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Gravitational Reference Sensor Front-End Electronics Simulator for LISA

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Abstract. At the ETH Zurich we are developing a modular simulator that provides a realistic simulation of the Front End Electronics (FEE) for LISA Gravitational Reference Sensor (GRS). It is based on the GRS FEE-simulator already implemented for LISA Pathfinder. It considers, in particular, the non-linearity and the critical details of hardware, such as the non-linear multiplicative noise caused by voltage reference instability, test mass charging and detailed actuation and sensing algorithms. We present the simulation modules, considering the above-mentioned features. Based on the ETH GRS FEE-simulator for LISA Pathfinder we aim to develop a modular simulator that provides a realistic simulation of GRS FEE for LISA.

1. Introduction

The LTP Data Analysis (LTPDA) toolbox provides a closed loop simulation of the Laser Interferometer Space Antenna (LISA) Technology Package (LTP). It is composed of modular units, each of which is implemented as a linear state space model [1].

Gravitational Reference Sensor Front End Electronics (GRS FEE) is modelled linearly in order to provide fast simulations at 10 Hz and 1 Hz frequencies. However, the linear model prevents reproduction of some complicated specific hardware details. These are for instance the non-linear multiplicative noise caused by the reference voltage instability and the thermal noise in dispersive elements of the circuit.

At the ETH Zurich we are improving the simulator to obtain a more realistic model for LISA Pathfinder GRS FEE. We introduce the main features of our model in section 2 and give a detailed description in section 3.

2. GRS FEE simulator for LISA Pathfinder

GRS FEE is responsible for capacitive actuation and sensing of the position of the proof masses in the LTP. Each proof mass is surrounded by an electrode housing [2]. Figure 1 shows the arrangement of the electrodes around the proof mass and illustrates the simplified electronic circuits of the actuation and sensing units inside FEE.

In the advanced simulator each of the actuation and sensing units is split into blocks. Splitting into blocks provides more flexibility to feed the complicated hardware details into the simulator,

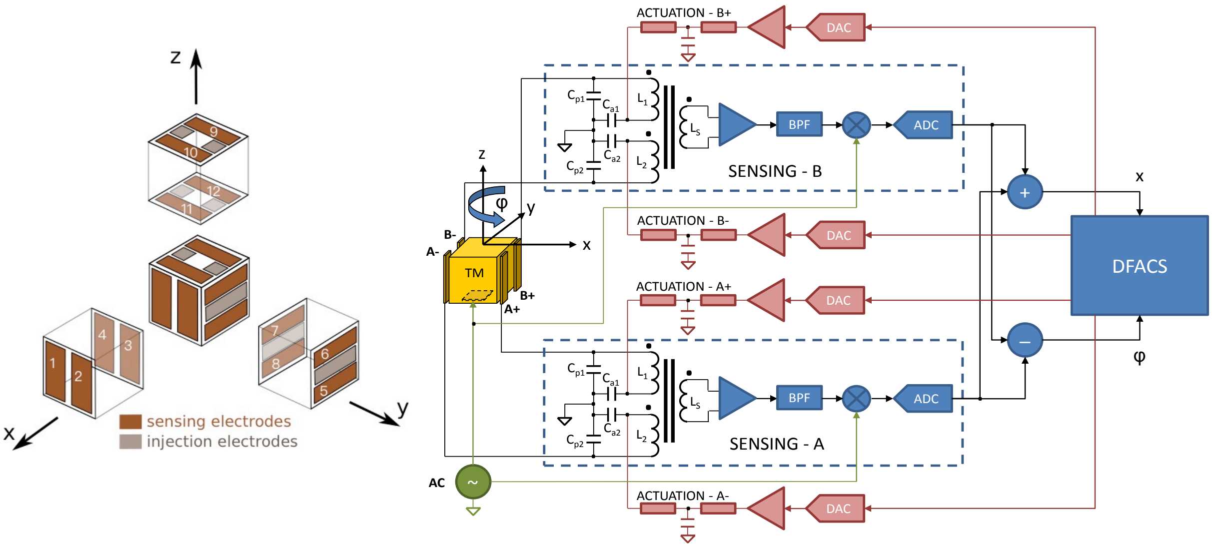

Figure 1. Arrangement of the sensing/actuation electrodes and the injection electrodes around the proof mass (left-hand side) and electronic circuit for sensing and actuation (right-hand side).

which also allows the non-linear simulations. The units and the corresponding division into blocks are elaborated as follows.

- Actuation unit
  The actuation unit is responsible for applying the forces commanded from the Drag-Free Attitude Control System (DFACS) to the proof mass. In modelling of the actuation unit the first step is to calculate the commanded voltages from the commanded forces ($F_{cmd} \rightarrow V_{cmd}$). Afterwards the commanded voltages are converted to the applied voltages ($V_{cmd} \rightarrow V_{appl}$) and finally the applied forces are computed from the applied voltages ($V_{appl} \rightarrow F_{appl}$). On board LISA Pathfinder the first step is the task of the onboard computer. In the second step the conversion from commanded to applied voltages is executed through the actuation electronics of the GRS FEE (see figure 1). The applied voltage to the electrodes causes a force and consequently the desired proof mass displacement.
- Sensing unit
  The sensing unit is mainly divided into the following blocks: First, the conversion from physical coordinates to the capacitance ($q_{ph} \rightarrow C$) and second the calculation of the readout coordinates from the capacitance ($C \rightarrow q_r$). On board LISA Pathfinder any displacement of the proof mass changes the distance to the corresponding electrode, which in turn results in the changes of capacitance. Thus, the readout coordinates can be calculated from the measured electrode capacitances.

Crosscorrelations of the blocks and also crosstalks between the units can be implemented in a separate block. This is specially important for noise identification. Figure 2 summarises the breakdown of the actuation and sensing units and depicts their correlation in a block diagram.

3. Detailed description of the blocks and development for LISA

To develop the GRS FEE simulator for LISA additional details should be considered and implemented. At the first stage of the development we propose modifications, which in particular

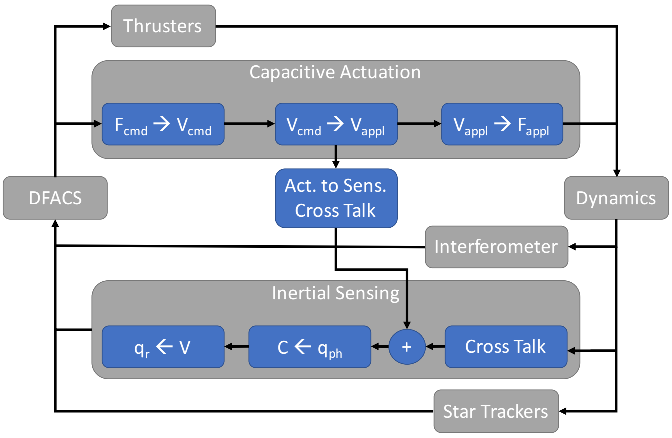

Figure 2. Sensing and actuation units of the GRS FEE.

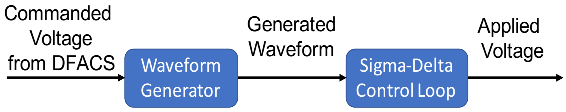

Figure 3. Detailed description of the conversion of commanded to applied voltage in the actuation unit

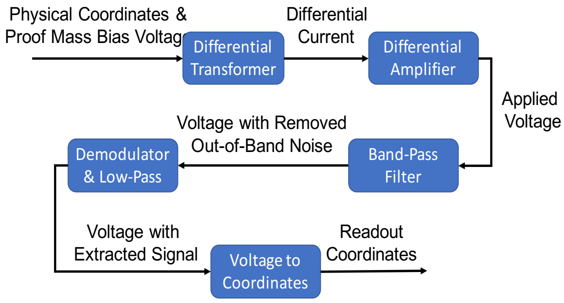

Figure 4. Detailed description of the sensing unit

refer to the actuation unit. At this stage the sensing unit is inherited from the GRS FEE simulator for LISA Pathfinder. The details on each block are described below.

3.1. Actuation unit

The most challenging part of the actuation model refers to the simulation of the block that converts the commanded voltages to the applied voltages. More details about this block are summarised in Figure 3 and described as follows.

The DFACS produce commanded forces (and consequently commanded voltages) in 10 Hz frequency and in double precision, however the electronics accept the inputs in 16 bit integers. Thus, the commanded voltages are truncated, such that the sample values accomplish the precision of the electronics.

The force applied to the proof mass is proportional to the square of the voltages injected to the electrodes surrounding the proof mass. A convenient way to apply a force with desired magnitude is to generate sinusoidal waves. This is done by a waveform generator. The commanded voltages are then amplitudes of the sinusoidal waves. In order to distinguish between actuation at the different degrees of freedom (DoF) a different frequency has been assigned to the generated wave at each DoF.

The generated waves enter a sigma-delta loop, which provides an analog signal at the electrodes. The sigma-delta loop includes a digital controller, a digital to analog converter, an amplifier and a feedback analog to digital converter, all operating at high frequency, in order to process the high resolution DFACS data more accurately [3].

3.2. Sensing unit

The sensing unit takes at the input the physical coordinates of the proof mass position and provides at the output the readout coordinates. Figure 4 depicts a detailed description of this unit.

The proof mass displacement changes the capacities at the surrounding electrodes. Two pairs of electrodes are responsible for sensing the translation and rotation. A differential transformer senses the differential current of the one electrode pair. The differential current is amplified by a trans-impedance amplifier. The amplified voltage is filtered to remove the out-of-band noise. Moreover, an AC voltage (bias) of 100 kHz is applied to the proof mass as a carrier signal. The proof mass displacement generates a low frequency signal. This is modulated to the 100 kHz carrier. Thus, the output of the bandpass filter has to be demodulated, in order to extract the voltages caused by the proof mass displacement. Finally, the readout coordinates are computed from the voltages.

4. Conclusion and outlook

Based on the ETH GRS FEE-simulator for LISA Pathfinder we are developing a modular simulator that provides a realistic simulation of the GRS FEE for LISA. The simulator considers, in particular, the non-linearity and the critical details of hardware. The simulation design and its features are presented. We aim to develop the non-linear FEE-simulator for LISA and finally to integrate it in LISA-Code [4].

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