Development of wind sensing coherent Doppler lidar at Mitsubishi Electric Corporation ~from late 1990s to 2013~

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INTRODUCTION

Since late 1990s, we have been developing the wind sensing coherent Doppler LIDARs. In the history of wind lidar, we have offered the following world-first topics, (1) wind sensing using eye-safe (1.5 micron) wavelength region, (2) instrumentation of compact fiber-based lidar, (3) product release of the fiber-based pulsed lidar, (4) middle-range (8 km) wind sensing with the high power fiber amplifier, (5) long-range (10 km) and real-time wind sensing using eye-safe wavelength, and (6) ultra-long-range (>30 km) wind sensing. Here, we introduce about these topics and shortly describe about our future perspectives.

WIND SENSING DEMONSTRATION USING EYE-SAFE WAVELENGTH

In late 1990s, we started to develop the eye-safe wind sensing coherent Doppler lidar with Er; glass microchip laser, and presented about the result of this first development in 1998[1]. This was the world-first wind sensing demonstration using this wavelength region. After that, we modified the laser transmitter using Er, Yb:phosophate glass laser[2], and improved the system performance[3]. The transmitter had the pulse energy of 11 mJ with the pulse repetition frequency (PRF) of 15 Hz, and the lidar system demonstrated the measurable range of 5 km. We also showed the wind field measurement with 3 axial mechanical scanner.

INSTRUMENTATION OF FIBER-BASED LIDAR

Fiber-based LIDAR has many advantages in the compactness and reliability owing to the utilization of COTS components used in optical fiber communication. Therefore, some research groups including us have started to develop this lidar almost instantaneously. In those days, polarization-maintained (PM) fiber components were very expensive and single-mode (SM) fiber components were used. This caused an issue in keeping the heterodyne-detection efficiency high because of the fluctuation of state of polarization occurring in SM fibers. To overcome this issue, we developed the function of automatic polarization control, and stabilize the detection efficiency high. Owing to this function, continuous long period measurement could be enabled, and we completed world-first instrumentation of this lidar in 2002. We started to present about this proto-type lidar in 2003[4], and published in the reviewed paper in 2007[5]. The first airborne experiment using this proto-type lidar was performed just after the instrumentation in 2002.

PRODUCT RELEASE OF FIBER-BASED PULSED LIDAR

After the above mentioned succession of instrumentation, we started to develop the product model, and released as a commercially available product on January in 2006. To our knowledge, this was the world-first product release of fiber-based pulsed lidar for wind sensing. The technologies used in this product are based on those developed in the proto-type model, but we performed some additional development for some points[6]. First, we modified the pulse modulator using double-pass method. Second, we newly developed FPGA (Field Programmable Gated Array) based real-time signal processor. Additionally, we used PM fiber components for this product. This lidar has been tested by several users for wind shear detection around the airport[7], wind resource assessment for wind energy, and urban meteorological measurement.

MIDDLE-RANGE (8 KM) WIND SENSING WITH THE HIGH POWER FIBER AMPLIFIER

Although there are many applications which our product model can be used, there are substantial needs for longer range measurement. For the longer range measurement using this fiber-based lidar, the stimulated Brillouin scattering (SBS) was the restricting factor in improving the transmitting peak power, which was 10 W for the above mentioned product. To overcome this issue of generation of SBS, we have invented the configuration which has a post optical amplifier near the telescope to transmit an output laser light to the atmosphere just after amplification. By using a rare-earth ion highly-doped fiber with a short length, we have demonstrated a peak power of 90 W. Since the above mentioned amplification fiber is the normal SM type, we can use the commercially available fiber-based optical circulator. This realized the easy production and extremely good system efficiency. Using this lidar, we improved significantly the measurable range to more than 8 km in the ground-based evaluation[8]. Airborne evaluation using this lidar was also performed, and the detection of the turbulence at the altitude of a few kilometers was demonstrated[9].

LONG-RANGE (10 KM) WIND SENSING USING EYE-SAFE WAVELENGTH

Until the beginning of 2000s, long-range (10 km) lidar had used the wavelength of 2 micron because of the maturity of solid state laser technology of this wavelength region. In 2003, we have developed the optical parametric amplifier for eye-safe wavelength, and demonstrated long-range wind sensing[10]. This lidar was used for measurement of several meteorological phenomena below the boundary layer[11].

ULTRA-LONG-RANGE (>30 KM) WIND SENSING

Recently, we have developed higher power laser amplifier using Er, Yb:glass planer waveguide[12]. This amplifier has the output power of 3.3 kW with the pulse width of 580 ns (i.e. pulse energy of 1.9 mJ) and the repetition rate of 4 kHz in addition to the good beam quality of M^2: 1.3. In 2011, we developed the lidar system using this amplifier and demonstrated the ultra-long-range wind sensing[13]. The measurable range is more than 30 km with the range resolution of 300m and the accumulation number of 16,000. To our knowledge, the laser transmitter has the highest figure of merit (pulse energy times square-root of PRF). Additionally, the demonstrated measurable range of more than 30 km is longest in the history of wind sensing lidar. The current target application of this development is the airborne clear air turbulence sensor. JAXA (Japan Aerospace Exploration Agency) will present about the airborne experiment using this lidar in the near future.

NEW LIDAR CONCEPT

We invented the new lidar concept of the automatic parameter control adaptive to atmospheric condition, and completed to file the several patents for this concept. This technology can be applied to all types of wind sensing lidar. In this conference, we start to present about this concept[14].

SUMMARY

We introduced the history of wind lidar in Mitsubishi Electric Corporation. We offered above mentioned world-first topics, and now we have technology for (1) compact and short-range (up to 2 km) lidar, (2) middle-range (8 km) lidar, and (3) ultra-long-range (>30 km) lidar. We also shortly introduced our new lidar. We will apply our lidar technology to the field of wind energy, meteorological sensing, and aviation safety.

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