The LISA Pathfinder Front-End Electronics

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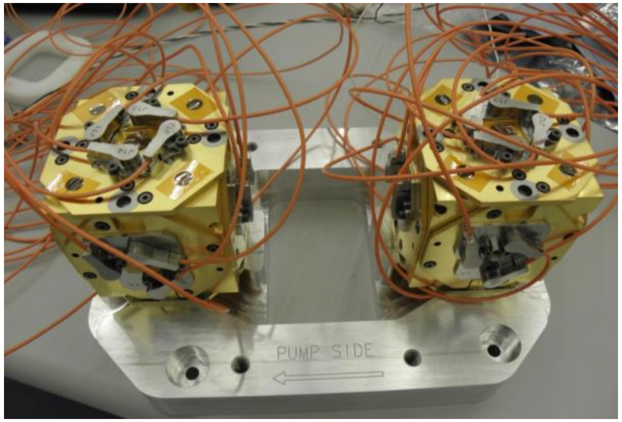
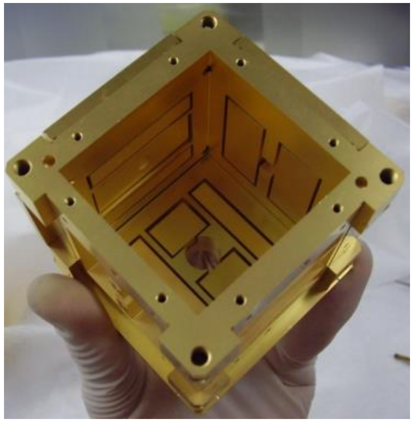
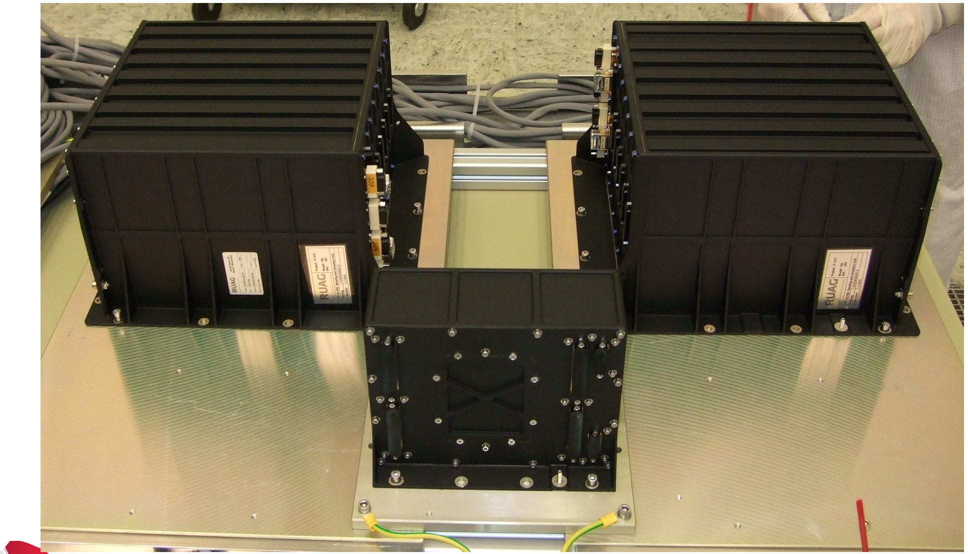
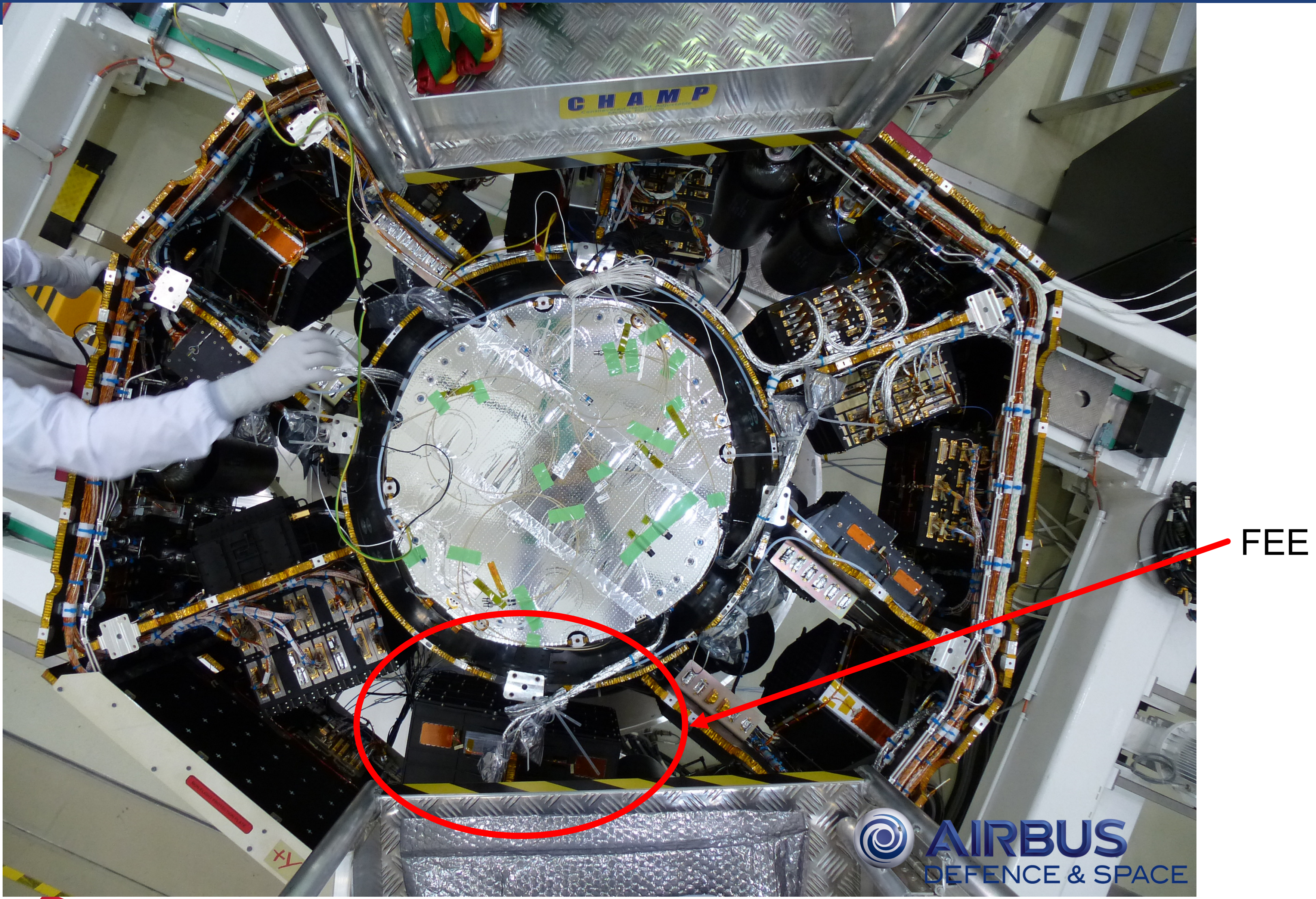
LPF Front-End Electronics (FEE)



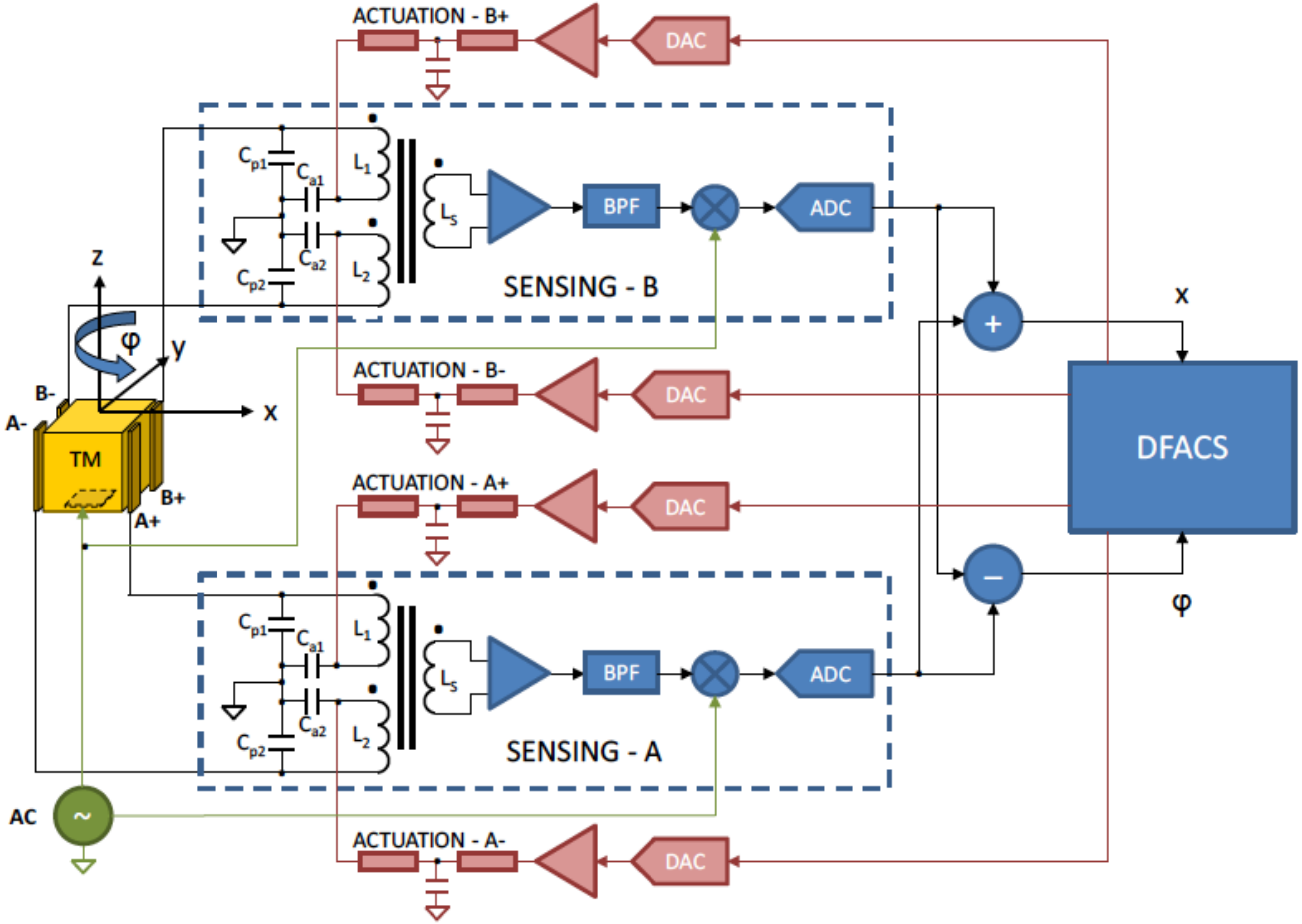




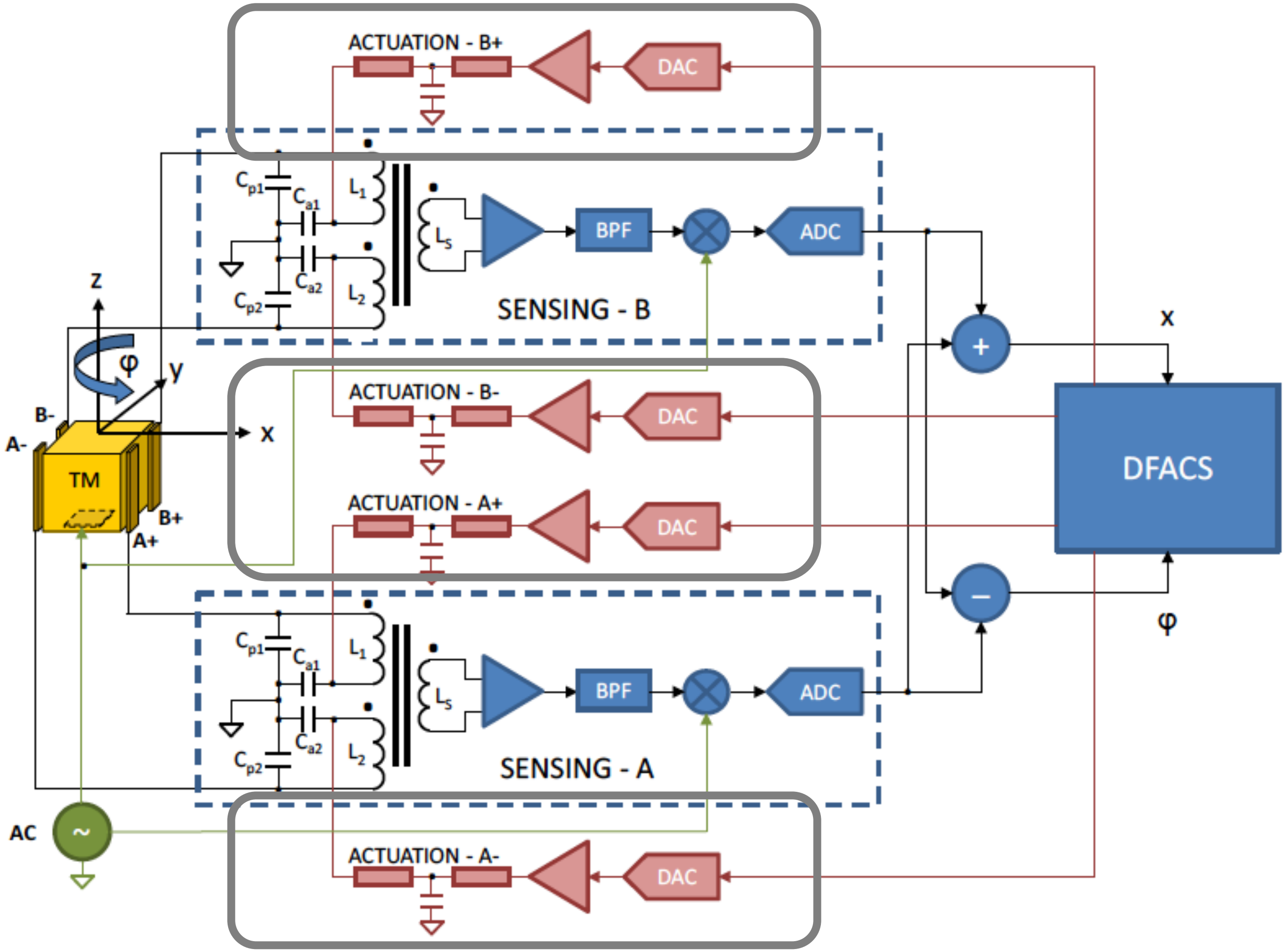
FEE primary and redundant units
+
Switching unit


FEE
CHAMP
AIRBUS DEFENCE & SPACE
+Y

LPF Front-End Electronics (FEE)



LPF Front-End Electronics - Actuation



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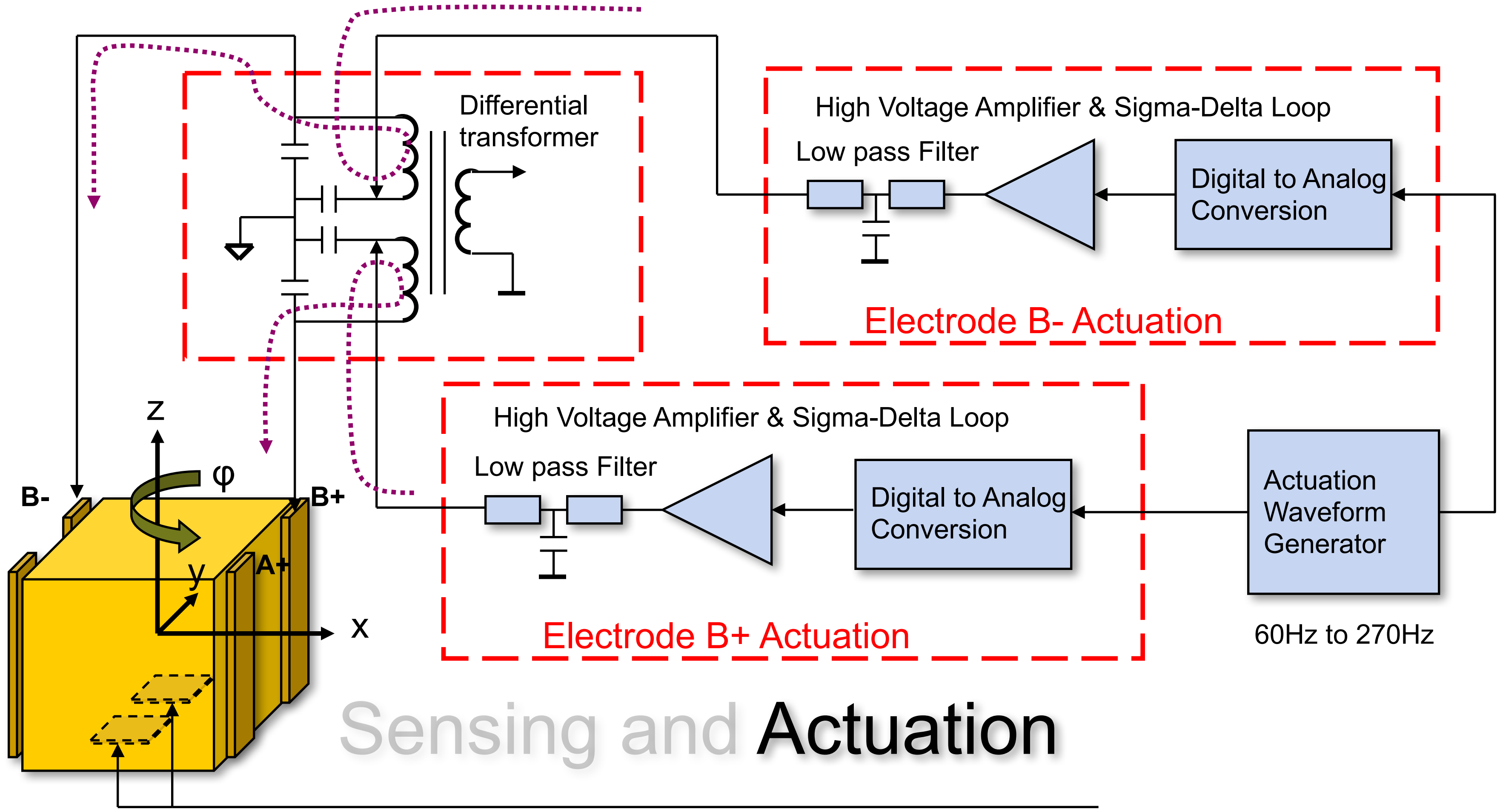
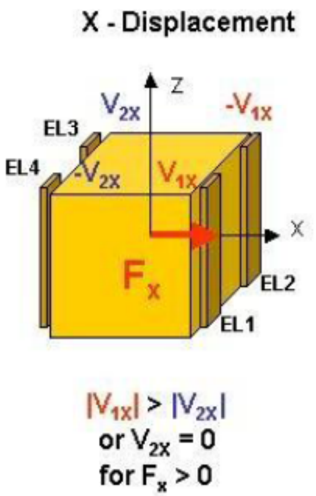
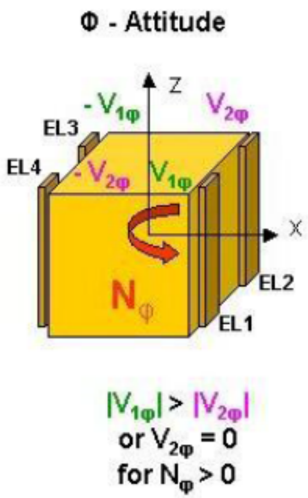


Test Mass (TM) Excitation (100kHz)

Actuation Scheme





$$V_1 = V_{1x}\sin(\omega_x t) + V_{1\varphi}\sin(\omega_\varphi t) + V_{1DC}$$

$$V_2 = -V_{1x}\sin(\omega_x t) + V_{2\varphi}\cos(\omega_\varphi t) + V_{2DC}$$

$$V_3 = V_{2x}\cos(\omega_x t) - V_{1\varphi}\sin(\omega_\varphi t) + V_{3DC}$$

$$V_4 = -V_{2x}\cos(\omega_x t) - V_{2\varphi}\cos(\omega_\varphi t) + V_{4DC}$$

$$V_{1x} = \frac{1}{2}\sqrt{\frac{d_x}{C_{0x}}}\sqrt{2F_x + 2F_{\max,x}}$$

$$V_{2x} = \frac{1}{2}\sqrt{\frac{d_x}{C_{0x}}}\sqrt{-2F_x + 2F_{\max,x}}$$

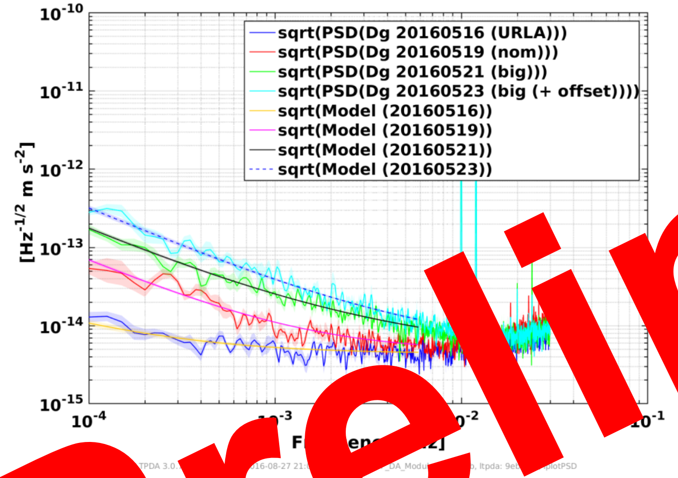
$$\left|\omega_{xx}^2\right| = \frac{2}{d_x}F_{\max}$$

- Constant Stiffness
- Neutral TM

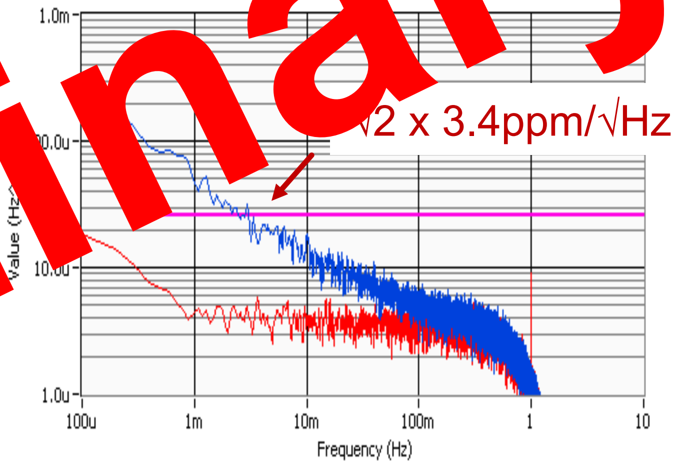
- $\omega_x = 2\pi\ 60$ Hz
- $\omega_y = 2\pi\ 90$ Hz
- $\omega_z = 2\pi\ 120$ Hz
- $\omega_\varphi = 2\pi\ 270$ Hz
- $\omega_\theta = 2\pi\ 240$ Hz
- $\omega_\eta = 2\pi\ 180$ Hz

Actuation Noise gain noise

- Expected from ground measurements 3 – 6 ppm/√Hz
- Measured during in-flight campaign 3 – 8 ppm/√Hz



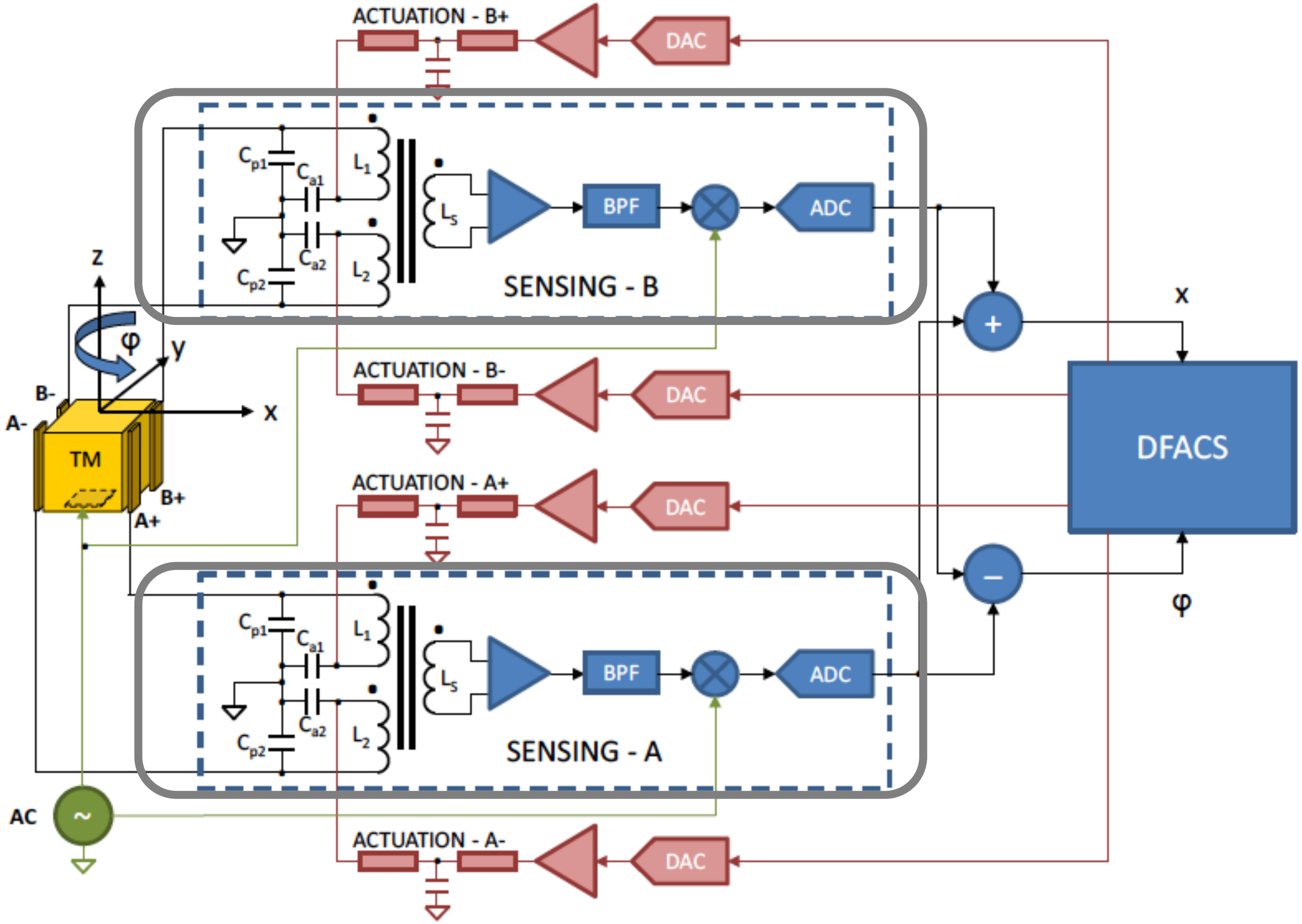
n- fli t m asurement campaign



√2 x 3.4ppm/√Hz

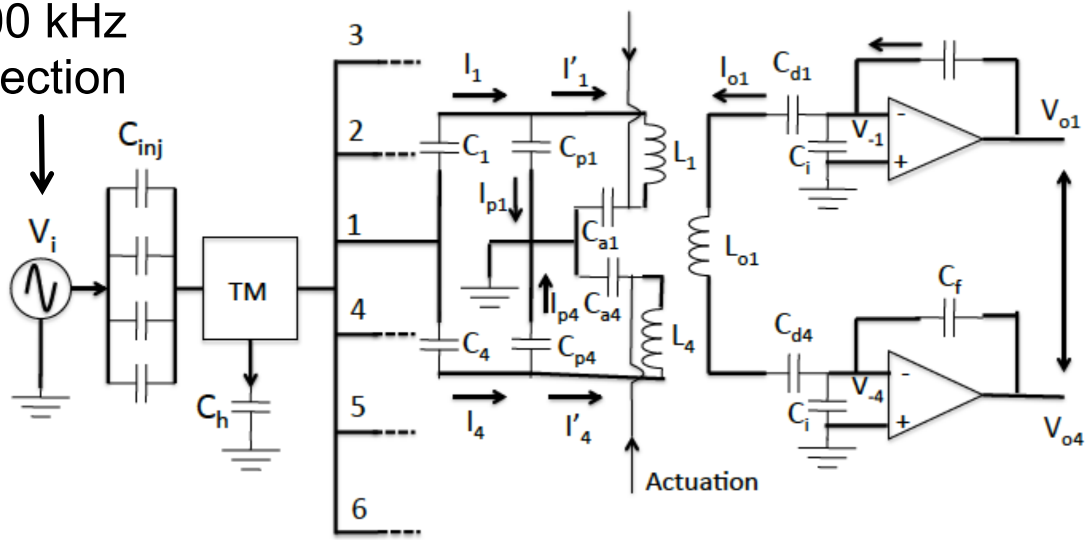
On-ground testing for electrode 10

LPF Front-End Electronics - Sensing



Sensing Bridge

100 kHz
injection

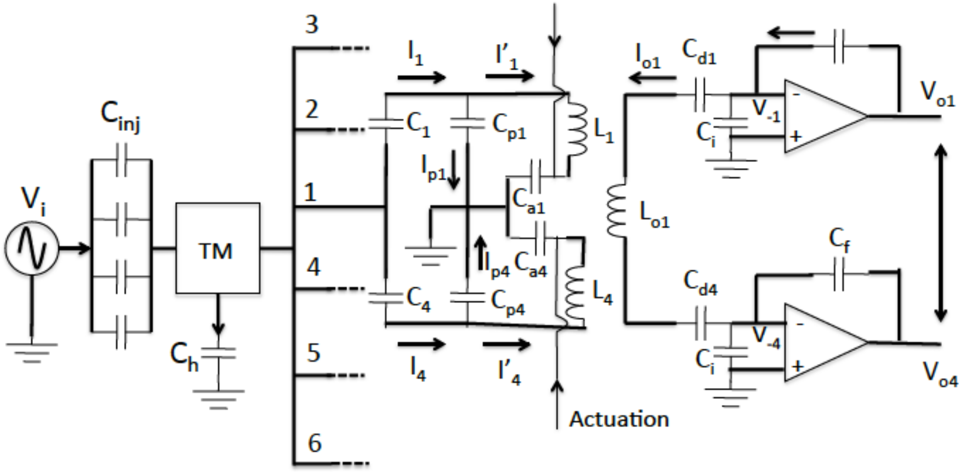


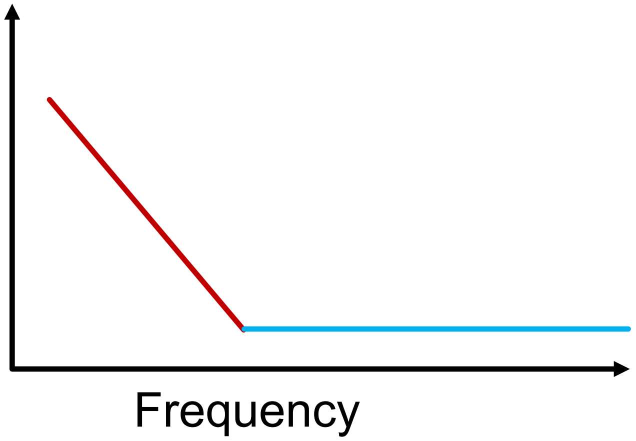
Resonant inductive - capacitive bridge

Resonance is tuned by C_{pi}

At resonance we have the lowest displacement to voltage noise and thus the best SNR.
Gain depends only on Cf and is quite flat around resonance thanks to TIA (trans impedance amplifier)

Sensing Bridge - Noise





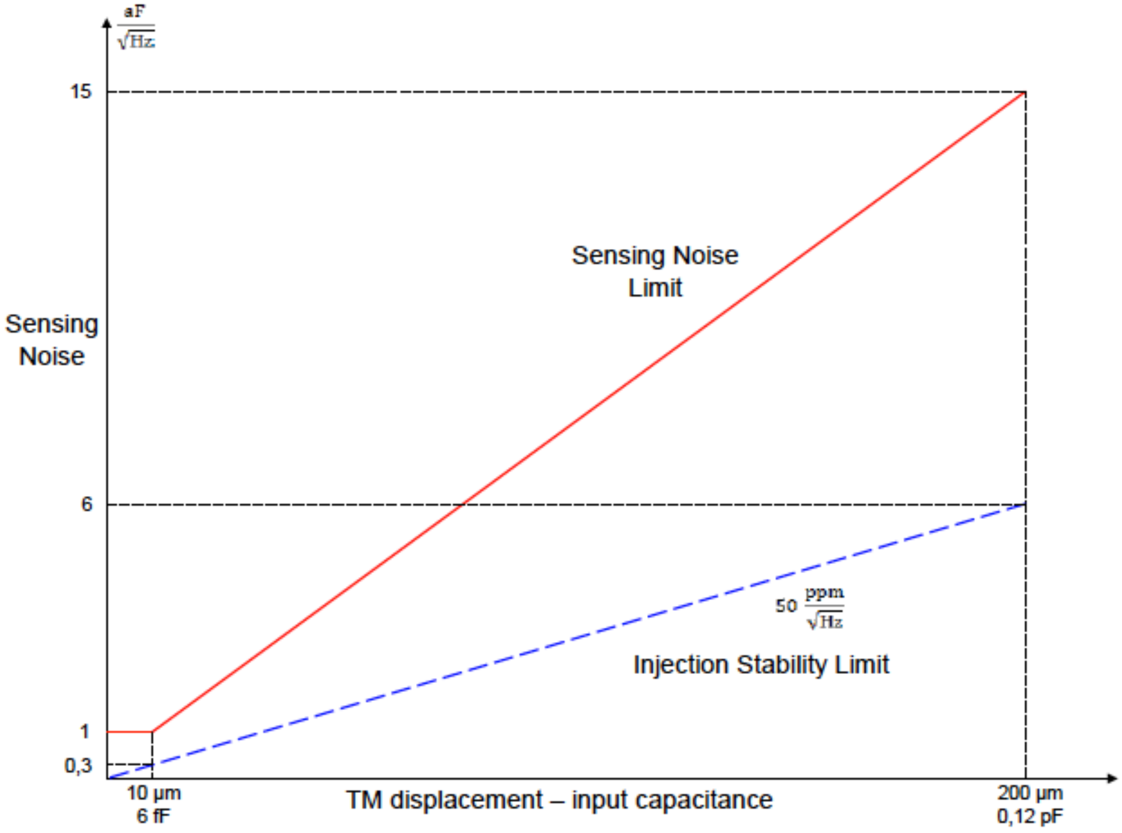
Low Frequency Noise

Voltage reference instability on injection voltage generates a coherent multiplicative noise on all channels

High Frequency Noise

Thermal noise in dispersive elements of the circuit dominated by the quality factor of the transformer bridge

Sensing Bridge – Noise Expectation



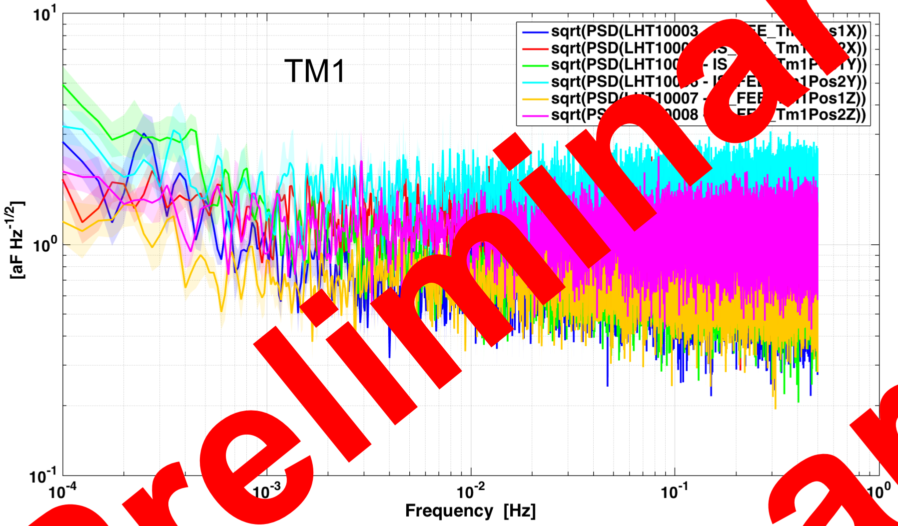
Requirement for the sensing noise in High Resolution mode

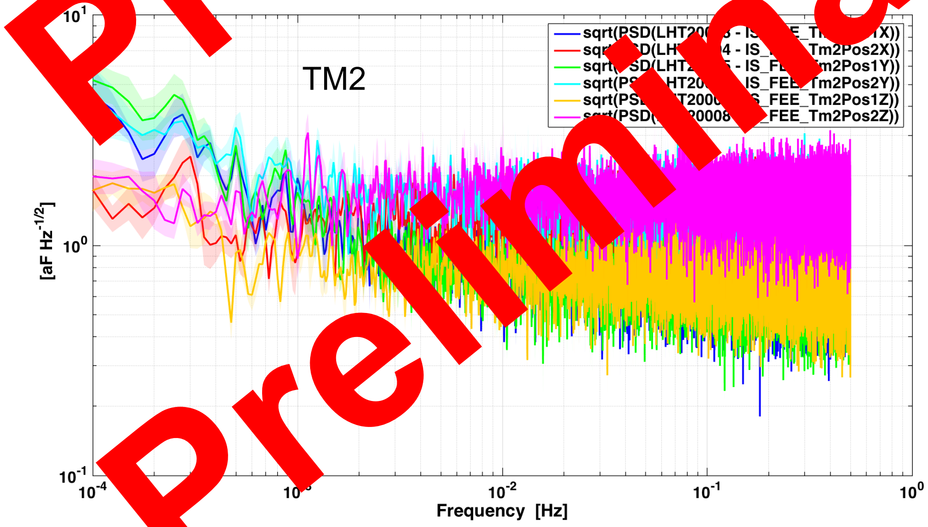
Requirement is flat in performance range, i.e. the first 10 µm in displacement. Then it is multiplicative with the displacement.

Injection instability is supposed to account up to a 30% of the total noise budget

Voltage reference noise has a typical 1/f noise shape that is the main source of the multiplicative noise

Sensing Noise – Measurements





When:
LPF Commissioning
2016/02/07 -> 2016/02/09 Actuation OFF
2016/02/09 -> 2016/02/11 Actuation ON

Measurement conditions:

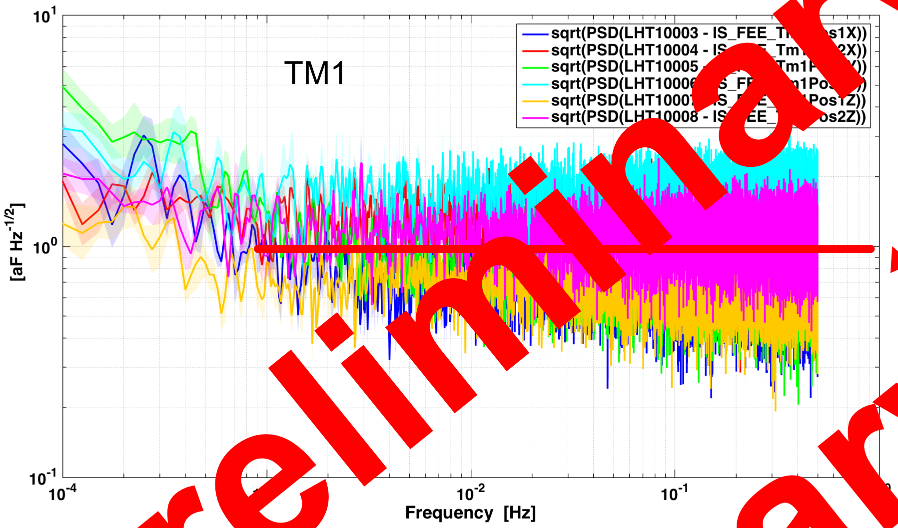
- TM1 and TM2 grabbed by plungers.
- Plungers bias on, nominal value ~0.6 V. Actuation ON. Actuation authority at nominal values F_{x2} = 2.2 nN -> V_{x2} = 3.15 V.

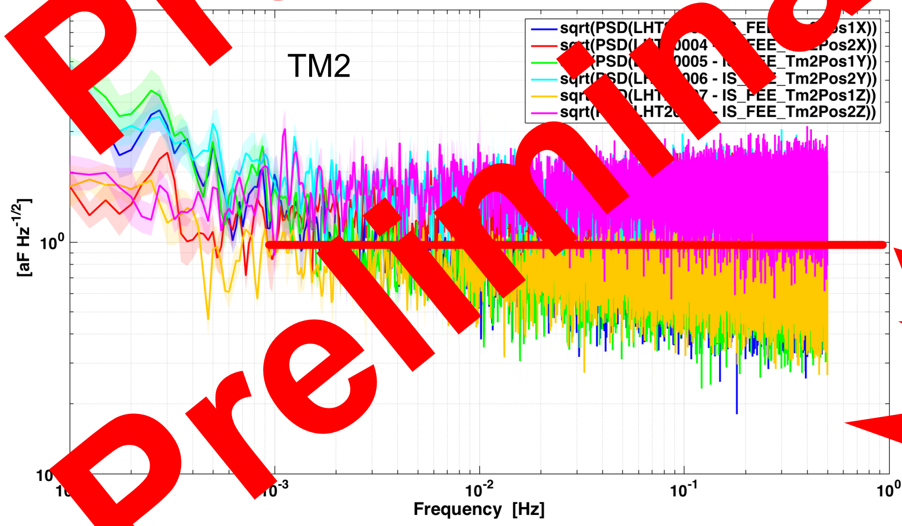
Analysis conditions:

- 6 overlapping segments (overlap percentage 50%)
- 40000 samples per segment in order to have 0.1 mHz as minimum frequency after discarding the first 3 bins (window systematic).
- Blackman-Harris window.
- Linear fit detrend on each segment.

No remarkable difference between actuation ON and OFF measurements

Sensing Noise – Measurements





When:
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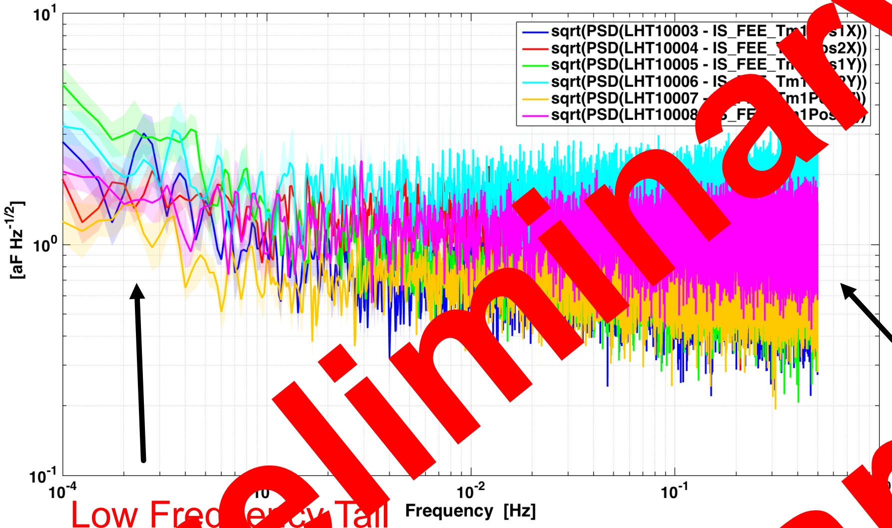
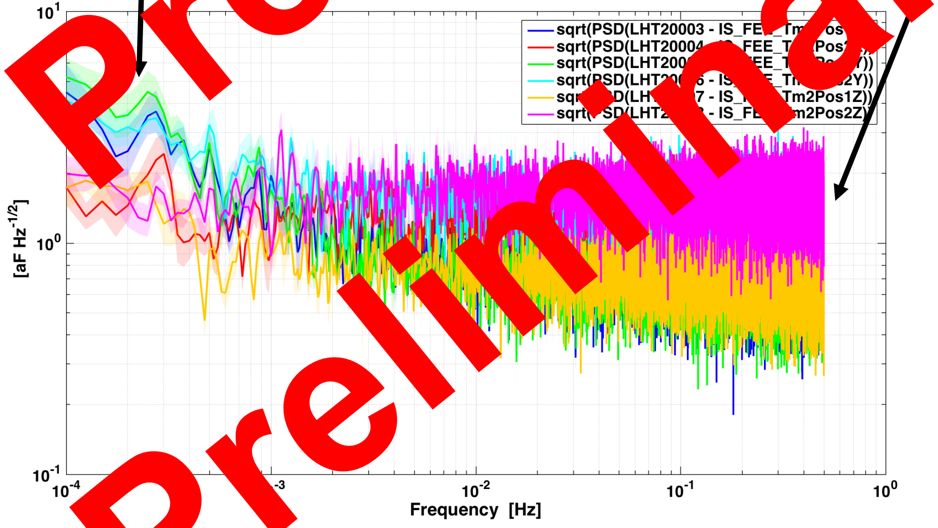
Meet requirements!!!

Sensing Noise – Measurements



Low Fre ency Tail



High Frequency Noise Floor

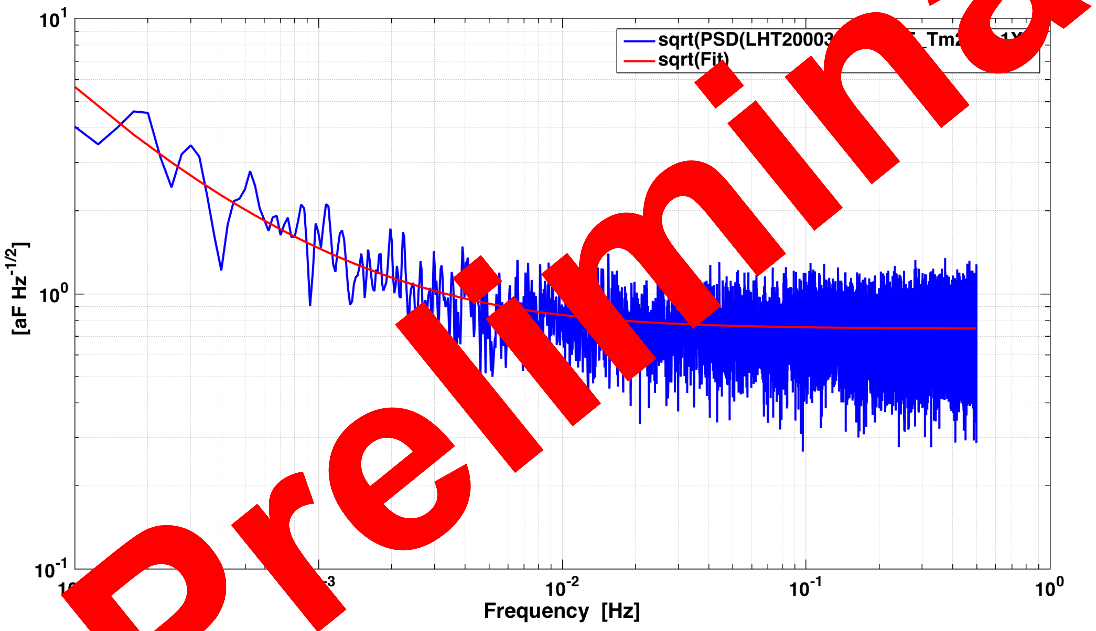
2(XYZ) channels noisier than 1(XYZ) channels

XYZ) channels RMS 0.49 – 0.54 aF

2(XYZ) channels RMS 0.82 – 1.20 aF

Sensing Noise Modelling

$$\mathrm{PSD}\ [\mathrm{aF}^2\ \mathrm{Hz}^{-1}] = A^2 + B^2 * (10^{-3}/f) + C^2 * (10^{-3}/f)^2$$



10^{-3} is introduced as a normalization term to 1 mHz. In this way A, B and C coefficients are expressed in aF/√Hz

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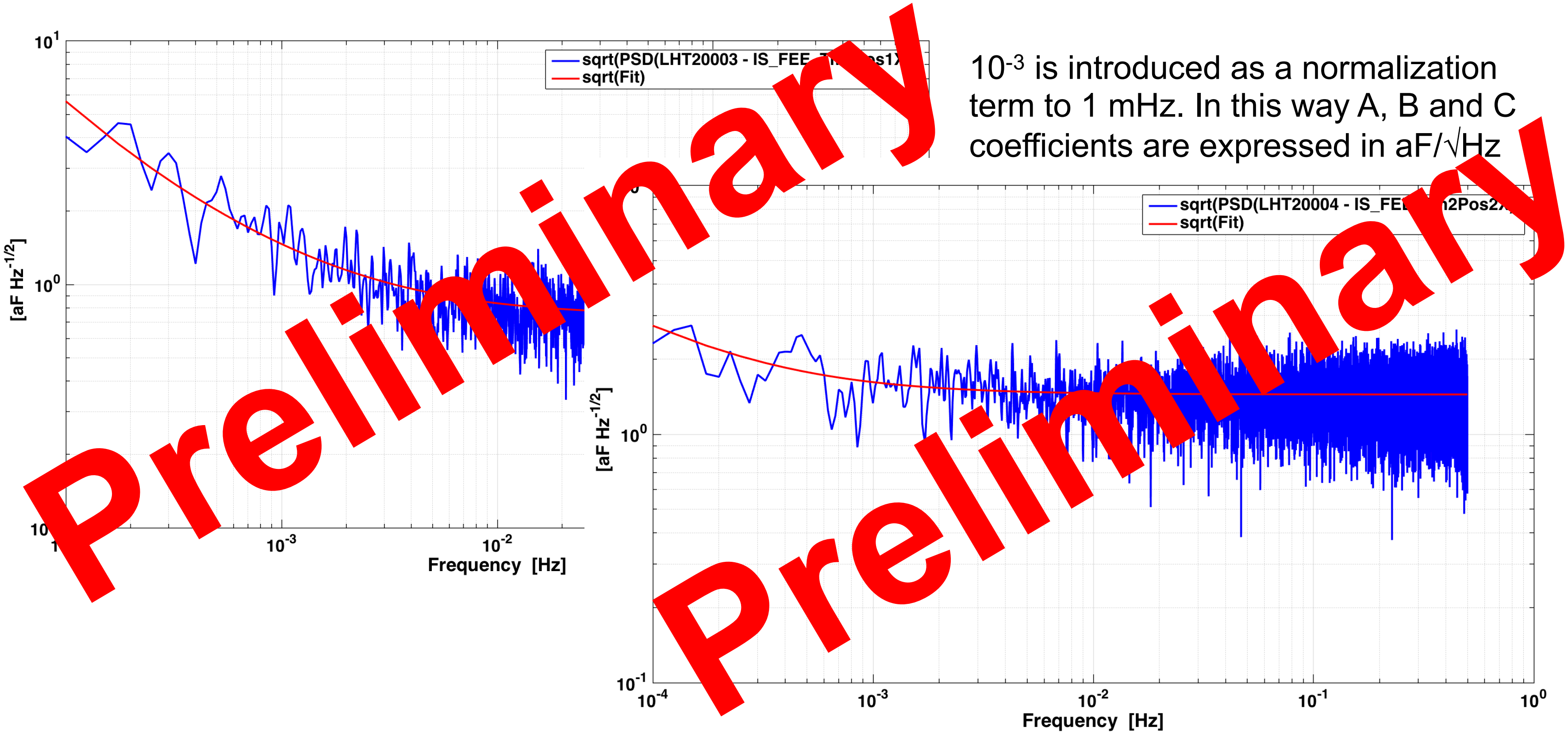

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Sensing Noise Modelling – Analysis – 1/F noise

PSD [aF^2 Hz^{-1}] = $A^2 + B^2 * (10^{-3}/f) + C^2 * (10^{-3}/f)^2$

$[(B_1 |POS|)^2 + B_2^2] (10^{-3}/f)$

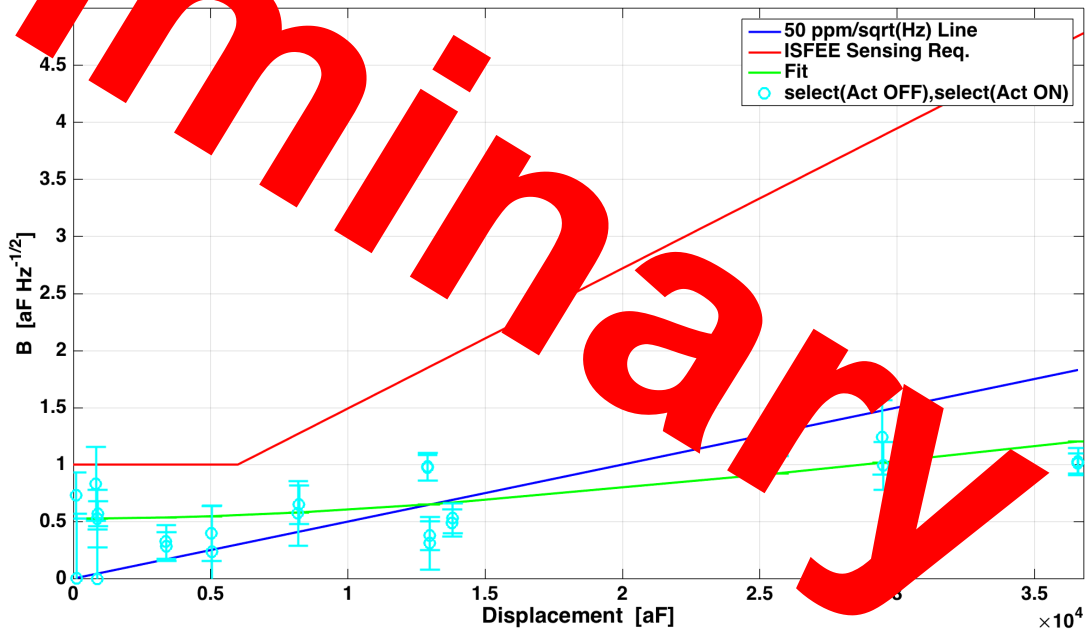
Assumption for a time domain model:

$X_{1/f} = B1|POS| X_c + B2 X_u$

X_c and X_u are uncoherent 1/f noise time series with power 1 aF^2 /Hz @ 1mHz

Plot B vs. Measured displacement

Fit the model for B



Coherence analysis shows that the position dependent contribution is compatible with a common (coherent) source. E.g. TM injection bias stability

Sensing Noise Modelling – Analysis – $1/F^2$ noise

PSD $[aF^2\ Hz^{-1}] = A^2 + B$ [illegible] $(10^{-3}/$ [illegible] $C^2 * (10^{-3}/ f)^2$

$[(C_1\ |POS|)^2 + C_2^2]\ (10^{-3}/f^2)$

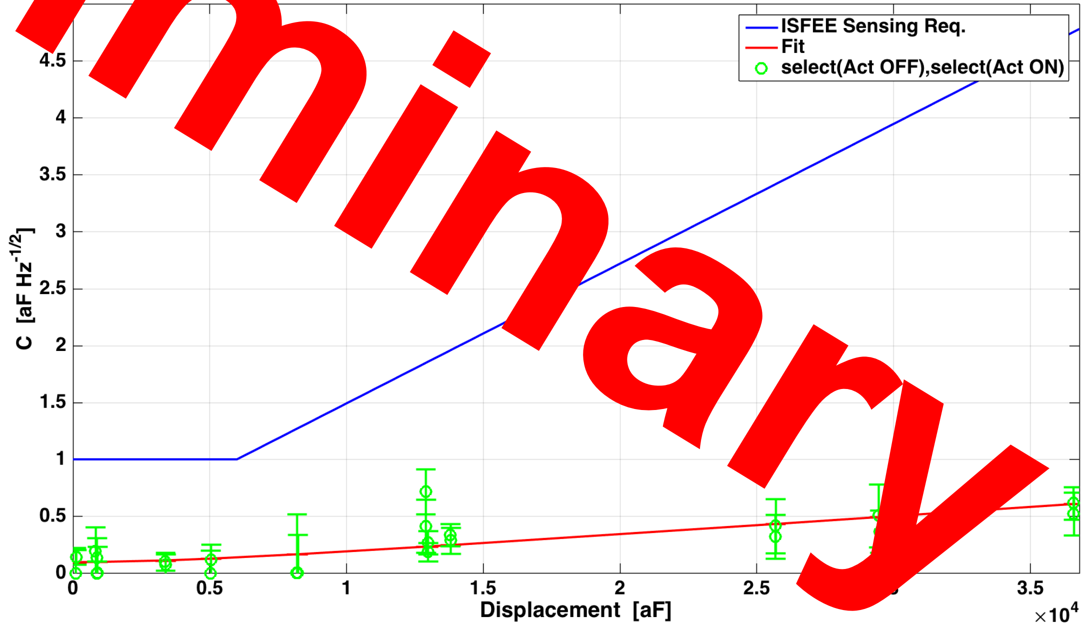
Assumption for a time domain model:

$X_{1/f} = B1|POS|\ X_c + B2\ X_u$

X_c and X_u are uncoherent $1/f^2$ noise time series with power 1 aF^2 /Hz @ 1mHz

Plot C vs. Measured displacement

Fit the model for C



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