

**SPIE Commercial + Scientific Sensing and Imaging
SPIE DCS 2016**

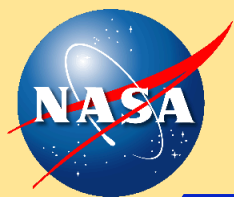


Low-Noise Free-Running High-Rate Photon-Counting for Space Communication and Ranging

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AGENDA



- I. NASA applications/requirements
- II. Silicon Geiger-mode avalanche photodiode array
- III. Mercury Cadmium Telluride (HgCdTe) linear-mode avalanche photodiode array
- IV. Summary

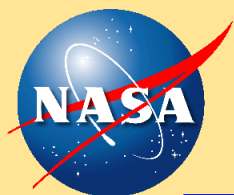


NASA-GSFC Single-Photon Counting Detectors

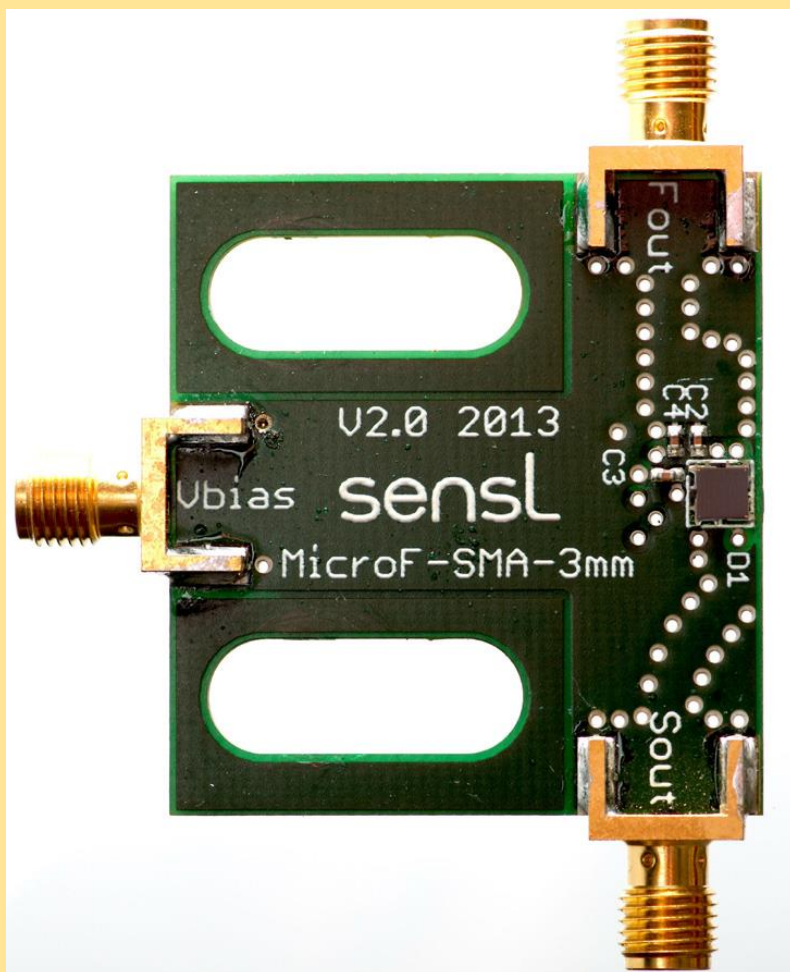
NASA Goals for Near-Earth Free-Space Communication



Photon-counting wavelengths	Favor 1550 nm, exploring 850 nm
Detection efficiency:	> 10%
Detector size:	> 200 μm diameter
2-D arrays	Act as single detector w/high speed output
Dark counts:	< 100 kcps
Maximum Count Rate:	>1 Gbps (through multiplexing)
Electrical bandwidth:	>1 GHz
Linearity:	> 98% fit
Timing jitter:	< 100 ps
Afterpulsing	< 1% in 1 μs
Operating temperature:	prefer thermo-electric cooler range
Space-qualifiable:	rad-hard, reliable, oversight protection



Sensl Silicon APD Array



Detector: Sensl MicroFM-SMA-10020

Lot # 131218

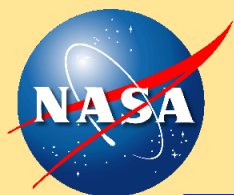
Active Area: 1mm x 1mm

of Cells: 1144

Fill Factor: 48%

Biased at -32V unless noted otherwise

NOTE: New “Red” version available with higher near-IR QE. NOT used in these tests.



Commercial transmitter 850 nm VCSEL (4 x 28G)



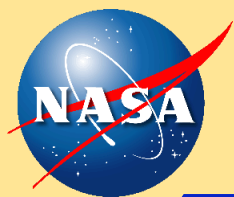
FINISAR®

Optical Transceivers
100GBASE-SR4 and OT
FTLC9141SENM



Distance:	100 m
Data Rate (max):	112 Gb/s
Protocol:	OTN OTU4 Compliant, 100G Ethernet Compliant
Low End Case Temperature (°C):	-5
High End Case Temperature (°C):	75
Diagnostics:	Digital
Transmitter:	4x VCSEL Array
Receiver:	PIN
Voltage Supply:	3.3
Connector:	MPO (MTP12)
Wavelength:	850nm Band

We used 10G version in this work.



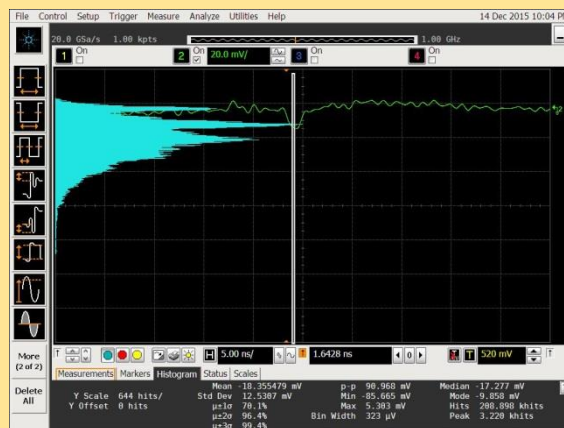
Detected photon number discrimination



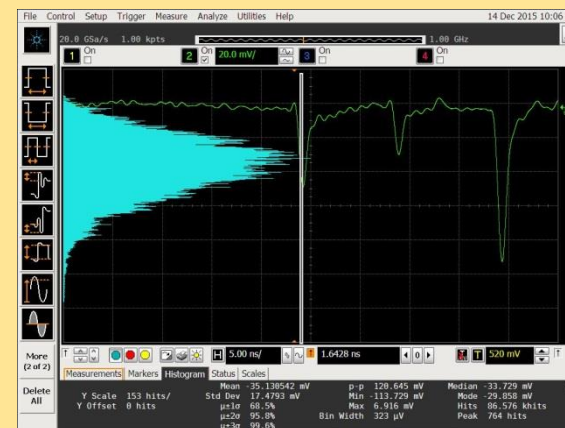
Goddard Space
Flight Center



$$\lambda = 0.8$$



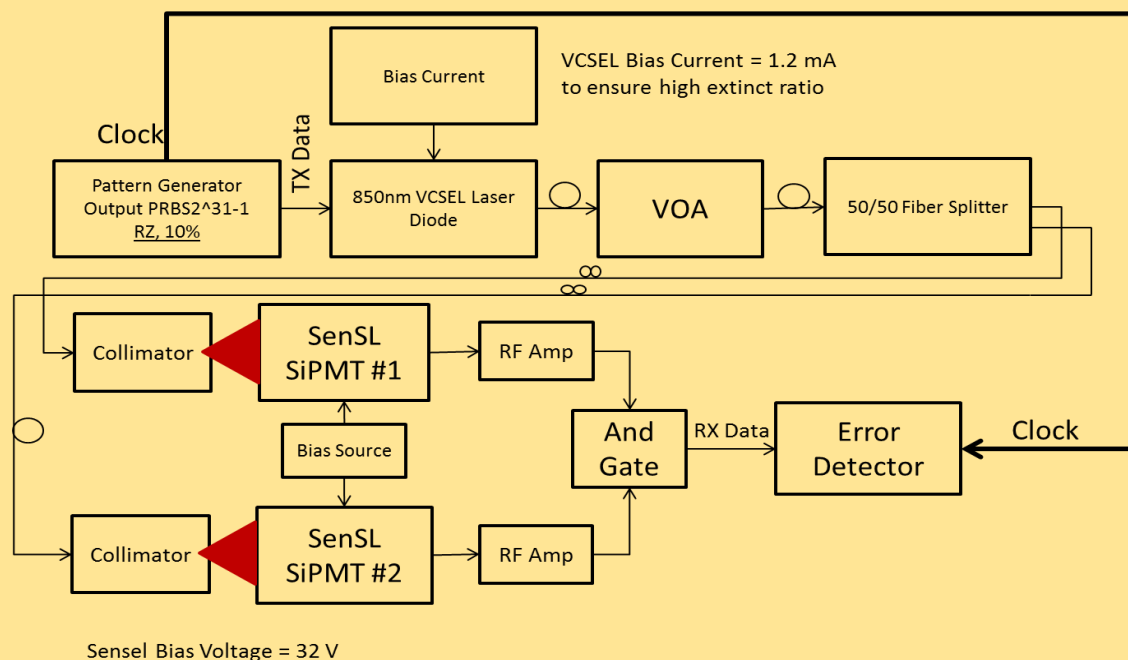
$$\lambda = 1.7$$

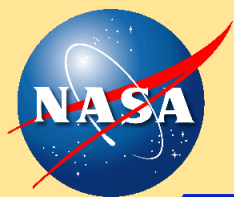


$$\lambda = 3.2$$



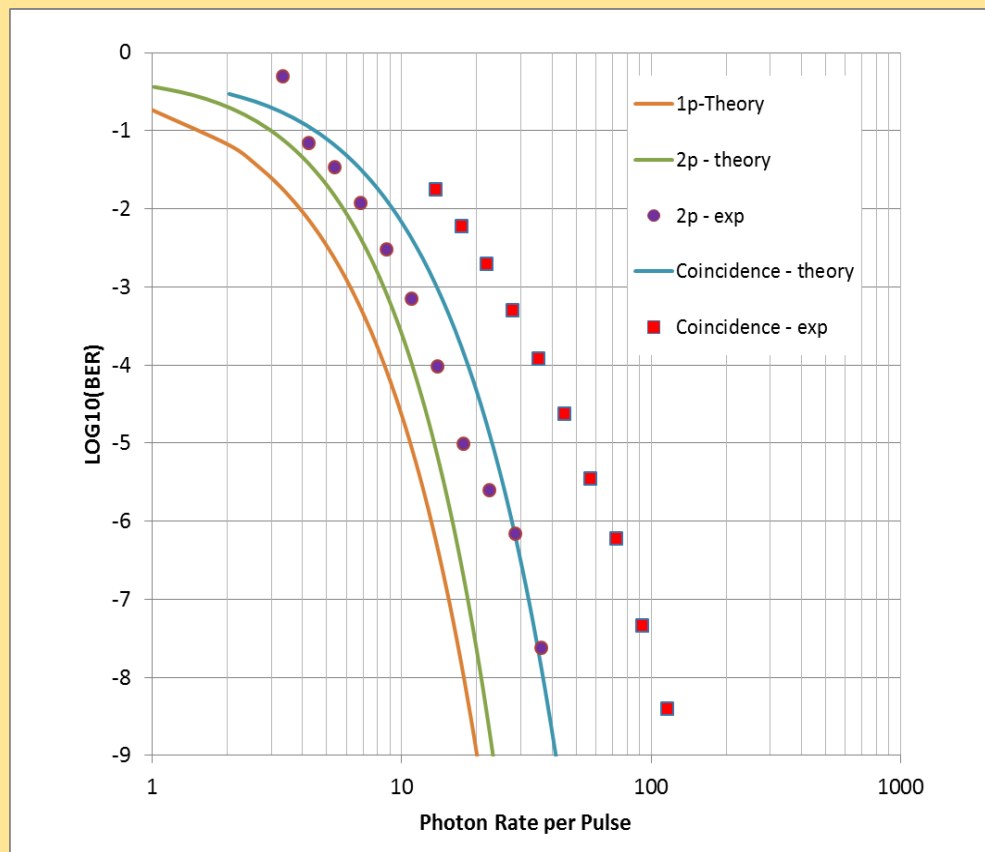
Free-space optical communication bench test diagram for the Sensl APD arrays using coincidence detection.



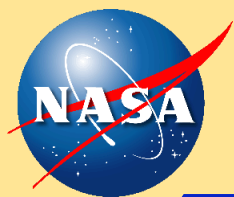


Sensl APD array

Communication performance (@850 nm)

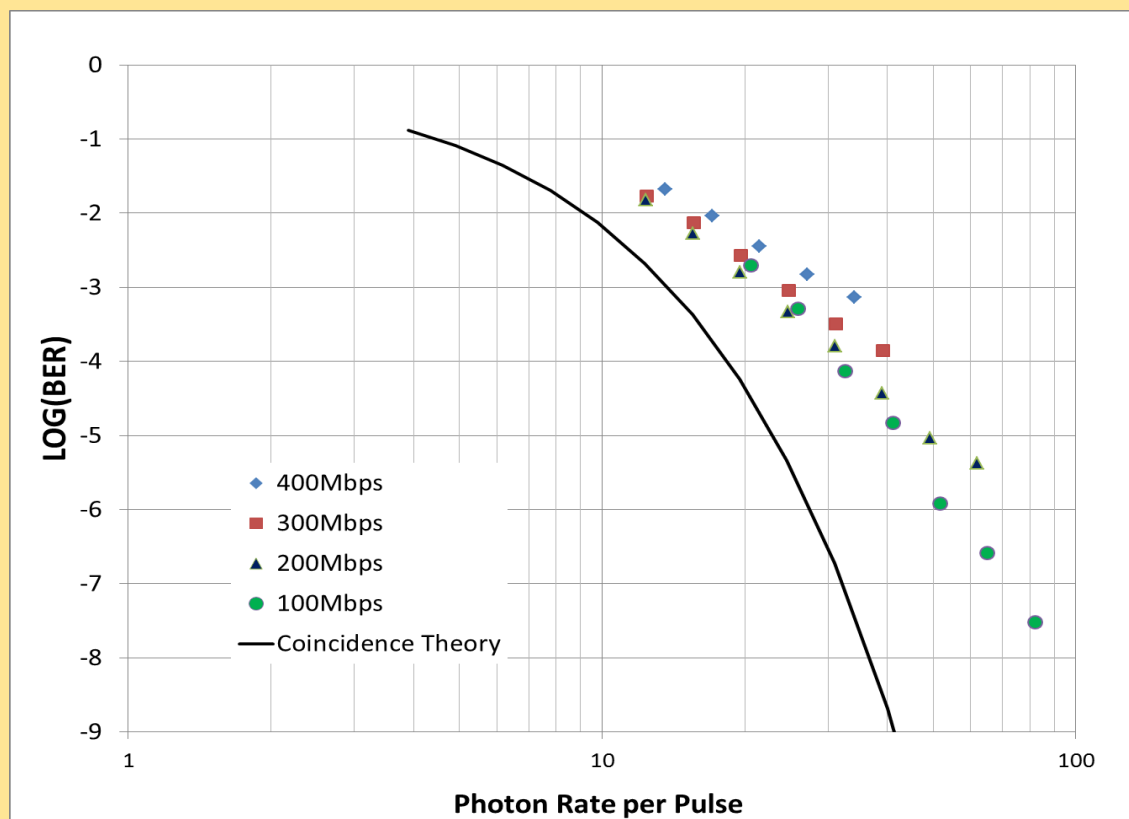


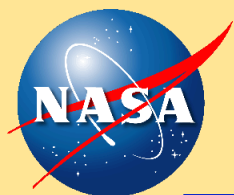
RZ-OOK 100 Mbps data rate with PRBS=2³¹-1



Sensl APD array

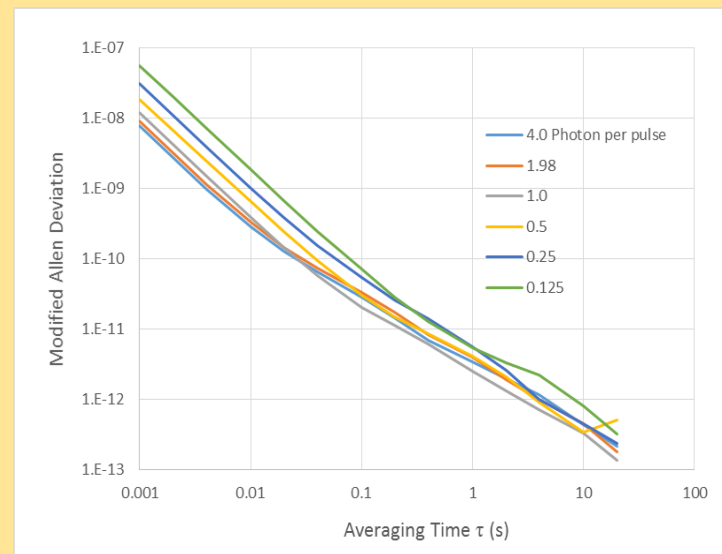
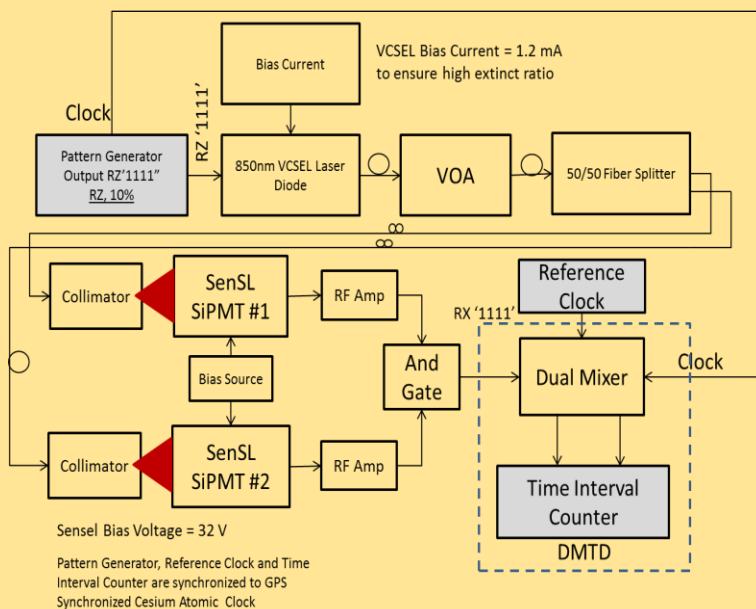
Communication performance with coincidence detection at various rates



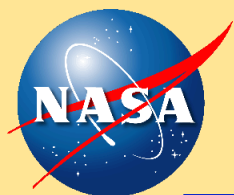


Sensl APD array

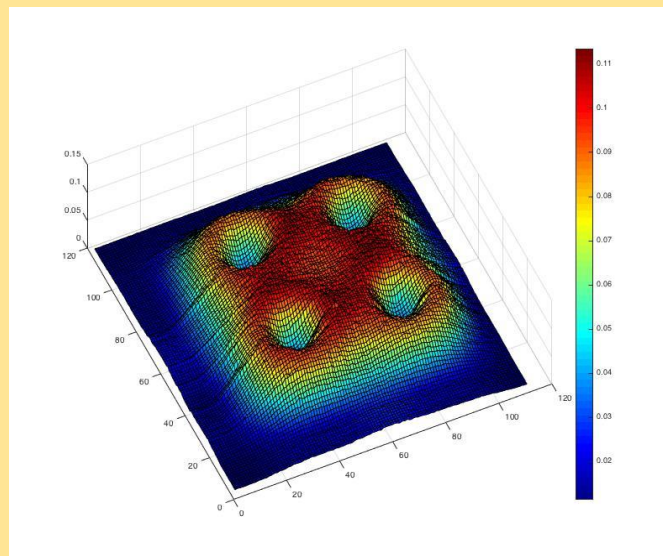
Ranging performance



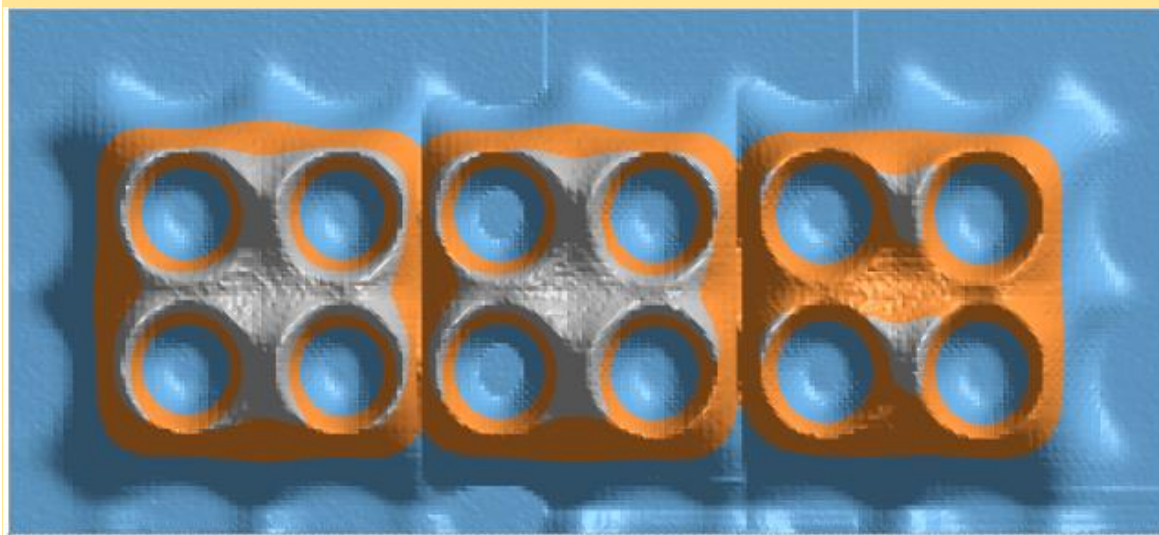
# ph per pulse	4	2	1	0.50	0.25	0.125
Modified Allan Deviation	3.48E-12	3.97E-12	2.49E-12	4.06E-12	5.54E-12	5.49E-12
Ranging Error (mm)	1.0	1.2	0.7	1.2	1.7	1.6



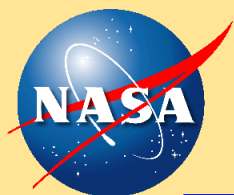
DRS Inc. HgCdTe APD



single pixel
consisting of
4 mesas with 11 V

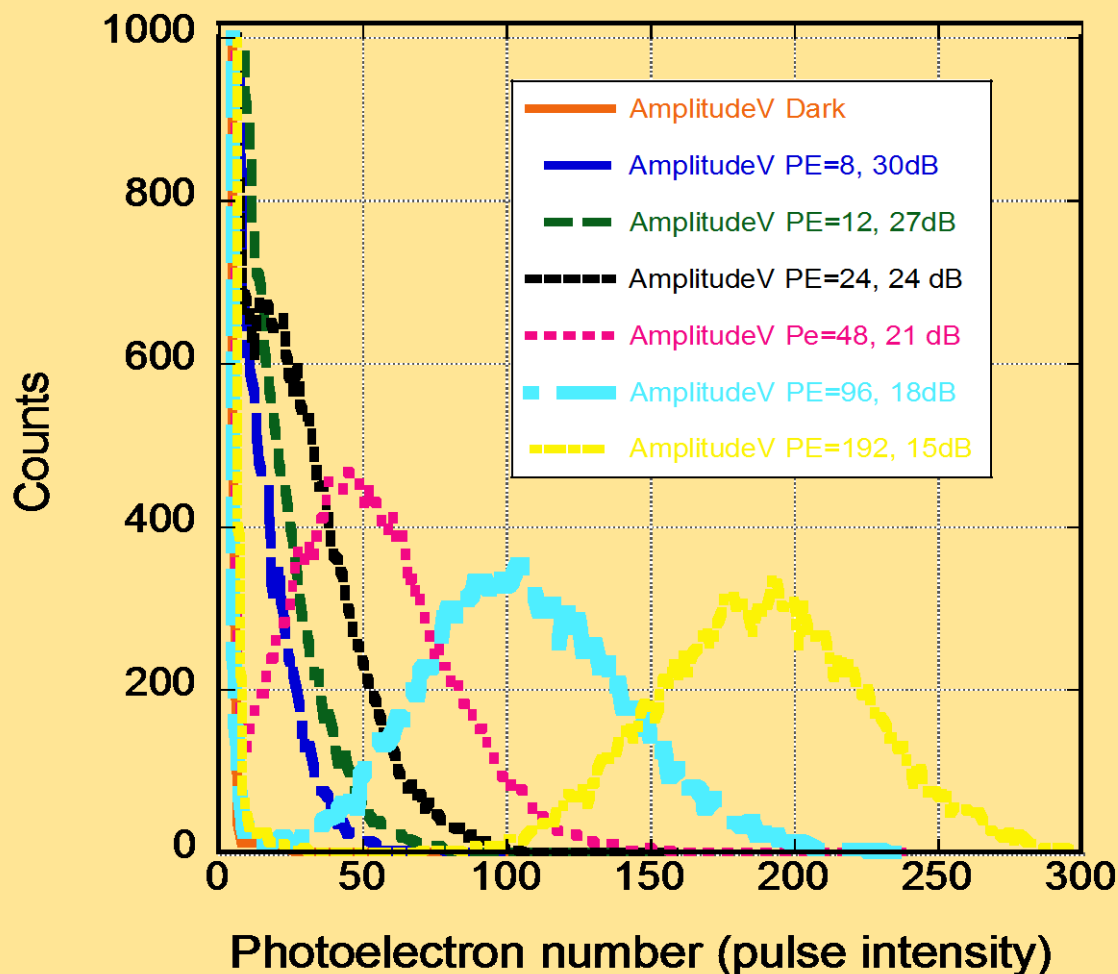


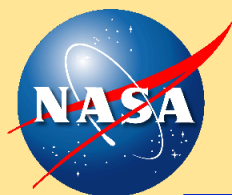
3 pixels



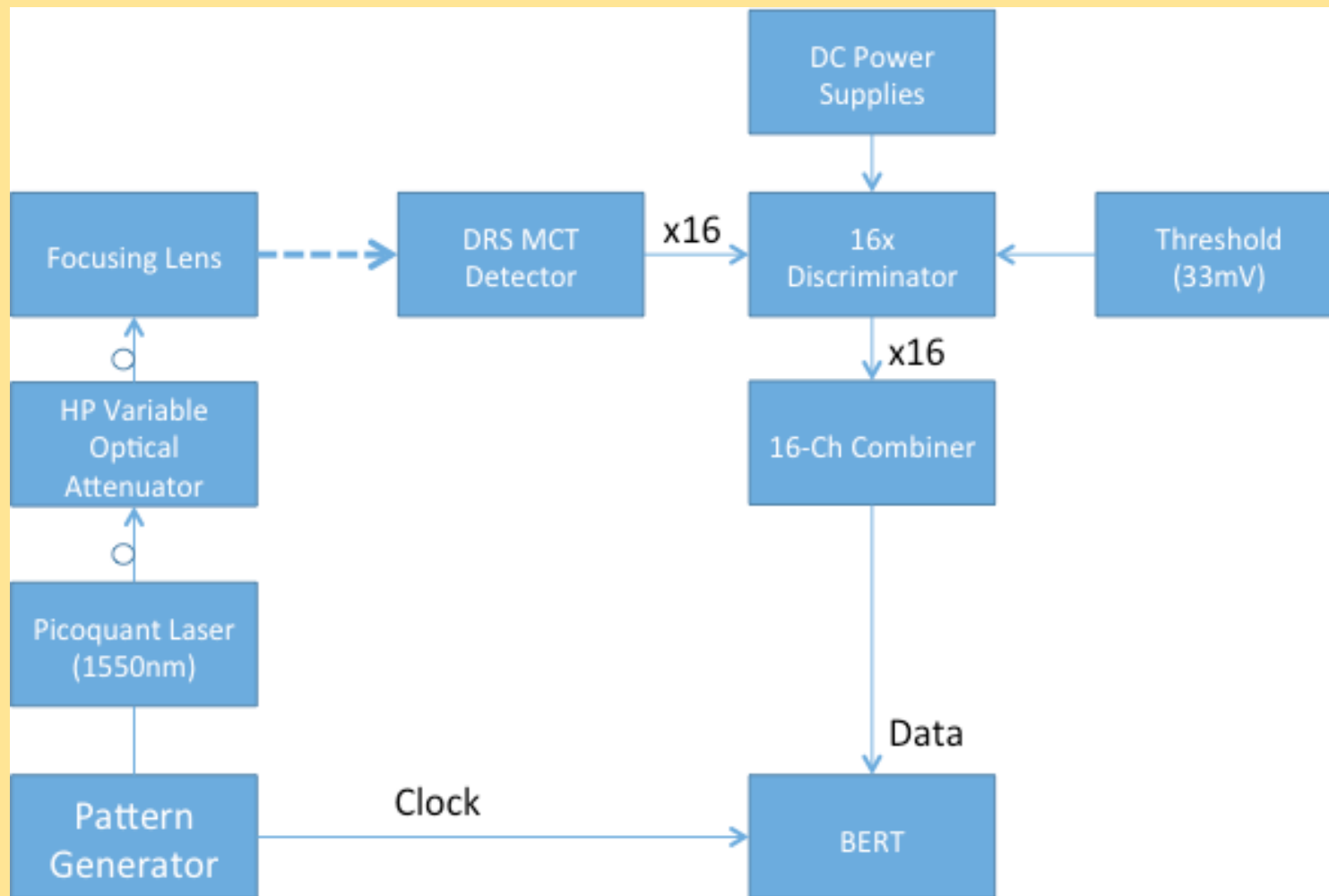
DRS HgCdTe APD

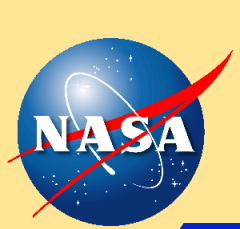
Intensity Pulse Height Distribution



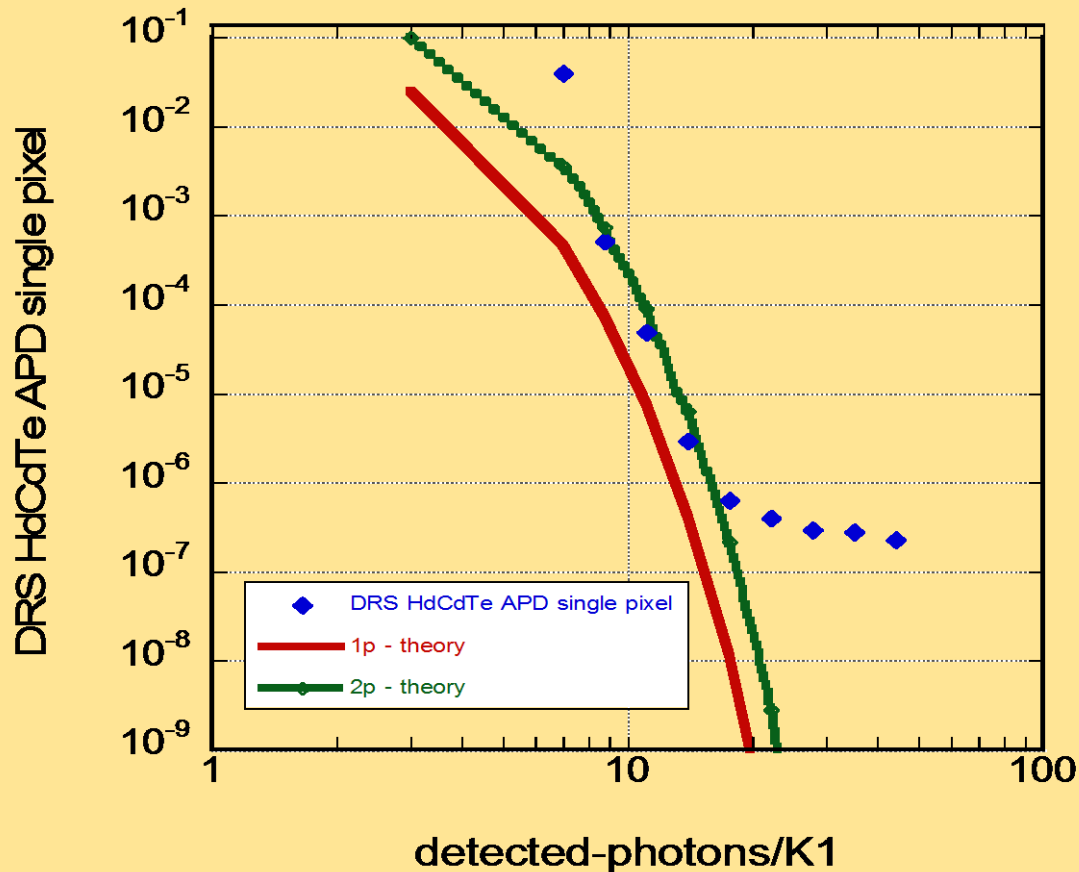


Communication performance (@1550 nm) test with DRS HgCdTe APD receiver

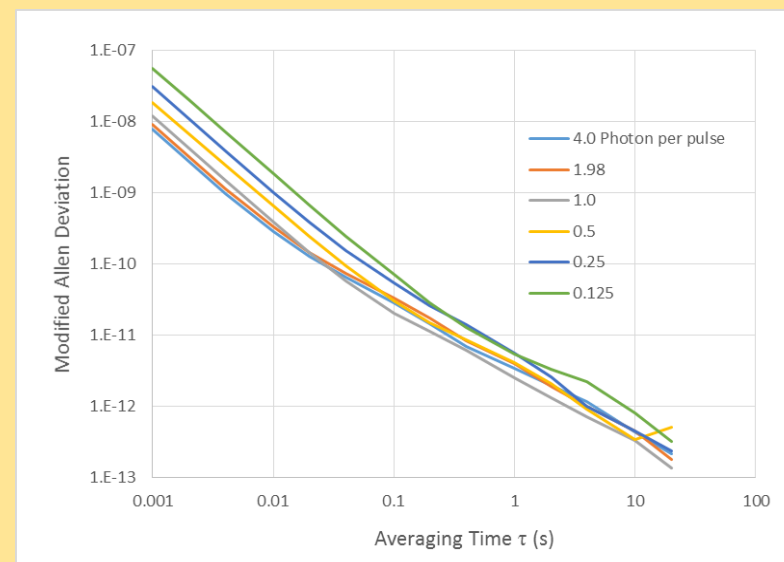
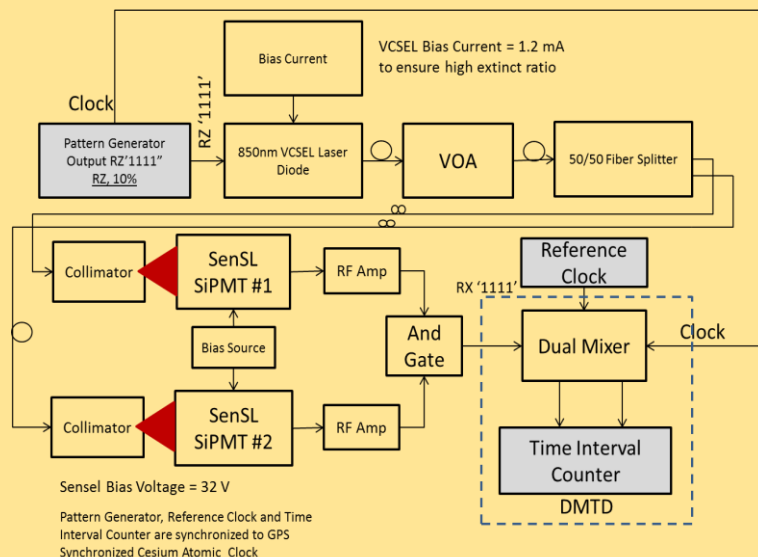




DRS HgCdTe APD experimental BER data from a single pixel

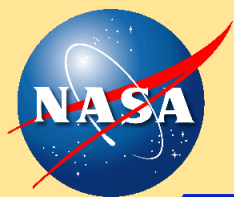


RZ-OOK 50 Mbps data rate with PRBS=2³¹-1



# ph per pulse	4	2	1	0.50	0.25	0.125
Modified Allan Deviation	3.48E-12	3.97E-12	2.49E-12	4.06E-12	5.54E-12	5.49E-12
Ranging Error (mm)	1.0	1.2	0.7	1.2	1.7	1.6

RZ-OOK 10 Mbps data rate with RZ'1111



SUMMARY



- I. Demonstrated photon-counting communication using three ideas:
 - 1) use an array of photon-counting elements wired together as a single detector
 - 2) use a high pass filter, ideally on each array element (or on the array output to only preserve the information-bearing portion of the waveform)*
 - 3) depending on the photon-counting element excess noise, use either a “two-photon” intensity threshold level or an AND-gate with coincidence detection.

* Pavlov, N. “Silicon Photomultiplier and Readout Method” USPTO Patent Application Publication, No. US2013/0099100 A1 (2013).

II. Commercial components

Commercial 850 nm VCSEL transmitters and silicon APD Geiger-mode arrays provide a viable path to low-cost high-rate (500 Mbps) free-space optical communication links.

III. HgCdTe APD

Demonstrated excellent communication performance at 50 Mbps @1550 nm with single-pixel HgCdTe APD.

IV. Demonstrated millimeter level accuracy of Photon Counting Ranging over Laser Communication Data Link

IV. Future

>1 Gbps with single array (in InGaAs) and multi-Gbps with WDM should be viable.