Development of a Safe Ground to Space Laser Propagation System for the OCTL

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- **Tier 0**: Confined within OCTL building under OSHA guidelines
- **Tier 1**: FAA controlled region ranging from dome out to 3.4km
- **Tier 2**: FAA controlled ellipsoidal region ranging to 20km @ zenith and 58km @ 20° elevation
- **Tier 3**: Space Command region extends from near-Earth to the ranges of geo-stationary and high elliptical orbiting satellites
Optical Communications Telescope Laboratory

- Located at the JPL Table Mountain Facility in Wrightwood, CA
- 1-meter telescope dedicated to day+night operations for optical communications
- R&D optical antenna to develop communication strategies for future ground stations

<table>
<thead>
<tr>
<th>Laser</th>
<th>$\lambda$ (nm)</th>
<th>Avg Pwr (Watts)</th>
<th>PRF (Hz)</th>
<th>Energy/pulse (Joules)</th>
<th>Peak Pwr (Watts)</th>
<th>Beam size at aperture (cm)</th>
<th>Pulse Width (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doubled Nd:YAG</td>
<td>532</td>
<td>12.5</td>
<td>1 - 50</td>
<td>0.25</td>
<td>0.4 x10^8</td>
<td>30x21</td>
<td>6.6</td>
</tr>
<tr>
<td>Yellow Laser</td>
<td>589</td>
<td>20</td>
<td>CW</td>
<td>N/A</td>
<td>20</td>
<td>36 dia.</td>
<td>N/A</td>
</tr>
<tr>
<td>Diode Array</td>
<td>810</td>
<td>2</td>
<td>CW</td>
<td>N/A</td>
<td>4</td>
<td>9 dia.</td>
<td>N/A</td>
</tr>
<tr>
<td>Nd:YAG</td>
<td>1064</td>
<td>32</td>
<td>1 - 50</td>
<td>0.6</td>
<td>1.2 x10^8</td>
<td>15x10</td>
<td>8</td>
</tr>
<tr>
<td>EDFA</td>
<td>1550</td>
<td>10</td>
<td>CW</td>
<td>N/A</td>
<td>20</td>
<td>11.8 dia.</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Safety Shutter Layout

External Laser Beam Safety Shutter

Photodiode Beam Detector

Solenoid Inter-Cavity Path Blocker

1.5-m x 2.4-m OPTICAL TABLE
Multi-Tier Integration Requirements

• Assemble and coordinate tier outputs before commanding laser shutter

• Each tier must:
  – Be capable of at-risk object identification
  – Provide output to signal object detection
  – Provide output to signal whether equipment is responsive
**Tier 1: ILI Imaging System**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required Maximum Operational Range</td>
<td>3.4 km</td>
</tr>
<tr>
<td>Operating Wavelength</td>
<td>7-14 μm</td>
</tr>
<tr>
<td>Field of View</td>
<td>12° x 9° (&quot;near&quot;)</td>
</tr>
<tr>
<td></td>
<td>46° x 35° (&quot;far&quot;)</td>
</tr>
<tr>
<td>Resolution</td>
<td>320 x 240 pixels</td>
</tr>
<tr>
<td>Power Requirements</td>
<td>15 VDC</td>
</tr>
<tr>
<td>Weight</td>
<td>5.1 kg</td>
</tr>
<tr>
<td>Image Acquisition Freq.</td>
<td>30 Hz</td>
</tr>
</tbody>
</table>

- Pair of LWIR detectors
- Packaged system includes object detection algorithms
- Requires access to telescope motion parameters
ILI System Response

ILI System Status Response

- System Functional
- System Not Responding

ILI System Detection Response

- Standby
- Object Detection

Narrow Field of View Camera:

Wide Field of View Camera:
Tier 2: Radar Detection System
(Radar Display Interface)

- Similar to AMOS RDI system
- Radar feed supplied by local TRACON
- Development awaits completion of joint NASA/FAA Memorandum Of Agreement

Picture courtesy Capt. J. Snodgrass
Maui Space Surveillance Center, USAF.
**Tier 2: Radar Detection System (Interim Approach)**

- Honeywell Weather Radar
- Requires access to site terrain map to avoid false detection caused by returns from local environment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Range</td>
<td>300 nm</td>
</tr>
<tr>
<td>Operating Frequency</td>
<td>9340 MHz</td>
</tr>
<tr>
<td>Total Field of View</td>
<td>11°</td>
</tr>
<tr>
<td>System Noise Figure</td>
<td>7 dB</td>
</tr>
<tr>
<td>RT Power Output</td>
<td>8 kW</td>
</tr>
<tr>
<td>Power Requirements</td>
<td>28 VDC</td>
</tr>
<tr>
<td>Weight</td>
<td>16 kg</td>
</tr>
<tr>
<td>Pulse Repetition Freq.</td>
<td>121 Hz</td>
</tr>
</tbody>
</table>
Radar System Response

Radar System Status Response
- XMIT/RCVR Unit Functional
- XMIT/RCVR Unit Not Responding

Radar System Detection Response
- Standby
- Object Detection

Graphs showing system output voltage over time.
Tier 3: Satellite Predictive Avoidance

- Laser registration (Cheyenne Mtn.)
  - Site information
    - Site coordinates and point of contact
  - Laser parameters
    - wavelength, divergence angle, energy, jitter angle, etc.
  - Written permission from target owner

- Predictive avoidance
  - OCTL operation times (when pulsed lasers will be used)
    must be submitted no later than 48 hours prior to operations
  - U.S. Space Command will issue times non-waived lasers
    cannot propagate 24 hours prior to operation
- Integrated system must maintain accurate time
Laser Safety Monitoring System

Predictive Avoidance File

Site Treeline Mask

Telescope Motion Vector

Application Software

I/O Board

Laser Shutters

System Time

IRIG B Time Code Reader

TCS IRIG B Time Code Generator

LSM Computer:
Dell™ OptiPlex GX260
Pentium® 4 Processor @ 2.26 GHz
256 MB RAM

JPW 8/29/2003
**LSM User Display**

- **“Equipment Status” row**
  - Displays operational status of each tier and the I/O board
  - **Green** = Equipment functional
  - **Red** = Equipment not responding

- **“Treeline” warning**
  - **Green** = Pointing above site terrain
  - **Red** = Pointing below site terrain

- **5 minute time history plot**
  - for detection status for each tier
  - Tier labels are highlighted according to corresponding detection status
  - **Green** = Safe for laser propagation
  - = Object Detection

- **5 minute time history plot of shutter response**
  - “Laser Beam” label is highlighted according to shutter response
  - **Green** = Verified that shutter commanded to open
  - = Verified shutter commanded to close

- **Running clock of current time**
  - Reference for time history plots
  - Evidence that software is executing

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*Slide 13*  
*JPW 8/29/2003*
Aircraft Detection Response Time

Tier 1
- ILI Scenario Study

Tier 2
- Total response time < 0.166 sec
  - Radar FOV = 11°
  - Commercial aircraft (600 mph) @ 3.4 km
    - Half FOV travel time = 1.2 sec
  - Enough time to prevent aircraft illumination? YES!

- Minimum allotted time for shutter response = 200 msec
Summary

- Developed a three-tier system for safe laser beam propagation through the atmosphere
  - Baseline for system development to support autonomous ground stations

- Integrated system uses
  1) Pair of LWIR cameras for ranges below 3.4 km (~2 miles)
  2) Radar detection system within FAA airspace
  3) Scheduled transmission windows approved by Laser Clearinghouse

- Scheduled for OCTL deployment in FY ‘04