Analog-to-Digital Converters (ADC) for Autonomous Driving

Abstract

Automotive sensors like Light Detection and Ranging (LiDAR) systems are critical to realizing Level-5 autonomous driving. However, current LiDAR systems use a multitude of discrete integrated circuits with costs out of reach to be ubiquitous by vehicle manufacturers. To reach a level where self-driving cars are as ubiquitous as smart phones, all components would need to be integrated in a few chips either as system-on-chips (SoCs) or multi-chip-modules (MCM)/chiplets. Highly integrated ADCs, either as part of chiplets/MCMs or SoCs, will be critical to enable integrated LiDAR systems.

Introduction

The advent of autonomous cars is imminent with benefits touted from dramatic decrease in accidents and fatalities, lesser traffic and even reduced carbon emissions due to lesser vehicle idling. Although the most advanced semi-autonomous driving systems, Tesla's Autopilot [1], uses only cameras and Radio Detection and Ranging (RADAR) sensors, it is a widely accepted fact that centimeter accurate LiDAR sensors are critical for the reality and safety of autonomous cars. Recognizing their importance, several leading car OEMs have invested heavily in developing LiDARs. However, LiDAR mass adoption is severely curtailed by the fact they are bulky and very expensive.

The rest of the paper is organized as follows: Section I gives a brief overview of a LiDAR system. Section II describes the types of the LiDAR receive chain, with advantages and disadvantages of each. Section III describes the issues facing ADC-based LiDAR systems, while Section IV describes Seamless Microsystems' solution to this issue and why chiplets will be preferable for Tier 1 suppliers to the automotive market.

I. LiDAR System Description

Although Frequency Modulated Continuous-Wave (FMCW) LiDARs [2] are gaining in popularity, most commercial LiDAR systems are based on the Time-of-Flight (ToF) principle. Figure 1 shows a simplified block diagram of a typical ToF LiDAR system [3]. A laser diode, either in 905nm or 1550nm wavelength region, is pulsed with a 3ns-5ns duration. This pulse is detected after a time delay τ at the receiver using Avalanche Photo Diodes (APDs) or PIN diodes, which convert the reflected light into an electrical signal. Upon further processing, a 3D map of the surrounding region can be obtained from the time delay τ after several laser firings.

ToF LiDAR systems may further be classified based on their receive chain as Geiger-Mode or Single-Photon systems and Full-waveform capture systems, as shown in Fig. 1. Geiger-Mode (GM) or Single-Photon (SP) systems have an array of photodetectors which are triggered in to an avalanche effect by the reflected light. The avalanche effect is strong enough to output a digital electrical pulse. The time stamp of this pulse is measured using Time-to-Digital converters (TDCs) with picosecond accuracy. The TDC outputs are processed by a digital backend to build the point cloud. GM/SP LiDAR systems have advantages in terms of processing simplicity and power consumption. However, GM/SP systems provide neither reflectance data (all pulse amplitude information is lost), which is required for quick object classification, nor pulse shape data which lead to errors in estimation and can be susceptible to interference from other LiDARs. Also, GM/SP can only detect the first return echo, thus making multi return echo detection impossible. These advantages limit the range and resolution of GM/SP LiDAR systems to below what is required for Level-5 Autonomous Driving [4].

Full-waveform (FW) capture LiDARs use a linear photodetector, like an APD or PIN diode, to convert the light pulse into an electrical signal. This signal is further amplified in the electrical domain and processed by ADCs, which convert the analog electrical signal into digital 1s and 0s, digitizing the "entire waveform". FW LiDARs allow complex signal processing on the digitized data to determine not only the time delay but also reflectance data. FW LiDARs enable multi-echo detection, and have superior range and accuracy compared to current state-of-the-art GM/SP LiDARs and are considered more suitable for Level-5 Autonomous cars.

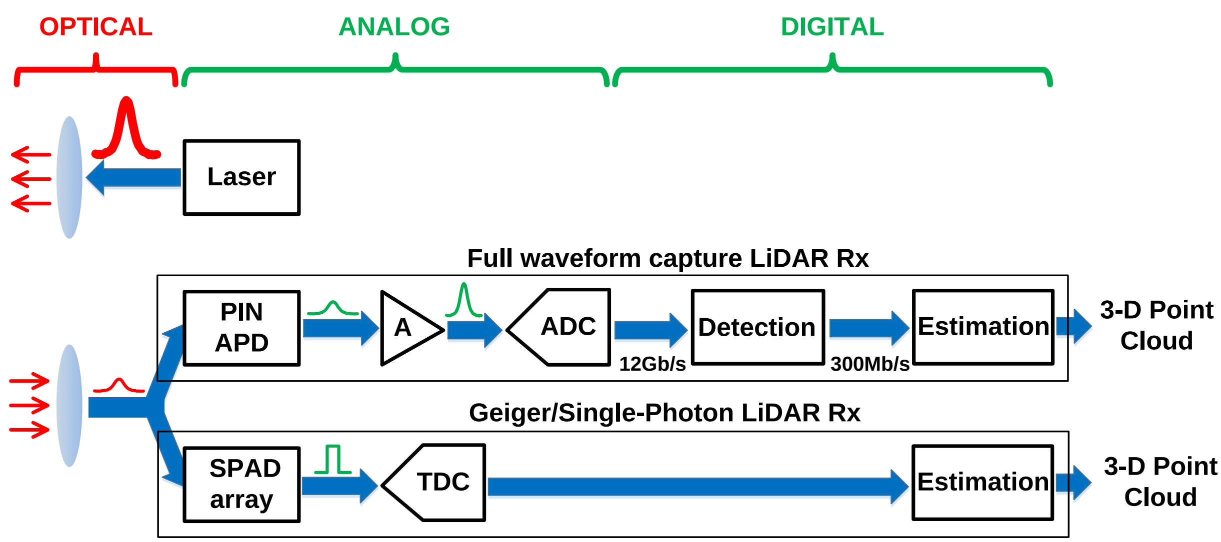

Figure 1. Example of a LiDAR system

II. Digitization Requirements for FW LiDARs:

ToF FW LiDARs use narrow pulse that are 3-5ns long, resulting in a digitization bandwidth of >200MHz. This requires the ADCs to sample at several GHz to obtain sufficient accuracy on the digitized pulse, limit noise aliasing and relax the requirements of the anti-alias filter before the ADC. Discrete multi-channel ADCs with multi-GHz sampling rates, 10-12 bits of resolution consume >1W per ADC channel and are also limited to less than 4 ADC channels per chip due to heat dissipation issues [5]. Such high-power consumption leads to heat dissipations issues that require dedicated cooling mechanisms, special packaging and heat sinks, all of which increase cost and form factor. Low-power, high-speed, cost-effective multi-channel ADCs are a severe limiting factor for the implementation of Level-5 compatible FW LiDARs.

III. Need for System Integration

In discrete chipset FW LiDAR receive chain implementations, the high-speed data transfer between the ADCs and the digital backend (ie. FPGAs) is becoming a bottle-neck. A ToF FW LiDAR sensor detects a 3-5ns laser pulse within a 2µs time window (assuming the LiDAR range is 300m, it takes light 2µs for a 600m roundtrip). The ADC is sampling and transmitting noise to the FPGA for most of the time, which is simply ignored. As shown in Fig. 1, the digital detection process results in a 40X reduction in data rate from the ADC, with a lot of power spent unnecessarily at the ADC-FPGA interface. The need for this >1GBps

I/O in the FPGA invariably demands the use of expensive FPGAs (>$200), although most operations performed by the FPGA are "simple". This leads to increased cost and power on the digital back-end.

IV. Seamless Microsystems' ADC Solutions for LiDAR

Power consumption, integration and cost issues of ADCs in LiDAR need to be solved to enable mass production of FW LiDARs. One example of ADC technology that would be indispensable in FW LiDARs is from Seamless Microsystems. The quad-channel SM250 ADCs are uniquely positioned to enable FW LiDARs to achieve the best sensitivity and range at an order of magnitude lower power consumption and cost. Sampling at 3GHz while achieving 60dB SNDR at 250MHz bandwidth, the over-sampled nature of the SM250M enables a significant relaxation on the anti-alias filter requirements. High clock jitter tolerance of the SM250M enables the use of low power compact ring oscillator base PLLs (phase locked loops) for sampling clock generation and distribution. This is enabled using Seamless' proprietary patented technology, Switched-Mode Signal Processing, that allows the ADC to leverage CMOS scaling by using lower power supplies and faster available transistors.

V. Discrete Chips or Chiplets or SoCs?

From the discussion in Section III, when LiDAR units exceed the 10s of millions, a multiple discrete chip solution becomes unfeasible due to cost and power issues. Multiple chips need to be integrated on either the same substrate i.e. System-on-Chips (SoCs) or in the same package as Multi-Chip-Modules (MCMs) or Chiplets. This will enable the cost and power reductions necessary to enable volumes in the 10s of millions. The advantage with chiplets is they are CMOS process agnostic i.e. different blocks (shown Fig. 1) could be fabricated in different process technologies and packaged in the same chip, where as in an SoC all blocks need to be in the same process technology, which might or might not be feasible.

Another factor that must be considered is automotive qualification. Every automotive component must go through a rigorous process of safety validation (ISO 26262 certification). Individual discrete chips that are used in such components need to pass AEC Q100 qualification, which tests for ESD, latch-up, long-term high temperature operation, mechanical shocking, etc. [6]. AEC-Q100 certification can only be carried out for production versions of the design (>10,000 units). LiDAR systems would already be in production in ~1M volumes, using chipsets which are individually AEC-Q100 qualified. Once the discrete chipsets are qualified, qualifying chiplets/MCMs, which consists of the same bare die that have already passed AEC-Q100 certifications, is much lower risk. In the case of a SoC, several IP blocks are integrated onto the same substrate. For an IP block to be AEC-Q100 qualified, it needs to be packaged and tested and since qualification needs >10,000 units, the cost can be prohibitive. Alternatively, the complete SoC, which includes the IP block, needs to be packaged and tested and that needs to pass AEC-Q100 certifications. But since the individual IP has not passed AEC-Q100, the resulting risk is much higher for the SoC to pass AEC-Q100. Or, the IP block could be tested within the SoC, meaning that a customer would have to provide debugging ports, test pins, etc. to ensure that it is AEC-Q100 compliant which significantly increases the time and effort required.

Conclusion

Autonomous drones and vehicles are the wave of the future and will need the integration of many electrical components to be as ubiquitous as smart phones. Many sensors will be required on each unit to meet full autonomy. Sensors such as RADAR/LiDAR have high bandwidth and resolution requirements and need full-waveform capture for accuracy at high ranges. Self-driving SoCs will most likely consist of chiplets due to the economics of deep finFET technology [7] and ADC IP such as Seamless Microsystems' SM250 will be needed to be integrated into them as chiplets to simplify the ISO 26262 certification process.

References

[1] Dikmen, M., & Burns, C. M. "Autonomous driving in the real world: Experiences with Tesla Autopilot and Summon." *Proceedings of the 8th International Conference on Automotive User Interface s and Interactive Vehicular Applications* (AutomotiveUI '16), pp. 225–228, October 2016

[2] Pierrottet, D., Amzajerdian, F., Petway, L., Barnes, B., Lockard, G., & Rubio, M. "Linear FMCW Laser Radar for Precision Range and Vector Velocity Measurements." *Material Research Society,* Materials and Devices for Remote Sensing and Optical Communications, San Francisco, January 2008.

[3] Ullrich, A., Pfennigbauer, M., "Linear LIDAR versus Geiger-mode LIDAR: impact on data properties and data quality." *Proc. SPIE 9832, Laser Radar Technology and Applications XXI*, May 2016

[4] Li, X., Yang, B., Xie, X., Li, D., & Xu, L. "Influence of Waveform Characteristics on LiDAR Ranging Accuracy and Precision." *Sensors*, vol. 18, no. 4, pp. 1156, April 2018

[5] Texas Instruments, Inc., part number ADS5409, 12-bit, 900 Msps ADC, 2014

[6] Automotive Electronics Council, "Failure Mechanism Based Stress Test Qualification for Integrated Circuits", *AEC Q 100 - Rev G,* 2007

[7] Dai, W., "IP vs. Chiplets SOC Disintegration Trend at Deep FinFET Submicron", *IP SoC Days 2018 Shanghai*, September 2018