National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

SIM PlanetQuest

Mask Design for the Space Interferometry Mission Internal Metrology

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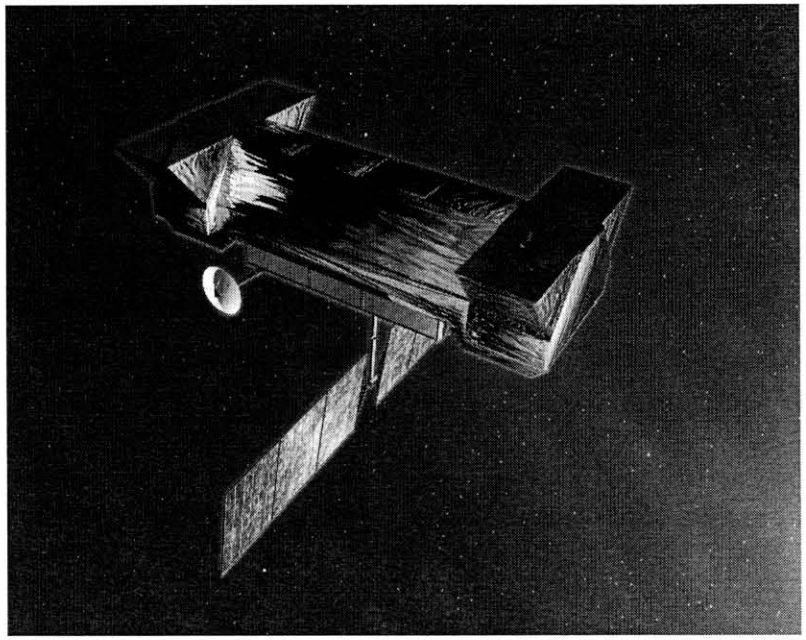
SIM Project Overview

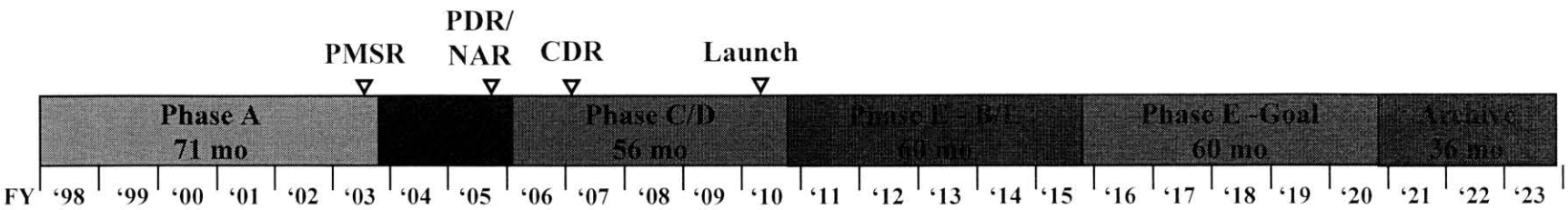
Salient Features

- 3 parallel Michelson Stellar Interferometers
- 10 meter baseline
- Visible wavelength
- Launch Vehicle: Atlas V or Delta IV ELV
- Earth-trailing solar orbit
- 5 year mission life with 10 year goal
- SIM: a JPL, Caltech, Lockheed Martin, NGST, KSC, and SIM Science Team partnership



Science Goals

- Find and characterize nearby planetary systems (mass/orbits of all planets found)
- Address key issues in astrophysics
- Develop a precision stellar optical reference grid



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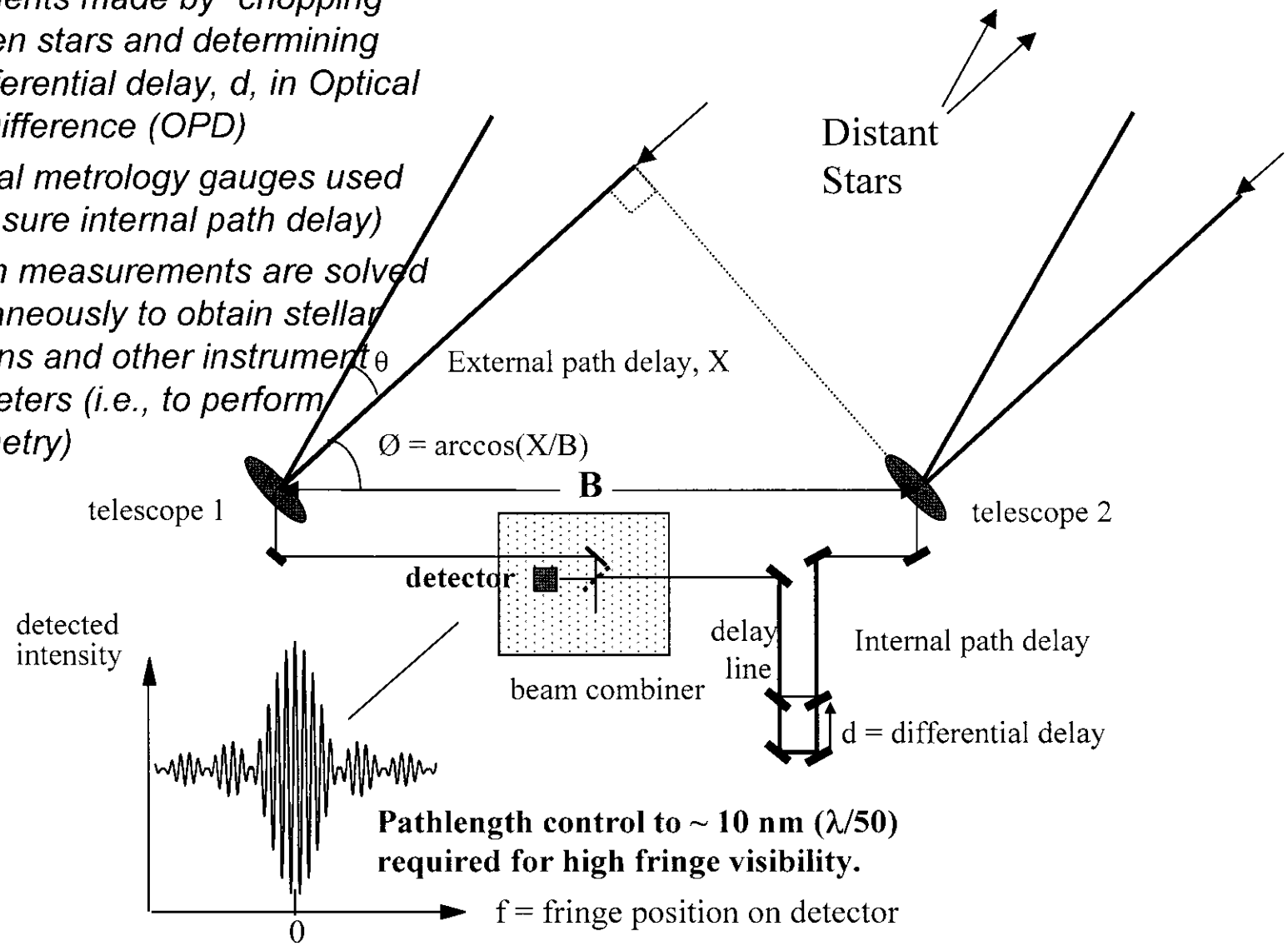
Measurements with SIM

Measurements made by "chopping" between stars and determining the differential delay, d, in Optical Path Difference (OPD)

(Internal metrology gauges used to measure internal path delay)

Many such measurements are solved simultaneously to obtain stellar positions and other instrument parameters (i.e., to perform astrometry)

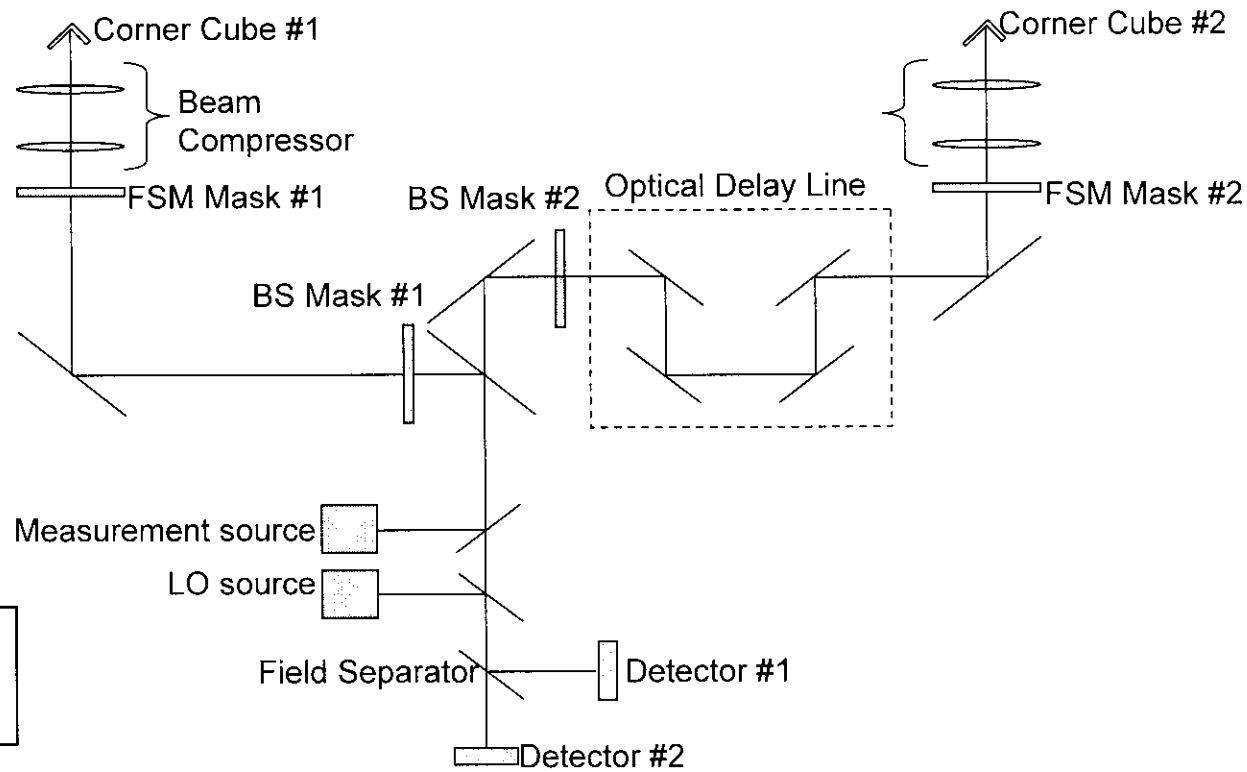


Pathlength control to ~ 10 nm (λ/50) required for high fringe visibility.

- The peak of the interference pattern occurs at zero OPD to star

Internal Metrology

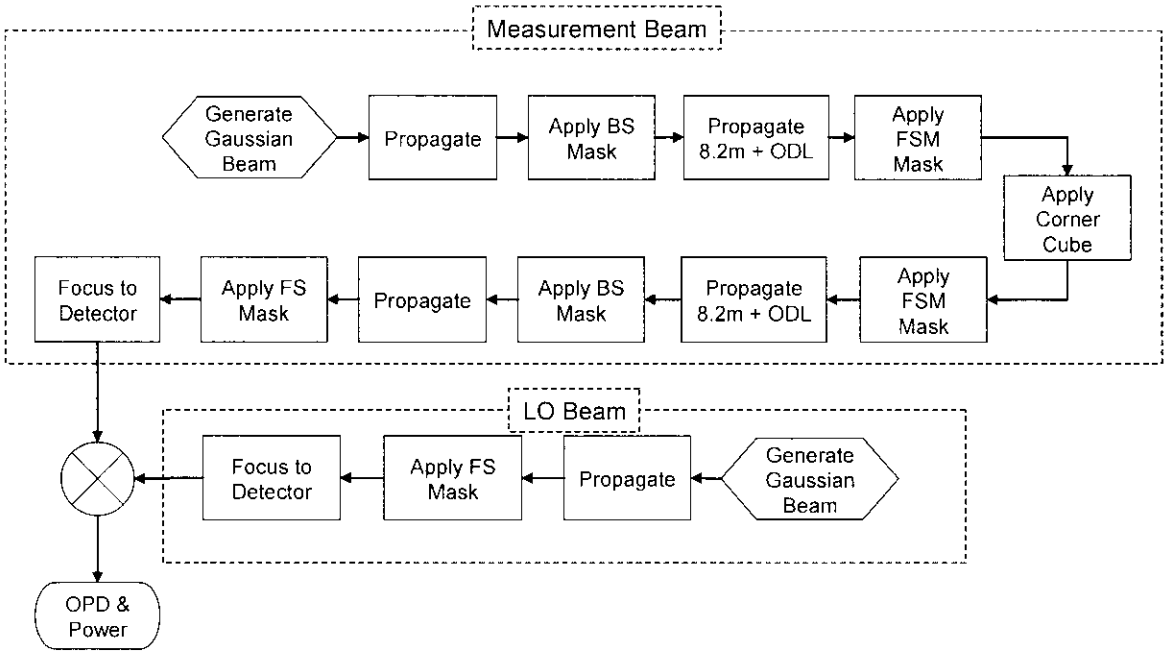
- Internal Metrology Measures the Optical Path Length of Each Interferometer Arm
- Heterodyned Laser Interferometer
- Parallel and Centered to the Star Light



BS = Beamsplitter
FSM = Fast Steering Mirror
LO = Local Oscillator

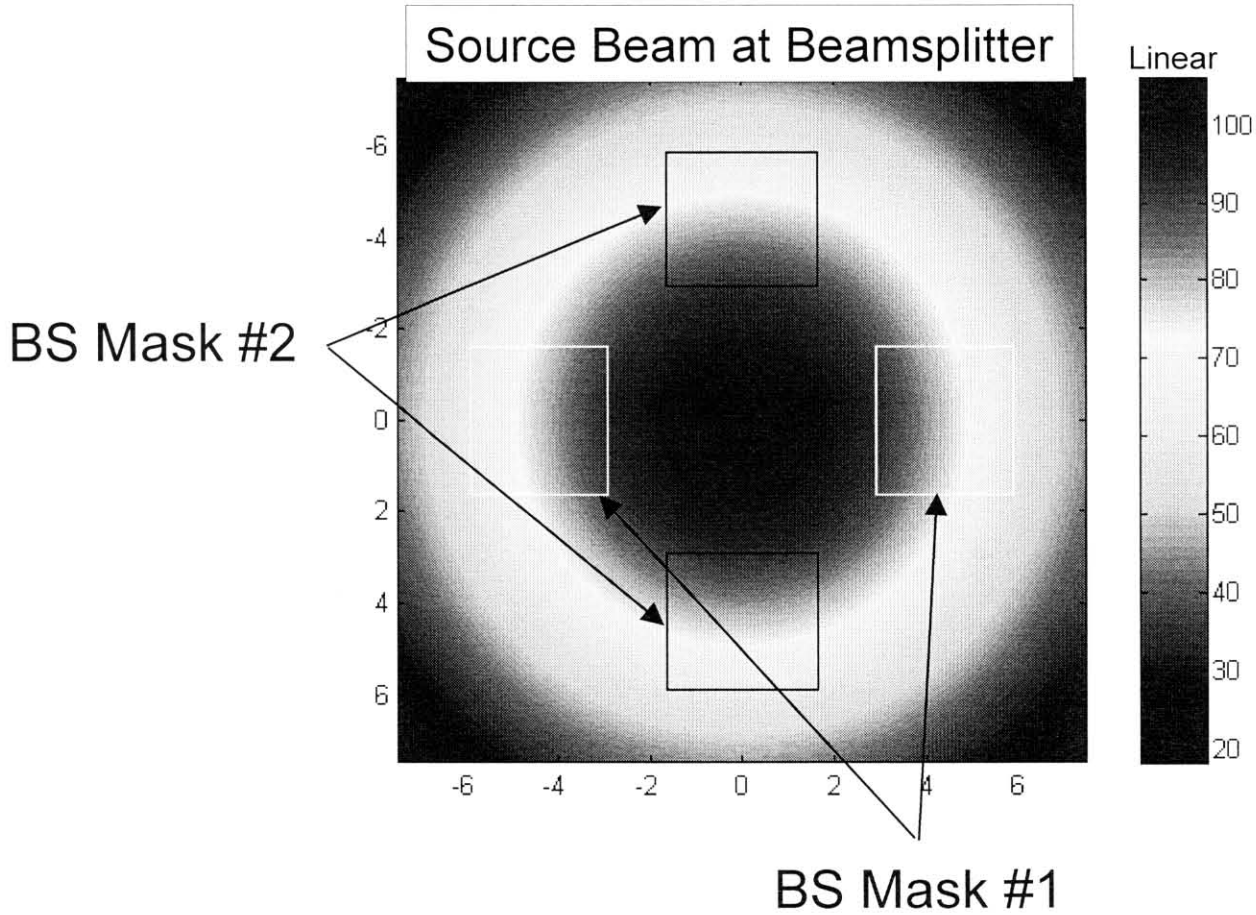
Numerical Model of Internal Metrology

- Scalar Diffraction
- Fresnel Approximation
- FORTRAN Library
  - K. Dutta and R. Benson, "Performance modeling of optical metrology systems," in Interferometry in Space, M. Shao, ed., Proc. SPIE, 4852, 839-848 (2002).
- Numerical Accuracy and Stability Near 1pm



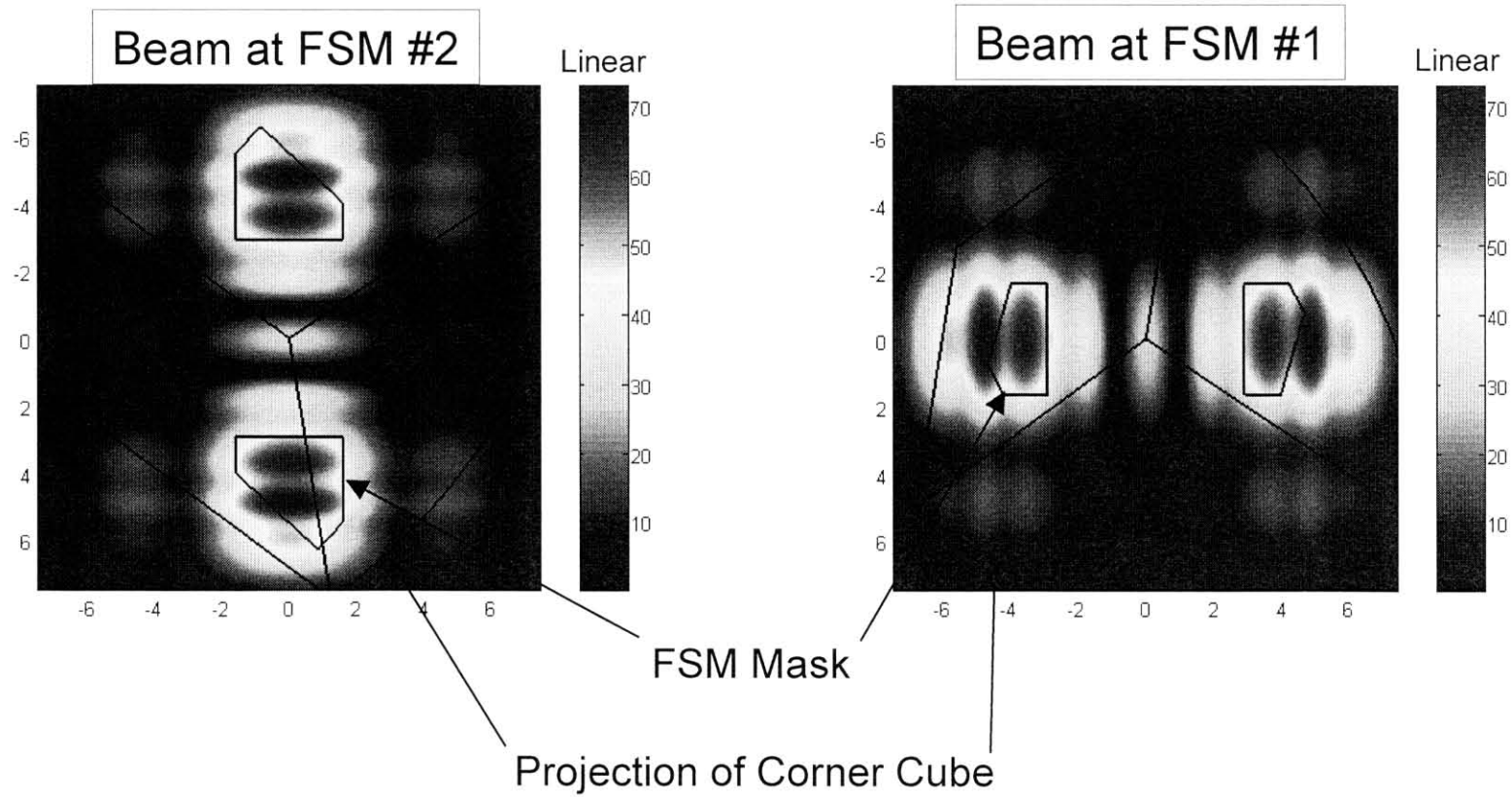
Wavefront Examples

SIM PlanetQuest



Wavefront Examples

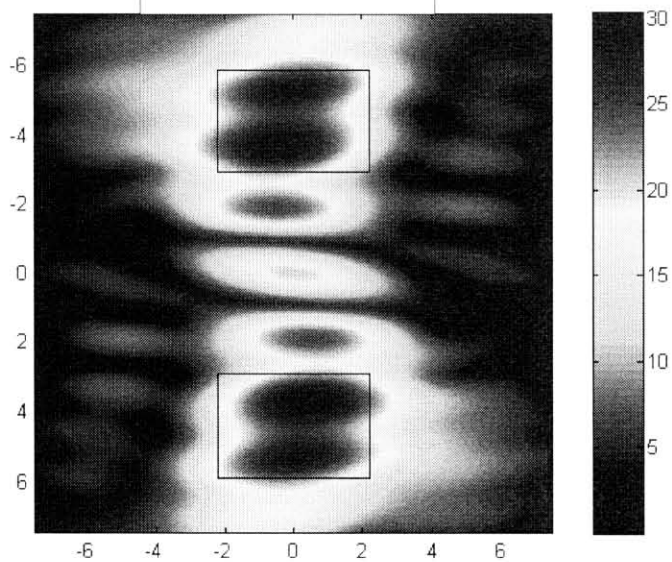
- Corner Cube Articulates with Siderostat
- Corner Cube Aperture is Field-dependent
- FSM Mask Prevents Corner Cube Clipping
  - Forces Field-independent Diffraction



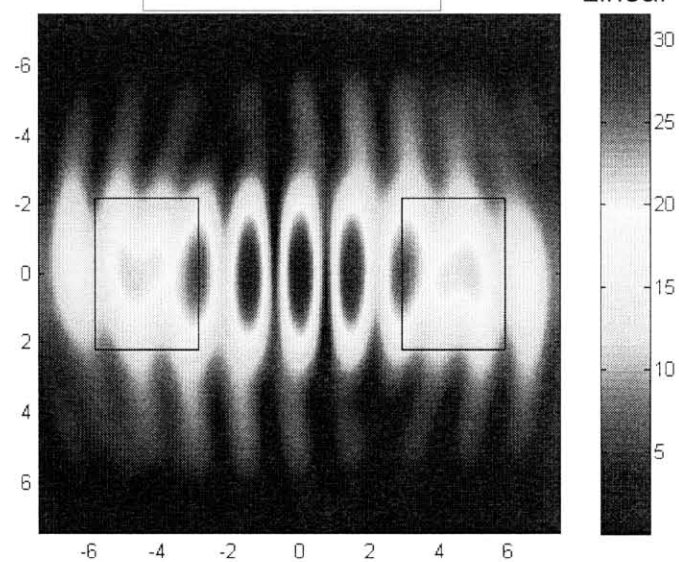
Wavefront Examples

Return to Beamsplitter

BS #2

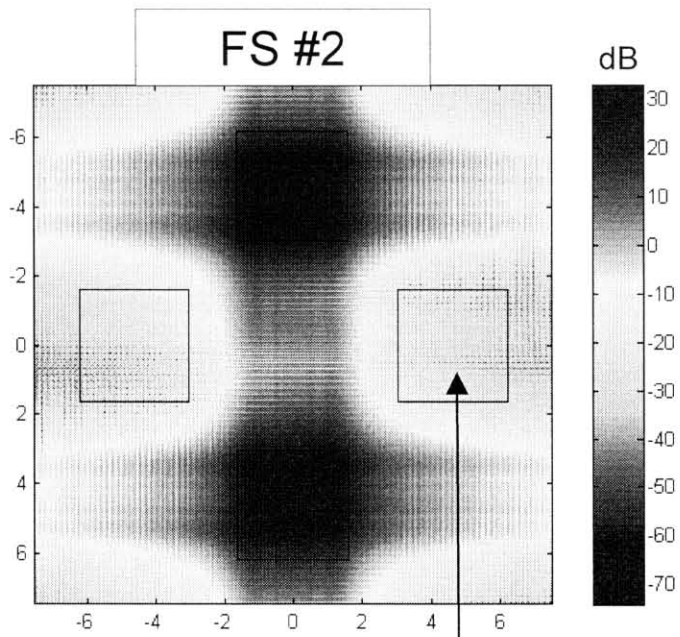


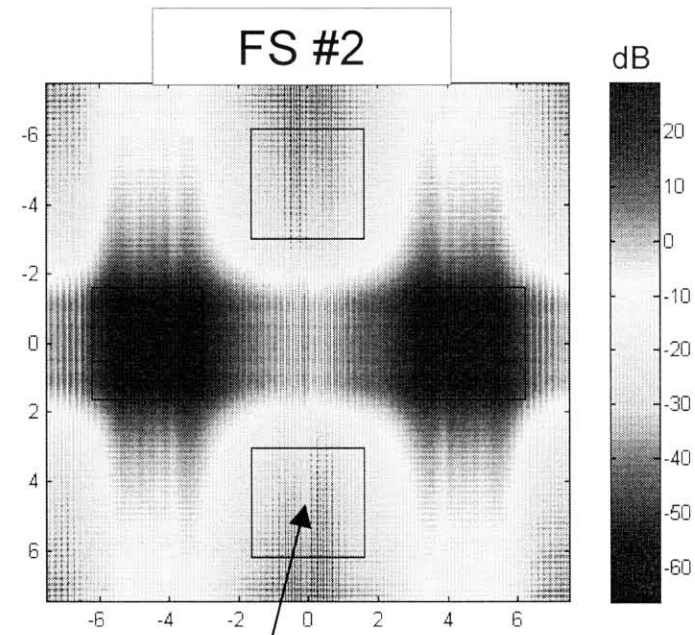
BS #1



Wavefront Examples

At Field Separator





Source of Cyclic Error (crosstalk)

Performance Metrics

- Performance Requirements:
  - Heterodyne Power
  - Cyclic Error (Crosstalk)
    - Crosstalk from One Arm into the Other

$$\mathbf{E} = \mathbf{A} + Be^{j\phi}; \quad \phi = k\mathrm{OPD}$$

    - Periodic in Wavelength
    - Cyclic Error, $\psi = \mathrm{Arg}(\mathbf{E}) - \phi = \mathrm{Arctan}\left(\dfrac{\sin\phi}{\dfrac{A}{B} + \cos\phi}\right) - \phi$
    - For *A*<<*B*, then amplitude of cyclic error = (*A/B*)/*k*

Performance Metrics

- OPD Error Residual
  - OPD Error = Δphase – Delay Line Movement
  - Metrology Beam Diffraction:
    - Fresnel# ≈ 2
    - Wavefront Phase is Not Strictly Linear with Propagation Distance
    - Other Field-dependent Effects:
      - Corner Cube Articulation
  - OPD Error = Measured OPD(θ_x,θ_y) – Delay Line Movement
    - Remove Best Fit Constant, Linear, Radial Quadratic
    - Metric = rms of Residual

Mask Design

- Location / Purpose:
  - FSM / Obscure Corner Cube Edges
    - Removes Corner Cube Articulation as a Source of Field-Dependent Error
  - Beam Splitter
    - Prevent Cross Talk Between the Metrology of Each Arm
  - Field Separator
    - Separate Metrology Beams from Each Arm for Heterodyning
- Trade-offs:
  - Large Masks for Better Power Throughput
  - Small Masks to Reduce Crosstalk

Mask Design

- Design Method:
  - Constrained Optimization
    - Sequential Quadratic Programming (Matlab)
  - Minimize rms OPD Residual
  - Constrain Heterodyne Power ≤ -20dB
  - Constrain Cyclic Error ≤ 3pm
  - 6 Free Parameters:
    - Beamsplitter mask (3 parameters)
    - Field Separator Mask (3 parameters)
    - FSM Mask Set to Match BS Mask and Corner Cube Aperture

Conclusions

- Design Results:

Metric	Requirement	Predicted Performance
Cyclic Error, Arm #1 (pm, rms)	< 3	0.6
Cyclic Error, Arm #2 (pm, rms)	< 3	0.3
Heterodyne Power, Arm #1 (dB)	> -20	-19.4
Heterodyne Power, Arm #2 (dB)	> -20	-17.2
OPD Residual Error (nm, rms)	< 1	0.89

- The System Meets the Requirements

Conclusions

- Click to edit Master text styles
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    - Third level
      - Fourth level
        - Fifth level