

Classical Optical Fiber Sensing for Geophysical Applications

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In cooperation with UNAVCO and Grand Resources, Inc.

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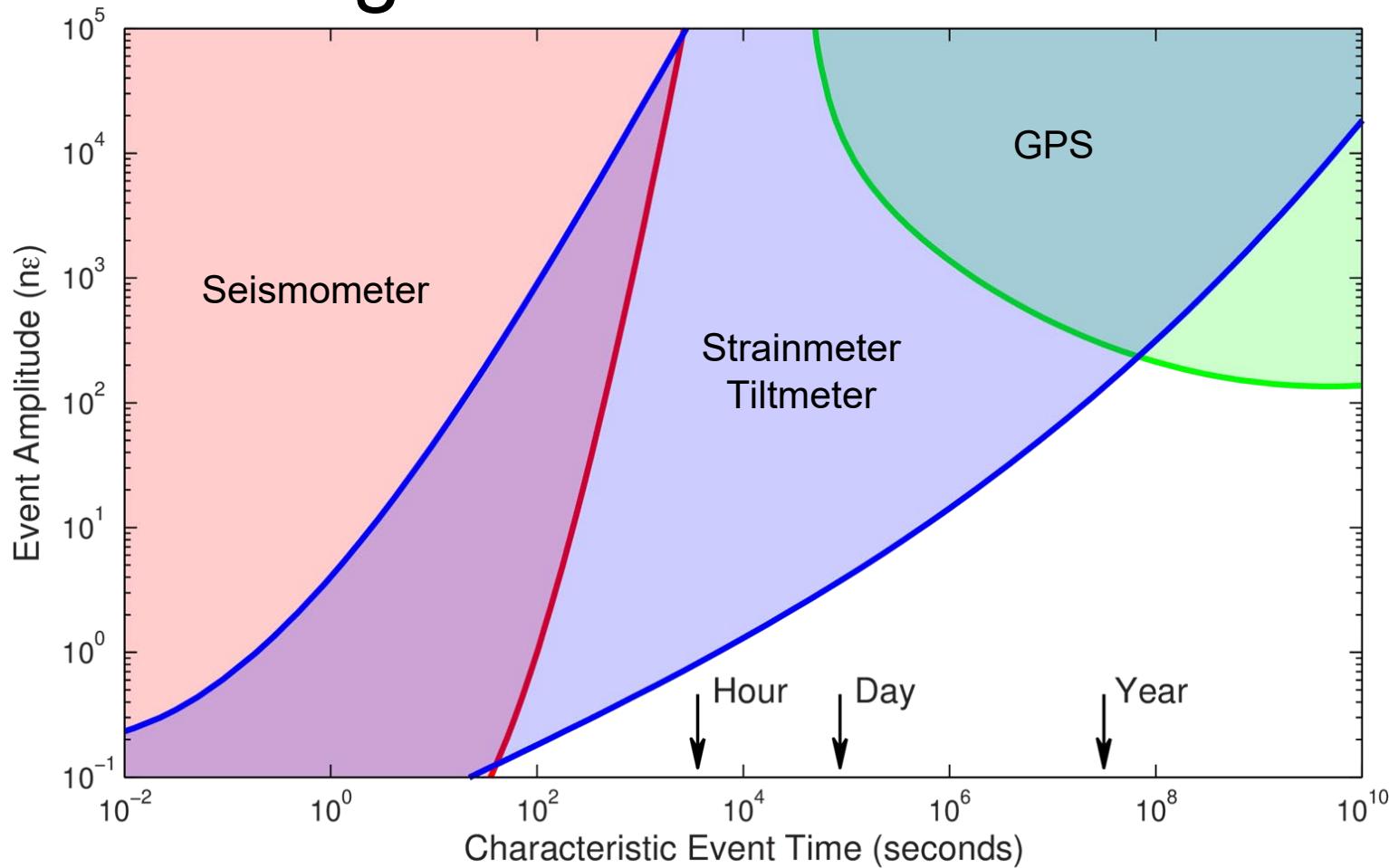
Background on Deformation

Strain is an important observable

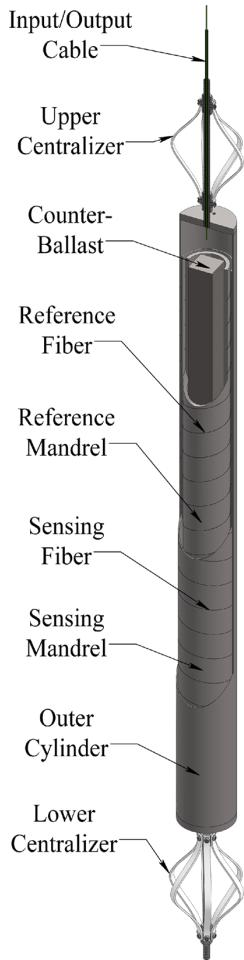
$$\Delta\sigma = C\Delta\epsilon$$

- Tectonic deformations
 - Aseismic, coseismic, post-seismic
- Slope stability
- Ocean ridge spreading
- Hydrocarbon reservoir management
- Sediment compaction
- CO₂ sequestration

Background on Deformation



Embedded Optical Fiber Systems

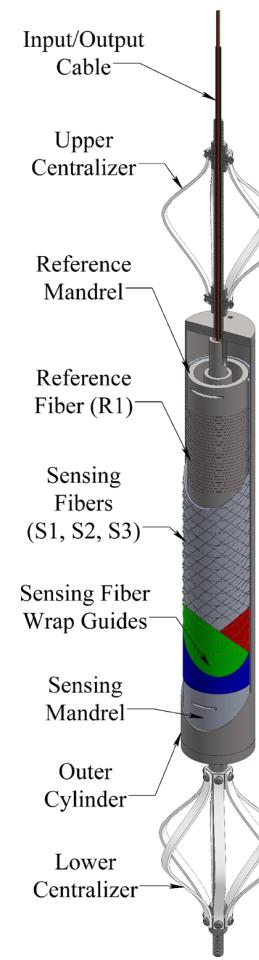
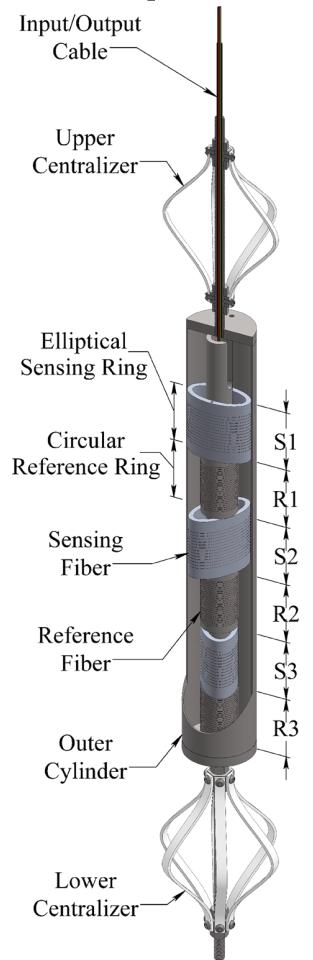
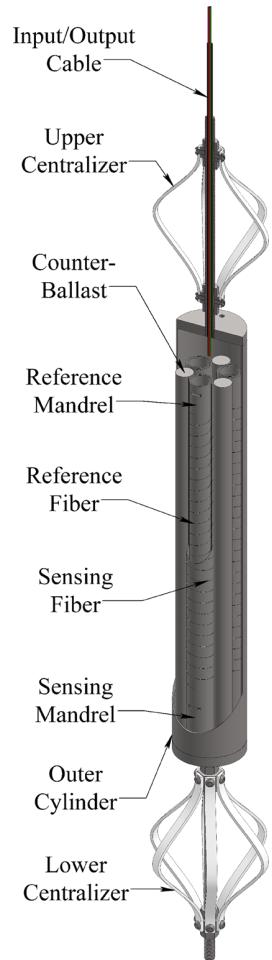


Optical Fiber Areal Strainmeter

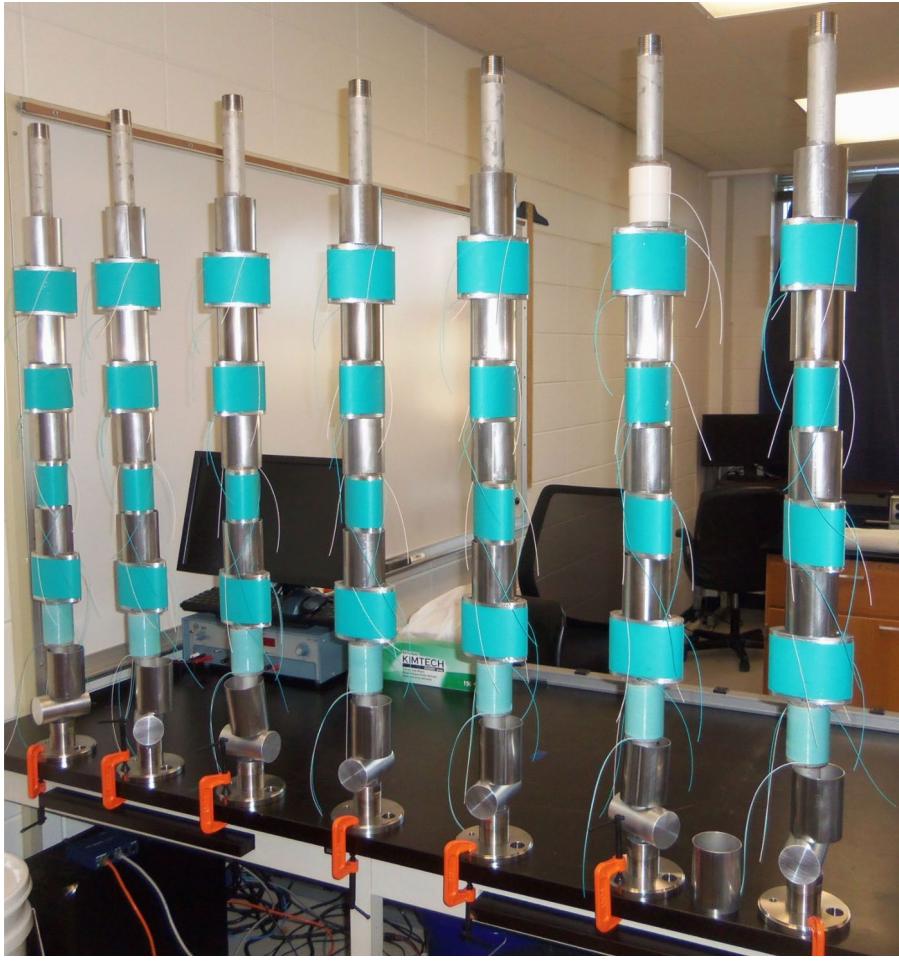
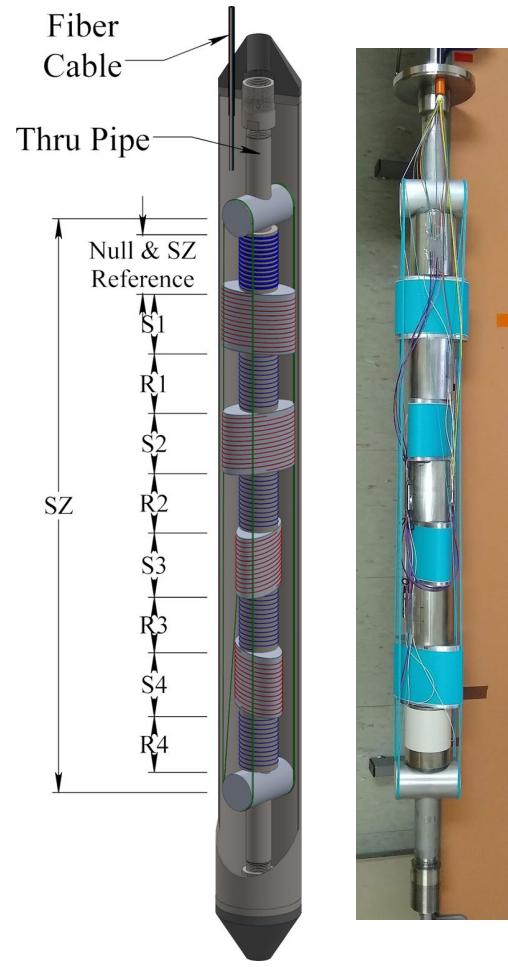
- Fully welded exterior
- Potted interior
- 220m of fiber
- 4×10^{-15} strain least-count
 - 0.1m borehole
 - 4×10^{-16} meters
 - Proton $\sim 1.6 \times 10^{-15}$ m



Embedded Optical Fiber Systems



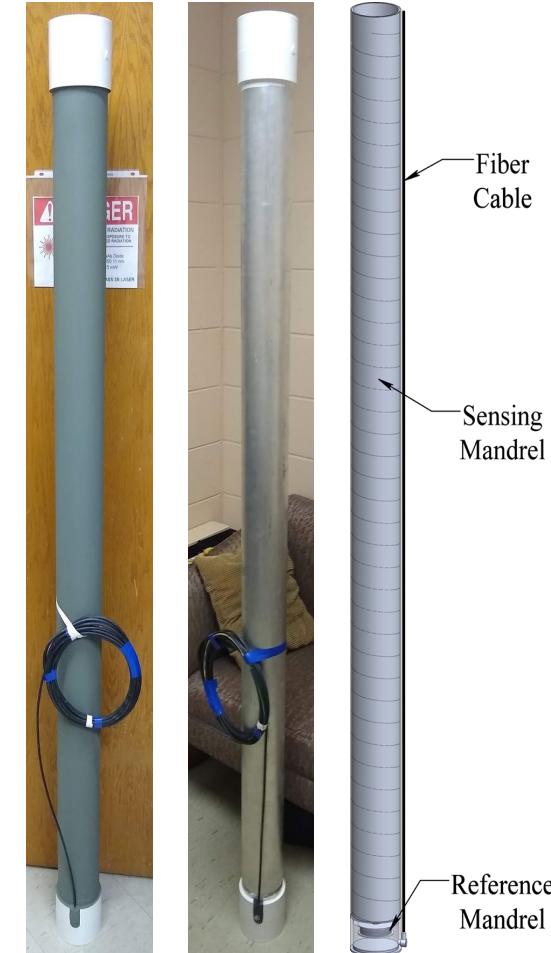
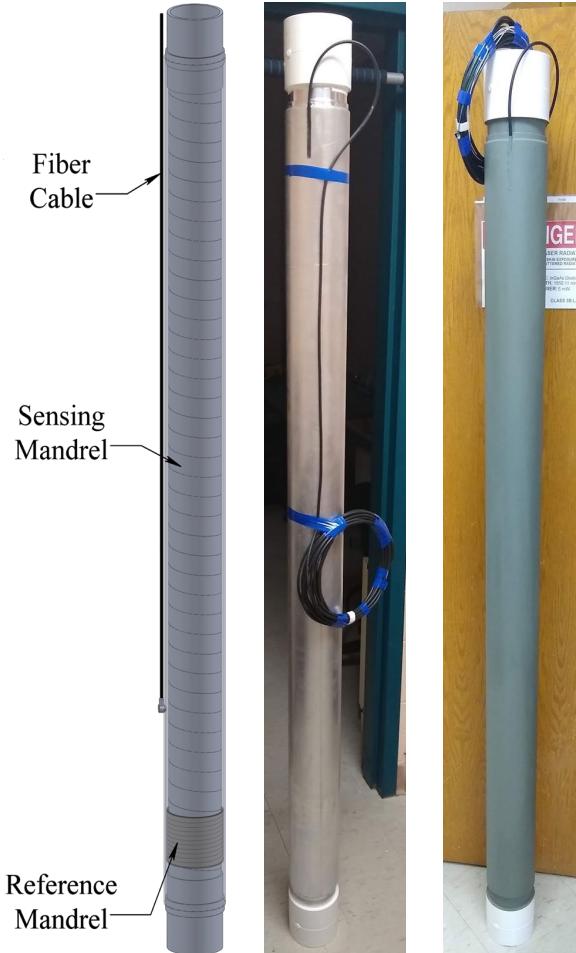
Embedded Optical Fiber Systems



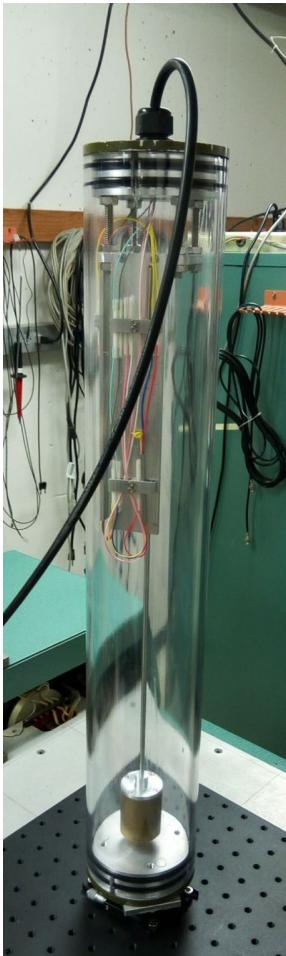
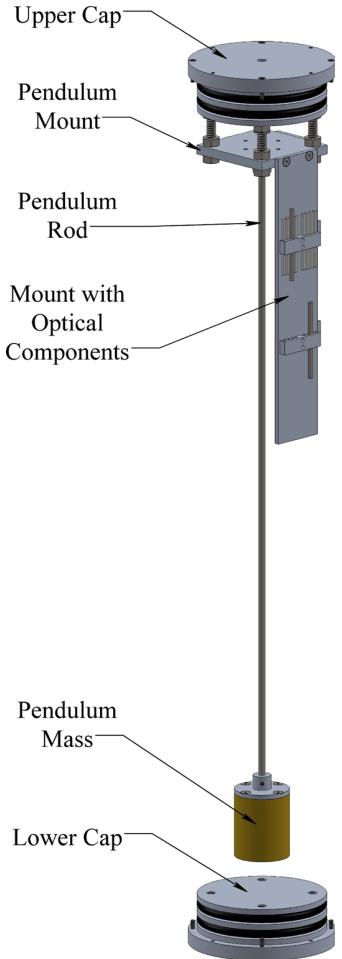
Embedded Optical Fiber Systems

Embedded Optical Fiber “Smart Casing”

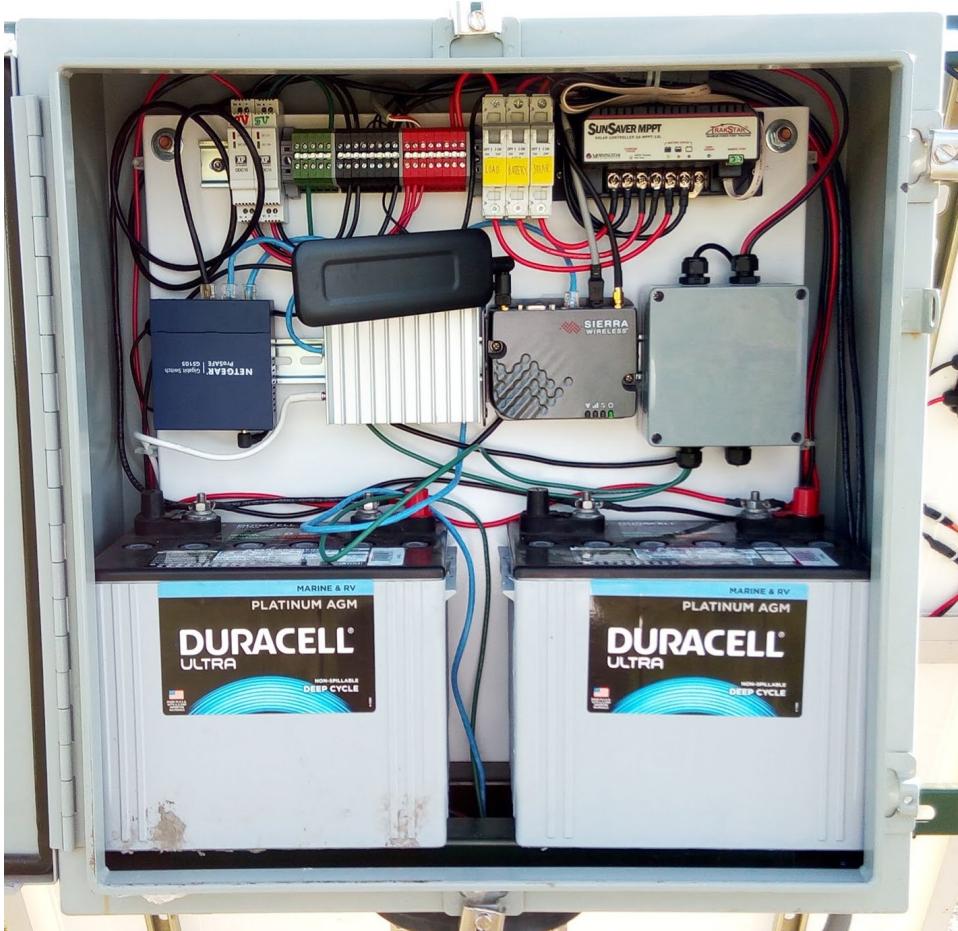
- Three designs
 - Open-closed
 - Open-open
 - Vector tilt



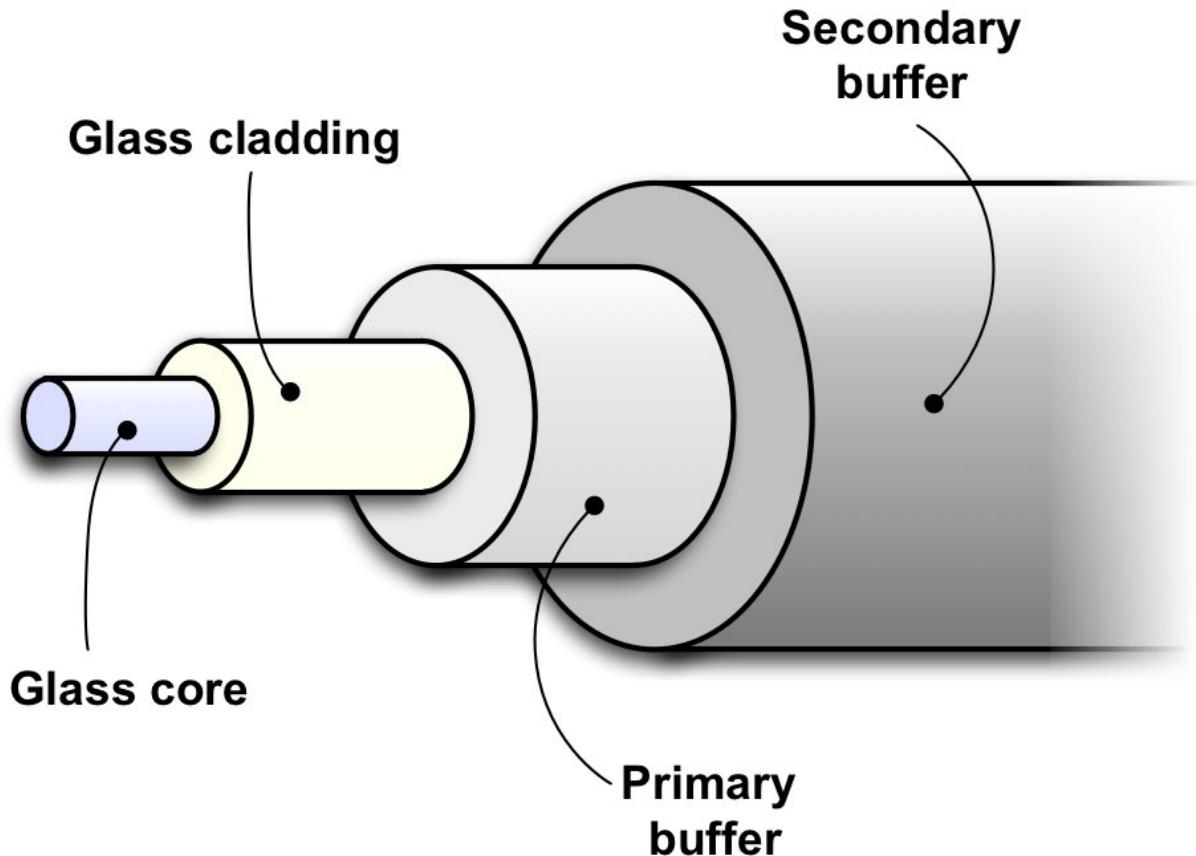
Embedded Optical Fiber Systems



Embedded Optical Fiber Systems



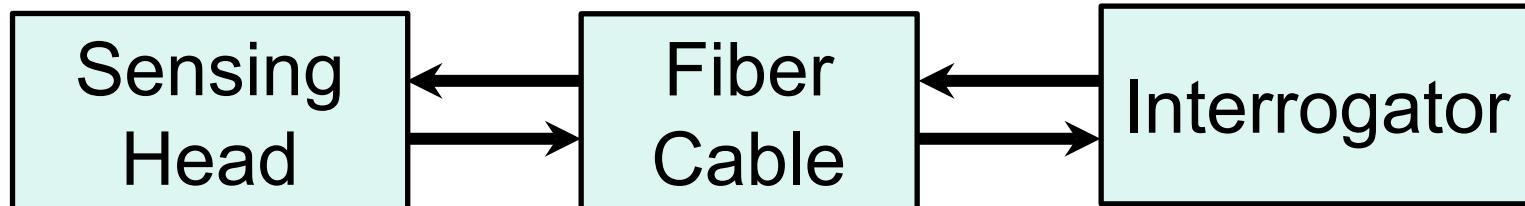
Optical Fiber Sensing Intro



Optical Fiber Sensing Intro

System components

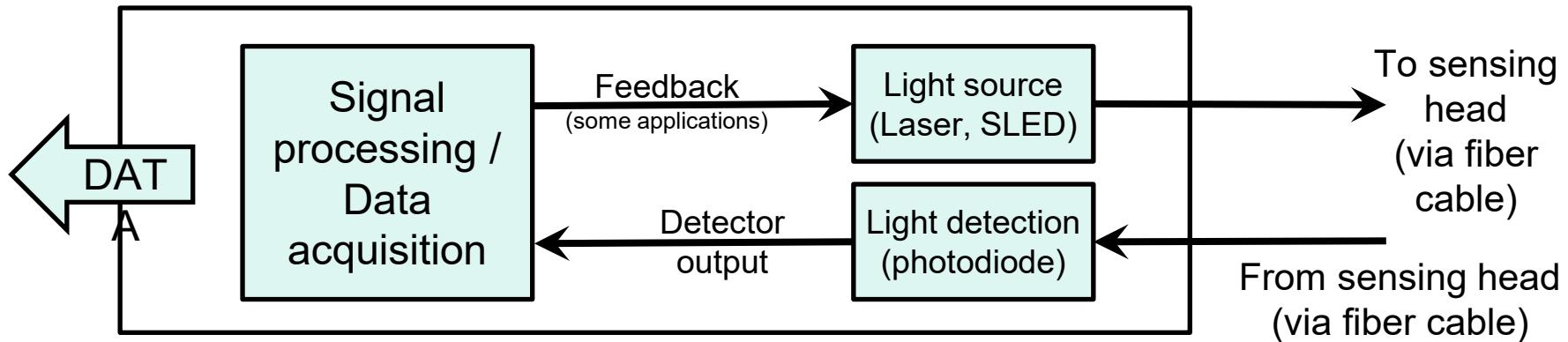
- **Sensing head** is exposed to environment (strain, pressure, vibration, temperature, etc.)
- **Optical Fiber cable** communicates between interrogator and sensing head
- **Interrogator** reads signal from sensing head



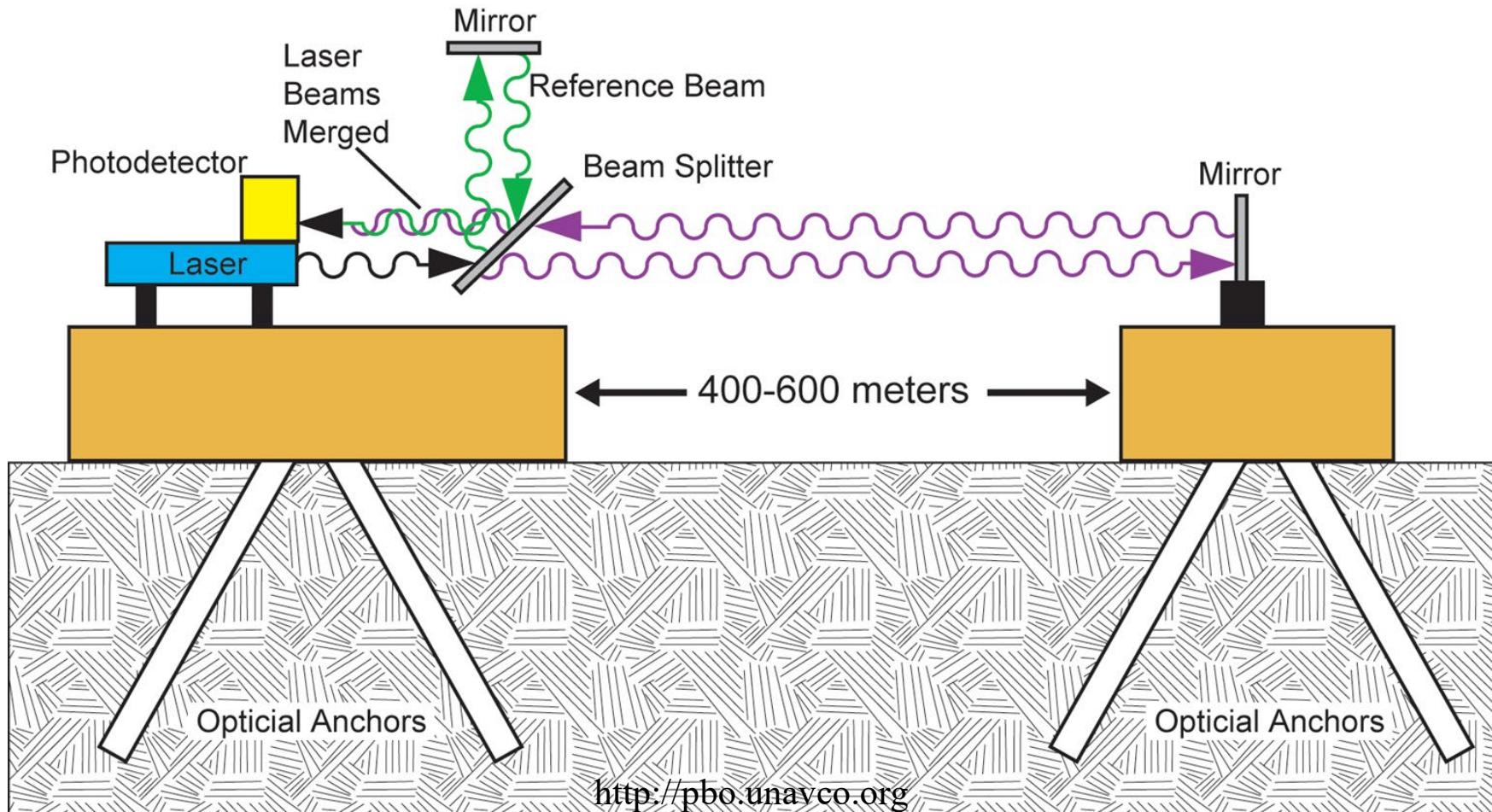
Optical Fiber Sensing Intro

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



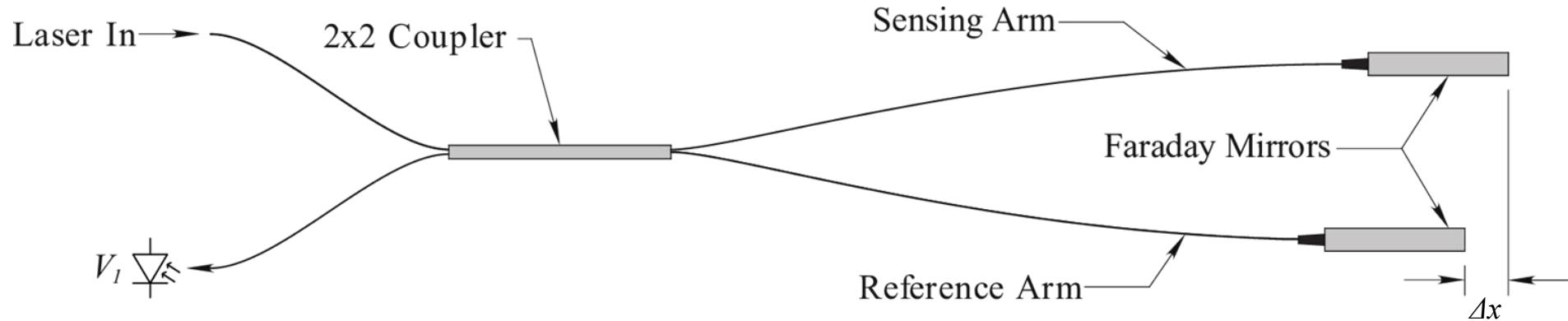
Interferometry Basics



Interferometry Basics

Optical Fiber Michelson Interferometer

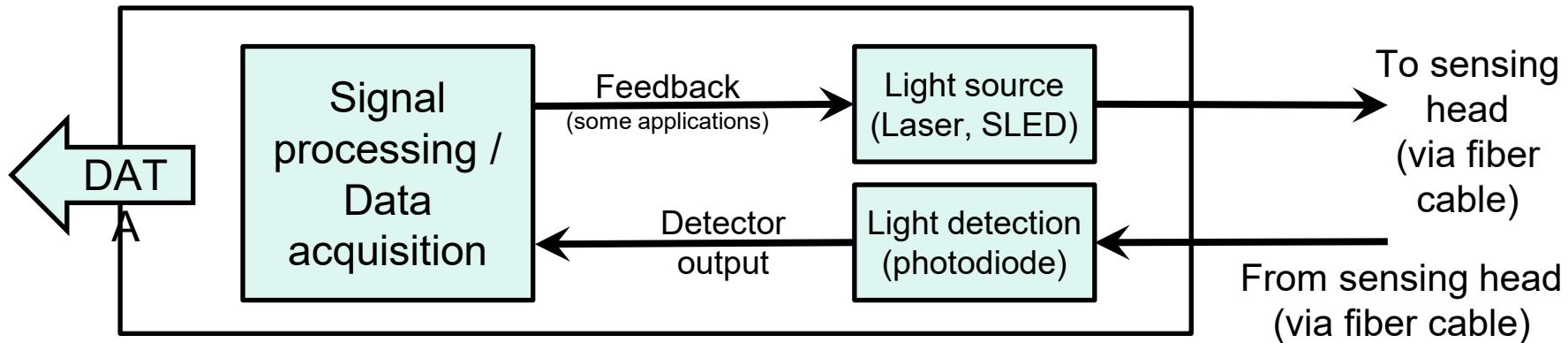
- 2x2 coupler acts as beam splitter (\$15)
- Faraday mirrors as retroreflectors (\$80 each)
 - Eliminates polarization fading



Optical Fiber Michelson Interrogator

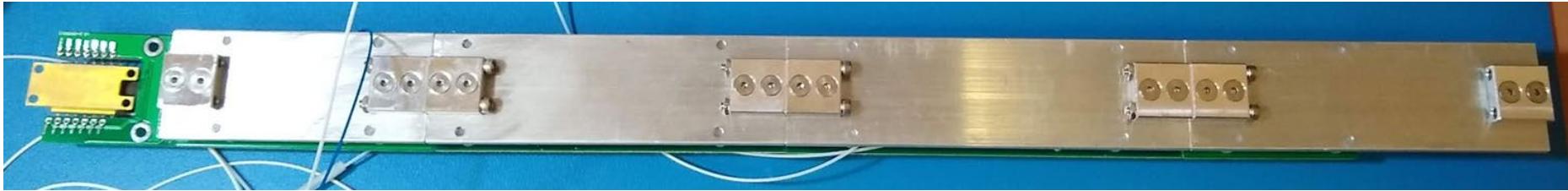
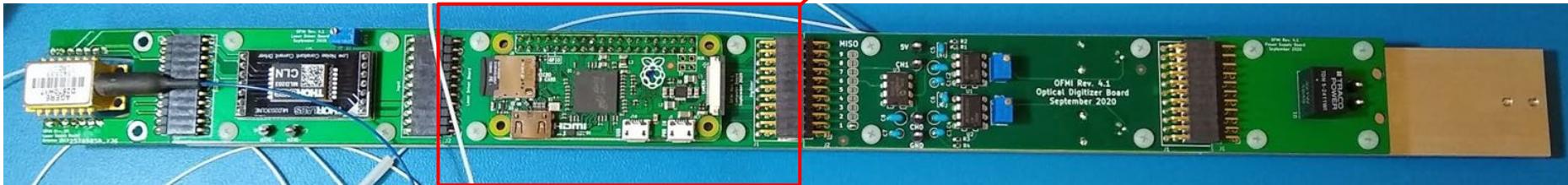
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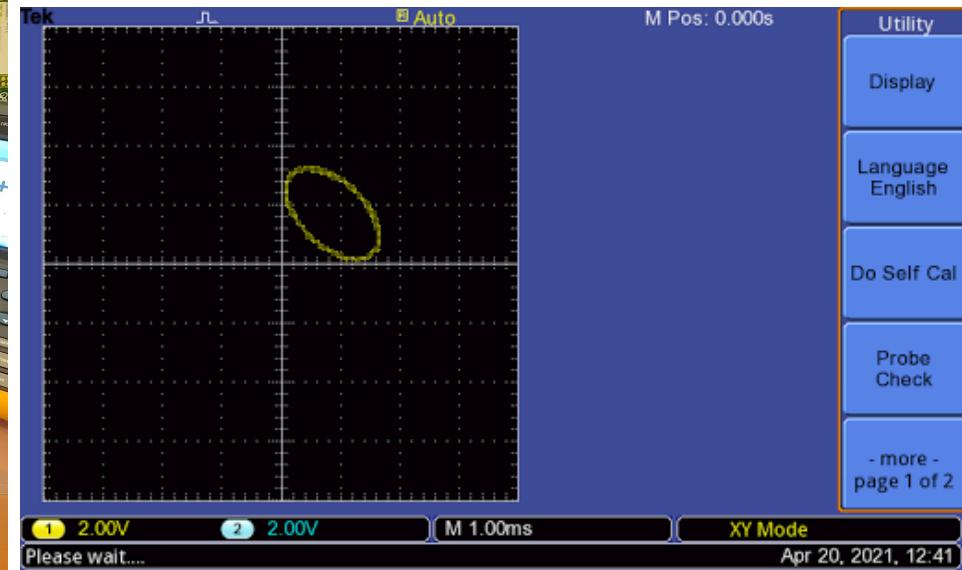
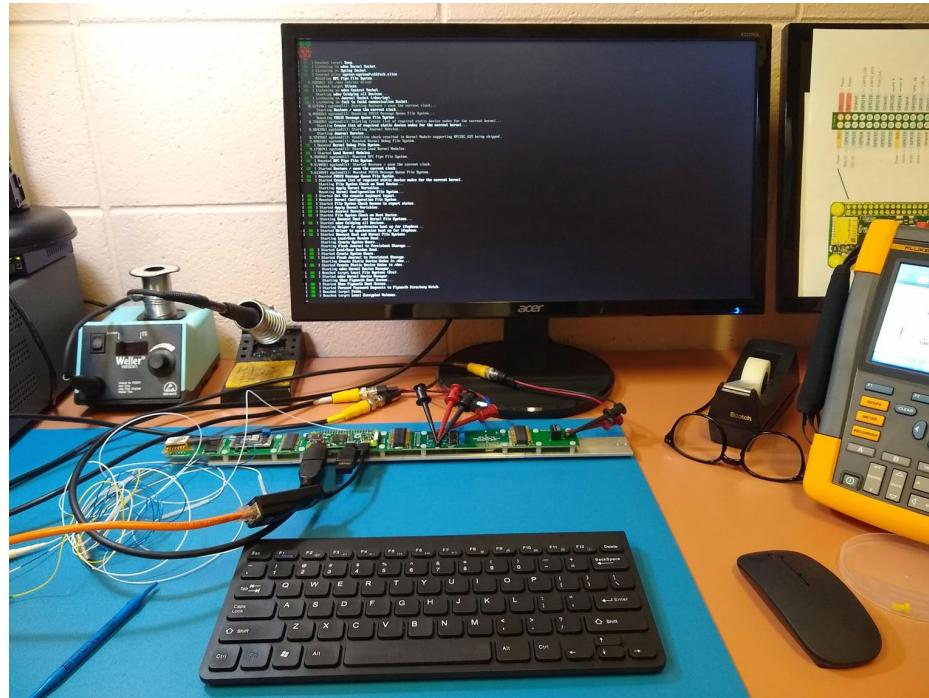
Optical Fiber Michelson Interrogator

- 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



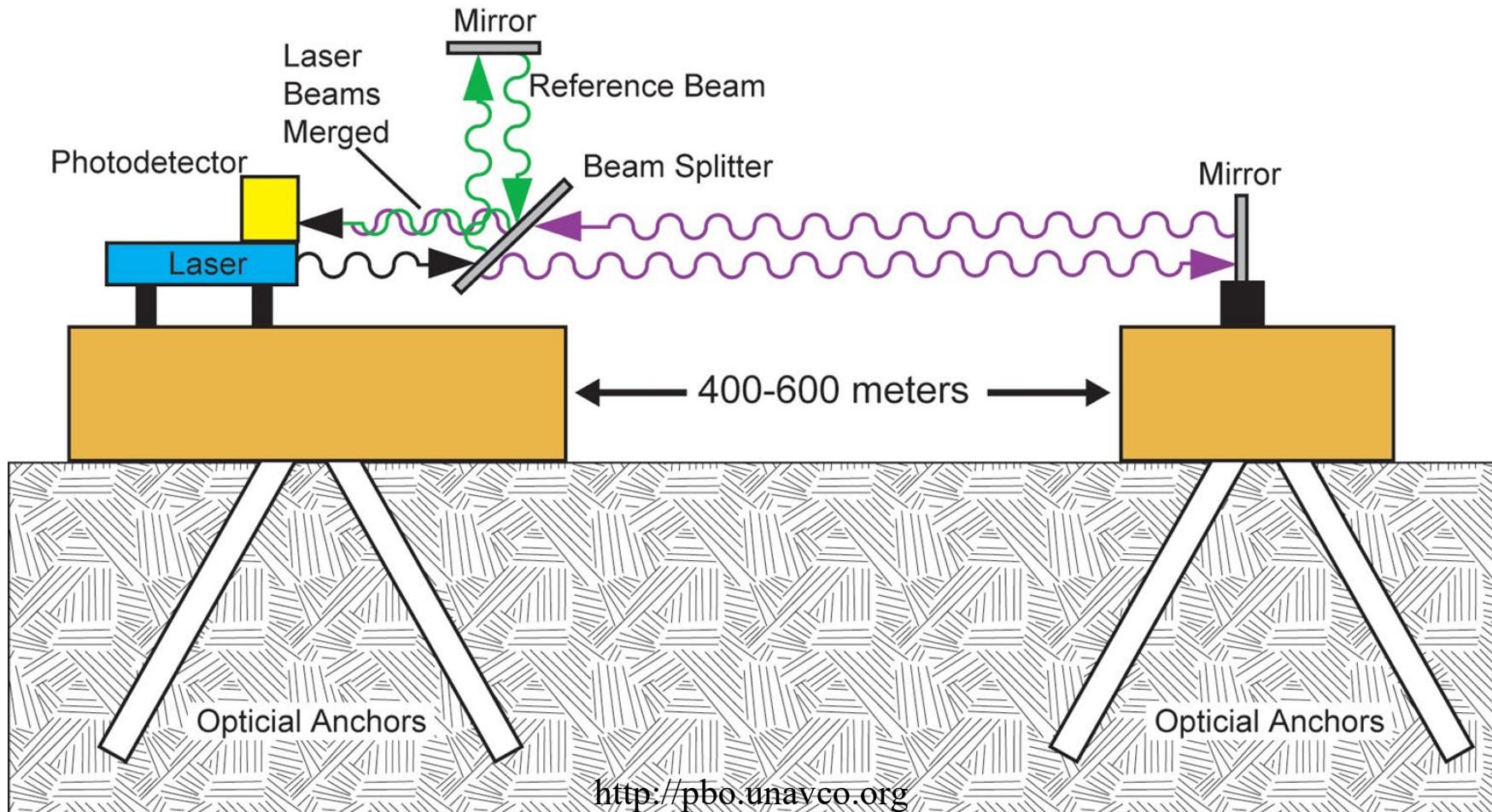
Kinemetrics
STS-5 and
Q330

- 1.3W



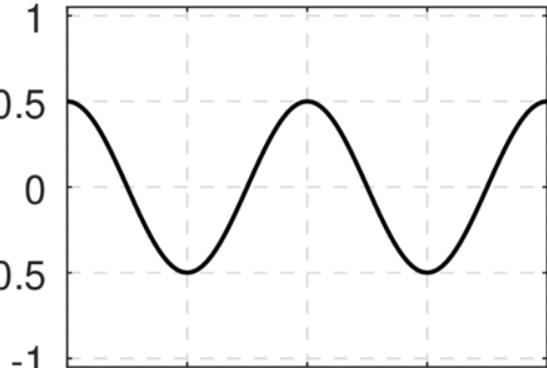
Interferometry Basics

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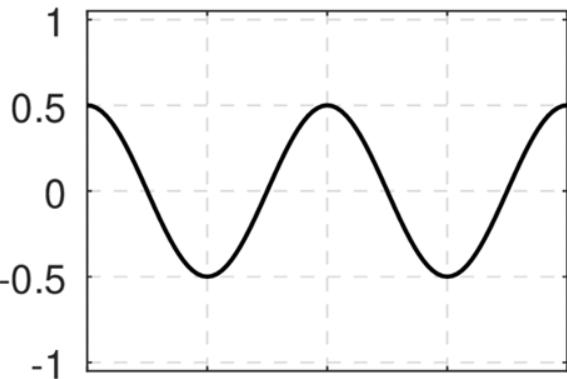


Interferometry Basics

Sensing

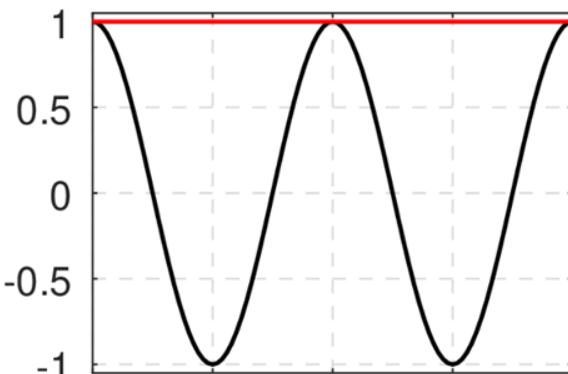


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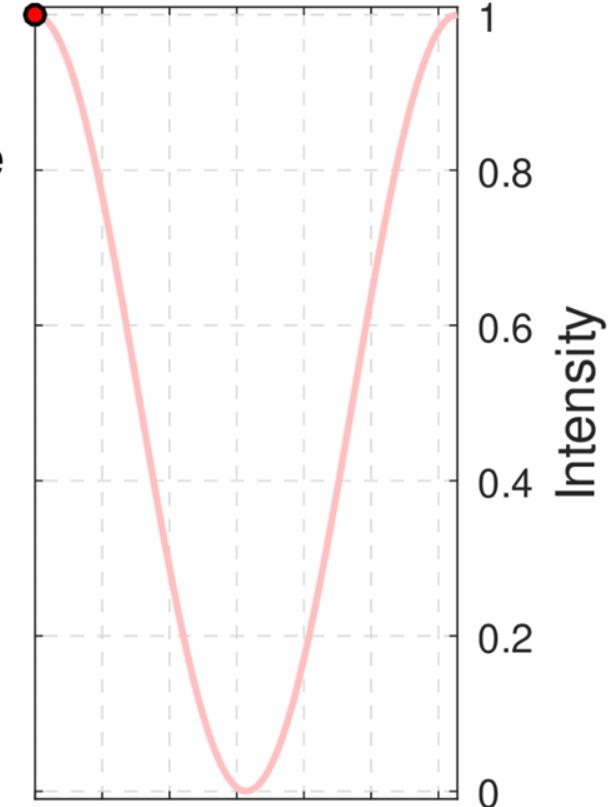


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Sensing + Reference



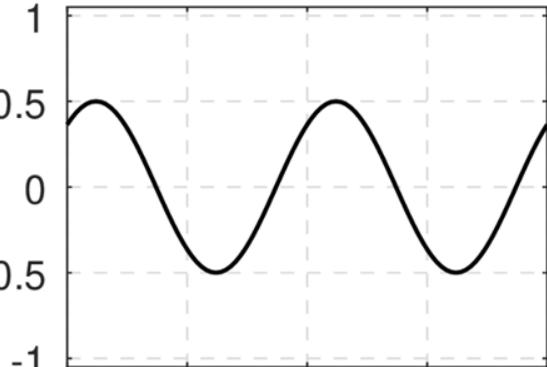
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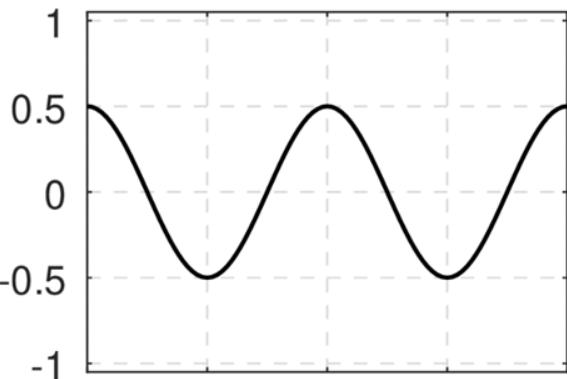
Δx

Interferometry Basics

Sensing

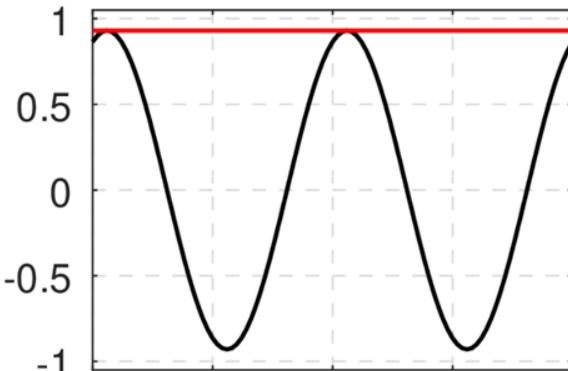


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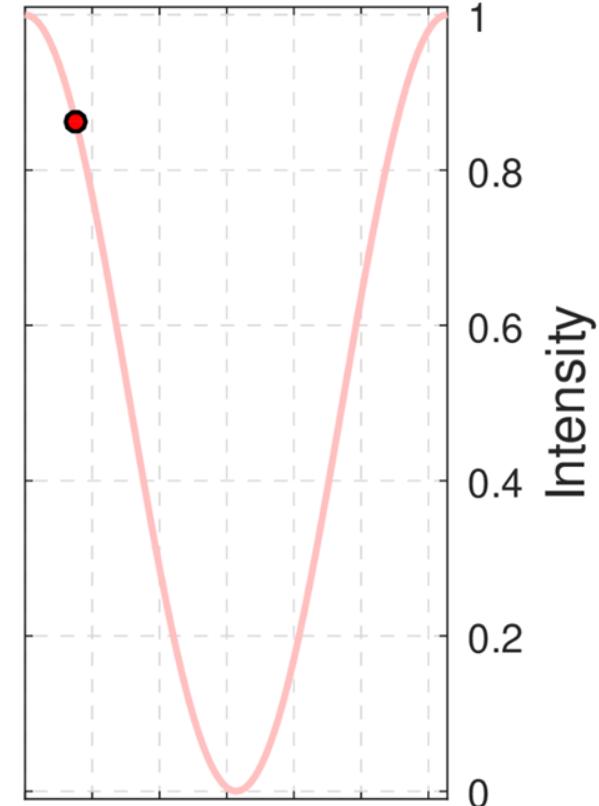
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Sensing + Reference



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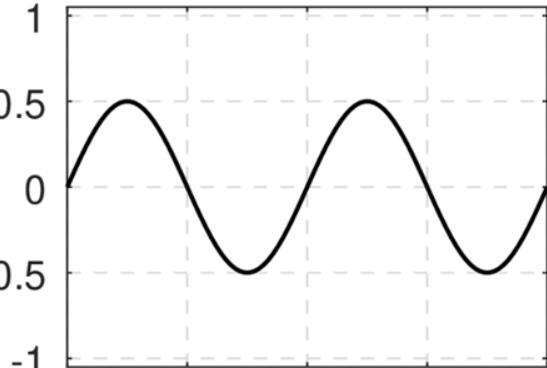
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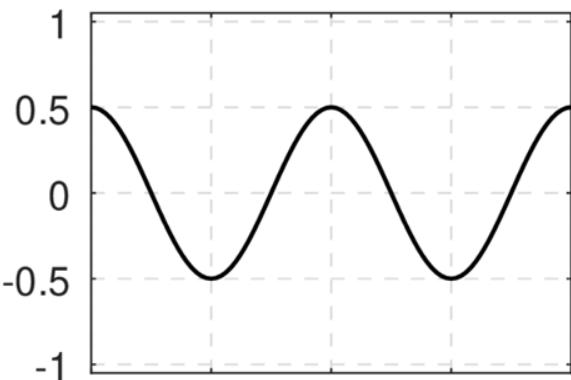
Δx

Interferometry Basics

Sensing

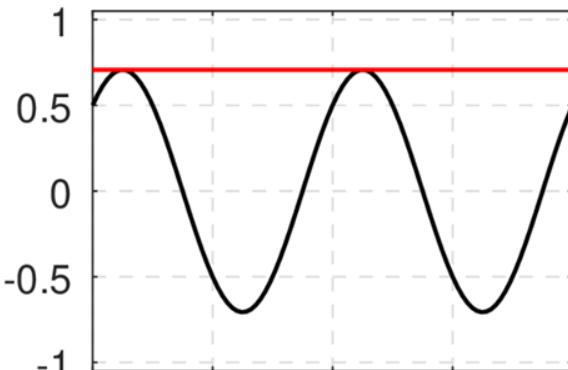


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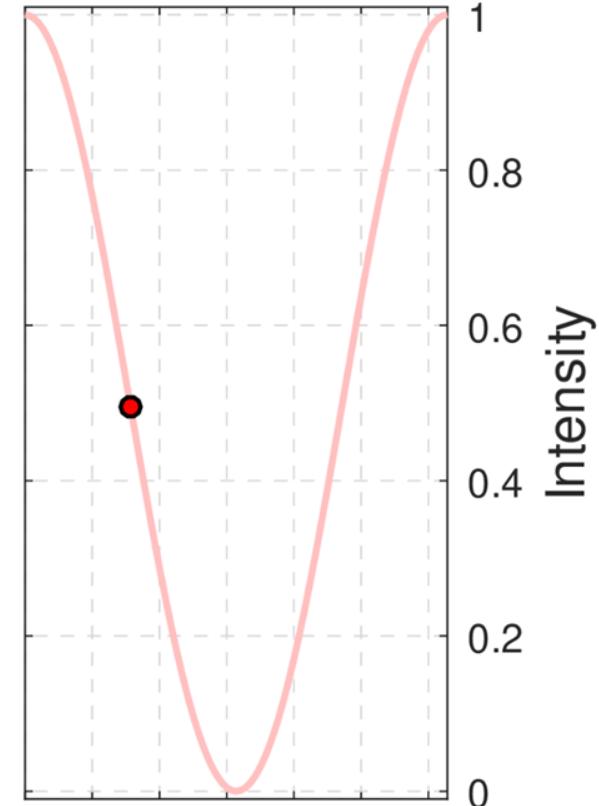
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Sensing + Reference



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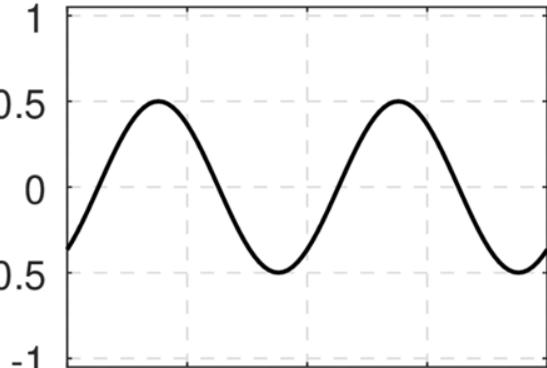
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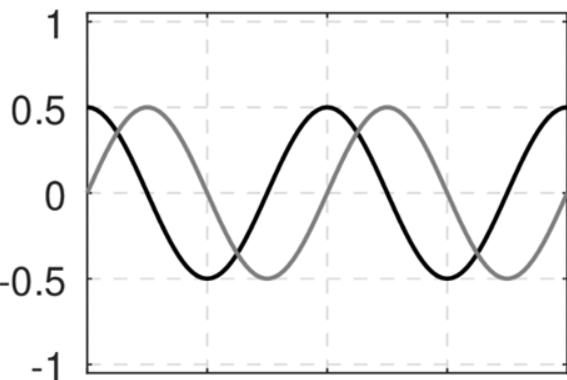
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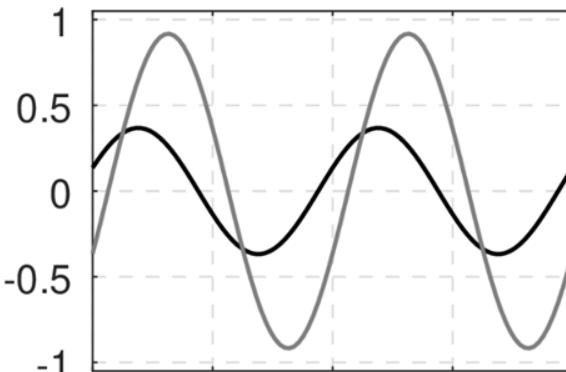


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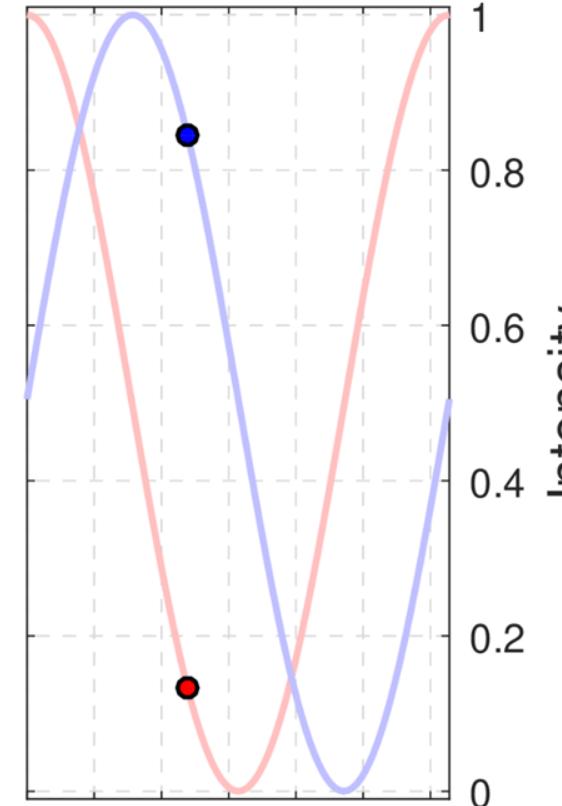


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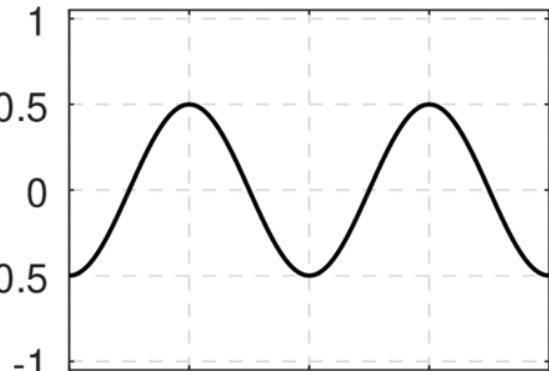
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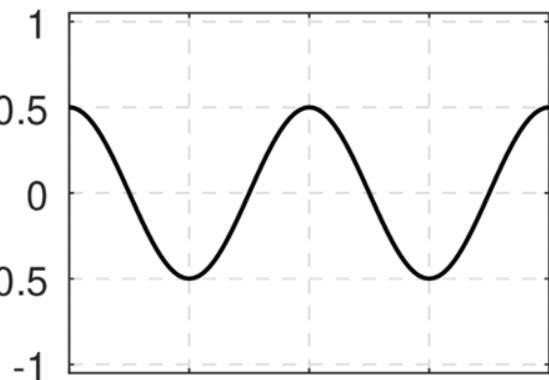
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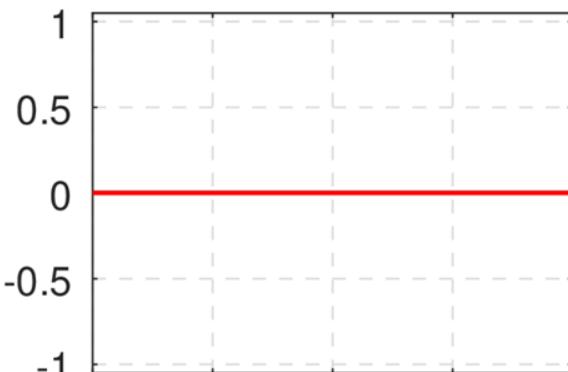


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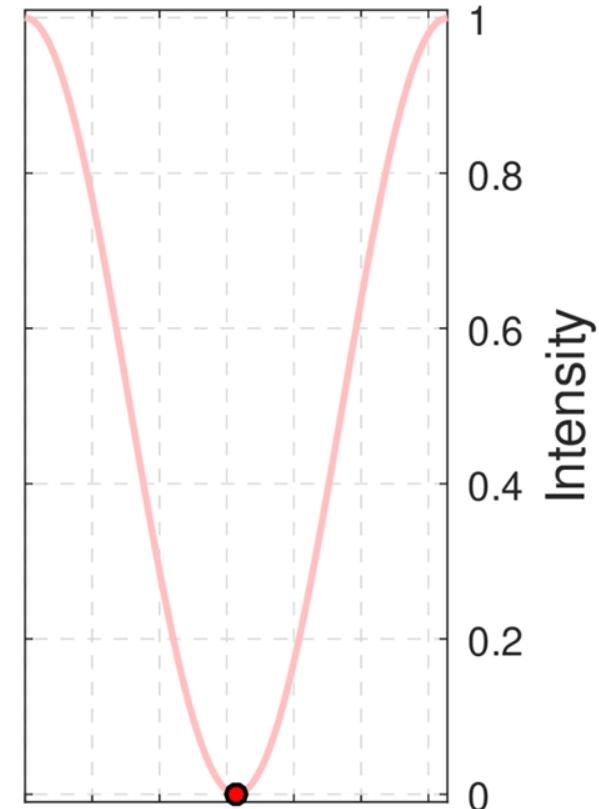


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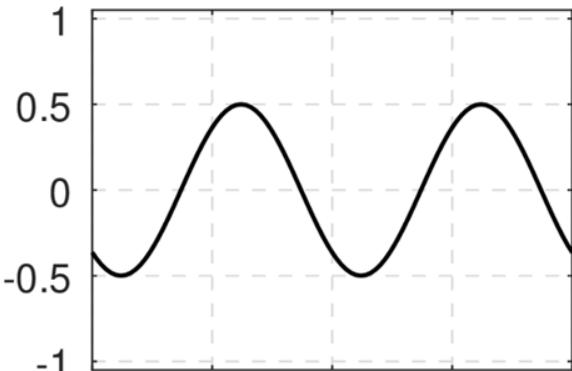
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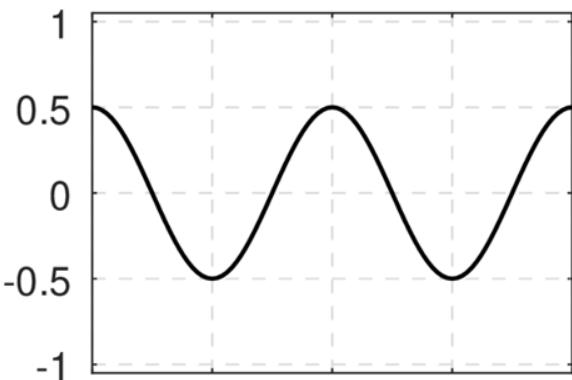
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Interferometry Basics

Sensing



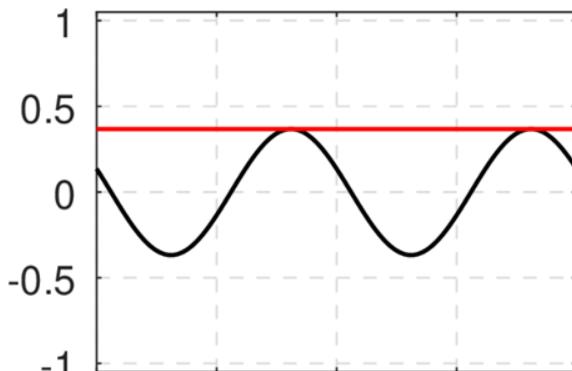
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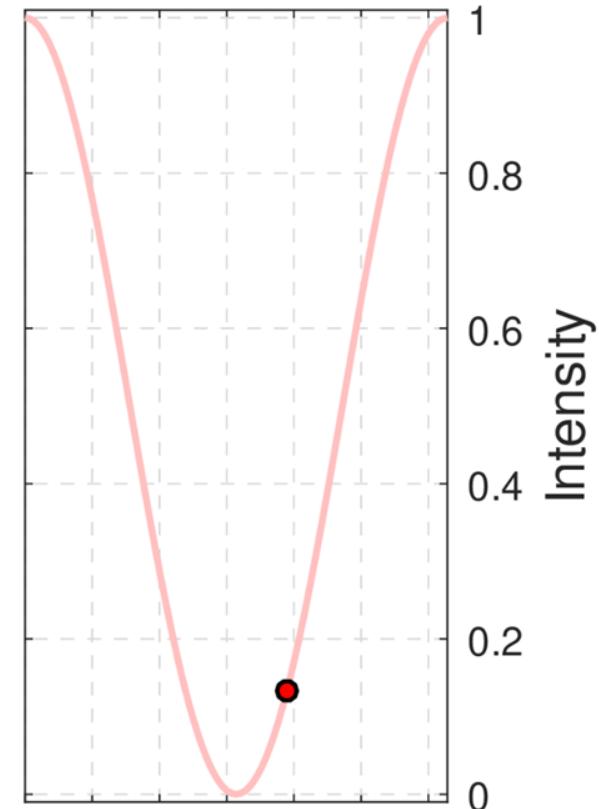
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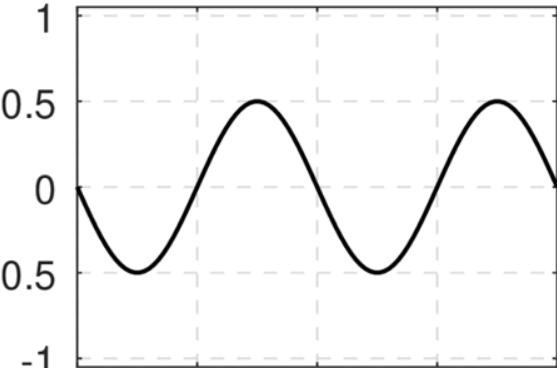
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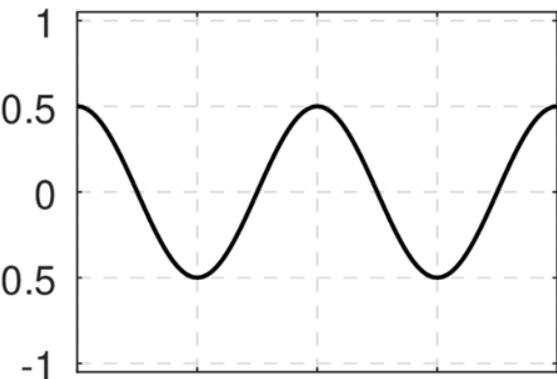
Δx

Interferometry Basics

Sensing



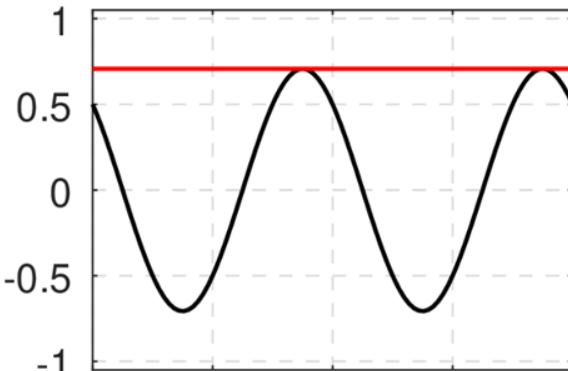
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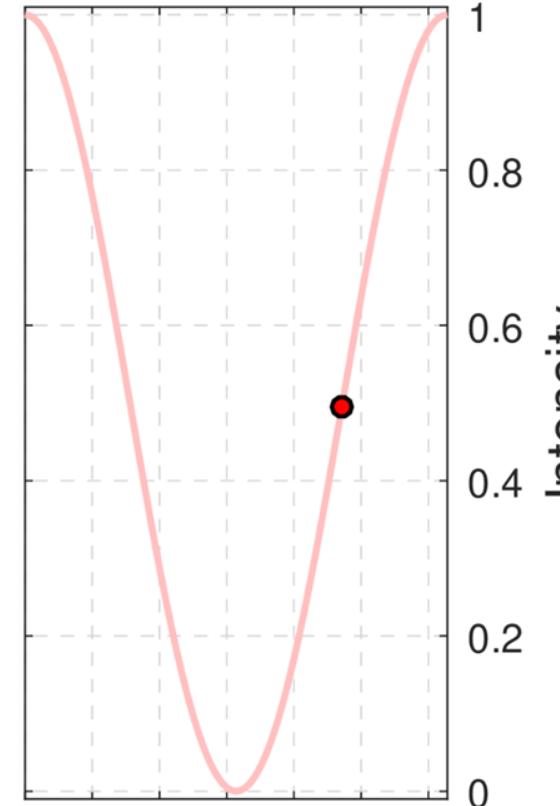
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Sensing + Reference



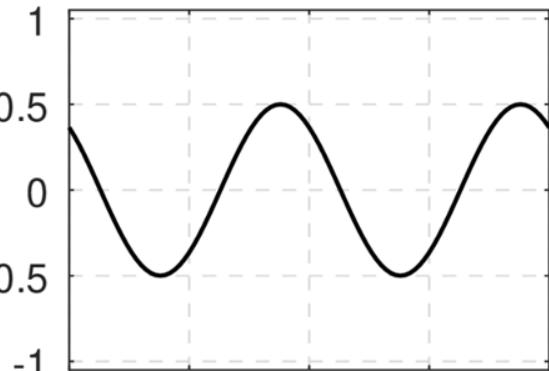
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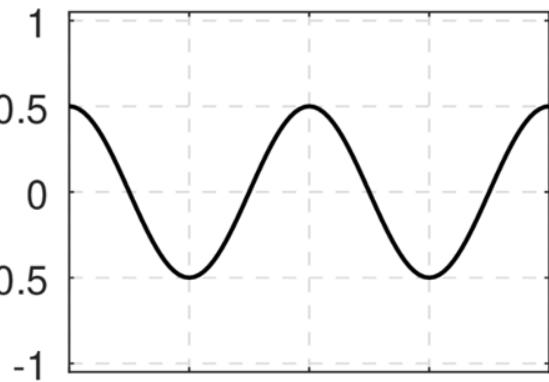
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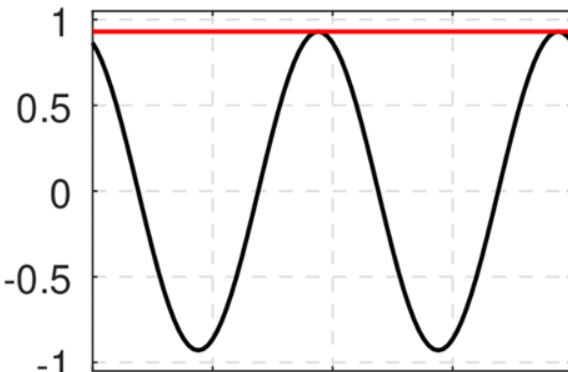
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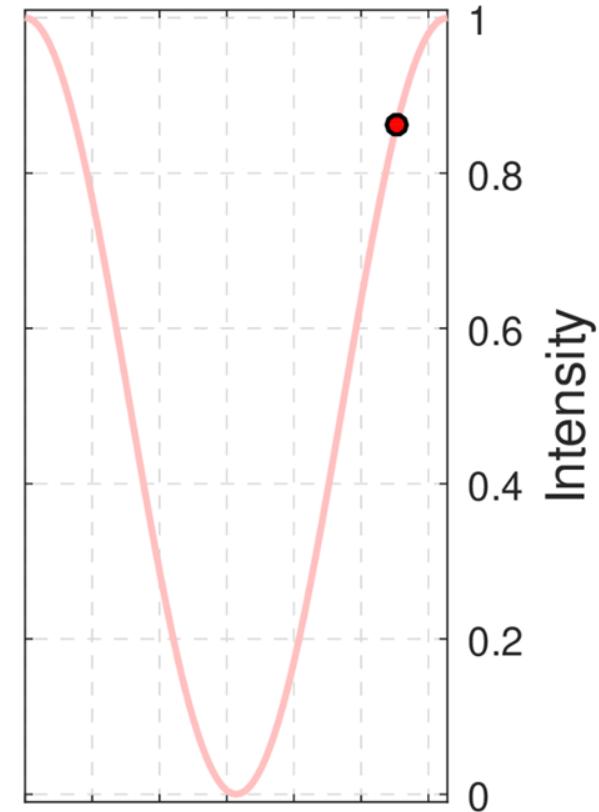
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Sensing + Reference



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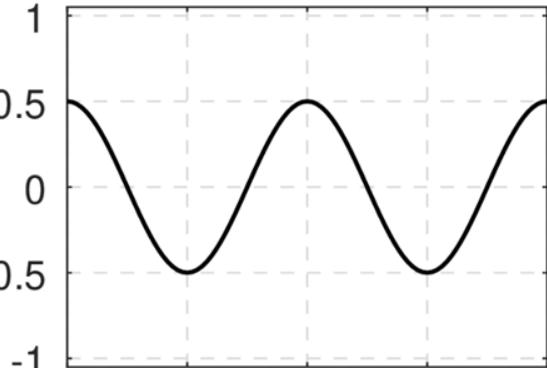
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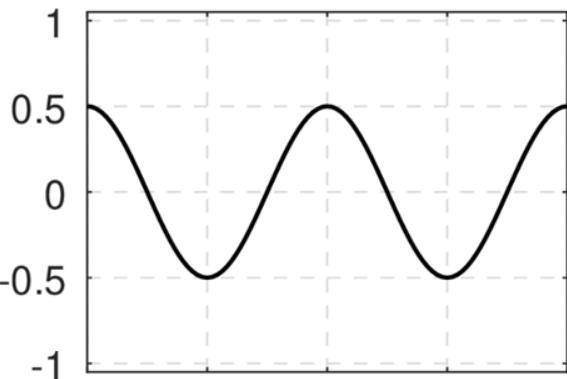
Intensity

Interferometry Basics

Sensing



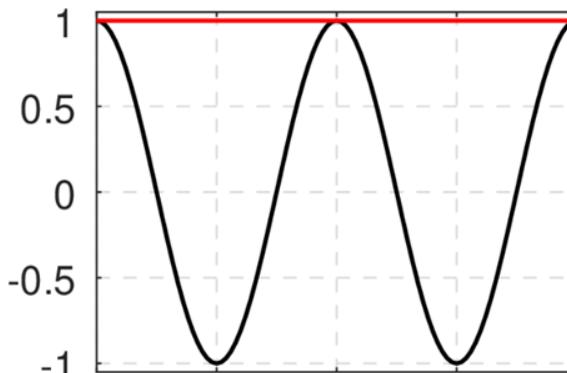
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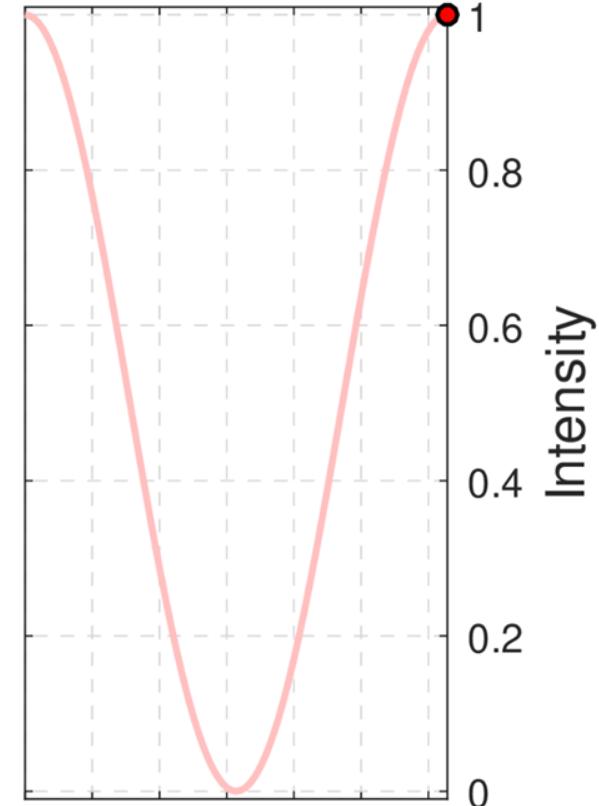
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Sensing + Reference



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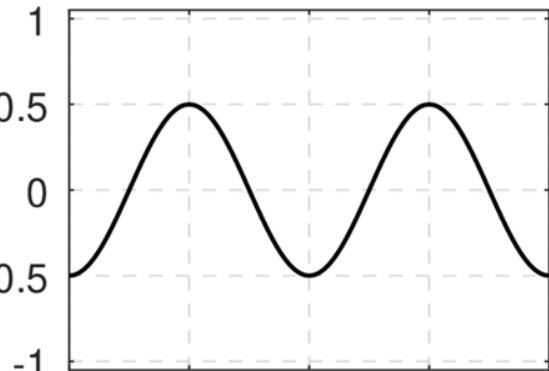
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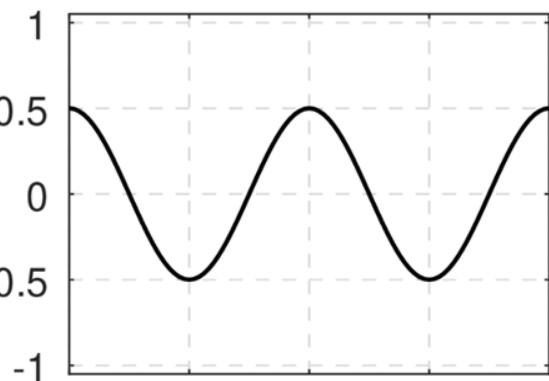
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Interferometry Basics

Sensing

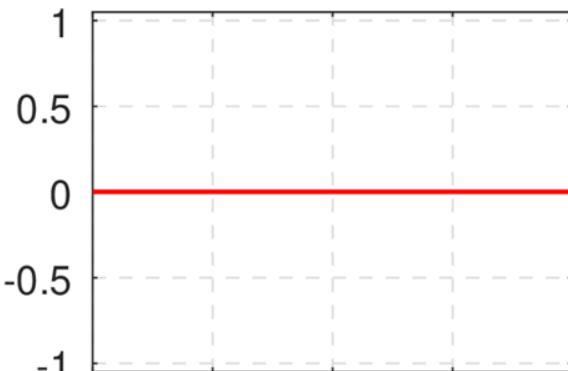


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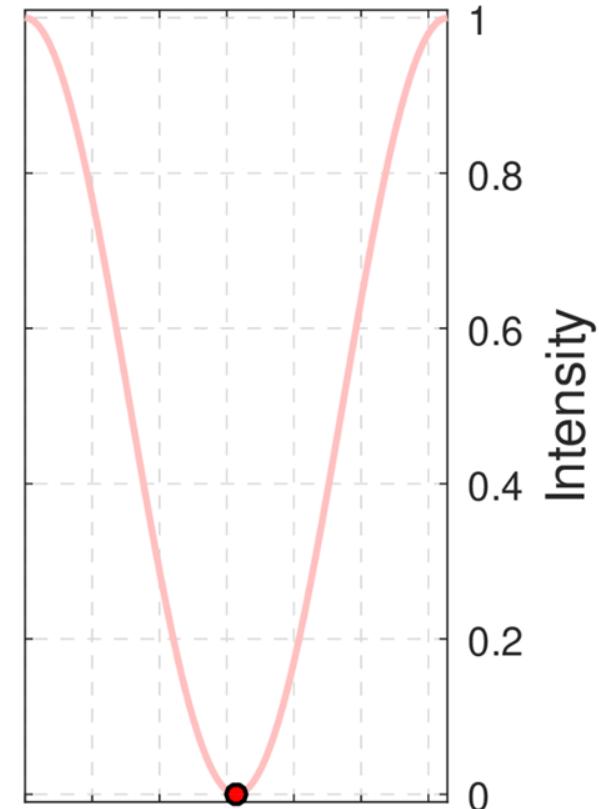


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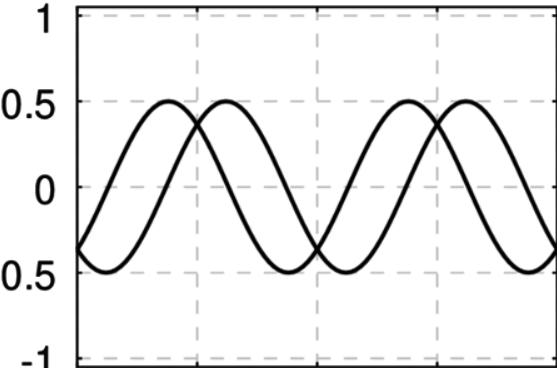
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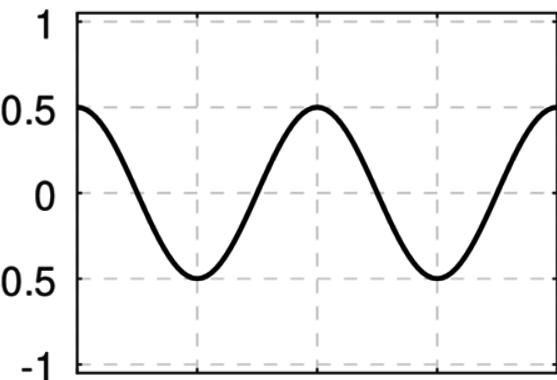
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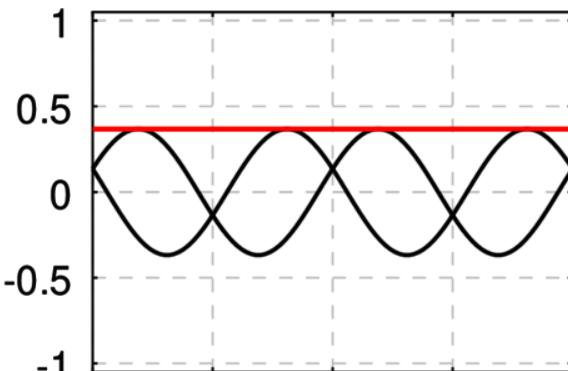


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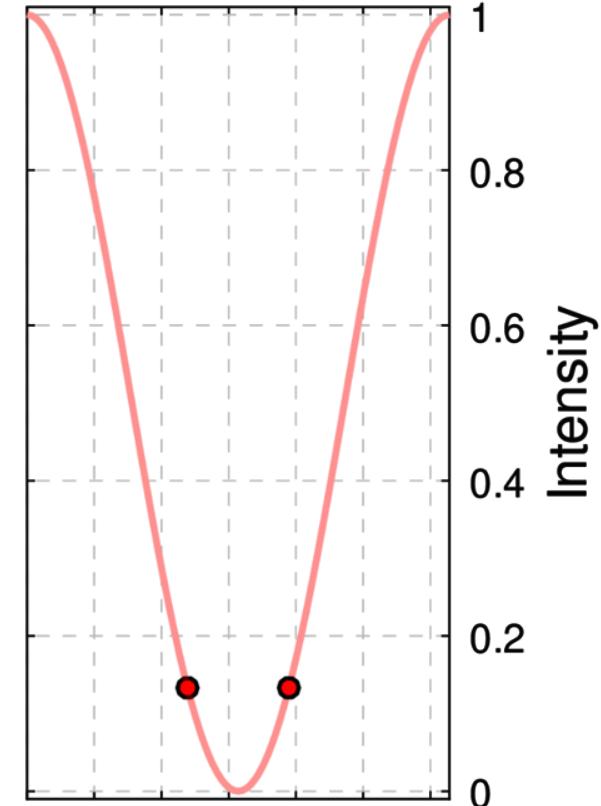
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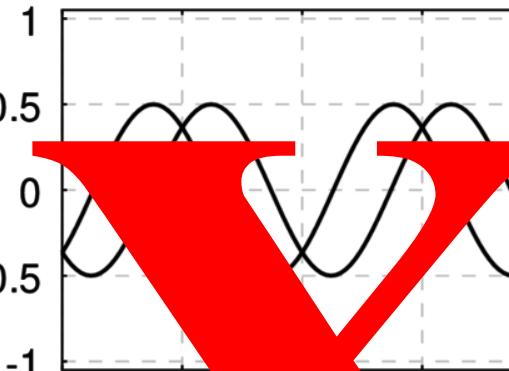
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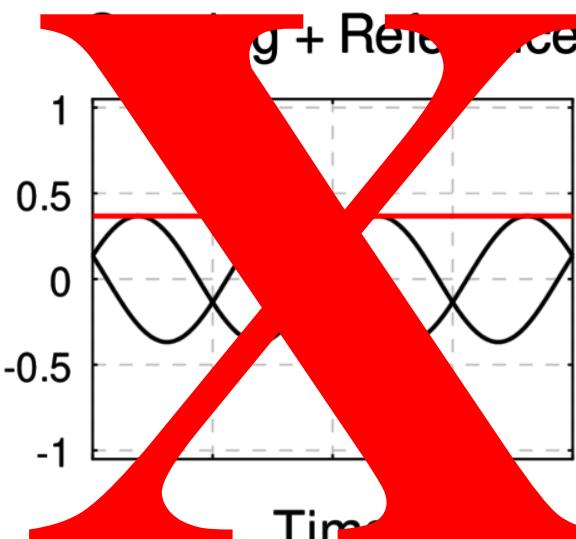
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Interferometry Basics

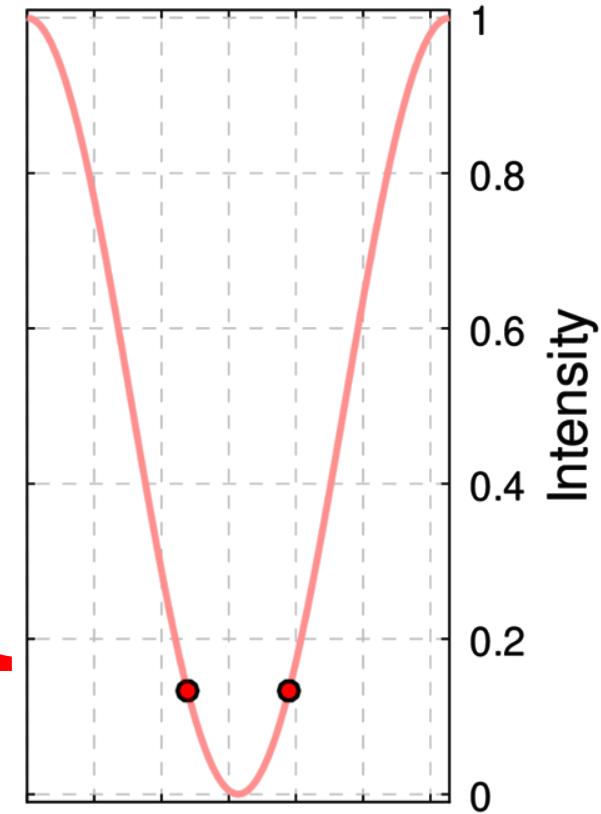
Sensing
Reference



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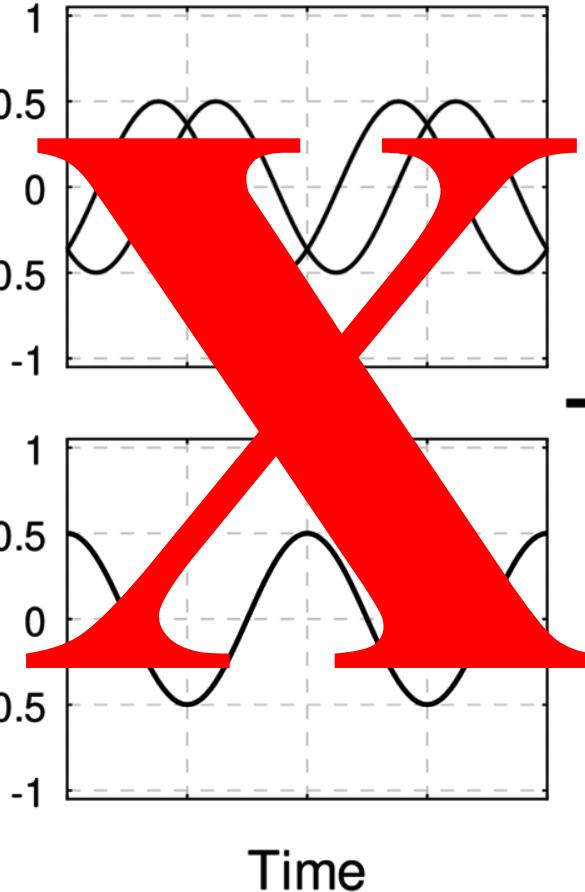


Δx

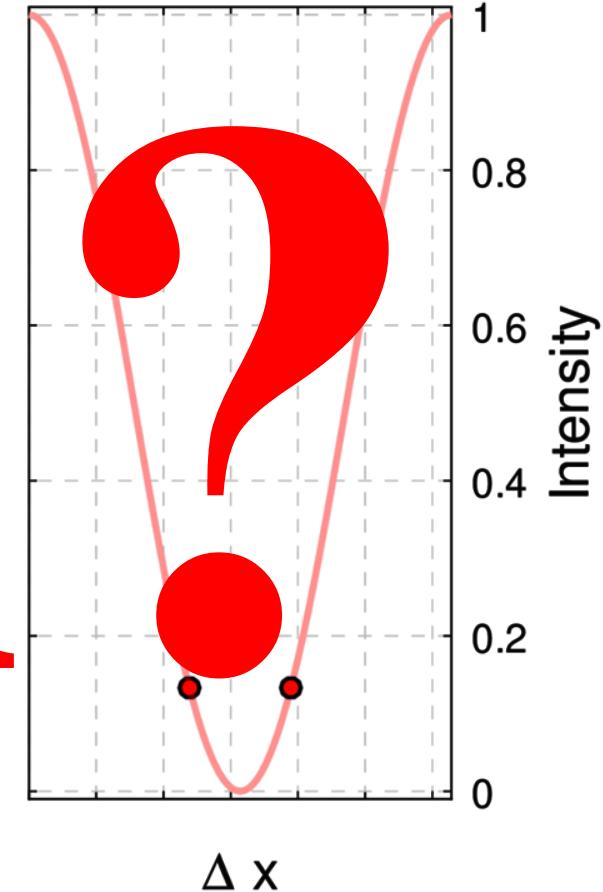
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Interferometry Basics

Sensing
Reference



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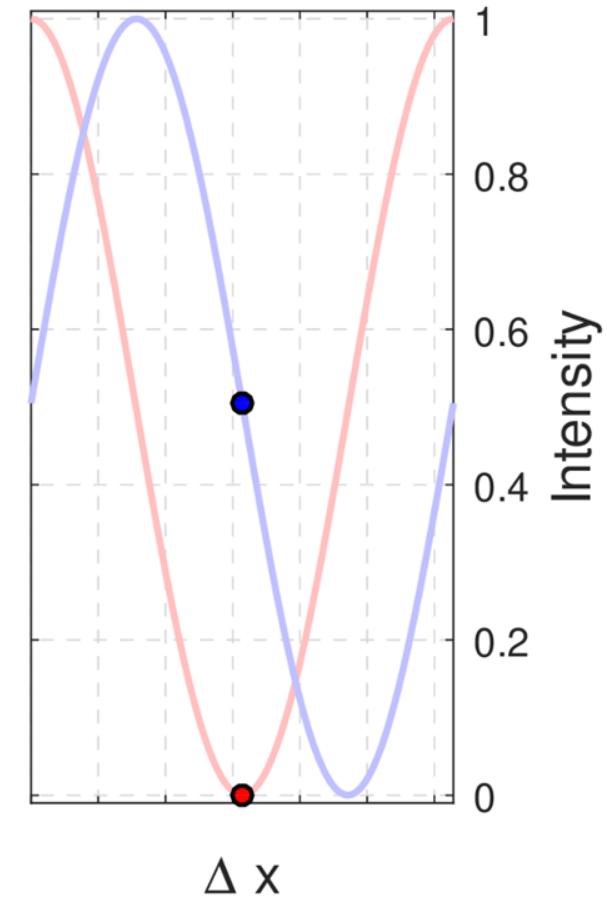
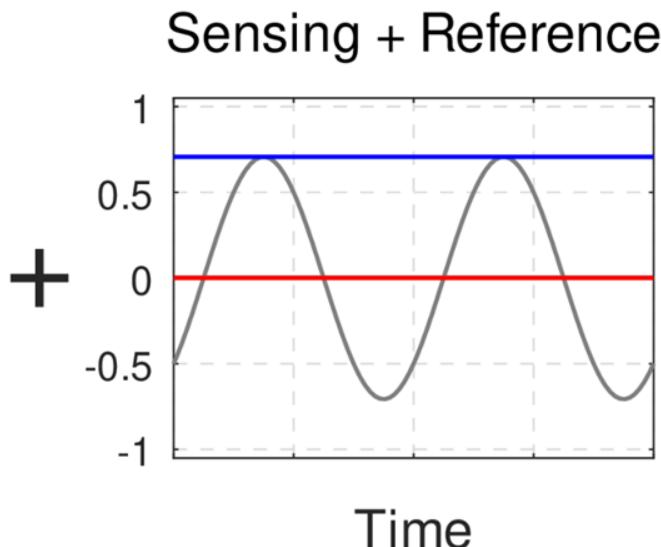
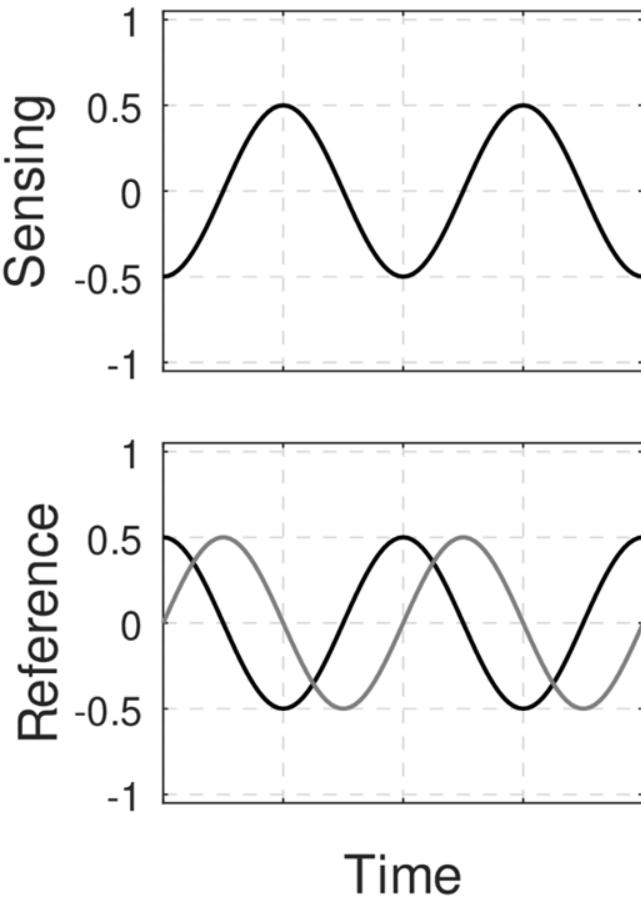


Interferometry Basics

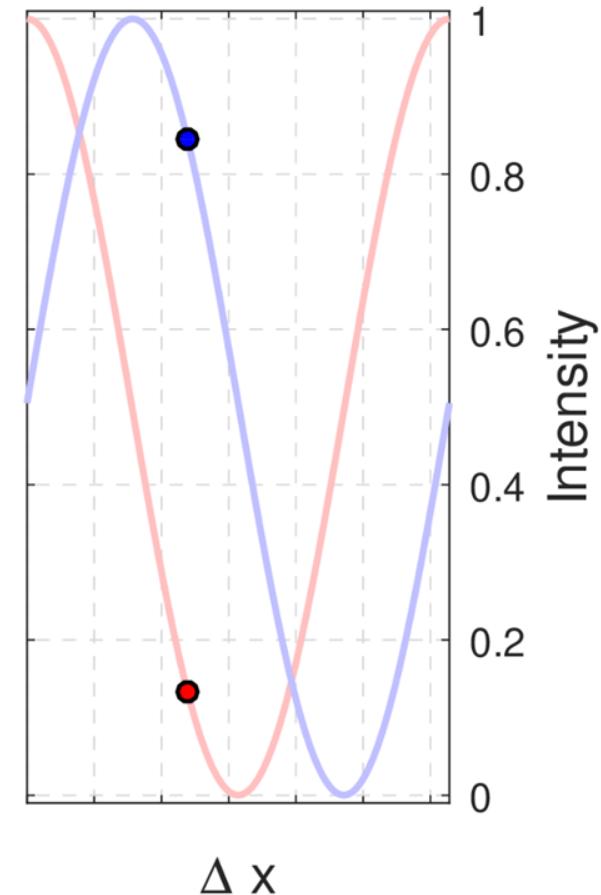
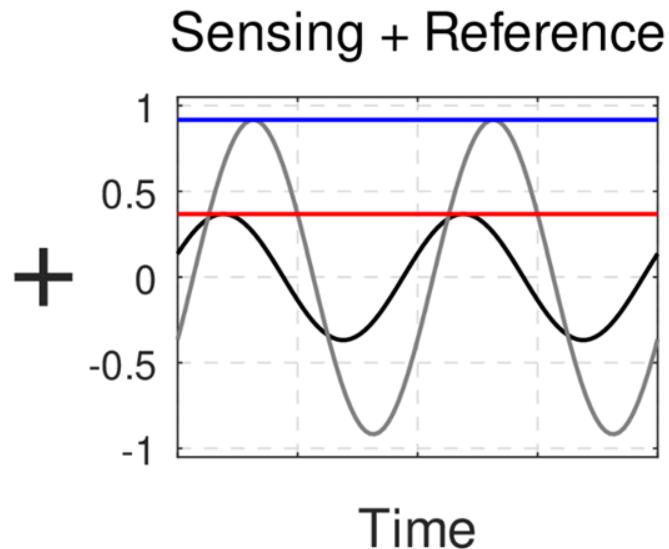
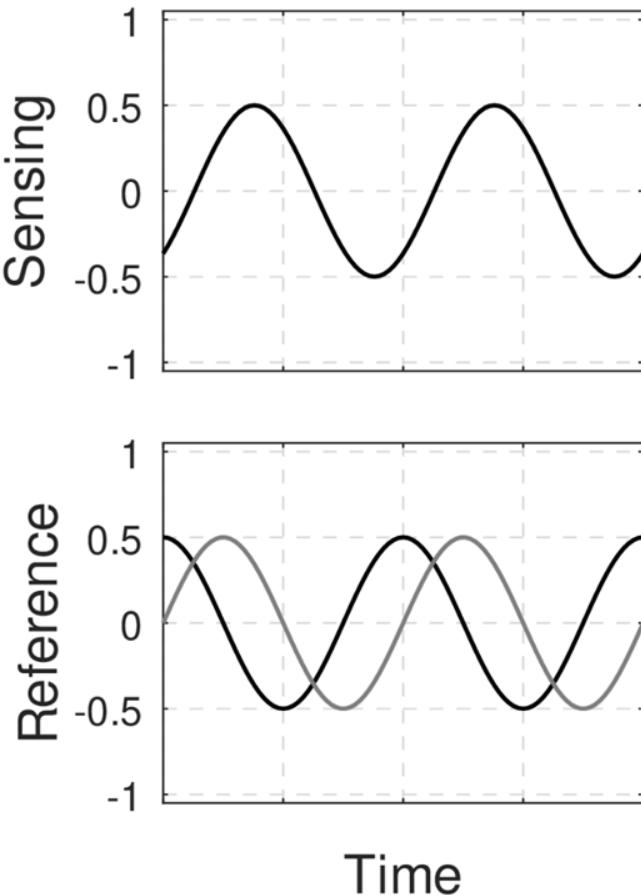


Aragorn, you need more interference fringes

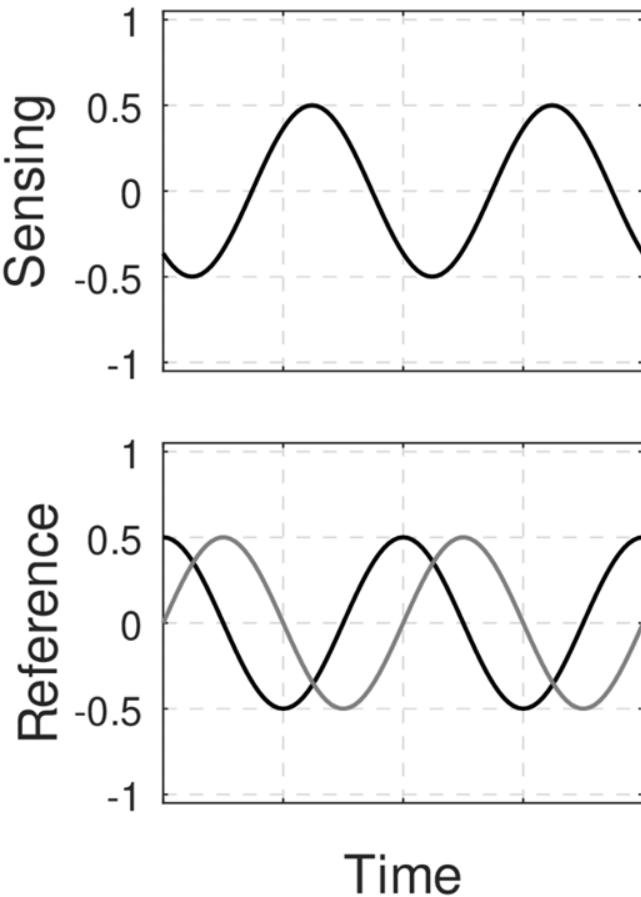
Intermediate Interferometry



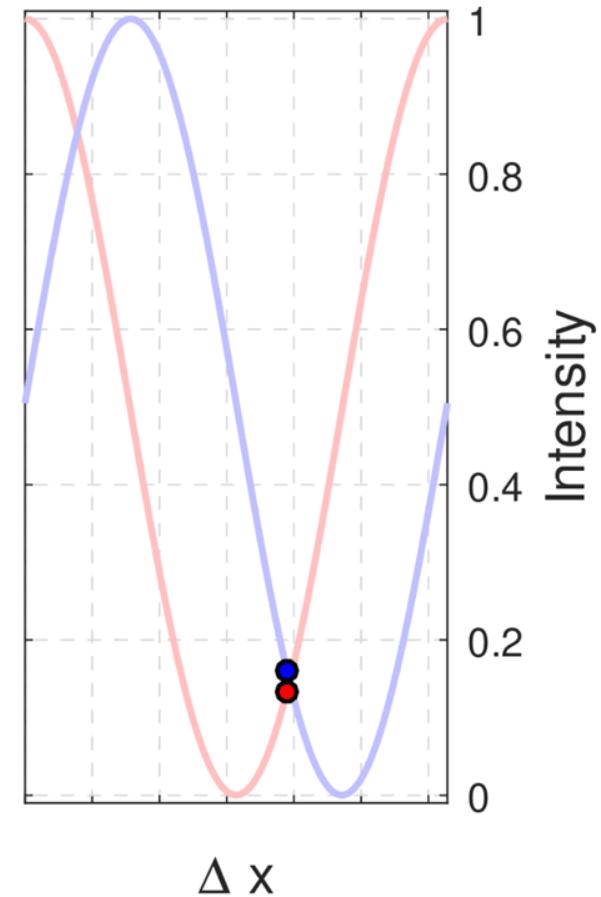
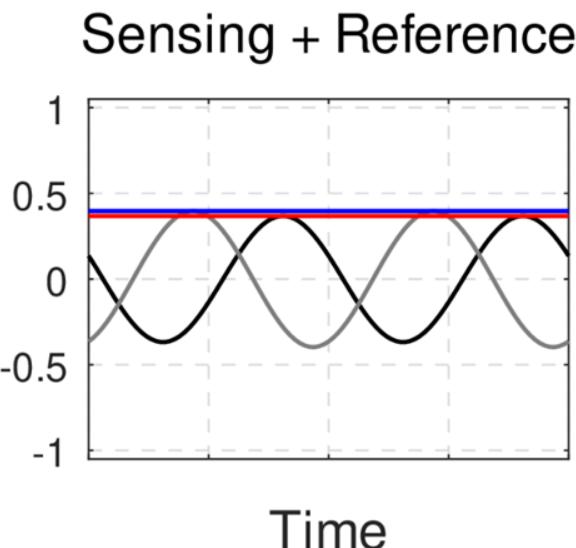
Intermediate Interferometry



Intermediate Interferometry



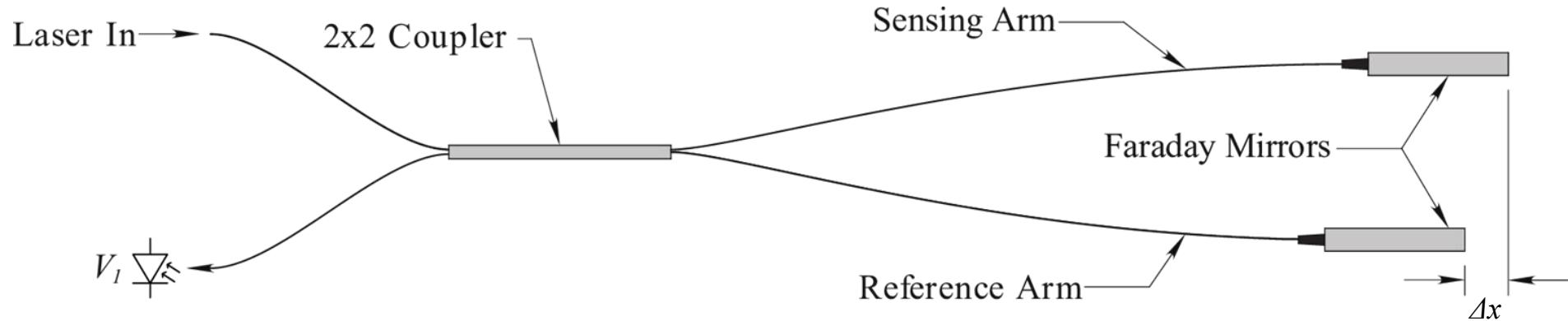
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Interferometry Basics

Optical Fiber Michelson Interferometer

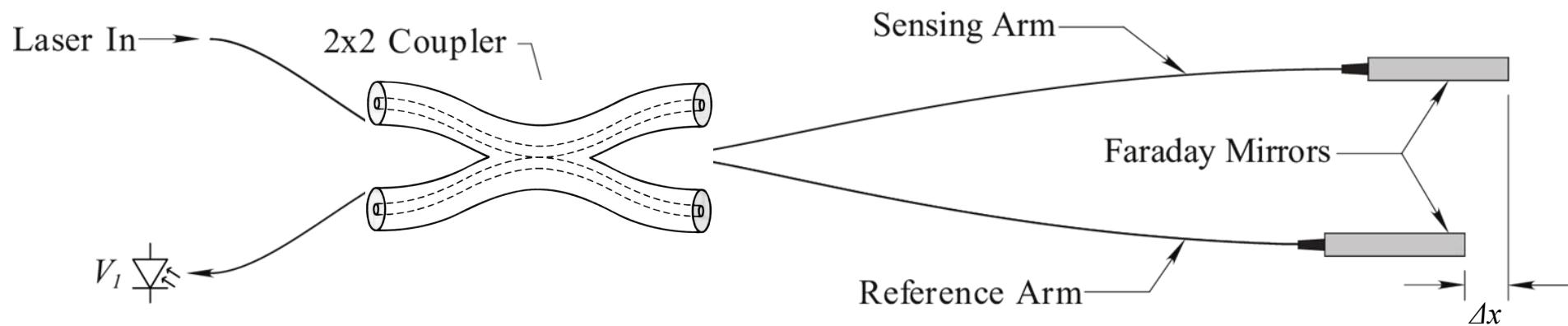
- 2x2 coupler acts as beam splitter (\$15)
- Faraday mirrors as retroreflectors (\$80 each)
 - Eliminates polarization fading



Intermediate Interferometry

Optical Fiber Michelson Interferometer

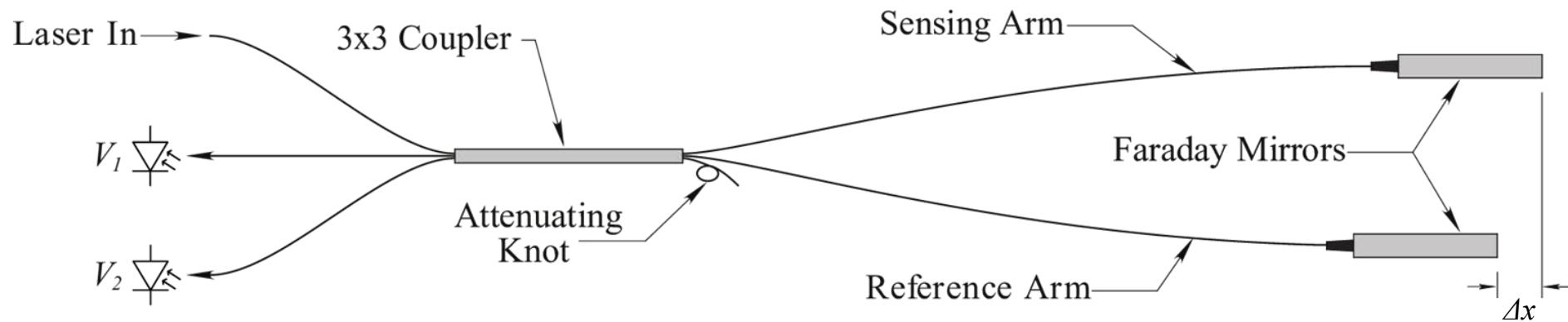
- Fused 2x2 coupler acts as beam splitter
 - Evanescent waveguide coupler



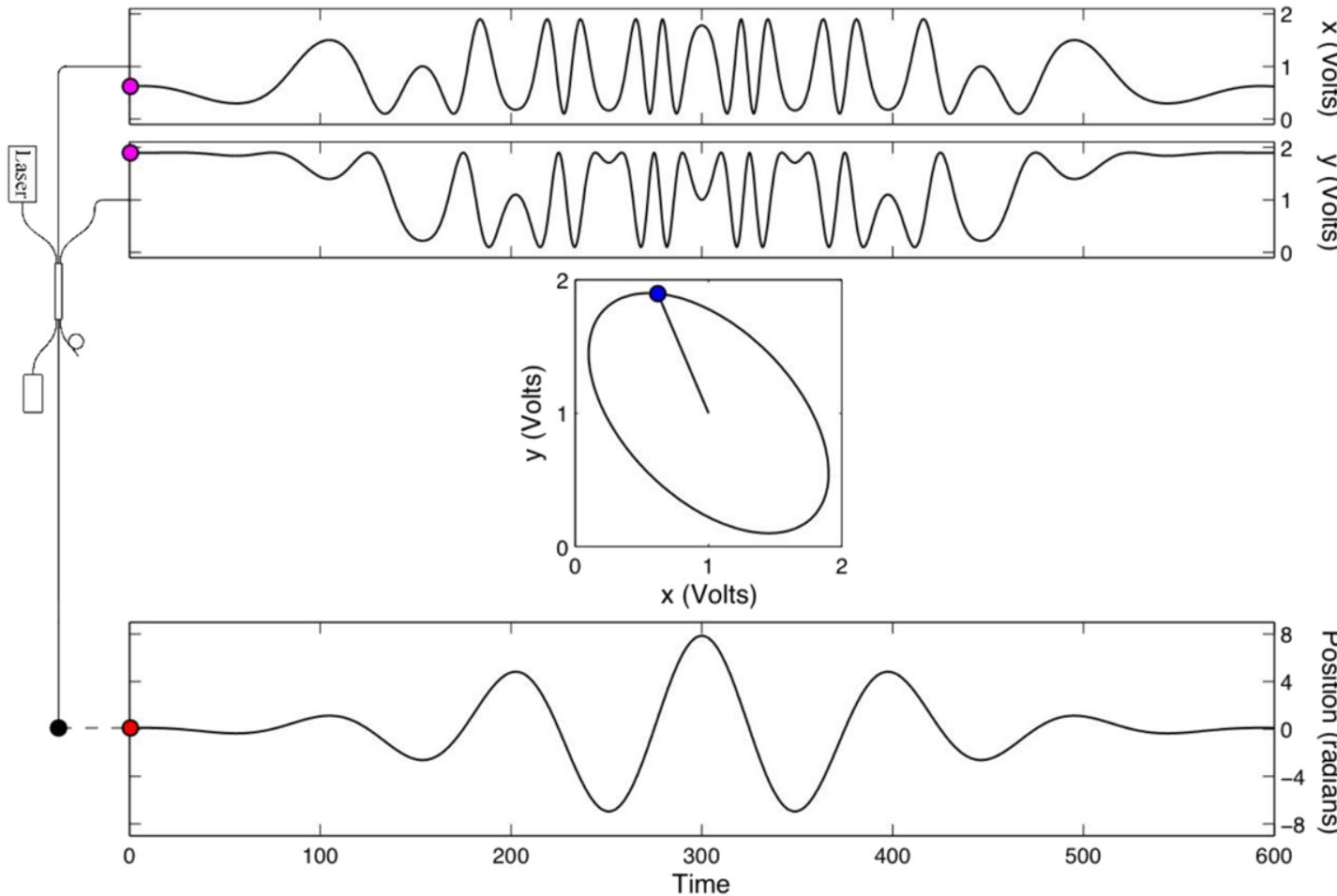
Intermediate Interferometry

Optical Fiber Michelson Interferometer

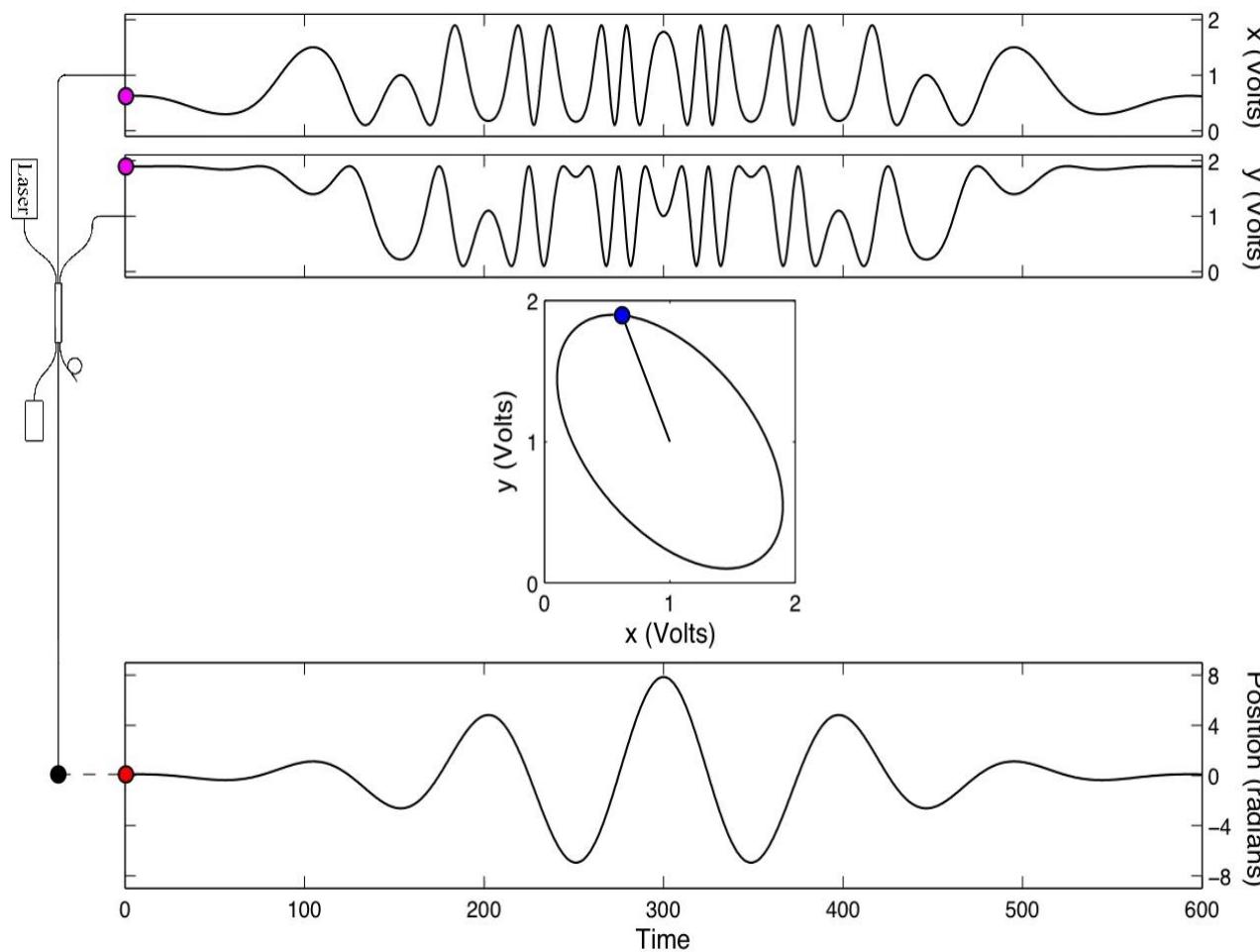
- Fused 3x3 coupler acts as beam splitter (\$65)
 - Returns fringes phase shifted by 120°



Advanced Interferometry: Fringe Counting



Advanced Interferometry: Fringe Counting



Advanced Interferometry: Fringe Counting

