LIGO

Minimizing the Resonant Frequency of MGAS Springs for Seismic Attenuation System in Low Frequency Gravitational Waves Interferometers

CALTECH

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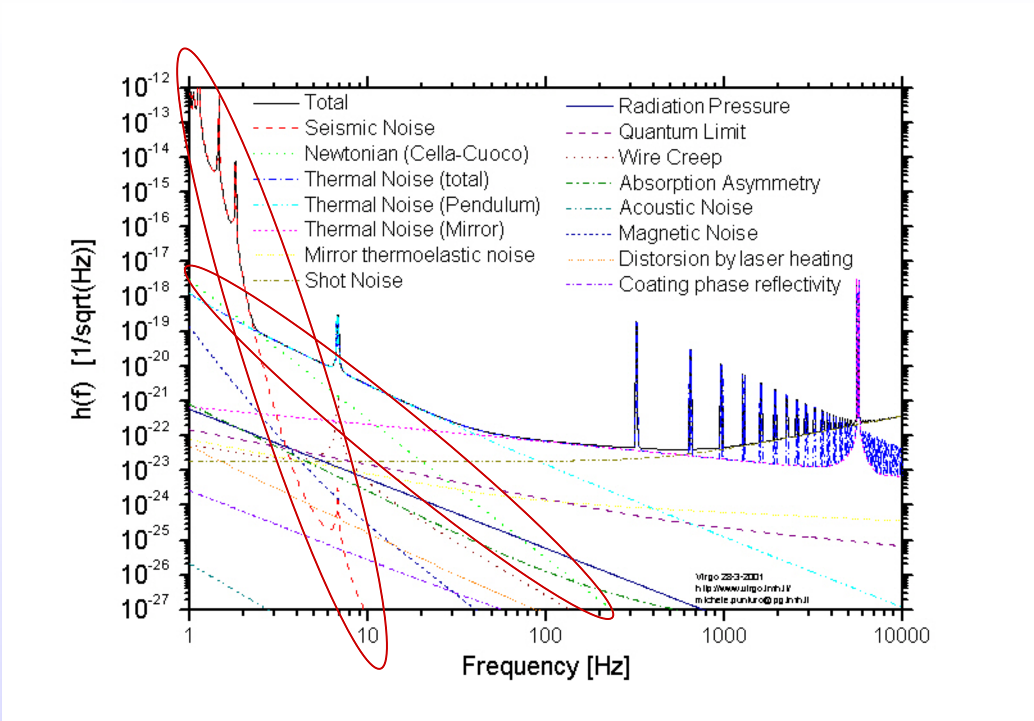
LIGO-G040340-00-R

Motivations

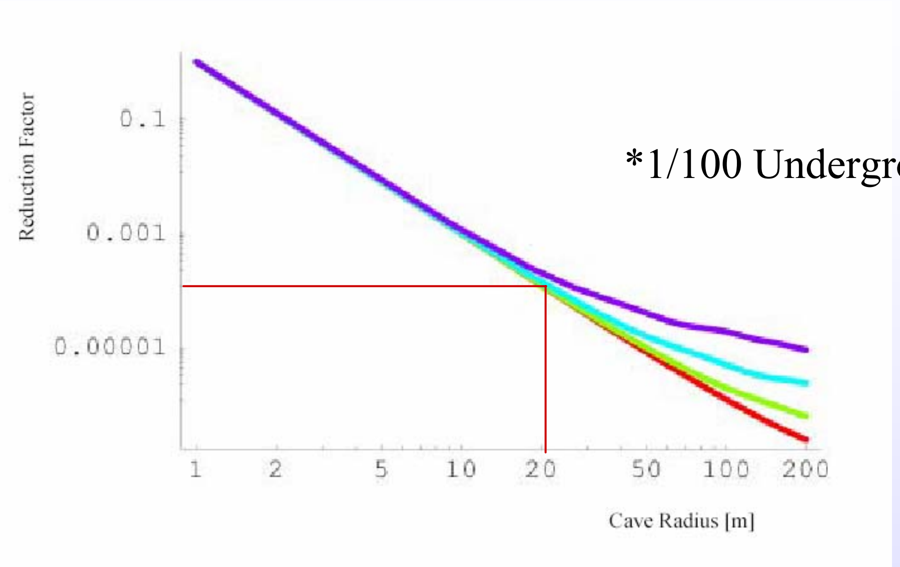


Ground Based Interferometer are Limited by Newtonian Noise under 10 Hz

Seismic Attenuation was Designed to Match that Limit

Recent Calculations Show the Possibility of Suppression of Newtonian Noise by Suspending the Test Masses in Deep Caves

Cella Suppression of Newtonian Noise



*1/100 Underground Seismic Amplitude

Giancarlo Cella Draft

Suppression of NN by a Factor of 10^{-6} in Amplitude, 30 in Frequency

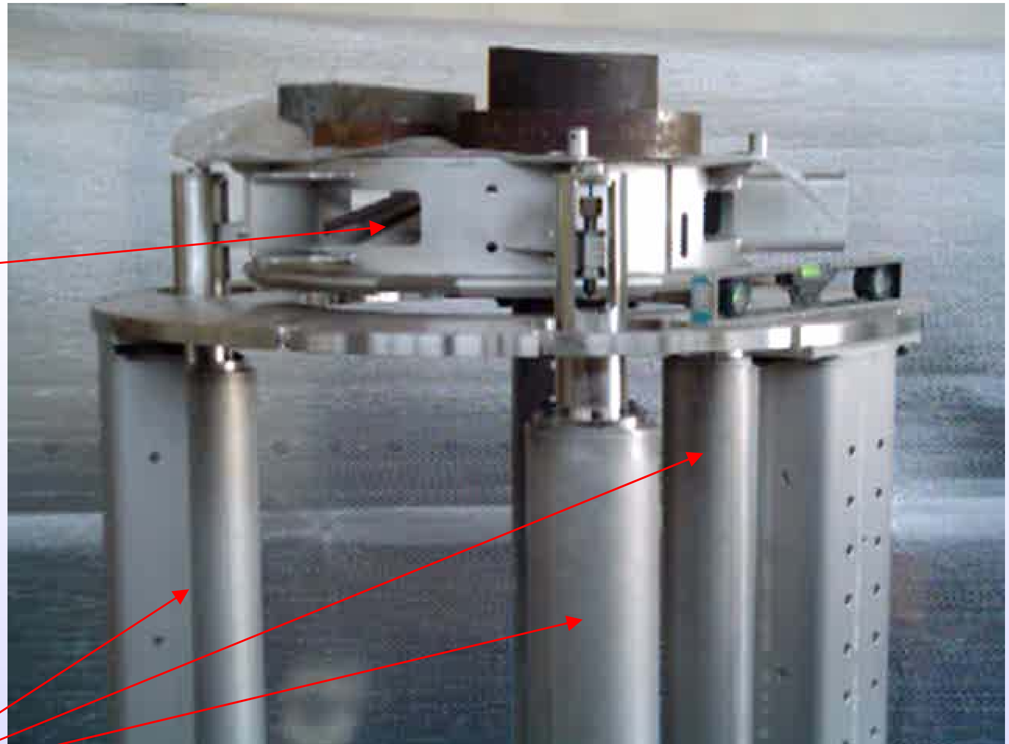
Seismic Attenuation Must be Redesigned to Match the New Limit

Horizontal Achievable with Longer Wires in Wells

Vertical Attenuation Requires New Development

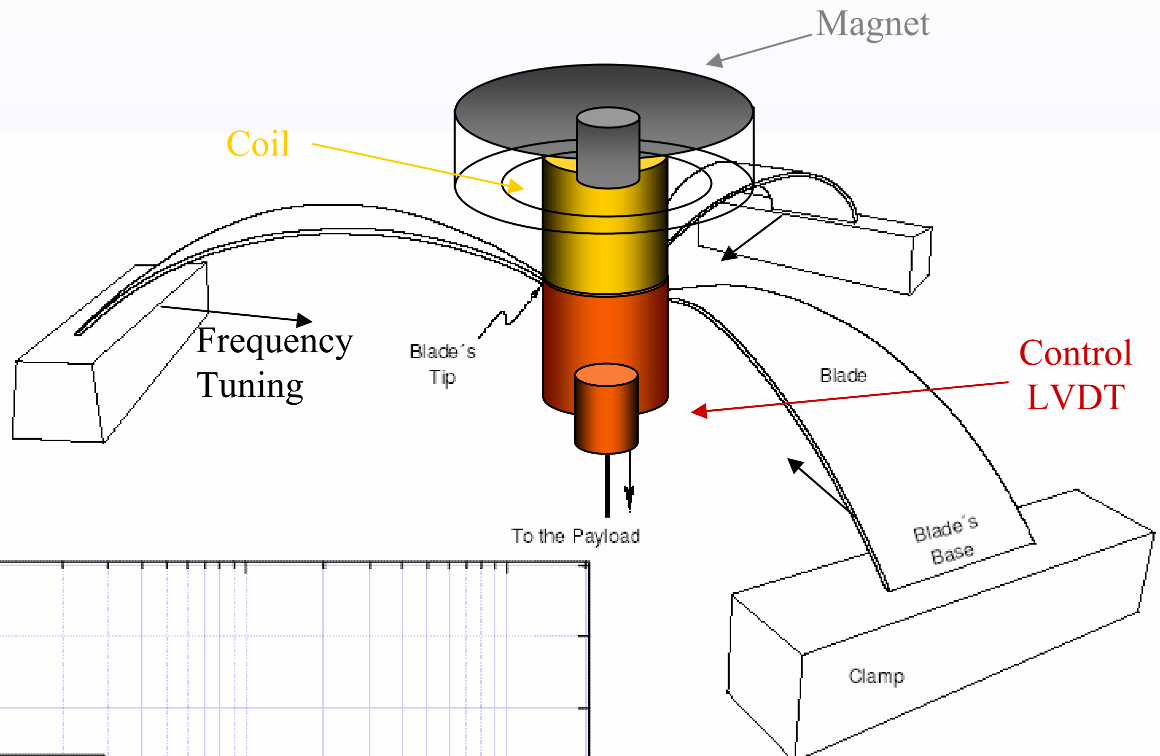
Horizontal Attenuation

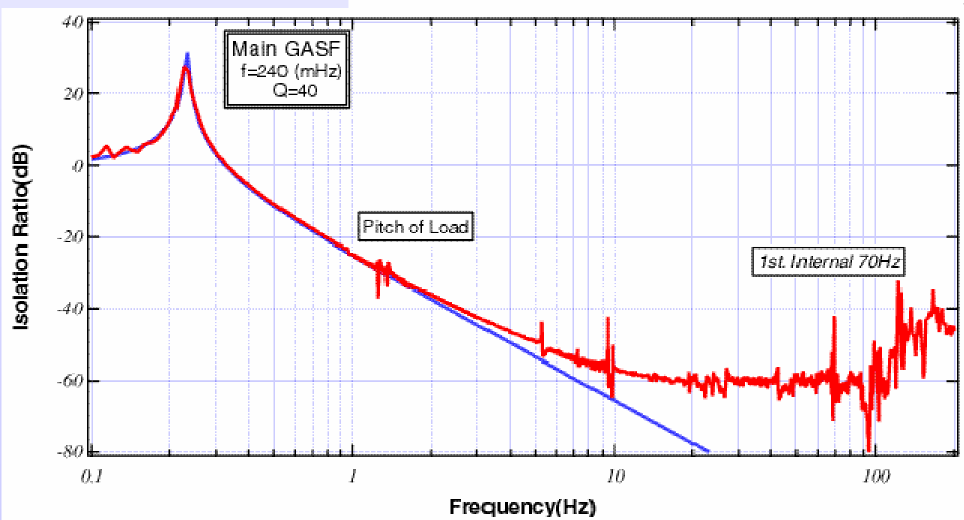
Filter



Inverted Pendula

Existing MGAS Spring

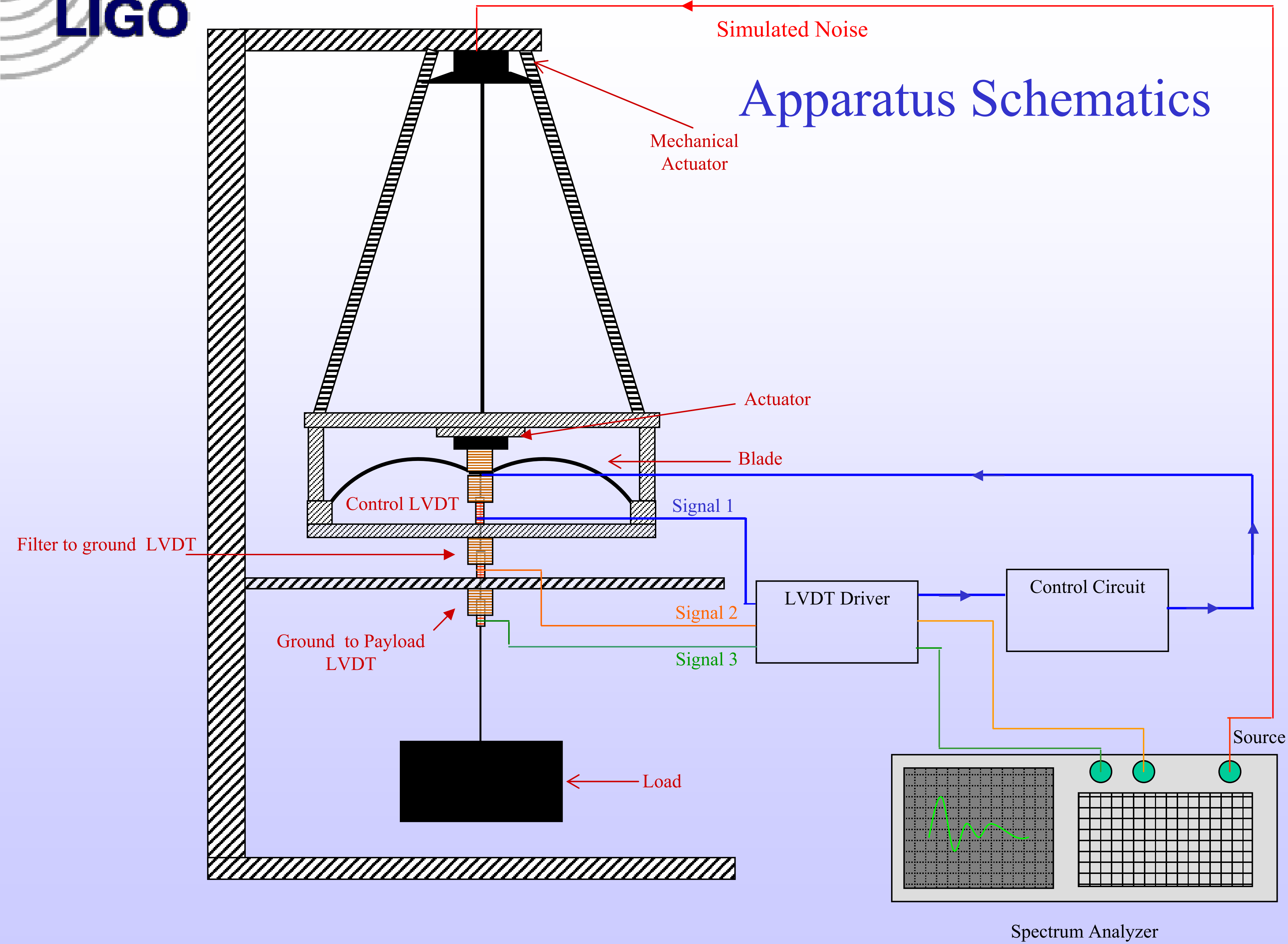




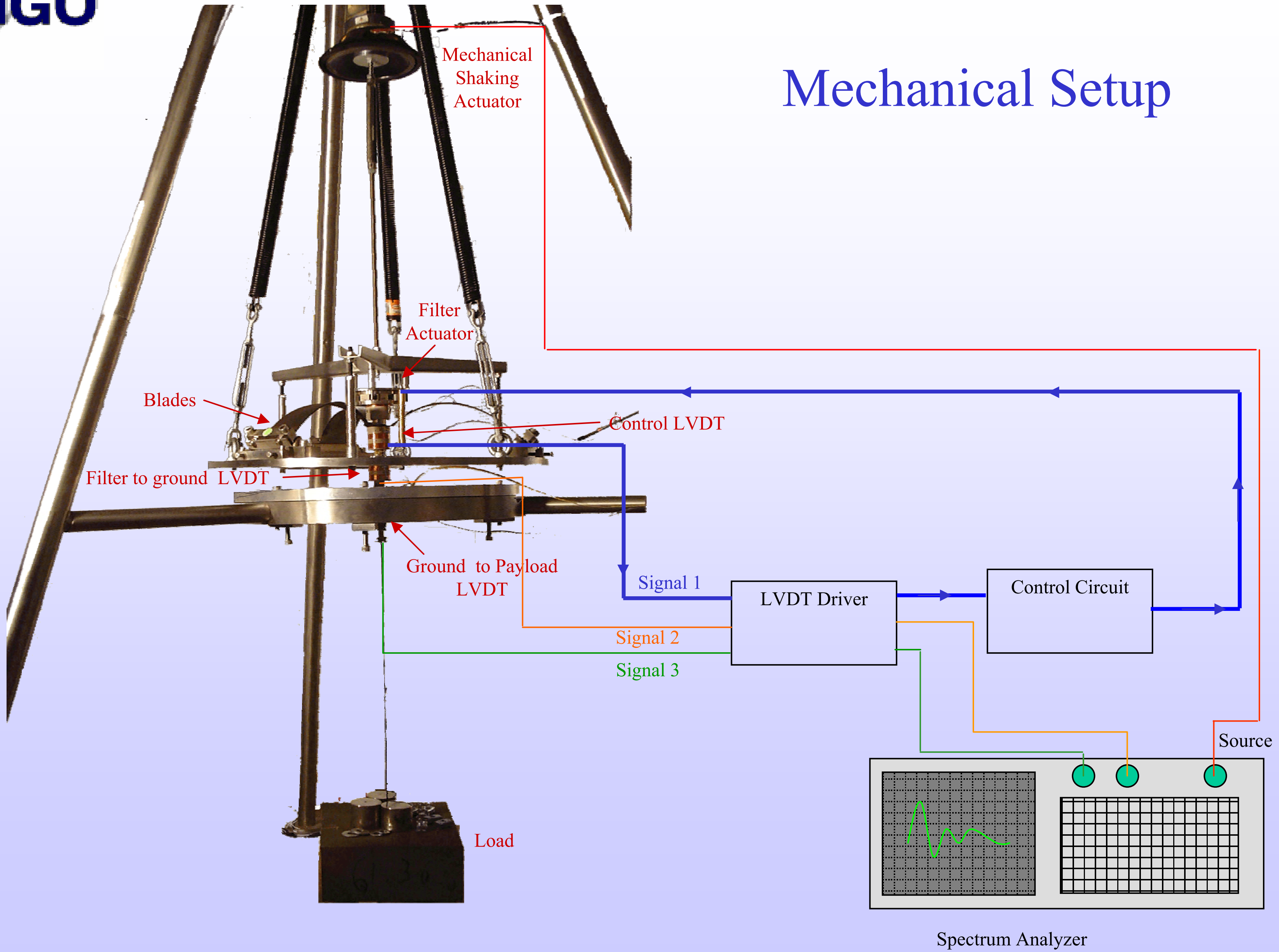
Practical Limit ”200mHz

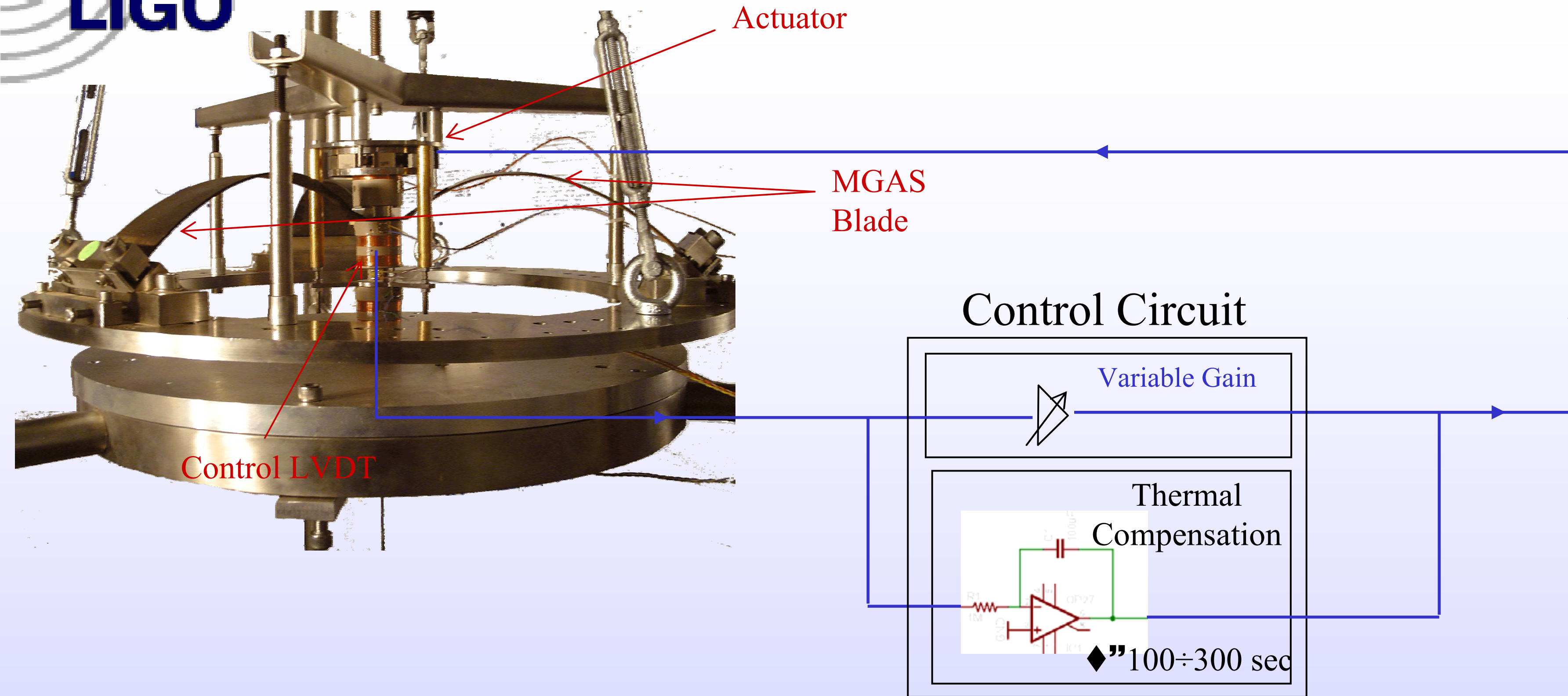
Method to Lower the Resonant Frequency below the Mechanical Limitations

Apparatus Schematics



Mechanical Setup



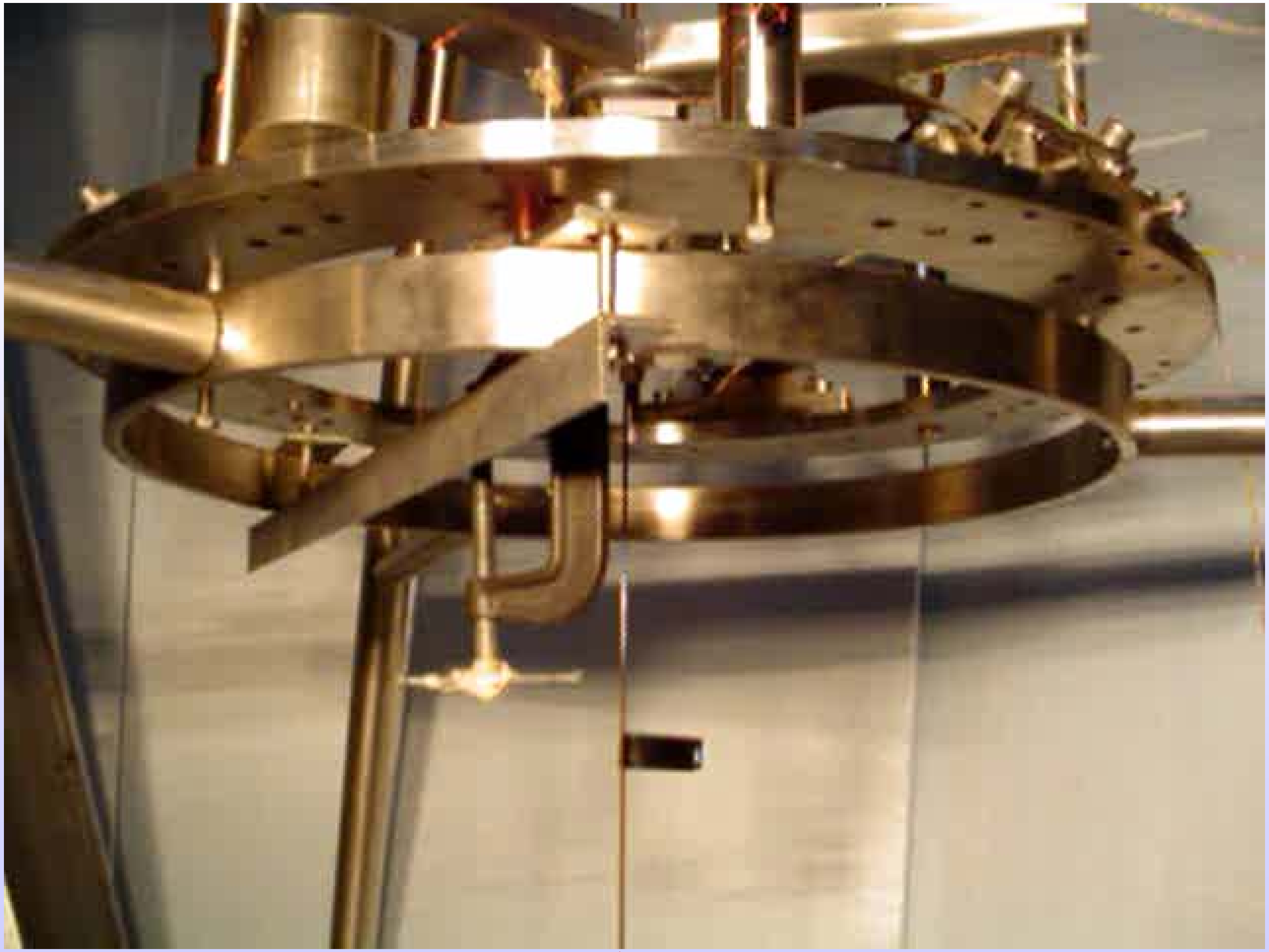


- LVDT
- Variable Gain → Tunable spring in parallel with MGAS spring
- Amplificator-Voice Coil

(Set Point Integrator → Thermal Drift Correction)

MGAS already neutralize > 90% of cantilever spring stiffness

Circuit corrects the last few per cent of stiffness and stabilizes performance

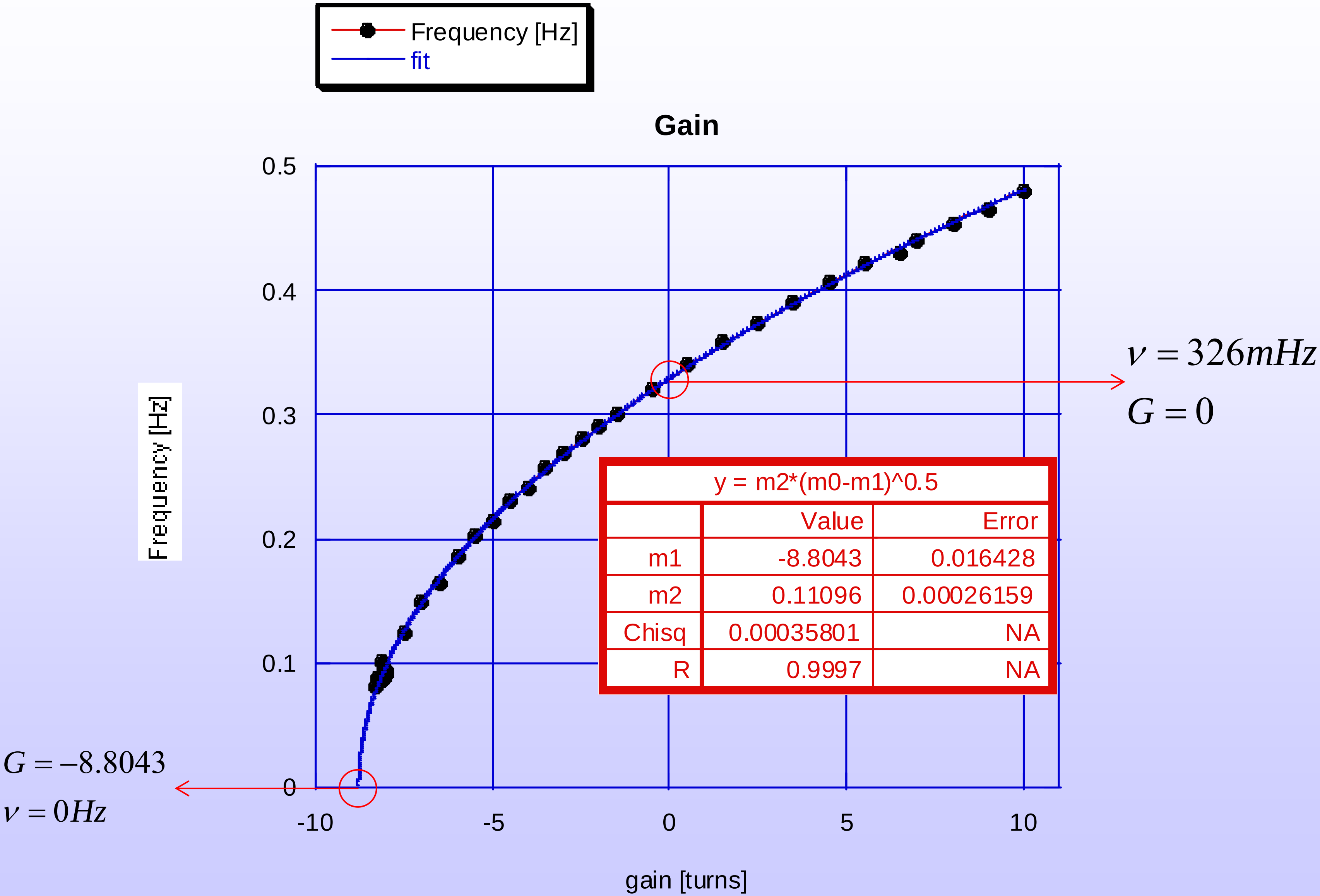


Payload

Characterization Work

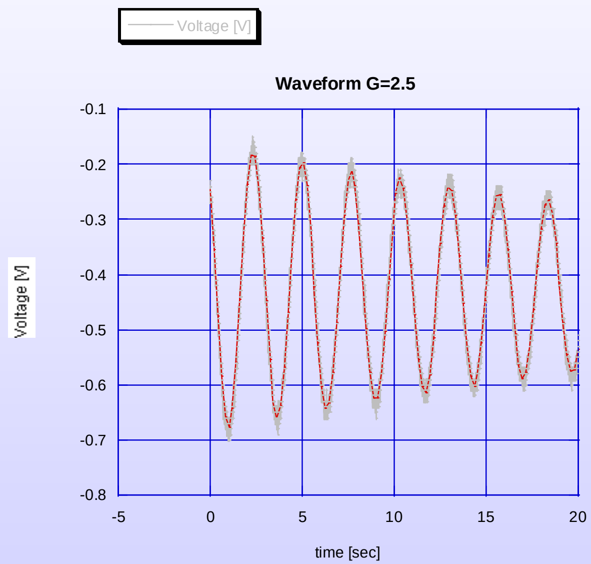
- Determination of the Working Point
- Circuit Calibration
- Frequency behavior as a function of the Gain
- Q Factor Analysis
  - Impulse Response
  - Frequency Response

After fixing the vertical height to the minimum frequency point we change the Gain to find the frequency behavior vs. gain



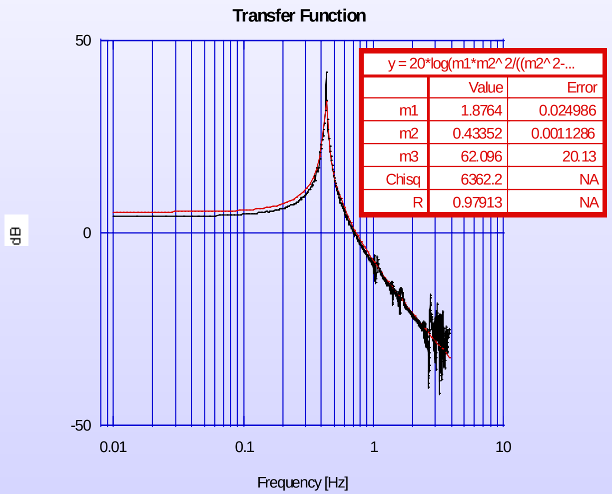
Q Factor Analysis; Two Methods

Fitting the Damped Exponential in Free Oscillations



$$Q = \tau \cdot \nu$$

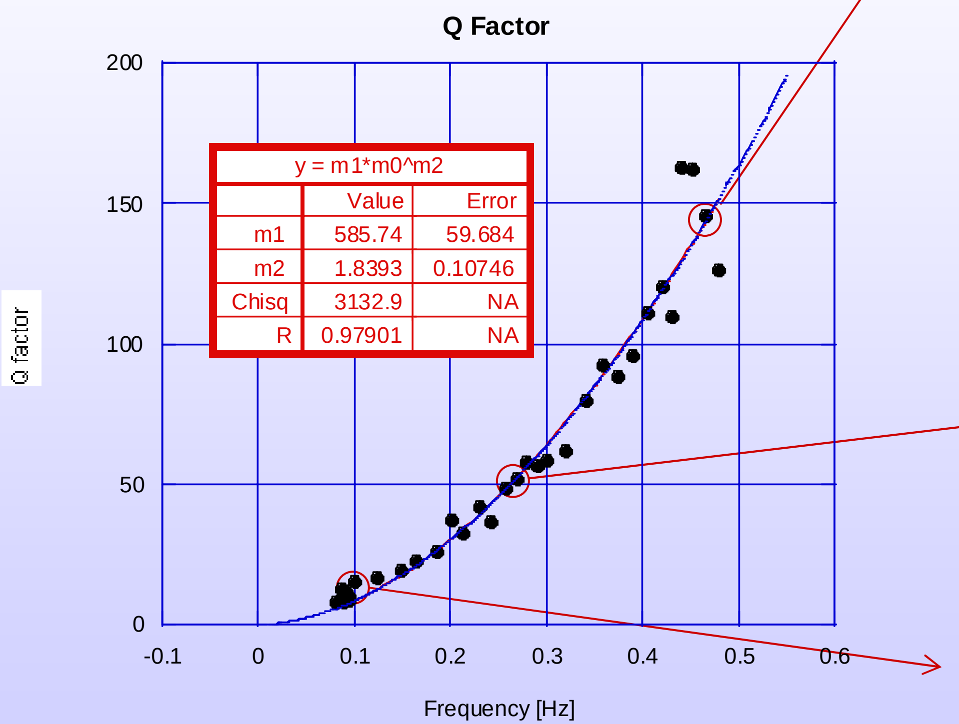
Fitting the Resonant Width in the Transfer Function

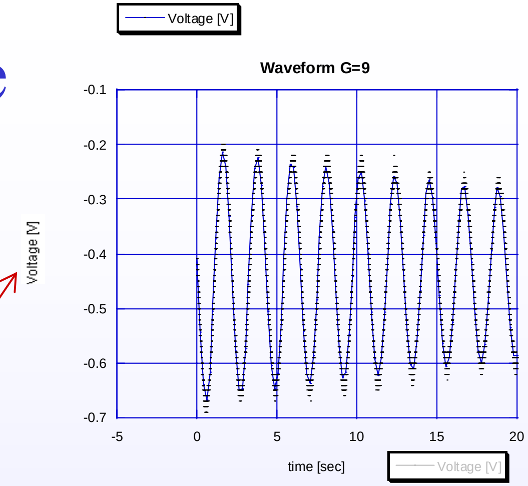


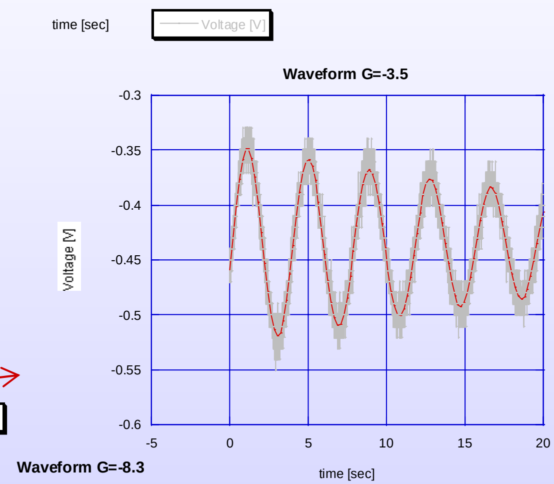
$$Q = \frac{f_0}{\Delta f}$$

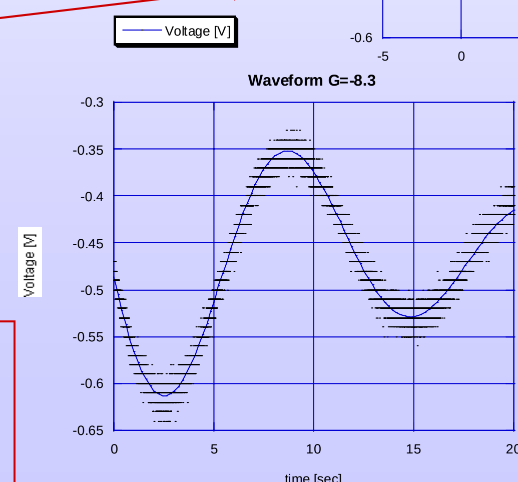
Impulse Response

$$Q_{factor} = \tau \cdot \nu$$





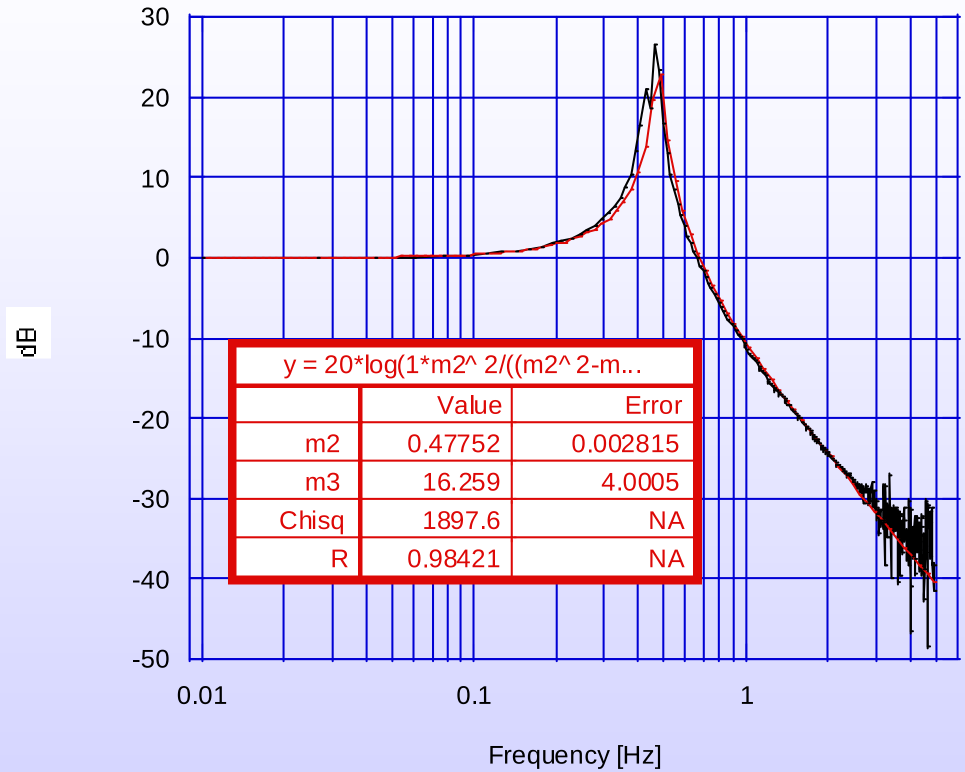




$$y = c_0 + c_1 \cdot \left(\cos\left(2\pi\nu t + \varphi\right) \cdot e^{-(t/\tau)} \right)$$

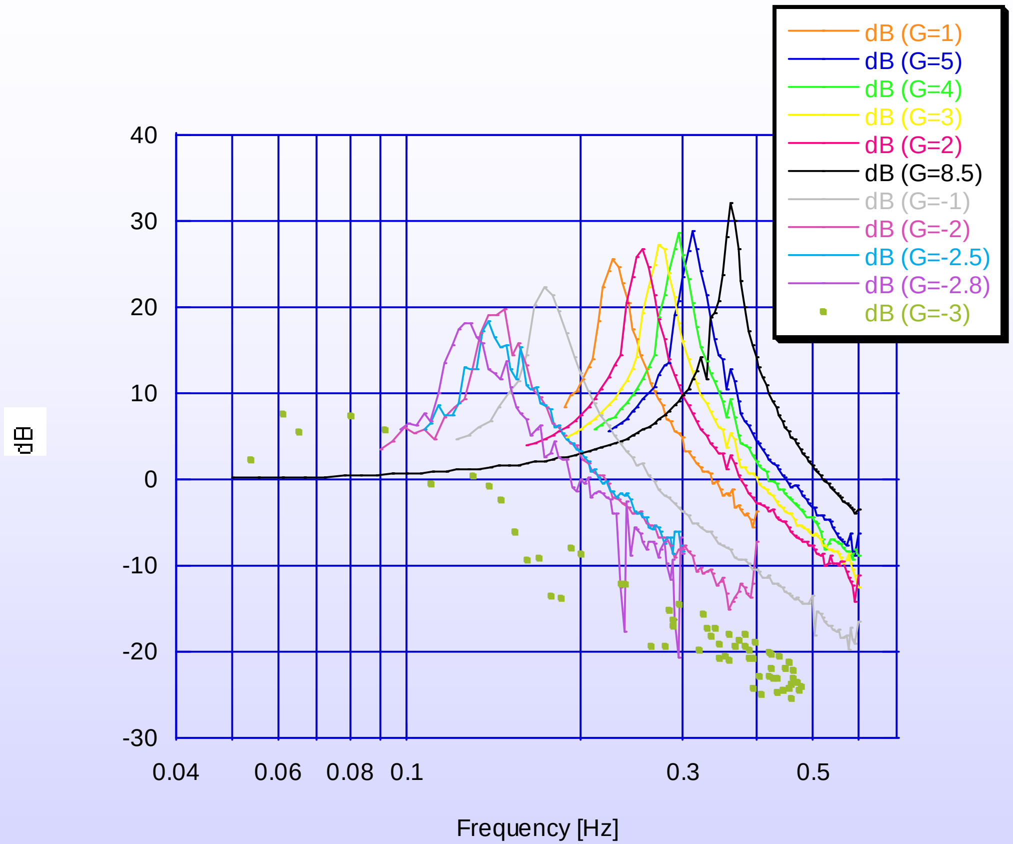
Transfer Function Measurement

(filter body to payload)



$$f\left(\nu\right)=20\log\left(\frac{H_0\cdot\nu_0^2}{\sqrt{\left(\left(\nu_0^2-\nu^2\right)^2+\frac{\nu^2\nu_0^2}{Q^2}\right)}}\right)$$

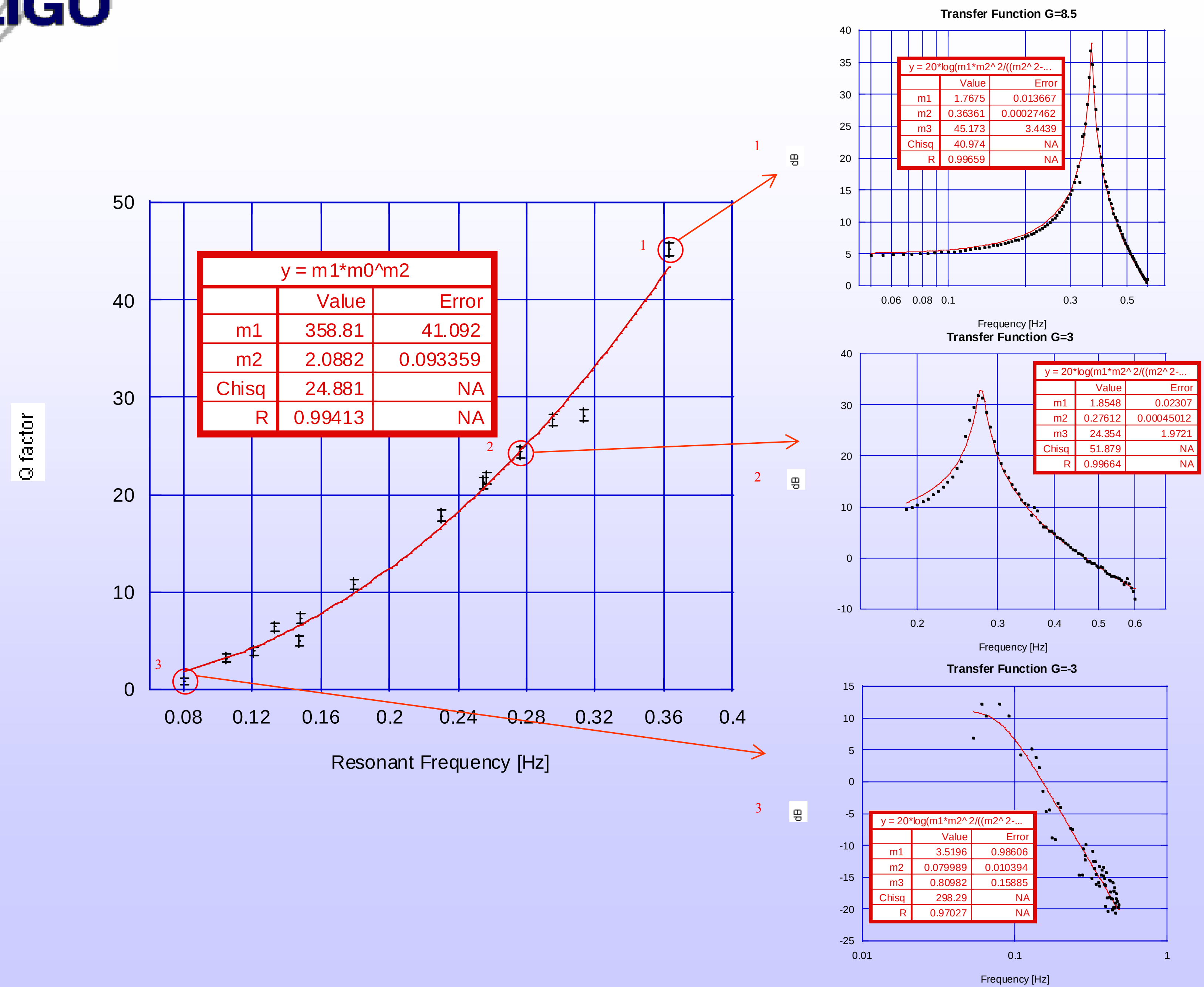
Transfer Function with Different Gain values



Lowering the system stiffness

As the Transfer Function is shifted to lower frequencies,

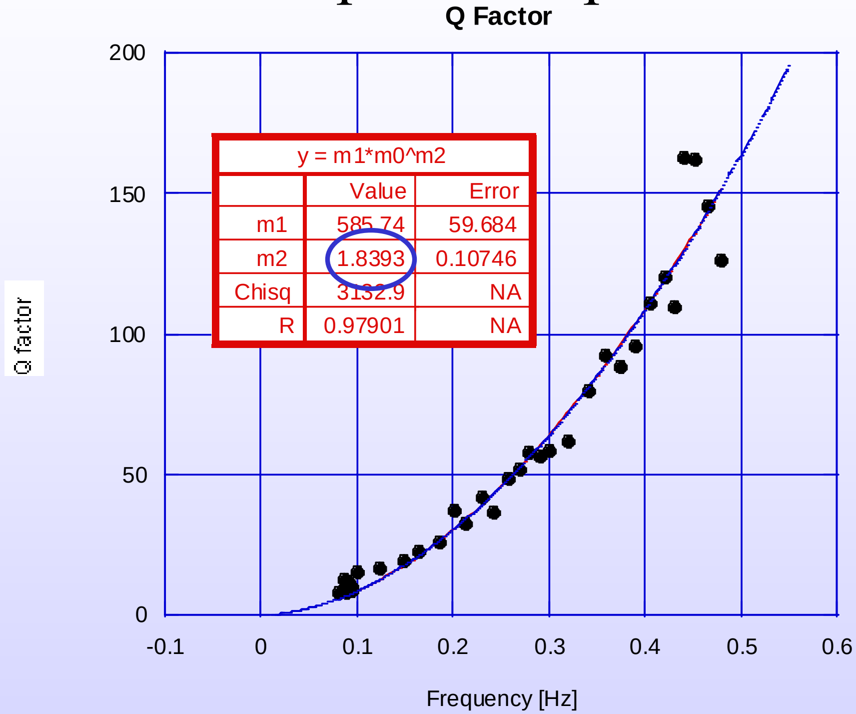
The Q factor decreases



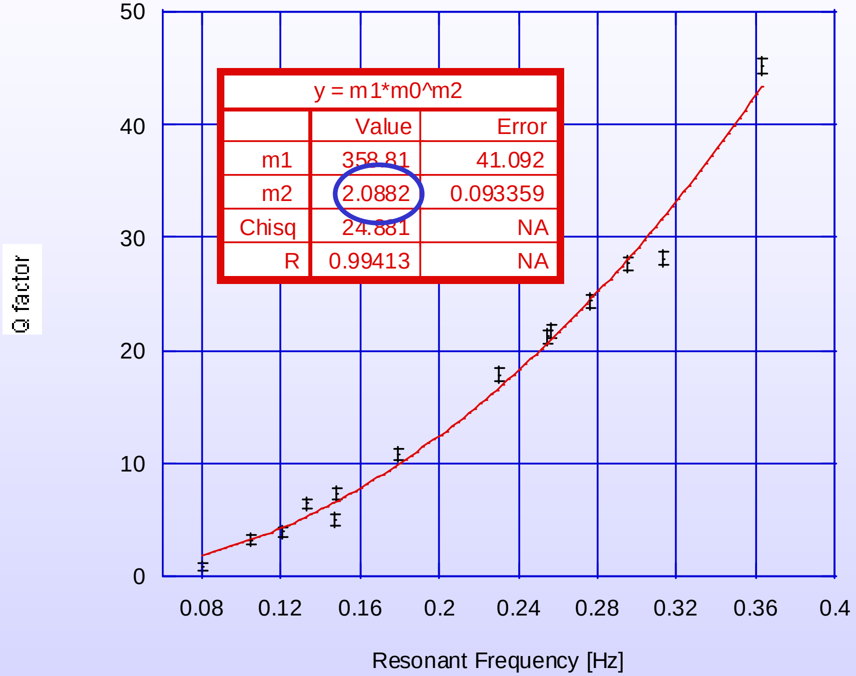
Q factor
Resonant Frequency [Hz]
y = m1*m0^m2
Value Error
m1 358.81 41.092
m2 2.0882 0.093359
Chisq 24.881 NA
R 0.99413 NA
Transfer Function G=8.5
y = 20*log(m1*m2^2/((m2^2-...
Value Error
m1 1.7675 0.013667
m2 0.36361 0.00027462
m3 45.173 3.4439
Chisq 40.974 NA
R 0.99659 NA
Frequency [Hz]
Transfer Function G=3
y = 20*log(m1*m2^2/((m2^2-...
Value Error
m1 1.8548 0.02307
m2 0.27612 0.00045012
m3 24.354 1.9721
Chisq 51.879 NA
R 0.99664 NA
Frequency [Hz]
Transfer Function G=-3
y = 20*log(m1*m2^2/((m2^2-...
Value Error
m1 3.5196 0.98606
m2 0.079989 0.010394
m3 0.80982 0.15885
Chisq 298.29 NA
R 0.97027 NA
Frequency [Hz]
dB

Q Factor Analysis

Impulse Response



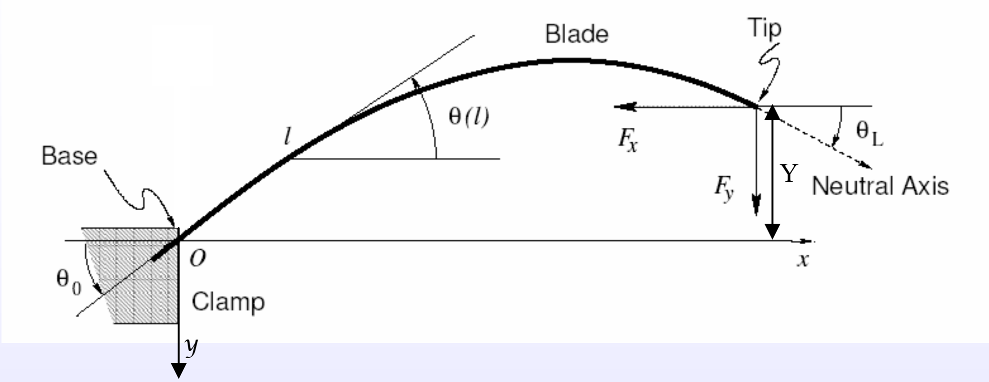
Frequency Response



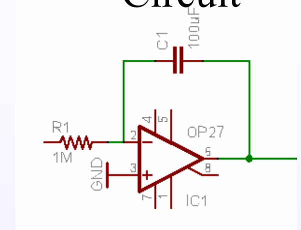
Both methods show a quadratic behavior for the Q factor

Implies structural, non viscous, damping

Need for Thermal Compensation



Thermal Compensation Circuit



♦”100÷300sec

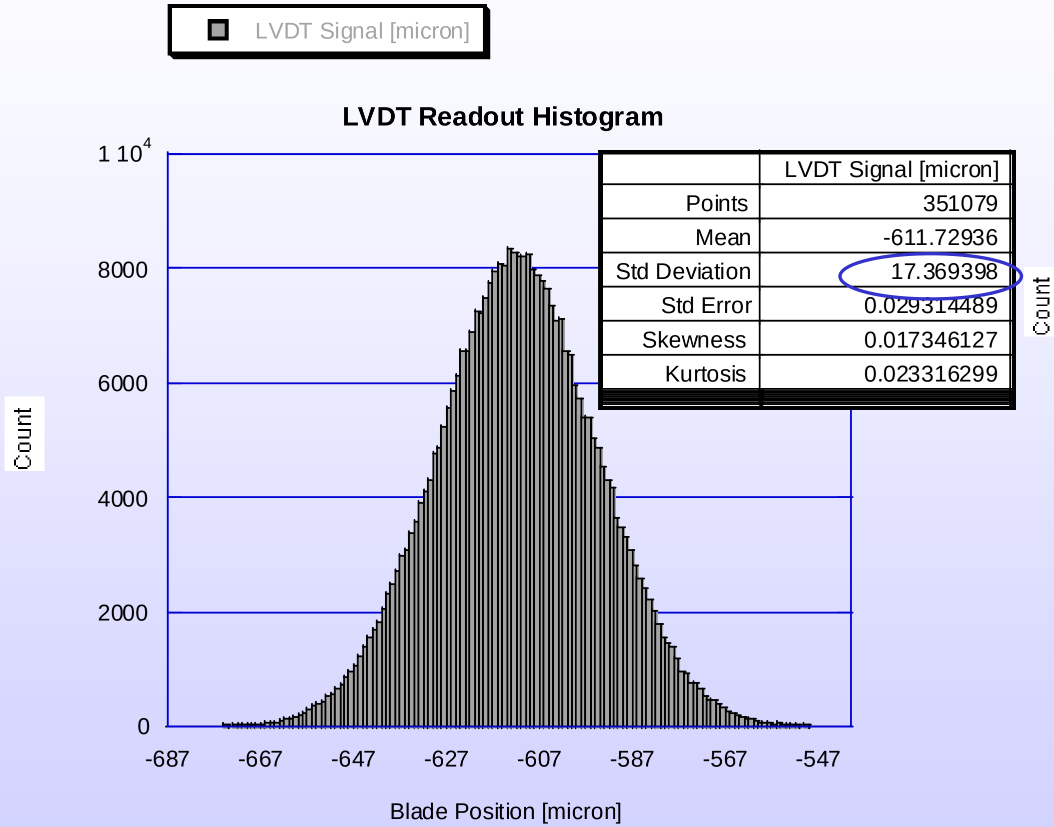
$$\frac{dY}{dT} : -\frac{g}{L\omega_y^2}\alpha_E$$

Where α_E is the thermal expansion coefficient given by the Young’s modulus

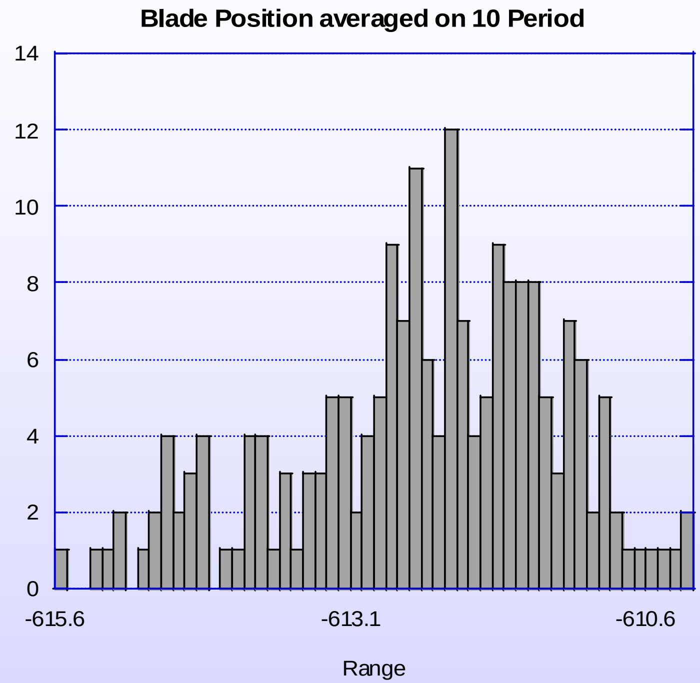
Virginio Sannibale et al.

The large thermal dependence of the blade working point with temperature, at low stiffness, makes it practically impossible to obtain very low resonant frequencies

Overnight Blade Tip Position stability Integrated on 10 Period



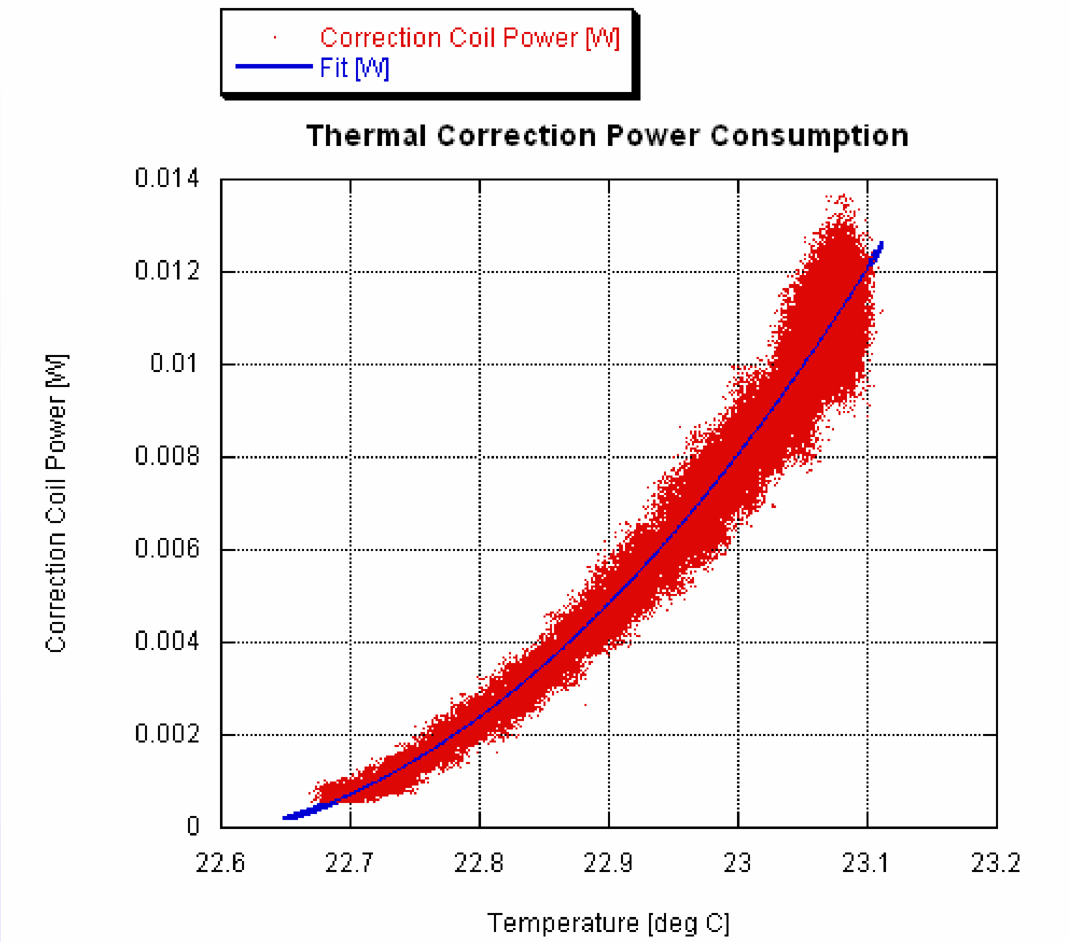
	LVDT Signal [micron]
Points	351079
Mean	-611.72936
Std Deviation	17.369398
Std Error	0.029314489
Skewness	0.017346127
Kurtosis	0.023316299



	Blade Position [micron] averaged 100 sec and decimated
Mean	-612.4834
Std Deviation	1.1317328
Variance	1.2808192
Std Error	0.08042875
Skewness	-0.51884154
Kurtosis	-0.25288313

These residuals are mainly the r.m.s. 100 mHz oscillator resonance excited by the seismic activity

Power Considerations

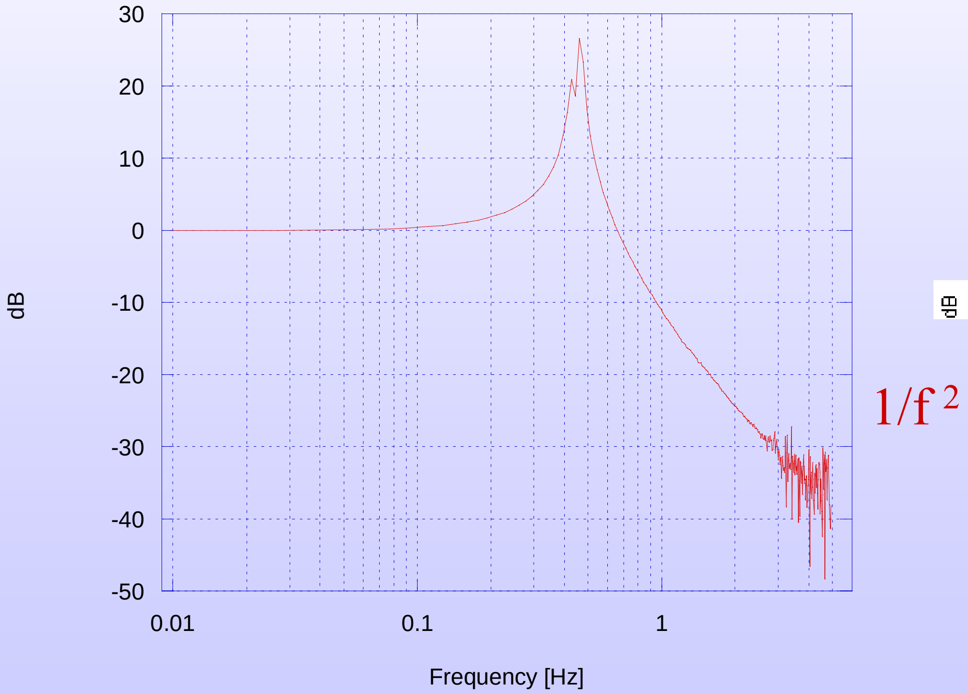


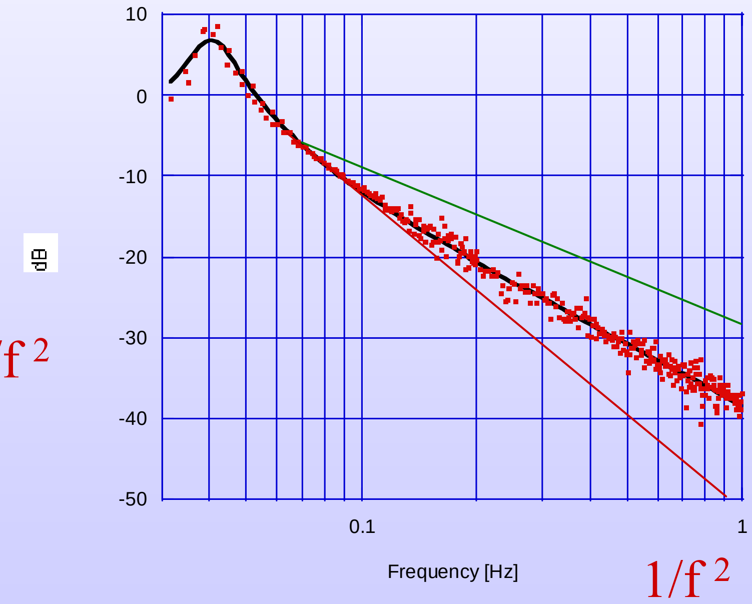
The Power consumption is of the order of ”10mW

Two Anomalies at Low Frequency are Discovered

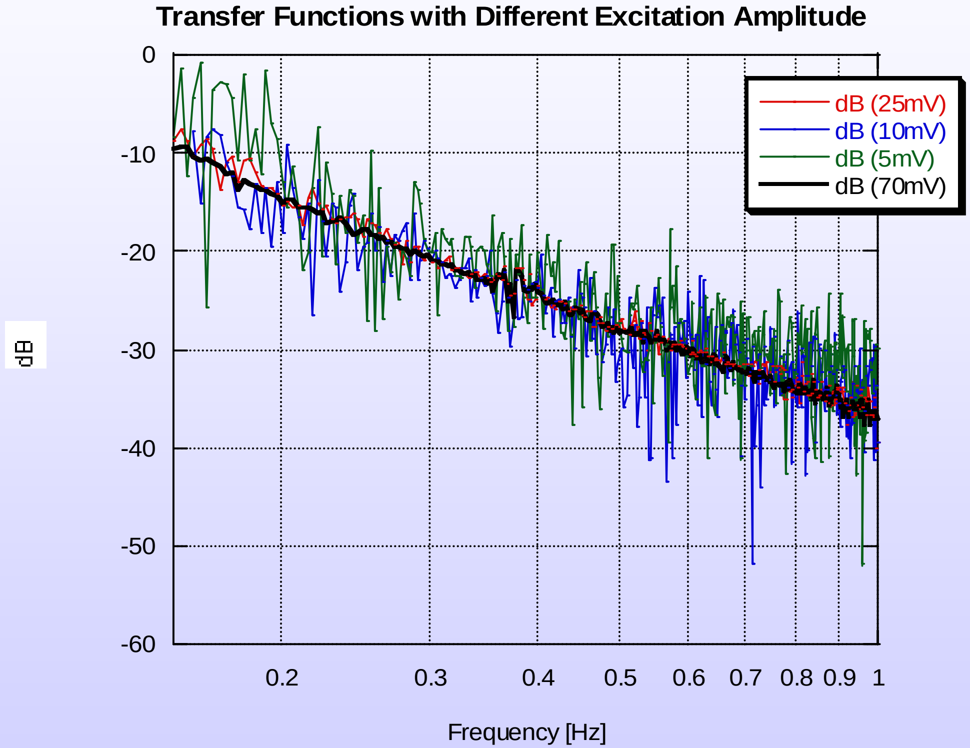
1. Slower Slope in the Lower Frequency Transfer Function Measurements

Right $1/f^2$ Behavior



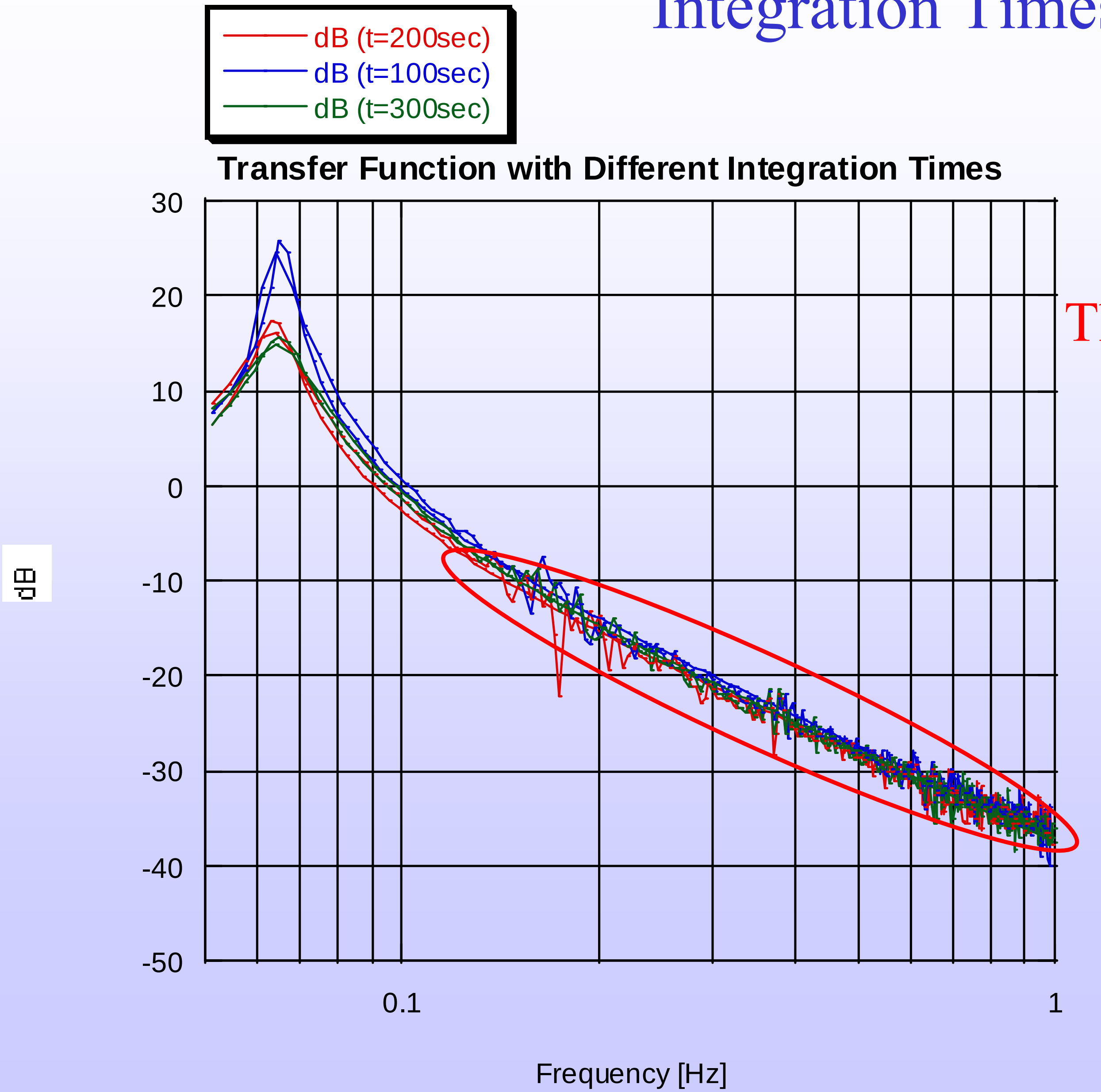


Transfer Function Measurements with different Excitation Amplitude



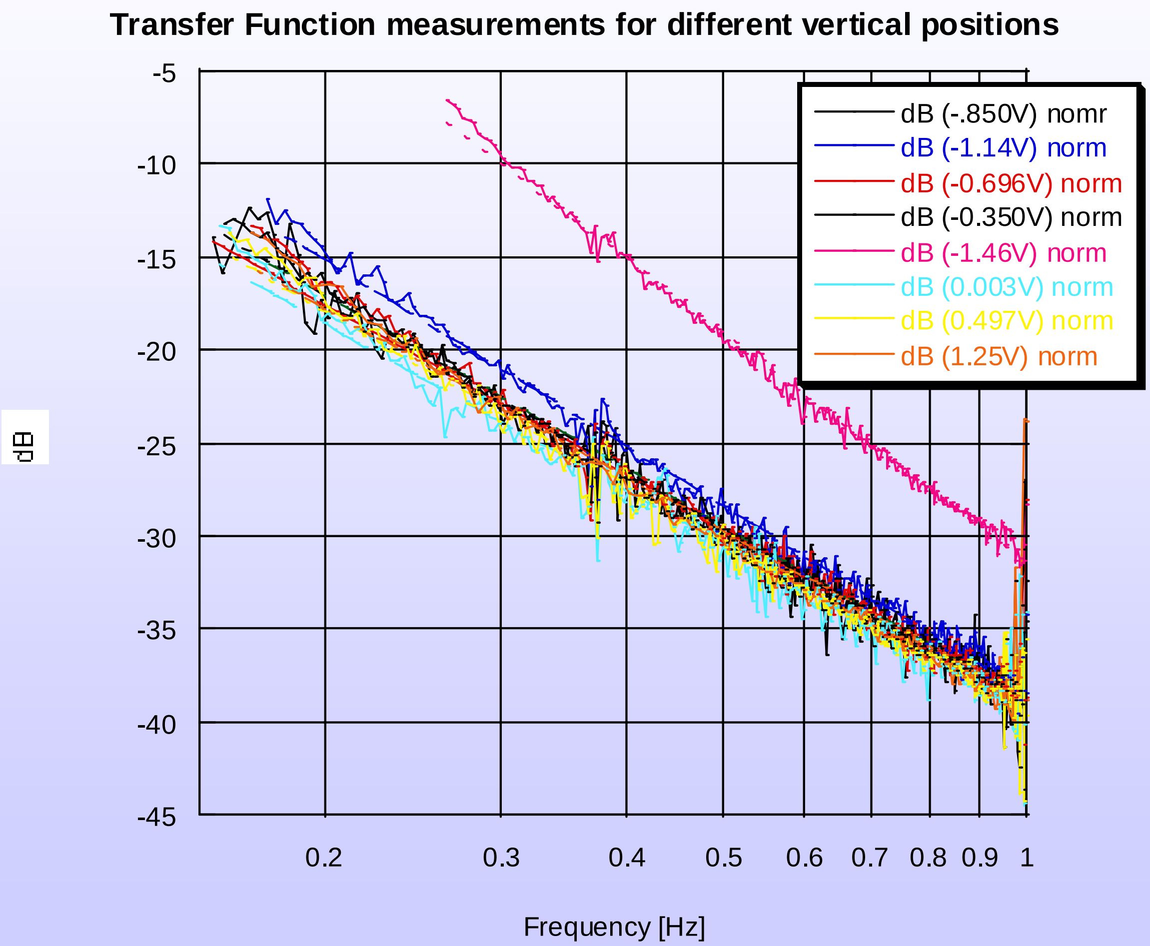
The slope does not change

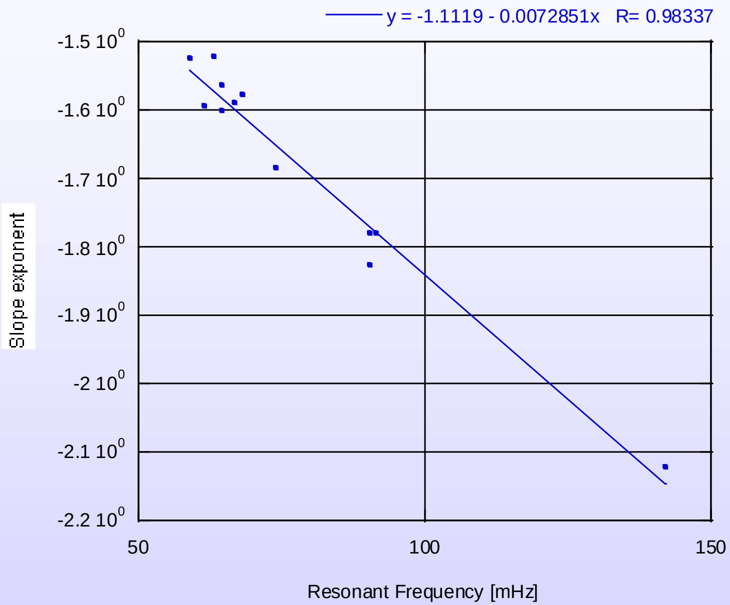
Transfer Function Slope for Different Integration Times



The Slope does not depends on the integration time

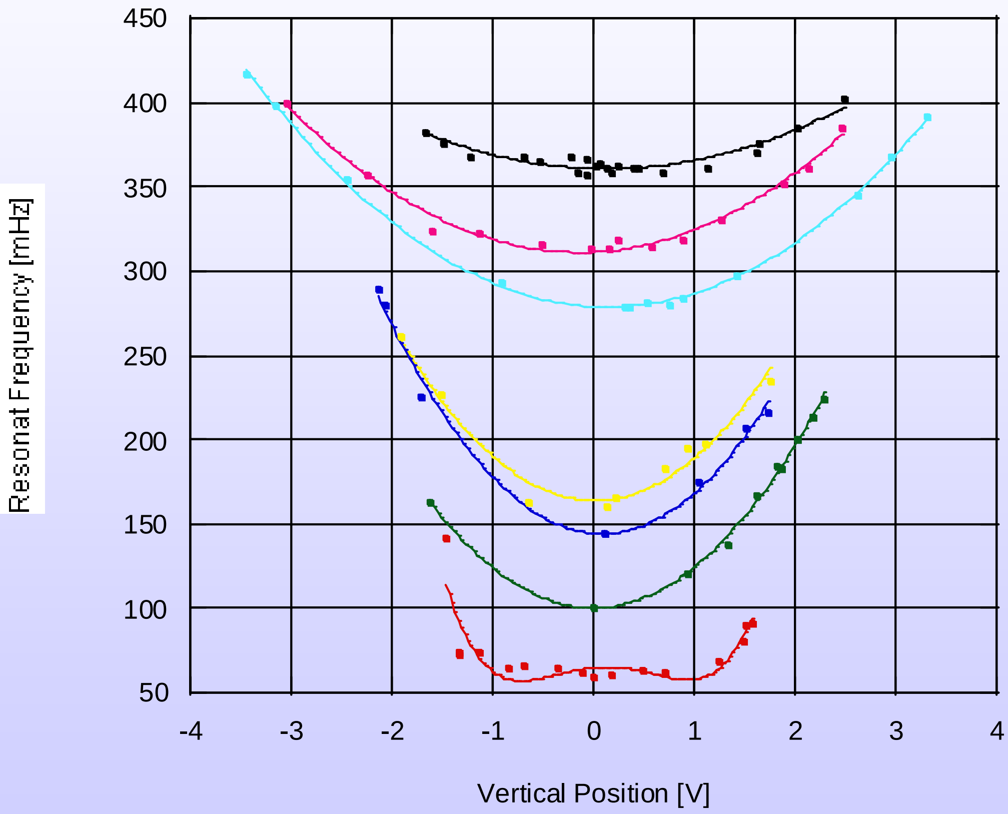
Slope for Different Vertical Positions





Need for more investigations

Second anomaly founded

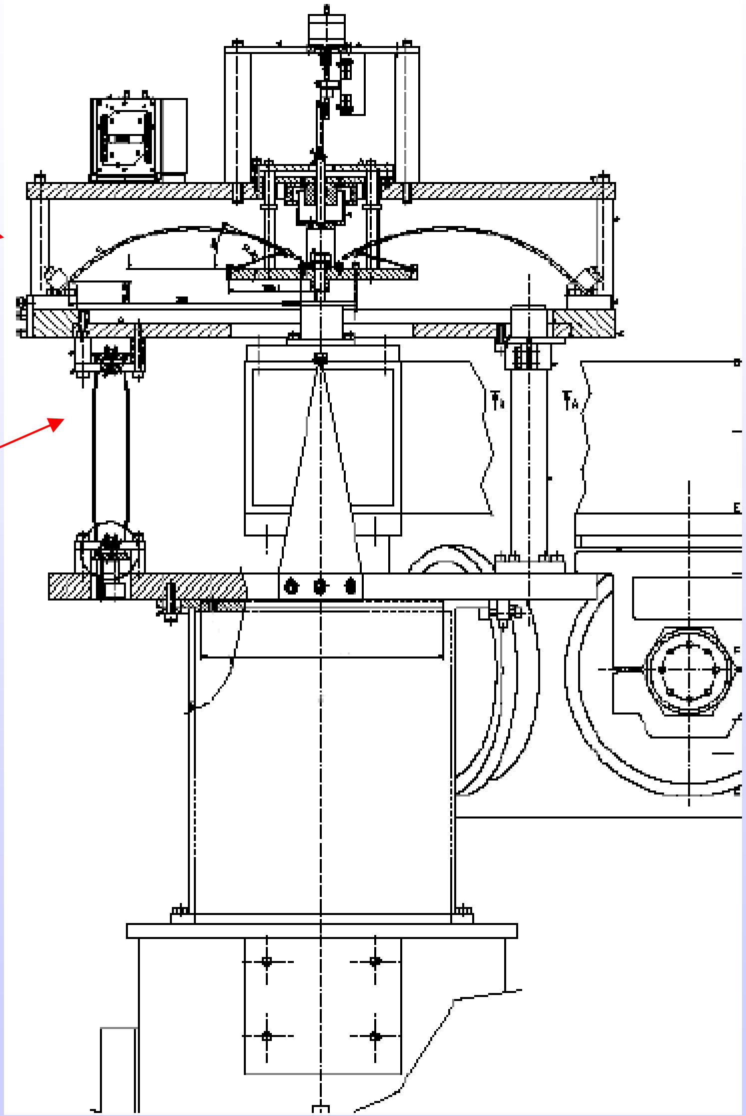


- So far the working point to frequency dependence has always been observed to be hyperbolic, getting narrower at lower frequency
- At lower frequency we find a departure from the hyperbolic behavior (the fit in the bottom data set is a fourth power polynomial)
- We suppose that higher order effect may be taking over when the anti-spring gets close to fully neutralize the spring constant
- The newly observed behavior is coincidental with the departure from 1/f2 of the attenuation transfer function
- We do not know yet if the two anomalous effects are correlated.

Is this useful for LIGO??

Vertical Attenuation

Horizontal Attenuation



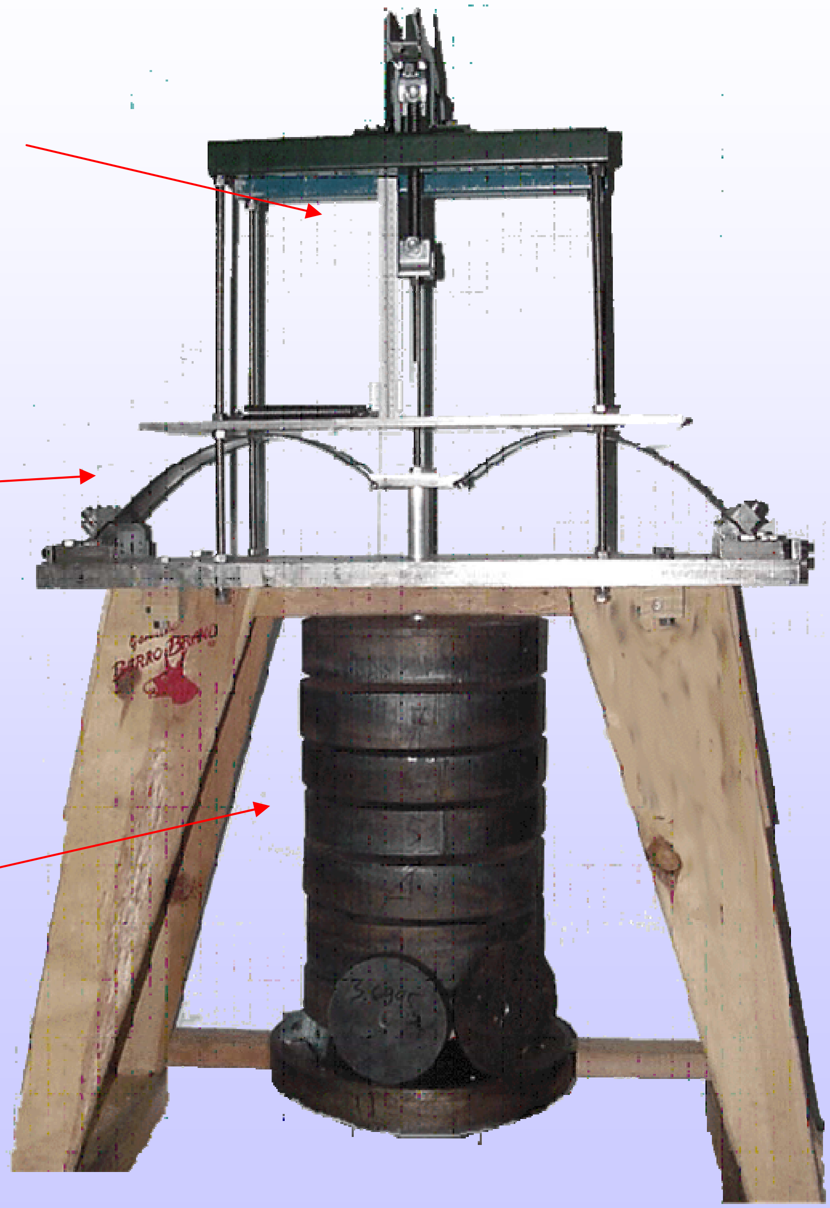
the LIGO Deep Fall Back solution prototype for one-pier preattenuators

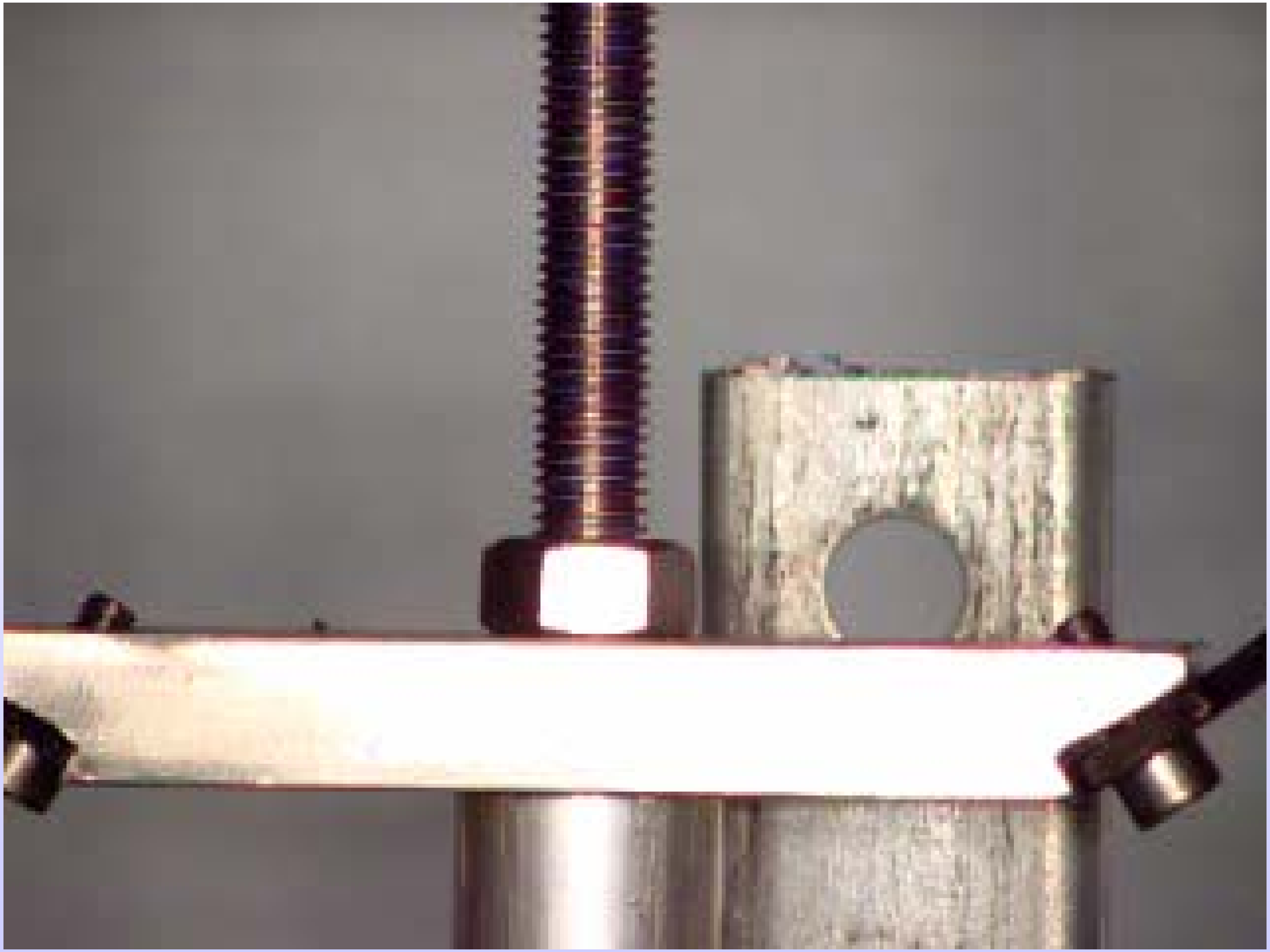
DFBS prototype

Bellow equivalent springs

Cantilevers

350 Kg Payload





Real time

DFBS Prototype

So far driven down to 120mHz despite the additional springs (4/3 of the equivalent bellow stiffness) in fully passive configuration

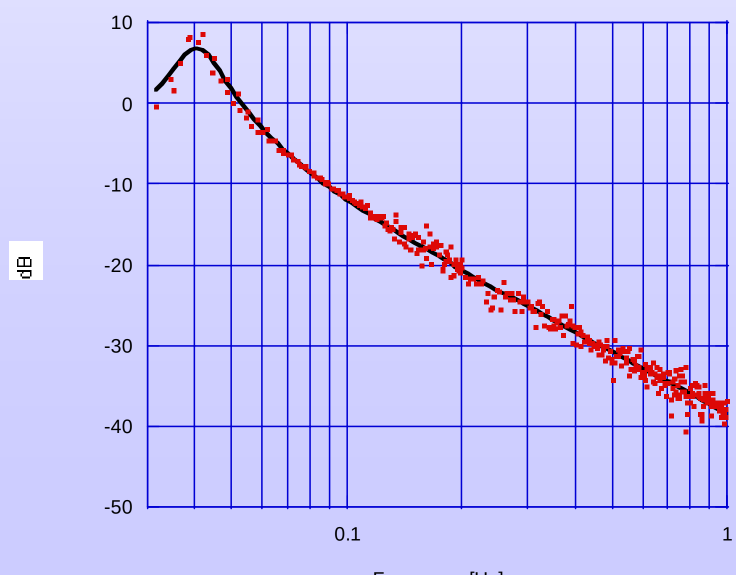
Expect ≤ 30mHz if tuned with electromagnetic anti-spring

attenuation plateau at 10^{-3} proven on preceding prototypes (expect similar performance)

Conclusions

• This development of Electromagnetic Correction Springs was designed to boost the Low Frequency attenuation performance of Geometric Anti Springs for future Underground Low Frequency Gravitational Wave Interferometric Detectors (Horizontal Attenuation was always easily available)

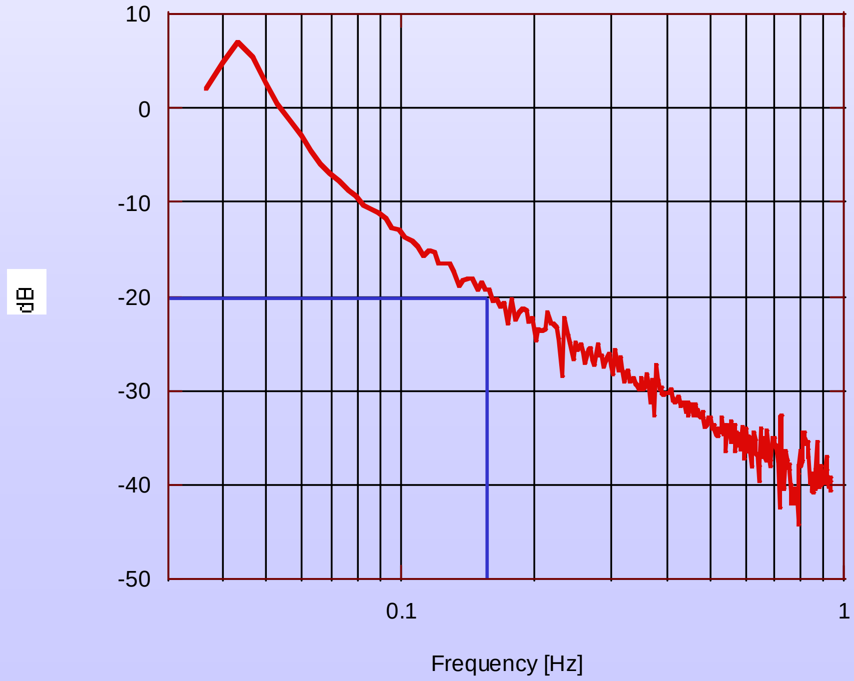
• This development allows for further depression of seismic perturbations, beyond the performance of the Superattenuators, reaching down to 1 Hz and even below.



Conclusions

- The retrofitting of this technology on existing system like the LIGO deep fall back pre-isolator solution may allow the introduction of attenuation factors as large as one thousand for frequencies above 1 Hertz

- Sizeable attenuation at the micro seismic peak at 150 mHz can be obtained as well



Next Steps

- Find the source of the less then $1/f^2$ behavior
- Repeat the Measurements with Accelerometers
- Study and Reduce the Control Circuit Noise Improving some of its Performances (Yanyi Chen)
- Make a Mechanical Thermal Compensation
- Use this Seismic Attenuation System on the Mexican Hat Interferometer (Barbara Simoni)