Modulated Laser Pulse based Water Vapor DIAL

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***Abstract*—A single pulse modulation and pseudorandom coded pulse modulation are utilized for water vapor DIAL in this paper. The water vapor profiles conducted from these modulation techniques are compared to the real observation data in summer in Japan. As a result, the single pulse modulation is appropriate for near region measurement, while pseudorandom coded pulse modulation is appropriate for far region measurement.**

I. INTRODUCTION

Water vapor plays a significant role in climate change, weather forecast as well as study of atmospheric activities. We are developing a differential absorption lidar (DIAL) for measuring accurate and high resolution water vapor profile in lower-tropospheric in Japan. The DIAL method using a pair of online and offline lasers can prevent a calibration issue of Raman lidar. In order to improve a compact and affordable system, we employ a diode laser based DIAL. The wavelength of diode laser can be widely tuned near infrared region. However, the peak power of diode laser is limited. Therefore, the modulated laser pulse technique is applied to overcome this disadvantage.

The modulated laser pulse technique utilizes a long macropulse instead of a single short pulse. The macropulse generated by a sequence of 100ns-width chips is repeated at the frequency of 10 kHz. Each macropulse is modulated by a pseudorandom sequence. The advantage of a longer macropulse is higher energy while the advantage of a shorter macropulse is higher resolution.

In scope of this work, both single pulse and pseudorandom coded pulse modulation are evaluated. The M-sequences, a common pseudorandom code, with various code lengths of 7 bit and 15 bit are used. The DIAL measurement error is represented by the relative error of the obtained water vapor profile and the real profile of water vapor in summer in Japan.

II. METHODOLOGY

The concept of modulated pulse technique is illustrated in Fig. 1. A single macropulse transmits N subpulses which are coded according to a pseudorandom sequence.

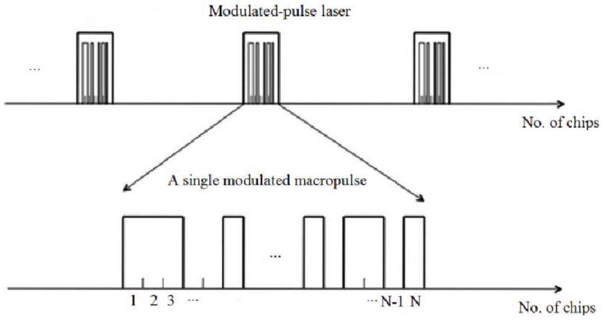

Fig. 1. Illustration of modulated pulse laser. [1]

In this work, we suppose that the subpulse width equals to chip width t_c and bit width t_b. Hence, the width of a single macropulse is given as $t_{macro} = N.t_b = N.t_c$.

The waveform of a single macropulse laser is determined by

$$x(t) = \sum_{i=0}^{N-1} a_i p(t - it_b), \quad (1)$$

where a_i , defined by pseudorandom sequence, equals 1 or 0, and $p(t)$, the envelope of a subpulse, is described as

$$p(t) = \begin{cases} 1 & (0 \le t \le t_b) \\ 0 & otherwise \end{cases}. \quad (2)$$

Similarly, the envelope of a macropulse is described as

$$m(t) = \begin{cases} 1 & (0 \le t \le t_{macro}) \\ 0 & otherwise \end{cases}. \quad (3)$$

A sequence of macropulse, repeated every period of t_{rep}, results in the complete laser waveform $s(t)$ as

$$s(t) = \sum_{j=0}^{\infty} x(t) m(t - jt_{rep}). \quad (4)$$

At receiver, the return signal $y(t)$ is a convolution form of modulated laser pulse and the medium response impulse $h(\tau)$ (i.e., backscattering response) and back-ground noise $n(t)$ (i.e., Poisson noise). For a single macropulse, the corresponding return waveform is given as

$$y(t) = \int_0^{t_{rep}} x(t-\tau)\, h(\tau) d\tau + n(t). \quad (5)$$

Consequently, the return signal is demodulated by cross-correlation of $x(t)$ and $y(t)$ as

$$z(t) = R_{yx}(\tau) = \int_0^{t_{rep}} y(t) x(t-\tau)\, dt. \quad (6)$$

Theoretically, a periodic cross-correlation $z(t)$ of the continuous and periodic return signal $y(t)$ leads to a neglected sidelobe result. However, we cannot keep the transmitted signal continuously in reality. By operating simultaneously a pair of online and offline wavelengths, the sidelope can be canceled in water vapor density result.

III. RESULTS

The waveforms of single macropulse in case of single pulse modulation, 7-bit pulse modulation and 15bit-pulse modulation with a bit width of 100 ns are presented in

Fig. 2. The H_2O DIAL parameters applied for our experiment are given in Table I.

The HITRAN database of water vapor absorption line is used for computation. The aerosol profile is assumed as a U.S. standard model with 23km ground visibility. Afterwards, the average gas concentration is basically computed from the ratio of return online and offline signals as well as the differential absorption cross section of online and offline wavelengths. [2]

The results of water vapor density profile for each study case are compared to the real water vapor density profile in summer in Japan as plotted in Fig. 3. In the lower region (Range < 0.75 km) as shown in the lower figure, the water vapor density from single pulse modulation (dotted line) resembles the real data (solid line) closely while the ones from 7bit-pulse modulation (dashed line), and 15bit-pulse modulation (dash-dot line) present large error. However, in the higher region (2.4 km > Range > 0.75 km) as shown in the upper figure, the water vapor density from 7bit-pulse modulation agrees well with the real data, whereas the one of single pulse modulation is out of the trend of the real data.

In detail, the relative error of each modulation case is plotted in Fig. 4. It is evident that the relative error of single pulse modulation (solid line) is lowest in the low region while the relative error of 7bit-pulse modulation (marked solid line) is lowest in high region. The maximum reached altitude with the relative error of less than 10% in case of single pulse modulation, 7-bit pulse modulation, and 15bit-pulse modulation are 1.4 km, 2 km, and 2.2 km, in respectively.

From the above results, we conclude that the single pulse modulation is appropriate for lower region while 7bit-pulse modulation is appropriate for higher region.

Table I. The H_2O DIAL parameters

Online wavelength	829.054 nm
Offline wavelength	829.124 nm
Pulse energy	1 µJ
Pulse width	100 ns
Repetition rate	10 kHz
Accumulation time	10 min
Sky spectral radiance	12.1 mW/m^2/nm/sr
Total optical efficiency of the receiver (day-time)	29%
Quantum efficiency	45%
Telescope diameter	35 cm
Field of view	224 µrad

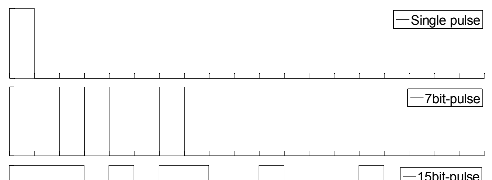

Fig. 2. Single macropulse in case of single pulse modulation, 7-bit pulse modulation and 15bit-pulse modulation.

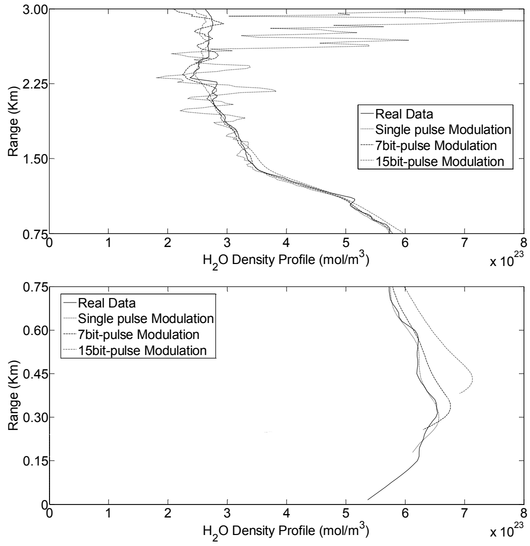

Fig. 3. H_2O density in summer in Japan (solid line) and calculated H_2O density from single pulse modulation (dotted line), 7bit-pulse modulation (dashed line), and 15bit-pulse modulation (dash-dot line) for lower and higher region.

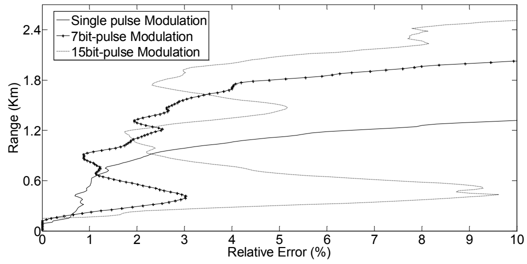

Fig. 4. Relative error of single pulse modulation (solid line), 7bit-pulse modulation (marked solid line), and 15bit-pulse modulation (dotted line).

IV. CONCLUSIONS

In this paper, we compare several modulated pulse techniques. A single pulse modulation shows lower error in low range and 7bit pulse modulation shows lower error in high range. By combining the advantage of both pulse modulation techniques, we are able to measure the water vapor density profile from low to high region.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial sponsor from the Tokyo Metropolitan Government in AHRF scholarship for Mr. Phong Pham Le Hoai.

REFERENCES

[1] B. Cochenour *et al.*, "Modulated pulse laser with pseudorandom coding capabilities for underwater ranging, detection, and imaging," Appl. Opt., Vol. 50, No. 33, 6168-6178 (2011).

[2] S. Ismail and E. V. Browell, "Airborne and space borne lidar measurements of water vapor profiles: a sensitivity analysis," Appl. Opt., Vol. 28, No. 17, 3603-3615 (1989).