12-Pixel WSi SNSPD Arrays for the Lunar Lasercomm OCTL Terminal

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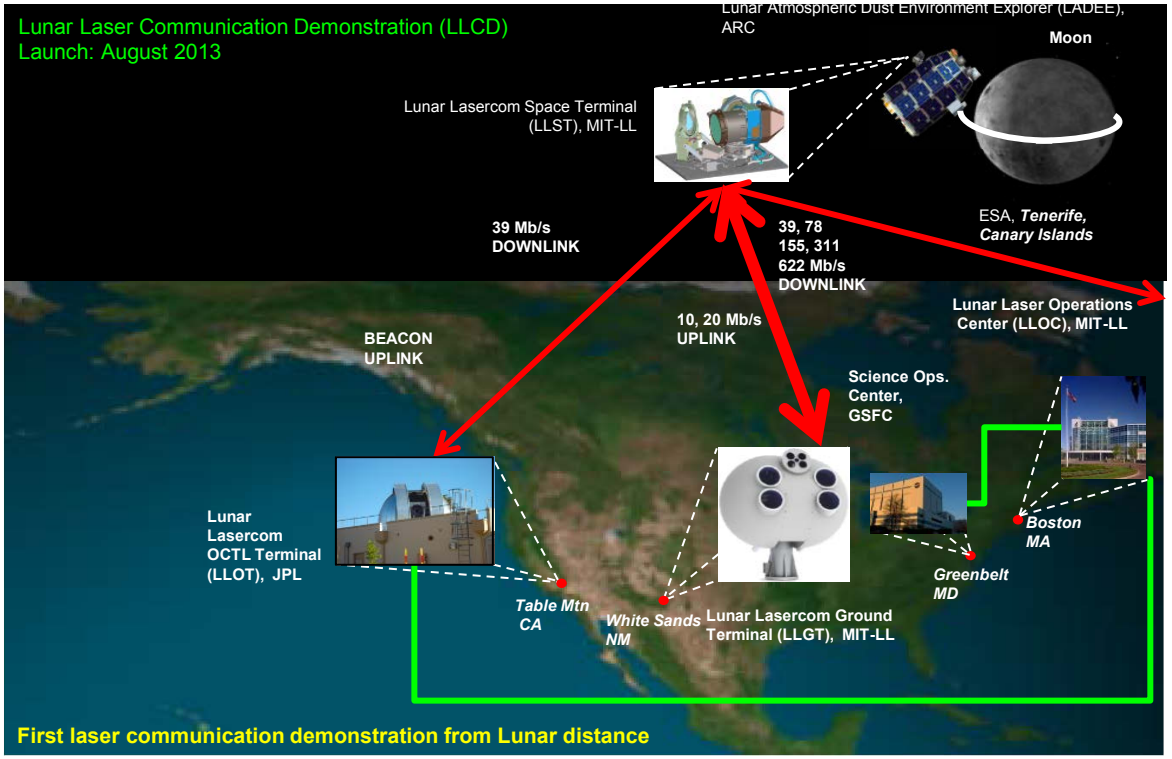
National Institute of Standards and Technology

LLCD Project Overview



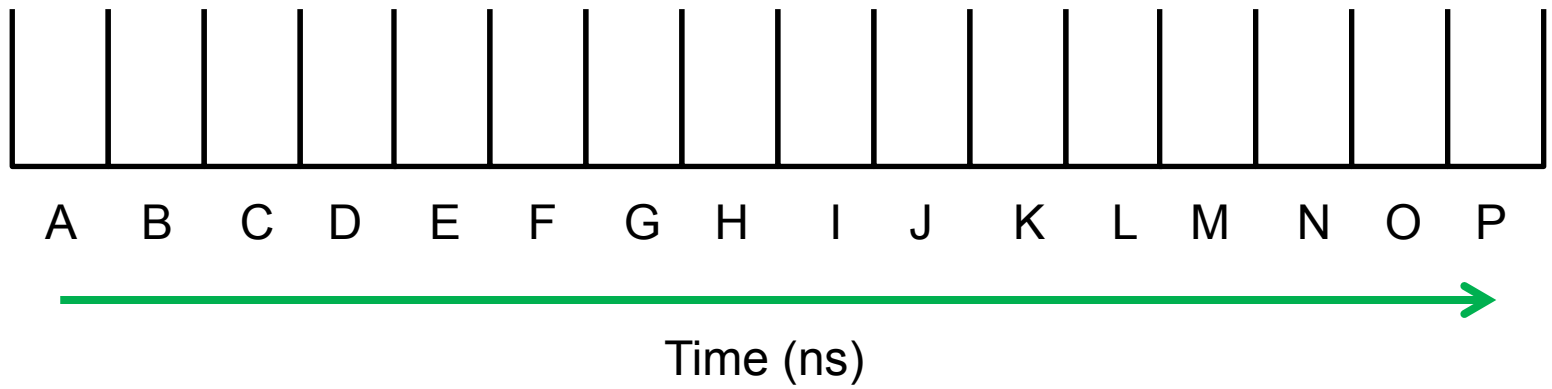
- Bidirectional laser communication demo from lunar orbit (400,000 km) at 1550 nm
- First demonstration of laser communication beyond earth orbit
- Uplink rates 10-20 Mbps, Downlink rates 39-622 Mbps
- Transmit Payload on LADEE Spacecraft (ARC) implemented by MIT-LL
- Managed by GSFC, Primary ground terminal implemented by MIT-LL
- Backup ground terminals implemented by JPL and ESA

LLOT Project Overview

- **LLOT is a backup ground station for the Lunar Laser Communication Demonstration (LLCD), located at Table Mountain, CA**
  - **16 day demonstration (August-October, 2013)**
  - **Link support at Sun-Earth-Probe (SEP) >10°**
  - **Transmit laser beacon to assist link acquisition**
  - **Receive downlink at 39 Mbps @ code-word error rate < 1E-5**
  - **Transmit limited real-time channel and link diagnostics to operations center**
  - **Process downlink in non-real time to extract information**

Pulse Position Modulation

- Data is encoded in optical pulse timing
- Ideal for “photon starved” applications such as deep space optical communication
- Send more data with less mass and power on the spacecraft
- LLST signals use PPM-16 encoding with 311 MHz – 5 GHz variable slot rate
- Fundamental channel capacity limit $\frac{h\nu}{2kTln2}$
- Requires detectors with high efficiency and sub-nanosecond time resolution



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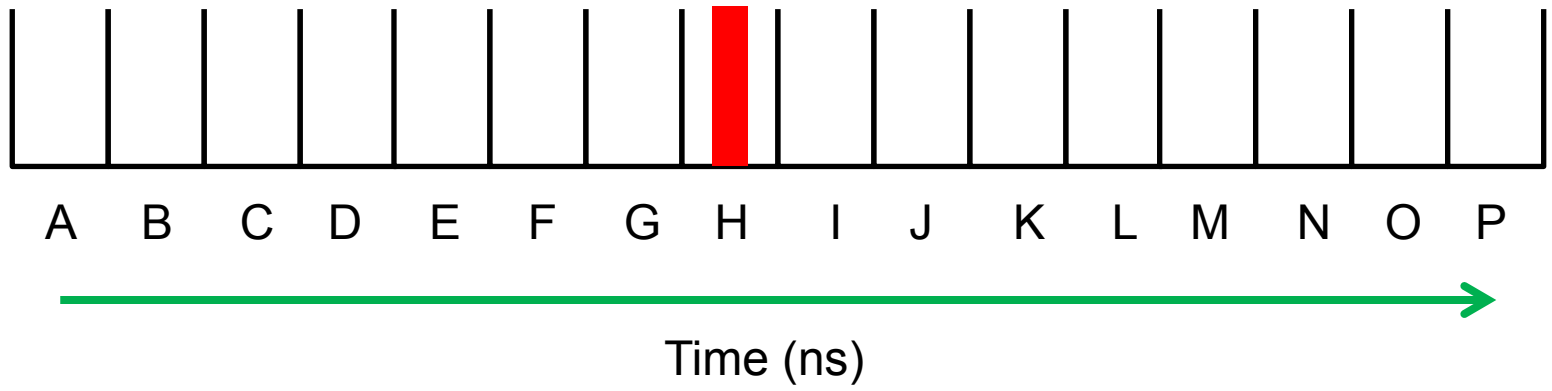

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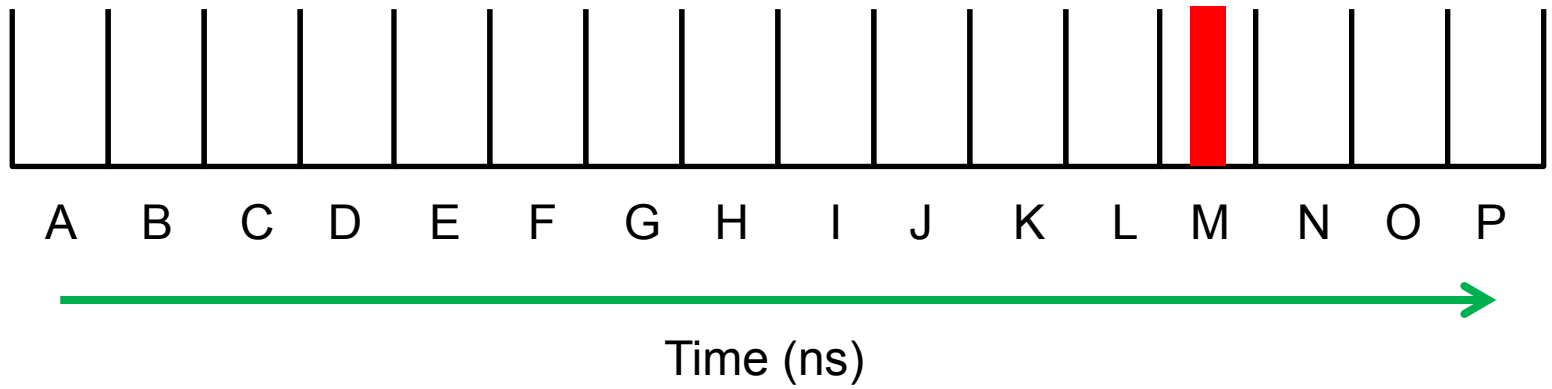
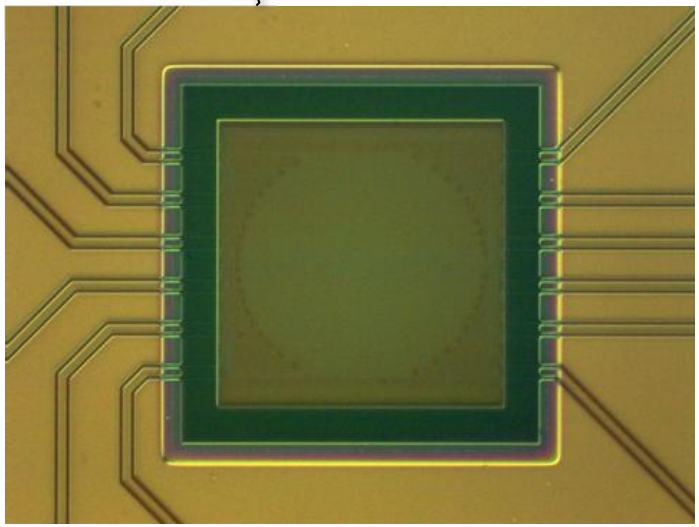


Detection Architecture

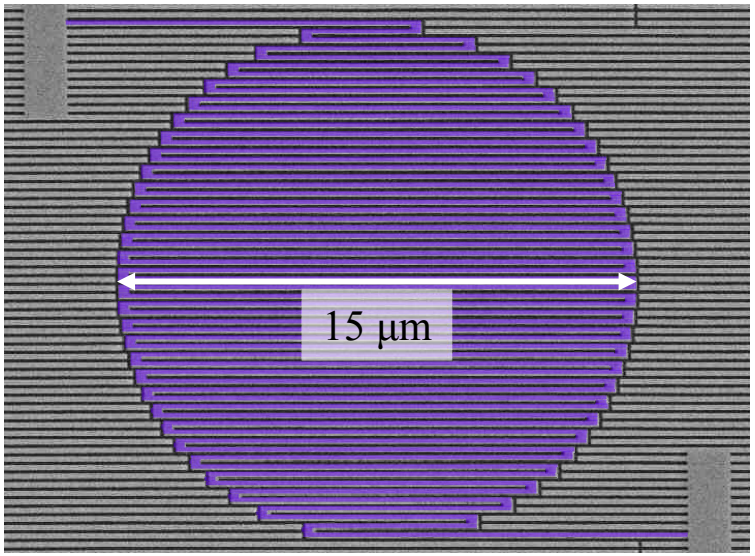
- 1.2-m telescope
- Signal coupled to GIF-625 multimode fiber

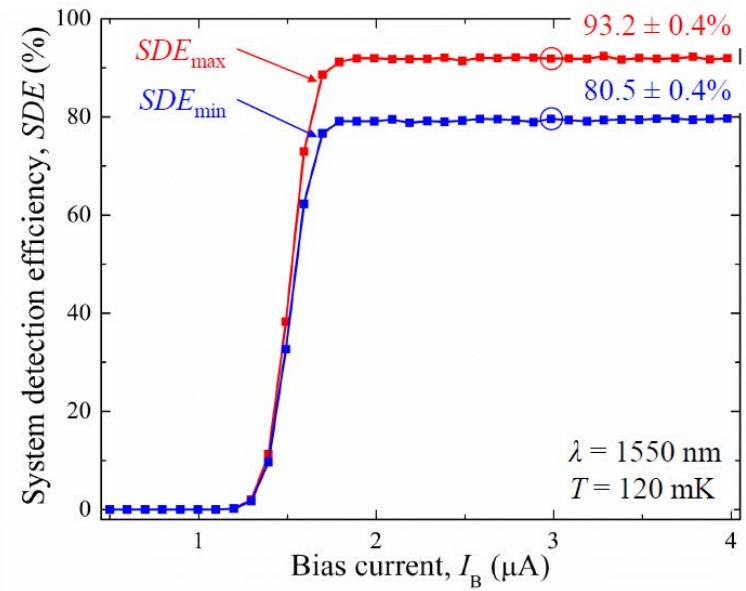


- 12-pixel WSi SNSPD array
- 64-µm diameter active area
- ~40% system detection efficiency
- All channels combined electronically
- Combined signal digitized @ 2.4 Gsps
- Receiver implemented in software

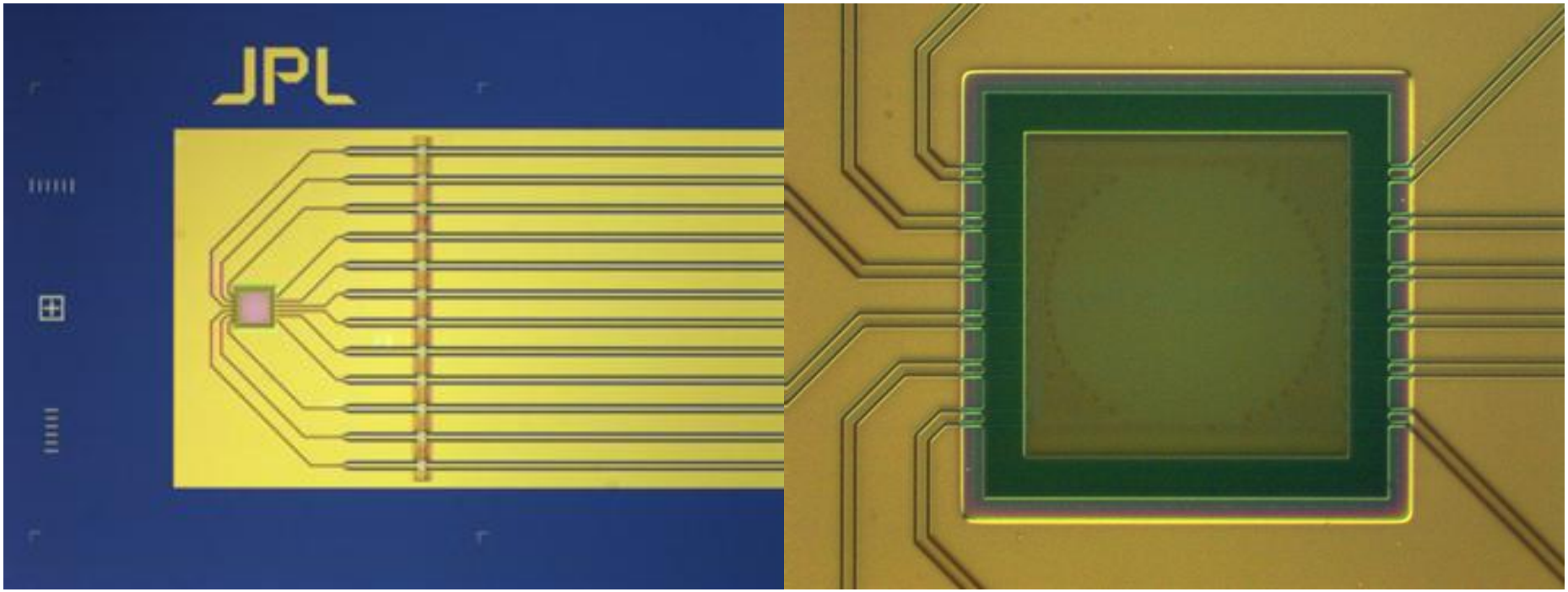
Single Pixel WSi SNSPDs

- Amorphous WSi, T_C = 3.1 K (bulk 5 K)
- Time-resolved single photon counting
- No intrinsic energy resolution
- 93% System Detection Efficiency with cavity
- < 100 ps timing jitter
- 20-60 ns recovery time
- 10-20 µm active area
- Device Dark Rate ~0.01 cps
- System Dark Rate ~1000 cps
- Cavity optimized for 1520-1610 nm
- Without cavity, operation shown 1 – 5 µm
- Operating temperature 1K
- Nanowires 4.5 x 120-160 nm
- 12-pixel arrays demonstrated for comm
- 64-pixel free space arrays in development



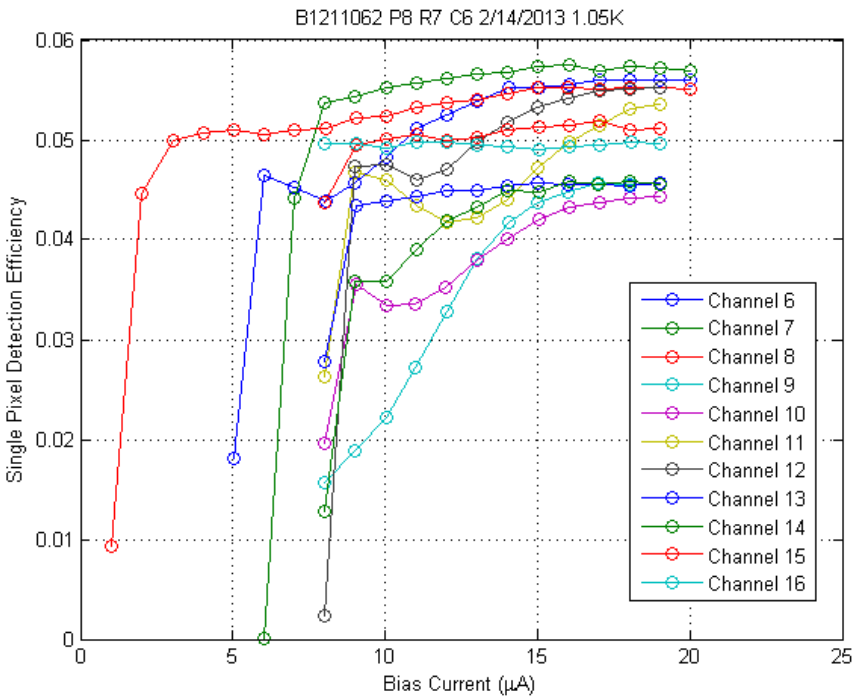


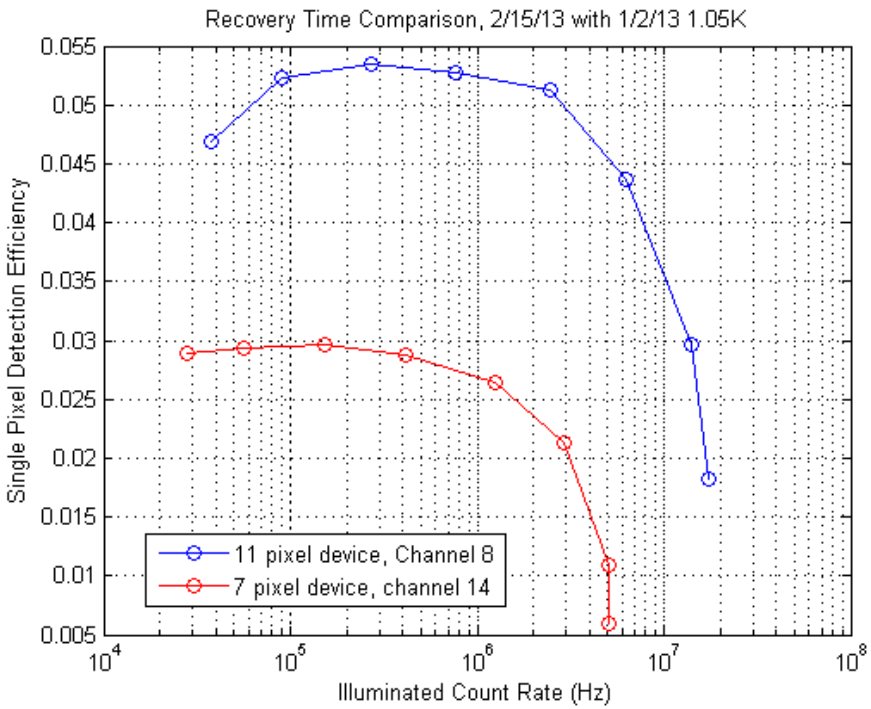
12 Pixel SNSPD Arrays



- 12 Counterwound Nanowires, 6 wires in each plane
- 64 µm diameter active area matched to GIF625 multimode fiber
- Quarter wave optical cavity to resonantly enhance absorbtion at 1.55 µm
- ~50% total array efficiency
- Max count rate ~10 MHz / channel
- Fabricated by Jeff Stern and Andrew Beyer

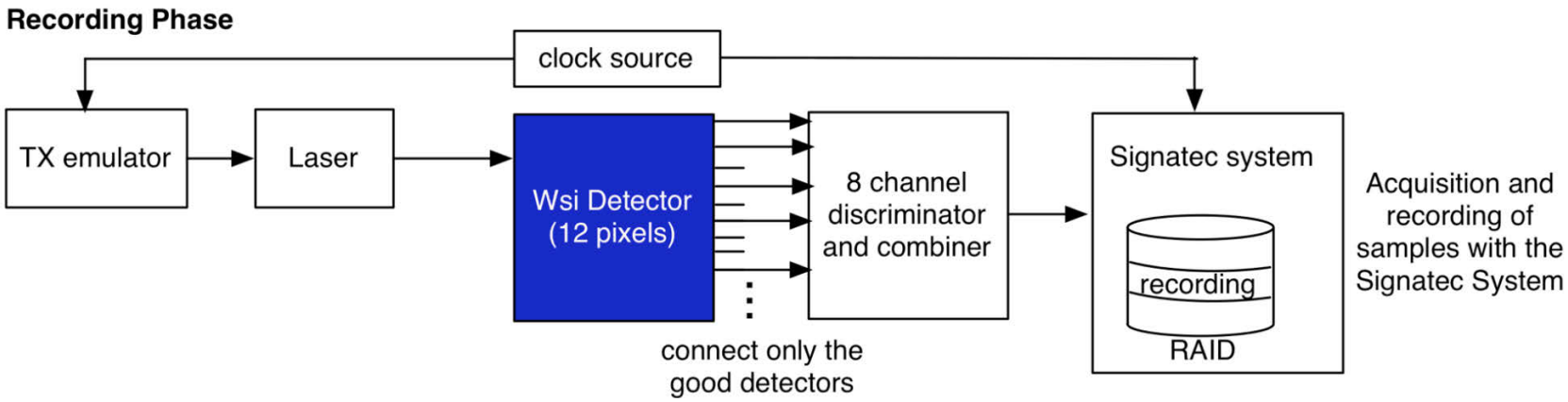
Array Performance





- All 12 channels are working and show saturated bias dependence
- Recovery time ~17 ns as measured from interarrival time histograms
- Maximum count rate ~10 MHz per channel
- 39 Mbps is safe, 155 Mbps may be possible

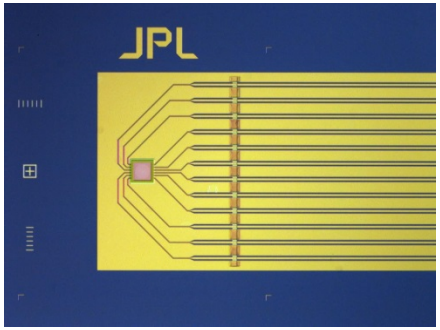
Link Closure Tests



- **Test signal generated using 1550nm laser modulated by waveform from transmit emulator; CW background generated by separate laser**
- **TX emulator configuration**
  - **Repeated all-zero PPM word for evaluating signal quality**
  - **Repeated single SC-PPM codeword for testing link closure**
- **Data sampled at ~1.25 GHz (1 sample/slot at 39 Mbps) and stored using Signatec signal acquisition system**
- **Transmitter and receiver clocks tied**
- **Interleaver not used**
  - **Interleaver reduces sensitivity to burst noise**

Link Closure Tests

- Device S1207251-P11-R11-C5
  - Better Device is now in hand
  - 7 out of 12 pixels are good on this device, total DE = 29%
    - Meets requirement of DE ≥ 28%
  - Operated at 1.0K

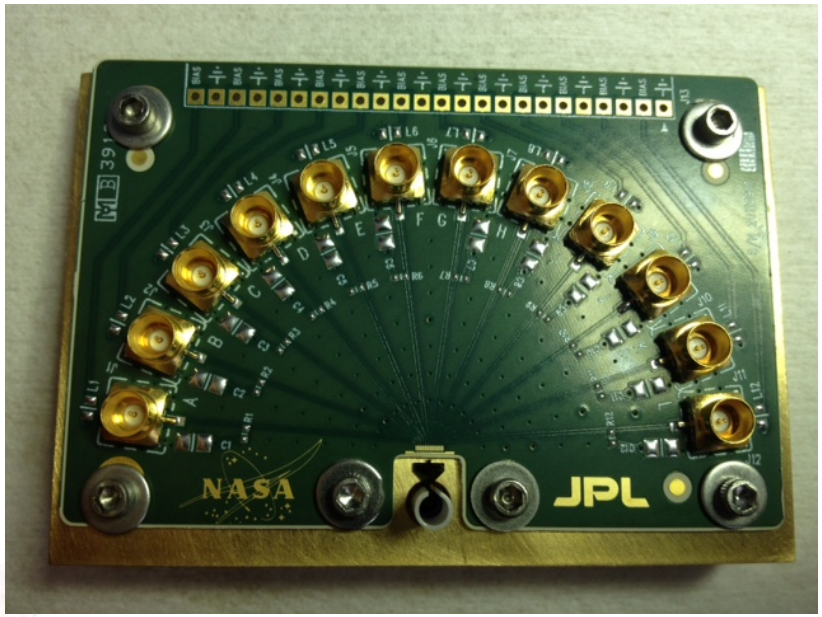


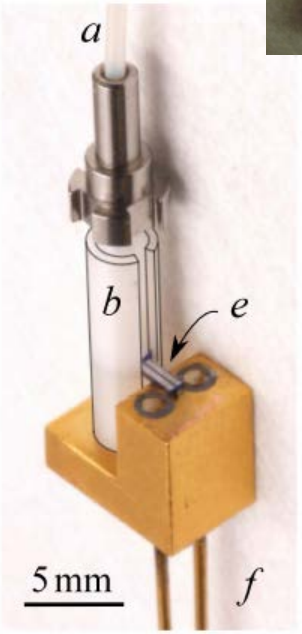
Ks = (signal photon rate)*DE/(19.5MHz)	Kb = (background photon rate)*DE/(312.5MHz)	Errors	Total CWs	CWER	Notes
3.93	0	0	8832	0	No background
3.97	0.0135	0	17664	0	Nominal signal:background ratio (SBR)
3.94	0.0269	0	17664	0	Nominal SBR with 3dB margin
3.99	0.0385	336	17664	1.9e-2	Worst case SBR
4	0.0769	17592	17664	0.996	Worst case SBR with 3dB margin

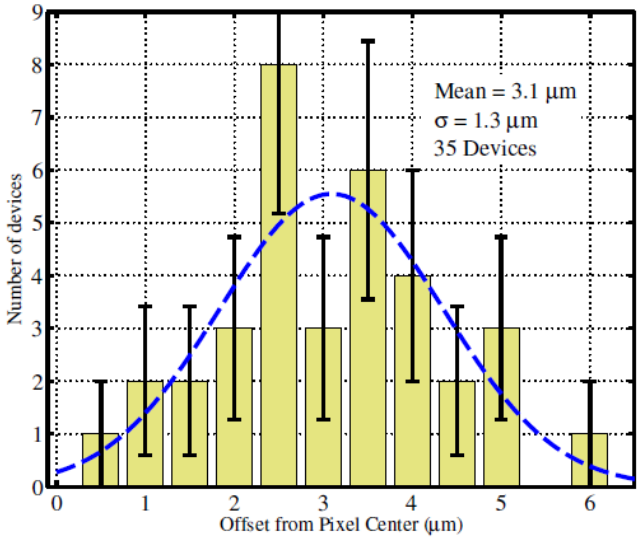
WSi detector closed the link at 39Mb/s with 3dB margin

Array Packaging

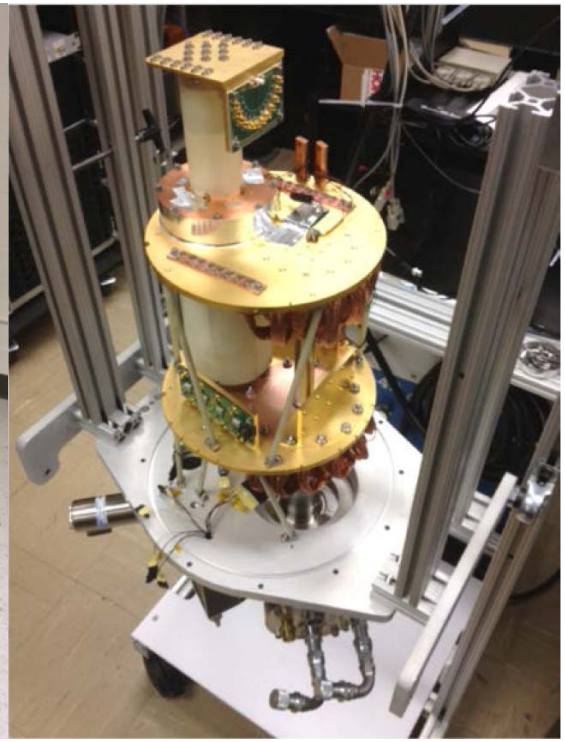
- Fiber Self-alignment concept developed by Sae Woo Nam / Aaron Miller at NIST
- Concept extended to 12-channel arrays for LLOT
- 12 waveguides connect nanowires to bond pads, then bonded to PCB with waveguides going to SMP connectors







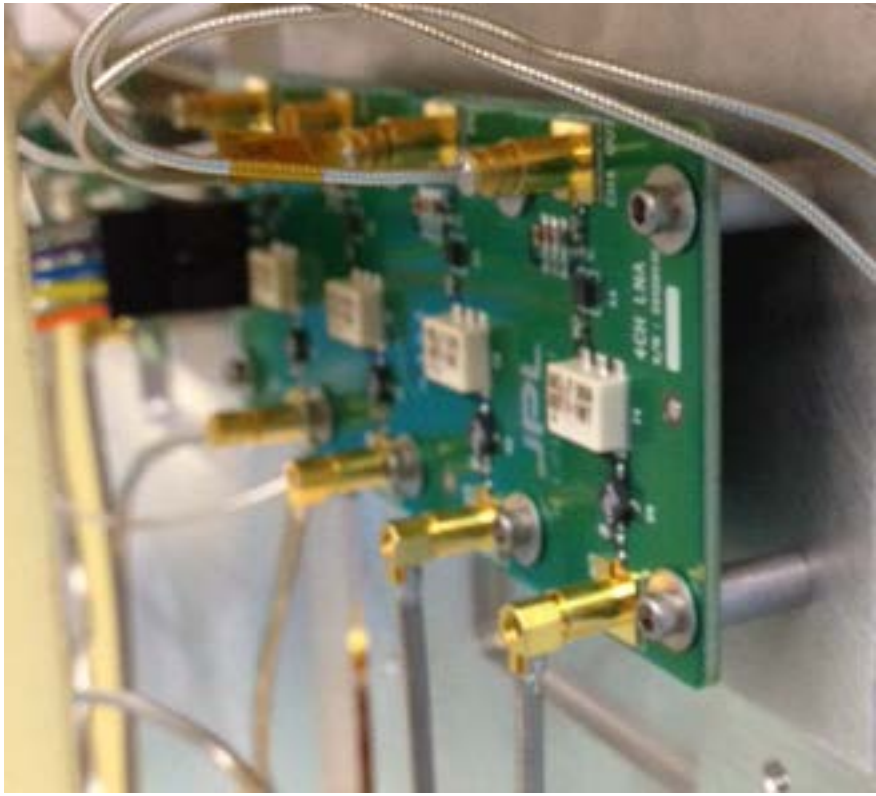
Cryogenic System

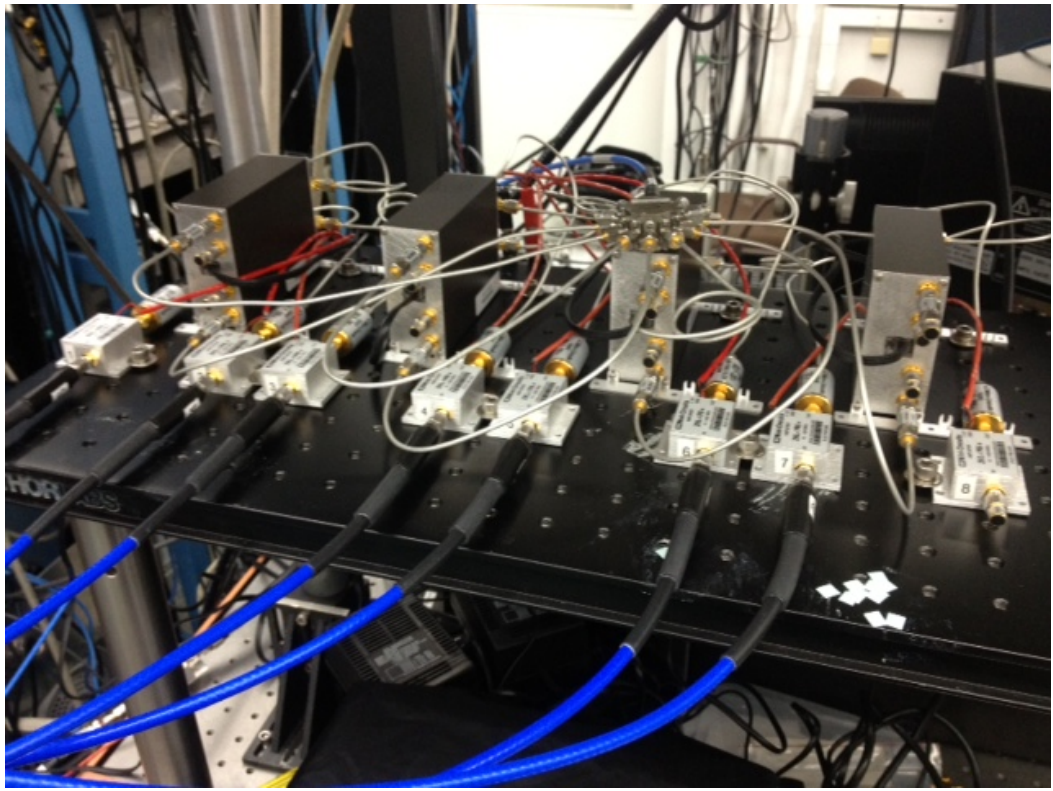


- Cryogen Free 1K fridge
- Closed-cycle He4 refrigerator
- Holds 780 mK > 12 hrs unloaded
- Backed by Sumitomo GM cooler with 3K and 40K stages
- Air-cooled compressor, 208V, well suitable for field operations.
- Now cold with many thanks to Marc Runyan!

Cryogenic Readout Electronics

- High bandwidth requires one cryogenic amplifier per channel
- Low-cost solution: Sirenza SGL-622Z
- ~90 K noise temperature at 20K with transformer coupling
- 5 MHz – 4 GHz amplifier band
- Not bad for 58 cents
- CuNi coax used from 1K -> 40K
- 3x 4-channel amplifier boards at 40K stage



Room Temperature Electronics

- Amplifier
- Filter
- Comparator
- ECL Converter
- Analog Combiner