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Optical setup for coating thermal noise measurements

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One of the fundamental limitations to the sensitivity of current gravitational wave (GW) detectors, especially in their mid-frequency range, is Brownian thermal noise. This noise source affects not only mirror coatings but also mirror substrates and suspensions, potentially limiting the sensitivity of third-generation GW detectors.

To overcome these limitations, the plan is to replace current fused-silica mirrors with silicon mirrors and cool them to 10K, which is a new material and operating temperature for GW detectors. This endeavour involves two pivotal aspects: the direct measurement of mirror thermal noise at cryogenic temperatures and the characterization of coating materials and techniques for the next-generation detectors.

This document presents an optical setup designed for measuring coating thermal noise (CTN), which manifests as fluctuations of length of an optical cavity due to the remaining motion present in the material of the coating of the mirrors. To measure these fluctuations, we apply the fluctuation-dissipation theorem to our setup.

This optical setup consists of a 1550 nm laser beam split into three beams, with two shifted in frequency using Amplitude Optical Modulators (AOMs). Control loops stabilize the laser frequency, stabilize the frequency-shifted beams, and lock the co-resonating modes within the cavity. The optical setup places a sample mirror within a high-Finesse optical cavity that allows the co-resonance of three modes: the fundamental laser mode (TEM00) and two higher-order modes (TEM02 and TEM20). CTN manifests as fluctuations in the resonant frequencies of the latter two higher-order modes.

The key distinction is that the CTN sensed by TEM02 differs from that sensed by TEM20 because they explore different areas of the mirror coating. In our experiment, CTN is determined by analysing the beat note signal between the resonant frequencies of TEM02 and TEM20. We've focused on the preparation and simulations to refine our setup. These simulations are important to ensure the experiment's success and help us to tackle potential problems.

Initially, this cavity will operate at room temperature and in-vacuum. Once we can demonstrate its functionality, our plan is to transition it to in-vacuum conditions at cryogenic temperatures.

The final goals of this experiment are to determine if direct measurement of coating thermal noise is feasible for third-generation GW detectors, identify optimal coating materials and techniques for maximizing detector sensitivity.

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