

# Classical Optical Fiber Sensing for Geophysical Applications

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Environmental Engineering and Earth Sciences

In cooperation with UNAVCO and Grand Resources, Inc.

Funded by U.S. Department of Energy National Energy Technology Laboratory



U.S. DEPARTMENT OF  
**ENERGY**



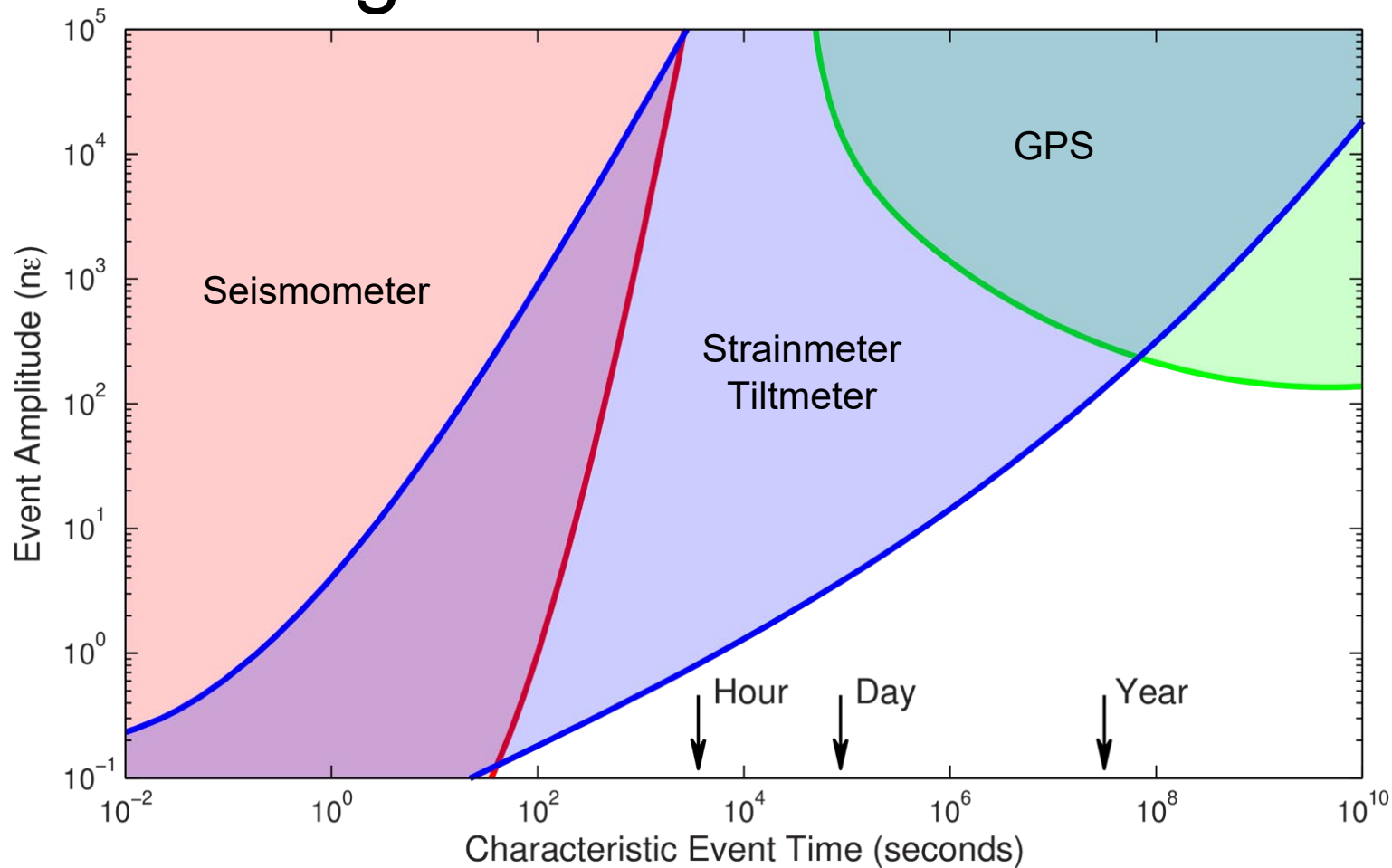
# Background on Deformation

Strain is an important observable

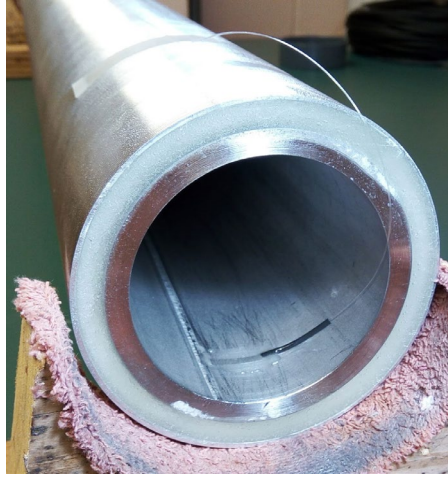
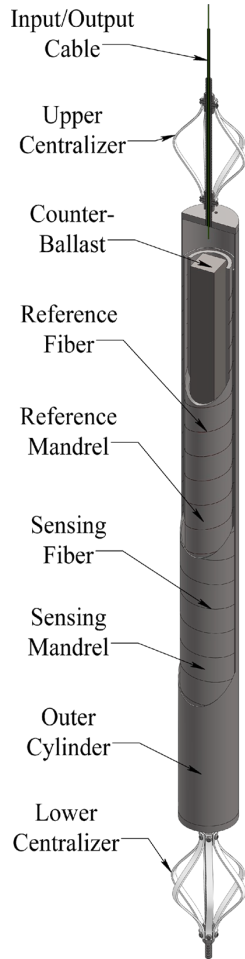
$$\Delta\sigma = C \Delta\epsilon$$

- Tectonic deformations
  - Aseismic, coseismic, post-seismic
- Slope stability
- Ocean ridge spreading
- Hydrocarbon reservoir management
- Sediment compaction
- CO<sub>2</sub> sequestration

# Background on Deformation



# Embedded Optical Fiber Systems

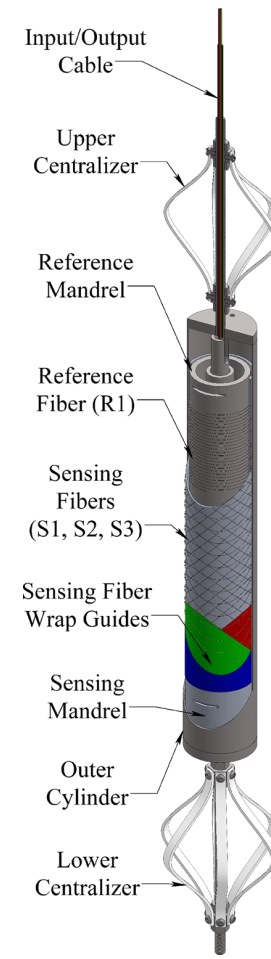
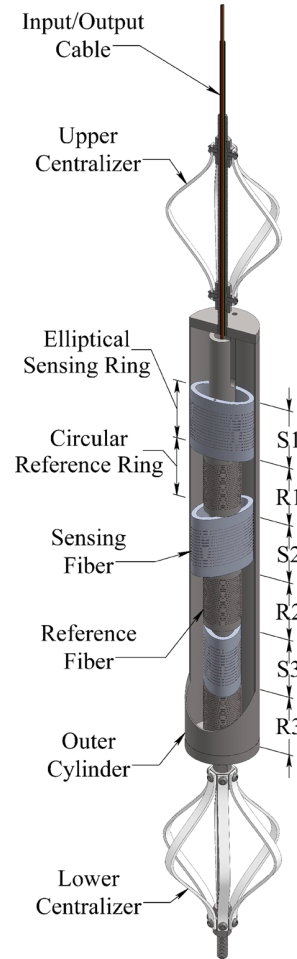
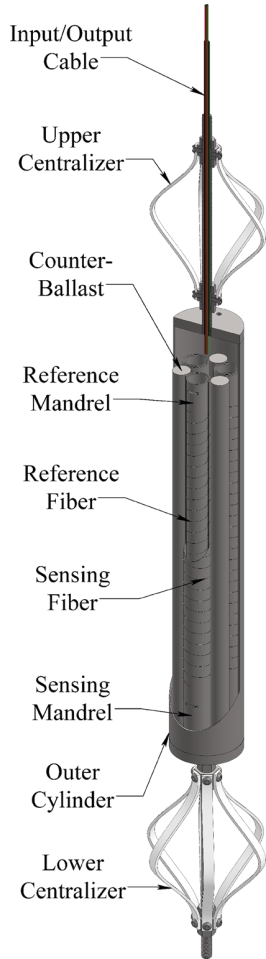


## Optical Fiber Areal Strainmeter

- Fully welded exterior
- Potted interior
- 220m of fiber
- $4 \times 10^{-15}$  strain least-count
  - 0.1m borehole
  - $4 \times 10^{-16}$  meters
  - Proton  $\sim 1.6 \times 10^{-15}$  m

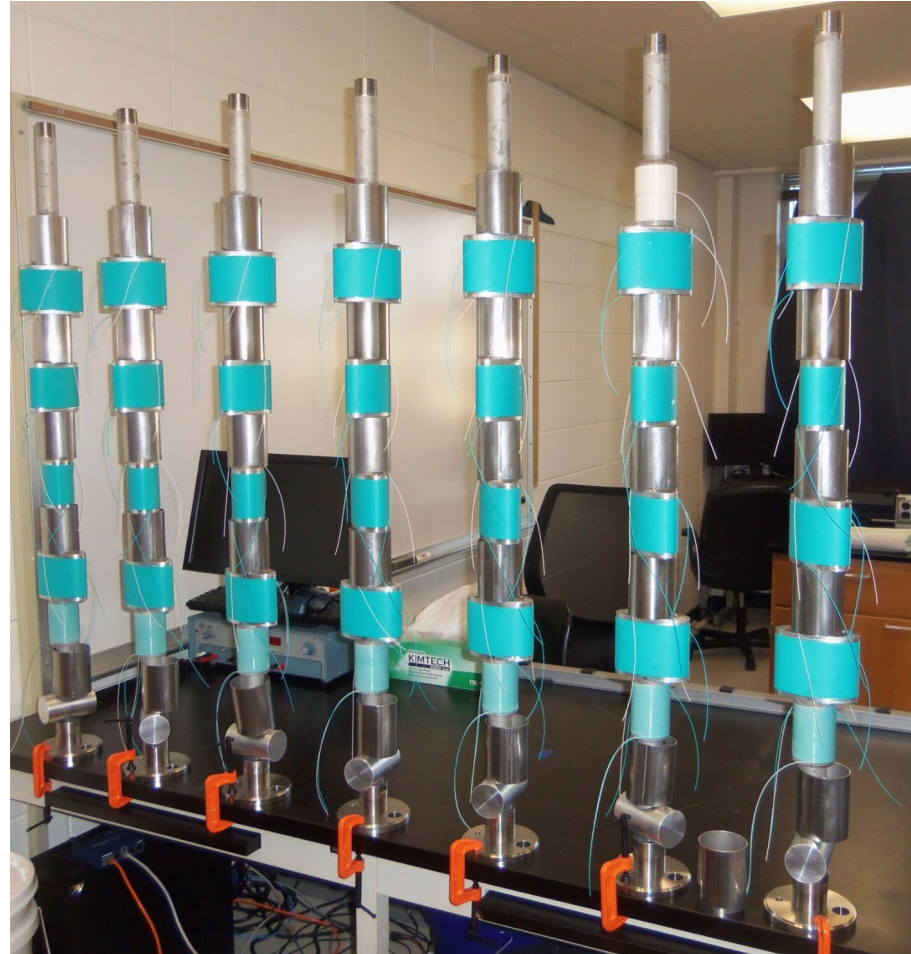
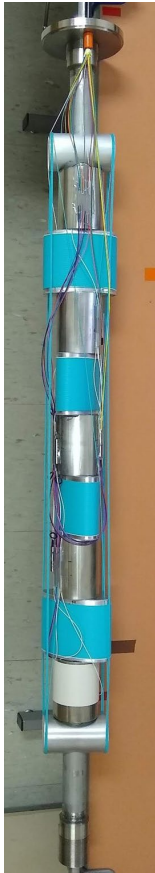
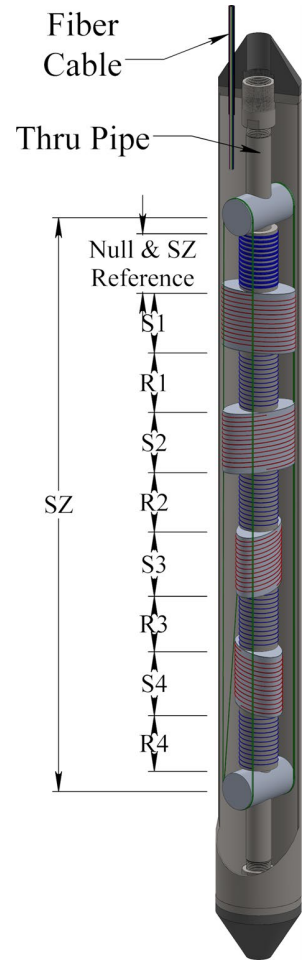


# Embedded Optical Fiber Systems





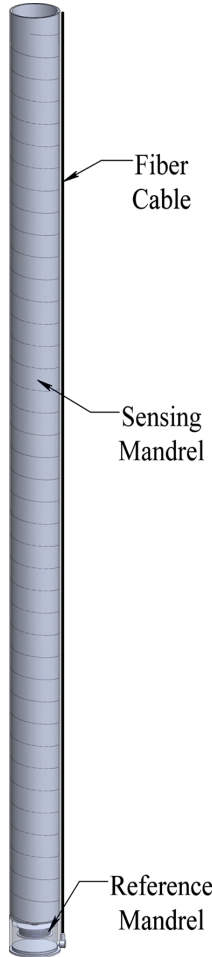
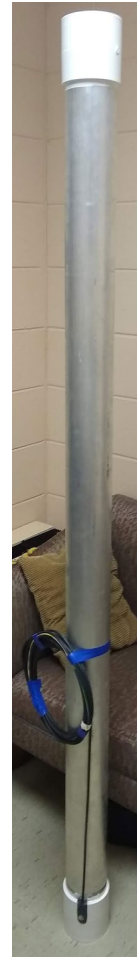
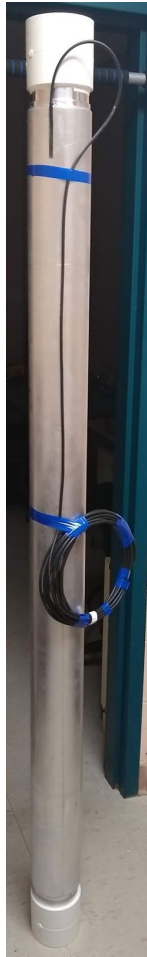
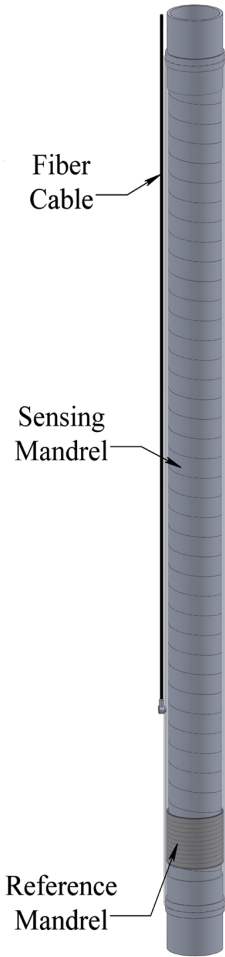
# Embedded Optical Fiber Systems



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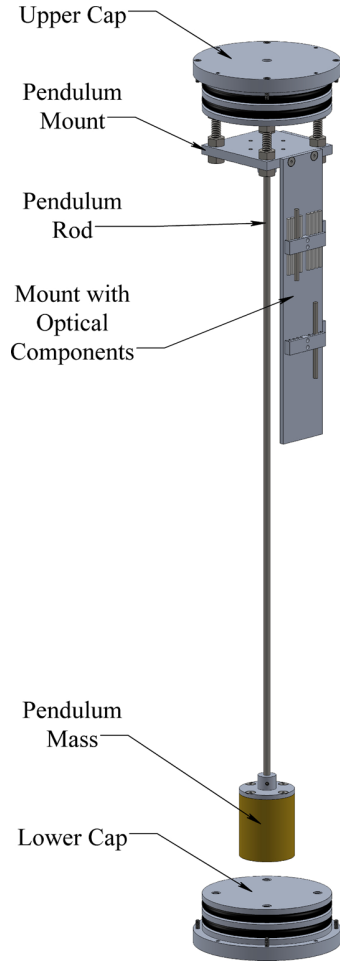
## Embedded Optical Fiber “Smart Casing”

- Three designs
  - Open-closed
  - Open-open
  - Vector tilt



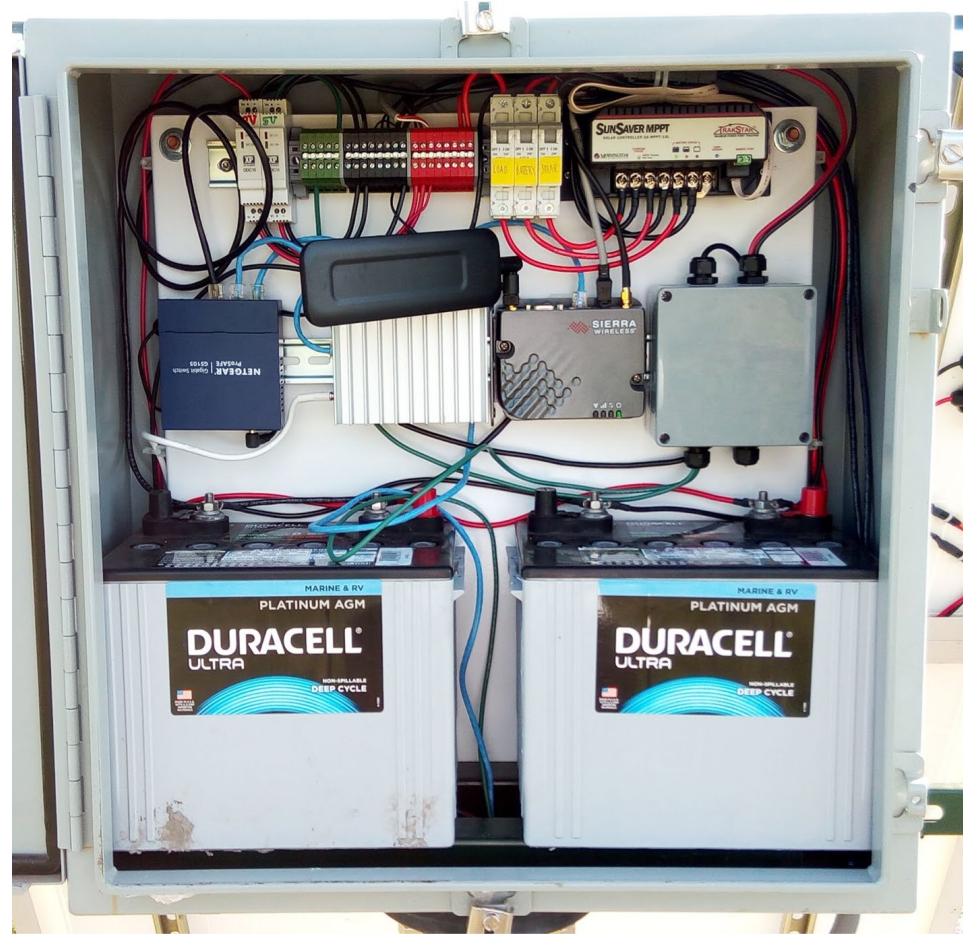


# Embedded Optical Fiber Systems

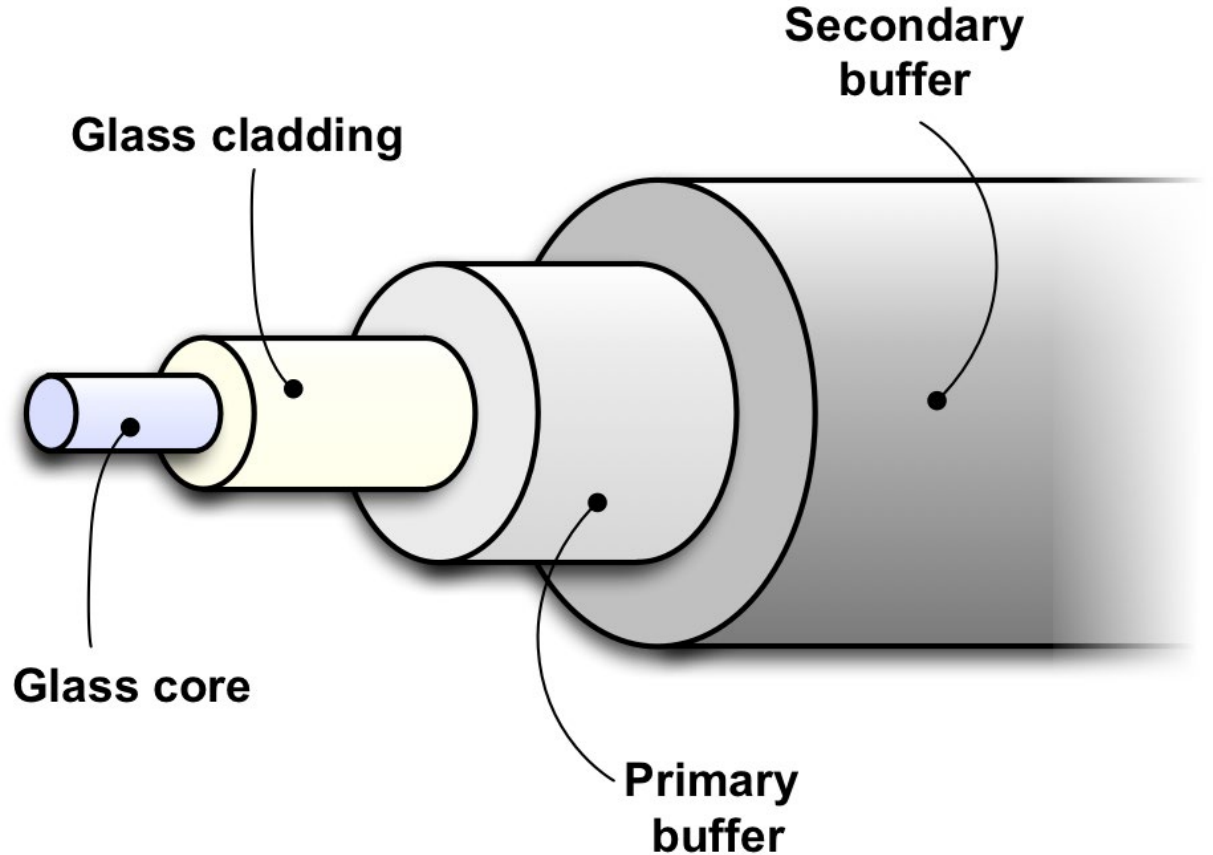




# Embedded Optical Fiber Systems



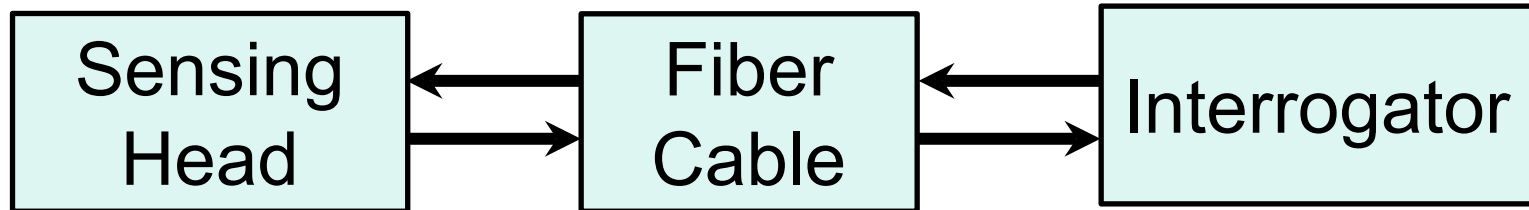
# Optical Fiber Sensing Intro



# Optical Fiber Sensing Intro

## System components

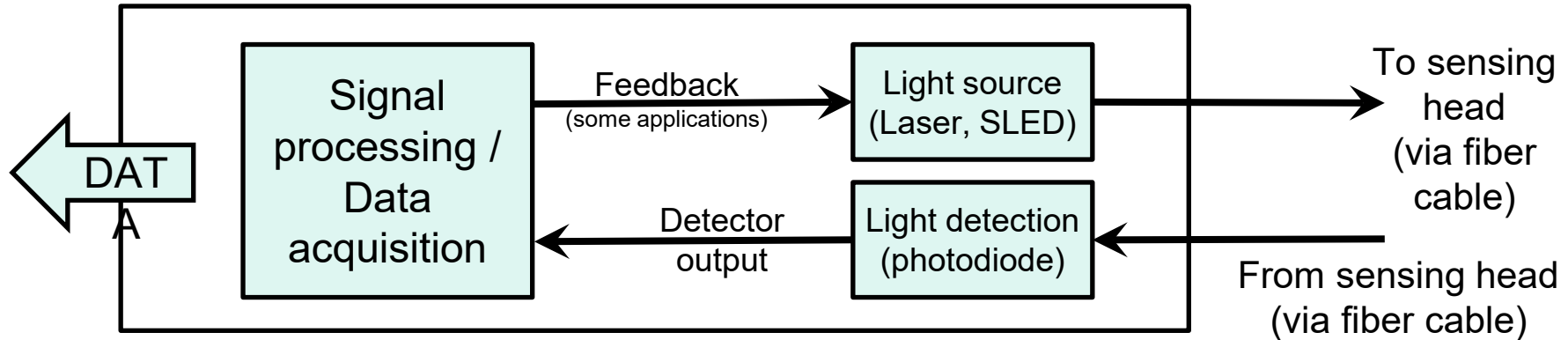
- **Sensing head** is exposed to environment (strain, pressure, vibration, temperature, etc.)
- **Optical Fiber cable** communicates between interrogator and sensing head
- **Interrogator** reads signal from sensing head



# Optical Fiber Sensing Intro

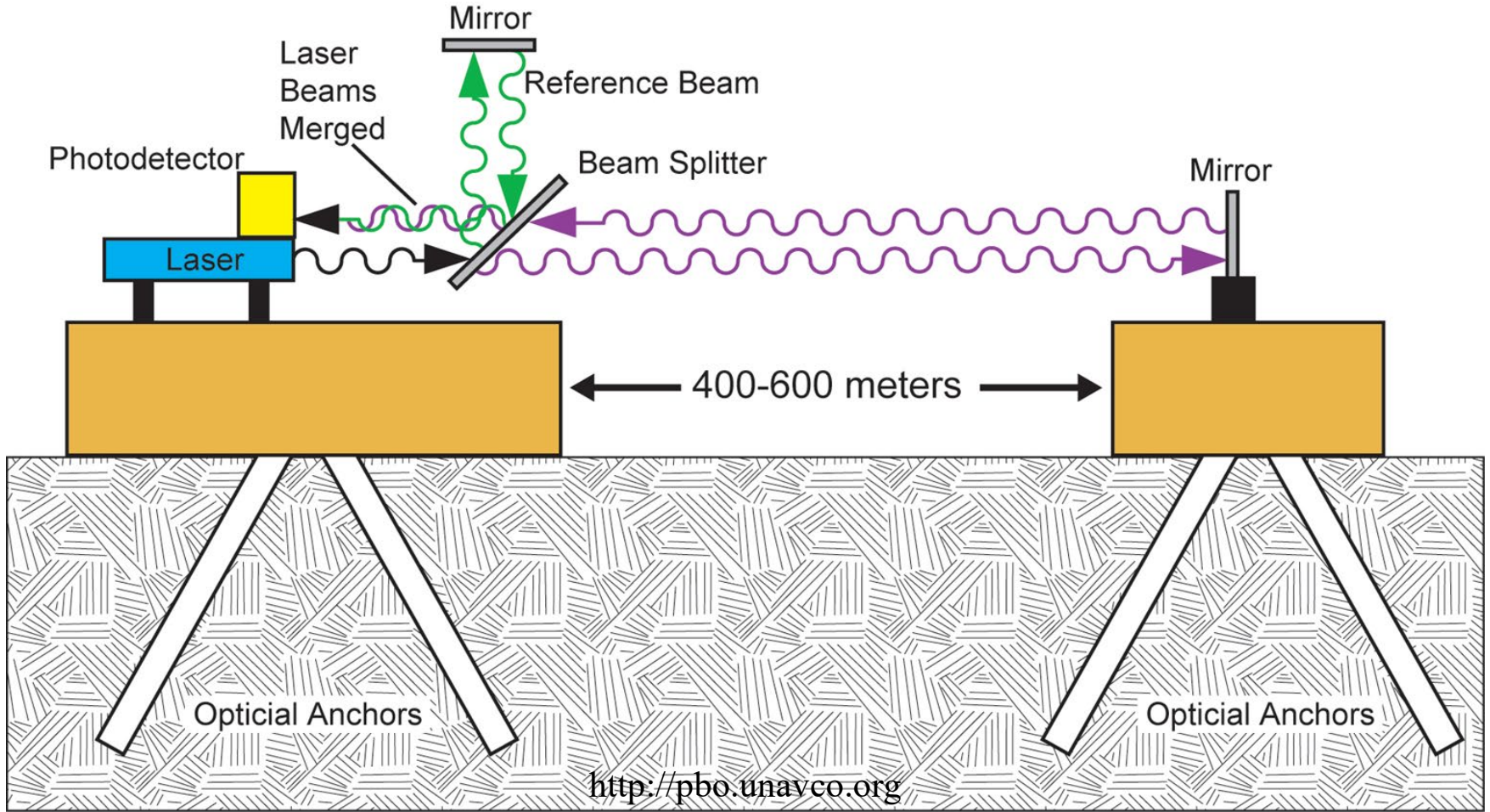
## Optical Fiber Sensor Interrogator

- **Light source** to illuminate sensing head
- **Photodetector** to convert returning light to voltage
- **Signal processor** to convert detected light into output proportional to desired measurement





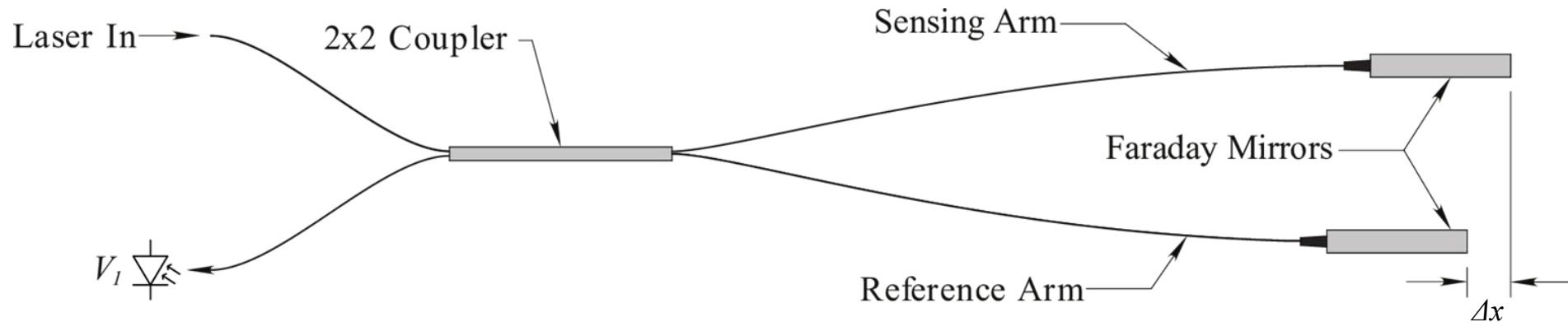
# Interferometry Basics



# Interferometry Basics

## Optical Fiber Michelson Interferometer

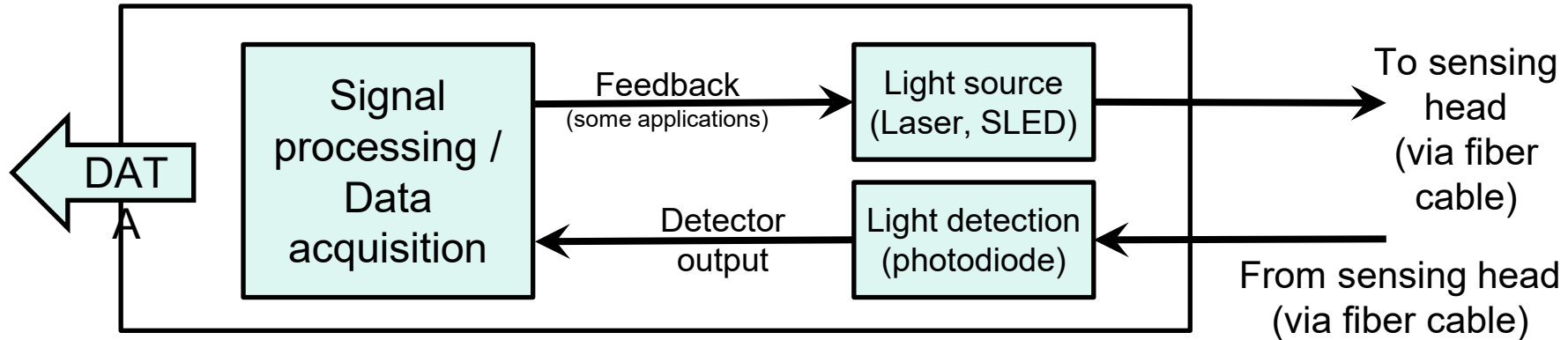
- 2x2 coupler acts as beam splitter (\$15)
- Faraday mirrors as retroreflectors (\$80 each)
  - Eliminates polarization fading



# Optical Fiber Michelson Interrogator

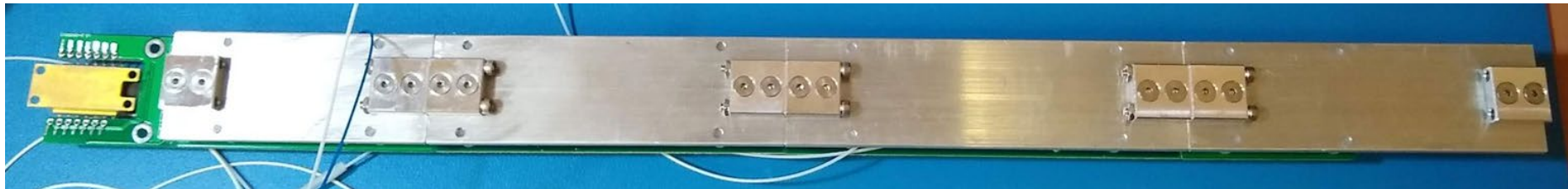
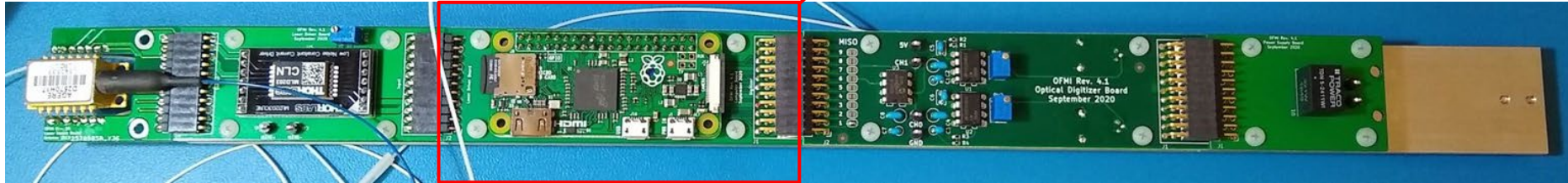
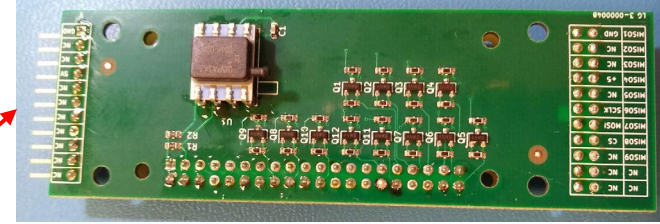
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# Optical Fiber Michelson Interrogator

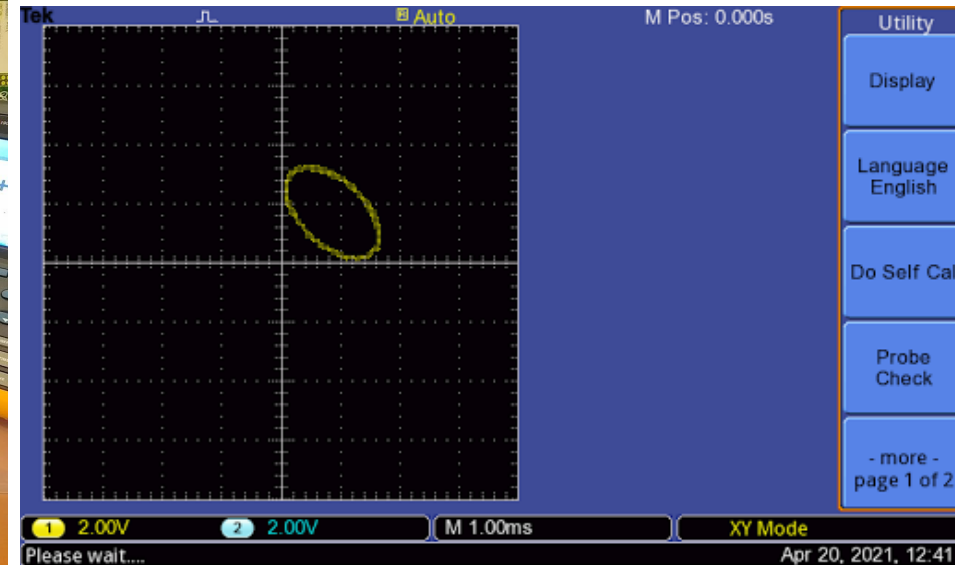
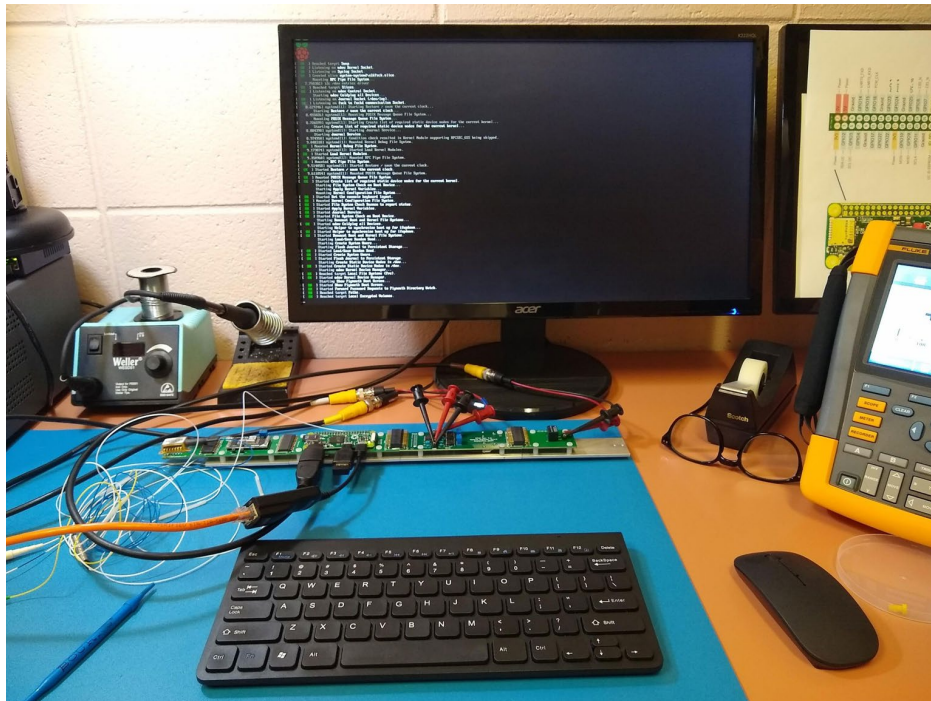
- OFMI Rev.4.1
  - Laser diode and current source
  - Computer (Raspberry Pi Zero)
  - Optical Digitizer
  - Power supply





# Optical Fiber Michelson Interrogator

- OFMI Rev.4.1 assembly and testing
  - 1.9W with laser maxed, 1.2W to 1.6W average



# Optical Fiber Michelson Interrogator

## UNAVCO GTSM

- 25W



## Clemson Strainmeters

- AVN4: 8W
- AVN3: 15W



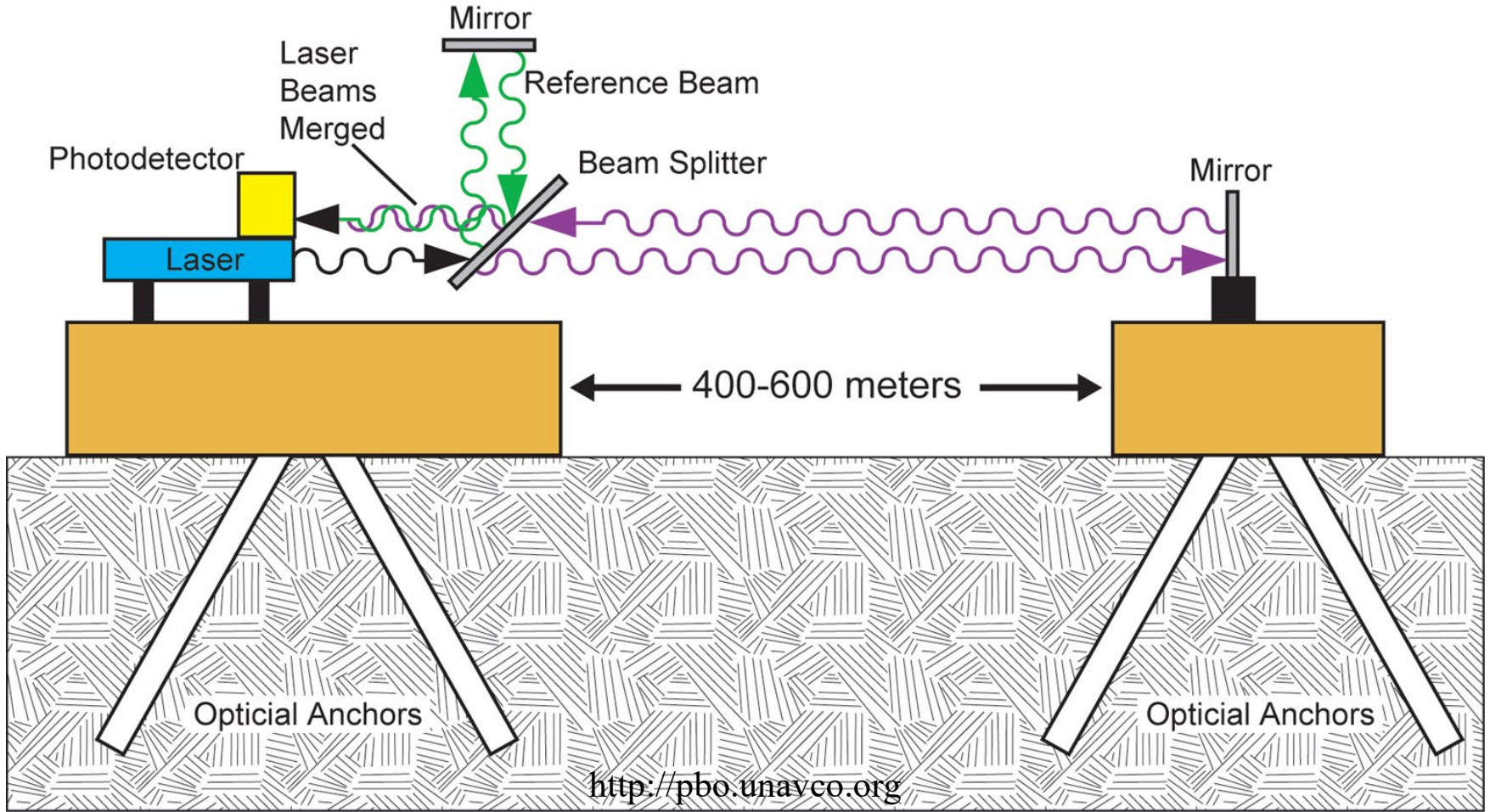
## Kinematics STS-5 and Q330

- 1.3W



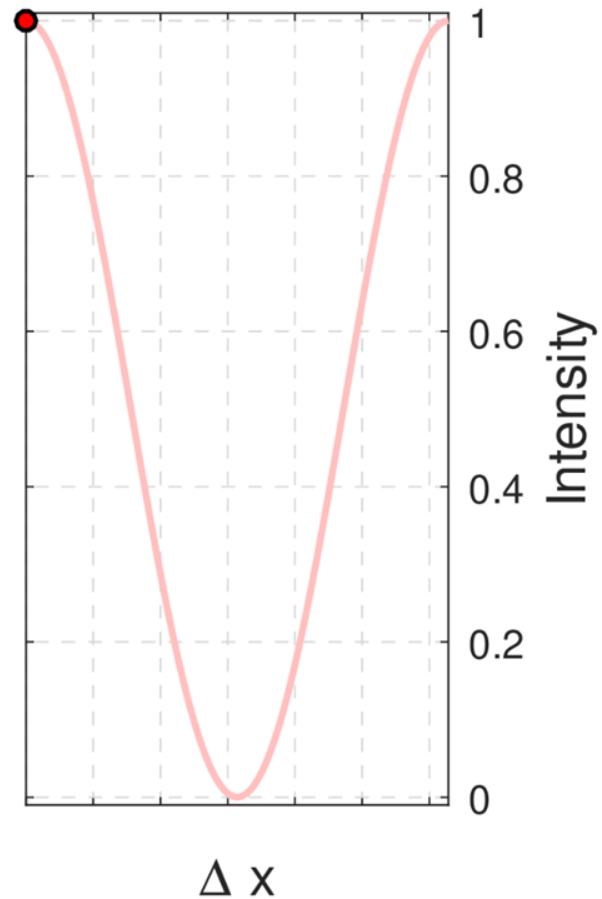
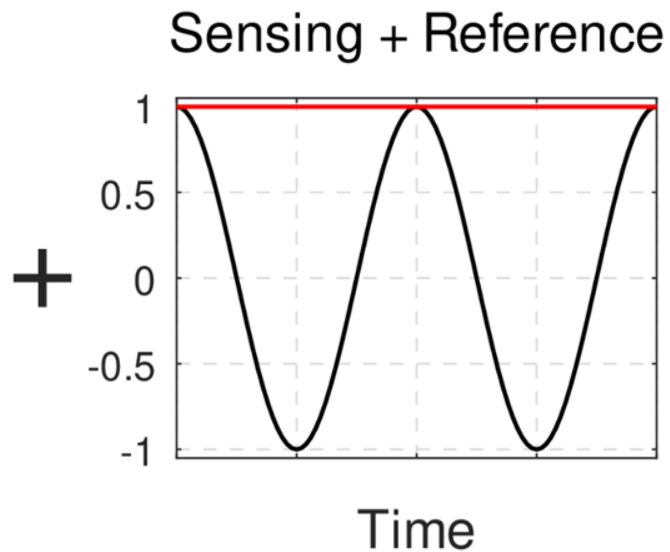
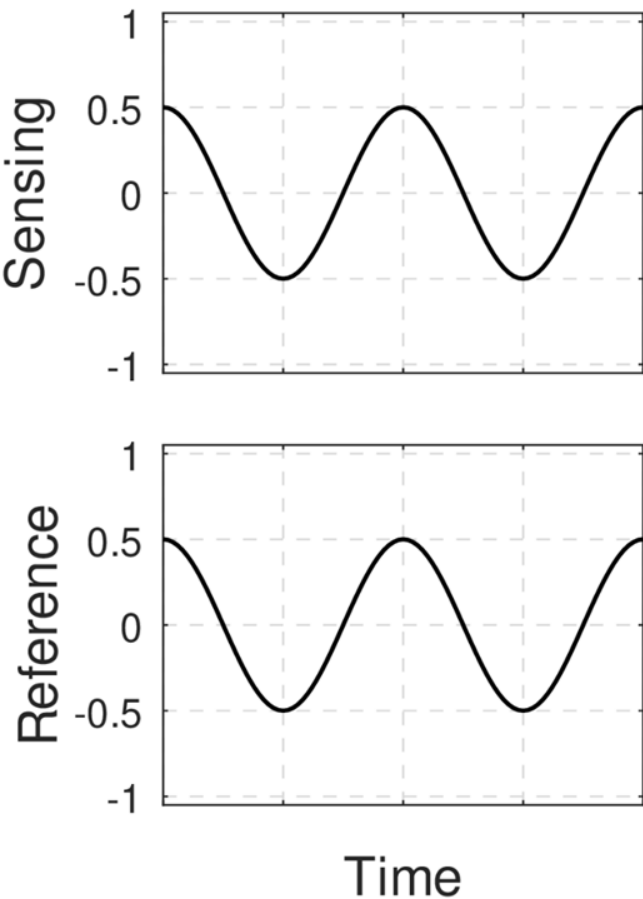
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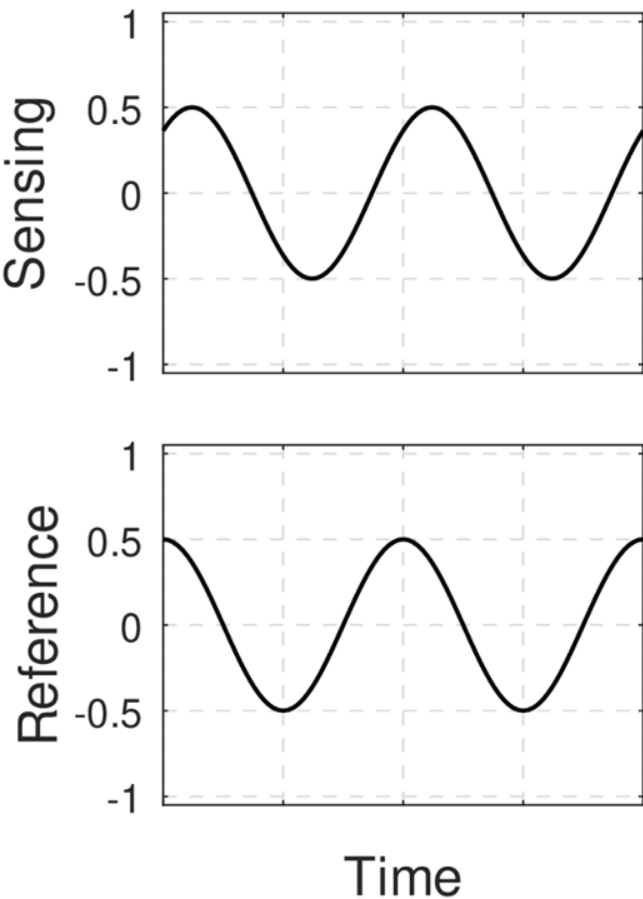




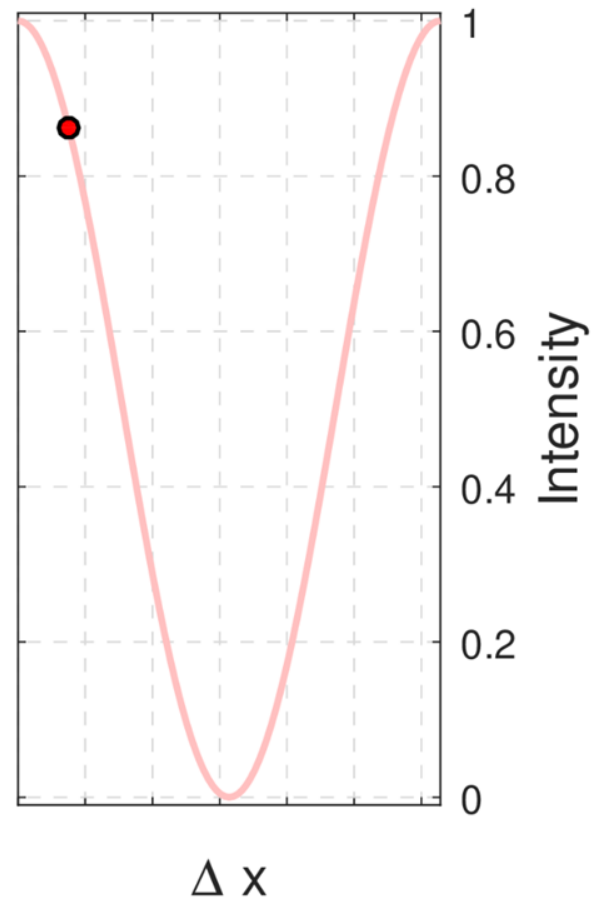
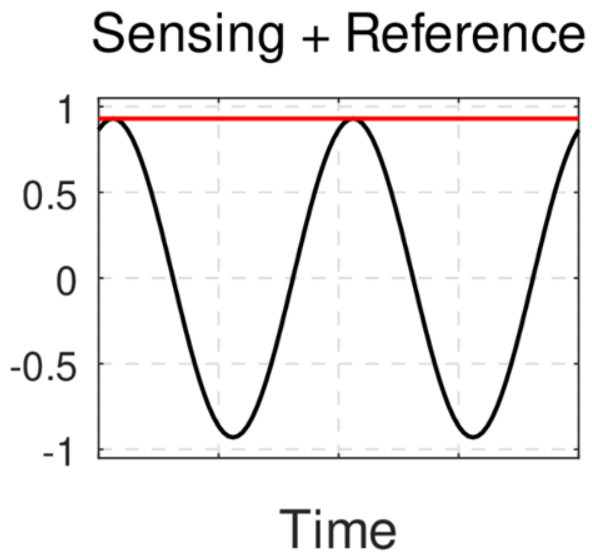
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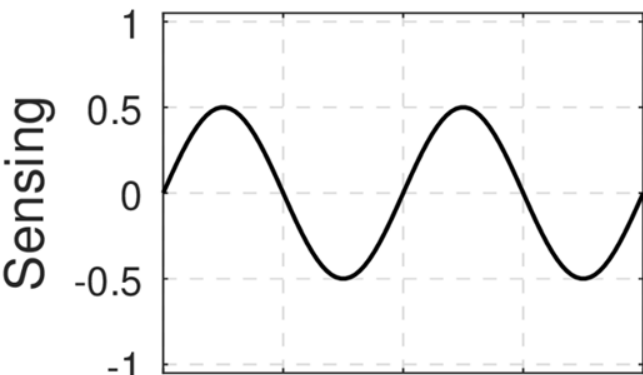
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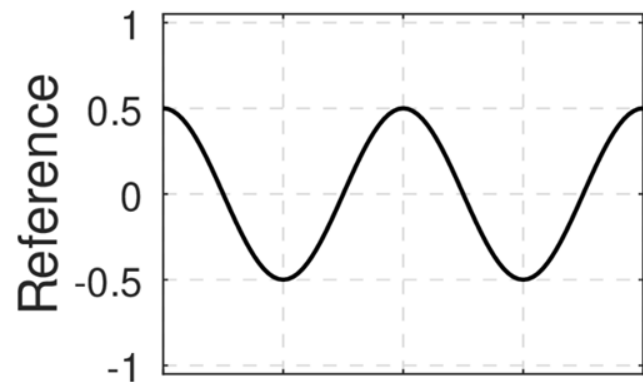
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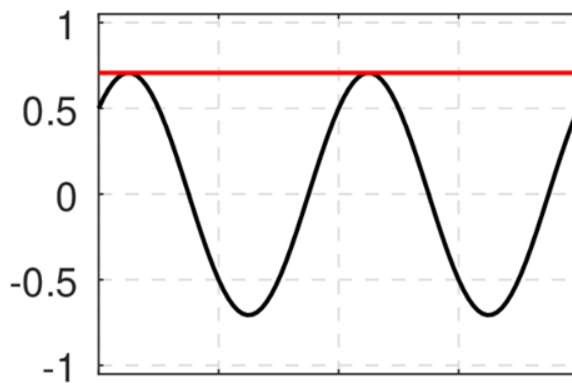


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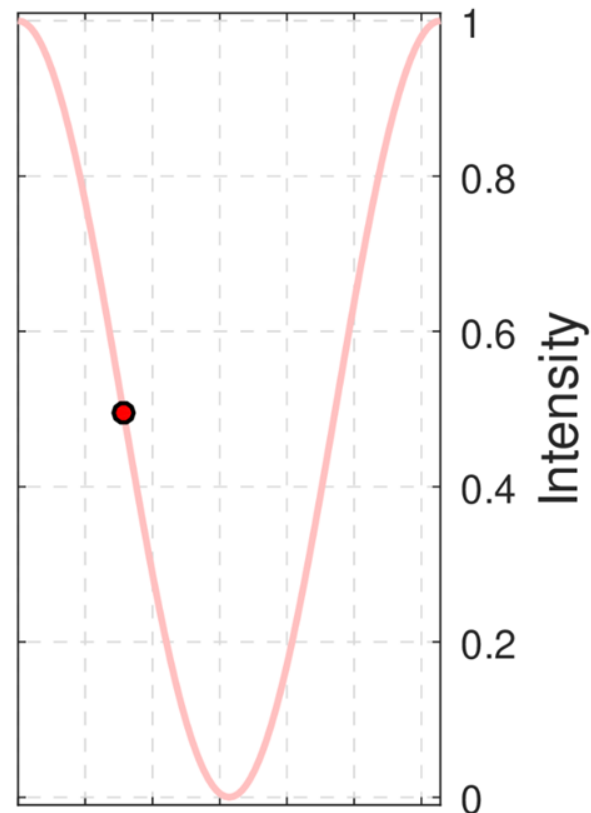


Time

Sensing + Reference

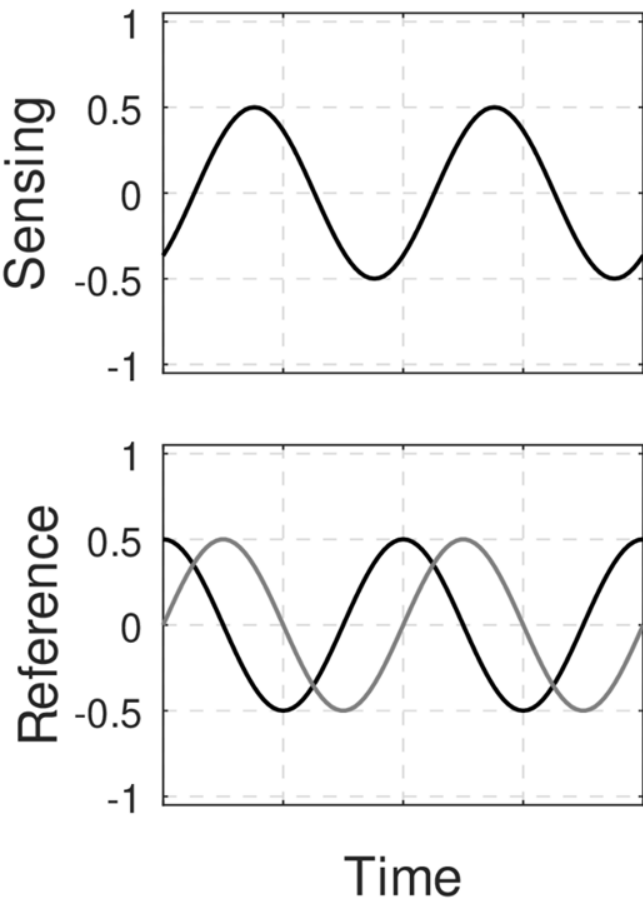


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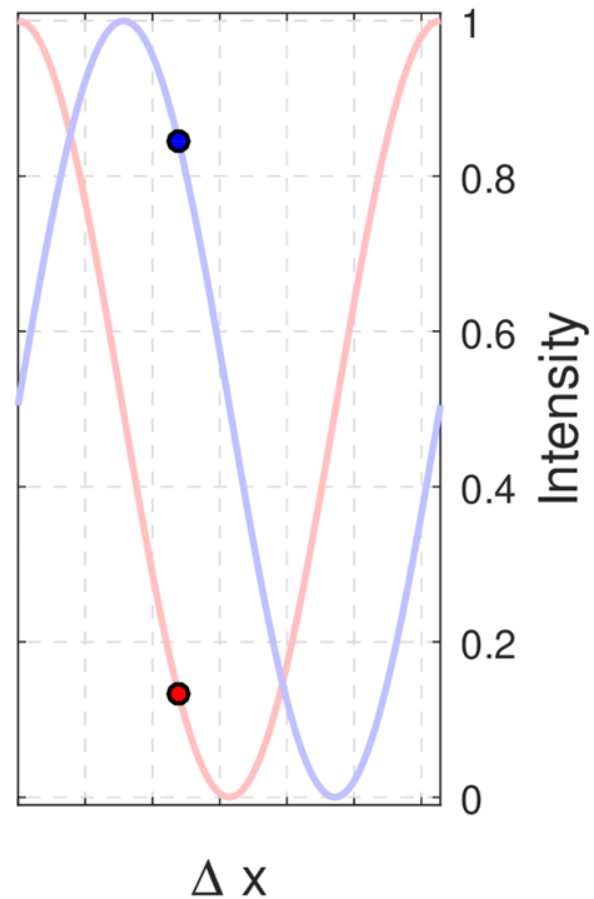
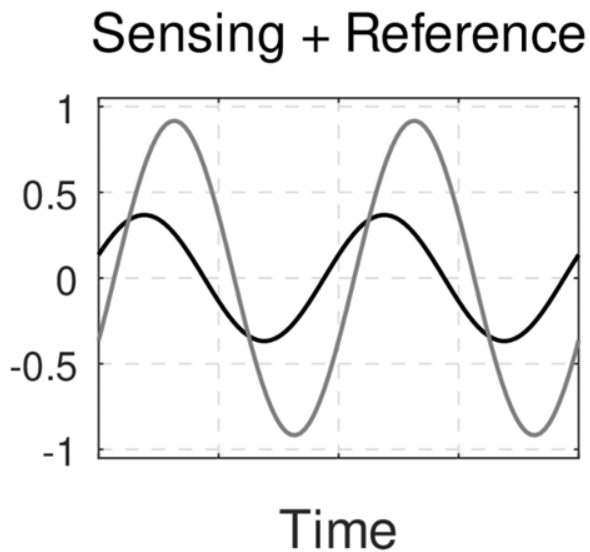


$\Delta x$

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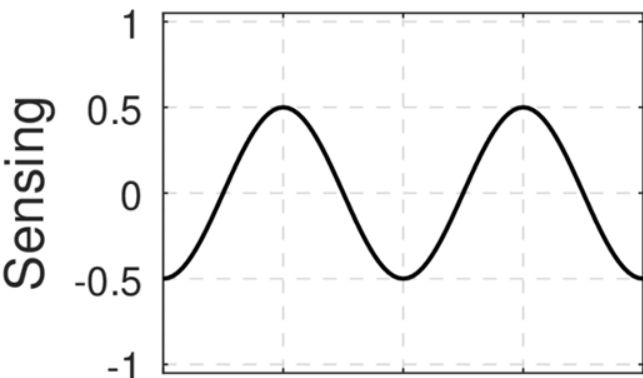


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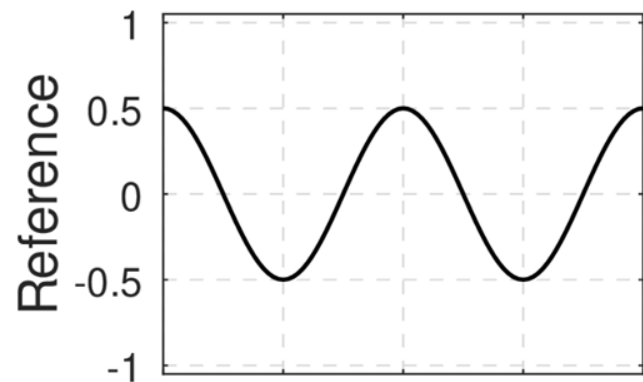




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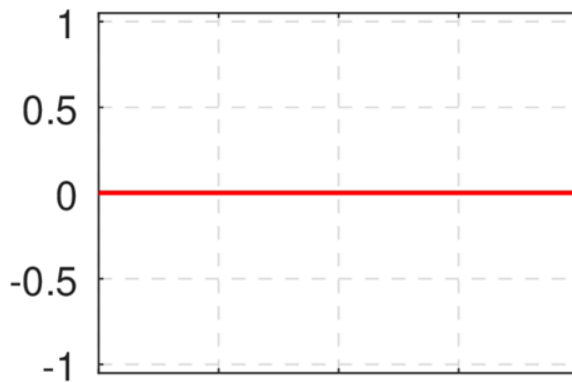


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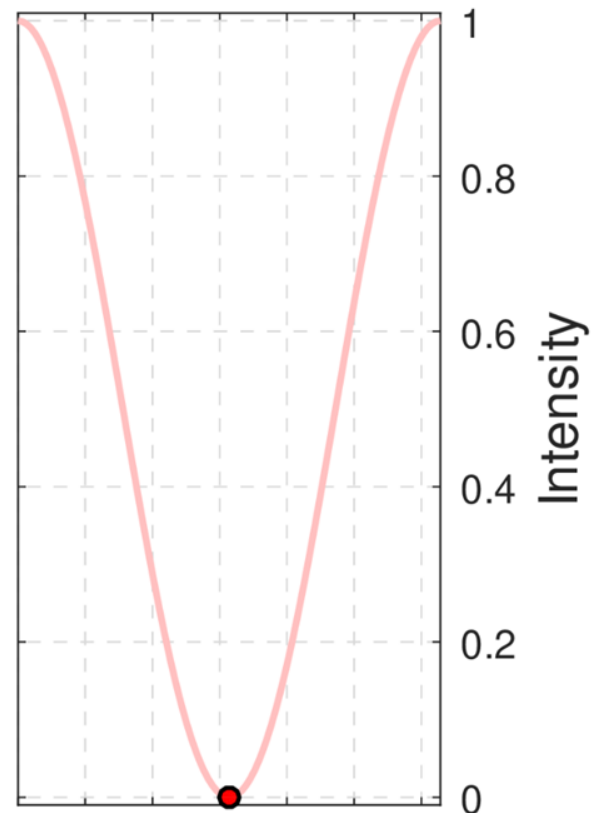


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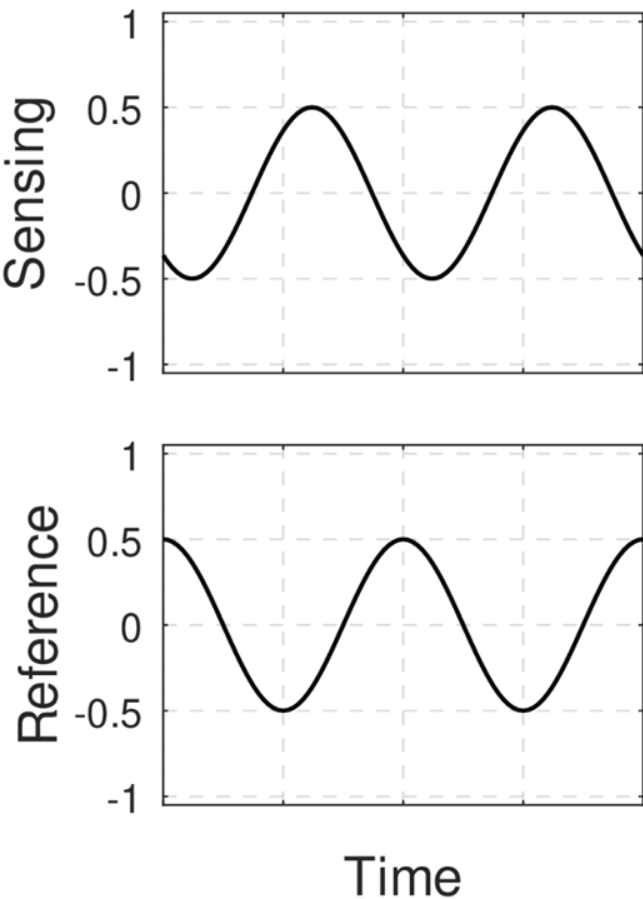


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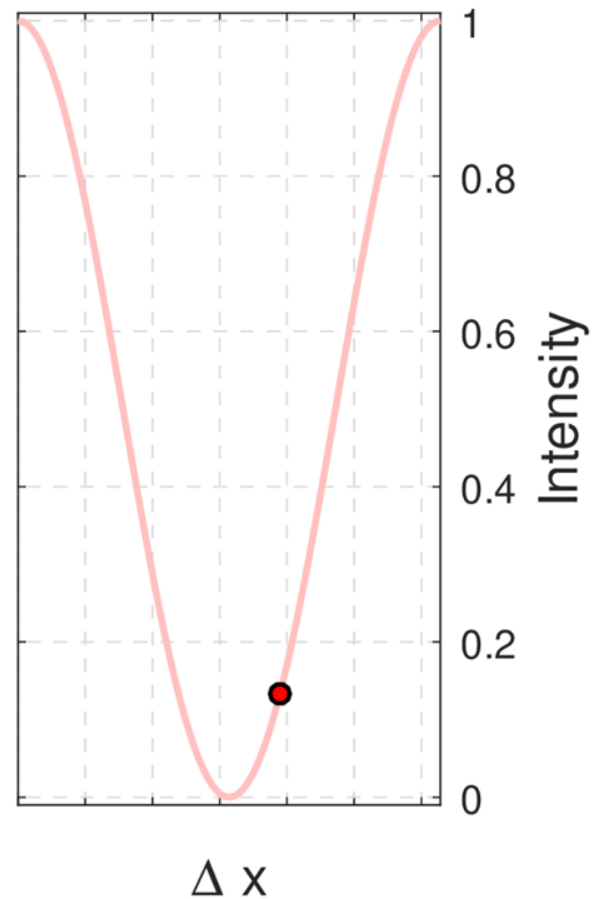
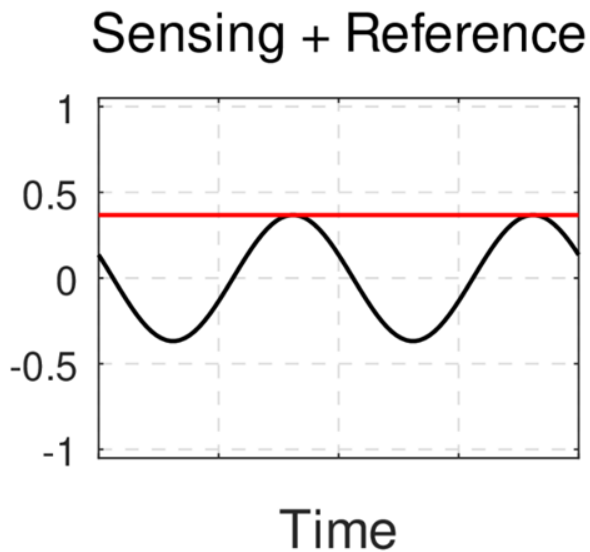


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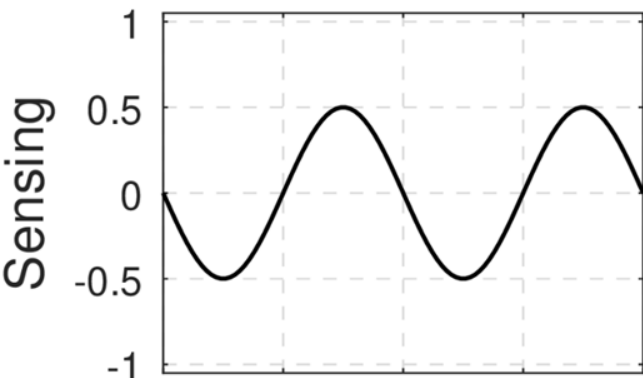
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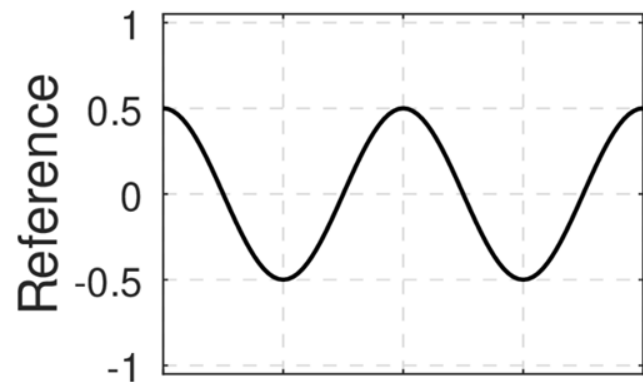
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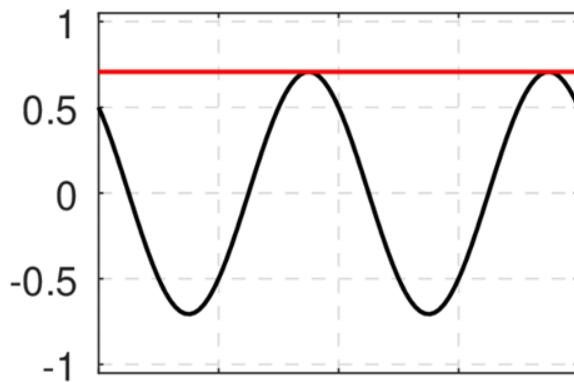


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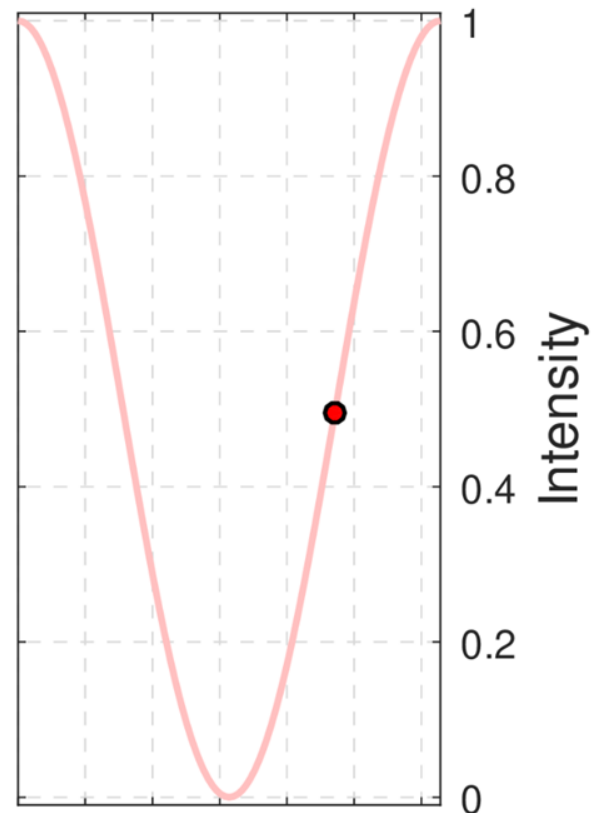


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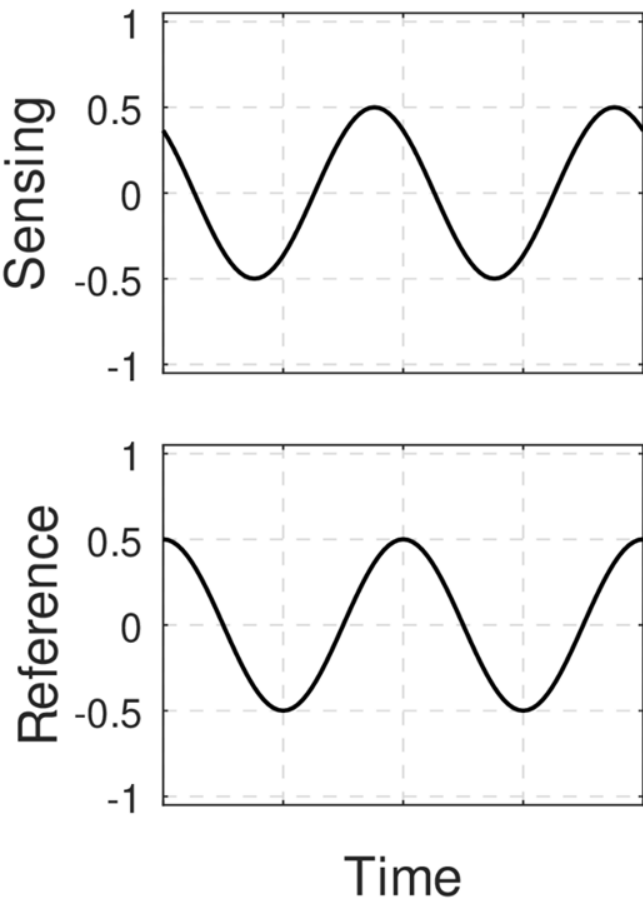


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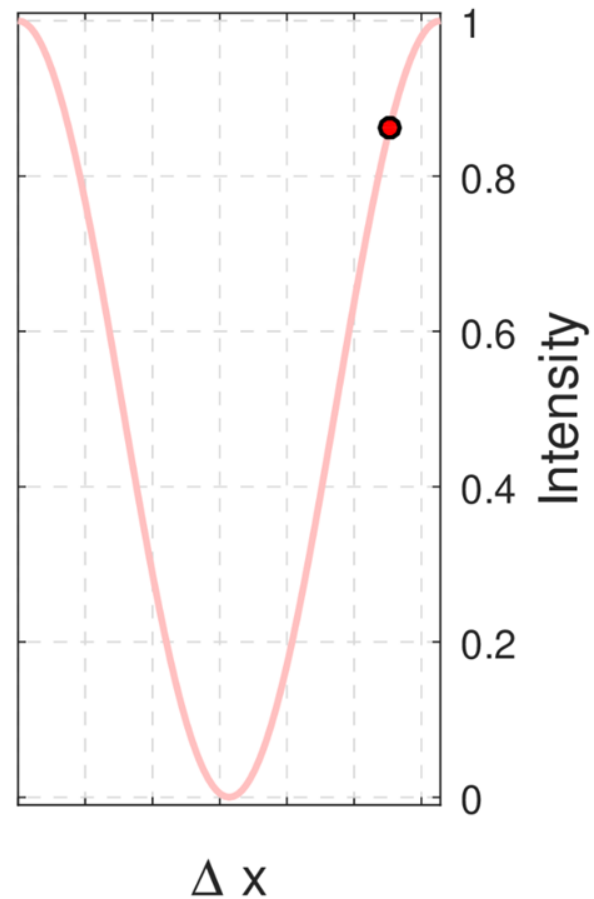
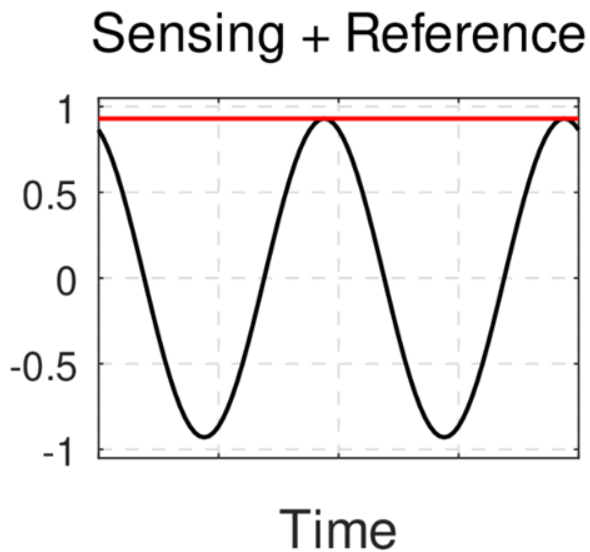


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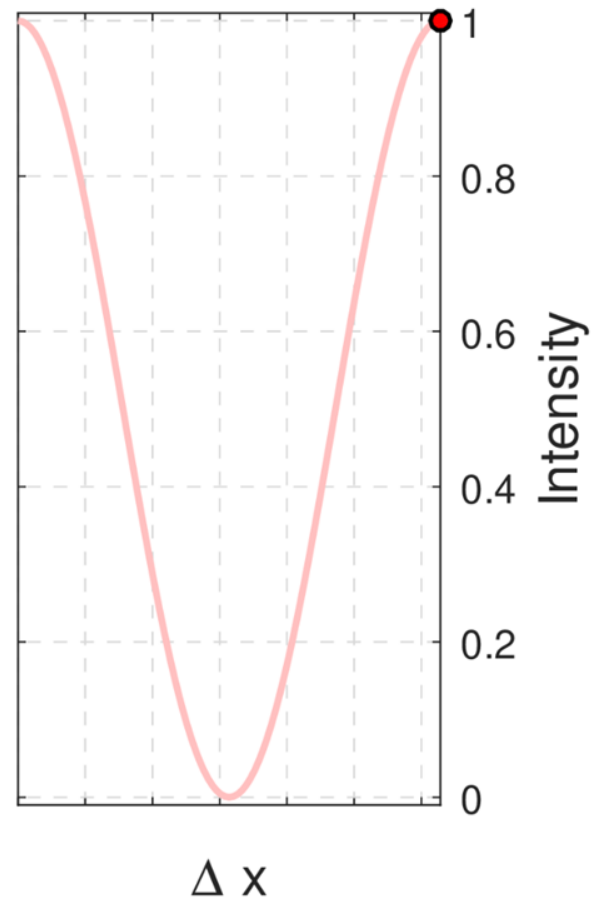
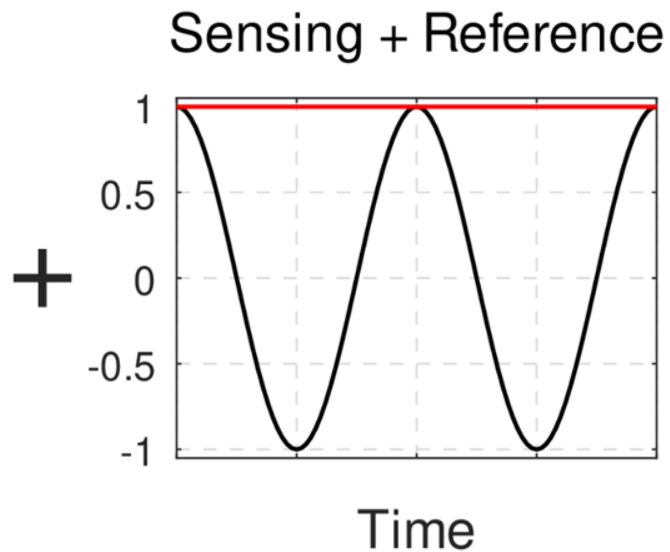
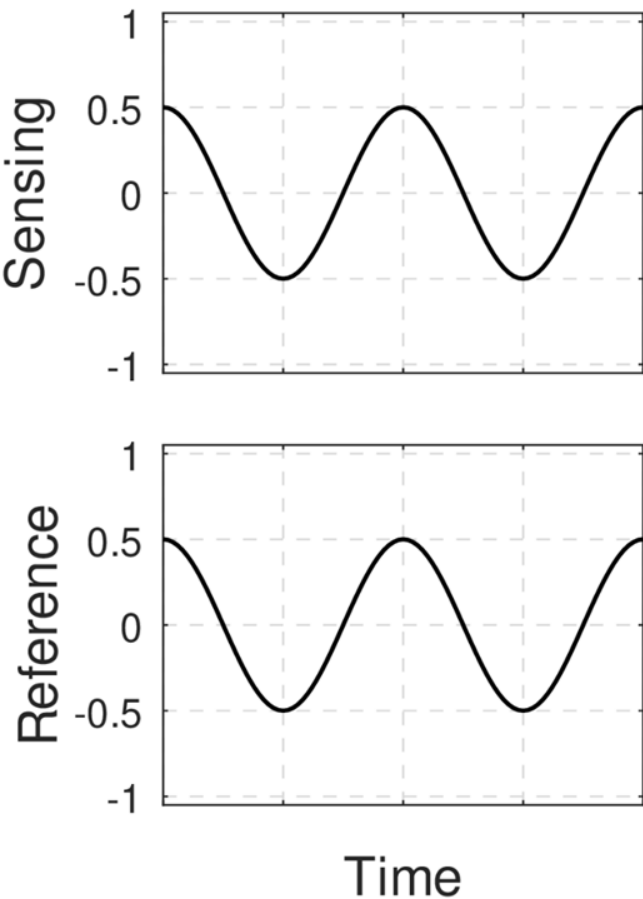


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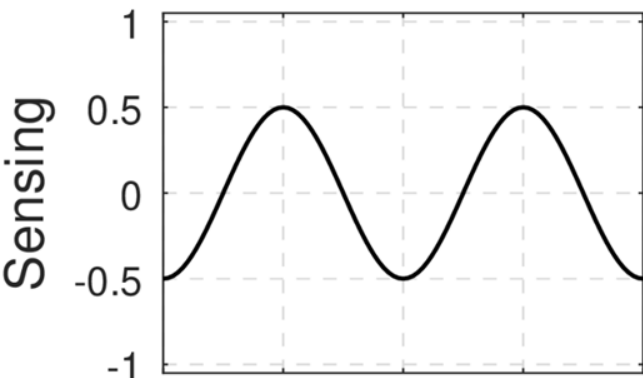




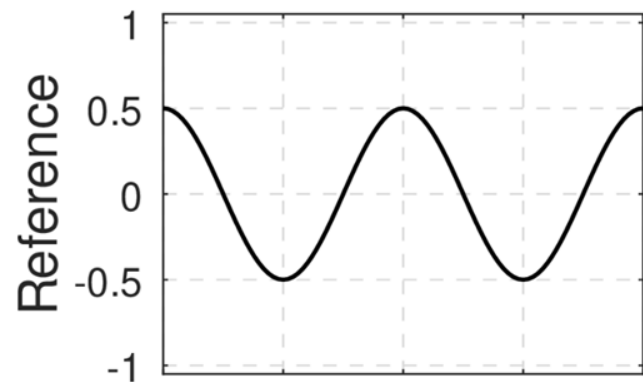
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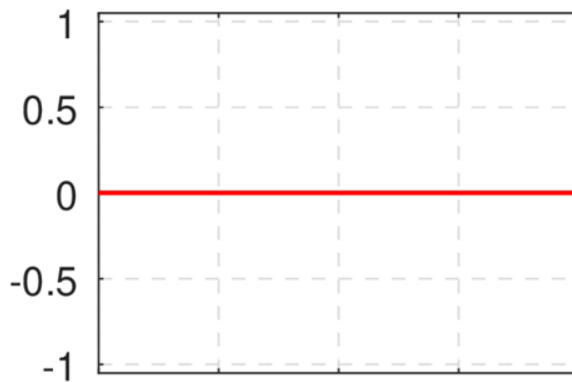


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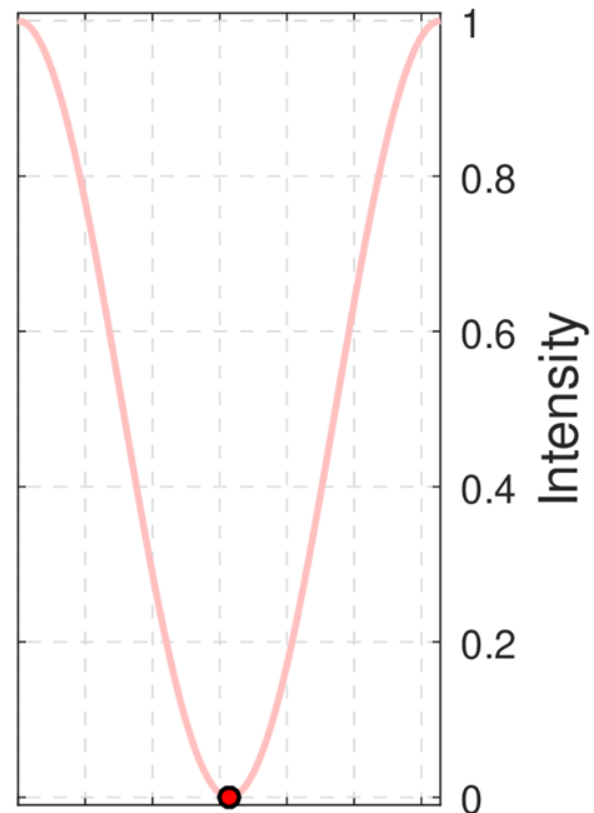


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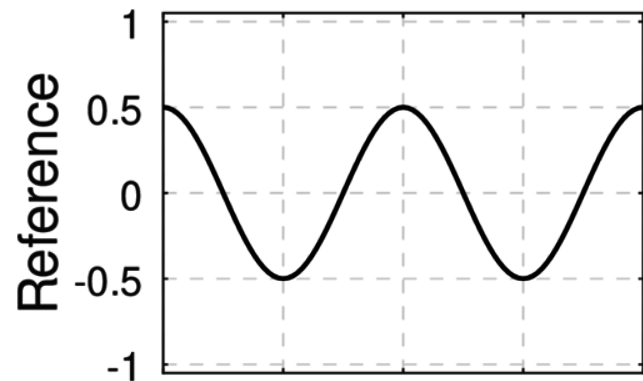
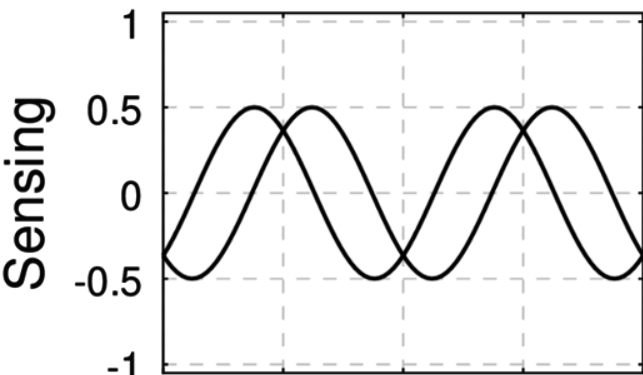


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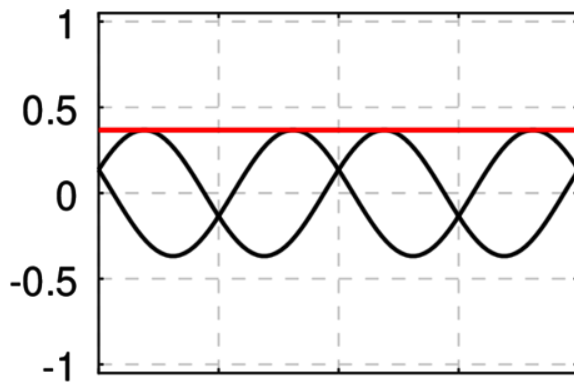
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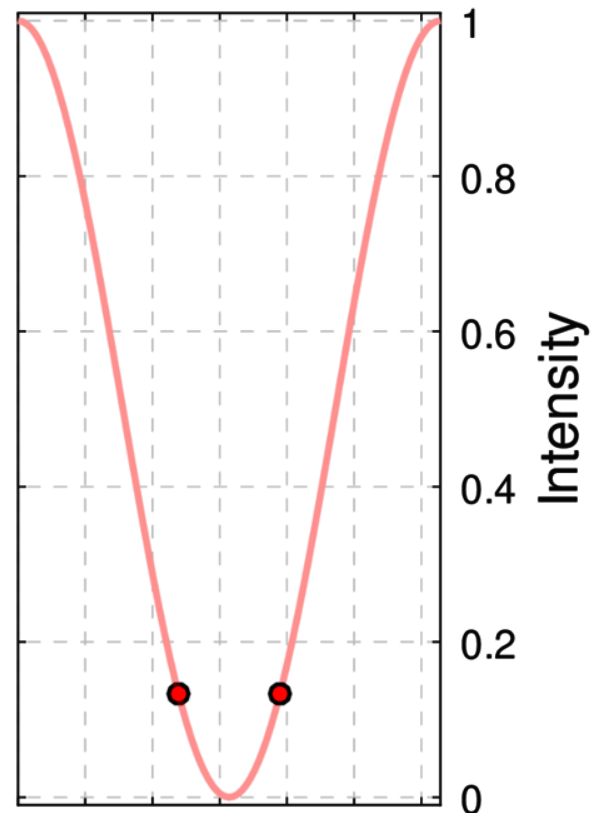


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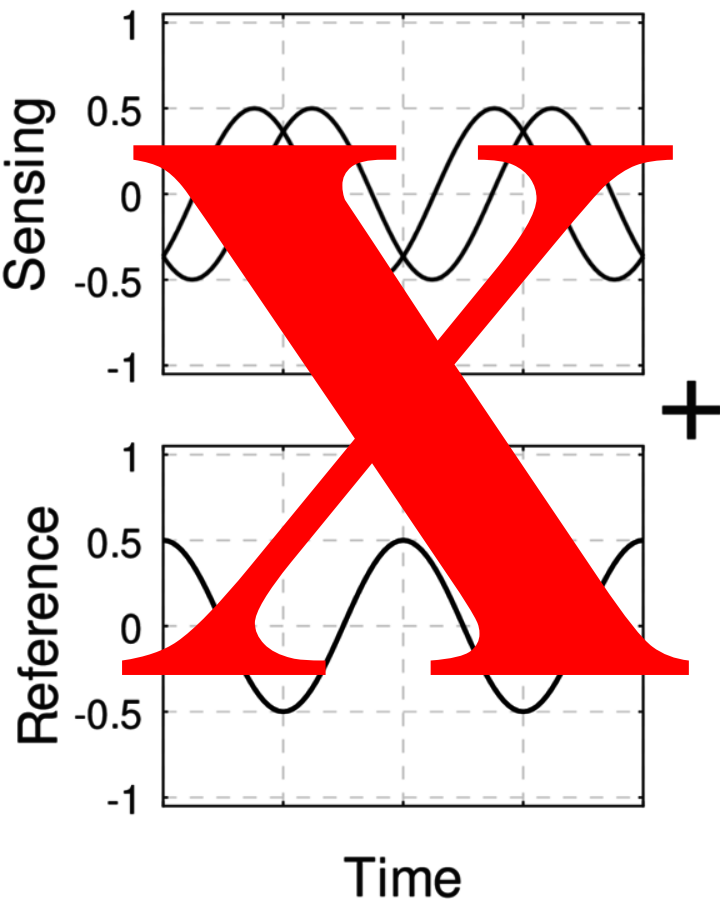


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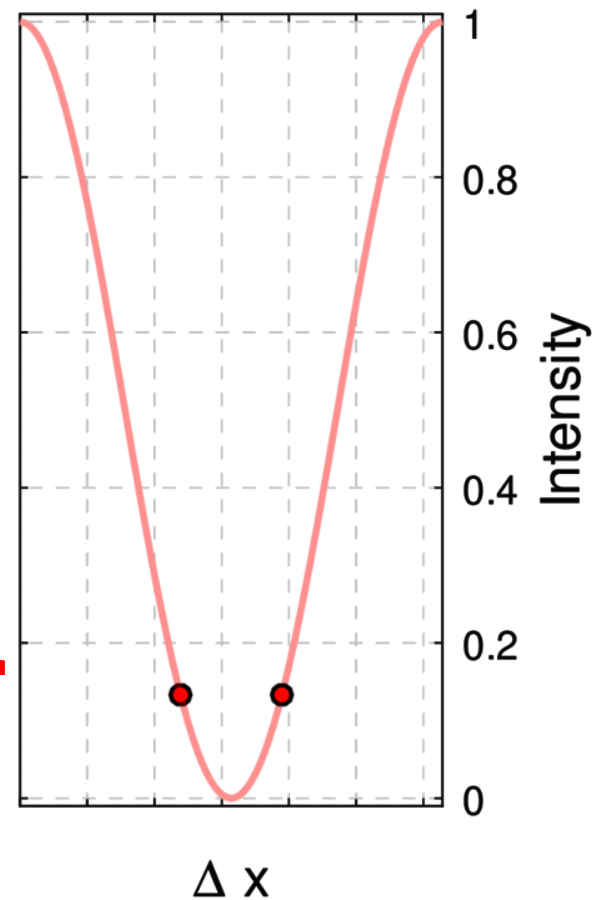
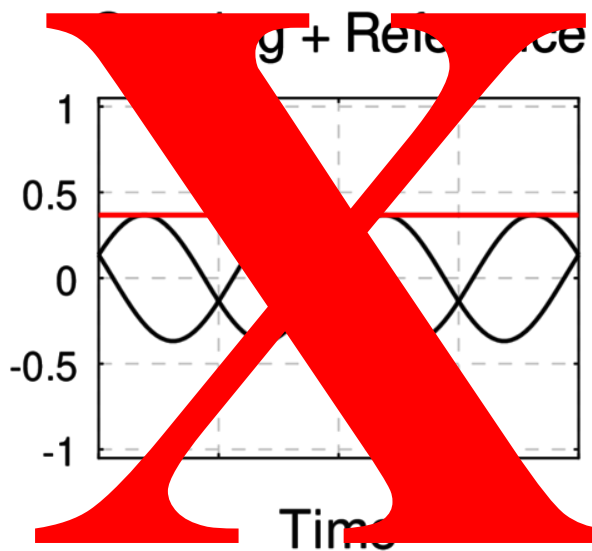


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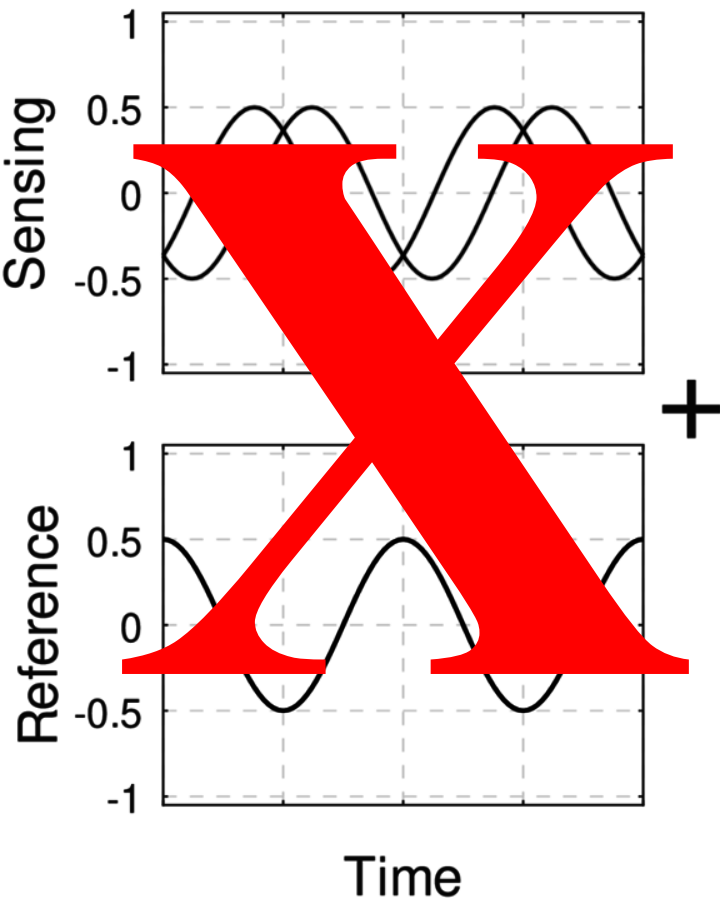


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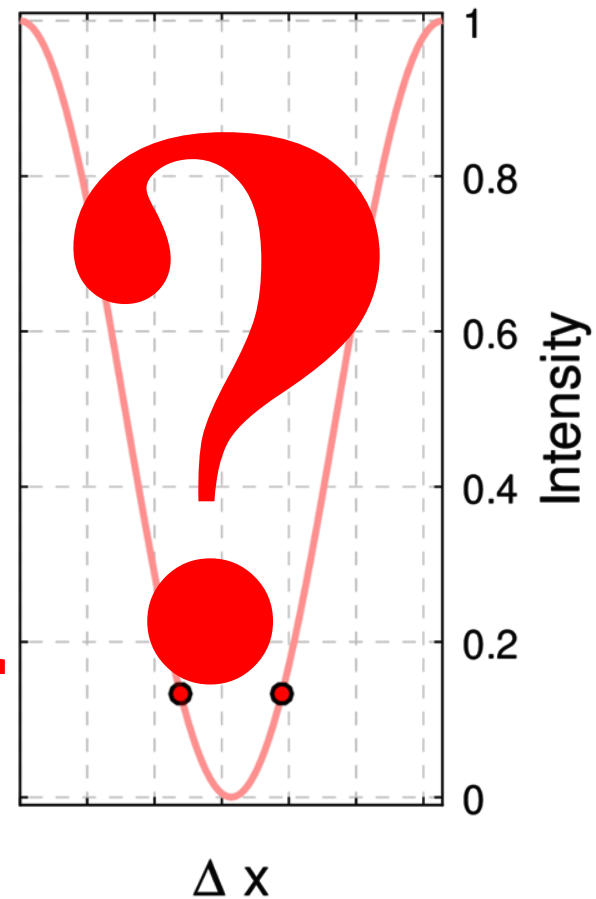
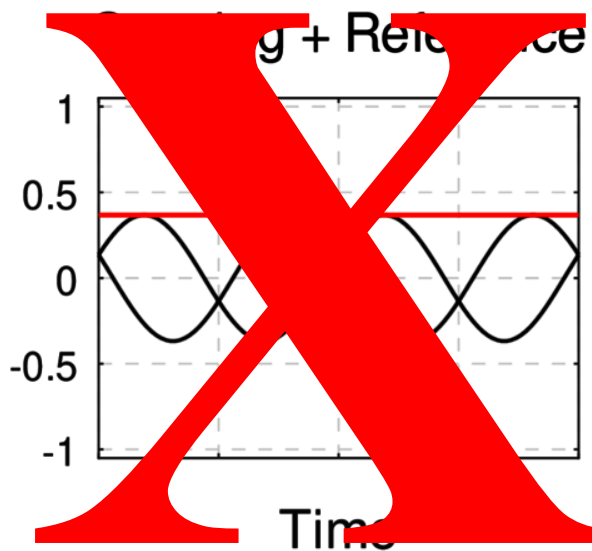




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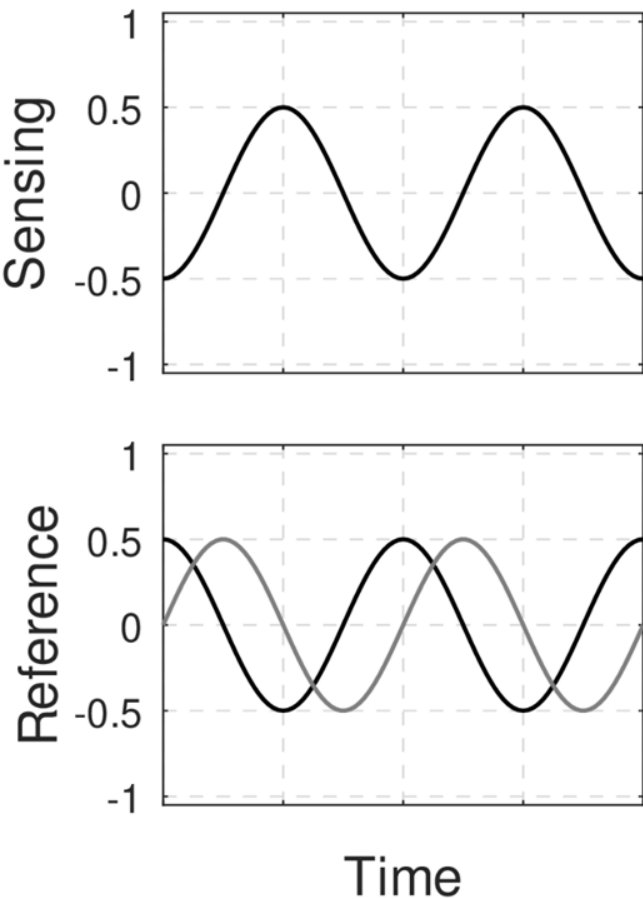


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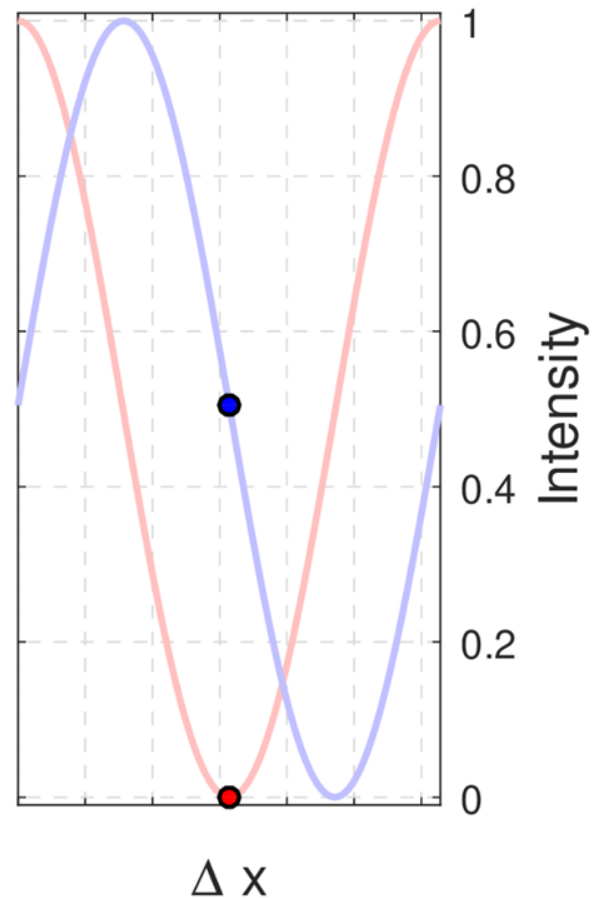
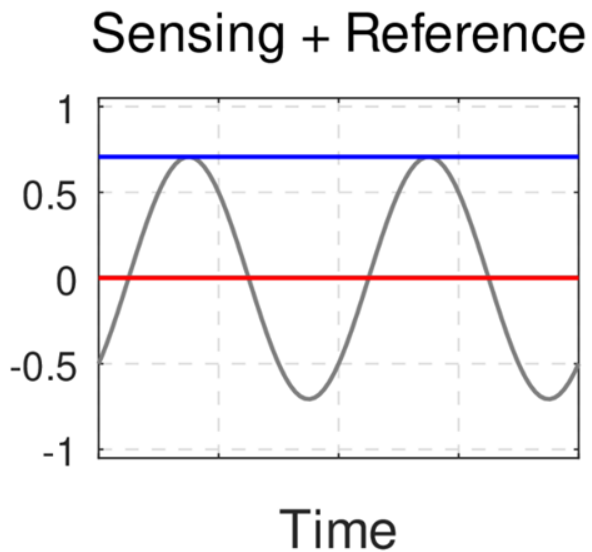


Aragorn, you need more interference fringes

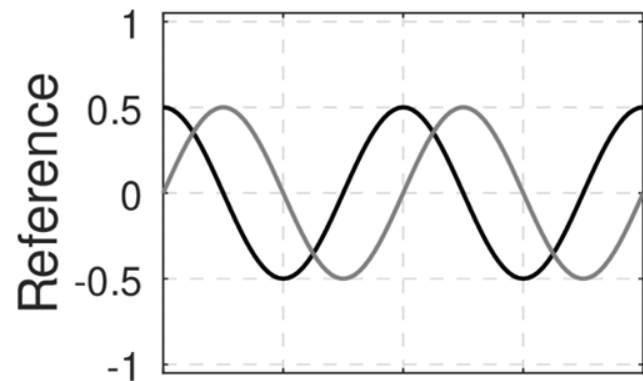
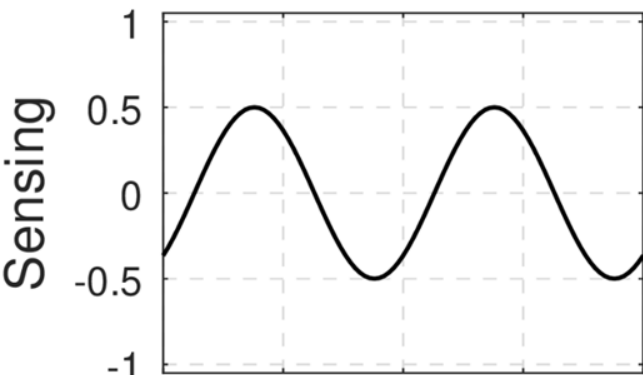
# Intermediate Interferometry



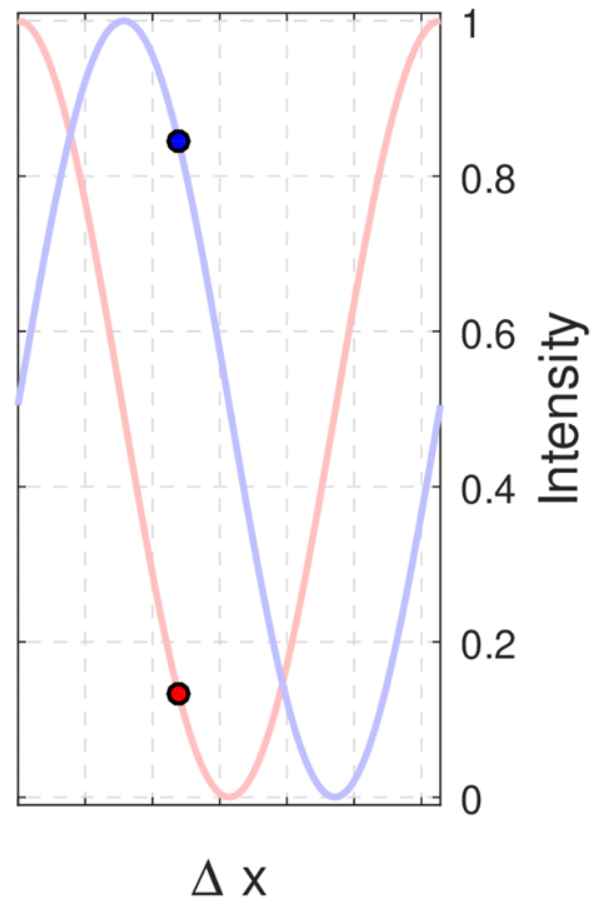
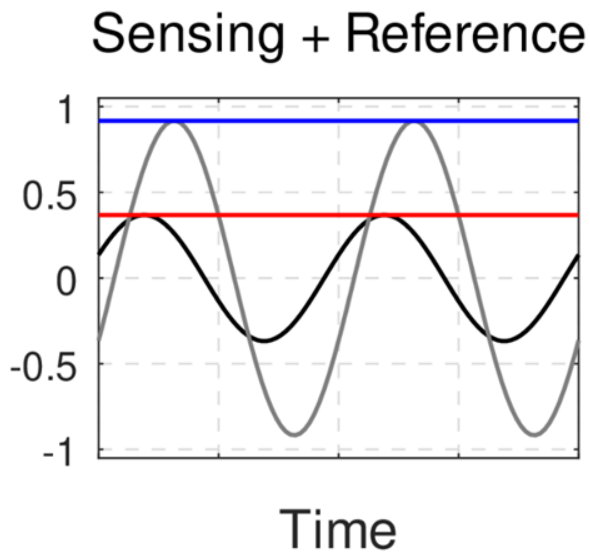
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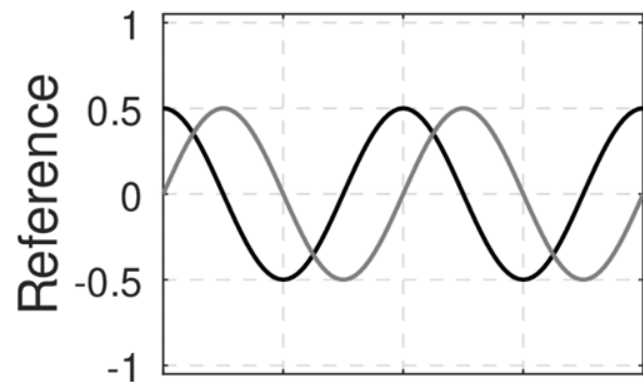
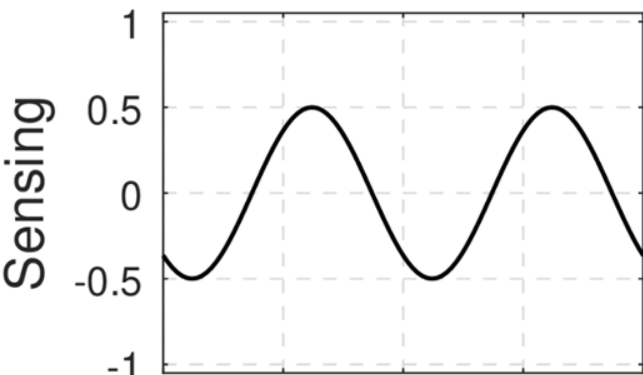
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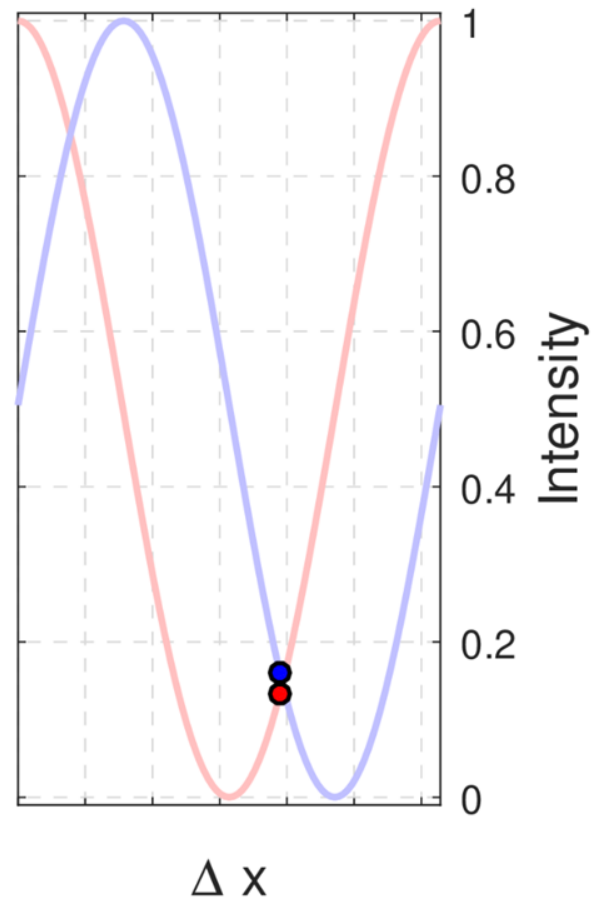
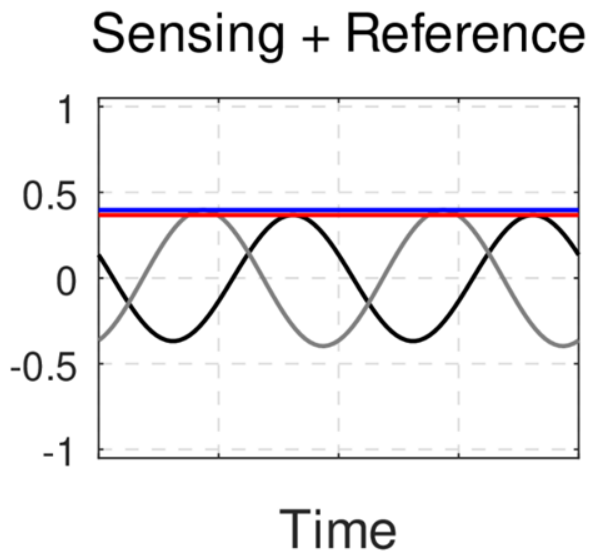
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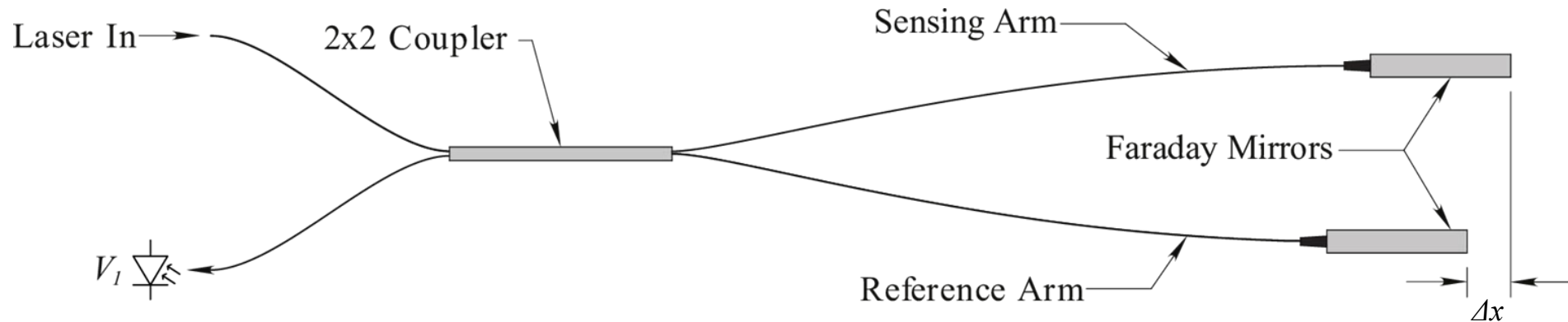




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## Optical Fiber Michelson Interferometer

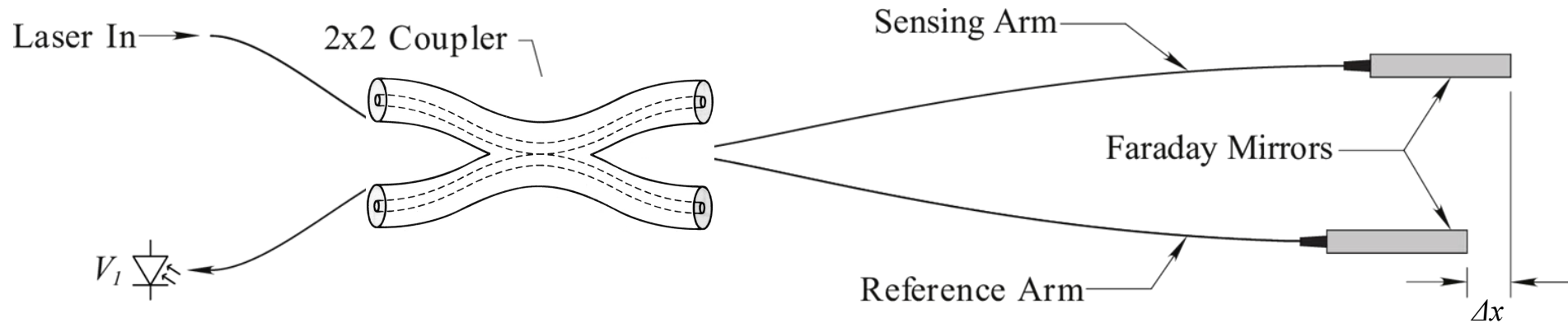
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- Faraday mirrors as retroreflectors (\$80 each)
  - Eliminates polarization fading



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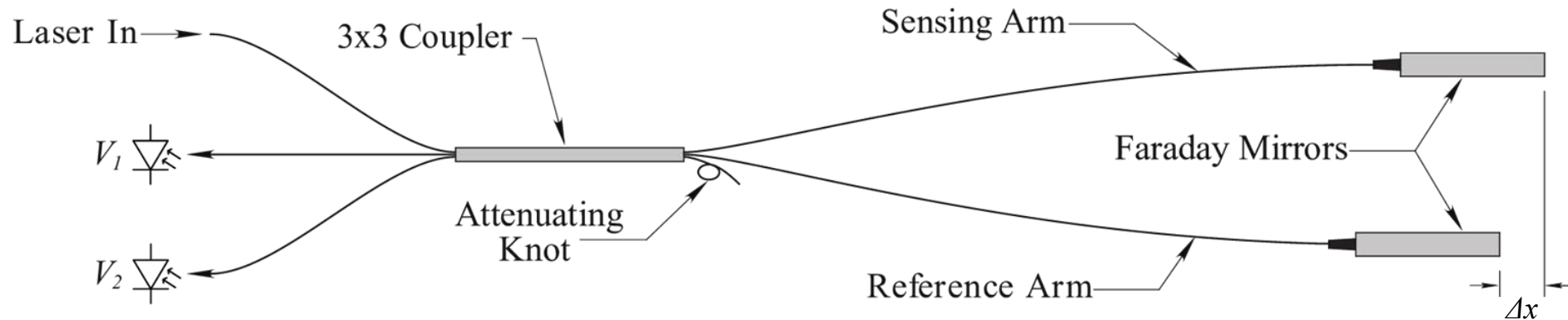
- Fused 2x2 coupler acts as beam splitter
  - Evanescent waveguide coupler



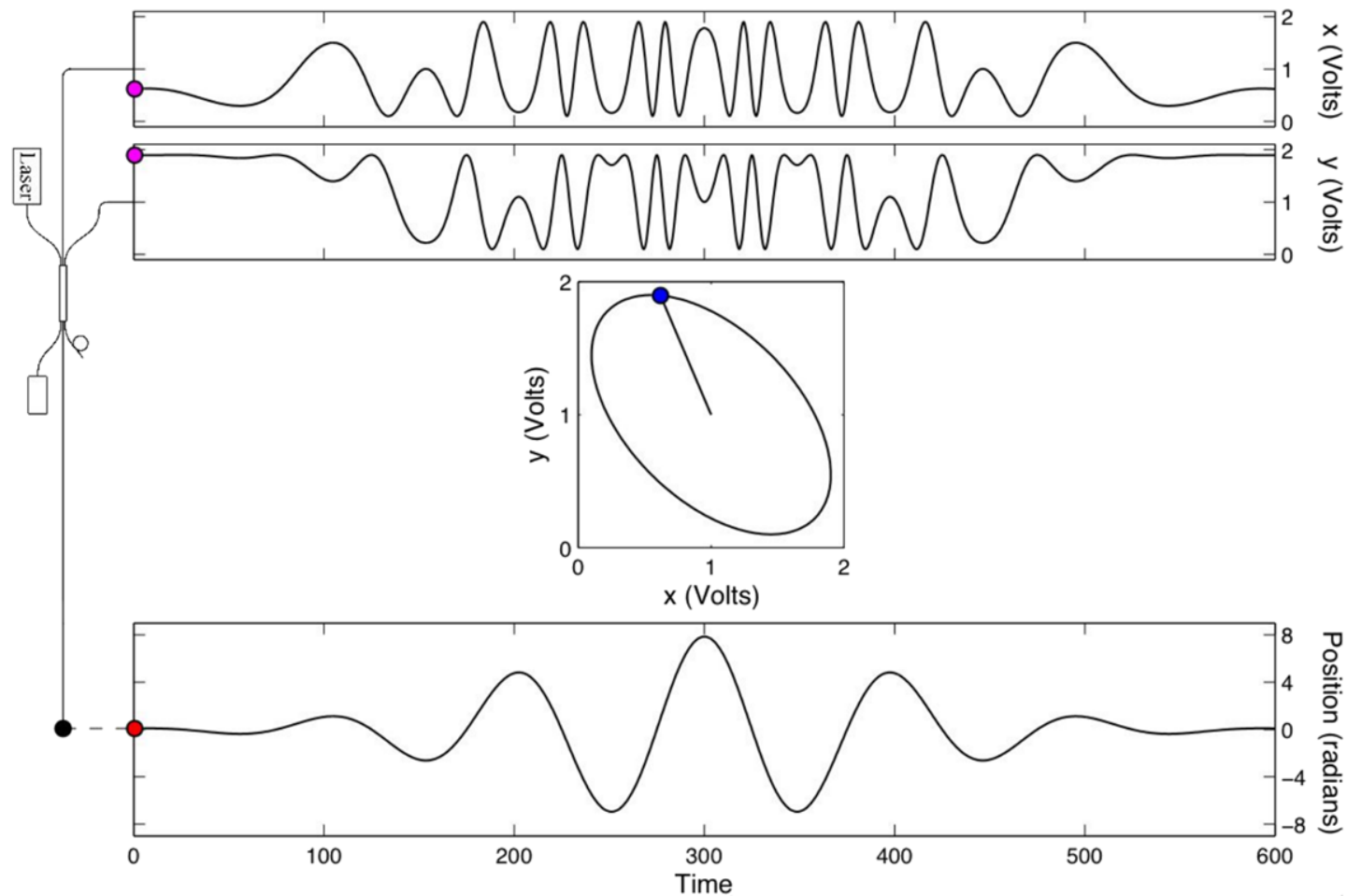
# Intermediate Interferometry

## Optical Fiber Michelson Interferometer

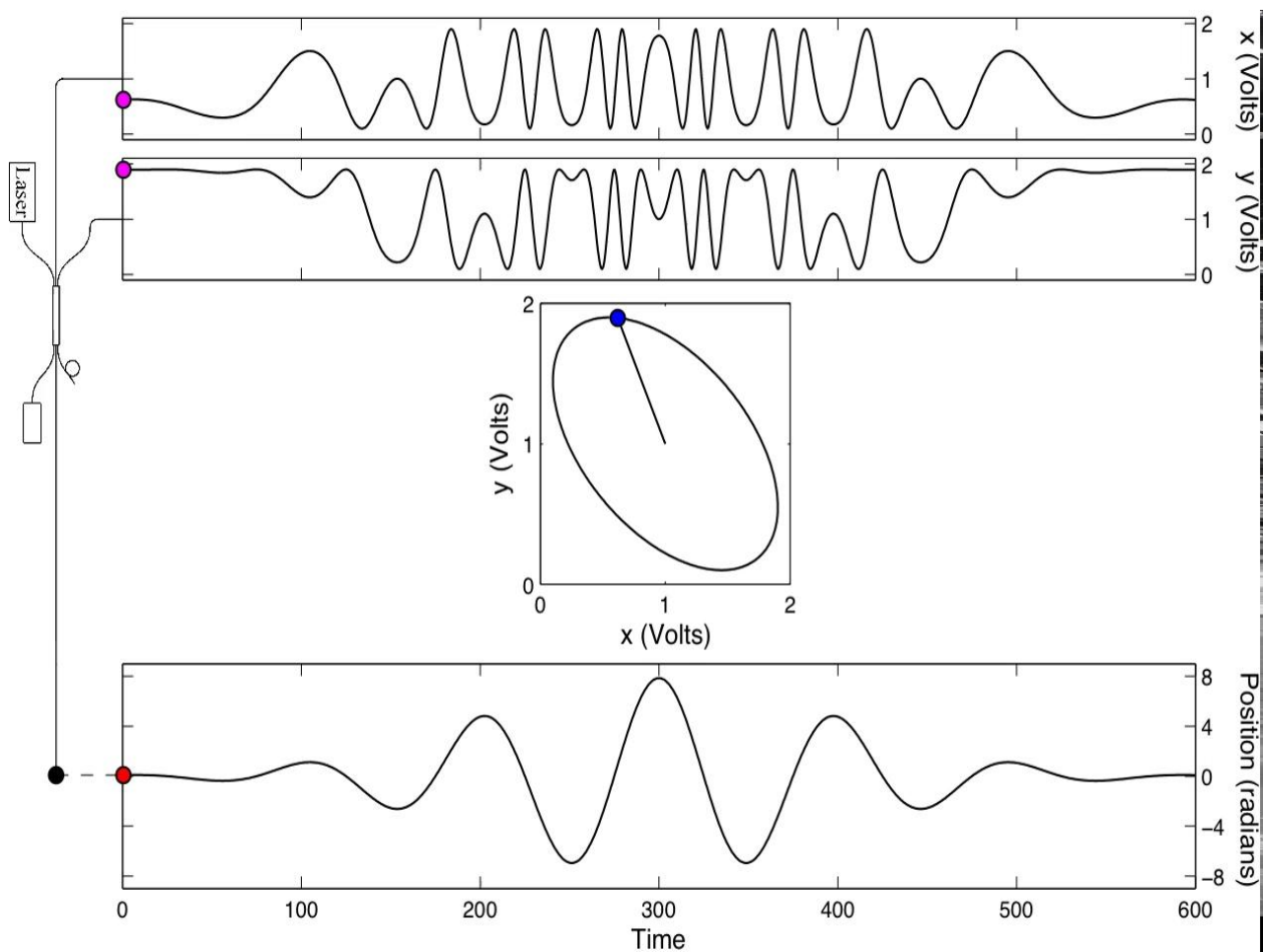
- Fused 3x3 coupler acts as beam splitter (\$65)
  - Returns fringes phase shifted by  $120^\circ$



# Advanced Interferometry: Fringe Counting



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