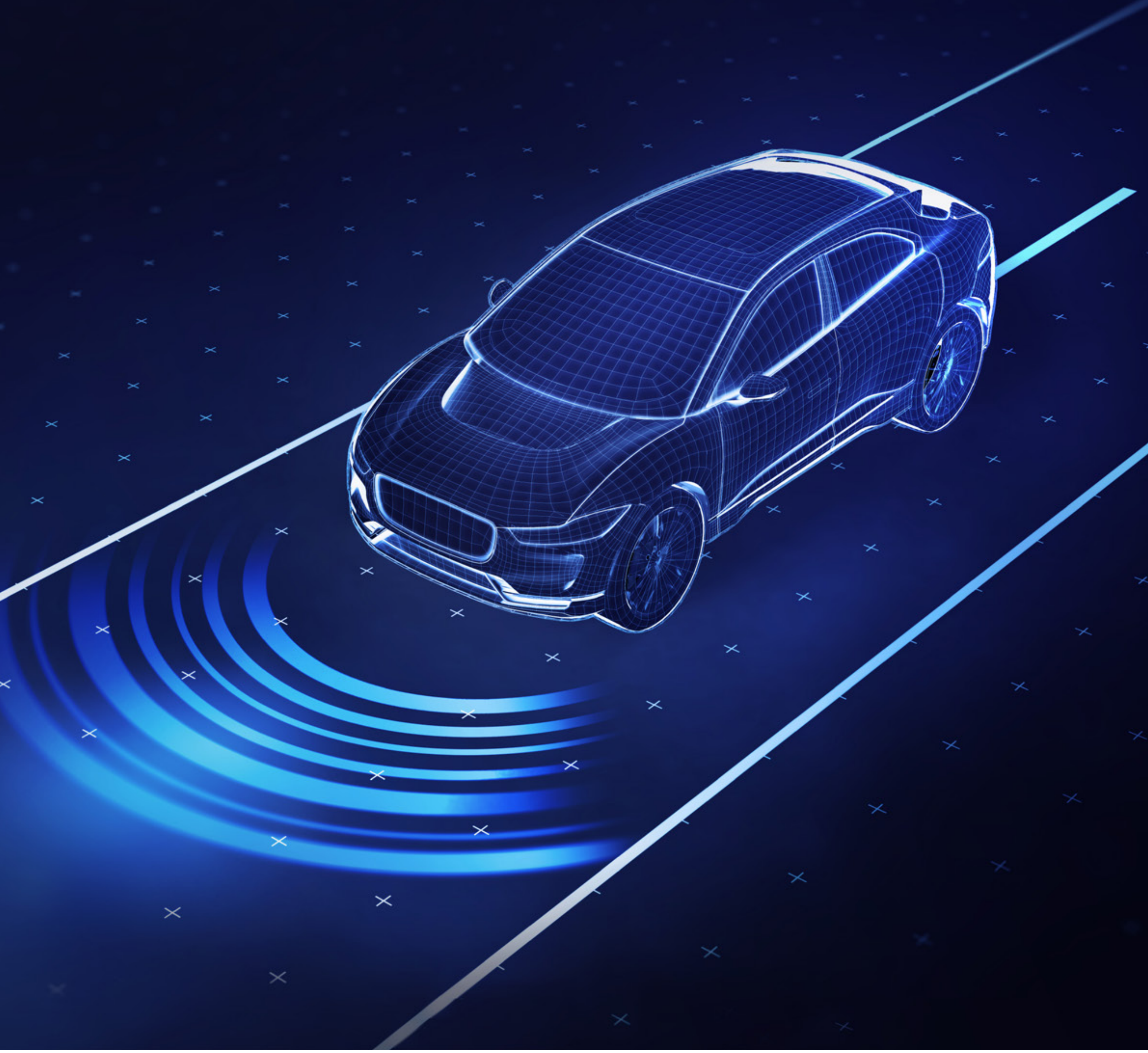
LiDAR and autonomous cars

No conventional solution



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Which is the best LiDAR technology for automotive applications? There is still no such thing. Florian Friedl, Group Leader Automotive & Optoelectronic Components at Hamamatsu Photonics, comments.

As a leading component manufacturer, Hamamatsu is well aware of the advantages and disadvantages offered by various systems, and the main differences will be explained in this article.

Whether in factories or cars, the use of smart and autonomous systems are increasing. An important condition for totally safe and functional systems are sophisticated sensors and imaging processes that provide true-to-life images of the surroundings. Advanced Driver Assistance Systems (ADAS) are currently employing around a hundred sensors to provide functions such as lane departure warning or automatic distance control. Full accuracy and fast reaction times are essential in this field, even at high speeds and in unforeseen situations.

One of the most promising developments in recent years has been the use of LiDAR (Light Detection and Ranging) systems, an optical method aimed at measuring distances and speed. Unlike the related radar system, LiDAR sensors identify the environment by means of light only, which is detected by a photosensor. But not all LiDAR is the same, and not all photosensors are equal. Which technology is the most suitable is not always clear to the manufacturer and depends on the specific application.

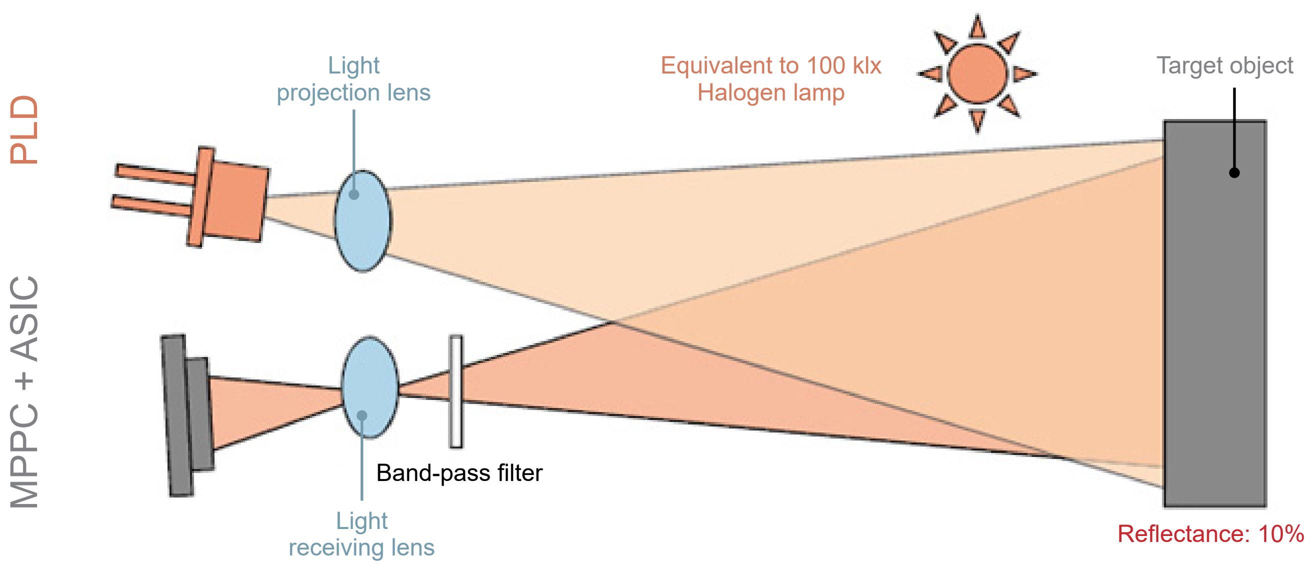
Hamamatsu Photonics, a leading manufacturer of optical products and semiconductor components, helps to select and assemble the right components. The Company's products extend to cover the entire range of LiDAR technologies.

Time-of-flight measurement or continuous frequency modulation?

Currently, there are two technological approaches to LiDAR: Time of Flight, also called TOF and Frequency-Modulated Continuous Wave (FMCW), which is based on frequency modulation. While TOF LiDARs are recognized as the norm FMCW systems are increasingly growing in popularity, for reasons such as they promise to overcome some of the problems of the time-of-flight approach.

Time of Flight: round trip for light

The basic principle of TOF LiDAR is simple: a light source emits a concentrated beam of light that is reflected by an obstacle - such as a pedestrian or a car - and bounces it back to a photosensor. The sensor calculates the distance of the object, based on the time needed by the reflected light to hit the sensor.



Lidar concept | Source: Hamamatsu Photonics K.K.

Pulsed lasers are often used as a radiation source, therefore the wavelength and polarization state of the pulse can be varied. Commonly, wavelengths range from 850 nm to 1,550 nm.

Lower wavelengths allow the use of silicon detectors, but the light is absorbed more easily and they are more harmful to the human eye, consequently they are not suitable for all applications. Light with a wavelength of 1,550 nm is therefore better suited for long distance detection and can produce accurate results, even at a distance of more than 200 meters with a reflection of 10 percent.

One challenge of TOF technology is the scattering of the light: only a small fraction of the emitted photons find their way back to the active area of the photosensor. Environmental influences, such as rain or air particles, as well as other reflective surfaces, absorb some of the light, thus reducing the amount of photons. At the same time, photons related to background noise hit the detectors, which could negatively influence the accuracy of the measurement. A filter that is strictly limited to the range of emitted wavelengths may help, but this “background noise” cannot be completely prevented, meaning that the accuracy of the LiDAR reduces with the increasing distance.

Frequency-Modulated Continuous Wave (FMCW): measurement by modulation

One method to reduce this problem of interfering frequencies could be FMCW LiDAR: instead of light pulses, a continuous, “chirped” laser beam is emitted, so the frequency of the signal keeps changing. The light beam is reflected by an object and returned to the photodetector. The decisive factor here however is not the time itself, but the difference in the frequency of the incoming signal compared to the signal emitted at the same moment. Based on this difference, the LiDAR can determine not only the distance but also the speed of the moving object.

Frequency synchronization requires a bit more computing power than a simple acquisition. Compared to a TOF LiDAR, the FMCW method takes a bit more time to create an accurate 3D environment model. Moreover, the technology is also relatively new and consequently often still bulky and expensive. On the other hand, FMCW LiDARs are less subject to noise and work well over long distances. Thus, the question about the “best” LiDAR technology largely depends on the application scenarios and general conditions. The choice of method is important, but there is another key consideration: the selection of the optimum photosensor.

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Photosensors: accuracy vs range?

LiDAR applications hold high expectations on photodetectors. Ideally, they should be sensitive enough to receive a large quantity of photons without getting too much extraneous noise. In automotive applications in particular, it is also essential that the sensors respond quickly and with full reliability. In addition, they should be cost-efficient, suitable for mass production and able to tolerate a whole range of different environmental conditions from temperature fluctuations to changing light conditions.

In any case, the greater the distance from the object to be detected, the lower the measurement accuracy. However, this principle is not equal for all types of photodetectors. Depending on the application, manufacturers can in fact choose from these three types of photosensors.

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PIN Photodiode

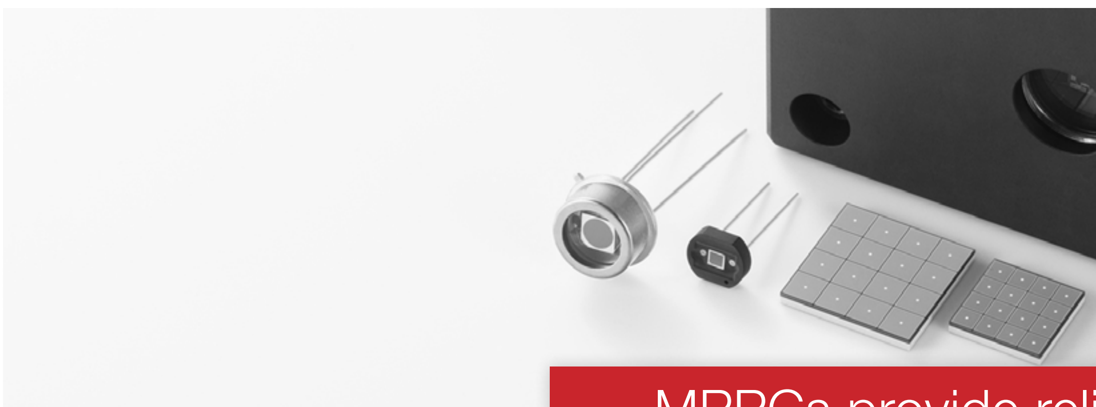
A PIN photodiode is the simplest and most cost-effective type of photosensor. Energy consumption is also low, with an operating voltage of up to ten volts. Over short distances, the light sensitivity is high and stable at the same time, and temperature fluctuations hardly affect the performance. The readout range is relatively high and even in strongly illuminated surroundings a PIN photodiode usually performs well. A transimpedance amplifier is usually used as the readout circuit. However, the gain is low typically around 1.

In the case of applications where the light does not have to travel long distances (for example some TOF applications), the use of a PIN photodiode is absolutely sufficient and offers manufacturers the best price/performance ratio. For example, the S13773, a Si PIN photodiode from Hamamatsu Photonics, is suitable for distance measurements in the spectral range 380 nm to 1,000 nm due to its fast response time, but it is not appropriate for conditions that require wavelengths of 1,550 nm. Applications with strong ambient light or significant temperature changes also benefit from using a PIN photodiode. The S13773, for example, can tolerate operating temperatures between -40 and +100°C.

APD

As the name suggests, Avalanche Photodiodes (APDs) use the avalanche effect to generate internal gain. This achieves gains of over 100, a greater range than PIN photodiodes. However, in order to prevent measurement inaccuracies from the background noise, manufacturers usually resort to a bandwidth filter. APDs are also very temperature sensitive and have an operating voltage of 100-200 V. In addition to Si APDs, there are also special InGaAs APDs, which are specifically designed for the 1,550 nm frequency range (Hamamatsu's G14858-0020AB).

For a long time, these two variants have been considered standard devices for their respective fields of application. Although APDs are more complex and expensive compared to PIN photodiodes, they are almost indispensable for longer-range applications. Nevertheless, Hamamatsu has recently appointed a third candidate in the race: so-called 'Multi-Pixel Photon Counters' (MPPCs).



Multi-Pixel Photon Counters (MPPCs/SiPMs)
Source: Hamamatsu Photonics K.K.

MPPCs provide reliable results, even at long distances granting a short response time.

MPPCs

MPPCs, also known as silicon photomultipliers (SiPM), consist of a series of APDs (hereafter referred to as channels) operating in Geiger mode. As a result, an MPPC sensor gets significant gain - up to a factor of 10^5 is easily achievable. At the same time, the use of several APDs connected in parallel prevents the loss of information about the number of incident photons. MPPCs are therefore also suitable for single-photon detection and can cope with suboptimal conditions with very weak light incidence. They provide reliable results, even at long distances granting a short response time. MPPCs are also insensitive to magnetic fields and in terms of temperature sensitivity they qualify between APDs and PIN photodiodes. Moreover, while MPPCs can be switched via a transimpedance amplifier just like PIN photodiodes or APDs, it is possible to utilise less complex readout circuits, such as a high-frequency amplifier.

1D MPPC (SiPM) Array + ASIC
Source: Hamamatsu Photonics K.K.

The motto “customizations instead of standard solutions” could not apply better to LiDAR systems.

MPPCs, also known as silicon photomultipliers (SiPM), consist of a series of APDs (hereafter referred to as channels) operating in Geiger mode. As a result, an MPPC sensor gets significant gain - up to a factor of 105 is easily achievable. At the same time, the use of several APDs connected in parallel prevents the loss of information about the number of incident photons. MPPCs are therefore also suitable for single-photon detection and can cope with suboptimal conditions with very weak light incidence. They provide reliable results, even at long distances granting a short response time. MPPCs are also insensitive to magnetic fields and in terms of temperature sensitivity they qualify between APDs and PIN photodiodes. Moreover, while MPPCs can be switched via a transimpedance amplifier just like PIN photodiodes or APDs, it is possible to utilise less complex readout circuits, such as a high-frequency amplifier.

In Hamamatsu's new generation of MPPC detectors, photon detection efficiency (PDE) has been further improved. This combination of features makes MPPC sensors an attractive alternative for many automotive applications that could previously only be covered by APD sensors. In addition to MPPCs, Hamamatsu will soon introduce 2D SPPC-Arrays. As with MPPCs, these "Single Pixel Photon Counters" can cover long range sensing and have similar characteristics for detection speed and temperature stability. The overall system costs could be cheaper than the costs of MPPC Modules.

It is worth then to point out: the road to fully autonomous industrial and automotive applications is rocky and deeply ramified. To deal with this complexity, individually adapted solutions are key and the motto "customizations instead of standard solutions" could not apply better to LiDAR systems. As a One-Stop-Shop, Hamamatsu can offer both unbiased opinion and advice. They can also supply all components from a photodetector to a laser diode, all from a single source. For lasers they can offer pulsed lasers, as well as continuous wave lasers with a very accurate NFP (Near Field Pattern). All components are perfectly fitted together and can be adjusted to the requirements of each individual application.

In cooperation with Storymaker GmbH and Nina Blagojevic

More information

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