Low-Coherence, High-Resolution Optical Reflectometry for Fiber Length Measurement

MSEE Thesis Defense

By

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Motivation

- Quantify crustal deformation using accurate optical fiber length measurement
- Exploit buried fiber insensitivity to environmental changes
- Develop high resolution system with large length change measurement range

Project Goals

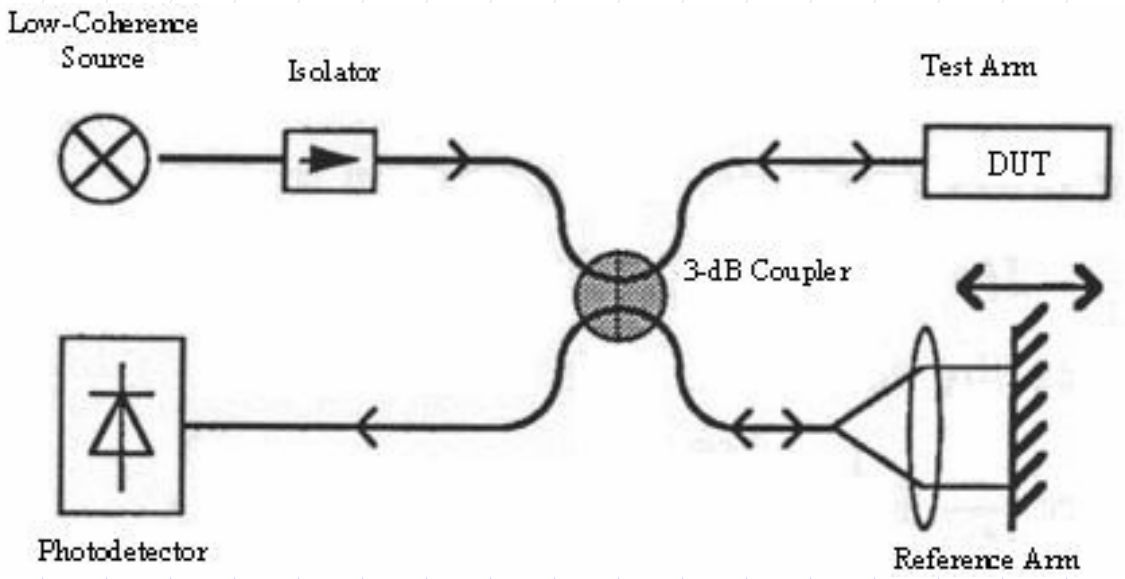
- Meet or exceed performance of currently used crustal measurement techniques
- Dynamic range on the order of meters
- System resolution of at least 1-3 millimeters
- Capability to handle fiber lengths up to several kilometers

Method

- System based on optical low-coherence reflectometry (OLCR) arrangement
  - Dynamic range extension using a series of fiber Bragg gratings
  - Novel technique for reducing polarization sensitivities in the interference signal detection

Conventional OLCR

- Based on Michelson interferometer arrangement
- Reflected signals from test and reference arms interfere when optical length difference is within a coherence length of the source



OCLR Measurement Performance

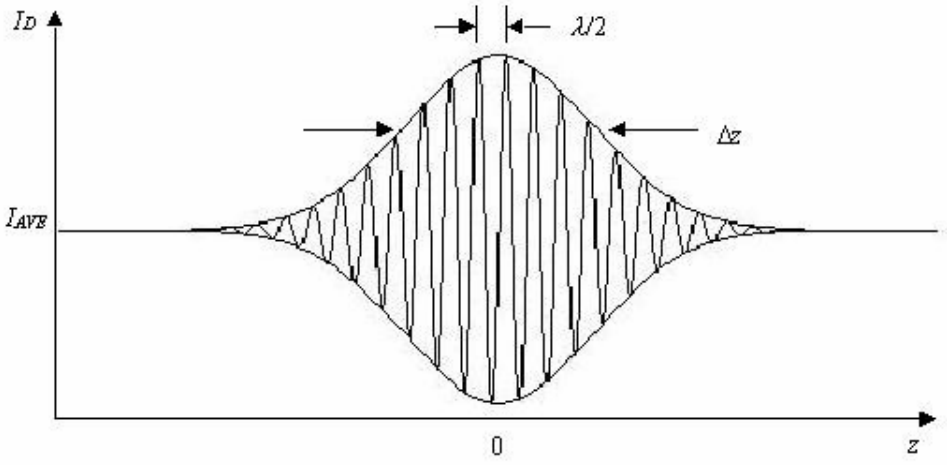
- Source coherence length

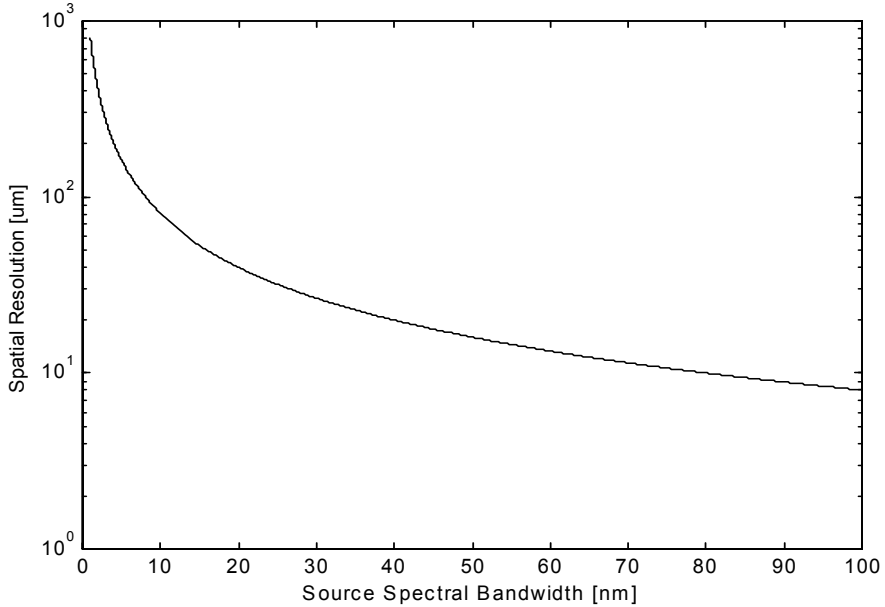
$$L_c = \frac{\lambda^2}{n\Delta\lambda}$$

- Resolution

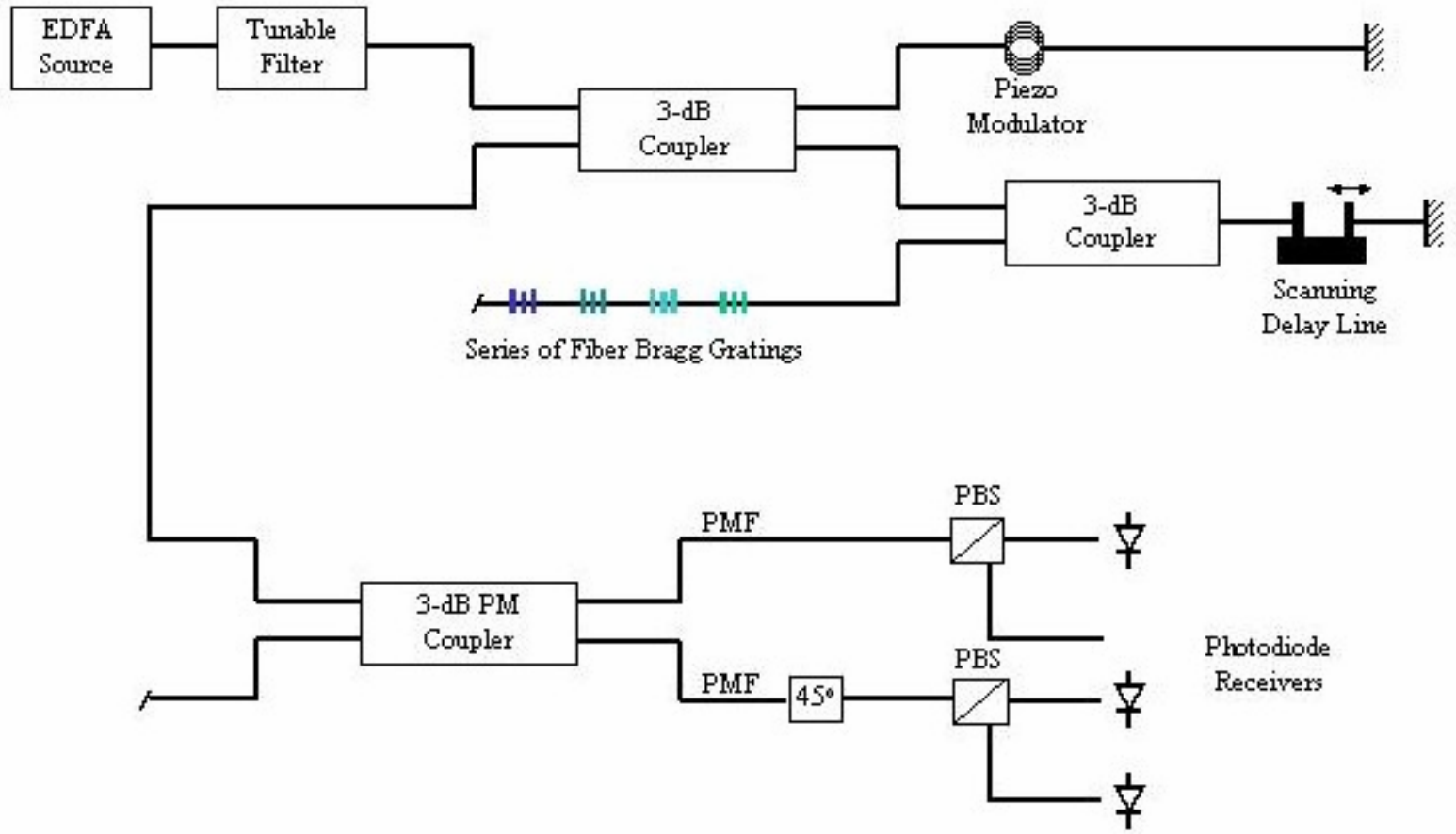
$$\Delta z \approx \frac{L_C}{2} = A\frac{\lambda^2}{2n\Delta\lambda}$$

- Dynamic range determined by scanning range of movable delay line or mirror



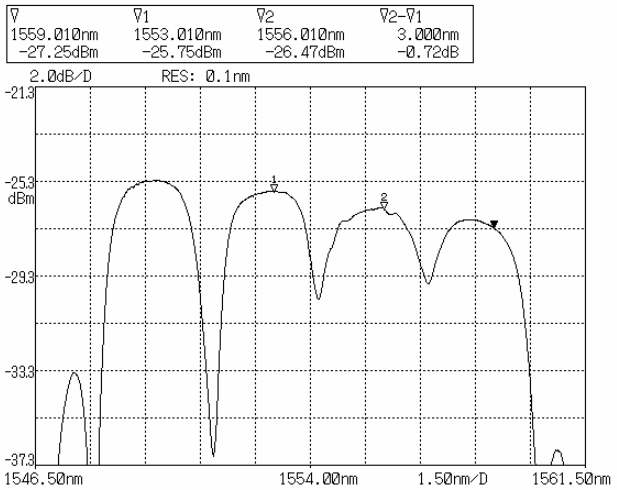


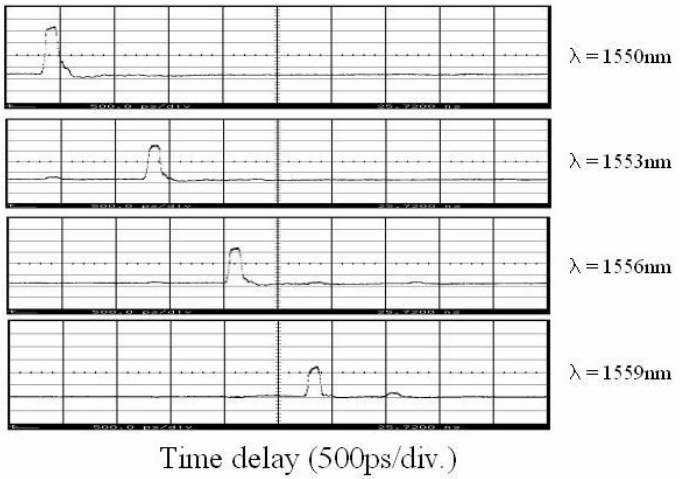
Project OLCR Measurement System



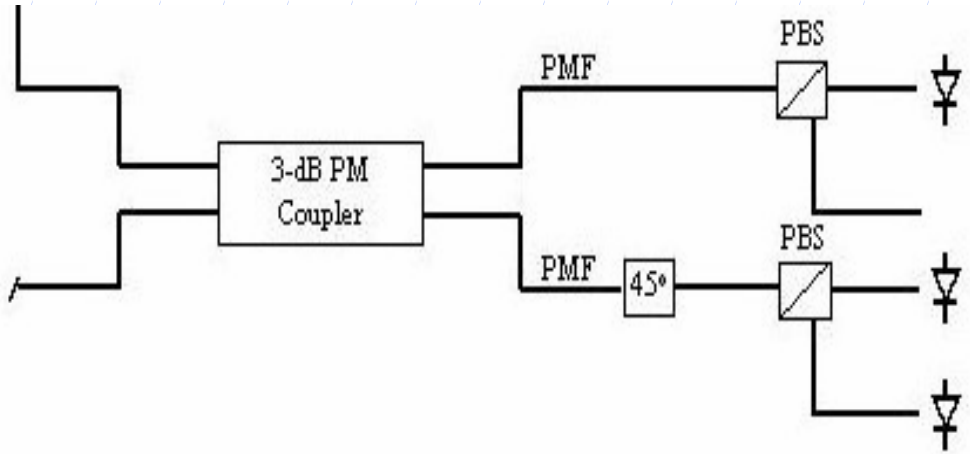
Dynamic Range Extension

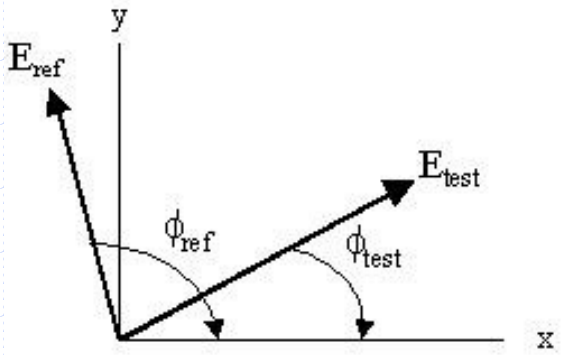
- Series of 4 fiber Bragg gratings each with bandwidth ranging from 1.74 – 2.2 nm
- Spacing between each grating effectively multiplies the scanning range of the delay line
- Electronically tunable optical filter with 1.5-nm bandwidth selects each individual wavelength
- Method demonstrates opportunity to utilize additional gratings up to the spectral width of the source





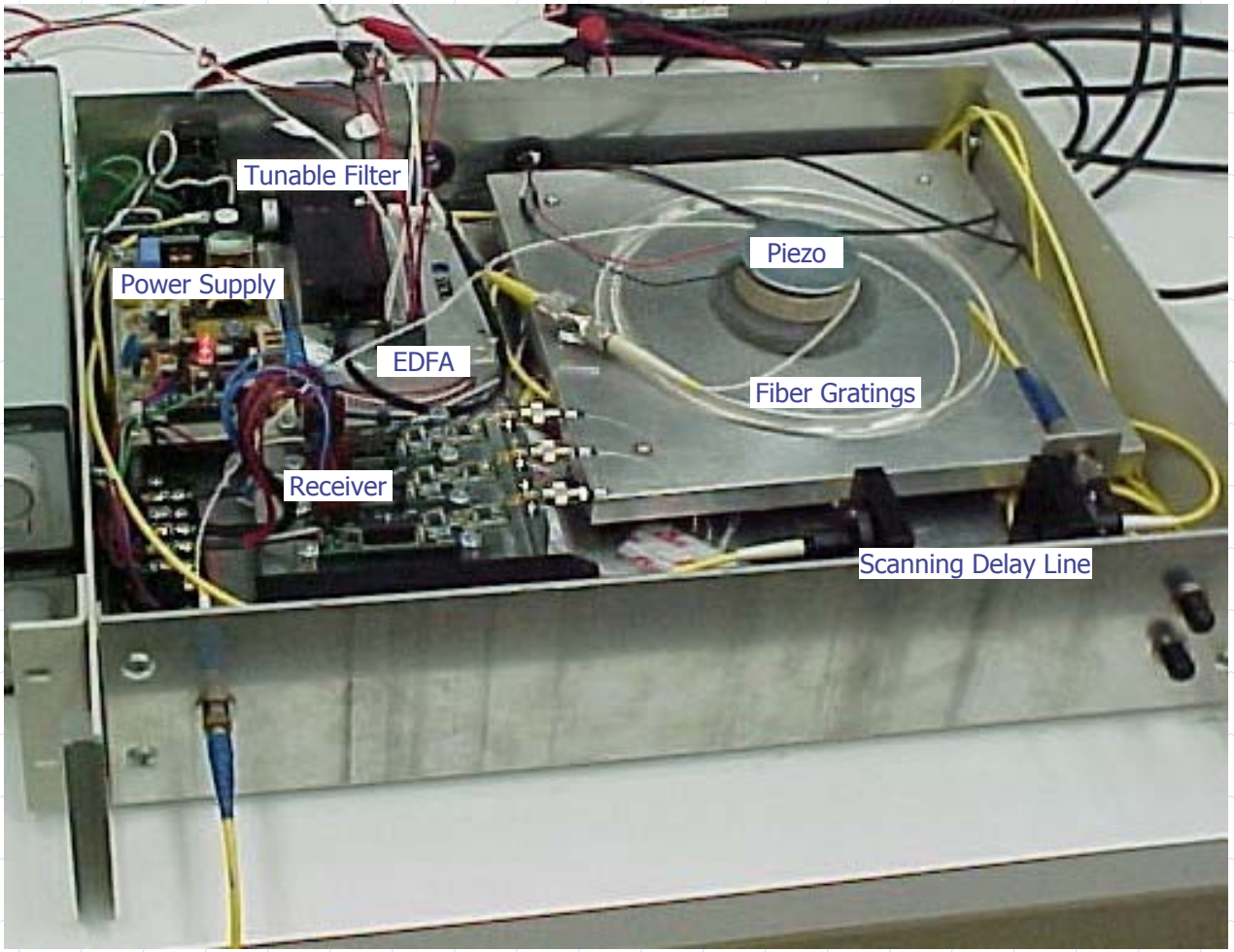
Polarization-Diversity Receiver



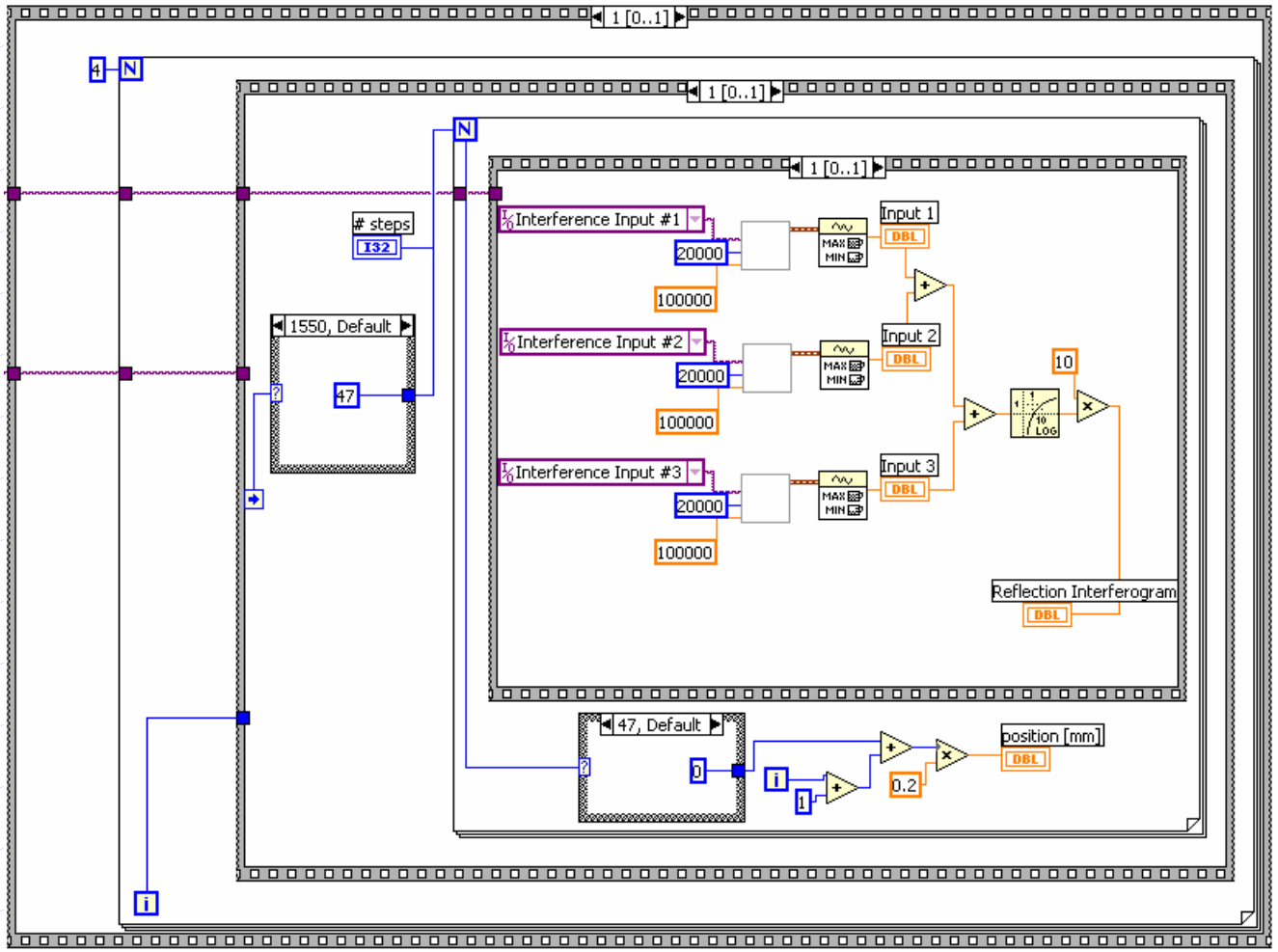


- Assumes reflected reference and test arm signals nearly equal
- Upper photodiode arm receives interference from orthogonal signals not aligned with polarization beam splitter (PBS)
- Lower two photodiodes receive interference from orthogonal signals aligned with PBS and summed with signal from upper
- MATLAB simulations predicted a maximum variation of 6.68 dB with no nulls in signal detection

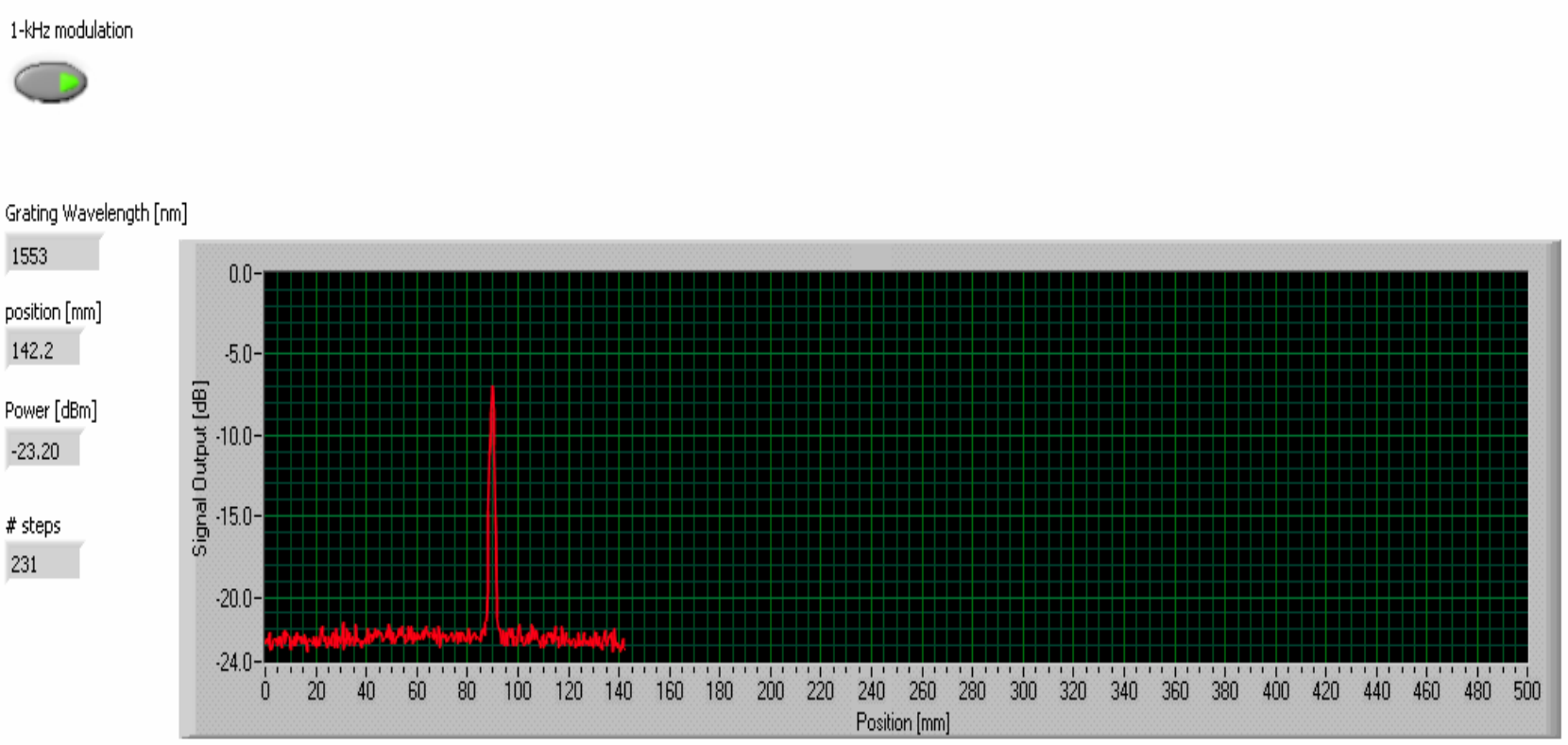
Assembled Project System



System LabVIEW Programming

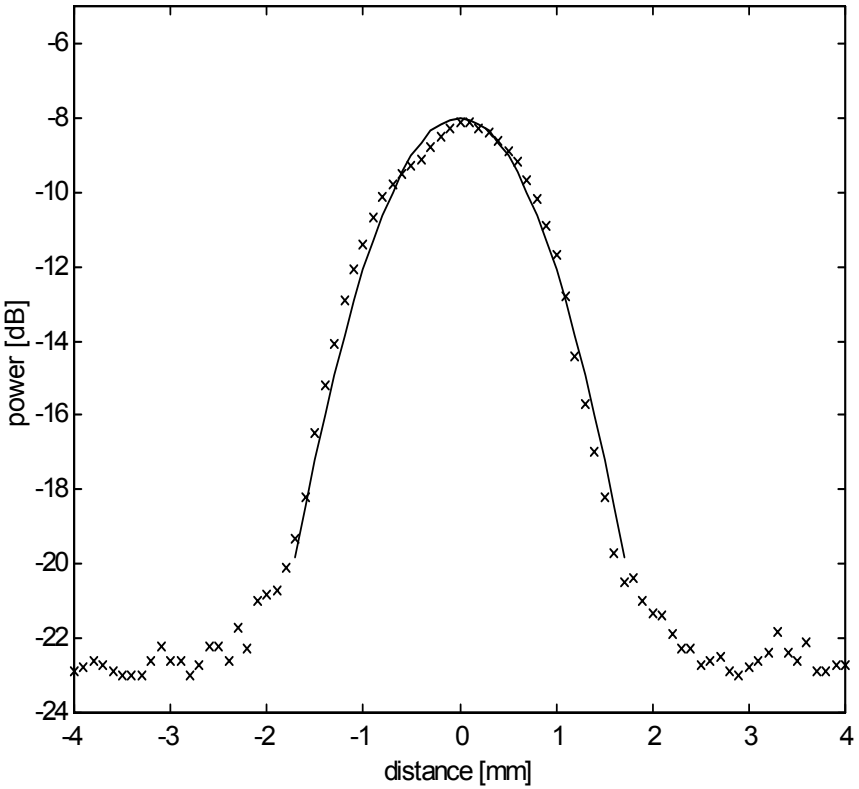


Graphical User Interface



Experimental Results

- Dynamic range exceeding 41 cm, with demonstrated method capable of attaining almost 375 cm
- Measurement resolution of 1.72 mm meets goal of 1-3 mm
- Signal-to-noise ratio of 16 dB exceeds predicted polarization-diversity receiver variation



Conclusions

- Optical fiber length measurement system assembled and demonstrated to meet performance of current methods to quantify crustal deformation
- New techniques for OLCR dynamic range extension and passive polarization-diversity detection developed

Future Work

- Precise optical fiber fault detection
  - Used in collaboration with OTDR methods to pinpoint fault location with millimeter accuracy
  - Receiver scheme must be modified to allow for weakly reflected test arm signal
- Expand dynamic range of conventional OLCR
  - Current range may not be large enough to scan optical networking devices with several components
  - Existing methods for polarization control could be used, or same modifications for weakly reflected signals incorporated