Development and deployment of a compact eye-safe scanning differential absorption lidar (DIAL) for spatial mapping of carbon dioxide for monitoring/verification/accounting at geologic sequestration sites

Project Number: DE-FE0001156

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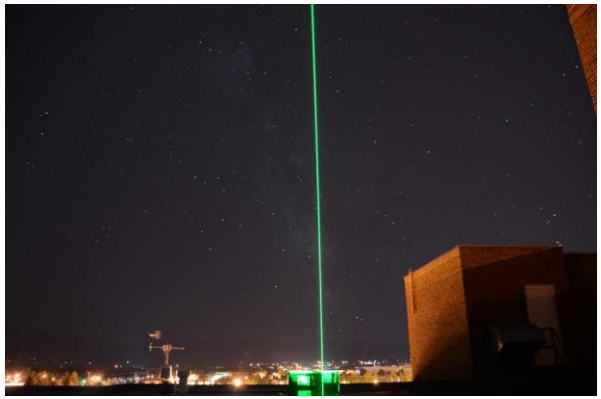


U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Building the Infrastructure for CO_2 Storage
August 21-23, 2012

Montana State University Bozeman

ZERT Zero Emissions Research and Technology

Big Sky Carbon Sequestration Partnership

Presentation Outline

- Program and Project Benefits
- Technical Status
  - Brief Introduction to differential absorption lidar (DIAL)
  - DIAL instrument description
  - Experimental results
- Program accomplishments and summary

Benefit to the Program

- Program Goals Addressed:
  - Develop technologies to demonstrate that 99% of CO_2 remains in the injected zones.
  - Conduct field tests for site operations (monitoring/verification/accounting)
- Project Benefits

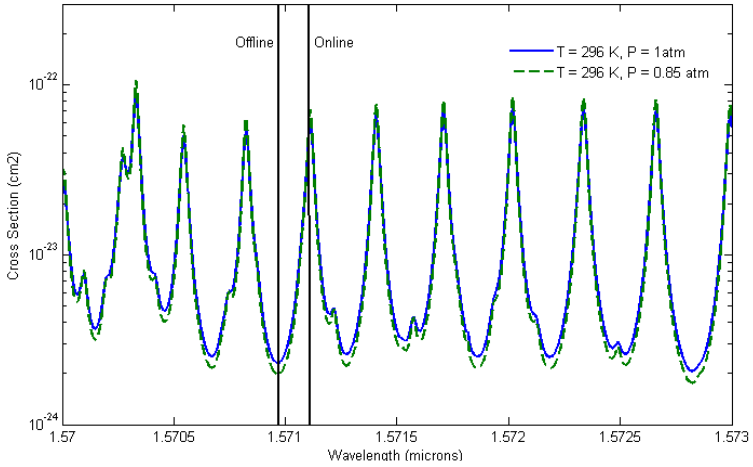
The research project is developing a differential absorption lidar for spatial mapping of CO_2 number densities for near surface large area monitoring. This technology contributes to the Carbon Storage Program's effort to ensure 99% CO_2 storage permanence in the injection zones.

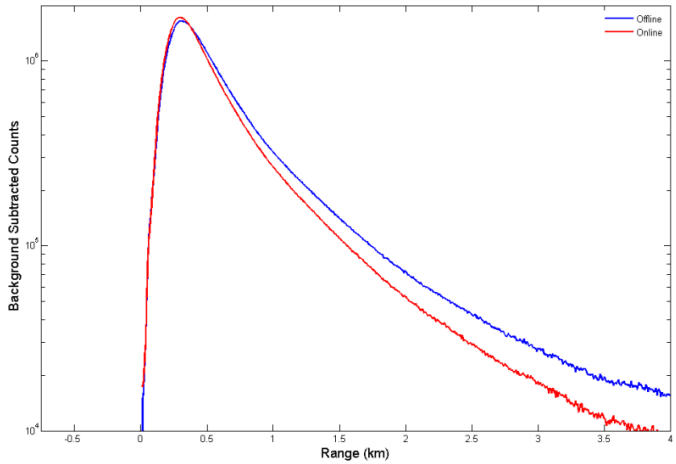
Project Overview: Goals and Objectives

- The project objectives for the proposed work include the development, testing, and deployment of a scanning eye-safe diode laser based differential absorption lidar (DIAL) for near surface mapping of carbon dioxide (CO_2) number densities.
  - Relates to the development of technologies to demonstrate that 99% on CO_2 remains in the injected zones.
  - Success criteria: Demonstration of instrument from a laboratory setting.
- Horizontal testing of the instrument will be conducted to determine the performance of the CO_2 DIAL instrument at the Zero Emission Research Technology (ZERT) field site during a controlled release experiment.
  - Relates to conducting field tests for site operations.
  - Success criteria: Demonstration of instrument during a ZERT controlled release experiment. Validation with in-situ Licor detector.
- MSU will then work with the Big Sky Carbon Sequestration Partnership to deploy the CO_2 DIAL instrument at a regional carbon sequestration demonstration project.
  - Relates to conducting field tests for site operations.
  - Success criteria: Deployment at the Big Sky Carbon Sequestration Partnership Site in north-central Montana for one month.

Technical Status: DIAL Technique

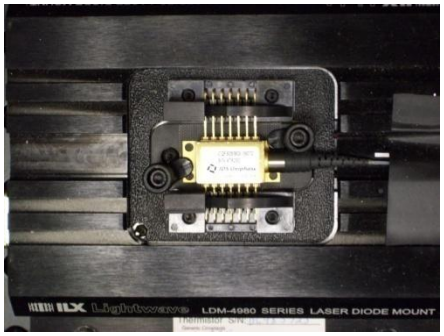
- The DIAL technique uses two closely spaced wavelengths and does not rely on an instrument calibration.
- The difference between the return signal for the two closely spaced wavelengths is related to the molecular number density.
- The number density can be calculated using the DIAL equation.

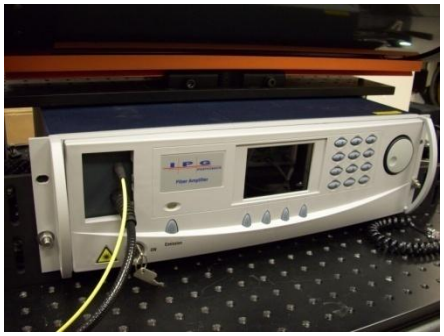


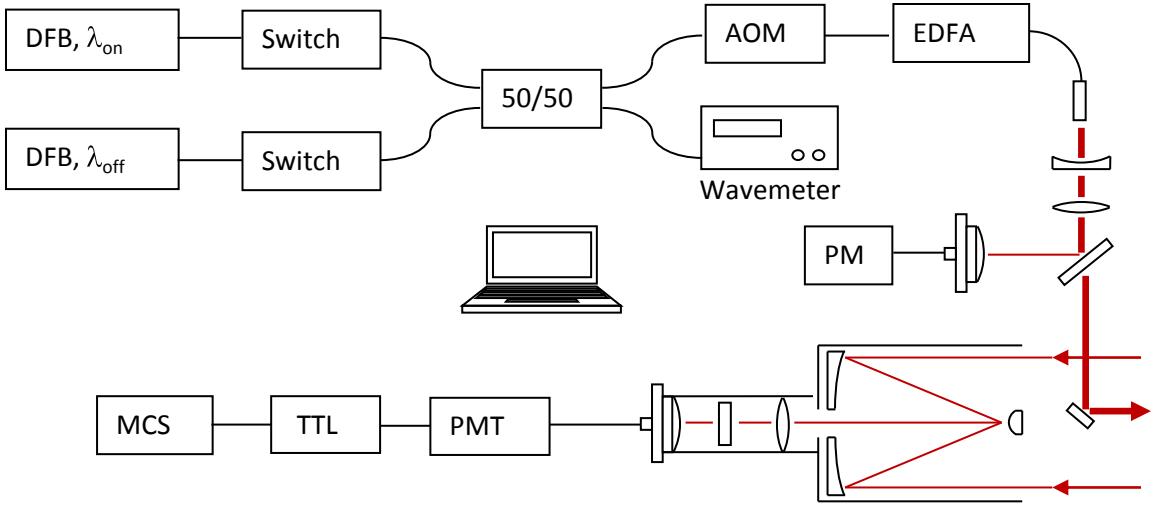


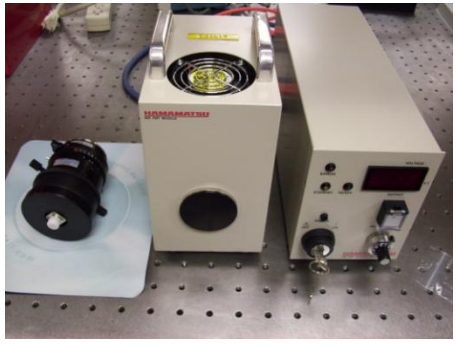
$$N(r) = \frac{1}{2\Delta r(\sigma(\lambda_{on},r) - \sigma(\lambda_{off},r))}\left[ln\left(\frac{P(\lambda_{on},r)P(\lambda_{off},r+\Delta r)}{P(\lambda_{on},r+\Delta r)P(\lambda_{off},r)}\right)\right]$$

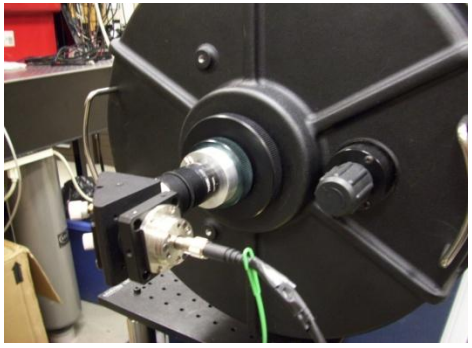
Technical Status: Instrument Schematic









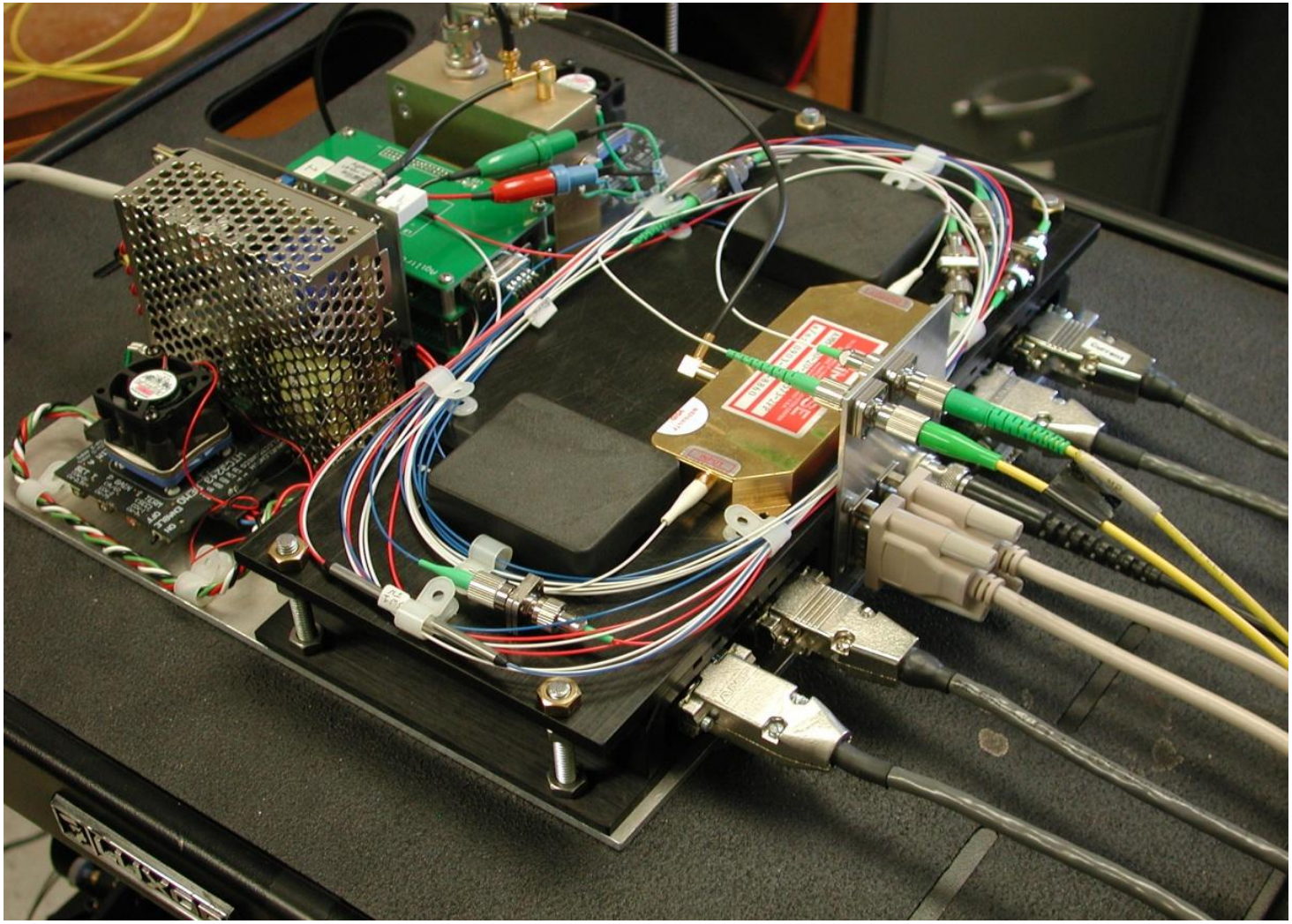


DFB Lasers	
Manufacturer	Eblana
Packaging	14 pin
Output Power	10 mW
Linewidth	<2 MHz
Side Mode Suppression	>40 dB

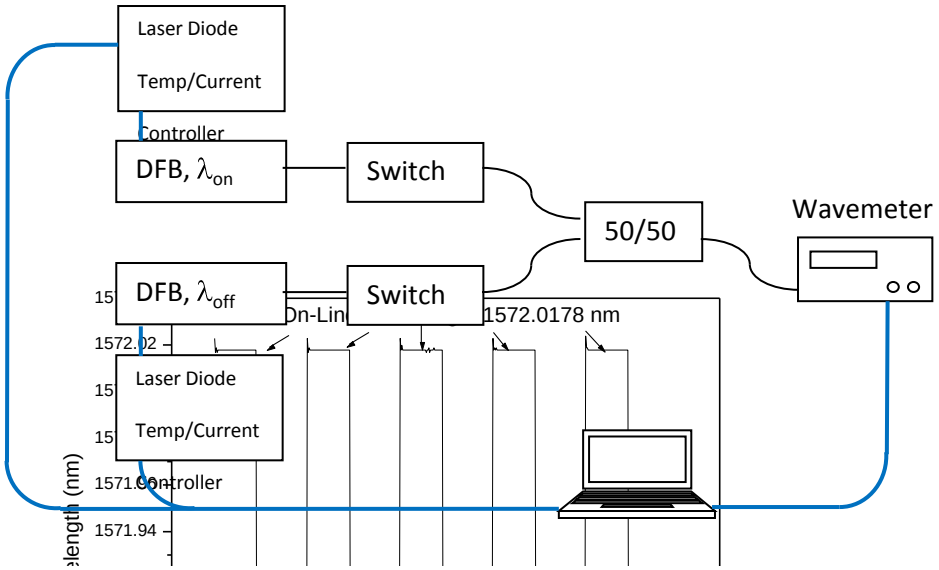
EDFA	
Manufacturer	IPG Photonics EAR-0.5K-1573-MT
Max. Output Power	0.5 W
Power Stability	0.54%
Wavelength Range	1.570 – 1.575 μm

PMT	
Manufacturer	Hamamatsu H10330-075A
Wavelength	0.95 – 1.70 μm
Gain (@-800 V)	$1X10^6$
Dark Current	300 nA
Quantum Efficiency	2%
Operating Temp.	TEC Cooled to -60 C

Technical Status: DIAL Laser Transmitter

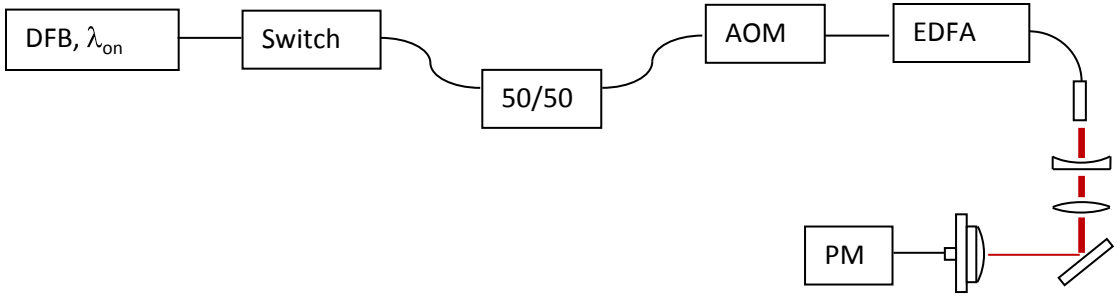


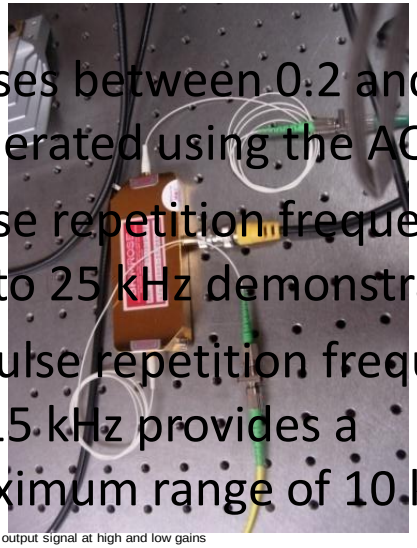
Technical Status: Wavelength Control



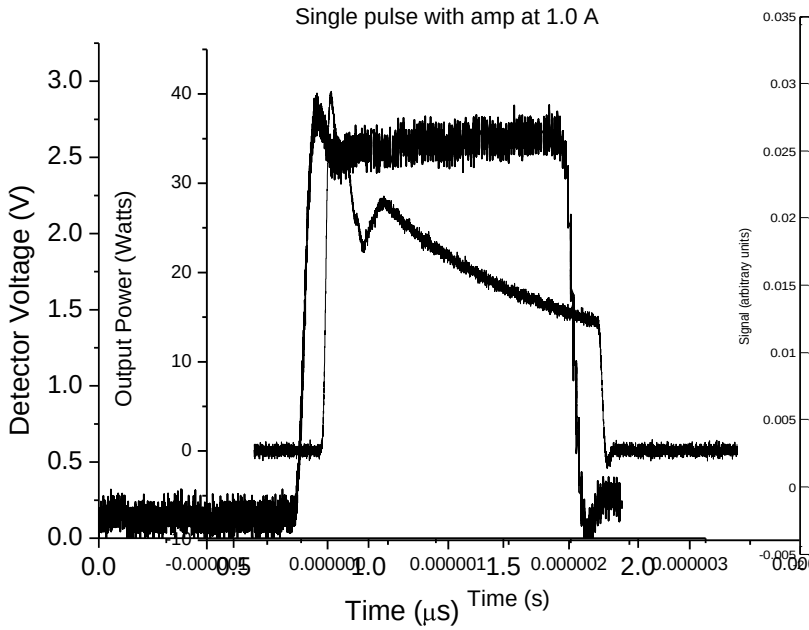
- A two laser scheme was developed so that switching times between on-line and off-line can be on the order of seconds.
- Initial locking use a single DFB laser. The wavemeter was used to monitor the operating wavelength and provide a control loop for tuning and locking.
- This locking scheme always ensures seed power to the EDFA to prevent damage due to stimulated Brillioun scattering
- This locking is robust, operating unattended over a period of 12 hours with this instrument and up to seven days on a water vapor DIAL.
- The setting time was on the order of several seconds.
- Locking stability is +/- 0.18 pm (+/- 20 MHz)

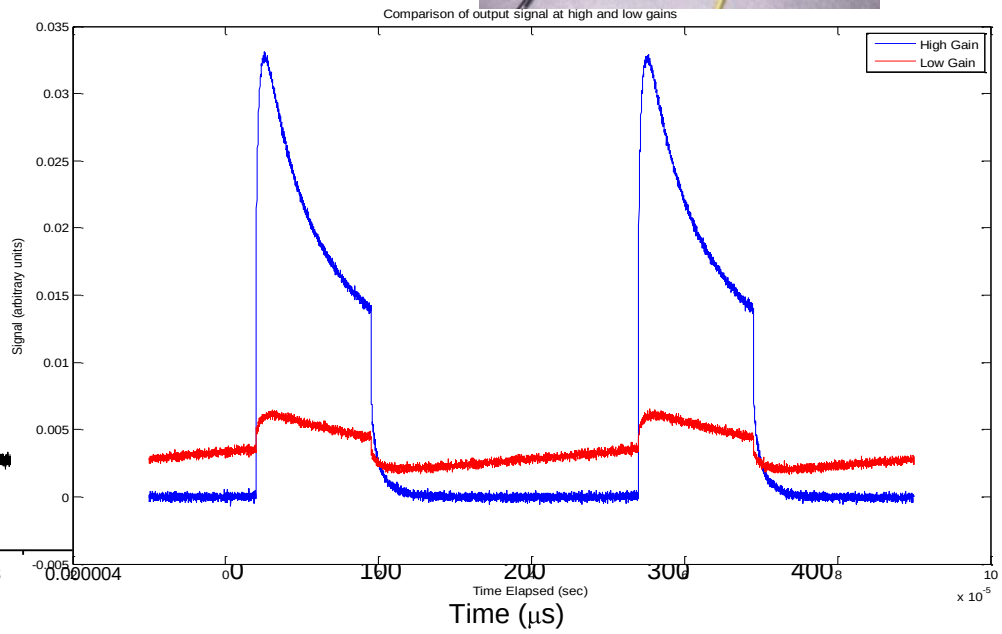
Technical Status: Pulse Generation



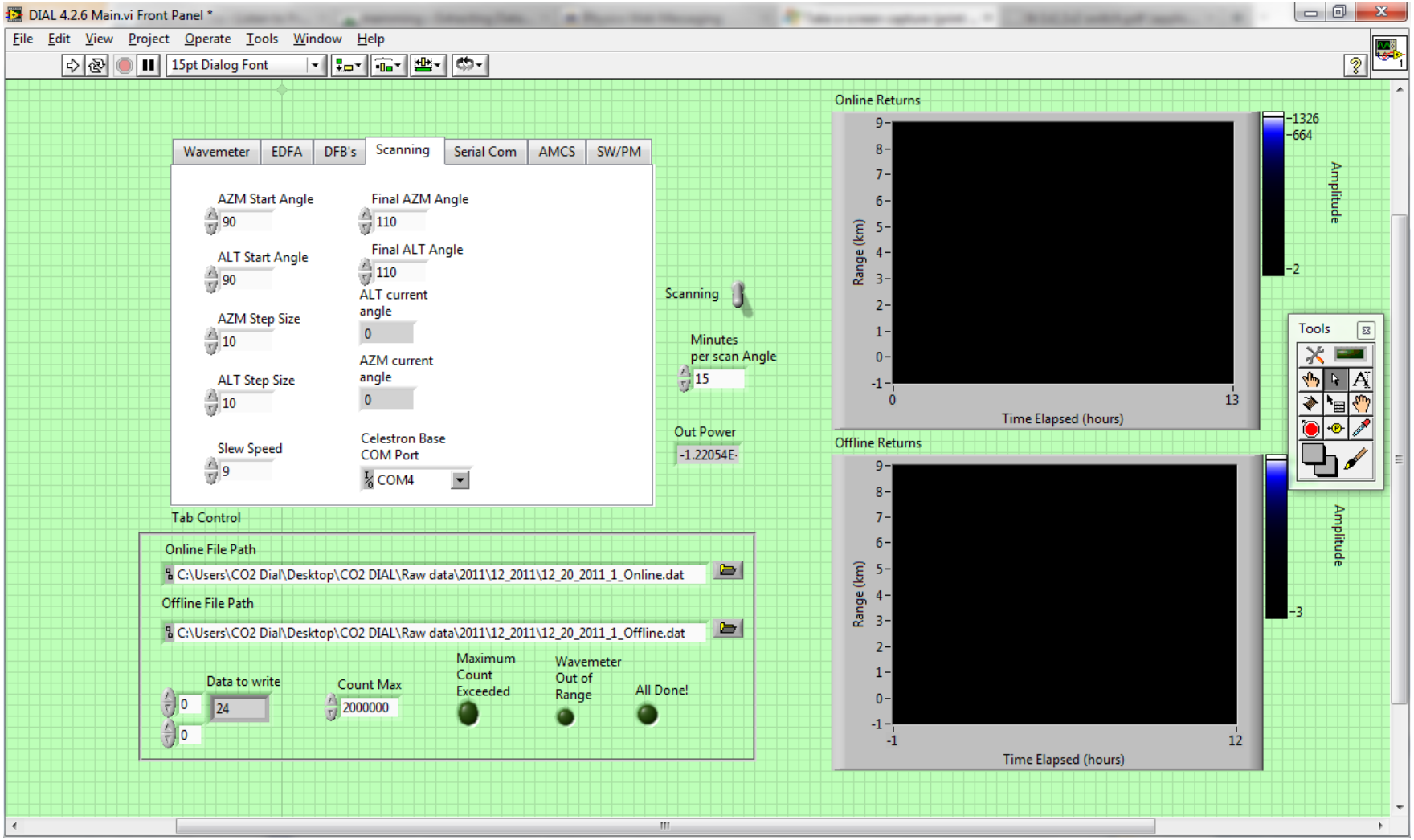


- Pulses between 0.2 and 2 μs generated using the AOM.
- Pulse repetition frequency of up to 25 kHz demonstrated.
- A pulse repetition frequency of 15 kHz provides a maximum range of 10 km.





Technical Status: Labview Control Program



Technical Status: CO_2 DIAL -- Scanning

Using existing telescope mount with motor drives provides a stable scanning method.

DIAL instrument, supporting electronics, and data acquisition computer in the cargo trailer at the ZERT site.

Technical Status: Eye Safety

American National Standard for Safe Use of Lasers
ANSI Z136.1-1993

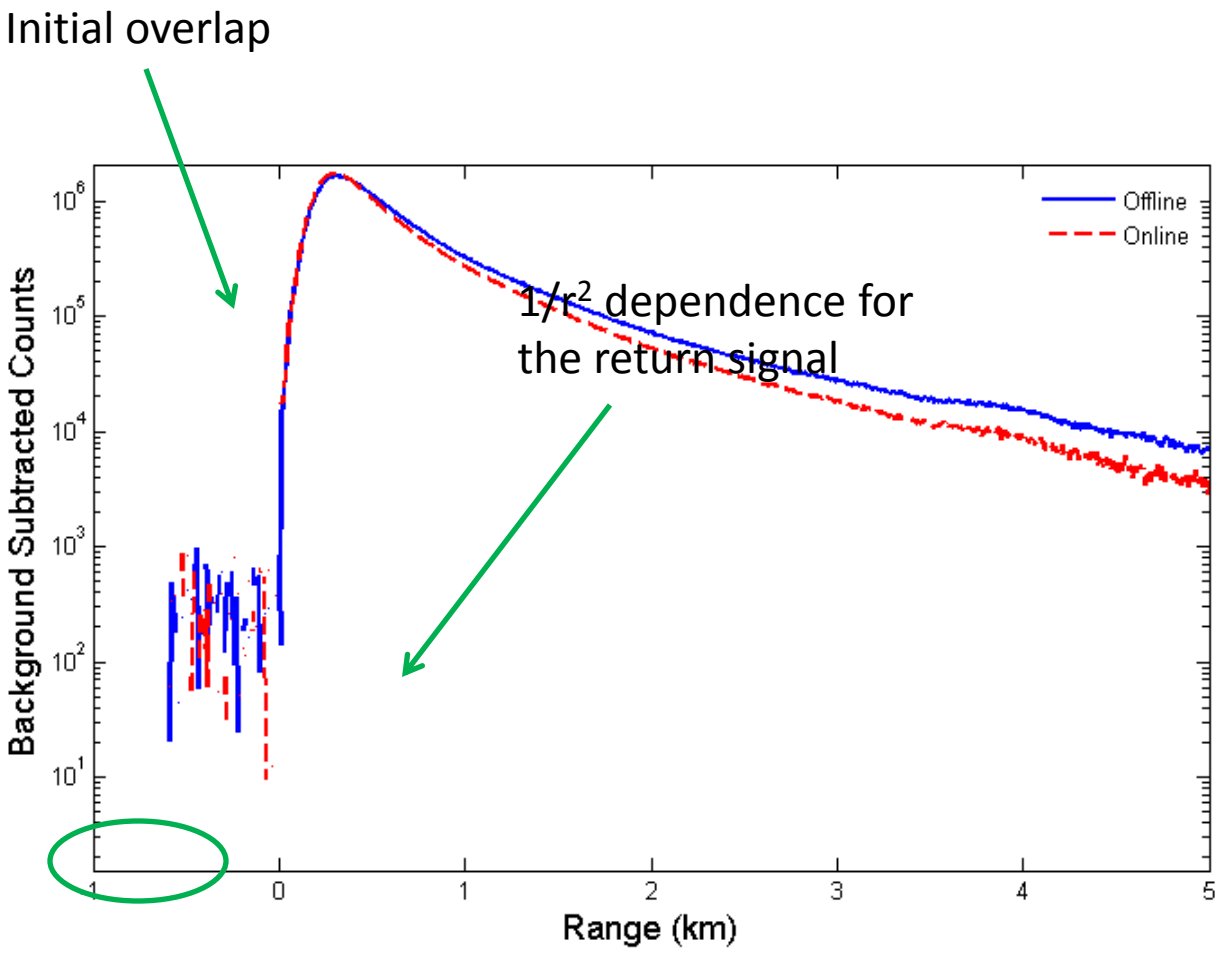
Wavelength: 1.571 μm
Pulse Repetition Frequency: 15 kHz
Pulse Duration: 200 ns

The Maximum Permissible Exposure (MPE) for a Non-Ocular-Eye-Hazard distance of 0 m is

MPE = 6.67 μJ/cm²

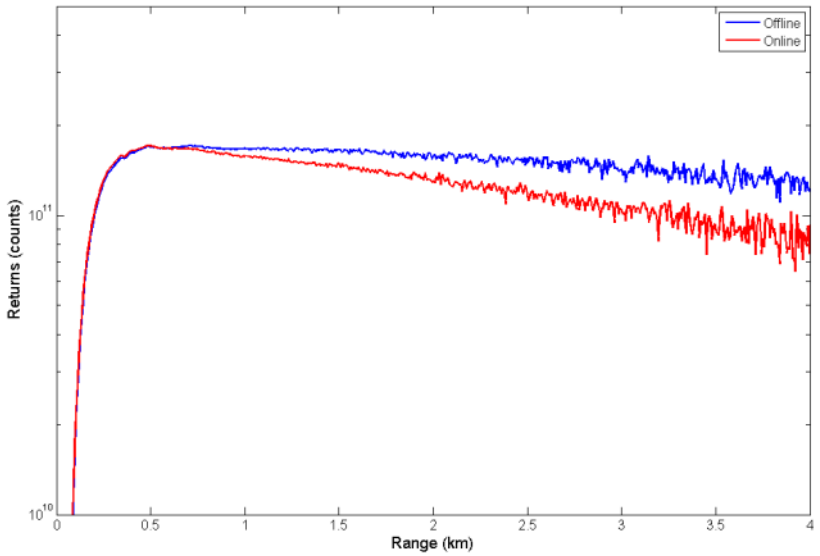
For the 5.0 cm diameter laser transmitter beam, the maximum pulse energy of 130 μJ must be maintained for the Non-Ocular-Eye-Safe distance of 0 m.

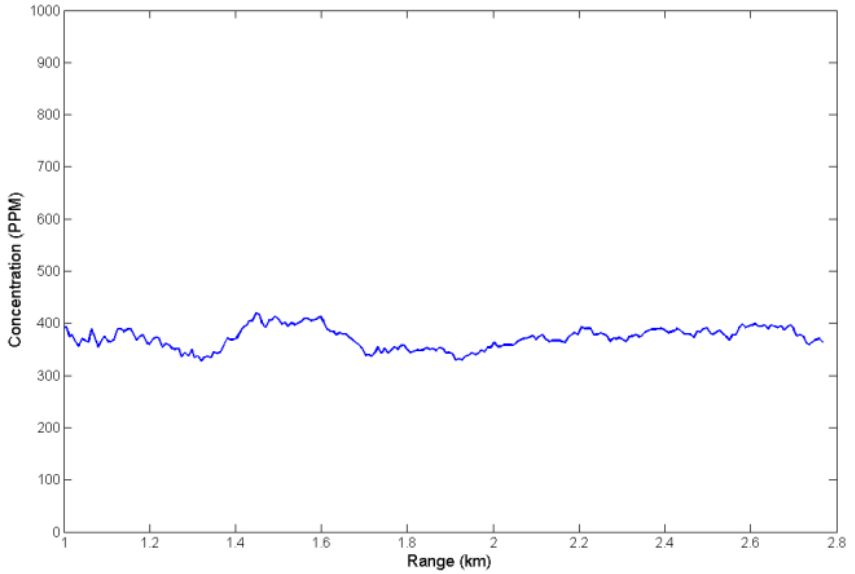
Technical Status: Data Collection Scheme

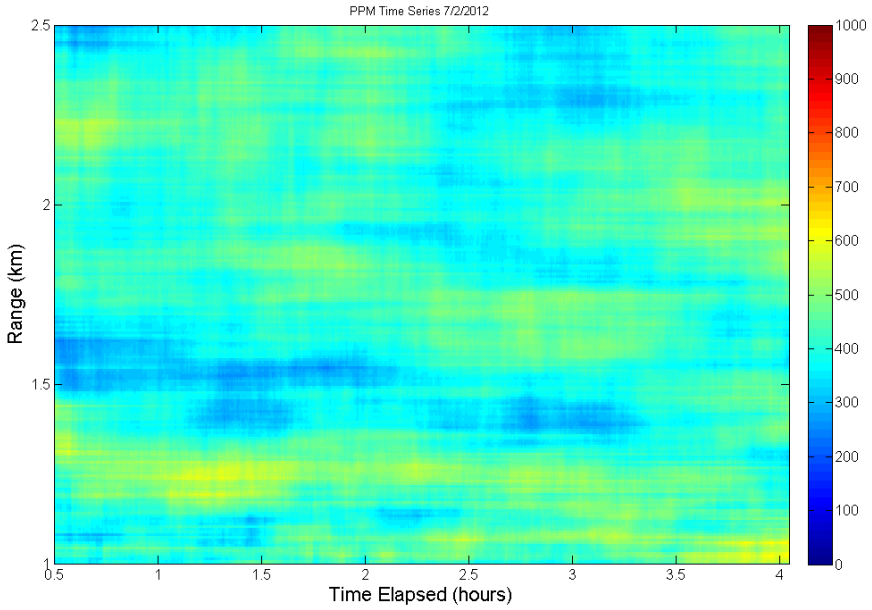


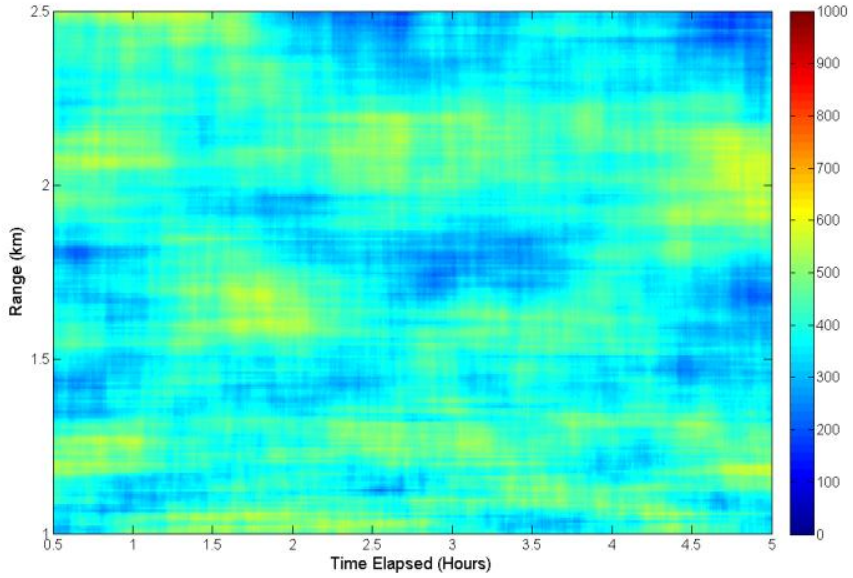
4 μs of background collected before laser pulse fires. Used for background subtraction

Technical Status: Data

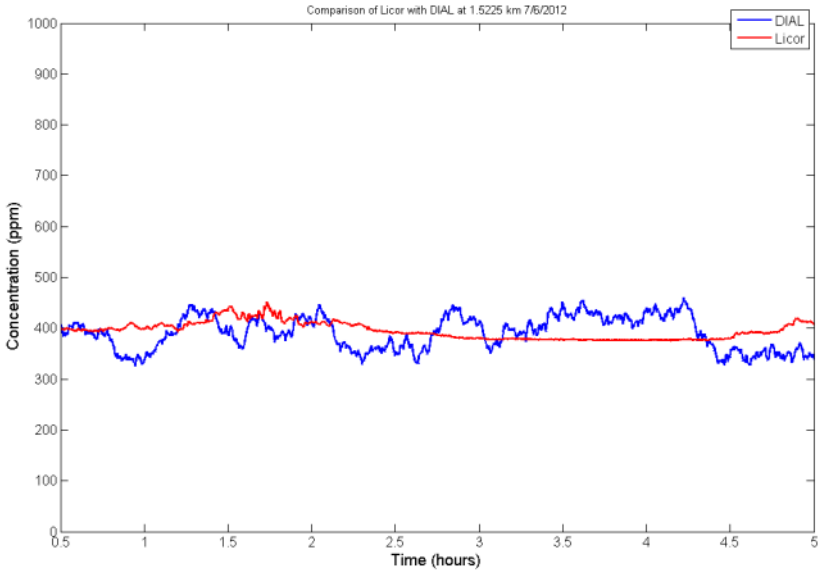


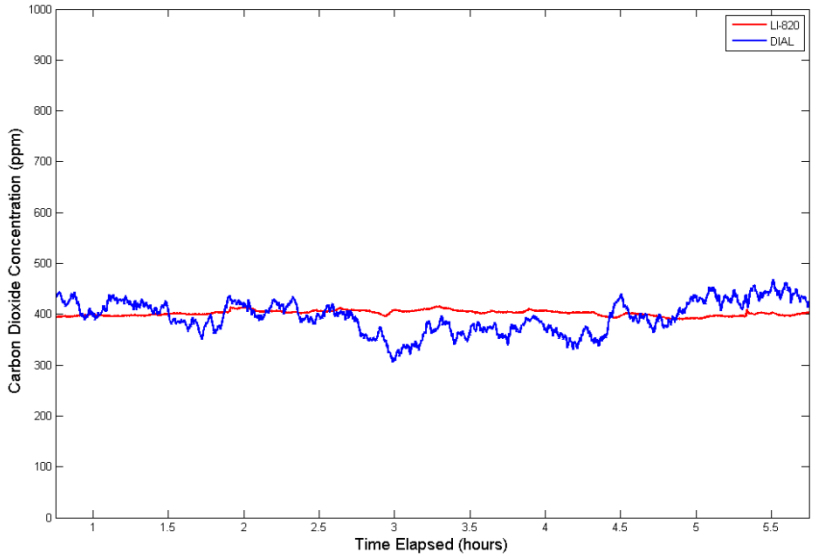






Technical Status: Data





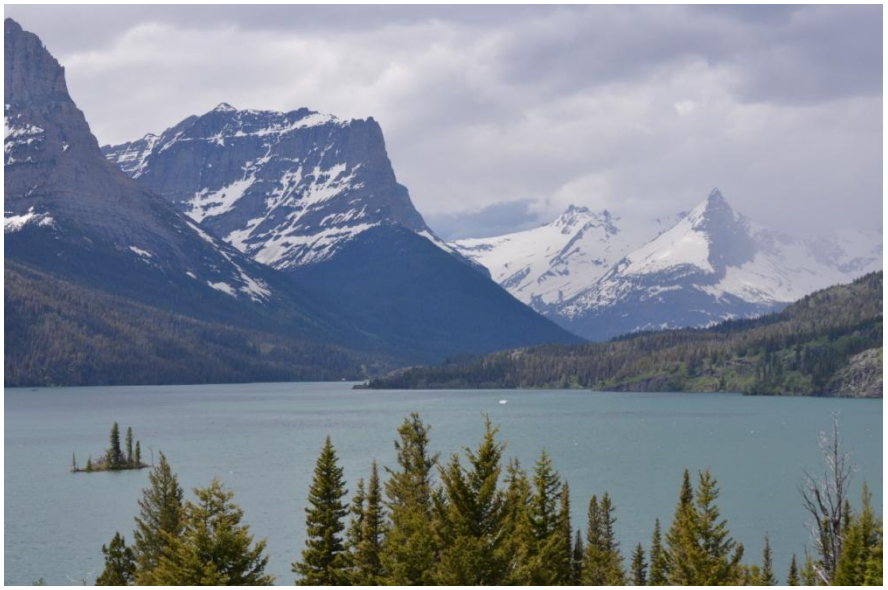
Accomplishments to Date

- A field deployable DIAL for spatial mapping of CO_2 has been developed.
- CO_2 profiles have been demonstrated over 3 km with continuous operation over 8 hours.
- CO_2 profiles have been validated using a co-located point source Licor detector.
- Instrument has been demonstrated at the ZERT field site.

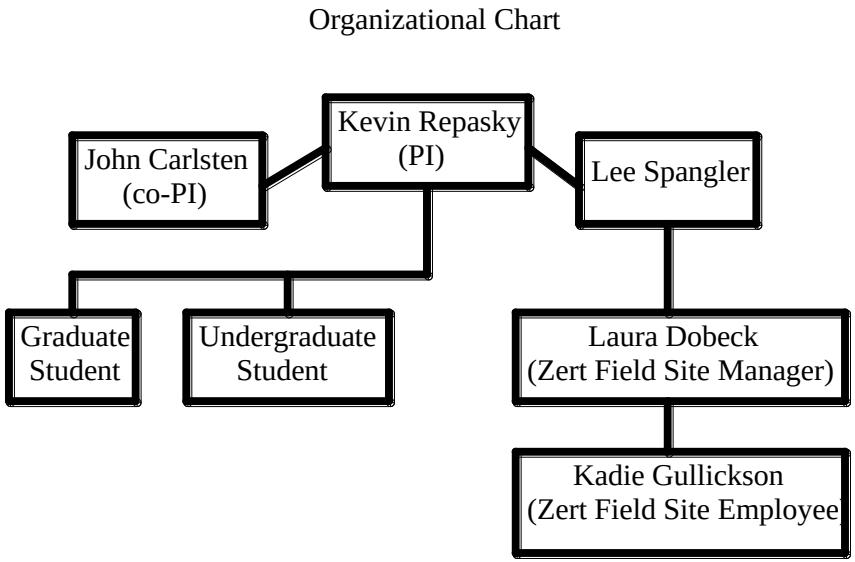
Summary

- The DIAL offers a potential large area monitoring technology for surface monitoring for carbon storage facilities.
- The DIAL has been successful deployed at the ZERT field site and data validated using in-situ point detectors.
- Future Plans
  - Deploy at the Kevin Dome site in North Central Montana.
  - Collaboration with NASA on CO_2 detection at 2 μm (Upenrda Singh, NASA LaRC, Langley, VA).
  - Collaboration with NIST on CO_2 detection (Stephen Maxwell, NIST Gaithersburg, MD).
  - Technology transfer: photon upconversion techniques for more efficient detection techniques (Advr, Bozeman, MT)

Thanks Kindly for Your Time



Appendix: Organization Chart



- Kevin Repasky: (PI) responsible for overall project.
- John Carlsten: (Co-PI) work with Dr. repasky to manage project and students.
- Lee Spangler: Hear of ZERT and BSCSP. Coordinate field work
- Laura Dobeck: Coordinate ZERT field experiments.

figure 5.

Appendix: Gantt Chart

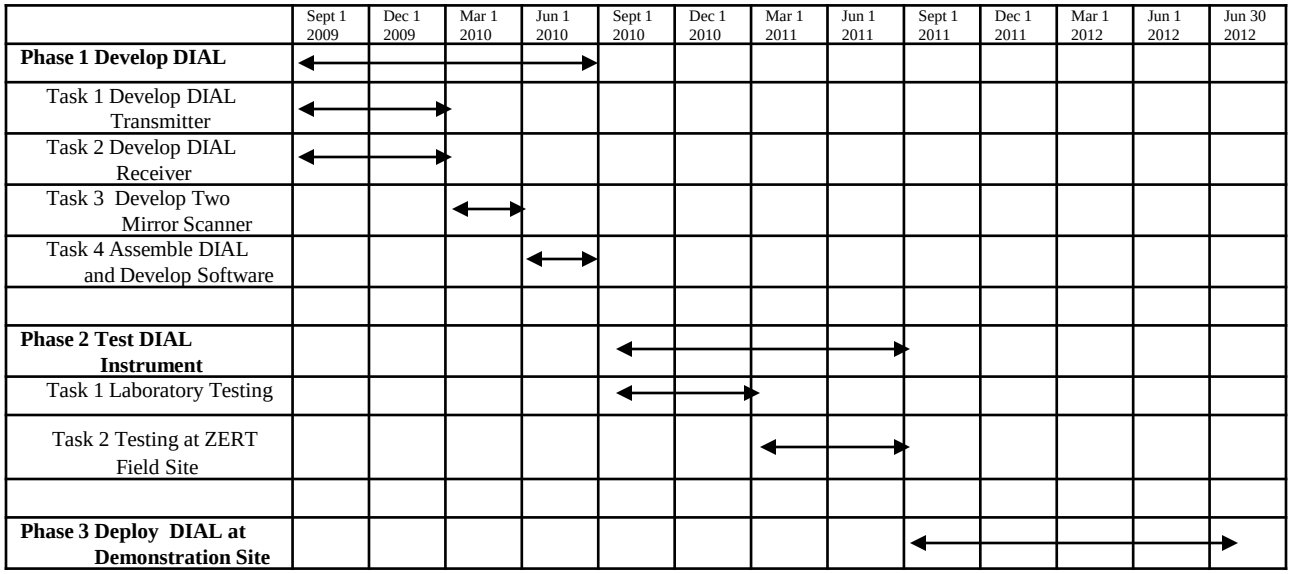


Figure 5 (From Proposal) Gantt Chart showing the proposed timeline to complete each task and phase of the proposed project.

Note: Due to permitting issues, A second summer of ZERT field work is being completed in the summer of 2012 and the instrument will be deployed at the BSCSP site in the summer of 2013.

figure 5.

Appendix: Presentations and Publications

- Presentations
  - "Development of a Differential Absorption Lidar (DIAL) for Carbon Sequestration Site Monitoring", William Johnson, Amanda Bares, Amin R. Nehrir, Kevin S. Repasky, and John L. Carlsten, American Geophysical Union, San Francisco, California, 2011, (contributed).
  - "Laser based detection of atmospheric carbon dioxide", K.S. Repasky, National Institute of Standards and Technology, Gaithersburg, MD, March 2012 (invited).
  - "Large area detection of CO2 for carbon sequestration", IEAGHG: Environmental Impacts of CO2 Storage Workshop, Bozeman, MT, July 2012 (invited).
- Papers:
  - "Differential Absorption Lidar (DIAL) for Carbon Dioxide Monitoring", William Johnson, Kevin S. Repasky, and John L. Carlsten, in preparation for submission to Applied Optics.