Acceptance testing of a large aperture dynamic wavefront sensor

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Introduction

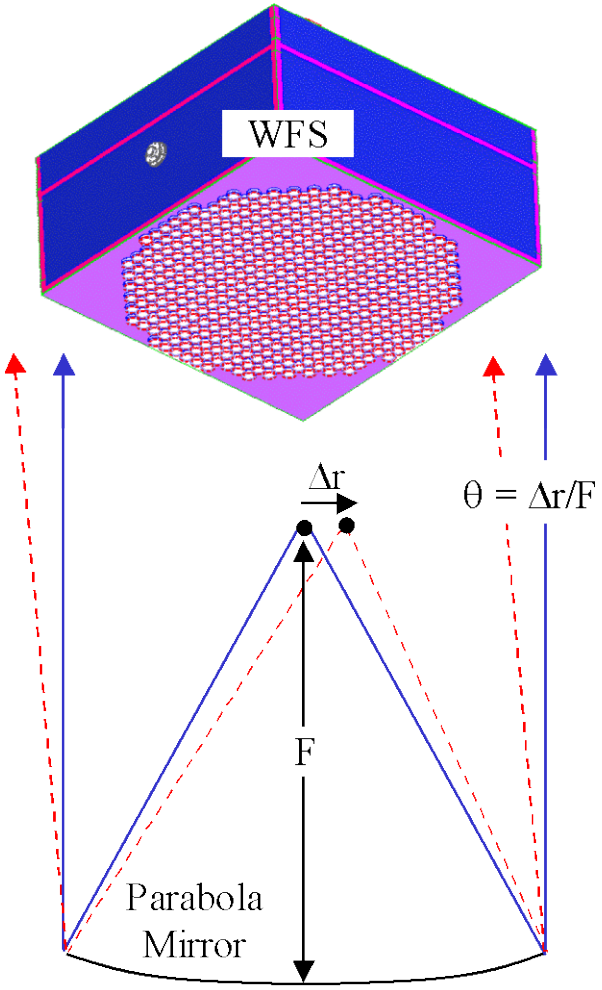
- Wavefront Sensor (WFS) Overview
- WFS test description
- Test preparation
- Test results
- Summary

WFS Overview

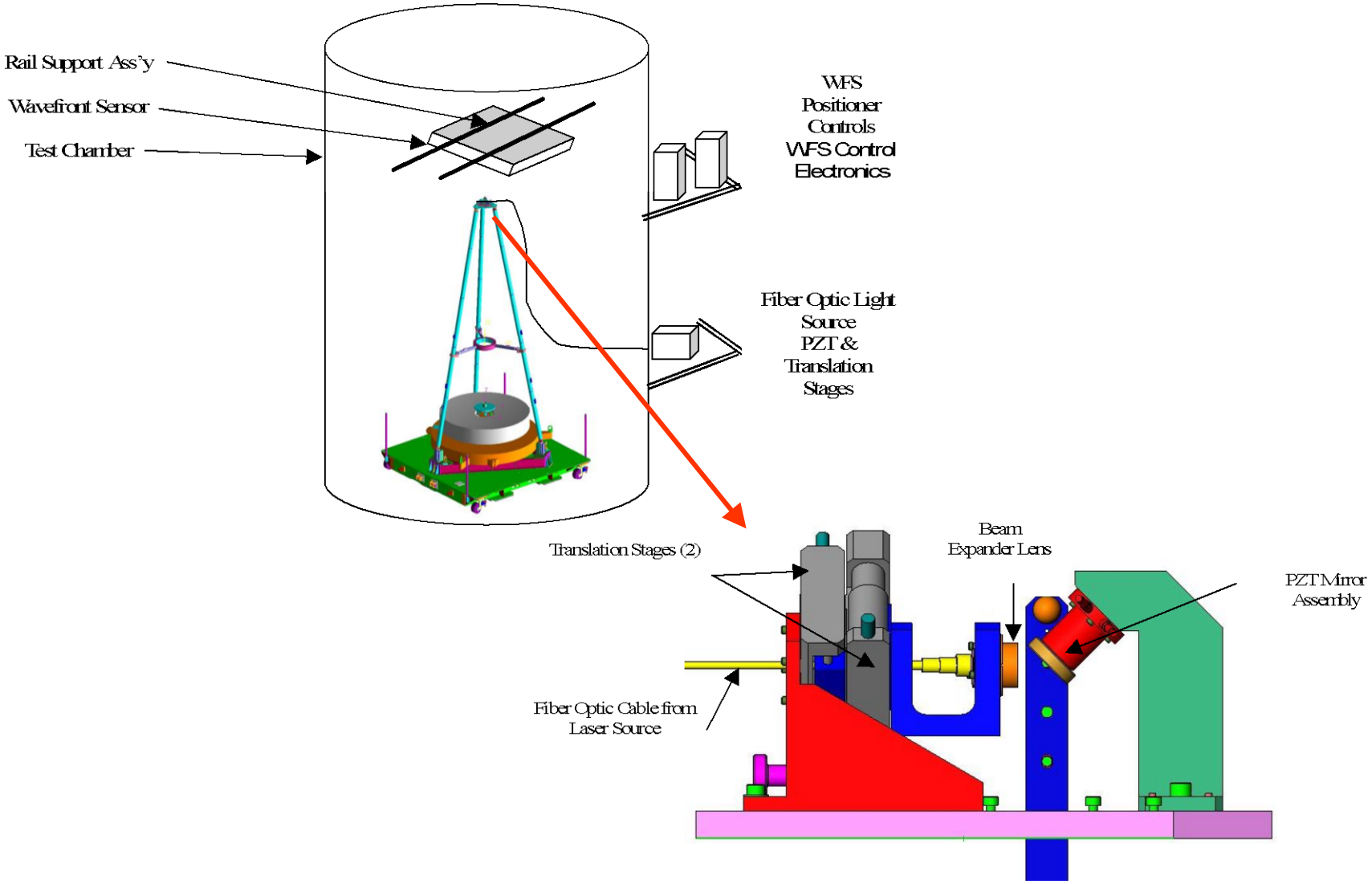
- **Based on Shack-Hartmann sensor**
- **Measures dynamic wavefront motion**
  - 5 nano-radian (nR) optical tilt sensitivity
  - 10 - 600 Hz wavefront motion
  - Up to 2.4 m diameter, 448 sensors, gridded array
  - Built by Optical Physics Company (OPC) under subcontract to Eastman Kodak Company
- **See "Design and Manufacture of a Large Aperture Wavefront Sensor", 5553-25**

Test Principles

- **13 system tests in vacuum environment**
- **Core test: Verify ±25 nR tilts at 10 - 200 Hz**
  - Full-aperture test
  - Calibrate: ±50 μR, 1 Hz
  - Seismic isolation required
- **Challenge: How do you create a 25 nR tilt?**

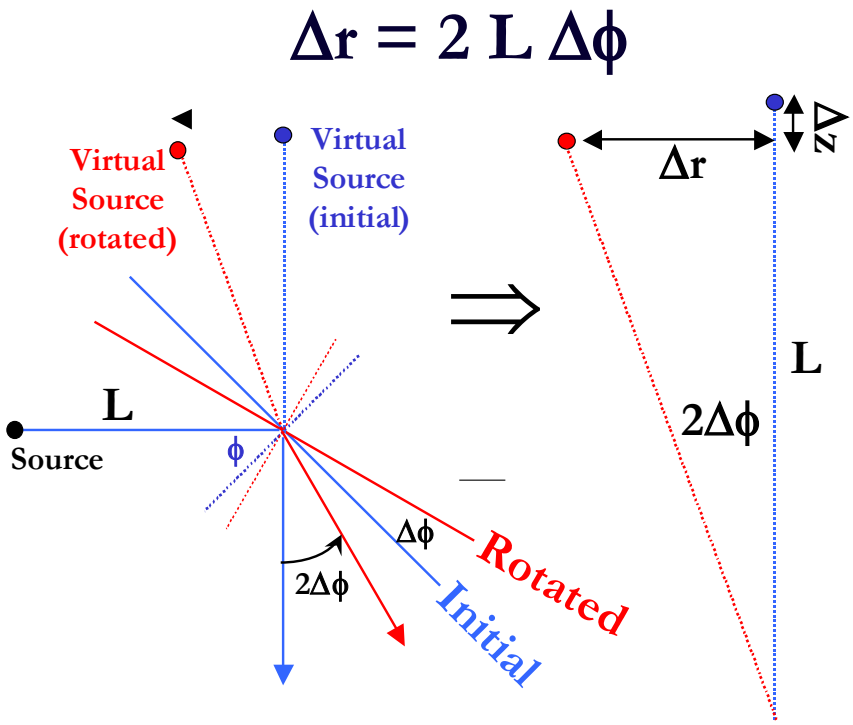


Test Implementation



Producing small wavefront tilts

- **Reflect laser source from fold mirror**
- **Tilt fold mirror to move virtual source**
- **$\theta = 2\,L / F\,\Delta\phi$**
  - Choose L/F small ~5e-3
  - Wavefront tilt 45° to sensor axes
  - 140x tilt "lever arm"
  - Use PZT for small $\Delta\phi$, 10e-6 rad
  - $\Rightarrow$ Small wavefront tilt, 1e-9 rad

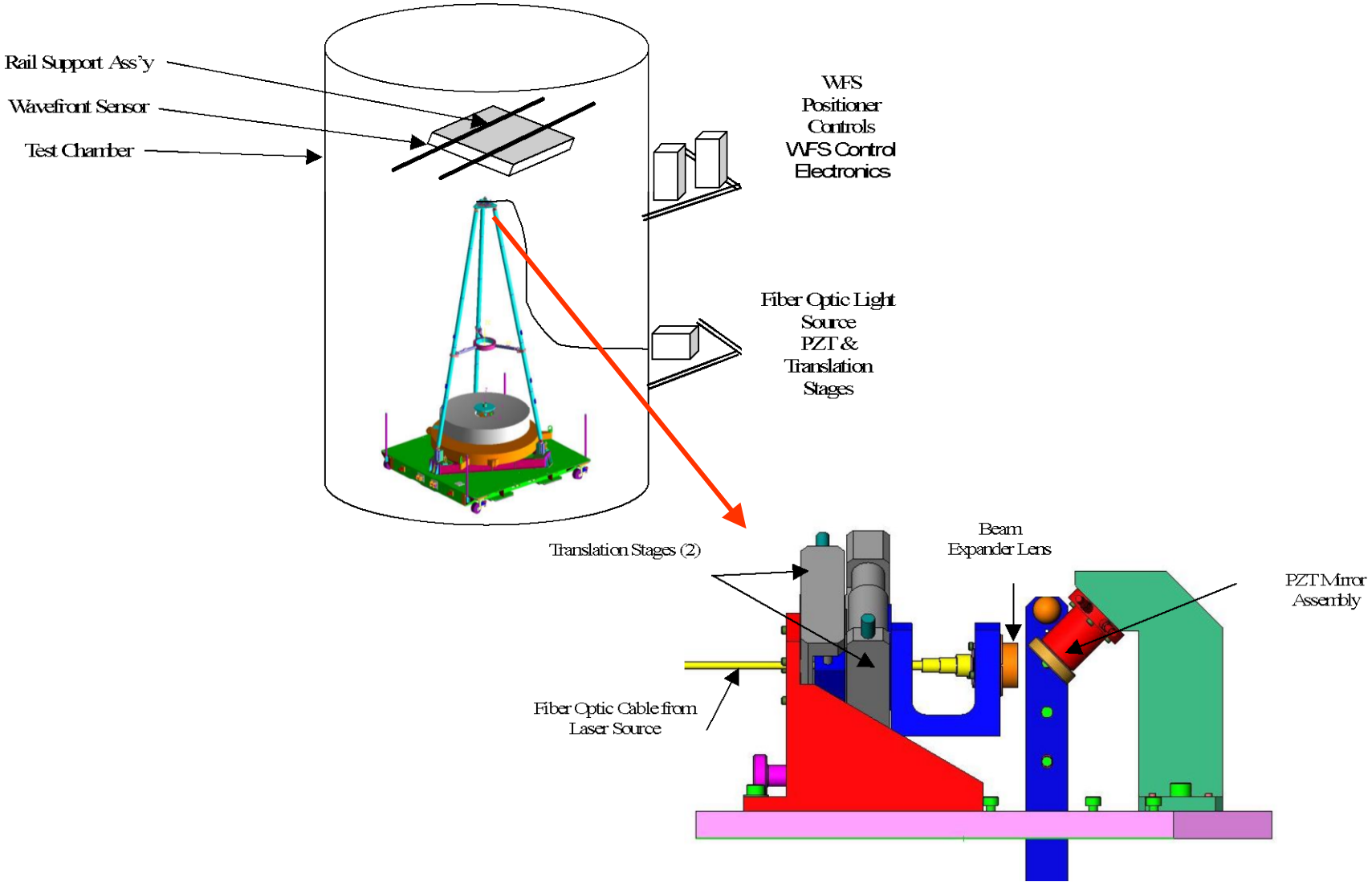


Characterizing PZT Motion

- **Desired wavefront behavior**
  - 6 - 100 nR wavefront tilt
  - 10 - 300 Hz
- **Characterize PZT**
  - 5 - 20 μR PZT / mirror tilt
  - (35 - 120 nR ± 5 nR wavefront tilt)
  - 10 - 50Hz
- **Measure PZT motion with Laser Vibrometer**
  - Fit plane motion to polynomial
  - Fit gives tilt motion in y-direction
  - Negligible residual piston
  - Small cross-talk from x-tilt

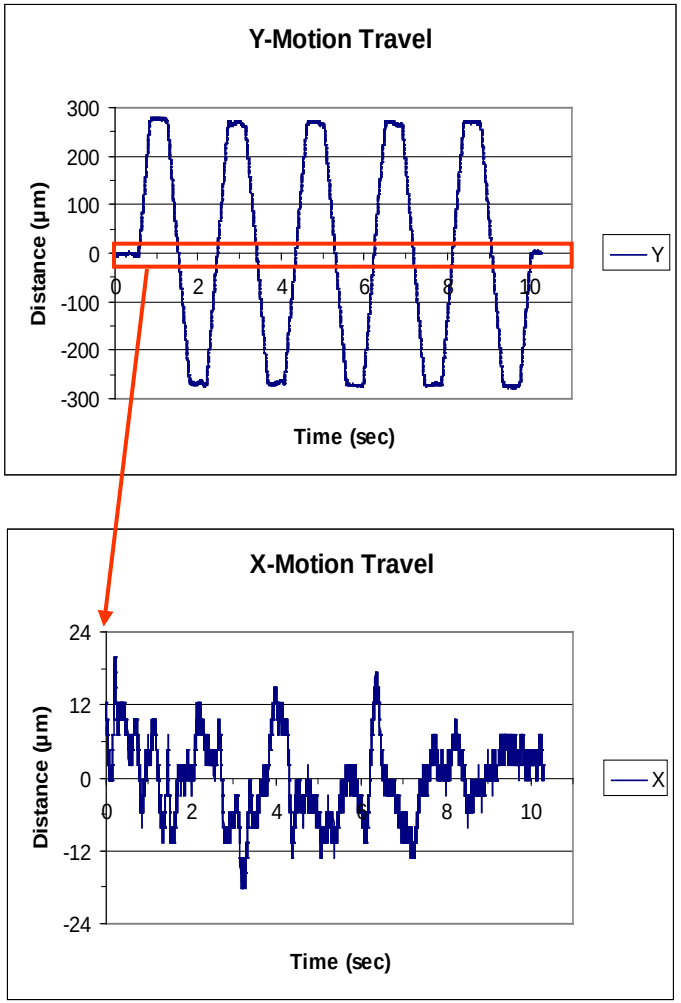
Effective Wavefront Tilt (nR)			
	10 Hz	20 Hz	50 Hz
35 nR	35	33	
60 nR	61	58	
125 nR	122	117	93

Test Implementation

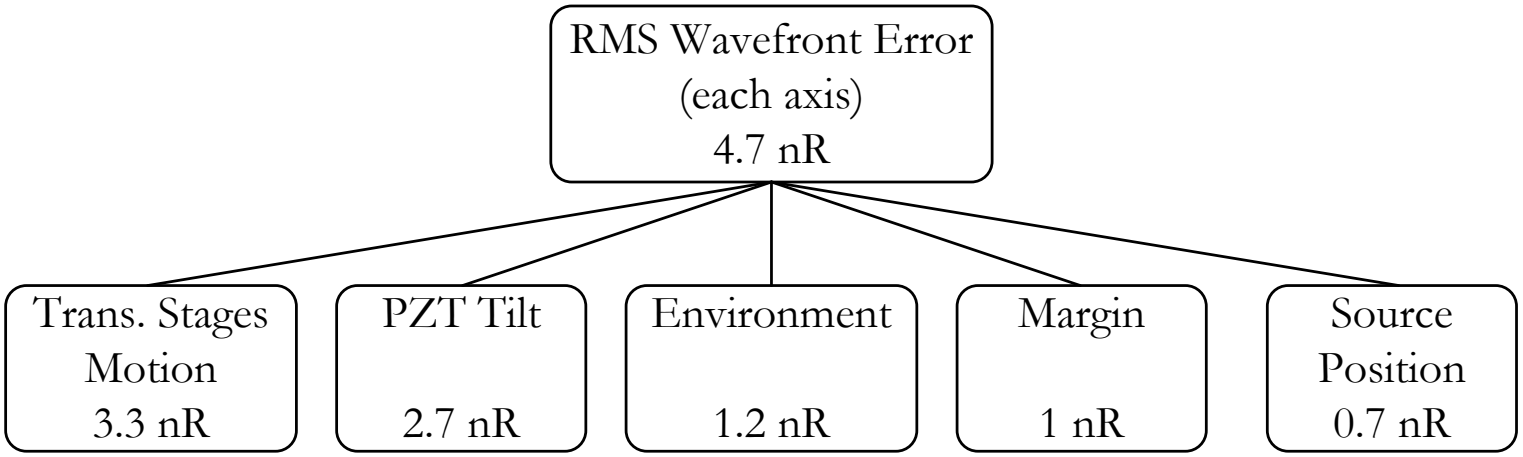


Characterizing Trans. Stage Motion

- **WFS calibration requires known, large tilt in X and Y**
- **Calibration signal**
  - Crossed translation stages
  - ±272 μm source motion for ±50 μR tilt
  - One axis at a time
- **Measure translation stage motion and cross talk**
  - 2% position error
  - 3% clocking error
  - 8 μm crosstalk error



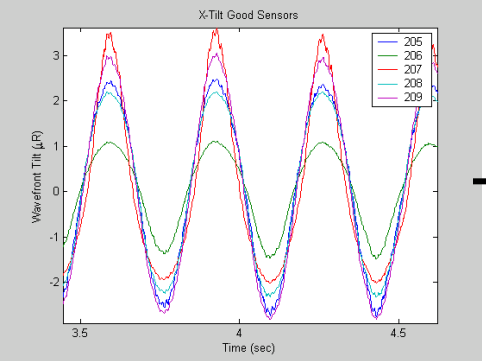
Error Budget



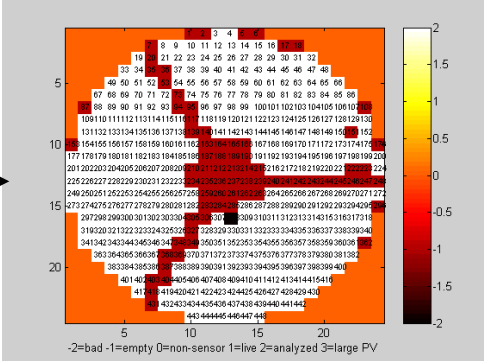
- **RMS input signal error**
  - 4.7 nR along each axis for 5 - 100 nR input tilt
  - Will increase with larger input signals
- **Major contributors**
  - Calibration signal (Translation Stage motion)
  - Input test signal (PZT motion control)

Data Analysis

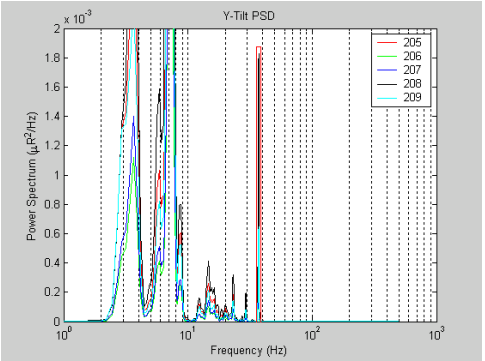
Import time series data: X- & Y-Tilt. Remove bias



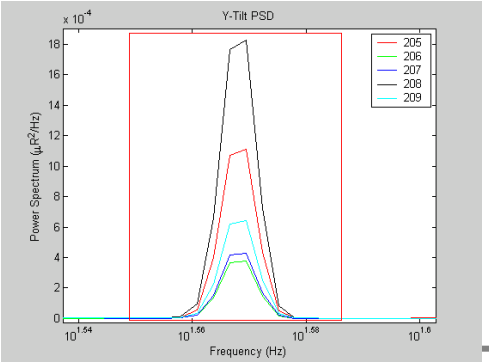
Identify & discard shadowed, bad sensors



Compute PSD



Select frequency range of test signal

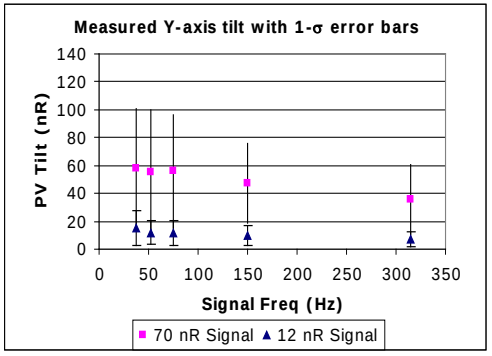


Compute amplitude, signal frequency

$$RMS^2 = \int PSD \cdot df$$

$$Amplitude = \sqrt{2} \cdot RMS$$

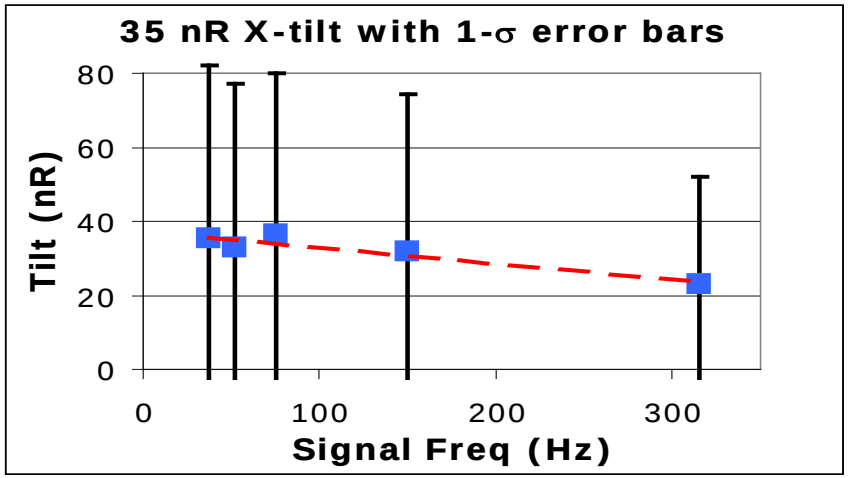
Average amplitude & display

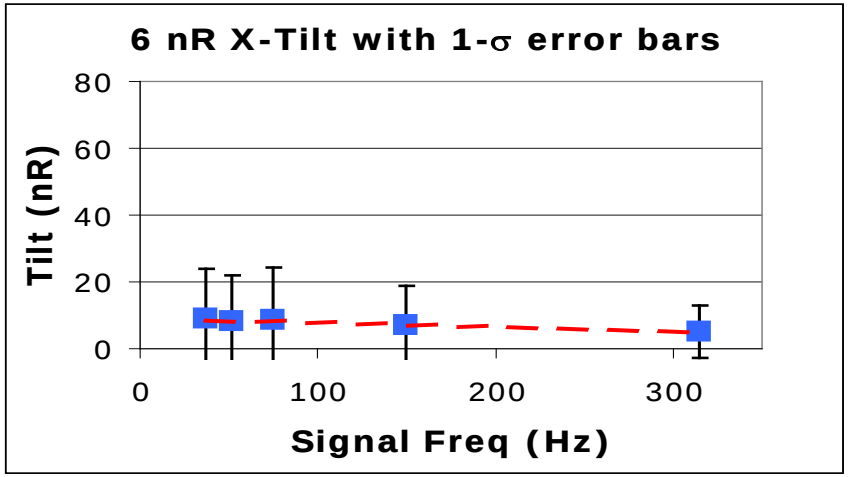


WFS

Test Results

- Good average result
- Similar results for Y tilt
- PZT motion decreases with frequency
  - Verified in post-test PZT cal
- Large standard deviation
  - ~50 nR rms

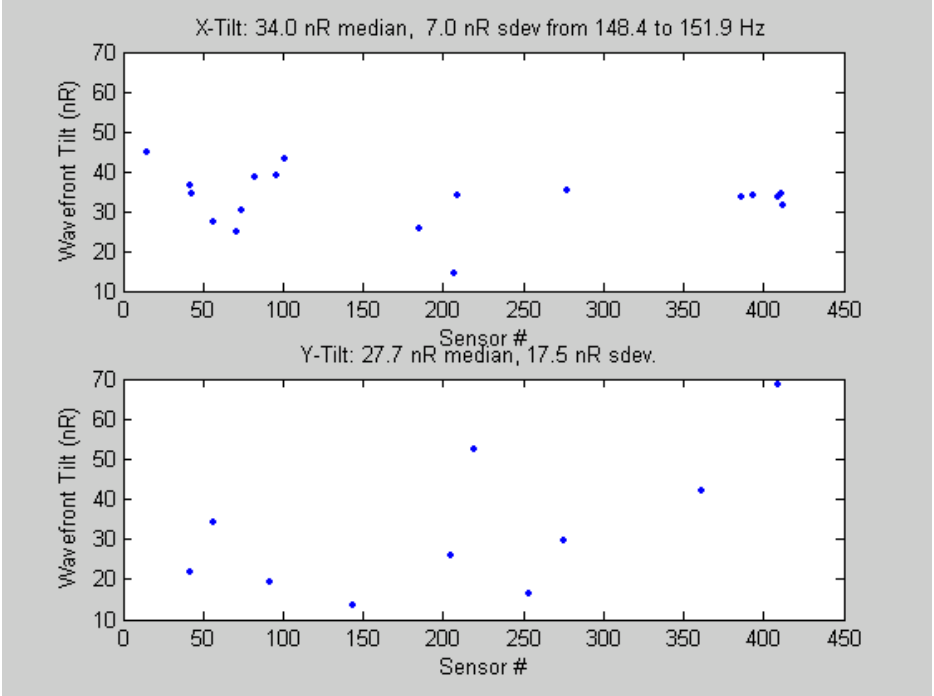




WFS

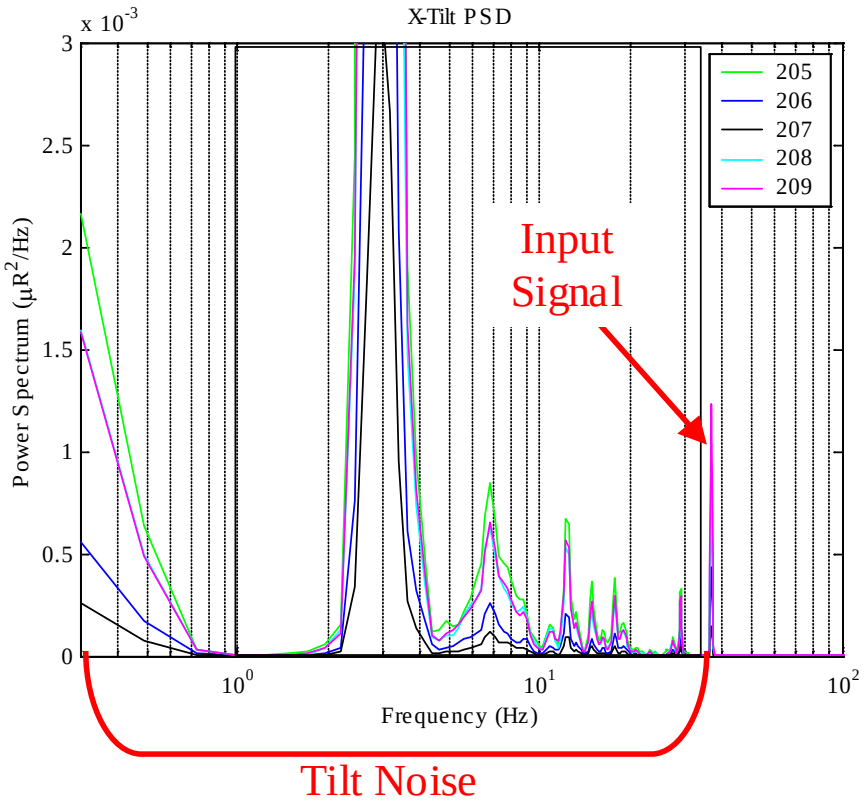
Test Weakness #1 – WFS Aiming

- **WFS aimed to edge of capture range**
  - Identified by bad sensor calibration values
  - Coarse tilt sensors mis-calibrated
- **Analyze aligned sensors**
  - Calibration value within 1/2% of nominal
  - 20 sensors in alignment
- **Greatly reduced standard deviation**
  - ~10 nR rms



Test Weakness #2 – Seismic noise

- **Tilts from seismics 1x – 10x input signal**
  - 500 nR - 2000 nR RMS tilt noise
  - 5 - 40 Hz
- **Input signal hardware not isolated**
- **Frequency-domain analysis enables data processing**



System Issues & Improvements

- **WFS isolation system failed during test**
  - WFS isolation system repaired
  - Reduce ambient seismic noise 8x
- **Parabola was not isolated from the floor**
  - Parabola system isolators added
- **WFS was not properly pointed to target**
  - WFS alignment sensors re-calibrated in June
- **Light level not optimized**
  - Intensity monitoring feature added WFS software
- **11 of 13 tests not completed**
  - Retest planned for Sept. '04

Successes

- Demonstrated creation of nano-radian wavefront tilts over large optical beam
- PSD analysis very effective in isolating true signal
- Valid tilt signals seen to 6 nR
- Excellent response seen from 35 - 315 Hz
- Experience gained in running WFS
- Retest in September, ‘04

Acknowledgements

- **Optical Physics Company for supporting WFS test**
- **Additional Eastman Kodak Co. team members**
  - Harold Morris
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  - Larry Polsky
  - Bill Miller