# Monitoring of Acoustic Emissions Using a Fiber Bragg Grating Dynamic Strain Sensing System

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# Dynamic Strain Monitoring System - requirements -

Goal:
Develop a network of high-frequency strain sensors with the following requirements:

- Always ready to detect and locate impact and other transient signals;
- Adaptive to detect dynamic strains (ultrasound-induced) in the presence of large quasi-static strains (structural deformation-induced) or thermal drift;
- Multiplexable for large sensor arrays.

Technology:
Optical Fiber Bragg Grating (FBG) Sensors and Multiplexed Two-Wave Mixing (MTWM) in adaptive photorefractive crystals.

# Talk Outline

- Fiber Bragg-Grating sensors as dynamic strain sensors
  - Current methods of demodulation
- Two Wave Mixing demodulator system
  - frequency response
  - sensitivity
  - cross-talk
- Applications:
  - acoustic emission

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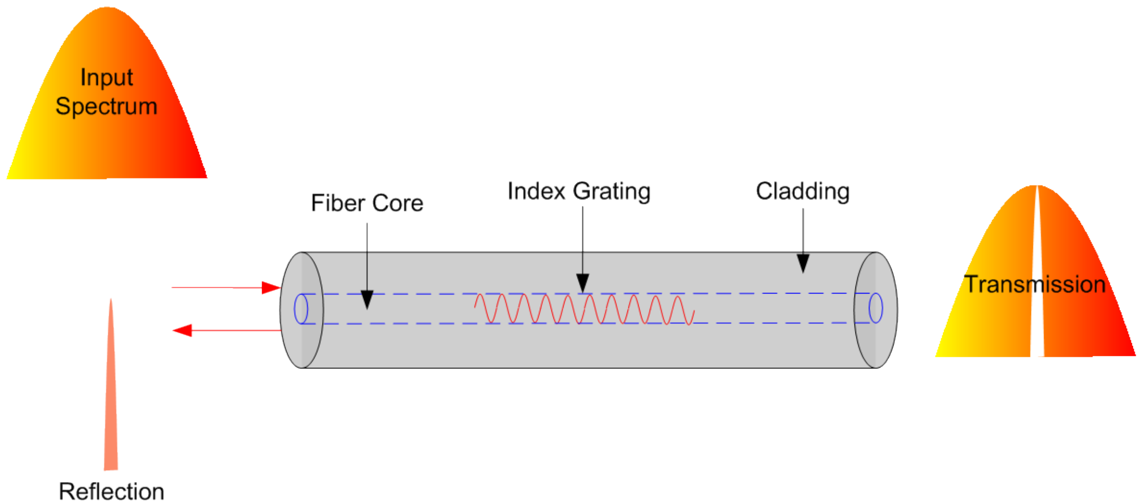
# Fiber Bragg Grating Sensors




Strain or temperature signal is spectrally encoded in the reflected / transmitted light from an FBG sensor.

$$\frac{\Delta\lambda_B}{\lambda_B} = [1 - \frac{n_{eff}^2}{2}[p_{12} - \upsilon(p_{11} + p_{12})]]\varepsilon_z + (\alpha_\Lambda + \alpha_N)\Delta T$$

$1\mu\varepsilon \rightarrow 1.2$pm  $1^{o}$C $\rightarrow$ 13pm

- Bragg-gratings are refractive-index gratings in the optical fiber.
- They are very easy to fabricate.
- They are local sensors
- Several sensors can be readily multiplexed.
- Useful as temperature, strain sensors.
- Can be used for **dynamic strain sensing**

*Ref: A.Othonos, and K.Kalli, "Fiber Bragg Gratings," Artech House, Boston. (1999)*

# Current Approaches for Spectral Shift Demodulation

| Demodulation Scheme | | Readiness | Adaptivity | Multiplexability |
|---|---|---|---|---|
| CCD Spectrometer / AWG | | Always | No | Demodulator for each sensor |
| Tunable Filter | | Intermittent – Scanned | Feedback | Filter for each sensor |
| Tunable Source | | Intermittent – Scanned | Feedback | yes |
| Interferometric | | Always | Feedback | Demodulator for each sensor |
| **MTWM system** | | **Always** | **Self** | **Single demodulator** |

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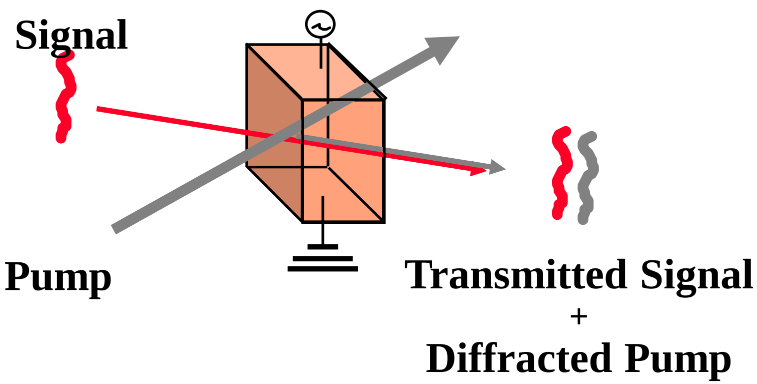
# Two Wave Mixing Interferometry in Photorefractive Crystals




**In a nutshell:**

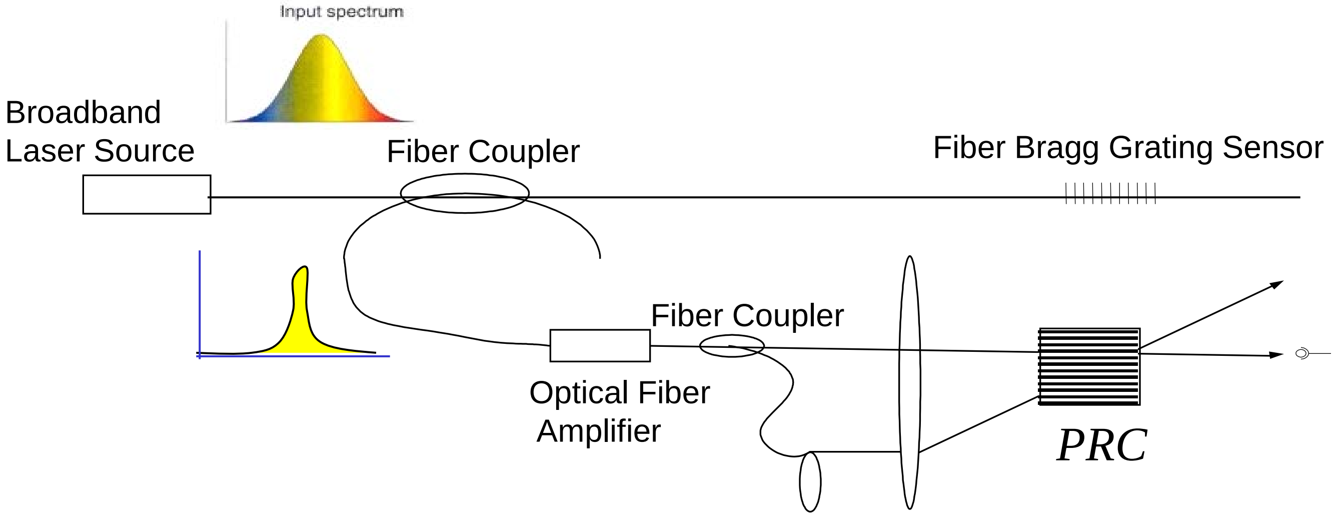
- PRC's act as "novelty filters"
- Output only "sees" sudden variations in the input
- what is new is dictated by the PRC response time

## Principle:

- Pump + Signal create a refractive index grating in the PRC
- Pump and signal beams diffract off the index grating
- Diffracted pump is a replication of the **quasistatic** signal beam
- **Dynamic** changes in the signal beam are not tracked by the PRC
- The transmitted signal beam effectively interferes with the diffracted pump beam and only dynamic changes in the signal beam are observed.

*Ref: Yi Qiao, Yi Zhou, and Sridhar Krishnaswamy, (July 2006), "Adaptive two-wave mixing wavelength demodulation of Fiber Bragg Grating dynamic strain sensors", Applied Optics, vol. 45, No. 21, pp 5132-5142.*

# TWM Interferometer for Spectral Demodulation

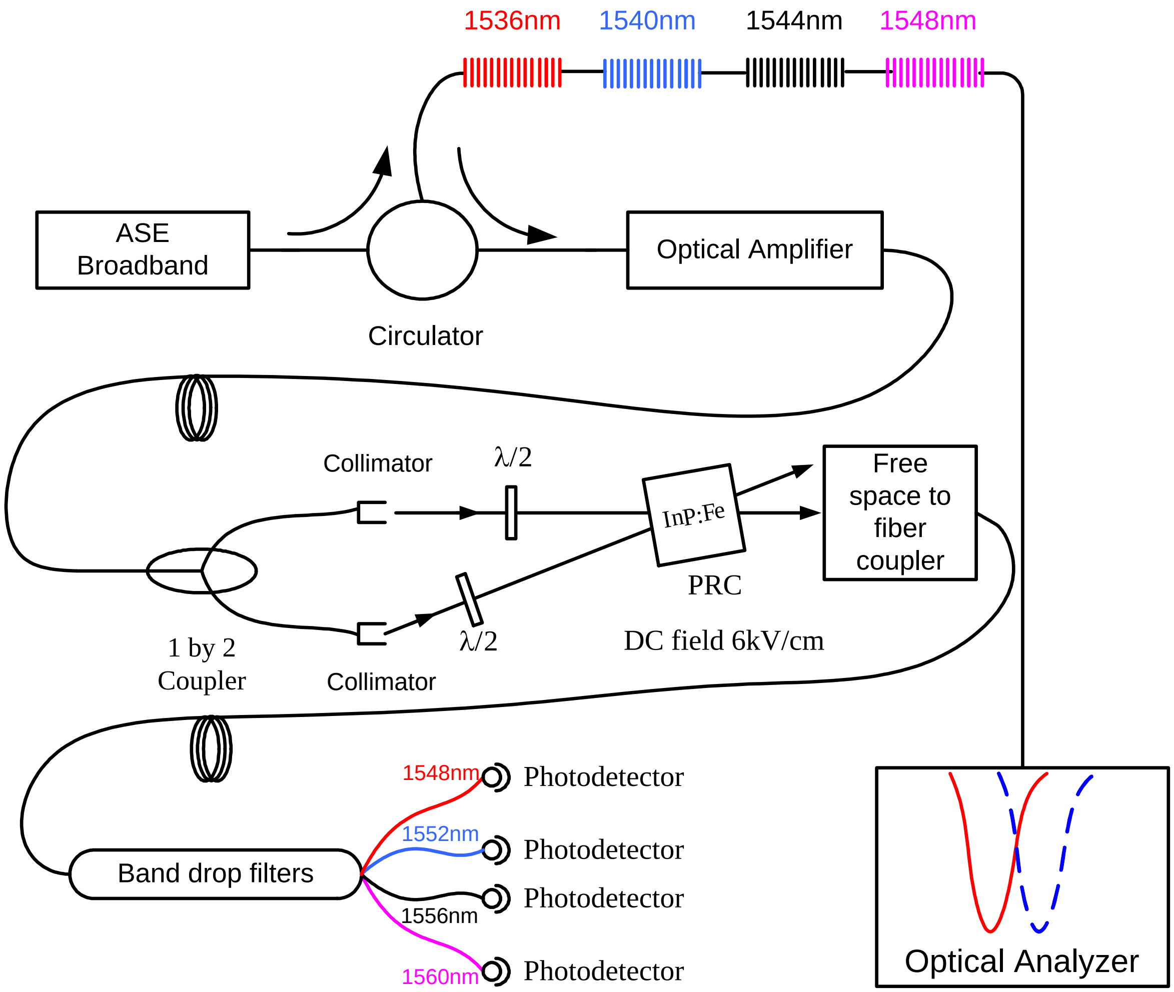



- *Bragg-sensor signal at $\lambda_B$ split into two legs with optical path difference OPD 'd'*
- *The two-beams are mixed in a PRC to create a grating.*
- *Path-mismatch causes a phase difference between the two legs of:*

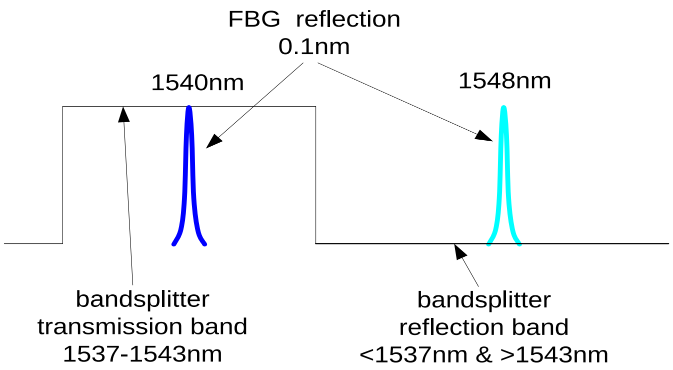
$$\Delta\Phi(t) = -\frac{2\pi d}{\lambda_B^2}\Delta\lambda_B(t) + \varphi_n$$

- *Quasistatic drift in $\lambda_B$ compensated for by creation of new grating in PRC*
- *Dynamic changes in $\lambda_B$ cause instantaneous phase shift at the PRC output.*

# Multiplexability




- A single TWM spectral demodulator can be used to demodulate multiple FBG sensors simultaneously by wavelength multiplexing.
- The different channels are separated after the PRC by band-drop filters.



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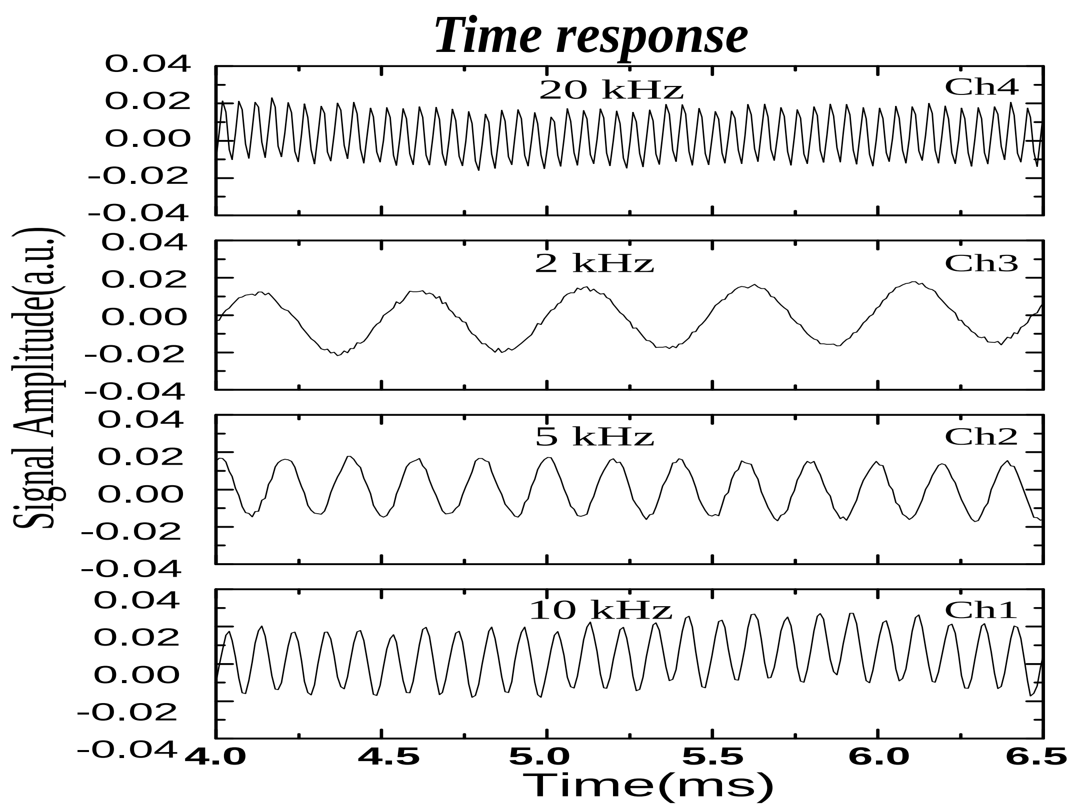
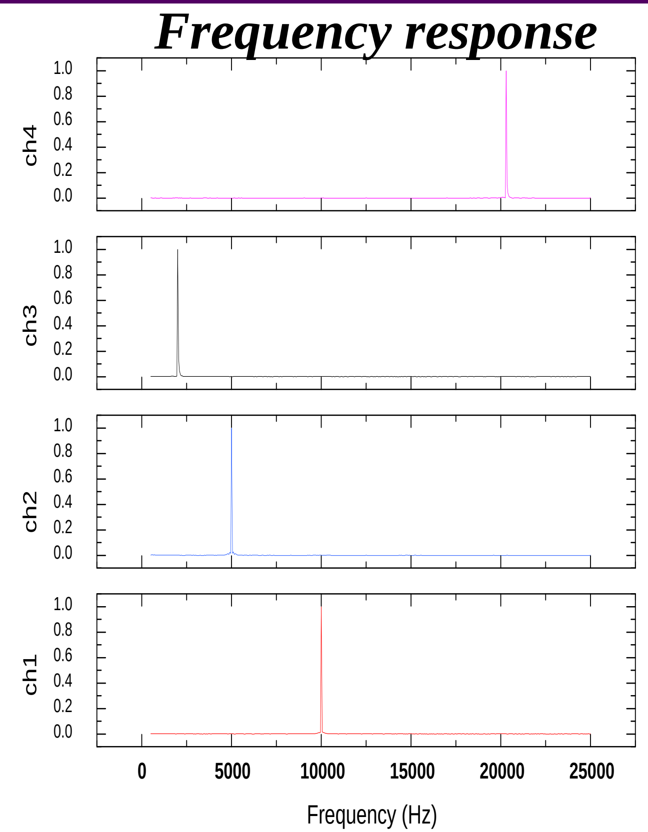
# Multiplexed 4-channel TWM spectral demodulator - crosstalk




- 20 kHz, 10kHz, 5 kHz and 2 kHz 5με strains were applied onto the four FBG sensors respectively.
- **No detectable cross-talk**

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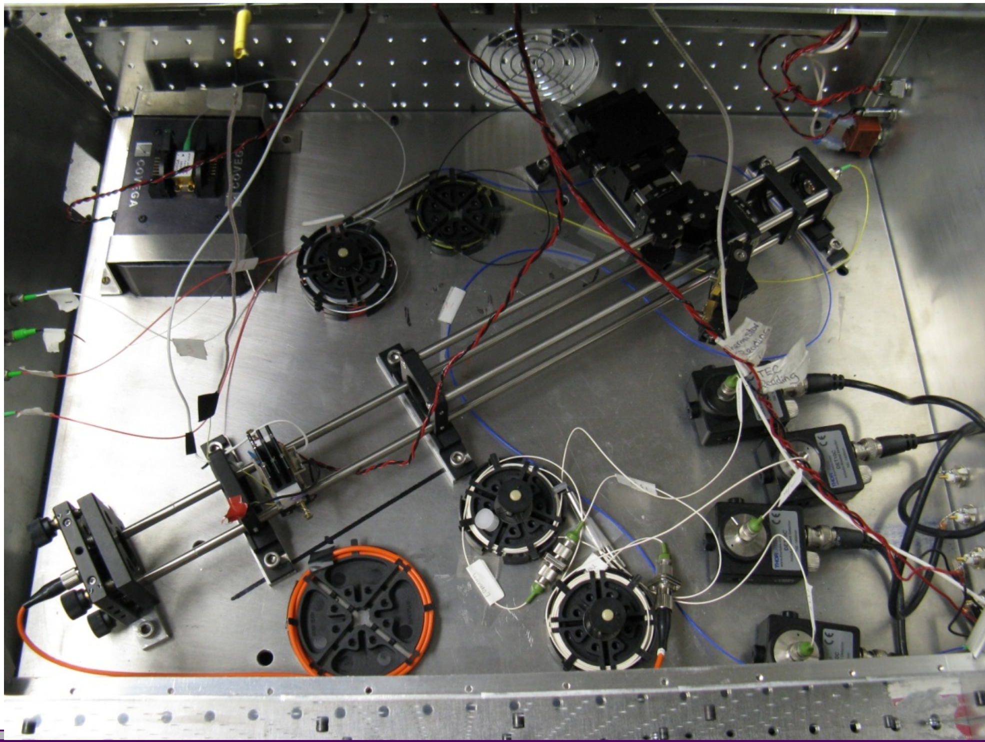
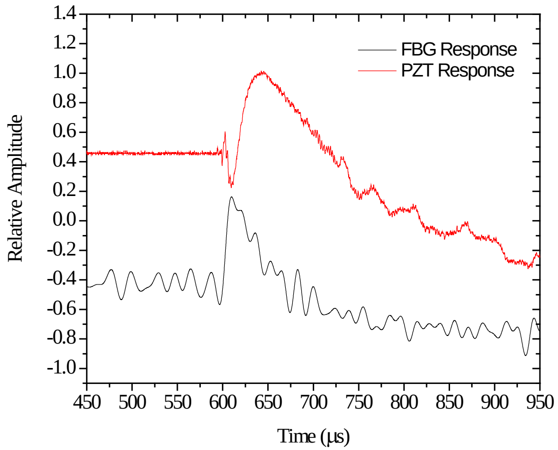
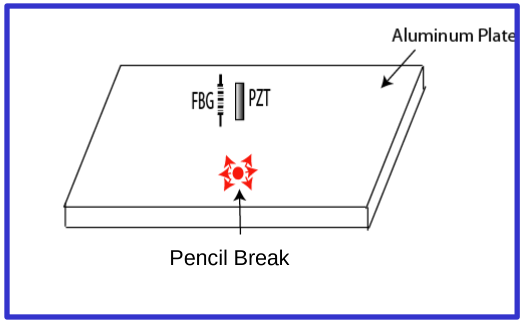
# TWM System NWU Prototype

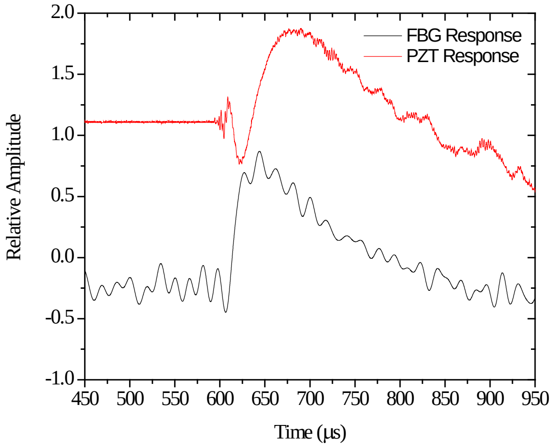
# Pencil Lead Break AE Data
# FBG vs. PZT



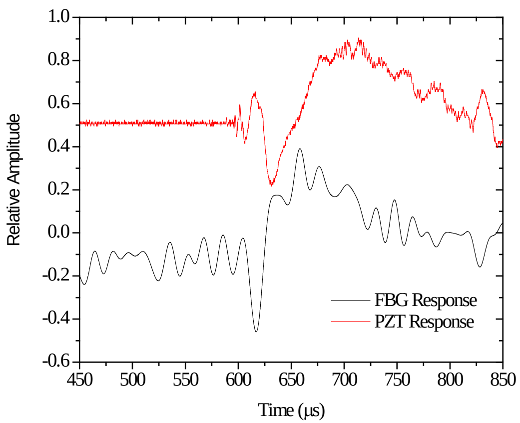

Source to Receiver Distance: 2 cm



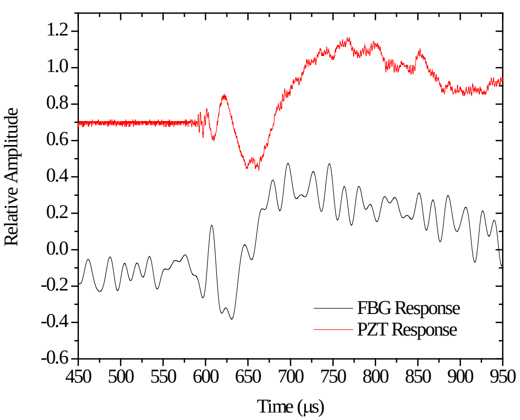

**Experimental Setup**




Source to Receiver Distance: 3 cm




Source to Receiver Distance: 4 cm




Source to Receiver Distance: 5 cm

# TWM Spectral Demodulation - Pencil Lead Break AE Monitoring -

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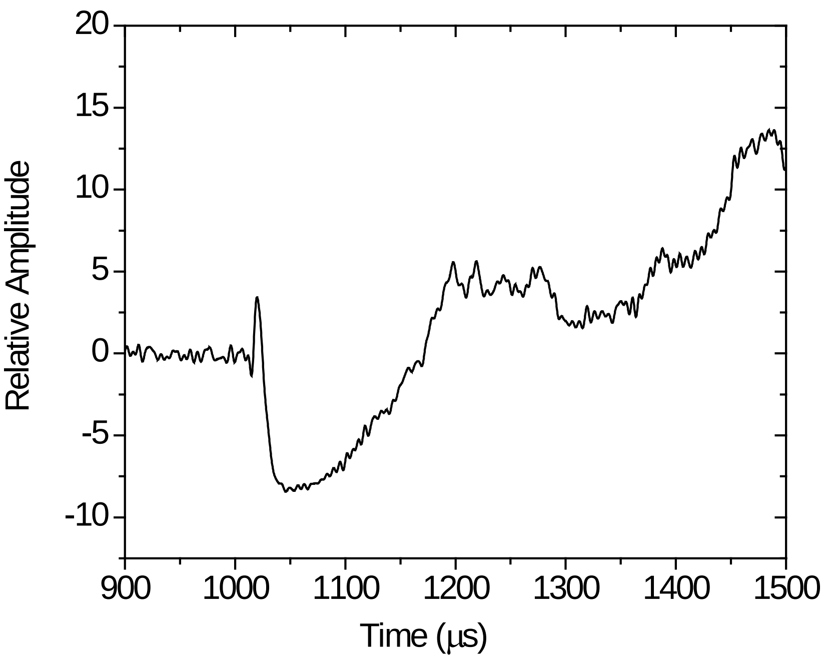
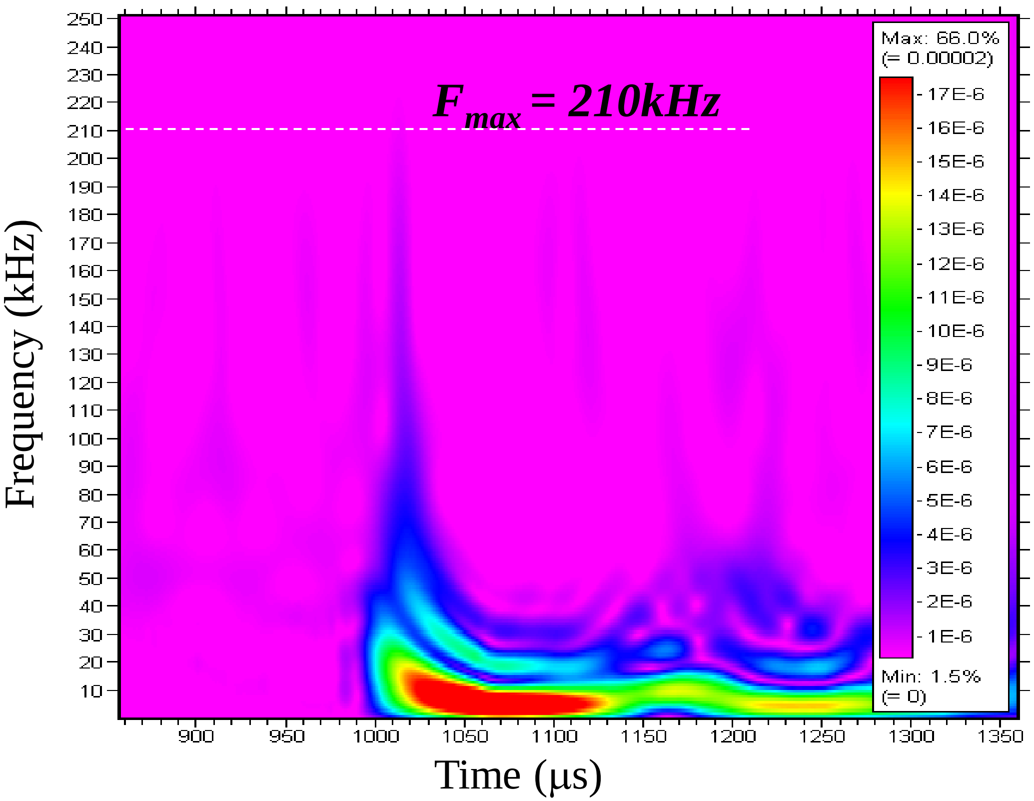
## Experimental Waveform




## Time – Frequency Transform



# Glass Fiber Composite Coupon

- Tyfo® SEH-51 Composite
  - Tyfo ® S Epoxy
  - Uni-directional Glass/Aramid custom weave [0/90]
- Composite Gross Laminate Properties:
  - $\sigma_u$ =575 MPa, $\varepsilon$=2.2%, E=26.1 GPa
  - Laminate Thickness: 1.3mm

*Collaborative work between NU & Harbin Institute of Technology (Li Hui)*

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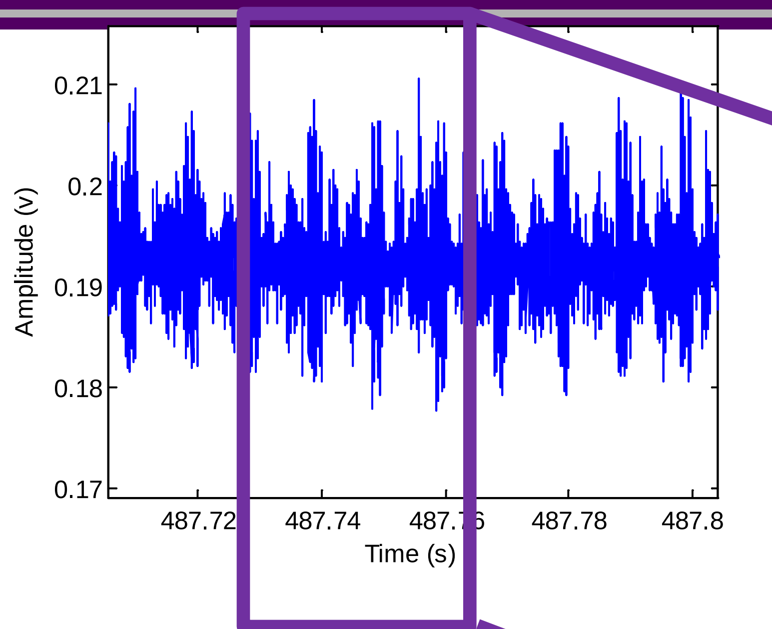
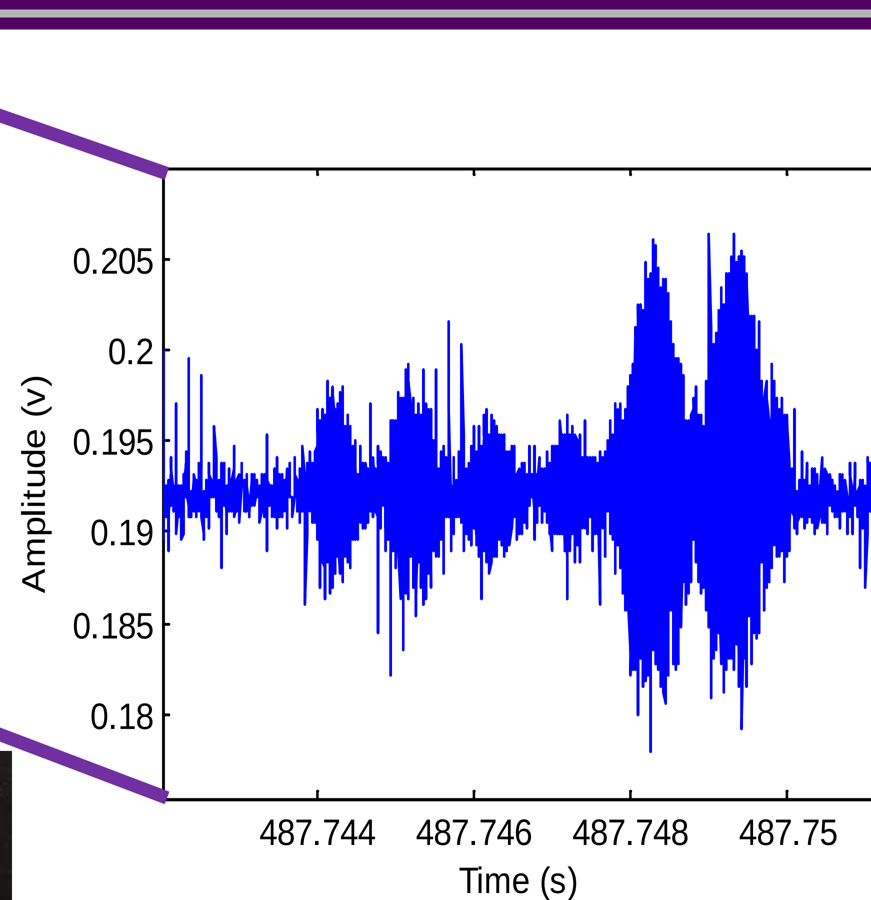
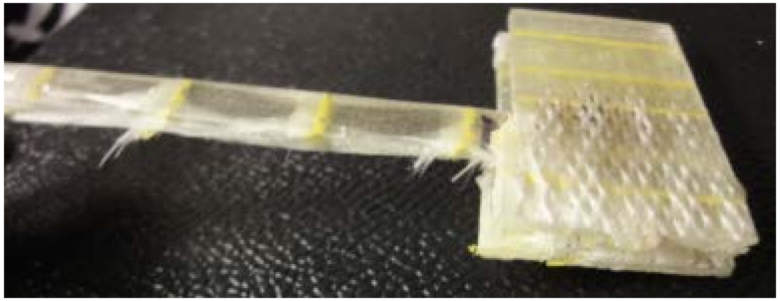
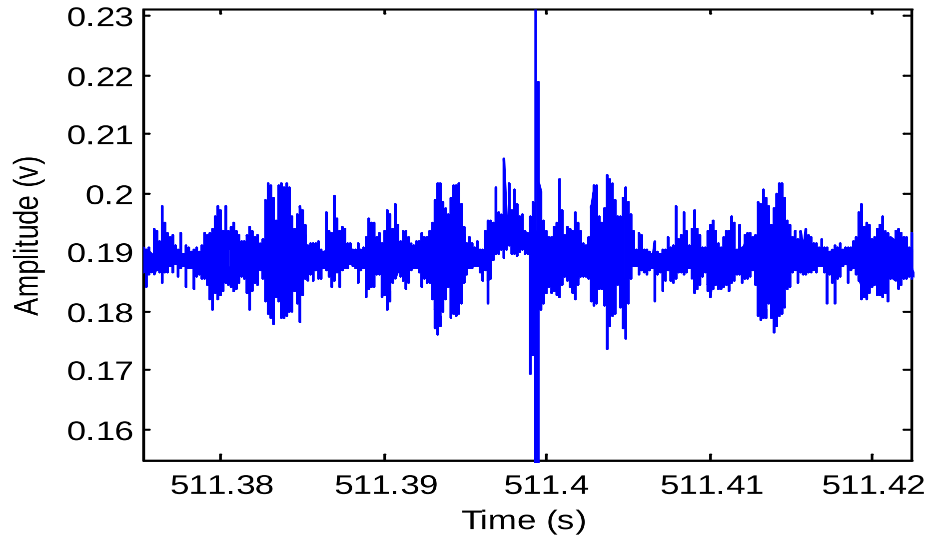
# Continuous AE – Matrix Damage

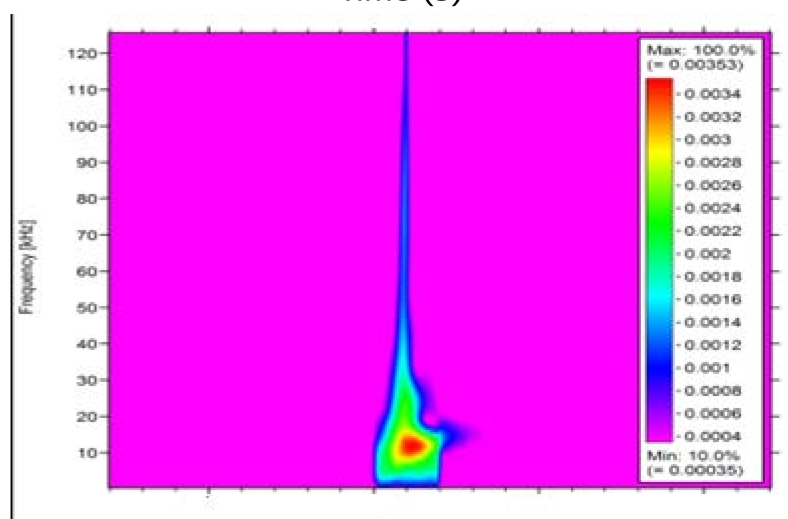


# Burst AE – Fiber Damage



# FBG Sensors Disadvantages / Advantages Over Piezoelectric Based Sensors

## DISADVANTAGES

- Systems are **more expensive** than piezoelectric based systems
- FBG sensors are **less sensitive** than piezoelectric sensors

## ADVANTAGES

- Smaller footprint
- Immune to electromagnetic signals or noise
- Minimum signal loss since cables are replaced by a fiber optic
- Exhibit long term stability
- Can be mounted underwater in needed
- Can be embedded within the structure
- Can be used in high temperature applications.

# Conclusions

TWM Wavelength demodulation demonstrated:

1. **Always On**: Wavelength demodulation induced by transient events is demonstrated.
2. **Adaptive**: The TWM wavelength demodulator is demonstrated to have adaptivity to quasistatic drift (both strains and temperature).
3. **Frequency response**: High pass – no upper limit from TWM.
4. **Multiplexability**: Little detectable cross-talk.

# Thank You!

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