# A Basic Approach for Speed Profiling of Alternating Targets with Photonic Doppler Velocimetry

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**Abstract:** Single tone continuous wave lidar system is utilized to construct the speed profile of an oscillating membrane by applying photonic Doppler velocimetry with amplitude-modulated light. Then short-time Fourier Transform is applied to acquire the profile. 
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## 1. Introduction

Over the past years, heterodyne or photonic Doppler velocimetry (PDV) is vastly used for detection of the particle velocities after small explosions, or in gas gun experiments, and in lidar systems [1]. The fundamental principle of PDV is triggering the heterodyne detection by combining the reflected beam from a moving target (Doppler-shifted light) with the reference arm as in a Michelson interferometer. The phase shift due to the displacement between the initial and final positions of a moving surface in a typical interferometry are analogous of frequency shift and velocity in PDV, respectively. A constant speed yields a single shift around the base band , but acceleration and deceleration of an oscillating target yields various frequency components, which are troublesome to distinguish in the frequency domain [2]. Previously, enhancement of range and depth resolution measurements by using single-tone and/or multi tone continuous wave (MTCW) lidar approach was demonstrated for quasi-CW lasers [3]. However, the technique is not performed for speed measurements with PDV by utilizing the frequency-shifted light from the targets in motion. The implementation of the modulation on top of the CW laser will further improve the system by increasing the detection range of the velocimetry, especially for high speed measurements by inducing additional beating tones. In this work, we demonstrated the velocity measurement capability of a single-tone CW lidar system near the base band by applying fast (FFT), and short-time Fourier Transform (STFT), respectively [4]. Such a fast approach can be used for wind-vector and ocean-surface wave speed profiling.

## 2. Methodology

The measurement setup for free-space PDV is given in Fig. 1. The same setup has been used for MTCW Lidar range finding measurements. A 1550nm narrow-linewidth laser diode (LD) is pigtailed to a 2mm aspheric collimator (CL) through a polarization controller (PC), Mach-Zehnder modulator (MZM) and Erbium doped fiber amplifier (EDFA). The MZM adds the RF tones on the CW or quasi-CW laser source. In this particular proof of the concept experiment we use single tone at 100MHz. A BS operating in the telecom wavelengths is used to separate the reference arm targeting the reference mirror (M1) and the measurement arm incident to the target mirror (M2), which is anchored on the oscillating membrane of a high-power (600W) speaker (Pyle PLPW6D). The speaker has a maximum longitudinal translation of 4mm and is intensity-modulated via a function generator. The displacement of the membrane is controlled by a 70Hz sinusoidal input with the 600mVpp, where the frequency response is ~93dB SPL (sound-pressure-level) as stated in the datasheet of the speaker [5]. The Doppler-shifted light and the local reference interferes back on the BS and directed towards InGaAs PIN photodetector (PD) through a focusing lens (L1). Finally, the time-domain measurements are performed by a digital storage oscilloscope (DSO).

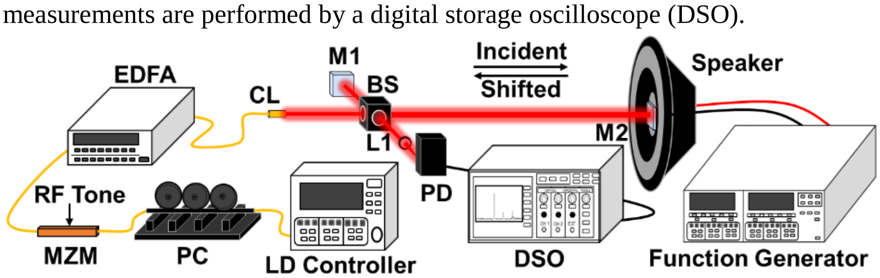


Fig. 1. MTCW lidar measurement setup with RF modulation for speed profiling of a commercial speaker with PDV.

The acquired data in time-domain is further transformed into frequency domain by applying FFT and STFT. The resultant frequency shifts are related to the velocity with $\Delta f = f_o \times (\Delta v/c)$, where $\Delta f$ is the measured frequency shift, $f_o$ is the optical carrier frequency and is 193.4THz, c is the speed of light, and $\Delta v$ is the speed of interest. First, by applying FFT to the large-window time domain it is possible to calculate the maximum resolvable speed of the system to determine the speed boundaries. Then we calculate the intermediary velocity components by narrowing the time window and creating multiple time windows with 1.25kHz resolution in frequency domain and applying STFT near the base band. By associating the zoomed time intervals with their corresponding shifts over couple of periods, it is possible to create a speed profile of a moving target in the time domain.

## 3. Experimental Results and Analysis

The FFT of the large time window data is presented in Fig. 2(a) in linear scale and the inset shows the dB scale to realize the transition from signal to noise floor. The maximum resolvable speed is related to the maximum observable frequency shift, and it is recorded as 11.76kHz which corresponds to 1.82cm/s. The maximum displacement of the speaker membrane is 4mm as stated in its datasheet [5]. Due to the power handling capability of the speaker, it is clear that the maximum displacement can be achieved by a 20Vpp sinusoidal input. In light of this information, the maximum speed of the speaker membrane is estimated as ~1.68cm/s at 70Hz oscillation frequency. Therefore, the measured speed is in a decent agreement with the expected result.

As is clear in Fig. 2(a), there exists many intermediary velocity components as a result of the potential accelerations and decelerations. In order to differentiate the remaining possible velocity components and map the speed profile, we narrowed down the time-scale and applied STFT. The narrowed down time-window is shown in Fig. 2(b) and the further zoomed time-scales subject to STFT are represented in different colors to achieve the intermediary velocity components. The inset indicates the corresponding frequency domain results of the selected time windows according to their color code. Here, the measured frequency shifts are 2.5kHz, 6.26kHz and 8.77kHz for the selected evenly spaced time-windows (0.8 ms), which maps to 0.39cm/s, 0.97cm/s and 1.36cm/s, respectively.

After post-processing and gathering the resultant velocity components by applying STFT, it is possible to match the calculated intermediary speed components with their emergence time. Then the speed profile of the speaker membrane oscillation is constructed as given in Fig. 2(c) over ~2 swings with respect to their measured optical intensities. In addition, the oscillation period is calculated as 70.22Hz while the function generator supplies a sinusoidal input at 70Hz, which shows a great correlation with the measured speed profile.

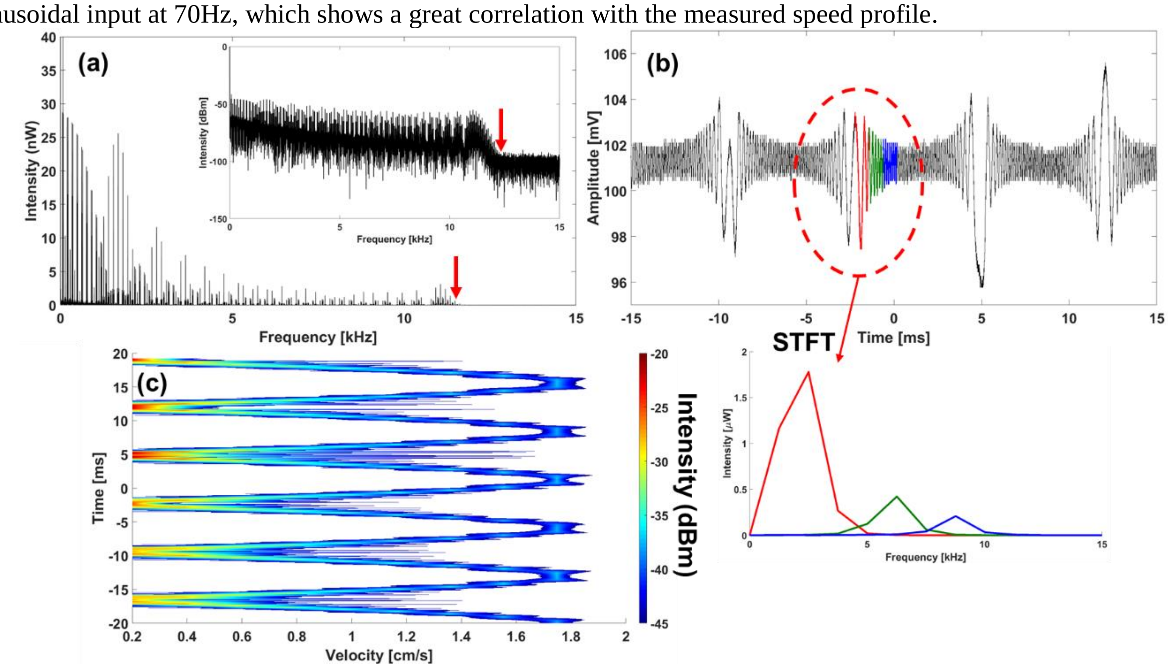


Fig. 2. (a) FFT of the wide-window time domain in linear scale, arrow shows the maximum Δ*f*. The inset shows the signal to noise floor transition in dB scale. (b) Narrow time domain response and application of STFT shown in red, green and blue. The inset shows the FFT of the corresponding time windows. (c) The speed profile of the speaker membrane oscillation with respect to the optical intensity.

## 4. Conclusion and Future Work

We performed PDV by utilizing STFT to acquire the velocity profile of an oscillating target by applying MTCW technique with single-tone. The technique can be further improved by increasing the frequency resolution to measure the low speeds while applying the STFT, or by observing the higher bands beating terms for high-speed components.
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## 5. References

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