Radio-Frequency Jitter Alignment Sensing (RFJAS) Scheme University of Florida

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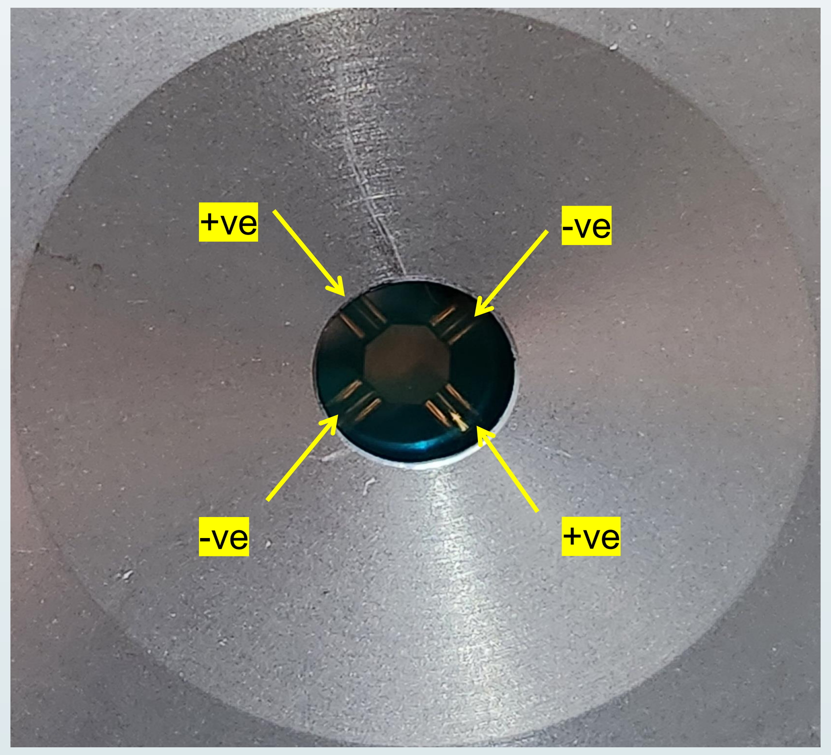
Abstract

Well-separated alignment signals of tilt and translation degrees of freedom are desired between a laser and an optical cavity. The Electro-Optic Beam Deflector (EOBD) is a good device to achieve a diagonal sensing matrix by creating jitter sidebands of the first higher order Gaussian mode, HG_{10}, around the carrier beam. RF jitter alignment sensing (RFJAS) scheme works when modulating the beam at the exact higher order mode separation frequency of the cavity, $f_{mod} = \delta f_{HOM}$.
It has some advantages over the current schemes. We can extract full alignment signals from one single element photodetector on reflection of the cavity, unlike wavefront sensing (WFS), the currently favored scheme, which requires two quadrant photodetectors and Gouy phase telescopes.
It is also possible to recover full alignment signals of two cavities in-line from one photodetector on reflection of each cavity using one EOBD driven at the δf_{HOM} of the first cavity.



EOBD: We see the octagonal Lithium Tantalate ($LiTaO_3$) crystal that is used to deflect the beam. Voltage is applied to the 4 electrodes, creating time-dependent $\vec{E}$ inside the crystal that changes the refractive index.

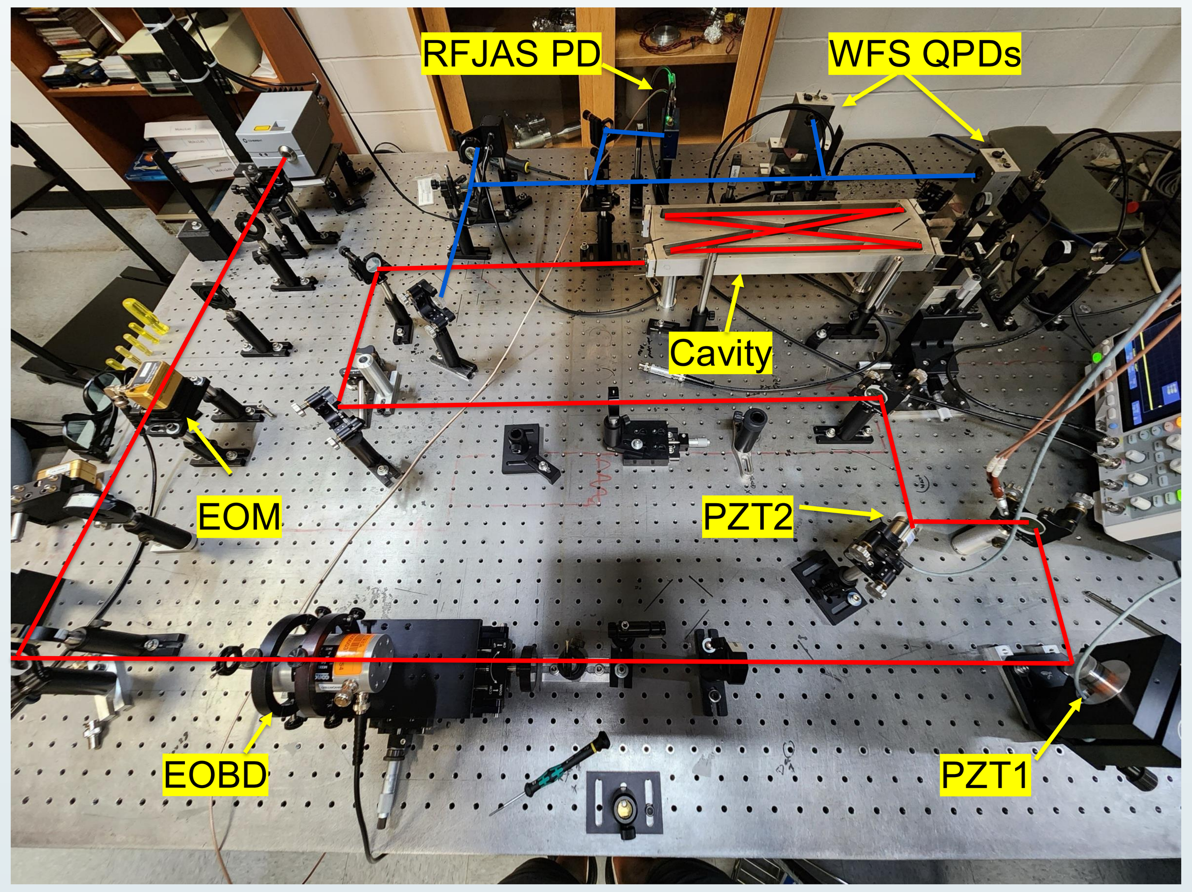
$$n_x(\vec{E}) = n_x + n_x^3 \vec{r}.\vec{E}$$

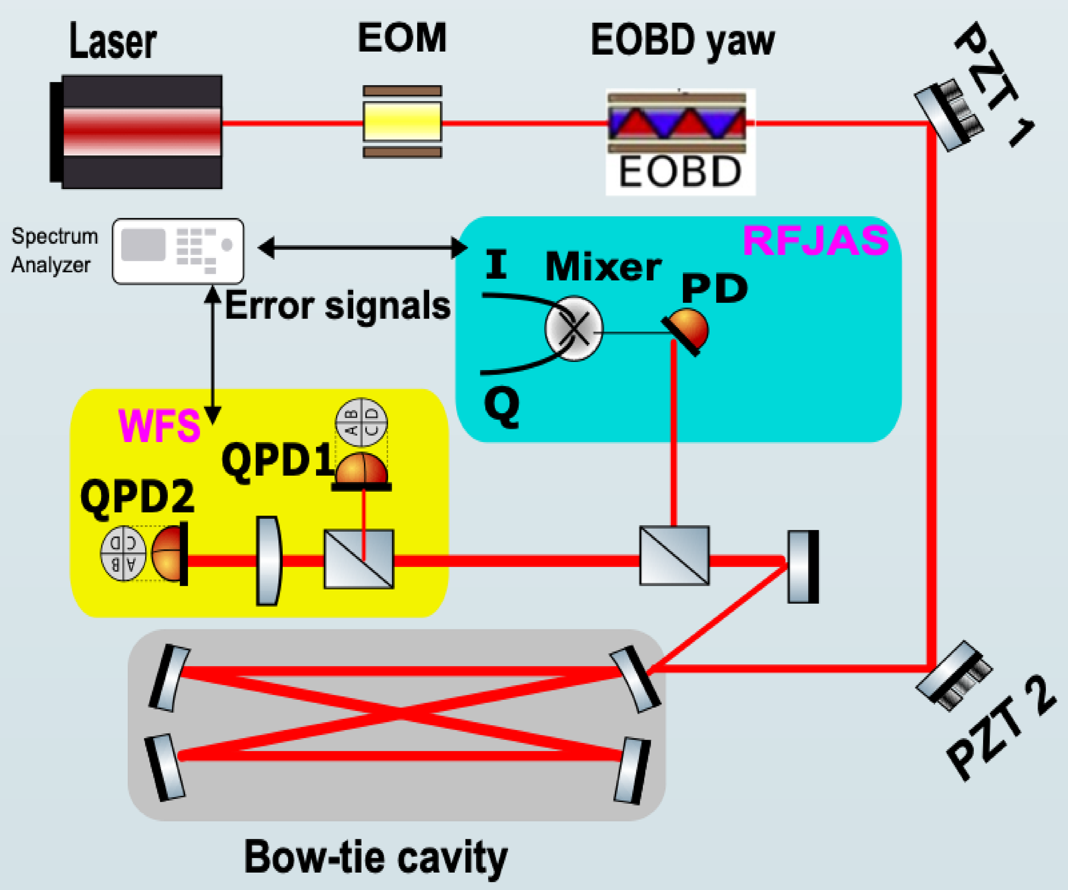
Introduction

Current gravitational waves (GW) detectors require to actively control the suspended optical cavities. Several optical alignment schemes are used at Advanced LIGO (aLIGO), chief among them being WaveFront Sensing (WFS). WFS relies on the beat signal between the fundamental Gaussian mode, HG_{00}, and HG_{10}. To generate alignment signals from this beat, 2 RF QPDs and Gouy phase telescopes are required.
We are suggesting a new alignment scheme that depends on generating side bands of the first higher order mode $HG_{10}(\omega \pm \Omega)$, where Ω is higher order mode separation frequency of the cavity. The beat signal between HG_{10} sidebands and HG_{10} due to misalignment can be detected using one single element photodiode on reflection to recover full tilt & translation alignment signals.

Methodology

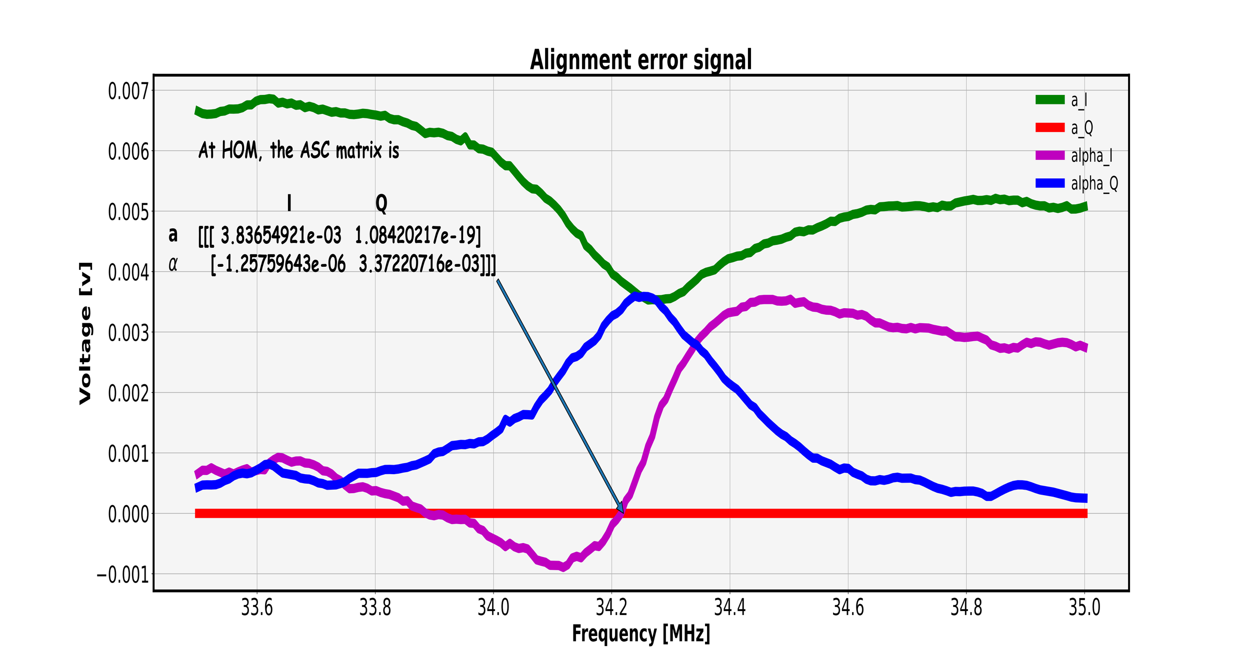
We drive the EOBD to generate HG_{10} sidebands using a Zurich Instrument (ZI) Lock-In Amplifier. A function generator is used to drive 2 PZTs in tilt (α) and translation (a) degrees of freedom (DOFs). The light goes to the optical bow-tie cavity and reflects off it. One photodiode on reflection for the PDH signal, and another is RFJAS PD that is used to generate alignment signals. After that, the light goes through Gouy phase telescopes for WFS signals. We generate signals from both schemes and compare them quantitatively on multiple areas, like noise, mode matching dependence, beam spot mis-centering and others.



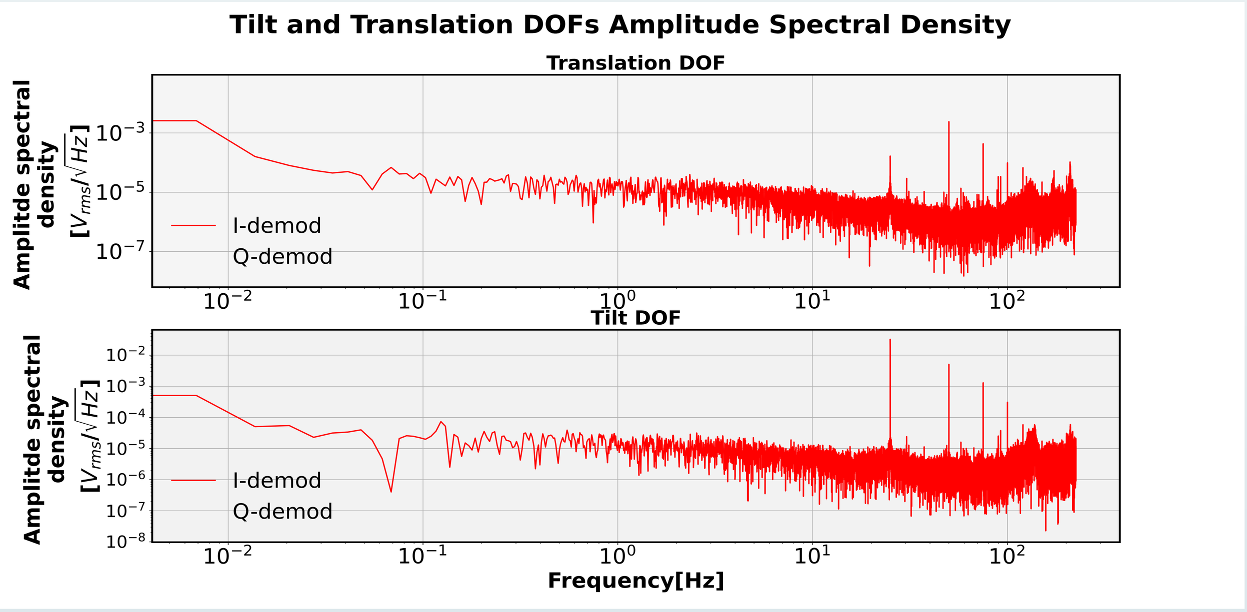


The current setup: We have a laser, then EOM for the PDH locking and WFS, EOBD for the alignment, PZTs to drive DOFs, and then the cavity. On reflection we have two PDs. One for PDH signal and the other is the single element PD to generate RFJAS signals. Gouy phase telescopes are after that for WFS signals.

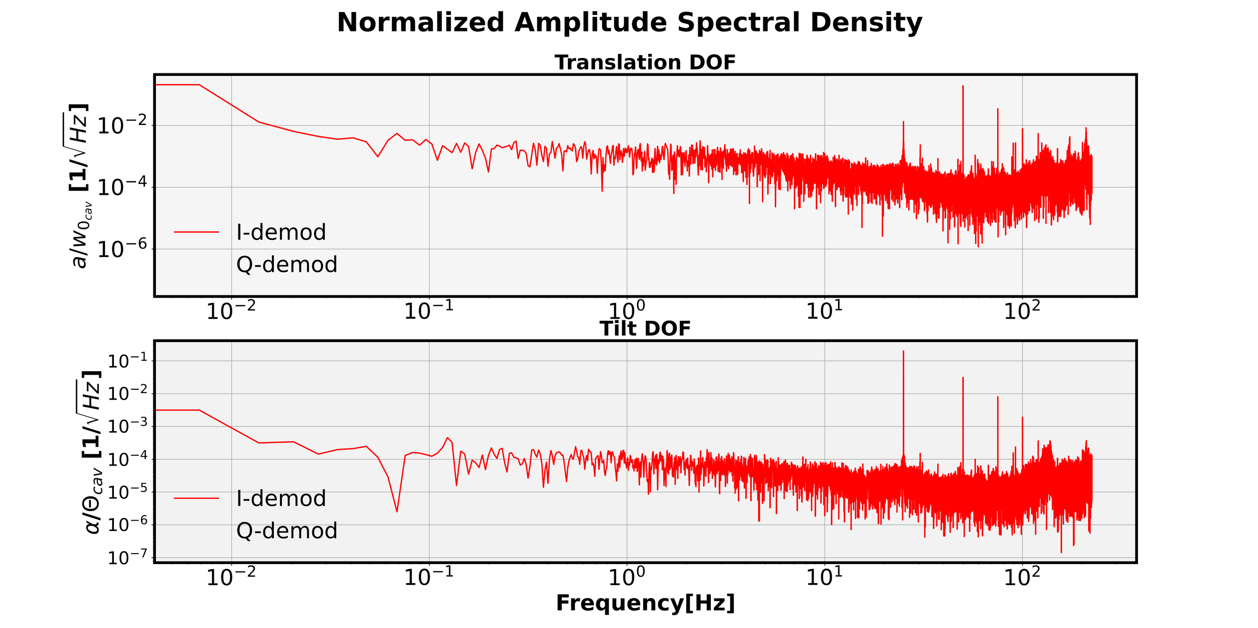
Results



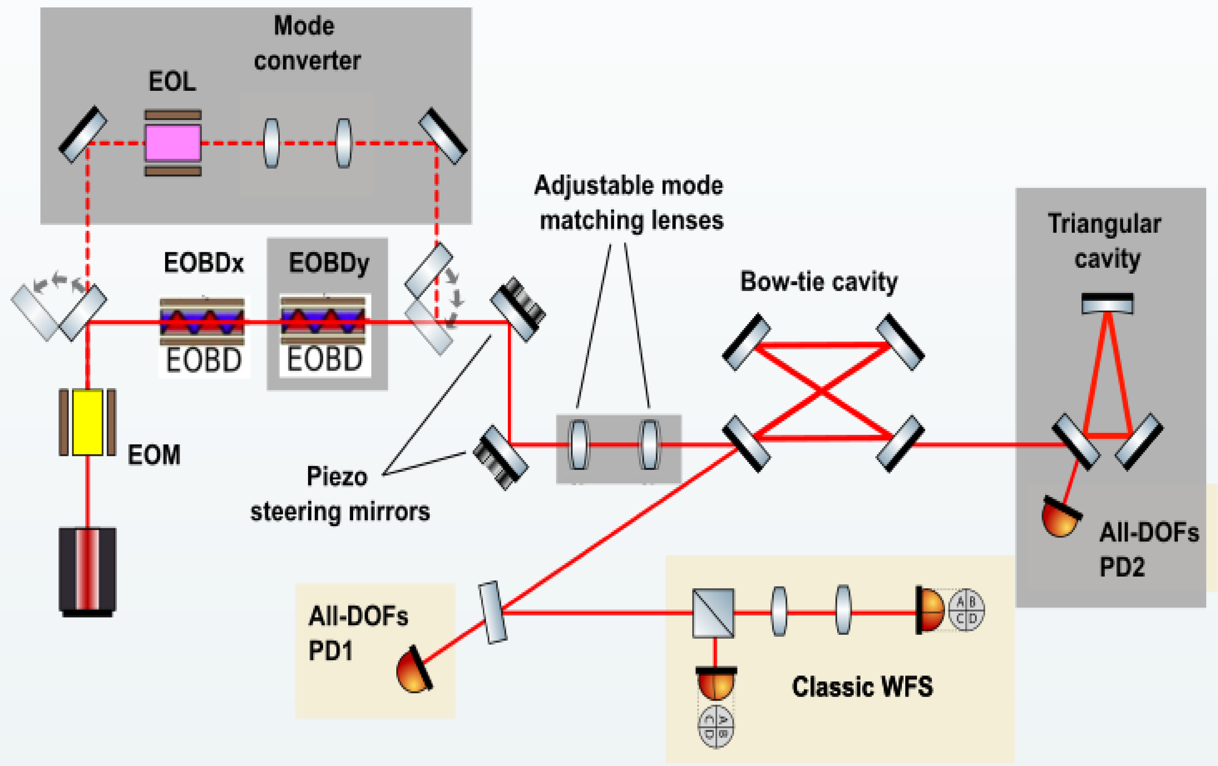
Alignment Signal: Frequency sweep of the alignment error signal matrix. We expect when we drive the EOBD at the HOM frequency, we get a well-separated alignment signals, and that's what we see here, at the right frequency and demodulation phase we get a diagonal sensing matrix.



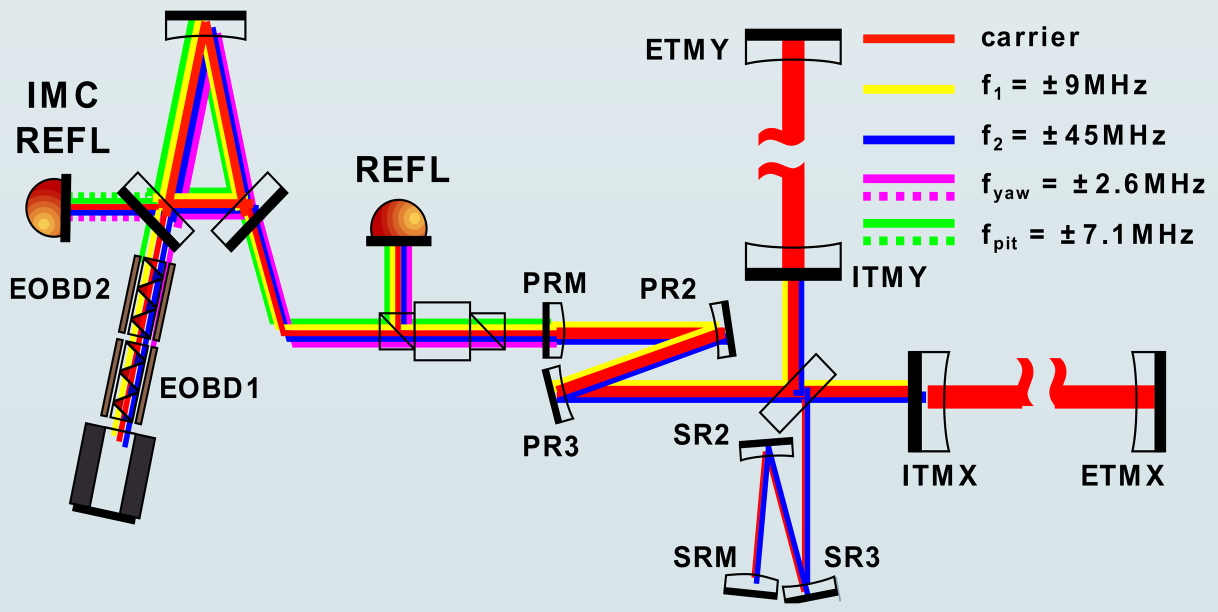
Amplitude Spectral Density: Above is the amplitude spectral density while driving each DOF at 25 Hz. In the graph below we normalize* the spectral density with respect to the misalignment coupling coefficients $\frac{a}{\omega_0}$ and $\frac{\alpha}{\Theta_{mod}}$ at each demodulation. The sensed DOF's noise is about 10-100 times better than the not sensed DOF.
* To a scaling factor



Future Work



Future Work: upper diagram shows the future work that could be implemented on our table-top experiment at UF. In gray boxes are the components and optics that are not currently set up. That includes Electro-Optic Lens (EOL) to generate alignment signals for mode-mismatch, and any 2nd order HG errors, and a 2nd cavity on transmission.
Lower diagram shows how this scheme could be used in aLIGO+ or next generations of GW detectors. Two EOBDs before the IMC that provide alignment signals for IMC and general alignment of core interferometer in pitch and yaw.



Conclusion

By injecting HG_{10} sidebands, we are able to separate the alignment signals of tilt and translation in I&Q demodulations for two cavities in line. Next step will be to quantitively compare this scheme with WFS in many aspects. Although RFJAS does not require QPDs, Gouy phase telescope, or beam centering loop, it does come with its own challenges like requiring a high speed jitter devices.
RFJAS might run along with WFS in the next upgrades of aLIGO, or the next generations of GW detectors.