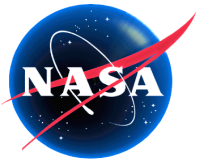
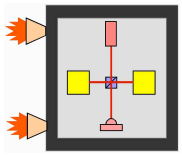




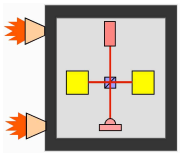
The ST7 Interferometer

Andreas Kuhnert
Robert Spero

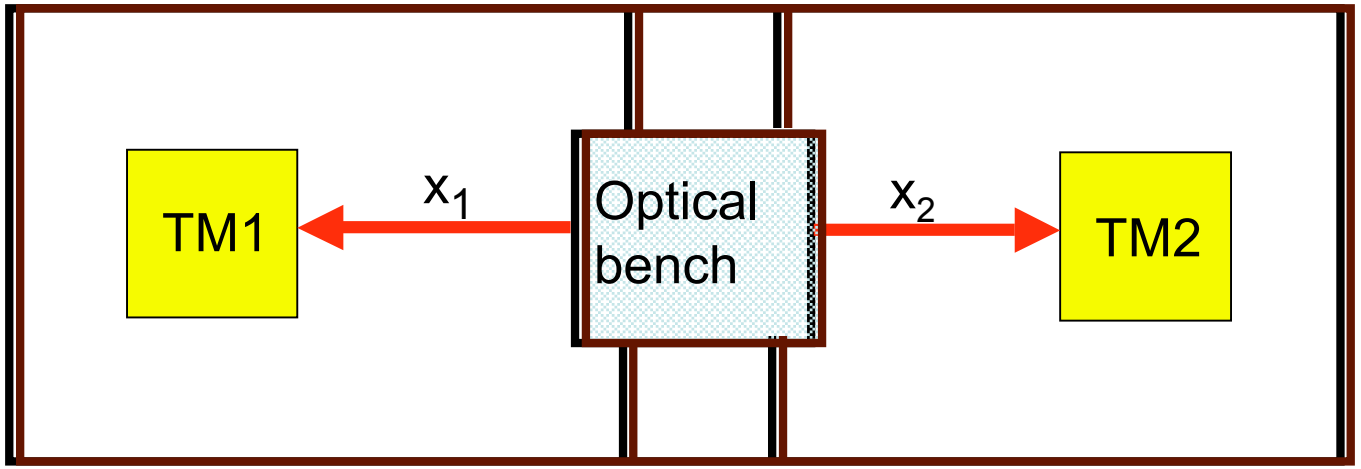
Jet Propulsion Laboratory
California Institute of Technology

LIGO-G040043-00-Z

ST7 Concept

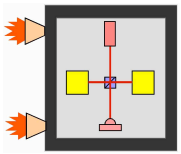


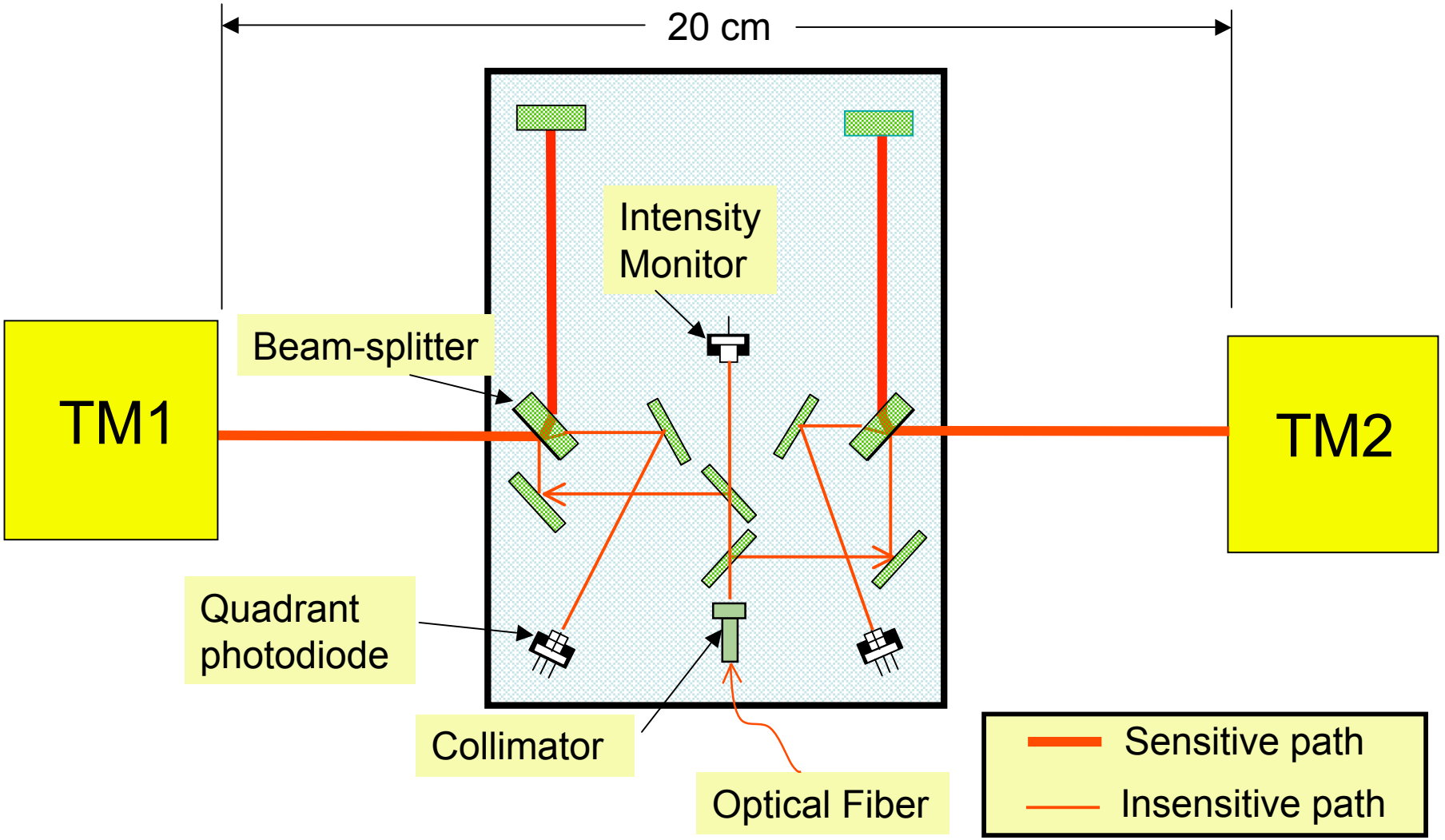
- Measure suspended masses within spacecraft
- Test thruster performance in drag-free control
- Hitch ride on LISA Pathfinder



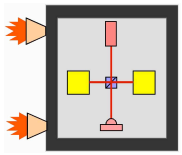
- Interferometer optical bench fixed to spacecraft
- x_1 and x_2 measured separately; $x_1 + x_2$ is low-noise

Optical Bench





Interferometer Features



Beam diameter 1 mm, Rayleigh range 70 cm, sensitive path lengths 10 cm.

No modulators, phasemeters, intensity stabilization, or frequency stabilization.

Requires test mass to be positioned near mid-fringe.

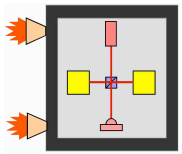
Intensity monitored, noise removed in data analysis.

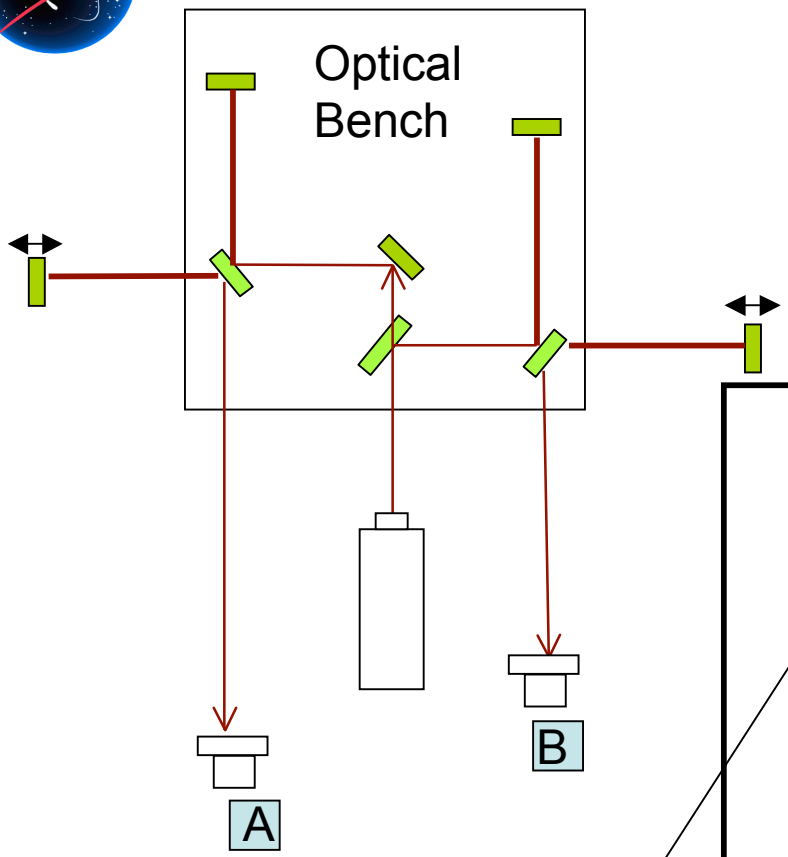
Separate measurements of both bench/test-mass distances.

Quadrant photodiodes monitor total fringe signal, and two axes of alignment.

Automatic alignment, autonomous operation.

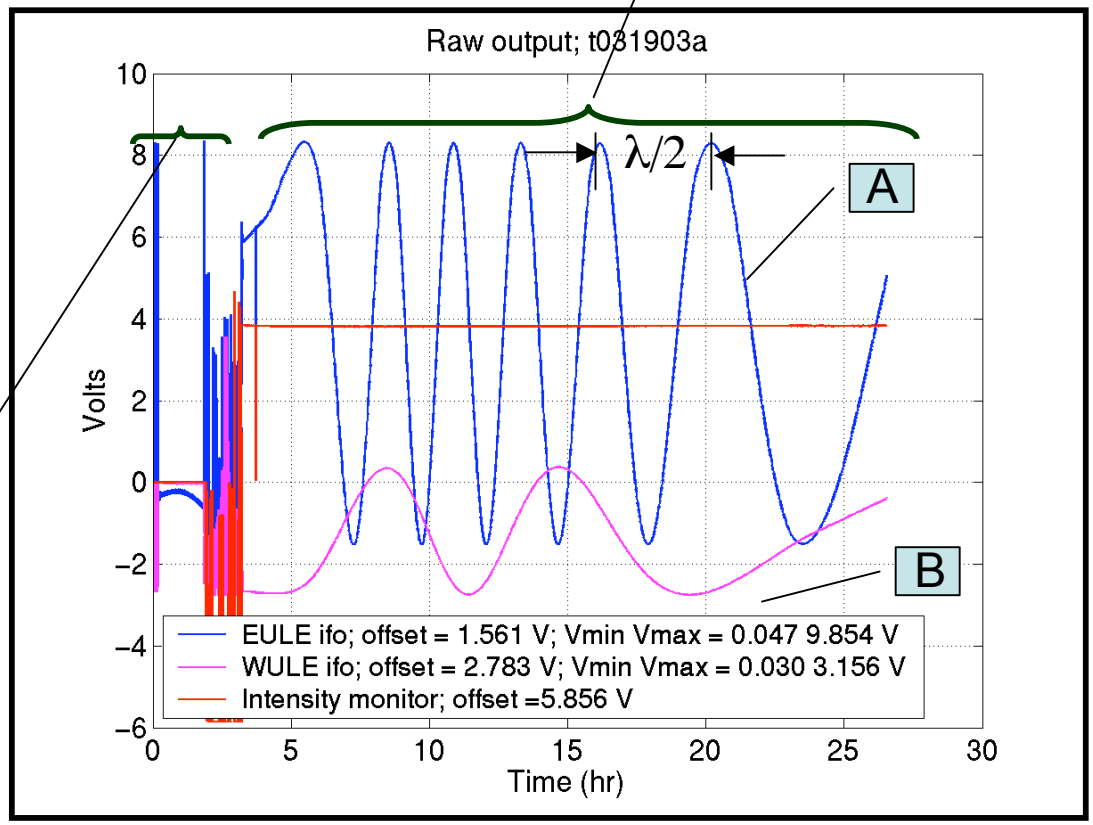
Homodyne Signal



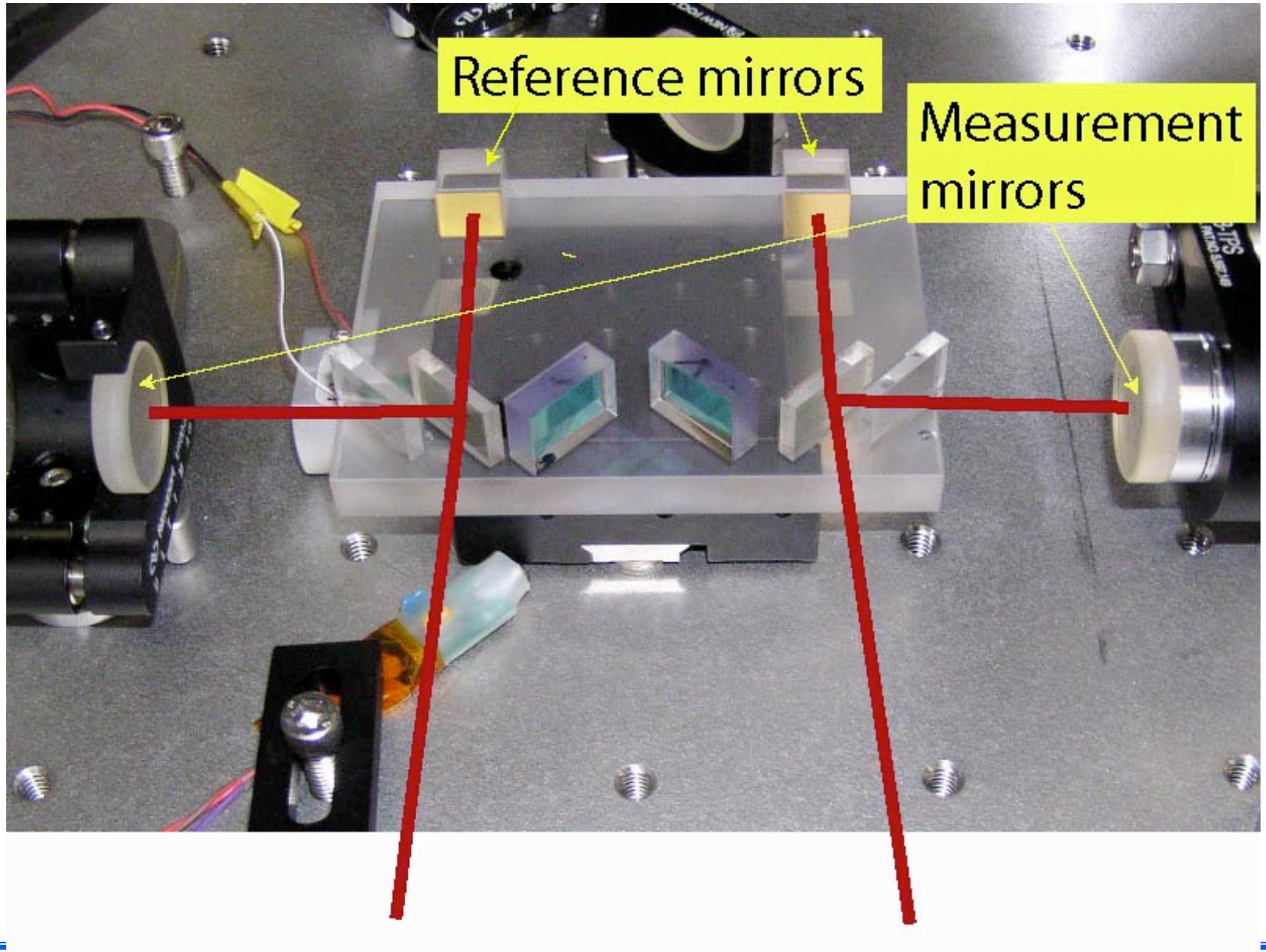


Thermal Expansion

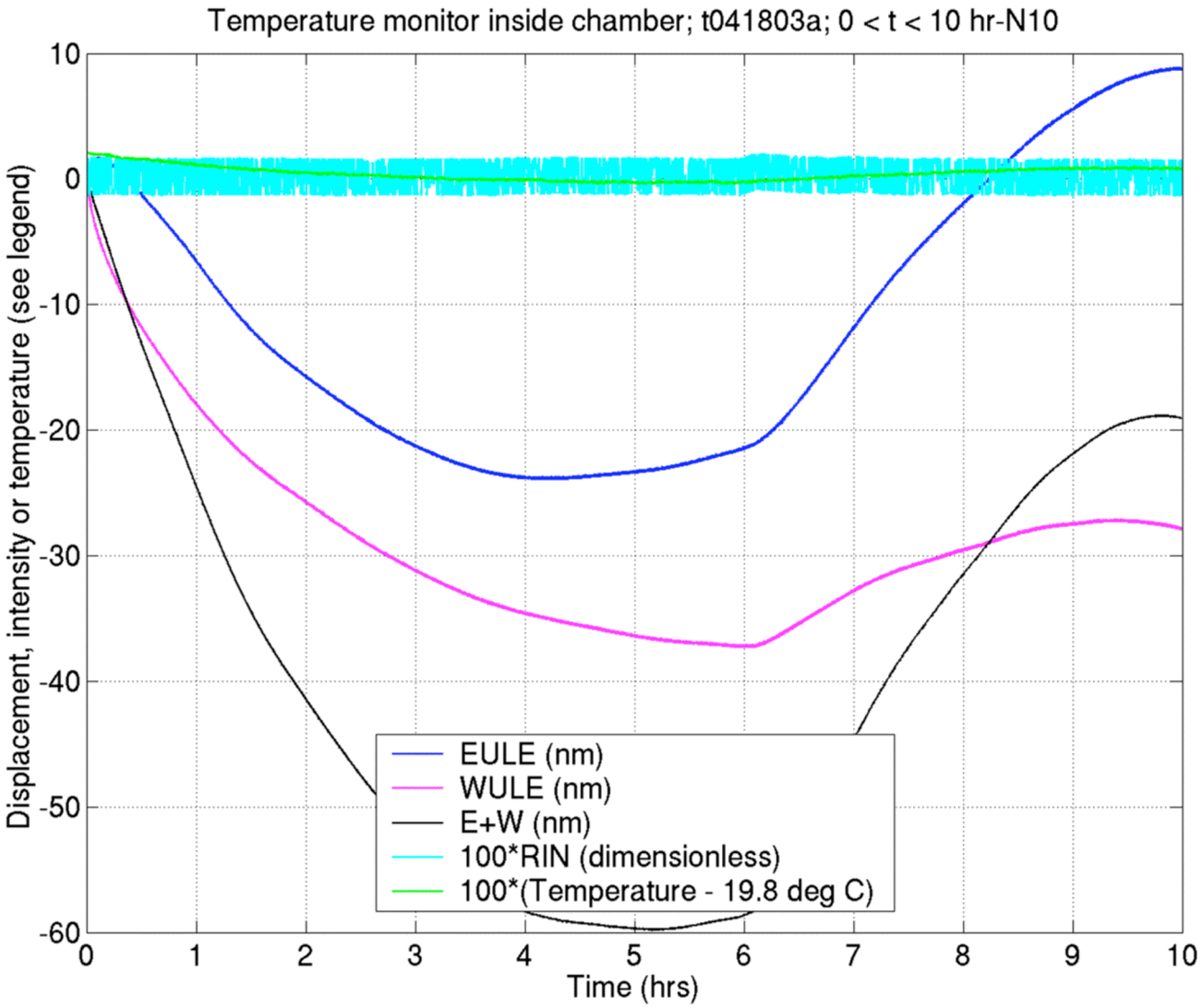
Manual Alignment



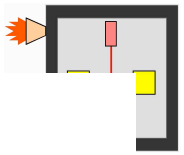
Contacted Optics in Vacuum Chamber

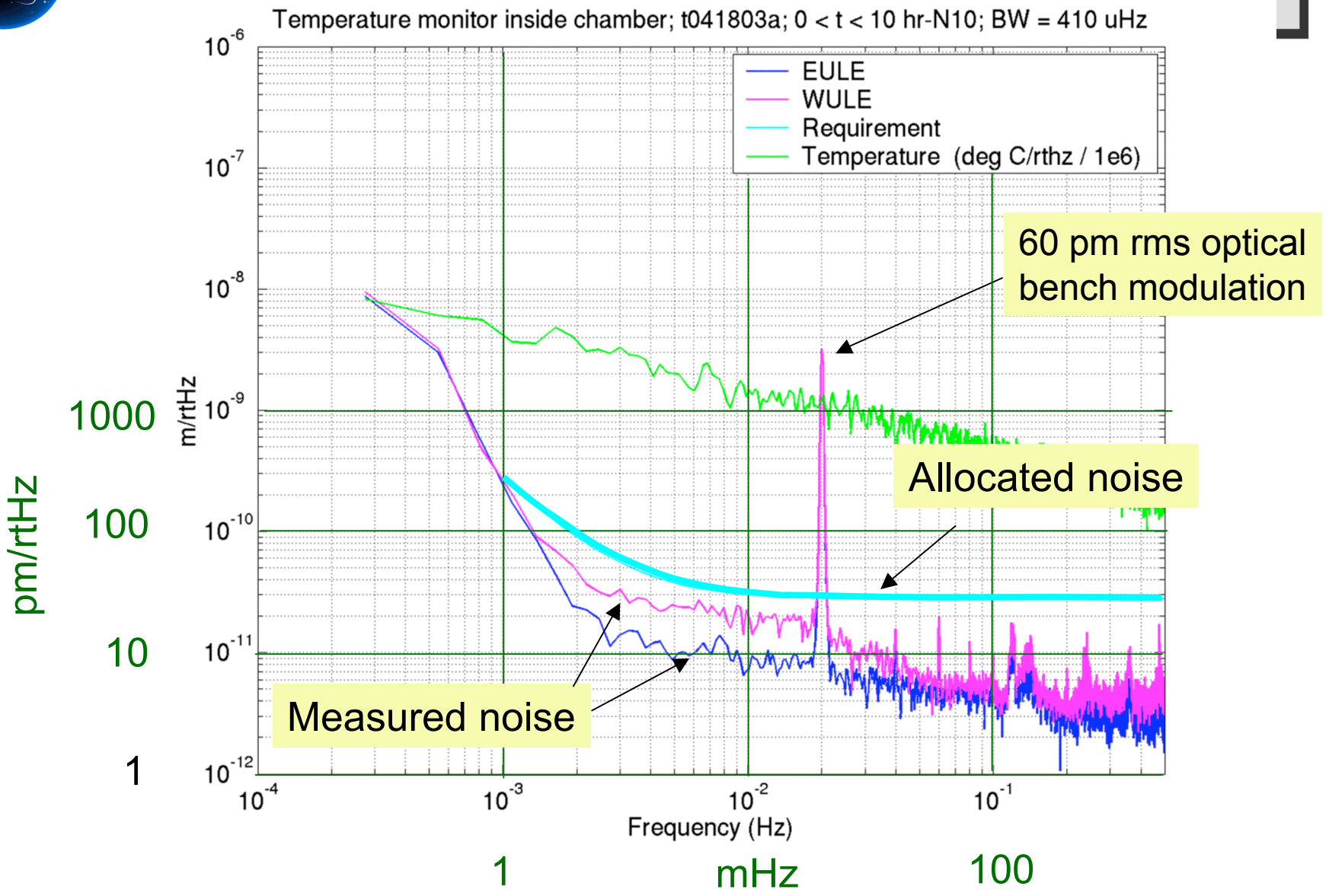


Testbed Drift

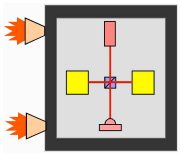


Testbed Noise

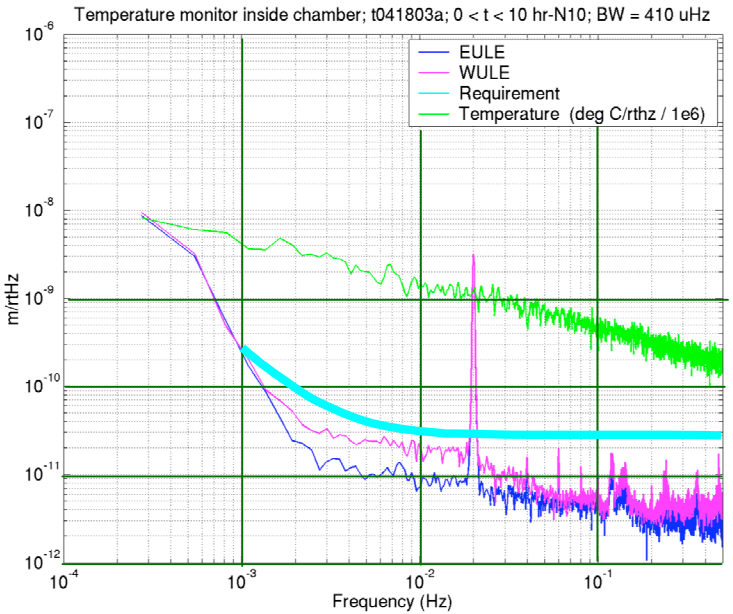




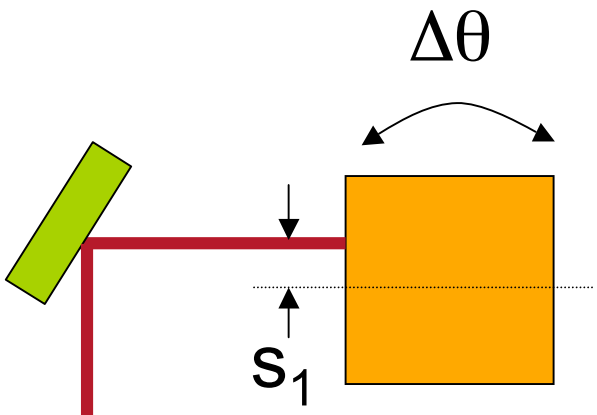
Measurements Demonstrate:



1. Analog electronics and ADC noise adequately low
2. Thermal sensitivity probably adequately low
3. Bench motion suppression typically x200, without calibration (x1000 needed)
4. Frequency stabilization not needed
5. Intensity noise can be suppressed in data analysis

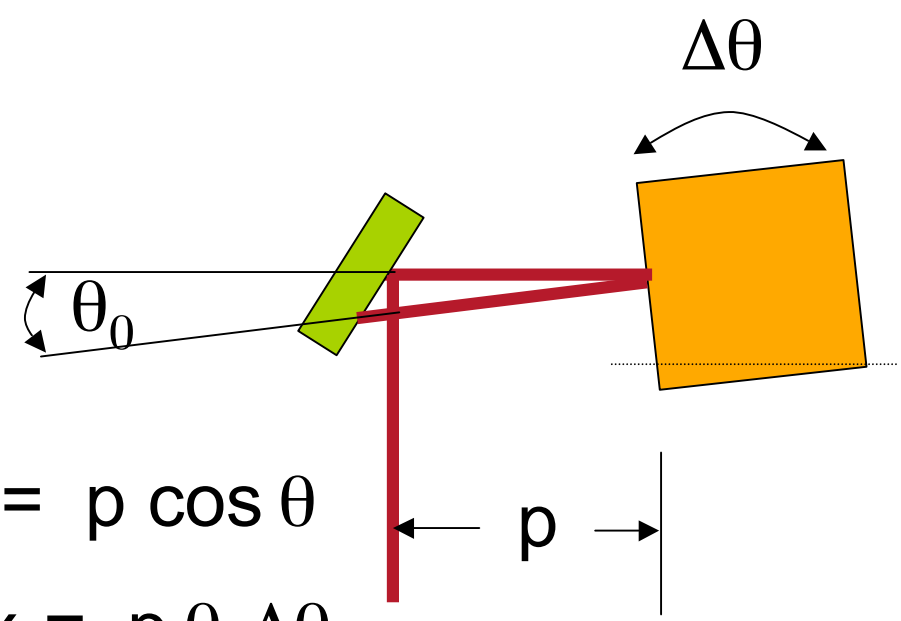


Alignment Sensitivity 1: Geometric error



$x_S = s_1 \sin\theta$

$\Delta x_S = s_1 \Delta\theta$



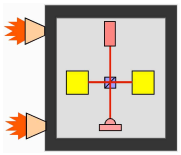
$x_c = p \cos\theta$

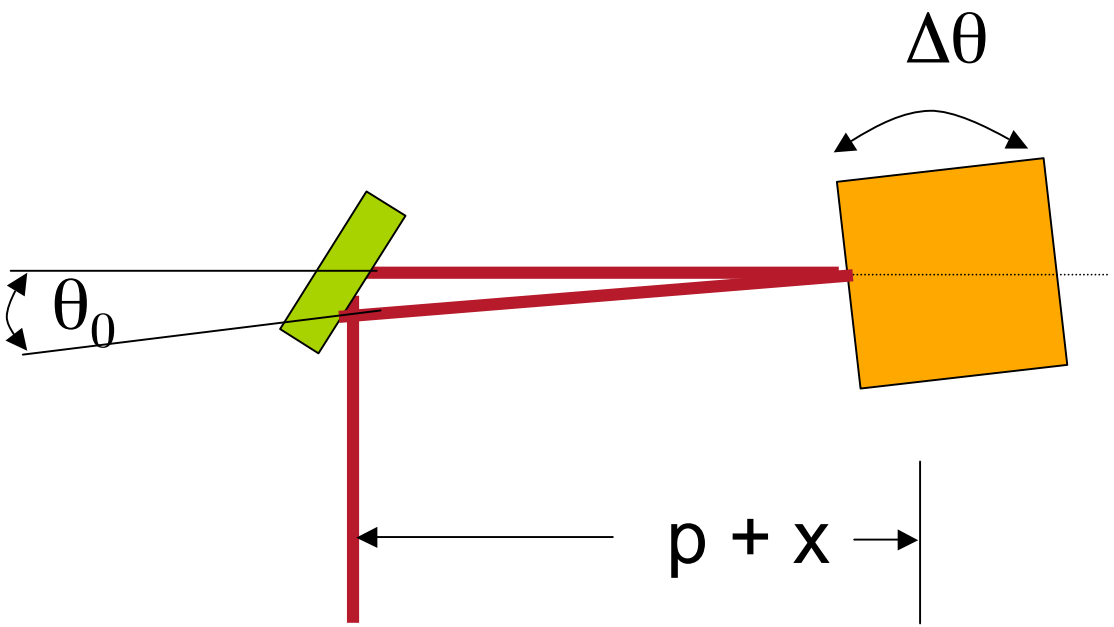
$\Delta x_c = p\,\theta_0 \Delta\theta$

$s_1 = 40\ \mu$; $p = 10$ cm; $\theta_0 = 400\ \mu$rad

Errors are correlated, and of same order: $s_1 \sim p\,\theta_0$

Alignment Sensitivity 2: Fringe position error



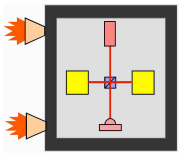


$\Delta x_x = \alpha x\ \theta_0 \Delta\theta,$

$\alpha = (\pi w/\lambda)^2 = 2.2 \times 10^6,$

w=beam radius

Total angle-jitter noise



$$\frac{dx}{d\theta} \approx h + \theta\,[\alpha x - p]$$

$$\tilde{x}(f) \approx \tilde{\theta}(f)\,(h + \theta\,[\alpha x - p])$$

Fringe center error, 30 nm

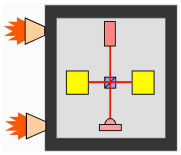
Misalignment, 400 μrad

Transverse error, 40 μm

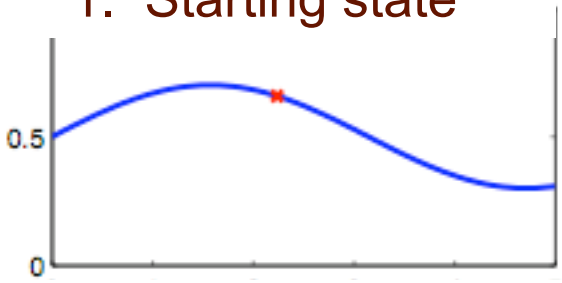
Test mass jitter, 1 μrad/rthz

Displacement noise, 30 pm/rthz

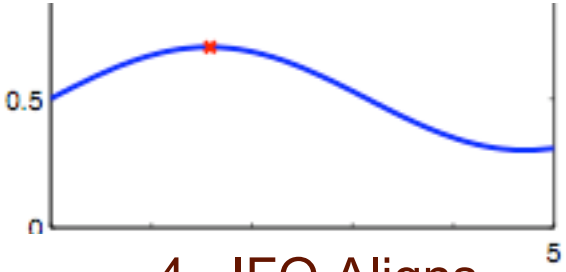
Initialization



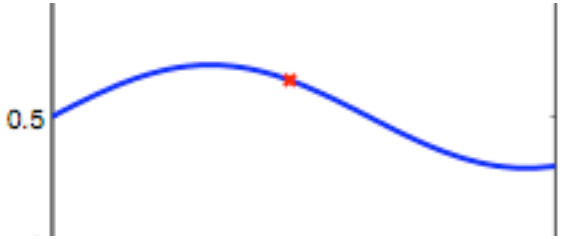
1. Starting state



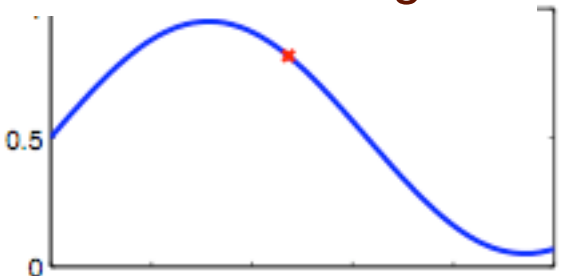
2. IFO finds bright fringe



3. GRS moves to quarter fringe



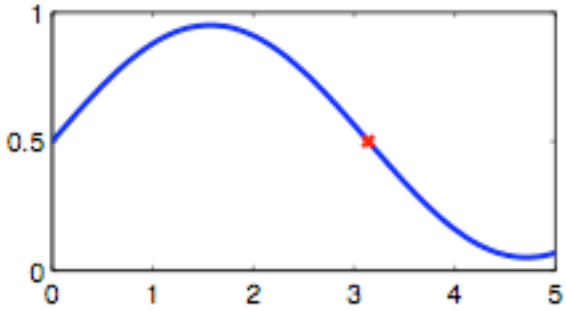
4. IFO Aligns



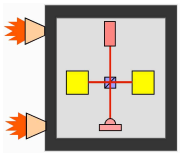
Position ⟶

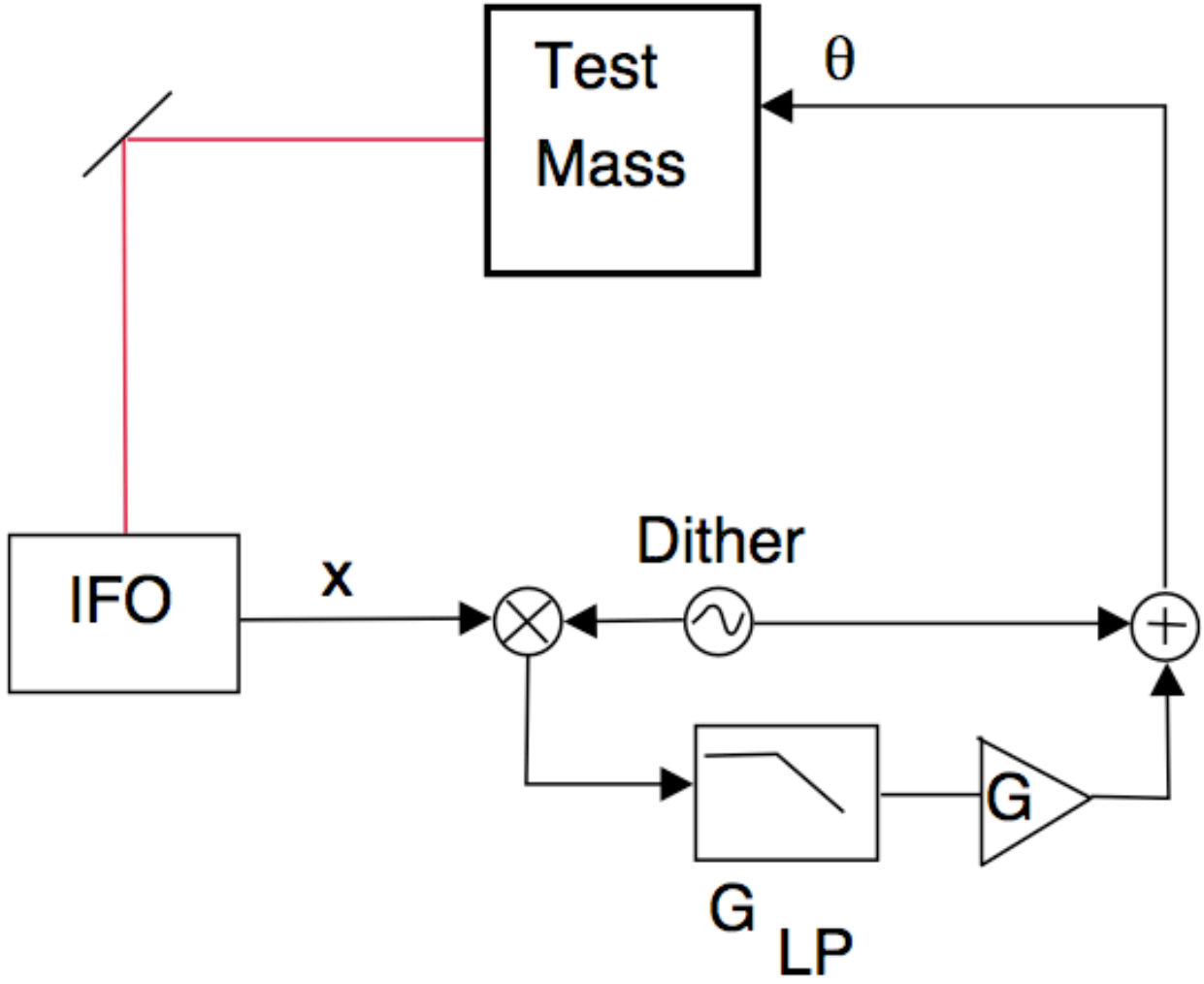
5. GRS to half fringe

Intensity ⟶

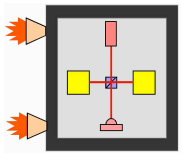


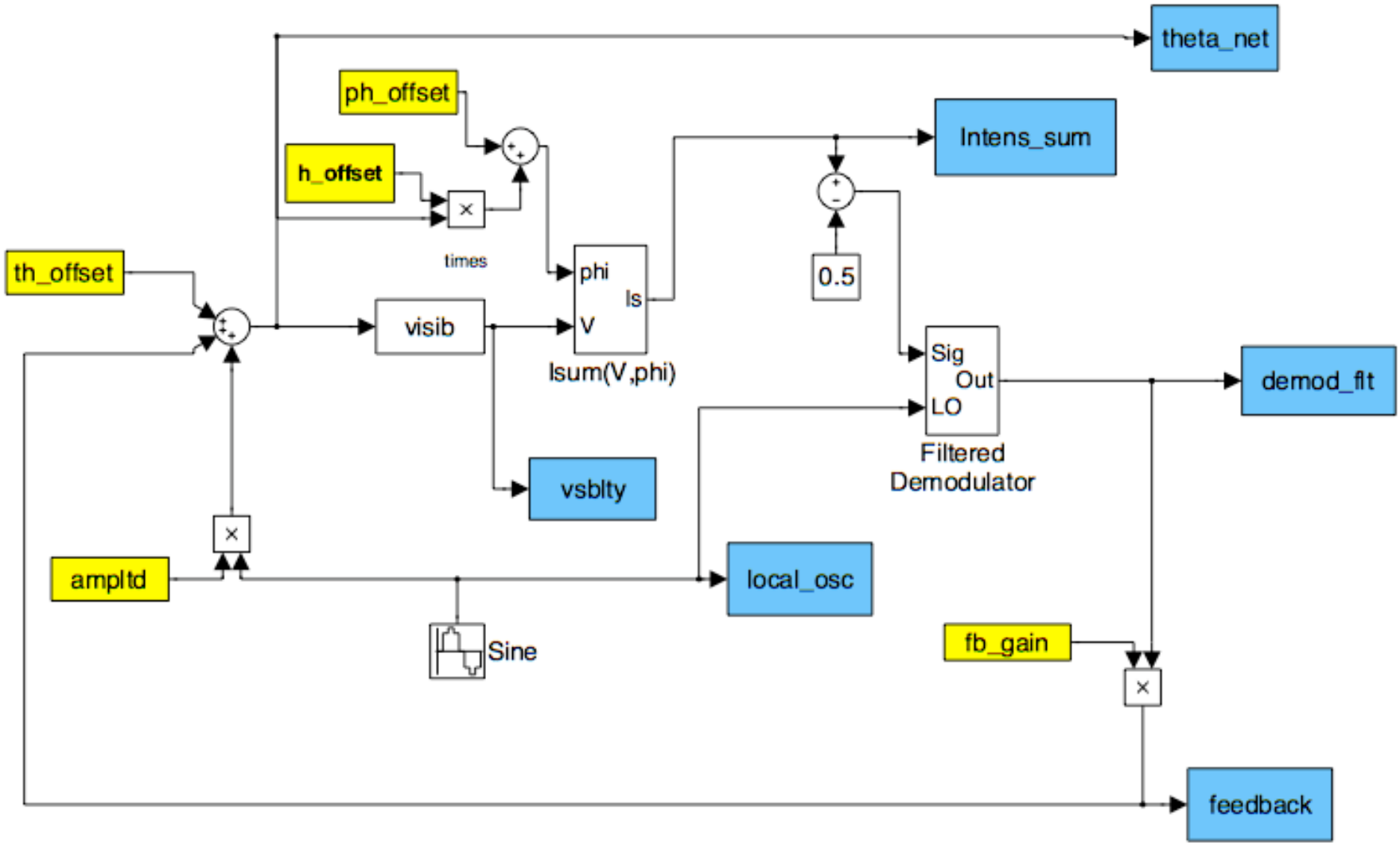
Dithered alignment -- concept



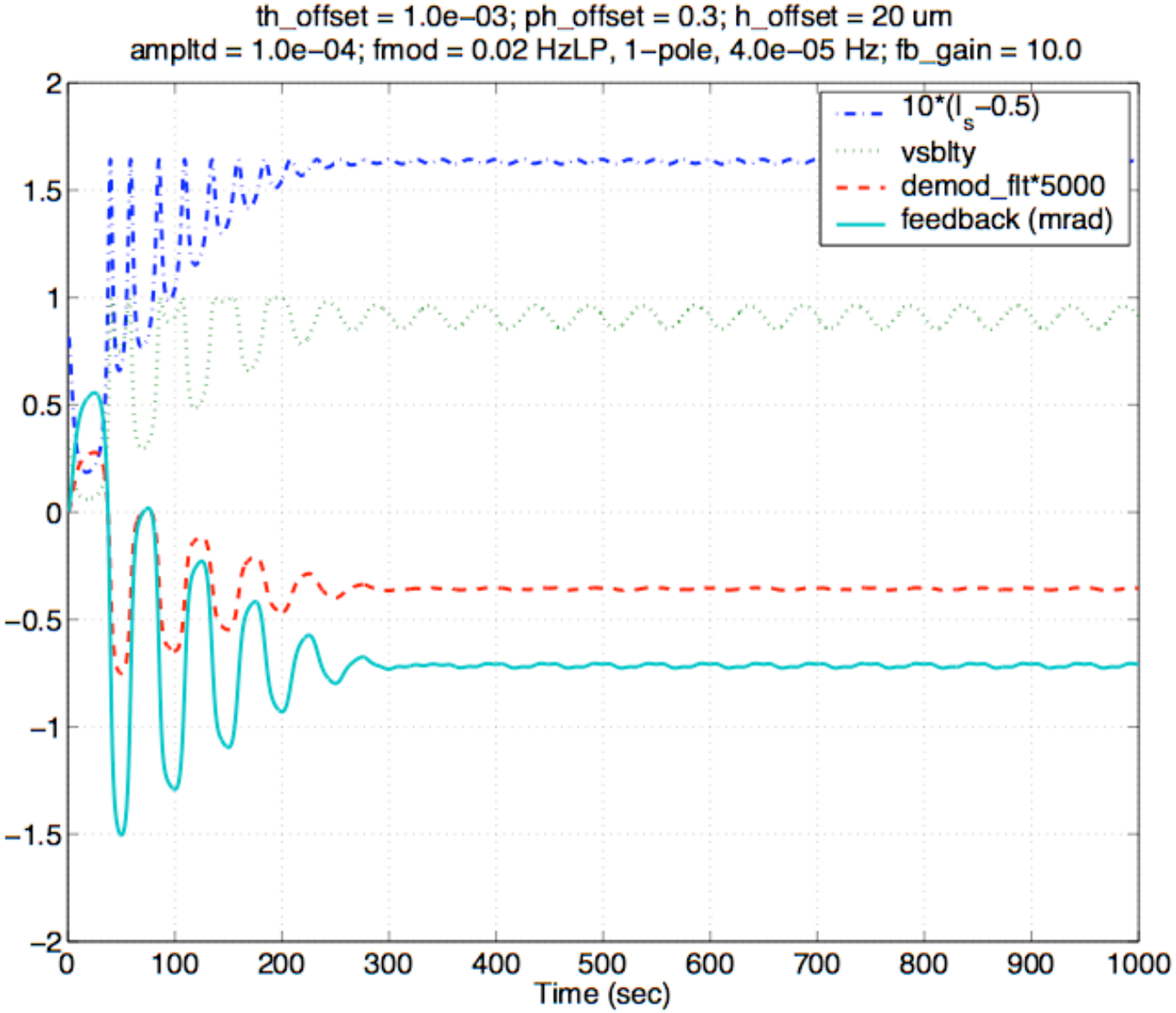


Dithered alignment -- Simulink model

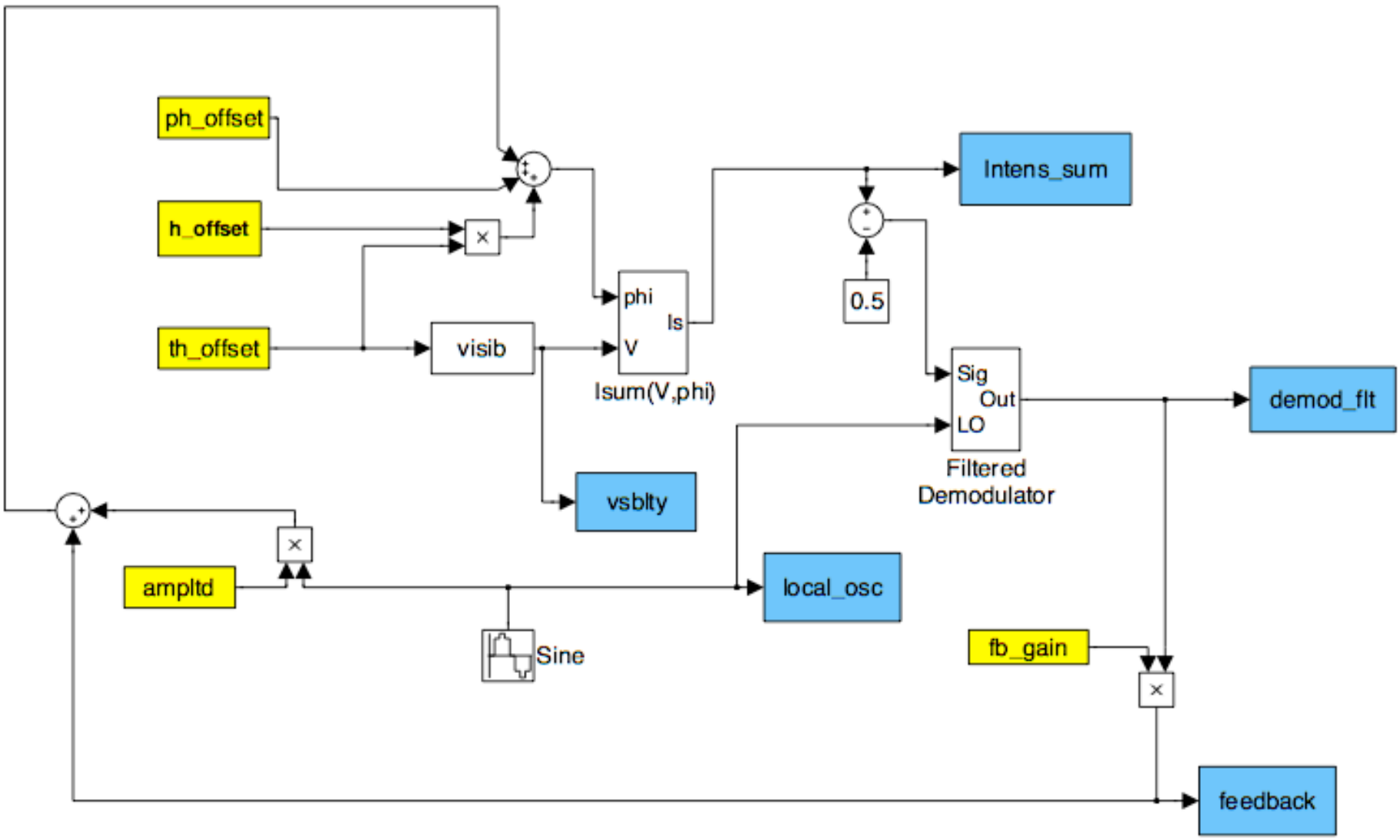




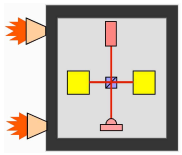
Dithered alignment -- Simulink run

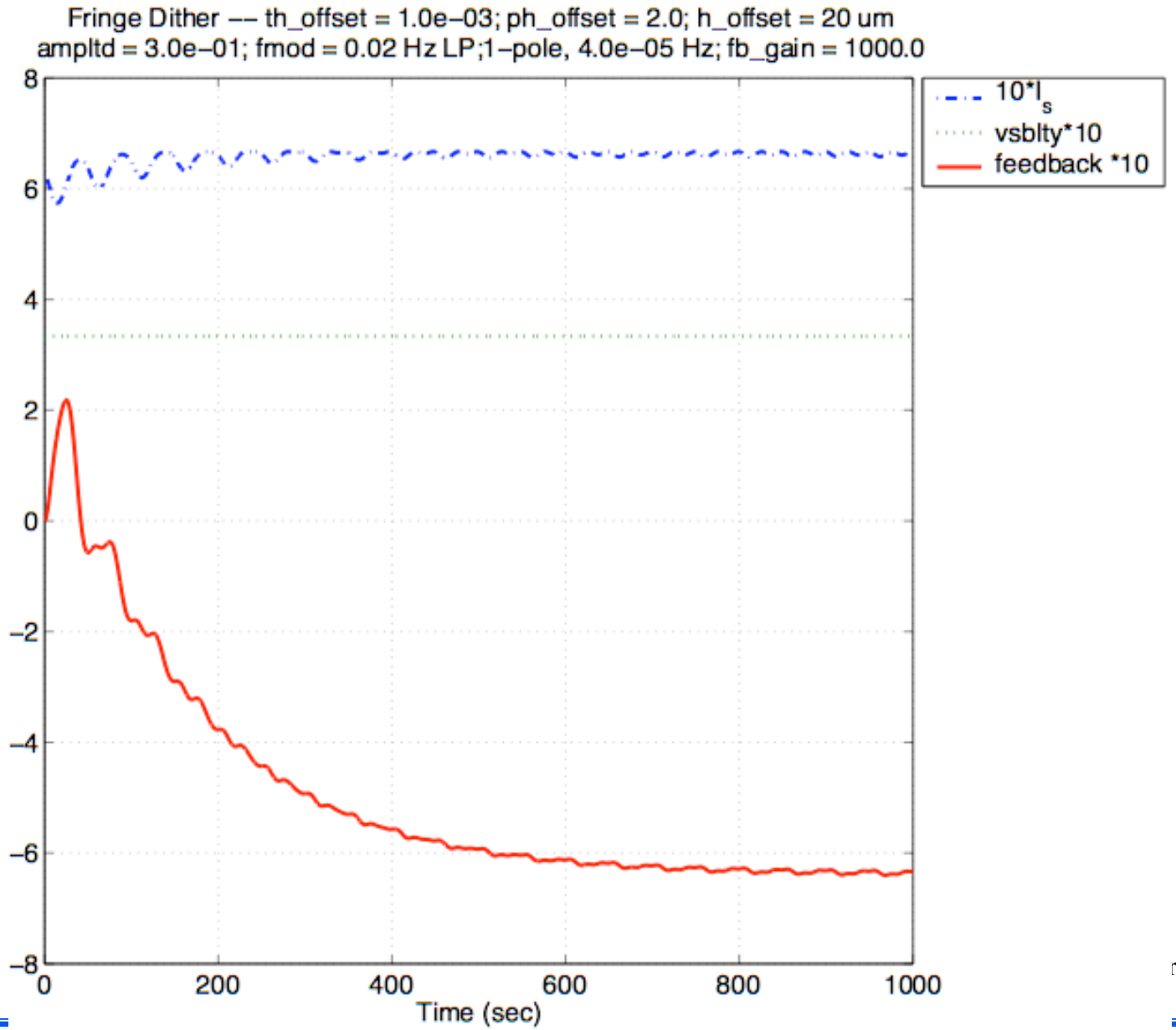


Bright fringe finder -- Simulink model

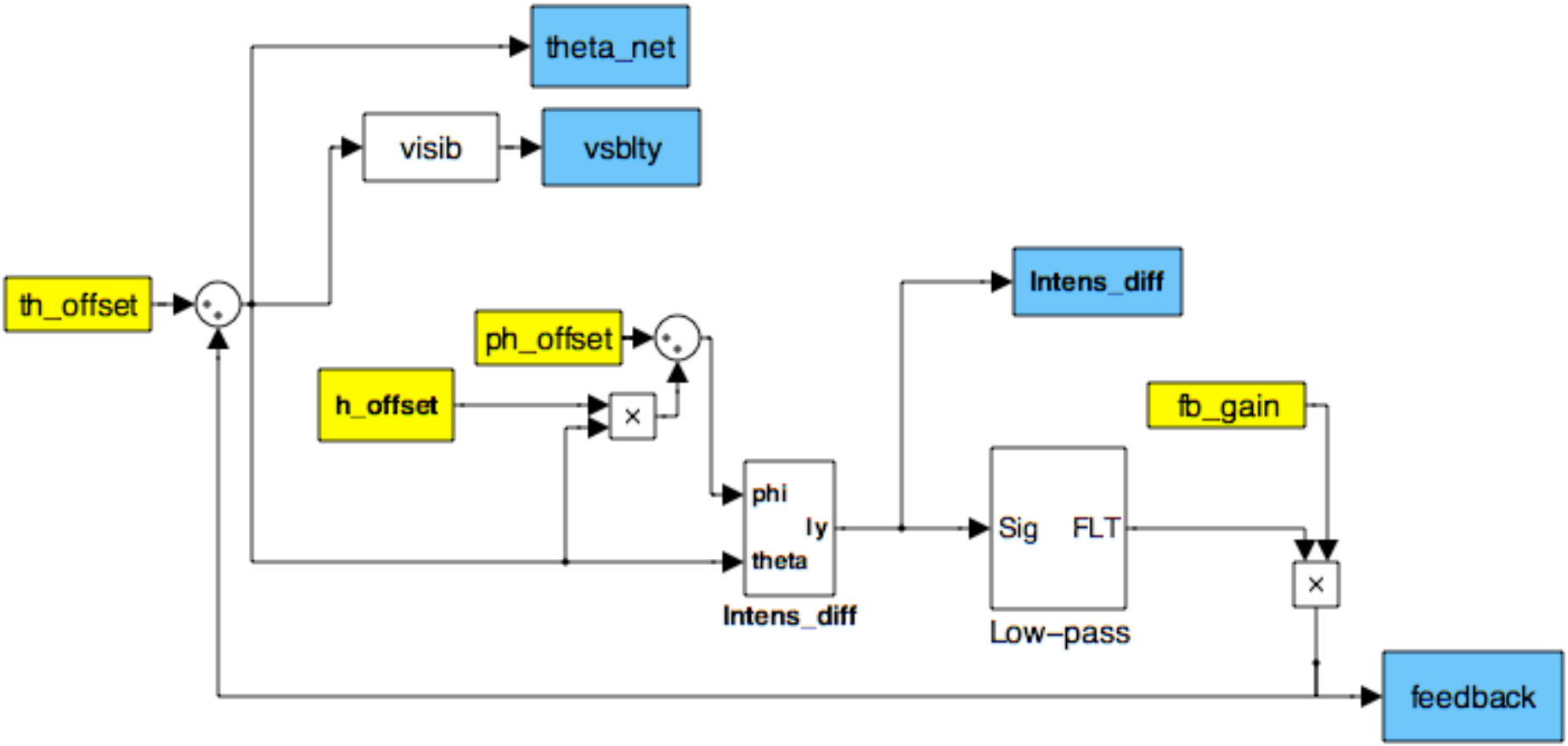


Bright fringe finder -- Simulink run

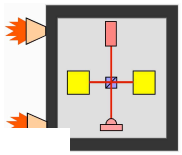


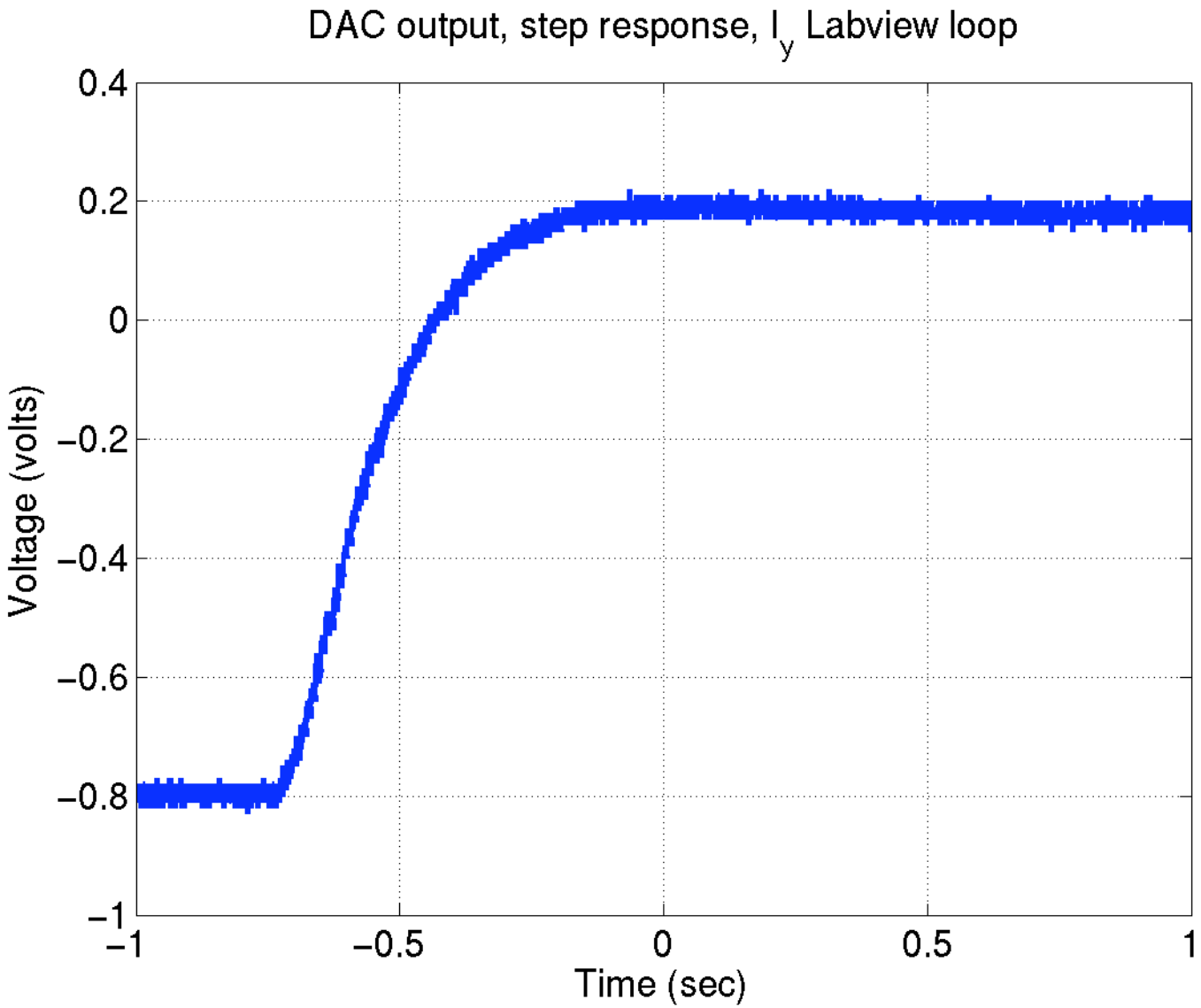


QPD difference alignment -- Simulink model

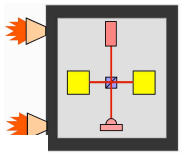


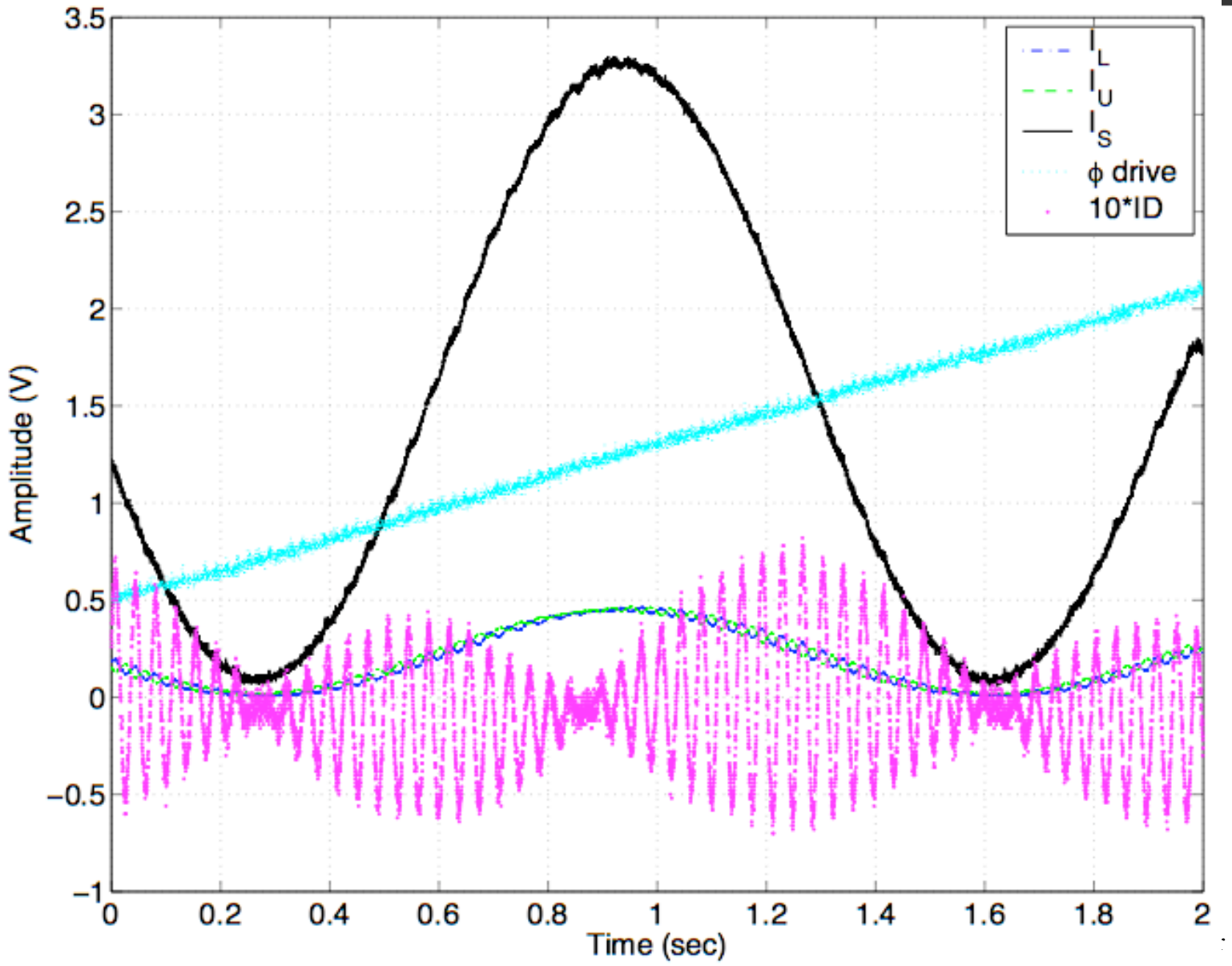
QPD difference alignment -- Experiment



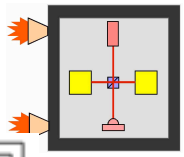


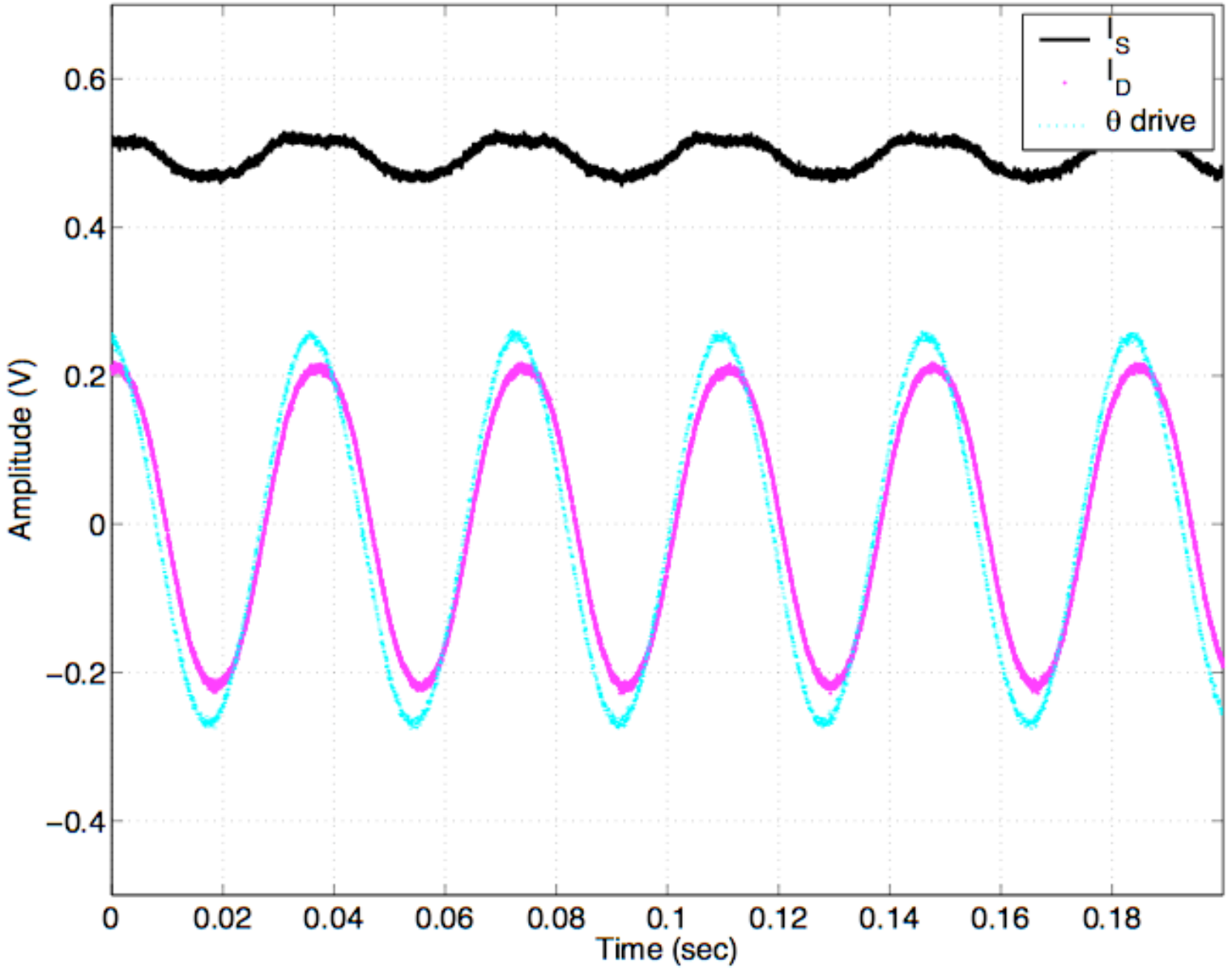
QPD difference signal alignment sensitivity



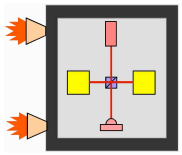


Sum vs. difference signals at half-fringe

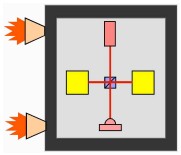




Backups

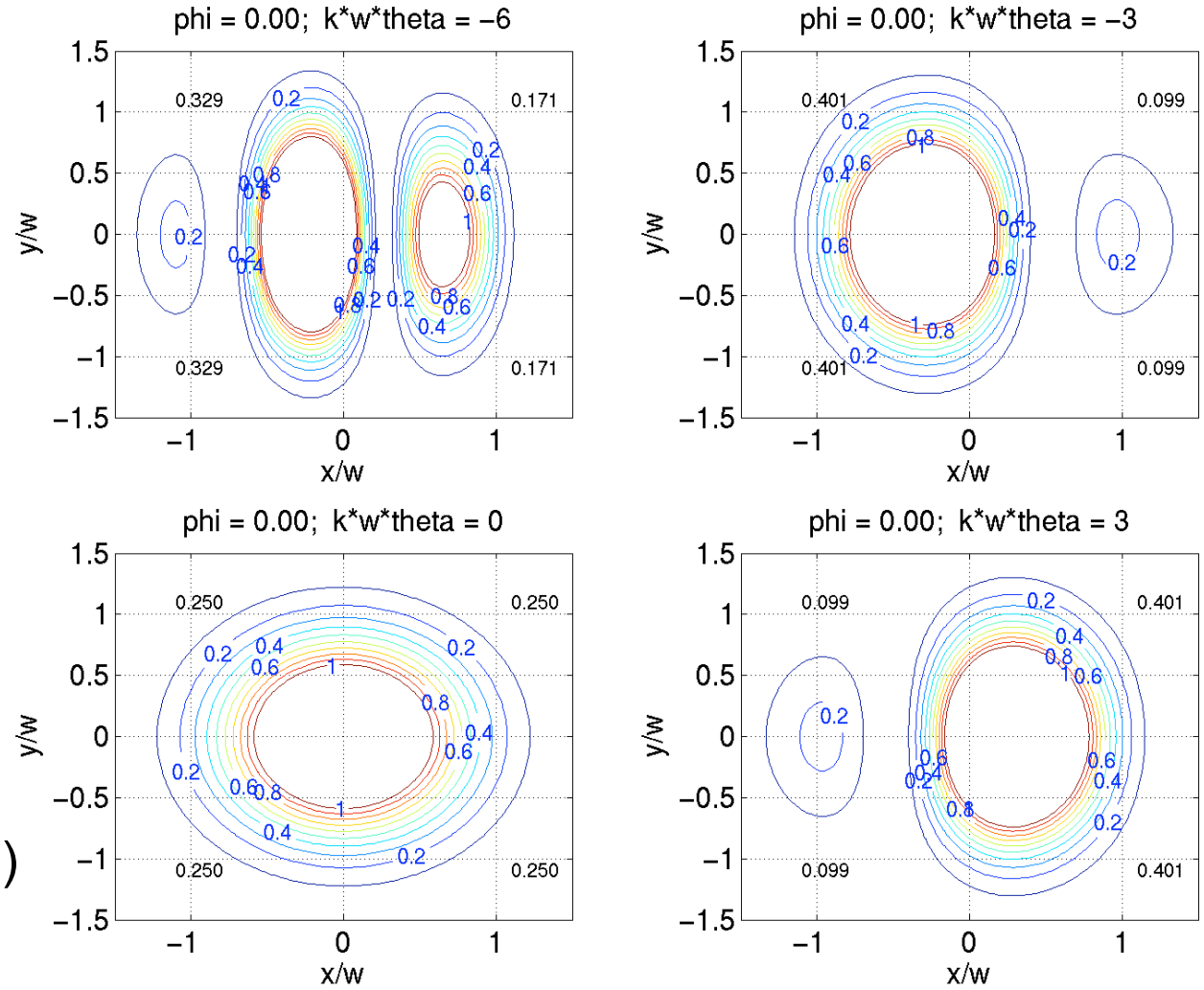


Intensity Pattern with Misalignment

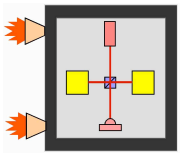


- Horizontal misalignment shown.
- Pattern insensitive to fringe offset near mid-fringe.
- Sample with 4 pixels (quadrant photodiode). Difference/sum response:

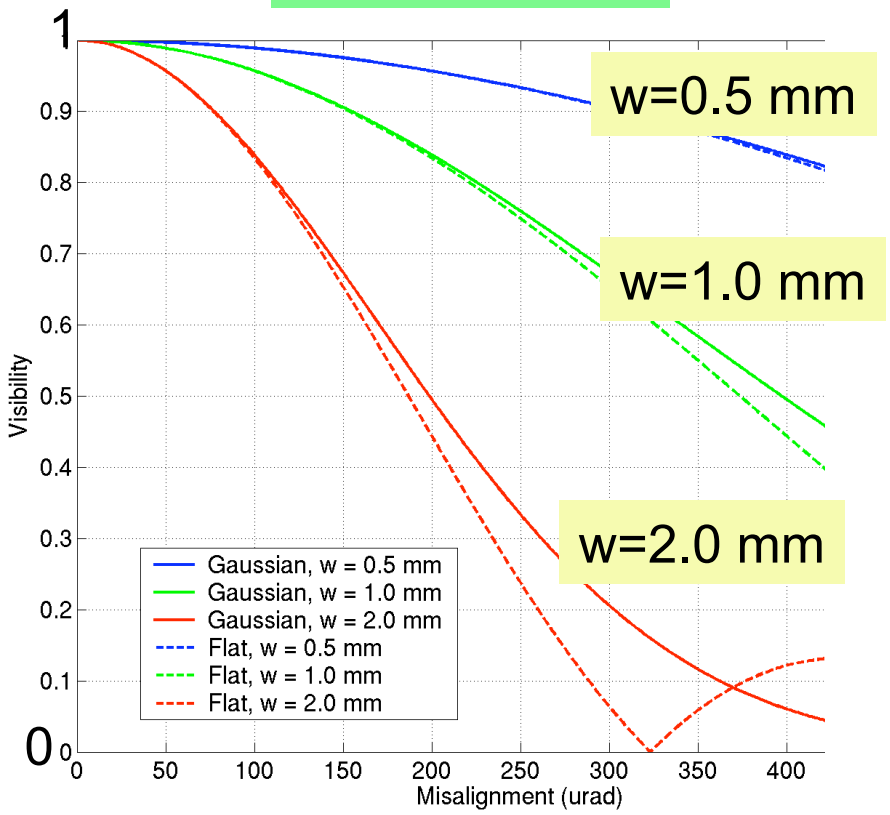
$$dQ/d\theta = \mathrm{sqrt}(8kw/\pi^3)$$



Static Misalignment and Static Longitudinal Error

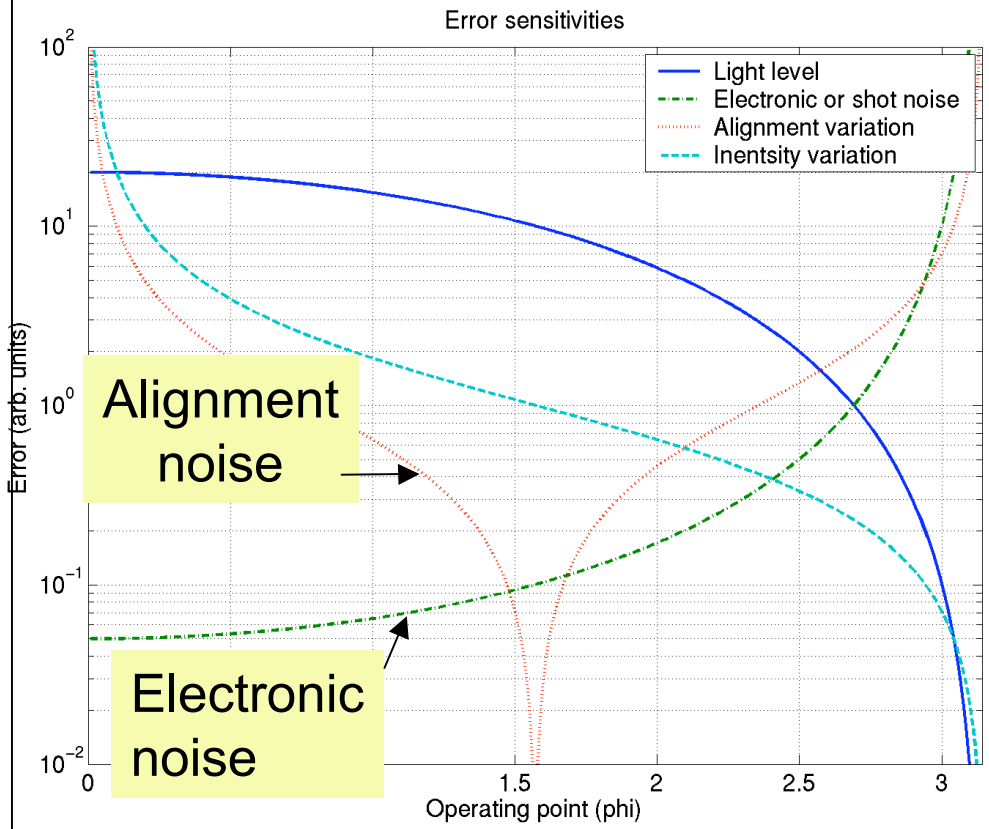


Fringe Visibility



Misalignment (μrad)

Error Sensitivity



Bright Mid Dark