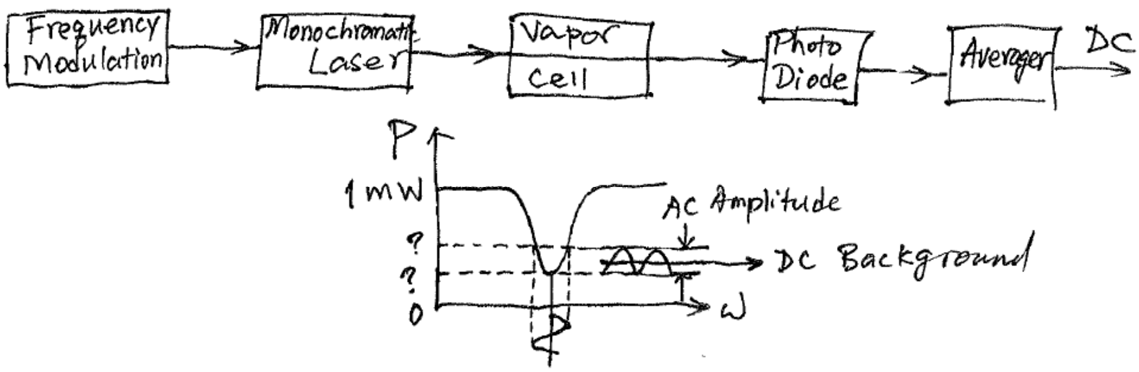
Fundamentals of Spectroscopy for Optical Remote Sensing
Homework #9 (Doppler-Limited Laser Spectroscopy)

1. A monochromatic laser beam with power P = 1 mW is sent through a 1-m long sample cell filled with absorbing molecules. The absorbing transition has the Doppler width $\Delta\omega_D = 2\pi \times 10^9$ Hz and a peak absorption coefficient $\alpha(\omega_0) = 10^{-3}$ cm^{-1}, where ω_0 is the resonance frequency of the molecule. The laser frequency is modulated while it is tuned to the molecular resonance frequency ω_0, i.e., $\omega_L = \omega_0 + \Delta\omega \cos 2\pi ft$, where $\Delta\omega = 2\pi \times 10$ MHz.
(1) Calculate the maximum AC amplitude of the detector output signal for a detector with a sensitivity of 1 V/mW.
(2) How large is the DC background signal if the detector output is averaged over time?



2. A monochromatic laser beam is sent through a sample of diatomic molecules. The laser wavelength is tuned to a vibration-rotation transition $(v'', J'') \rightarrow (v', J')$ with an absorption cross section of $\sigma_{ik} = 10^{-18} cm^2$, where $v_i'' = 0, J_i'' = 20$ and $v' = 1, J' = 20$.
(1) Estimate the fraction n_i/n of molecules in the level ($v_i'' = 0, J_i'' = 20$) at T = 300 K (vibrational constant $\tilde{\nu}_e$ = 200 cm^{-1}, rotational constant B_e = 1.5 cm^{-1}).
(2) Calculate the absorption coefficient for a total gas pressure of 10 mbar.
(3) What is the transmitted laser power P_t behind an absorption path length of 1 m for an incident power P_0 = 100 mW?

3. (1) Summarize how to detect atoms or molecules using spectroscopy methods.
(2) Summarize the approaches of how to improve detection sensitivity.
(3) Choose two of the following spectroscopy methods to describe their principles, experimental setup, required detectors, and applications: photoacoustic spectroscopy, optothermal spectroscopy, ionization spectroscopy, optogalvanic spectroscopy, cavity ring-down spectroscopy, and frequency-modulation spectroscopy.