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Autodyne lidar for environmental DIAL applications

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Abstract:
Autodyne lidar with CO2-laser is a good system for remote measurements of environmental gases 1 as a number of them have absorption bands in spectral region 9-11 ¹m. In this report we present an analytical approach for calculation of the parameters of a parametric autodyne lidar for environmental DIAL applications.
This approach allows one to express analytically the parameters of the atmosphere, such as the absorption coefficient and the distance to remote target, through experimentally measured values. A model of parametric autodyne lidar based on two level laser scheme has been considered. The aim is to derive analytical dependencies of lidar field on parameters of the atmosphere. Two nonlinear differential equations for laser field amplitude at resonator mirrors are derived. Using reflectivity of the remote mirror as a small parameter (it can reach 10¡ 9 in field experiments) a perturbation theory has been built, which allows one to reduce nonlinear lidar equations to a couple of linear differential equations with diving force. These equations have been solved both analytically, using proper approximations, and numerically. From the analytical solution two important expressions for the absorption coefficient and the distance to the target have been derived. Two types of lidar mirror modulation mostly used in experiments have been considered, harmonic-like oscillation and a saw-tooth-like oscillation. Comparison of the two mirror modulation schemes leads one to conclusion that the harmonic modulation has two apparent disadvantages. The first one is that in this case one has to deal with specific and short time intervals when the mirror passes its equilibrium point in order to filter out the maximal beating frequency, whereas the saw-tooth modulation results in a fixed beating frequency and then there is no need to deal with a wide signal spectrum. The second (probably minor) disadvantage is that the maximal beating frequency in case of harmonic-like modulation is higher than the constant beating frequency in case of saw-tooth-like modulation (provided both amplitude and frequency of mirror oscillations are identical in both cases). This difference however may become important when very large distances should be measured. For instance, assume the distance is about 300km and the mirror oscillation amplitude and frequency are 1¹m and 1KHz respectively. Then the maximal beating frequency in case of harmonic modulation is about 600MHz, while in case of saw-tooth modulation the beating frequency is about 350MHz.
The results of this approximate analytical calculation are in excellent agreement with those of exact numerical solution of the nonlinear lidar equations. The described model has been also extended in two directions: (i) to take account for the absorption decay with height, and (ii) to describe an airborne/spaceborne lidars.

References:
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