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CFF2 10:30 am

Phase-coded LIDAR

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1. Introduction

Continuous wave (CW) LIDARs possess certain advantages over pulsed LIDARs including a reduction in peak power, fiber based operation, and ease of amplification. CW LIDARs typically rely upon modulation techniques such as chirping and pseudo-noise (PN) coding in order to obtain range information. Chirped techniques have complications resulting from nonlinear frequency chirp.[1] PN coded LIDAR,[2] is an alternative approach, which utilizes on/off keyed unipolar baseband PN codes. However, most unipolar codes exhibit significant side-lobes in their autocorrelation functions. This leads to a poor gating contrast.

Our approach represents an important improvement to the PN coded LIDAR technique. We modulate the laser with a bipolar phase coded PN microwave signal rather than a baseband unipolar sequence. Hence, we can use the bipolar phase codes that have been developed for microwave ranging systems. Furthermore, as we have demonstrated, the LIDAR return signal can be processed using techniques and components that are already in place for microwave ranging.

2. Experiment

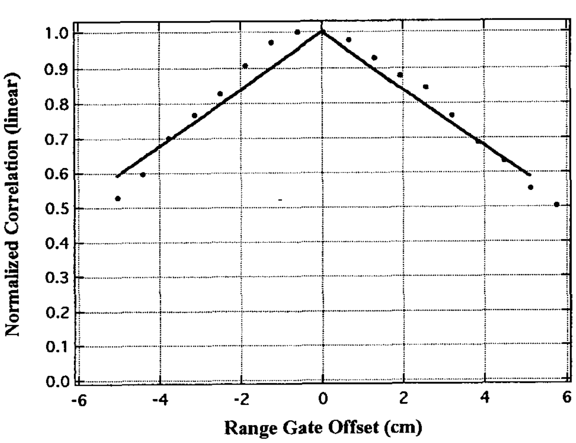
In our experiment, a 1550 nm, CW, single mode, 4 mW optical power laser was sent through a Mach-Zender modulator (MZM), biased at quadrature. A 9.7 GHz microwave carrier was bipolar phase shift keyed (BPSK) by a $2^{23} - 1$ maximal length PN code at a clock rate of 1.3 GHz. The phase-coded carrier was then modulated onto the optical carrier at the MZM. The modulated laser beam then passed through an optical fiber circulator and was coupled from fiber to free space via a collimator. For the purpose of demonstration, the laser was incident on a mirror target at a distance of L = 4.27 m. The target was mounted on a shaker that was driven with a 650 Hz audio tone, simulating target vibration. The retro-reflected return signal from the target was coupled back into the fiber and delivered to a photodiode through an optical circulator. The transmitted beam was also partially reflected at the fiber/air interface, before the collimating lens, providing the local oscillator for coherent optical detection at the photodiode. The received signal from the photodiode was then correlated with a delayed reference version of the PN code, by multiplication in a balanced mixer. The delay of the reference code sets the range gate. If the trip time of the coded signal through the optical system matches the reference code delay, the transmitted carrier phase inversions are removed and the microwave carrier is restored.

Figure 1 shows the measured correlated carrier level vs. offset between the range gate setting and the actual target range. While the theoretical correlation function is a triangle, band-limiting of the digital modulation signal in the experimental setup results in a function that is smooth. Our measured range resolution, defined as the full-width at half maximum of the triangular fit is 12.4 cm. The lower bound of the range resolution corresponds to half of the non band-limited PN code bit width or 11.5 cm.

Furthermore, the peak to background correlation level was measured to be ~32 dB. The background level was due primarily to incomplete rejection of the microwave carrier in the transmitter's balanced mixer. A custom design tailored for our frequency of operation would improve the performance significantly. Additionally, due to coherent detection, target vibrations with an amplitude as small as half an optical wavelength will lead to a large amplitude modulation of the de-spread carrier. Hence, this approach allows us to find the vibration signature of a target that lies within the range as determined by the range gate setting. In this experiment, we added a distinct vibration frequency of 650 Hz to the target by mounting it on a shaker, and found that the AM spectrum of the recovered and down-converted carrier clearly bears the 650 Hz vibration signature.

3. Summary

In conclusion, we note that these results demonstrate the principle of operation for a bipolar phase coded LIDAR with range gated vibration signature capability. While this experiment was performed at close range and a moderate PN code rate of 1.3 GHz, one could envision extending the code rate to approximately 10 Gb/s in order to obtain a range resolution on the order of 1.5 cm. Furthermore, the addition of EDFA's and telescope apertures would allow the system to range distant targets.



CFF2 Fig. 1. Normalized correlated carrier level vs. offset between the range gate setting and the actual target range. Points: measured, Solid line: fit to triangle.

References

1. E.C. Burrows and K.Y. Liou, "High resolution laser LIDAR utilizing two-section distributed feedback semiconductor laser as a coherent source," Electron. Lett. 26, 577–579 (1990).
2. Yves Emery and Christina Flesia, "Use of the A1- and the A2-sequences to modulate continuous-wave pseudorandom noise lidar," Applied Optics 37, 2238–2241 (1998).

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Performance of a Breadboard Lidar Receiver at 1570 nm for Remotely Sensing Atmospheric CO_2 Concentration

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We are developing a differential absorption lidar technique to remotely measure the atmosphere CO2 concentration from aircraft. It uses two alternating multi-kilohertz pulsed lasers, one "on-line" at a CO2 absorption wavelength about 1570 nm and one "off-line" at a nearby wavelength. The two lasers are co-aligned and pointed at the ground. The receiver detects the ground echoes from both lasers and measure the ratio of the echo pulses energies to determine the absorption due to the CO2 in the column along the optical path. The goal is to achieve a signal to noise ratio (SNR) of 500 to 1000 in each measurement after averaging over a few tens of seconds for detecting CO2 concentration to a few parts per million. A more detailed description of the approach is given in Reference 1.

The laser transmitter uses seeded fiber laser amplifiers, which have a limited peak power and require high receiver sensitivity to detect the signal. We use an InAlAs/InGaAs photomultiplier tube (PMT) which the quantum efficiency can be as high as 4% near 1.6 micron wavelength at a dark count rate of about 200,000/s when cooled to –80 degree Celsius. Photon counting technique is used to achieve a near quantum noise limited performance, which is several orders of magnitudes higher than those using InGaAs PIN photodiodes despite their high quantum efficiency.

Our breadboard receiver consisted of a commercial InAlAs/InGaAs PMT by Hamamatsu (R5509-72). The photon counting efficiency was measured to be about 1.5% at 1550 nm at a dark count rate of 130,000/s under 1500 volts supply voltage. The photocathode quantum efficiency measured by the manufacture was 2.4% (spectral response 3 mA/W from 1550 to 1590 nm). The output pulse width was measured to be 4 ns and the dead time between adjacent photon counts appeared to be limited only by the pulse width.

Our test setup to characterize the detector consisted of a 1550 nm cw laser followed by an acoustic-optical modulator as the signal source, a fiber attenuator to adjust and calibrate the signal level, and a multichannel scaler for receiver data