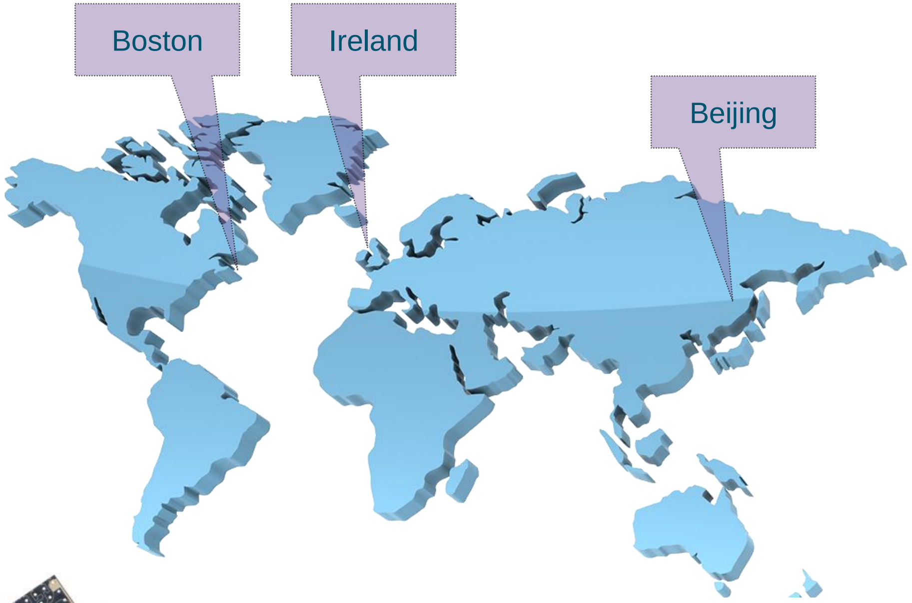
SiPM and SPAD Arrays for Next Generation LiDAR

Salvatore Gnecchi, PhD
Senior LiDAR Engineer

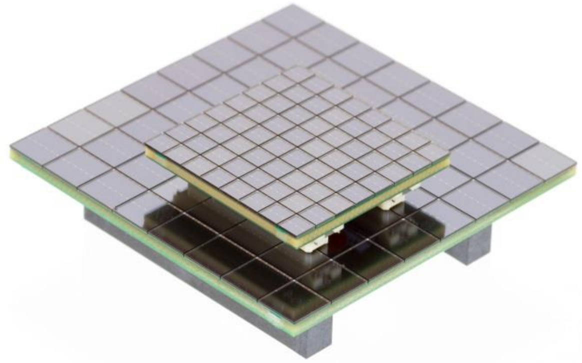
International SPAD-Sensor Workshop

SensL Quick Facts

Business	Low Light Sensors
Markets	Medical Imaging Radiation Detection Automotive LiDAR
Model	Fabless Semiconductor

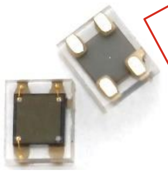


- Established 2004
- ISO9001:2008 Certified



LiDAR Product & Demonstrator Roadmap

Products

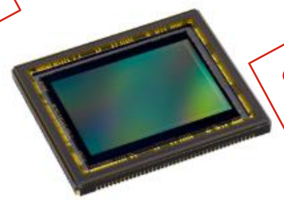


Released

RA-Series SiPM

Sampling

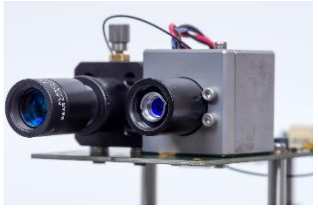
1x16 SiPM Array

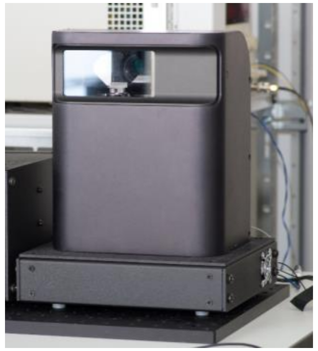


Sampling
Q2 2019

3D ToF SPAD Array

Demonstration Platforms





Gen 1 – Single Point
- 30m indoors
- February 2016

Gen 2 – Single Point
- 100m outdoors
- Low reflective targets
- September 2016

Gen 3 – 3D ToF Imaging
- 100m+ outdoors
- Low reflective targets
- June 2017

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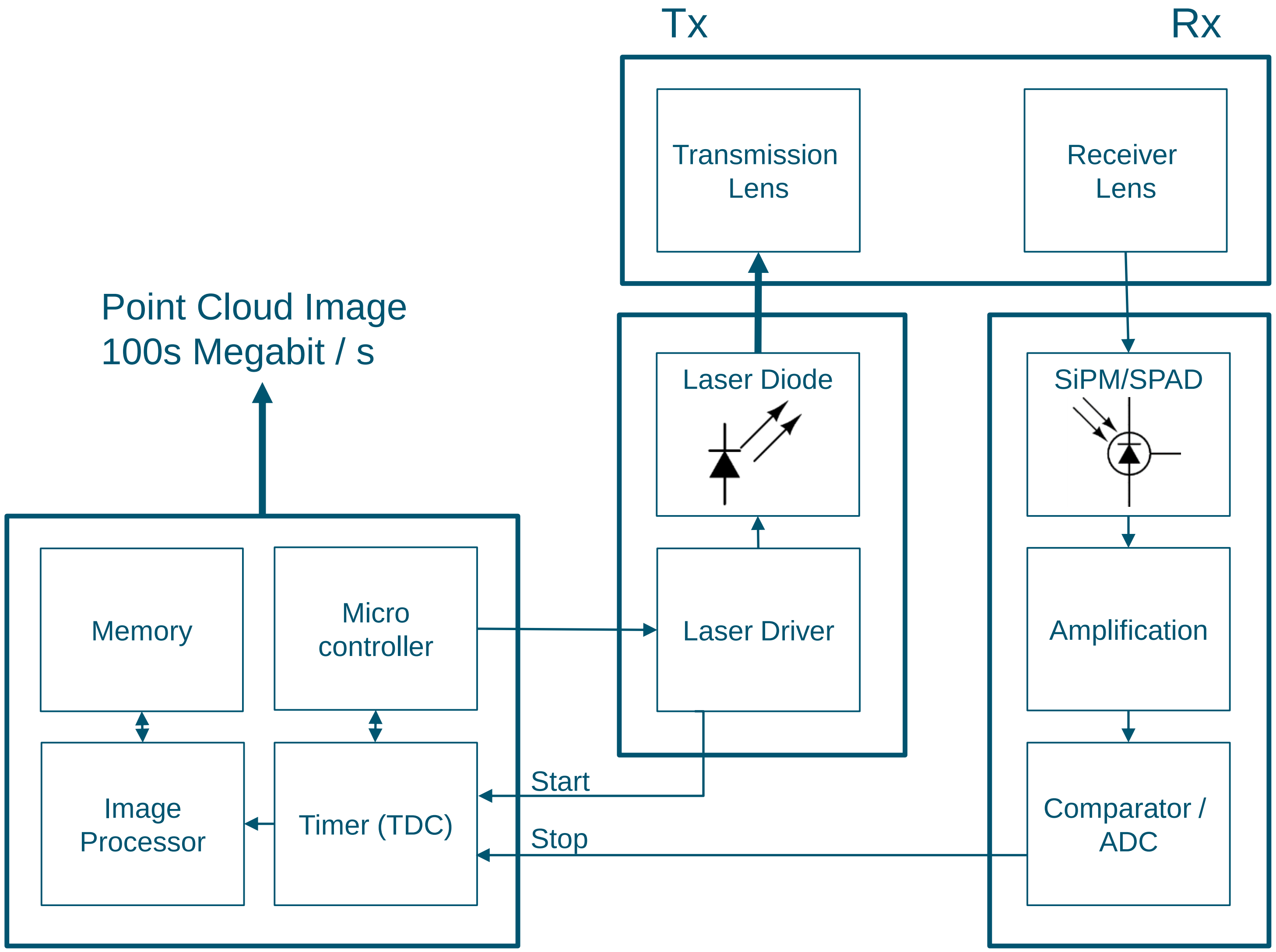
Agenda

- Anatomy of a LiDAR system
  - Tx: eye safe laser beam
  - Rx: high sensitivity SiPM/SPAD sensors
- Challenges for long distance outdoor LiDAR systems
- Current LiDAR systems solutions based on SiPM sensors
- Future LiDAR sensors based on SiPM/SPAD array sensors
- SensL Gen3 demonstrator

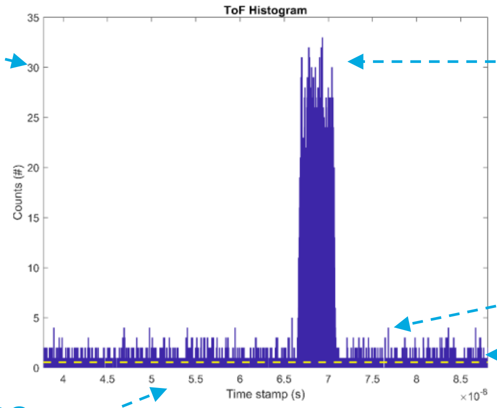
Anatomy of a LiDAR System



Direct ToF LiDAR Measurement Techniques

- **Single shot:** one laser pulse per measurement (**SiPM**)
  - A single returned pulse is time stamped and the range determined
  - High optical SNR required

- **Multishot:** multiple laser pulses per measurement (**SiPM or SPAD**)
  - Laser pulses are time stamped & histogrammed
  - Range is determined from the histogram data
  - Increases SNR extending range



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Challenges for Long-distance LiDAR Systems

- Tx: Laser diodes / Scanning method
  - High and eye safe laser peak power required for long distance
  - High repetition rate for high frame rate systems
  - Short laser pulses for power optimization
  - Wavelength drift over temperature
    - Allows for narrower bandpass filters to be used and improve ambient rejection
  - Solid-state scanning methods
    - MEMS
    - OPA
- **Rx: SiPM/SPAD**
  - High responsivity at 905 nm and 940 nm for long range
  - High dynamic range for ambient light rejection
  - Compact size – cost effective
  - High pixelization
    - For high angular resolution
    - For best SNR performance
  - High data rate
  - Fast read out

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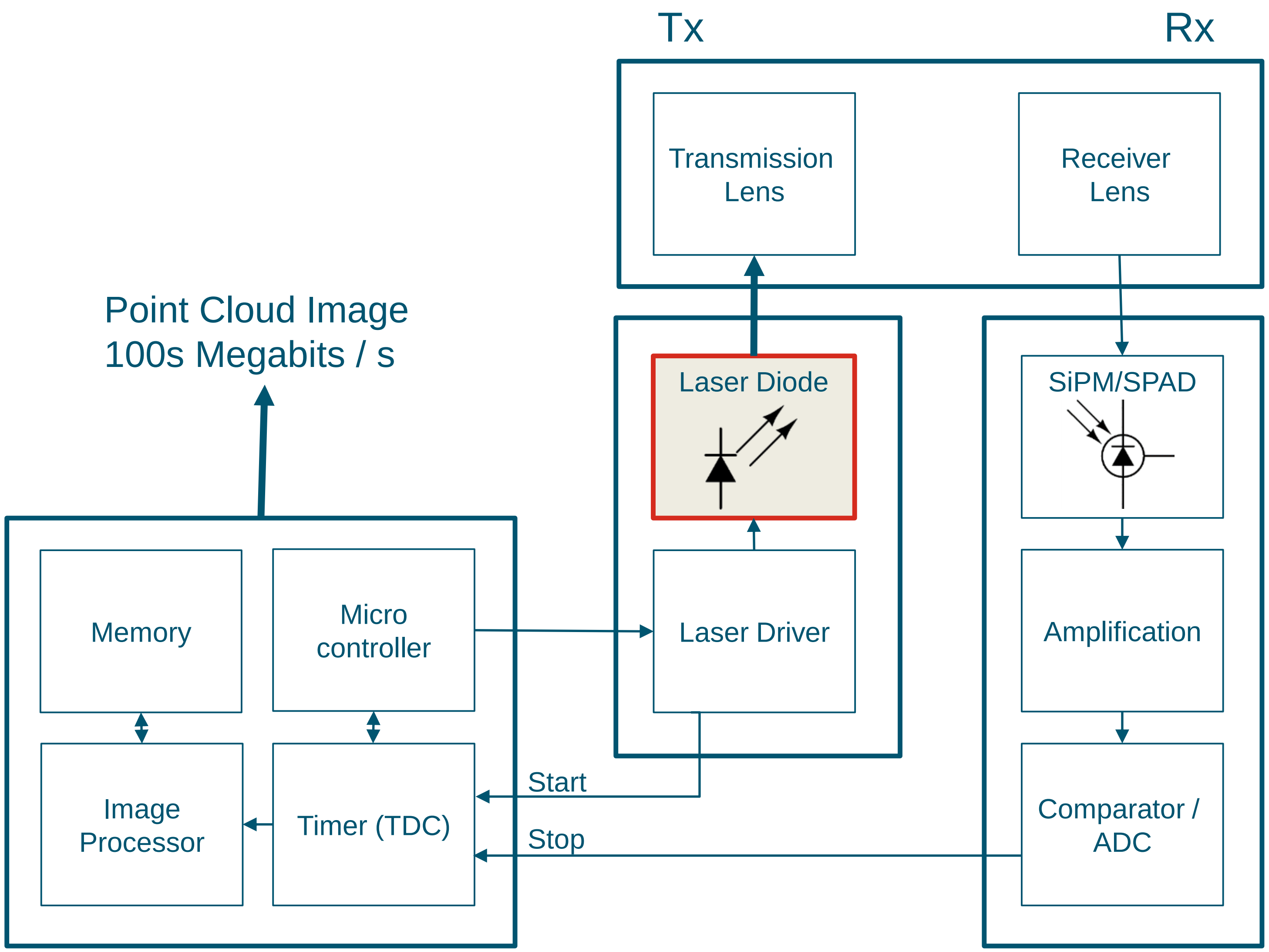
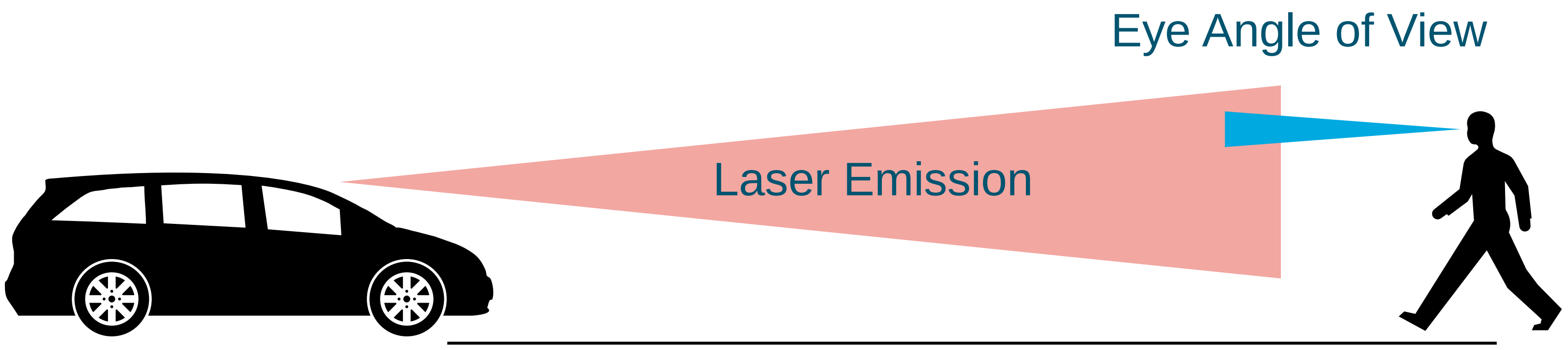
Anatomy of a LiDAR System



Laser Eye Safety and LiDAR Systems



- Long range LiDAR requires high peak power lasers
- Laser power is spread over a wide angle of view (AoV)
- Aperture of the human eye has a limited AoV
- Important factors to meet eye safety limits from IEC 68025
  - Shorten the laser pulse to reduce energy per pulse
  - Increase the laser aperture for light leaving the LiDAR system

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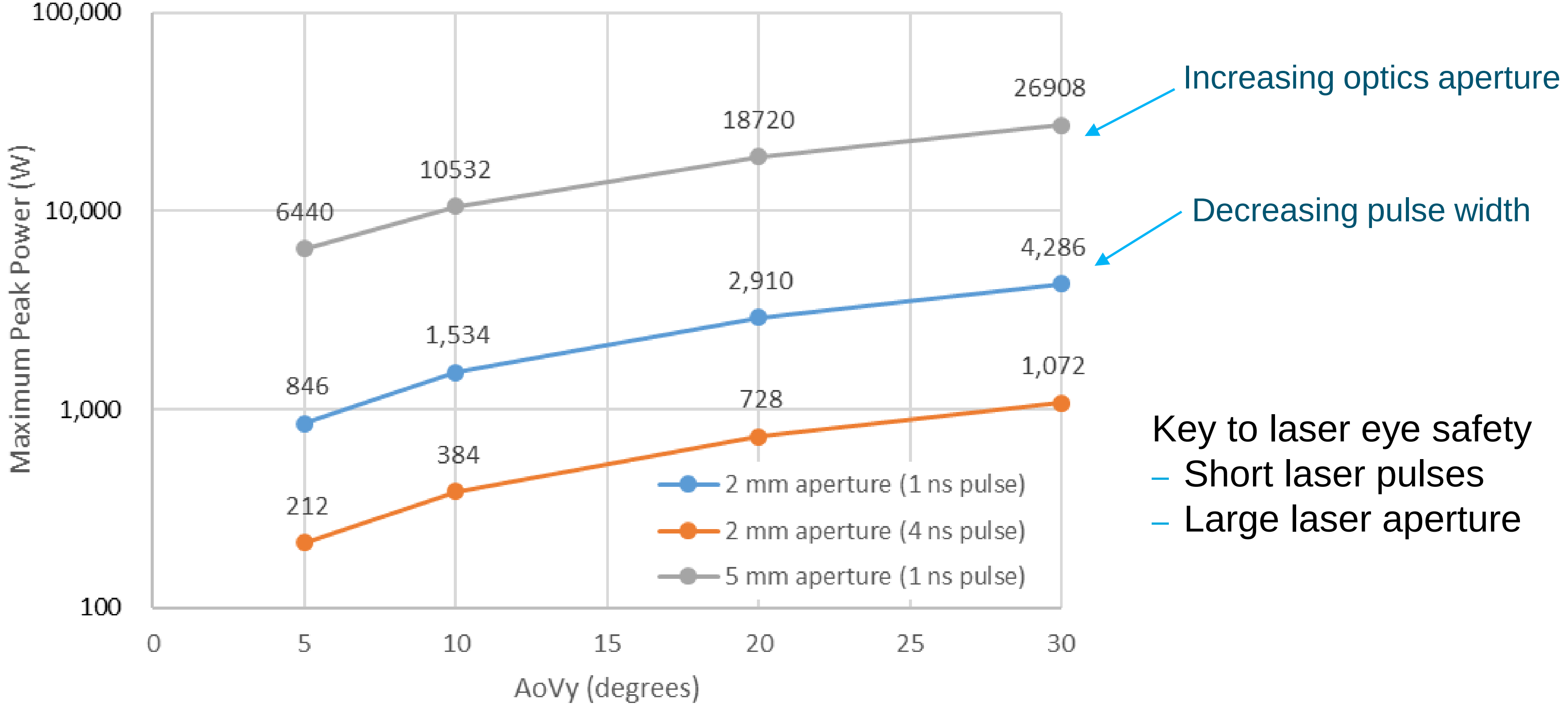
Laser Eye Safety

Maximum scanning system laser power at 905 nm

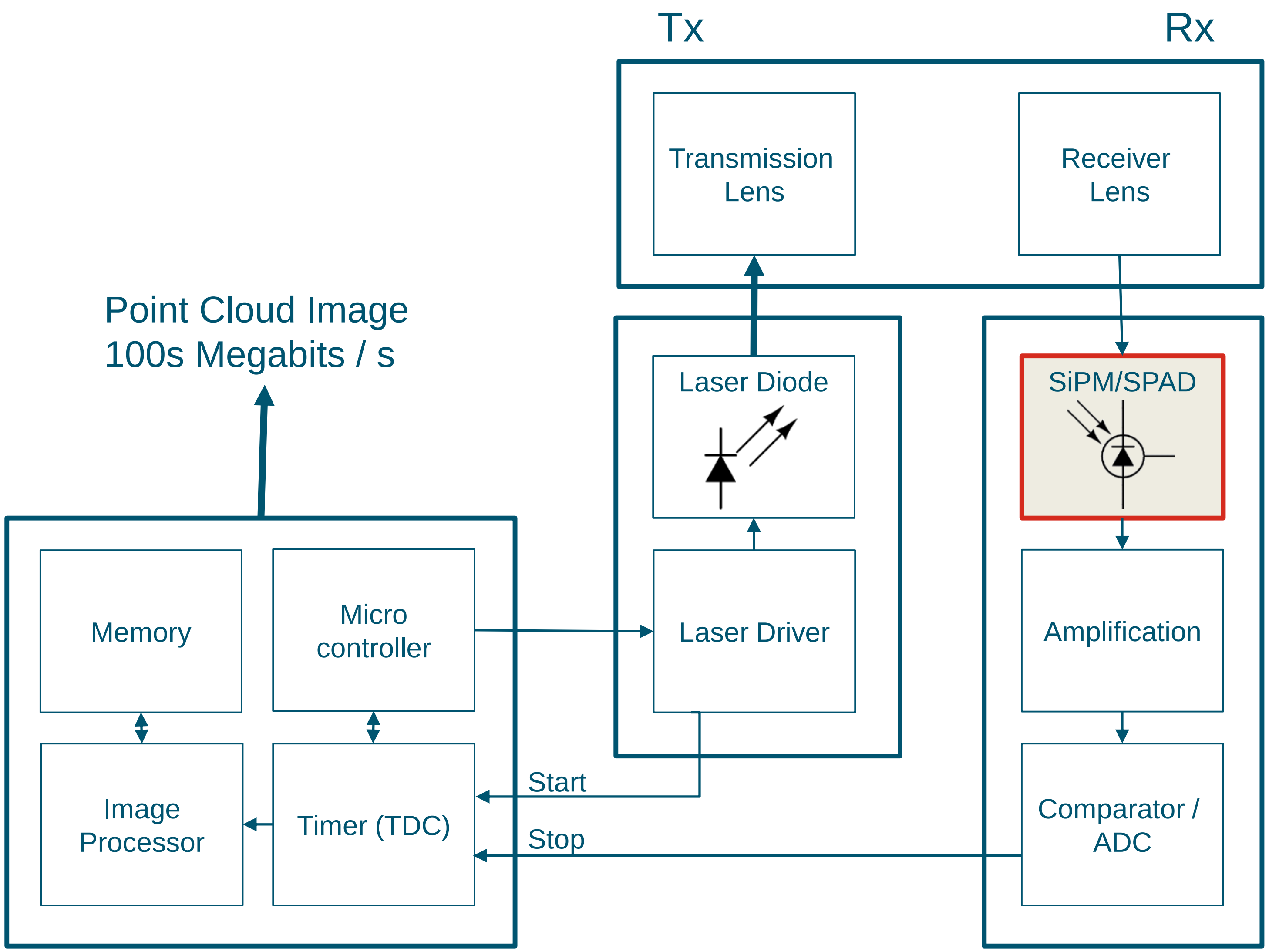


Key to laser eye safety
- Short laser pulses
- Large laser aperture

Maximum Permissible Exposure (MPE) IEC 68025-1 (2014)

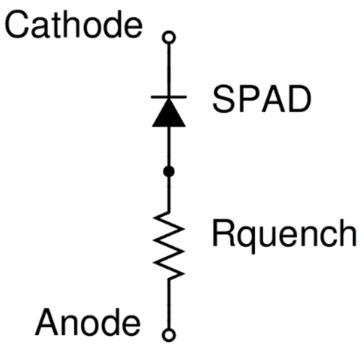
$AoV_x = 0.1^\circ$, assumes viewer is 10 cm (4'') from laser aperture

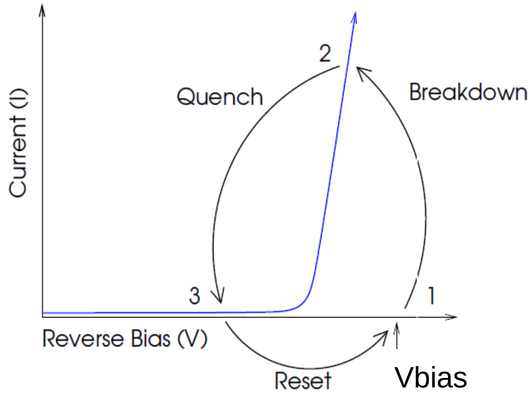
Anatomy of a LiDAR System



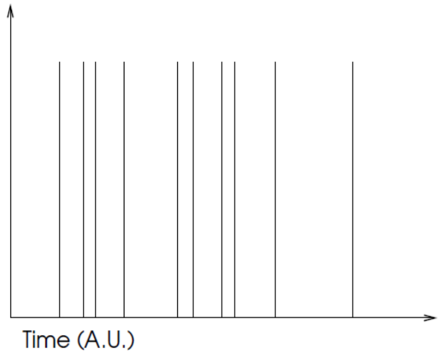
Nomenclature: SPAD and SiPM

Single microcell/SPAD

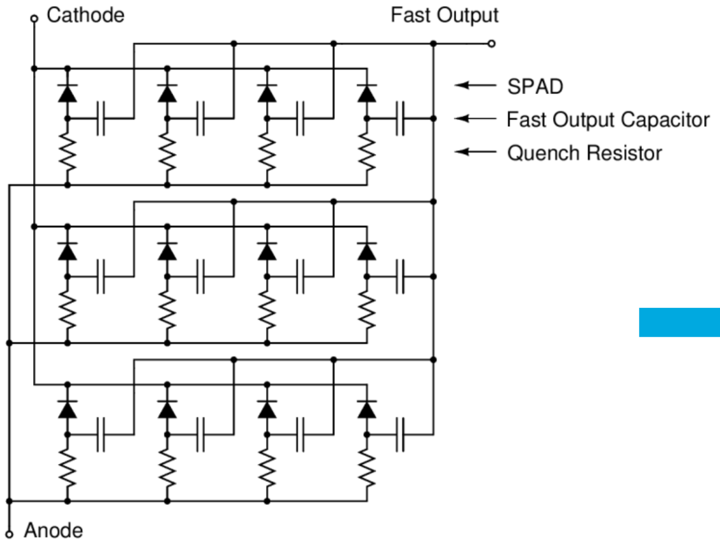




Time or count single photons

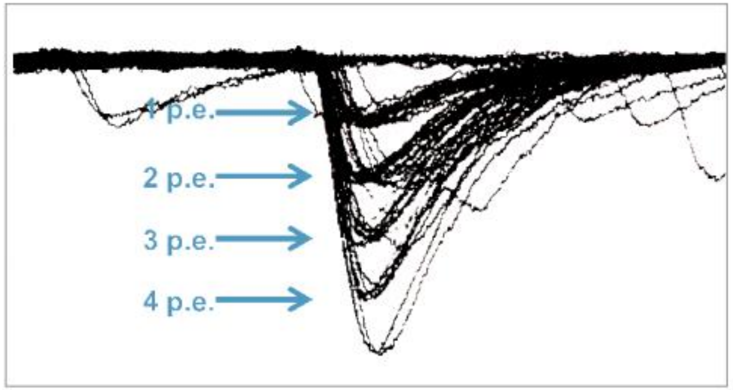


SPAD



Example of 12 microcell/SPAD SiPM

Time or count multiple photons



SiPM

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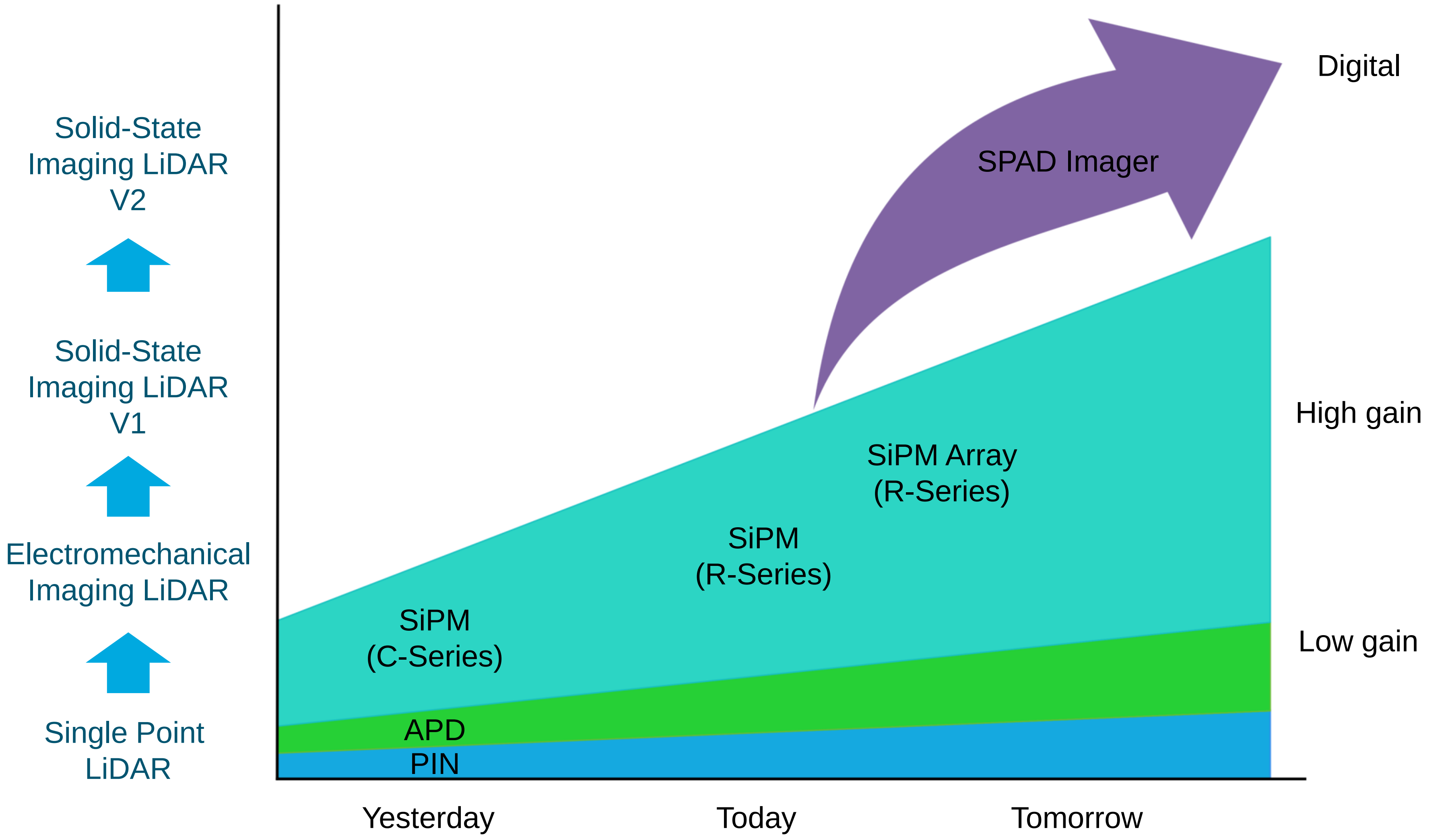
LiDAR Sensor Technology Evolution



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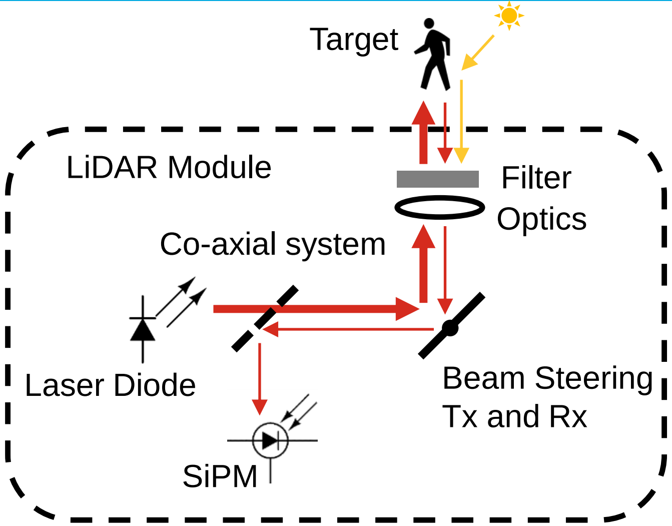
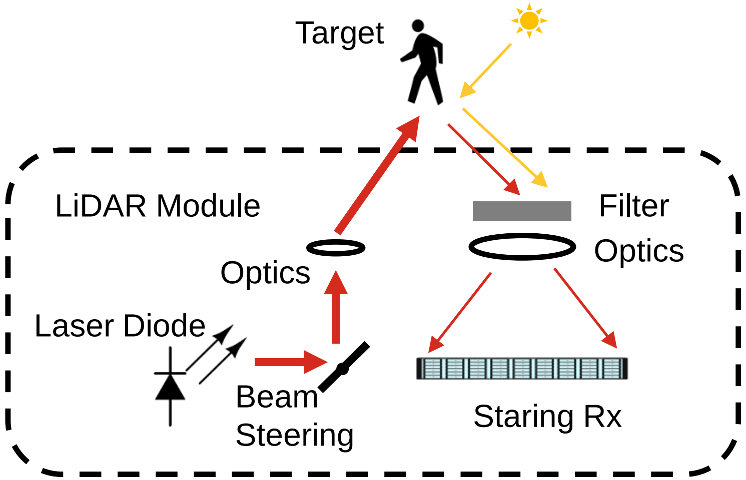
Long-distance LiDAR Systems Evolution

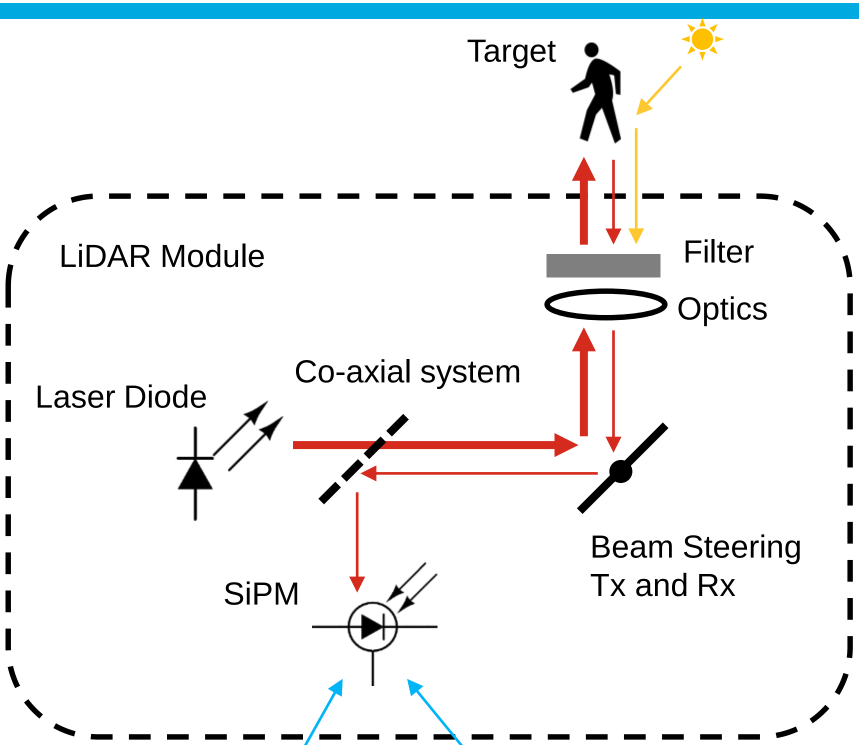
- **Today:** Electromechanical scanning TX \ RX (coaxial)
  - Single point (2D scan)
    - Single SiPM
  - Vertical/Horizontal line (1D Scan)
    - SiPM array
- **Future:** Solid-state scanning TX \ Staring RX
  - Single point (2D scan)
    - MEMS mirrors for TX
    - SiPM/SPAD array for RX
  - Vertical/Horizontal line (1D Scan)
    - MEMS mirrors/array for TX
    - SiPM/SPAD array for RX

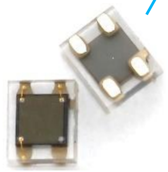




LiDAR Design with SiPM
Practical Solutions for Todays LiDAR Modules

- Beam Steering
  - 1D or 2D
    - Electromechanical or MEMS
- Laser Diode
  - High peak power (1000s W)
    - 905 nm commercially available
    - 940 nm solar minimum advantage
  - High pulse rep. rate (100s kHz)
  - Short pulse width (1ns or less)
- Optics
  - Small AoV per pixel
  - Optical bandpass filter (10 to 50 nm)
    - Driven by laser technology
  - Small aperture size
    - For optimal SNR and system size
- SiPM Sensor or SiPM Array
  - High responsivity @ 905 & 940 nm (100kA/W+)
  - High dynamic range
  - Highly uniform (+- 10% output)
  - Low voltage (<50V)





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Discrete SiPM

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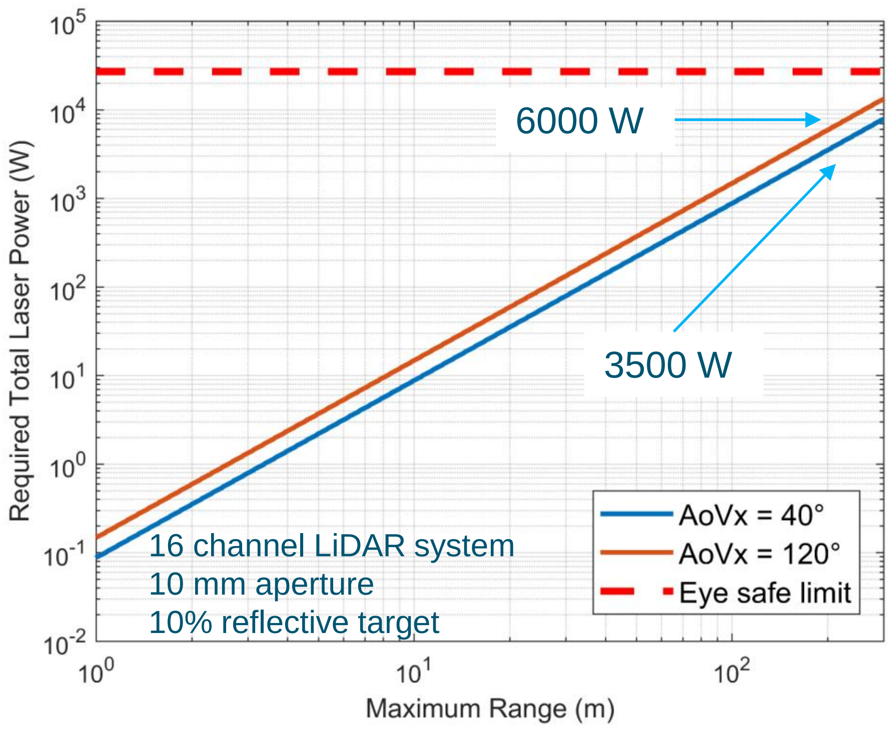
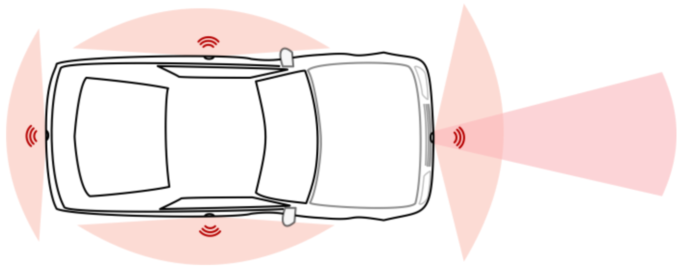
SiPM Array

How to Range >200m With SiPM Technology

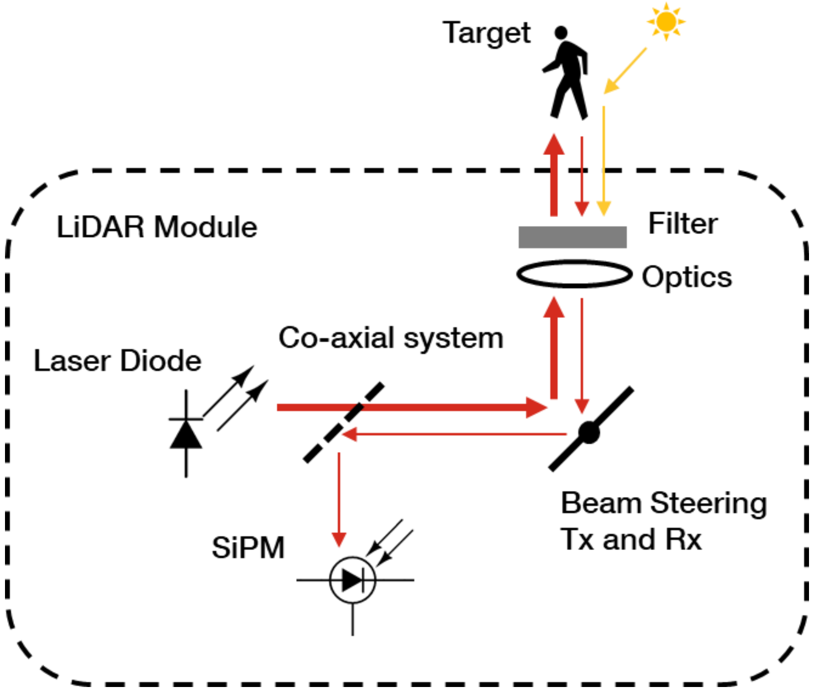




Multiple AoV LiDAR system

- Ranging Solution
  - 40° x 30° Long range
  - 120° x 30° Short range
- Sensor Specification
  - 1x16 SiPM
  - R-Series
- Resolution
  - AoVx = 0.1°
  - AoVy = 1.9°
- Laser Specification
  - 905 nm or 940 nm
  - 1ns laser pulse
  - 500 kHz repetition rate
  - Maintains eye-safety for both systems

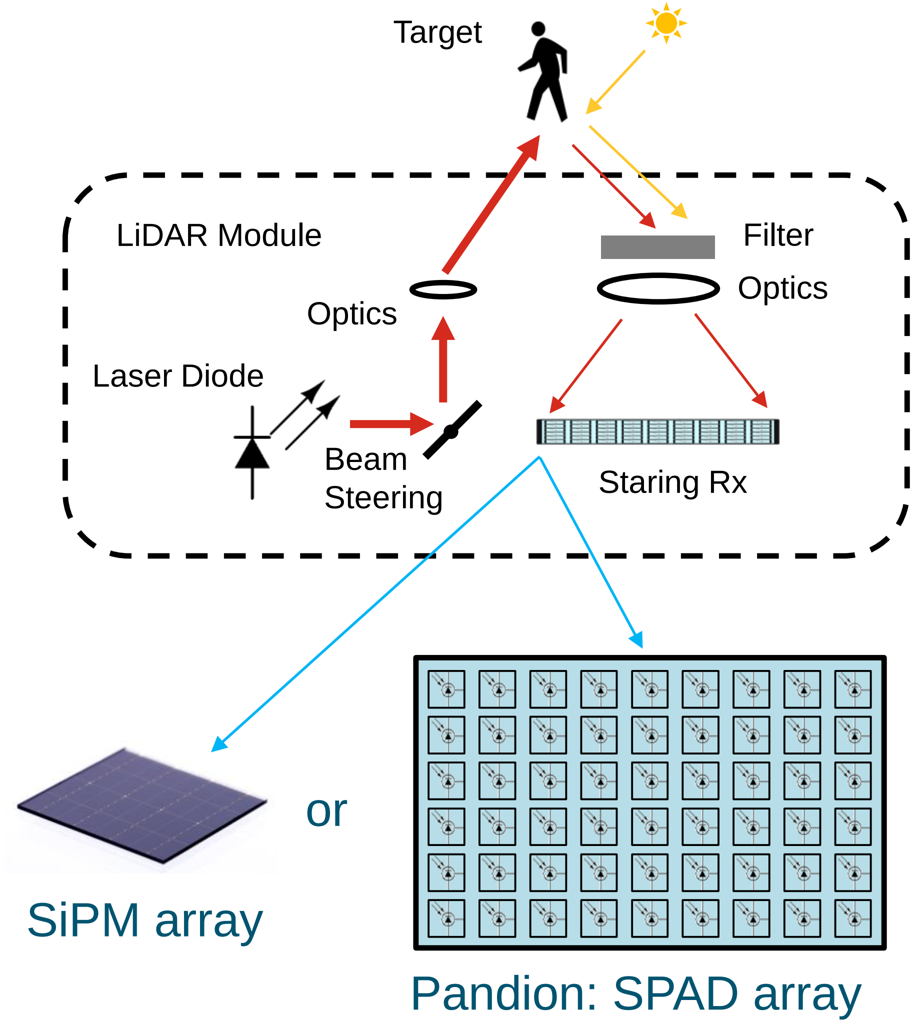
Challenges with Today's LiDAR Systems?



1. Poor angular resolution in the y-direction
2. Steering the received light onto the sensor

Future LiDAR Design with SPAD or SiPM Arrays

- Beam Steering
  - TX scanner
    - MEMS, optical phase array, other
  - Ultra compact LiDAR solution
    - No RX beam steering required
- Laser Diode
  - High peak power (1000s W)
  - High pulse rep. rate (100s kHz)
  - Short pulse width (1ns or less)
- Optics
  - TX can be miniaturized
  - RX optimized for SPAD or SiPM array
    - Small AoV per pixel



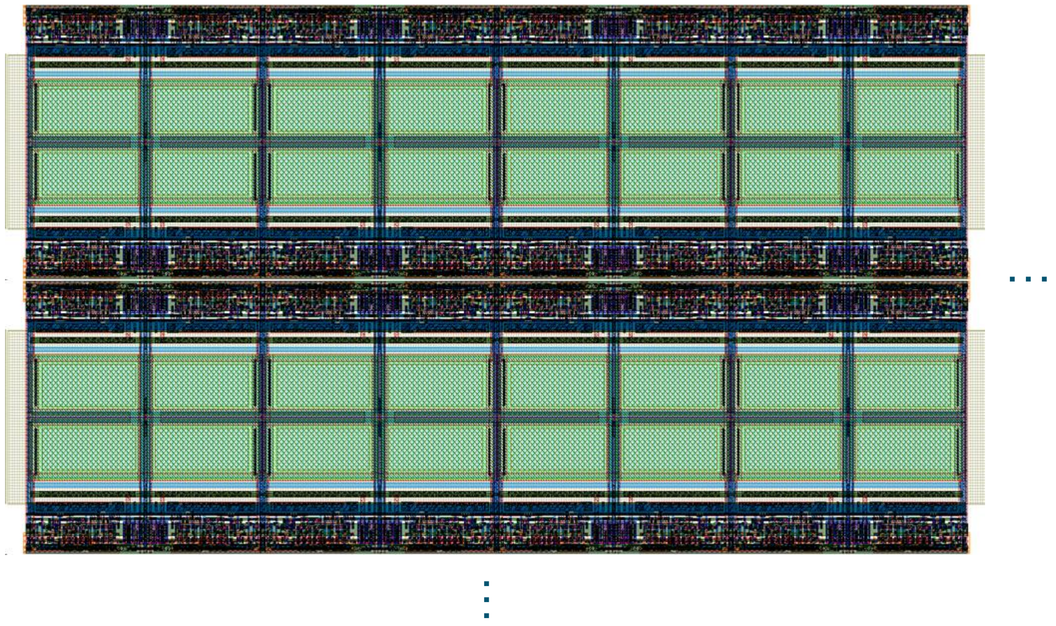
SensL Pandion SPAD Array
for Next Generation LiDAR System

- 400×100 SPAD array
- High dynamic range
- High raw data output rate
- Optimised for vertical line scanning

- 0.1° x-y angular resolution

- Suitable for >100m ranging at 10% reflectivity in full sunlight

Pandion pixels



Sampling Q2 2019

Gen 3 Imaging LiDAR Demonstrator

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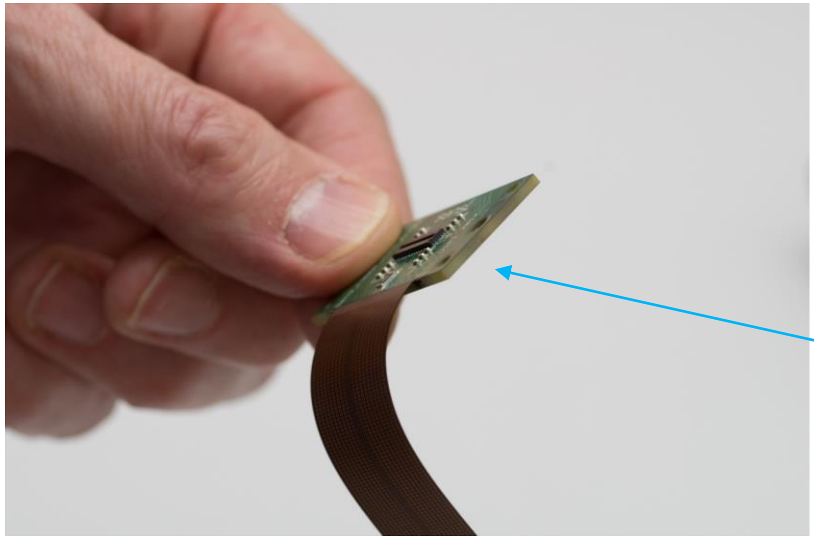
Anatomy of the Gen 3 Imaging LiDAR System

Parameter	Value
AoV	80° x 5.53°
Pixel AoVx	0.1°
Pixel AoVy	0.325°
Aperture Rx	22 mm
Image Size	800 x 16 pixels
Data Rate	6 Mbits / s
Num. Laser Diodes	16
Pulse Width	1 ns
System Peak Power	400 W (Internal)
System Size	22cm x 18cm x 13cm

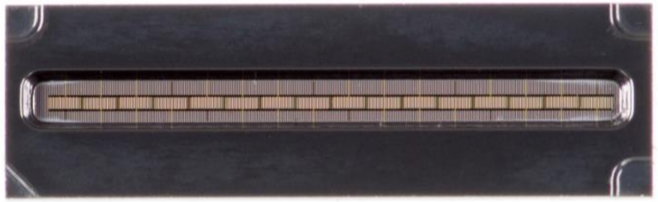
Specifications Summary



1x16 SiPM Array on flexible PCB

22 cm

Gen 3 Scanning LiDAR



1x16 Monolithic SiPM Array

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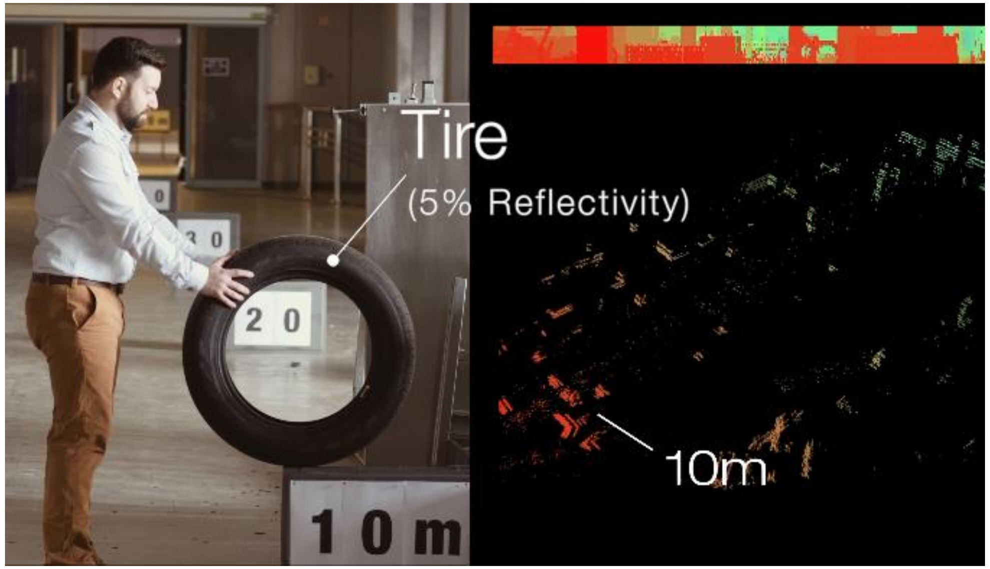
3D ToF Imaging LiDAR with SiPM
Gen3 Demonstration Video

- Demo Objectives:
  - Demonstrate SiPM advantages
  - Long distance low reflective target ranging
  - Imaging
- 1x16 SiPM Array
  - Monolithic SiPM array
  - Compact Rx
- System overview
  - 80° x 5° AoV
  - 16 channels acquired simultaneously
  - Imaging and depth displayed simultaneously

3D ToF Image



CMOS Camera Image

Full Video Link
https://www.youtube.com/watch?v=Lg2L7v5vb7M

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Thank You

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