Aircraft Lasercom Terminal
Compact Optical Module
(ALT-COM)

Bradley Scoville - ECE
Steven Rose – Physics

Worcester Polytechnic Institute
Major Qualifying Project

Advanced Lasercom Systems and Operations – Group 66

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- Timothy Williams
- Dr. William Wilcox
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

Link of focus: Air-to-space
Tracking Testbed

Tracking Testbed emulates aircraft to satellite communications

Project focus: Reduce size and weight of existing 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

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

<table>
<thead>
<tr>
<th>Test</th>
<th>Beam Divergence (1/e²)</th>
<th>Beam Size (1/e²)</th>
<th>Wavefront Error λ = 1.55 μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Req.</td>
<td>0.53 mrad comm</td>
<td>~4.4 mm</td>
<td>&lt;0.07 waves rms</td>
</tr>
<tr>
<td></td>
<td>2.67 mrad beacon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Result</td>
<td>0.58 mrad comm</td>
<td>3.7 mm</td>
<td>&lt;0.03 waves rms</td>
</tr>
<tr>
<td></td>
<td>3.02 mrad beacon</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Requirements satisfied
Power Measurements

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

Test: Free-space and fiber-coupled power measurements

Results:

<table>
<thead>
<tr>
<th>Tx Component</th>
<th>Associated Loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waveplates</td>
<td>0.06</td>
</tr>
<tr>
<td>PAM</td>
<td>0.14</td>
</tr>
<tr>
<td>PBS1</td>
<td>0.22</td>
</tr>
<tr>
<td>FSM</td>
<td>0.20</td>
</tr>
<tr>
<td>Total Loss</td>
<td>0.62</td>
</tr>
</tbody>
</table>

Satisfied for Tx path

<table>
<thead>
<tr>
<th>Rx Component</th>
<th>Associated Loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSM</td>
<td>0.20</td>
</tr>
<tr>
<td>PBS1</td>
<td>0.22</td>
</tr>
<tr>
<td>PBS2</td>
<td>0.22</td>
</tr>
<tr>
<td>Insertion Loss</td>
<td>3.7</td>
</tr>
<tr>
<td>Total Loss</td>
<td>4.34</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Jitter</th>
<th>Az</th>
<th>El</th>
<th>Units</th>
<th>Az</th>
<th>El</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied</td>
<td>109.5</td>
<td>131.5</td>
<td>µrad (rms)</td>
<td>211%</td>
<td>254%</td>
<td>% Beamwidth</td>
</tr>
<tr>
<td>Residual</td>
<td>13.9</td>
<td>13.8</td>
<td>µrad (rms)</td>
<td>27%</td>
<td>27%</td>
<td>(4/π)*(λ/D)</td>
</tr>
</tbody>
</table>

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
  - 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

<table>
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<tr>
<th>Requirement</th>
<th>Met?</th>
</tr>
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<tbody>
<tr>
<td>Beam divergence ($1/e^2$)</td>
<td>✓</td>
</tr>
<tr>
<td>Wavefront Quality</td>
<td>✓</td>
</tr>
<tr>
<td>Beam Size</td>
<td>✓</td>
</tr>
<tr>
<td>Tx/Rx Throughput</td>
<td>✓/✗</td>
</tr>
<tr>
<td>Stroke of Mirror</td>
<td>✓</td>
</tr>
<tr>
<td>Mode Switch Speed</td>
<td>✓</td>
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<td>PAM command</td>
<td>✓</td>
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<td>Tracking Control Loop</td>
<td>✓</td>
</tr>
<tr>
<td>Spiral Scan</td>
<td>✓</td>
</tr>
<tr>
<td>Residual Jitter</td>
<td>✓</td>
</tr>
<tr>
<td>Mirror Bandwidth</td>
<td>✗</td>
</tr>
</tbody>
</table>
4-inch Beam Platform Jitter Test

Jitter PSD in Az (4-inch beam)

Jitter PSD in El (4-inch beam)

FSM Throw Limitation in Az (4-inch beam)