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Mode matching sensing through RF Higher Order Modulation

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Quantum noise is a fundamental limit in Gravitational Waves (GW) detectors and is made up of shot noise (SN) at high frequencies (above about 100Hz) and radiation pressure noise (RPN) at lower frequencies. To reduce this noise, GW interferometers use a technique called squeezing with which we can improve only one of the contributions, while worsening the other: so far, the choice has been to improve SN, which is limiting the performance at high frequencies.
In the upgrade Advanced Virgo+, we need to reduce RPN as well, therefore the squeezing method needs a frequency dependency. To do this a 300m long cavity, called Filter Cavity (FC), will be used. However, one of the main optical loss term is due to the possible mismatch between the fundamental mode of the laser and the one supported by the cavity. This can be described in terms of higher-order mode (HOM) content of the former in the base defined by the latter. When a cavity is locked on the fundamental mode, these HOMs are reflected and carry important information on the origin of the mismatch. In particular, we are interested in mismatch due to differences in dimension and positions of the waist, which give rise to the Laguerre-Gaussian mode LG10.
We are developing an innovative method to sense this mismatch based on RF Higher Order Mode Modulation. This technique aims at sensing the beat signal between the carrier LG10 mode reflected by the cavity and the LG10 sideband generated by a lensing modulator called electro-optical lens (EOL). The EOL works on a frequency such that one of the two generated sidebands is resonant inside the cavity. In this way the reflected LG10 carrier and sideband can generate a beat signal on a photodiode. I/Q demodulation at the sideband frequency allows for extracting the real and imaginary part of the LG10 mode, which are the waist size and waist position mismatch, respectively.

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