Fiber-based Coherent Lidar for Target Ranging, Velocimetry, and Atmospheric Wind Sensing

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ABSTRACT: By employing a combination of optical heterodyne and linear frequency modulation techniques and utilizing state-of-the-art fiber optic technologies, highly efficient, compact and reliable lidar suitable for operation in a space environment is being developed.
OCIS Codes: (280.3640) Lidar; (280.3340) Laser Doppler Velocimetry

1. INTRODUCTION

Capabilities of coherent lidar in profiling atmospheric winds and measuring the velocity of hard targets are widely recognized and well understood through numerous ground-based and airborne measurements [1]. This paper reports on the development of a multi-functional all-fiber coherent lidar capable of high-resolution target ranging and velocimetry and measuring atmospheric winds with the primary goal of aiding NASA's Space Exploration initiative for manned and robotic missions to the Moon and Mars. Future exploratory missions to the Moon and Mars will be more focused towards landing at locations with high scientific value. This may include targeting sites near cliffs, valleys or other geographically interesting terrain [2]. For example, NASA is considering the craters of lunar South Pole for its next sample return mission to the Moon because these rough sites have permanent dark areas with a possibility of under-surface water. Landing on such rough terrains will entail precision soft landing and hazard avoidance capabilities [3]. The coherent lidar being reported in this paper will be capable of providing the necessary data for safely navigating the lander to its pre-selected site. The lidar will provide precision range to the ground and approach velocity data, and in the case of landing on Mars, it will also measure the atmospheric wind and density.

The lidar obtains accurate range information from a frequency-modulated laser beam whose instantaneous frequency varies linearly with time, and the ground vector velocity is directly extracted from the Doppler frequency shift [4]. Utilizing the high concentration of aerosols in the Mars atmosphere (approximately two order of magnitude higher than the Earth), the lidar can measure wind velocity with less than a watt of optical power. Operating in 1.57 micron wavelength regime, the lidar can use the differential absorption (DIAL) technique to measure the average CO_2 concentration along the laser beam using, that is directly proportional to the Martian atmospheric density. Employing fiber optics components allows for the lidar multi-functional operation while facilitating a highly efficient, compact and reliable design suitable for integration into a landing vehicle.

2. LIDAR SYSTEM DESCRIPTION

The lidar employs the Frequency modulated-continuous wave (FM-CW) technique commonly used in radars for high resolution range measurements. As shown in Figure 1, the transmitted waveform will be delayed by t_a, the light round trip time, upon reflection from the target. When mixing the delayed return waveform with the transmitted waveform at the detector, an interference signal will be generated whose frequency is equal to the difference between the transmit and receive frequencies. This difference frequency is directly proportional to the target range. When the target or the Lidar platform is not stationary during the beam round trip time, the signal frequency will be also shifted due to the Doppler effect. Therefore by measuring the frequency during "up chirp" and "down chirp" periods of the laser waveform, both the target range and velocity can be determined.

Earlier FM-CW coherent lidars suffered from the laser technology limitations in generating narrow linewidth beam and ability in producing linear frequency modulation waveforms [5]. But, recent advances in photonic technologies mainly due to substantial investment by the telecommunication industry have now created new

opportunities for developing FM-CW coherent lidars capable of producing high precision range and velocity data and that are compact, rugged, and efficient meeting the stringent requirements of planetary exploration missions.
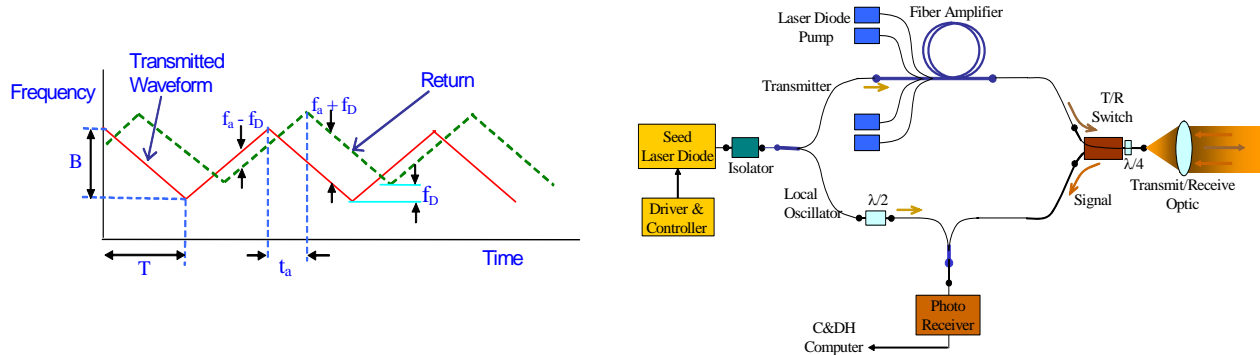

Figure 1. (a) Transmit and return frequency waveforms; (b) All-fiber Coherent Lidar Schematic.

The design of the breadboard lidar developed for this work is described in Figure 1(b). A low power semiconductor InGaAs laser operating in the eye-safe region of the near infrared spectrum at 1.57 microns is used as the seed source. The seed laser uses an external cavity Bragg grating to generate a very narrow linewidth and stable output of a few milliwatts. The seed laser generates the required frequency modulation waveform by controlling its cavity length using a PZT actuator. Part of the laser beam is split for use as the local oscillator for optical heterodyne detection. The remaining part of the diode laser output is amplified by a single mode Erbium-doped fiber amplifier to increase its power to several watts. The fiber amplifier output is expanded and transmitted by a lens. The reflected laser radiation is collected by the same lens and focused into an optical fiber. A transmit/receive switch directs the returned radiation to a detector where it is mixed with the local oscillator beam.

Breadboard measurements were performed using a sandpaper target mounted on a rotating motor placed at a distance of about 250 meters. Figure 4 shows two spectrograms of the received signals from the diffuse target in a stationary position and moving at about 20 m/sec speed. For the stationary target, the range is directly related to the peak frequency of the signal spectrum. When the target is moving, the Doppler shift causes a difference in frequency during the up-ramp and the down-ramp. The target range is simply proportional to the sum of two peak frequencies and the target velocity is related to their difference. Additional measurements are planned to demonstrate the lidar capabilities in measuring atmospheric winds and CO_2 concentration.
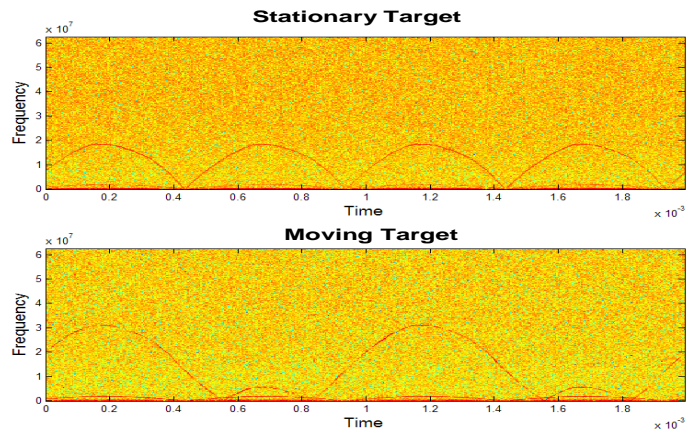

Figure 2. Spectrograms of the received signals from the sandpaper targets at 250 m.

3. References

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