Sodium Lidar laser/telescope alignment technique applied to satellite-Earth optical communications

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***Abstract*—The angle between emitted laser and a telescope line of sight is discussed for the case of a sodium lidar. The alignment method has been quite empirical so far but we have developed a quantitative and simple alignment technique that uses backscattered laser light from atmosphere below 20 km altitude. In the case of the Na lidar, by using the technique, the angle between the laser and the telescope line of sight is assured to be less than 0.25 mrad. Applying this technique to beacon laser alignment of laser satellite communication systems, the angle of the laser and the telescope line of sight can be expected less than 0.1 mrad (satellite orbit; 600 km, telescope/laser distance on the ground; 1 m).**

Keywords—sodium lidar; optical alingment; laser; satellite; laser communication

I. INTRODUCTION

Laser satellite communication systems get a lot of attention as a next-generation data communication technology. There are a lot of advantages such as large quantities of data transmission over long distances through space, or little power consumption, etc. However, there are still a lot of challenges to be overcome in the communication. One of the basic and important issues is the alignment between emitting beacon laser from a ground station and line of sight (LOS) of a telescope that receives the beacon laser from a satellite. One of the methods for the alignment is to use a corner cube reflector (CCR) placed at some horizontal distance (a few kilometer) from the ground station. However, if the CCR is placed near the ground station, the laser and the telescope LOS cross each other at large angles and it causes a large difference at a satellite orbit. Then it is of great importance to establish the assured alignment techniques. In contrast, a sodium lidar observation has a long history and the laser and the telescope LOS alignment is commonly done. However, the alignment method has been personal, empirical and non-quantitative.

This paper introduces a sodium lidar system with its simple and quantitative alignment technique between the laser and the telescope LOS. Although the alignment was developed for the sodium lidar, since this alignment technique does not need backscatter signal from the sodium layer, the technique can be applied to laser satellite communication systems as well as any other lidar observation. The advantage of this technique is that it is not necessary to place any physical target like a CCR but to use atmospheric backscattered photons. Then the angle between the laser and telescope LOC can be quantitatively estimated.

II. SODIUM LIDAR AND LASER/TELESCOPE ALIGNMENT

A. Sodium lidar

A sodium lidar is an active remote sensing system to measure sodium density, background temperature and wind in the altitude range between 80 and 120 km. The lidar consists of a pulse laser at 589 nm and a receiver telescope with an optical detector. Table 1 shows lidar parameters of our sodium lidar deployed in Tromso (Norway) [1-3]. To detect the backscattered light with the telescope, the laser point in the sodium layer should be in the telescope field of view. This is the same configuration between the beacon laser, the satellite and the receiving telescope in the laser satellite communication systems. The typical laser alignment of the sodium lidar is to monitor the backscattered photons from the sodium layer. The photoncounting signal is monitored typically with an oscilloscope (Figure 1). However, due to largely varying sodium density by atmospheric waves or seasonal variations often decreases the signal down to noise level. Consequently, it is not always easy to find out whether or not the laser point is placed in the telescope field of view. So we developed more practical and quantitative technique for the laser alignment.

TABLE I. System parameters of the sodium lidar in Tromso.

Transmitter		**Receiver**	
Laser Power	4.0 W	Telescope	Cassegrain
wavelength	589 nm	Diameter	35 cm
Laser beam divergence	0.3-0.5 mrad	Field of view	1-3 mrad
Laser bandwidth	40-50 MHz	Detector	Hamamatsu H7421-40
		Detection mode	Photon counting

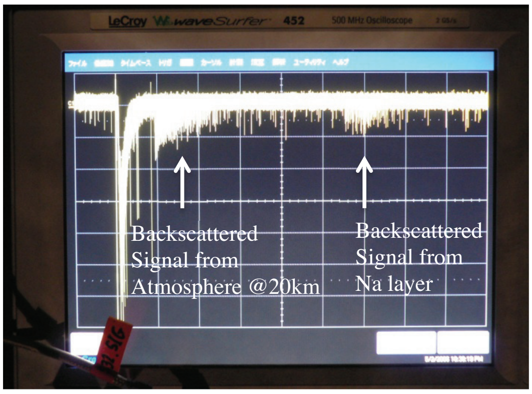

Fig. 1. Backscattered signal intensity displayed on an oscilloscope. The measurement is triggered by the laser emission.

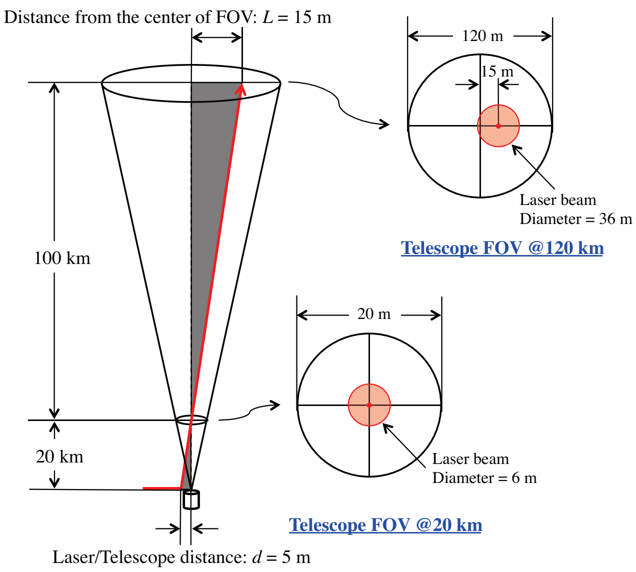

Fig. 2. Schematic drawings of the alignment method. The laser divergence and the telescope FOV are 0.3 mrad and 1 mrad, respectively.

B. Laser/telescope alignment

In contrast to the time-dependent weak sodium layer signal, the signal from lower atmosphere (Rayleigh scattering signal) is always strong and can easily be detected. In our new alignment technique, we only monitor Rayleigh signal, e.g., at 20 km without monitoring the sodium layer. Note that this means the alignment technique can be applied not only sodium lidar observations but laser satellite communication systems as well as other type of lidar systems. Tuning an X-axis of the emitting mirror changes the laser tilt, then the signal intensity at 20 km changes between noise level (the laser is off the telescope FOV at 20 km) and a certain signal level (in the FOV). Back-and-forth tuning enables us to find the middle of the FOV on the X-axis direction. Repeating X- and Y-axis tuning, the laser can be placed in the center of the FOV at 20 km (Figure 2). At 120 km height, the distance between the center of the laser and the FOV center can be calculated from the hatched homothetic triangles in the Figure 2. Using the parameters from Table 1, the laser is only 15 m off from the center of the FOV, which is completely within the FOV at 120 km. In this case, the laser and the telescope angle is attained with 0.25 mrad. Note that compared with this case, if the laser/telescope distance is smaller than 5 m or the alignment altitude is higher than 20 km, the angle of the laser and telescope becomes better.

III. APPLICATION TO LASER SATELLITE COMMUNICATION

A. Laser/telescope alignment

National Institute of Information and Communications Technology (NICT), Japan, has a pair of telescopes for the laser satellite communication systems; one is a 1.5-m diameter of receiver telescope and the other is a 20-cm diameter of for the beacon laser on the receiver telescope. The distance between the telescopes is 1 m. Assuming the satellite orbit is 600 km, the angle of the laser and the telescope LOS were calculated for some alignment altitudes (Table II). Since the distance between the transmitter/receiver telescopes is only 1 m, the crossing angle is relatively small compared with the sodium lidar, then even the 10 km altitude is used for the alignment, the crossing angle is only 99 μrad which is good enough.

TABLE II Calculated results of the distance between the laser and the center of FOV at the orbit altitude of 600 km. Note that the FOV diameter at that altitude is 600 m for 1 mrad FOV.

Alignment altitude [km]	5	10	20	30	40
Angle [μrad]	200	99	50	33	25
L[1] [m] @600km	111	59	29	19	16

[1] *L denotes the distance between the laser and the telescope LOS*

IV. CONCLUSIONS AND FUTURE FORSIGHT

The practical and quantitative laser and the telescope LOS alignment technique is described. For the case of the laser satellite communication systems, the angle accuracy is expected less than 99 μrad. However, this technique is limited to the pulse laser system. Further discussion will be needed.

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