ASEN 6519. Lidar Remote Sensing

HW Project #1 – Range-Resolved Lidar Simulation of Resonance Fluorescence Lidar

This project is to simulate the range-resolved Na Doppler lidar signals by integrating the knowledge we gained through the lidar class. The knowledge includes our understanding of
(1) Different scattering processes and the computation of their effective cross section;
(2) The lidar equation and the lidar remote sensing procedure;
(3) The roles of atmospheric number density and atomic specie density in the lidar equation;
(4) The signal-to-noise ratio (SNR) related to the uncertainty caused by photon noise.

This project contains the following tasks (related parameters are listed at the end of the assignment) –

(1) Write a computer code to compute the absorption and effective cross sections of the Na D2 line for the following conditions:
(a) for V_R = 0 m/s, T = 150, 200, 250 K; (b) for T = 200 K, V_R = -50, 0, 50 m/s.

Plot the cross sections versus frequency offset, and give the numbers for the maximum absorption and effective cross sections in the plot. This will help you to see the temperature dependence of Doppler broadening and wind dependence of Doppler shift.

<u>Conditions</u>: Table 5.1 in the textbook provides the fundamental parameters for Na spectroscopy. The frequency offset (relative to the center of the line) range is from -2500 to 2500 MHz. Assume laser line shape is a Gaussian with rms width of 60 MHz.

<u>Rationale for this assignment</u>: Only when we clearly understand and are able to calculate the interaction between photons and atoms interested, we can correctly simulate the lidar returns or invert the lidar photon counts into meaningful physical parameters that we are trying to measure. Such radiation-matter interaction is used in both lidar simulation and data processing procedures. Thus, this assignment is the step to compute the light-atom interaction used in the resonance fluorescence lidars. Understand the Na spectroscopy, especially the absorption cross section [Eq. (5.41)] and the effective cross section [Eq. (5.43)] in the textbook will help you in this homework.

<u>Suggestion</u>: Since you will repeatedly use the absorption or effective cross section in lidar simulation and data retrieval, you may consider making this part of computation as functions so that you can call these functions with different input parameters (like T, V_R, and frequency).

(2) Simulate the range-resolved photon count return from 30-150 km by a Na Doppler lidar, considering Rayleigh scattering signal from all altitudes, Na resonance fluorescence signal from 75-115 km, and background photon counts for all altitudes. Plot the range-resolved photon count profiles. (Put altitude to x-axis)

The Na Doppler lidar uses 3-frequency technique (see our textbook and lecture notes for the details). Please simulate the entire 30-150 km profiles for the peak frequency and simulate the Na signals from 75-115 km for all three frequencies.

The atmospheric number density and temperature profiles are taken from a MSIS00 model profile (posted at the class website). The Na layer can be simulated using a Gaussian distribution with the peak at 91.5 km, rms width of 4.6 km, and column abundance of 4×10^9 cm^{-2}. The temperature profile in the Na layer is taken from the same MSIS00 model profile. The vertical wind in Na layer is assumed to be V_R = 0 m/s.

Let us use the background count of 0.3 count/shot/km for nighttime and 90 counts/shot/km for daytime. Of course, we know that the daytime background counts depend on the time of the day, seasonal change of the solar radiation, and the local weather conditions, so it won't be a constant but a changing value in reality.

(3) Add the photon noise with Poisson distribution to the range-resolved lidar profile (30-150 km) for the peak frequency to simulate the actual lidar returns with photon noise. Try this for 300 and 3000 shots of integration, respectively, and also try for both nighttime and daytime background cases. Plot the photon count profiles. (Put altitude to x-axis)

Rationale for this assignment: You will gain direct experience of how background noise affects the SNR, and how integration can help improve SNR.

(4) Derive the signal-to-noise ratio (SNR) equation when considering the Rayleigh, Na, and background photon counts, and then calculate SNR for the range-resolved photon count profile from 30-150 km. Plot the SNR profile in absolute number and dB, respectively. (Put altitude to x-axis)

Rationale for this assignment: Computing SNR is the first step of error analysis for both lidar simulation and real lidar data retrieval. In later project, you will be required to do error and error propagation analyses, based on the SNR.

Related atomic parameters: see the textbook

Related Na Doppler lidar parameters are

Laser pulse energy: 20 mJ
Laser repetition rate: 50 Hz
Laser wavelength: 589.1582 nm (in vacuum)
Transmitter mirror reflectivity: 99% for each mirror and total of 3 mirrors
Telescope primary mirror diameter: 75 cm
Telescope primary mirror reflectivity: 90%
Telescope secondary mirror reflectivity: 90%
Fiber throughput: 75%
Transmission of receiver optics: 90%
Interference filter peak transmission: 85%
PMT quantum efficiency: 40%
Geometric factor for above 20 km: 1
Lidar station base altitude: 1.6 km
Added daytime spectral filter transmission: 40%

Related atmosphere parameters are

Lower atmosphere transmission at 589 nm: 70%
Atmospheric transmission from 30 to 75 km: 100%
Atmospheric number density: taken from MSIS00 number density
Atmospheric temperature: taken from MSIS00 number density
Mean sodium column abundance is 4×10^9 cm^{-2}
Na layer: Gaussian, peak at 91.5 km, rms width of 4.6 km

You are required to show your MatLab code with your computation results (numbers and figures).

HW project #1 is due on Monday, October 15, 2012 in class.