Metrology Truss Demonstration with the Kite testbed

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August 26, '02
SPIE

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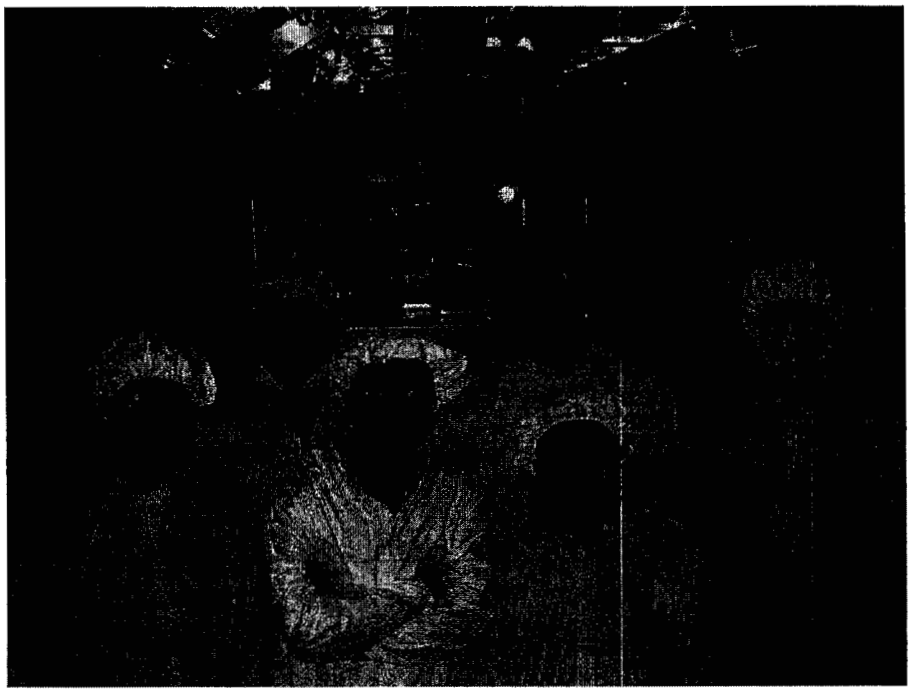
Outline

- Review of Kite's role
- Kite Architecture
- Derived Requirements
- Performance Tests
- Results



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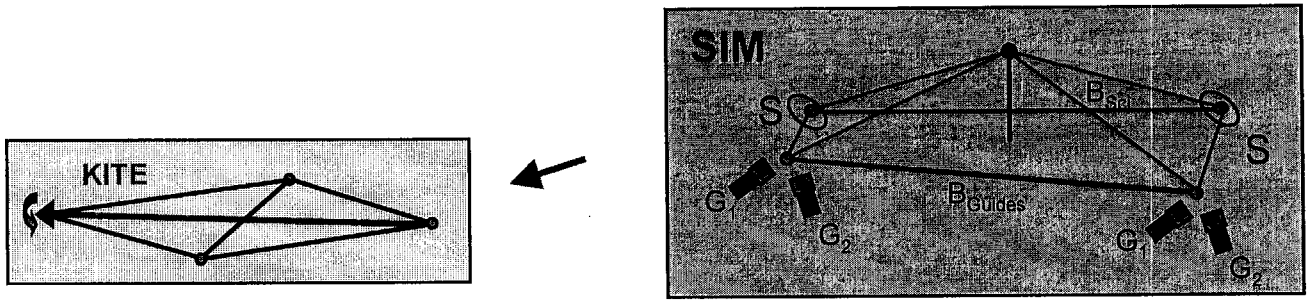
The Role of Kite

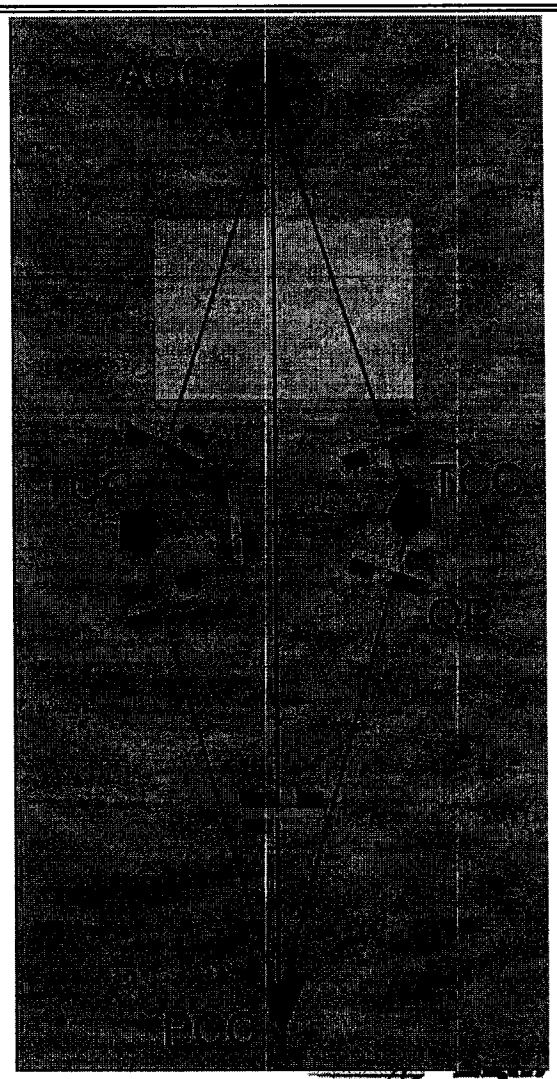
- The role of Kite is to verify SIM external metrology performance
- SIM external metrology tracks baseline changes as the fiducials move
- Testing up to now has been 1D (2-gauge)
- The Kite 2D truss will show it can track similar changes to the level required by the SIM performance model – currently AEB38



- Ideally, Kite performance should be limited by the gauge performance, where the gauge performance is derived from the SIM error budget.

Kite Approach and Architecture

- Build a **redundant** metrology truss:
  - 4 fiducials (2 corner cubes + 2 triple corner cubes)
  - 6 metrology gauges connecting the 4 vertices
  - All in a plane (to required level)
- Compare the readings from one gauge with prediction using the other 5 as a CC is articulated by various amounts of tip and tilt or translation
- Account for CC imperfections using CC calibration and model



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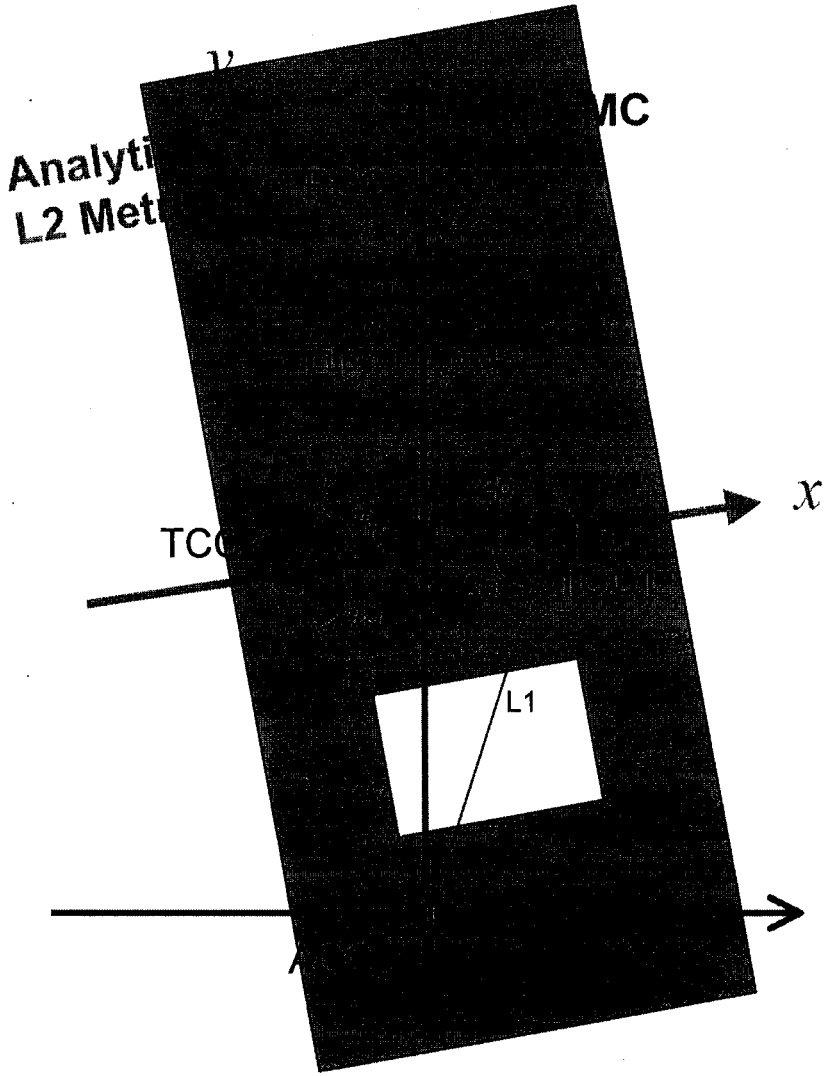
Kite Numbering Scheme



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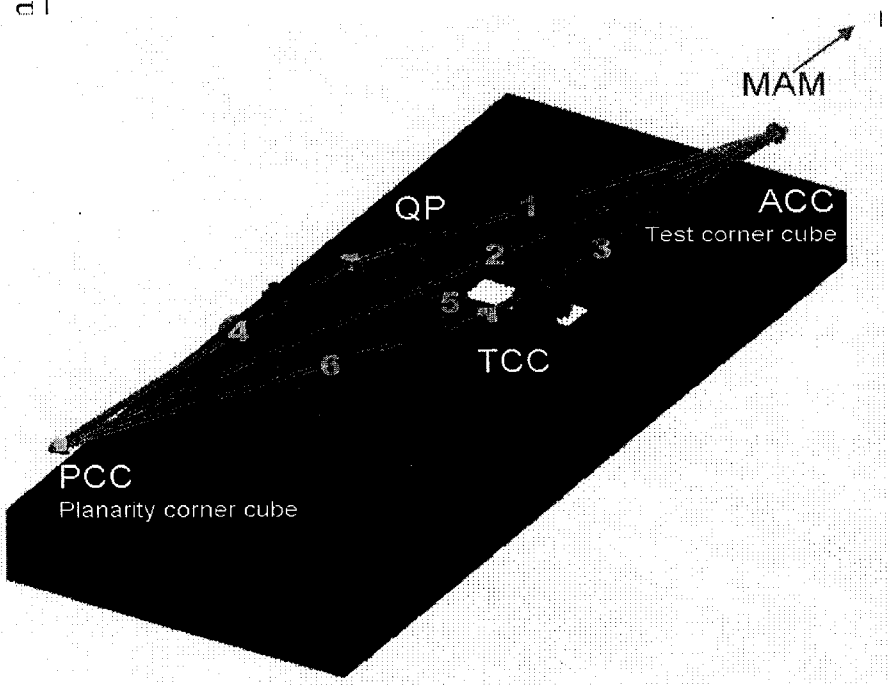
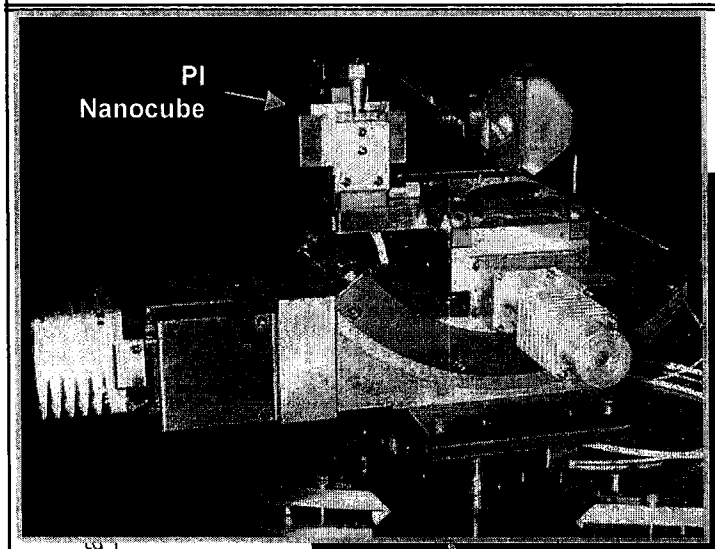
Kite Testbed Configuration

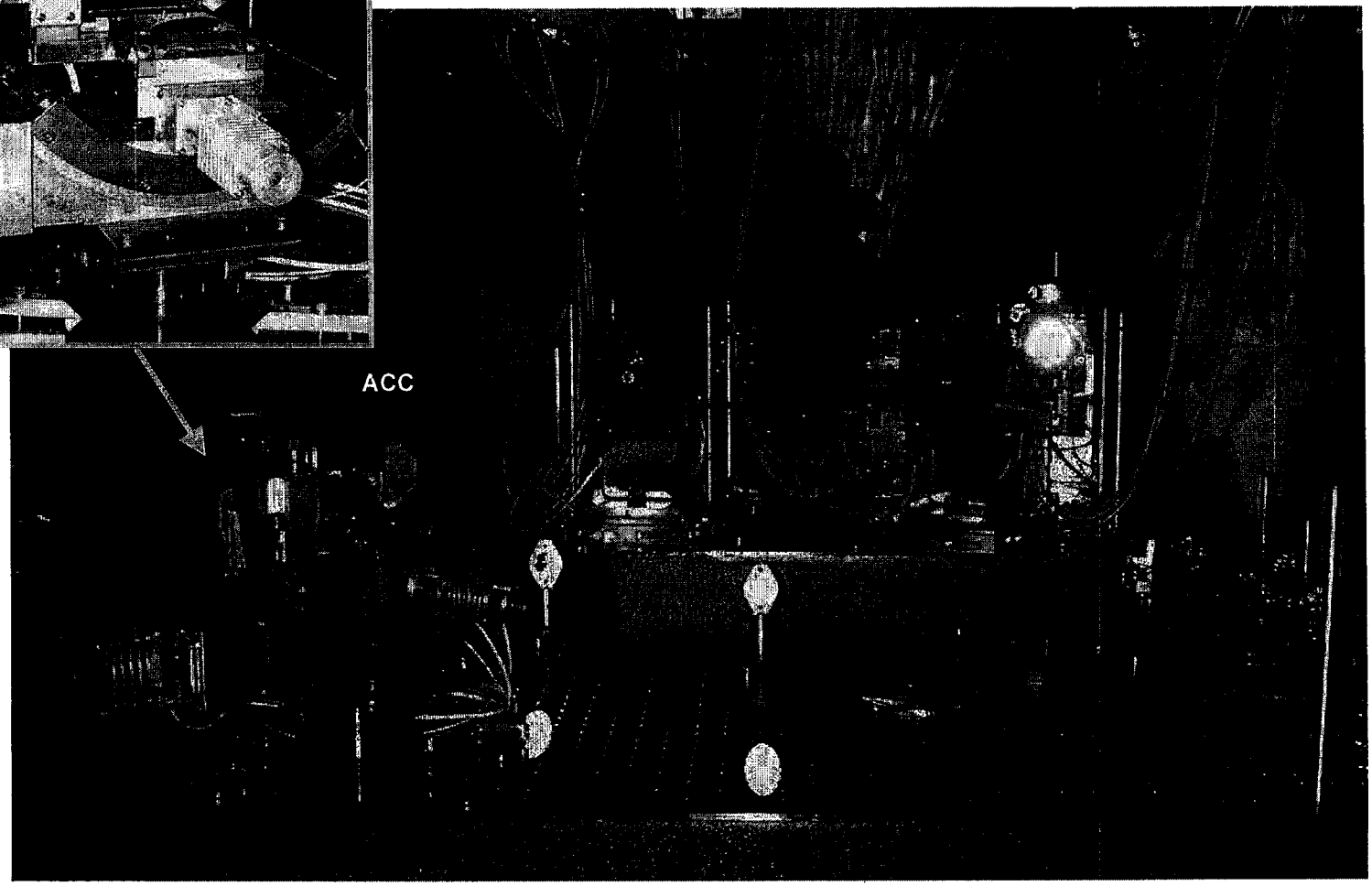
- Kite table is situated in the MAM vacuum chamber
- Large aspect ratio dictated by triple corner cube constraints



The Test Corner Cube (ACC)

6-axis control of the corner cube





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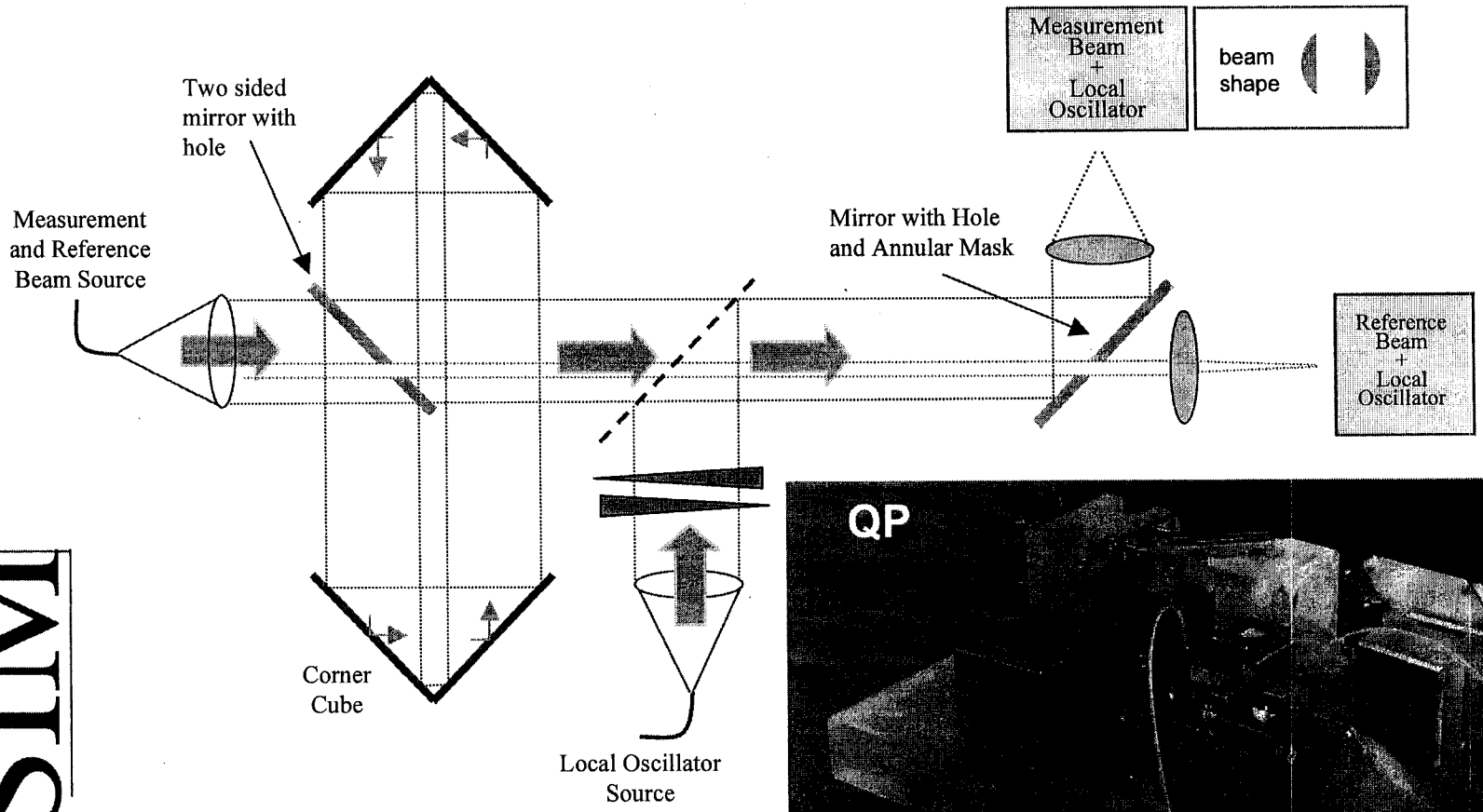
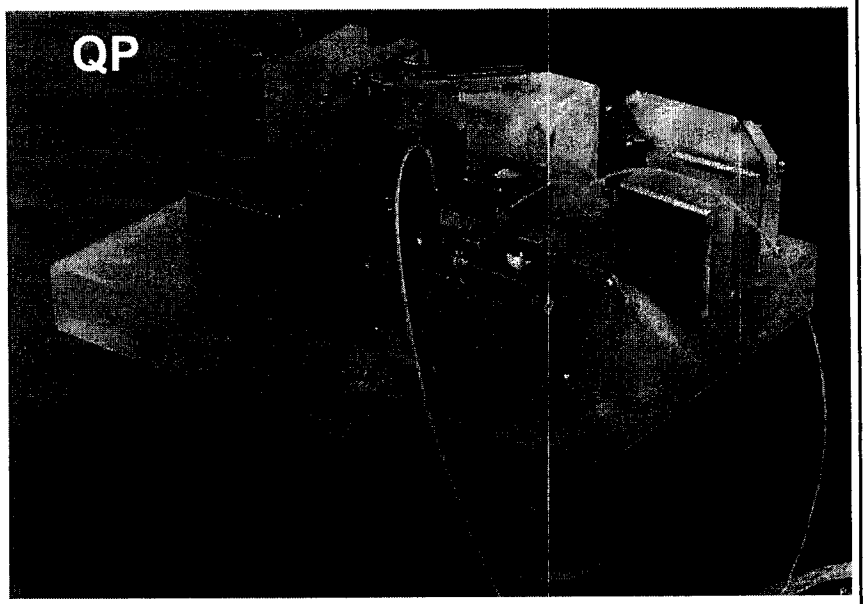
Kite Beam Launcher (QP)





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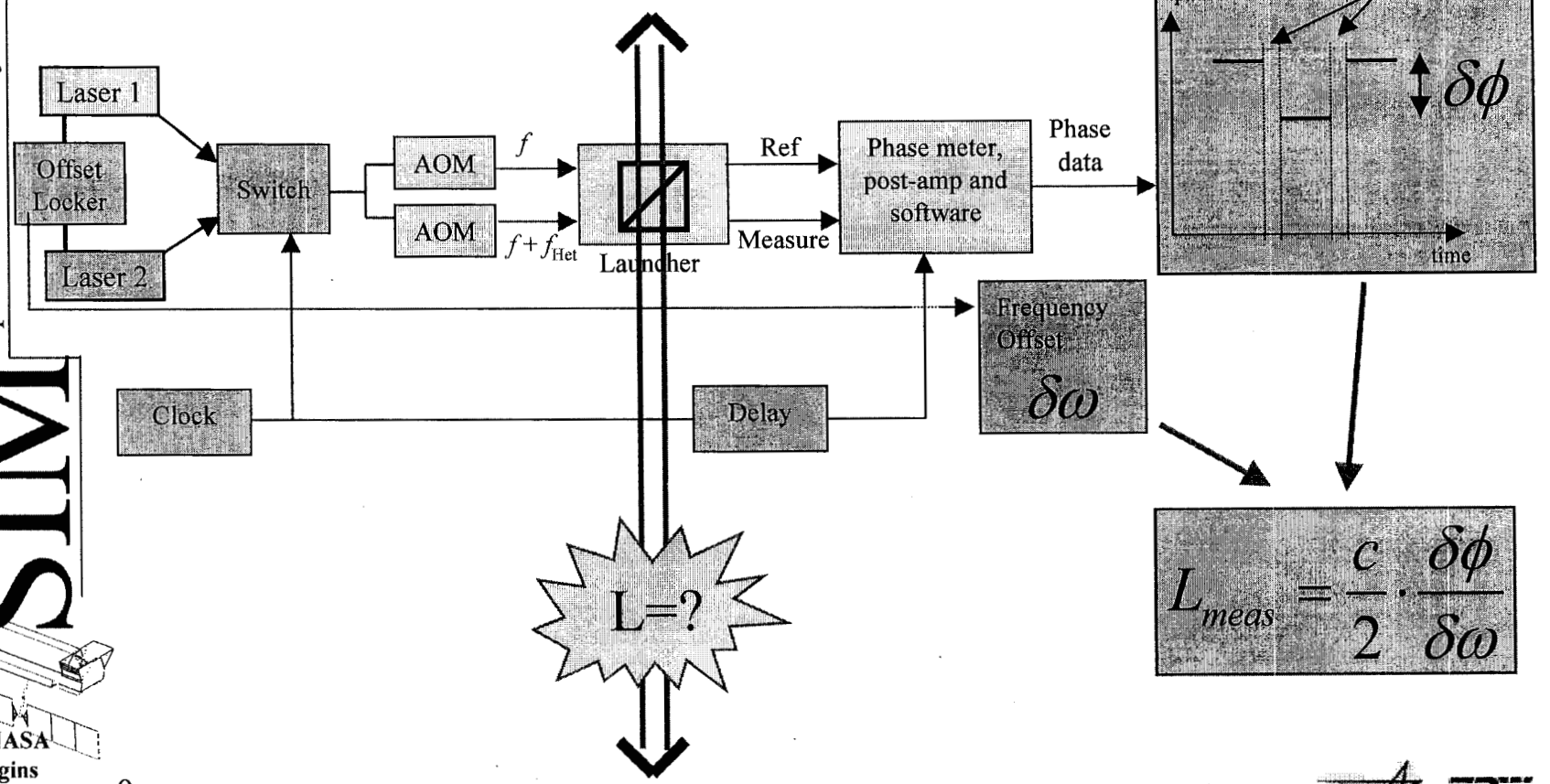
Absolute Metrology

- SIM external metrology requires knowledge of absolute distances to 3 μm
- For Kite, the requirement is 10 μm
- Based on Switched Heterodyne Architecture



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Absolute Metrology Gauge Offset Calibration

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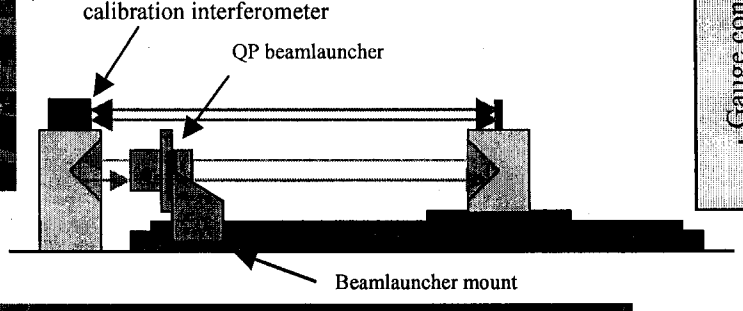
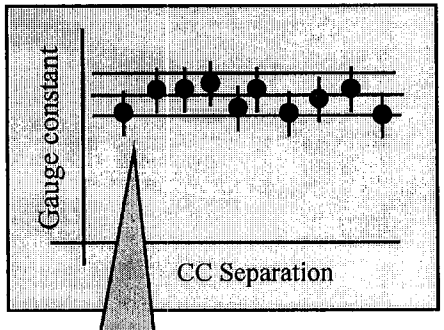
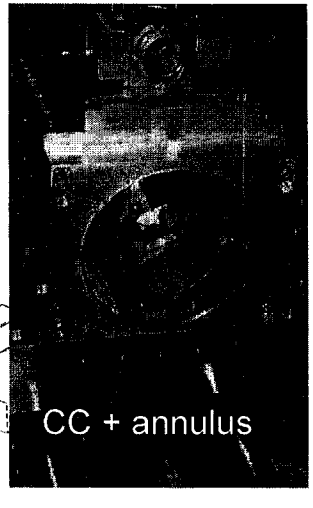
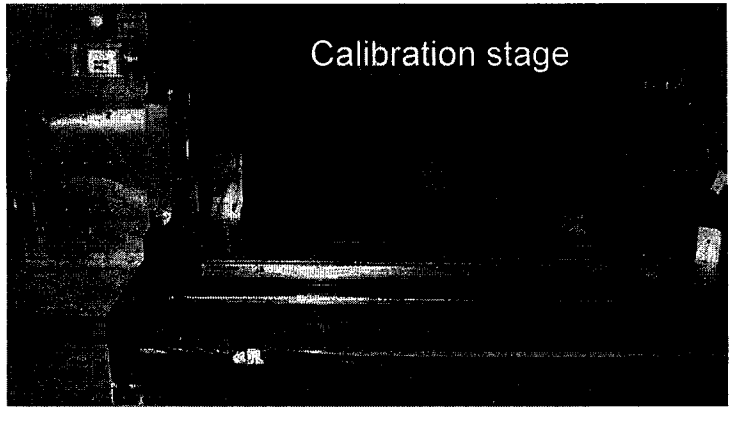
- Basic approach:
  1. bring two fiducials into repeatable, measurable separation via contact
  2. measure the change in the distance as they are separated
  3. insert Abs Met gauge: "Gauge constant" = Abs Met – Calibration
  4. repeat for a range of fiducial separations





Vertical spread measures absolute metrology system performance





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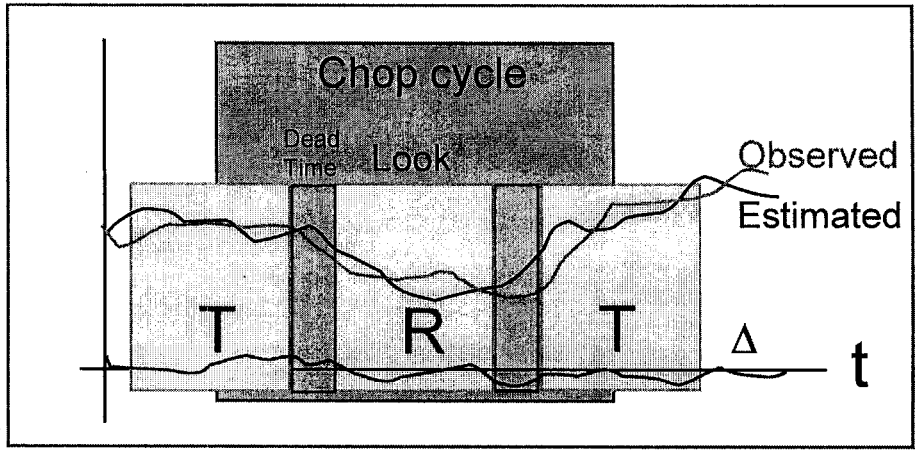
LOCKHEED MARTIN TRW

Definitions

- Look
  - A segment of data yielding a single average measurement
  - Looks are separated by dead time arising from slew and settle
- Delta
  - The difference between the reading of one gauge and the estimate using the other 5 gauges
- Chop
  - The difference between one delta and another



Side-bar on Abbreviations

FI	Field-Independent
FD	Field-Dependent
DT	Deformed Truss
WA	Wide Angle
NA	Narrow Angle

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Kite Performance Metrics

- WA metric
  1. Compute Δ and average into 30 second bins
  2. Every hour take the measurements and estimate a linear drift in the metric over 1 hour
  3. Remove drift from metric
  4. Compute standard deviation of remaining 30 second bins

- NA Metric
  1. Compute the Δ for each time sample and average the Δ's per look
  2. Compute per-chop averages with SIM timing: R(15s) – 15s – T(30s) – 15s – R(15s)
  3. Average over 10 chops – call this the 10-chop average
  4. Remove any linear field-dependence
  5. Repeat 1-4, many times and compute the standard deviation: σ(*10-chop average*)

- Optimal Metric
  1. Designed to minimize the metrology errors in all areas except item of interest
  2. Similar to the NA metric, except:
     1. The duration of each look is not constrained to SIM timing (we would chop faster)
     2. The number of chops is not constrained to 10 (we would do more)
     3. Any linear field-dependence is not removed

Narrow Angle vs. Wide Angle

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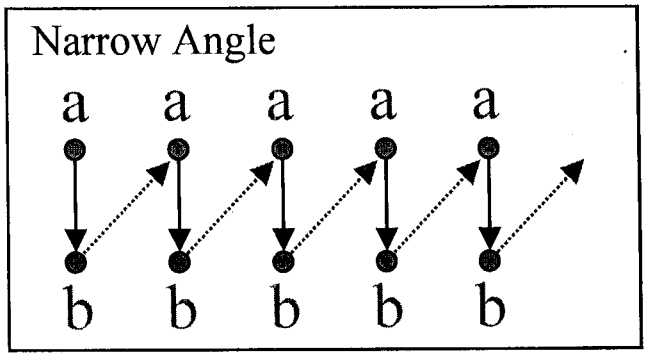

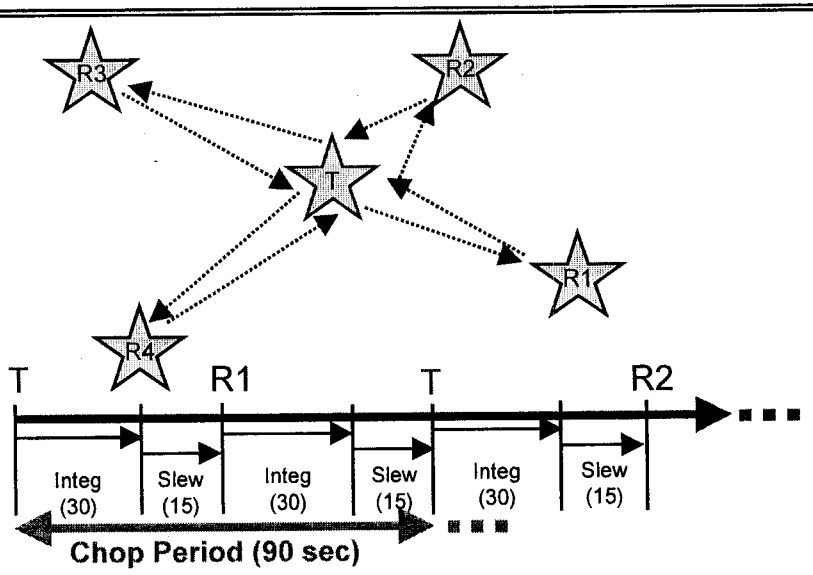

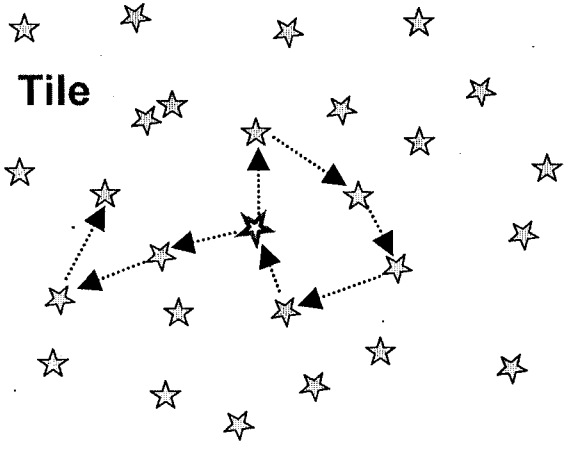

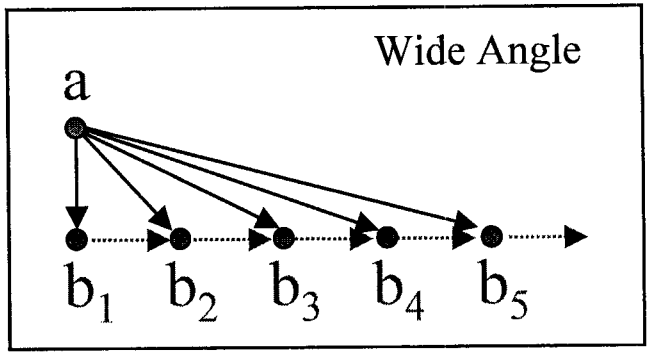

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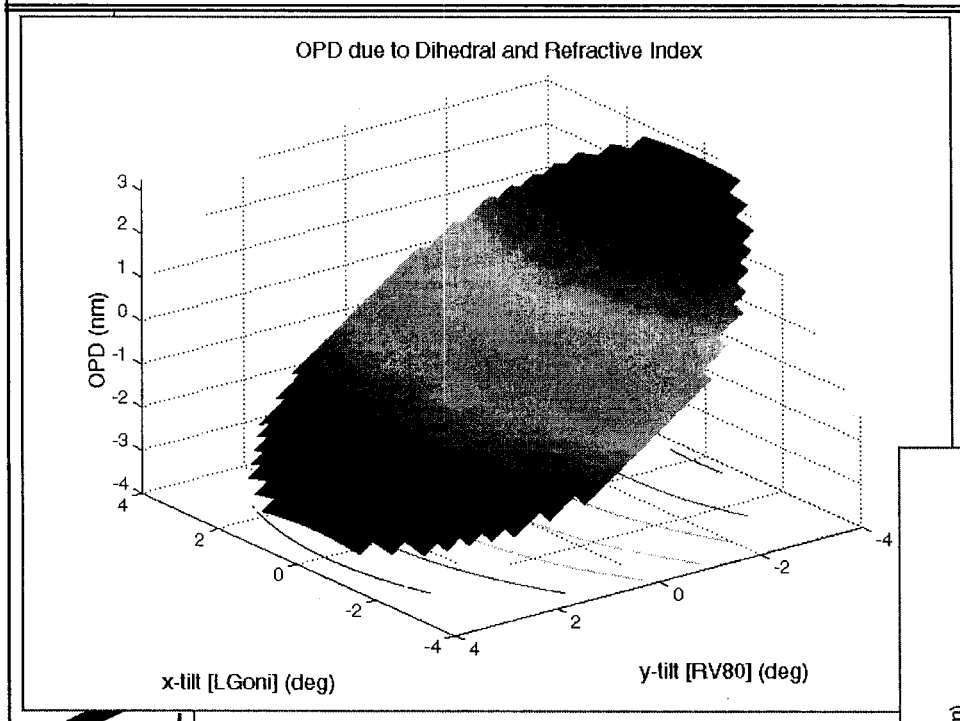
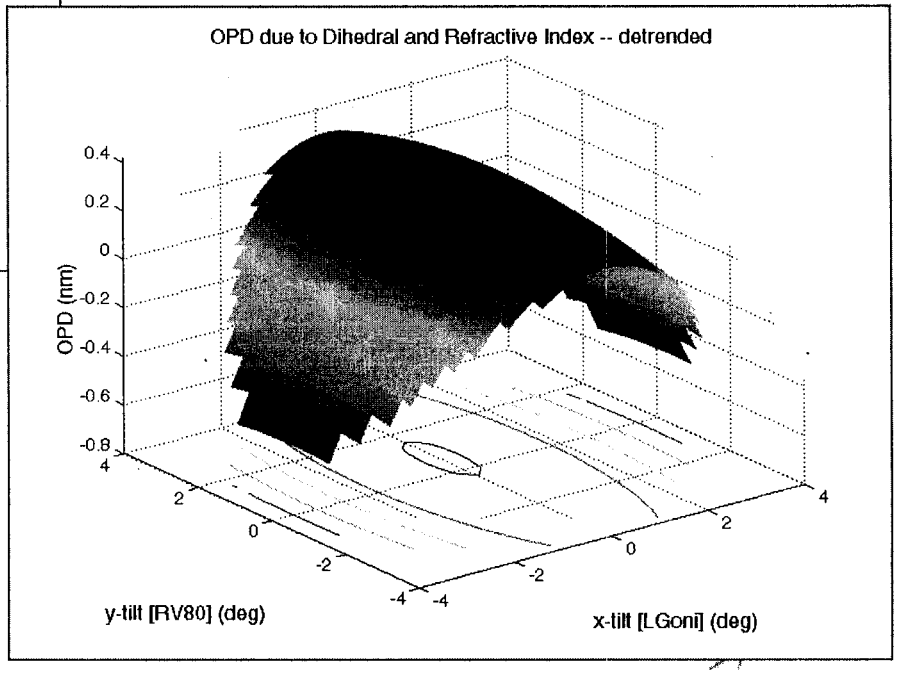
Corner Cube Model





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Narrow-Angle Flow-down to Kite

- Narrow-angle testing involves chopping
- The SIM allocations are based on 10-chop averages
- The Kite requirements include test-specific factors

SIM Narrow-Angle Error Budget Item	SIM Goal Allocation	Requirement / Goal	Kite Metric / SIM "look"	Kite Requirement	Kite Test Category	Performance Metric
Absolute Metrology Error	2.5 pm	3 uas / 1.1 uas	Sqrt(2)	10 pm	DT	Optimal
Rel. Metrology External Error	7 pm	3 uas / 1.1 uas	2	42 pm	FI	NA
Siderostat / Corner Cube	4 pm	3 uas / 1.1 uas	Sqrt(2)	17 pm	FD	Optimal
All-in one test				45 pm	All	NA

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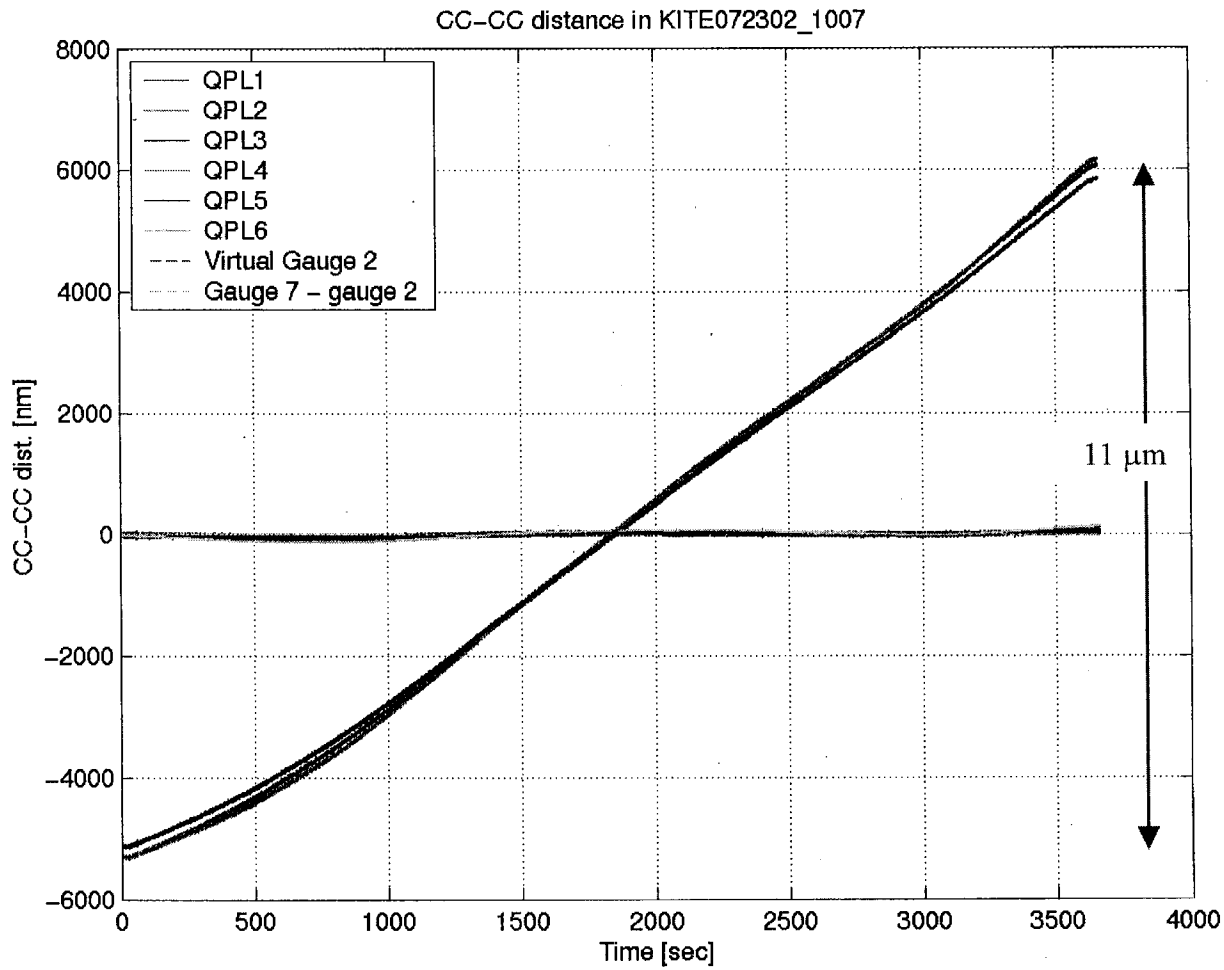
Wide-Angle Flow-down to Kite

- Wide-angle budget deals with precision in a measurement
- The SIM allocations are based on single-look accuracies
- The Kite requirements are in terms of the Kite metric

SIM Wide-Angle Error Budget Item	SIM Goal Allocation	Requirement / Goal	Kite Metric / SIM "look"	Kite Requirement	Kite Test Category	Performance Metric
Absolute Metrology Error	52 pm	30 uas / 4 uas	Sqrt(2)	552 pm	DT	Optimal
Rel. Metrology External Error	122 pm	30 uas / 4 uas	Sqrt(2)	1294 pm	FI	WA
Siderostat / Corner Cube	54 pm	30 uas / 4 uas	Sqrt(2)	573 pm	FD	Optimal
			All-in-one test:	1519 pm	All	WA

1-hour Field-Independent Test



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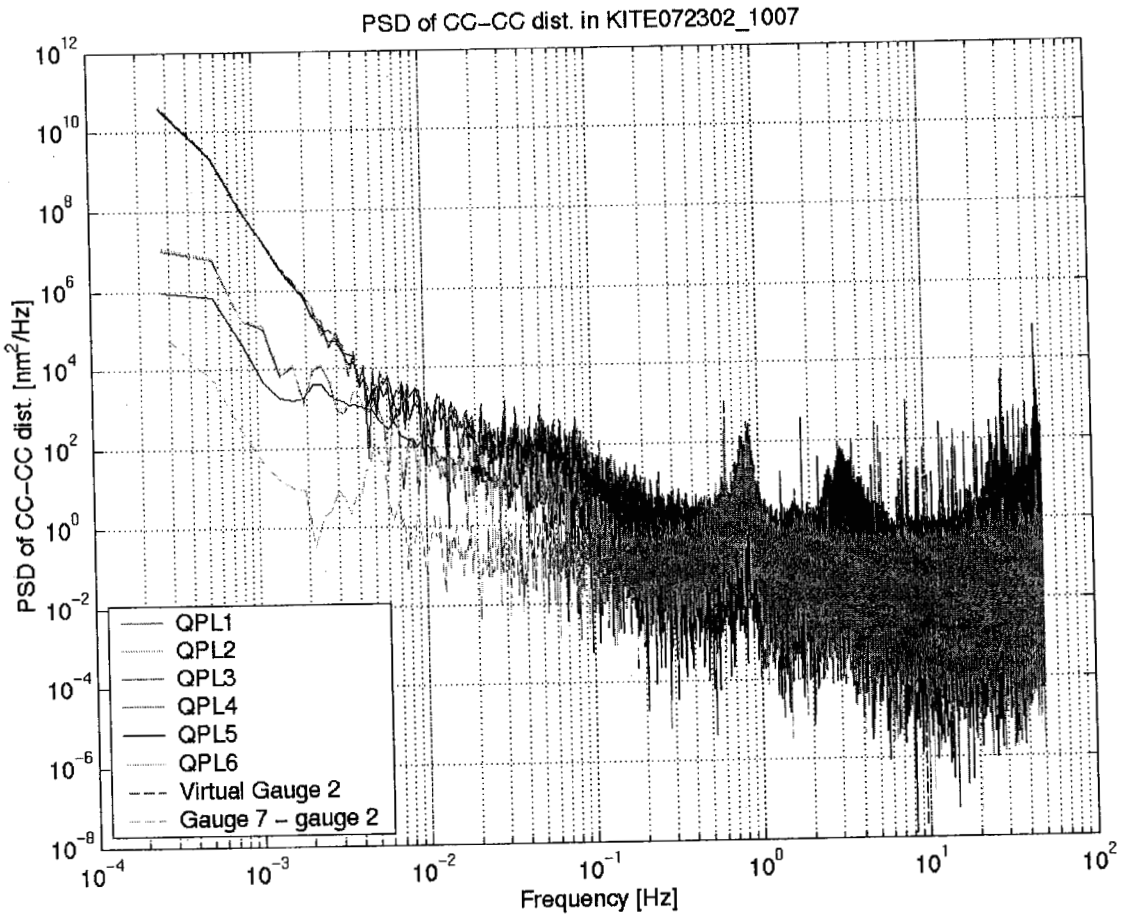
1-hour FI Data PSD's



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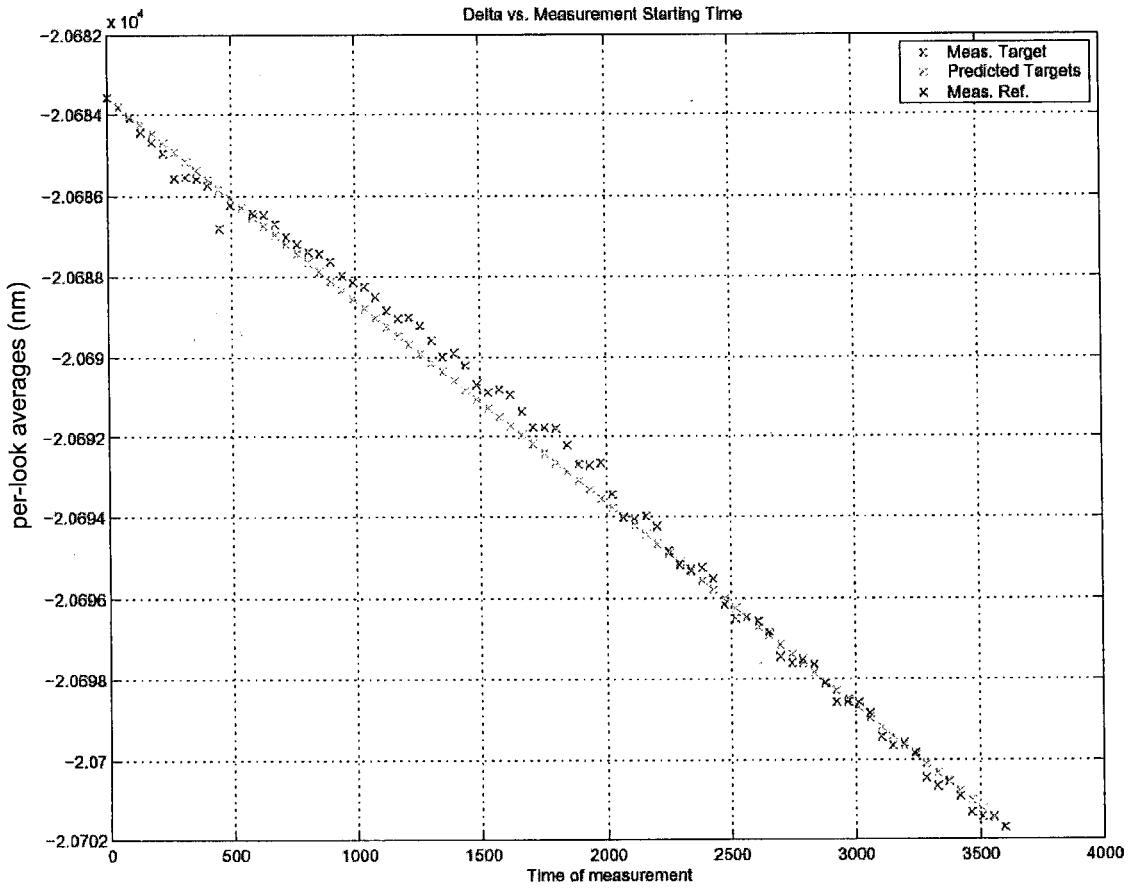
1-hour DT Data - Per-Look Averages



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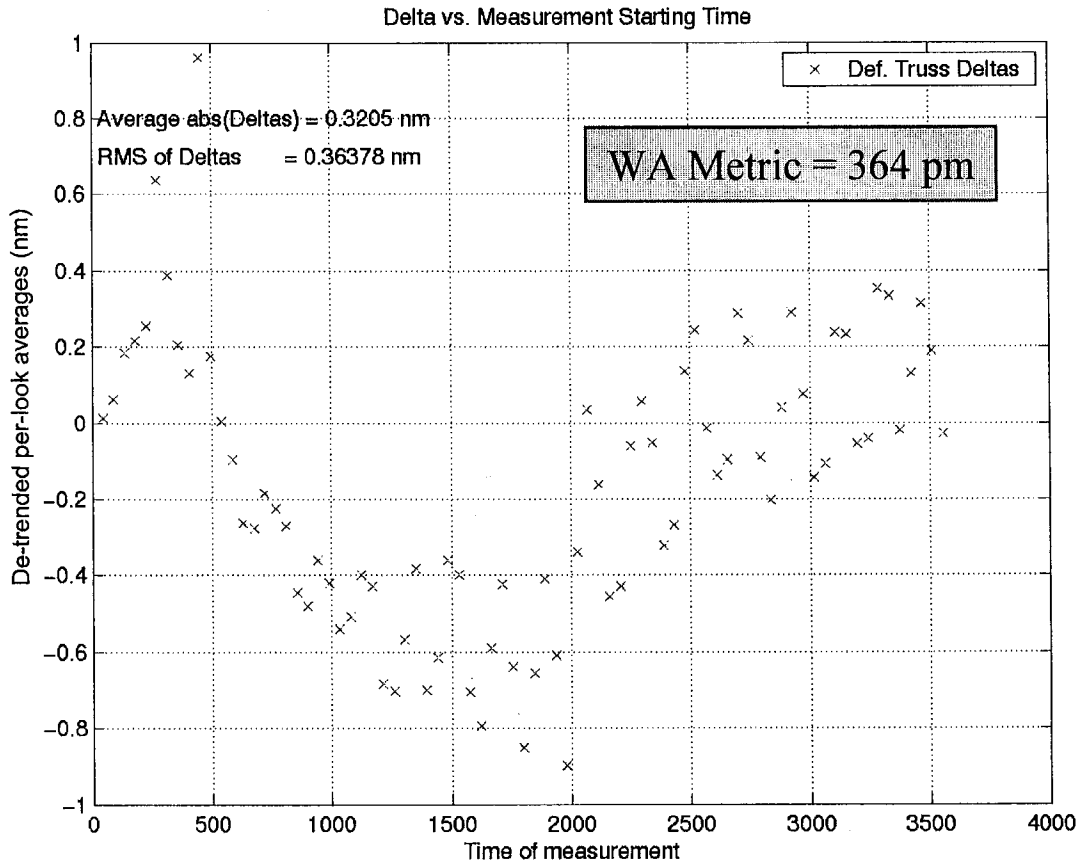
1-hour DT Data – WA metric

- The WA metric is more stringent
- Allows comparison of result with combined FI and DT allocations



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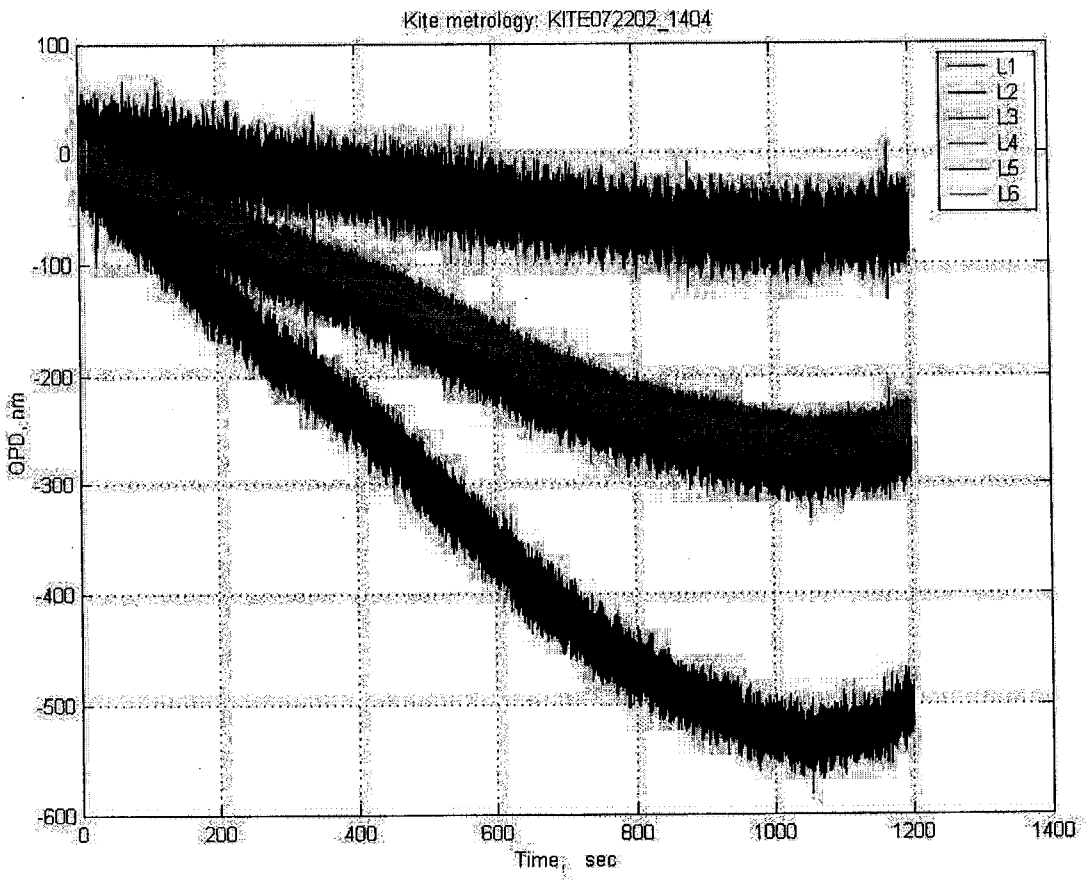
Sample of a Narrow Angle FI Test

- 10 SIM chops take 900 seconds. This run is a little longer.



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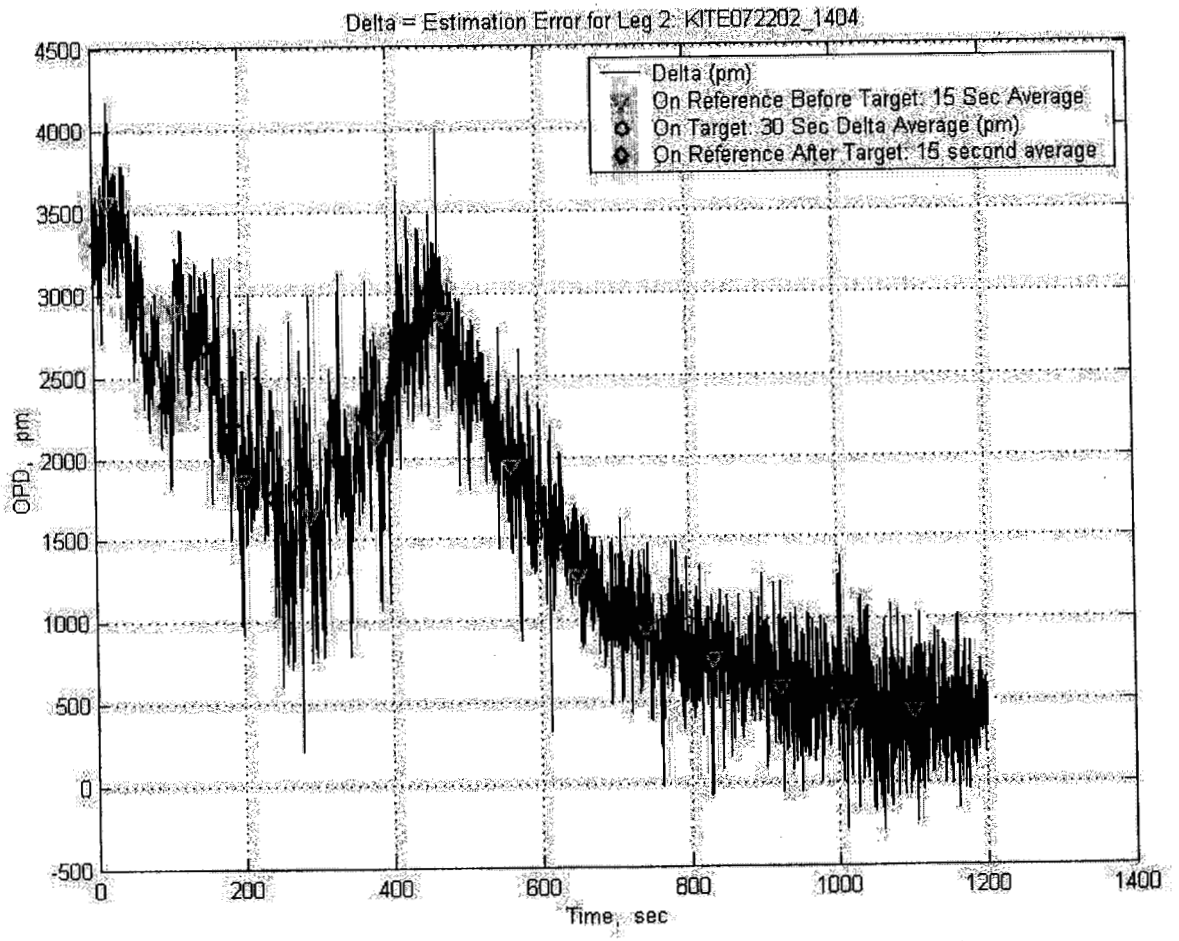
Narrow Angle FI Test – cont.



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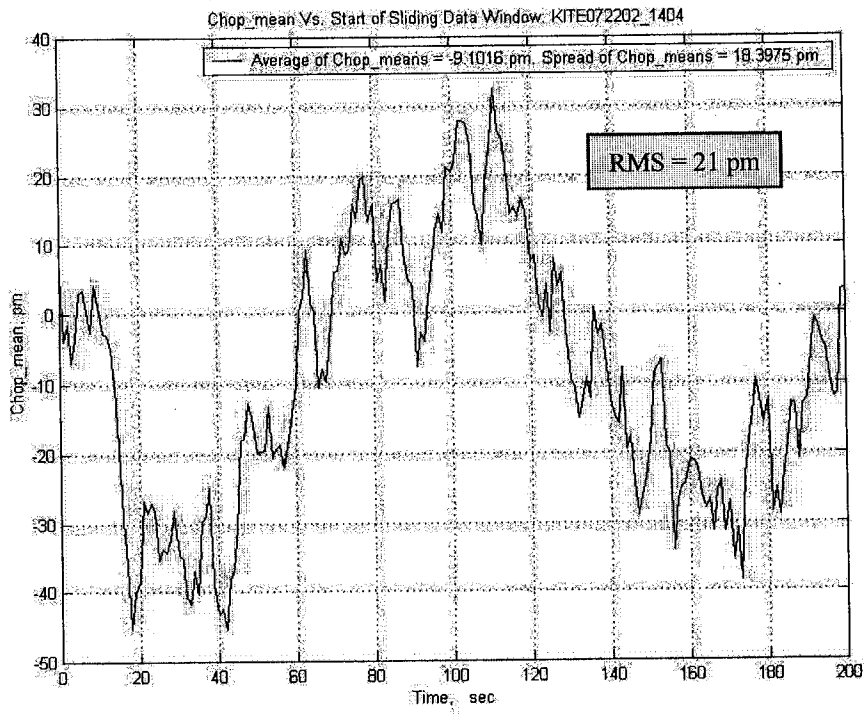
Narrow Angle FI Test – cont.

1. Form chops starting beginning of the run
2. Compute the 10-chop average
3. Slide the 10-chop window over by one data point
4. Re-compute the 10-chop average
5. Repeat for 200 points
6. The RMS of the 10-chop averages is an estimate of the NA metric



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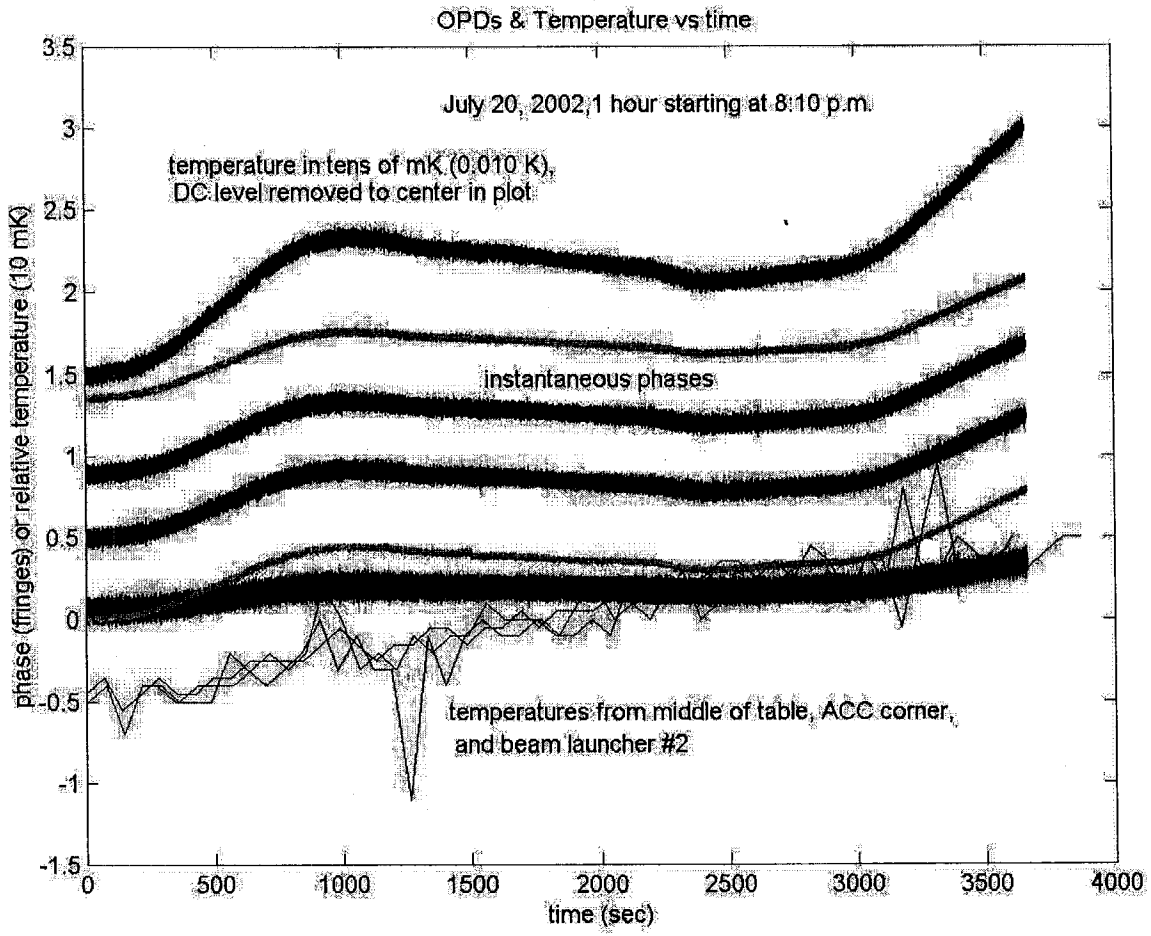
OPD versus Temperature



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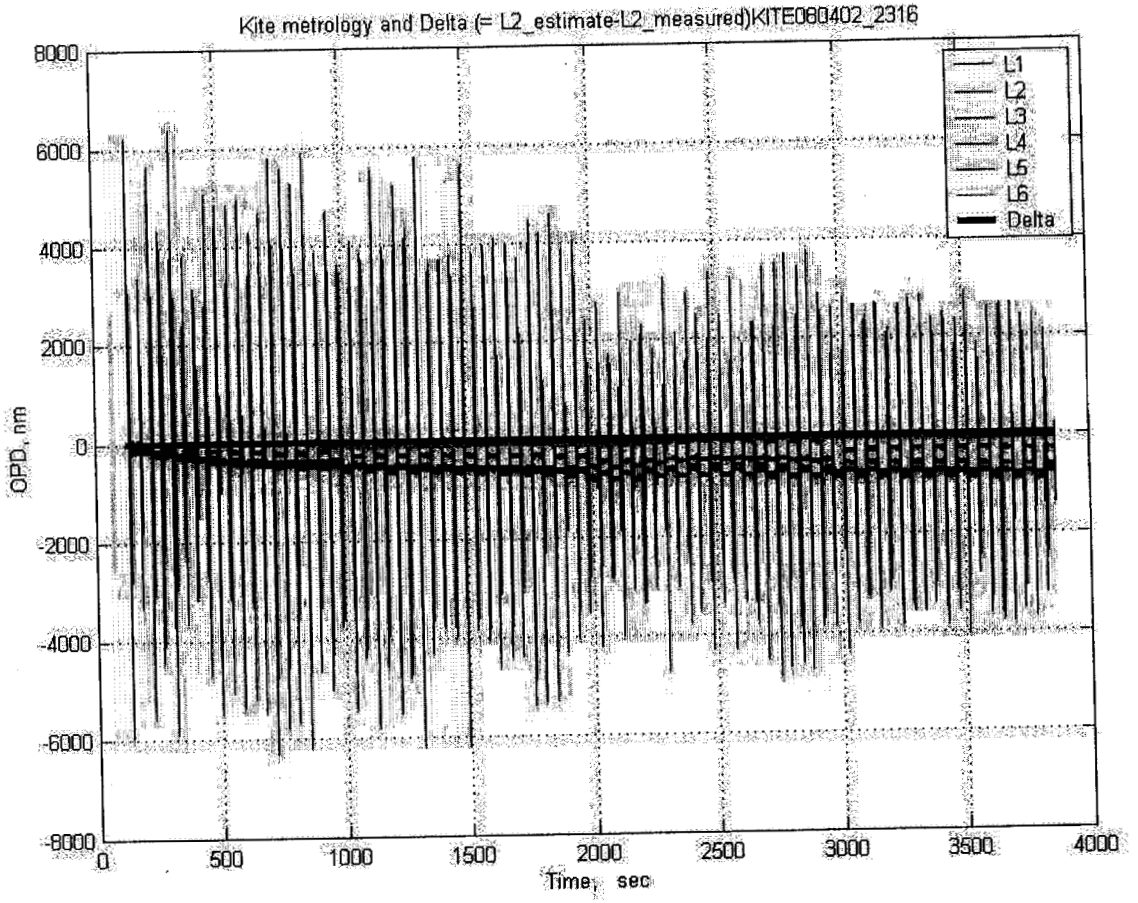
NA FD Combined Test



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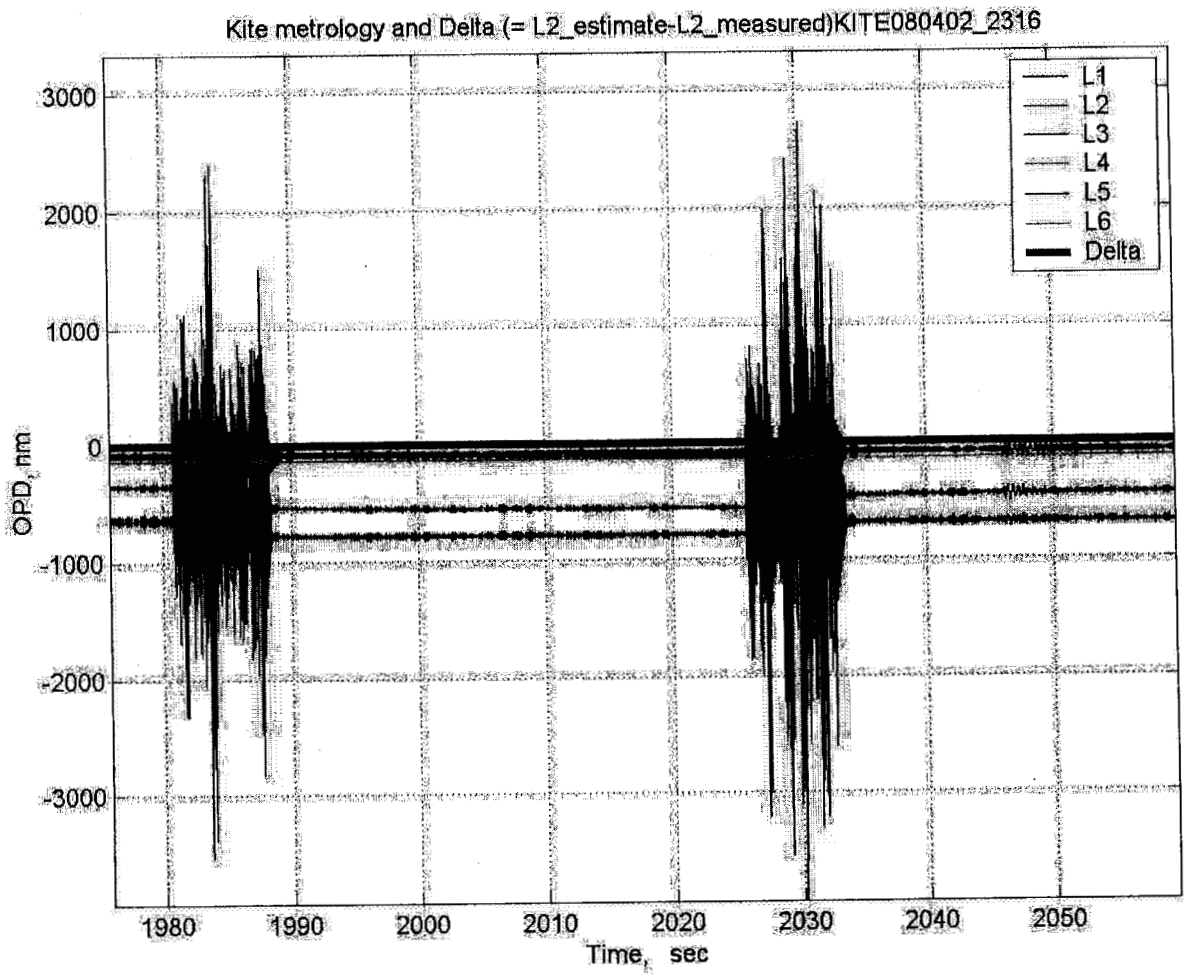
NA FD Combined Test



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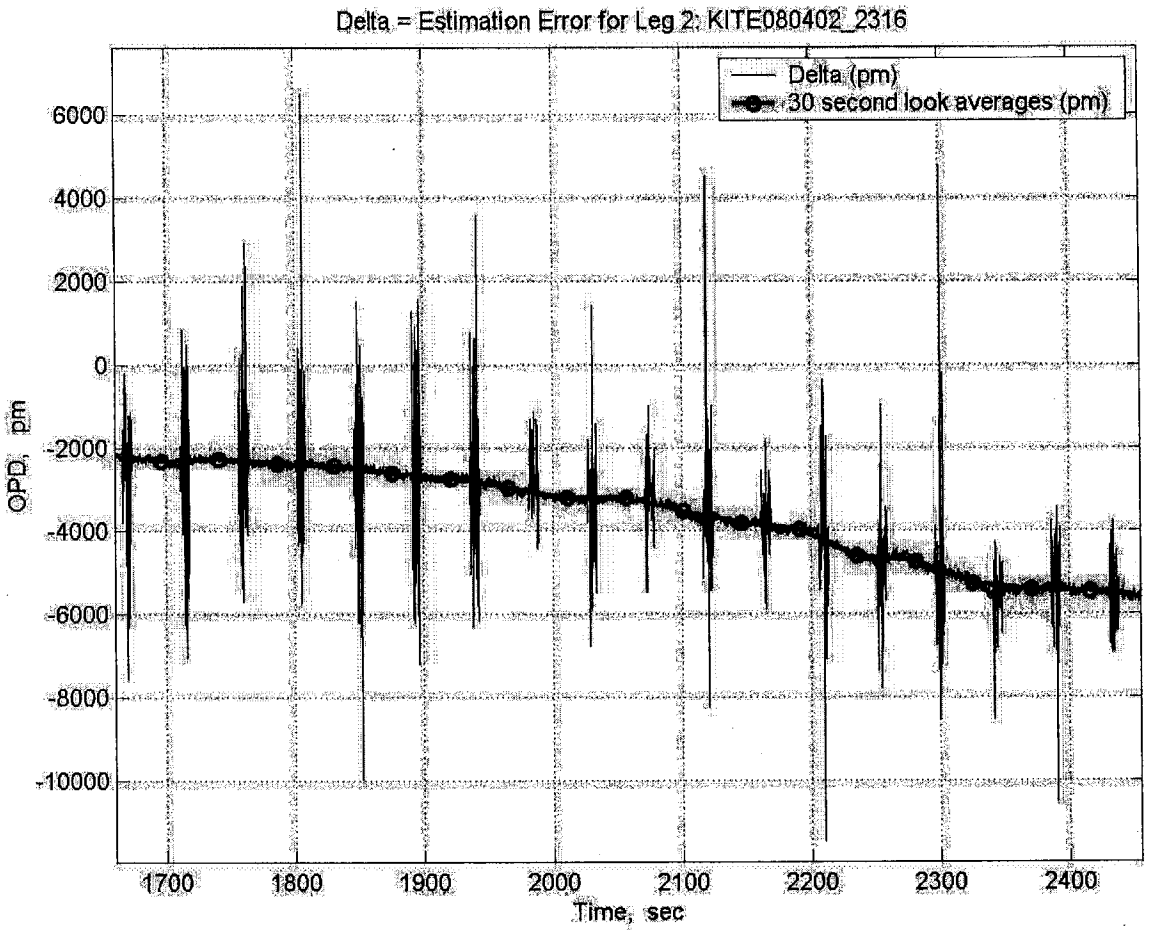
NA FD Combined Test



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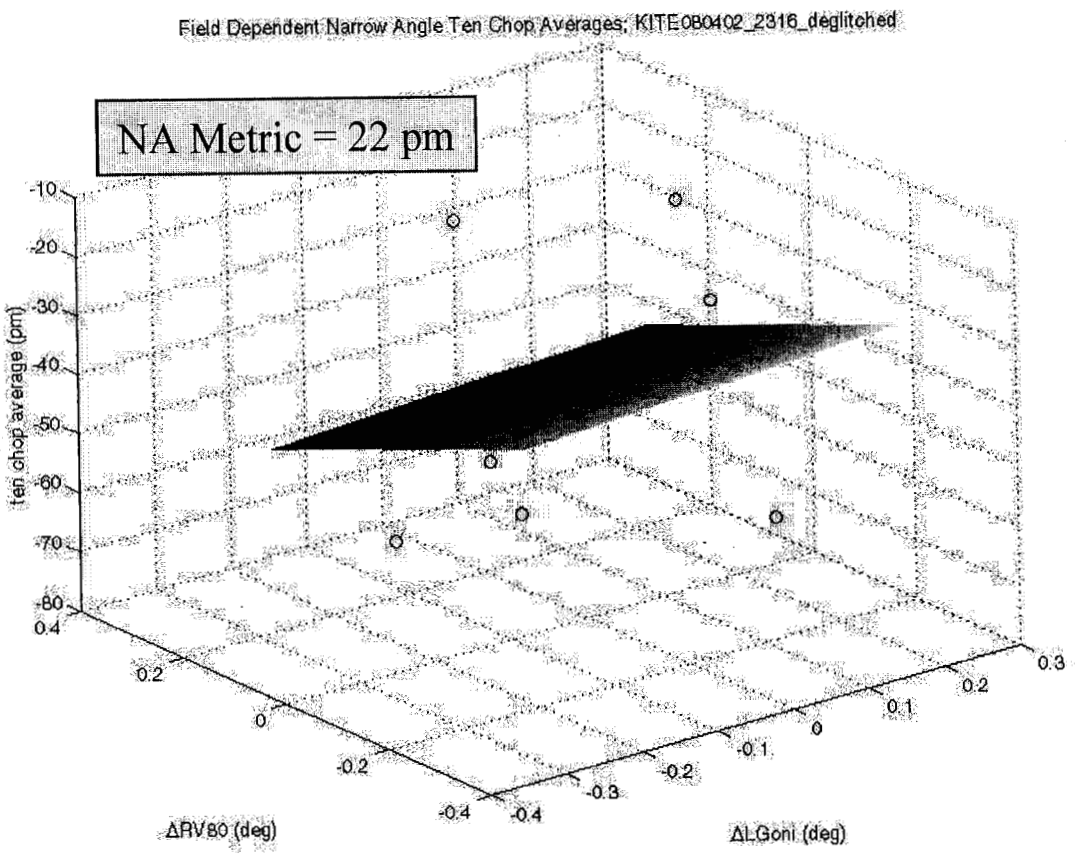
NA FD Combined Test



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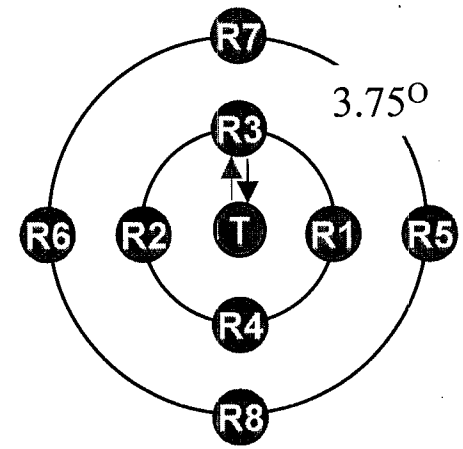
Wide Angle FD Test

- Objective
  - Demonstrate that the kite part of the SIM FD WA error budget can be met
  - Demonstrate that WA field dependent calibration function generated from component measurements meets the budget.
- Test Plan
  - Articulate angle of corner cube over 9 star positions and +/- 3.75 degrees
    - Use optimal metric; additionally:
      - Remove calibration function from field dependent measurements
      - Remove linear field dependent term and radial quadratic term (TBR)
    - Find out how many chops of T-R-T are necessary to meet requirements
  - Repeat test after a few days to show that metric continues to meet requirements

Field-Dependent Test	Wide Angle
Angular Range	+/- 3.75 deg
Duration	Fast
Performance Requirements	573 pm
Performance Metric	Optimal



Summary of Results

- The Kite testbed has demonstrated that the metrology truss is capable of performing at the required levels for
  - NA operation
  - WA relative and absolute metrology
- WA field-dependent testing is under way

Error Budget Item	NA		WA		Test Type
	Requirement	Achieved	Requirement	Achieved	
Absolute Met	10 pm		552 pm	360 pm (preliminary)	PI
Relative Met	42 pm		1300 pm		FI
Camera/Tube	17 pm		573 pm	220 pm (preliminary)	FIP
Combined	44 pm	22 pm (preliminary)	post-milestone		All in One

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Conclusions

- The Kite testbed has demonstrated that a pico-meter class metrology truss can be built
- The data support the feasibility of SIM external metrology approach
- Areas of continued work:
  - Absolute metrology robustness
  - Corner Cube Model
  - Automatic Pointing performance

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