An Introduction to Automotive Lidar

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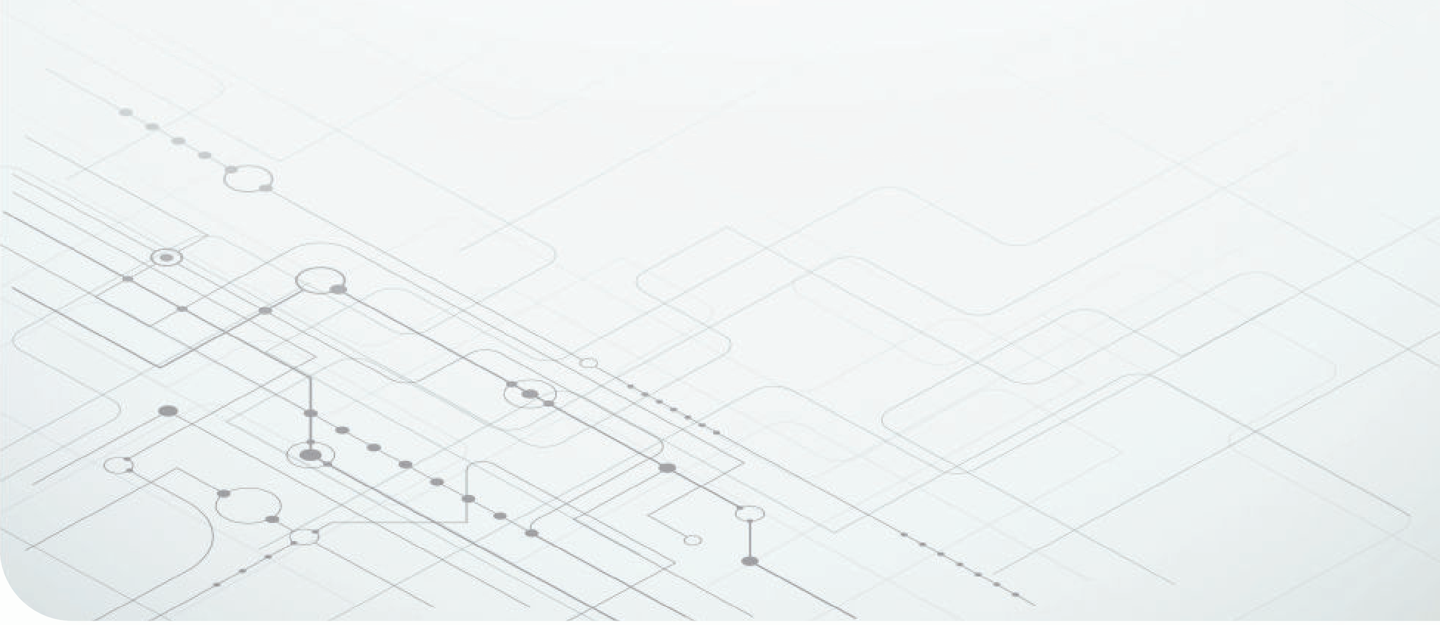

Lidar, which means light detection and ranging but is sometimes called time of flight (ToF), laser scanning or laser radar – is a sensing method that detects objects and maps their distances. The technology works by illuminating a target with an optical pulse and measuring the characteristics of the reflected return signal. The width of the optical pulse can range from a few nanoseconds to several microseconds.

Figure 1 shows the basic principle of lidar, with light shining out in certain patterns and information extracted based on the reflections gathered at the receiving end. Pulse power, round-trip time, phase shift and pulse width are common parameters used to extract information from light signals.

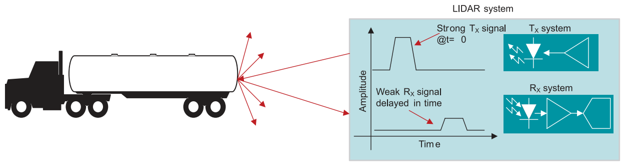

Figure 1. *Pulsed ToF-based lidar system.*

Why choose light? What differentiates lidar from other existing technologies such as radar, ultra sonic sensors or cameras? What's driving the hype around lidar? This white paper addresses these questions in the context of long-range lidar, which is going to be an important sensor for autonomous driving. In addition to autonomous vehicles, lidar has applications in 3D aerial and geographic mapping, safety systems in factories,smart ammunition and gas analysis.

Detection and imaging in autonomous cars

Manufacturers are outfitting modern cars with a wide array of advanced control and sensing functions. Collision warning and avoidance systems, blind-spot monitors, lane-keeping assistance, lane-departure warning and adaptive cruise control are established features that assist drivers and automate certain driving tasks, making driving a safer and easier experience.

Lidar, radar, ultrasonic sensors and cameras have their own niche sets of benefits and disadvantages. Highly or fully autonomous vehicles typically use multiple sensor technologies to create an accurate long- and short-range map of a vehicle's surroundings under a range of weather and lighting conditions. In addition to the technologies complementing each other, it is also important to have sufficient overlap in order to increase redundancy and improve safety. Sensor fusion is the concept of using multiple sensor technologies to generate an accurate and reliable map of the environment around a vehicle.

Ultrasonic waves suffer from strong attenuation in air beyond a few meters; therefore, ultrasonic sensors are primarily used for short-range object detection.

Cameras are a cost-efficient and easily available sensor; however, they require significant processing to extract useful information and depend strongly on ambient light conditions. Cameras are unique in that they are the only technology that can "see color." Cars that have the lane-keep assist feature use cameras to achieve this feat.

Lidar and imaging radar share a broad array of common and complementary features that can map surroundings as well as measure object velocity. Let's compare the two technologies in several categories:

- **Range.** Lidar and imaging radar systems can detect objects at distances ranging from a few meters to more than 200 m. Imaging lidar has difficulty detecting objects at close distances. Radar can detect objects from less than a meter to more than 200 m; however, its range depends on the type of system: short-, medium- or long-range radar.
- **Spatial resolution.** This is where lidar truly shines. Because of its ability to collimate laser light and its short 905- to 1,550-nm wavelength, infrared (IR) light spatial resolution of approximately 0.1 degrees is possible with lidar. This resolution enables high-resolution 3D characterization of objects in a scene without significant back-end processing. On the other

hand, radar’s wavelength (4 mm for 77 GHz) has challenges resolving small features at long distances.

- **Field of view (FOV).** Solid-state lidar and radar both have excellent horizontal FOV (azimuth), while mechanical lidar systems, with their 360 degrees rotation, possess the widest FOV of all advanced driver assistance systems (ADAS) technologies. Historically, lidar has better vertical FOV (elevation) than radar. Lidar provides angular resolution (for both azimuth and elevation), which is one primary feature necessary for improved object classification.
- **Weather conditions.** One of the biggest benefits of radar systems is their reliability in rain, fog and snow. The performance of lidar generally degrades under such weather conditions. Using IR wavelengths of 1,550 nm helps lidar achieve improved performance under adverse weather conditions.
- **Ambient light.** Lidar and cameras are both susceptible to ambient light conditions. At night, however, lidar and imaging radar systems offer very high performance because they provide their own illumination. Radar and modulated lidar techniques are resistant to interference from other sensors.
- **Cost and size.** Radar systems have become mainstream in recent years, making them highly compact and affordable. As lidar has become more popular, its cost has dropped precipitously, with prices dropping from approximately US$50,000 to below US$10,000. The mainstream use of radar in modern-day vehicles is made possible by increased integration, which reduces system size and cost. The mechanical scanning lidar system from a few years ago – commonly seen mounted on various autonomous self-driving robotaxis – is bulky, but advances in technology have shrunk lidar over the years. The industry shift to solid-state lidar will further shrink system size and lower costs.

Lidar types

Among the different types of lidar systems available, the focus of this paper is primarily on the narrow-pulsed ToF method. There are two types of beam steering in lidar systems:

- **Mechanical lidar** uses high-grade optics and a rotating assembly to create a wide (typically 360-degree) FOV. The mechanical aspect provides a high signal-to-noise ratio (SNR) over a wide FOV, but results in a bulky implementation (although size has also been shrinking).
- **Solid-state lidar** has no spinning mechanical components and a reduced FOV; thus, it costs less. Using multiple channels at the front, rear and sides of a vehicle and fusing their data creates an FOV that rivals mechanical lidar.

Solid-state lidars have multiple implementation methods, including:

- **Microelectromechanical systems (MEMS) lidar.** A MEMS lidar system uses tiny mirrors whose tilt angle varies when applying a stimulus such as a voltage. In effect, the MEMS substitutes mechanical scanning hardware with an electromechanical equivalent. The receiver light collection aperture that determines the receive SNR is typically quite small (a few millimeters) for MEMS. To move the laser beam in multiple dimensions requires cascading multiple mirrors. This alignment process is not trivial, and once installed, it is susceptible to shocks and vibrations typically encountered in moving vehicles. Another potential pitfall with a MEMS- based system is that automotive specifications start at –40°C, which can be challenging for a MEMS device.
- **Flash lidar.** Flash lidar operation is very similar to that of a standard digital camera using an optical flash. In flash lidar, a single large-area laser pulse illuminates the environment in front of it, while a focal plane array of photo detectors placed in proximity to the laser captures the back-scattered light. The detector captures the image distance, location and reflected intensity. Since this method captures the entire scene in a single image compared to the

mechanical laser scanning method, the data capture rate is much faster. In addition, since the entire image is captured in a single flash, this method is more immune to vibration effects that could distort the image. A downside to this method is the presence of retroreflectors in the real-world environment. Retroreflectors reflect most of the light and back-scatter very little, in effect blinding the entire sensor and rendering it useless. Another disadvantage to this method is the very high peak laser power needed to illuminate the entire scene and see far enough. To comply with eye safety requirements, flash lidar is primarily used in short- to medium-range detection systems.

- **Optical phase array (OPA).** The OPA principle is similar to phased-array radar. In an OPA system, an optical phase modulator controls the speed of light passing through the lens. Controlling the speed of light enables control of the optical wave-front shape, as shown in Figure 2. The top beam is not delayed, while the middle and bottom beams are delayed by increasing amounts. This phenomenon effectively “steers” the laser beam to point in different directions. Similar methods can also steer the back-scattered light toward the sensor, thus eliminating mechanical moving parts.

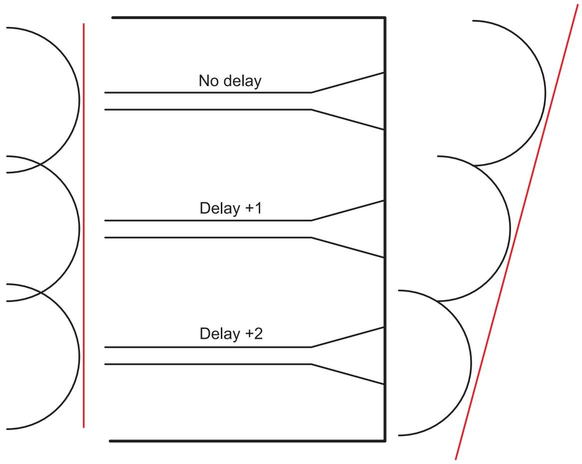

Figure 2. An OPA.

- **Frequency-modulated continuous wave (FMCW) lidar.** While the methods listed so far are based on the ToF principle using narrow light pulses, FMCW lidar uses a coherent method, producing brief chirps of frequency- modulated laser light. Measuring the phase and frequency of the return chirp enables the system to use the Doppler principle to measure both distance and velocity. The computational load and optics are simpler with the FMCW method, although the chirp generation adds complexity. The laser power required for FMCW systems is considerably lower than what pulsed ToF systems require, making FMCW suitable for very long-range sensing applications. They also perform well in adverse weather conditions such as fog, rain and snow.

The Lidar subsystem

Figure 3 shows the entire functional lidar module subsystem, including the signal chain, power,interface, clocking and monitoring or diagnostics subsystem. The main subsystems of the lidar signal chain comprise a transmitting system (Tx), a receiving system (Rx) and a custom digital-processing system to extract point-cloud information. TI offers device options for the function blocks shown in teal.

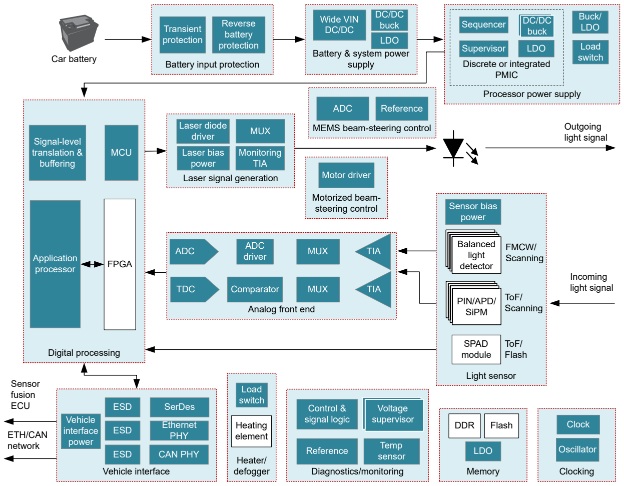

Figure 3. Lidar module showing signal chain, power, interface, clocking and monitor or diagnostics subsystem.

Lidar system integration

For systems that require high density on further integration, TI offers lidar laser drivers for the Tx path and amplifiers that handle the connection in the Rx path from the photodetector directly to an analog-to-digital converter (ADC) or a time-to-digital converter (TDC). The LMG1025 is a discrete laser driver that drives an external gallium nitride field-effect transistor (FET) capable of producing 1.25nS pulses. TI's integrated LMH13000 laser driver does not require an external FET and can drive lasers with adjustable current from 50mA up to 5A, creating pulses <1nS. The LMH13000 is also approximately four times smaller than discrete laser driver solutions. Using multiple LMH13000 devices in parallel can increase the amount of current going to the laser.

TI's receive path amplifiers include the LMH32401 and LMH32404 for ADC-based systems and the LMH34400 for TDC-based systems. These devices are beneficial to lidar applications because they integrate a high-speed transimpedance amplifier (TIA) compensation network, and include features such as ambient light cancellation, input overcurrent clamp protection and a multiplexer mode.

The ambient light cancellation circuit enables better detection of the input current by removing DC ambient light signals, and saves board space because you can use this circuit instead of AC coupling between the photodiode and amplifier. The input overcurrent protection clamp absorbs and diverts excess current to the positive supply when the amplifier detects its nodes, entering a saturated condition that allows the amplifier to return to a linear state much faster and limiting pulse extension to less than a few nanoseconds. The integrated lidar TIAs have integrated output switches that enable the connection of multiple photodiode and amplifier channels to fewer ADC and TDC channels, and thus eliminate the need for a discrete multiplexer. This makes it possible to use multiple sensors while saving board space that would ordinarily be taken by multiple ADC and TDC channels.

Conclusion

The world is embarking on an exciting journey and exciting journey toward the commercialization of autonomous cars, and the technologies and architectures fueling this space are in a constant state of flux. Lidar is a relative newcomer to this arena, but the advantages that this technology offers are spurring rapid innovation and can achieve higher performance, smaller size and comparable cost than more established sensor systems.

Additional resources

- Check out **TI's ADAS applications** and **TI reference designs**.
- Explore TI's portfolio of automotive-qualified **high-speed operational amplifiers**, **high-speed analog-to-digital converters** and **temperature sensors**.
- Read these related white papers:
  - *Making Cars Safer Through Technology Innovation*.
  - *Scalable Electronics Driving Autonomous Vehicle Technologies*.
  - *Paving the Way to Self-Driving Cars With Advanced Driver Assistance Systems*.

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