

# Practical Solutions for Enhancing Autonomous Vehicle Safety Using LiDAR-based 3D Sensing

Optical sensing will play an increasingly important role in the evolving automotive landscape. The greater the level of automation, the more information—and more precise information—the vehicle requires. Currently, automotive OEMs are focused on designing accurate and reliable advanced driver assistance systems (ADAS) for consumers, representing an automation level of 2 and up. In addition, they are developing fully autonomous vehicles with an automation of level of 4+. Both of these types of systems rely heavily upon optical sensors to identify environmental factors such as other vehicles and oncoming objects quickly and accurately.

Enhanced driver safety functions to fully autonomous vehicles

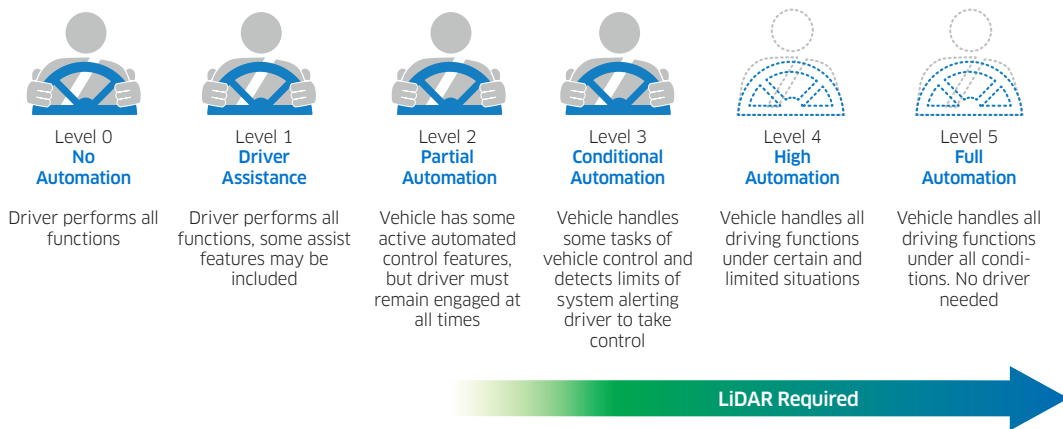


Figure 1: The automation levels of autonomous vehicles according to the Society of Automotive Engineers.

Optical sensors can track objects within a certain range of the vehicle. A simple use of this information is to alert the driver of any movement within the range (driver assistance). With more information, such as how fast the object is moving and its direction of travel, the vehicle can better assess a situation. For example, the vehicle could slow itself or stop if the driver fails to notice an object moving behind the vehicle when backing up.

When more precise information is available, objects can be recognized and their behaviors more accurately predicted. If the object is a ball, its path of motion is readily discernible. If the object is a child, the vehicle can take immediate preemptive action (i.e., braking and/or turning). The greater the availability and precision of information available, the better the decisions the vehicle can make.

There are several technologies—radar, imaging, LiDAR, and thermal—being used to capture information about the environment around a vehicle. Each provides data that is useful at different ranges for different use cases.

It has become clear that LiDAR-based 3D sensing is an essential technology for enabling the evolution from driver assistance to fully autonomous vehicles. LiDAR provides critical data about the surrounding environment that ADAS requires to be able to offer reliable safety. As vehicles become more autonomous and take over additional driving functions, ADAS will become increasingly dependent upon LiDAR to enhance perception capabilities in all operating conditions.

To meet the high-volume, high-quality, and cost-sensitive requirements of the automotive industry, OEMs need to implement LiDAR sensors in a way that efficiently integrates functionality without sacrificing capabilities. This article will outline a practical approach for utilizing innovative LiDAR technology while balancing cost, manufacturability, performance, and reliability.

### LiDAR Basics

A basic LiDAR-based system includes a light source, beam steering capabilities, image components, detection, and packaging (see Figure 2). Currently, LiDAR is used to gather environmental information for both short range and long range applications.

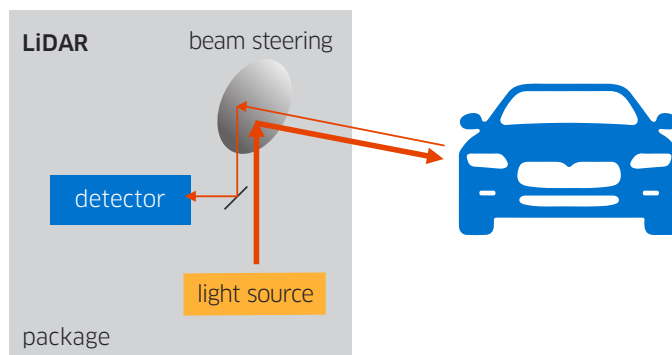


Figure 2: A basic LiDAR-based system, including light source, beam steering capabilities, detection, and packaging.

Given the complexities and variances of vehicles and the environments in which they must operate, LiDAR must meet stringent requirements to be useful in automotive applications. The detection system must have immunity to light and other LiDAR signals (such as those from oncoming cars). For reliability, the system must also be robust to ever-changing environmental factors such as vibration and thermal changes.

### Short-Range LiDAR

Short-range LiDAR is used to capture data in the area immediately around the vehicle. To accomplish this, vehicles need a wide field of view (FoV) 360° object detection. Short-range LiDAR applications are typically used when a vehicle is moving at slower speeds in a complex urban environment, where time of flight (ToF) is the most efficient and cost-effective technology to deploy. In a ToF system, a 1D array of emitters launches a short pulse onto the scene of interest (see Figure 3). The reflected pulse is captured by a 1D array of detectors, which provides a large collection aperture. Measuring the time delay between sending and receiving the pulse enables the system to compute how far an object is from the vehicle.

An advantage of ToF is that the array of emitters and detectors enables efficient field of view coverage. The photonics in a ToF array are relatively low in complexity compared to other approaches. However, detecting weak reflected pulses in the presence of receiver noise can be extremely challenging. This impacts the system's effective range.

To address this, ToF-based systems are moving to narrower, higher peak power pulses, which leads to an improved signal-to-noise ratio (SNR) and improved range. In addition, by maintaining greater wavelength stability, the system can improve its immunity to other light/LiDAR that may be present in the environment.

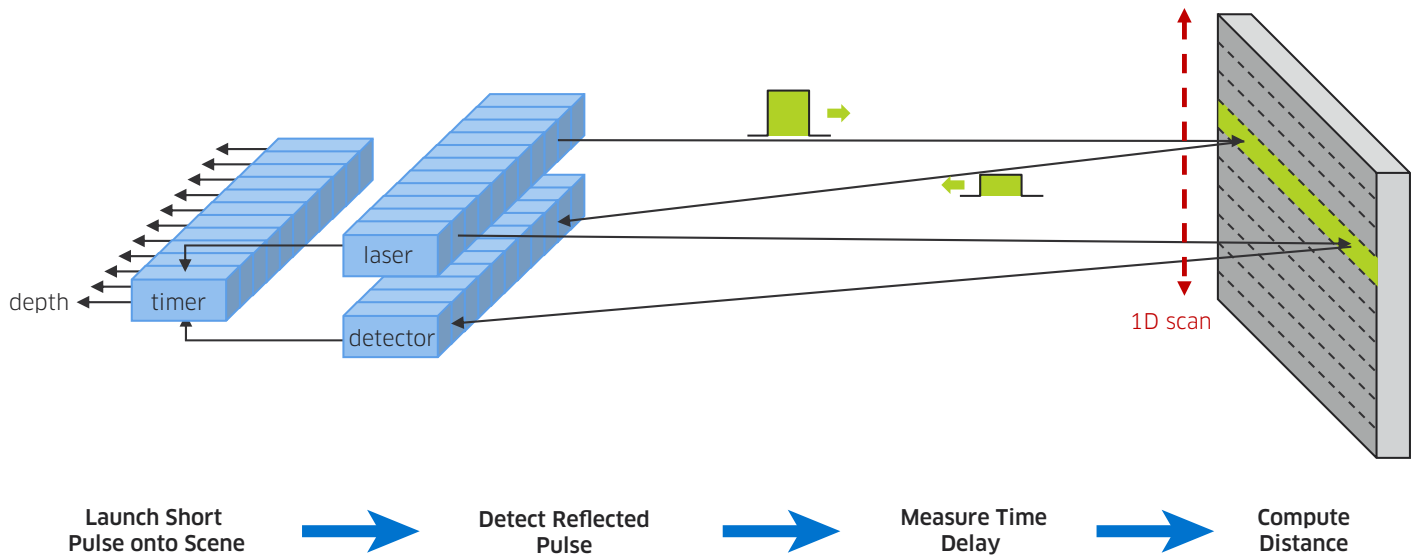


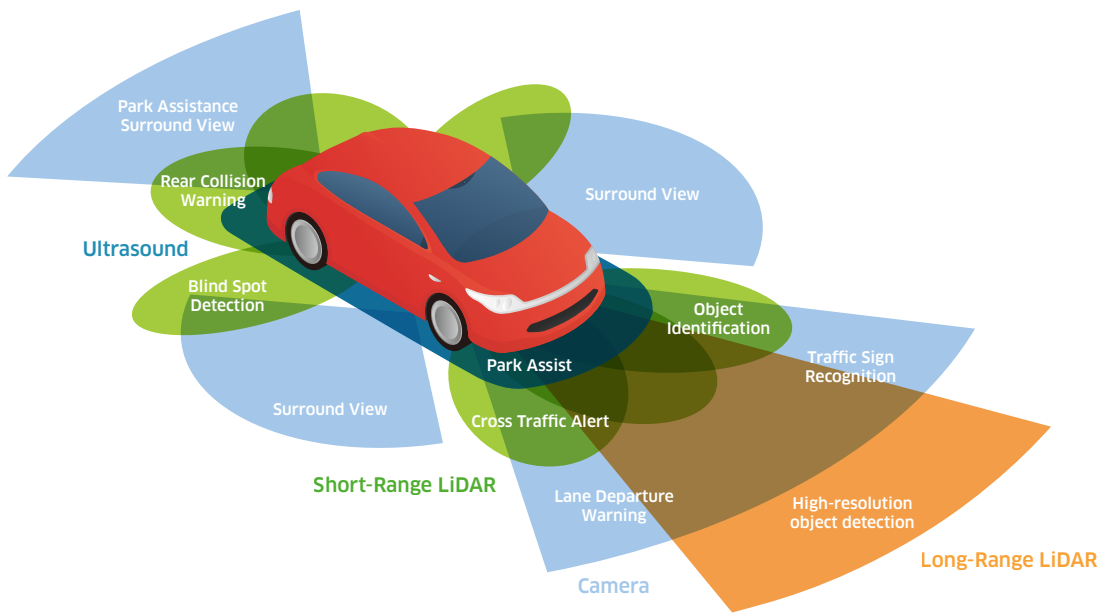
Figure 3: Time of flight (ToF) provides an efficient and cost-effective approach using LiDAR to sense the area immediately around a vehicle (short range).

**Long-Range LiDAR**

Long-range LiDAR focuses on detecting objects up to 200 m from the vehicle. In addition, both the vehicle and objects may be in motion. Long-range LiDAR generally employs a narrower FoV concentrating on the forward facing direction of travel. To meet autonomous vehicle requirements, LiDAR resolution needs to be

fairly accurate, on the order of ~20 cm at 200 m (Figure 4). The greater the precision, the more information that can be made available to the ADAS for processing. Another important requirement is the ability to meet class 1 eye safety regulations.

<b>Range</b> 0 – 200 m	<b>Resolution</b> ~20 cm at 200 m	<b>Field of View (FoV)</b> 20° <sub>vert</sub> X 50° <sub>horiz</sub> to 30° X 120°
<b>Object Reflectivity</b> 10%	<b>Probability of Detection</b> 98%	
<b>Measurement Frame Rate</b> 10 Hz to 25 Hz		<b>Immunity to ambient light and other LiDAR systems</b>



<b>Eye Safe</b>	Class 1	<b>Physically Compact</b>	Minimum Visual Design Distraction	<b>Robust to Automotive Environment</b>	Thermal and Vibration Tolerance
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Figure 4: LiDAR detection systems must meet the stringent requirements for autonomous vehicles.

The FoV generally ranges from 20° vertical x 50° horizontal up to 30° by 120°. Other relevant requirements include object reflectivity the system must detect (10%) and probability of detection (98%). For today’s applications, the measurement frame rate needs to be between 10 and 25 Hz.

Long-range LiDAR is well addressed using frequency modulated continuous wave (FMCW) implementation. In FMCW-based LiDAR, the system begins by launching frequency-modulated light from a laser (see Figure 5). The reflected signal is mixed with the frequency-modulated light to detect the frequency difference, enabling the system to determine how far an object is from the vehicle.

Coherent mixing of the returning signal with the higher power local oscillator (LO) results in high sensitivity even in the presence of receiver noise, leading to greater range and immunity to ambient light and other LiDAR signals. The primary disadvantage of an FMCW approach is that it requires 2D scanning with a minimum dwell time per pixel i.e. based on the round-trip time of the reflected signal, generally more complex photonics, and typically favors a more narrow FoV.

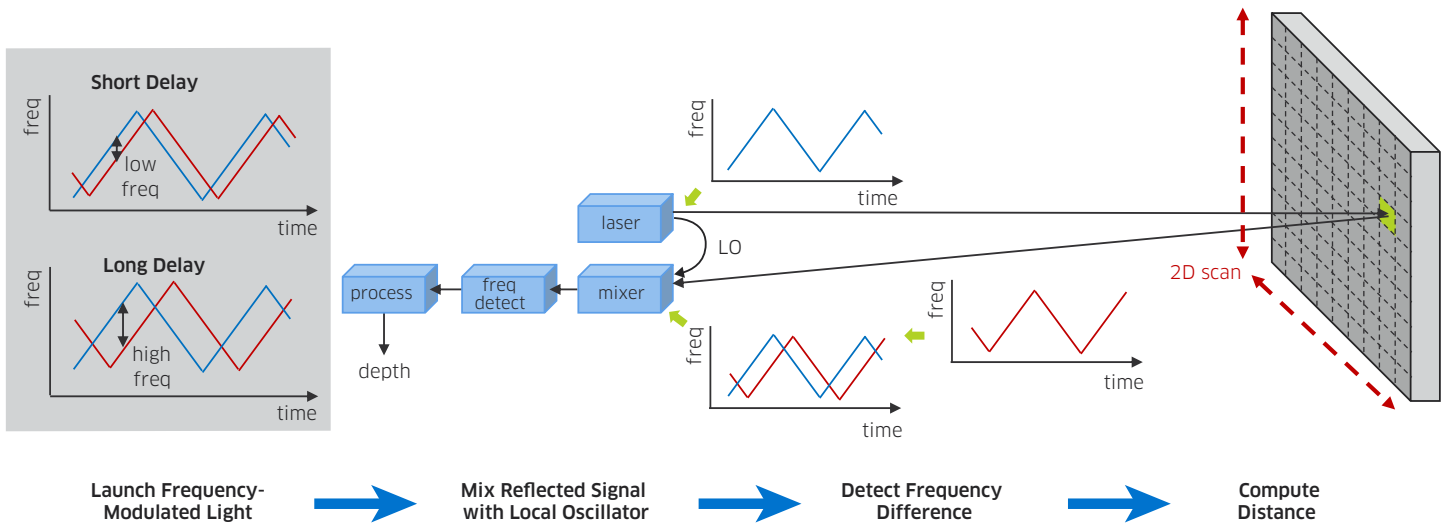


Figure 5: Frequency modulated continuous wave (FMCW) is well suited to a long-range LiDAR implementation.

**The Power of Integration**

The traditional path for technology is for systems to be made from multiple discrete components. As manufacturing techniques improve, more and more of the system can be integrated, resulting in smaller, more cost-effective components that can be easily integrated into larger systems.

To address the challenges associated with LiDAR and specifically FMCW LiDAR, photonics manufacturers are moving towards highly integrated solutions that reduce system size, cost, and power consumption. Combining the many parts of an FMCW LiDAR system—laser, laser monitor, detector, mixer, receiver, scanning mirror, and circulator—into a LiDAR optical sub-assembly (LOSA) significantly reduces the complexity for OEMs (Figure 6). Rather than require OEMs to become photonics experts, a LOSA enables OEMs to easily bring LiDAR into applications. In this way, they can focus on their own value-added expertise while ensuring their systems have reliable, high performance LiDAR capabilities.

The expertise of the LOSA manufacturer determines how efficient integration of LiDAR systems can be. LiDAR systems can be extremely complex, and there are many different tradeoffs that can be made. These tradeoffs go far beyond simply balancing power, cost, size, performance, and reliability. Every part of the system contributes to each of these characteristics, leading to multidimensional tradeoffs.

One of the advantages of integration is that these tradeoffs can be made by a manufacturer with extensive experience. For example, Lumentum is one of the world’s leading optical companies with vertical integration expertise in optical communications, datacom, commercial lasers, and 3D sensing. Lumentum has real-world experience with optics and photonic materials covering the design, processing, manufacturing, and wafer fab infrastructure required for reliable, high-performance LiDAR systems.

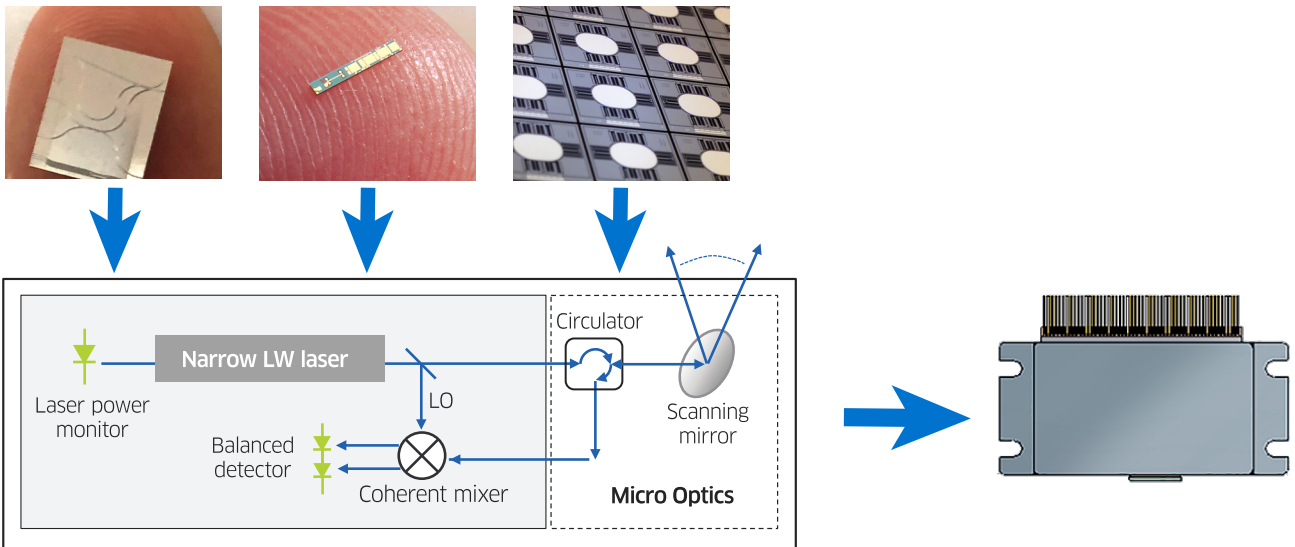


Figure 6: Combining the many parts of a FMCW LiDAR system into a LiDAR optical sub-assembly (LOSA) significantly reduces complexity for OEMs.

**There are many ways that Lumentum balances the tradeoffs for LiDAR systems.**

*Heterogeneous Approach:* Today, a fully monolithic approach to FMCW LiDAR is not practical. For instance, performance penalties increase the laser power required, which has a strong impact on yield, power dissipation, and reliability. For this reason, Lumentum uses heterogeneous functional integration, integrating photonics and optomechanical technology. Placement of optomechanical components can be automated using pick and place assembly, ensuring reliability. The stability of optomechanics enables the system to maintain its alignment over a range of temperature, shock, and vibration conditions. This heterogeneous approach provides other benefits as well.

*Wafer Yields:* With its world-leading indium phosphide (InP) laser technology, Lumentum is able to implement processes that minimize wafer losses while also maximizing yields at the integration level. This results in a balance between performance, cost, manufacturability, and reliability.

*Laser Integration:* Lumentum has created an integrated LiDAR system with separate laser and power amplifier sections. This provides the flexibility needed to achieve greater noise optimization and improve laser performance. Using wavelength-stabilized lasers achieves the narrow linewidth (<100 kHz) required to maintain coherence over the long distances (>200 m). Fast control of the laser frequency is enabled using carrier-injected phase modulation. Use of a single 1550 nm wavelength (frequency-modulated) laser optimizes both performance and eye safety.

*Microelectromechanical Systems (MEMS):* Lumentum is able to leverage its 20-year history with MEMS to design and manufacture the scanning mirror within a LiDAR system. The high reflectivity of MEMS mirrors and low loss efficiently launches the optical signal power onto the scene reducing the need for added laser power to overcome scanner loss. Low scanner loss also improves the system range as less returning signal light is lost. Built using an electrostatic approach, these MEMS controllers minimize power consumption. They also enable 2D steering without requiring laser wavelength tuning, thus reducing system complexity.

By using the largest practical aperture, the LiDAR assembly is able to optimally trade off between tilt range, speed, and optomechanical sensitivity. The large tilt angle not only increases field of view, it supports the use of multiple beams sharing the same scanner (known as split FoV). Tilt range, however, must be balanced with hinge stress. Because these automotive systems will be in constant use over decades, these MEMS systems need to maintain high reliability over billions of cycles.

*Sensitivity:* In order to sense objects at long distances, such as 200 m, the amount of signal that returns and is captured by the receiver is very low due to both the diverging and spreading nature of the optical beam as it propagates towards the target as well as returning from the target. The loss due to this spreading can be as large as 100 dB. In addition, the percent of the optical signal that reflects from an object's surface is anticipated to be as low as 10% further reducing the amount of signal power that is ultimately returned to the LiDAR unit. Therefore, in order to successfully and accurately detect this small returning signal, and with sufficient measurement confidence, the LiDAR receiver must have very high sensitivity. This level of sensitivity can be difficult to achieve. Therefore it is critical that losses from all LiDAR optics are minimized. If they are not, this will impact the overall achievable range of the system.

Lumentum's integrated coherent receiver technology provides high sensitivity. Low losses over the receive path reduces performance requirements for the laser and improves sensitivity. Such a balanced receiver also rejects any ambient light or signal from other LiDAR systems to provide precision and immunity to interference.

*Packaging:* Packaging plays an essential role in LiDAR performance and reliability as well. The use of laser, MEMS, and thermoelectric cooler components requires hermetic packaging. The cost of hermetic packaging, however, scales with size, as does the cost of most optical components. Thus, overall footprint is an important cost driver.

The ability to integrate components allows Lumentum to eliminate intermediate levels of packaging that would otherwise be required if an OEM were to build their own LiDAR assembly. In addition, with its specialized optomechanics expertise, Lumentum has been able to reduce package size through integration that eliminates the need for fiber between components. Doing this also enables automated assembly and reduces coupling losses.

Compact optomechanics provide several additional benefits such as increased mechanical stability and lower cost. More compact optomechanics minimizes the thermal mass and area that requires cooling, leading to lower power consumption. This also minimizes external window size, which in turn reduces cost, lowers the power required to keep the window de-iced, and results in better aesthetics.

## Summary

LiDAR enables robust ADAS-based (2+) and fully autonomous (4+) vehicles by capturing data essential for reliably assessing environmental conditions at both short and long distances. With the accuracy provided by LiDAR, vehicles have more accurate information available so that they can make better—and safer—decisions. This accuracy and reliability will be even more critical as autonomous vehicles continue to evolve and take over more of the driving process.

However, implementing LiDAR in a practical manner requires designers to make multidimensional tradeoffs. Pressure to meet stringent performance and reliability requirements have to be balanced with system cost and scalability for volume manufacturing. Today, FMCW technology offers a promising approach for long-range LiDAR, particularly its performance, efficiency, and high immunity to external interference.

The challenges of designing an efficient, reliable, and precise LiDAR system are best met not with a custom design but through a heterogeneous integrated approach. With LiDAR optical sub-assemblies like those from Lumentum, OEMs can leverage the expertise of world-leading photonics experts. These compact, manufacturable solutions enable cost-effective and wide-scale deployment of LiDAR with the high performance and reliability required for automotive applications.



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