National Aeronautics and Space Administration

Silicon Photonic Transceiver for Spacecraft Navigational Lidar

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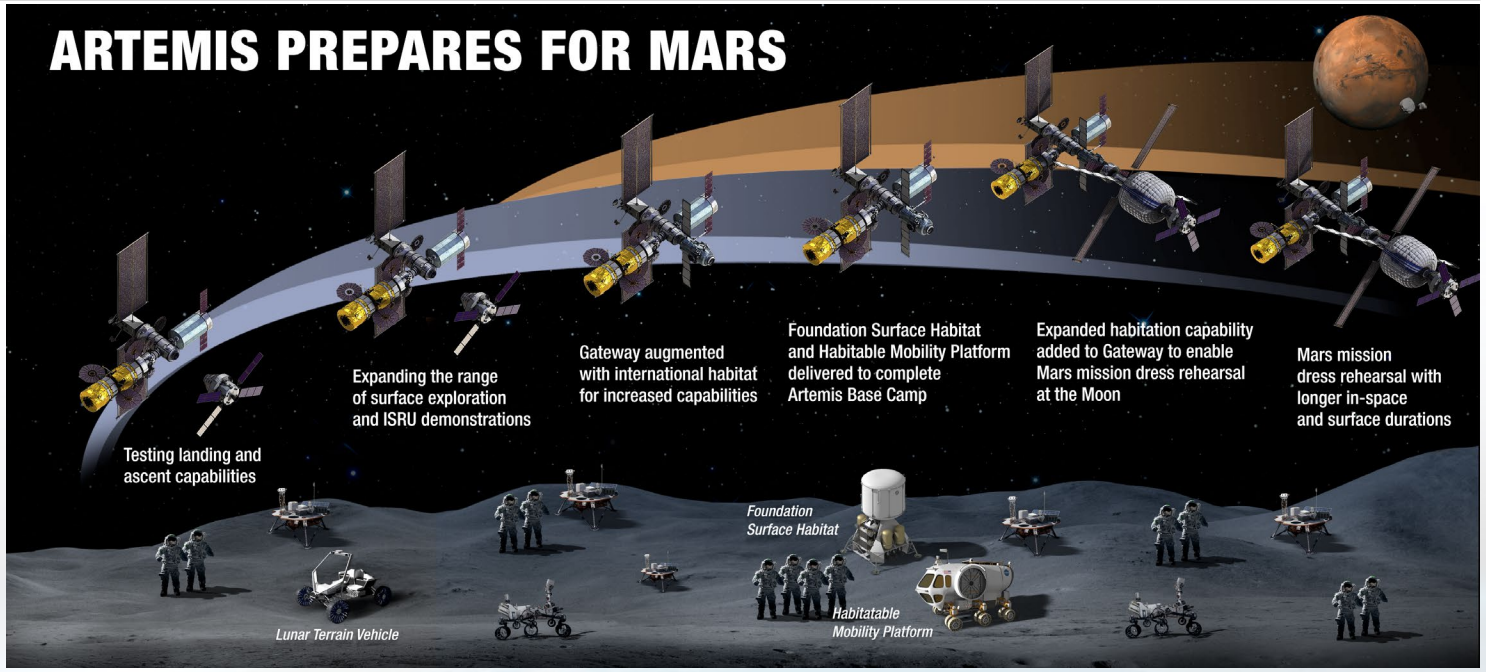
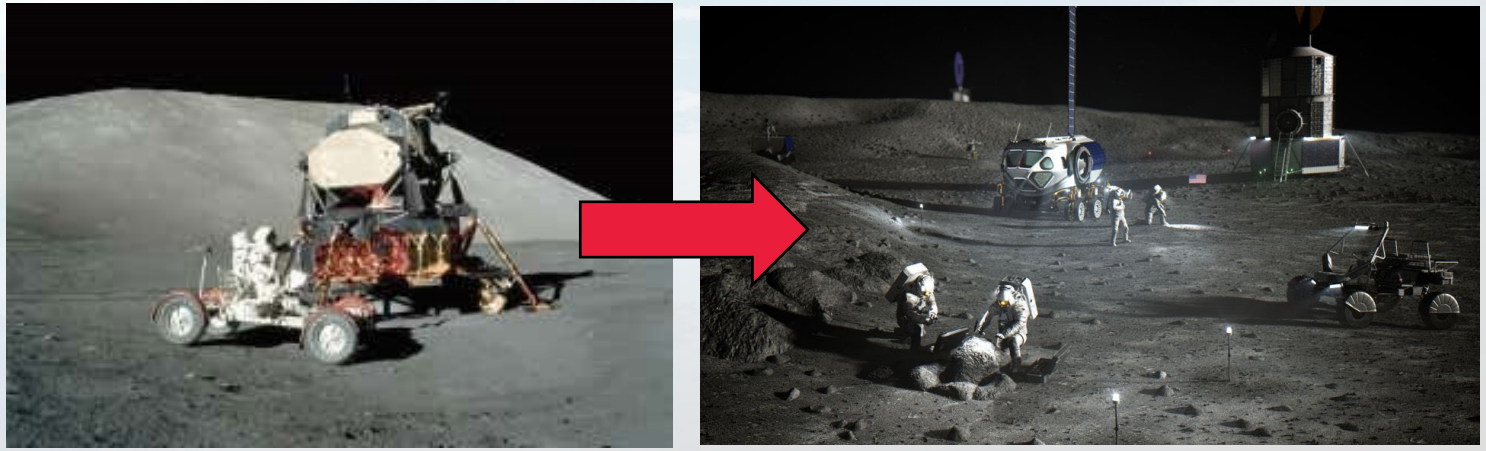
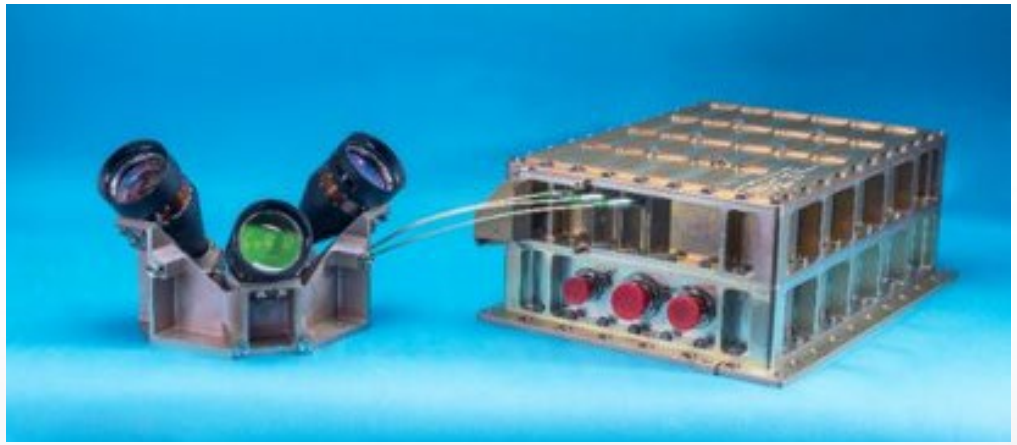
NASA Moon to Mars

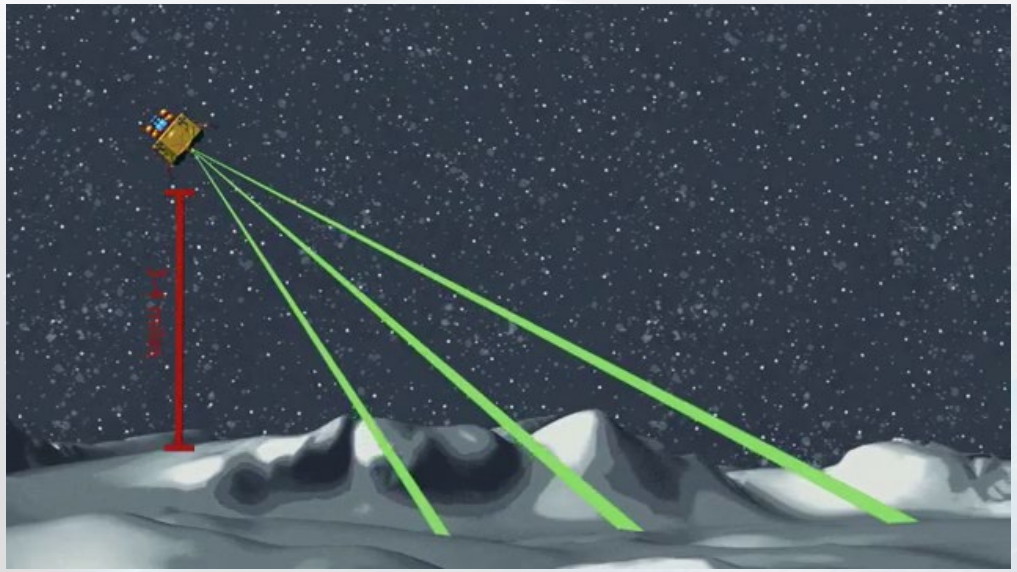
- NASA is planning for sustained human presence on the Moon and Mars
- Operational lunar and Martian bases need periodic resupply, multiple landers
- New/improved sensors need to land payloads in close proximity (<1 km) and with high precision (< 100 m)





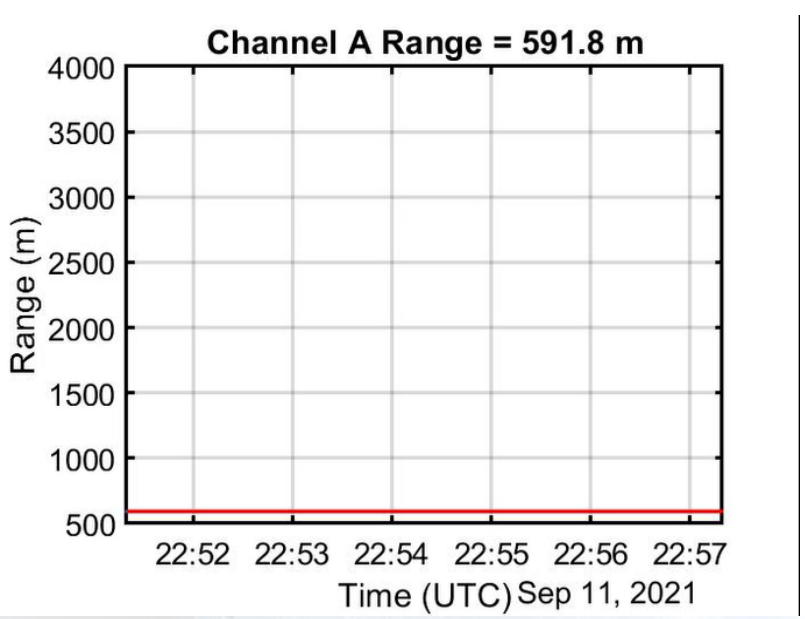
Navigation Doppler Lidar Enables Moon to Mars

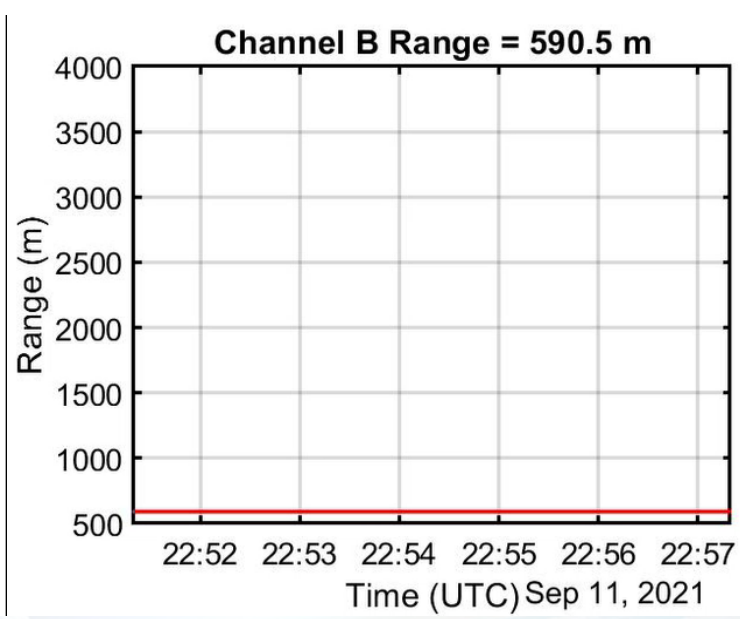


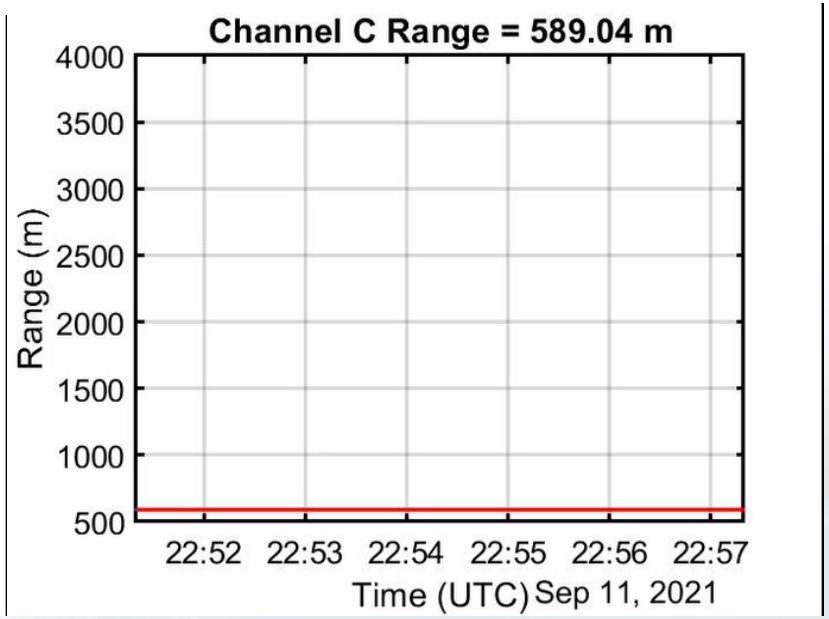


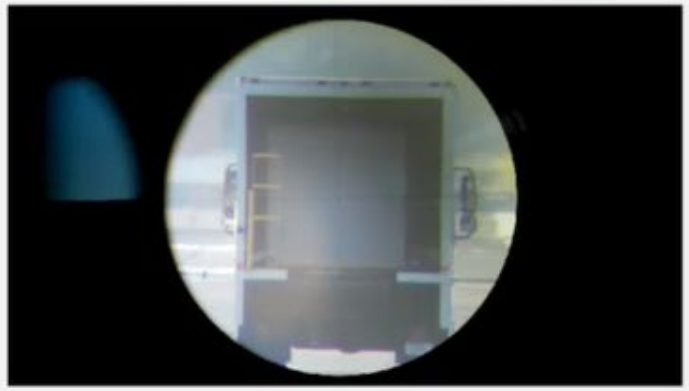
- **Navigation Doppler Lidar (NDL)**
  - Frequency-modulated continuous wave (FMCW) lidar system
  - 1550 nm, fiber-optic system
- NDL measures spacecraft attitude, velocity, and altitude during descent
  - <1 cm/s velocity resolution, ~10 cm range resolution
  - >5 km operational range
- Precise measurements enable reduced landing uncertainty
- Small size allows for redundancy, supports small landers
- 2 NDL units flying to the moon in 2023

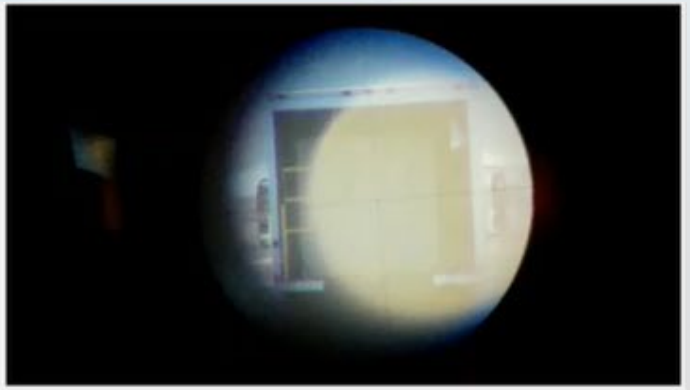
NDL In Action





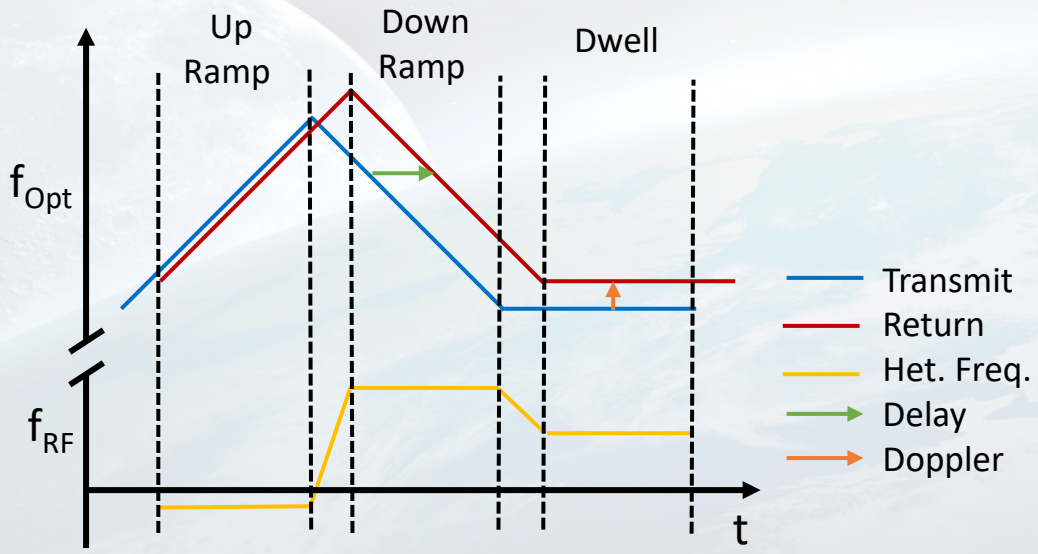




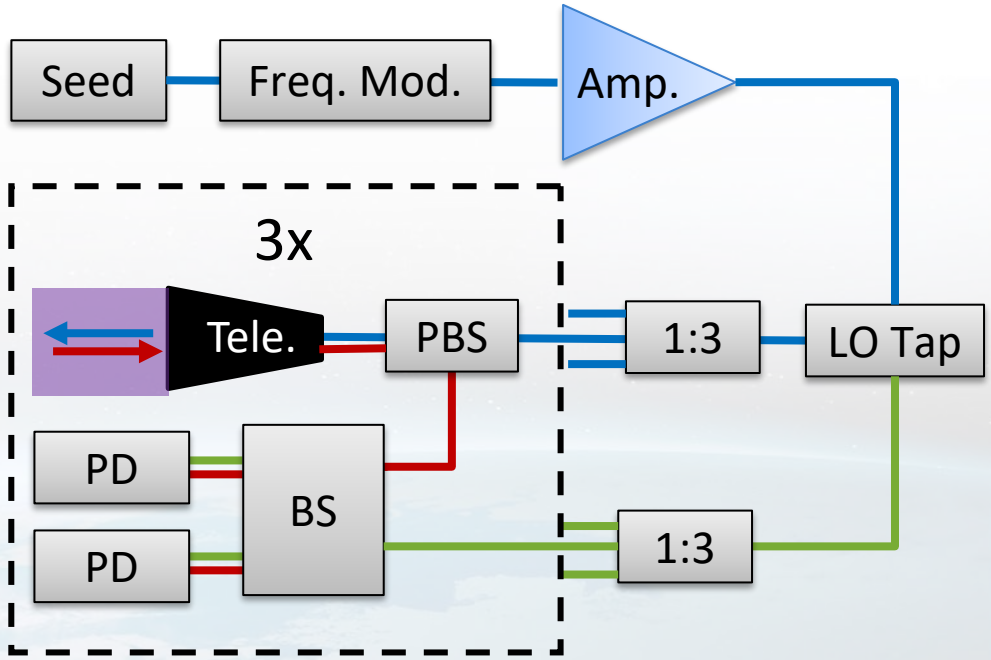


NDL Operational Schematic

- **FMCW for range/velocity measurements**
- **3 channels allow for vectorial position/velocity**



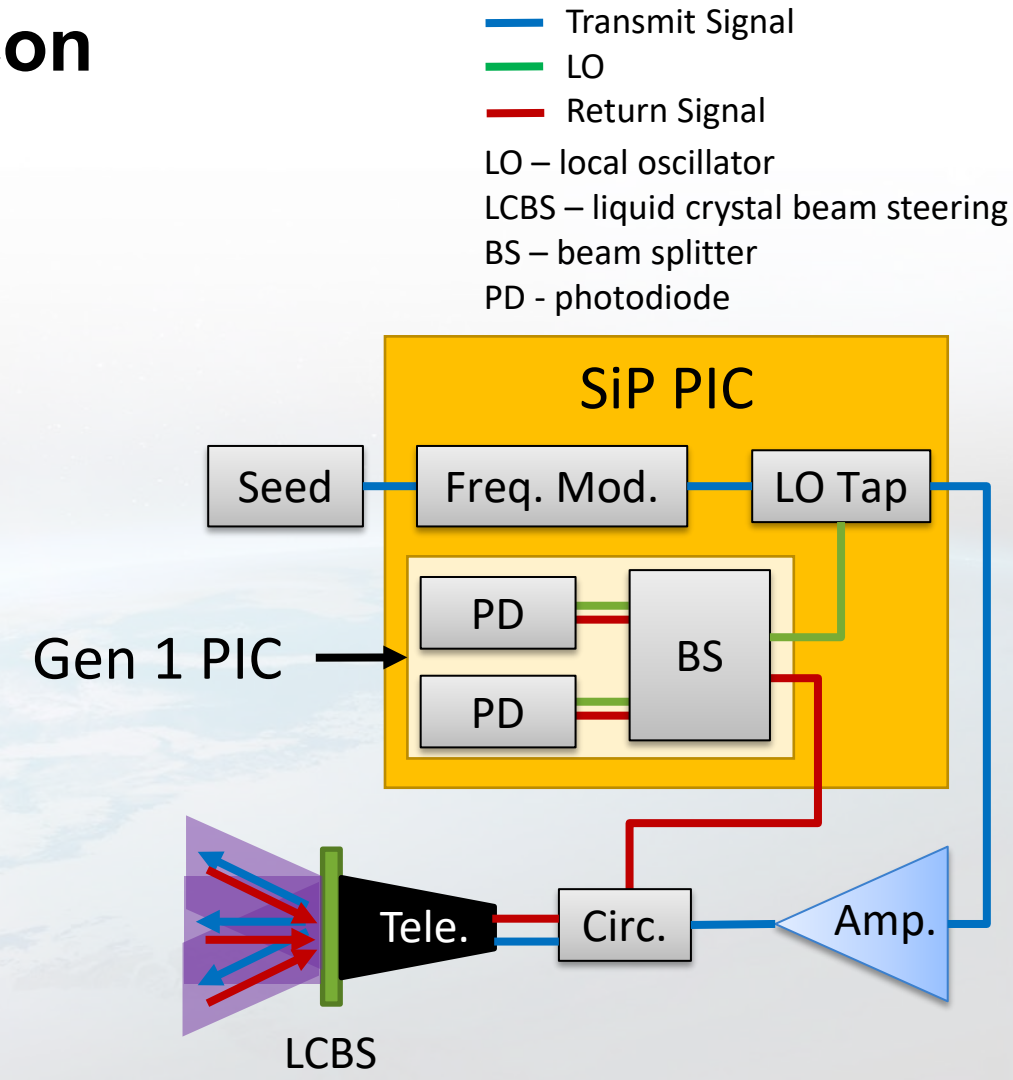
NDL Flight Units



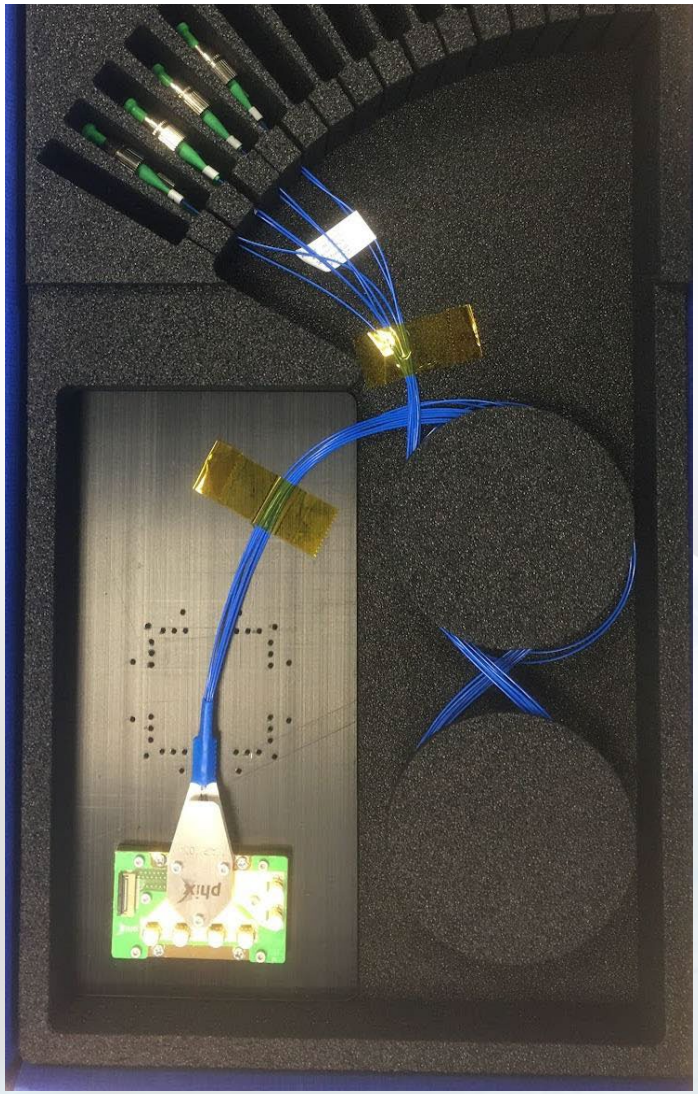
LO – Local Oscillator
BS – Beam Splitter
PD – Photodiode
PBS – Polarizing Beam Splitter

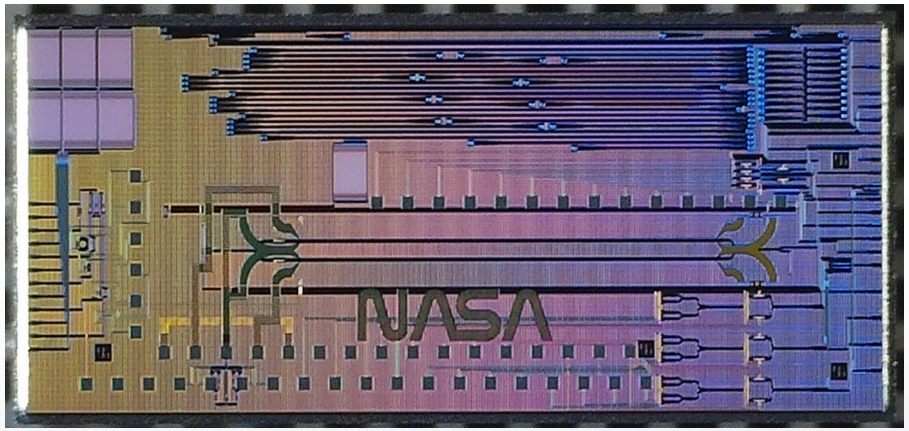
NDL Next Generation

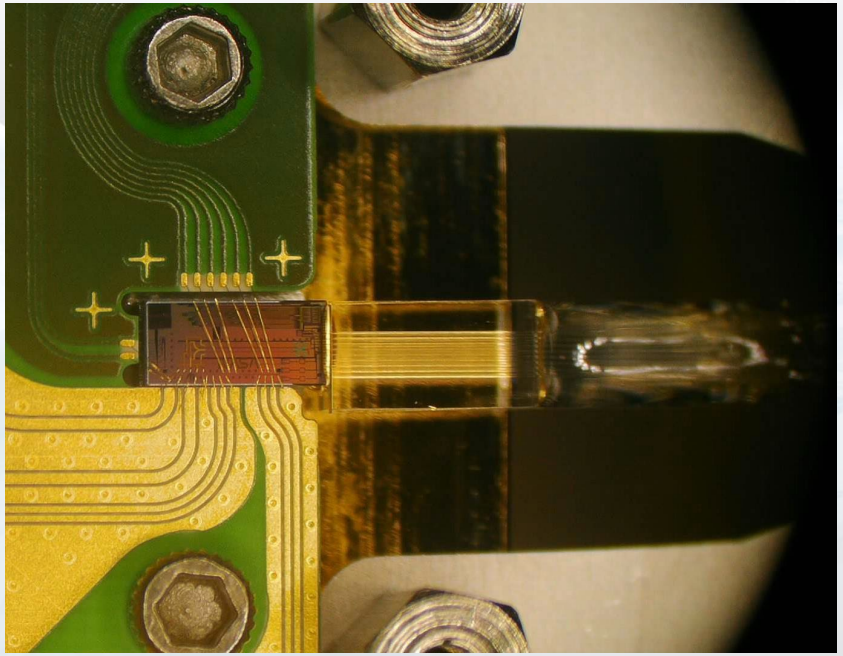
- **Incorporate many components into silicon photonic PIC including**
  - Modulator
  - LO tap
  - Balanced receiver
- **Use liquid crystal multi-angle beam steering to reduce channel count**
- **Reduced system size, more robust to environment, low assembly complexity, improved performance (hopefully!)**

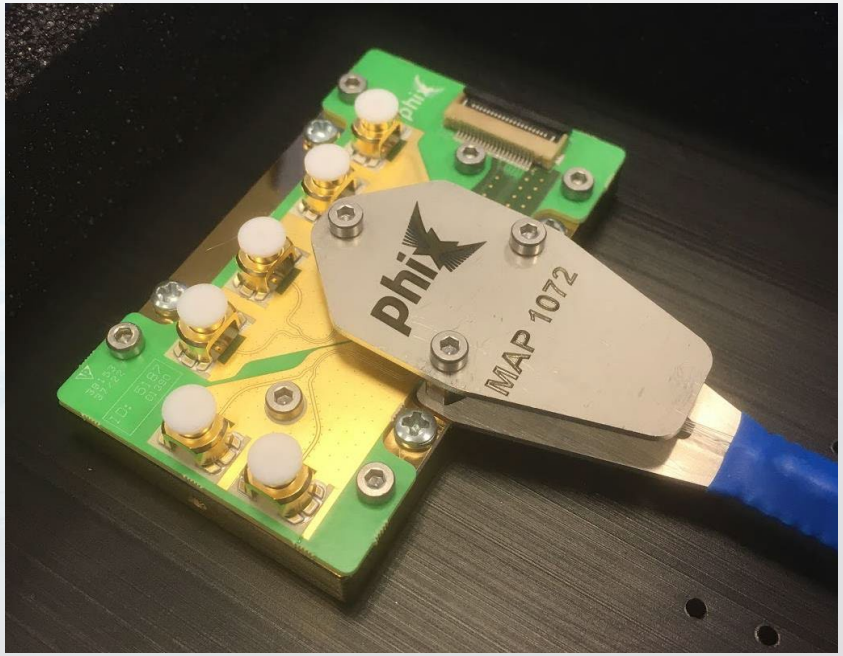


Gen. 1 PIC and Packaging – Open Top

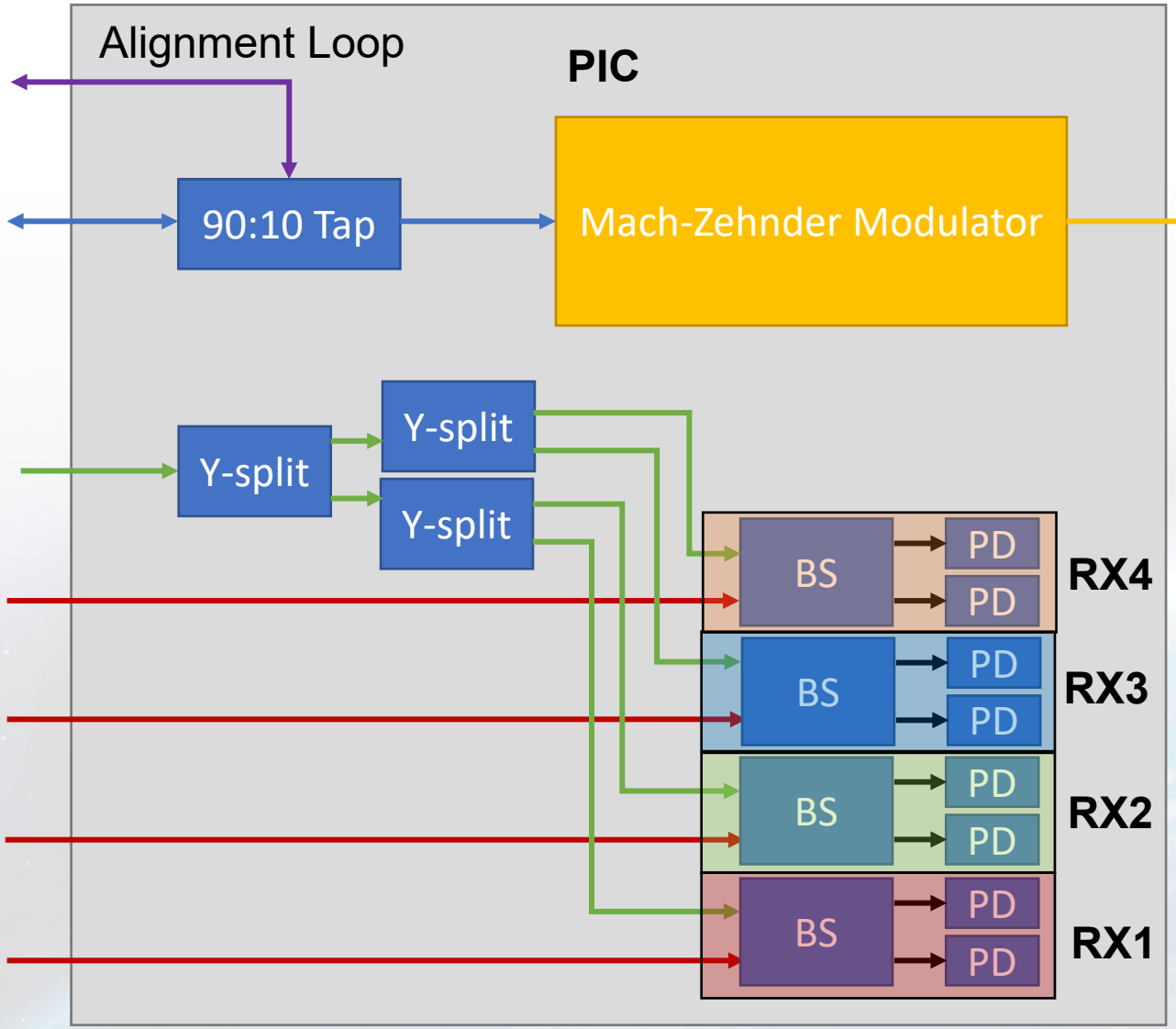




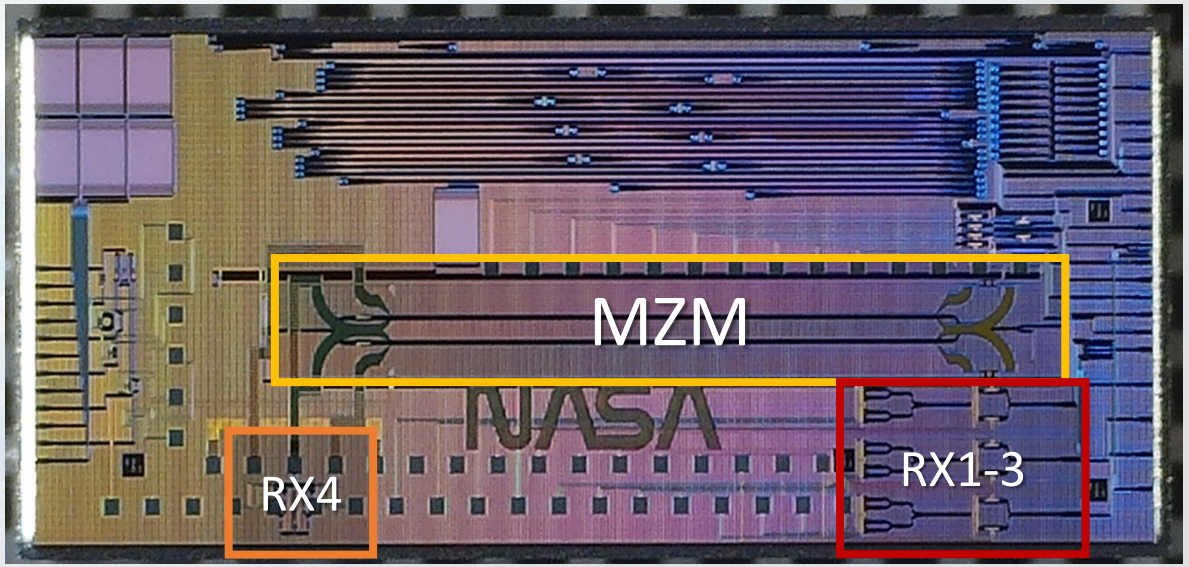




Gen 1 PIC Overview

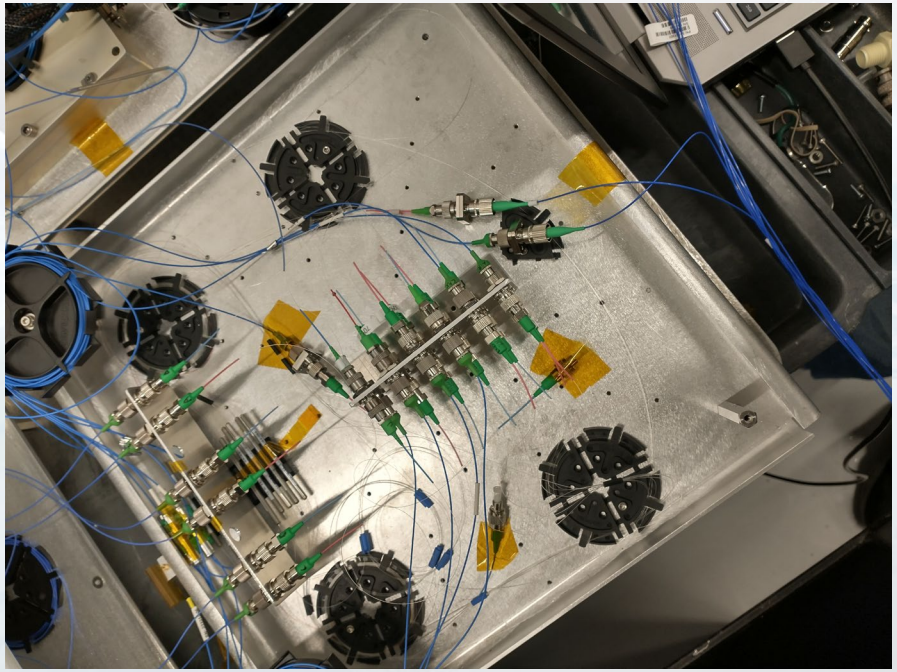


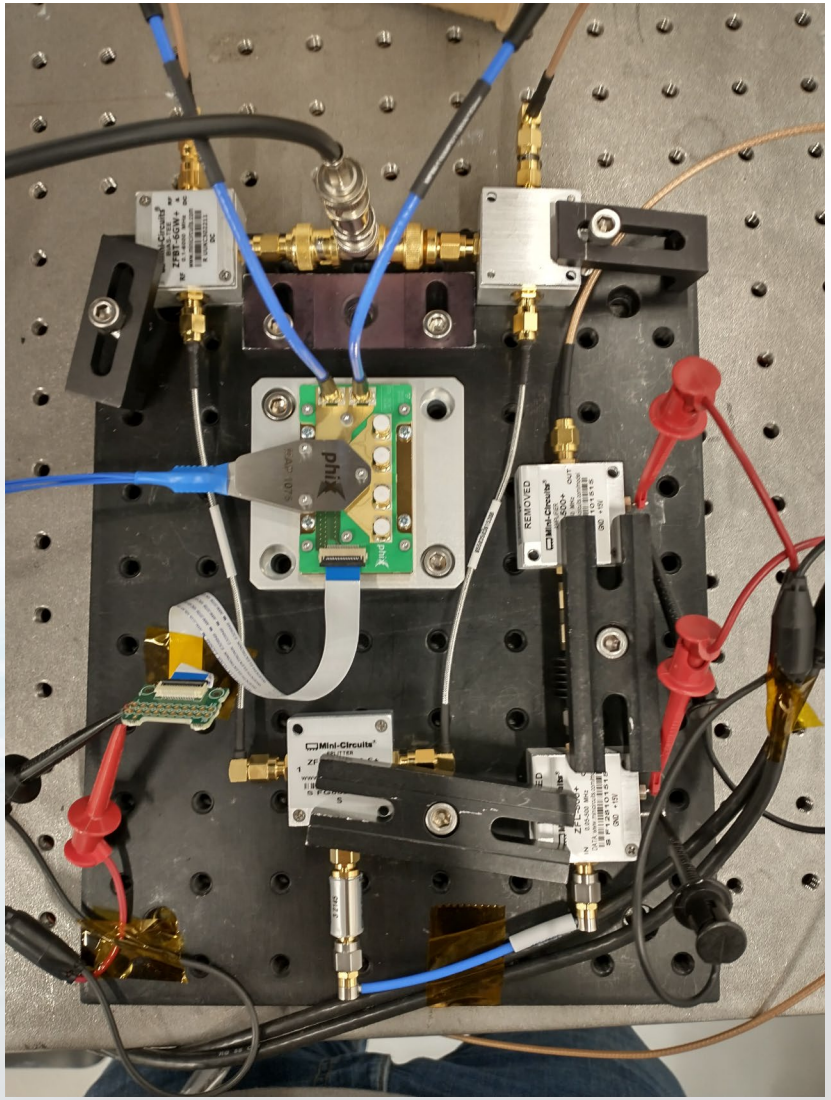
- MZM for evaluation
- 4x balanced receivers
- Single LO input



PIC Receiver Demo with NDL

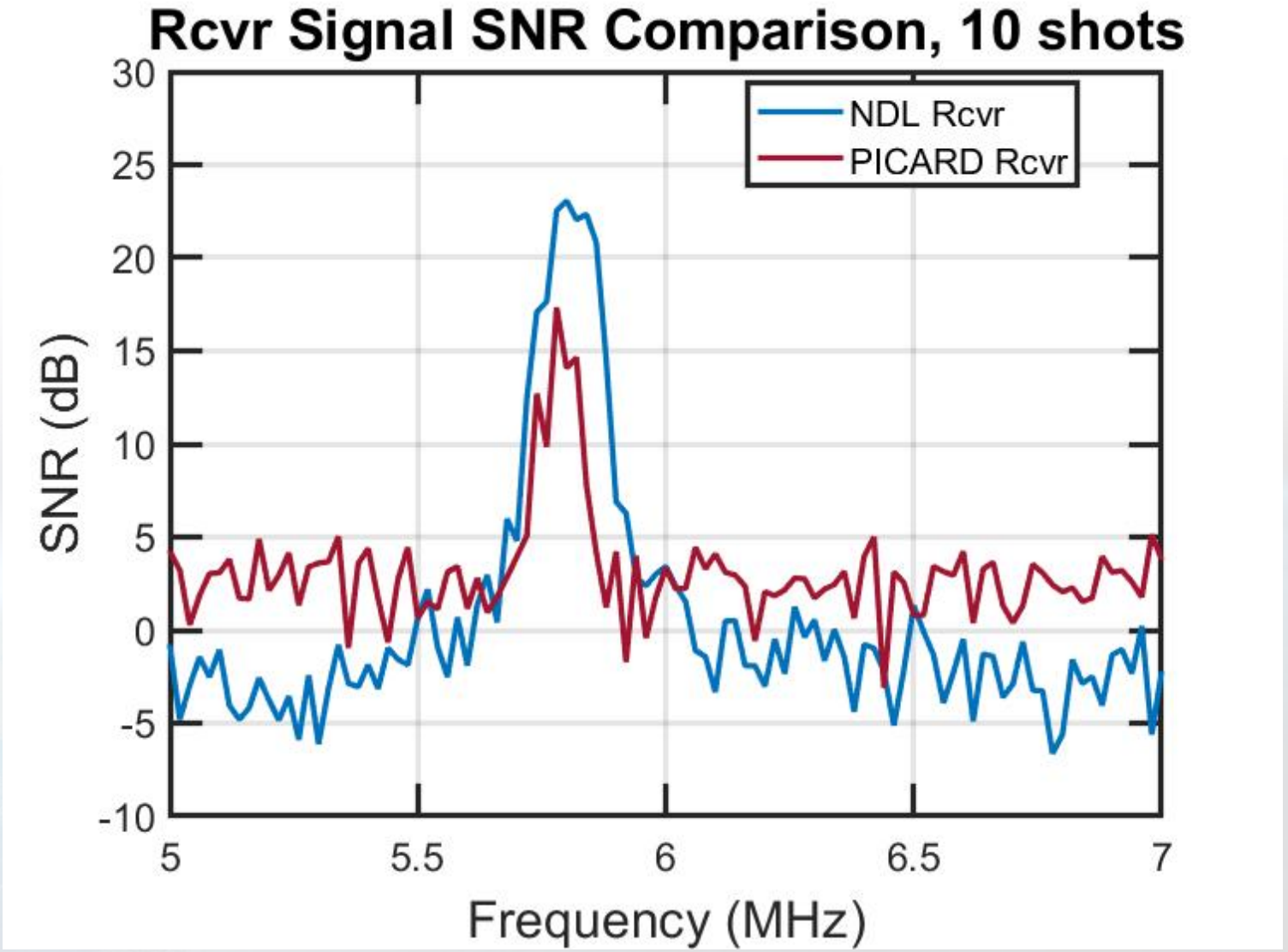
- **Breadboard receiver with PIC**
  - PIC PDs with off-chip bias tees, RF amps, filter
- **Use NDL test unit for lidar measurement**
  - Beam on belt sander provides ~6 MHz Doppler frequency





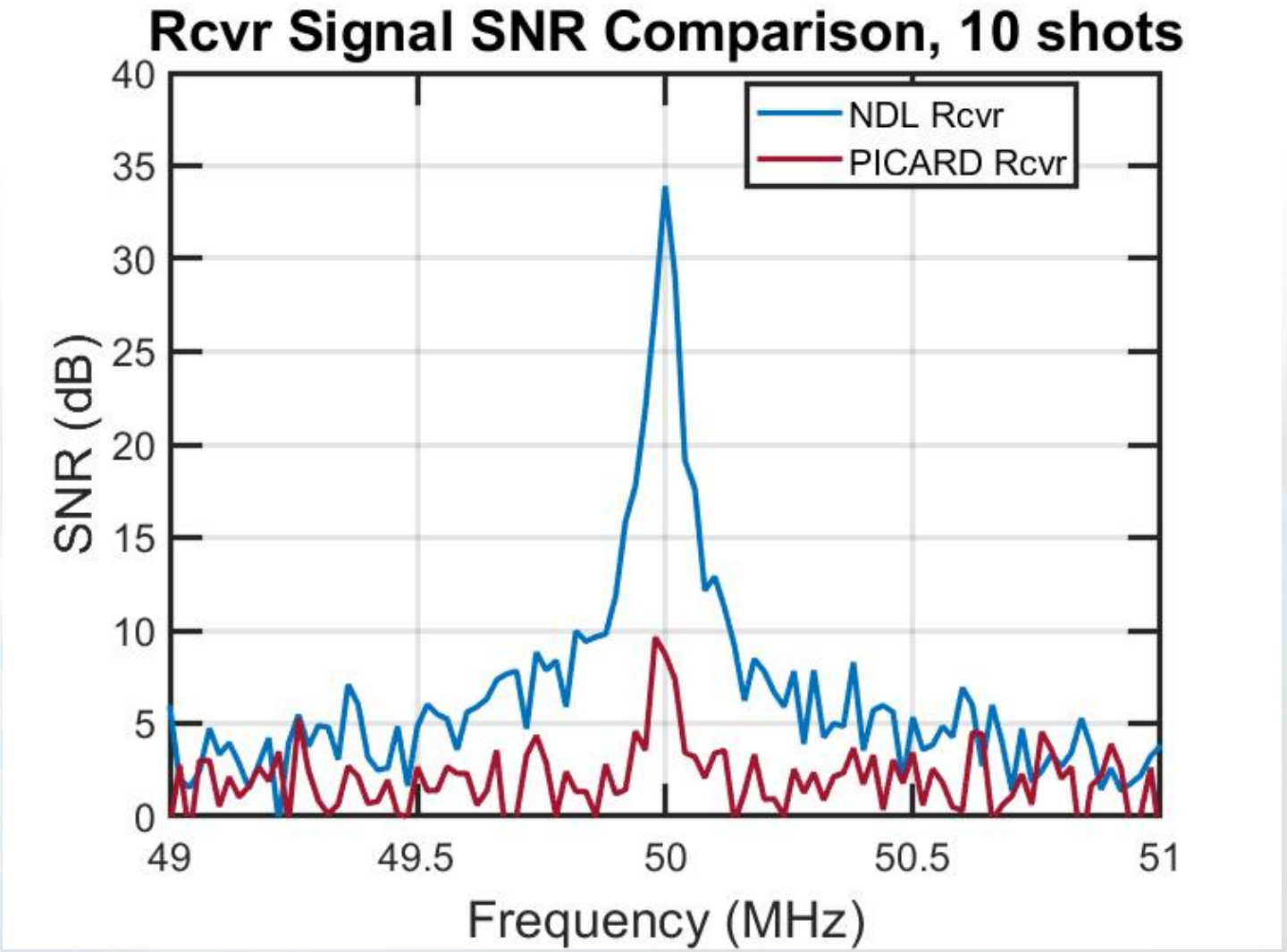
Receiver Measurements – The Bad News

- **~10 dB SNR drop**
- **Partially explained by 5-6 dB estimate of total coupling loss**
  - Targeted/expected 3 dB, unknown cause for excess loss
- **More testing planned, current receiver non-optimal**



Receiver Measurements – The Good News

- **~25 dB additional common mode noise suppression**
- **Existing spurs on NDL system require digital filtering, can cause measurement issues**
  - Imperfect synth modulation imprints 50 MHz spurs on LO
- **Improved common mode rejection improves NDL performance**



Future Work

- **Signal power drop higher than expected**
  - Further characterization required to identify source of loss
  - Improved coupling efficiency
- **Modulator characterization and revised design for single sideband operation**
- **Hermetic package with in-package receiver electronics**
- **Space-qualification/environmental test campaign -> TRL 6**

Summary

- **Developed open-top silicon photonic PIC for space-based lidar system**
- **Initial version showed reduced SNR but improved common mode rejection**
- **Demonstration with existing lidar system**
- **Further development focusing on**
  - Incorporating more functionality on the PIC
  - Hermetic packaging and environmental testing for space qualification

Thanks to the NDL Team

Keep an eye out for us on the Moon in 2023!