FIRST / SPIRE

GSFC Mechanism Prototype 1 modes and control

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Table of contents

Figures

Tables

1 INTRODUCTION

The purpose of this document is to report on GSFC first prototype mechanics regarding the measured mechanical modes, a tetntative of origin of this modes and on the control capability to achieve the scan requirement of the Spectrometer Mechanism under closed loop.

2 MEASUREMENT AND MODELISATION OF THE MECHANICS

2.1 Frequency response of the mechanics

Globally, and after a first frequency identification, the frequency response of the system shows a main stiffness at about 0.4 Hz followed by a resonance and antiresonance around **30 Hz**, a mode @ around **55** Hz, and then another resonances @ **130** Hz and **250** Hz.

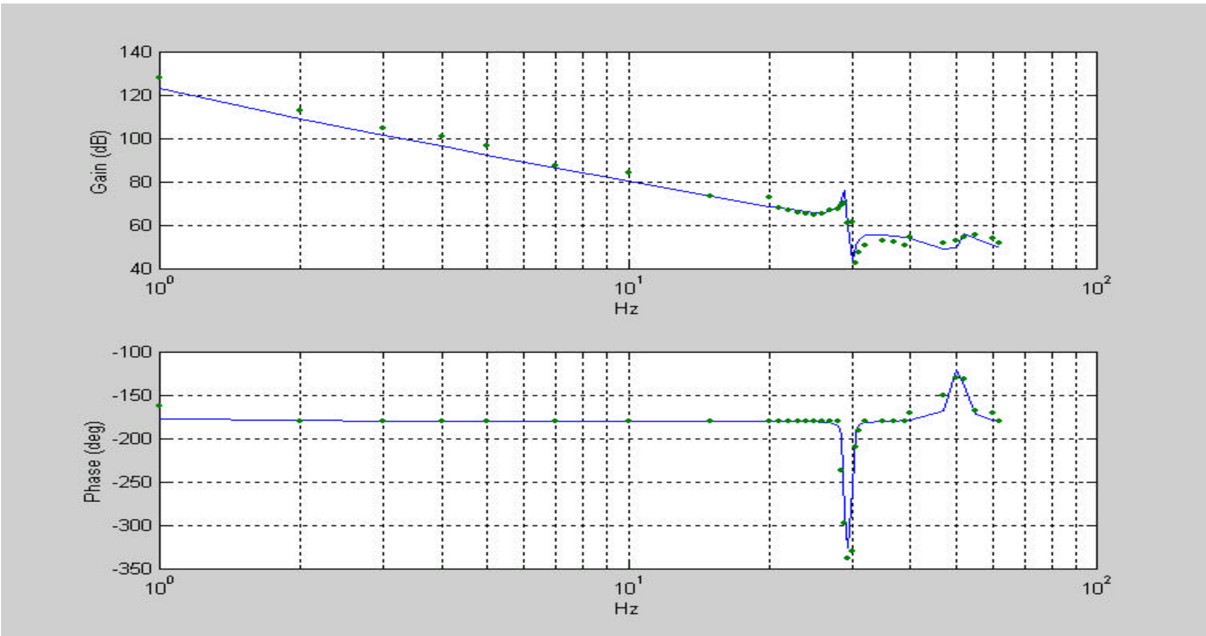
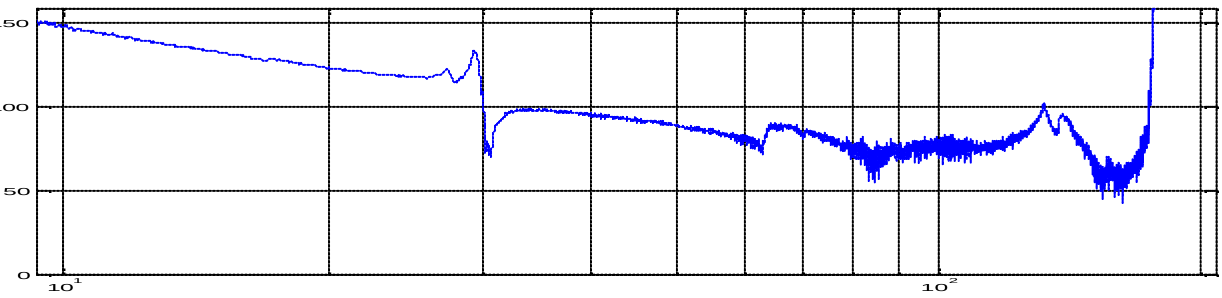


Figure 1: Frequency response of GSFC Mechanics Prototype 1 (up to 100 Hz)

2.2 Disparity of the mechanical response

In fact, the measurements at various carriage position show a disparity in the value and the damping of the main modes, as shown on next figures.



Chirp5200.mat

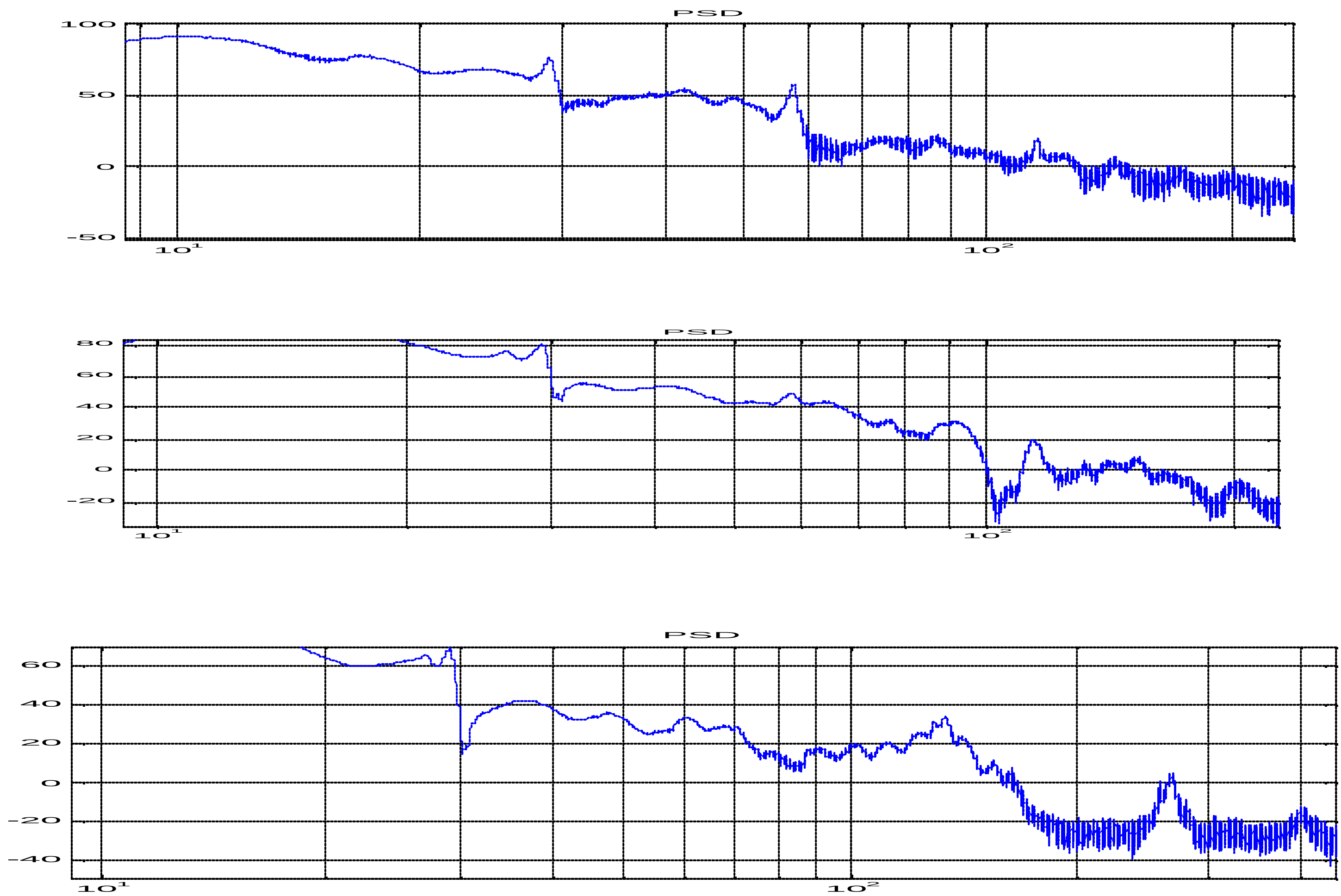


Figure 2 Mechanical modes depending on experiment conditions

2.3 Non linearities in the frequency response

Additionnaly, the 30 hz resonance-antiresonance damping is not linear, depending on the level of the sine stimulus, ie it appears only after a threshold of stimulus. This level could be explained by the friction existing at compensation level which damps the 30 Hz for low signals. For very low sine stimulus, the 30 Hz does not appear as a resonance with a 180 degree phase shift. Then the phase shift between the stimulus and the encoder signal appears and increases when applying an increasing stimulus. The following figures show the response at 30Hz depending on the level of the stimulus, due to non linear effects.

In these conditions it shall not be possible to compensate exactly the modes by notching. It is the reason why the the notching shall be very large only to insure closed loop stability, but without the possibility to damp the modes which shall be visible with residual effect in closed loop operation.

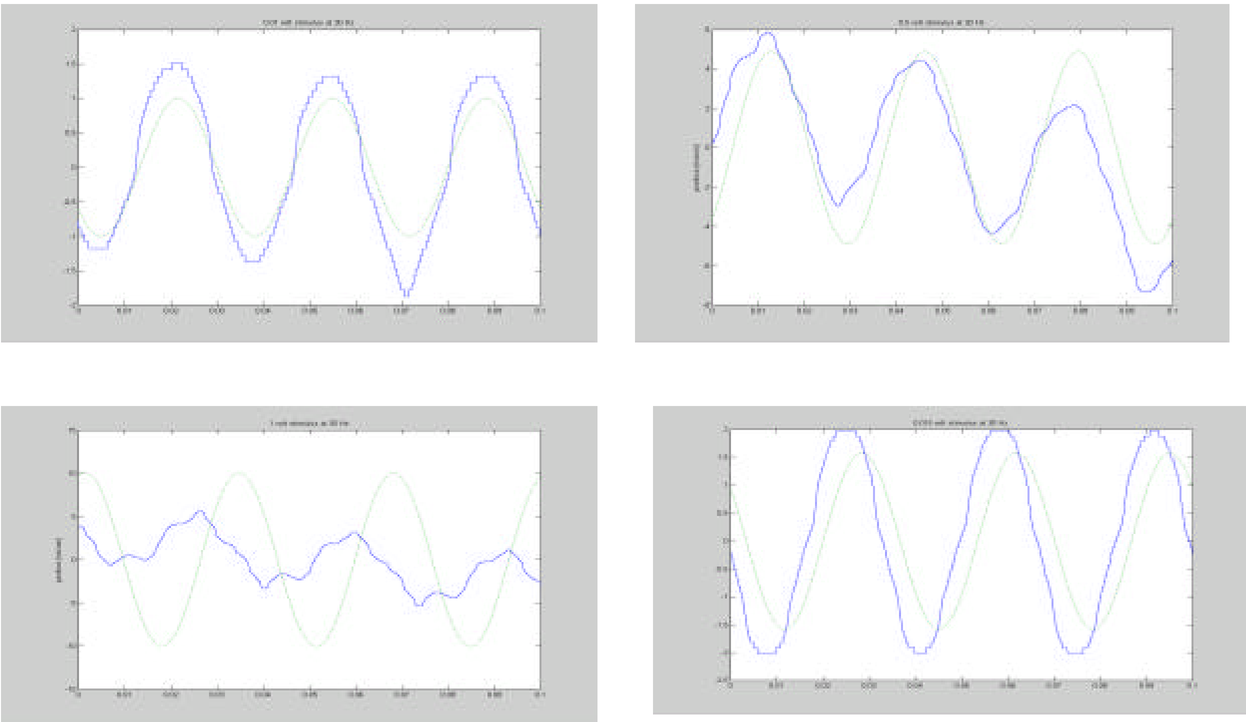


Figure 3: Responses at 30Hz at various stimulus amplitude

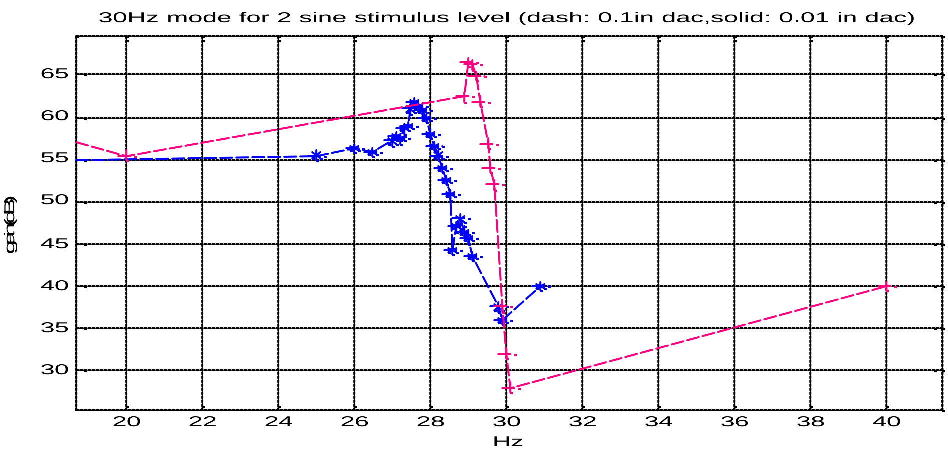


Figure 4 : 30Hz mode disparity vs stimulus amplitude

2.4 Modelisation of the mechanics

The 30 Hz mode could be due to the frame longituninal deformation (deformation of the parallelogram) due to pivot sharing effort associated with a torsion effect due to the fact that the encoder and the motor are not on the same geometrical center of gravity. This deformation is composed with a 2 mass spring system which induces a resonance/antiresonance effect. The 2 mass-spring model can be explained by the fact that there are 2 semi pendulum with intermediate mass.

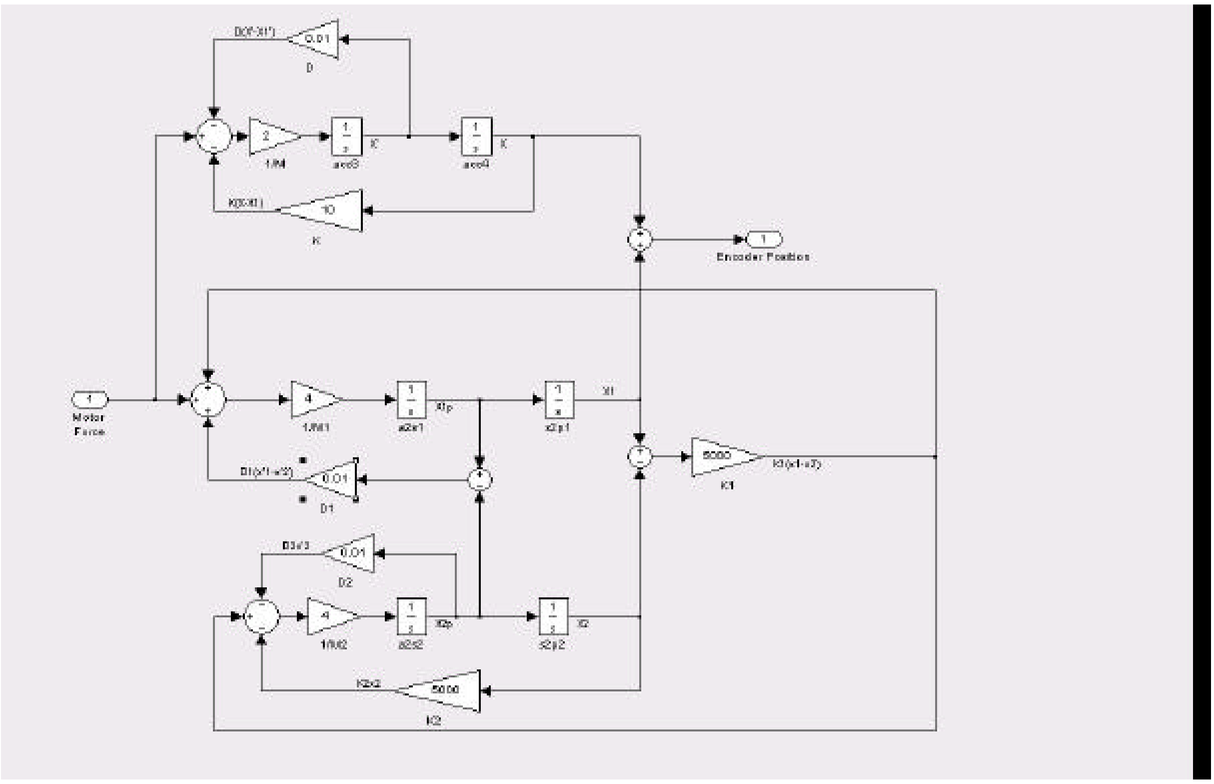


Figure 5: Mechanism model

2.5 Analysis of non linearities

The different behaviours can be explained by the fact that the damping achieved by the friction does not act when the signal increases. The resonance/antiresonance disappears more or less when applying an additional mass increasing of about 200 g on the top of the mechanism. This could be explained by the increase of the friction level.
The two cases are illustraded on next figures using the mathematical model.

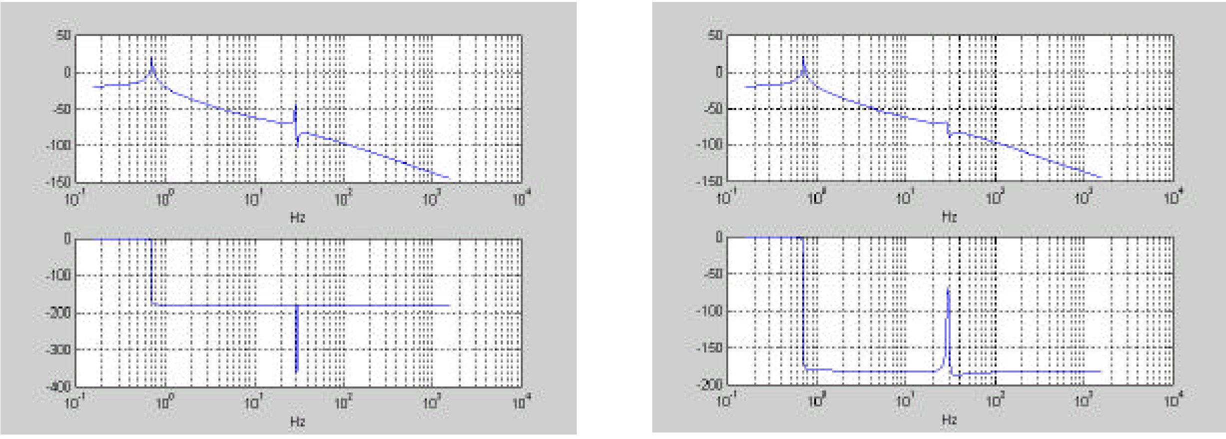


Figure 6: Mechanics frequency response with low damping (left) and high damping (right)

This explanation is not quite satisfactory since the mass increase of the intermediate stage changes in the real world the resonant-antiresonant mode shape (see next figure).

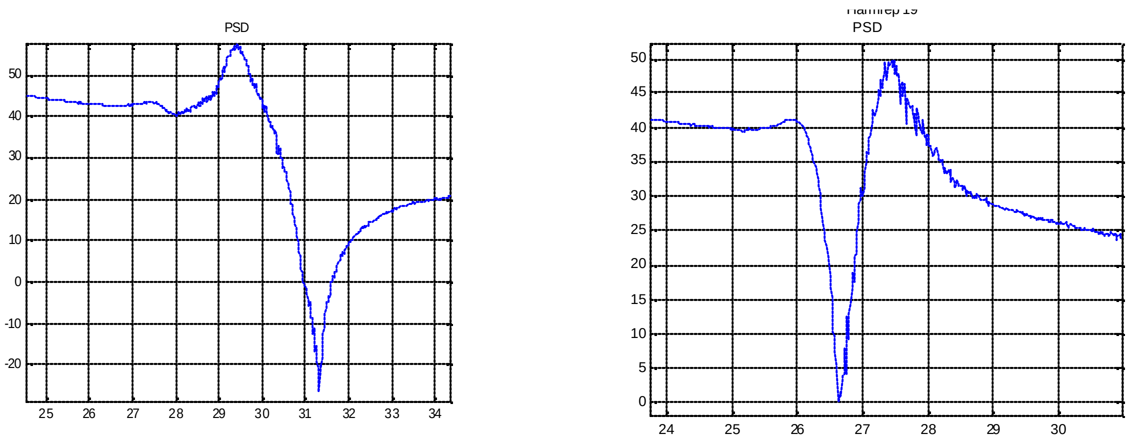
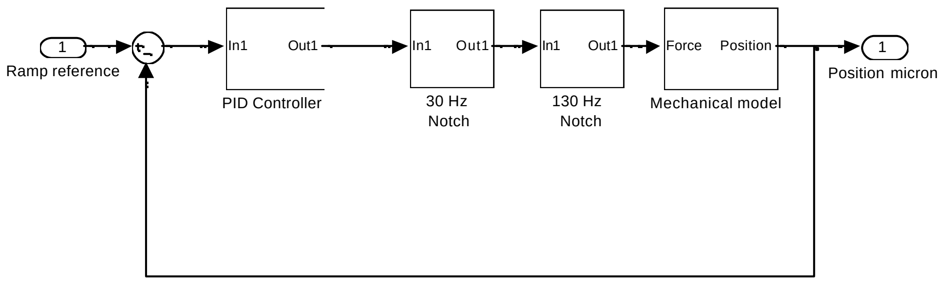


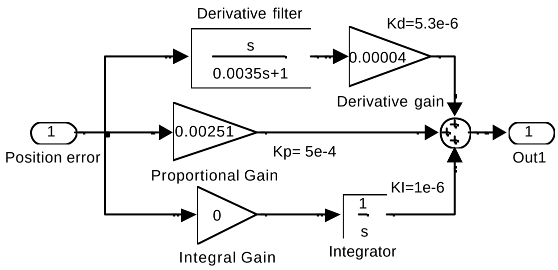
Figure 7: frequency reponse @ 30Hz without and with additional mass on top

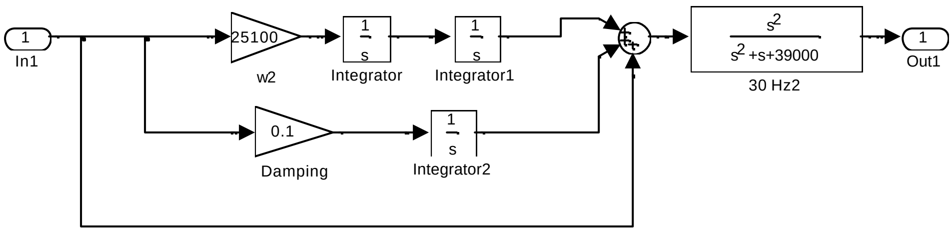
3 CONTROL OF THE MECHANISM

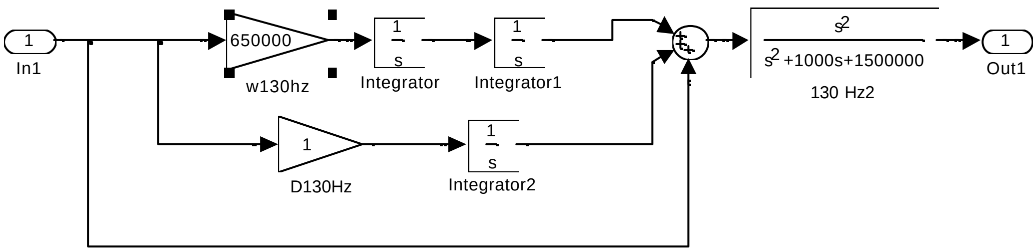
3.1 Controller model

The control loop is closed using a PID controller with a notching at 30 and 130 Hz.





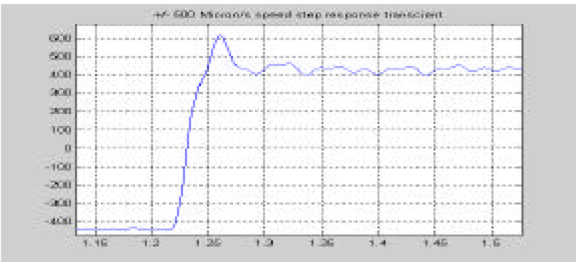




3.2 Results on the test bench

3.2.1 Control time response and bandwidth

The closed loop is tuned to yield a 50 ms time response, but with an undampped mode at 30 and 60 hz. (linear combination of the 2 resonances). About the 30 Hz, we are limited by the torsion effect and not really by the longitudinal displacement. Indeed, in the former case, the motor can not control the mode since the motor can not counter act in rotation. In the case of the longitudinal displacement, we can damp the mode clossing the loop at a higher frequency (in this case we try to avoid the torsion mode). Due to the non linearity of the 30 hz behaviour, the notching is not achieved precisely.



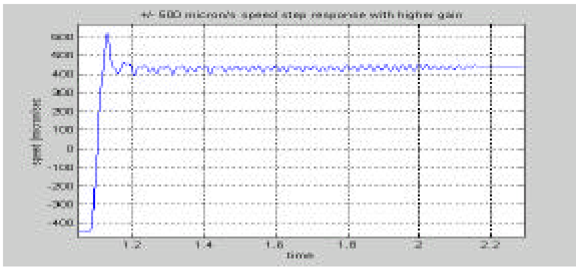
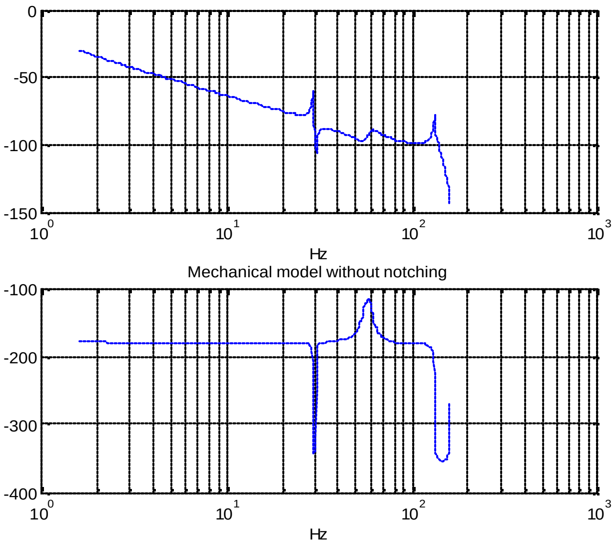
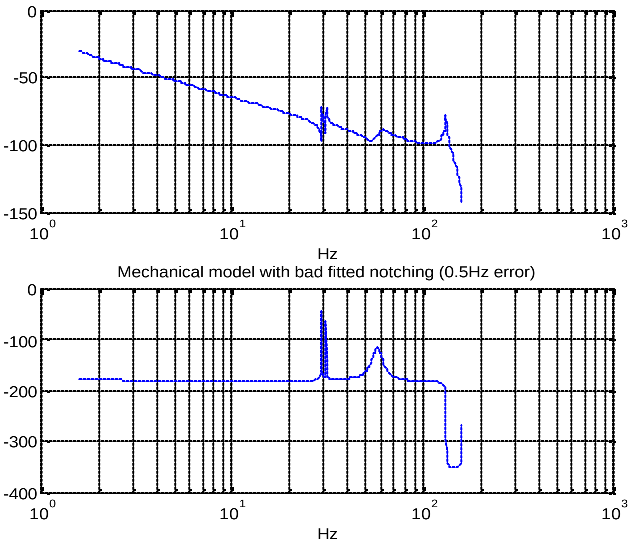


Figure 8: Time response of the control with two set of PID parameters

3.2.2 Effect of a bad notching

We see hereafter the consequence of a bad notching. If the resonance frequency moves, the notch induces a parasitic resonance. The notch effect is efficient over a very narrow frequency range (<<0.5 Hz) due to the very high proximity of the resonant/anti-resonant frequencies associated with a very low mechanical damping of the modes. One can foresee to add mechanical damping using Eddy current damping devices.

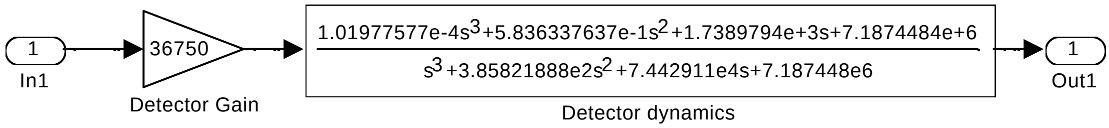




3.2.3 Stability of the speed control

3.2.3.1 Specification of speed stability

It is required that the speed shall not fluctuate more than 10 µm/s rms over the scan, after detector filtering. The detector filtering consist of a 3rd order filter with a 29 Hz cut-off frequency. The model shown hereafter is deduced from JPL detector data.



The detector response is shown on the following transfer function plots.

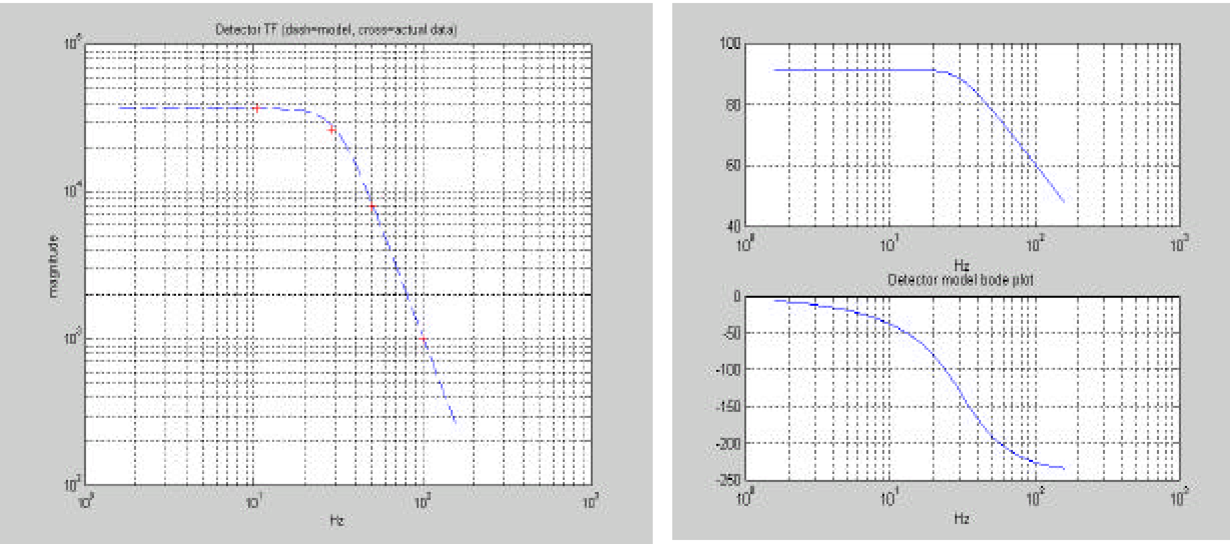


Figure 9: Spire detector frequency response

3.2.3.2 Speed stability results

In these conditions, ie in very stable conditions in the laboratory without external disturbance (measured < 10mg), and with a closed loop at 20Hz, the velocity specification are achieved since the undampped mode at 30 hz is less than 5 µm/sec after a 3th order filter at 29 Hz modelling the detector filtering. The closed loop at about 20 Hz (50 ms time response) may be sufficient in flight if the external disturbances on the satellite are very low.

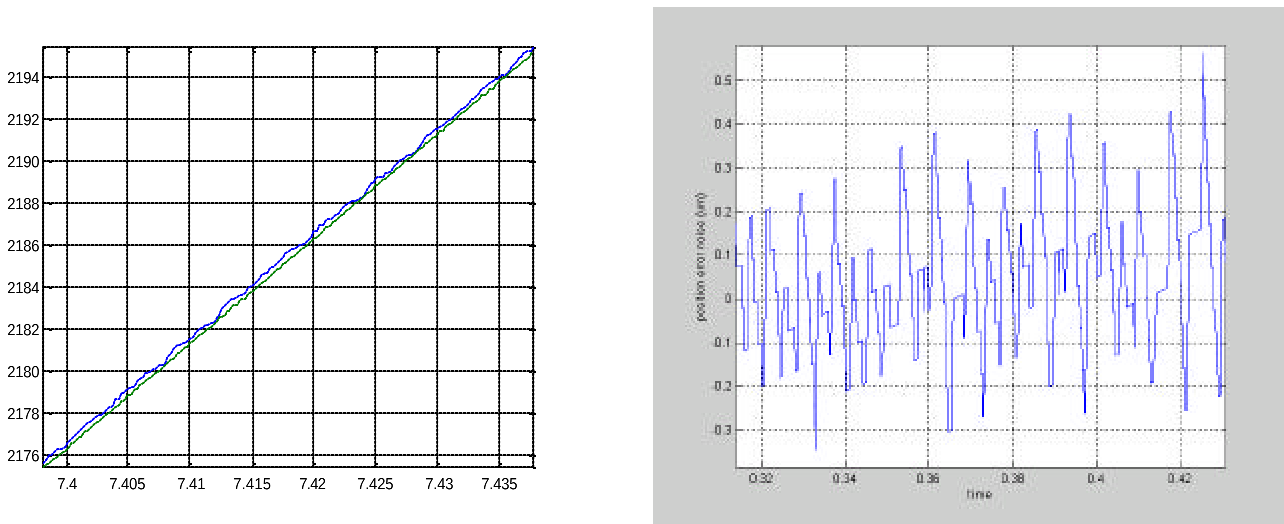


Figure 10: Position fluctuations during a 500 mm/s scan

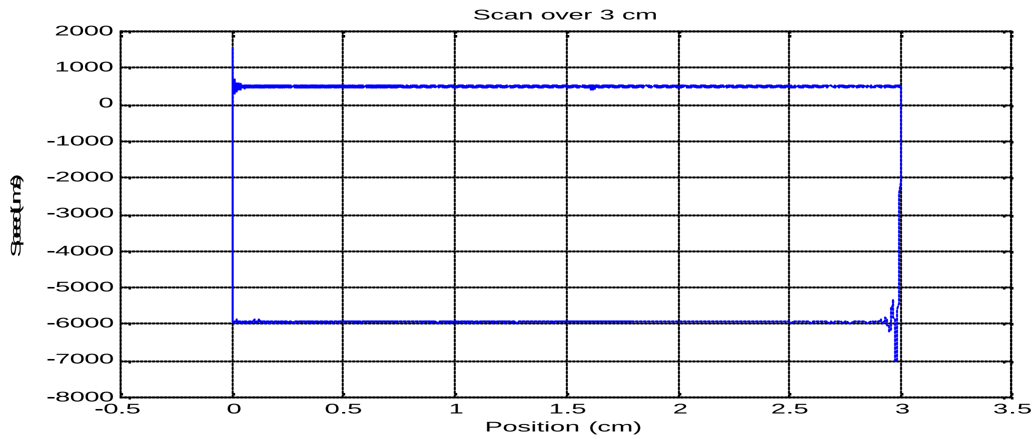


Figure 11: Filtered Speed over a 3cm scan

3.2.3.3 Speed stability vs. scan position

The speed stability performance is not the same depending on the scan position: since the mechanical modes are not constant according to the scan position, the notching is not equally efficient for all positions. A compromise has been done to optimize speed stability for a short range of few millimeters at one end of the scan in order to obtain good performances near the ZPD. The speed stability vs. the scan position is shown in the next table.

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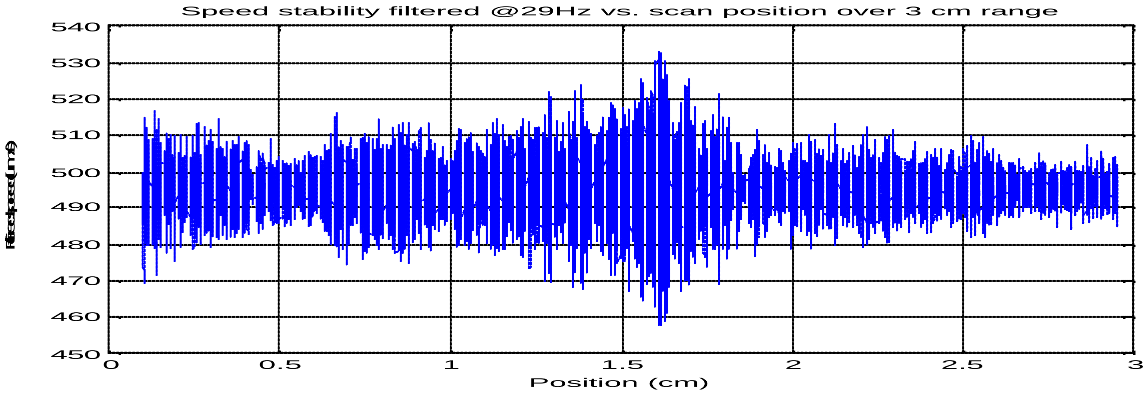


Figure 12: Speed stability vs. scan position

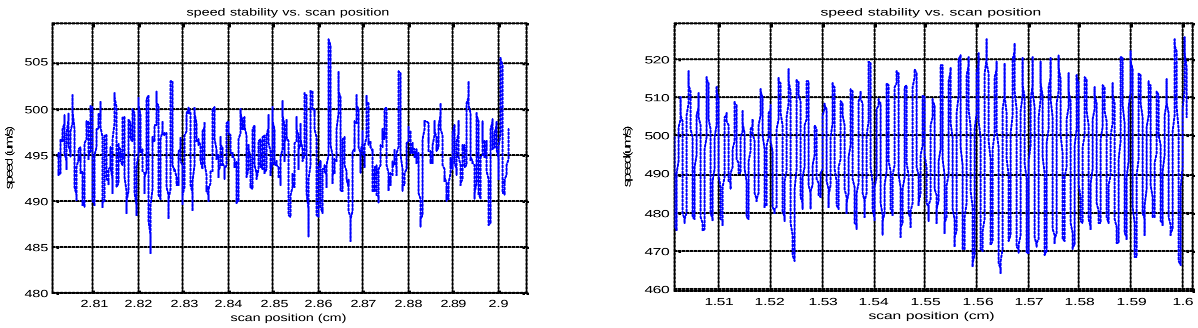


Figure 13: Best and worst cases of speed stability

Scan position (cm)	Filtered Speed fluctuation (um/s)
0.1	8.6
0.2	6.3
0.3	6.5
0.4	4.3
0.5	4.1
0.6	6.9
0.7	7.6
0.8	8.2
0.9	6.1
1.0	6.8
1.1	8.2
1.2	9.6
1.3	10.3
1.4	10.2
1.5	14.5
1.6	17.4
1.7	9.1
1.8	6.2
1.9	4.8
2.0	5.5
2.1	5.3
2.2	6.2
2.3	4.5
2.4	4.2
2.5	5.1
2.6	3.3
2.7	3.2
2.8	3.4
2.9	3.7

Table 1: Filtered speed fluctuation rms values vs. scan position

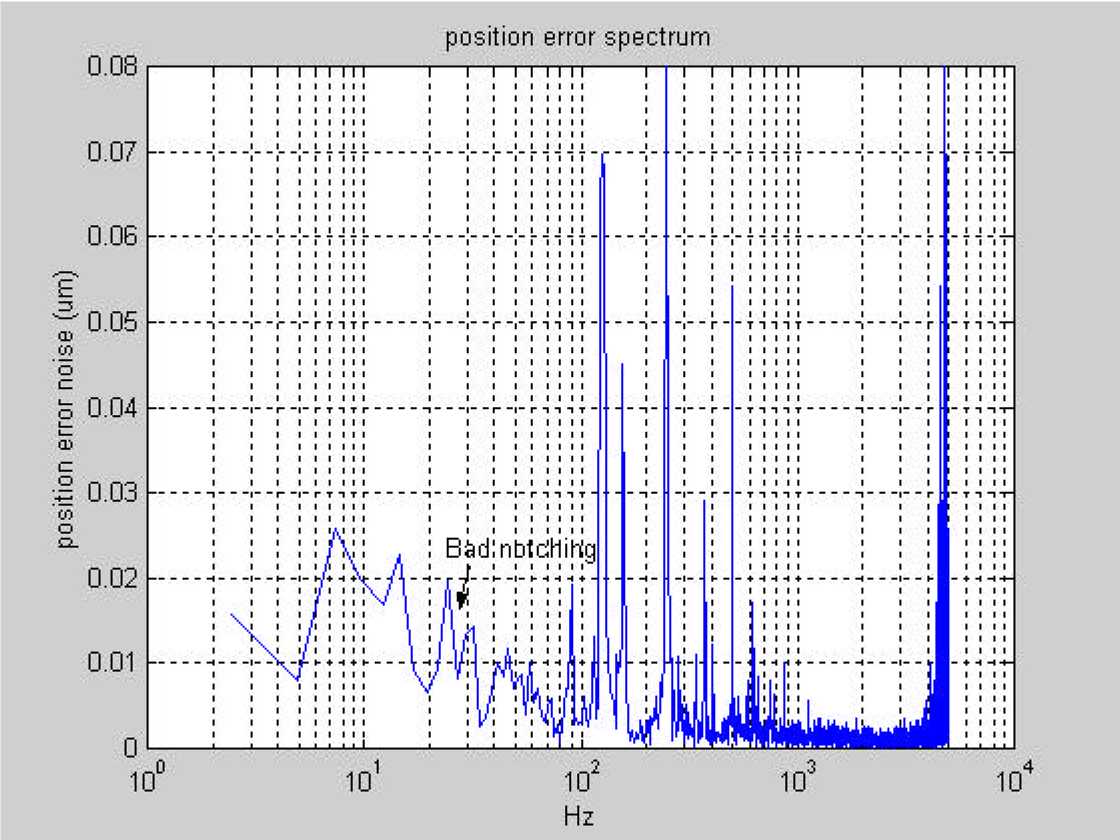


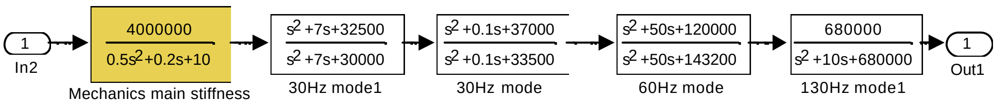
Figure 14 : position error spectrum

3.3 Simulation of the FTS on MATLAB

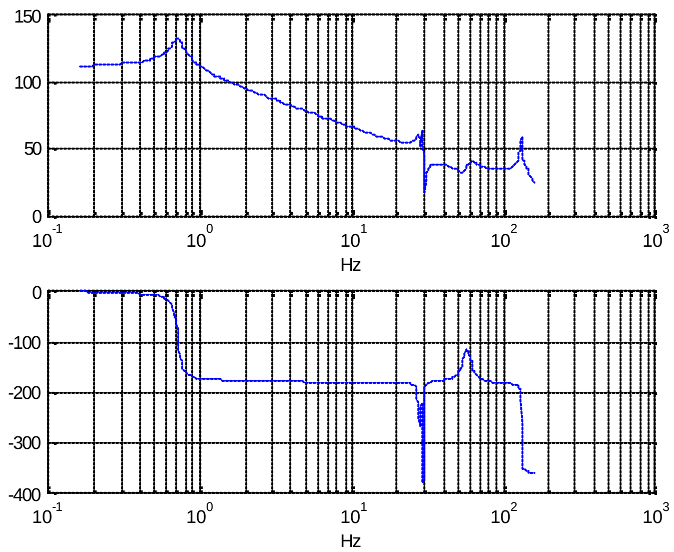
3.3.1 Mechanical Model

In order to get a mathematical model of the process which can be uses for a FTS simulator, a mechanical transfer function is deduced from the actual process identification.

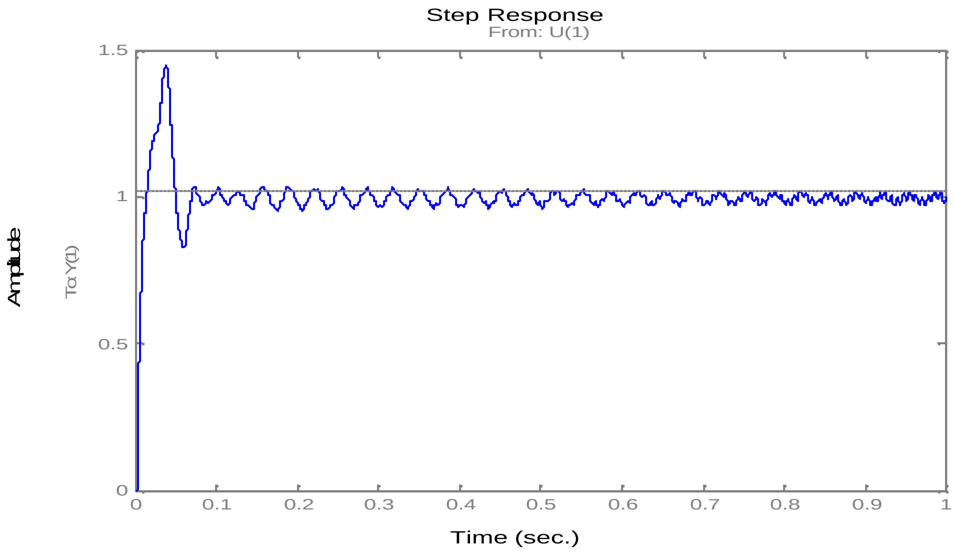
The mechanical model is shown next figure (file mectf.mdl)



The transfer function is shown next figure, to be compared with measurements on the actual process.



3.3.2 Speed step response simulation



The simulation shows more or less the same dynamic behavior with the undamped 30 Hz mode associated with 130Hz oscillations, due to the poor stability margin of the servo closed loop.

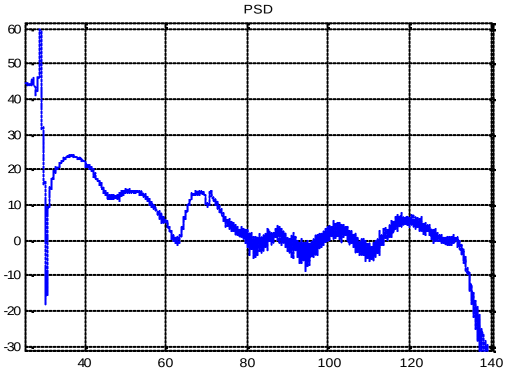
4 ANNEXES

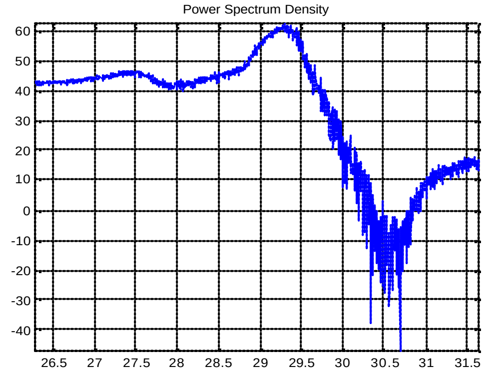
4.1 Detailled results of identification

4.1.1 Harmonic responses using a chirp signal

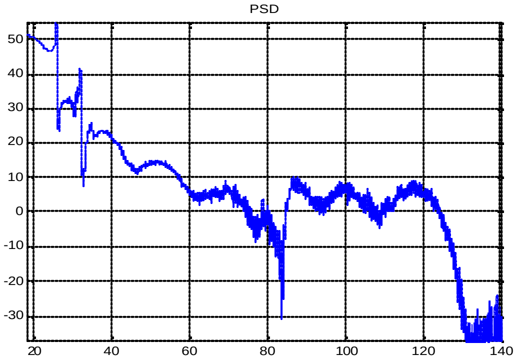
In the following measurements we try to measure with maximum accuracy the various modes to be compensated by notching. The following table shows the various experiment conditions.

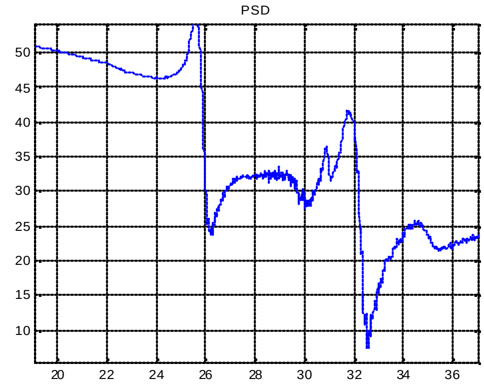
File title	Freq min	Freq max	Duration/ Tsamp	Stim. Level	Resonance freq	Zero frequency	Damping	FTS Position (cm)
Harmresp1	5	150	300/0.001	0.01	**29.3**	**30.5**		+1
Harmresp7	5	150	300	0.05	28.35	30.55		+1
Harmresp8	5	150	300	0.003	**29.4**	**30.8**		+1
Harmresp9	5	150	300	0.005	27.4 29.6	28.1 30.8		+1
Harmresp10	5	150	300	0.1	26 28.85	27.5 30		+1
Harmresp11	5	150	600	0.1	26 28.8	27.5 30		+1
Harmresp16	5	150	500/0.001	0.01	29.2	30.6	77dB	+1
Harmresp12	5	150	800	0.05				0
Harmresp13	5	150	500	0.003				0
Harmresp2	5	150	300	0.01	25.6 30.7 31.8	26.1 31.2 32.5		0
Harmresp3	5	150	300	0.01	**29.4**	31.3		+2
Harmresp15	5	150	300	0.05				+2
Harmresp4	5	150	300	0.01	***26.8*** **29.4**	27.2 30.85		+0.5
Harmresp5	5	150	300	0.05	26.35 **29.2-30.9**	27.3 30.9		+0.5
Harmresp14	5	150	500	0.05	***26.3*** ***30.5***	27.3 31.5		+0.5
Harmresp6	5	150	300	0.001	***26.8***-27.4 30	27.4 31.8		+0.5
Harmresp17	5	150	400	0.1 #0.01				Left –1.5 cm R=22Ω
Harmresp18	5	150	400	0.1#0 .01				Middle:0 R=22Ω
Harmresp 19	5	150	400	0.1#0 .01				+1 with additiional mass R=22Ω



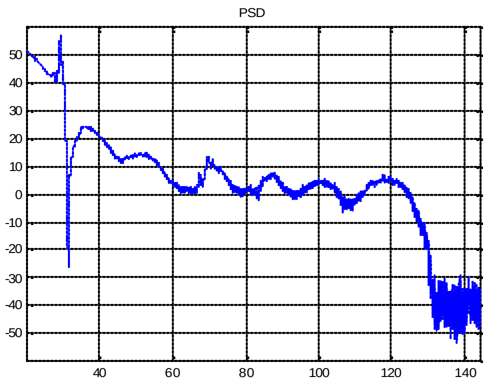


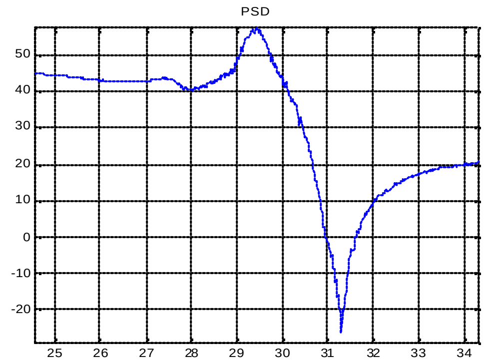
Harmresp1



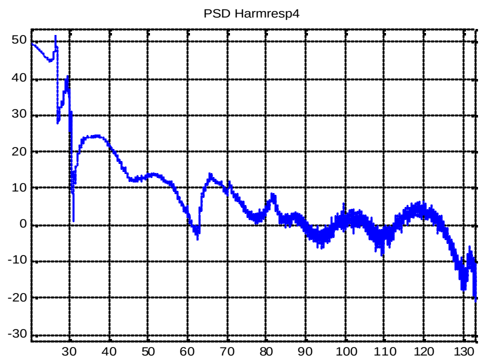


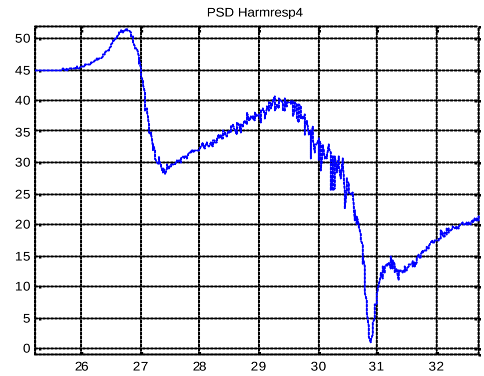
Harmresp2



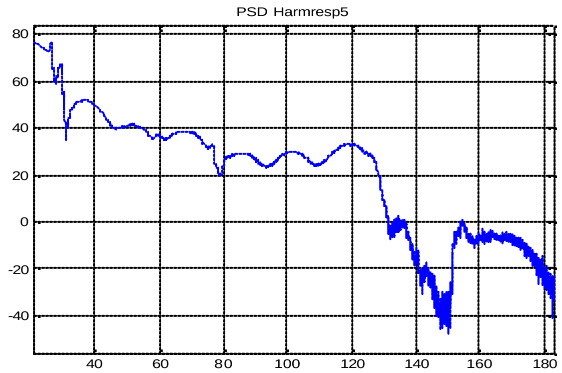


Harmresp3

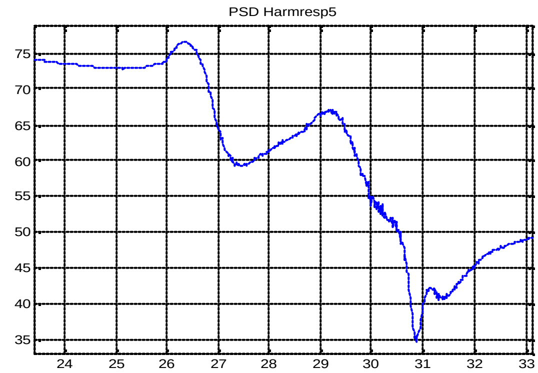




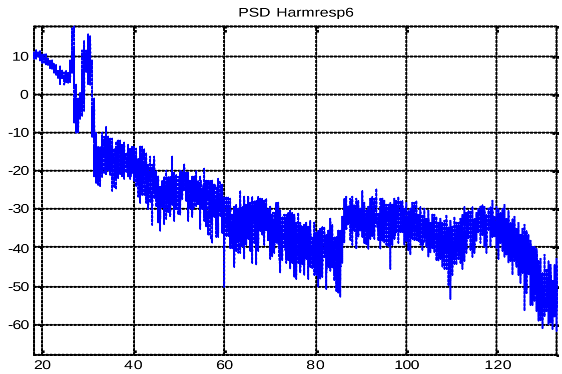
Harmresp4



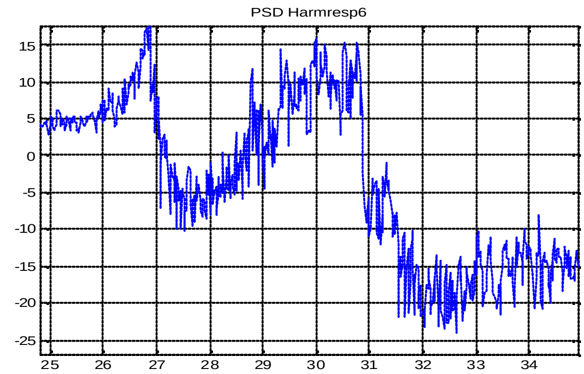
PSD Harmresp5
80
60
40
20
0
-20
-40
40 60 80 100 120 140 160 180



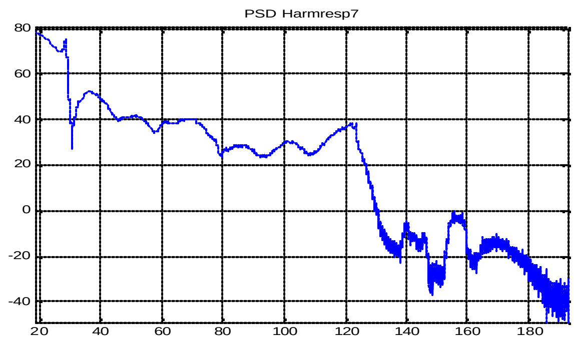
PSD Harmresp5
75
70
65
60
55
50
45
40
35
24 25 26 27 28 29 30 31 32 33



PSD Harmresp6
10
0
-10
-20
-30
-40
-50
-60
20 40 60 80 100 120



PSD Harmresp6
15
10
5
0
-5
-10
-15
-20
-25
25 26 27 28 29 30 31 32 33 34



PSD Harmresp7
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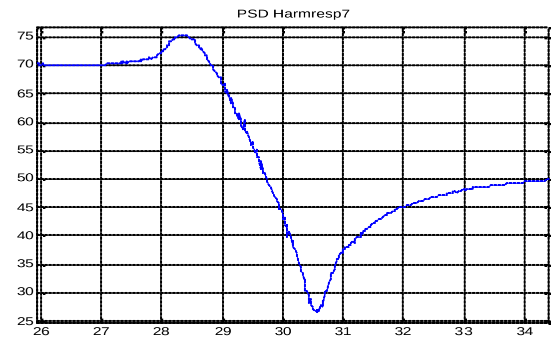
60
40
20
0
-20
-40
20 40 60 80 100 120 140 160 180



PSD Harmresp7
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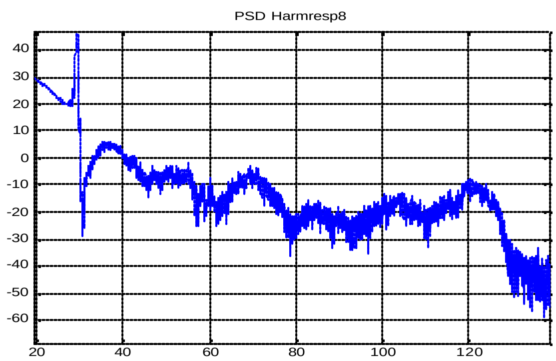
70
65
60
55
50
45
40
35
30
25
26 27 28 29 30 31 32 33 34



PSD Harmresp8
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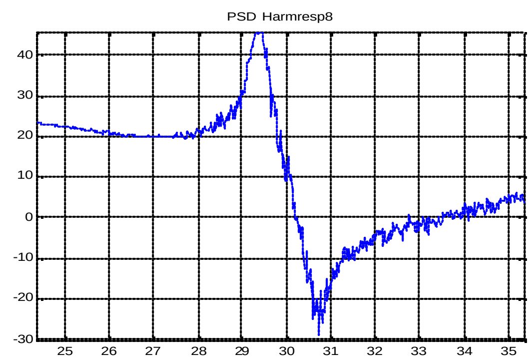
30
20
10
0
-10
-20
-30
-40
-50
-60
20 40 60 80 100 120



PSD Harmresp8
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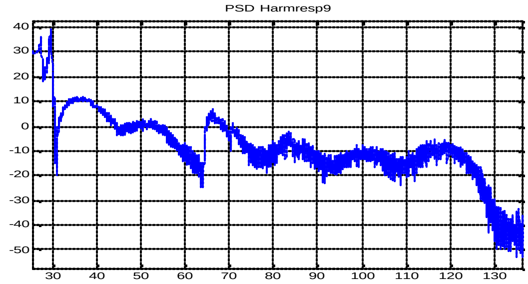
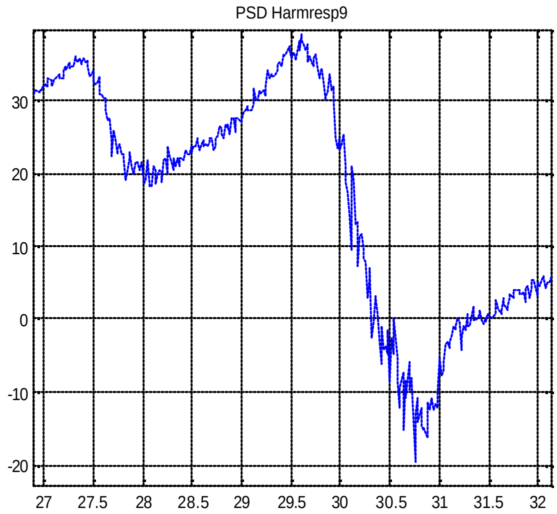
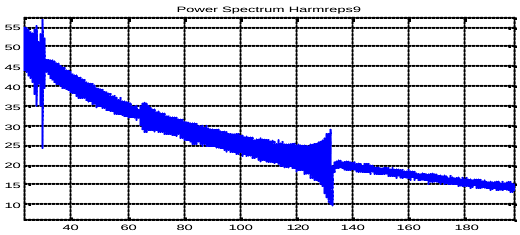
30
20
10
0
-10
-20
-30
25 26 27 28 29 30 31 32 33 34 35



PSD Harmresp9
40 30 20 10 0 -10 -20 -30 -40 -50
30 40 50 60 70 80 90 100 110 120 130



PSD Harmresp9
30 20 10 0 -10 -20
27 27.5 28 28.5 29 29.5 30 30.5 31 31.5 32



Power Spectrum Harmreps9
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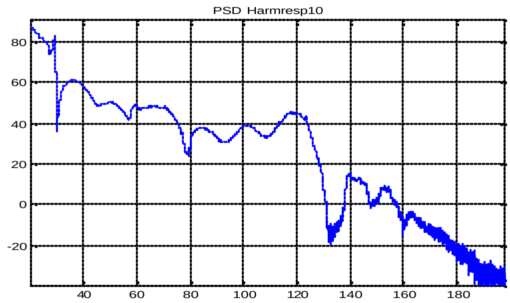
40 60 80 100 120 140 160 180



PSD Harmresp10
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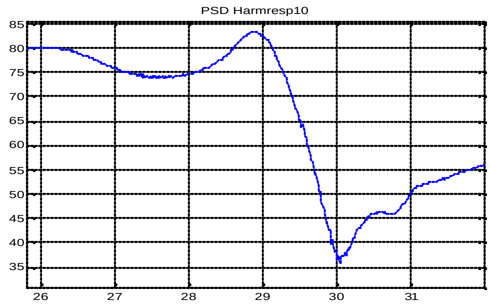
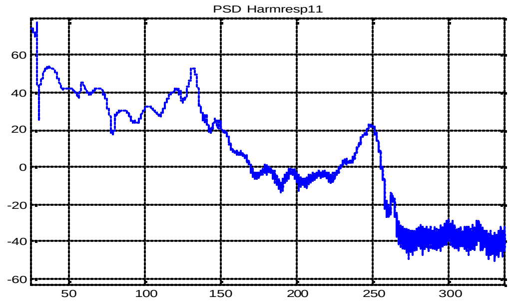
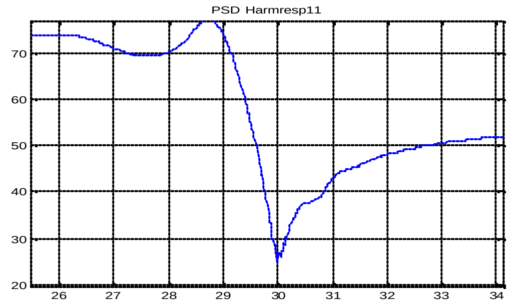
40 60 80 100 120 140 160 180



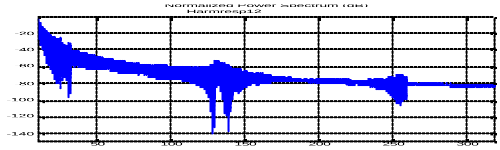
PSD Harmresp10
85 80 75 70 65 60 55 50 45 40 35
26 27 28 29 30 31



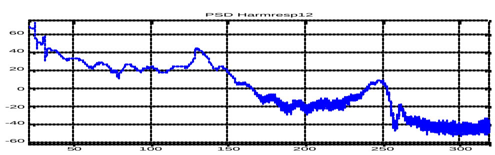
PSD Harmresp11
60 40 20 0 -20 -40 -60
50 100 150 200 250 300



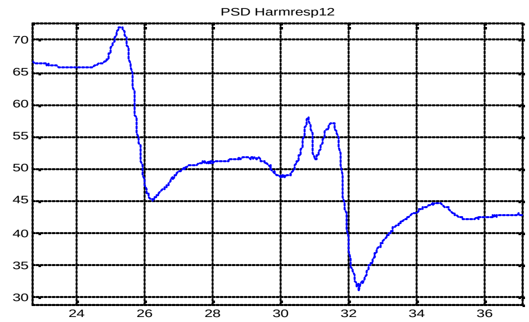
PSD Harmresp11
70 60 50 40 30 20
26 27 28 29 30 31 32 33 34



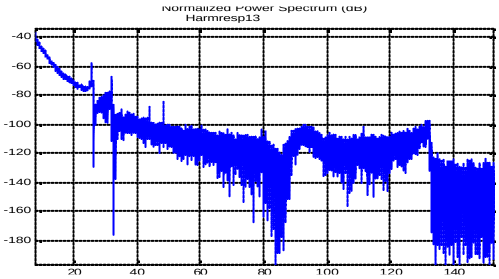
Harmresp12
-20 -40 -60 -80 -100 -120 -140

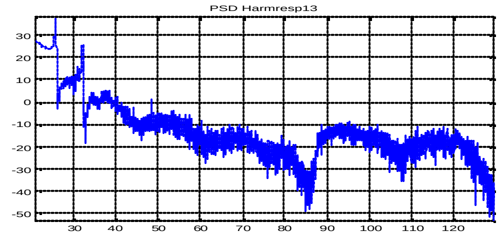


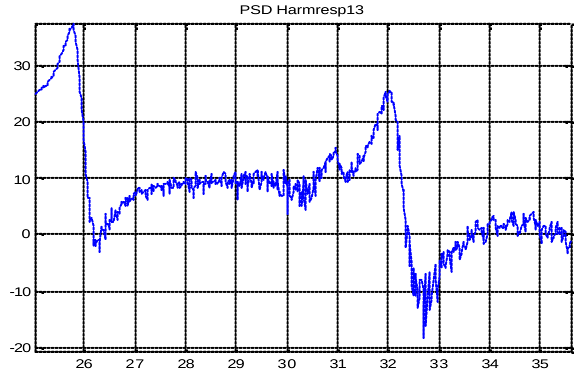
PSD Harmresp12
60 40 20 0 -20 -40 -60
50 100 150 200 250 300

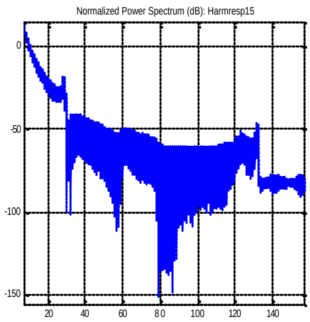


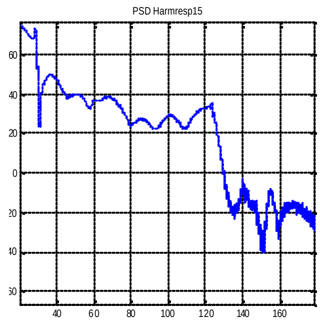
PSD Harmresp12
70 65 60 55 50 45 40 35 30
24 26 28 30 32 34 36

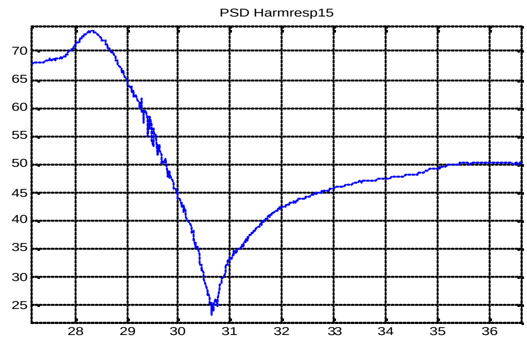

Normalized Power Spectrum (dB)
Harmresp13

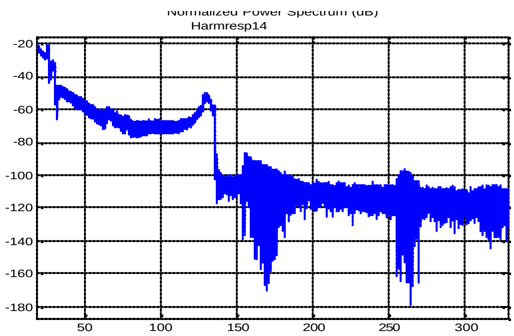

PSD Harmresp13

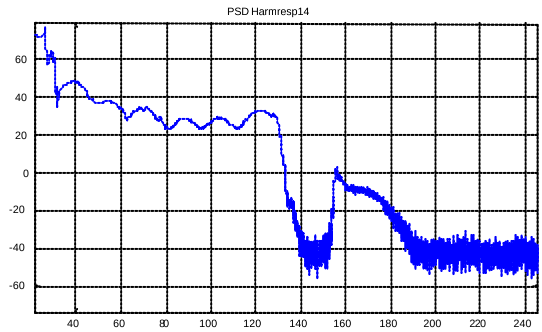

PSD Harmresp13

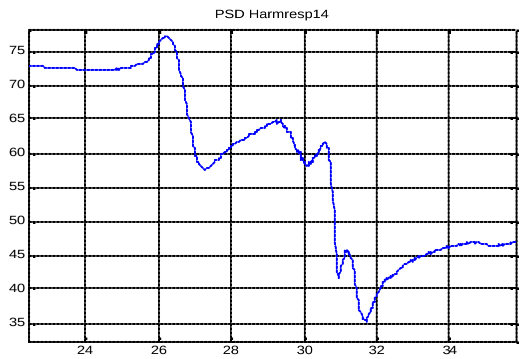

Normalized Power Spectrum (dB): Harmresp15

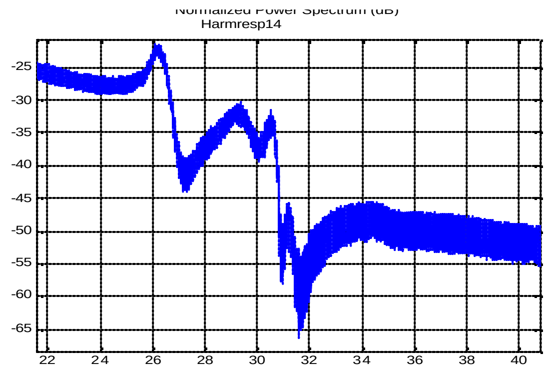

PSD Harmresp15

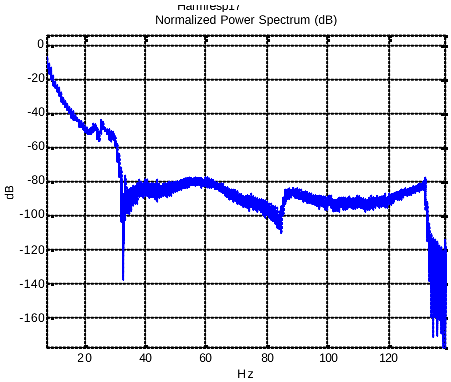

PSD Harmresp15


Normalized Power Spectrum (dB)
Harmresp14

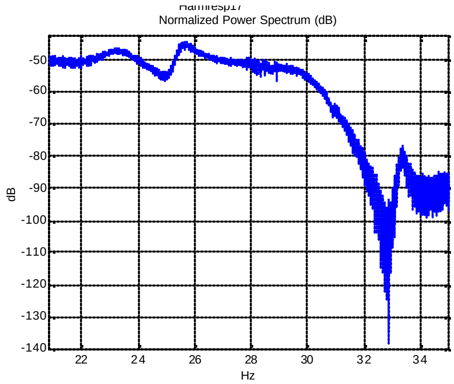

PSD Harmresp14


PSD Harmresp14

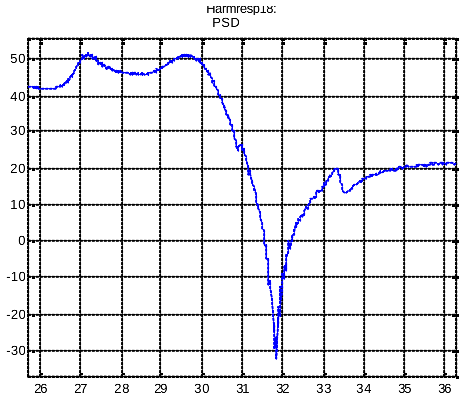

Normalized Power Spectrum (dB)
Harmresp14



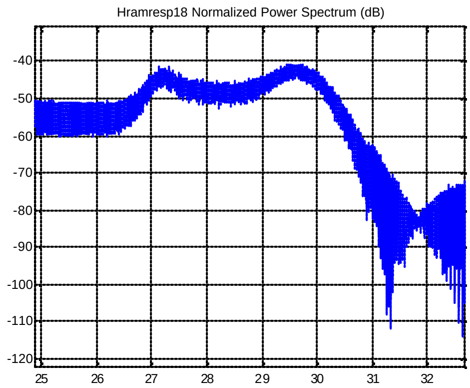
Normalized Power Spectrum (dB)
dB
Hz



Normalized Power Spectrum (dB)
dB
Hz



Harmresp18:
PSD



Hramresp18 Normalized Power Spectrum (dB)

4.1.2 Point to point harmonic response

4.1.2.1 Measurements @0.01 indac

Hz	Encoder amplitude (µm)	Remarks
1	5500	115 dB
2	1200	101 dB
4	260	88 dB
8	70	77 dB
10	50	74 dB
20	12	61.5 dB
28.9	26.5	
29	43	
29.1	41	
29.2	35	
29.3	25	
29.5	14	
29.6	10	
29.7	8	ΔΦ 350
29.8	6	ΔΦ 350
29.9	1.5	ΔΦ 360
30	0.8	
30.1	0.5	
30.2	0.6	
30.3	0.8	
30.5, 30.6	No measurable	
40	2	46 dB

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4.1.2.2 Measurements @ 0.1 indac

Hz	Encoder amplitude (µm)	Remarks
5	400	
10	100	
20	25	
25	120	
26	130	
26.5	125	
27	145	
27.1	155	
27.2	150	
27.3	170	
27.4	180	
27.5	225	
27.6	245	
27.7	230	
27.8	220	
27.9	200	
28	160	ΔΦ 270
28.1	135	
28.2	120	
28.3	100	
28.4	85	
28.5	70	
28.6	33	
28.7	45	
28.8	50	
28.9	42	
29.0	38	
29.1	30	
29.8	15	ΔΦ 290
29.9	12.5	ΔΦ 330
30.9	20	