LISA Symposium

An Acquisition Control for LISA

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Outline

- Acquisition basics
- Strategies
- Issues
- Acquisition process
- Acquisition Sequence
- Acquisition Model
- Results (defocus on 57 DOF model)
- Summary
- Future

Acquisition Basics

- Constellation acquisition
  - Not to be confused with "acquisition" as in buying stuff
  - Defined as the process of bringing the three LISA spacecraft from "zero" to all six links phased locked and optimized (ready for science)
  - Re-acquisition is a simpler (and faster) process with much smaller alignment and bias uncertainties
- Process
  - Spacecraft star tracker to telescope alignment calibrated with natural stars
  - "Playlist" and ephemeri uplinked to all three spacecraft
  - Spacecraft attitude (by star tracker) and point ahead prescribed
  - For each link….autonomous process, but monitored by ground
    - Pointing acquisition (three strategies: defocus, scan, super-CCD)
    - Phase acquisition (scan frequency and lock to incoming)
  - Tune up constellation
    - Verify inter-SC clock, comm. and ranging
    - Phase: Gain tuning for laser and offset/arm-lock loops
    - Pointing: Brightness and "flat-spot" search and optimization
    - Engineering Mode checkout, calibrations, and trial data runs

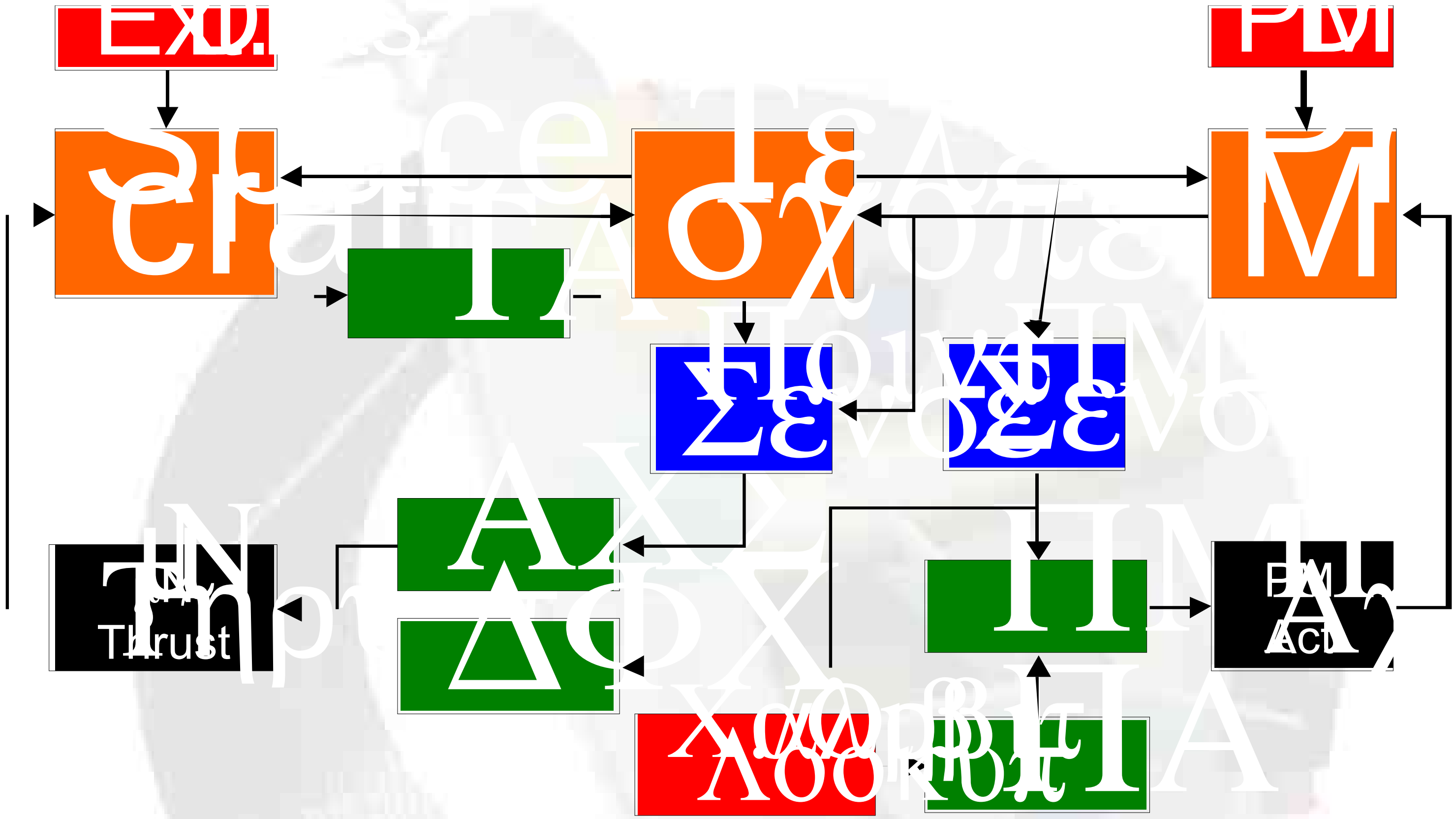
The Three Strategies

- Defocus
  - Spoil beam to cover uncertainty cone
    - 4 μrad beam spoiled 10 x (to 40 μrad), 100x weaker=~0.7 pW
  - Receiver fixed stares until integration time (SNR) good enough
    - This sets time required for "gyro-mode" stability
- Scan
  - Scan over uncertainty cone (continuous or step/stare)
  - Receiver fixed stares until integration time (SNR) good enough
    - This sets scan rate and time required for "gyro-mode stability"
- Thru-telescope Star Tracker
  - Natural star fixes with visible CCD through LISA telescopes
    - < 1 μrad NEA for 0.05 deg FOV down to magnitude (m_v) of 16, for 1 sec integration
  - Issue of "imaging quality" FOV with telescope prescription

Issues

- Defocus
  - Fiber positioner mechanism complexity is driving issue
  - Requires pointing stability over the phase-lock-up time
  - Can be mitigated by both ends defocus and co-re-focusing
- Scan
  - Pointing stability over scan time is driving issue
  - Can be mitigated with “gyro-mode” operation of GRSs
  - Scan can always be done, even if another strategy is chosen as prime
- Thru-telescope star tracker
  - FOV of telescope is driving issue
  - Requires good alignment knowledge on bench [or searching]
  - Eliminates requirement to have high performance SC star trackers

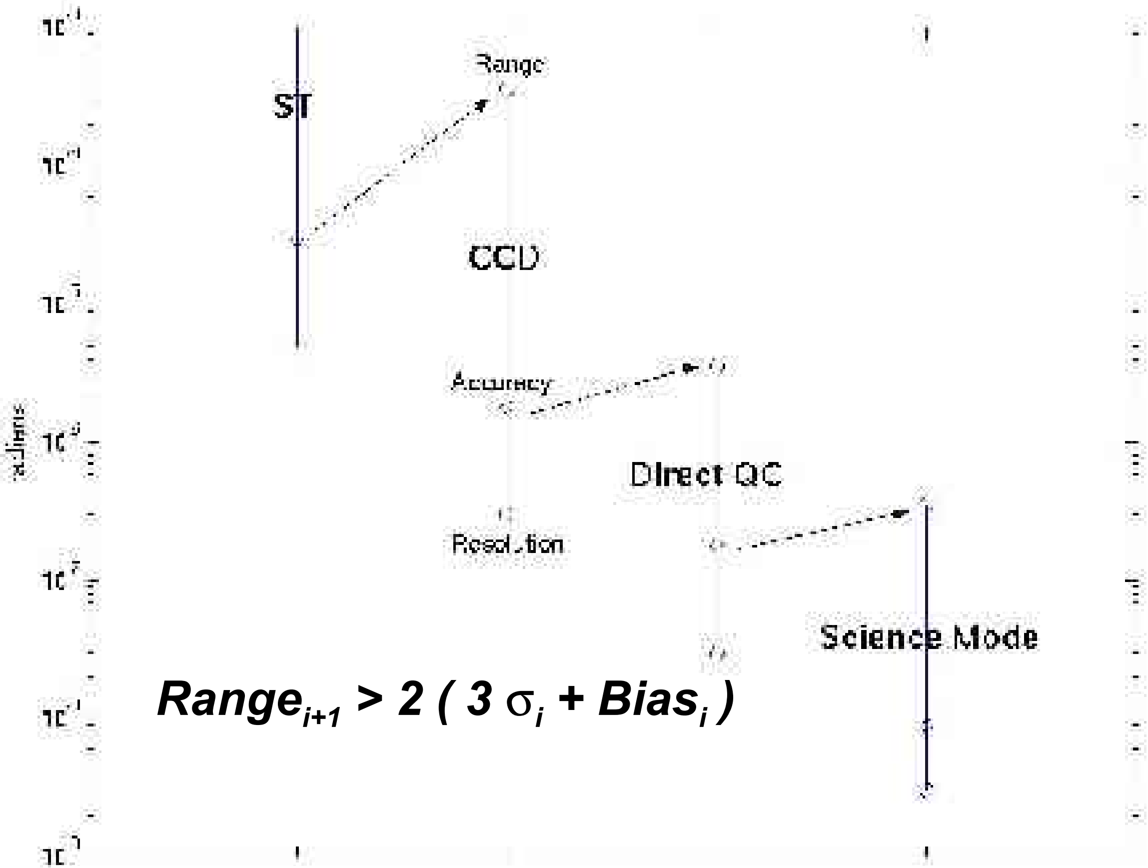
Disturbance Reduction System



DFC=Drag Free Control System
TA=Telescope Articulation
ACS=Attitude Control System
PM=Proof Mass Suspension
PA=Point Ahead & Acquisition

Acquisition Error Bands

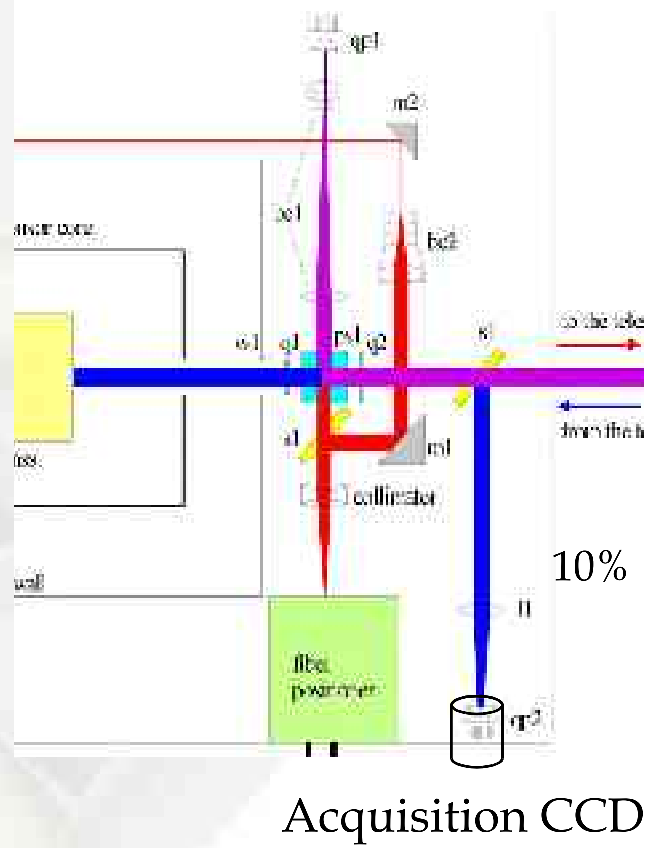
Sensor	Resolution (1 Hz effective bandwidth)	Range	Alignment Bias to Next Sensor
Star Tracker	5 microrad	Full sky	20 microrad
CCD	0.3 microrad	360 microrad	0.9 microrad
Direct QC	30 nanorad	3.6 microrad	90 nanorad
Science Mode	3 nanorad	360 nanorad	N/A



$$Range_{i+1} > 2\,(\,3\,\sigma_i + Bias_i\,)$$

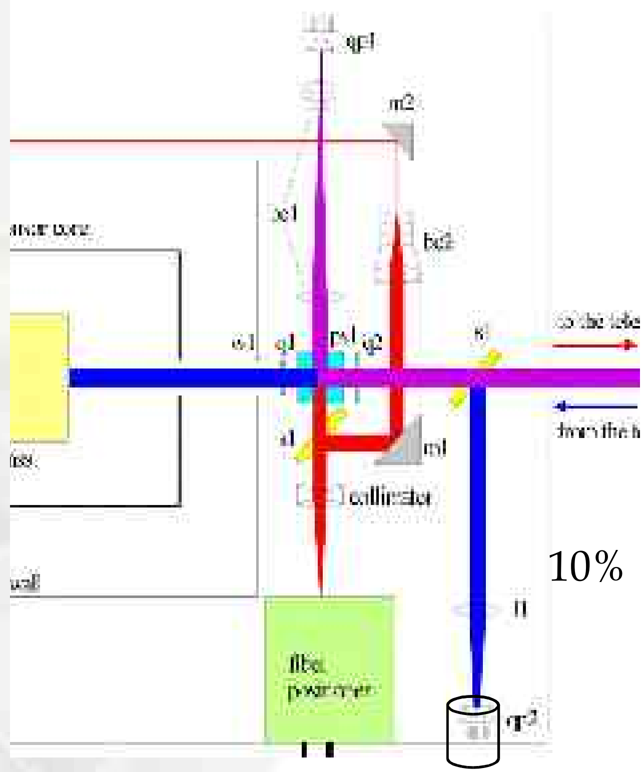
Defocus Strategy: Single-Link Process

- Initiated from ground command and done autonomously
  - Spacecraft point at each other based on ephemeris information and star tracker measurements (Tracker mode)
  - The gravitational sensors are placed in accelerometer mode
  - Both spacecraft switch to the gyro mode: A Kalman filter that blends attitude error info from the star trackers with the rotational acceleration measurements from the gravitational sensors (Gyro mode)
  - The transmitting S/C spoils its outgoing beam
  - Looks for the incoming beam (from other S/C) in its acquisition CCD (CCD Mode): local laser is off
  - Centers on and switches to the Quad Cell detector (Direct QC Mode)



Defocus Strategy: Single-Link Process

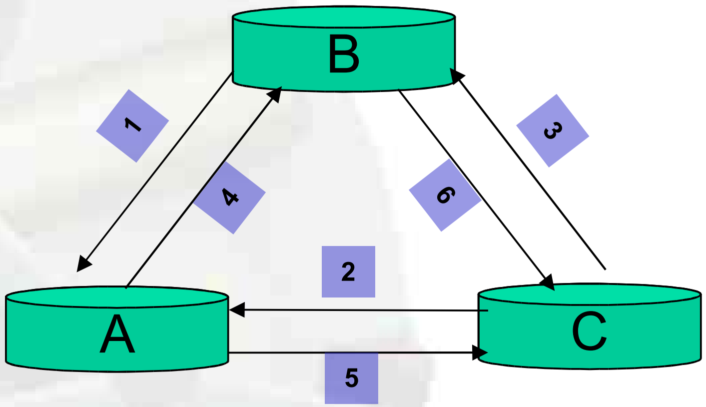
  - The CCD mode may be bypassed if the performance of the Gyro mode allows
  - Centers on the Quad cell and turns the local laser on for Heterodyned waverfront sensing
  - The S/C is put pack in the Gyro mode during the 300 sec it may take for locking the beams
- Biases are calibrated out at each step making re-acquisition simpler
  - Star tracker biases can be calibrated prior to the acquisition sequence
  - Alternatively, a bias estimator may be implemented
  - The estimator requires the adjacent arm to be in one of enhanced modes



Acquisition CCD

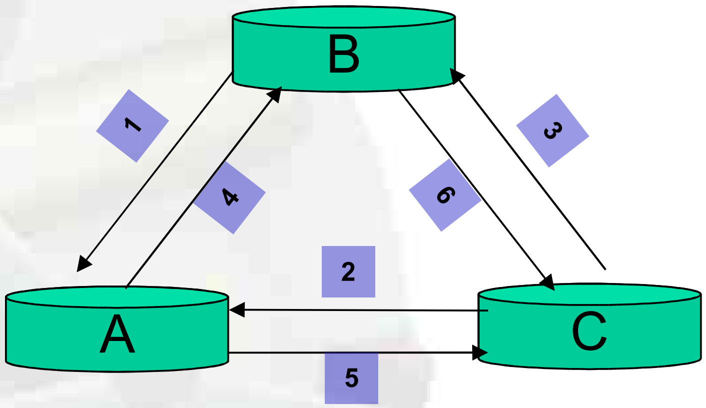
Defocus Strategy: Acquisition Sequence

- Links 1 thru 3 are established first using the described process
- When establishing link 4 the local laser in S/C B must be initially turned off: **link 1 will be temporarily lost**
- Enhanced attitude knowledge is possible since link 2 is still active
- Current strategy is to use the sensor data from link 2 along with the attitude error estimate from the Kalman filter (Enhanced Gyro Mode)
- An alternative approach is to leave the attitude loop in an open-loop mode with thrusters firing at the last mean torque levels.
- Links 5 and 6 follow the same approach.



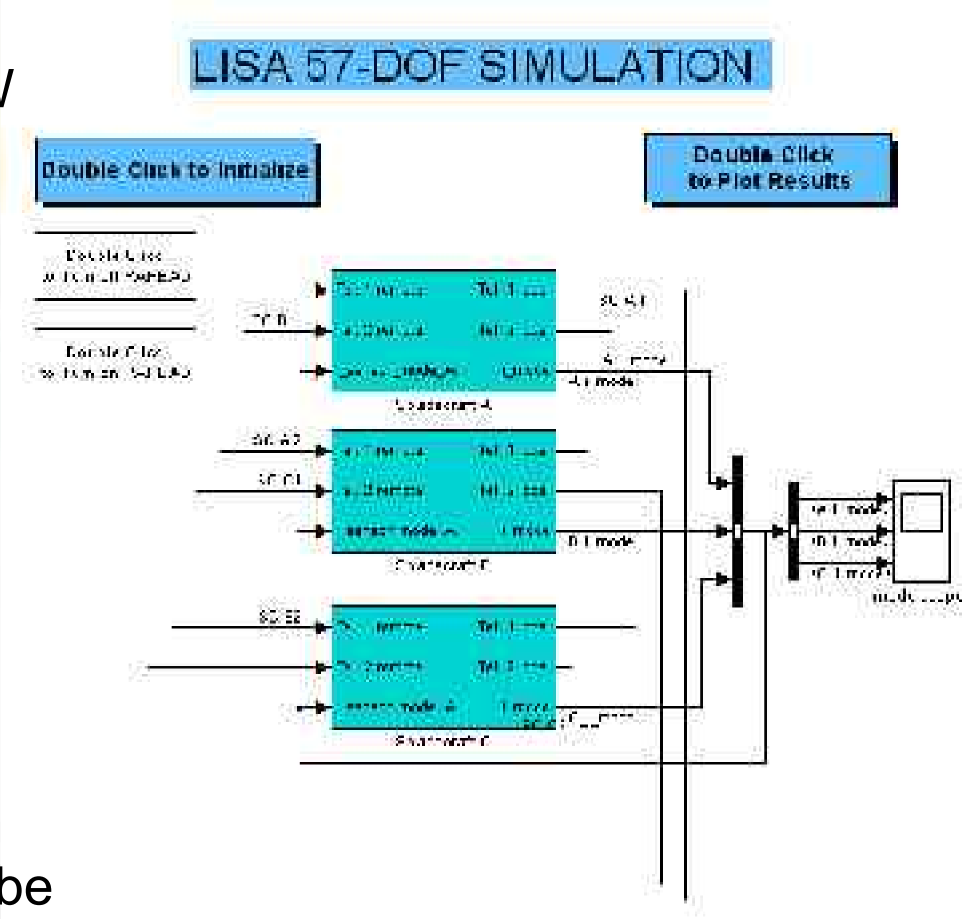
Attitude Error Determination

- Three cases considered for attitude determination
- No available fine attitude sensor Measurements:
  - Star tracker + GRS accelerometer data (Kalman Filter)
  - Open-loop telescope articulation
- One link of fine sensor data available:
  - Fine sensor data used with the Kalman filter providing attitude error about the LOS
  - Open-loop telescope articulation
- Two links of fine sensor data available:
  - Fine sensor data is exclusively used to compute attitude and articulation errors



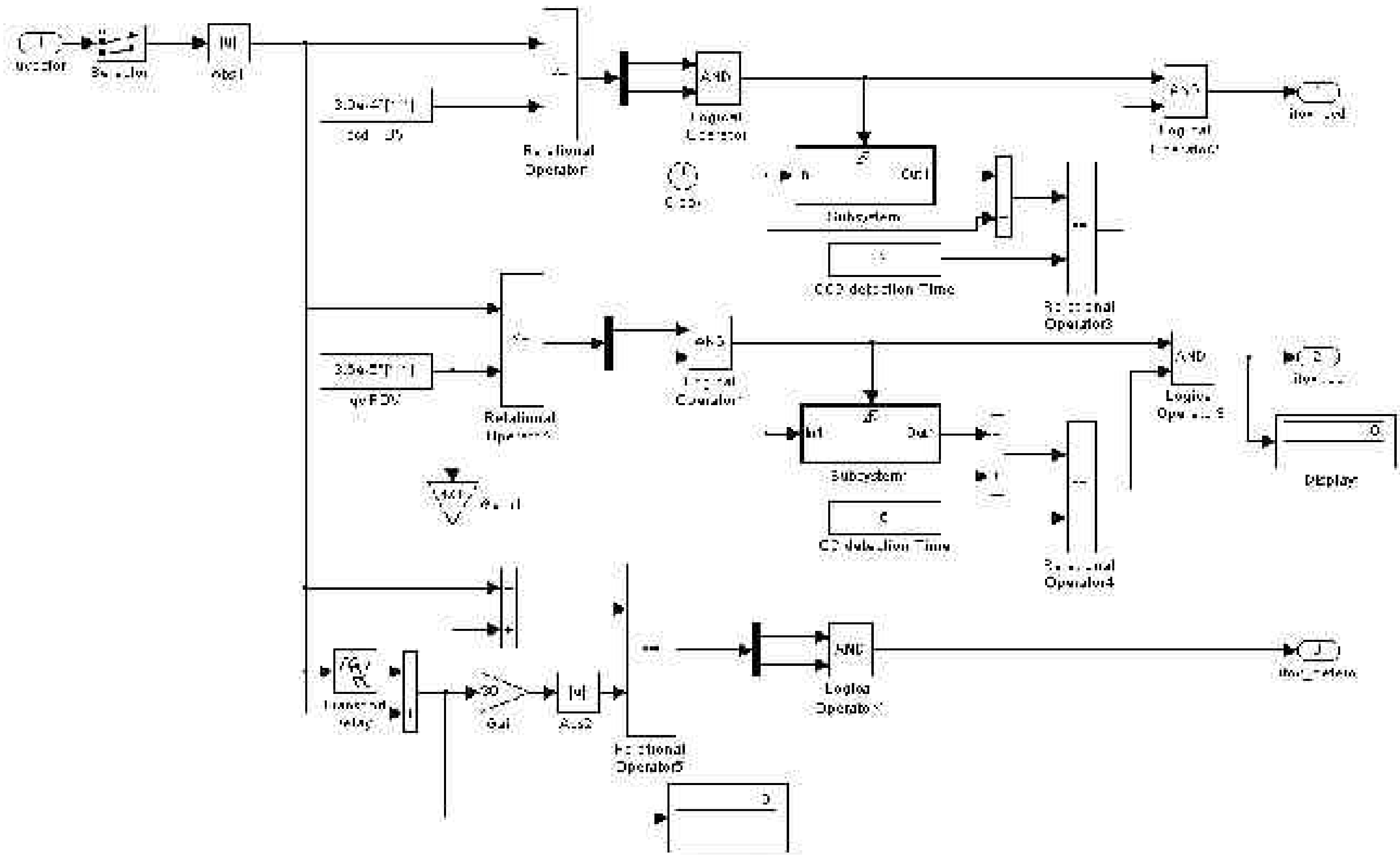
Acquisition Model

- Supports LISA acquisition control analysis
- Uses SIMULINK and STATEFLOW
- Include full rigid-body dynamics of the LISA formation
  - Same DRS control system in each S/C
  - Natural orbits from design optimization
  - Point-ahead compensation
- Currently supports the defocus strategy
- Scanning and other strategies will be supported in the near future



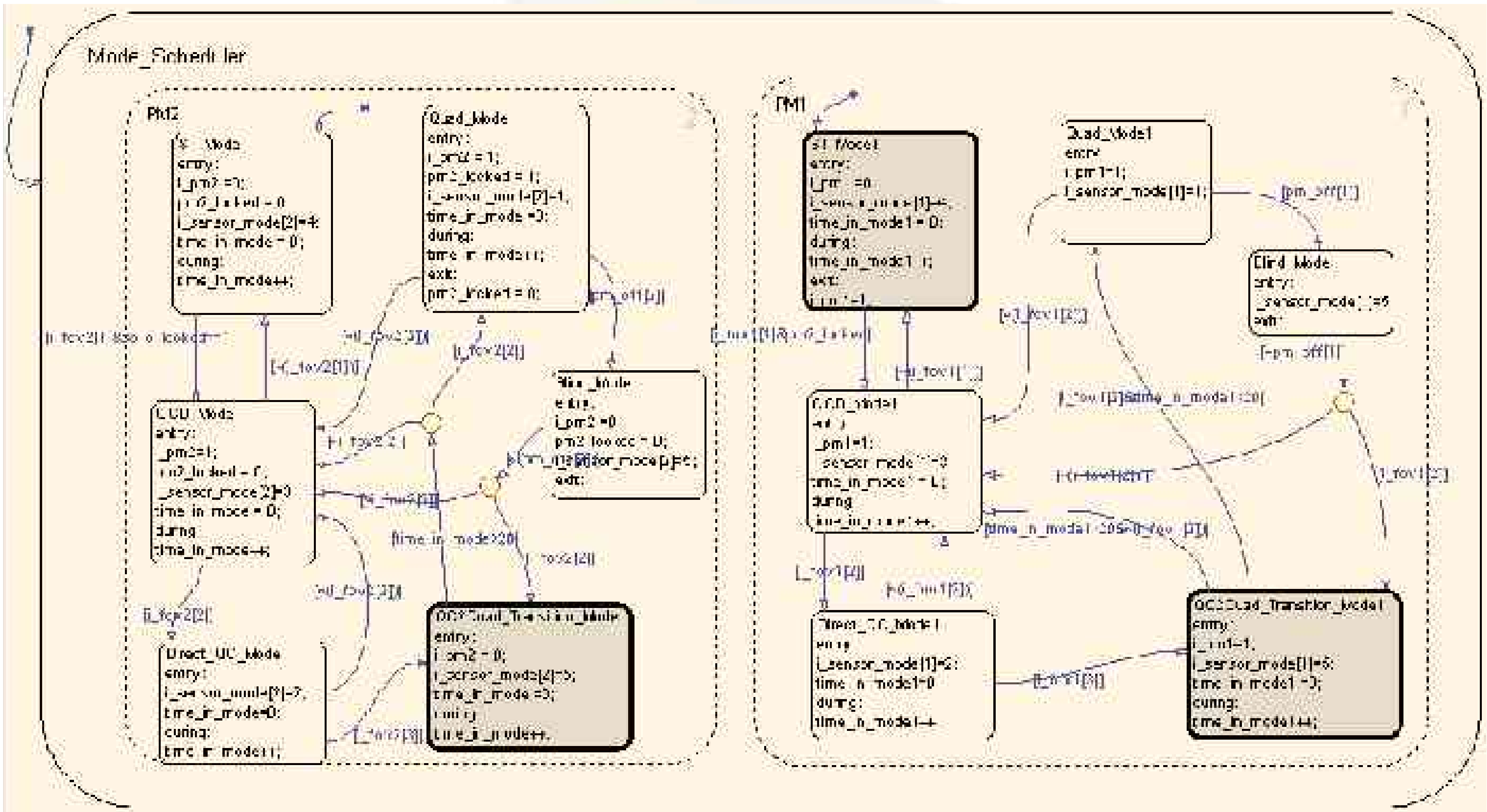
Sensor Transition

- Autonomous sensor selection and transition based on active and expected field of view



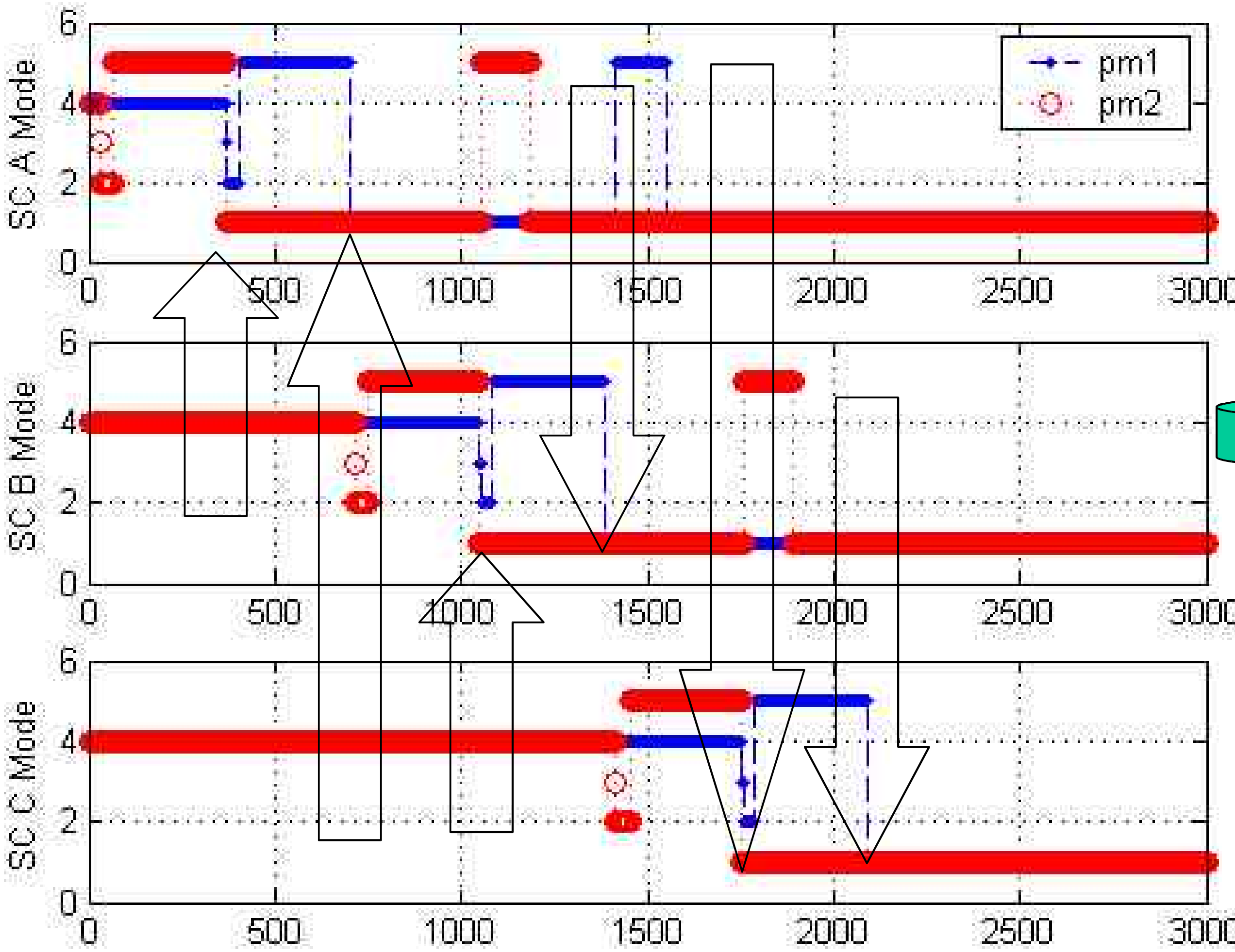
Scheduling Logic

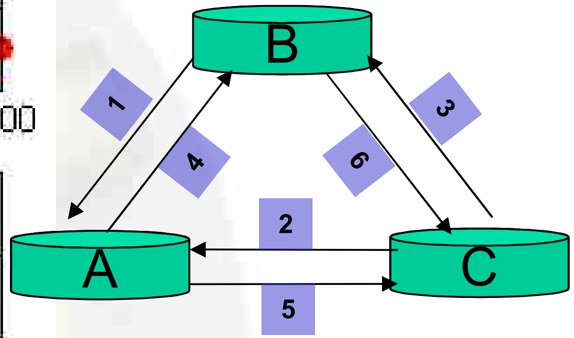
- STATEFLOW is ideal to model the transition logic between the sensors as the incoming light comes into and stays in the FOV



Simulation: Mode Transitions without Bias Estimation

Link: 1 2 3 4 5 6

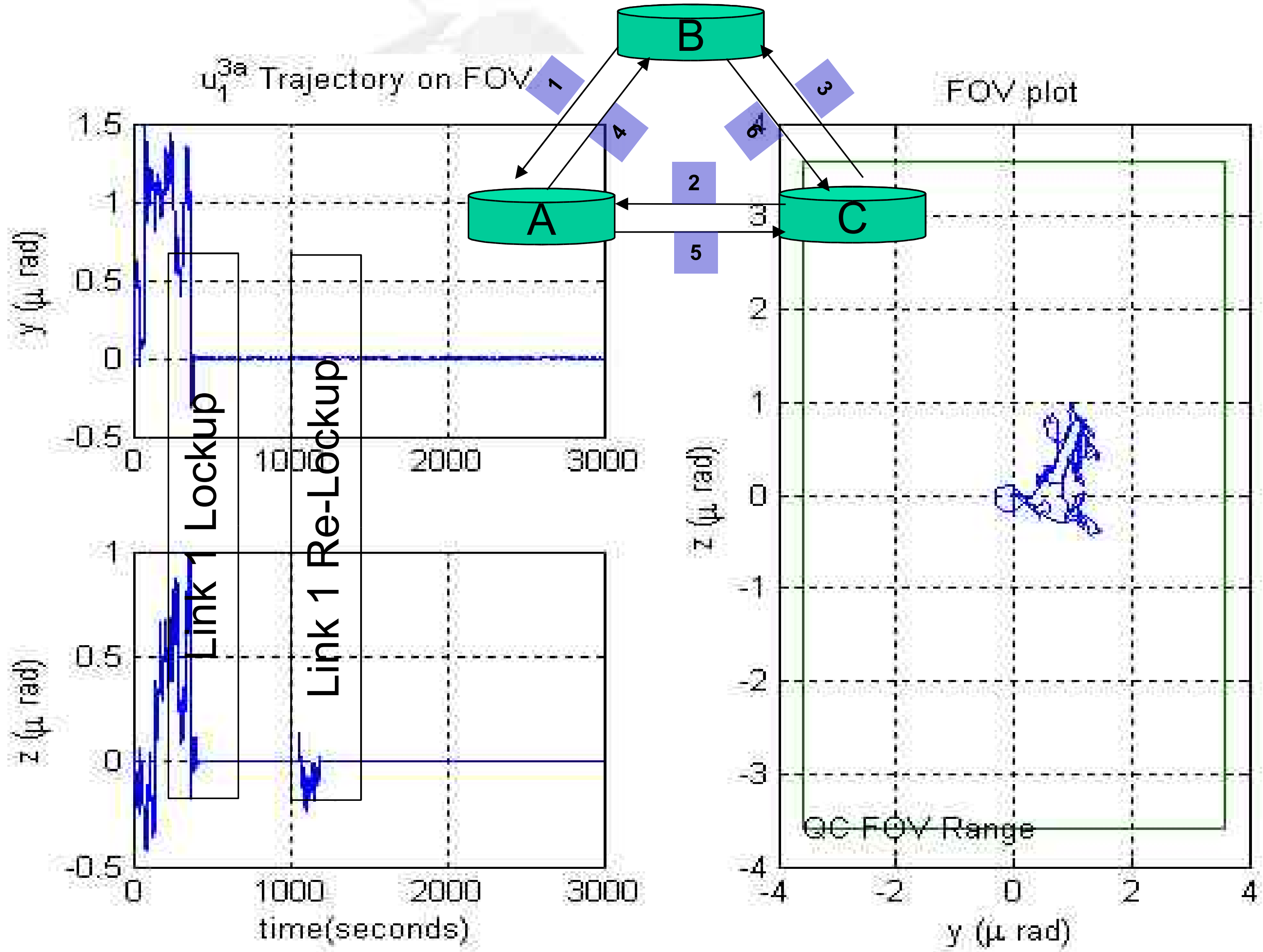




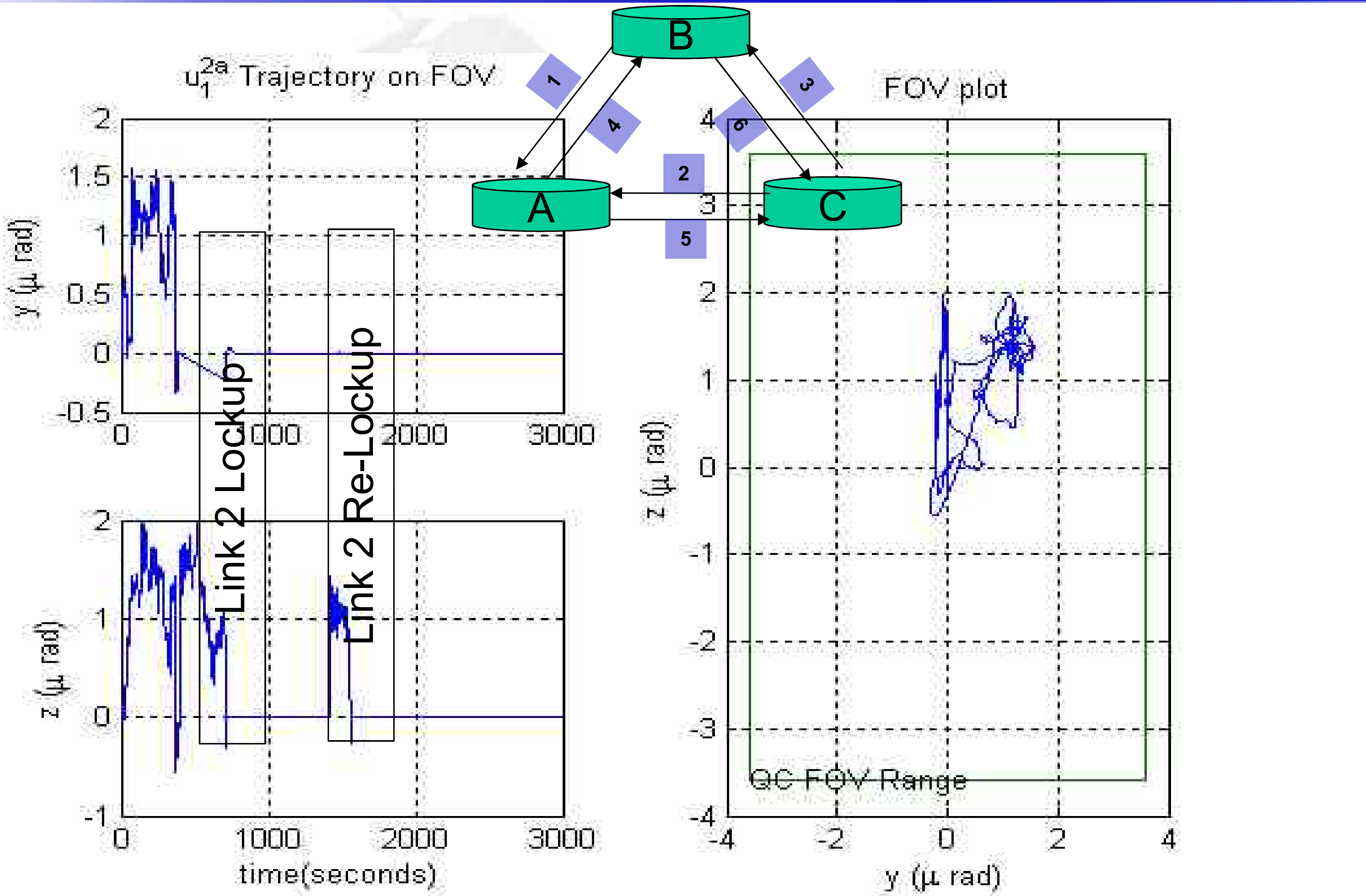
Mode 1: QC/Heterodyne
Mode 2: QC/Direct
Mode 3: CCD
Mode 4: ST/Gyro
Mode 5: Gyro/Enhanced*

* Incoming laser information cannot be used.

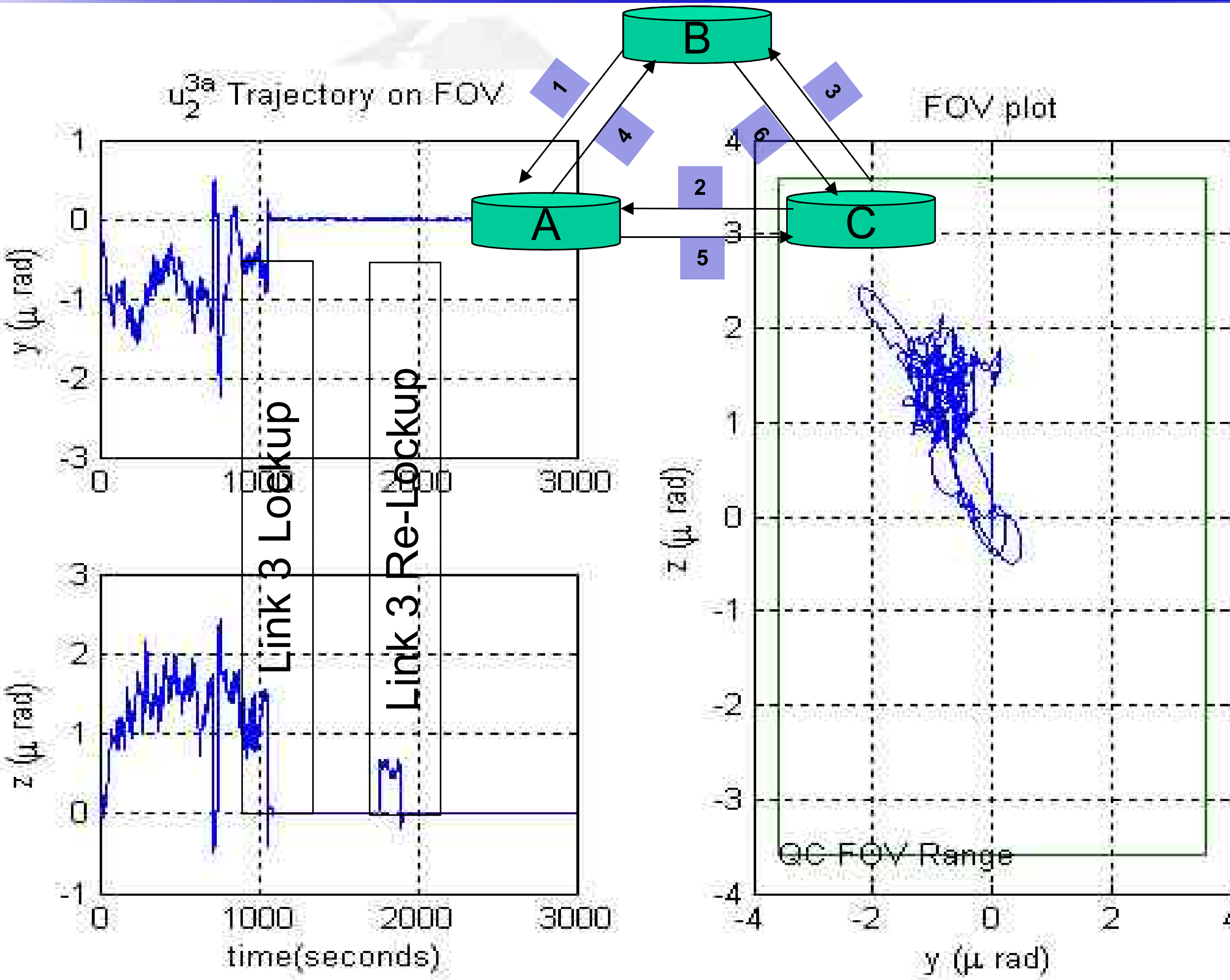
Spacecraft A: PM2 Pointing



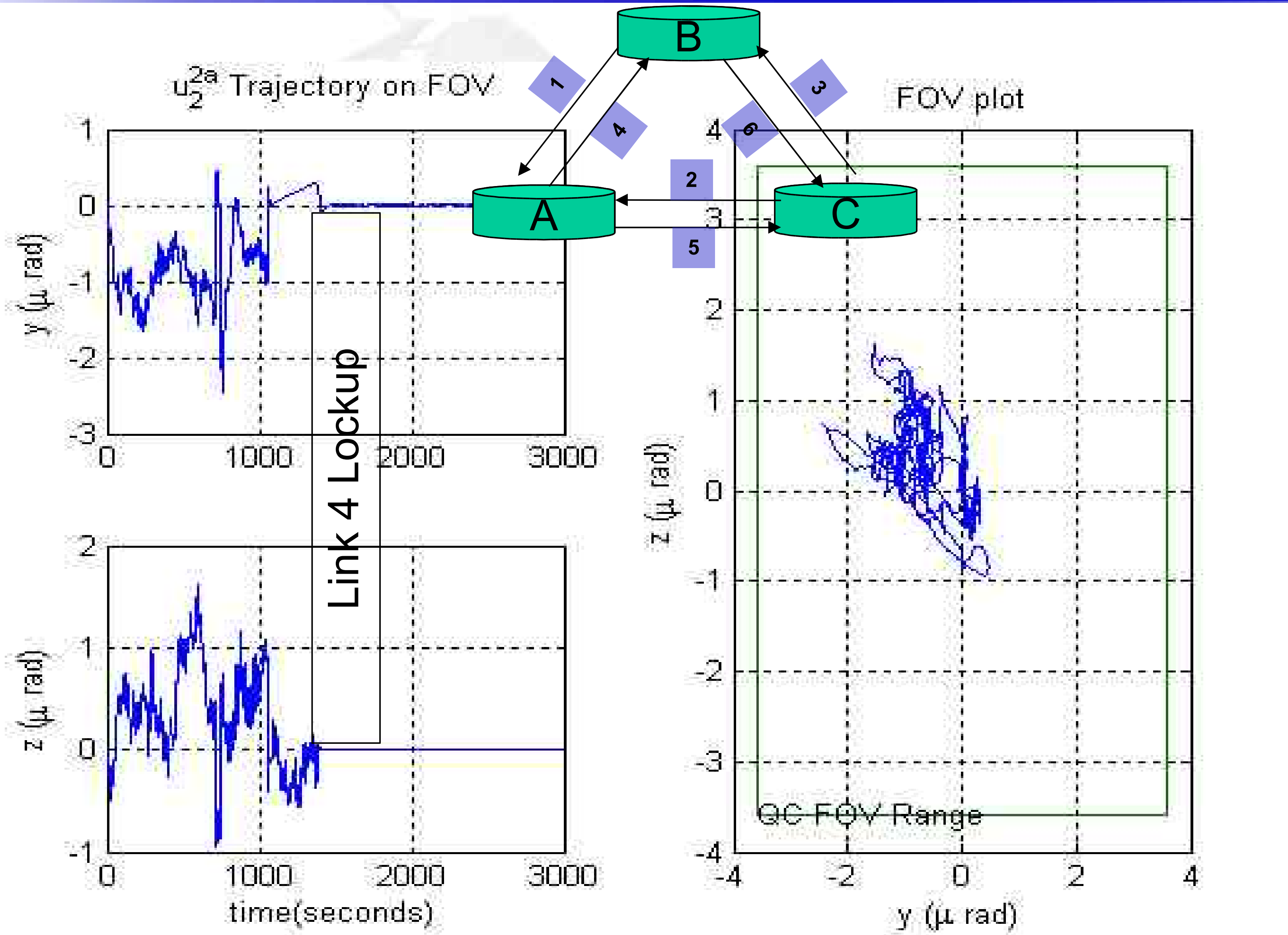
Spacecraft A: PM1 Pointing



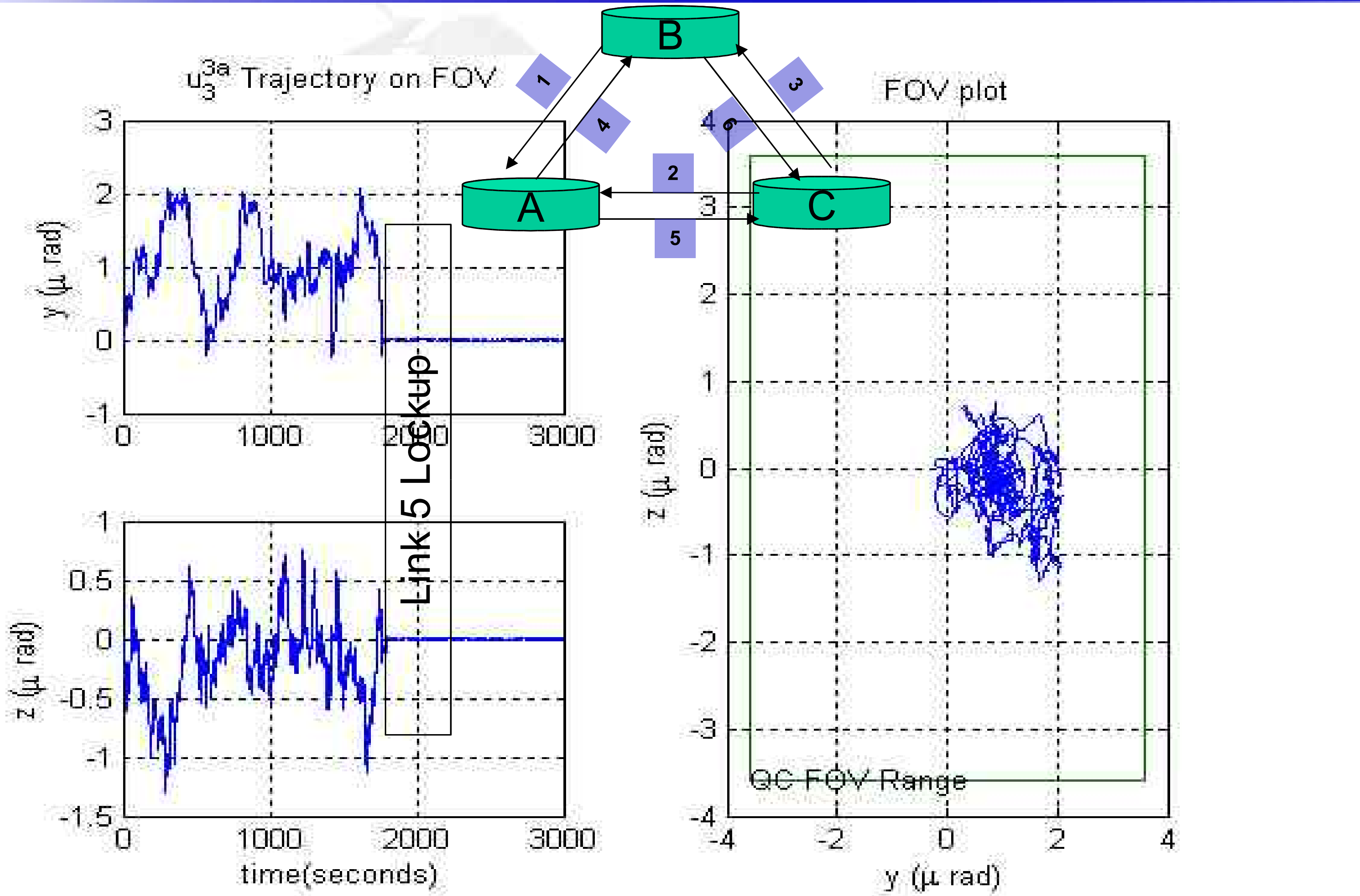
Spacecraft B: PM2 Pointing



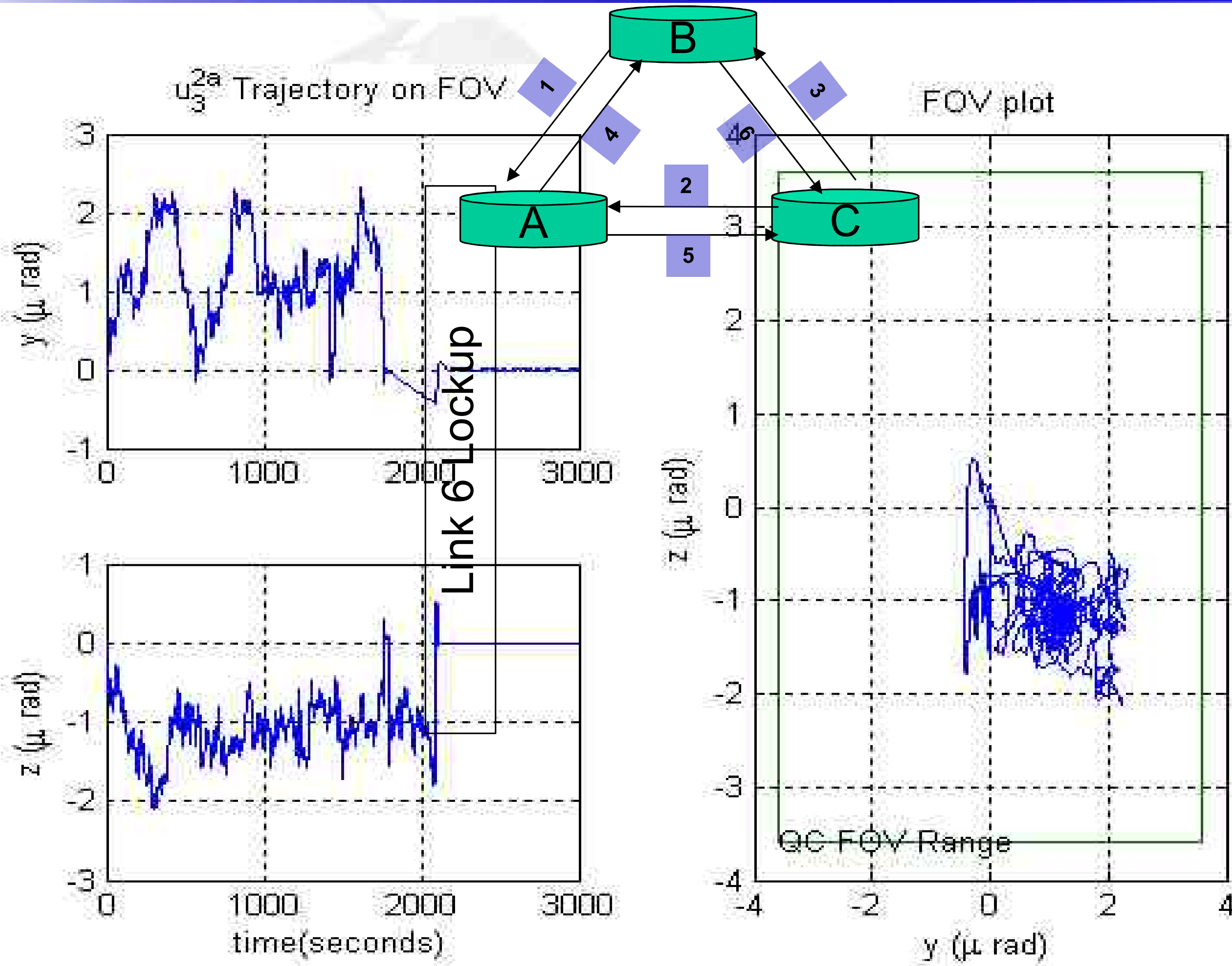
Spacecraft B: PM1 Pointing



Spacecraft C: PM2 Pointing

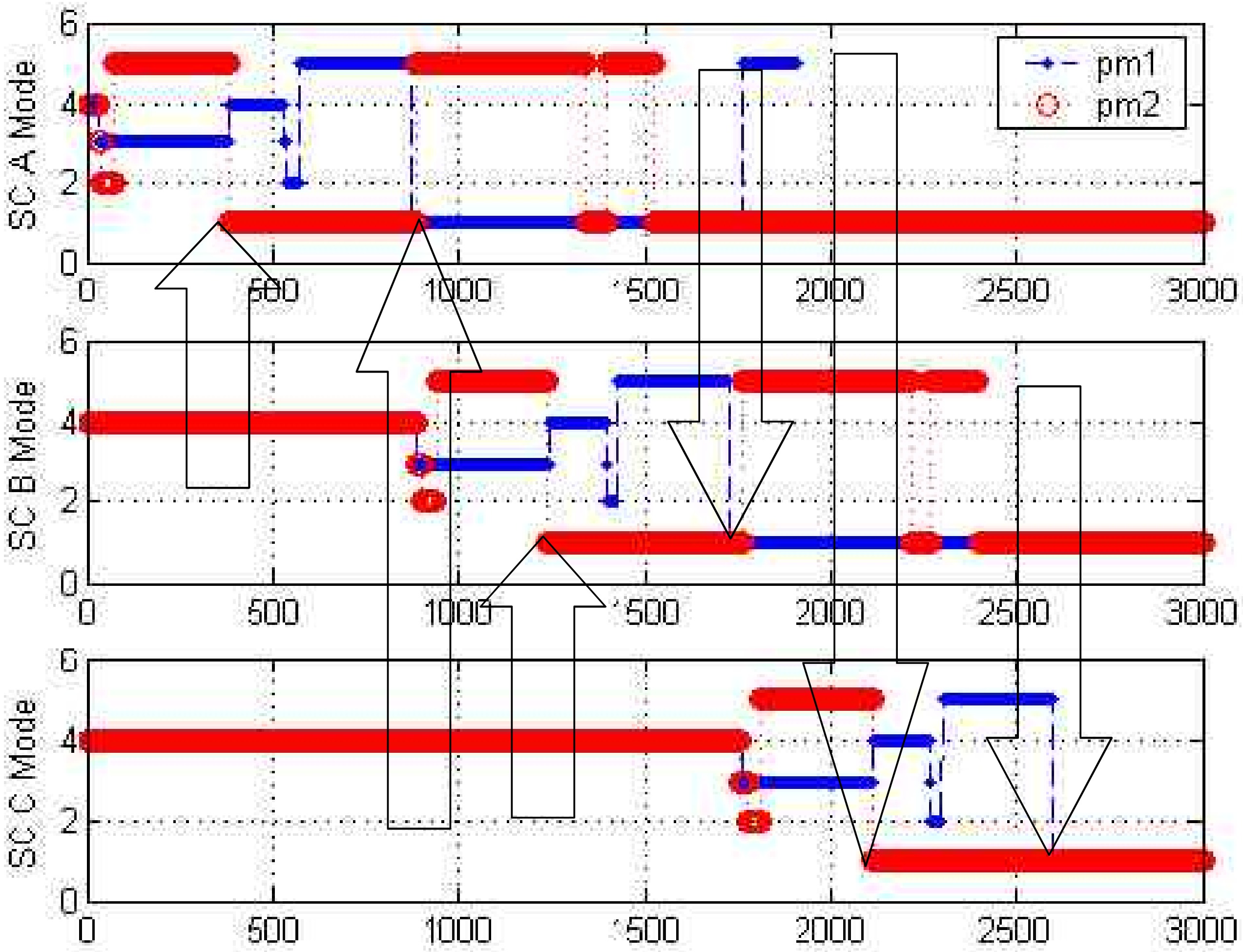


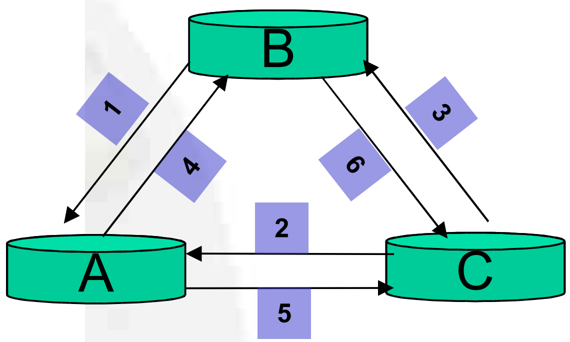
Spacecraft C: PM1 Pointing



Simulation: Mode Transitions with Bias Estimation

Link: 1 2 3 4 5 6





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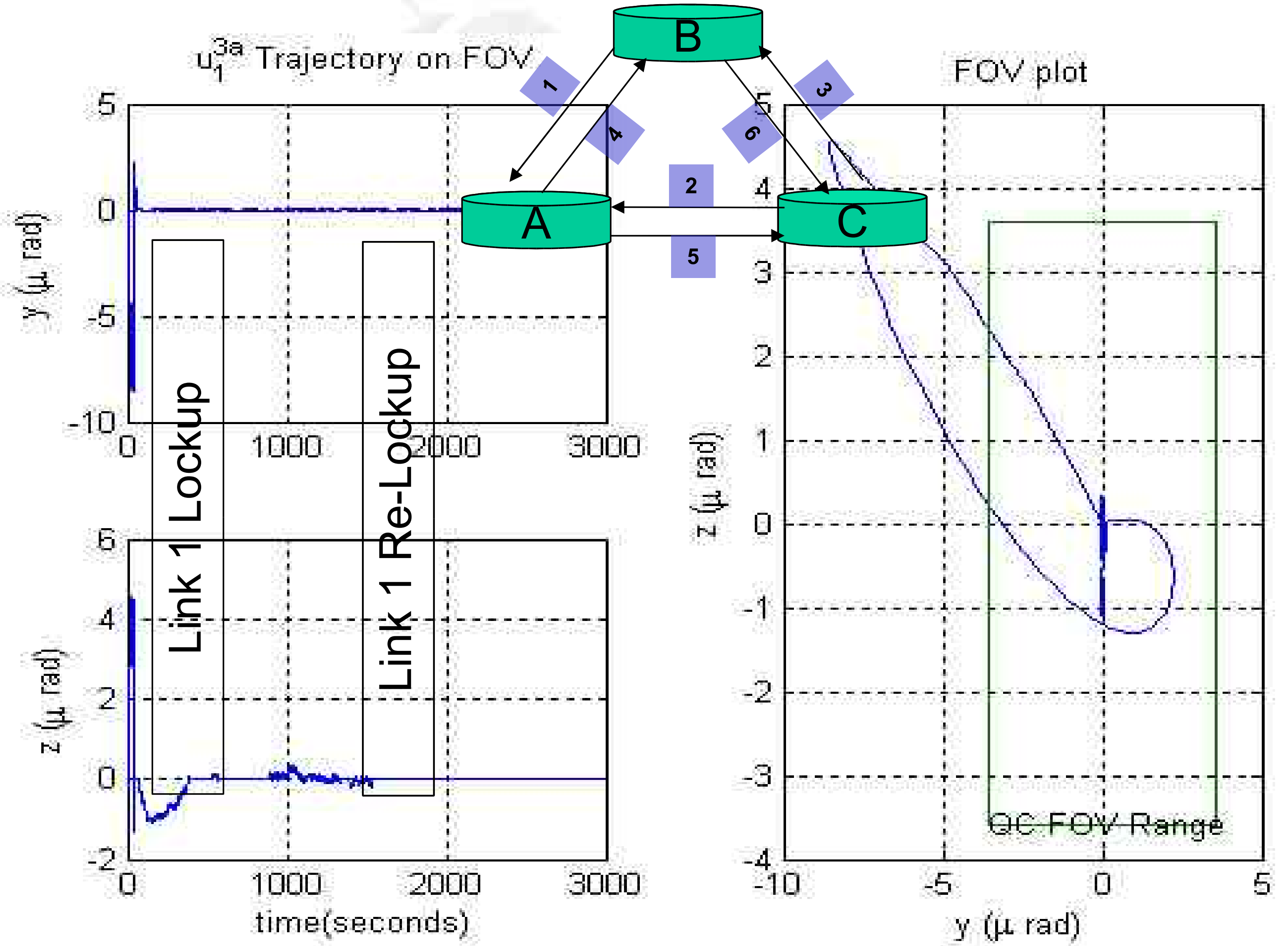
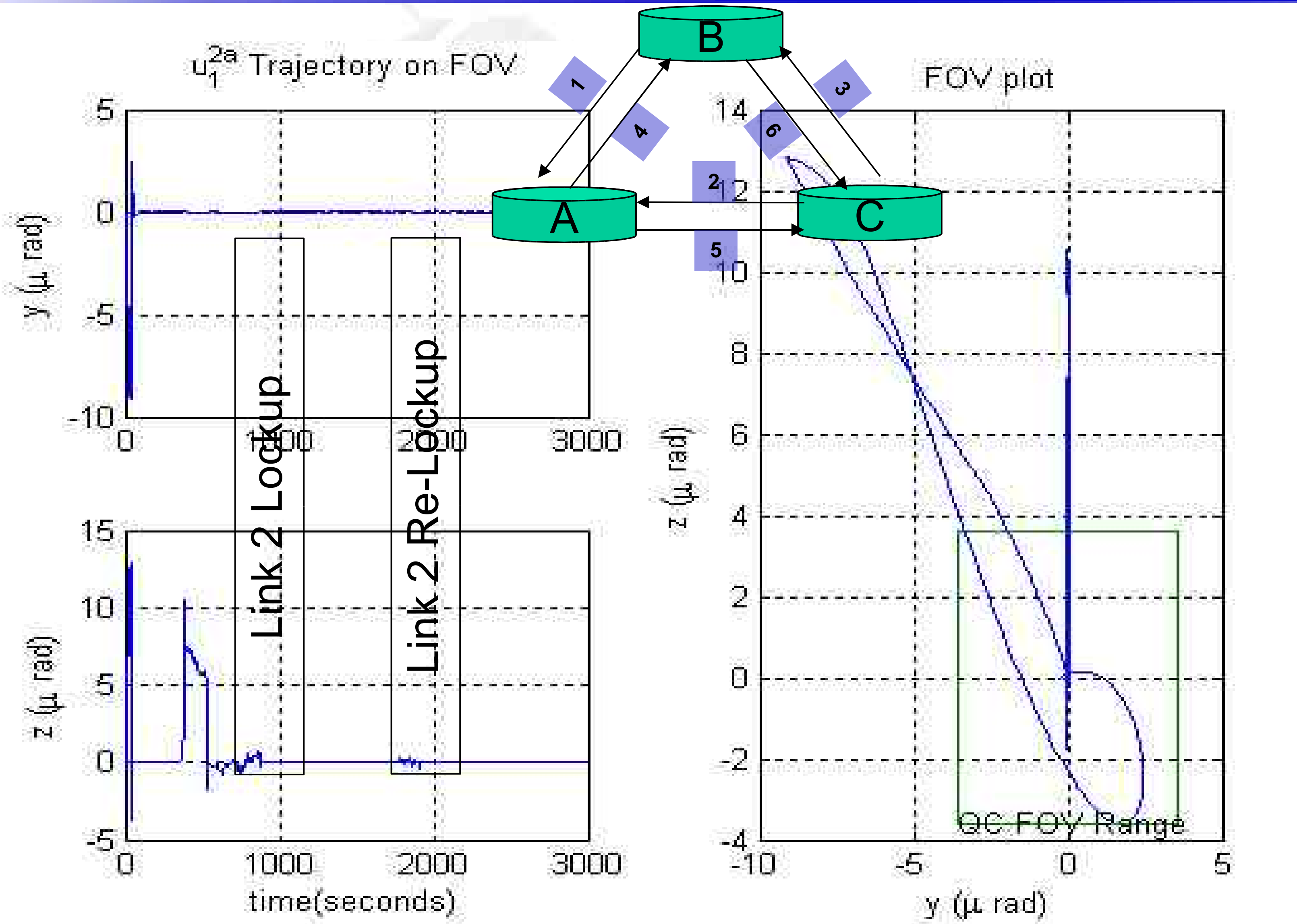
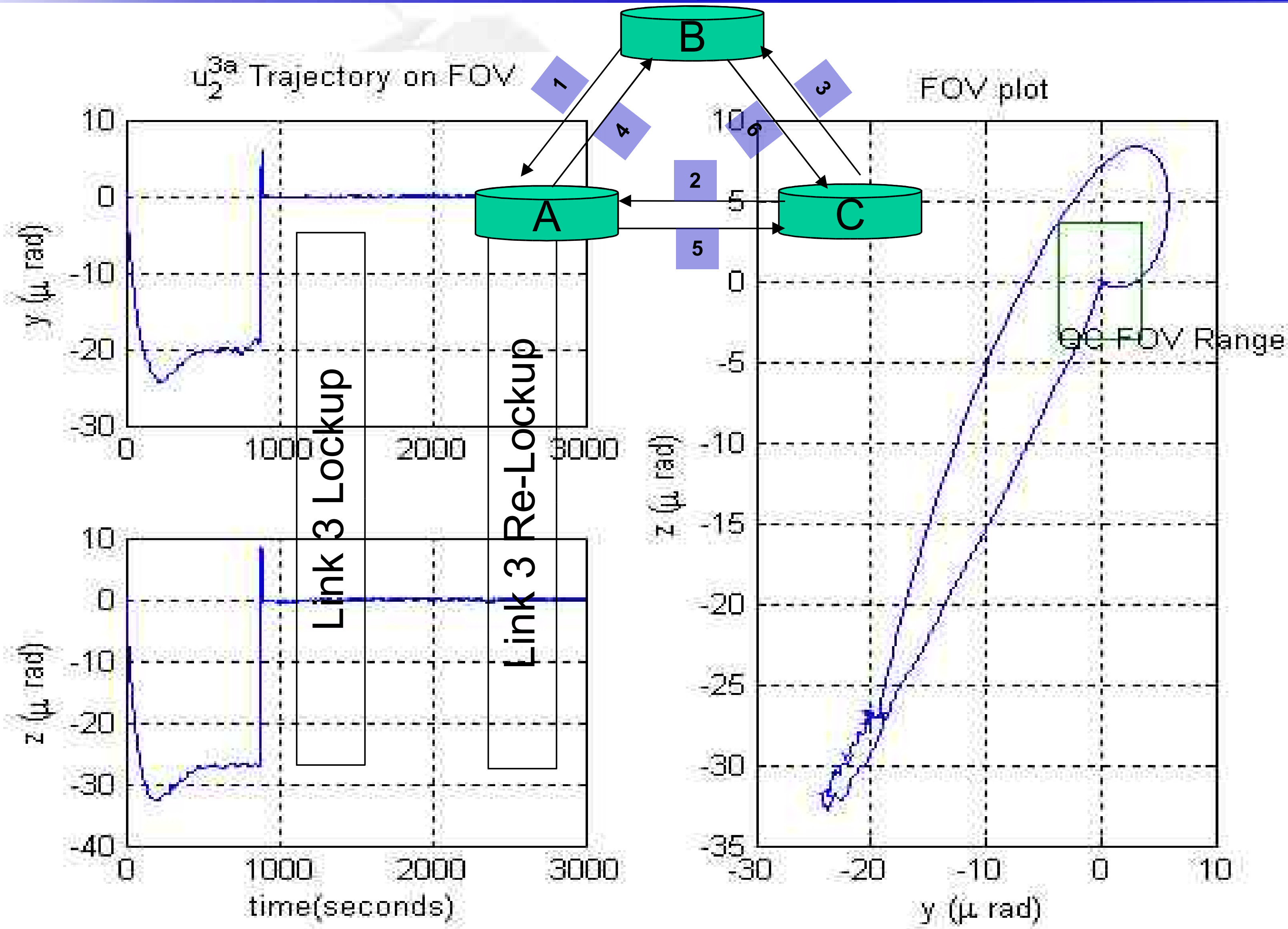
Spacecraft A: PM2 Pointing



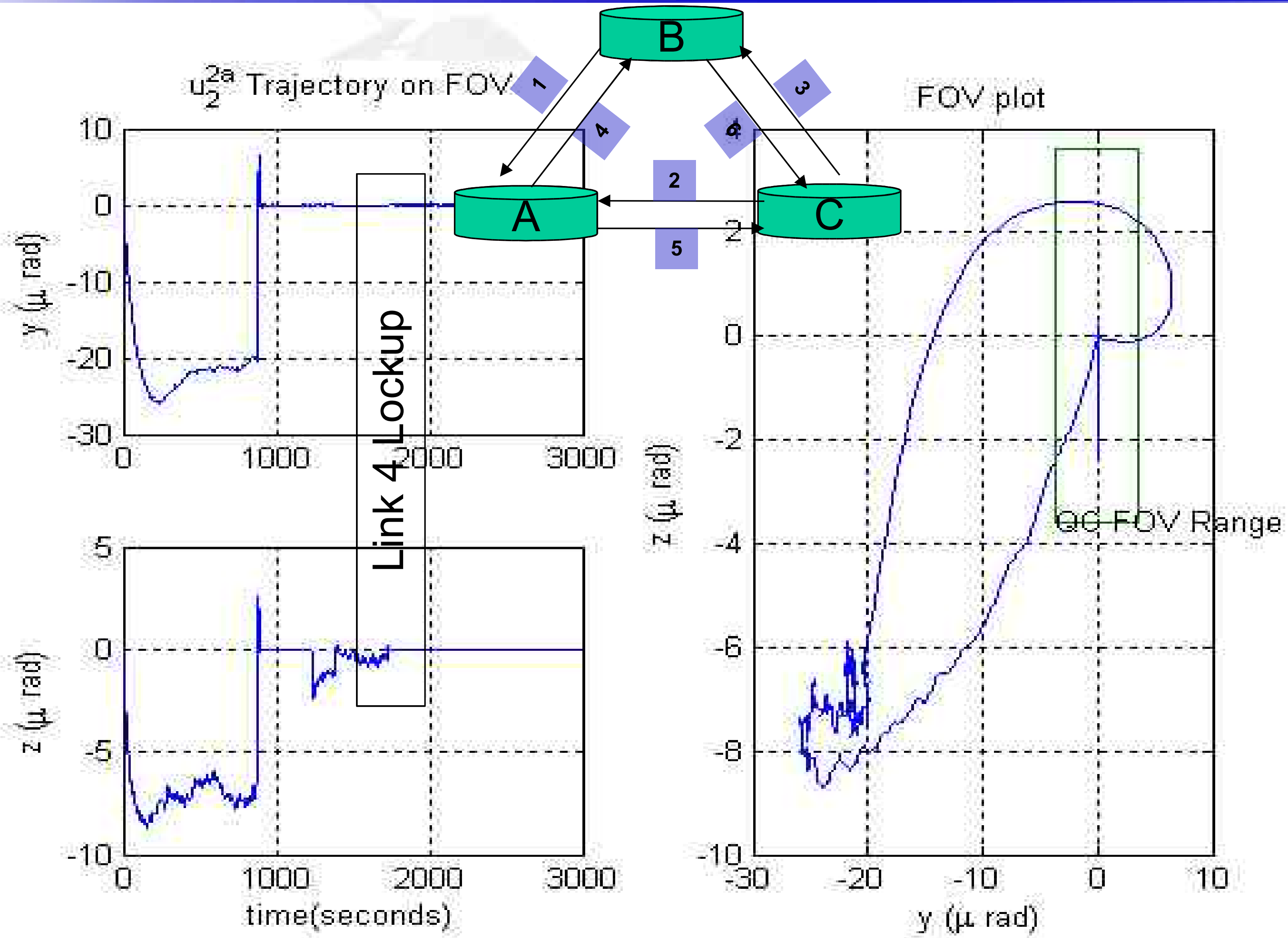
Spacecraft A: PM1 Pointing



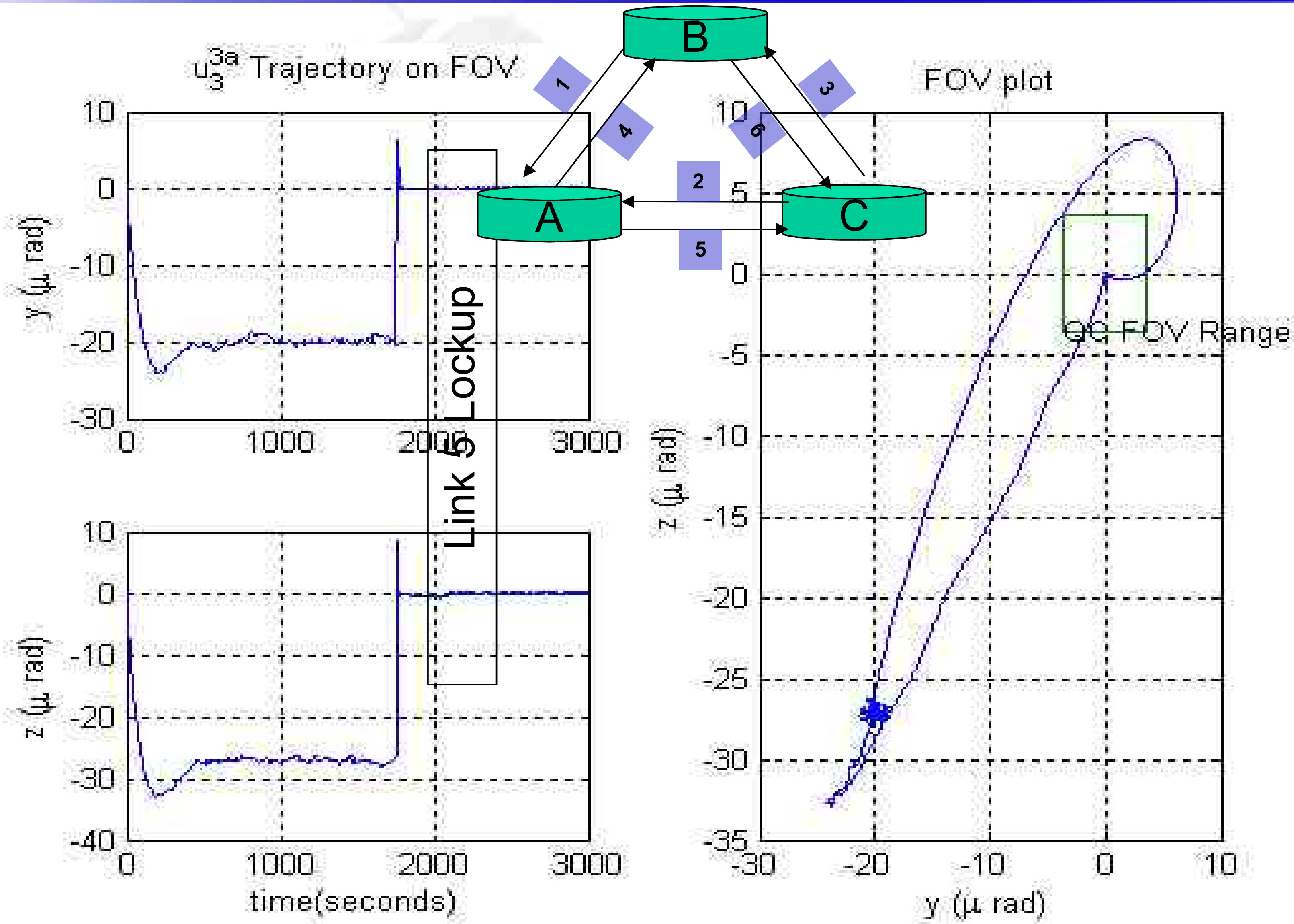
Spacecraft B: PM2 Pointing



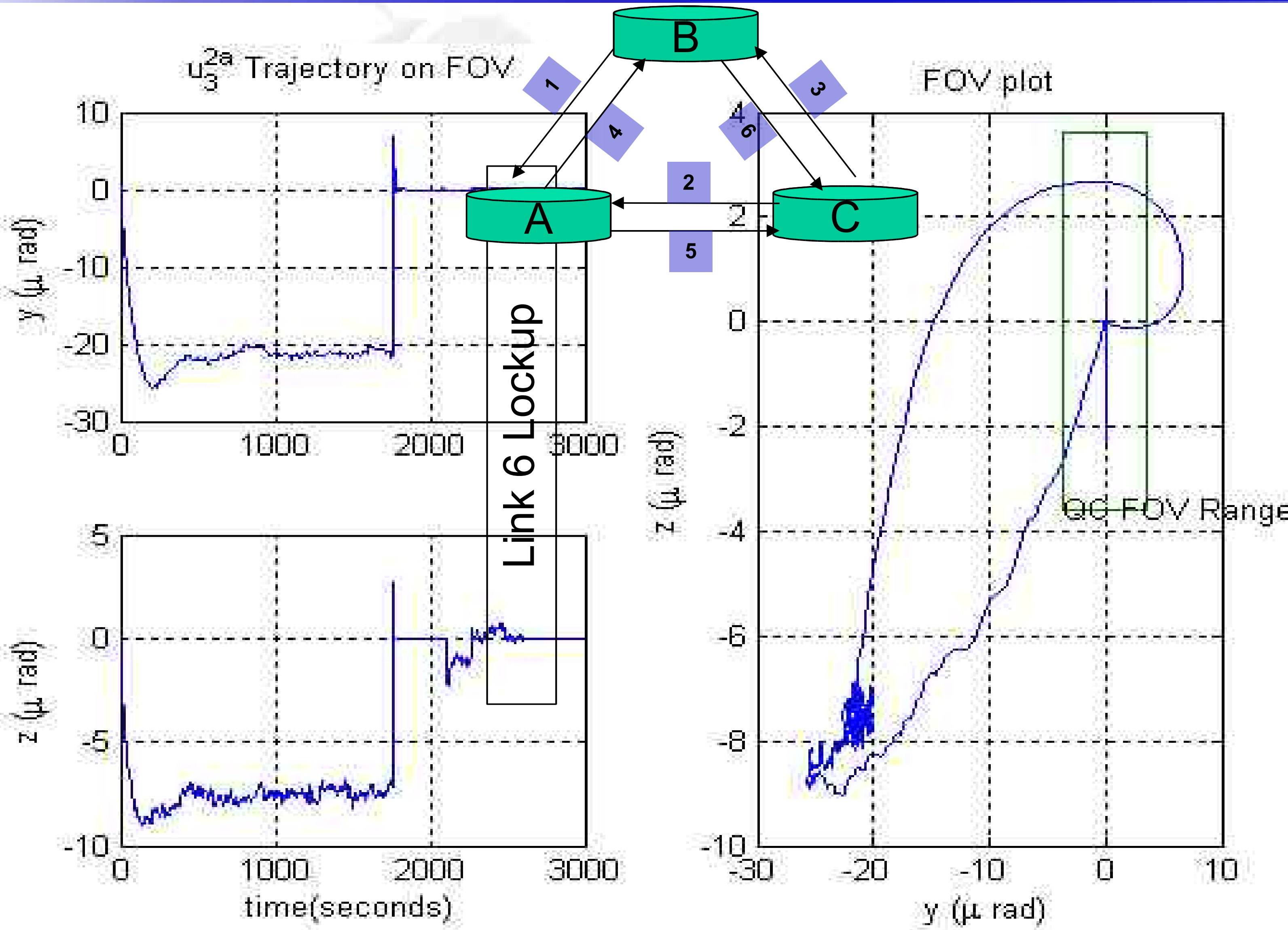
Spacecraft B: PM1 Pointing



Spacecraft C: PM2 Pointing



Spacecraft C: PM1 Pointing



Summary

- An observatory laser acquisition strategy based on defocusing has been developed
  - Includes all six links
  - Requires an order to the sequence
  - Uses a Gyro mode for enhanced pointing stability
  - Star tracker bias estimation/calibration can be done a priori or with the acquisition algorithm
- A 57-dof Acquisition model has been developed
  - SIMULINK for time-domain analysis
  - STATEFLOW for switching logic
- Simulation results confirm the feasibility of this acquisition strategy

Future

- Trade of all three strategies need completion
  – Defocus: stray light, mechanism complexity
  – Scan: gyro-mode stability, stray light
  – Thru-telescope star tracker: confirm feasibility
- To complete this, several engineering questions must be answered
  – Gyro-mode stability performance
  – Acquisition CCD performance with stray light
  – Quad cell mode (incoherent) performance
  – Proof mass alignment
  – Star tracker to CCD alignment
  – CCD to quad photodiode alignment
  – Local laser to quad photodiode alignment