Signal to Noise Ratios of Pulsed and Sinewave Modulated Direct Detection Lidar for IPDA Measurements

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Abstract: The signal-to-noise ratios have been derived for IPDA lidar using a direct detection receiver for both pulsed and sinewave laser modulation techniques, and the results and laboratory measurements are presented.

1. Introduction

Integrated path differential absorption (IPDA) lidar are used to remotely measure the column density of gases in the path to a scattering target [1]. Usually a direct detection receiver is used to measure the ratio of the laser echo signal with the laser wavelength tuned onto the gas absorption line (on-line) to that tuned off the line (off-line). When using transmitters based on tunable diode lasers followed by modulators and amplifiers, the modulation pattern is flexible, and the laser can operate CW or with its intensity modulated with pulses or different patterns. For space measurements there is interest in examining laser modulation techniques in order to minimize the transmitted laser power to achieve a high received signal-to-noise ratio (SNR).

Here we consider the performance of two measurement techniques for direct detection IPDA lidar. One is the pulsed modulation, where the laser wavelength is switched between on-line and off-line wavelengths on alternate pulses [2]. The other technique uses two CW lasers modulated by sinewaves of different frequencies and using lock-in type processing at each frequency in the receiver [3]. In this case, both the on-line and off-line lasers transmit simultaneously but are intensity modulated at different frequencies. Figure 1 shows a schematic of the laser signals for these two modulation techniques. Figure 2 shows the corresponding receiver block diagrams.

Generally the pulse modulation and detection is a time resolved measurement and requires a higher peak power laser operating at a relatively low duty cycle. Sinewave modulation and lock-in type detection approach uses a laser operating at lower peak power and higher duty cycle, and a very narrow electrical bandwidth post detection receiver to reject noise. The on-line and off-line lasers can be transmitted at the same time without interference. This paper compares the received SNR as a function of the average received laser power for both approaches.

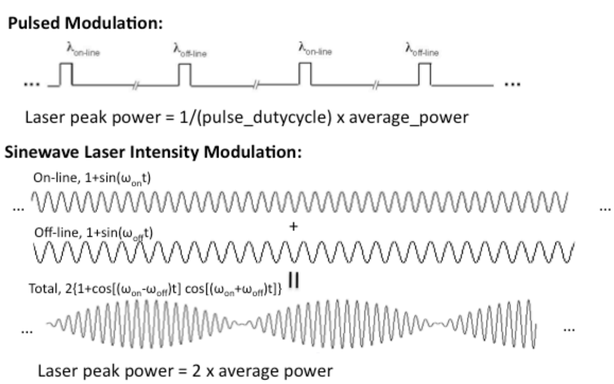


Figure 1. Pulsed and sine wave modulation of the laser power.

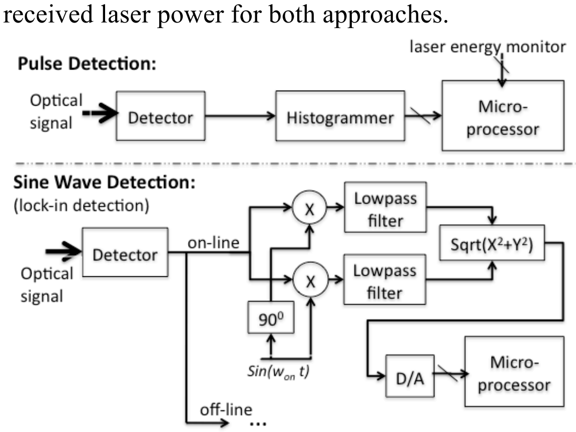


Figure 2. Receiver block diagrams for the receivers using pulsed detection and sine wave modulation lock-in detection. Two similar post detector circuits are used for the lock-in detection, one for each modulation frequency.

2. Receiver SNR – Theory

We have derived the expressions for the mean signal and noise variance from the direct detection receiver for both cases, assuming a ideal modulation of the laser power, an ideal photon counting detector and processing electronics. The SNR for the pulsed modulation can be written as

$$SNR \equiv \frac{mean}{stdev} = \frac{1}{\sqrt{2}} \cdot \frac{\frac{\eta_{\det}}{hf}\left\langle P_{sig} \right\rangle}{\sqrt{\frac{\eta_{\det}}{hf}\left(\left\langle P_{sig}\right\rangle + P_{bg}\tau_{pw} f_{pulse}\right) + \frac{I_{dark}\tau_{pw} f_{pulse}}{q}}} \sqrt{T_{\text{int}}} \tag{1}$$

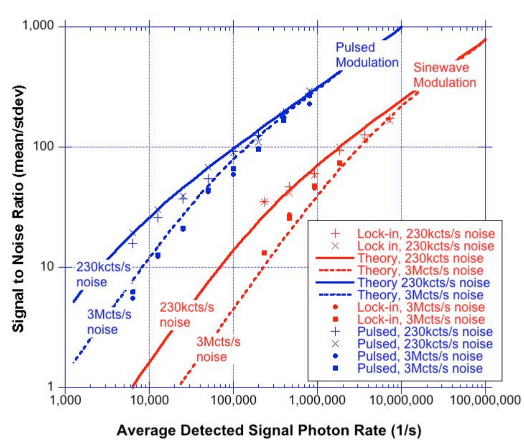
where η_{det} is the detector quantum efficiency, hf is the photon energy, $\langle P_{sig} \rangle$ is the average received signal power, P_{bg} is the CW background power, τ_{pw} is the pulse width, f_{pulses} is the pulse rate, I_{dark} is the detector dark current, q is the electron charge, and T_{int} is the receiver integration time. For sine wave modulation and lock-in detection, the receiver shot noise may be derived from frequency domain [4] and SNR can be expressed as

$$SNR = \frac{mean}{stdev} = \frac{\frac{1}{2} \cdot \frac{\eta_{\det}}{hf} \cdot \frac{\left\langle P_{sig}\right\rangle}{2}}{\sqrt{2\left[\frac{\eta_{\det}}{hf} \cdot \left(\left\langle P_{sig}\right\rangle + P_{bg}\right) + \frac{I_{dark}}{q}\right] BW \cdot \sqrt{2}}} = \frac{1}{4\sqrt{2}} \cdot \frac{\frac{\eta_{\det}}{hf} \cdot \left\langle P_{sig}\right\rangle}{\sqrt{\frac{\eta_{\det}}{hf} \cdot \left(\left\langle P_{sig}\right\rangle + P_{bg}\right) + \frac{I_{dark}}{q}}} \cdot \frac{1}{\sqrt{2BW_n}} \tag{2}$$

where BW_n is the receiver noise bandwidth. If an ideal integrators is used as the lowpass filters, noise bandwidth and the integration times follows the relationship $BW_n = 1/2T_{\text{int}}$. The results are plotted in Figure 1, which shows the SNR for pulsed detection is at least 4 times that of sinewave detections. Since the pulse duty cycle $\tau_{pw} f_{pulse} << 1$, the background noise and detector dark noise have much less impact on pulse detection than on sinewave modulation.

3. Receiver SNR – Experiment

We conducted laboratory experiments to measure the SNRs for both pulse detection and lock-in detection under similar conditions. The power from the 1060 nm laser diode was modulated by a waveform generator. A near infrared photomultiplier was used as photon counting detector. For pulsed detection a multichannel scaler was used as a time resolved histogrammer. For lock-in detection, a bandpass filter was used after the detector followed by an oscilloscope to record the analog waveforms into a PC for the signal processing. Figure 3 shows the measurement results along with the calculations from Eqs. (1) and (2) and the parameter values used in the experiments.



Experiment Parameters:

Laser: 1060 nm laser diode, intensity modulated by an arbitrary waveform modulator

Detector: Hamamatsu H10330-75 PMT used in photon counting configuration

Pulsed Modulation:

Pulse width: 1 μsec, rectangular shape

Pulse rate: 10 kHz, alternating on line and off-line

Receiver integration time: T_{int}= 0.2 sec

Sinewave Modulation Lock-in Detection:

Sinewave frequency, on-line: 50 kHz

Sinewave frequency, off-line: 51 kHz

Anti alaising filter before oscilloscope: 10 kHz bandpass

Lowpass filter type: 9th order Bessel

Lowpass filter bandwidth: 5 Hz

Figure 3. Measurement of the receiver SNR for both pulse and lock-in detection (symbols) along with the theoretical calculations (lines) using Eqs. (1) and (2). The parameter values are also listed.

Figure 3 shows that there is good agreement between the theory and the measurements. At high signal conditions, where the performance is limited by signal shot noise, the pulsed SNR is 4 times higher that of sinewave modulation. It also shows that the pulsed modulation requires about 1/16 the average laser power to achieve the same SNR compared to sinewave modulation. The differences become larger at lower signal levels. More details about the derivation and experiment will be described in the presentation.

References

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