Sensing is life

Emitters for AM LiDAR Applications

DVN LiDAR Community – Workshop

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2022-09-13

Agenda

1.	Emitter Technology: EEL, VCSEL, Fiber Laser, FMCW	3
2.	NIR versus SWIR - Technology and Market Outlook	9
3.	Scanning technologies - Market Outlook	14
4.	Automotive Use Cases and their Specification Requirements	18

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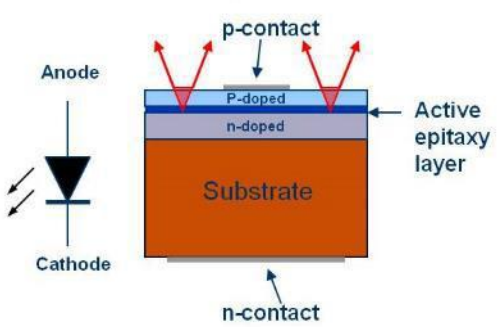
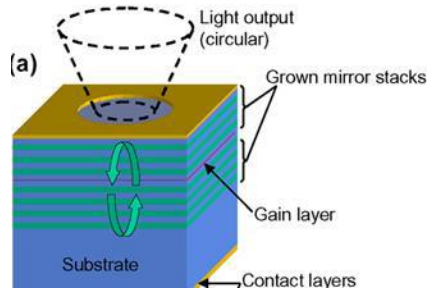
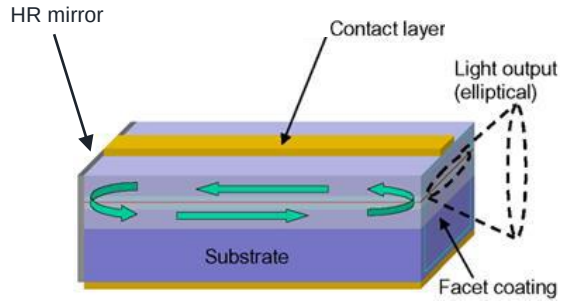
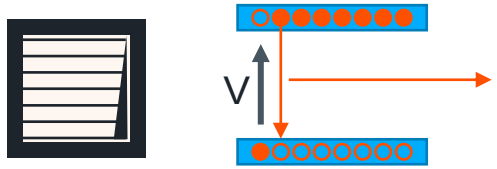
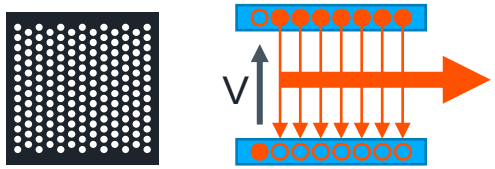
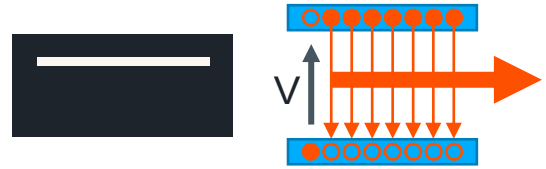
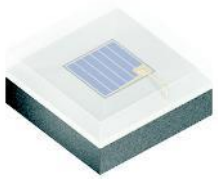
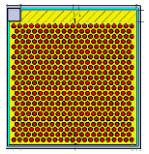
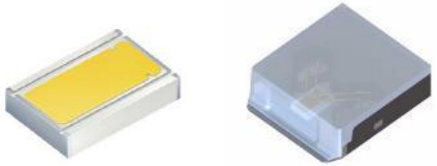
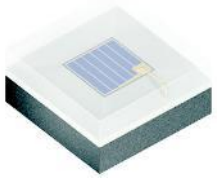
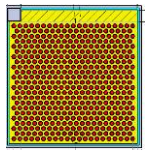
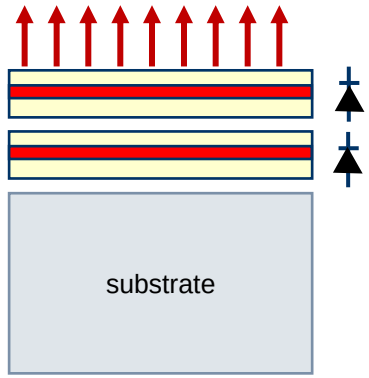
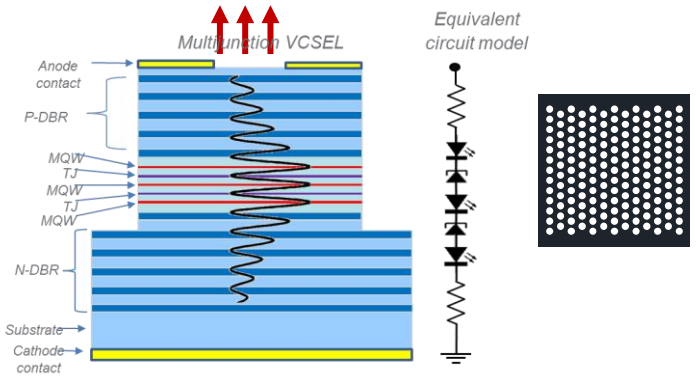
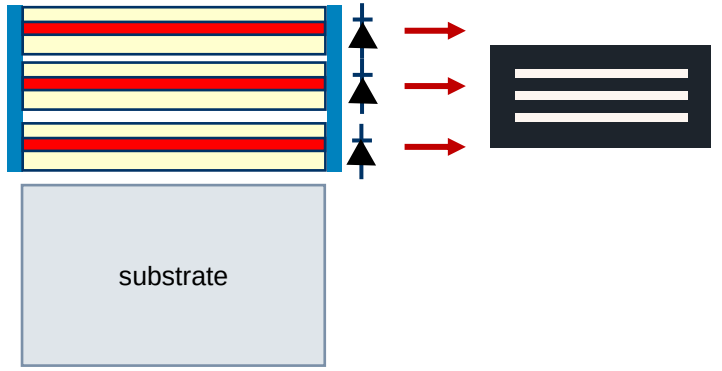
Emitters for LiDAR Systems

IRED, VCSEL and EEL – Chip Concepts

	LED	VCSEL	EEL
Structure			
Emission pattern	 Spontaneous emission	 Stimulated emission	 Stimulated emission
AM qualification	 Package with full AEC-Q	 Bare die with partial AEC-Q	 Bare die with partial AEC-Q Package with full AEC-Q

Emitters for LiDAR Systems

IRED, VCSEL and EEL – Multi-Junction Technology

LED	VCSEL	EEL
		
		

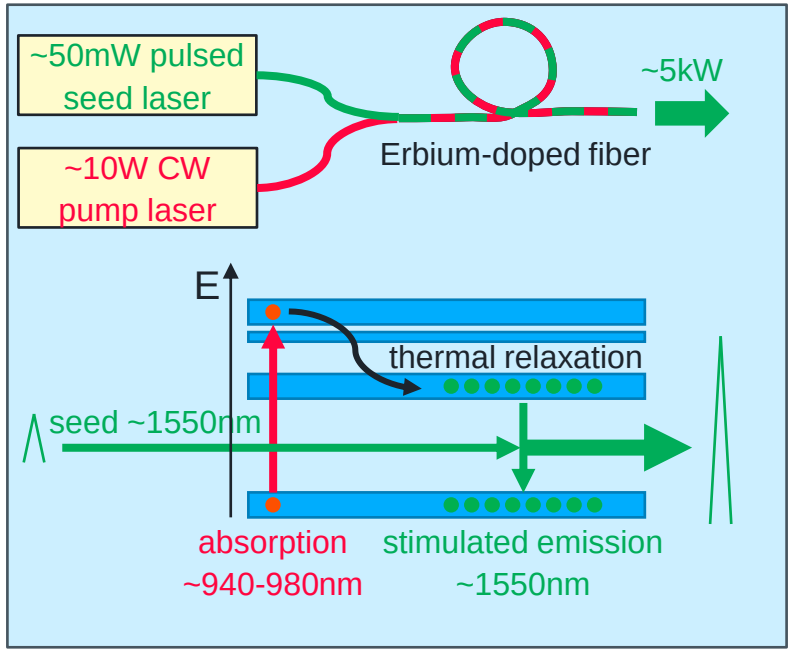
Multi-junction: key benefits in a nutshell

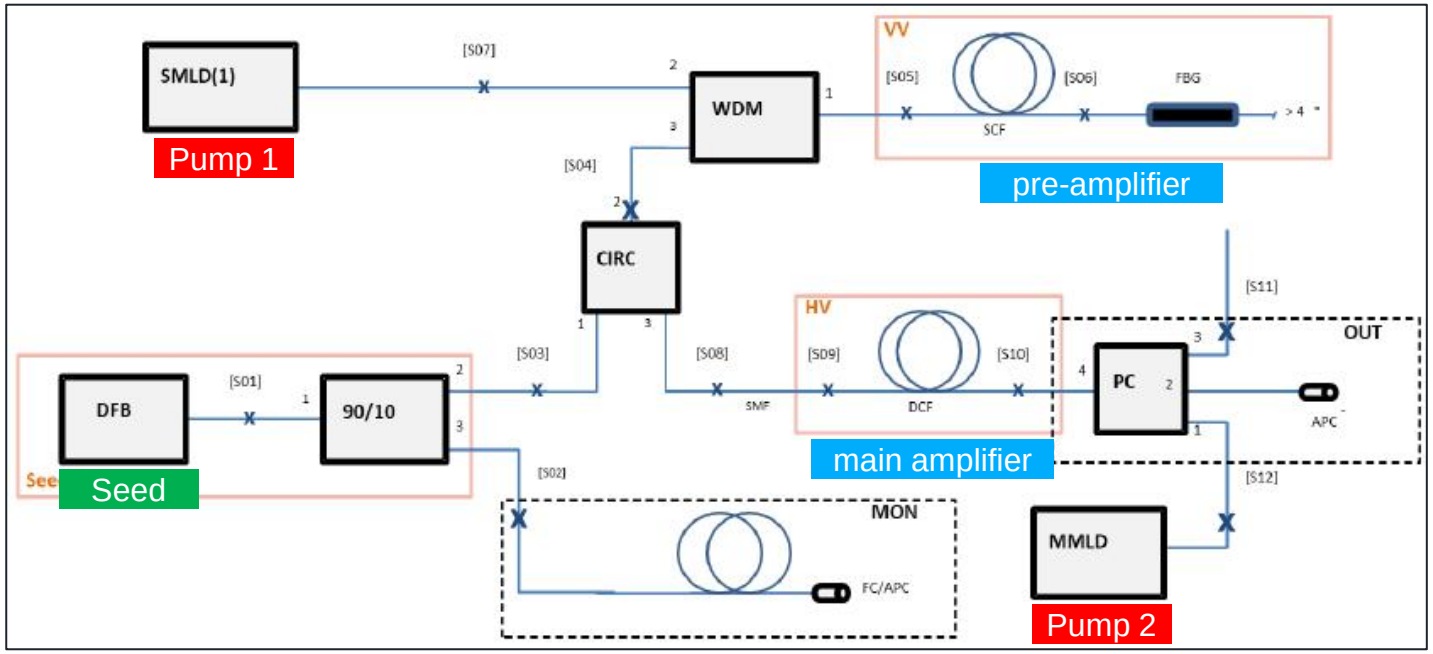
- Multi-junction device has less ohmic losses→ higher efficiency (e.g., simplifying thermal management)
- Lower current is needed to reach the same output → easier driver design, faster switching
- Increased power density leads to a reduced emission / component size → simplifying optics and system architectures

Emitters for LiDAR Systems

Fiber Laser

1550nm Fiber Laser





Fraunhofer IOF

- Optical pulse of seed laser diode is amplified by rare-earth doped active fiber
- Various design options: one or two amplifier stages, one or two-pass amplifiers, filters to reduce amplified spontaneous emission, etc.
- Seed and pump lasers need to be temperature controlled.
- For AM LiDAR we think that a two-stage amplifier is necessary.

Emitters for LiDAR Systems

Photonics Integrated Chip (PIC) for Frequency Modulated Continuous Wave (FMCW)

FMCW PIC

Modulator
creates the frequency chirp (e.g., current)

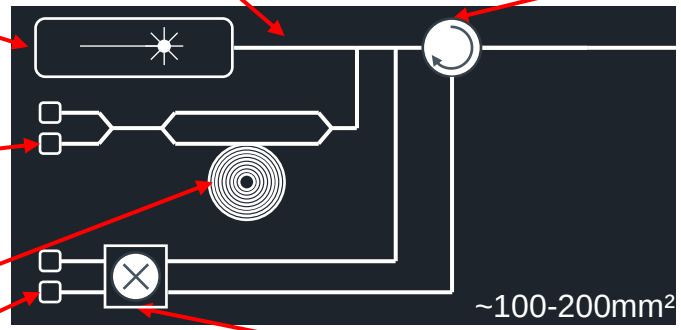
Laser
CW laser with long coherence length (e.g., DFB)
External with optical isolator or assembled onto PIC

Detectors
imbalanced Mach-Zehnder Interferometer for detection of modulation → feedback to modulator

Delay line
up to a few 10 cm length, ~10mm Ø

Waveguides
Confines the light

Optical circulator
Directional element for light. Light from the laser is directed to the outside, light from outside is directed towards detectors



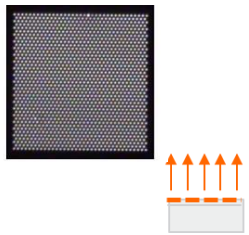
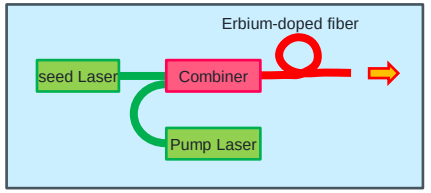
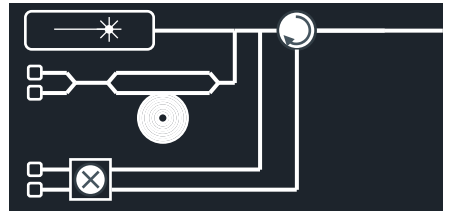
Detectors
Coherently mixed light is detected
By using two balanced detectors, only AC part is detected and DC part (noise, e.g., sunlight) is rejected

Combiner
Coherently mixes light from outside with direct light from laser

- 3 chirps take about 10µs → 100k pixel per second for one core → need few dozen cores
- laser needs to be temperature controlled
- laser and optical circulator not integral part of PIC

Emitters for LiDAR Systems

Comparison of key parameters for LiDAR application

				
	EEL	**VCSEL**	**Fiber Laser**	**FMCW**
Wavelength	905 nm	905 nm / 940 nm	**1550 nm**	**1550 nm**
Spectral Width	7 nm	**1 nm**	**<1 nm**	<100kHz (0.001pm)
Optical Peak Power	500 (1000) W	1000 W	**5 kW**	<200mW cw / core
Emission Aperture	12,000 µm²	1 mm² = 1,000,000 µm²	**150 µm²**	**<100µm²**
Power Density	**~45 kW/mm²**	~1 kW/mm²	**~30 MW/mm²**	~2 kW/mm² cw
Radiation Characteristic	Elliptical: ± (5° x 12°)	**Gaussian: ± 10°**	**Gaussian: ± 3°**	**Gaussian: ± 3°**
Wavelength Shift vs Tj	0.03 - 0.3 nm/K	0.07 nm/K	needs TEC	needs TEC
LiDAR Performance	+	+	**++**	**++**
AM Maturity	**++**	**+**	0	-
size	**++**	**++**	-	0
cost	**++**	**++**	--	--

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Technology solutions for AM LiDAR

NIR EEL + VCSEL solutions dominate the LiDAR space

NIR (850/905/940nm) Technology Comparison – EEL / VCSEL

Technology: EEL advantages

- Higher power density of EEL implies smaller emitter optics for scanning LiDAR
- Larger optical aperture per detector pixel for EEL for same detector size gives higher SNR
- Polarization of EEL enables coaxial system designs with higher efficiency
- Resolution for EEL based scanning systems not limited by 2D SPAD pixel count

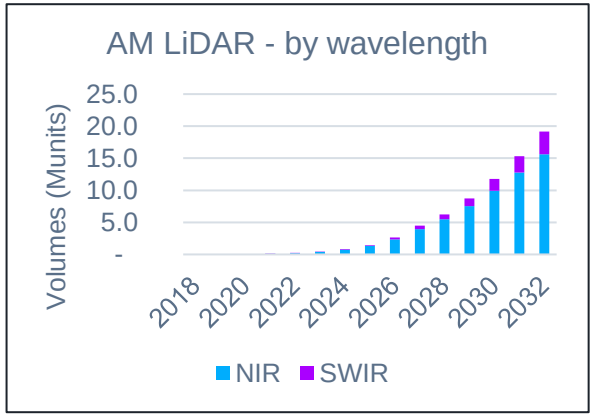
Technology: VCSEL advantages

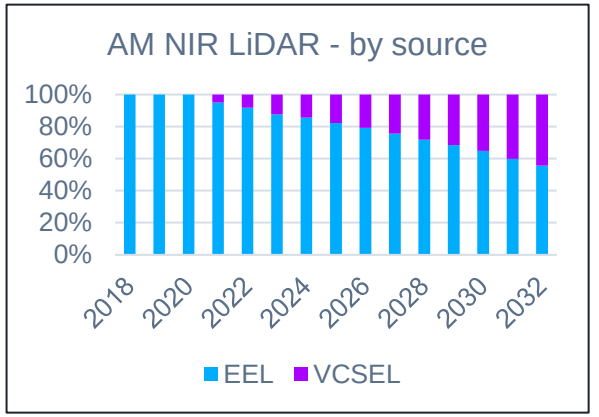
- Narrow spectral linewidth enables smallest bandpass for VCSEL.
- No moving parts for global and rolling shutter flash systems

Match to use cases

- NIR EEL and VCSEL rely on mature technology, proven in the market
- EEL are most suitable light sources for long range scanning LiDAR systems for TJP and HWP
- Flash VCSEL or scanning EEL are a good match for short range LiDAR in urban pilot or TJP

LiDAR Market Trends





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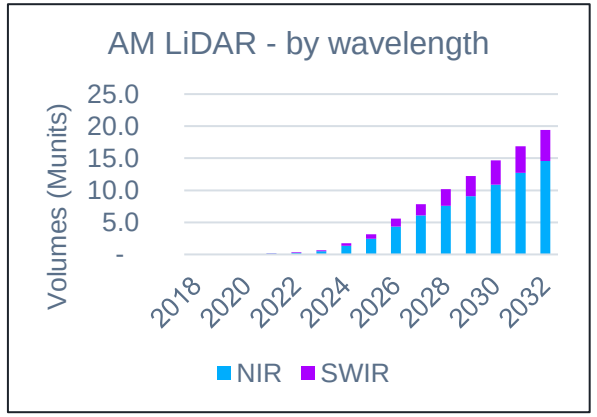

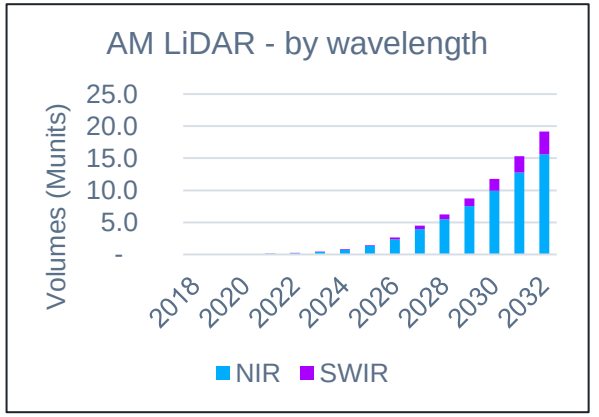

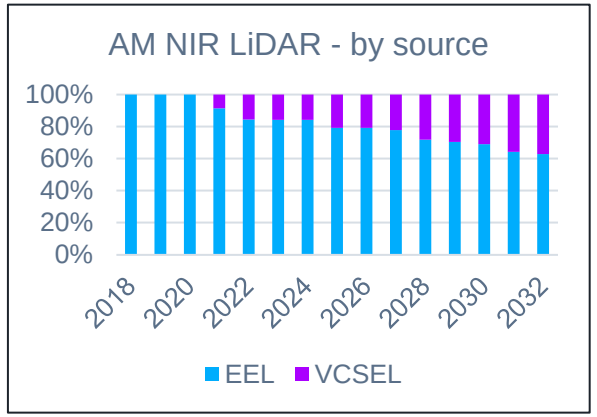

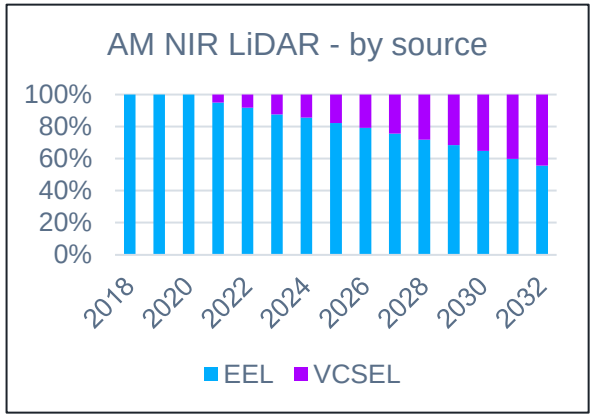

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Technology solutions for AM LiDAR

1550nm will remain niche market during the coming years due to high cost and technological hurdles

SWIR (1550nm) Technology Comparison – SWIR EEL / Fibre Laser / FMCW

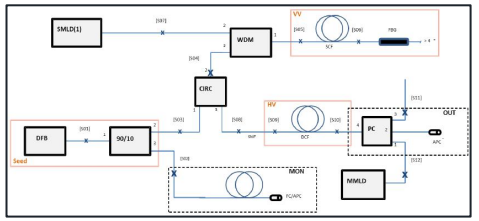
SWIR EEL

- not efficient enough to allow meaningful eye-safety limited LiDAR system, no penetration expected

Seminex homepage

Fibre laser

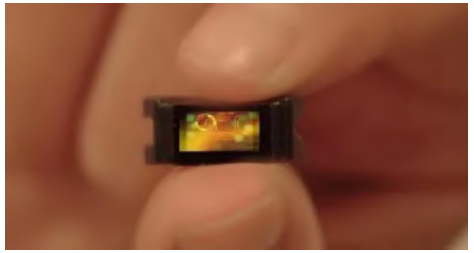
- market share is getting lower, as high cost forces it into cost-insensitive niche markets



Fraunhofer IOF

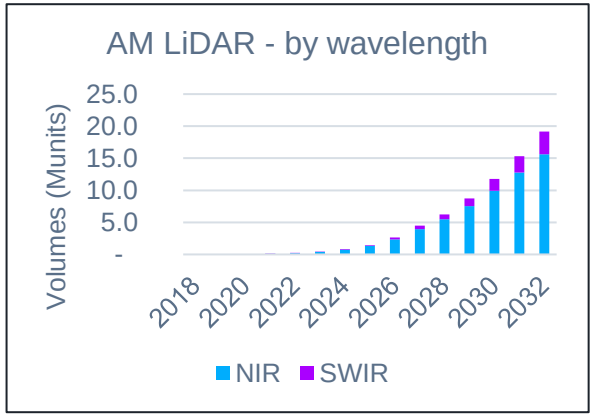
FMCW

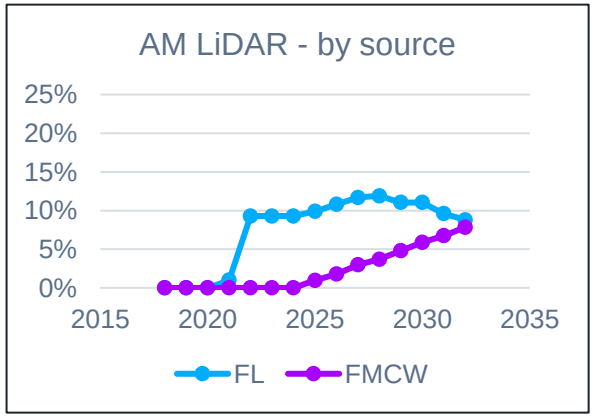
- Technical and financial hurdles for FMCW very high, leading to expected delay in introduction towards 2030+
- Scanning is complicated and time-consuming: a high parallelization will be required (emitter & sensor) to reach sufficient resolution
- Cost pressure will require a full Si-integration, as parallelization will be unfeasible expensive otherwise



SILC homepage

LiDAR Market Trends





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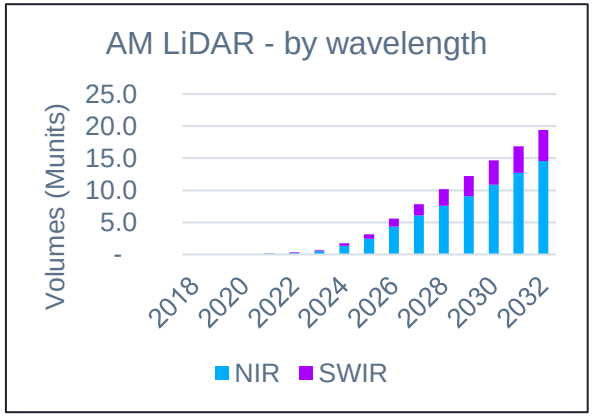
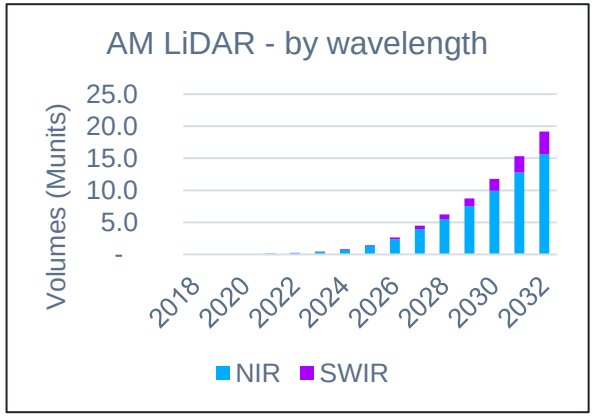
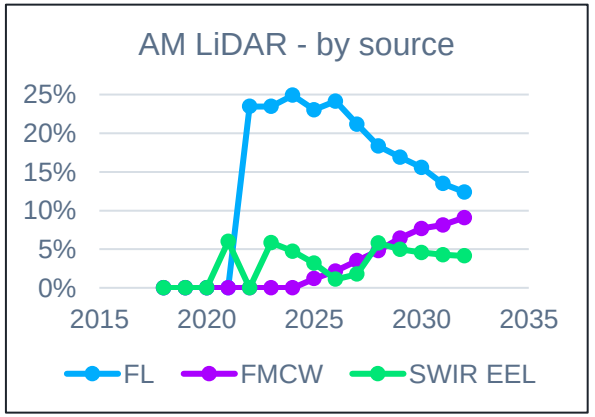
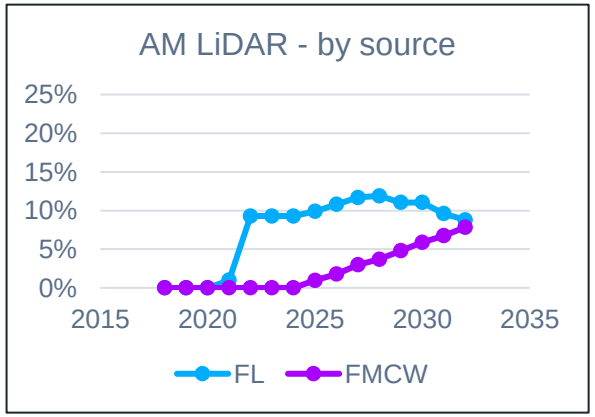
LiDAR Market Trends









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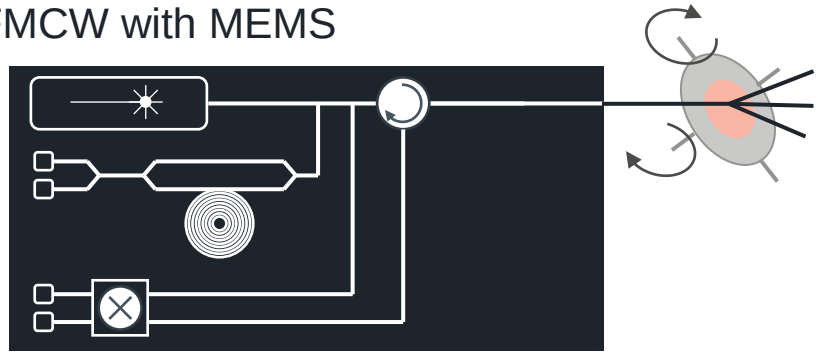
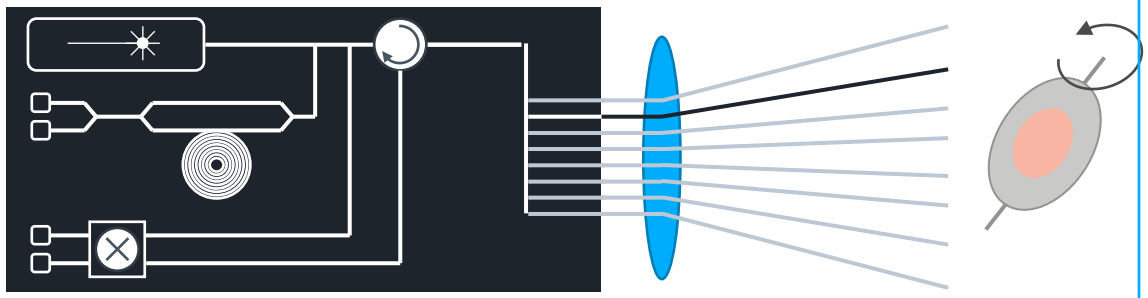
LiDAR Technologies – Scanning / Flash Systems

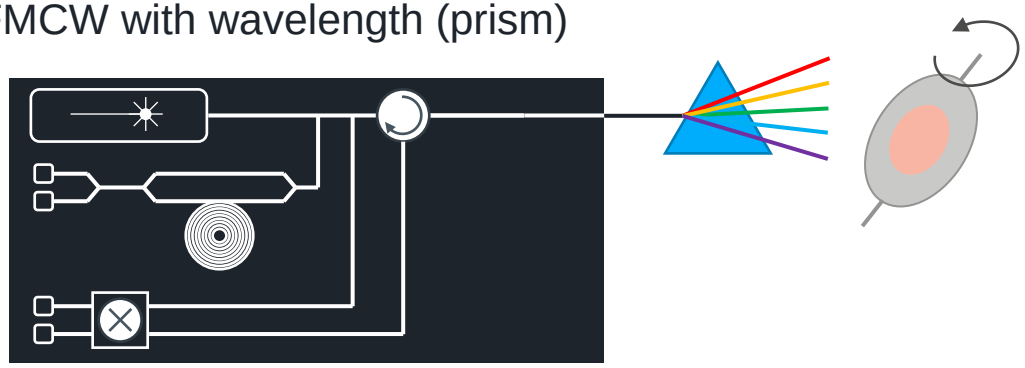
FMCW with MEMS



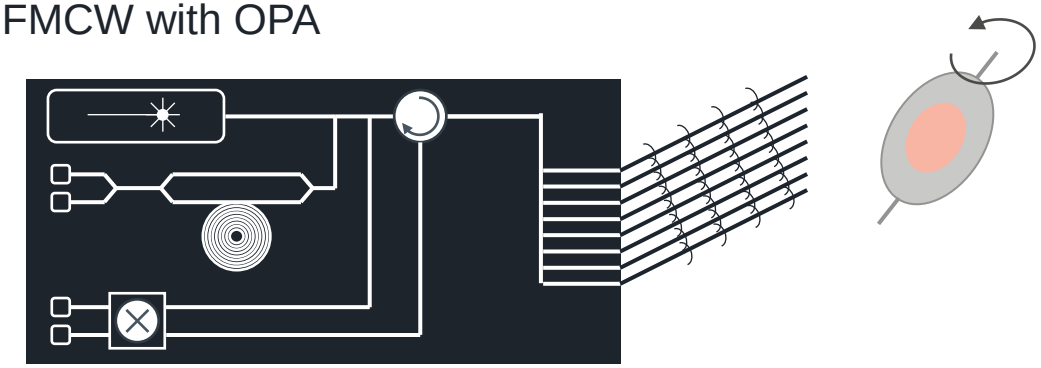
FMCW with focal plane switching



FMCW with wavelength (prism)



FMCW with OPA



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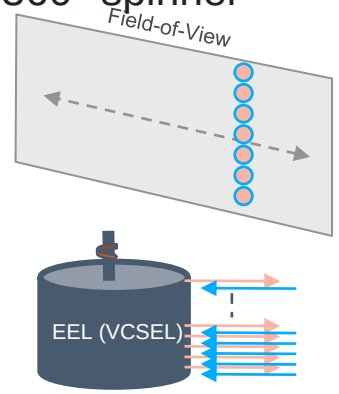
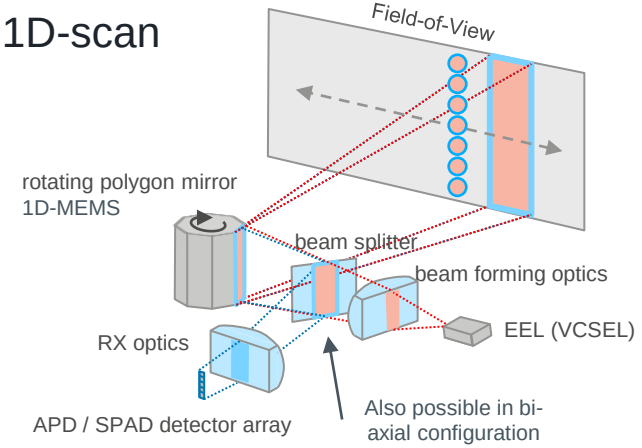
LiDAR Technologies – Scanning / Flash Systems

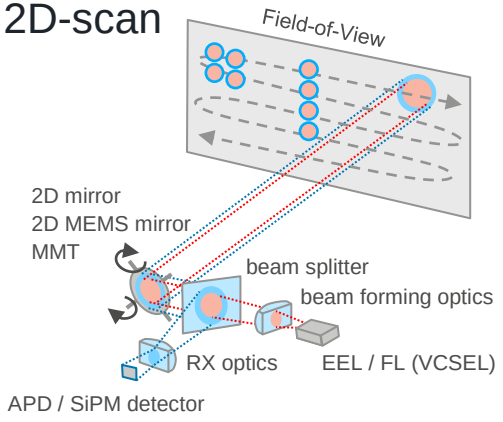
360° spinner



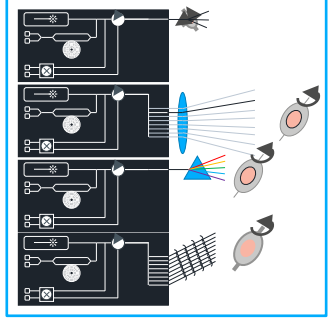
1D-scan



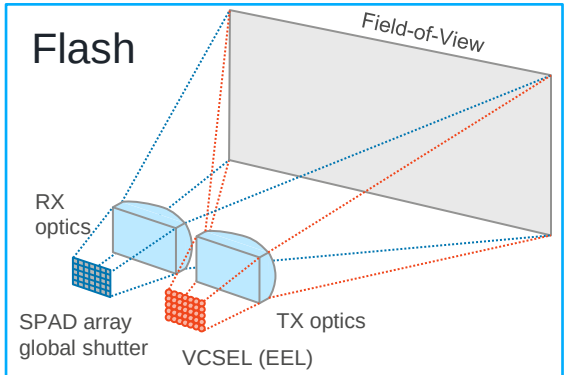
2D-scan



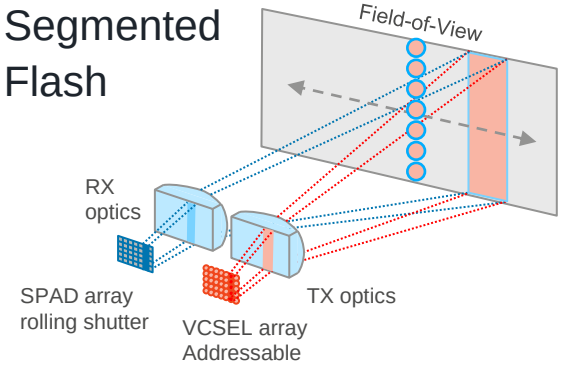
FMCW



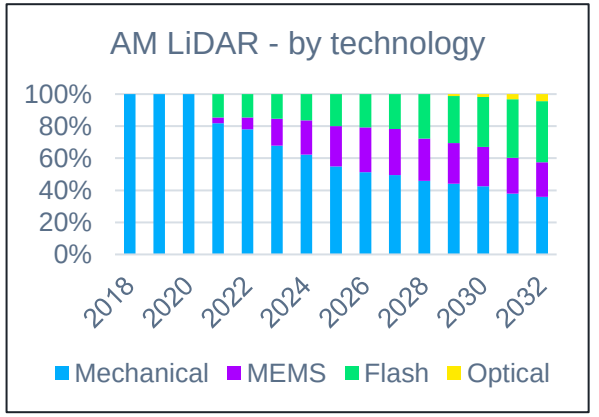
Flash

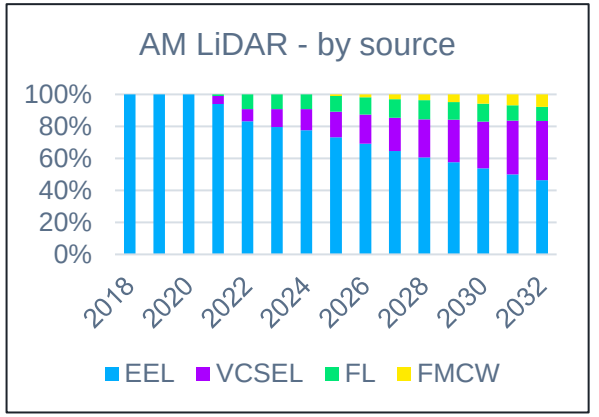


Segmented Flash



LiDAR Market Trends





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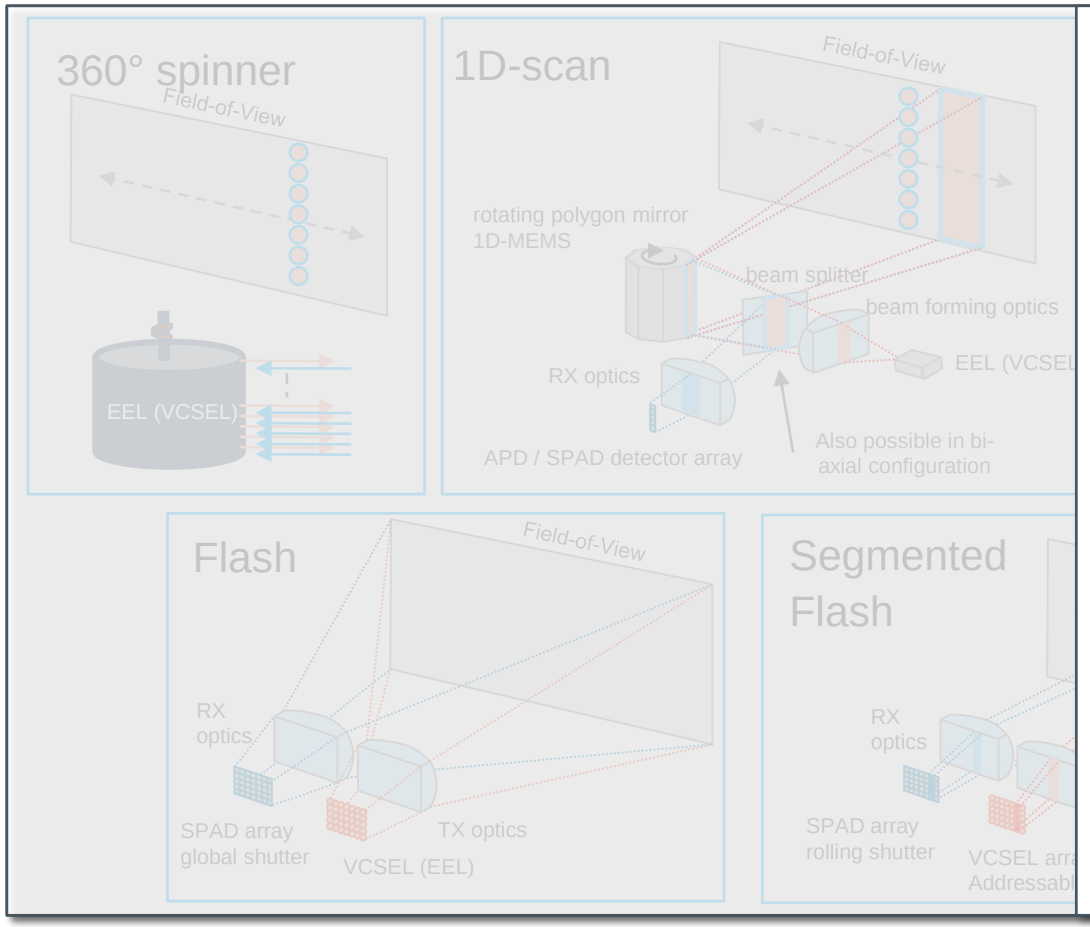
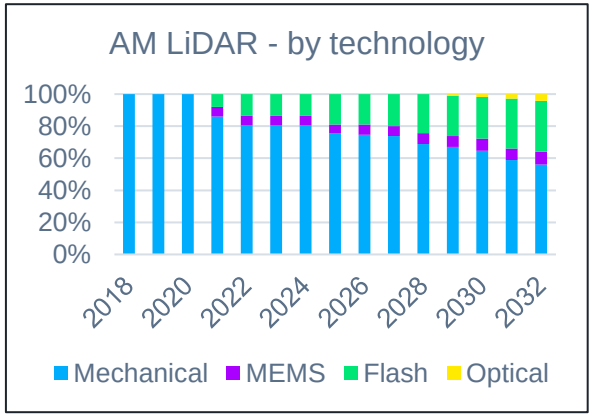
Technology solutions for AM LiDAR

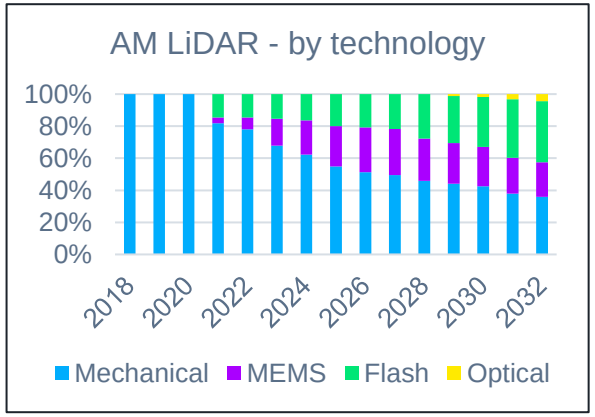
LiDAR solutions with a mechanical scanner and NIR EEL will dominate the market, flash is appearing

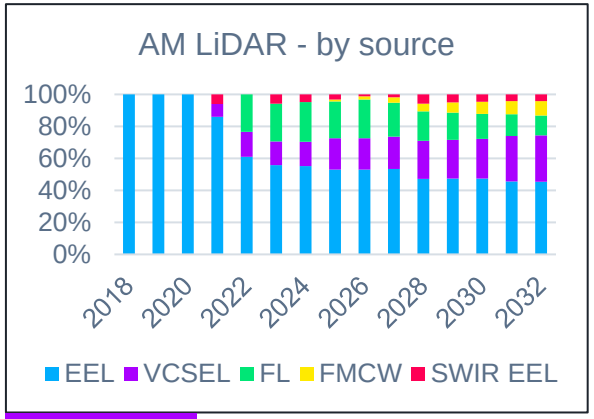
LiDAR Technologies – Scanning / Flash Systems

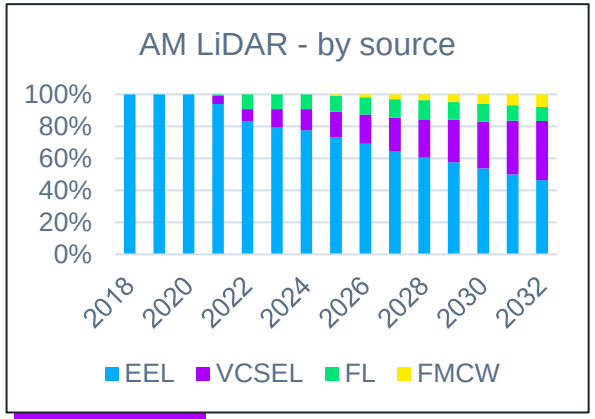


LiDAR Market Trends









2021

Yole LiDAR report Sep. 2021

2022

Yole LiDAR report Aug. 2022

Agenda

1.	Emitter Technology: EEL, VCSEL, Fiber Laser, FMCW	3
2.	NIR versus SWIR - Technology and Market Outlook	9
3.	Scanning technologies - Market Outlook	14
4.	Automotive Use Cases and their Specification Requirements	18

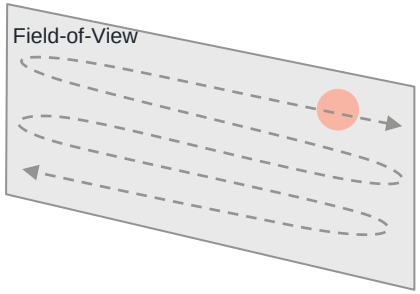
LiDAR system requirement engineering examples

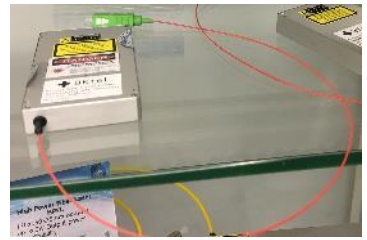
Don’t over-specify – go with good enough for the application

Maximum specification for autonomous driving

2D scanning – 1550nm fiber laser – >>500m range (200km/h)

2kW x 1ns x 120° x 20° / 0.01° / 0.01° x 25Hz x 10% = **10kW** electrical power

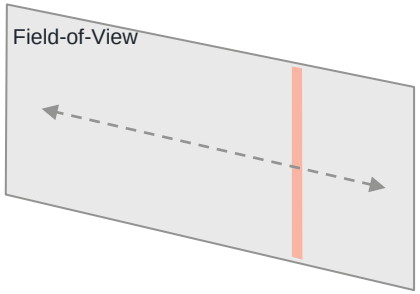




Low end specification for highway pilot

1D scanning – 905nm EEL – ~200m range* (130km/h)

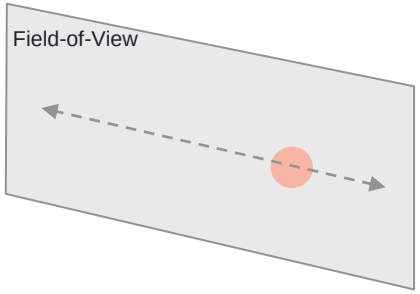
350W x 4 x 1 ns x 21 shots x 120 / 0.1° x 25Hz x 15% = **6W** electrical power



Specification for vacuum cleaning robot

IND – 360° scanning – 905nm EEL – ~10m range

15W x 5ns x 360 / 0.05° x 10Hz x 20% = **30mW** electrical power

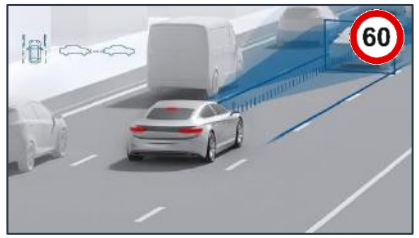


*Range estimation 905nm EEL from: https://www.eetimes.com/demystifying-lidar-an-in-depth-guide-to-the-great-wavelength-debate/

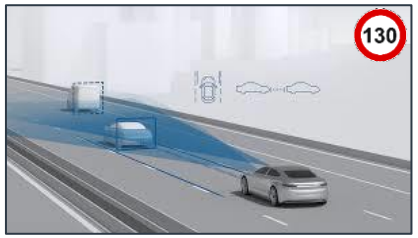
LiDAR in Automotive Applications

Each use case requires different specifications and leads to different LiDAR technology

LiDAR use cases



L2 Traffic Jam Assist (TJA)
L3 Traffic Jam Pilot (TJP)*



L2 Highway Assist (HWA)
L3 Highway Pilot (HWP)*

Traffic Jam and Highway Pilot introduction

- Traffic Jam: Audi L2 TJA in 2018. Honda, Daimler L3 TJP in 2022. BMW L3 TJP in 2023?
- Highway: Stellantis L3 HWP in 2024? GM L2 in 2023? VW L2-4 in 2025? Volvo in ??
- Many topologies seen in market, higher volumes require scalable and affordable solutions

Traffic Jam and Highway Pilot LiDAR specifications

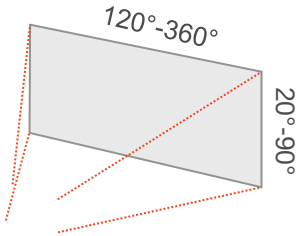
- Traffic Jam: ~50m – 80m range, ~120° x 25° FoV, ~0.1-0.3° resolution
- Highway: ~150 – 200m range, ~120° x 25° FoV, ~0.05-0.1° resolution

LiDAR specifications

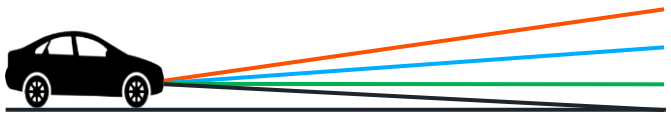
Range

Speed	[km/h]	0…60	70	80	90	100	110	120	130
min detection range*	[m]	46	50	60	75	90	110	130	150

Field of View



Resolution



	10m	50m	150m
human / car (1.5m)	8.5°	1.7°	0.60°
road cone (36cm)	2.1°	0.4°	0.15°
tire (10cm)	0.6°	0.1°	0.05°

Frame rate

10 Hz – 25Hz

*L3 legislation: Automated lane keeping, ECE/TRANS/WP.29/2022/59/Rev. 1

LiDAR in Automotive Applications

Each use case requires different specifications and leads to different LiDAR technology

LiDAR use cases

Urban pilot (UP)

Parking

Urban Pilot and Parking

- While expected to be largest market, use cases and requirements not well understood
- Sensor content expected increase, optimal configuration to be assessed

Question for Audience:

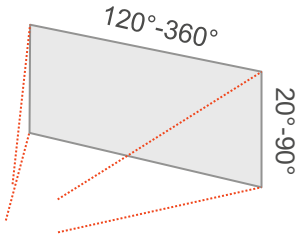
- Which scenarios will urban pilot and parking cover?
- What are the requirements for the related short-range LiDAR: range, FoV, resolution?
- 160° x 90° with 0.4° → 400 x 225 pixel does not match 200 x 56 pixel of Sony IMX459

LiDAR specifications

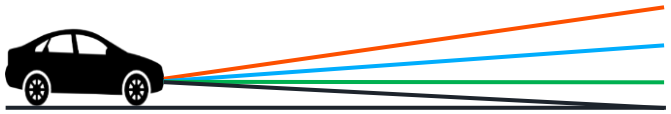
Range

Speed	[km/h]	0…60	70	80	90	100	110	120	130
min detection range*	[m]	46	50	60	75	90	110	130	150

Field of View



Resolution



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Frame rate

10 Hz – 25Hz

Sensing is life