3-IV A1 STUDY OF LIGHT BEAM PROPAGATION IN THE ATMOSPHERE BY LASER-RADAR TECHNIQUES USING RAMAN SCATTERING AND ABSORPTION SPECTROSCOPY

Takao Kobayasi, Masanori Jyumonji and Humio Inaba

Research Institute of Electrical Communication,Tohoku University
Katahira 2-Chome, Sendai, Japan

Introduction

Great interest has been concentrated in high power lasers as sources for both optical radar and communication experiments in the atmosphere. There are a number of propagation problems to be throughly studied, including molecular and aerosol scattering,molecular absorption, and turbulence. The purpose of this paper is to discuss the performances of the two specific schemes for studying light beam propagation,(1)laser-Raman radar, and(2) resonance absorption method, designed as single ended optical transmissometers.

Lase radar techniques have so far been based on detecting elastically backscattered light which is a combination of Rayleigh scattering by air molecules and Mie scattering by particulate matter such as aerosols and water droplets. Some of the photons in the laser beam are inelastically backscattered at shifted frequencies due to Raman scattering by atmospheric molecules. Because the Raman scattered light from individual constituents is shifted by proper frequency intervals , a means is thereby provided for isolating the scattered light of each of various atmospheric species, and for understanding the nature of almost all molecular constituents.

The laser-Raman radar scheme has been proposed[1] and confirmed experimentally[2-7] to measure simultaneously the composition and the number density of the atmospheric molecules. The resonance absorption scheme has also been discussed priviously[8] to detect small concentration of atmospheric pollutants.

We consider here some potentialities of these two optical schemes in the application to the specific problem of measuring transmission and absorption properties of the laser beam in the atmosphere.

Laser Radar Systems

The laser radar system used in the experiments basically consists of a laser transmitter and a optical receiver. In the laser-Raman radar, a Q-switched ruby laser at 6943 Å was mainly employed along with a pulsed nitrogen laser at 3371 Å with 50 pps repetition operation. Atmospheric backscatter was collected by a 30-cm diam, 150-cm focal length reflecting telescope. A grating monochrometer, as a spectral analyzer, was set to select the Raman-shifted components. The output of the monochrometer was detected by a photomultiplier, and then desplayed on a 30-MHz oscilloscope. For the resonance absorption scheme, the above mentioned transmitter was replaced by a frequency-tunable dye laser, pumped by a nitrogen laser pulse.

Raman Backscattering Scheme

The Raman backscattered power from atmospheric molecules at a range R is given by the laser-Raman radar equation:

$$P_r = W_0 \; S \; T(\omega_0) T(\omega_R) \; N(R) \; \sigma_R \; / \; R^2 \qquad 1)$$

where W_o is laser output energy, S is system sensitivity, $T(\omega_0)$ and $T(\omega_R)$ are transmittance of the laser light at the frequency of ω_o and of the Raman echo at ω_R, N(R) is concentration of specific molecule, and σ_R is Raman backscattering cross-section of the molecule.

Fig. 1 shows typical example of the oscilloscope traces obtained in the

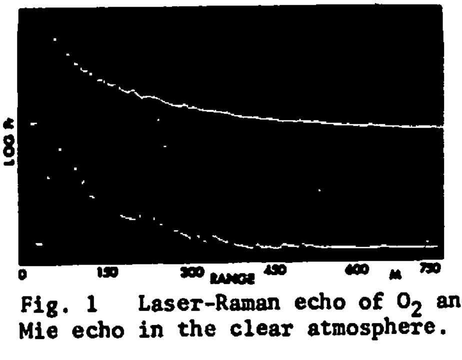

Fig. 1 Laser-Raman echo of O_2 and Mie echo in the clear atmosphere.

clear atmosphere. The upper trace corresponds to the Raman shifted component of oxygen molecule centered at 7793 Å, and the lower to the unshifted component centered at 6943 Å, observed simultaneously for comparison. The Raman component appeared almost consitent with the expected range dependence from 1), whereas the unshifted component was fluctuating from shot to shot due to the density and size variations of the aerosols in the optical pass. This result, together with the uniform distribution of the air molecule such as N_2 and O_2 lead to the effectiveness of applying the Raman scattering in the measurement of atmospheric transmission of the optical beam.

From the above equation, the product of transmittances at ω_o and ω_R to the range R is related to the received power by

$$T(\omega_o)T(\omega_R)=P_r(R)R^2/P_r(R_o)R_o^2 \qquad 2)$$

where R_o is the closest range where the laser beam overlaps the receiver field-of-view. Since the visual range V and visual extinction coefficient β are related through the relation $V\cdot\beta = 3.9$, both quantities can be evaluated by assuming $T(\omega_o)=T(\omega_R)=T(\omega)$ and using the relation $T(\omega)=\exp(-\int_o^R\beta(R)dR)$. This method of measuring optical transmission in a single station is useful, especially in the close range of the order of 1-km, depending on the system sensitivity.

Resonance Absorption Scheme

Recent development for generating tunable coherent beam by the dye laser and parametric oscillator has made it possible to avoid strong absorption bands by tuning the laser frequency. One can also study the molecular absorption spectra by sweeping the laser output frequency. As one of preliminary experiments, the solar spectrum through the earth's atmosphere was measured by the receiver with high resolution as shown in Fig. 2. The major absorption lines are identified due to water vapor. Sodium lines are solar origin.

For studying the transmission characteristics of the laser beam generated by the tunable dye laser, the backscatter from the particulate matters in the air or solid targets was received and analyzed spectroscopically. Based on this scheme, we could derive molecular absorption as a function of range, as well as its average number density over the optical pass. Experimental result and analysis will be presented in detail along with the discussion.

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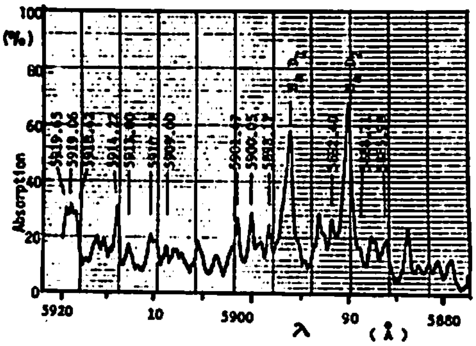

Fig. 2 Absorption spectrum of water vapor in the atmosphere.