Improvement of a1319 nm laser radar using non-identical telescopes

Marcos J. Fabio, Linwood Creekmore, Rodney I, Stewart, Patrick Shealey, Darry Saunders, Erica Pinkney, and Demetrus Rorie

April 6, 2004

I. ABSTRACT

Measuring ice sheet surface elevation and vegetation canopy height by lidars carried by satellites is getting more practice. Those lidars use short duration and high peak power transmits pulses to achieve the necessary resolution and sensitivity. The high peak power operation results in limited lidar lifetime and a low pulse repetition frequency (PRF), which provides insufficient spatial samples along the satellite track. To overcome those disadvantages of high peak systems the search group in the university of Kansas has developed a low peak power laser radar using modern RF techniques and fiber-optic technologies developed in support of the communication industrial. [1] Also receiver sensitivity below –100 dBm with transmit pulses with 40 μs duration, 260 MHz bandwidth and a 4 kHz PRF were reported. However the two-stage down-conversion receiver with envelope detection associating with telescope-to-optical fiber coupling still have room to be improved and in my article we will discuss one possible way to reduce insertion losses in coupling.

II. INTRODUCTION

The range accuracy σ_R is the major performance parameter in altimeter system, which is determined by the received signal bandwidth B and the signal-to-noise ratio SNR [2].

$$\sigma_R = KC/B\ (SNR)^{1/2}$$

when SNR >>1. K is a constant associated with the type of algorithm applied and $B \cong 1/\tau$ for high peak power systems and τ is short pulse's duration. For example (of the group of the University of Kansas) to achieve a fine range accuracy σ_R = 10 cm, a long-duration (τ = 40 μs) and a low peak power (P<1 W) were used. The transmitted pulse is modulated by a signal with a bandwidth commensurate with the desired range accuracy. To readily separate the modulation signal from the optical carrier in the receiver the group of the University of Kansas selected amplitude modulation and this modulation can reach multi-gigahertz bandwidth under the help of the advanced fiber-optic technologies. A chirp waveform, which is produced digitally using direct digital synthesis (DDS), was used as the modulation signal [3] and it consists of a sinusoid whose frequency varies linearly from f_1 to f_2, and thus the signal bandwidth is the absolute number of difference between these two frequencies. For example if f_1 is 100 MHz and f_2 is 360 MHz and then B is 260 MHz. As in conventional RF and microwave radar systems, once the chirp signal has been recovered in the receiver, the signal is dechirped and low-pass filtered. The signal output from this process is a sinusoid of duration τ and frequency f_R where

$f_R = 2BR/c\tau$ and R is the range to the target. R can be determined by digitizing and analyzing. In the laser radar system the transmitted optical signal and the reference for the local oscillator are obtained from a common laser. The transmitting laser signal is intensity modulated by the chirp waveform while the local oscillator signal is frequency shifted by 600 MHz by using an acousto-optic modulator (AOM). Therefore the received signal is coherently down converted to an intermediate frequency of 600 MHz and envelope detected by following RF up conversion to about 3.6 GHz, then mixed with a baseband chirp signal, filtered and digitized. 100 mW lighteave electronics is necessary to provide optical signal power for both the transmitted signal as well as the LO signal. Usually the output of the photo detector is short-noise limited with an SNR << 1 and therefore signal processing gains are required to achieve the SNR required for accurate range measurement (SNR >> 1). In envelope detection, the envelope signal is recovered and the carrier signal is rejected. The carrier frequency must be at least ten times greater than the maximum frequency of the envelop waveform, which is why we unconverted the signal to 3.6 GHz, to perform envelop detection efficiently. When SNR << 1, the receiver system was designed to have a linear transfer characteristic, which means a I dB of change in receiver optical signal power is translated into about 1 dB of change in the detected signal power and SNR. The envelope can be regarded as sidebands about the RF carrier; the product of the carrier and sideband generates a quadratic term. When both carrier and the sidebands are attenuated by the optical losses, the product of these two terms is affected doubly by the optical path loss, and consequently the envelope detector has a nonlinear transfer characteristic. Direct down conversion [1] of the RF signal to baseband is an alternative to replace envelope detection. Rather than mix the photo detected RF signal up to 3.6 GHz, the alternative is to mix it down to baseband where it is dechirped and processed as before. This method provides a more linear transfer characteristic than envelope detection however in direct down conversion the perturbations of the optical frequency and phase remain in the detected signal [1]. The phase stability of the detected signal, both intrapulse and pulse-to-pulse, is now impacted by laser phase noise, atmospheric turbulence, Doppler effects, etc.

III. FIBER-TO-TELESCOPE INTERFACE ISSUES

The fiber-optics technology to be used as transceiver including both the transition from SMF fiber to free space by using a pair of identical telescopes and the maximum theoretical coupling efficiency is about 80% (or 1 dB loss) due to mismatches in the field distribution between the telescope and the fiber [4]. When the random light reflected and coupled back into SMF with the application of lidar, the maximum coupling efficiency may be only about 42% (or 3.8 dB loss)[5]. For coupling efficiency issue, when the numerical aperture (NA) of both fiber and telescope match each other coupling efficiencies will reach the maximum. The NA of SMF-28 fiber at 1300 nm to

1500 nm is about 0.11, which corresponds to an f/ratio of 4.5 using

$$f/ratio = (2NA)^{-1}$$

To optimum coupling to SMF, the telescope's f/ratio should be between 7.6 and 3.3 [4]. Since the Celestron 5 in diameter Schmidt-Cassegrain telescope has an f/ratio of 10, which corresponds to an NA of 0.05, a focal reducer must be used to convert the telescope's f/ratio to f/5. The fiber-to-telescope interface consists of a bare, polished fiber end placed in the telescope's focal plane. The group of University of Kansas mounted an FC/PC connector sleeve on a fixture on the rear cell of the telescope so that a simple SMF patch cord could be readily attached to deliver the light to the telescope. The cost of this solution is around 4% reflection at the fiber/air interface and the transmit signal reflection from the fiber end may overwhelm the receiver and mask the weak return signal. The measured insertion loss of Kansas group is around 12 dB when two identical telescopes were aligned and their beams collimated and hence the efficiency of our fiber-to-telescope interface is around 25% (or 6 dB loss).

After studying of the research in the group of the University of Kansas we think there is one possible to reduce the insertion loss for the whole system. The NA of single-mode fiber can be designed to about 0.05, which corresponds to an f/ratio of 10, and to optimum coupling to this signal-mode fiber, the telescope's f/ratio should be between 16 and 8 which just match the NA of the Celestron 5 in diameter Schmidt-Cassegrain telescope. Thus the focal reducer can be taken out of the system that can result in less insertion loss and the most important is that the beam size must be reduced by reducing NA number of the fiber while keeping the same focal length of the telescope. With the same power applied on the system, the smaller size beam strengths the intensity of beam and therefore the resolution and sensitivity of lidar will be improved and meanwhile the insertion loss will be reasonable reduced to 10 dB.

IV. SUMMARY

We studied the remote sensing technology particular in fiber-telescope coupling and based on our knowledge we suggest a possible solution to improve the coupling efficiency and roughly and reasonably calculate the total insertion loss.

V. ACKNOWLEDGMENTS

First and foremost we would like to thank Dr. Linda B. Hayden and the entire faculty and staff of the ONR program for all of the help and encouragement provided for our research. We would especially like to thank Dr. Lei Zhang for all of the time, patience and knowledge that he shared with us.

VI. REFERENCES

[1] C. Allen and S. Gogineni, "A fiber-optic-based 1550-nm laser radar altimeter with RF pulse compression," Proceedings of the 1999 international Geosciences and Remote Sensing Symposium (IGARSS'99), Hamburg, Germany, pp. 1740-1742, June 1999.

[2] Jelalian, A. V., Laser Radar Systems, Artech House, Norwood, Massachusetts, p. 45, 1992

[3] Kachelmyer, A. L., “Range-Doppler imaging: wave-forms and receiver design, “Laser Radar III, R.J. Becherer, Ed., Proc. SPIE, vol. 999, pp. 138-161, 1988

[4] Shaklan, S. and R. Roddier, “Coupling starlight into single-mode fiber optics,” Applied Optics, 27 (11), pp.2334-2338, 1988

[5] Winzer, P.J., and W.R. Leeb, “Fiber coupling efficiency for random light and its applications to lidar,”Optics letters, 23(13), pp. 986-988, 1998