Advanced ATP Concepts and Design for High Data Rate LEO-GEO Optcomm Transceiver

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OUTLINE

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- LEO-GEO-Ground Optical communications Concept
- Advanced concepts of LEO-GEO Optical Transceiver
- Design for High Data Rate LEO-GEO Transceiver
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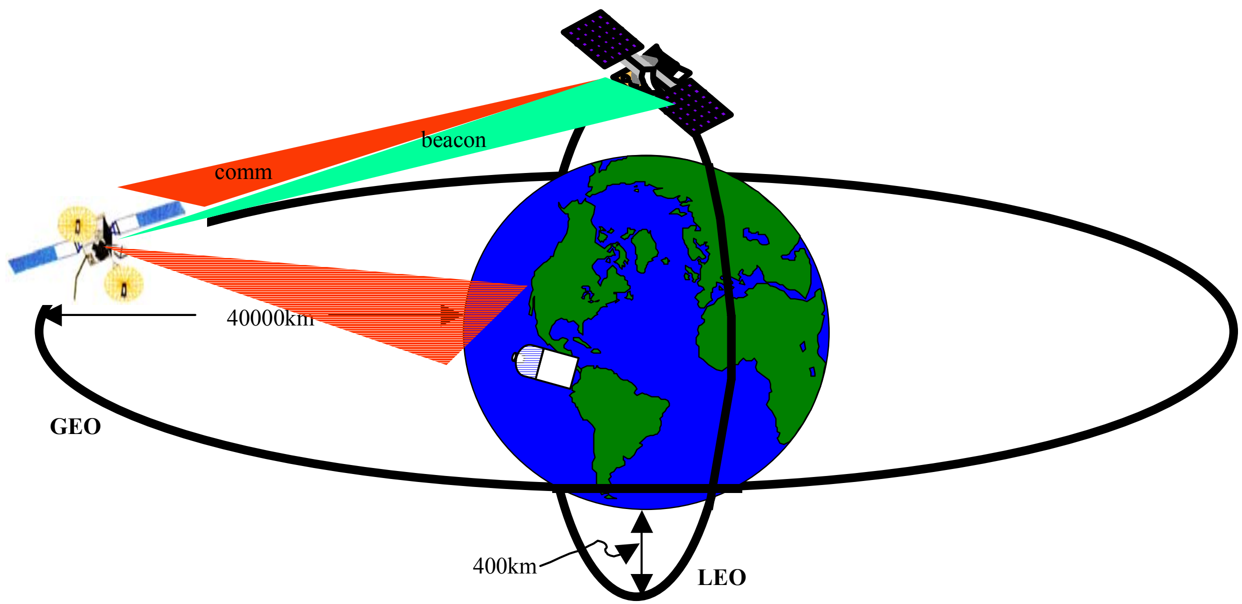
INTRODUCTION

- LEO-GEO-Gnd Optical Communications for High Data Rate Transmissions (e.g., 10 Gbps or higher)
- Past experiments, e.g. SILEX, proved feasibility
  - Technically, ATP performance sufficient for higher data rate (LEO: 0.85urad bias, 0.08urad jitter, radial, GEO: 1.5urad bias, 0.12urad jitter, radial)
- Need for advanced features for competition with RF

LEO-GEO-Ground Optical communications

Concept

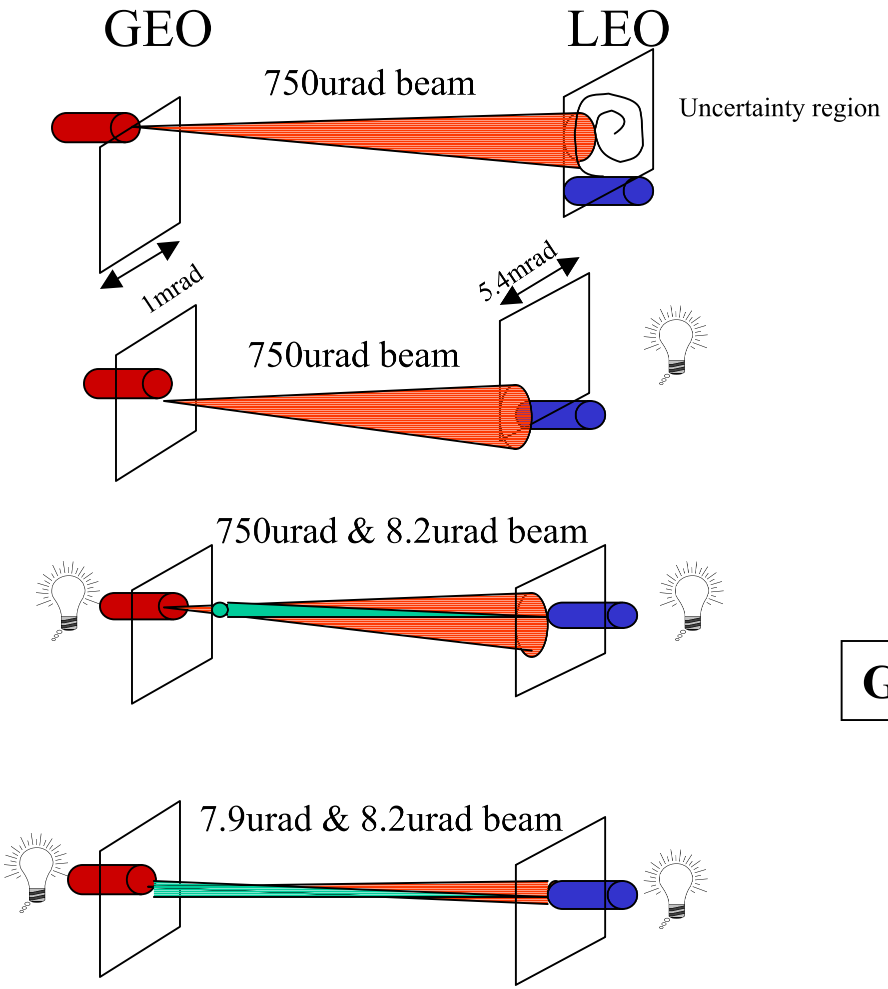


LEO-> GEO: High volume science data
GEO->Ground: Data relay

Typical LEO-GEO ATP Operations

GEO terminal	LEO Terminal
Notify LEO terminal for initiation of beacon signal	Move gimbal towards GEO terminal
Move Gimbal to LEO terminal	Stare for beacon
Turn on beacon	Detection of beacon
Open loop scanning	Issue acknowledge signal to GEO
Wait for acknowledge signal	Transmit high rate data to GEO terminal
Receive acknowledge signal	Maintaining tracking of beacon signal
Stop scanning	
Tracking LEO signal	
Ready for high rate data	
Receive high rate data	

Typical LEO-GEO ATP Operations



Open Loop Scanning

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Initial Detection

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LEO telecom beam

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GEO receives LEO telecom beam & Tracking

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Transition from GEO Beacon to GEO Telecom Beam

Advanced concepts of LEO-GEO Optical Transceiver

- Lower Tracking Loss
- No search acq. & re-acq.
- One beacon acquisition/tracking
- Reduced ephemeris update rate
- Miniaturization
- All optical system

Lower Tracking Loss

What causes “Tracking Loss”?

- ➢LEO/GEO to GND: Mostly beacon fades due to atmospheric effects.
- ➢**LEO-GEO**: S/C vibration that exceeds the design range in magnitude.

Solution

- ➢LEO/GEO to GND: Since only the intensity of beacon fades and beacon stays within the tracking FOV, measuring S/C vibration (with inertial sensors) and using that information for tracking can keep maintaining the link.

- ➢**LEO-GEO**: Suppression of S/C vibration using passive and active isolation methods.

Lower Tracking Loss

BENEFITS

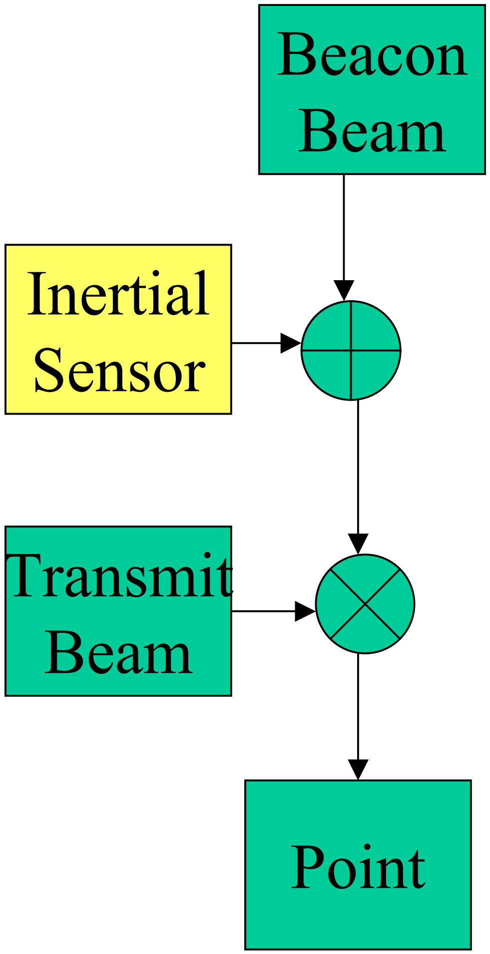
Longer duration links, increased data volume throughput, lower BER at Gbps data rates

IMPLEMENTATION APPROACH

Widen beacon beam to capacity. Inertial sensors are used to continue pointing during beacon fades/outages, Vib. Suppression

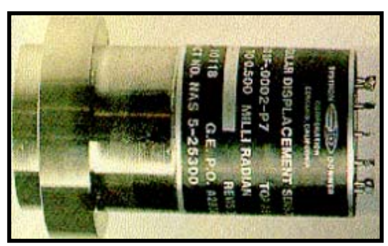
IMPLEMENTATION COMPONENTS

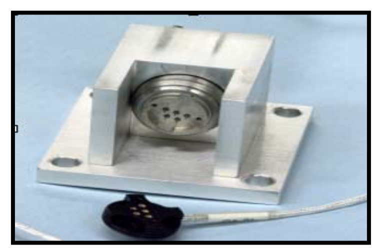
Wider beacon beam, inertial sensors, Vibration suppression



Commercially available Inertial Sensors

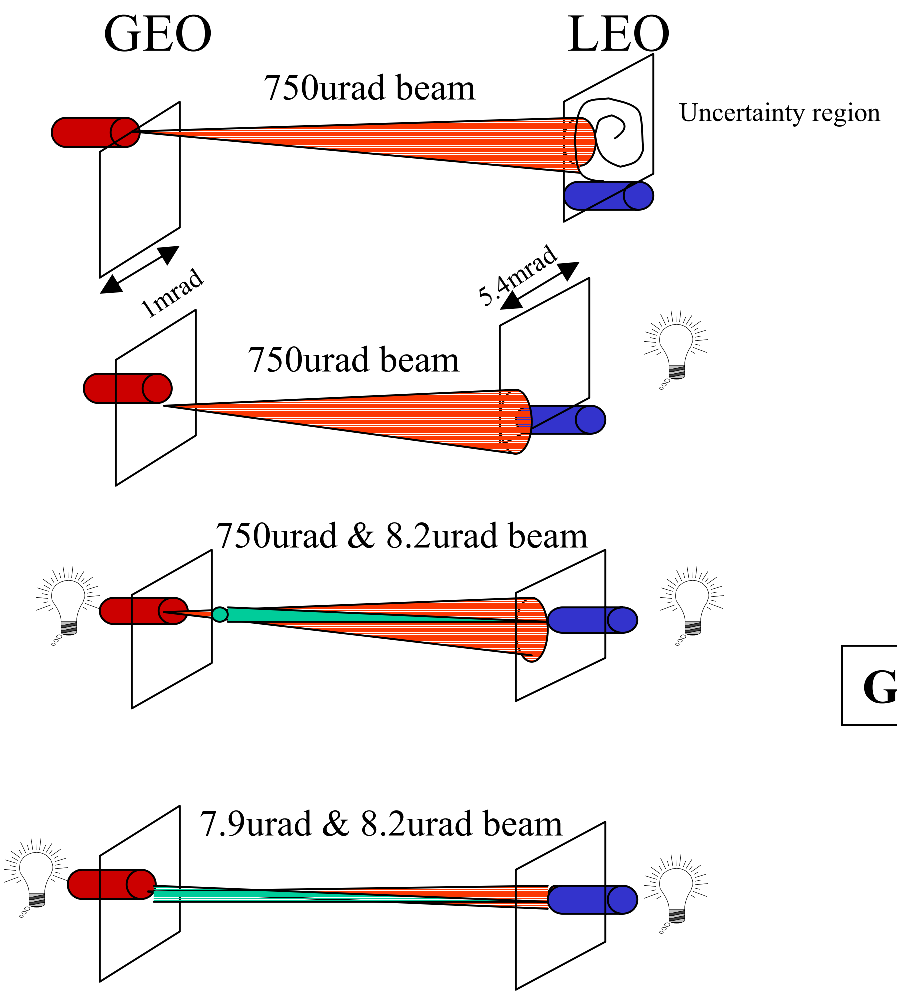
Type	Gyro (Navigation Grade)	Angle Displacement Sensor (SD-8301)	Angular Rate Sensor (ATA ARS-12)	Accelerometer (Honeywell QA-3000)
Bandwidth	>1 Hz	2-2 kHz	1-1 kHz	1 to 500 Hz
Noise	0.06 μrad	0.03 μrad	0.10 μrad	76 μg
Mass	6.8 ~17 kg	0.3 kg	0.1 kg	0.08 kg
Cost	~$1 million	$70,000/axis	$6,000/axis	$10,000/axis
Power	25 to 50 W	300 mW, max	300 mW, max	280 mW, max
Comments	Bandwidth, mass, power, cost	Long-lead time (2 yr)	Flight-qualified version under development	Flew on Pathfinder, IPEX-I and II





Honeywell QA-3000

No search acquisition and re-acquisition



Open Loop Scanning

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Initial Detection

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LEO telecom beam

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GEO receives LEO telecom beam & Tracking

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Transition from GEO Beacon to GEO Telecom Beam

Conventional Method: Long scanning time

No search acquisition and re-acquisition

- Narrow beacon beam requires scanning over the uncertainty cone
- It takes considerable amount of time if we take account re-acquisition time.
- In order to minimize the number of scanning, beacon beam divergence needs to be increased such that it fills the uncertainty cone.
- This will lower the beacon intensity. Therefore, longer integration time is required to obtain same amount of photons.
- This, in turn, requires the use of inertial sensors to maintain stable pointing.

No search acq. & re-acq.

BENEFITS

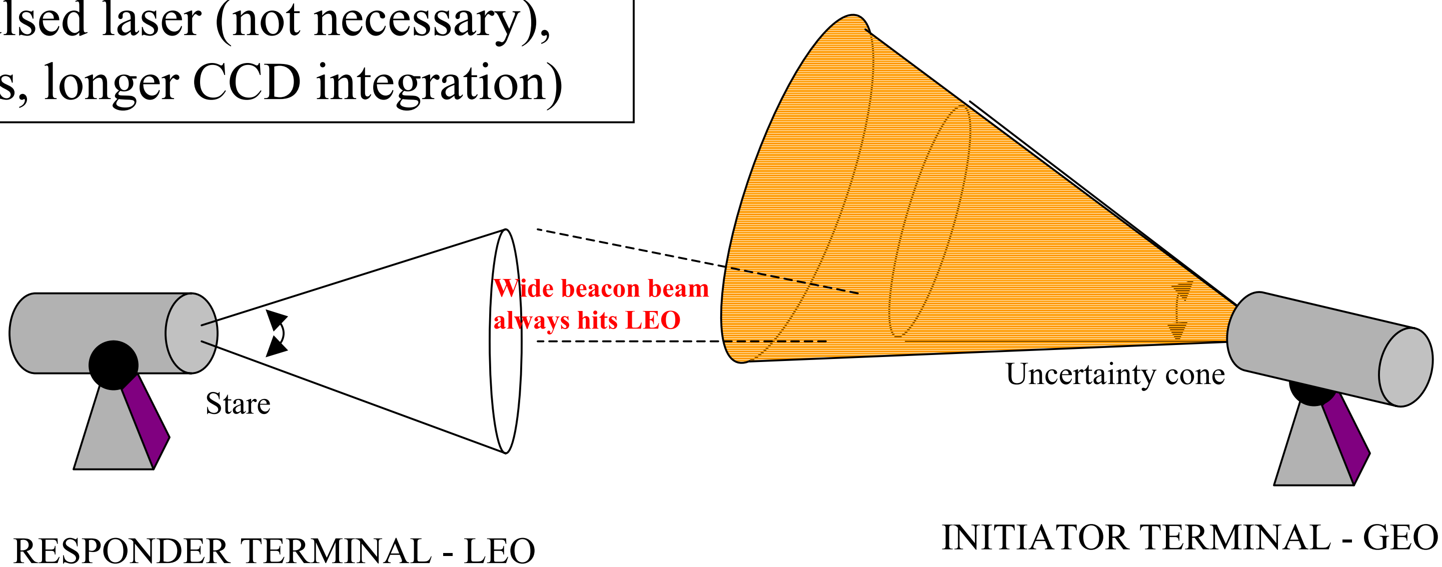
Reduces tracking loss probability. Reduces acquisition time. Increases acquisition probability.

IMPLEMENTATION APPROACH

Increase beacon beam divergence > uncertainty cone. Compensate reduced photons on detector by integrating longer with inertial sensors to maintain pointing in between.

IMPLEMENTATION COMPONENTS

Wide beam, pulsed laser (not necessary), (inertial sensors, longer CCD integration)



One beacon acquisition/tracking

- In acquisition/tracking transition, two different laser beams have been used due to different beam widths.
- This can be simplified if one laser beam can be used for both purposes.

One Beacon Acquisition/Tracking

BENEFITS

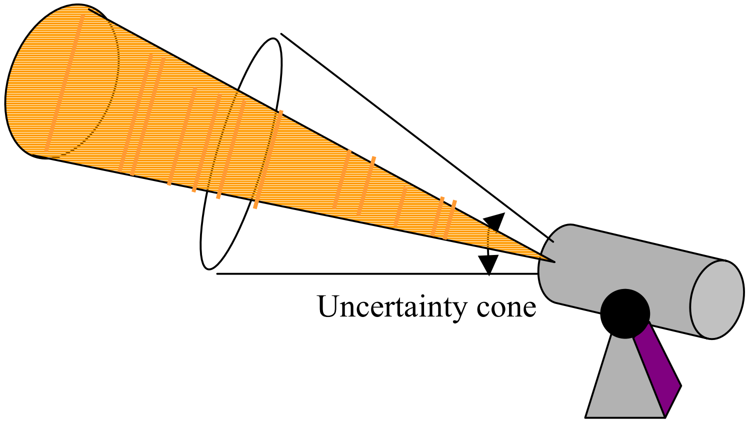
Same laser during acq/trk, simpler/less optics. Robust acq/trk handover. Less components. Lower SWP

IMPLEMENTATION APPROACH

Compensate reduced photons on detector during tracking by integrating longer with inertial sensors to maintain pointing in between. May also increase photon density by using high power pulsed lasers (with synchronization)

IMPLEMENTATION COMPONENTS

Wide beacon beam, pulsed laser, inertial sensors, longer CCD integration



INITIATOR TERMINAL - GEO

Reduced ephemeris update rate

- For more accurate S/C position, more ephemeris updates are necessary, which requires more than single ground station.
- On-board GPS/INS provides information that allows ATP to maintain position uncertainties low. Therefore, single ground station for telemetry and data.
- Latest accuracy: 2 meters accuracy (1 sigma) for LEO and 6 meters for GEO and HEO (1 sigma), or 0.5urad and 0.4urad assuming 400km and 40,000km. – Northrop Grumann
- Ephemeris (or orbital) data is constantly being transmitted by the Ground stations.
- Orbit prediction data is required for command/timeline generation. Receivers maintain an "almanac" of this data for all satellites and they update these almanacs as new data comes in.
- Typically, ephemeris data is updated hourly. However, it depends on the accuracy requirements. It can be from 6hrs to even 30 days.

Reduced ephemeris update rate

BENEFITS

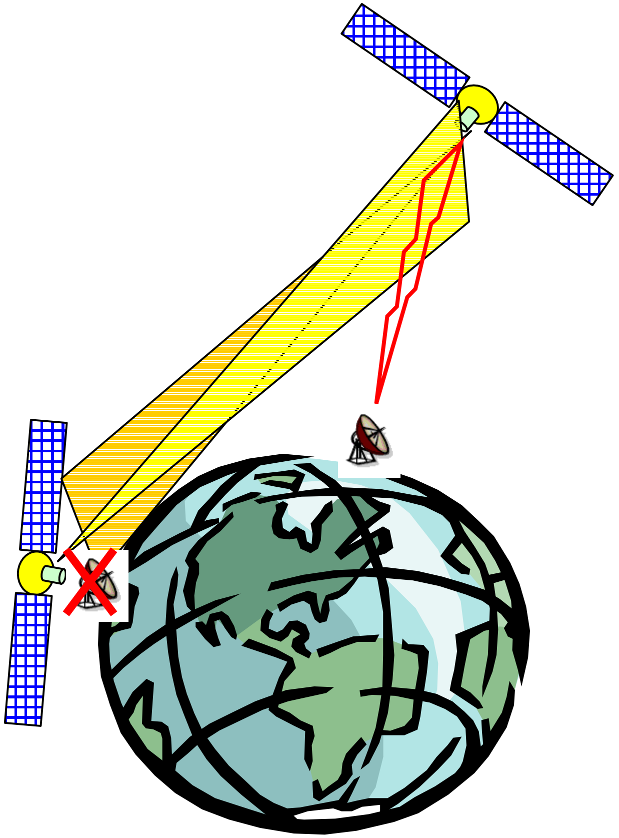
Single ground station for ephemeris

IMPLEMENTATION APPROACH

On-board GPS/INS provides information that allows ATP to maintain position uncertainties low. (Ephemeris ~10 urad, GPS ~1 nrad)

IMPLEMENTATION COMPONENTS

GPS/INS



Miniaturization of ATP system

BENEFITS

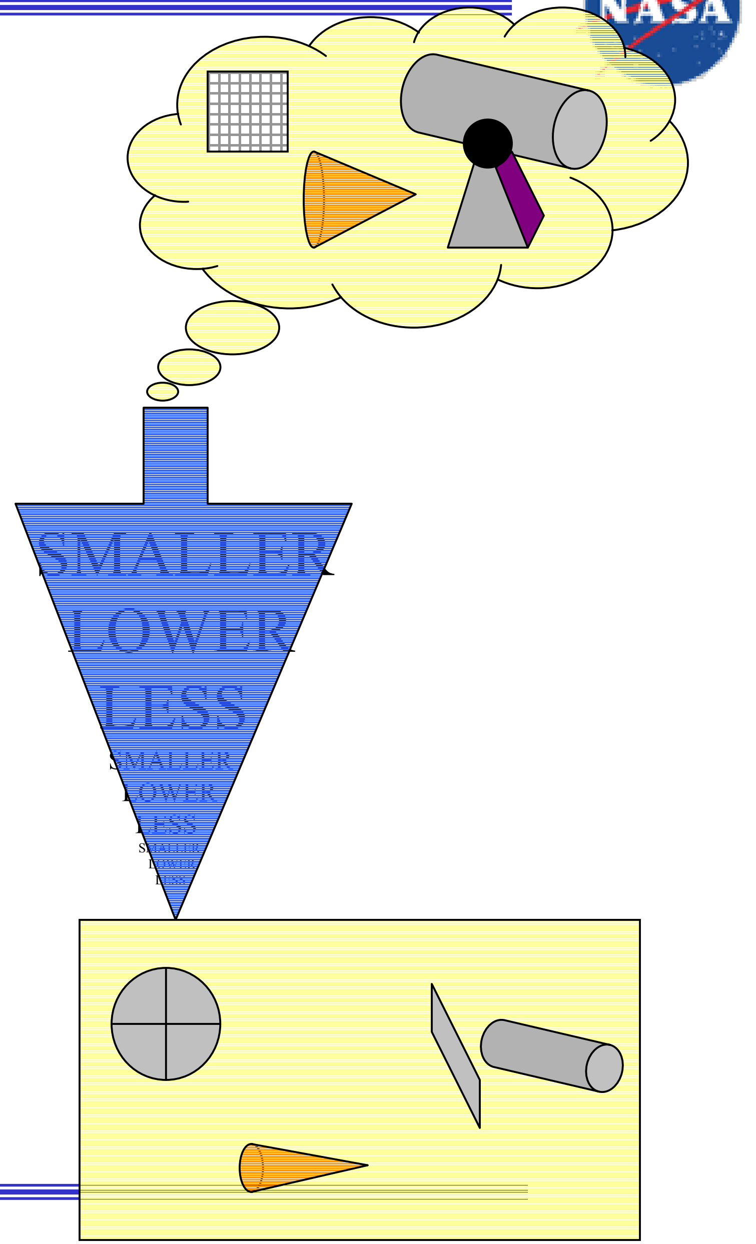
Lower size, weight, and power (SWP)

IMPLEMENTATION APPROACH

Analysis to determine if lower SWP components can meet requirements.
Search for components with TRL > 5

IMPLEMENTATION COMPONENTS

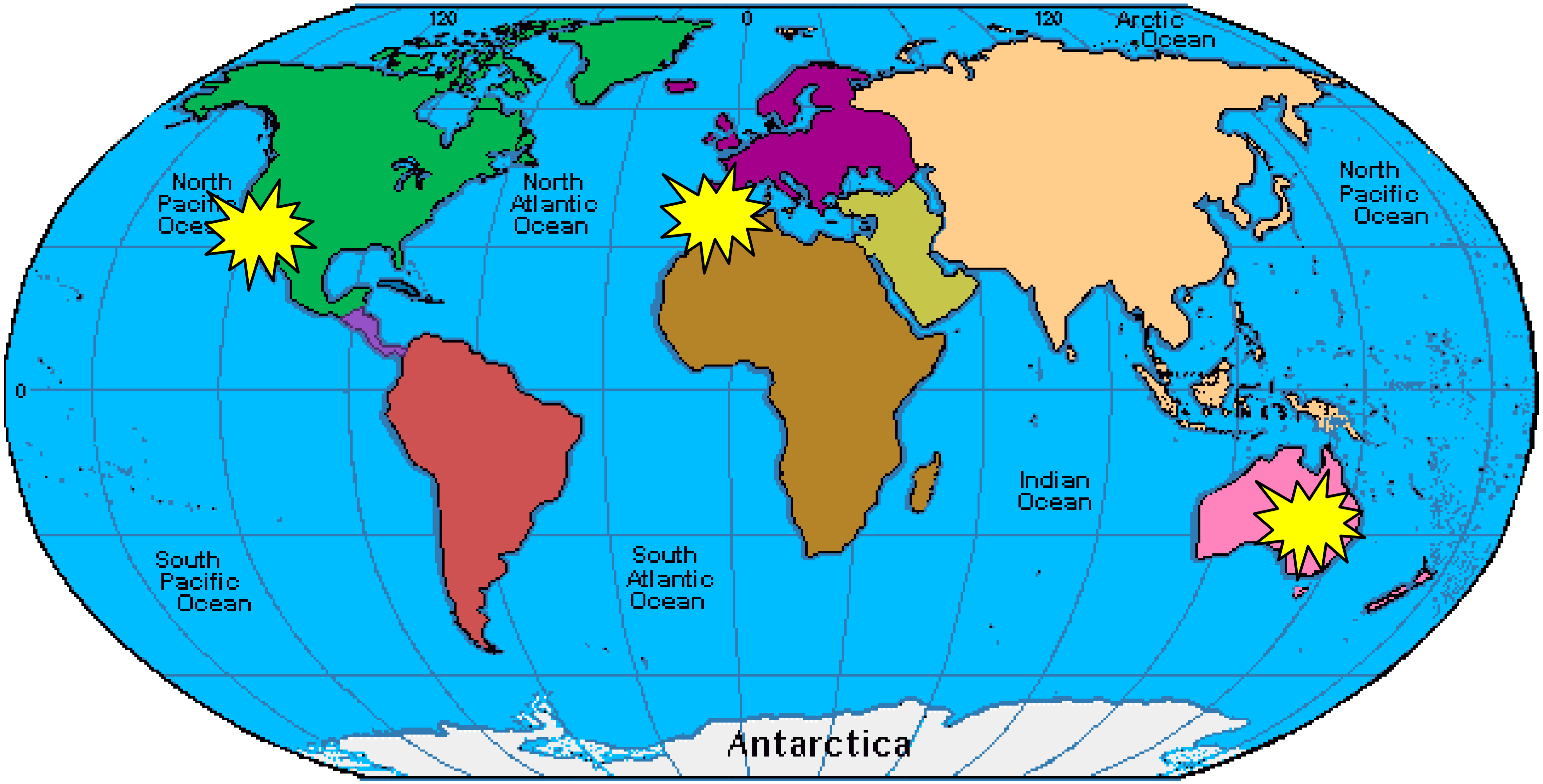
Quad detectors, HIT, APS, non-mechanical FSM, gimbal flats



All optical system

- RF comm is required for current optical communications due to command and tracking info.
- Challenges to an all-optical system: Link availability is limited (66% availability due to weather conditions if assuming three 10m optical receivers co-located with current DSN stations)
- Solution – Clustered Optical Subnet (COS, Cluster of three 10m optical stations) -> 96% availability or 8 LDOS (Linearly Dispersed Optical Subnet) deployment – 93% availability

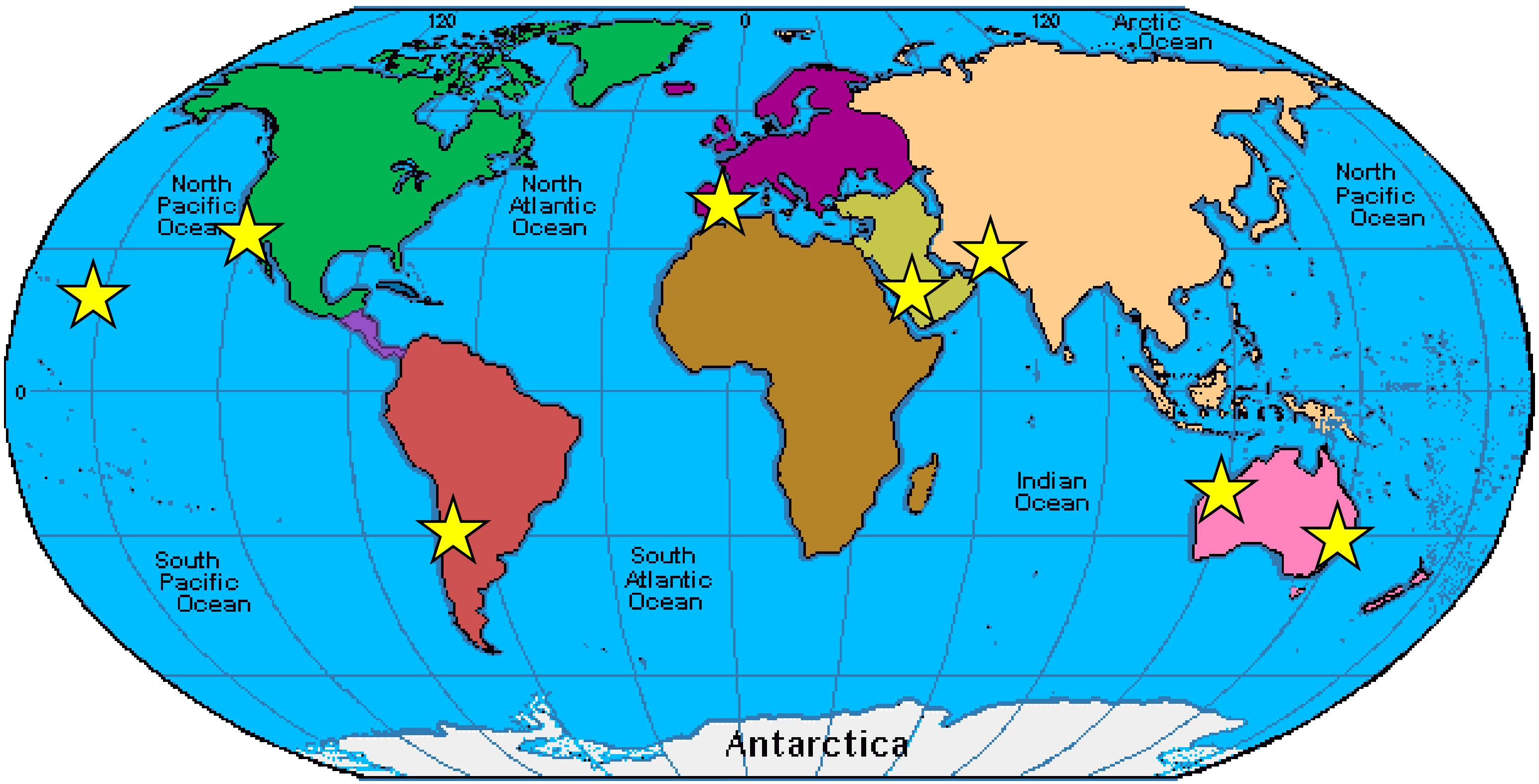
COS ≡ Clustered Optical Subnet



Cluster of three 10 m optical stations

8-Station LDOS Deployment

LDOS ≡ Linearly Dispersed Optical Subnet



Proposed 10 m optical sites

All Optical System

BENEFITS

No RF comm is required to enable comm link

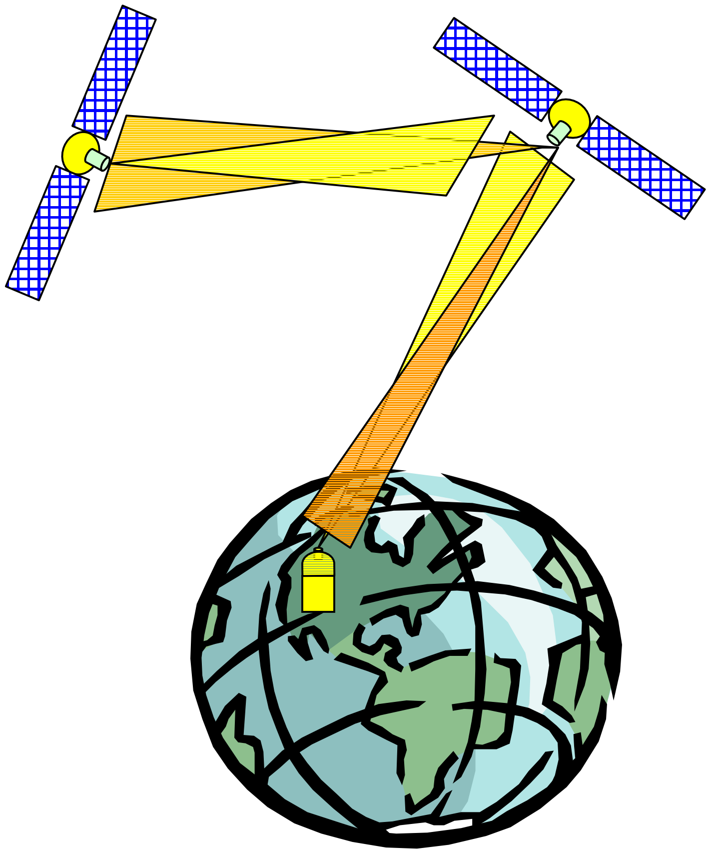
IMPLEMENTATION APPROACH

Uplink ephemeris and command via GND-to-GEO optical channel. Ephemeris and command are sent to LEO from GND or relayed thru GEO

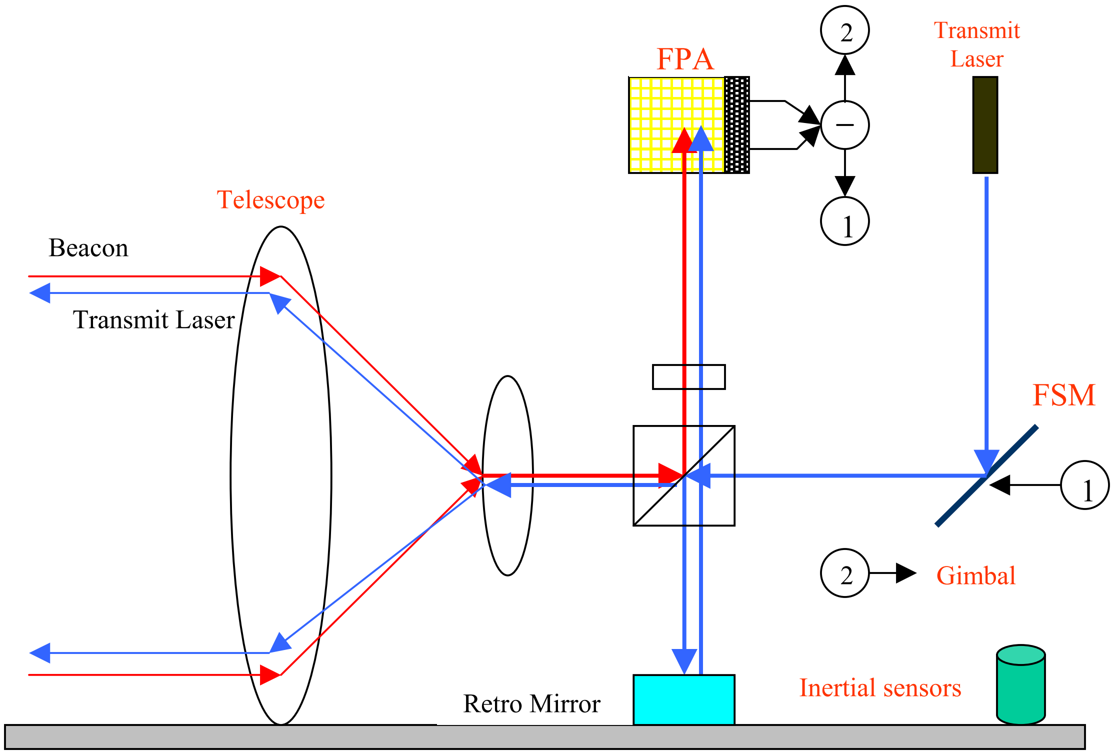
IMPLEMENTATION COMPONENTS

More ground stations

, GPS/INS, wide beacon beam,

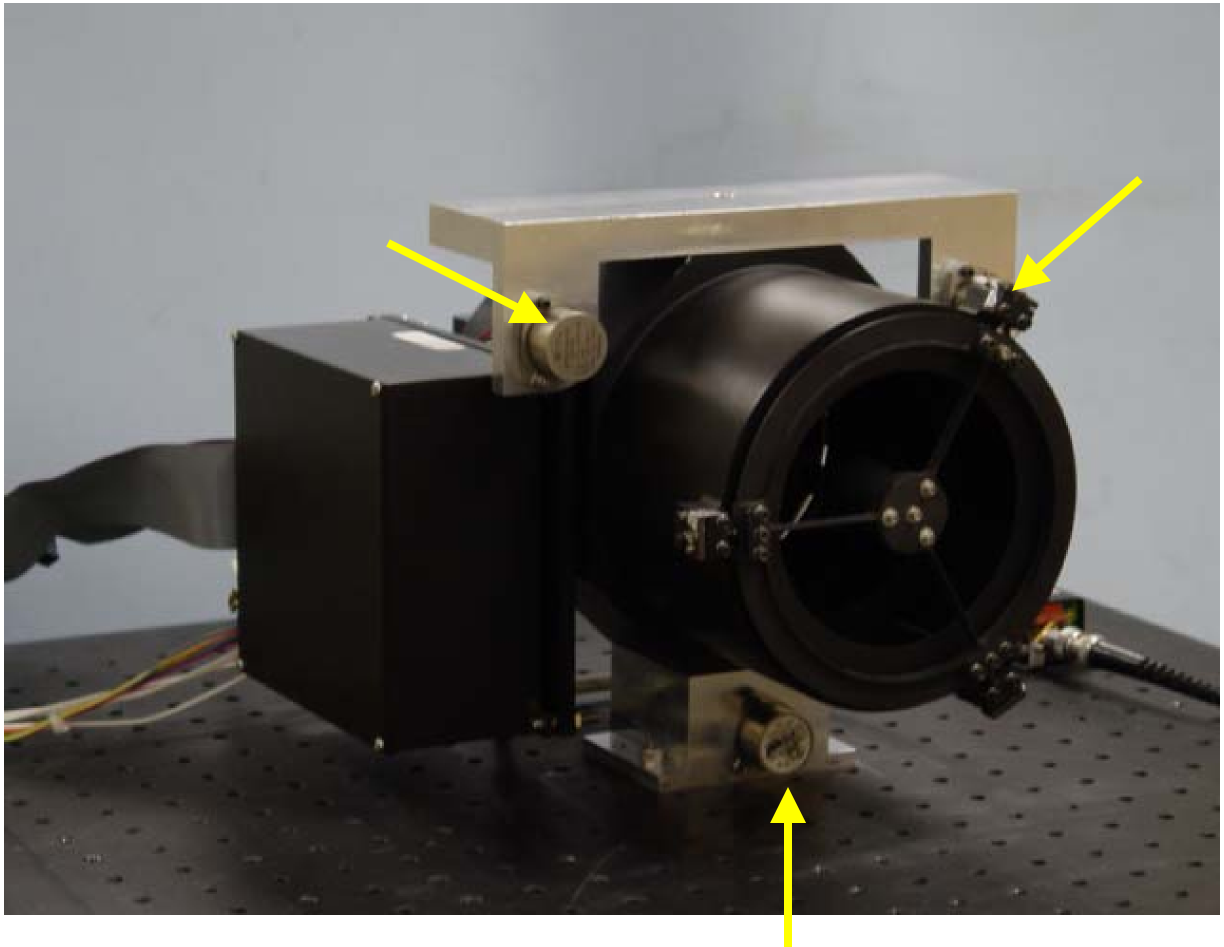


Baseline JPL LEO-GEO Optical Comm Design



JPL is pursuing implementation of the advanced features for the future optical communications terminal

Inertial sensors (accelerometers) integrated into OCD



Conclusion

- New features beyond functional level is necessary to make optical comm more competitive with RF comm (e.g., Ka-Band)
- 6 new advanced concepts studied for the next generation LEO-GEO optical communications transceiver (underlying problems/feasible solutions).
- Some of advanced features are currently being tested and implemented.