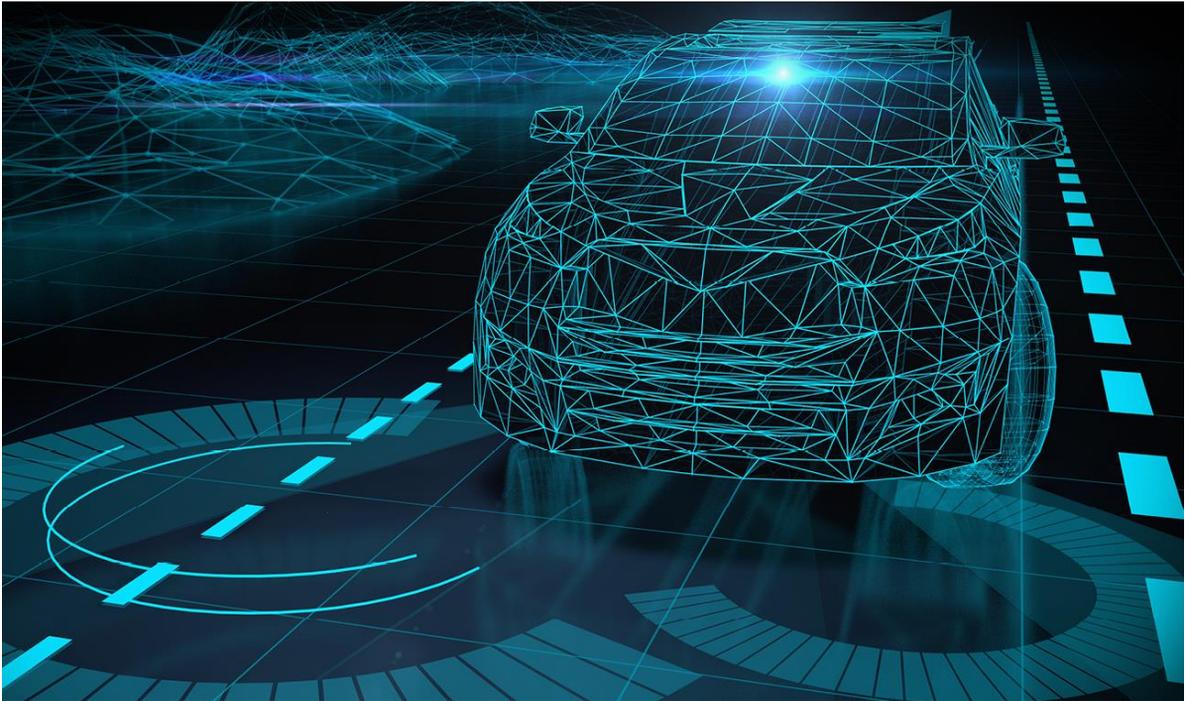


Renevo Capital Limited
MARKET RESEARCH REPORT
European LiDAR Ecosystem

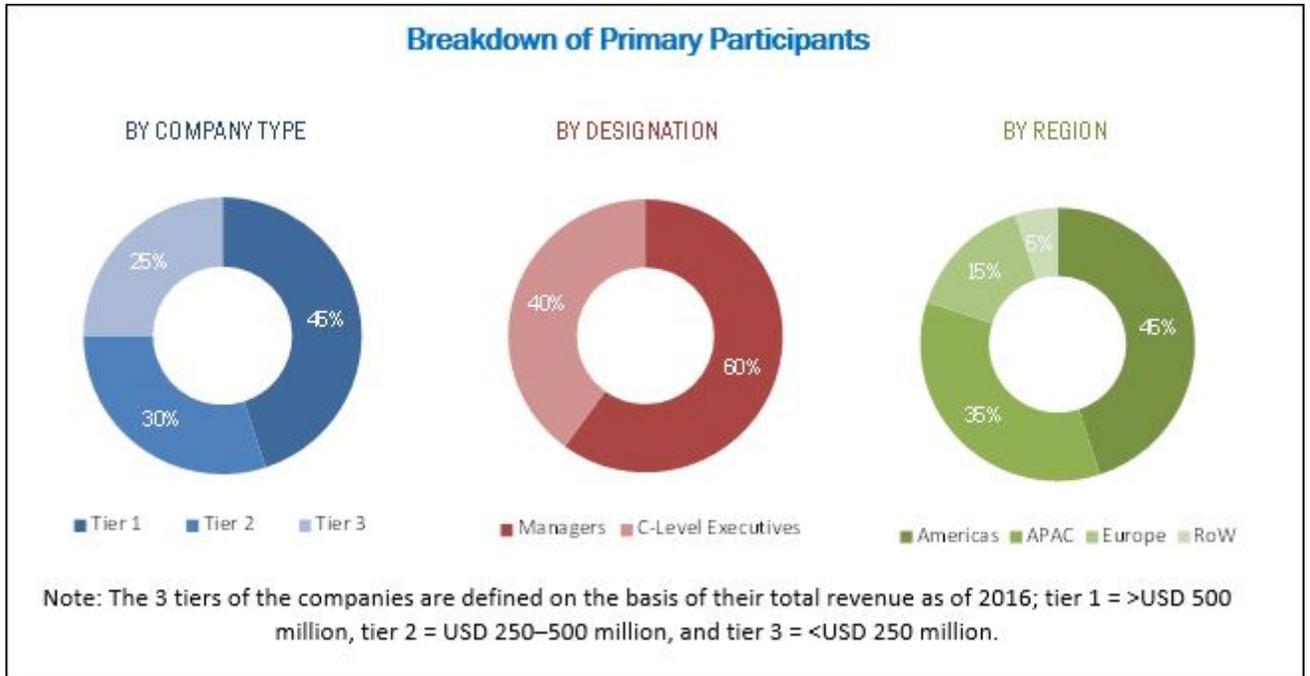


RCL
RENEVO CAPITAL LIMITED

October 2018

Headline Figures:

- The global LiDAR market is expected to reach **\$1,809.5M** by 2023 from \$819.1M (2018), at a **CAGR of 17.2%**
- The European LiDAR market is anticipated to grow to **\$324M** by 2024. The market growth is expected at the **CAGR of 12.28%** in the forecast period 2017-2024



Drivers:

- Use of drones
- Potential in delivery and automation sectors
- Government support
- 3D printing
- Rise in use for engineering projects
- Need for strong security accuracy
- Conducting geological surveys

Inhibitors:

- High cost of equipment and surveying applications
- Unawareness on its value
- Lack of education on its development
- Regarding airborne LiDAR, there are some regulatory and environmental issues
- Reliability concerns

LiDAR for Autonomous Vehicles:

- The market for the ADAS driverless car is estimated to grow at the **highest rate**
- The growth of this market is attributed to rising adoption of solid-state LiDAR in ADAS and driverless cars for assuring safety
- Moreover, automotive giants are adopting LiDAR systems for their L3-level vehicles to boost the sales of these vehicle types
- By 2030, driverless vehicles and services will be a **\$1 trillion** industry

European Advantage:

- Europe has a well developed manufacturing sector, especially automotive, and is expanding rapidly into software
- European governments are among the best in holistic development and are investing aggressively in LiDAR development technology
- UK government has been collecting LiDAR data from the past 17 years and has made it available to the public; Netherlands and Spain have similar open scans

Europe



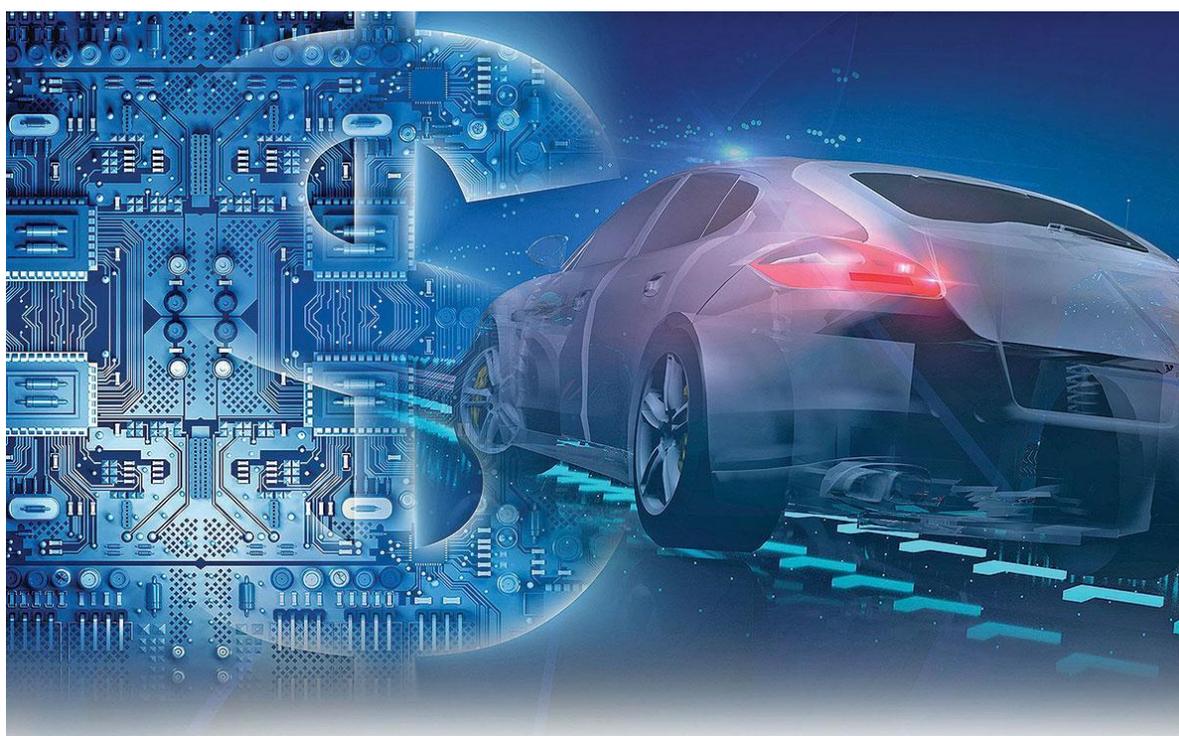
North America



Asia



Detailed insight into selected European players



- **Unlike the other territories, where much of the innovation is driven by small / early stage VC backed companies, Europe's LiDAR and autonomous car development is driven by large multi-national players – through both internal development or external acquisitions**

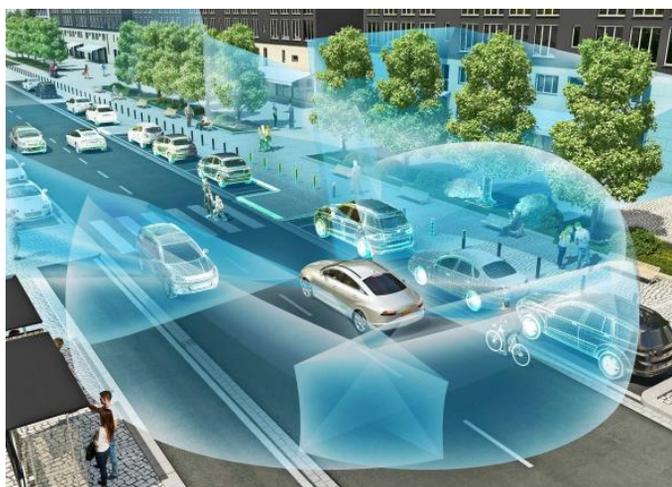


CUBE Project:

- Continental uses high-precision GPS geolocation as a reference and has developed innovative algorithms to improve location accuracy
- The central control unit ADCU (Assisted & Automated Driving Control Unit) compares the current echo from the installed radar sensors with the known radar echo from an echo map. By permanently comparing the sensor data and the echo map, the vehicle is able to determine its precise position
- This function even operates correctly even when the environmental conditions change, as often happens in cities – for example, due to parked cars or road works
- The third element involved in position determination is a radio solution with radio transmitters on the edge of the route that provide precise distance measurements to further improve position determination
- The CUBE project is one of the three pillars underpinning Automated Driving: Cruising Chauffeur, Self-Driving Car and Automated Parking

Acquisition of Hi-Res 3D Flash LiDAR from Advanced Scientific Concepts (ASC):

- This innovative technology will further enhance the company's Advanced Driver Assistance Systems product portfolio with a future-orientated solution to add to the group of surrounding sensors needed to achieve highly and fully automated driving
- Continental is working on a family of sensors to address different requirements around the vehicle, to allow function optimized mapping and segmentation of the entire surrounding



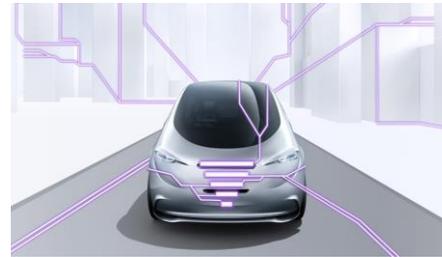
Continental will begin producing the new solid-state sensing devices for vehicles in **2020**

One significant advantage of the Hi-Res 3D Flash LiDAR sensor technology is that it provides both real-time machine vision as well as environmental mapping functions



Teaching the Vehicle How to Drive:

- Starting with innovative driver assistance systems for improved safety, security and comfort, Bosch is developing highly automated functions that simplify driving
- Bosch offers technologies covering all levels of automation and for automated parking, many of which are already being deployed in volume production
- Portfolio for automation: Driver assistance systems, Partially automated driving, Highly automated driving, Fully automated driving, Conditionally automated driving



Investment in TetraVue:

- Bosch VC co-leads \$10M Series A funding round in February 2018
- TetraVue is a leader in ultra-high resolution 3D data and imagery, which will help enhance the capabilities of automated vehicles
- This investment adds to the growing Robert Bosch Venture Capital portfolio of companies in the field of sensors and software for automated vehicles, such as AIMotive and Chronocam
- TetraVue’s technology helps to address the challenges associated with automated vehicles encountering unexpected and dangerous obstacles during operation
- TetraVue’s core technology differentiation is its patented “light slicer” technology, which uses time and distance measurements to find optical intensities using standard CMOS sensors. The company’s innovative approach yields many benefits and USP’s including higher reliability to meet automotive requirements, low latency, and ability to produce ultra-high resolution images for a wider range of distances at a lower cost
- **Bosch to sell lased based radar by 2020**

Bosch and Daimler to Test Self-Driving Taxis in 2019:

- AI-infused vehicles will improve traffic flow, enhance safety and offer greater access to mobility. In addition, analysts predict it will cost a mere 17 cents a mile to ride in a driverless car you can summon anytime. And commuters will be able to spend their drive to work actually working, recapturing an estimated \$99 billion worth of lost productivity each year



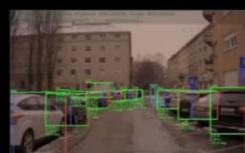
Perception



Free Space Perception



Distance Perception



Weather



LIDAR Perception



Camera-based Mapping



Camera Localization to HD Map



LIDAR Localization to HD Map



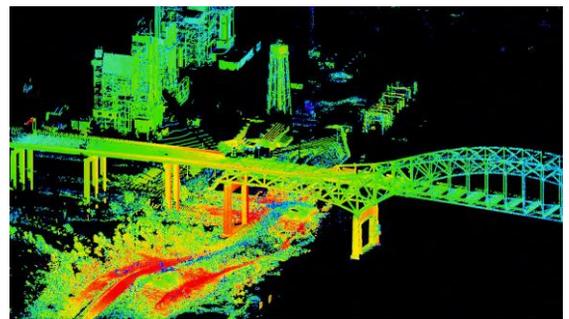
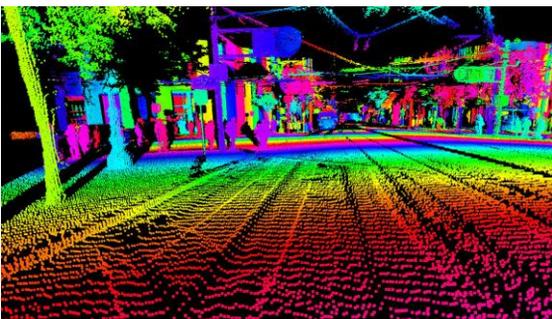
Path Perception



Scene Perception

Digital Measuring of the World:

- BMW uses HERE (along with Audi and Daimler), a mapping technology to develop high-precision digital road maps which provide a basis for autonomous driving
- These latest HD maps show a wealth of information, not just roads and routes. Accurate to the centimetre, the environment is contained completely in the many billions of pixels
- The idea is for BMW to provide real-time, camera-based information on the driving environment. The data is then aggregated at the back end and used to update the highly precise digital map. Crowdsourcing on the road would have huge advantages – as soon as the critical mass of vehicles with on-board sensors is reached, it will be possible to keep the map material up-to-date at all times. In other words, the map will achieve real-time capability



Partnership with Innoviz:

- Israeli start-up Innoviz's sensor uses MEMS involving a fixed laser beam that's redirected in multiple directions via a tiny spinning mirror. The result is a compact, cost-effective system that offers equivalent coverage as larger spinning lasers
- Moving forward, the plan is to integrate Innoviz's technologies into the Intel-Mobileye platform for the purposes of testing and mass production
- In addition to the hardware, Innoviz's solution also provides a software solution by translating the data it sees into a 3-D point cloud, ready for the manufacturer's system to process. This removes a piece of the proverbial puzzle for automakers just jumping into the automation sector and acts as a value-add
- **BMW intends to launch self-driving cars by 2021**



Invests in Blackmore Sensors:

- \$18 million Series B led by BMW i Ventures to increase autonomous vehicle safety with new technology – March 2018
- Blackmore boasts its cost-effectiveness and use of frequency-modulated continuous wave (FMCW) LiDAR as critical differentiators in the industry
- The continued emittance of the laser from the device allows it to detect not only the distance of objects in front of the vehicle, but also the velocity at which those objects are moving at the same time



The Human Machine Team:

- Passengers can interact intuitively with the vehicle using gestures, eye-tracking or touch
- The F 015 is able, among other things, to communicate audibly and visually with its environment and, for example, to project a zebra crossing onto the road
- With the further development of existing driver assistance systems, such as Active Distance Assist DISTRONIC, which is capable of semi-autonomously following the vehicle in front in a traffic jam, we are adopting the so-called evolutionary approach



Contract with Velodyne:

- Fully automated and driverless test vehicles from Mercedes-Benz equipped with Velodyne’s industry-leading 3D real-time LiDAR
- Selected the VLP-32C Ultra Puck as a critical sensor supplier for further development of automated and driverless vehicles
- Mercedes-Benz has developed an intelligently integrated setup of different sensors that will now include Velodyne LiDAR sensors
- The so-called ‘sensor fusion’ enables a continuous situational analysis of the combined data from the various sensors. The goal is to guarantee reliable results to allow a robust planning of safe trajectories for automated vehicles

Set to Launch Self-Driving taxis in California in 2019:

- Plan to start out using a fleet of S-Class luxury sedans and B-Class hatchbacks, with long-term plans for vehicles designed for autonomous driving
- Partnering with Bosch, who has a strong track record in building active safety systems and some of the semi-autonomous systems now on luxury cars
- Also will work with NVIDIA, whose Pegasus AI supercomputer marks its best combination yet of minimal power consumption with maximum performance—try 300 trillion operations every second



Introduction of the Drive Me Trial in Gothenburg:

- They start using Volvo’s driver assistance technology, and will gradually be introduced to more advanced systems for assisted driving
- They believe the first unsupervised autonomous driving vehicles will be in the market by 2021
- Uniqueness of the trial is it’s user-centric focus that guides in the verification of their technology, overall contributing to moving from supervised to unsupervised driving
- The Drive Me programme is partly funded by FFI - Strategic Vehicle Research and Innovation, a partnership between the Swedish government and automotive industry

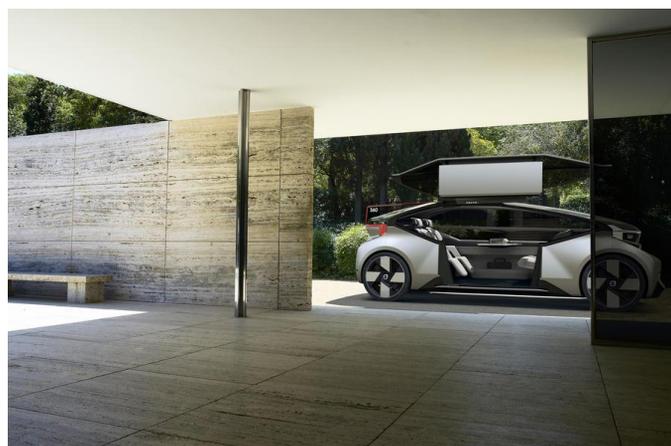


Invests in LUMINAR:

- Volvo’ recently launched venture capital fund has invested an undisclosed amount in the LiDAR maker
- Luminar, which uses a different part of the infrared light spectrum and wields just two lasers, claims a robust range of more than 250 meters, plus a price point that makes it a viable add-on to consumer cars
- The fund’s approach is a search narrowed by our strategic interest in technology trends in artificial intelligence, electrification, autonomous driving and digital mobility services

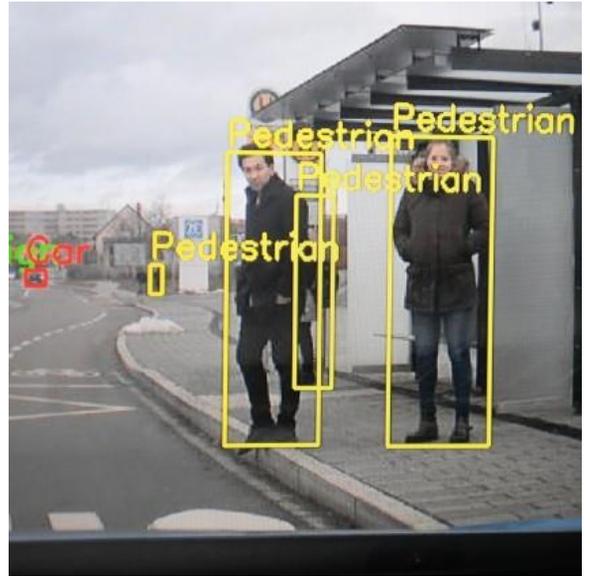
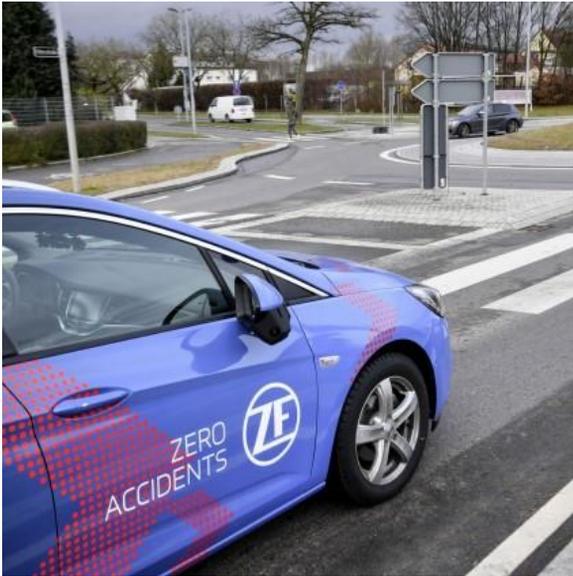
The Future of Autonomous Vehicles at Volvo:

- Plan to offer a truly autonomous car by 2021, where drivers will have the option to “eat, sleep, work, watch a movie, relax, do whatever,” while their autonomous car drives on the highway
- Refers to its mapping technology and laser sensors as the Highway Pilot
- In September 2018, Volvo introduced its 360c Concept car, a fully-autonomous vehicle
- Volvo imagines the interiors as a space which could compare to an office or a break room
- Conceived as a Level 5 autonomous vehicle, meaning it requires no driver input at all, the cabin abandons the traditional two- and three-row seating of today’s family car



ZF's Development of their 'Dream Car':

- Gains vast data volumes in city traffic, by evaluating signals from front, side and rear cameras, LIDAR and radar sensors as well as GPS map and position information
- Massive computing power through the ZF ProAI (joint project with NVIDIA)
- Development of modules through Level 1 to Level 5
- ZF has various projects to support their development: automated driver systems, concept cockpit, highway driving assist, AC2000 radar, and the Tri-Cam camera



Acquires a 40% stake in Ibeo Automotive Systems:

- Ibeo is a market leader in lidar technology and in developing environmental recognition software with a particular focus on applications for autonomous driving
- Together with ZF, Ibeo will make the next technological leap and a significant step for vehicle applications: The LiDAR generation developed in cooperation with ZF will reproduce a three-dimensional image of the environment without the rotating mirrors contained in current LiDAR systems
- Under the auspice of ZF, Ibeo plans to establish an Autonomous Driving Competence Center, aiming at developing solutions for highly automated driving

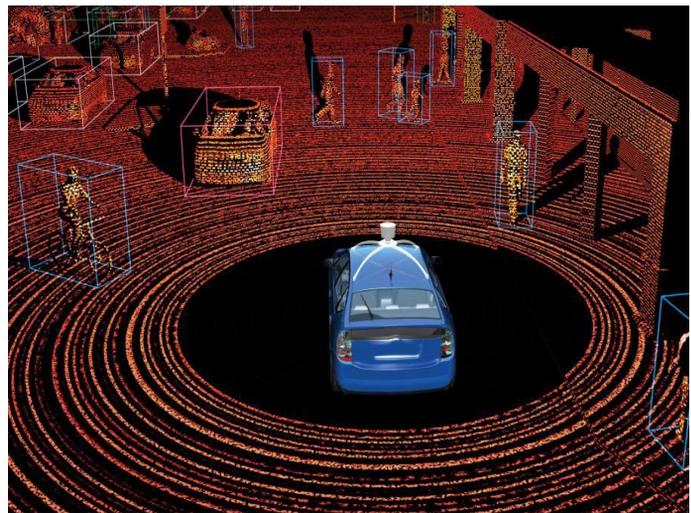
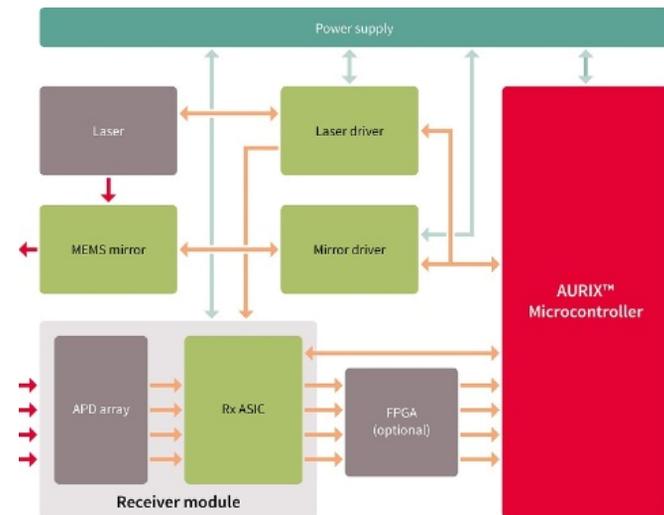
ZF's Supercomputer, ProAI:

- ProAI acts as a central control unit within a test vehicle and with this ZF is taking a modular approach to the development of automated driving functions
- The goal is a system architecture that can be applied to any vehicle and tailored according to the application, available hardware and desired level of automation
- The ProAI Control Unit developed in partnership with NVIDIA is now production-ready and is already in development for a number of applications
- Recently announced that an agreement has been reached with Chinese manufacturer Chery to deliver ProAI units to them by 2021
- Along with NVIDIA, ZF has announced their ProAI will be used in Baidu's Apollo pilot



Infineon LiDAR Sensors:

- Provides highly flexible solutions with best in class product performance, which were created by design to complement each other
- Using the latest developments in technology within a small form factor, cost-effective solid state LiDAR sensors for mass-market adoption can be developed to enable very accurate object tracking and recognition
- Infineon will manufacture and supply several automotive qualified components for a LiDAR sensor to support SOP 2020+: MEMS mirror, ASIC to drive and control the MEMS mirror, receiver module, AURIX microcontroller as well as power supply/management components
- Infineon has partnered with Baidu on their Apollo program, striving for autonomous driving development



Acquisition of Innoluce (October 2016):

- With this acquisition it delivers expertise in all three complementary sensor systems which provide the redundancy required for autonomous driving
- Fostering autonomous driving, Infineon already helped to bring radar technology as an additional safety feature to the vehicle mass market: the use of proven technologies from chip mass production and a new chip packaging technology reduced both manufacturing costs and size of radar systems significantly

Infineon opens the door for mass-deployable lidar systems for Automated Driving

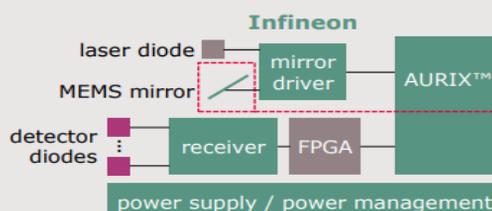


Classification of long-range lidar systems

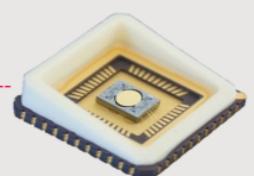
mechanically moving mirror	solid state optical system		
	scanning optical phased array	flash lidar	scanning MEMS-based mirror
<ul style="list-style-type: none"> ⊕ proven concept ⊖ bulky ⊖ expensive 	<ul style="list-style-type: none"> ⊕ allows optical beam forming ⊖ high demand of laser power, especially for long-range 	<ul style="list-style-type: none"> ⊕ entire situation captured in real-time ⊖ more complex laser system (more expensive, higher power demand) 	<ul style="list-style-type: none"> ⊕ robust signal path ⊕ more compact and cost-effective ⊕ roadmap for higher level of integration ⊖ more complex to scale field of view

- > Lidar is Infineon's AD portfolio expansion adjacent to radar
- > Infineon intends to repeat its radar success story
- > In addition to MEMS, room to increase BoM by receiver, microcontroller, power management ICs

1st System reference design

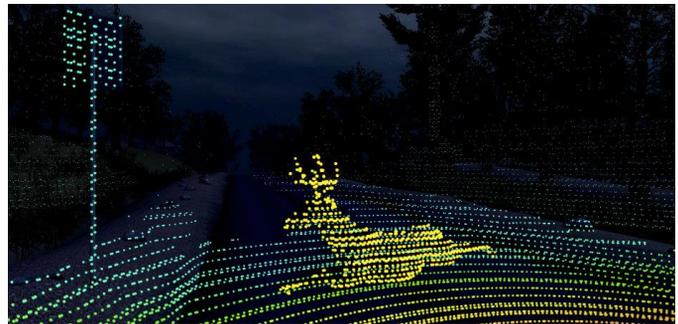


MEMS mirror



Osram's LiDAR Expertise:

- In 2016, presented a prototype laser which has an extremely short pulse length and four parallel output channels. It therefore offers completely new options for detecting objects and a unique vertical detection zone. This milestone in modern laser technology will be used for the first time in scanning LiDAR sensors based on micro-electromechanical systems (MEMS). Such solutions do not need any mechanism to redirect the laser beam so they are less susceptible to wear and tear
- The 4-channel LiDAR laser consists of a laser bar with four individually controllable laser diodes and a control circuit integrated into the module. The entire module is surface-mountable, which reduces assembly costs and the time needed for fine adjustment at the customer

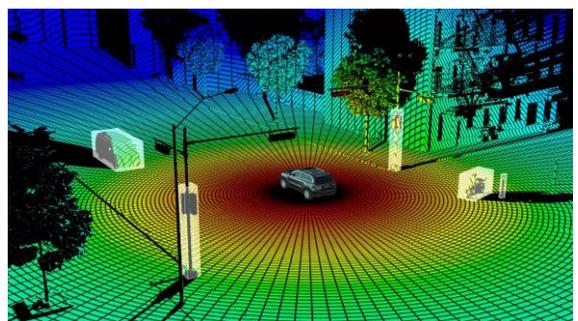
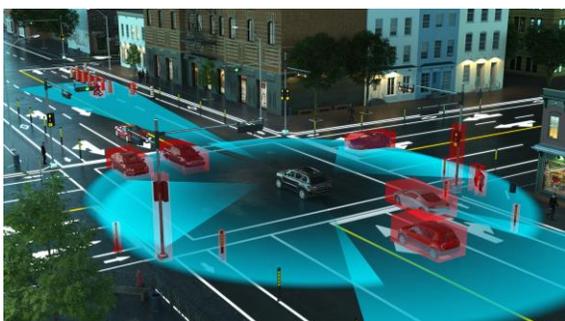


Invests in LeddarTech (July 2017):

- Osram has acquired a strategic 25.1 percent share in LeddarTech Inc., a Canadian company that develops a proprietary LiDAR technology integrated into semiconductors and sensor modules for self-driving cars and driver assistance systems
- LeddarTech specializes in solid-state LiDAR (Light Detection And Ranging) systems that use infrared light to monitor the area around them, and its advanced optical sensing technology is complementary with Osram's semiconductor products

Invests in Blickfeld (August 2018)

- \$5.7 million from existing investors OSRAM Ventures, High-Tech Gründerfonds, Tengelmann Ventures, and Unternehmertum Venture Capital Partners
- Blickfeld works on LiDAR sensors for environmental detection used in autonomous driving, robotics, and the Internet of Things applications
- The company's technology is based on commercial off-the-shelf components combined with its proprietary patented silicon micromirrors



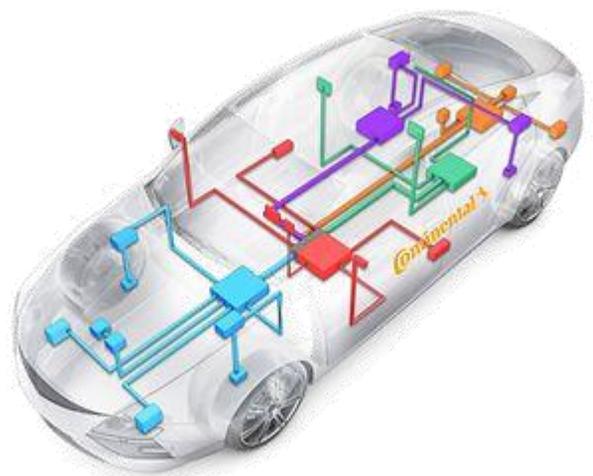
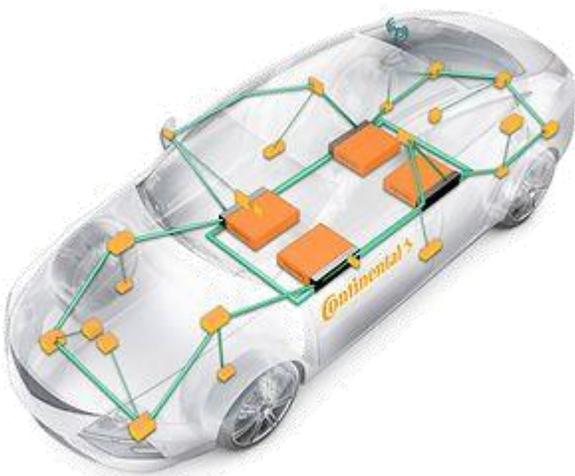
Partnership with Vergence Automation to Develop New LiDAR and 4D Camera:

- Working with Minnesota-based start-up Vergence Automation on advanced imaging technology including pulse-infrared lasers and 4D cameras for use in on-board sensor systems
- The pulse length has also been reduced from 20 nanoseconds (ns) down to 5 ns. With a duty cycle of 0.01% and a short pulse length, the company has ensured that eye safety standards are met despite the high output of the lasers
- Osram's collaboration with Vergence Automation aims to leverage both companies' technologies into new integrated imaging solutions



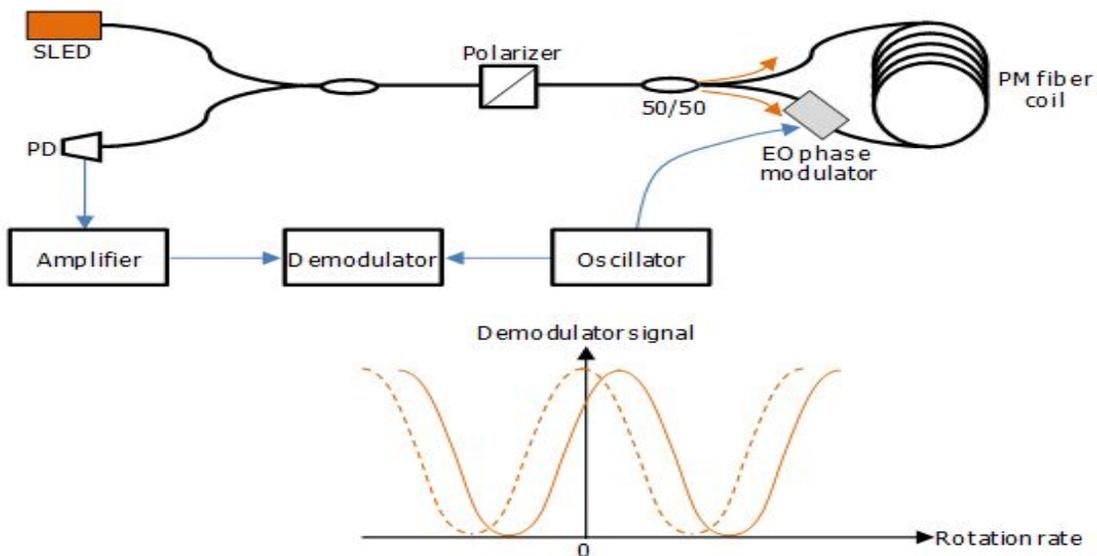
Aquantia, Bosch, Continental, NVIDIA and Volkswagen join together to form the Networking for Autonomous Vehicles (NAV) Alliance

- The NAV Alliance was formed to drive the ecosystem development required for next generation Multi-Gig Ethernet networking in vehicles
- Self-driving cars have become data centers on wheels constantly analyzing vast amounts of data to endeavor to ensure the safest and most secure experience for passengers, pedestrians, and other vehicles
- Akin to a very advanced nervous system, this next-generation networking architecture is based on an array of ECUs, CPUs, GPUs, high-definition cameras, sensors, gateways, and storage devices, all connected through a high-speed, Multi-Gigabit/s Ethernet network that works to seamlessly move data throughout the vehicle securely and reliably
- NAV Alliance provides a platform for the automotive industry to develop the next generation of in-vehicle Network infrastructure for autonomous vehicles and facilitate wide deployment of networking technologies and products. The Alliance was founded by leading vehicle manufacturers, technology suppliers and networking players in the automotive market, sharing the goal of developing the ecosystem that is required for next-generation Multi-Gig Automotive Ethernet networks in the vehicle



Fibre Optic Gyroscopes (FOGs) offer numerous advantages to LiDAR technology:

- Best at stabilising and guidance
- No emitted acoustic noise
- Reliable, requiring low maintenance
- High performance
- Scalable
- Proven – has been put through rigorous tests under the most severe requirements



Despite this, their application and consideration for autonomous vehicles has been limited. There are too few suppliers (depicted below), and they focus more on military application



The main inhibitor preventing wide-scale adoption is price. The market is waiting for someone to provide a cost-effective way of producing FOGs on a large scale and integrating them into autonomous cars

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