LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Noise requirement for the test mass electro-static driver

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1 Introduction

A low-noise, lower range driver for the test mass electro-static actuator is being designed for use in interferometer low-noise operation (the UK high-voltage driver will continue to be used for lock acquisition). This note specifies the maximum voltage noise for this low-noise driver.

2 Force noise per actuator quadrant

The voltage noise in the actuator quadrants will be independent of each other, so I start by defining the force noise per quadrant. The force coefficient for the ETM is still somewhat uncertain. John Miller's FEA model gave 4e-10 N/V^2, but measurements give factors of 2-4 smaller values (see LHO log entry 12220). It was recently suggested that the ring heater structure could be altering the field lines in a way that reduces the net force. I assume a force coefficient of 2e-10 N/V^2 for the full ETM/ERM electrode pattern, or a force coefficient of $\boldsymbol{a}$ = **5e-11 N/V^2 per quadrant**. The force noise per quadrant, assuming the bias path is sufficiently low-pass filtered that its noise is negligible, is thus:

$$F_q = 2a \cdot V_b \cdot v_n = 10^{-8} v_n \cdot (V_b/100) N/V$$

3 Force noise for both ETMs

Since the ESD force coefficient for the ITMs is about 30 times smaller than the ETMs, I neglect them in the calculation. The total force noise from the 8 ETM/ERM quadrants is:

$$F_{esd} = \sqrt{8} \times 10^{-8} v_n \cdot (V_b/100) N/V$$

4 Maximum allowed force noise from ESD

For the maximum force noise, I use an Advanced LIGO configuration that is good for low frequency noise, namely with 25 W input power (other variable parameters do not significantly impact the noise below 30 Hz). The limiting strain noise in this case is 1.6e-23 Hz$^{-1/2}$ at 20 Hz (see LIGO-T1200307, e.g.); the arm differential displacement noise is 6.5e-20 m/Hz$^{1/2}$ at 20 Hz (this frequency is chosen because a $1/f^2$ line is tangent with the strain noise spectrum at about 20 Hz).

The maximum displacement noise from ESD noise is 10 times smaller than this value, which gives a maximum (total differential) ESD force noise of:

$$F_{max} = 40\ kg\ \cdot (2\pi \cdot 20\ Hz)^2 \cdot 6.5 \times 10^{-21}\ m/\sqrt{Hz} = \ 4.1 \times 10^{-15}\ N/\sqrt{Hz}$$

5 ESD signal path voltage noise

The maximum voltage noise on each ESD quadrant signal path comes from the previous two equations:

$$v_n(f \geq 20Hz) \leq \frac{4.1 \times 10^{-15}\ N/\sqrt{Hz}}{\sqrt{8} \times 10^{-8} \cdot (V_b/100) N/V} = 150\ nV/\sqrt{Hz} \cdot \left(\frac{100\ V}{V_b}\right)$$

Between 10-20 Hz the interferometer strain noise falls a bit faster than f^{-2}, so the noise at 10 Hz can be a bit higher; I set v_n (10 Hz) < 250 nV/Hz$^{1/2}$.