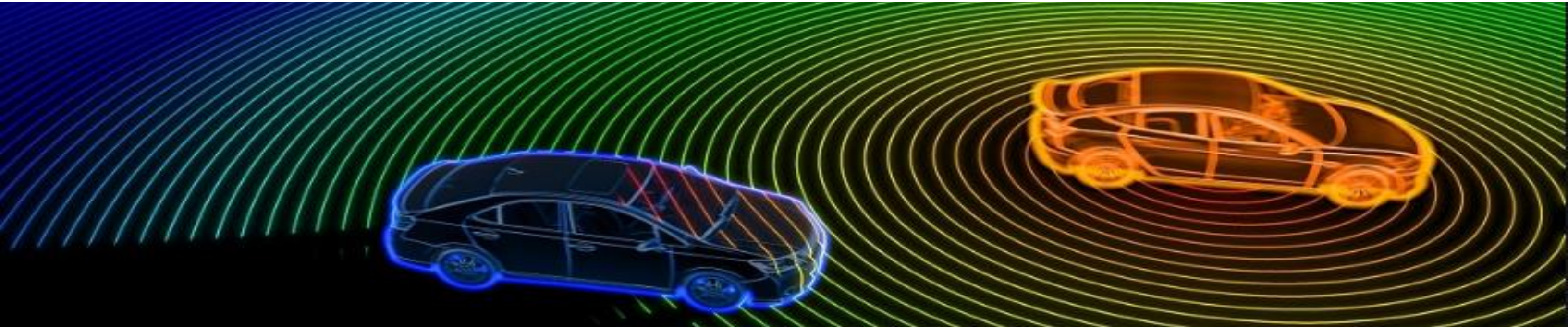

LiDAR Implementations for Autonomous Vehicle Applications

A whitepaper by Omni Design Technologies

Introduction

Light Detection and Ranging (LiDAR) is a key technology used to detect and map surrounding objects. Along with radar, camera, and ultrasound, it forms the sensor platform for the on-going development of autonomous vehicles. While radar is robust, reliable, and unaffected by weather conditions, it lacks accuracy and resolution that is needed to correctly identify many object types. Cameras present visual representation of surroundings but require significant computing power and the lighting and weather conditions can severely impact vision. Ultrasonic sensors are mainly used to detect objects in close proximity. LiDAR provides excellent range with high resolution and can be combined with data from other sensors to accurately represent vehicle's environment. LiDAR is also much less affected by the lighting and weather conditions than cameras due to the active laser illumination of the target at infrared wavelengths. Innovations spanning from hardware to software will accelerate the technology adoption. This whitepaper provides an overview of various types of LiDAR systems and addresses requirements in development of LiDAR products.

Principles of LiDAR Systems

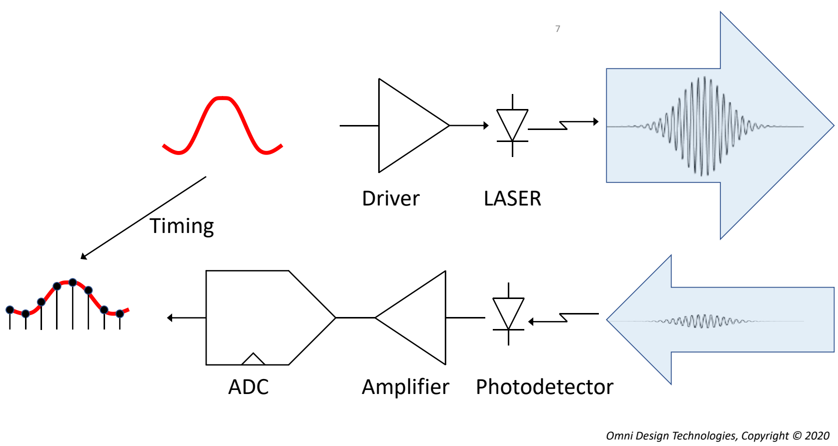

Figure 1. Pulse detection LiDAR.

In its simplest implementation shown in Figure 1, LiDAR works by emitting a short pulse of laser light and by measuring the time delay until the pulse returns to the sensor after being reflected back by the object under consideration [1]. The distance to the detected object can be computed since it is represented by half the round-trip time delay

$$R = \frac{c}{2} ToF$$

where R is the distance to the target, c is the speed of light (300,000Km/s in vacuum) and the time of flight (ToF) is the total time elapsed between the emission and the detection event. For example, for ToF of 10ns, the measured distance is 1.5m. This process is repeated to scan the surroundings and the raw data is processed to create a 3D point cloud. The larger the detection range, the greater the time needed to produce the map since the laser light will have to traverse a longer distance. Due to its simplicity, the pulsed based LiDAR is popular and is the commonly deployed LiDAR system.

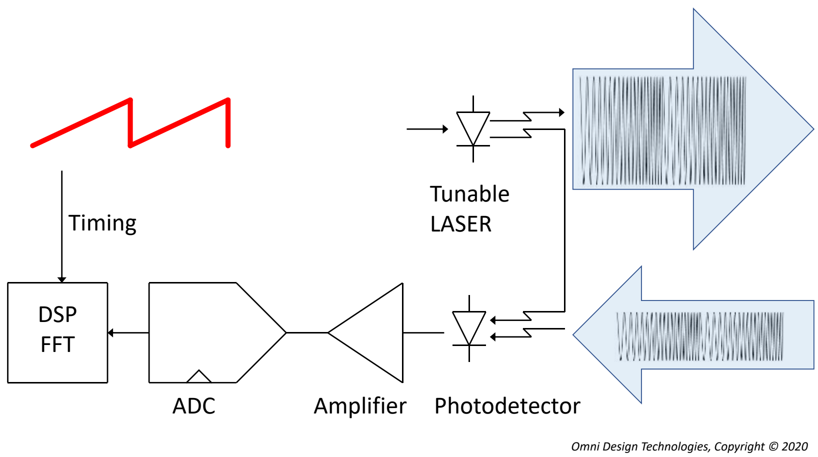

Figure 2. FMCW LiDAR.

Continuous-wave LiDAR, unlike pulsed LiDAR, use either amplitude modulation or frequency modulation of the light source. In amplitude-modulated continuous-wave (AMCW) LiDAR, the distance is measured by computing the difference in the phase between the transmitted signal and the received signal [2]. Frequency-modulated continuous-wave (FMCW) LiDAR, shown in Figure 2, relies on a chirp, whereby the frequency of the light source increases or decreases with time [2-3]. The transmitted chirp and the returned chirp are mixed at the photodiode, which detects the difference in frequency of those two signals. When the frequency changes at a constant rate, the difference in frequency between the transmitted and received signal provides an estimate of the distance to the target. The beat frequency that results from mixing the two signals encode the distance to the target. Further processing can also extract the target's relative velocity and the coherent light detection makes the system robust against interference.

LiDAR systems typically operate at 905, 1300 or 1550nm wavelength [2]. Lasers with wavelength less than 1400nm can reach the human retina, and the average power must be kept below the safety level to comply with eye-safety standards. Lasers with wavelength of 1550nm are less likely to reach the retina and can support a higher peak power eye safety level but is more expensive [4].

LiDAR System Overview

Hardware implementation of the LiDAR systems can be accomplished in a few different ways. A common beam-steering implementation is the mechanical spinning LiDAR [2]. Typically mounted on top of the vehicle, the transmitter and receiver assembly physically rotate 360° to scan the environment for a wide field of view (FOV). Although this approach provides a detailed mapping with high signal-to-noise ratio (SNR), the LiDAR module is large and bulky and the production of such complex mechanical moving parts is expensive. Maintenance can also be an issue since the assembly is subject to wear and tear from the constant motion.

A MEMS based LiDAR implementation is much more affordable and scalable for deployment. Since it relies on silicon technology, components can be efficiently mass produced. A MEMS based LiDAR uses mirrors to electromechanically tilt the light beam to steer it in specific directions. Issues related to robustness in extreme temperature conditions and impact of large vibrations are still be addressed; nevertheless, it is a promising technology for mass deployment [5].

In optical phase array LiDARs, the beam is steered by waveguides instead of mechanical moving parts [3,6]. This is accomplished by tuning the phase in the antenna array in different parts of the light beam which shapes the optical wave. It can achieve high scanning speeds and stable beam steering. Limited steering angle and side lobes are the drawback of this technology.

Flash LiDAR operation is similar to that of a digital camera. It captures the details of the surroundings in a single flash by illuminating the complete FOV, which leads to mechanical and optical simplicity [7]. It is more immune to vibration effects and avoids issues that arise from any movement in the LiDAR system or object during the scan. However, further development is needed to make it suitable for long-range applications.

LiDAR Electronics

Early LiDAR systems for autonomous vehicles were implemented using discrete semiconductor components such as Transimpedance Amplifiers (TIAs), programmable gain amplifiers (PGAs), and Analog-to-Digital-Converters (ADCs) assembled on a PC board along with other logic components to relatively quickly demonstrate proof of concept and build prototypes. Over the past few years, developers of autonomous vehicles have adopted the use of LiDAR systems and have started deploying them in production. Autonomous vehicles have started appearing on the streets with the ubiquitous single mechanical spinning LiDAR on the top of the vehicle.

To make LiDARs accessible to the mass market and to have multiple LiDARs be installed in an autonomous vehicle, there is a need to build the LiDAR components at a significantly lower cost, that use an order of magnitude lower power and have a smaller form factor that could be hidden behind the automotive skin.

This has led developers of LiDARs to integrate more of the electronic components such as TIAs, PGAs, and ADCs and the digital logic into a System-on-Chip (SoC) to meet the market requirements of capability, power, cost and form factor. These SoCs are highly complex and require high performance digital and mixed-signal circuits to be integrated on the same chip – leading to new design techniques and innovative semiconductor Intellectual Property (IP) components that enable such SoCs. This whitepaper will discuss the development of SoCs using these semiconductor IP components such as TIAs, PGAs, and ADCs integrated within the SoC.

SoC Design Requirements

Figure 3 shows a simplified block diagram of a Pulsed-based LiDAR system [8-10]; the implementation details will vary based on the system requirements. In the transmitter, a pulse is generated and amplified by the laser driver. Then, the resultant laser beam is transmitted through the optics. In the receiver, the reflected light signal is detected by the photodiode, which produces a current proportional to the returned signal strength. The current signal is converted to voltage by TIA. The TIA requires bandwidth that is large enough to detect narrow pulses that are several nanoseconds wide, with low-input referred noise to keep the noise floor of the receiver sufficiently low. The interface between the photodiode and the TIA is critical as it impacts the LiDAR range precision. For high detectable range, large linear dynamic range is needed in the TIA [8]. The signal often also goes through additional selectable gain stages based on allocations of architectural specification. In ToF LiDARs, a Time-to-Digital converter (TDC) can be used instead of an ADC to measure the time difference. However, a high-speed ADC-based system enables sophisticated signal processing of the return signal and has several other performance advantages [10].

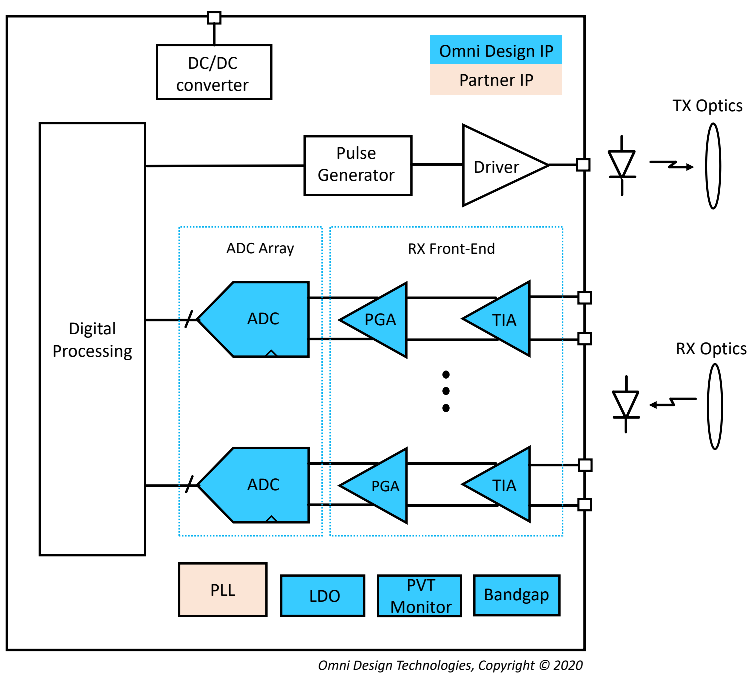

Figure 3. Pulsed-based LiDAR block diagram and available Omni Design IP

In addition to the above specifications, components (including the integrated circuits in the SoC) must meet the requirements set for automotive electronics. AEC-Q100 is an industry standard failure mechanism based stress test qualification for integrated circuits. It specifies a temperature grade from 0 to 3 depending on ambient temperature during operation. The components must comply with key test categories that include but are not limited to environmental stress, aging, packaging/assembly integrity, electrical verification, die fabrication, etc. In addition to AEC-Q100, there are other AEC-Q standards for discrete semiconductors, optoelectronic, passive components, and multi-chip modules.

ISO 26262 is a functional safety standard for electrical and/or electronic systems in production automobiles. ISO 26262 specifies a target Automotive Safety Integrity Level (ASIL) from A (lowest risk level that includes the possibility of equipment damage) to D (highest risk level that includes likeliness of serious injury). ASIL grade level depends on the likelihood and impact of failures. SoCs and IPs are typically developed for safety element out of context (SEooC), which allows component developers to define safety performance independently of OEMs, suppliers, or vendors. Every significant block needs to go through failure modes, effects, and diagnostic analysis (FMEDA) as part of architecture and design review.

Omni Design's Solution for LiDAR Application

Omni Design offers highly power-efficient high performance IPs in advanced process nodes for use in SoCs for LiDARs. These IPs are compliant with the automotive standards referenced earlier and cover the full receiver-chain – e.g. front-end TIA, PGA, data conversion, etc. In addition, Omni Design can integrate many instances of these IPs to deliver highly complex analog macro blocks that form the core analog/mixed-signal capability of the LiDAR SoC.

For example, Figure 4 shows a high-performance receiver front-end IP designed in finFET technology. The TIA provides current to voltage conversion, which is then followed by a PGA, and additional signal conditioning.

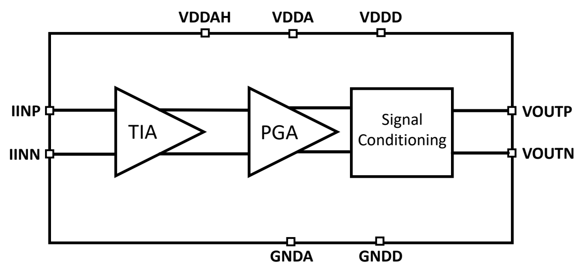

Figure 4. Omni Design's LiDAR receiver front-end IP

The ADC IPs used in LiDARs can have sampling rates that range from a few Mega samples per second (Msps) to as high as multi Giga samples per second (Gsps) with resolutions ranging from 10-bits to 14-bits. They are optimized to maximize speed while minimizing power consumption and silicon area. They also have to meet other key requirements such as functional safety, synchronized clocking of an ADC array for phased array support, and excellent matching between channels. A partial list of ADC IPs available from Omni Design are shown in Table 1. These IP cores are available in various process nodes including 28nm and finFET technologies.

The ADC IPs from Omni are designed to include any required foreground and background calibration for correcting various non-idealities such as time-interleaving artifacts and capacitor mismatch. For example, ODT-ADS-12B6G-16 in Figure 5 is a high-performance time-interleaved ADC. This 12-bit 6GSPS ADC supports input signals up to Nyquist frequency and features SNR and SFDR of 56dB and 62dB, respectively. The design of the data converters leverages Omni Design's proprietary platform-based development methodology that enables the design of these converters using modular building blocks which results in substantial reduction in risk in schedule and volume production.

Product Name	Resolution (bits)	Speed (MSPS)
ODT-ADP-14B1P2G-28	14	1200
ODT-ADP-14B600M-28	14	600
ODT-ADP-14B300M-28	14	300
ODT-ADP-14B50M-28	14	50
ODT-ADS-10B2G-28	10	2000
ODT-ADS-10B150M-28	10	150
ODT-ADS-6B1G-28	6	1000
ODT-ADS-6B500M-28	6	500
ODT-ADS-12B6G-16	12	6000
ODT-ADS-12B2G-16	12	2000
ODT-ADS-12B1G-16	12	1000
ODT-ADS-12B200M-16	12	200
ODT-ADS-12B20M-16	12	20
ODT-ADS-10B2P5G-16	10	2500
ODT-ADS-12B16G-7	12	16000

Table 1. Partial List of ADC IPs available from Omni Design

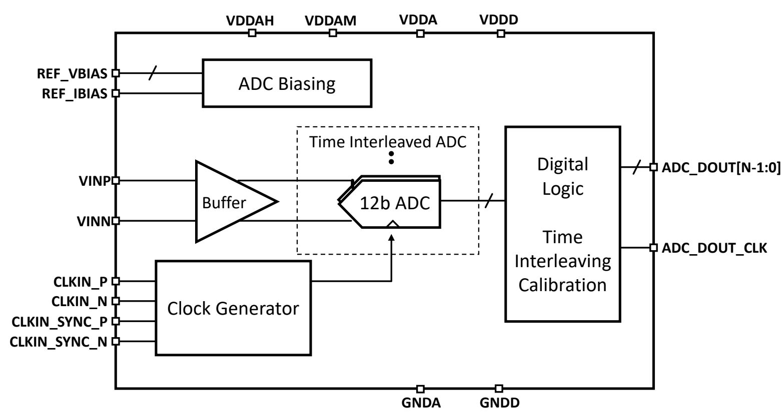

Figure 5. ODT-ADS-12B6G-16: 12-bit 6GSPS ADC

For performance critical LiDAR applications, integration of IPs at the AFE level presents a significant challenge, and careful attention to detail is required. These mega macros include bumps, ESDs, and can include third party phase-locked loops (PLL) IPs. Omni Design provides all the necessary deliverables to enable the integration of the AFE into the ASIC: analog, digital, scan chain, behavioral models, and detailed integration documentation. Omni Design has an extensive experience designing analog mega macro blocks that can be integrated into the SoC. The ODT-AFE-4A1P-16 in Figure 6 is an example of a high performance AFE.

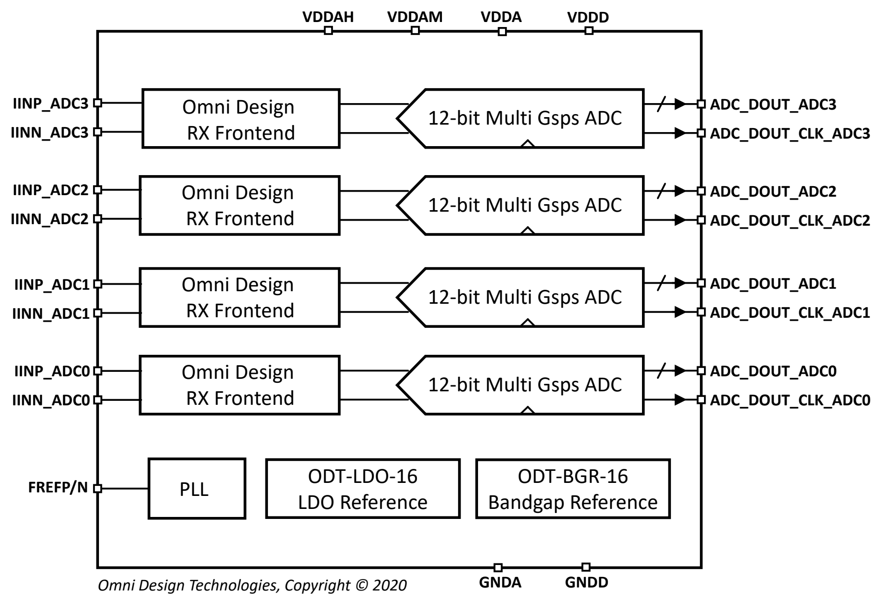

Figure 6. ODT-AFE-4A1P-16: LiDAR AFE

Omni Design offers a broad range of auxiliary IPs and can integrate them into an analog mega block customized to each customer's specific requirements. Omni Design's process/temperature/voltage sensor IP (PVT) offers excellent trimmed and untrimmed temperature and voltage accuracy. Omni Design also offers low-dropout voltage regulators (LDOs) that can be used to provide clean supply voltages to the analog/mixed-signal IPs. Finally, Omni Design's bandgap voltage reference allows for precise, low noise voltage/current generation for the analog mega block.

Summary

Integration, power consumption, cost, and form factor are becoming critical factors in enabling the mass deployment of LiDARs in autonomous vehicles. This is driving a significant market shift towards use of SoCs that integrate all the electronics functionality onto a chip rather than on a PC board. The SoCs used in LiDARs must meet the exacting architectural and technology specifications that are continuing to evolve. In addition, automotive reliability and functional safety requirements need to be carefully integrated into the SoC and component development process. Omni Design offers a broad range of analog mixed-signal IP optimized for LiDAR systems as well as the ability to integrate these IPs into mega blocks customized for a specific customer's requirements.

For a full listing of IP Cores that are required for LiDAR solutions, please visit our website at omnidesigntech.com or contact Omni Design at info@omnidesigtech.com

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