Understanding LiDAR - Optical Axis

Abstract. This document introduces LiDAR optical configurations: biaxial and coaxial optics. Several typical LiDAR implementations from existing commercial products and research are presented.

Keywords: LiDAR, Biaxial Optics, Coaxial Optics, Perforated Optical Elements, Beam Splitter

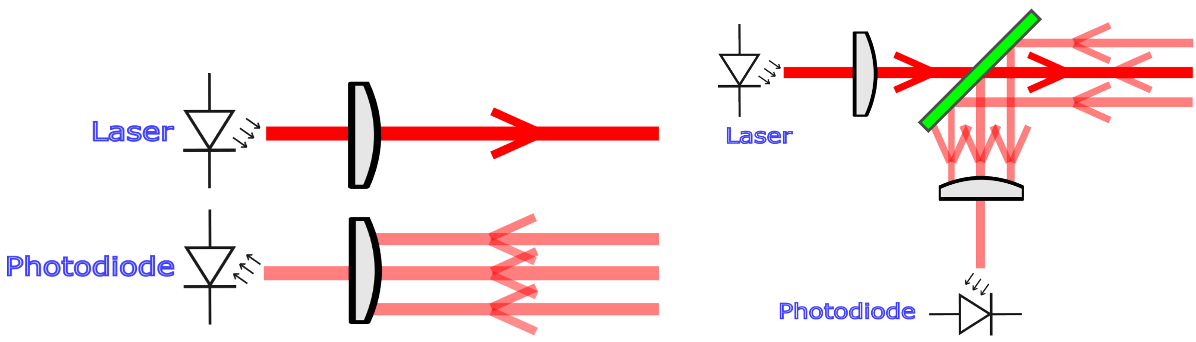
1. Introduction

LiDAR is a essential sensor for depth acquisition. It brooms as advanced driver assistance systems (ADAS) are emerging. Although there are multiple LiDAR systems, such as AMCW and FMCW, direct time of light (ToF) LiDAR still dominates the commercial markets at this moment due to the simple design and available economical components. This manuscript will thus only focus on ToF LiDAR.

2. LiDAR Architecture

A ToF LiDAR is mainly comprised of an optical transmitter and an optical receiver. The distance is calculated by timing the round-trip travel time (τ) of an emitted optical pulse. The distance d can be expressed as: $d = \frac{1}{2} \cdot c \cdot \tau$, where c is the speed of light.

LiDAR can be divided into either biaxial or coaxial systems, as shown in Fig. 1, with regarding to the optical axes of its transmitter and receiver. Biaxial LiDAR has the potential to reduce internal surface scattering, but its detection depth is limited by its overlap function. Coaxial LiDAR can detect near distance but the internal surface scattering should be mitigated carefully.



(a) Biaxial optical path

(b) Coaxial optical path

Figure 1: LiDAR optical paths

3. Biaxial optical path

The first spinning LiDAR invented by David Hall is a biaxial LiDAR [2], as shown in Fig. 2. The transmitter (30) is on its right side, while its receiver (32) is on its left side. Note that lenses are not shown here. In addition, some MEMS LiDAR also adopt biaxial configuration. In Fig. 3, multiple collimated laser beams are steered by a same MEMS mirror to achieve larger field of view, while a detector array collects the reflected beams separately [6].

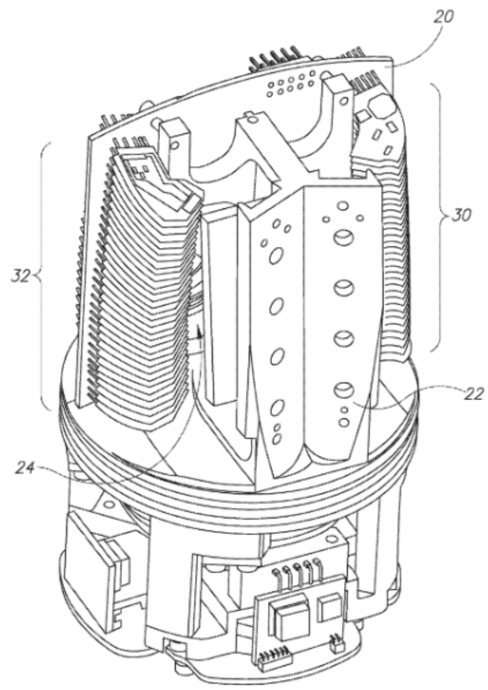


Figure 2: A biaxial LiDAR - Velodyne

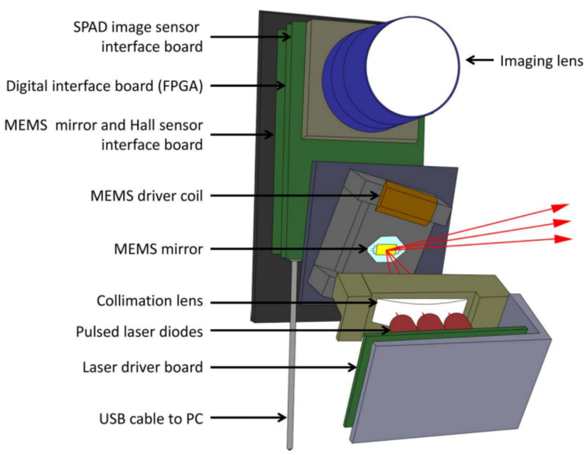


Figure 3: A biaxial MEMS LiDAR

4. Coaxial optical path

Coaxial LiDAR couples the optical of transmitter and receiver together on a same optical axis seamlessly, which enables near-zero distance measurement. To reduce near-distance blindness, most of current LiDAR for autonomous driving are based on coaxial configuration. Accurate alignment is granted by precision manufacturing and assembly. Internal surface scattering is mitigated by surface treatment and gated signal detection.

4.1. Perforated elements

Perforated structures on existing off-the-shelf optical elements are popular in research or prototyping. They are either available immediately, e.g. perforated off-axis parabolic mirrors, or can be self-customized by simple machining, such as hole drilling.

MIT Lincoln Laboratory developed a series of LiDAR based on perforated mirrors [7, 8], as shown in Fig. 4. A diffractive element diffracts one laser beam spot into an array of beam spots (32×32) before the opening. The equivalent total field of view is $10.8°$. Thus, the opening hole diameter is relatively large.

Fig. 5 shows another typical coaxial LiDAR based on a perforated parabolic mirror developed by Toyota Central R&D Labs., Inc. The laser is collimated into a small diameter (e.g. < 5 mm) first. Thus, it can travel through the perforated small hole. The relatively smaller diameter compared to the total effective aperture wouldn't degrade the signal-to-noise ratio (SNR) dramatically. With the development of silicon photon multiplier (SiPM) detectors, a LiDAR with a perforated large open hole can still keep a reasonable SNR.

In addition, a lens with a perforated hole can establish a similar configuration.

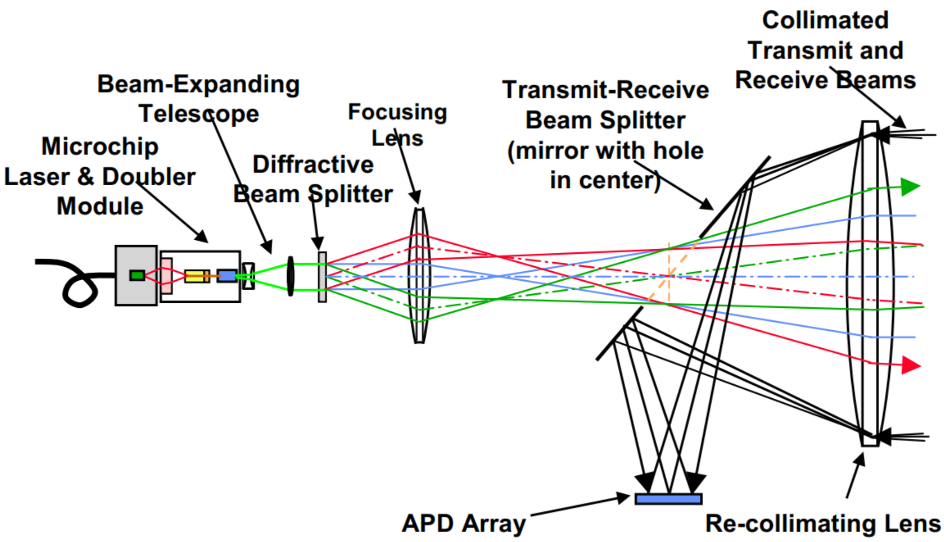
4.2. Beam splitter

Beam splitter is another type of optical element to create coaxial LiDAR (Fig. 6). It is easy to implement, but can only collect a quarter of energy on its receiver side.

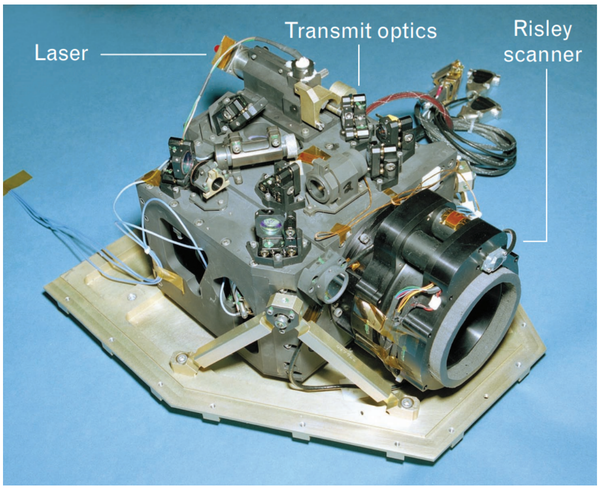
Another practical design is to insert a small reflective mirror to reflect the laser beam, while collecting the reflected back laser through the peripheral field of view [9]. Fig. 7 shows a Livox LiDAR schematic as an exact example, where the reflective mirror is not in scale. Robosense further optimizes this configuration by using a mirror with reflective infrared coating but with a transparent rectangular opening in center (Fig. 8). Hesei uses a similar design but with a complementary beam splitter whose center region is infrared reflective.

5. Summary

The critical optics to configure LiDAR into biaxial or coaxial systems have been introduced here. Both perforated machining and selectively coating can create the critical optics to couple transmitter and receiver optical paths.



(a) Schematic



(b) Prototype

Figure 4: LiDAR based on a flat perforated mirror

References

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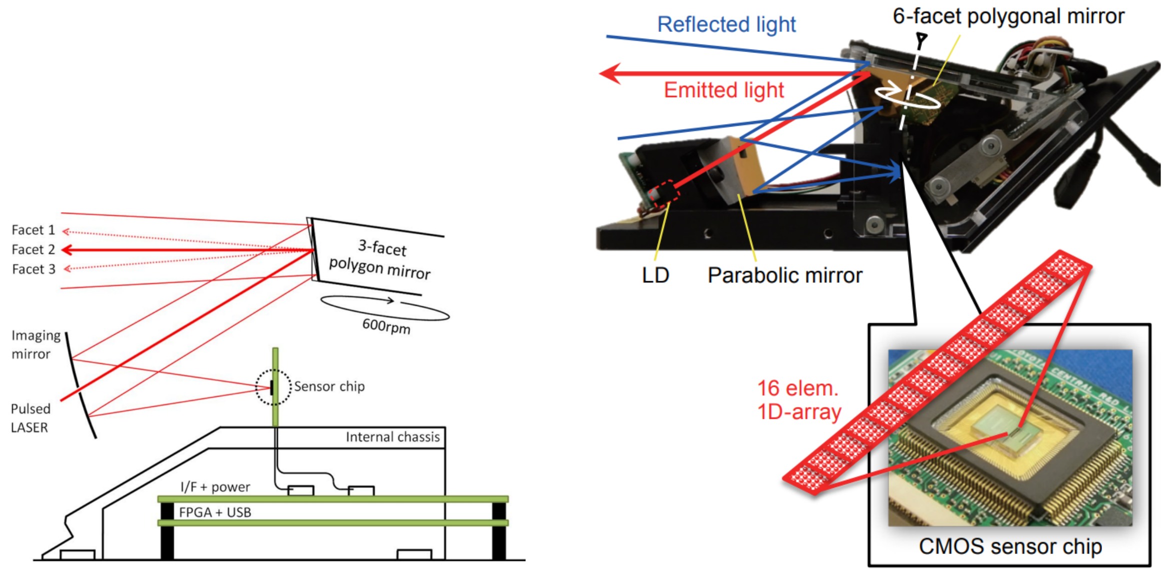

(a) Schematic (b) Prototype

Figure 5: A coaxial LiDAR based on a perforated mirror

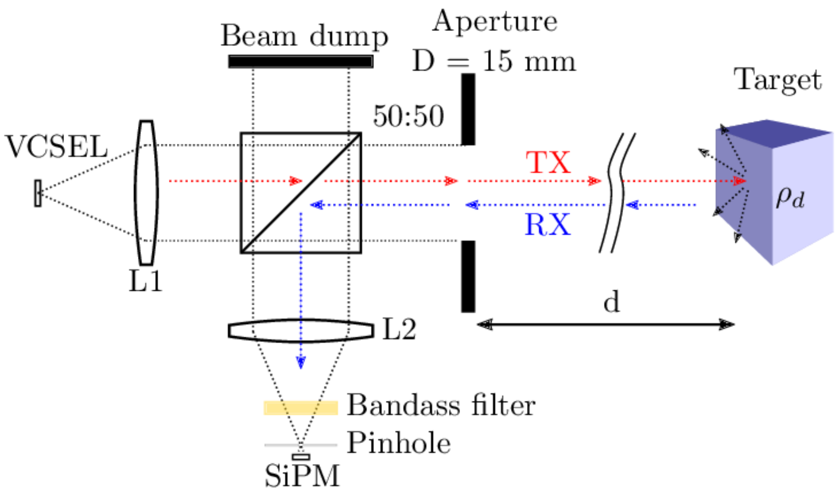

Figure 6: A coaxial LiDAR based on a beam splitter.

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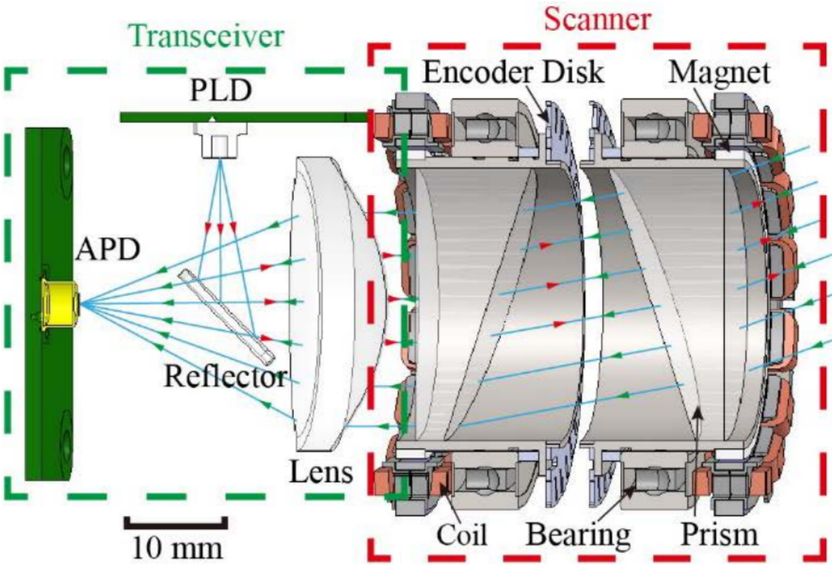
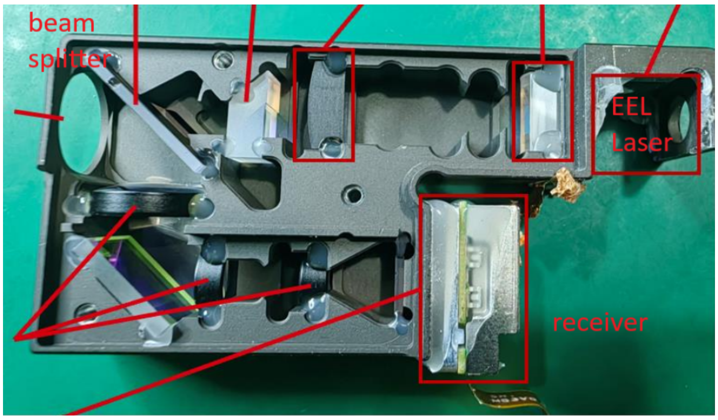
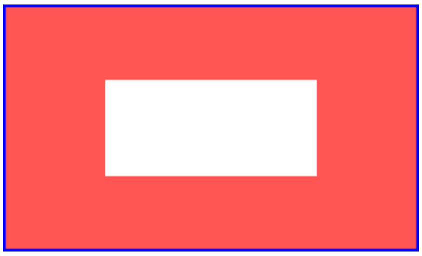


Figure 7: Livox coaxial LiDAR.



(a) Optical module



(b) Beam splitter – IR reflective coating only at edge

Figure 8: Robosense optical module

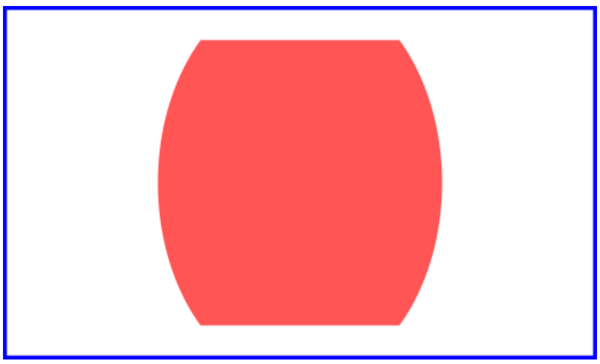


Figure 9: Beam splitter in Hesei AT128 LiDAR – IR reflective coating at center.