European Organization for Nuclear Research

FINAL FOCUS: COMBINATION OF PRE ISOLATOR AND ACTIVE STABILISATION

K. Artoos, C. Collette, R. Leuxe, C.Eymin, P. Fernandez, S. Janssens*

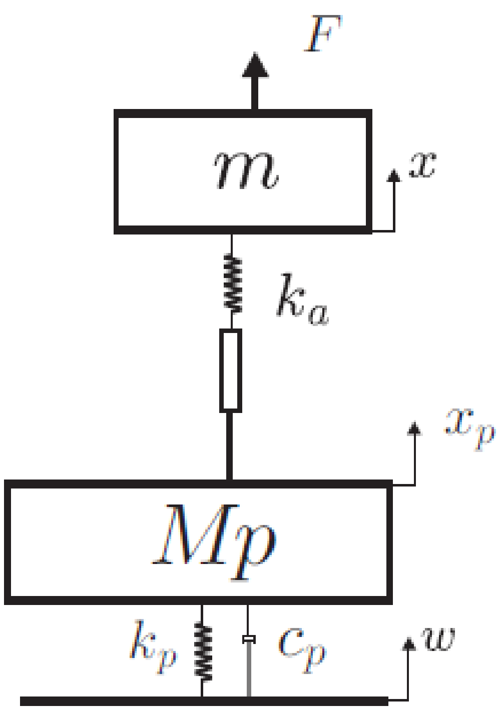
The research leading to these results has received funding from the European Commission under the FP7 Research Infrastructures project EuCARD

Outline

- How to perform active control on the preisolator to damp the 1 Hz resonance
- Issues with using the preisolator as it is
- Further research proposal
- Question about accelerometer feedback

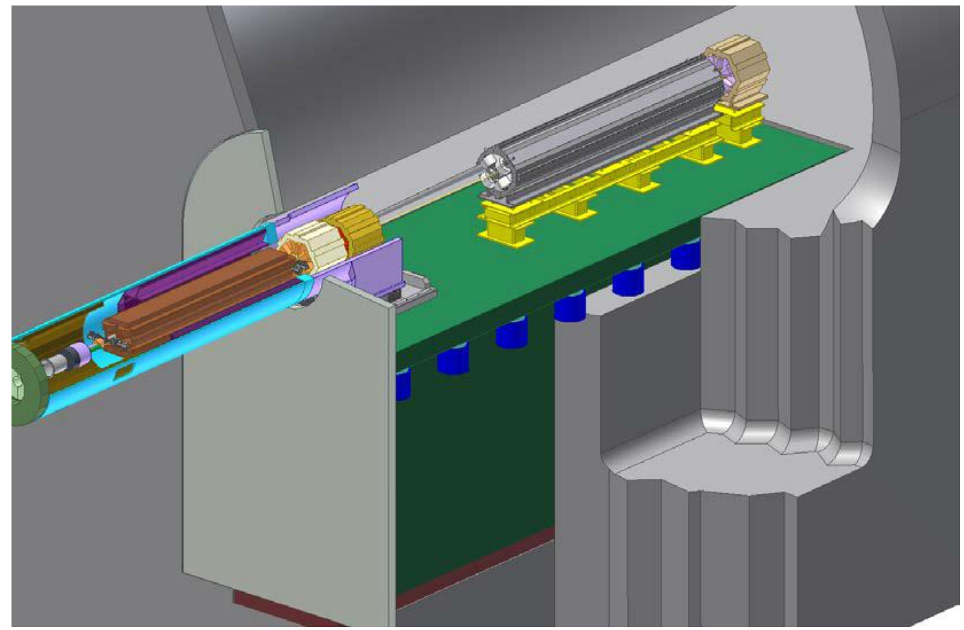
Preisolator

$$M\ddot{X} + C\dot{X} + KX = F$$



m=50
ka=480e6
ξ=0.01

Mp =40000
fp =1 Hz
ξp=0.01

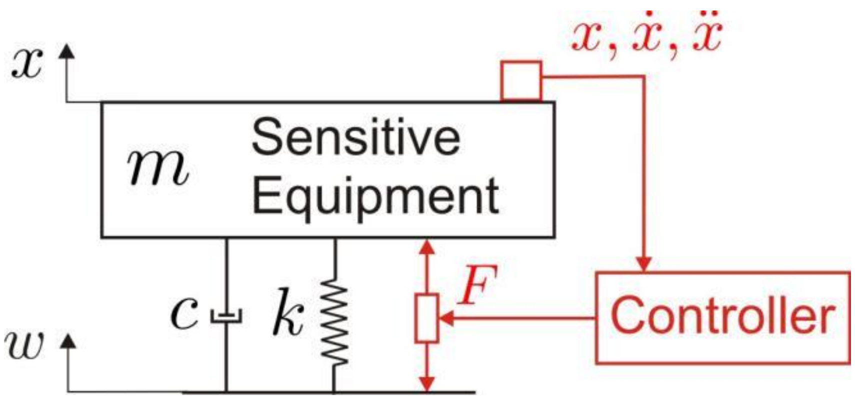


What is needed to damp/influence peak of pre-isolator mode?

Perfect feedback (no filtering and sensors)

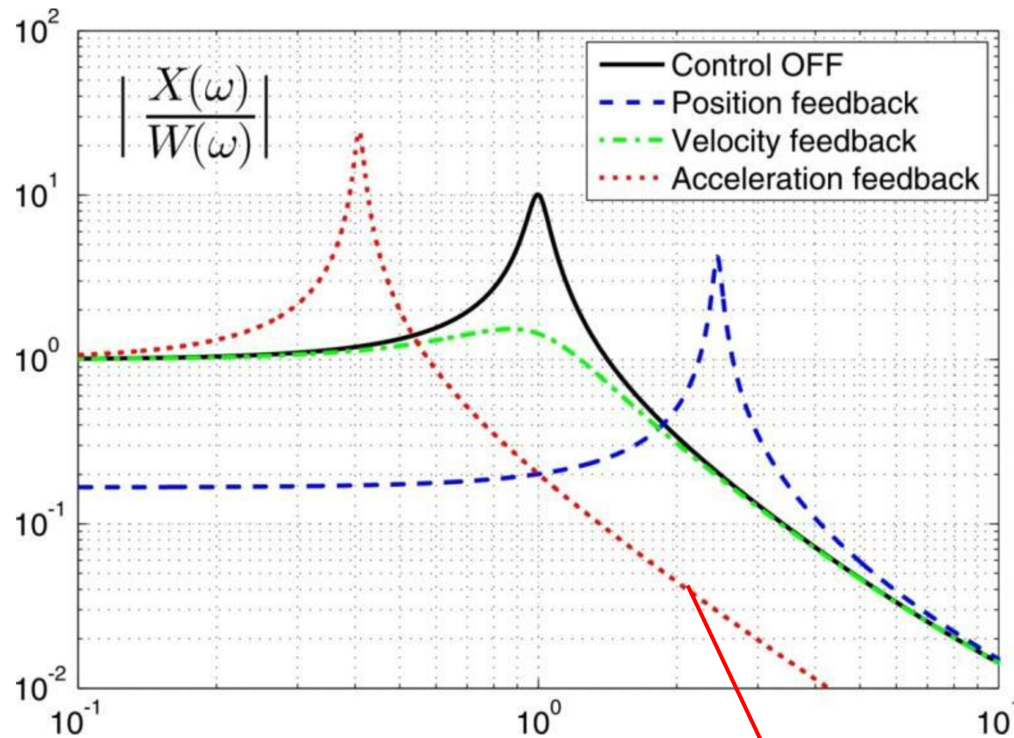
Active Isolation Strategies

Feedback control principle



$$F(t) = k_d x + k_v \dot{x} + k_a \ddot{x}$$

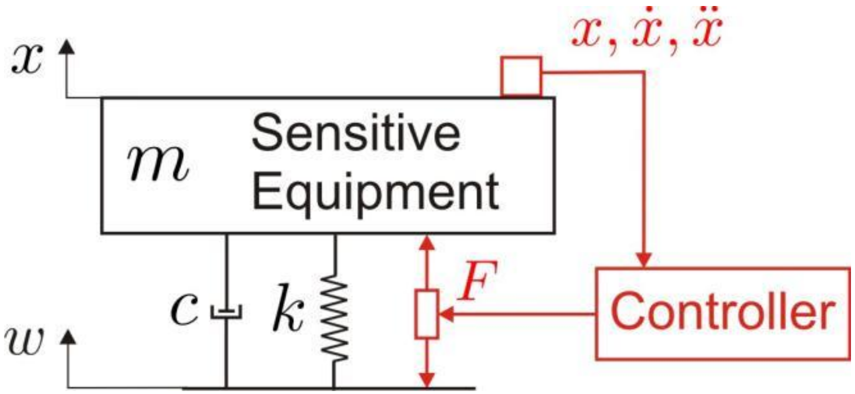
$$\frac{X(s)}{W(s)} = \frac{cs+k}{(m+k_a)s^2+(c+k_v)s+(k+k_d)}$$



Add virtual mass

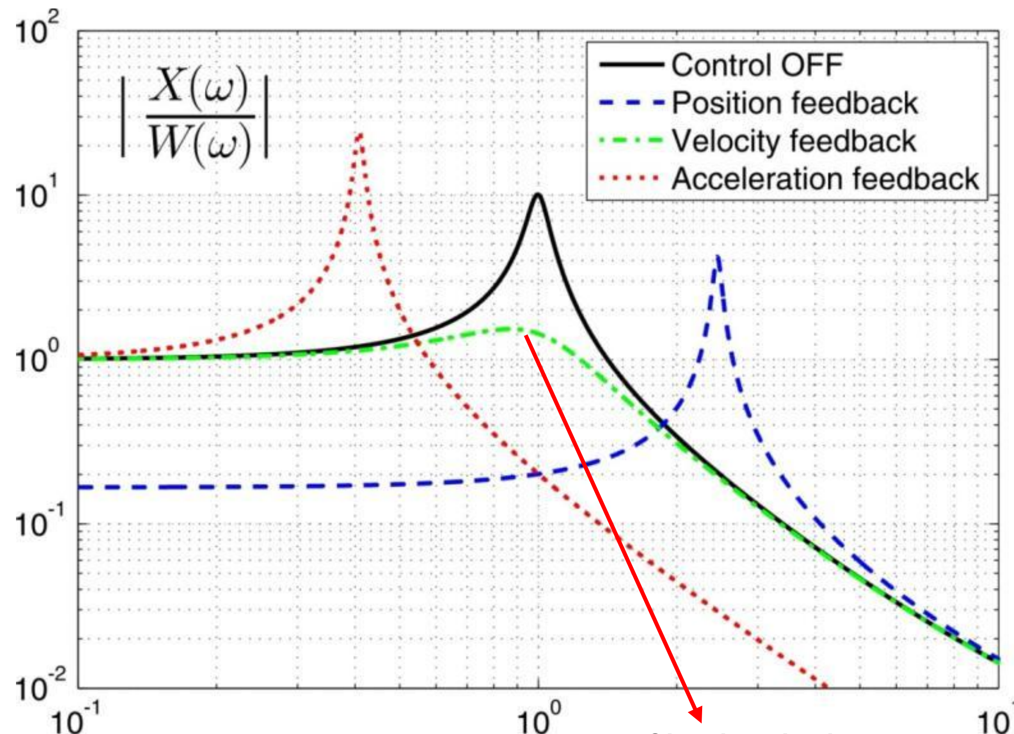
Active Isolation Strategies

Feedback control principle



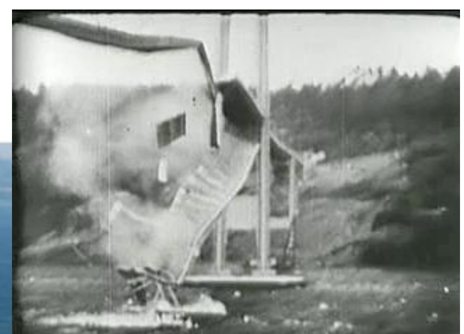
$$F(t) = k_d x + k_v \dot{x} + k_a \ddot{x}$$

$$\frac{X(s)}{W(s)} = \frac{cs+k}{(m+k_a)s^2+(c+k_v)s+(k+k_d)}$$



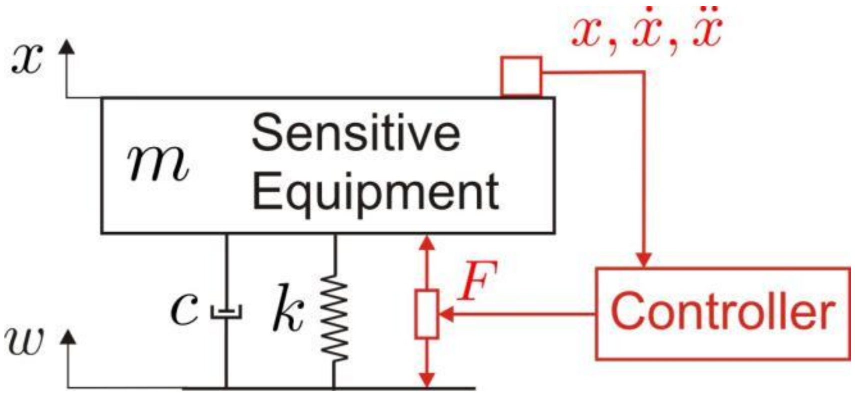
Sky-hook damper

(D.C. Karnopp, 1969)



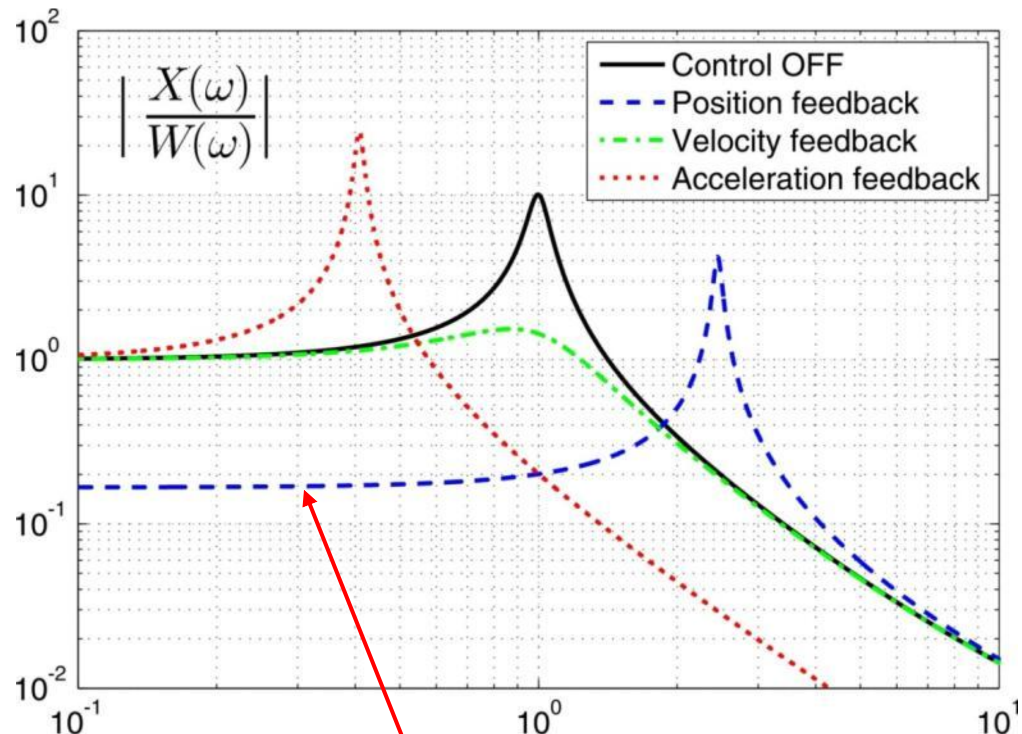
Active Isolation Strategies

Feedback control principle



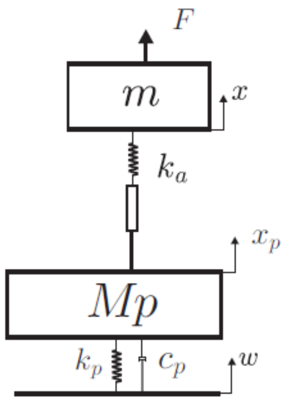
$$F(t) = k_d x + k_v \dot{x} + k_a \ddot{x}$$

$$\frac{X(s)}{W(s)} = \frac{cs+k}{(m+k_a)s^2+(c+k_v)s+(k+k_d)}$$



Virtual stiffness added

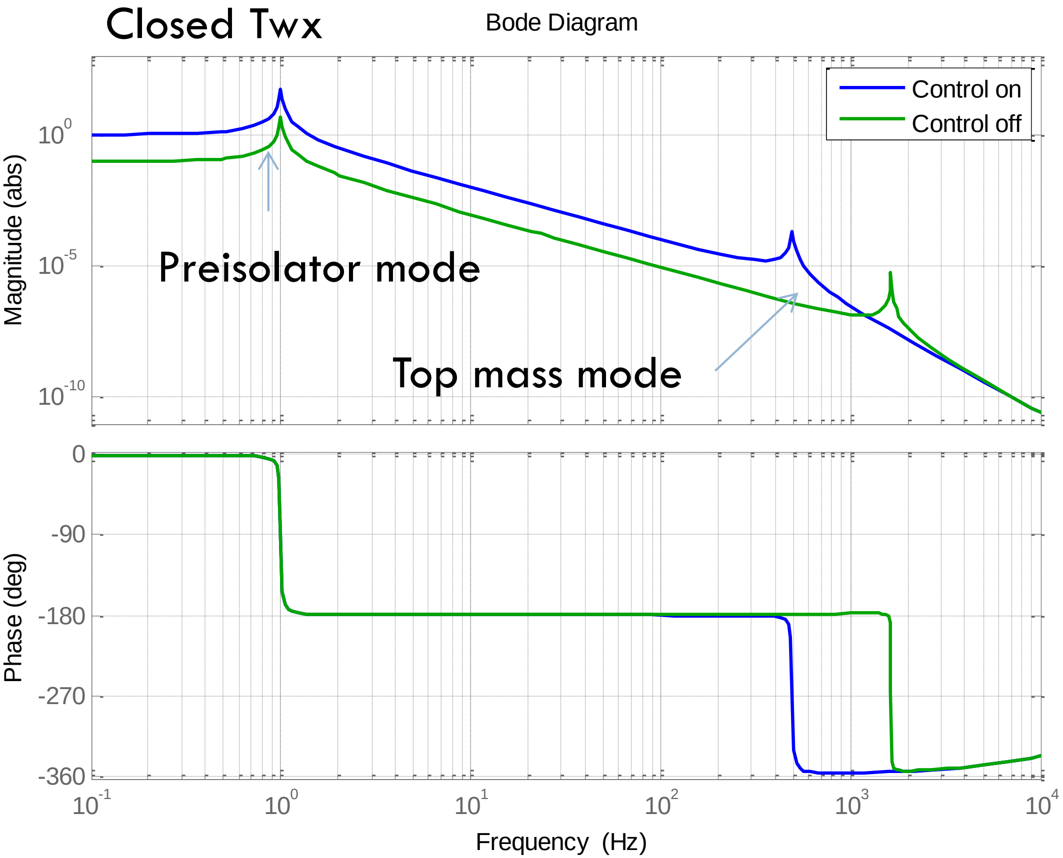
Active Isolation Strategies



Qd0 stabilization system as it is

Position feedback x

Closed Twx

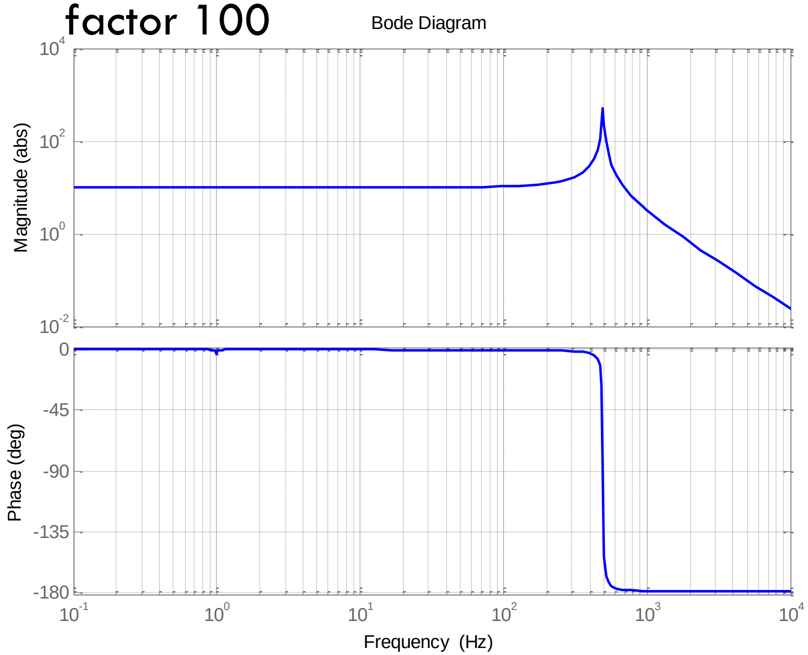


Reduces transmissibility

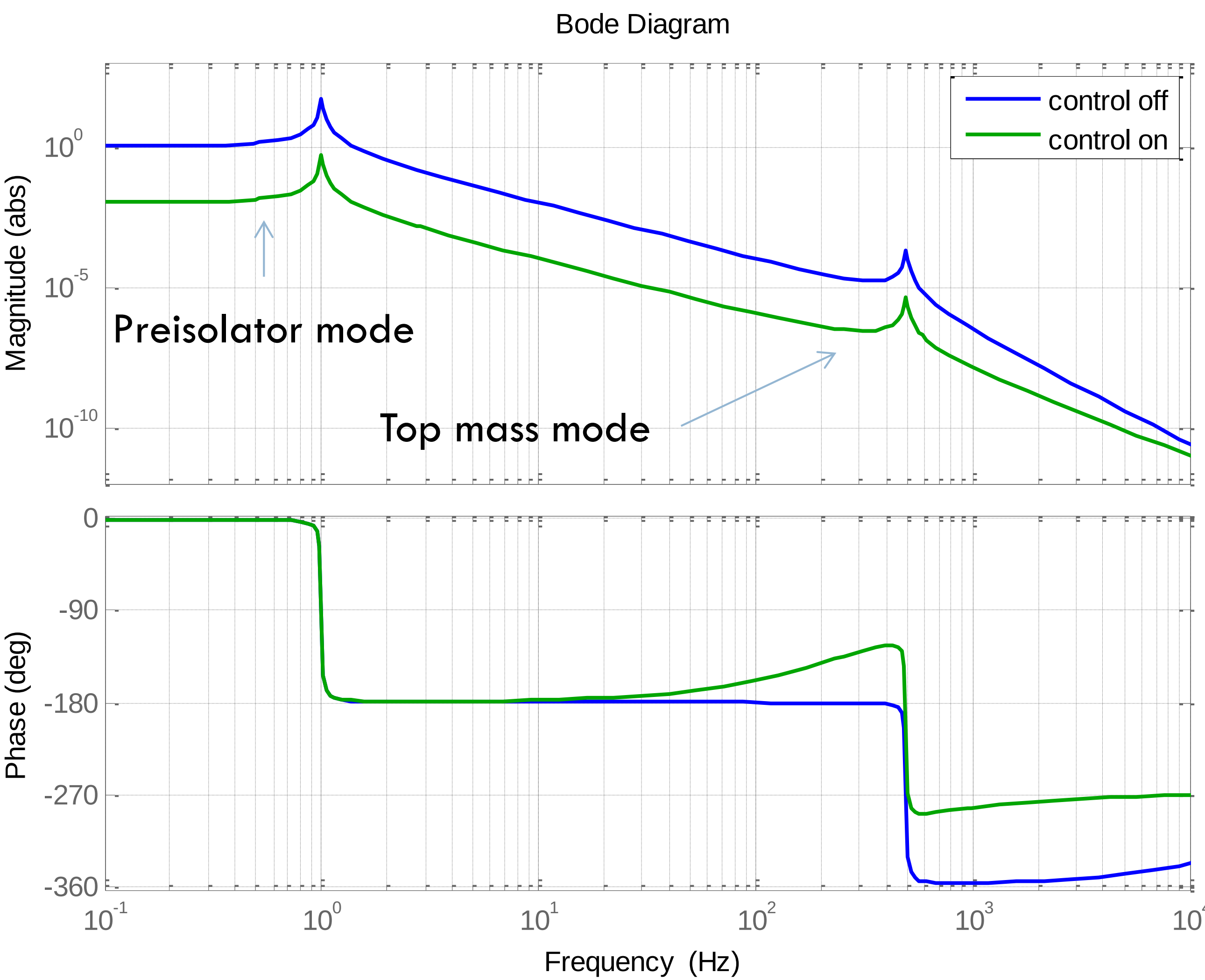
Doesn't damp first mode

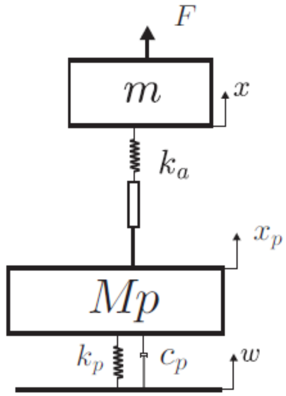
Always stable

Authority at 1 Hz needed with factor 100



Active Isolation Strategies





QD0 stabilization as it is

Feedforward of x_p

Reduction of transmissibility

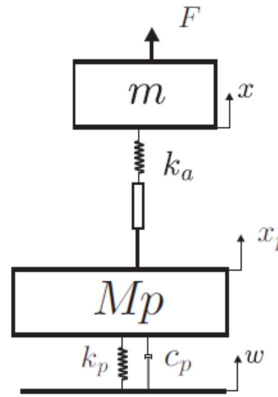
No damping of the mode

Top mass mode doesn't move

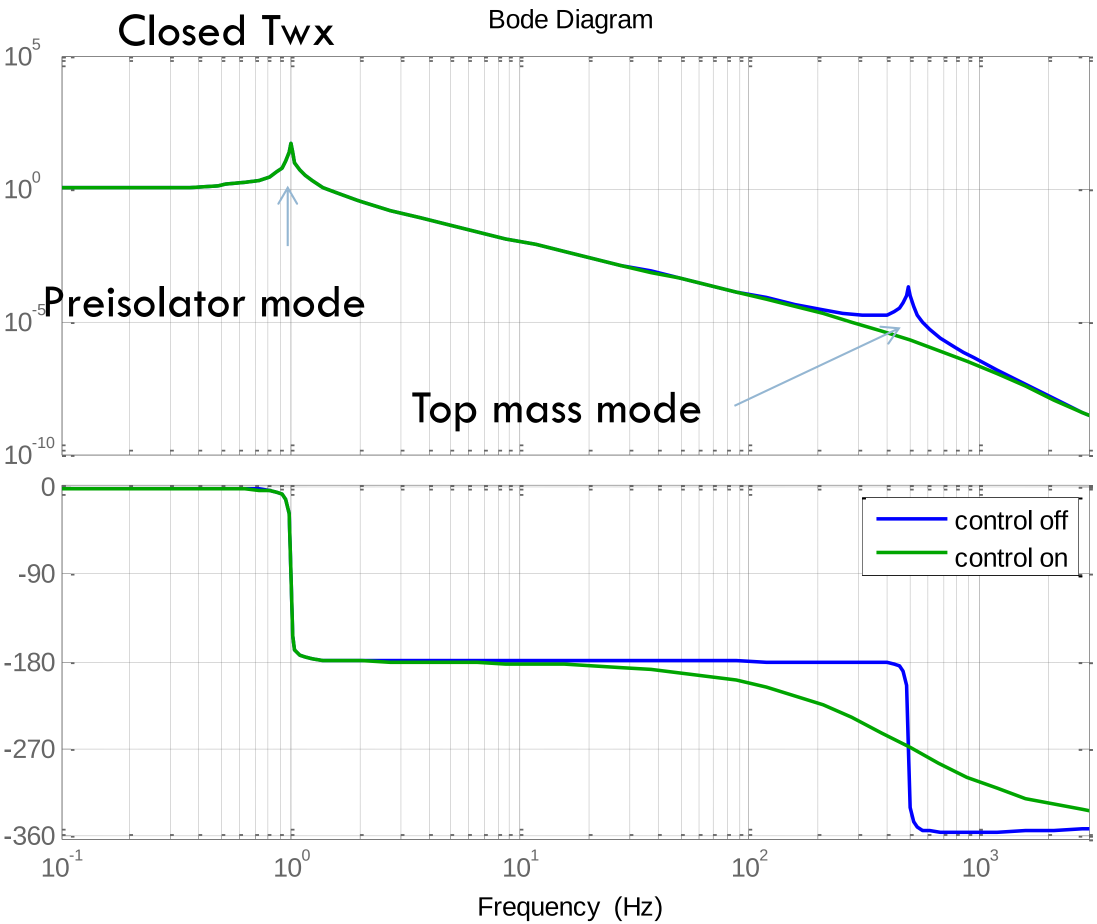
(as no added stiffness due to ff)

Authority at 1 Hz needed with factor 100

Active Isolation Strategies



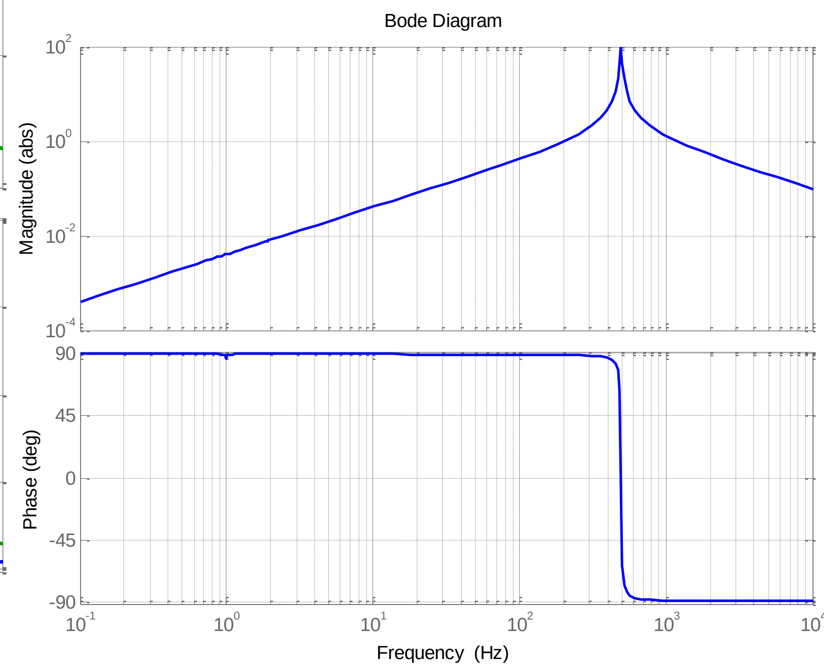
Damping with velocity feedback $\dot{x}$



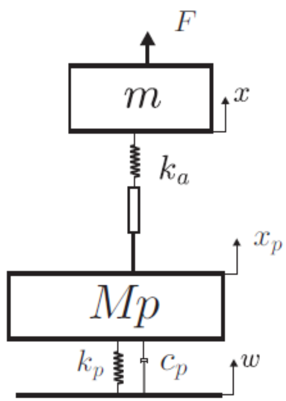
Only effect on second mode

Always stable

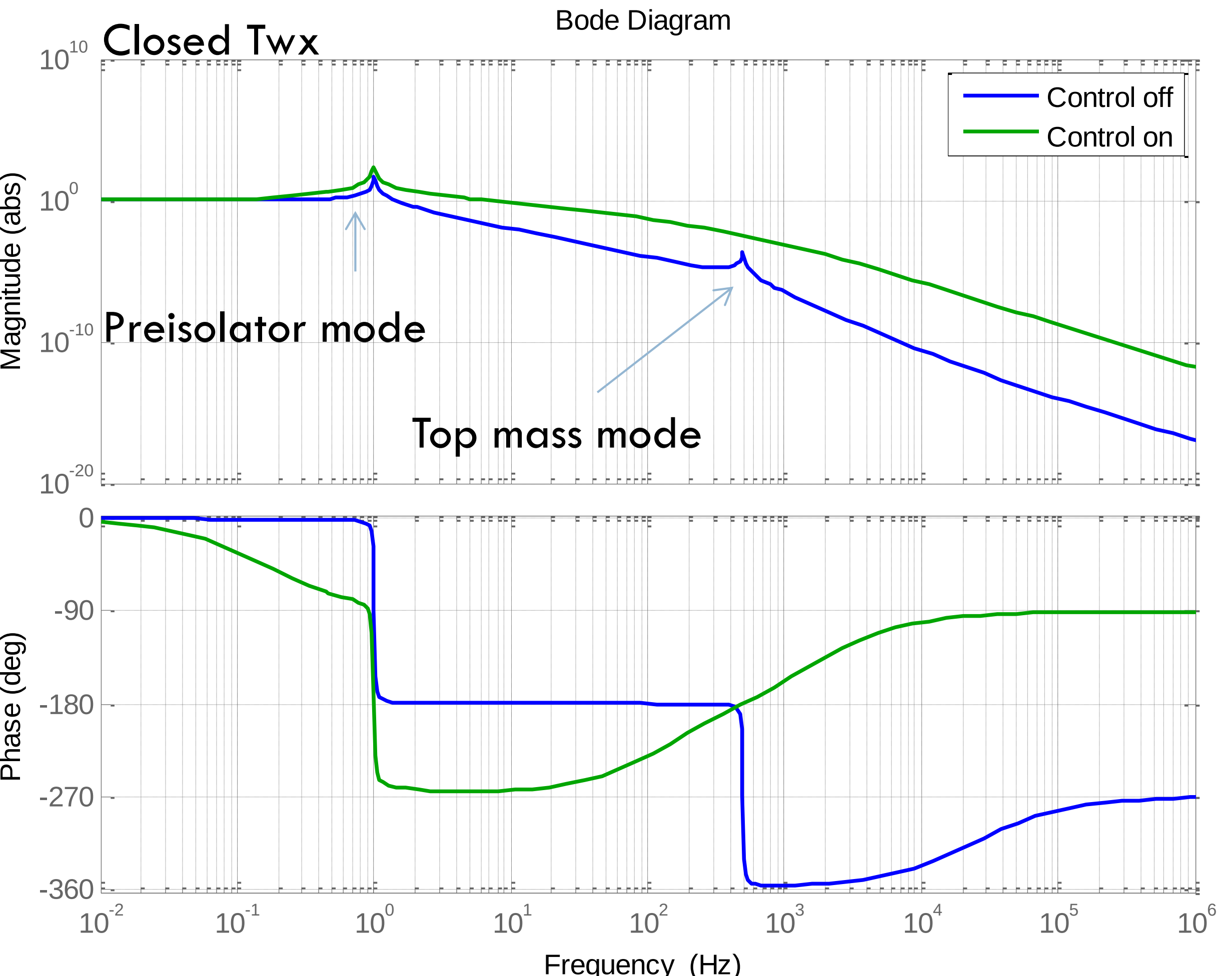
(similar results with IFF+noise issue)



Active Isolation Strategies

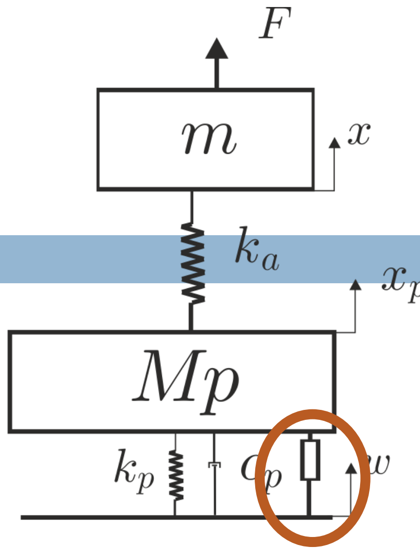


Velocity feedforward $\dot{x}_p$



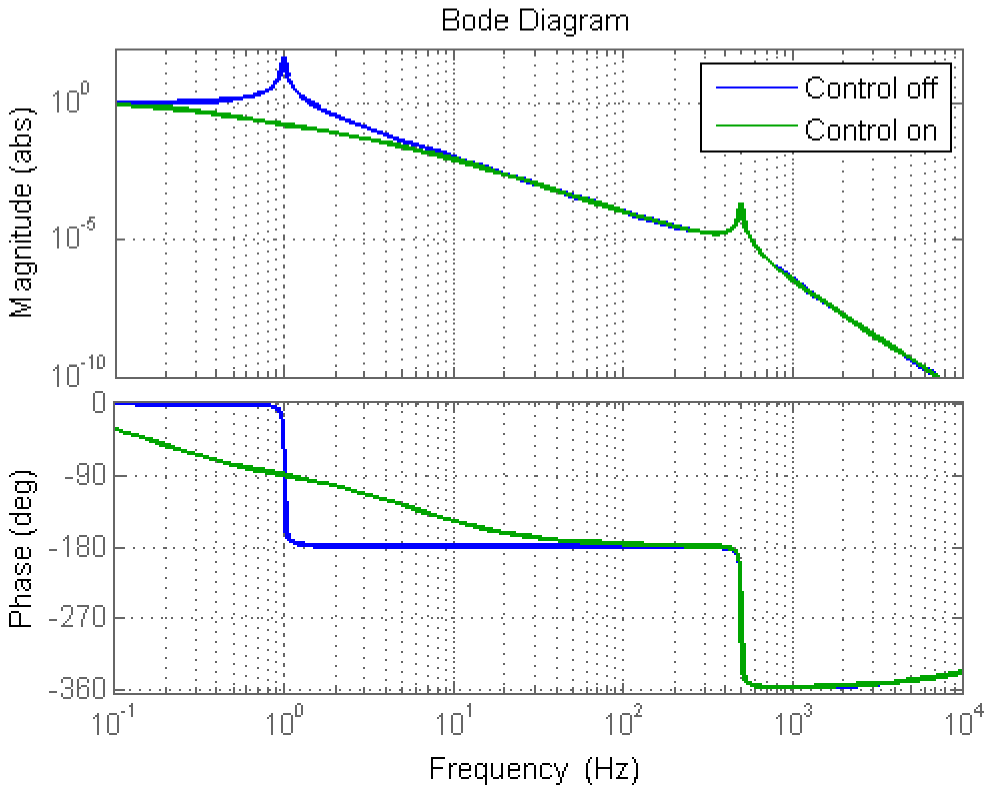
Doesn't work as it just injects noise due to phase difference

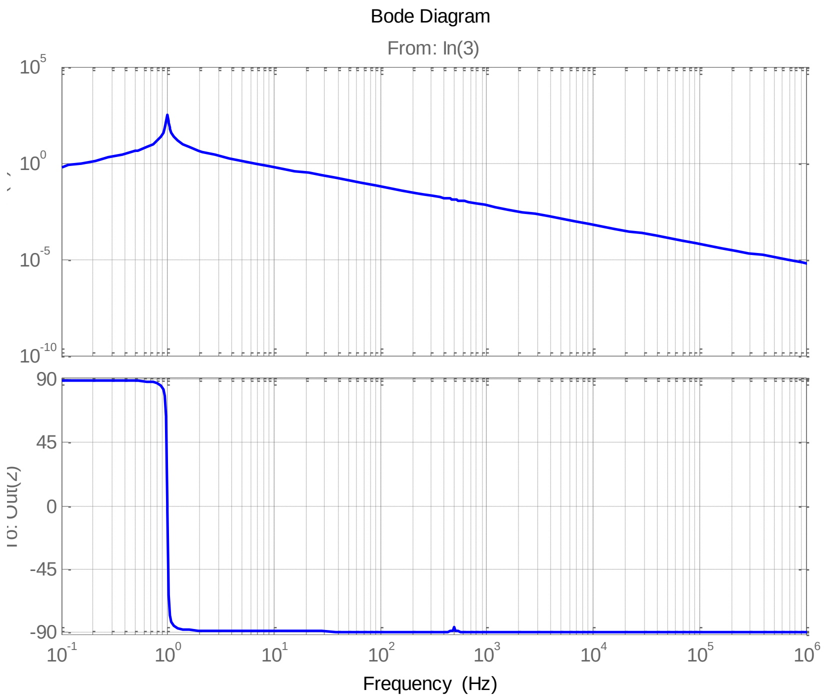
Active Isolation Strategies



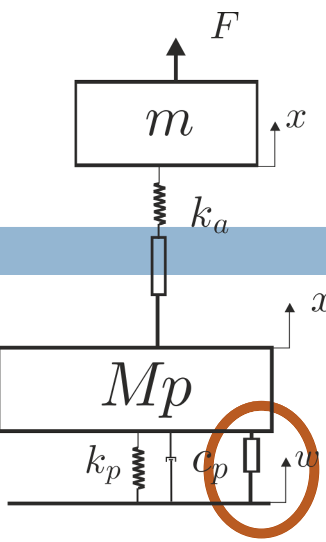
Proposed velocity feedback of $\dot{x}_p$

Damps first mode critically

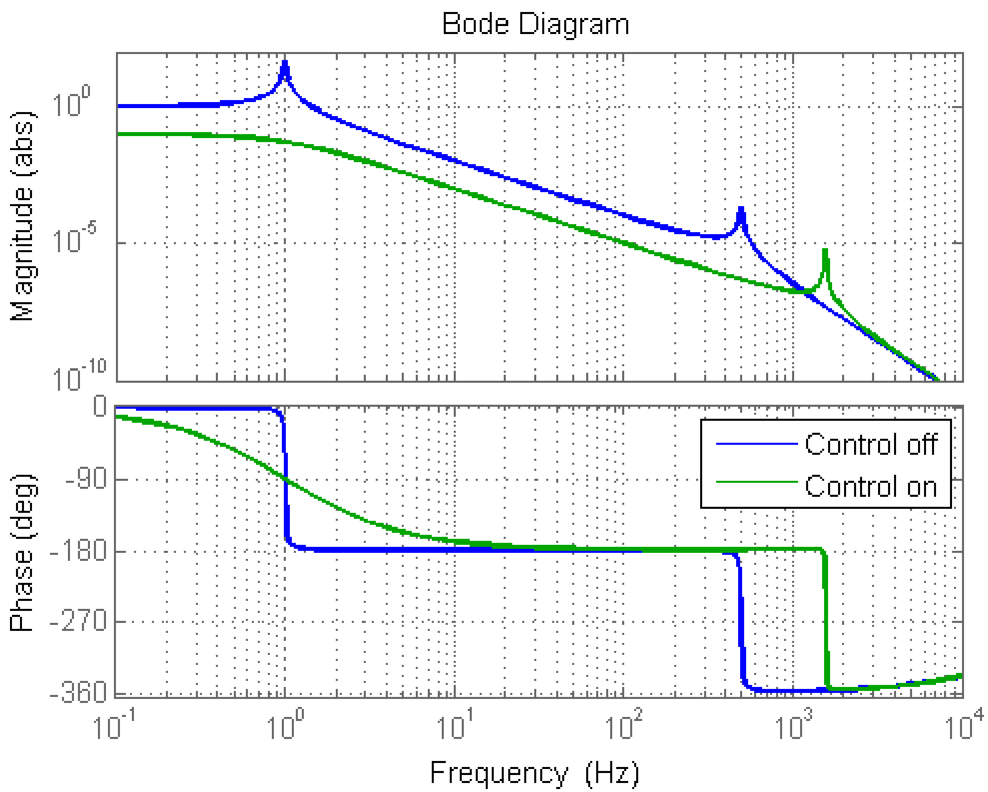




Active Isolation Strategies

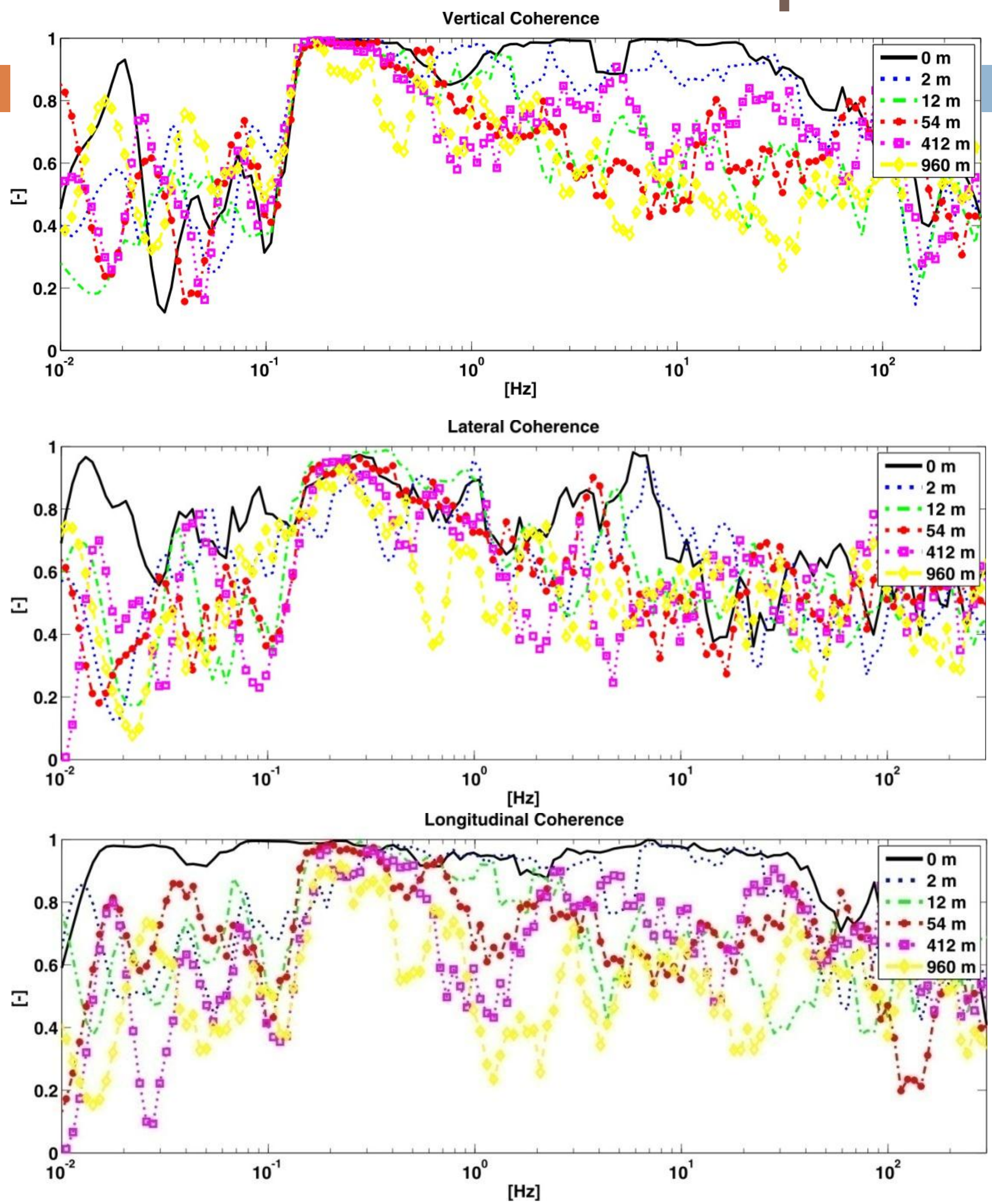


Combination of x and $\dot{x}_p$ feedback



Damps the peak and reduces transmissibility

Issues for the preisolator



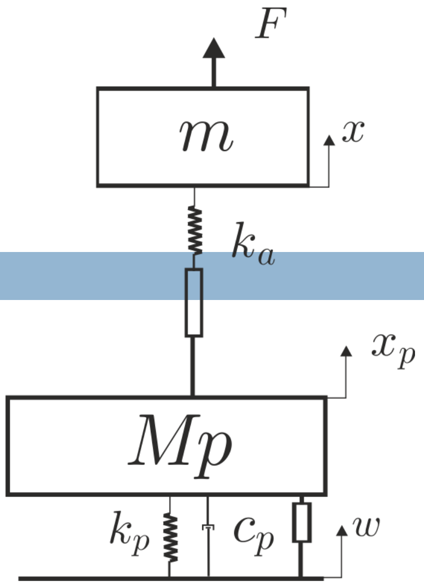
3D coherence of ground motion

Measurements performed in LHC tunnel by K. Artoos and M. Guinchard.

Ground motion > 12 m @ 1 Hz is not coherent

=> Active damping and transmissibility reduction necessary at 1 Hz

Issues for the preisolator



$$k_p = \omega_p^2 M_p = 6.31 N/\mu m$$

$$F_{air} = \frac{1}{2}\rho v^2 A$$

$$\rho_{air} = 1.1644 kg/m^3 @ 30^o C$$

$$A = 8m \times 2.5m$$

$$F_{air} = 11N@1m/s \qquad \delta_{air} = 1.7\mu m!$$

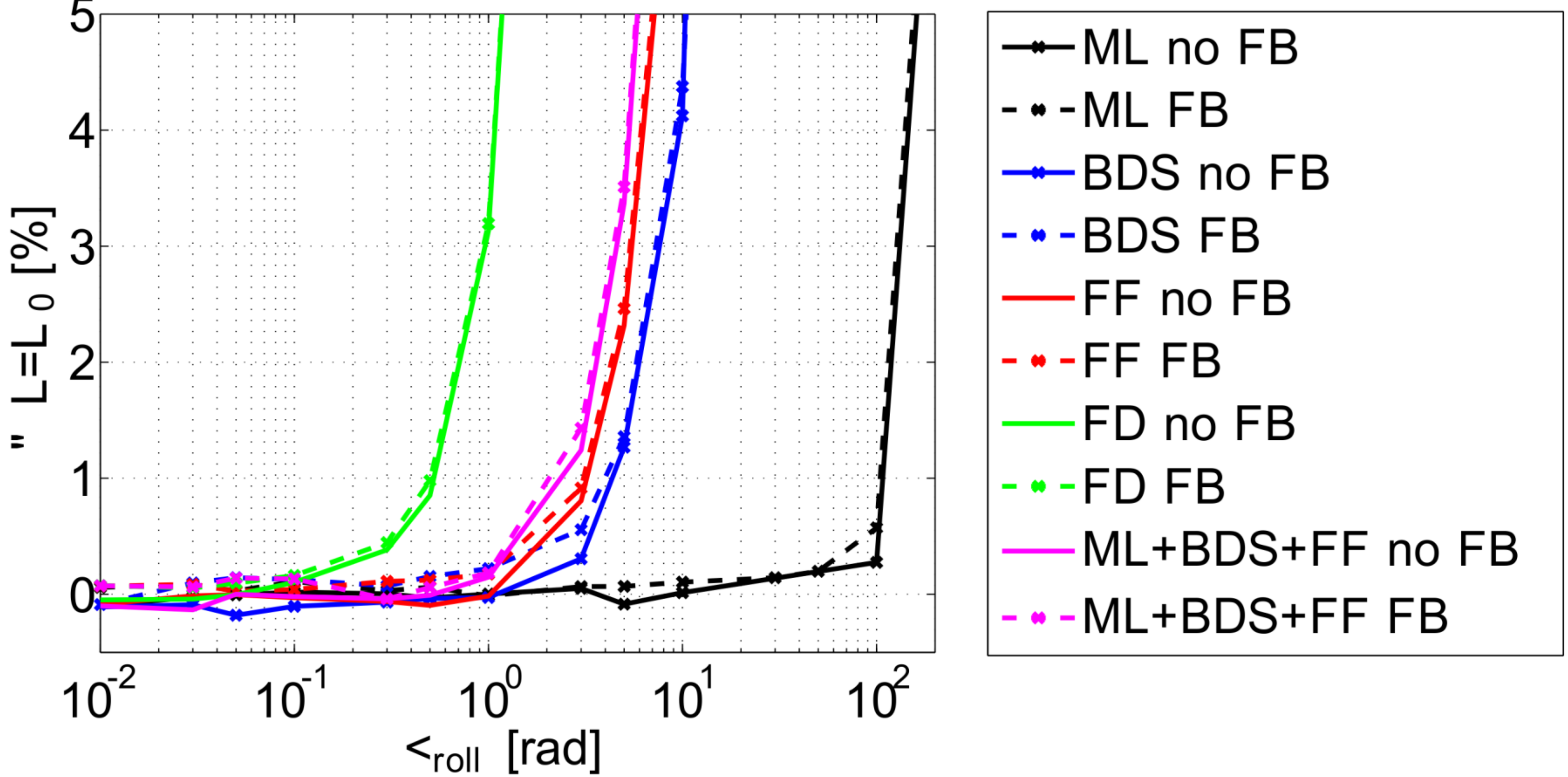
$$F_{air} = 0.11N@0.1m/s \qquad \delta_{air} = 17nm!$$

+pressure on vertical plane on surface of magnets which has a moment arm!! +other noise sources coming from the detector
=> Increasing with position feedback necessary!

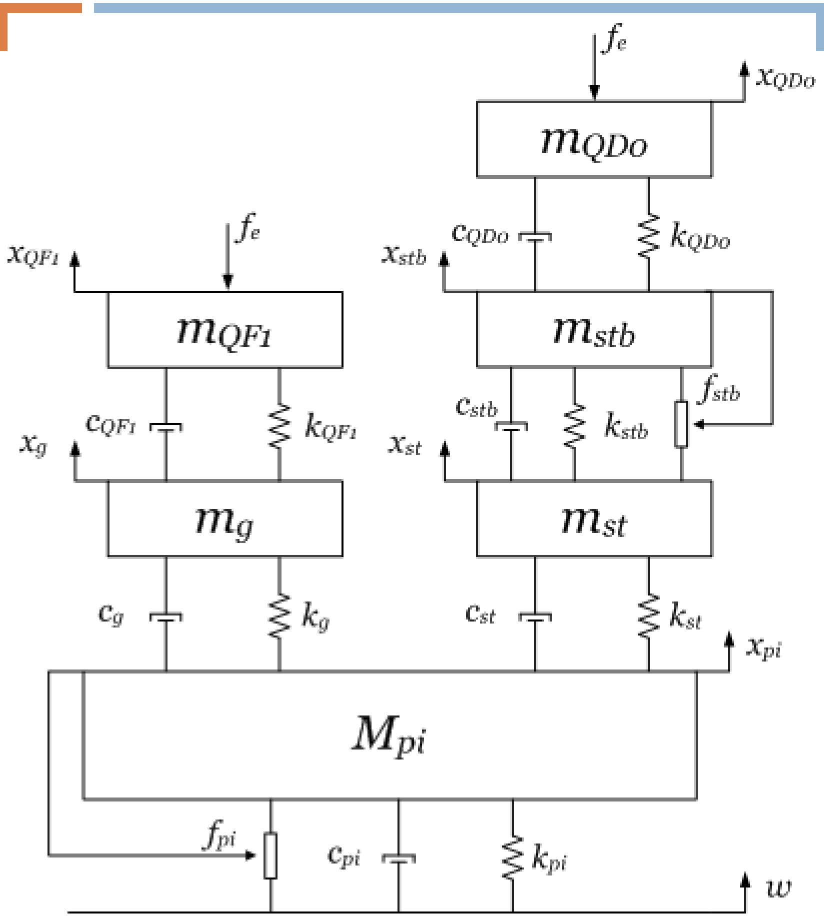
Issues for the preisolator

Preliminary max roll simulations vs luminosity loss
=> Max 1 μrad!

J. Pfingstner



Further simulations with PID



pi – pre-isolator
g – pre-alignment mechanics & support girder
st – pre-alignment mechanics & support tube
stb – LAPP stabilization system

More complex model has been made

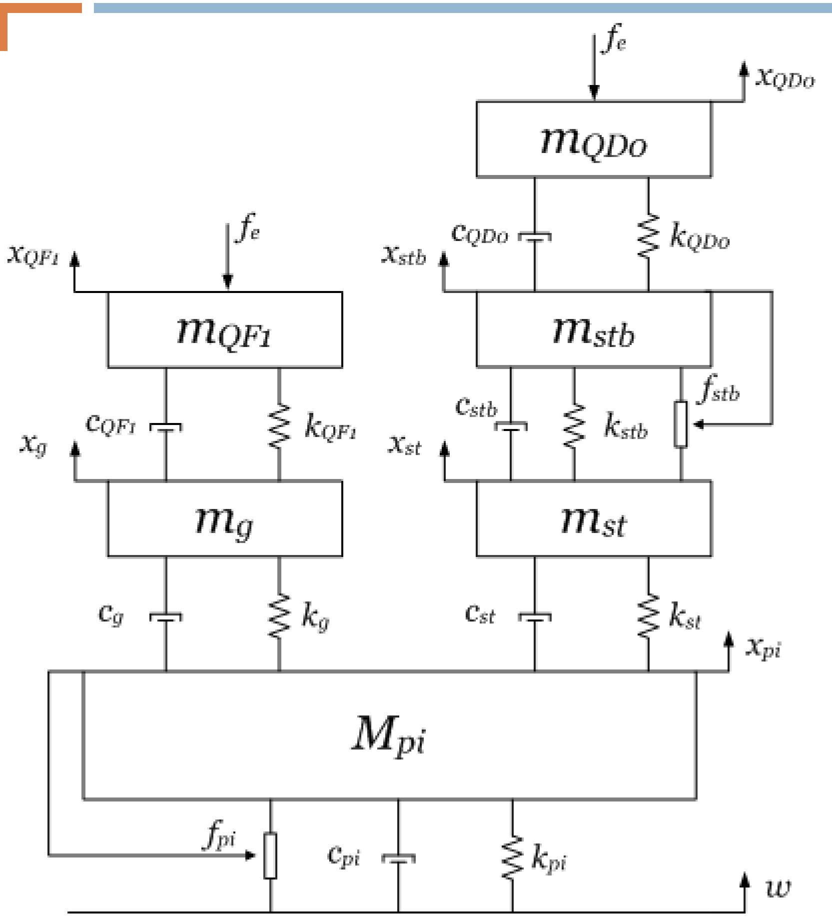
With PID feedback for x_p =>improved position, damping and compliance

With proposed CERN MBQ stabilization (as example)

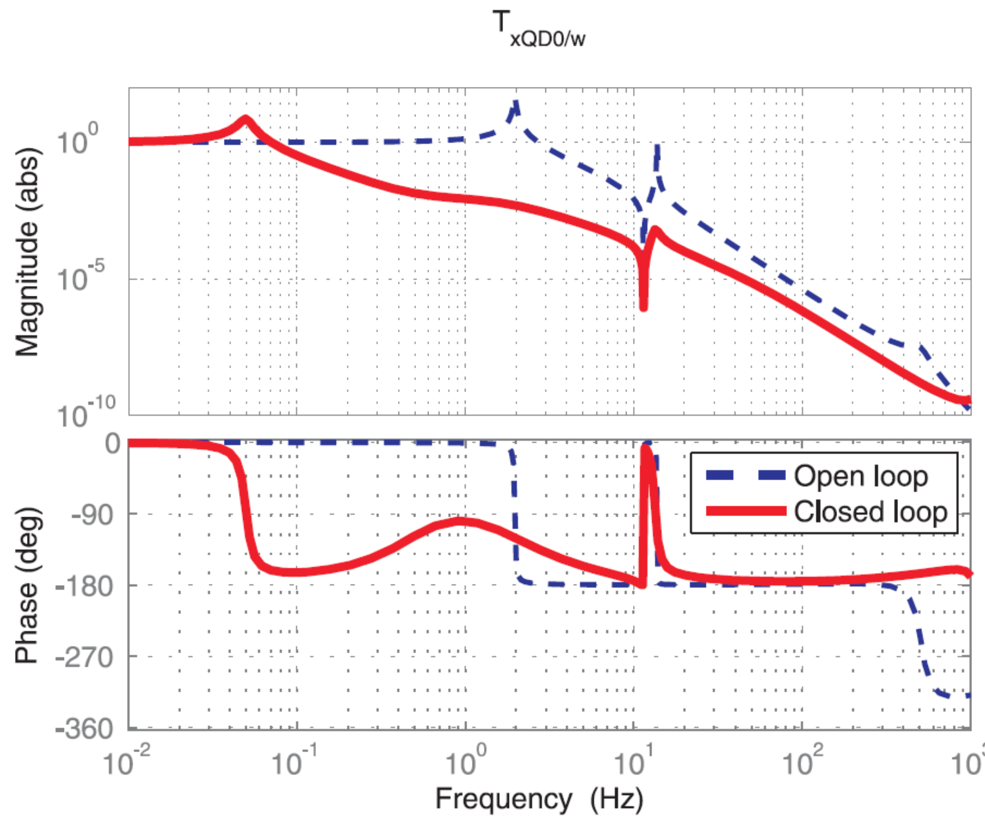
$$
\begin{aligned}
&M_{pi}\ddot{x}_{pi} + k_{pi}(x_{pi} - w) + k_{st}(x_{pi} - x_{st}) + kg(x_{pi} - x_g) = k_{pi}\delta_{pi} \\
&M_g\ddot{x}_g + k_g(x_g - x_{pi}) + k_{QF1}(x_g - x_{QF1}) = 0 \\
&M_{QF1}\ddot{x}_{QF1} + k_{QF1}(x_{QF1} - x_g) = fe_{QF1} \\
&M_{st}\ddot{x}_{st} + k_{st}(x_{st} - x_{pi})) + k_{stb}(x_{st} - x_{stb}) = k_{stb}\delta_{stb} \\
&M_{stb}\ddot{x}_{stb} + k_{stb}(x_{stb} - x_{st}) + k_{QD0}(x_{stb} - x_{QD0}) = -k_{stb}\delta_{stb} \\
&M_{QD0}\ddot{x}_{QD0} + k_{QD0}(x_{QD0} - x_{stb}) = fe_{QD0}
\end{aligned}
$$

$$
\begin{aligned}
Mg &= 50 \\
MQD0 &= 15000 \\
Mpi &= 40000 \\
MQF1 &= 15000 \\
Mst &= 40 \\
Mstb &= 150
\end{aligned}
\qquad
\begin{aligned}
w_g &= 2\pi 200 \\
w_{QD0} &= 2\pi 50 \\
w_{pi} &= 2\pi 2 \\
w_{QF1} &= 2\pi 100 \\
w_{st} &= 2\pi 300 \\
w_{stb} &= 2\pi 100
\end{aligned}
\qquad
\xi_i = 1\%.
$$

Further simulations with PID



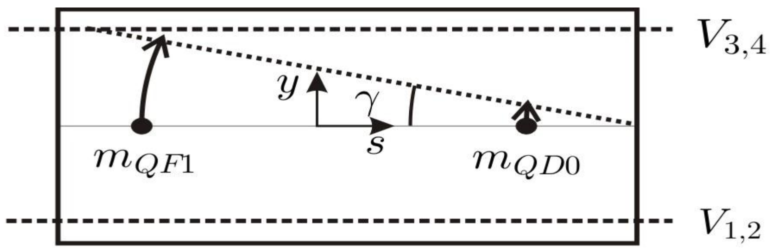
pi – pre-isolator
g – pre-alignment mechanics & support girder
st – pre-alignment mechanics & support tube
stb – LAPP stabilization system

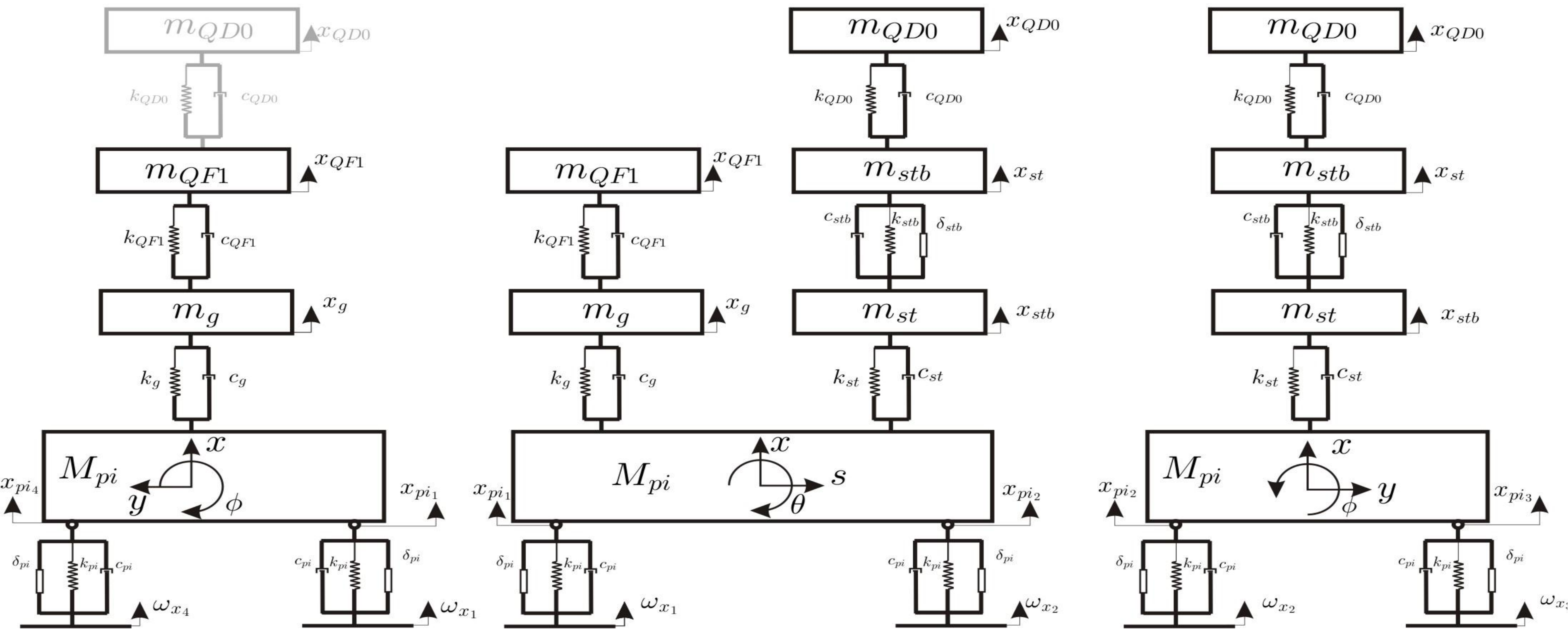


Possible transfer function between ground and QD0 + no drift at low freq
Possibility to change Preisolator position
!!!No noises or filters in it!!!!

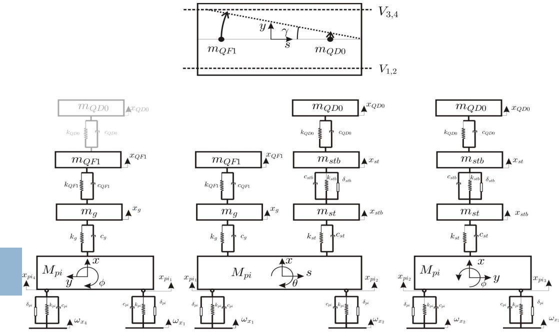
Further Research proposal (tender/inhouse)

More complex model
=>Investigate modes
with changing magnet
positions





Further Research proposal (tender/inhouse)



Research goals

1. Make a dynamic model of the system presented. For this model:

~2 months

- give the transfer functions between all degrees of freedom and the ground
- make a table of all the modal frequencies and their decomposition in eigenvectors
- graphical representation of the evolution of the modal frequencies and their decomposition for a changing γ from 0 up to 15 degrees which changes the position of m_g, m_{QF1}, m_{st}, m_{stb}, m_{QD0}.
- What is the effect of increasing the 1st mode to 20 Hz?

2. Propose the best active damping (velocity feedback, Integrated Force Feedback,…) system which:

- damps the 1st mode of M_{pi} critically
- Reduces the 1st mode from 20 Hz to 1 Hz through active control
- uses existing technologies compliant with the environmental parameters,
- does decrease the drop off above $2\omega pi$ in the transfer function between w_{pi} and x_{pi}, for the ground vibrations specified, due to noise or any other limitations (actuator or sensors).
- Specify the number actuators/sensors (The 4 specified are a suggestion).
- Is it better to use a global controller or have each leg have its own SISO controller and decouple them with joints?
- Simulate the performance of the proposed isolation system in an environment with ground vibrations and applying actual sensor/actuator, sensitivity, noise and resolution.

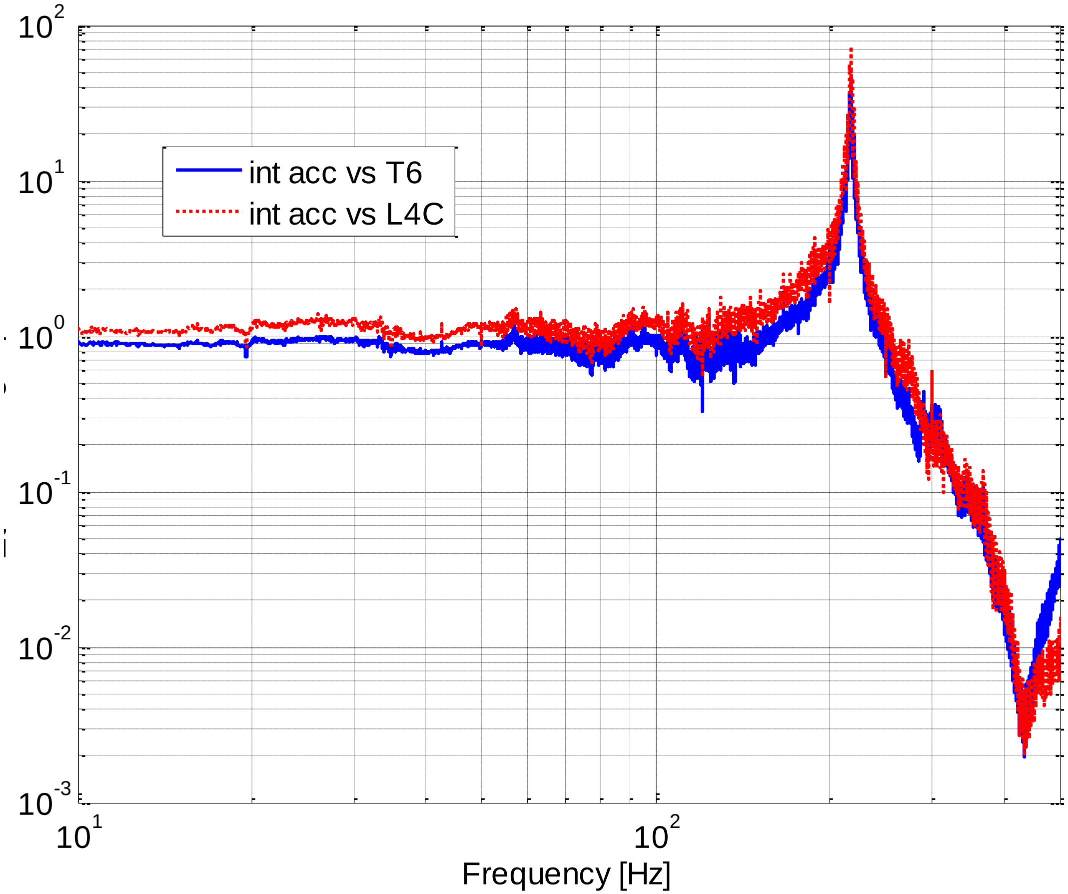
~5 months

Further issues

- The alignment stage (would fall off now)
- Effect of the 2nd and 3rd mode on luminosity
- Effect of phase difference between two preisolator blocks
- Further issues?

Question accelerometer feedback

Measured sensitivity endevco M86



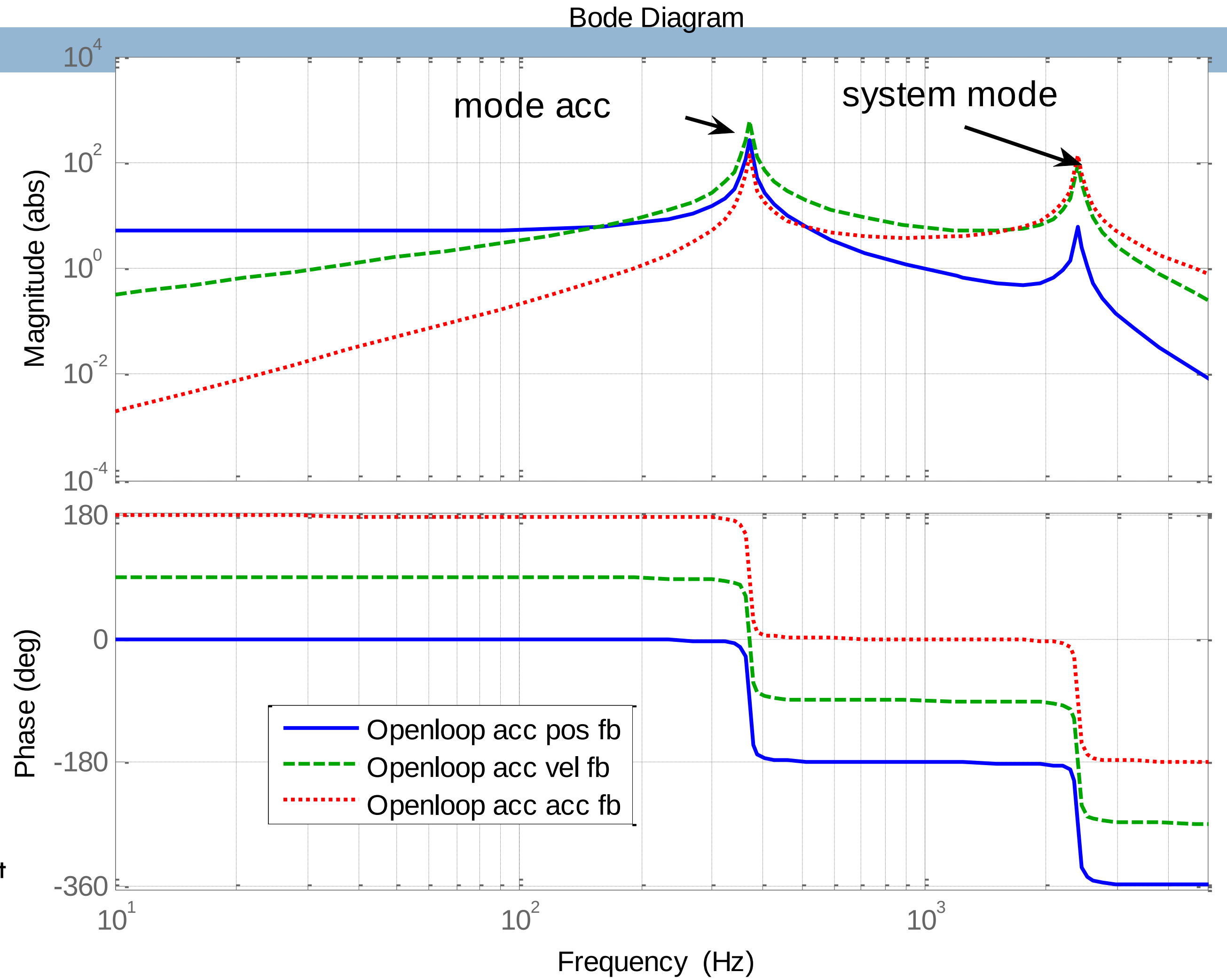
Sensitivity curve of accelerometer has resonance at ~200-300 Hz

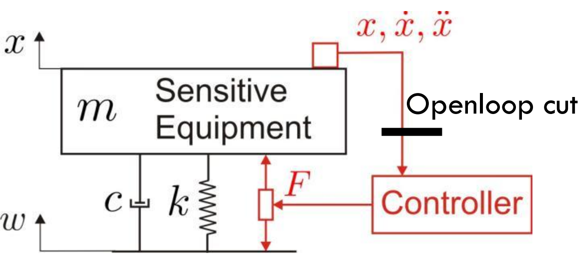
->issue with stability when resonance of system and accelerometer meet

Question accelerometer feedback

Openloop:
Stable if for Mag>1
Phase -180<phi<180

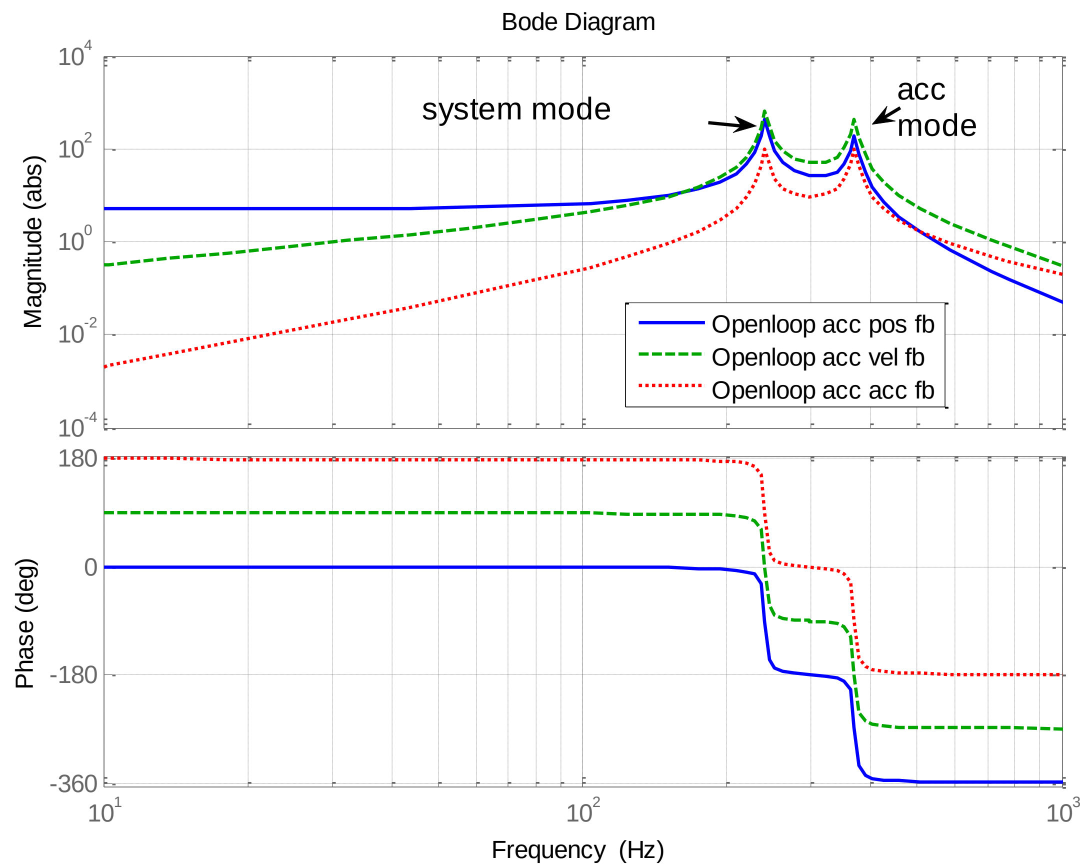
System mode high:
Acc fb ok
Vel fb unstable
Could be made stable
Pos fb unstable
Could be made stable





Question accelerometer feedback

System mode low:
Acc fb ok
Vel fb unstable
Pos fb unstable
 Only pole cancellation



Pole cancellation -> very good knowledge of system necessary, difficult for complex system -> acc mode needs to be far away from system modes

Conclusion

Active control of the preisolator block is needed:
-to perform damping of the resonance
-to provide positioning/alignment capabilities/synchronize with other preisolator
-to improve compliance of the system

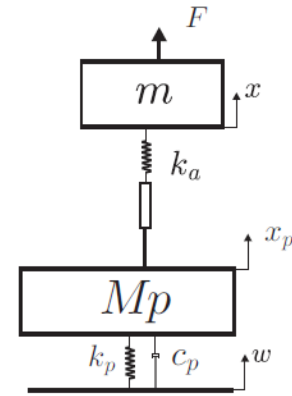
Proposed solution for a PID on the preisolator

Further study required with full model=> Tender/inhouse study?

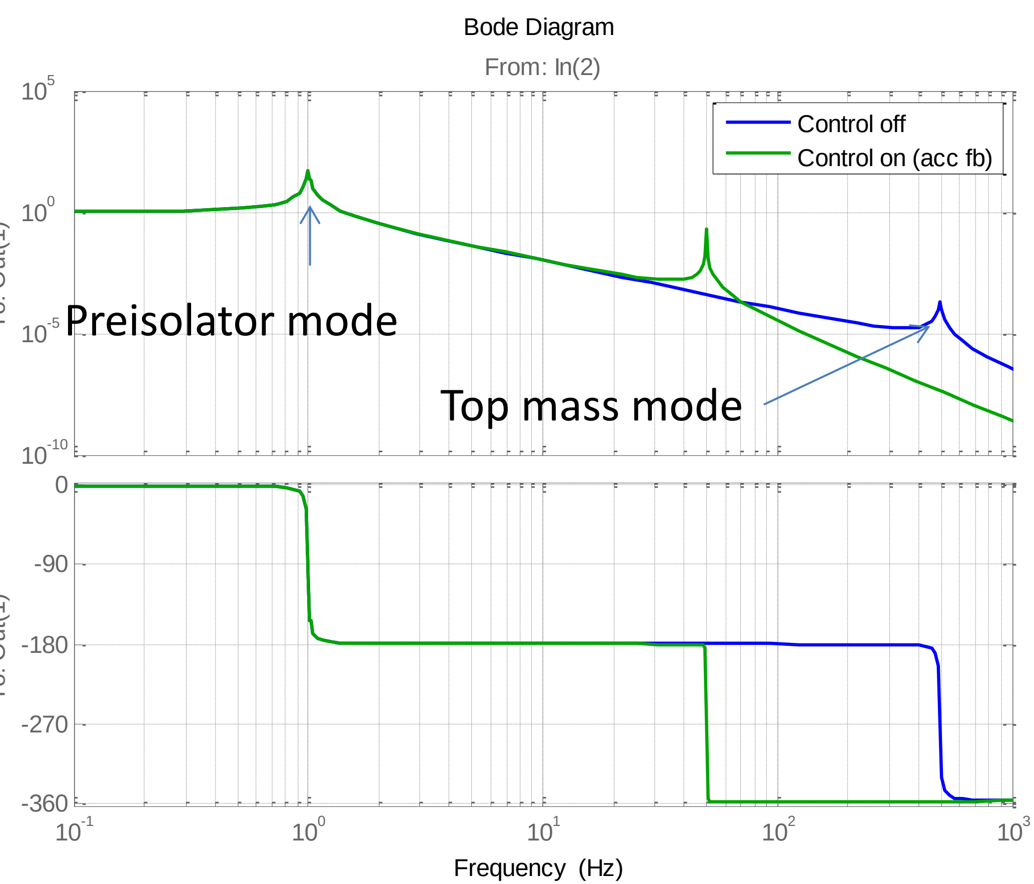
Stef's learning moment about accelerometer feedback

Spares

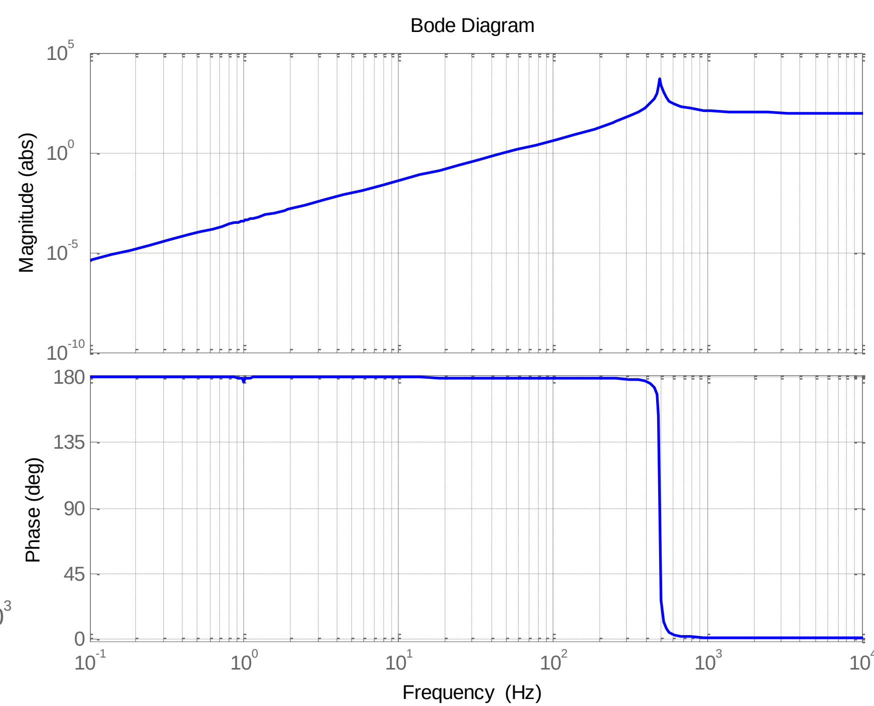
Pre-isolator feedback
$\ddot{x}$ acc fb



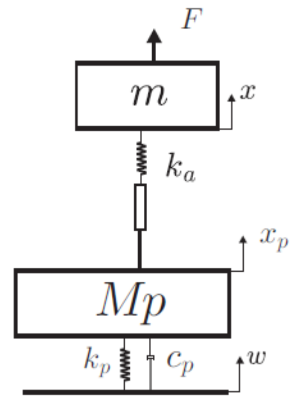
Closed Twx



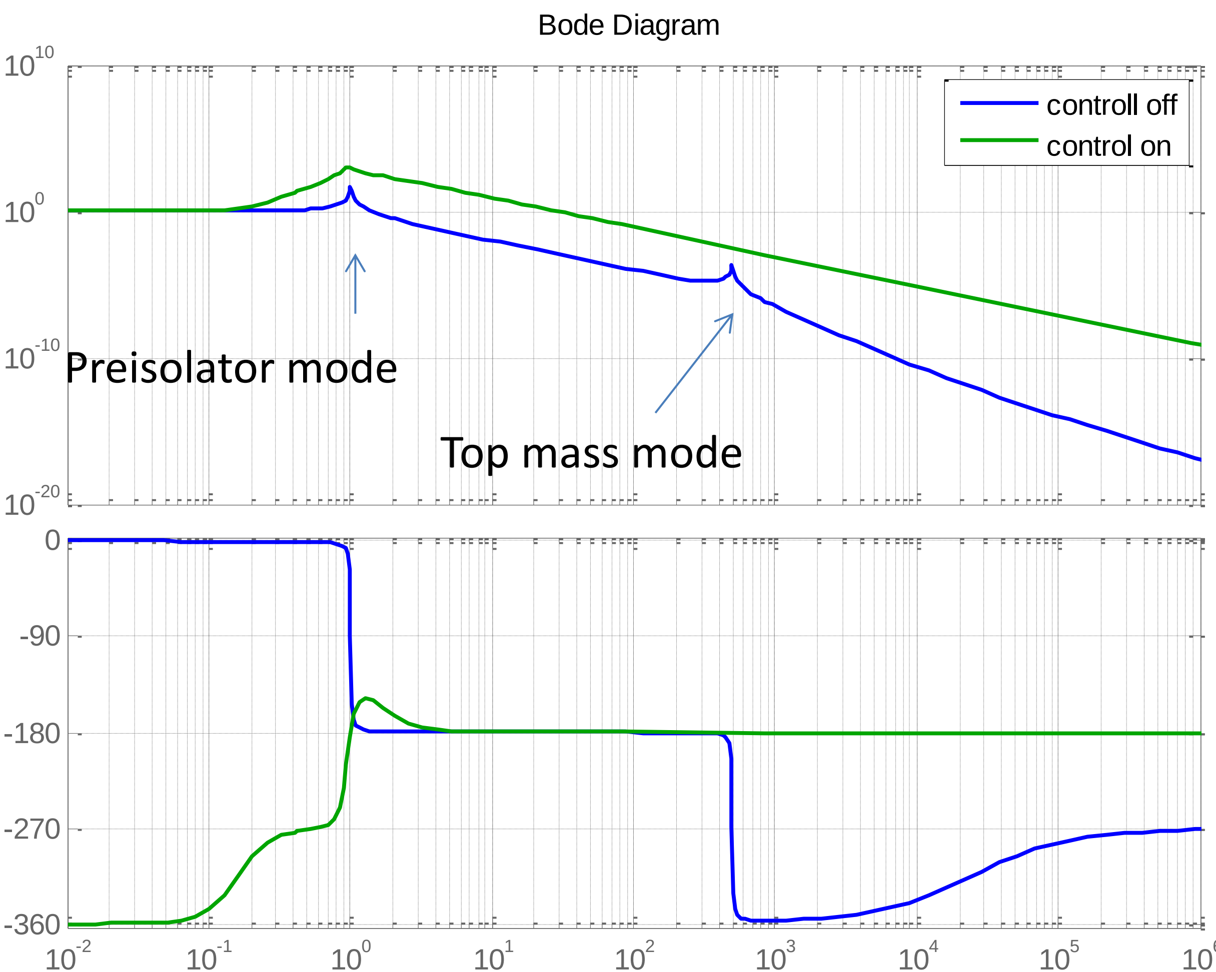
Only effect on second mode
Always stable



Pre-isolator feedback
$\ddot{x}_p$ acc ff



Closed Twx



Doesn't work!