Aircraft Lasercom Terminal Compact Optical Module (ALT-COM)

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Major Qualifying Project

Advanced Lasercom Systems and Operations – Group 66

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Outline

- Introduction to Lasercom
- Current Terminal
- Project Objectives and Requirements
- Design
- Test Results
- Conclusions

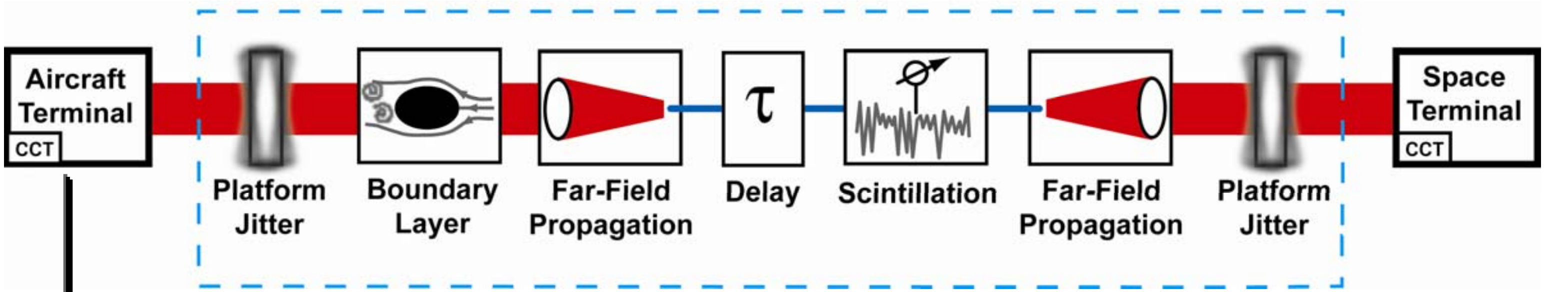
Free-Space Laser Communication (Lasercom)

Benefits of Lasercom

- High Data Rates
  - 10 – 40 Gb/s
- Low Probability of Interception
  - Narrow beam for communication
- Unregulated Frequency Range
  - No license required

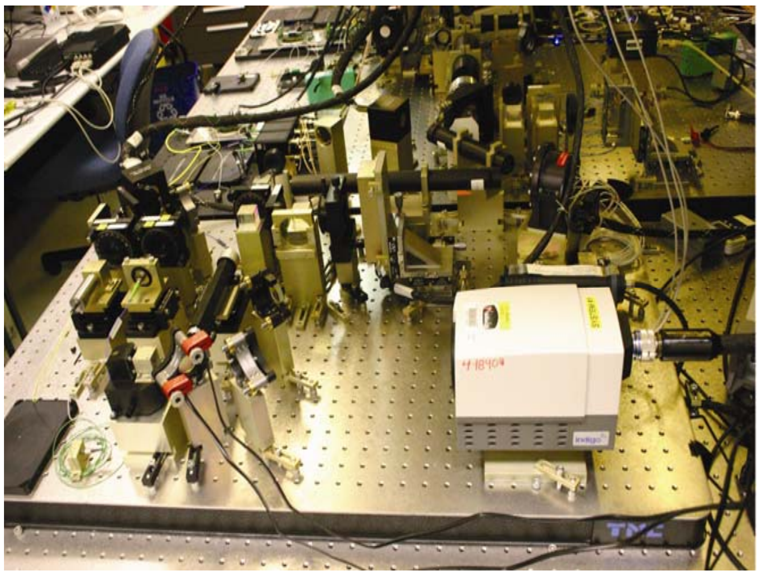
<u>**Link of focus: Air-to-space**</u>

Tracking Testbed



Tracking Testbed emulates aircraft to satellite communications

<u>Project focus: Reduce size and weight of existing aircraft terminal</u>



TTB Aircraft Terminal

- **Communication and Beacon Beams**
  - **Collimated beam for high data rates**
  - **Divergent beam for acquisition**
- **Point-Ahead Mirror**
  - **Leads communication beam ahead of target**
- **Tracking Feedback Loop**
  - **Stabilizes out platform jitter**

Project Objectives

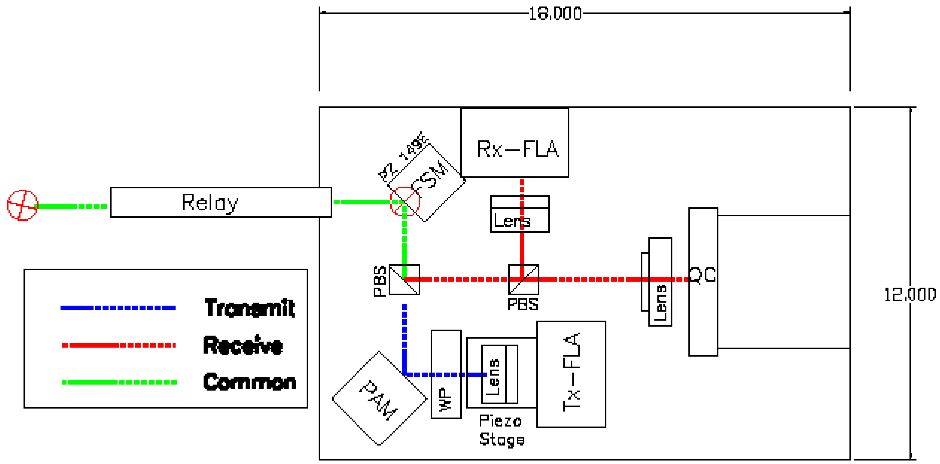
- **Path-to-Flight Design**
  - Transition from laboratory-grade hardware
- **Minimize Size, Weight, and Cost**
  - Common optics for beacon and communication signals
  - Tracking with one detector (quad-cell)
  - Commercial, off-the-shelf parts used
- **Investigate New Hardware**
  - Automated positioning stage for adjustable beacon-to-comm transmitter
  - Compact fast-steering mirror for tracking
- **Characterizing New and Existing Components**
  - Tracking feedback loop bandwidth
  - Beam characterization

Design Requirements

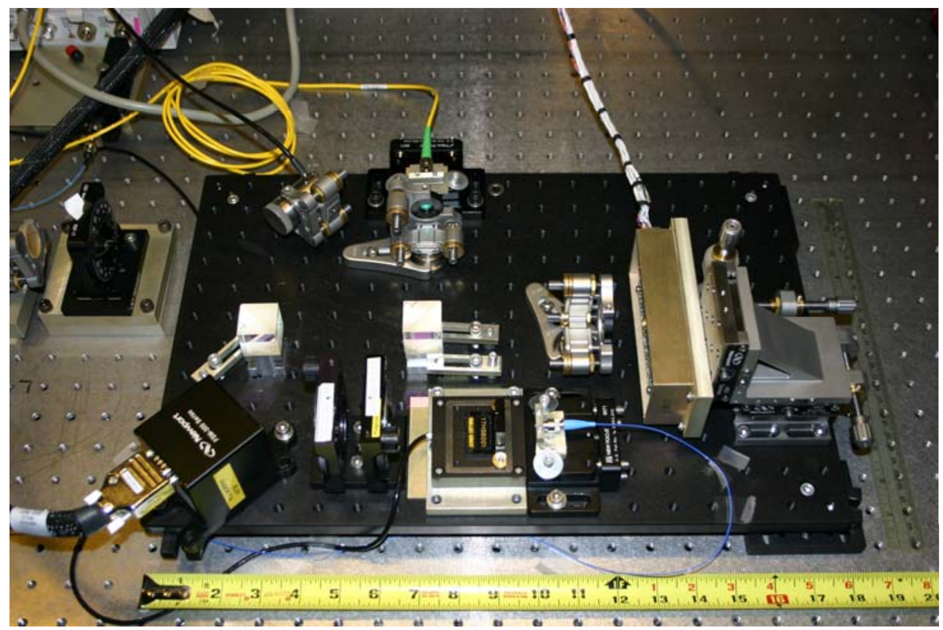
- Optical Performance and Characterization
  - Beam quality
  - Losses
- Control Performance and Software Functionality
  - Mirror control
  - Tracking feedback loop
- New Component Assessment
  - Fast steering mirror (FSM)
  - Jitter rejection

Requirement	Parameter
Beam divergence($1/e^2$)	0.53 mrad / 2.67 mrad
Wavefront Quality	<0.07 waves rms in comm
Beam Size	~4.4 mm in diameter ($1/e^2$)
Tx/Rx Throughput	<3 dB loss in both paths
Stroke of Mirror	+/- 1 mrad in Az and El
Mode Switch Speed	<50 msec
PAM command	Fixed position +/- 10 mrad
Tracking Control Loop	Mirror receives command
Spiral Scan	Modify and run
Residual Jitter	<20 µrad to 1 kHz
Mirror Steering	At 1 kHz

ALT-COM Layout



- Combined Tx fiber launch for Beacon + Comm beams
- New fast-steering mirror
- Tracking by quad-cell detector
- 24 x 36 in. → 12 x 18 in. (1/4 of original area)



Requirement: Layout on 12 x 18 in. optical breadboard

Results: Built and tested on required breadboard

Requirement satisfied

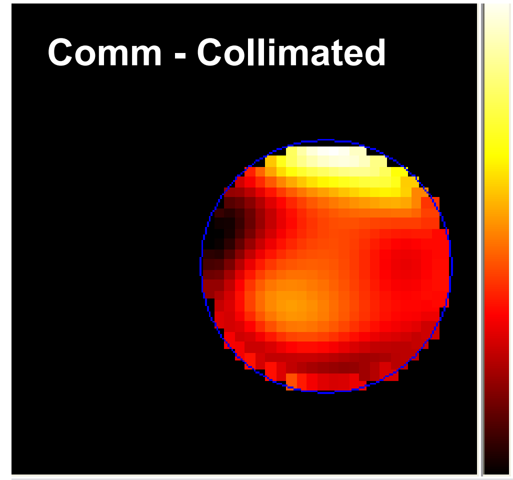
Beam Characterization

Beacon/Comm. Transmitter Stage

- **Requirement: Switching Speed <50 msec**
- **Test: Oscilloscope readings at receive fiber**
- **Results:**

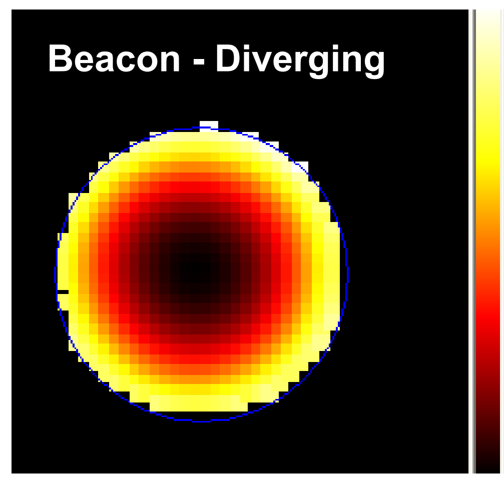
  8.7 ± 1.1 msec for beacon to comm

  9.4 ± 0.8 msec for comm to beacon



Wavefront Error Measurements

Test	Beam Divergence ($1/e^2$)	Beam Size ($1/e^2$)	Wavefront Error $\lambda = 1.55\ \mu m$
Req.	0.53 mrad comm 2.67 mrad beacon	~4.4 mm	<0.07 waves rms
Result	0.58 mrad comm 3.02 mrad beacon	3.7 mm	<0.03 waves rms



Requirements satisfied

Power Measurements

Requirement: <3 dB loss in both Tx and Rx paths

Test: Free-space and fiber-coupled power measurements

Results:

Tx Component	Associated Loss (dB)
Waveplates	0.06
PAM	0.14
PBS1	0.22
FSM	0.20
Total Loss =	0.62

Rx Component	Associated Loss (dB)
FSM	0.20
PBS1	0.22
PBS2	0.22
Insertion Loss	3.7
Total Loss =	4.34

Satisfied for Tx path

Unsatisfied for Rx path

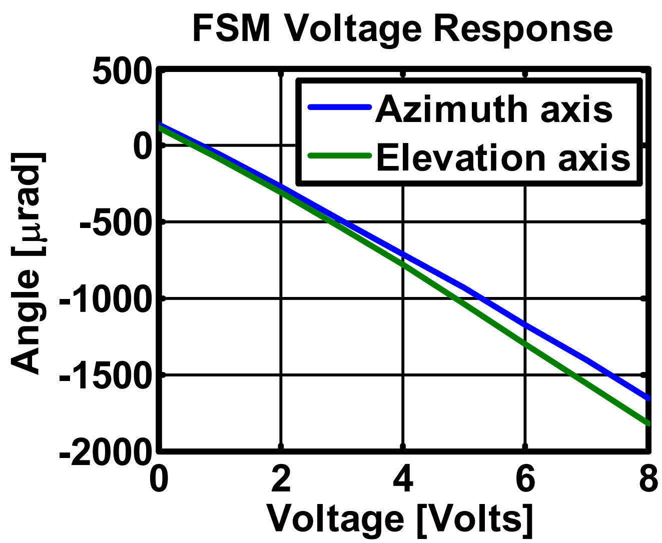
Fast-Steering Mirror Characteristics

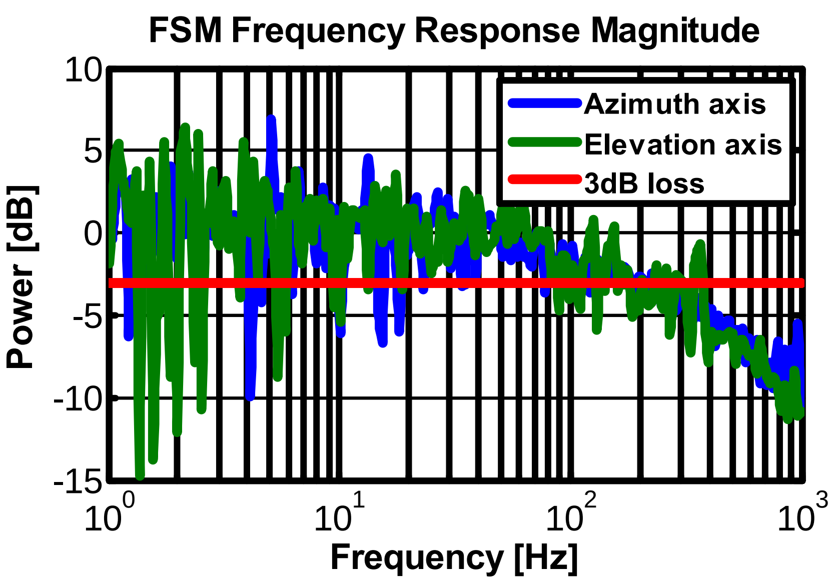
Requirement: Angular range of mirror ±1 mrad

Test: Stepped voltage to fast-steering mirror input

Results: Azimuth limited by ±0.85 mrad

Requirement satisfied within tolerance





Requirement : Mirror steering at 1 kHz (with 25-mm mirror)

Test: Swept sinusoid on fast-steering mirror

Result: Bandwidth of 200 Hz

Does not satisfy requirement

Note: Elevation resonances after 200 Hz

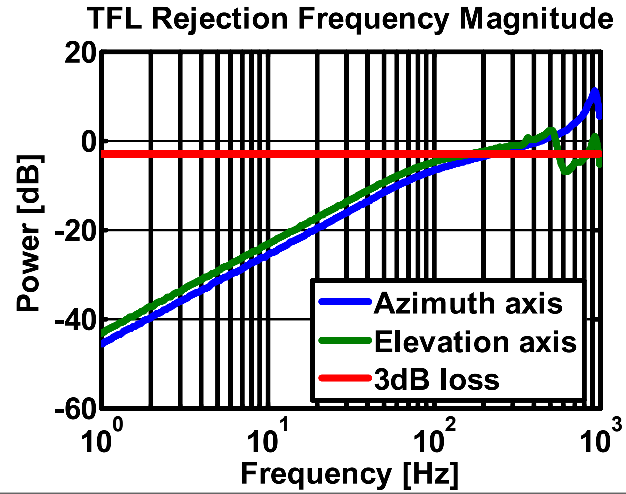
Tracking Loop Performance

Requirement: Fast-steering mirror responds to QC drive signals

Test: Feedback enabled, applied platform jitter with point-ahead mirror

Results: Tracking successful

Requirement satisfied

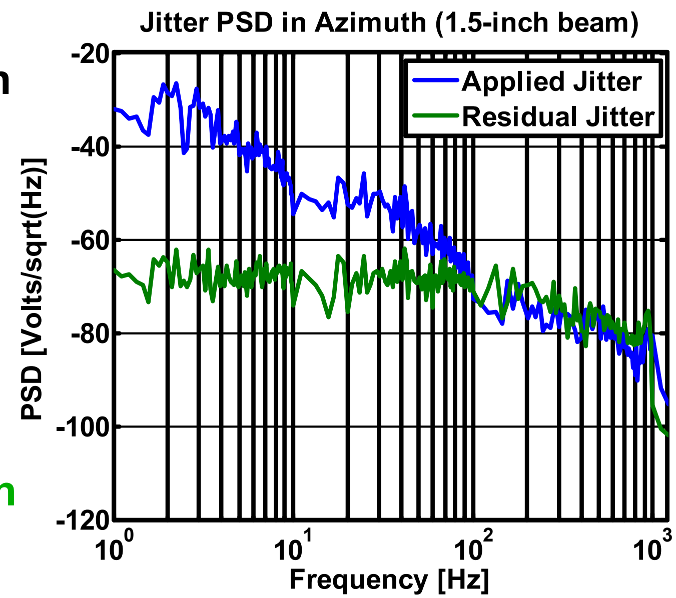


Requirement: Residual jitter <20 µrad to 1kHz

Test: Command point-ahead mirror in random fashion to 0.5, 1.5 and 4 in. beam platform jitter models

Results: 0.5, 1.5 in. residual jitter <20 µrad

Jitter	*Az*	*El*	*Units*	*Az*	*El*	*Units*
Applied	109.5	131.5	µrad (rms)	211%	254%	% Beamwidth
Residual	13.9	13.8	µrad (rms)	27%	27%	(4/π)*(λ/D)



Applied jitter of 2.5 beamwidths cut to 0.25 beamwidth

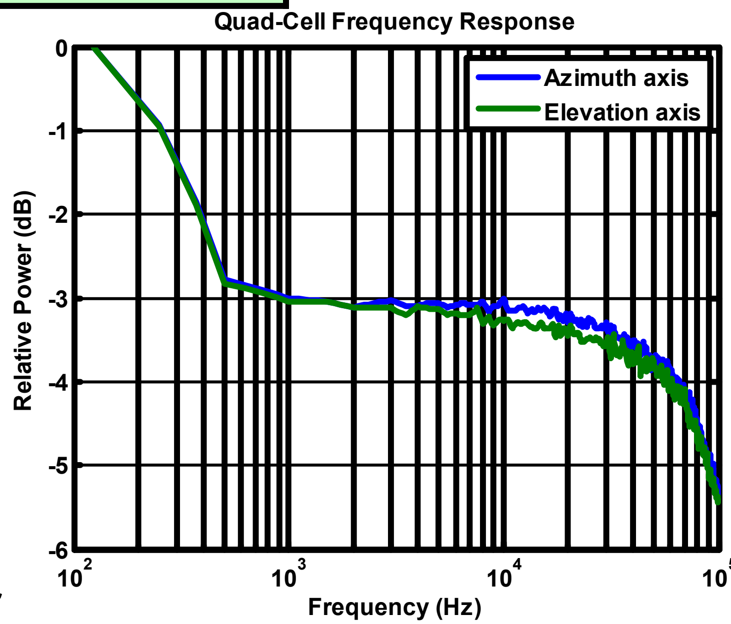
Requirement satisfied for 0.5, 1.5-in. cases

Lessons

- Beam coupling for flat and angled connectors

	Flat	Angled
Alignment	Easy	Difficult
Throughput	Higher power	Lower power
Interference	Strong	Negligible

- Oscillating regulator
  - Bad component
  - Problem found by frequency response

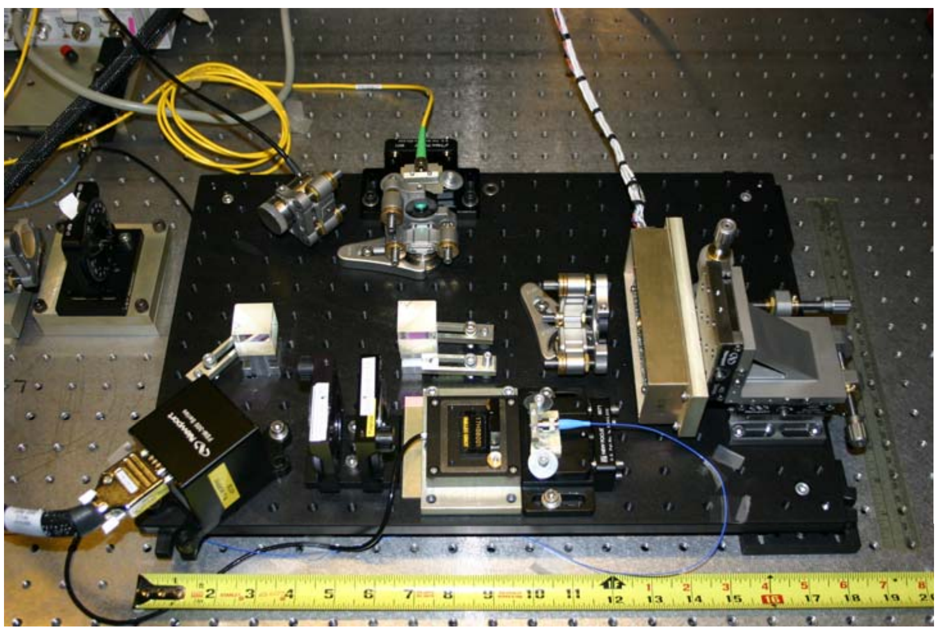


- Fast-Steering Mirror
  - Works for lower bandwidth applications
  - Potential improvement with smaller mirror

Conclusions

- Built and tested terminal
- Beacon control system functional and switches fast enough
- Tracking loop successful
- Evaluated Fast Steering Mirror
- Future work:
  - Nutator for fiber alignment
  - Investigate additional FSM

Requirement	Met?
Beam divergence ($1/e^2$)	✓
Wavefront Quality	✓
Beam Size	✓
Tx/Rx Throughput	✓ / ✗
Stroke of Mirror	✓
Mode Switch Speed	✓
PAM command	✓
Tracking Control Loop	✓
Spiral Scan	✓
Residual Jitter	✓
Mirror Bandwidth	✗



4-inch Beam Platform Jitter Test