Electrostatic drive (ESD) results from GEO T050263-00-K

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1 Purpose

A review of the understanding of electrostatic drives for Advanced LIGO. Mainly to be sure we are all making the same assumptions about ESD performance when designing loops, etc.

References:

controls prototype ESD mask ? (can't find on DCC)

electrostatic drive plans: E040379-00-K

2 GEO 600 ESDs

The GEO 600 drives are used with close to 650 V DC bias on one set of electrodes, and a high-voltage AC signal on the other set. A drive consists of 4 electrode pairs. These are 3 mm from the test mass which is silica with an antireflection coating.

Each set of electrodes consists of interleaved conductor strips and gaps, each about 3 mm wide. The total active area of the drive is about $200\,\mathrm{cm}^2$.

The drive calibration is known to better than 10% at 100 Hz and is 2.9×10^{-13}m/V at 100 Hz. The suspension response at 100 Hz is modelled to be (to a few % accuracy) 4.5×10^{-7}m/N. The force constant is therefore 6.4×10^{-7}N/V, all figures with 650 V bias.

A better way to characterise the drive is to write $F = \alpha V^2$, when $dF = 2\alpha V dV$. So $\alpha = 4.9 \times 10^{-10}\mathrm{N/V}^2$.

3 Extrapolation to Advanced LIGO

The Advanced LIGO test masses are to be spaced 5 mm from the drive electrodes (baseline). This requires the gaps in the electrode pattern to be increased to about 5 mm, the electrodes themselves may also be extended to greater area. This has been done for the controls prototype drive. The greater separation makes about a factor of 2 weaker drive, but this is easily compensated by increasing the area (the proposed design for the controls prototype tests is about double the area of the GEO 600 drive, it could probably be further optimised).

Depending on the final layout chosen, the drive should be a little stronger than that in GEO 600, so it is reasonable to take the GEO 600 figures as a starting point.

It was assumed that, giving the digital origin of all signals, all non-linear correction, bias generation etc. should be carried out in the digital domain. The output to the baseline drive design would be 5 channels (one common and 4 quadrants) which could be driven with any desired differential voltage to meet the requirements of various operating modes. This encourages digital generation of the optimum differential voltage ready for symmetrical amplification.

Flexibility was then increased by providing two levels of gain (and range and output noise) per channel so that asymmetrical drive arrangements (strong bias, weak signal) can be generated optimally with nearly fixed DAC range, and reasonable noise requirements for signal transmission.

The (non-baseline) idea of adding a 6^{th} electrode, common to the 4 quadrants but perhaps 30 times more weakly coupled than the main common electrode, increases flexibility to transmit all signals at high level, should that prove desirable. (Particularly for use in final science mode if there are no photon actuators.)

4 Open questions

Due to problems in GEO 600 with voltages approaching or exceeding 1 kV, and the availability of simple, reliable and low cost 800 V devices, it was felt that 800 V was a reasonable target for maximum differential voltage. This decision was based on very weak and uncertain arguments and should be put on a better footing as soon as possible.

At some point in the development of ESDs within GEO there was some encouragement (based on some results from MSU) to try AC bias. We have not explored this option so far. The motivation to try AC bias could arise at any time, but its necessity will not likely be unambiguously determined before implementation on Advanced LIGO. This motivated the design of amplifiers that could cope with any practical AC bias (so in the LIGO world 8192, or 16384 Hz would be the worst case motivated by reduction of aliasing. Of course much lower frequencies should also be considered).

The baseline fast actuator for Advanced LIGO science mode is the photon drive. We have made the assumption that it is best to design the ESD to do this job in case it is later discovered that there is a problem with the photon drive. This assumption has been a major design driver.