Ultra-Compact LADAR Systems for Next Generation Space Missions

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About Bridger Photonics

• **Core technologies**
  – **Precision LADAR**
    • Frequency-controlled broadband lasers
    • Ultra-high resolution position detection & imaging
  – **Precision LIDAR**
    • Monolithic, compact, narrowband mJ pulsed lasers
    • Detection of meth labs, CO$_2$ and chem/bio
  – **Advanced Imaging**
    • Feature specific imaging
    • MEMS focus control

• **Team**
  – **Twelve Employees**
    • Two Ph.D.s, five Masters
  – **Board of Business Advisors**
    • Expertise in financing, product development, marketing, business development.

• **Performance**
  – **Rapid growth**
    • 3 years of operation, 2 → 12 employees, >$1M annual revenues
Motivation

- **Short Range**
  - Autonomous docking
  - Spacecraft inspection
  - Proximity detection and warning
- **Medium Range**
  - Precision formation flying
  - Scanned 3D imaging of other spacecraft and debris
- **Long Range**
  - Orbit determination
  - Target identification using advanced imaging techniques
  - High res. terrestrial imaging

Bridger Photonics has developed an advanced LADAR system that provides extremely precise and absolute distance measurements.
# Technology Comparison

<table>
<thead>
<tr>
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<th>Traditional Pulsed LADAR</th>
<th>Ultra-Compact FMCW LADAR</th>
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</thead>
<tbody>
<tr>
<td><strong>Range Resolution (Optical Bandwidth)</strong></td>
<td>~1 cm (15 GHz bandwidth)</td>
<td>&lt;50 micron (&gt;3 THz)</td>
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<tr>
<td><strong>Sensitivity</strong></td>
<td>Detector Limited</td>
<td>&lt;100 attowatts ($10^{-18}$) return power</td>
</tr>
<tr>
<td><strong>Receiver Bandwidth Requirements</strong></td>
<td>15 GHz</td>
<td>15 MHz</td>
</tr>
<tr>
<td><strong>Electrical Efficiency</strong></td>
<td>3% - Solid State Lasers</td>
<td>30% - Diode Lasers</td>
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<td><strong>Operational Flexibility</strong></td>
<td>Low resolution imaging and ranging</td>
<td>High resolution and coherent imaging and ranging</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>High peak power limits SWAP and increases potential for damage</td>
<td>Robust package based on COTS telecom components</td>
</tr>
<tr>
<td></td>
<td>Not sensitive to optical phase</td>
<td>Phase sensitive (SAL, vibrometry, velocity)</td>
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Laser sweep non-linearities degrade the performance of typical FMCW LADAR systems.
Bridger’s innovation enables a sweep linearity of 2 parts in $10^8$ over 5 THz.
Some LADAR Definitions

• Range resolution depends only on optical bandwidth providing a fair way to compare ranging systems.

• Range precision is dependent upon signal-to-noise ratio (i.e. depends upon Tx powers, receiver size, receiver bandwidth, etc.)

Range Resolution

\[ \Delta R = \frac{c \tau_p}{2} = \frac{c}{2B} \]

15 GHz \( \rightarrow \) 1 cm

Range Precision

\[ \sigma_R \approx \frac{\Delta R}{\sqrt{SNR}} \]
Precision LADAR

- Precise measurement of absolute distances to objects
  - Range resolution < 50 μm, range precision < 100 nm
  - Range window up to 100 m, standoff distance up to 14 km
  - Measurement speed from 10 Hz to 30 kHz depending on bandwidth

- Can break the fringe ambiguity of an interferometer
  - Could be paired with interferometric techniques for astounding absolute dimensional metrology
3D Imaging and Thickness Characterization

- Enables *in situ* inspection of parts, components or optical surfaces

### Sapphire Wafer Thickness Profile

- Mean Thickness = 633.0764 µm
- STD = 12.9159 nm

- Estimated Relative Range
  - Front Mean Position = 0.17128 m
  - STD = 73.868 nm
  - Back Mean Position = 0.17192 m
  - STD = 73.1432 nm
  - Mean Thickness = 633.0764 µm
  - STD = 12.9159 nm

- Front + 1 µm
- Back + 2 µm

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Long-Range Capabilities

- Enables formation flying and space situational awareness

2" Monostatic Tx / Rx

2.5" Retroreflector

100 mm

250 mm

~900 m Range

110 micron peak width

Relative Power (dB)

Relative Range (mm)

Range: ~900 m

Also ranged out to 14km with 3 mW
Synthetic Aperture LADAR

- Synthesize larger aperture by translating a small aperture
  - Conventional imaging: 18 m aperture for 5 cm resolution at 500 km
- Must maintain coherence over the synthetic aperture
- Ideal for small satellites: improved resolution in a compact form factor
- Current results: Beating “diffraction limit” by factor of 1000

\( D_{\text{spot}} \approx 3 \text{ m} \)

\( D_T \approx 0.25 \text{ m} \)

\( D_{\text{SA}} \approx 100 \text{ m} \)

\( N = 800 \)

\( \Delta X = 3 \text{ mm} \)

\( R = 500 \text{ km} \)

\( D = 500 \text{ km} \)

\( V = 1 \times 10^3 \text{ m/s} \)

\( \text{Return Powers} \approx 10^{583} \text{ pW} \) (0.1 scatterer & no atm. loss)
Non-Mechanical 3D Imaging

- Being developed for sand penetration and ground imaging in degraded visual environments
- System performs 3D imaging without a mechanical scanner
- Tested demonstrator at Yuma Proving Grounds
- Observed sub-mm diameter wire above sandy background

* Image taken from defenseindustrydaily.com
Compressive Sensing

- Reduced data rate:
  - System captures data in compressed format, eliminates need for data compression and post processing before downlink

- Reduced hardware:
  - Less detectors / ADCs; systems can be single-pixel

- Could be paired with FMCW ladar or other ladar techniques to perform 3D imaging
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