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Laser Interferometer Gravitational Wave Observatory (LIGO) Project

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Refer to:	**LIGO-T030066-00**
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Subject: **Schnupp Asymmetry of the 4K Interferometers**

Summary:

The Schnupp asymmetry of the two 4K interferometer is too short by 55 mm. The design required the reflected rf sideband amplitude to be +10% (under-coupled). The current setup indicates an amplitude of –7% (over-coupled) when the system is fully heated. This results in a sign change of the reflected signal used to control the laser frequency during locking or while the thermal heating takes effect. Worse, the signal is likely to become useless when the rf sideband amplitude goes through zero. It looks like the Schnupp asymmetry has been calculated correctly for the 2K interferometer and later applied to the 4K interferometers without taking into consideration the difference in modulation frequency.

Options:

The following three options are available to fix the problem:

- Fix the asymmetry of the 4K interferometers by moving ITMX 28 mm away from the beam splitter and by moving ITMY 28 mm towards the beam splitter. This may require to move the ETM mirrors by the same amount.
  Pros: straight forward and guaranteed to work
  Cons: requires in vacuum work
- Operate the 4K interferometers in a suboptimal state where their sideband build-up in the PRM is limited by the amount of thermal lensing (present situation).
  Pros: no change in present setup
  Cons: effects from the suboptimal configuration are not understood (yet)
- Try to use the non-resonant sidebands to either replace the main sidebands in the reflection signal or at least bridge the signal when it goes through zero.
  Pros: optimal configuration without in vacuum work
  Cons: LSC photodetector may not work at 60 Mhz to 70 MHz, may require increase in modulation depth of non-resonant sideband, the PRC servo becomes a non-minimal phase system and will be close to impossible to control

Considering that the false zero is fairly close to the double cavity pole the last option is not compatible with the current PRC bandwidth.

Formulas:

We are following Refs. [1,2] and write the reflected and transmitted rf sideband fields, r_{sb} and t_{sb}, as:

$$r_{sb} = \frac{r_5 - r_M}{1 - r_5 r_M} \quad \text{and} \quad t_{sb} = \frac{\sqrt{1 - r_5^2}\sqrt{1 - r_M^2}}{1 - r_5 r_M} \tag{1}$$

where r_5 is the amplitude reflectivity of the power recycling mirror and r_M is the amplitude reflectivity of the Michelson. We can write

$$r_5 = \sqrt{1 - T_5} \quad \text{and} \quad r_M = \cos\frac{\omega_M a}{c} \tag{2}$$

where T_5 is the power transmission coefficient of the recycling mirror, $\omega_M = 2\pi f_M$ is the angular frequency of the rf modulation and a is the Schnupp asymmetry (difference between the two pathes from the RM to the ITMs).

Values:

The asymmetry is taken from Ref. [3], whereas the recycling mirror power transmission coefficients are taken from Ref. [4]. The rf modulation frequencies are taken from the current settings of the LHO interferometers.

Table 1: Values and Results

Parameter	2K	4K current	4K nominal	Unit
a	300	300	**355**	mm
T_5	2.81	2.70	2.70	%
f_M	29.508	24.482	24.482	MHz
r_5^2	97.19	97.30	97.30	%
r_M^2	96.60	97.65	96.72	%
t_{sb}^2	99.06	99.51	99.03	%
r_{sb}	+9.7	**–7.0**	+9.9	%

References:

[1] Fritschel et al., "Readout and control of a power-recycled interferometric gravitational-wave antenna", Appl. Opt. 40 (2001) 4988.

[2] T970084-00, D. Sigg., "Frequency response of the LIGO interferometer".

[3] E000053-02, D. Coyne, "LIGO cavity lengths and core optic positions".

[4] http://www.ligo.caltech.edu/~gari/COCAsBuilt.htm