LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
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Modal Model Update 10

Noise Coupling and Random Imperfections

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1 Abstract

Using realistic imperfections of detector parameters and including them simultaneously into the interferometer and mode cleaner equations, yields coupling terms of input beam noise into displacement noise of a size which was expected from the LSC PDR for all, but the oscillator phase noise. The oscillator phase noise requirement is now 95 dBc at 150Hz.

2 Definitions

2.1 Approach

In order to investigate the couplings of noise on the input light to the gravitational wave read-out port in the presence of interferometer imperfections a Monte-Carlo code was developped which randomly varies interferometer parameters around their nominal values and calculates the noise induced displacement signal at the antisymmetric port. The noise coupling is caclulated for a static imprefections, but for input beam noise at a given frequency; for the calculation presented in this document 150 Hz was chosen.

The basic interferometer equations can be found in refs. [1,2]; the audio-sideband extensions are described in refs. [5,6] and therein. The simulation includes a complete LIGO configuration interferometer and the mode cleaner [4].

2.2 Noise Levels on the Input Beam

The following noise levels on the input beam were used to perform the Monte-Carlo calculations; they are specified on the light entering the mode cleaner:

Parameter	**Value**	**Unit**
Frequency of noise	150	Hz
Laser frequency noise	$3x10^{-7}$	Hz / √Hz
Laser amplitude noise	$5x10^{-8}$	/ √Hz
Oscillator phase noise	80	dBc
Oscillator amplitude noise	$5x10^{-8}$	/ √Hz
Beam jitter[1]	$6x10^{-10}$	rad / √Hz
Beam displacement	$3x10^{-8}$	m / √Hz

1. specified at the beam waist of the mode cleaner

The values are taken from the LSC PDR. However, values for beam jitter and beam displacement noise are taken to be 1000 times larger (in units of beam divergence angle and waist size) to account for the spatial mode filtering provided by the mode cleaner.

2.3 Allowed Imperfections

There is a distinct difference how the resonance condition is achieved between the code and the real system when imperfections are present. The code will first calculated the case without longitudinal imperfections and zero the round-trip phase and phase differences in the arm cavities, in the recycling cavity and in the Michelson asymmetry, respectively; putting the carrier on the exact double resonance. Only then, longitudinal displacement variations are added. In reality, the feedback system will measure and zero demodulated signals at the extraction ports. Hence, it will concurrently force the RF sidebands to be resonant in the recycling cavity and to be of equal strength at the antisymmetric port; also, it adjusts the arm cavity lengths to set the carrier on the double resonance and to minimize the leakage field at the antisymmetric port. This difference then makes it that a macroscopic length mismatch between the recycling cavity and the arm cavities leads to non-resonant RF sidebands for the code, but only to a slightly off-resonance carrier in the arms for the real case. Similarly, the feedback system measuring the error signal at the antisymmetric port will adjust the differential arm length to minimize the leakage field irrespectively of a small Michelson length error.

The results presented in this document therefore will not include imperfections of the recycling and the Michelson length comparable to what is tolerated in reality.

Imperfections are varied randomly following a Gaussian distribution. The following parameters were used in the simulation with the specified standard deviation for their variation:

Parameter	σ-variation	Unit
differential arm cavity length	0.5×10^{-13}	m
common arm cavity length	0.5×10^{-12}	m
Michelson length	0.5×10^{-13}	m
Recycling cavity length	0.5×10^{-10}	m
Mode cleaner length	1×10^{-13}	m
Sideband frequency	100	Hz
ITMX angle	0.001	div. angle
ETMX angle	0.001	div. angle
ITMY angle	0.001	div. angle
ETMY angle	0.001	div. angle
RM angle	0.001	div. angle
MC1 angle	0.001	div. angle
MC2 angle	0.001	div. angle
MC3 angle	0.001	div. angle
ITMX amplitude reflectivity	75	ppm
ITMY amplitude reflectivity	75	ppm

Parameter	σ-variation	Unit
ETMX amplitude reflectivity	20	ppm
ETMY amplitude reflectivity	20	ppm
RM amplitude reflectivity	150	ppm
beamsplitter amplitude reflectivity	1000	ppm
MC1 amplitude reflectivity	250	ppm
MC2 amplitude reflectivity	250	ppm
RF phase (antisymmetric port)	3	°
Pockels cell AM, I-phase	0.001	
Pockels cell AM, Q-phase	0.001	
Laser AM at the RF frequency, I-phase	1×10^{-6}	
Laser AM at the RF frequency, Q-phase	1×10^{-6}	

3 Results

A number of 1000 simulations were carried out for each source of input beam noise. The 'expected' noise coupling is deduced from the 333th highest value, assuming that based on a Gaussian distribution roughly $\frac{1}{3}$ of the used values for imperfections are lying above the requirements.

Noise Source	typ. noise coupling	Unit
Laser frequency noise	5×10^{-21}	m / √Hz
Laser amplitude noise	8×10^{-21}	m / √Hz
Oscillator phase noise	2×10^{-20}	m / √Hz
Oscillator amplitude noise	7×10^{-21}	m / √Hz
Beam jitter[1]	7×10^{-21}	m / √Hz
Beam displacement	6×10^{-20}	m / √Hz

1. specified at the beam waist of the mode cleaner

The results are shown in Fig. 1. As can be seen the design goals [7] for laser frequency noise, laser amplitude noise, oscillator amplitude are all at the expected level sufficient for initial LIGO design. On the other hand the oscillator frequency noise requirement has to be adjust to 95dBc at 150Hz due to previously not accounted terms coming from the interaction of different noise sources. It can also be seen that the mode cleaner indeed gives about a factor of 1000 suppression of beam jitter and beam displacement noise.

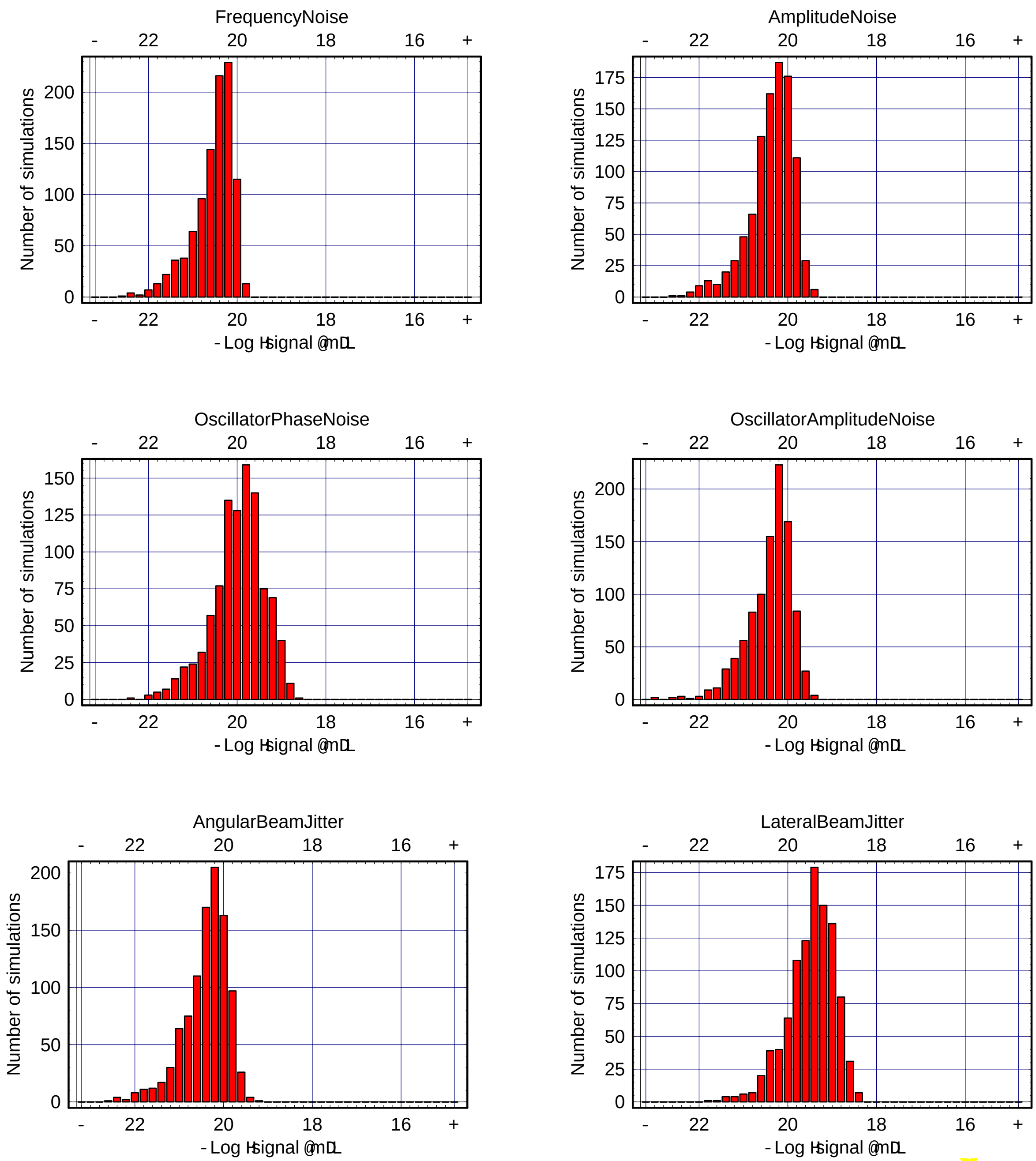

Figure 1: Histograms of input beam noise simulations with detector imperfections.

4 REFERENCES

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