LIGO-xxxxxxx-xx-x	Feb. 28, 2012

GEO Squeezing Noise Budget

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Draft

Table 1: OMC parameters. Many numbers come from p.12 of the GEO-HF logbook.

quantity	symbol	value	units
Finesse	F	160	
round trip length	L	0.658	m
g-factor	g	0.735	
waist size	ω_0	450	µm
free spectral range	FSR	455.6	MHz
Michelson sideband power transmission	T_{MI}	1.01	%
SRC sideband power transmission	T_{SR}	2.71	%

Table 2: Optical losses of squeezed beam.

component	power loss	notes
squeezer path Faraday	3.3%	
output port Faraday	3.3%	guess, experienced twice
BDO1 transmission	1%	experienced twice
MSR transmission (when locked)	1%	above 1 kHz
OMC mode-matching loss	6%	
OMC AR coating loss	1%	
OMC internal losses	14%	deduced from other measurements
OMC trans PD detection loss	9%	
TOTAL	63.9%	multiplied in series

1 Introduction

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2 Overview of squeezing setup

3 OMC parameters

Table 1 summarizes the OMC design parameters.

4 Optical losses

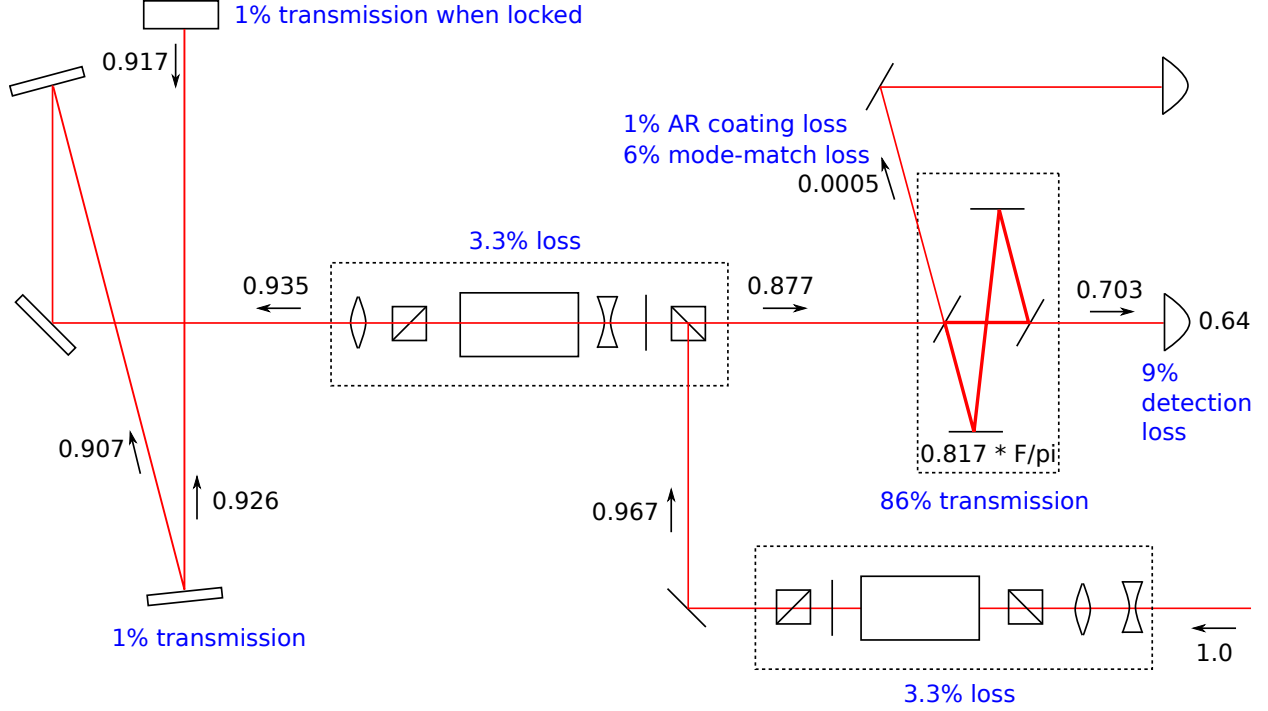Table 2 summarizes our optical loss budget for the squeezer path.

Figure 1: Optical losses.

5 Phase noise from RF sidebands

The presence of both the carrier contrast defect and the RF sidebands in the OMC transmitted light results in jitter of the squeezing quadrature. Figure 2 provides a pictorial view of the role of the sidebands in modulating light at the output port.

Rewriting Eq. 90 from T0900325, the rms fluctuation of the squeezing quadrature angle, Γ_{rms}, is dependent on the ratio of carrier light with signal, P_{CR}, to light without signal that is transmitted through the OMC. Examples are the contrast defect carrier, P_{CD}, and the sidebands, P_{SB}:

$$\Gamma_{\mathrm{rms}} = \sqrt{\frac{P_{\mathrm{SB}}}{P_{\mathrm{CR}}}\left(\frac{1}{\eta} + \epsilon^2\frac{1-\eta}{\eta}\right)} \tag{1}$$

All powers in this equation are for those transmitted through the OMC, and the variables η and ϵ are defined as follows:

$$\eta = \frac{P_{\mathrm{CR}}}{P_{\mathrm{CD}}} \tag{2}$$

$$\epsilon = \frac{1}{2}\frac{P_{\mathrm{SB+}} - P_{\mathrm{SB-}}}{P_{\mathrm{SB+}} + P_{\mathrm{SB-}}} \tag{3}$$

The sideband imbalance is quantified by ϵ and a sample measurement of the imbalance (from several years ago) is shown in Figure 3. Currently, $\epsilon = 0.15$. The contrast defect, commonly quoted as $1/\eta$, can be measured by comparing the power transmitted through the OMC with and without the dark fringe offset. The contrast defect is approximately 5%.

light into interferometer   light out of interferometer

CR

=>   +   CD

CR

SB-   SB+   SB-   SB+   SB-   SB+
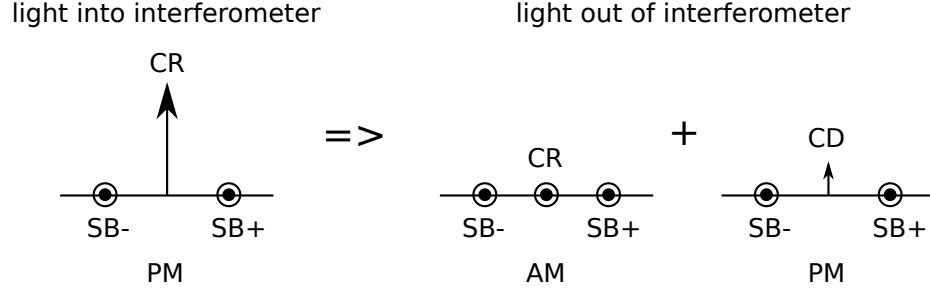
PM   AM   PM

Figure 2: The RF sidebands (SB+ and SB-) are generated via phase modulation of the carrier field. The Michelson interferometer rotates the differential carrier field (CR) by 90 deg, but leaves all other fields the same, including the RF sidebands and the contrast defect (CD). The result is that at the output port, the RF sidebands are amplitude modulation (AM) on the carrier, yet continue to be phase modulation (PM) on the contrast defect.
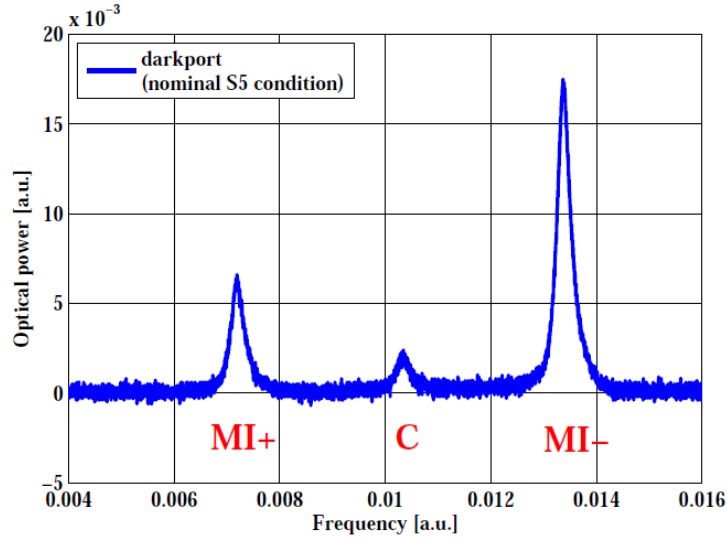
Figure 3: Snapshot of a scan of the output port by Stefan Hild showing the sideband imbalance. In this particular plot, $\epsilon = 0.23$. It was more recently measured to be $\epsilon = 0.15$.
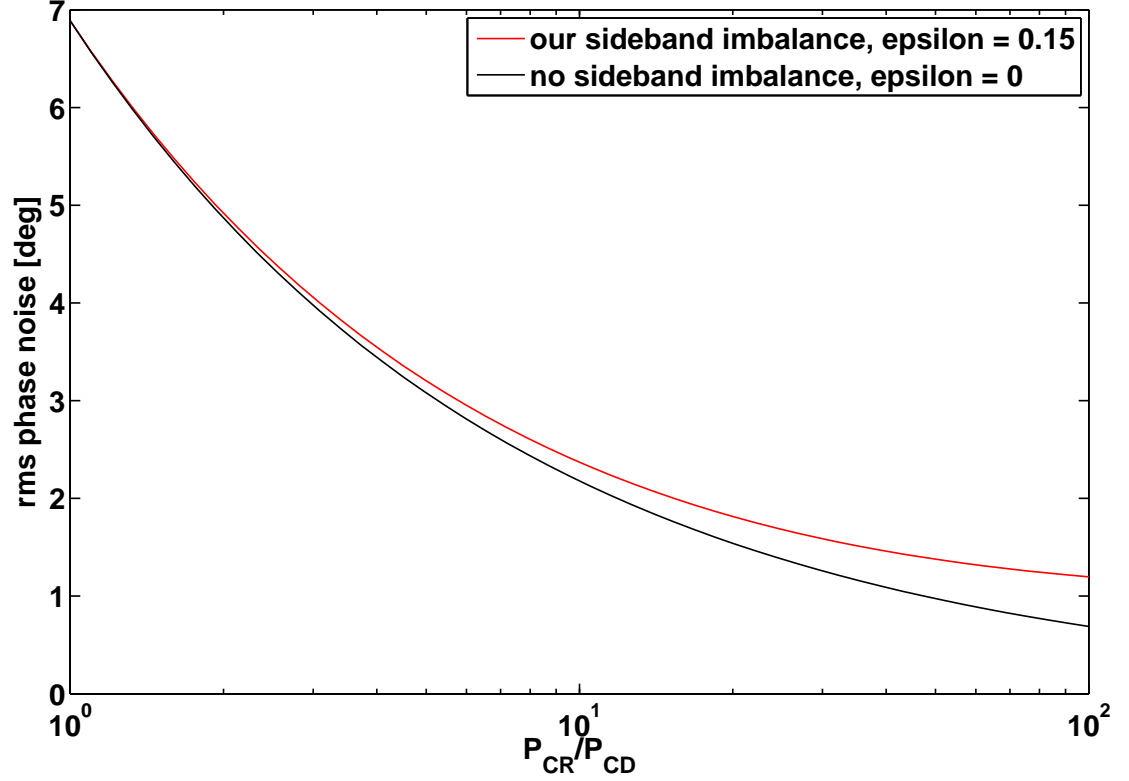
Figure 4: RMS phase noise as a function of the ratio of carrier to contrast defect in the OMC transmitted beam. The typical operating point for GEO is $P_{CR}/P_{CD} = 20$, which corresponds to an RMS phase noise of $1.8°$.

Figure 4 shows the dependence of phase noise on contrast defect for our current sideband imbalance. We expect an rms phase noise of about $2°$.

5.1   Manipulating Γ_{rms}

We changed the rms phase noise up to a factor of 4 by reducing the sideband amplitude and increasing the dark fringe offset. The result is an improvement in observed squeezing of 1.9 dB to 2.8 dB.
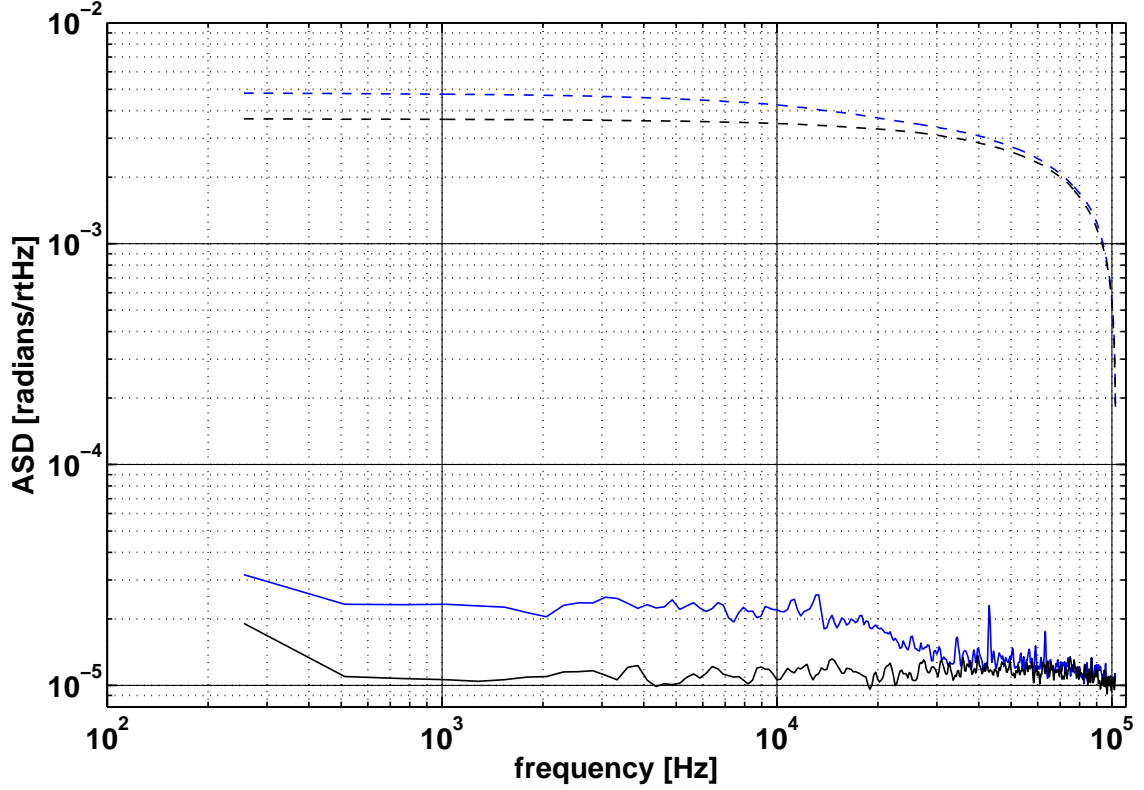
Figure 5: Calibrated squeezer error point (blue curve), measured as the beat between the squeezer sidebands and the RF Michelson sidebands in reflection of the OMC. We are limited by dark noise (black curve) above 40 kHz.

5.2   Squeezer phase error point

Our current setup for creating a squeezer to GEO output relative phase error signal uses the beat of the squeezer sidebands with the Michelson sidebands in reflection of the OMC which are at 15.2 MHz and 14.9 MHz, respectively. A sample error point spectra is shown in Figure 5 and demonstrates that we measure only 5 mrad rms phase noise. Our sensor is not measuring the 35 mrad ($\approx 2°$) predicted by the RF sideband model of Eq. 1.

5.3   Contrast defect

We implement a slow servo called the *noiselock loop* that serves to change the squeezing quadrature in order to maximize the strain sensitivity. The need for such a servo arises from the existence of contrast defect carrier in the OMC transmitted beam. As long as

the amplitude of the contrast defect remains constant in time, so does the squeezing angle. However, when the amount of contrast defect changes, so does the angle of the quadrature that produces the best squeezing.

6 Higher order modes

We test the effect of higher order modes on the squeezing quadrature jitter by placing an aperture in the beam path after the OMC.

7 Ideas for improvements

1. 2nd OMC

2.

8 Acknowledgements