Optimum Conditions for Doppler-Broadened Nice-Ohms – How to Reach an Allan Deviation in the 10^{-14} cm^{-1} Range Using a Tunable Laser

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NICE-OHMS has demonstrated exceptional detection sensitivity (DS). In its first realization, based upon a well-stabilized fixed-frequency Nd:YAG laser, targeting C_2HD by its sub-Doppler (sD) mode of detection, it demonstrated a noise equivalent absorption per unit length (NEAL) of 10−14 cm^{-1} over 1 s. The realization of Doppler-broadened (Db) NICE-OHMS based on tunable lasers, which is the preferred mode when the technique is used for trace gas detection, has, up to now, not produced comparable DS. To remedy this, we have methodically scrutinized the technique and identified actions to reduce the amount of background signals and noise and assessed the conditions that maximize the signal and the signal-to-noise conditions. In particular, background signals from residual amplitude modulations (RAM) have been reduced by identification of the origin of RAM from fiber-based EOMs and the optimum use of such. Signals from etalons have been reduced by the introduction of etalon-immune distances (EID), which constitute separations between optical components for which an etalon will contribute equally to each mode of the light, which implies that they will not contribute to the NICE-OHMS signal. The optimum conditions for Db NICE-OHMS with respect to modulation index, frequency, and order, demodulation phase, cavity length, and scanning range have been assessed. By constructing a NICE-OHMS system around a tunable fiber-laser that adheres to most of these conditions, a white noise equivalent absorption coefficient (NEAC) of 2.6 x 10^{-13} cm^{-1} $Hz^{-1/2}$ and a minimum NEAC of 8.8 x 10^{-14} cm^{-1} at 30 s have been obtained. This is similar to that of the first NICE-OHMS demonstration using a fixed-frequency laser (since the NEAL value assessed by sD detection corresponds to a NEAC of 8 x 10^{-14} cm^{-1}). This demonstrates that Db NICE-OHMS based on tunable lasers can achieve similar NEAC as sD NICE-OHMS assessments based on well-stabilized fixed-frequency lasers.