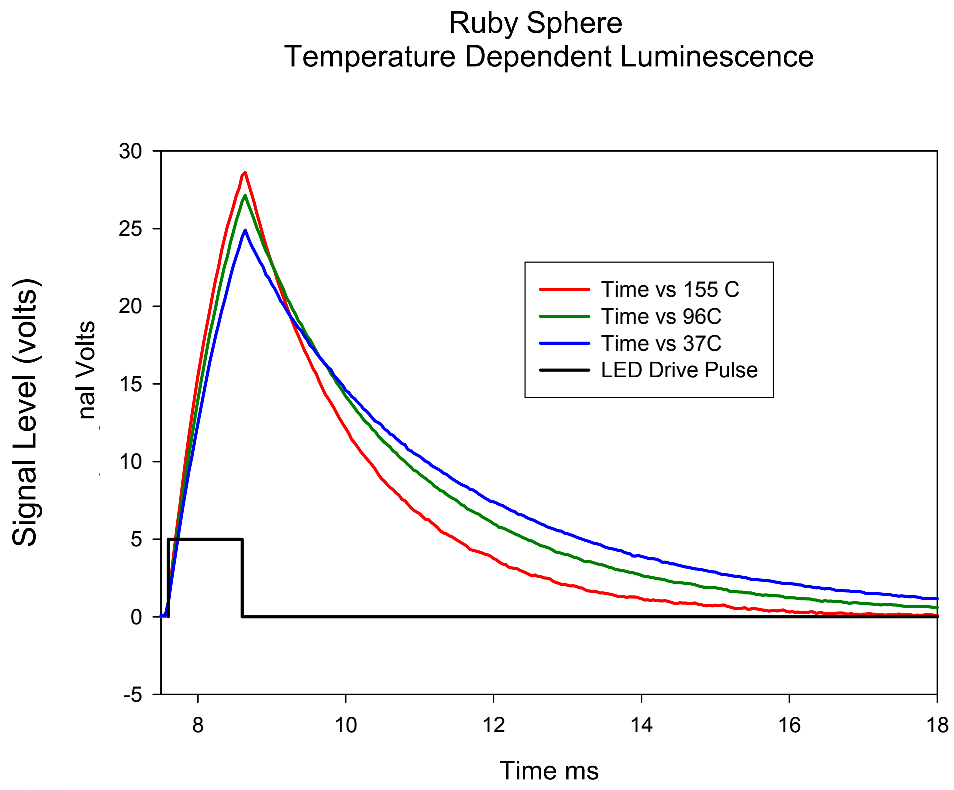
Decay Time Measurements of 300 micron Probe with
Ruby Sphere and single 300 micron Fiber - 10 Averages



Probe calibration curve showing the luminescent decay lifetime versus temperature from 30 to 155°C.

The inset illustrates the potential measurement precision achievable with this technique.

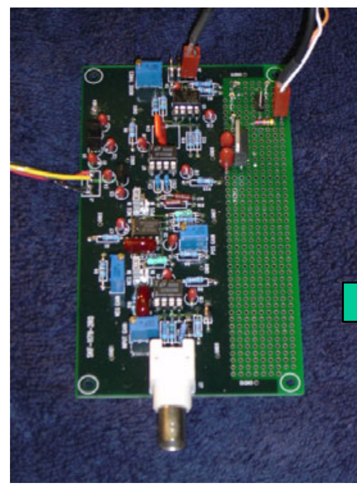
Technical Accomplishments - Fiber Optic Probes



Luminescent decay variation of Ruby versus temperature

Technical Accomplishments - Measurement Electronics

Signal Processing Development Platform



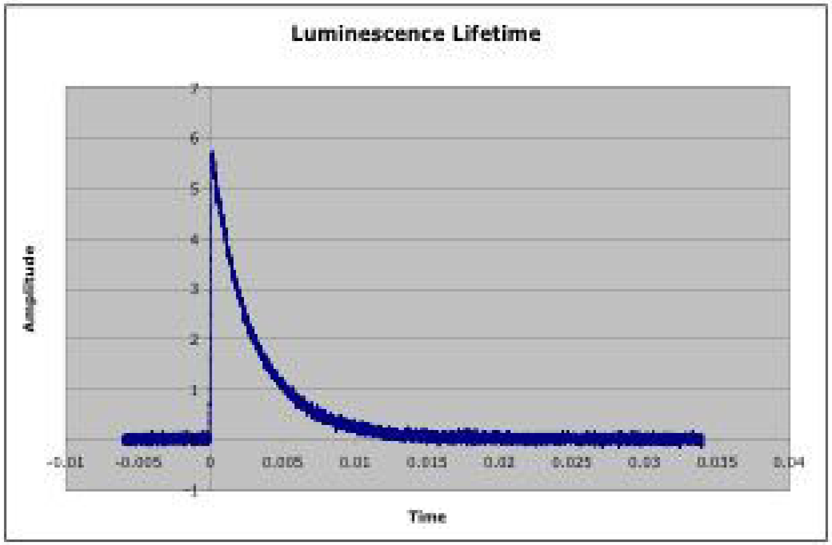
Dedicated Electronics

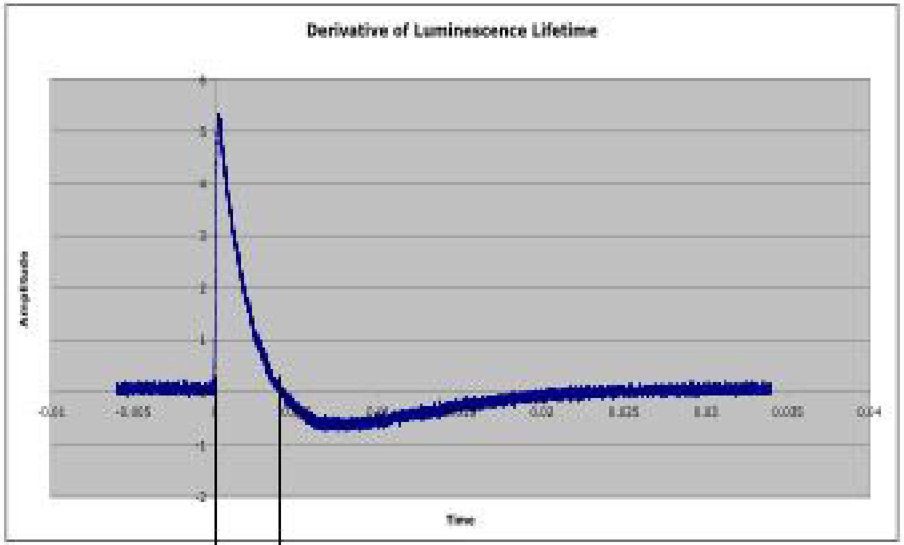
Electronics package completed to meet milestone #2

Low cost Module

Evolution from instrument to multi-chip module will reduce cost by orders of magnitude.

Technical Accomplishments - Measurement Electronics



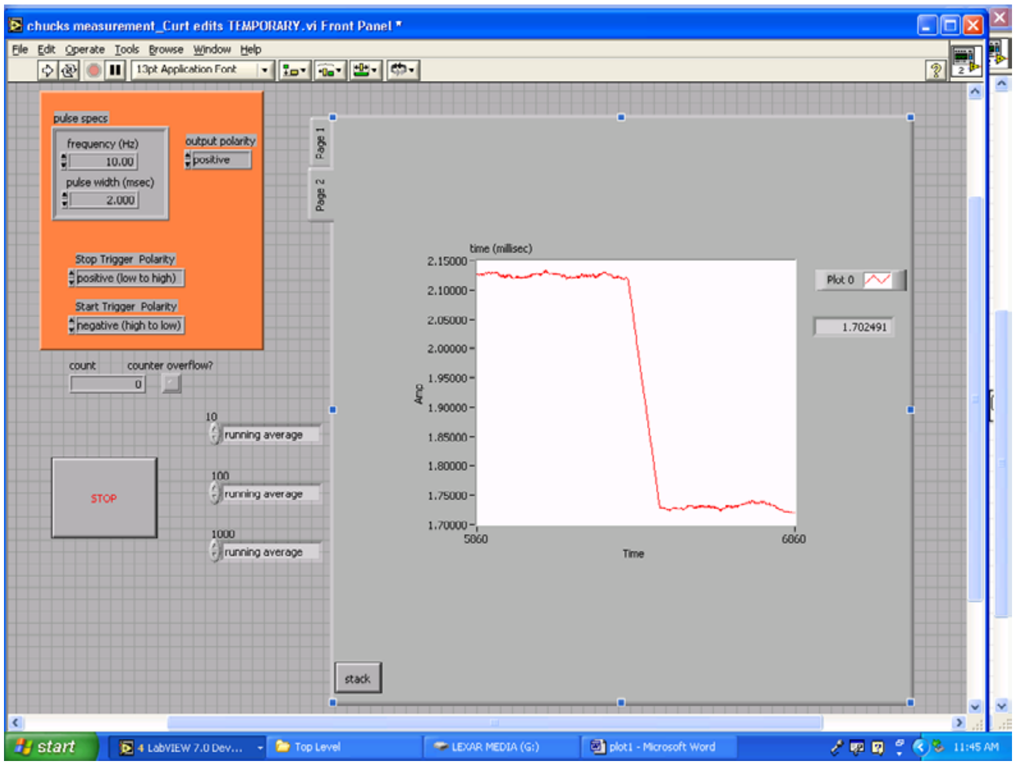


Input to the signal processing electronics

Time interval to zero crossing

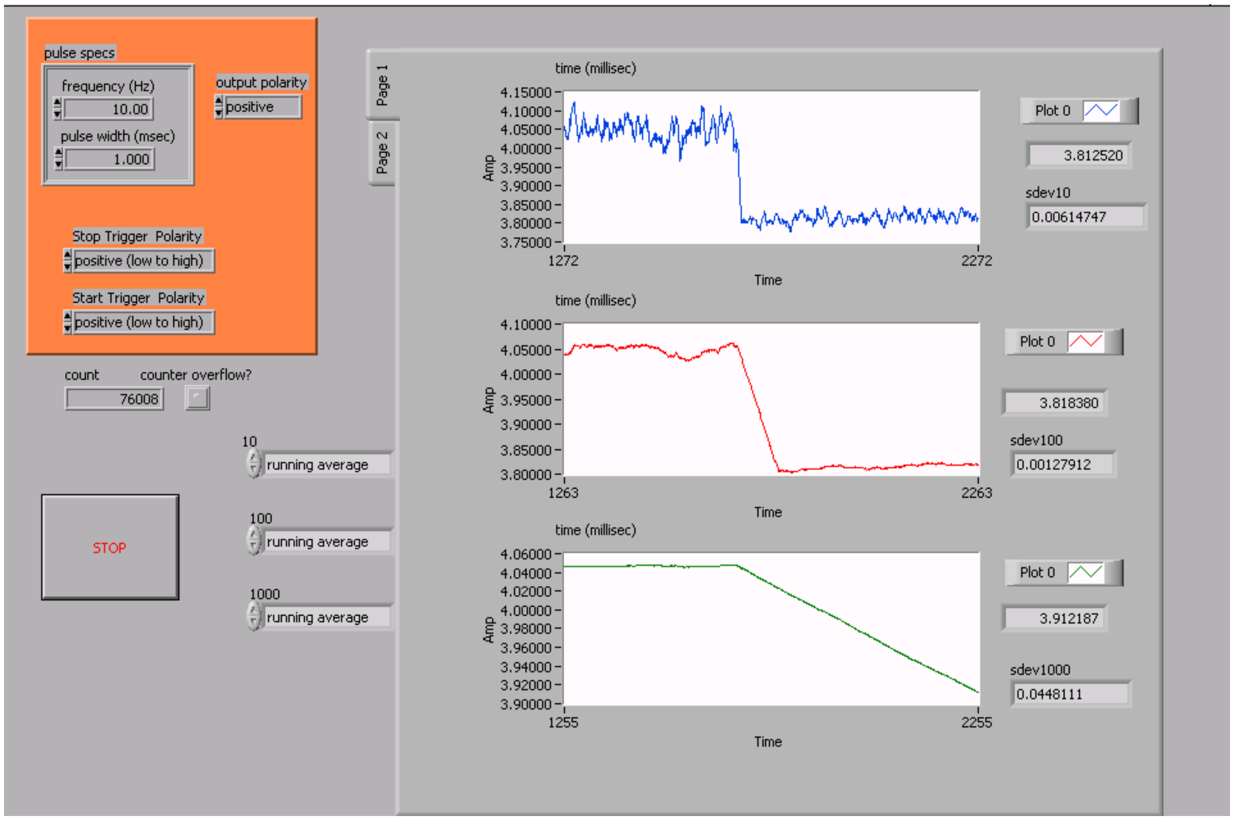
Signal processing electronics output is a pulse whose width is proportional to temperature. Converting the measurement from a direct determination of the lifetime (via complex curve fitting routines) into a time measurement makes the system more robust and much lower cost.

Technical Accomplishments - Data Analysis



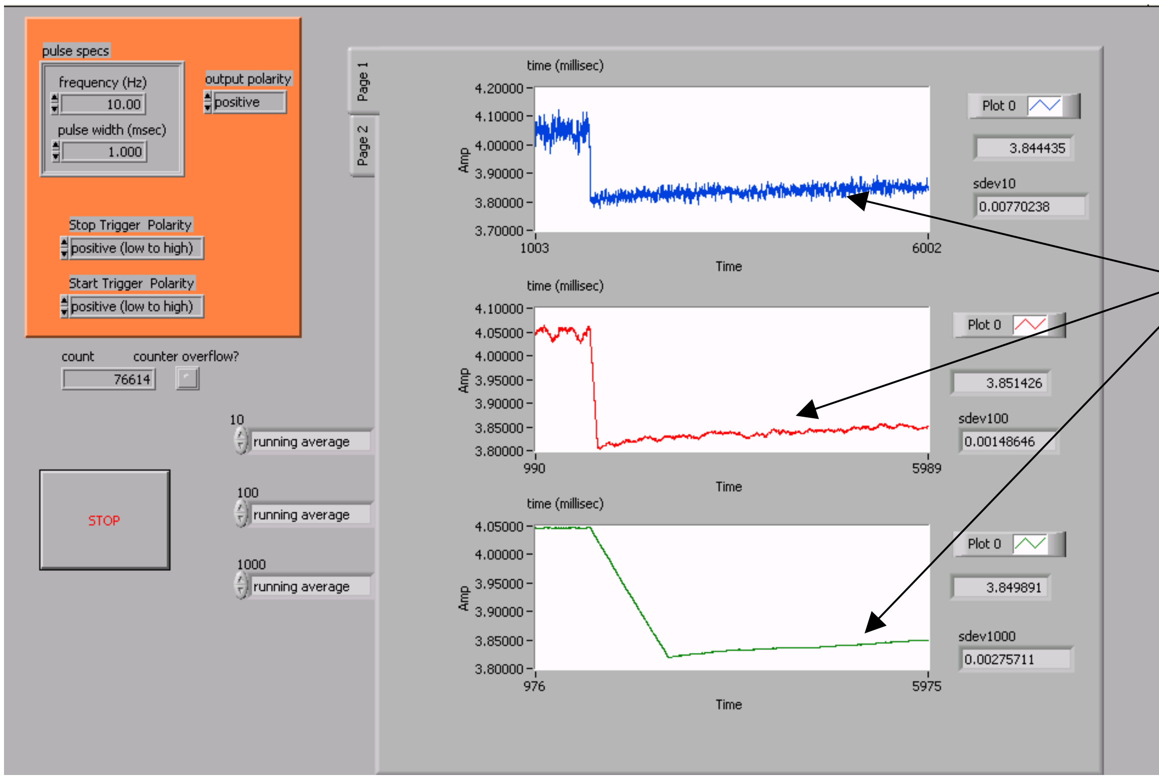
Experimental interface used to characterize system response time, resolution and stability.

Technical Accomplishments - Probe/System Response Time



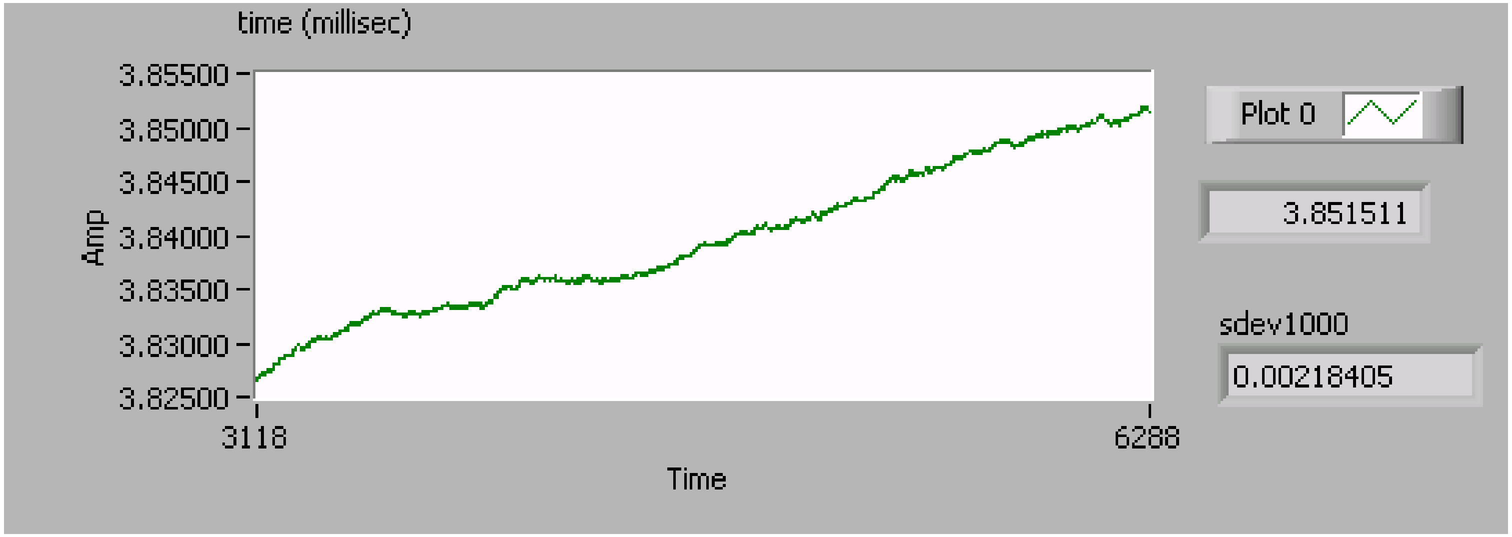
- The theoretical limit to the measurement response time is determined by the lifetime of the luminescent media.
- The low thermal mass of the probe allows temperature changes >100C/sec to be detected.
- A balance between averaging out noise and response time will likely result in practical response times on the order of 20 to 50 milliseconds.
- Shown is a probe response time of 47°C/second.

Technical Accomplishments - Probe/System Resolution



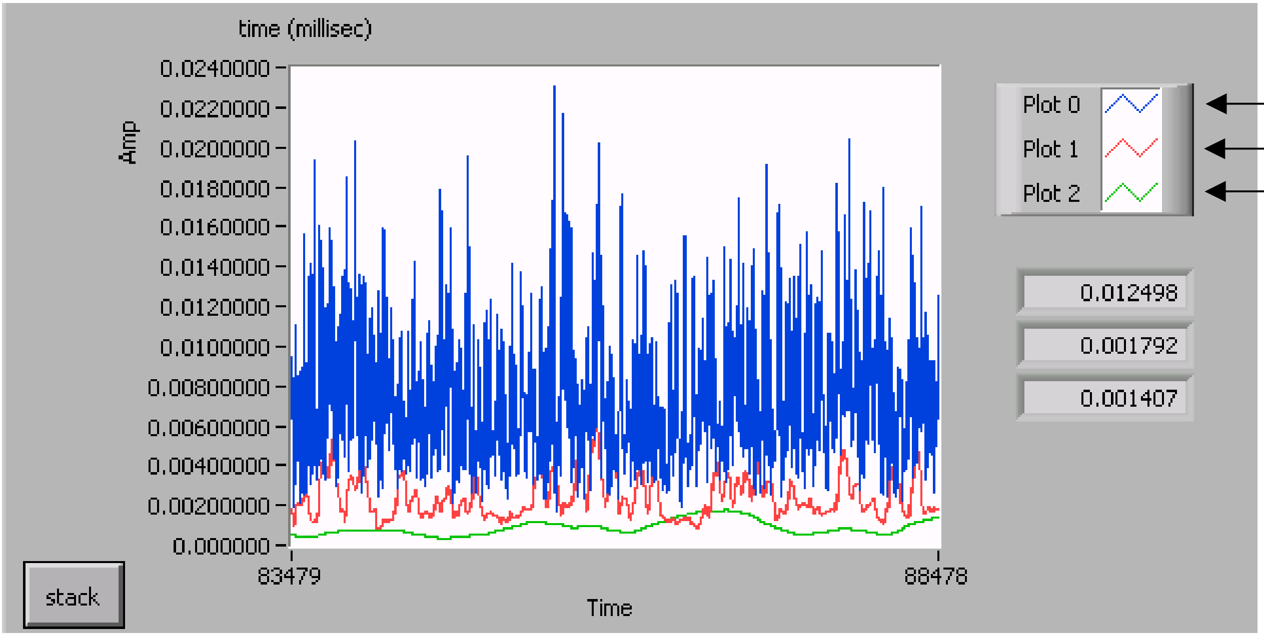
- proceeding from the temperature excursion created by moving the probe from a room temperature bath to a 70°C bath, the gradual bath cool-down can be detected.

Technical Accomplishments - Probe/System Resolution



Expanded view of probe response during bath cool-down.
4°C over 5 minutes

Technical Accomplishments - Probe/System Stability



Over an 8 minute period, the standard deviation of the data collected illustrates stable and consistent performance.

Safety

- Project activities at ORNL are covered by a formal, integrated work control process for each project/facility
  - Definition of task
  - Identification of hazards
  - Design of work controls
  - Conduct of work
  - Feedback
- Each work process is authorized on the basis of a Research Safety Summary (RSS) reviewed by ESH subject matter experts and approved by PI's and cognizant managers
- RSS is reviewed/revised yearly, or sooner if a change in the work is needed
- Staff with approved training and experience are authorized through the RSS

Interactions & Collaborations

OEMs

Plug Power - planning field test
United Technologies - technical exchange
Nuvera Fuel Cells - technical exchange
General Motors - preliminary discussion
Ford - preliminary discussions

Leveraging

- several other projects at ORNL contributed to signal processing technique development (sponsors: AISI, NASA, Rolls Royce, DOE/Science)

Technology Developers

PNNL - doped fibers
Nufern - doped fibers
Romack - probe construction
Oregon State University - technical collaboration, visiting researcher
Translume - technical collaboration

Weaknesses from Last Review Meeting:

• Needs more industry collaboration - since last year we have interacted with (4) end users/developers, have NDA in place with (1) organization and planning collaborative tests, and presented papers/posters at national conferences.

Reviewer Comments from Last Review Meeting:

• Why is monitoring temperature critical?
    ✓ detection of gradients, burn-through, maximize power density & MTBF
• Needs to be endurance and materials compatibility tested.
    ✓ Planning aggressive environmental tests when probe designs are more mature
• Information on thermal gradients is more beneficial than single point.
    ✓ Sensor/system design will accommodate multiplexing, advanced concepts may provide breakthrough on mapping.
• Collaboration with other research institutions (e.g. Penn State)
    ✓ PSU technology may provide opportunity to expand capabilities
• Understand where temperature measurement is really needed.
    ✓ Field tests and probe designs are being driven by specific partner inputs.

Future Plans

Remaining FY 2003
- Instrument fuel cell test fixture.
- Conduct collaborative test with OEM partner and optimize performance.
- Develop plan for endurance and material compatibility testing.
- Continue advanced concept development.

Milestone #3

FY 2004
- Perform long-term field tests.
- Characterize endurance and materials compatibility issues.
- Develop commercialization plan
- Characterize opportunities to broaden capabilities of this platform for other measurements (e.g. humidity, hydrogen concentration, detection of other species, etc.)