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Backscattering from the AS port: A Comparison of P. Fritschel's Estimate and AOS T060263

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Table of Contents

Abstract

The scattered light noise calculation for backscattering from the AS port made by P. Fritschel, 12/22/06, http://ilog.ligo-wa.caltech.edu:7285/advligo/ScatteredLight, is compared with the calculation presented in T060263, Stray Light Control Conceptual Design Requirements. The two different approaches are shown to be equivalent.

1 Introduction

This note compares the scattered light noise calculation for backscattering from the AS port made by P. Fritschel, 12/22/06, http://ilog.ligo-wa.caltech.edu:7285/advligo/ScatteredLight, with the calculation presented in T060263, Stray Light Control Conceptual Design Requirements.

The K values used to determine the scattered light requirements in T060263 were based on transfer functions derived by H. Yamamoto, T060073, Transfer Functions of Injected Noise.

The requirement for the product of the scattered light field amplitude and the surface displacement derived by P. Fritschel was based on T. Corbitt's quantum noise code.

It will be shown that the two different approaches give equivalent results.

2 Analysis

2.1 AOS Scattered Light Requirements for ADLIGO

The requirement for the maximum scattered light from a moving surface in the AS port is expressed as

$$\sqrt{\frac{P_{sc}}{P_0}} A_{SEI} K_{AS}(f) < \frac{1}{10}$$

where P_{sc} is the power scattered from the surface, $P_0 = 125W$ is the PSL laser power entering the IFO, A_{SEI} is the amplification (attenuation) of the seismic ground motion at the scattering surface, and $K_{AS}(f)$ is the K-factor for scattering into the AS port.

The K-factor is derived from the transfer function ratio for the AS port calculated by Hiro.

$$K_{AS}(f) = \left(\frac{SNXXX}{DARM}\right)_{SR}(f) \frac{4\pi}{\lambda} \frac{x_g(f)}{Lh_{SRD}(f)}$$

where $\left(\frac{SNXXX}{DARM}\right)_{SR}(f)$ is the noise/signal transfer ratio of DARM signals caused by scattered light fields injected into the signal mirror to gravity wave induced fields (shown in Fig. 5 of T060073 as the red curve titled SR, and reproduced in Figure 1), and $\frac{x_g}{Lh_{SRD}}$ is the ratio of the ground displacement spectral density to the minimum detectable SRD displacement spectral density at a particular signal frequency.

The minimum detectable SRD strain spectral density was assumed to be the suspension thermal noise for frequencies between 10 Hz and 23 Hz, and the mirror coating thermal noise for frequencies between 23 Hz and 1000 Hz, as shown in figure 1 of M060056-06 Advanced LIGO Reference Design (the figure is reproduced below, Figure 2).

The coating thermal noise strain is approximately equal to the quantum noise limit at 300 Hz.

$$h(300) = 1.8 \times 10^{-24} / \sqrt{Hz}$$

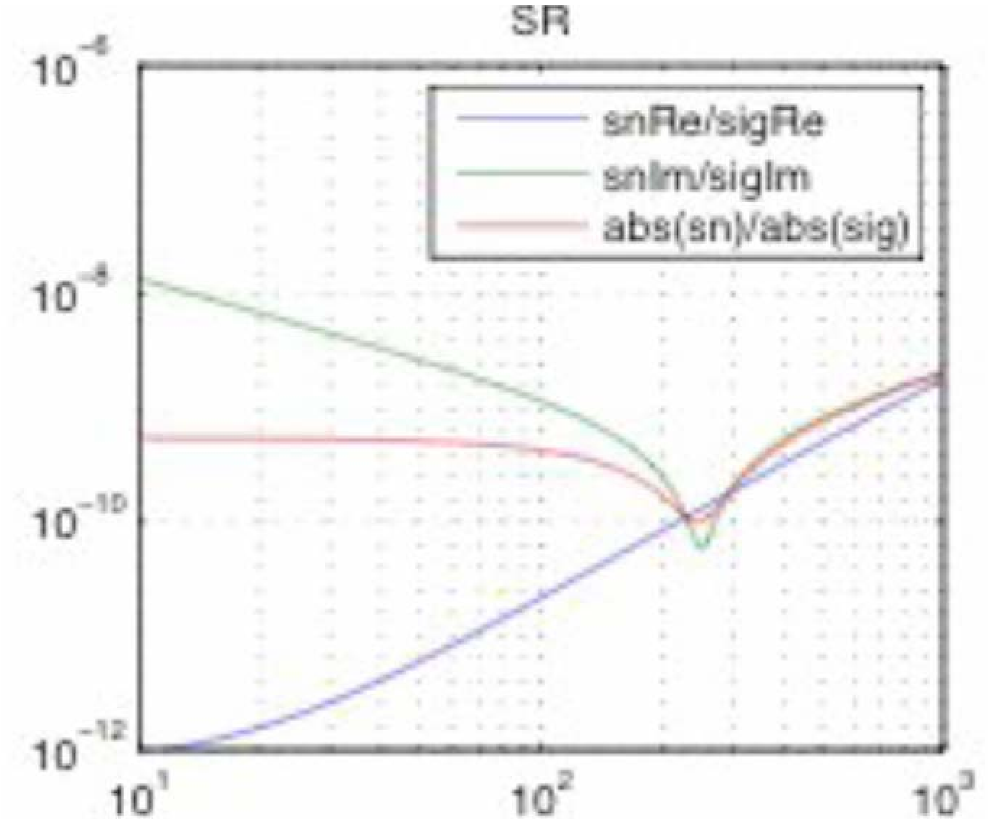

Figure 1: Ratio of Transfer Functions: SNXXX/DARM

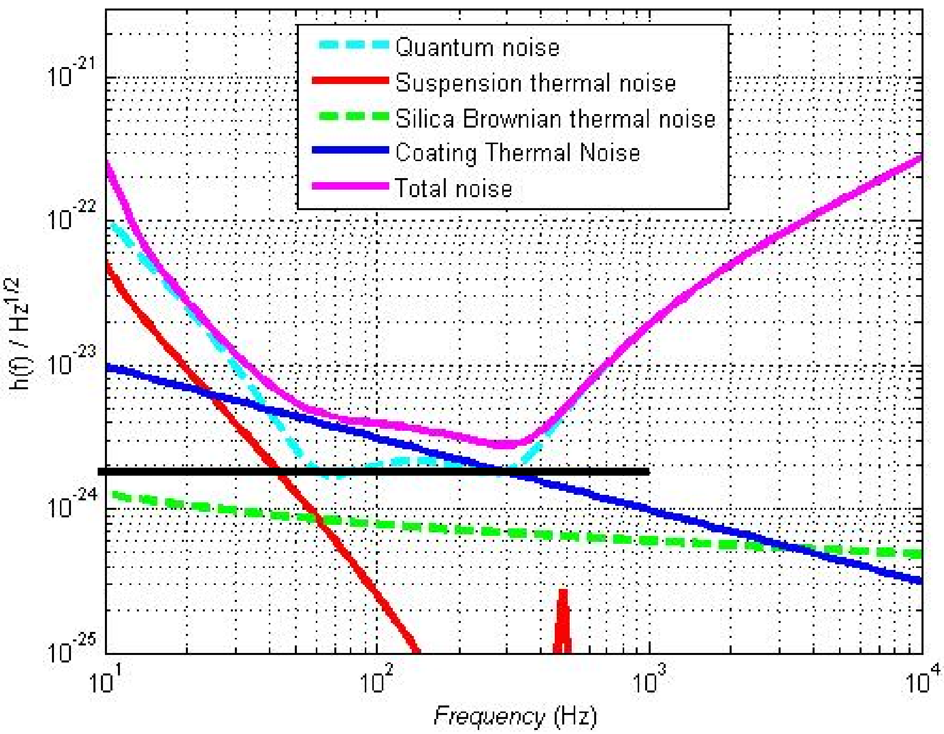

Figure 2: Strain Spectral Density, Advanced LIGO

The ground displacement spectral density at 300 Hz was extrapolated with a $1/f^2$ fit to the LLO ground noise spectra shown in figure 1 of E990303-03 Seismic Isolation Subsystem Design Requirements Document (the extrapolated black line is shown in the reproduced Figure 3).

$$x_g(300) = 4.4\times10^{-13} m/\sqrt{Hz}$$

$$(\frac{SNXXX}{DARM})_{SR}(300) = 1.9\times10^{-10} m$$

Using these values, the K-factor for the AS port is

$$K_{AS}(300) = 1.4\times10^{5}$$

2.1.1 Restatement of the AOS Scattered Light Requirement

Using the expression for the displacement of the surface given by

$$x_{sc} = x_g A_{SEI}$$

we can restate the scattered light requirement as follows:

$$\sqrt{\frac{P_{sc}}{0.1}} x_{sc} < \frac{1}{10}\sqrt{\frac{P_0}{0.1}}\frac{x_g(f)}{K_{AS}(f)}$$

The requirement at 300 Hz is

$$\sqrt{\frac{P_{sc}}{0.1}} x_{sc} < 1.2\times10^{-17} m - \sqrt{W}/\sqrt{Hz}$$

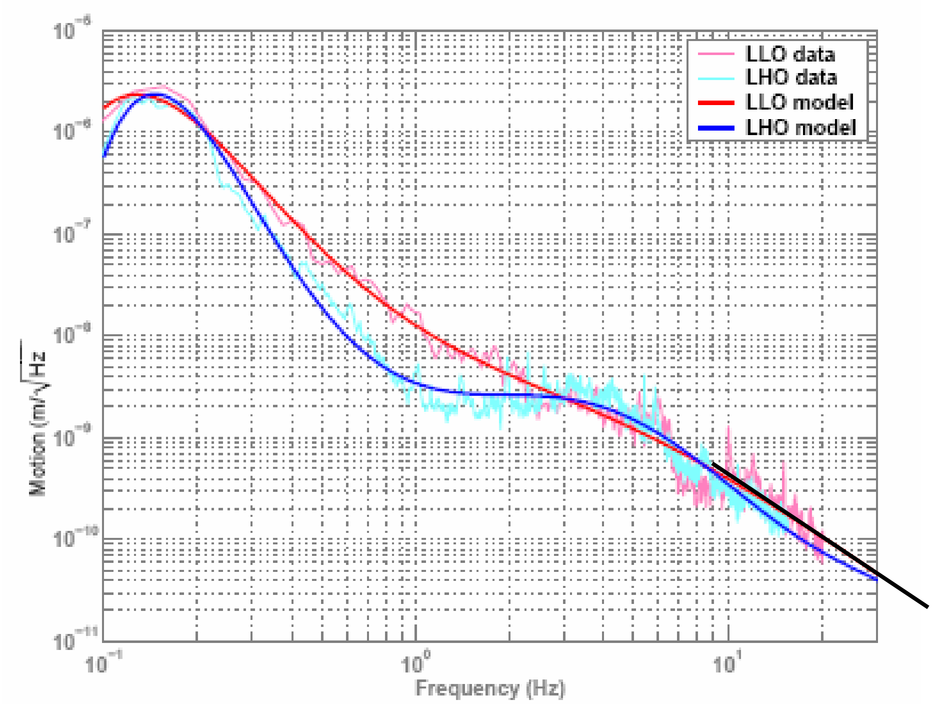

Figure 3: Ground Noise Spectra

2.2 P. Fritschel's Scattered Light Requirement

P. Fritschel used T. Corbitt's quantum noise code to calculate the scattered light requirement for a 0.1 W beam incident on a scattering surface in the AS port. He proposed that the scattered light noise should be < 1/10 the quantum noise displacement spectral density for f > 10 Hz--he assumed a constant value for the quantum noise across the spectrum (shown as the black line in Figure 2).

His requirement is stated as follows:

$$\sqrt{\frac{P_{sc}}{0.1}}x_{sc} < 1.0\times10^{-17}\,m - \sqrt{W}\,/\,\sqrt{Hz}$$

P. Fritschel's result agrees closely with the AOS result at 300 Hz.

3 Conclusion

The formalism used by AOS for establishing the scattered light requirement and the approach proposed by P. Fritschel are equivalent, and they agree numerically at 300 Hz, where the minimum displacement spectral density that was chosen has approximately the same value for both approaches. Referring to Figure 2, it will be seen that P. Fritschel's requirement, which is based on a constant quantum noise limit with a value approximately equal to the value of the mirror coating thermal noise at 300 Hz, is more stringent than that set by the mirror coating and suspension thermal noise floor for frequencies < 300 Hz; and is less stringent than the mirror coating thermal noise floor for frequencies > 300 Hz.

The remaining differences in the actual scattered light power noise calculations are due to disagreements on the appropriate values of BRDF for the various scattering surfaces. In particular, P. Fritschel uses a BRDF value for the vacuum window in the AS optical path that is 1E-4 smaller than the value used in the AOS document, because it includes an additional factor 1E-4 to account for the Fresnel reflectivity of the polished surface.

The backscattering BRDF of an uncoated, super polished window should be measured to resolve this discrepancy.