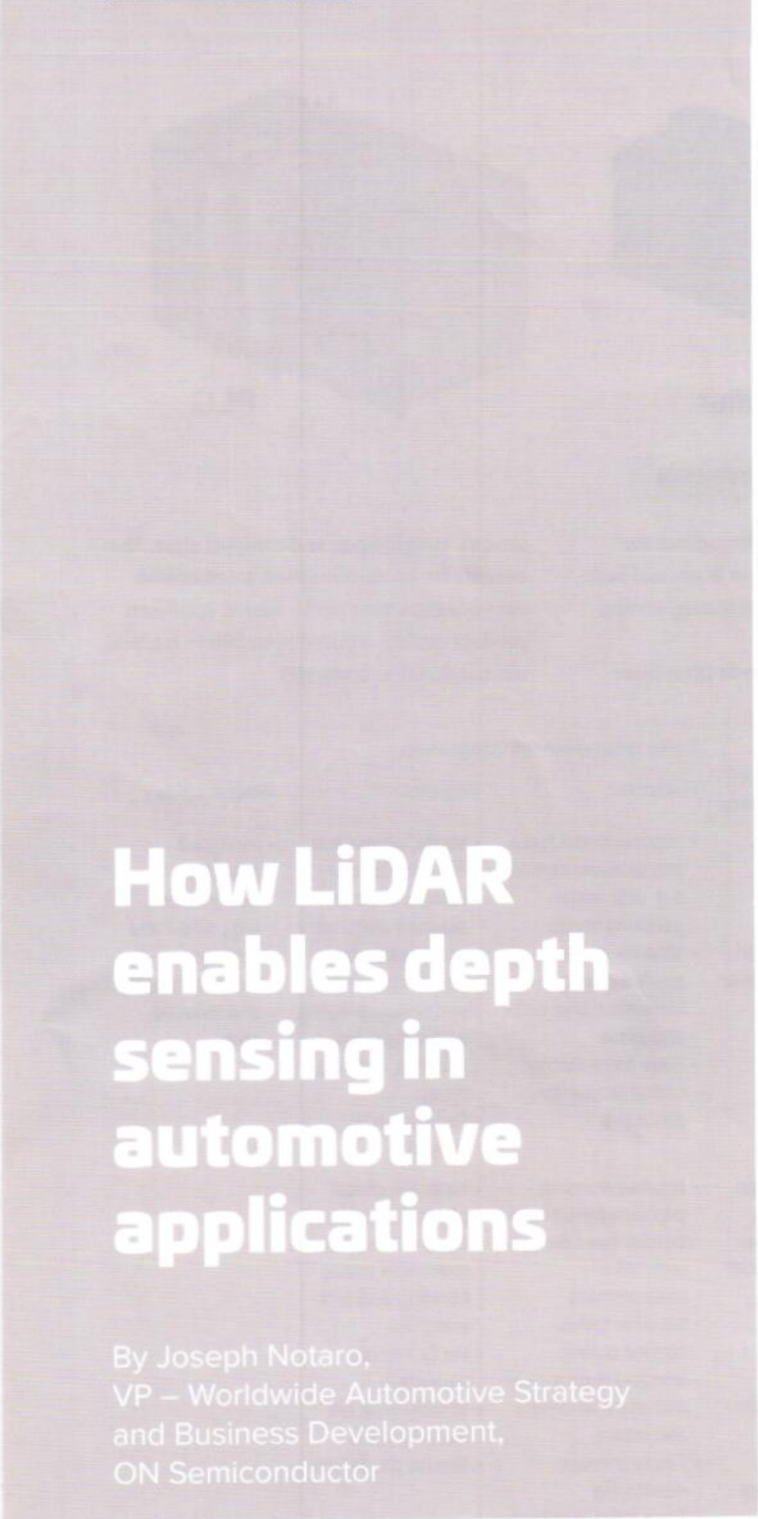

How LiDAR enables depth sensing in automotive applications

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LiDAR stands for light detection and ranging, a means of sensing distance using a laser. It measures the time it takes for a reflection to come back from an object. Different wavelengths can be used depending on the application, but the most common is infrared (IR).

Most of the time, the human brain is good at inferring relative depth/distance and size of objects, an essential skill, especially when driving a vehicle. However, imaging systems struggle to do this well, especially as standard image sensors present a 3D scene as a 2D image.

> **LiDAR's ability to work effectively in all lighting conditions makes it a reliable always-on protection in many applications**

Using two image sensors in a stereoscopic arrangement similar to the human eyes allows for extraction of depth data, but with limitations on accuracy and dependence on ambient light levels. Using LiDAR allows measurement independent of light conditions and removes ambiguity from an image. The distance of an object is calculated by combining a light pulse aimed toward and reflected from an object with accurate timing measurement.

LiDAR applications

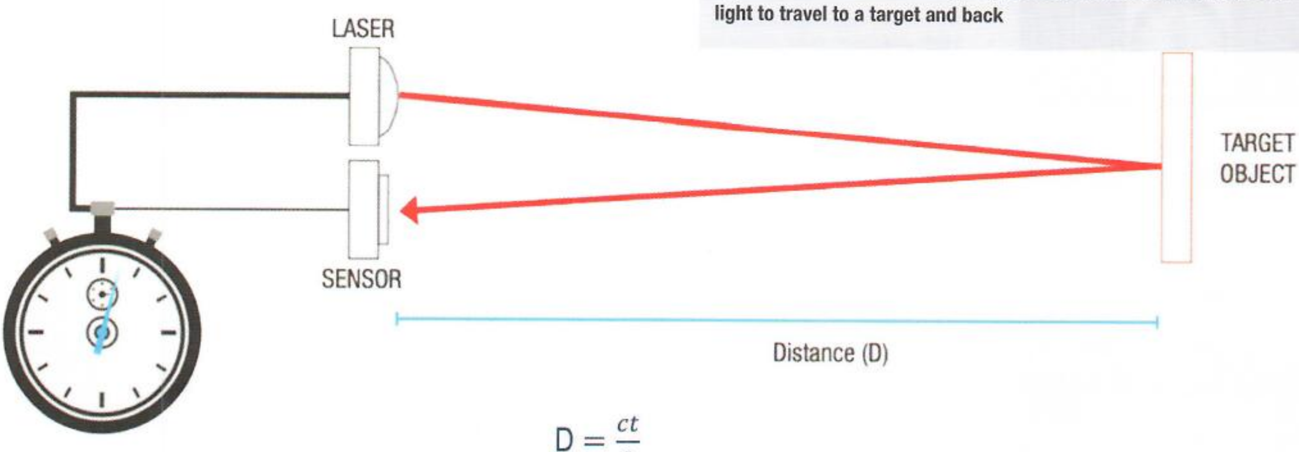
There are many applications for LiDAR in the automotive world, especially on semi-autonomous vehicles that operate at SAE Levels L3-L5 – from sensing objects around the vehicle to seeing hundreds of meters ahead. It is also commonly used on delivery robots and in applications requiring autonomous perception.

However, the technology is also widely used in outdoor applications where processable 3D depth maps are rapidly generated with very high accuracy – a process that typically requires days of effort with traditional surveying techniques. For example, LiDAR is used in agriculture for surveying land, to develop maps and to assess crop condition, thereby allowing farmers to model and forecast crop yields and select the best treatments. Levels of grain in silos and liquids stored in tanks can be instantly measured using LiDAR fitted to the top of these structures, without contact with the contents.

Environmental organisations assess deforestation, measure coastal erosion or monitor glacial regression with LiDAR. Furthermore, in these applications, mounting LiDAR on unmanned aerial vehicles (UAVs)/drones helps survey remote, inaccessible areas.

Smart factories use LiDAR on automatic guided vehicles (AGVs), which transport raw materials for processing and moving finished goods to the dispatch area. LiDAR is very powerful when used by robots in smart factories, helping them to perform precision tasks and making them aware when humans are present, adding to their safe and considerate operation.

Industry uses LiDAR to quickly survey sizeable construction projects such as railroads and highways. It can also be used as a safety aid, protecting certain areas from unwanted or unintended incursion. This is valuable where hazardous substances are present or where large machines are operating. LiDAR's ability to work effectively in all lighting conditions makes it a reliable always-on protection in any application.



$$D = \frac{ct}{2}$$

Figure 1: A direct time-of-flight system measures the time taken for light to travel to a target and back

LiDAR types

The principle behind the most common type of LiDAR, a direct time-of-flight (dToF) system, is very simple: time is measured for a light pulse to travel to a target and back to the sensor. Since the speed of light is a known physical constant, it is a simple task to calculate the distance between the transmitter/detector and the reflective target.

This technique generally uses a single, very-short pulse emitted by a light source (most commonly a laser) that simultaneously activates an accurate timer. When the light pulse hits an object within range, it is reflected back to a highly-sensitive light sensor, typically co-located with the laser. Once the return pulse is detected, the timer is stopped and the time taken to travel to the object and back read.

Knowing the elapsed time (t) between the pulse being sent and the echo being received, it is a simple matter to calculate the distance (D) to the target object using the speed of light constant (c).

The dToF approach is fast and can measure multiple echoes, allowing detection of several objects within the LiDAR's field of view. It can be used with high precision in both long- and short-range applications (0.1m-300m).

There's also an indirect time-of-flight (iToF) LiDAR which uses a continuous beam of light, also from a laser. This method does not measure the elapsed ToF directly but determines it from the phase difference between the transmitted and received waveforms.

This technique is more appropriate for relatively short-range (< 10m) applications, especially indoors where light conditions are less challenging than outdoors where contrasts are greater. It is limited to detecting single objects, as it can only detect the strongest echo.

The third type of LiDAR is frequency-modulated continuous wave (FMCW), used for short- and long-range applications. This technique uses a tunable laser to produce a continuous wave of light that is mixed with the reflected light at the detector. This mixing creates a beat frequency between the local and reflected waveforms, from which the object distance and directional velocity can be calculated.

While FMCW can provide excellent ranging performance and also capture directional velocity information, the system cost of such a LiDAR setup is quite high, because of the tunable lasers used with polarisation control and the reliance on short-wave infrared wavelengths, which require exotic semiconductors for the laser and the detector.

The 'Great Wavelength Debate'

One of the most debated topics around LiDAR is which wavelength to use. IR is used in preference to visible light since there's less background IR, allowing for better signal-to-noise ratio (SNR), making detection of the returned light easier.

Within the IR spectrum there are multiple suitable wavelengths, including in the near infrared (NIR) spectrum (850nm, 905nm, 940nm) and the short-wave infrared (SWIR) spectrum (1350nm, 1550nm). Deciding which of these to use is the crux of the 'Great Wavelength Debate'.

The three most important criteria to consider are system performance, availability of suitable components and overall system cost.

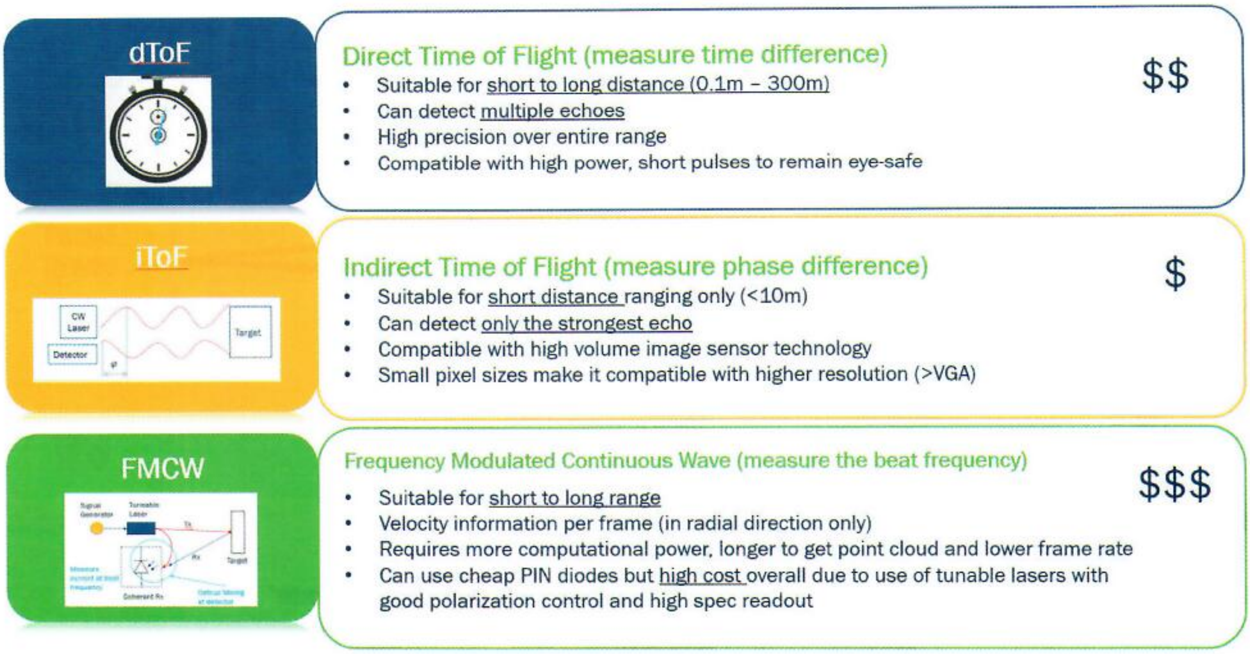
The detector is one of the most fundamental components of any LiDAR system. Silicon-based (CMOS) detectors detect light with wavelengths in the range 400-1000nm, making them sensitive to visible and NIR light, but not to SWIR light. To detect SWIR light, III/V semiconductors such as InGaAs alloys are necessary, which are very expensive compared to silicon.

Component availability is another consideration, especially with the laser emitters. Edge emitting lasers (EELs) are being superseded by vertical cavity surface emitting lasers (VCSELs) that are easier to package into arrays and offer a stable wavelength over temperature. While VCSELs are currently less power-efficient and more expensive, as they become more widely adopted this is expected to improve.

However, there are several suppliers for SWIR EELs, but currently only one for SWIR VCSELs, while there are multiple vendors of NIR VCSELs. Therefore, choosing NIR promises greater security in the supply chain.

Detection range is important, since this increases the reaction time available, offering greater safety. However, overly powerful lasers can damage eyes, so IEC 60825 stipulates the maximum permissible exposure (MPE) for a 1ns laser pulse.

While NIR must have a lower MPE, laser power can be increased if the pulse width is shortened, and, with the use of sensitive detectors, ranges up to 300m are achievable. In good weather, the range of SWIR will exceed that of NIR, but SWIR is more adversely affected by moisture like rain or fog, so system performance based on NIR



Direct Time of Flight (measure time difference) $$

- Suitable for short to long distance (0.1m – 300m)
- Can detect multiple echoes
- High precision over entire range
- Compatible with high power, short pulses to remain eye-safe

Indirect Time of Flight (measure phase difference) $

- Suitable for short distance ranging only (<10m)
- Can detect only the strongest echo
- Compatible with high volume image sensor technology
- Small pixel sizes make it compatible with higher resolution (>VGA)

Frequency Modulated Continuous Wave (measure the beat frequency) $$$

- Suitable for short to long range
- Velocity information per frame (in radial direction only)
- Requires more computational power, longer to get point cloud and lower frame rate
- Can use cheap PIN diodes but high cost overall due to use of tunable lasers with good polarization control and high spec readout

Figure 2: Comparison of LiDAR-based depth sensing methods

will degrade less rapidly than a SWIR system, providing more consistent performance across all-weather conditions.

Considering all this, NIR is generally accepted as the preferred wavelength for automotive LiDAR. It allows the use of silicon-based devices as opposed to more expensive materials, such as InGaAs, and perhaps more importantly, components are available from multiple suppliers. While both NIR and SWIR are capable of eye-safe operation, NIR uses lower-power lasers and can meet automotive LiDAR requirements.

From a commercial perspective, NIR is significantly cheaper – an always significant consideration in automotive applications. A survey by IHS Markit (Amsrud, 2019) showed cost of about $4-20 per channel for lasers and detectors, whereas for a comparable SWIR system this is around $275. Even with further development and increased volumes, predictions are that NIR will remain between 10x and 100x cheaper than SWIR.

LiDAR component technology

One of the most important elements of any LiDAR system is the sensing element that captures and quantifies the reflected laser light. While several technologies can be used for this, silicon photomultipliers (SiPMs) generally offer the best performance, primarily because their high gain permits them to detect single photons, in the order of 1,000,000. As a result, SiPMs have become more widely used in recent years, becoming the sensor of choice for LiDAR depth-sensing applications. These devices can deliver the highest SNR performance for long-distance ranging in high-contrast conditions, compared to legacy detectors like avalanche photodiodes (APDs) which offer much lower gain and need to integrate incoming signals.

Additional benefits, including lower supply biases, better uniformity and reduced sensitivity to temperature changes, make SiPMs an ideal upgrade for systems that use APDs. The higher sensitivity of SiPMs also enables the use of smaller form-factor optics, allowing for easier LiDAR integration into vehicles. As SiPMs are produced in a high-volume CMOS process, these high-performance devices have the lowest detector cost, further enabling the proliferation of LiDAR.

The ArrayRDM-0112A20-QFN from ON Semiconductor is a monolithic 1×12 array of 0.47mm x 1.12mm SiPM pixels based on the advanced, proprietary, RDM SiPM CMOS process, specifically developed for high sensitivity to NIR light. It achieves industry-leading 18.5% photon detection efficiency (PDE) at 905nm wavelengths, with a response of over 100kA/W.

The high internal gain of the SiPM allows sensitivity down to the single-photon level, which in combination with the high PDE detects the faintest return signals, enabling LiDAR to operate over greater distances, even with low-reflective targets. The array is packaged in a robust 10mm x 5.2mm QFN package allowing access to the twelve individual pixels.

Specifically designed for automotive LiDAR systems (including Flash, mechanical or MEMS scanning LiDAR), the array is the first to carry AEC-Q102 approval for automotive qualification, developed in accordance with IATF 16949.

Incredibly useful

LiDAR is an incredibly useful technology, because it determines depth rapidly and accurately, whether as a single point or a 3D map of an object or large site as part of a scanning system. One key decision to make when planning a LiDAR design, however, is the wavelength of the IR light to be used. Based upon performance, component availability and commercial considerations, NIR is most often the preferred choice.

In most LiDAR implementations, the laser light source can be relatively simple, but the choice of detector has a significant impact on system performance. The latest SiPM array from ON Semiconductor offers excellent detection performance and is the first SiPM detector to carry AEC-Q102 approval. EW