Development of High Sensitivity Fiber for Distributed Acoustic Sensing

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Barry Freifeld

Lawrence Berkeley National Laboratory

Robert Mellors and Michael Messerly

Lawrence Livermore National Laboratory

U.S. Department of Energy

National Energy Technology Laboratory

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Presentation Outline

- Fiber-optic DAS sensing 101
- Fiber Bragg Gratings
- Outline of Proposed Work – engineered fiber to improve S/N
  - LLNL Draw tower facility
  - Fiber test plan (Richmond Field Station)

This project just started in June – no new results are available yet.

Fiber Fundamentals

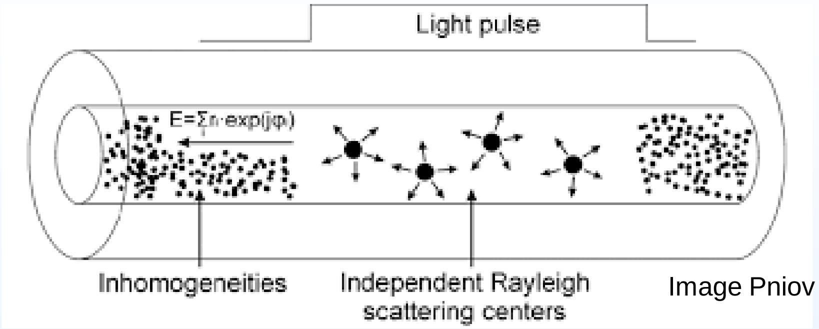
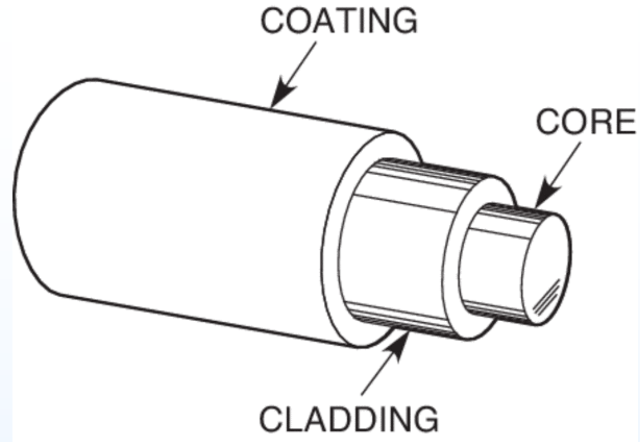


Image Pniov et al. 2015



(A) $$loss\,[dB/km] = \frac{0.75 + 66\Delta n}{(\lambda\,[\mu m])^4}$$

Δn Index difference core to cladding

λ Wavelength

(B) $$\Omega \cong \pi NA^2 = 2\pi n \Delta n$$

Fiber's numerical aperture

Refractive index of silica

0.2 dB/km SMF-28

DFOAS signal generated by a 10m segment of fiber is A*B = $(4.5 \times 10^{-4})\cdot(4.2 \times 10^{-3}) = 1.9 \times 10^{-6}$

DAS Sensing 101

- DAS is based on phase sensitive OTDR (Rayleigh Scattering)
- There are several (many) different photonic pathways to extracting phase information from backscattered light (see A. Hartog's book: CRC Press - An Introduction to Distributed Optical Fibre Sensors)

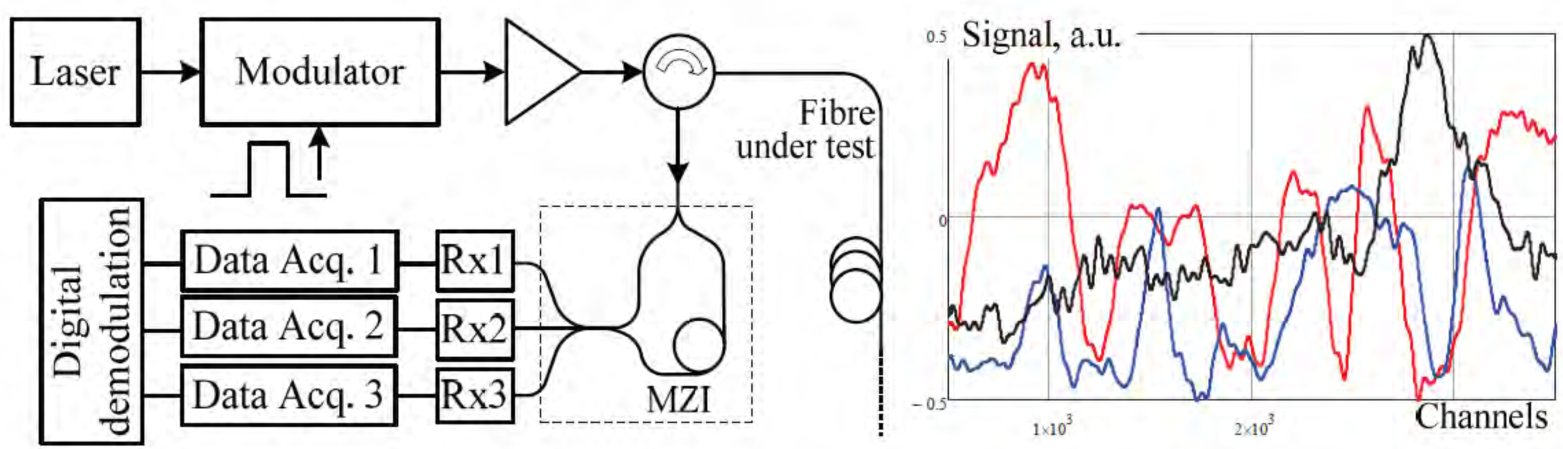
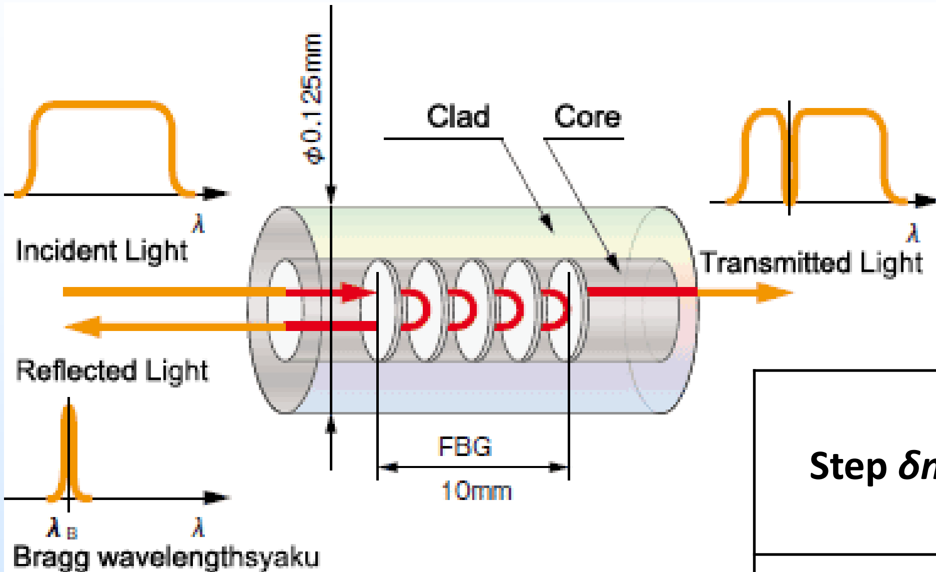


***Figure 2** Schematic arrangement and specimen signals for DVS system with interferometric phase demodulation.*

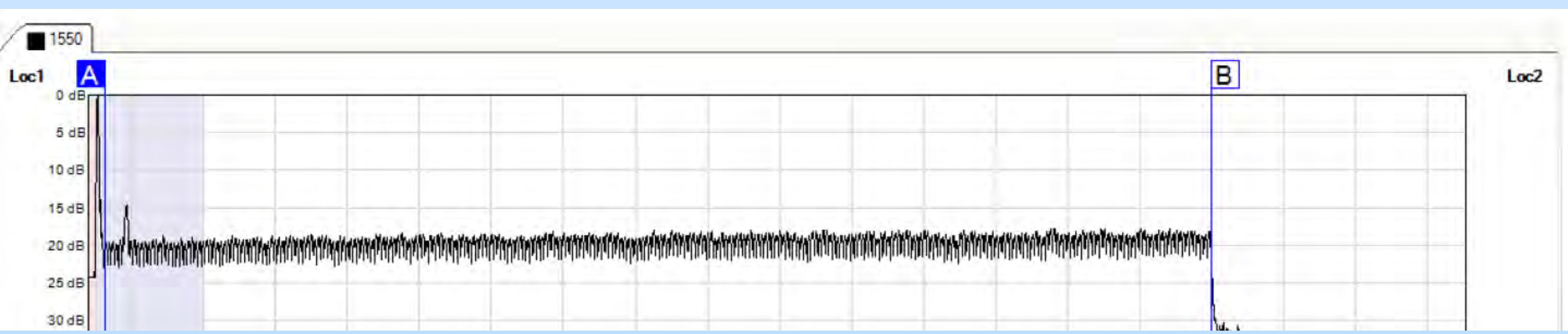
FBG Fundamentals



Reflection from discrete step:

$$R \cong (\delta n/2n)^2$$

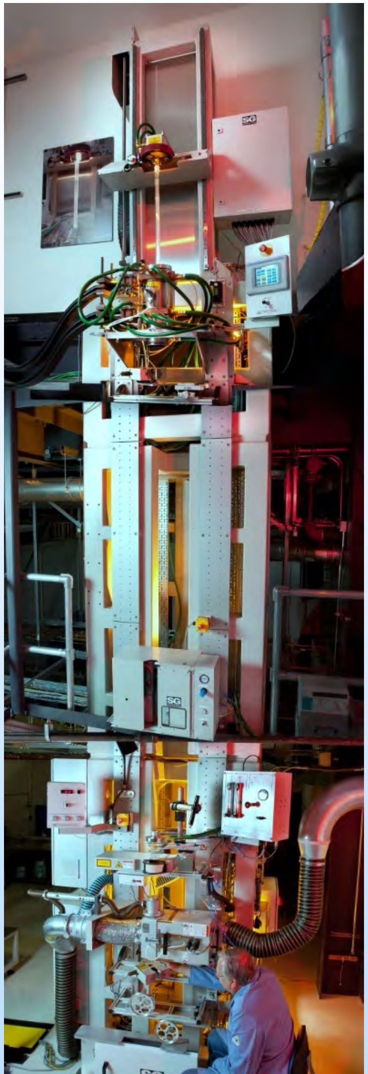
Step δn	Reflectance, R	Signal lost after 1000 reflectors
4.0×10^{-3}	1.9×10^{-6}	0.2%
13×10^{-3}	19×10^{-6}	2%



LLNL-LBNL High Sensitivity Fiber Fabrication Plan

Subtask Description
Task 1 Project Management and Planning
Task 2 Investigate Writing Index Steps in Optical Fiber with LEDs
Task 3 Investigate Writing Index Steps in Optical Fiber with visible and UV lasers
Task 4 Specify, procure and install an optical system for fabricating engineered DAS fibers on the LLNL draw tower system
Task 5 Fabricate a custom fiber having in-line aperiodic index structures
Task 6 Field testing of an engineered fiber with aperiodic index structures

LLNL optical fiber fabrication



3-story tower

Glass working lathe

Preform assembly

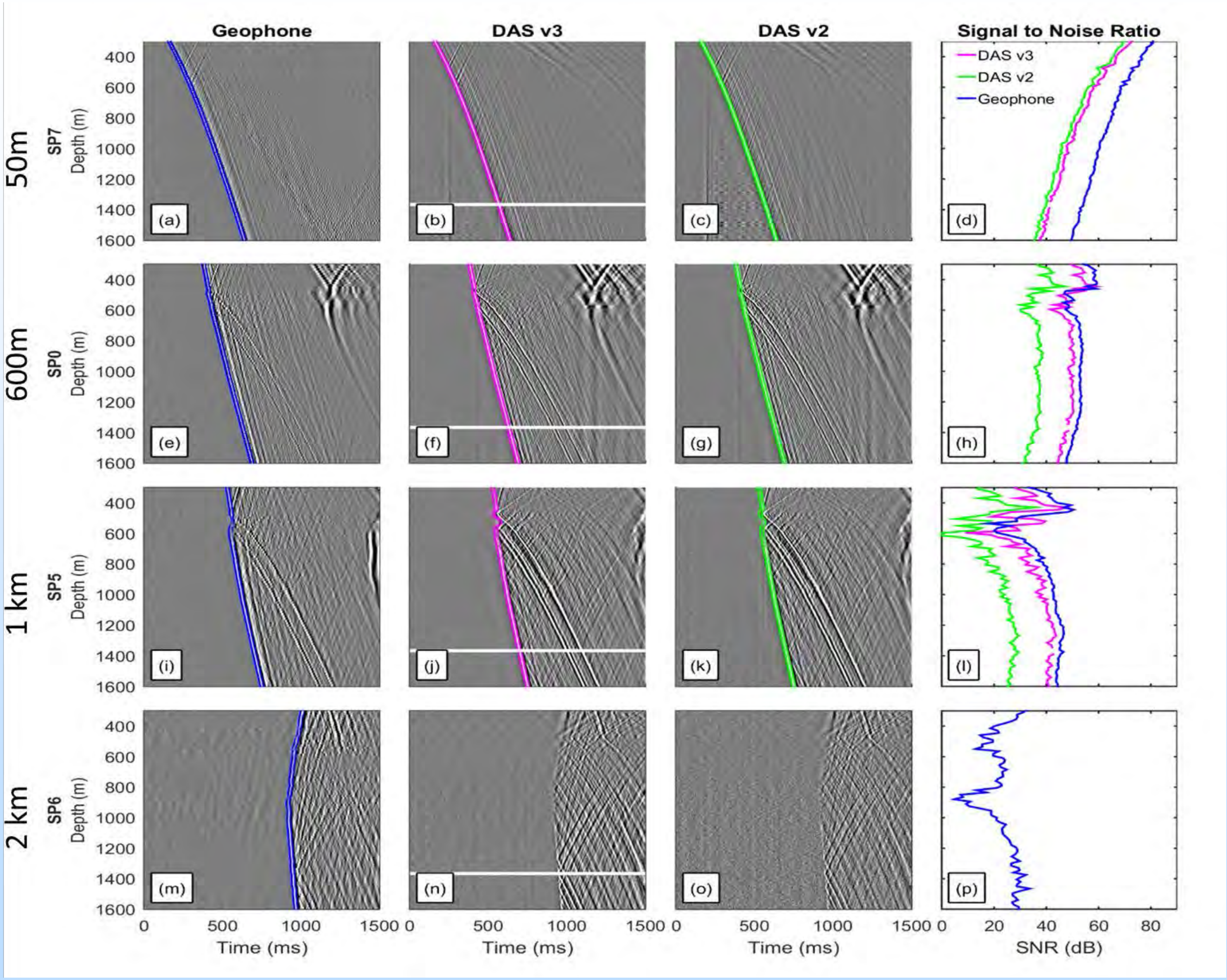
Preform in 2000C furnace

Development of Optical Fiber Test Facility

- Seismic source test pad (SOVs, piezo-sources)
- HDD test borings (permanent conduit to install/remove sensing strings)
- Deep test well

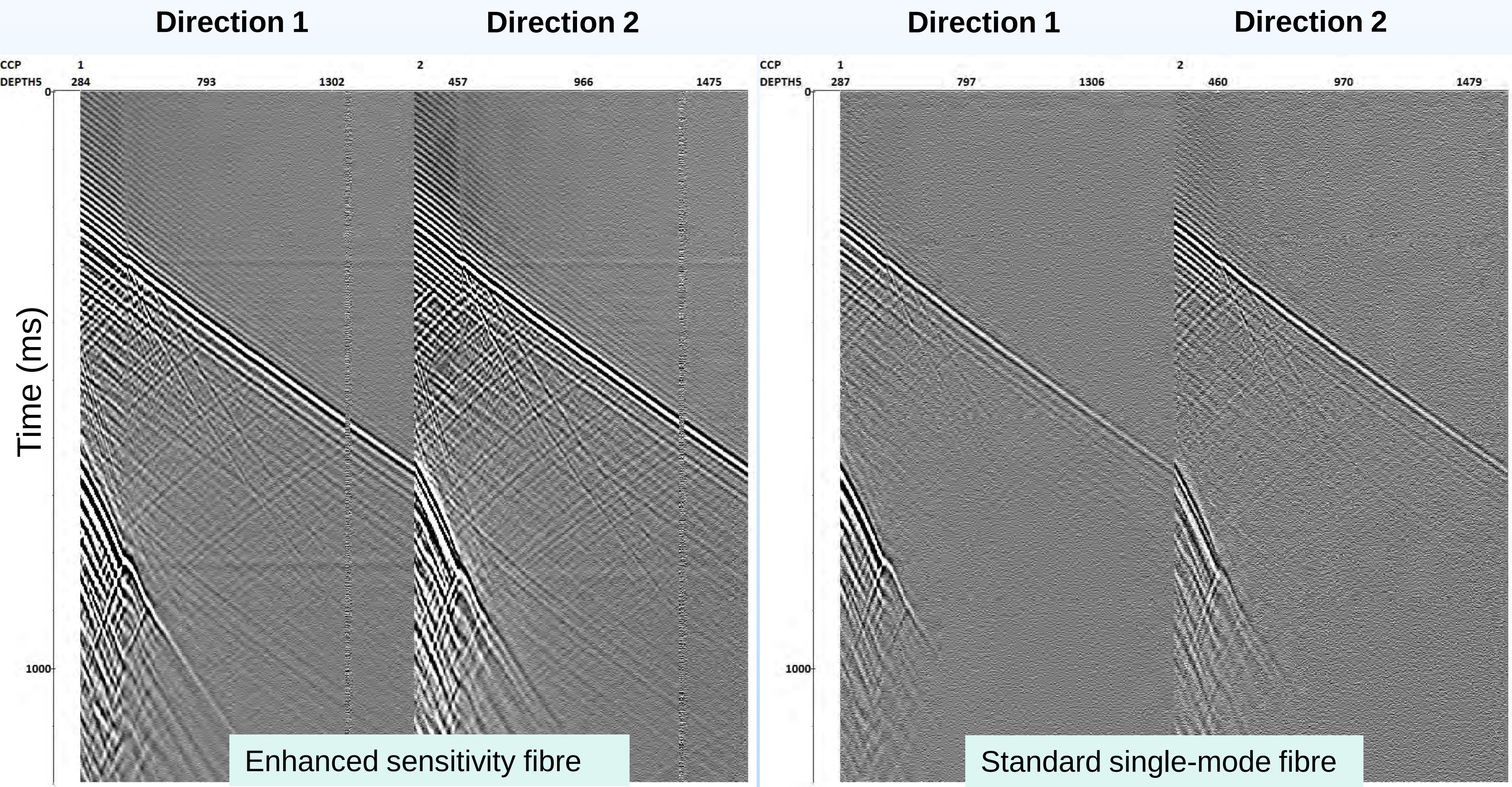
Silixa Carina Fiber

[Correa et al., 2017]



Conventional SMF vs Silixa Constellation (May 2017)

SOV 2 (165 s to 80 Hz sweeps), stack 14 sweeps



Synergy Opportunities

The benefits of this project can tie into all ongoing projects that use DAS sensing. Improvements in SNR will open up new applications and monitoring methodologies for DAS that are currently limited by the lower sensitivity in comparison to conventional seismic sensors.

Project Summary

- The Engineered Fiber project was just initiated.
- LLNL is testing methodologies for writing aperiodic structures into optical fiber. This will include methods using UV-LEDs and lasers
- LBNL is planning to construct cables using the new fiber first on the benchtop and eventually at our fiber test facility
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Appendix

– These slides will not be discussed during the presentation, but are mandatory.

Benefit to the Program

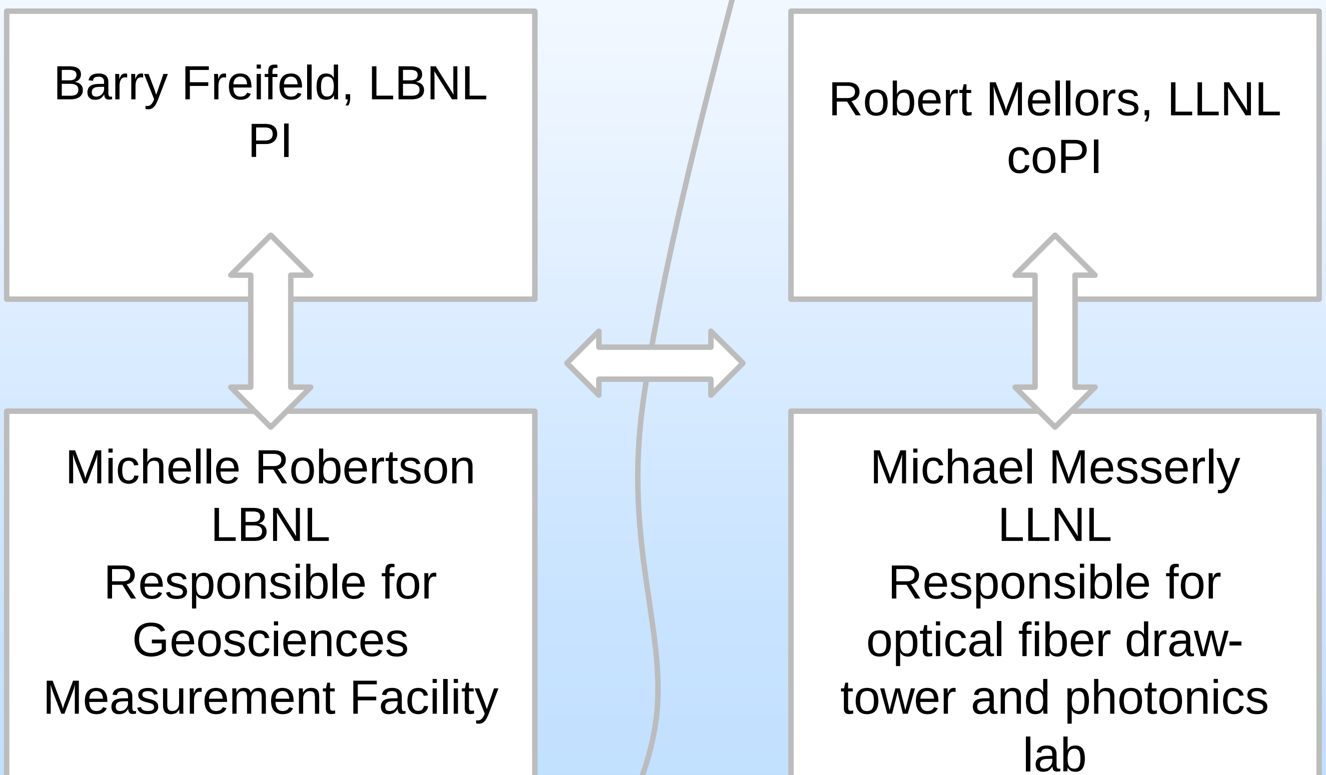
- DAS sensing is recognized as a methodology that can cost effectively be used for multi-decadal monitoring of GCS
- The primary limitation of DAS sensing is its low SNR, which has limited to applications with a strong signal content, like VSP monitoring.
- Developing high sensitivity DAS fiber will lead to new applications (such as surface reflection monitoring) and consider to reduce the overall cost of an effective seismic monitoring program.

Project Overview

Goals and Objectives

- Describe the project goals and objectives in the Statement of Project Objectives.
  - How the project goals and objectives relate to the program goals and objectives.
  - Identify the success criteria for determining if a goal or objective has been met. These generally are discrete metrics to assess the progress of the project and used as decision points throughout the project.

Organization Chart



Sensing cable design and seismic test evaluation

Optical fiber modification and characterization

Gantt Chart

Milestone Reporting accompanies Quarterly report	Q3 FY18			Q4 FY18			Q1 FY19			Q2 FY19		
Subtask Description	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**
Task 1 Project Management and Planning												
Task 2 Investigate Writing Index Steps in Optical Fiber with LEDs			A			B						
Task 3 Investigate Writing Index Steps in Optical Fiber with visible and UV lasers			C			D						
Task 4 Specify, procure and install an optical system for fabricating engineered DAS fibers on the LLNL draw tower system						E			F			
Task 5 Fabricate a custom fiber having in-line aperiodic index structures									G			H
Task 6 Field testing of an engineered fiber with aperiodic index structures									I			J

Bibliography

– New project just initiated (no publications yet)