Modelling of mid-IR on-chip Doppler FMCW LiDAR System

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***Abstract*—We propose a generic model that can simulate the functioning of doppler LiDAR system from given target speed, working distance and modulation pattern. Simulations confirm that our model yield system performance consistent with the theoretical calculations.**

Keywords—LiDAR, Doppler.

I. Introduction

In order to abandon the steering wheel and make the self-driving car from concept on paper to real-life commodity, many technical issues remained to be solved. Light Detection and Ranging (LiDAR) provides a good solution for one of the most critical issue of autonomous driving, the mapping of surrounding environment and the detection of obstacles. For the autonomous driving assistance to be safe, reliable and eventually take over the wheels, the precision of 3D mapping, the speed of beam steering and signal detection have to surpass minimal acceptable performance threshold [1,2,3].

Before the development of LiDAR system, it is desirable to be able to simulate the performance of the system with various LiDAR design parameters. This allows for the optimization of the performance and the study of potential application scenarios. It also provides the possibility of development signal processing algorithm before data is obtained from experiment. The FMCW LiDAR system can be simulated with frequency domain method by convoluting the spectra of mix signal with the frequency response of the FFT window [4]. This provides much faster computation speed especially with large FFT length, however, it is more difficult to measure the impact of signal loss and have realistic direct reconstruction of a functioning LiDAR system.

In this paper, we build a FMCW LiDAR system model with the capacity to simulate doppler effect and perform measurement of target velocity and distance simultaneously in the time domain. The model has been used to simulate triangular wave FMCW LiDAR system with three difference working distance and target velocity.

II. Doppler FMCW LiDAR system with triangular wave modulation on laser frequency

Fig.1. shows a schematic diagram of the triangular wave modulated FMCW LiDAR. The laser central frequency is modulated with a triangular wave pattern with equal rising and falling ramp. The light is split into two paths by a power splitter. One of the signals goes to a mirror target with 20% of reflectivity to simulate a Lambertian reflector. The signal is being delayed by τ which is a function of time as the target is

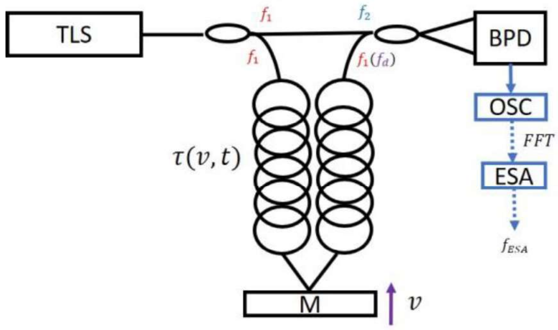
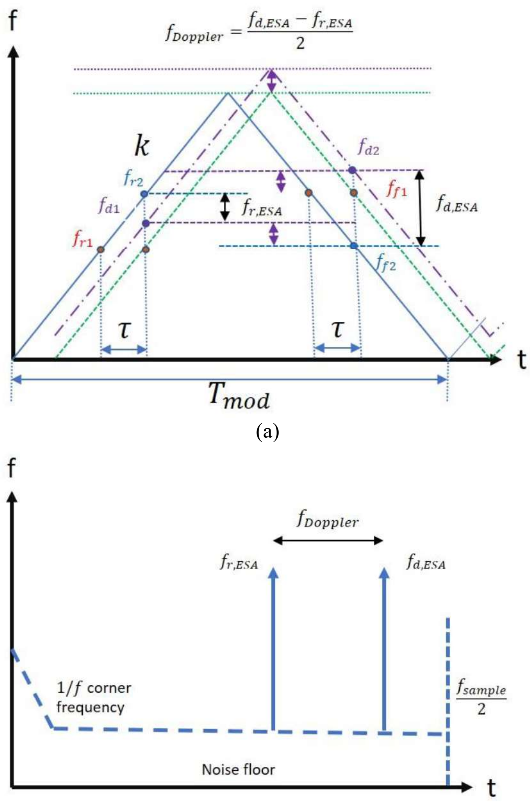


Fig. 1: System diagram of onchip FMCW doppler LiDAR system.

moving with velocity v. The reflected signal is mixed with the LO signal and the signal delay time is translated into the beat frequencies in the ESA. As the target is moving towards the



(a)

(b)

Fig. 2: Laser triangular wave modulation pattern and the delayed reflected signal (a). ESA spectrum (b).

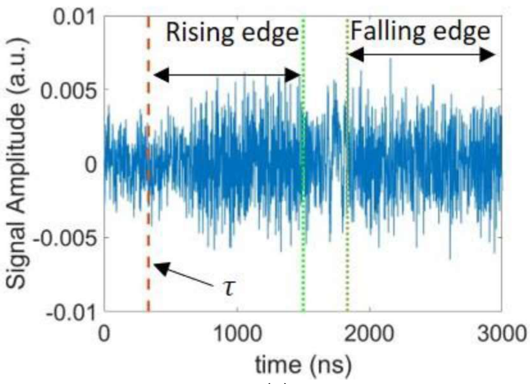
laser source, the observed reflected laser frequency is higher than the emitted laser frequency. This create a different beat frequency with LO signal when the tunable laser source is on the rising ramp and falling ramp.

Fig.2. shows the triangular wave modulation pattern and the ESA spectrum. The laser is delayed by τ when propagating between target and laser source. The blue line stands for the LO laser frequency. The green dash line stands for the delayed laser frequency when the target is not moving. The dash purple line stand for the delayed laser frequency when the target is moving towards the laser source. f_{r2} and f_{f2} represent the transmitted (local oscillator) signal frequency on the rising and falling ramp. f_{r1} and f_{f1} represent the reflected signal frequency on the rising and falling edge without doppler effect (static target). f_{d1} and f_{d2} represent the reflected signal frequency on the rising and falling ramp with doppler effect present (moving target). $f_{r,ESA}$ indicate the beat signal frequency from the rising ramp LO-delayed signal beating and $f_{d,ESA}$ indicate the beat signal frequency from the falling ramp.

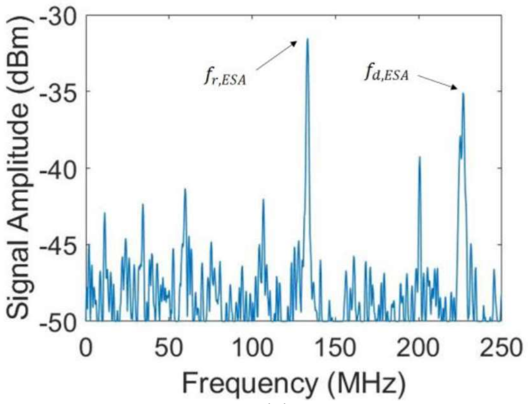
III. Simulation Result

The FMCW LiDAR simulations are carried out on Lumerical interconnect. Since Lumerical interconnect does not provide a built-in component with extendable length as a function of time. The total simulation time 3μs is sliced into 500 time segments with each segment having different delayed fibre length. FFT is performed on the combined tailored time domain signal to extract the doppler spectrum.

Three different LiDAR configurations are investigated for three different autonomous driving scenarios. The sampling

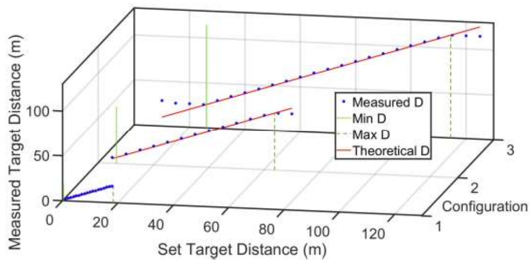


(a)

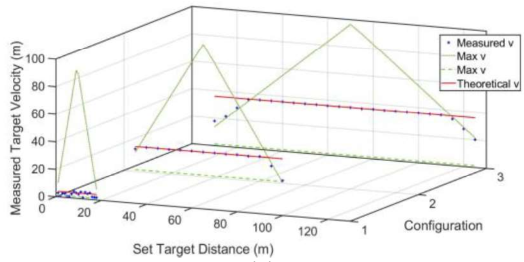


(b)

Fig. 3: Simulation result for configuration 1. Mixed signal detected on balanced detector (a) and spectrum (b).



(a)



(b)

Fig.4: Set and measured target distance (a) and velocity (b) for three different configurations.

frequency f_{sample} is set to be $500MHz$. laser central frequency is $1550nm$. Laser frequency deviation is $\Delta f = 400MHz$. The number of samples is 2^{11}. The

Fig.3.(a) and Fig.3.(b) shows the simulation result for LiDAR configuration (1), when the set target distance and velocity are 100m and 36m/s respectively. The beat frequency is $f_{r,ESA} = 132.333MHz$ and the dropping edge beat signal frequency $f_{d,ESA} = 222.667MHz$. This give a calculated target distance of $100.0368m$ and velocity of $36.0375m/s$.

Fig.4.(a) and Fig.4.(b) shows the set and simulated target distance and velocity measurement as a function of seted target distance for three FMCW LiDAR configurations. Each with different working distance and modulation period. The distance calculation shows a standard deviation of 0.3616m.

IV. Conclusion

We proposed a triangular wave modulated FMCW doppler LiDAR model for simulating the system performance of the LiDAR design under various autonomous driving when the vehicle or target is moving. The numerical simulation for different FMCW LiDAR configurations is presented.

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