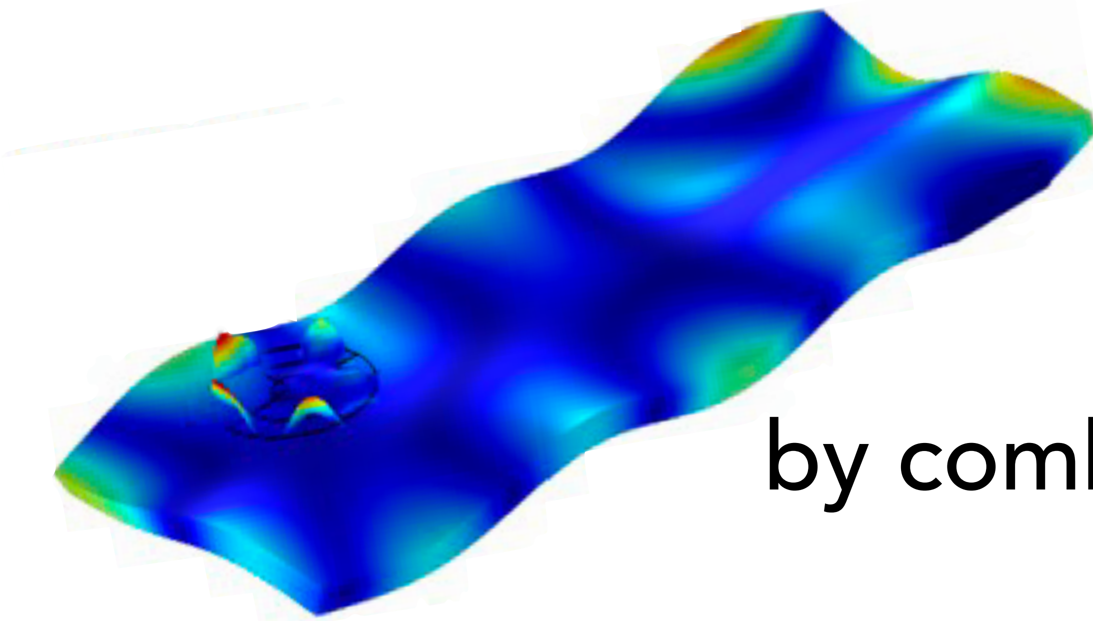

Broadband vibration mitigation by combining Acoustic Black Hole effect & Contact Non-Linearities

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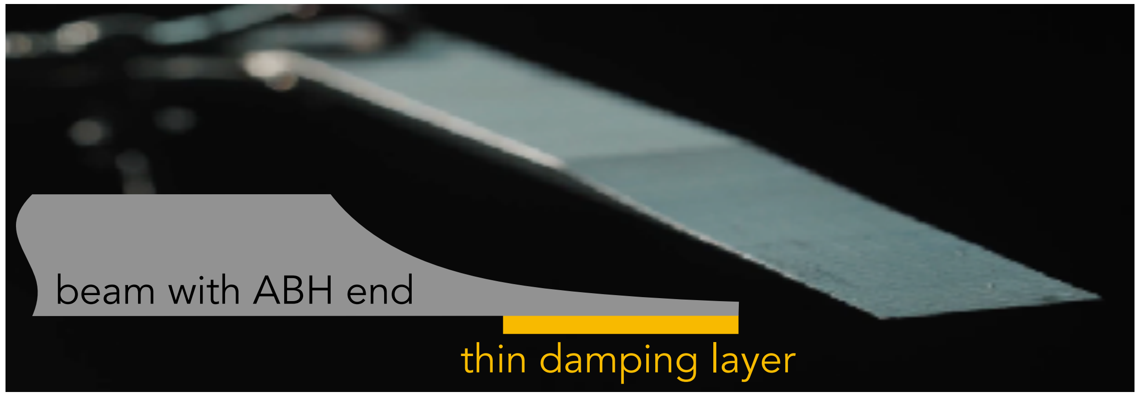
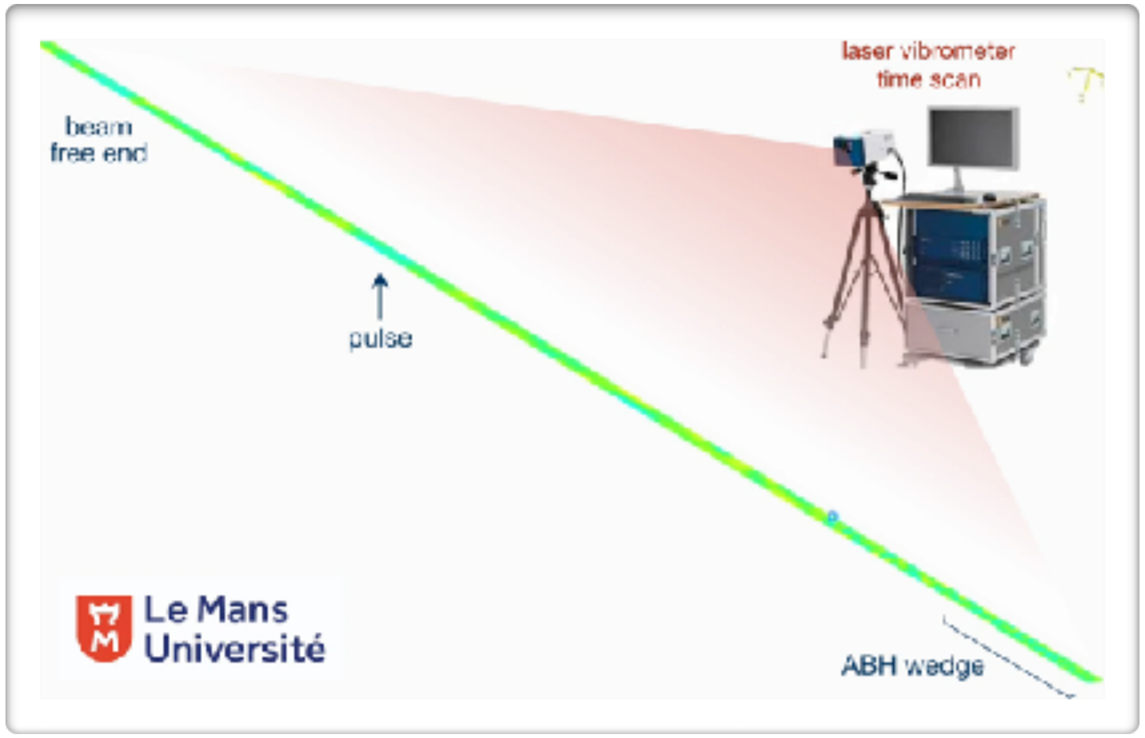
About the VI-ABH principle

ABH effect

- High damping at HF
- But no damping at LF

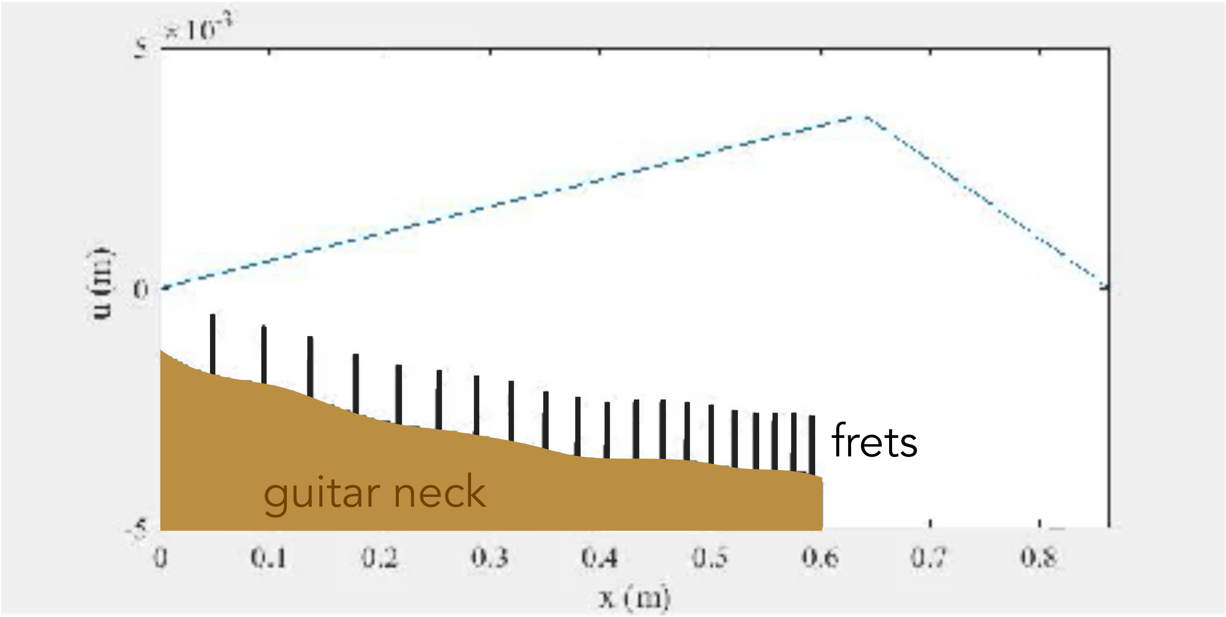




[Pelat *et al.*, JSV 476, 2020]

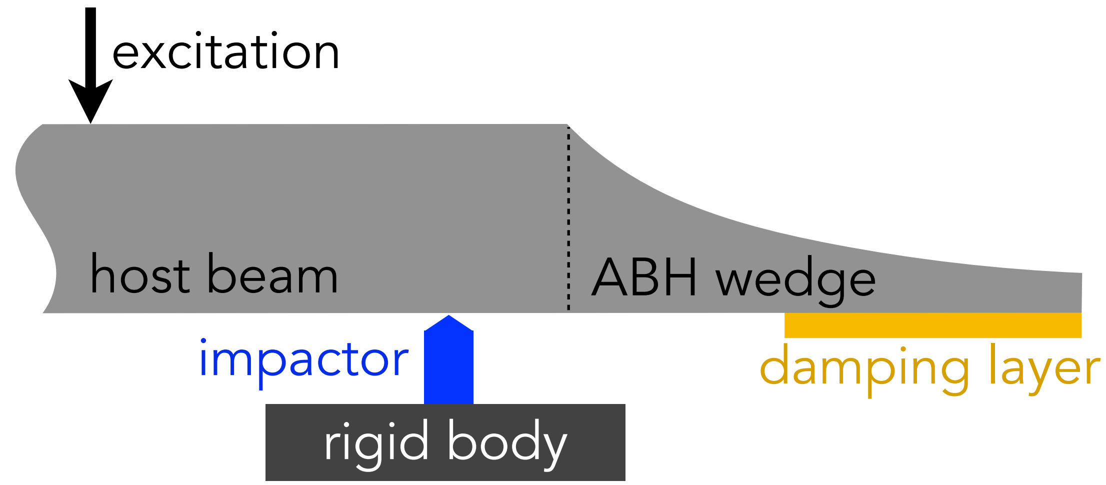
Contact non-linearities

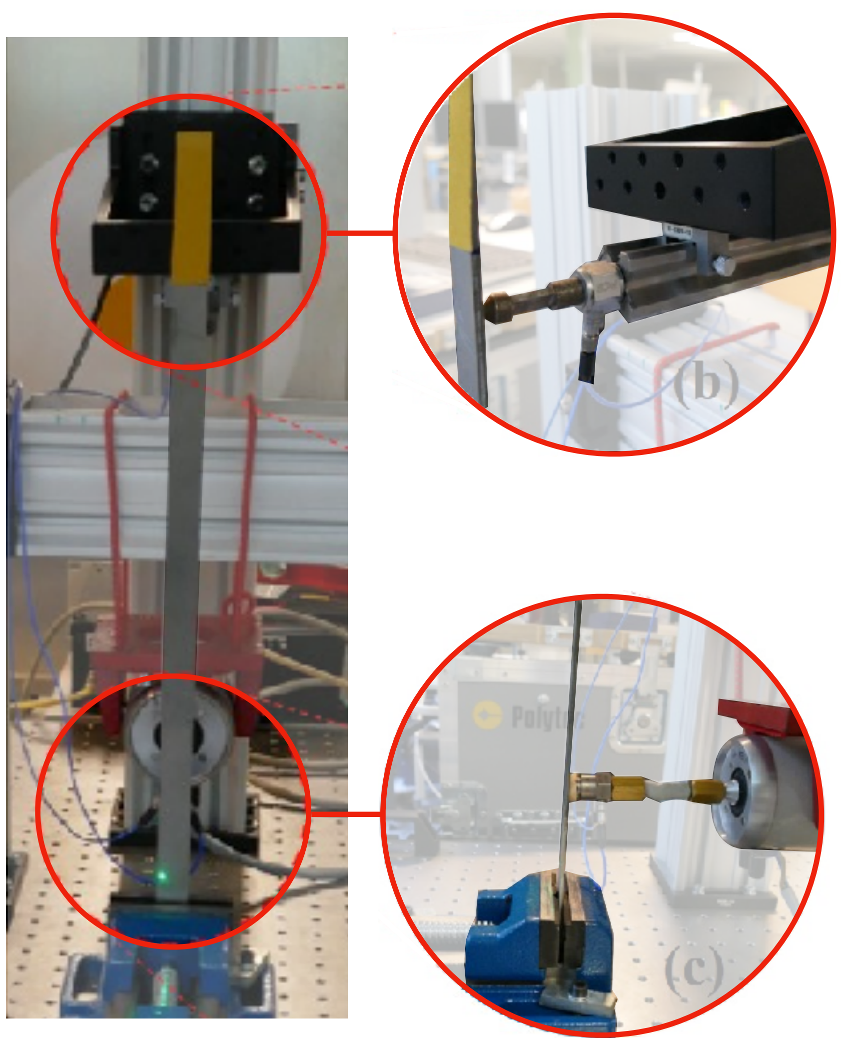
- Energy transfer from LF to HF



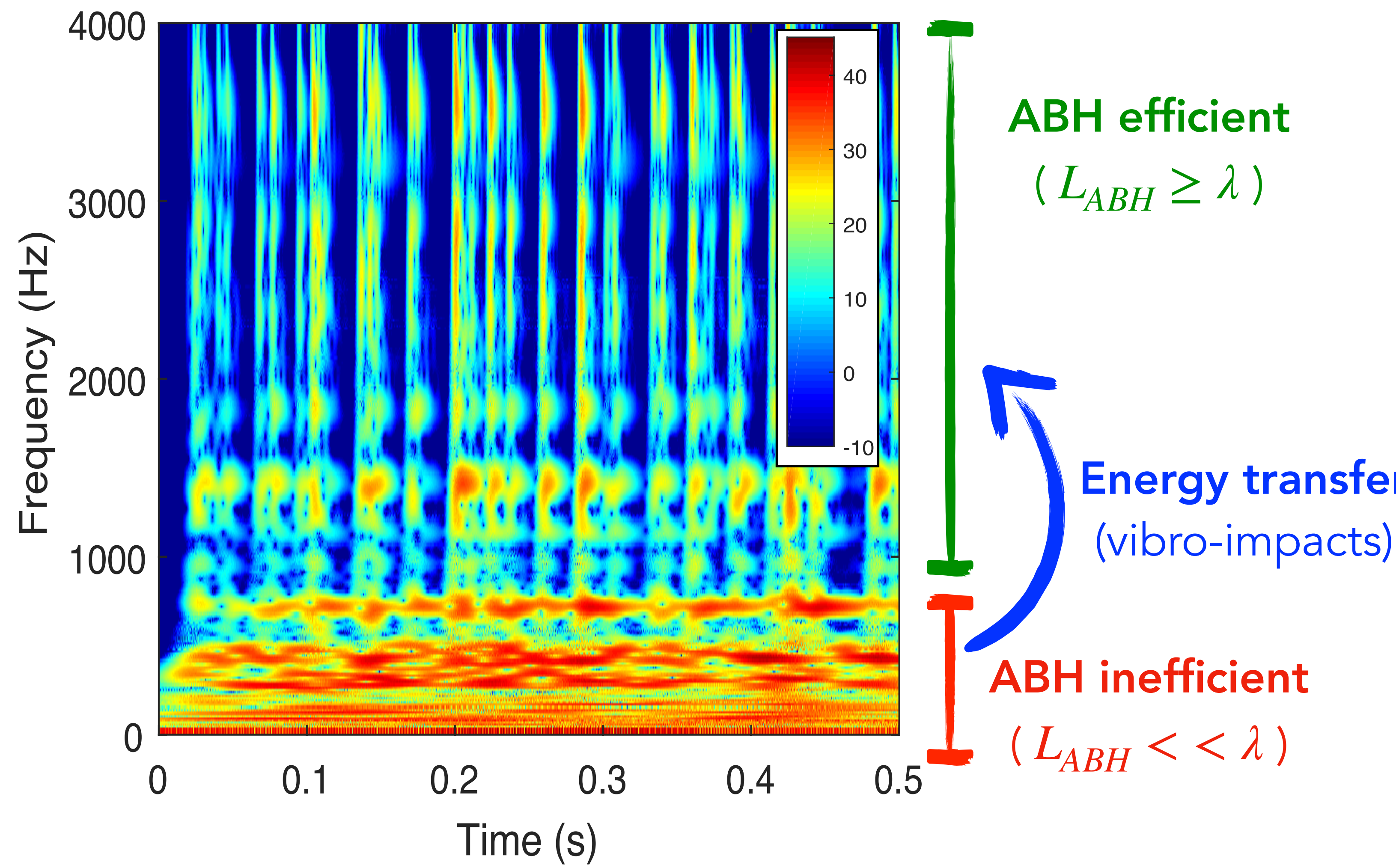
[Issanchou *et al.*, JSV 393, 2017]

Experimental evidence of the VI-ABH



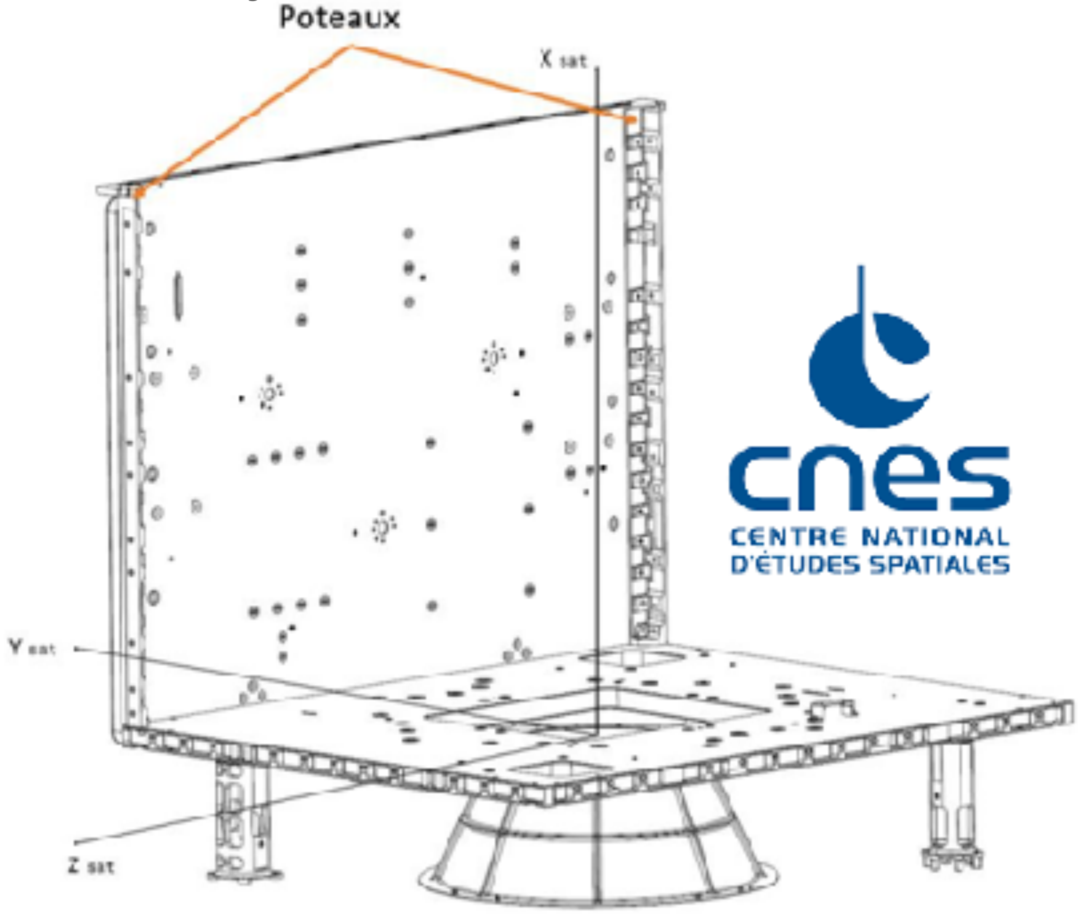


[Li *et al.*, Appl. Acou. 182, 2021]

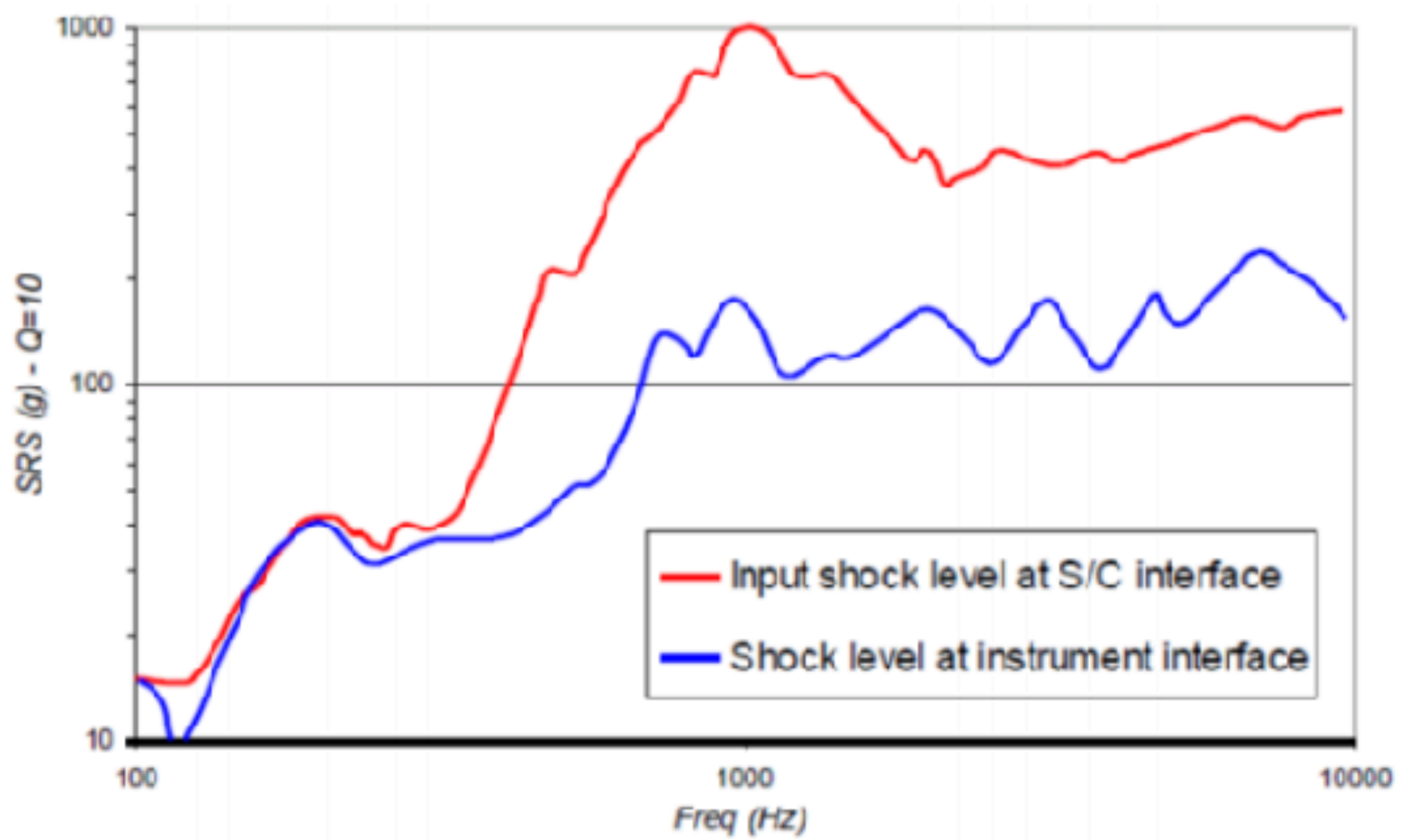


How to implement VI-ABH principle to attenuate shock vibrations in satellites ?

Honeycomb satellite walls

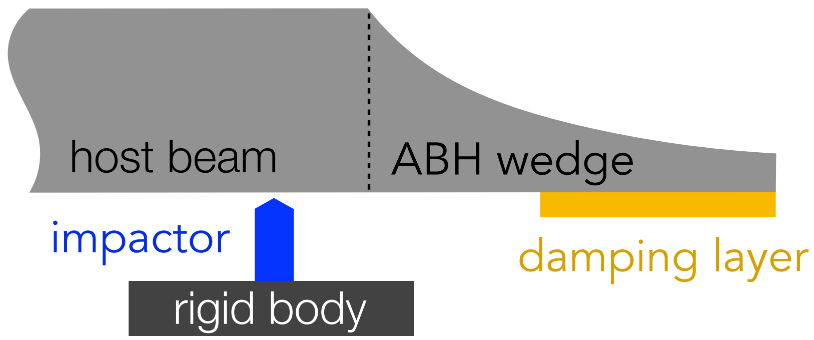


Typical shock excitation



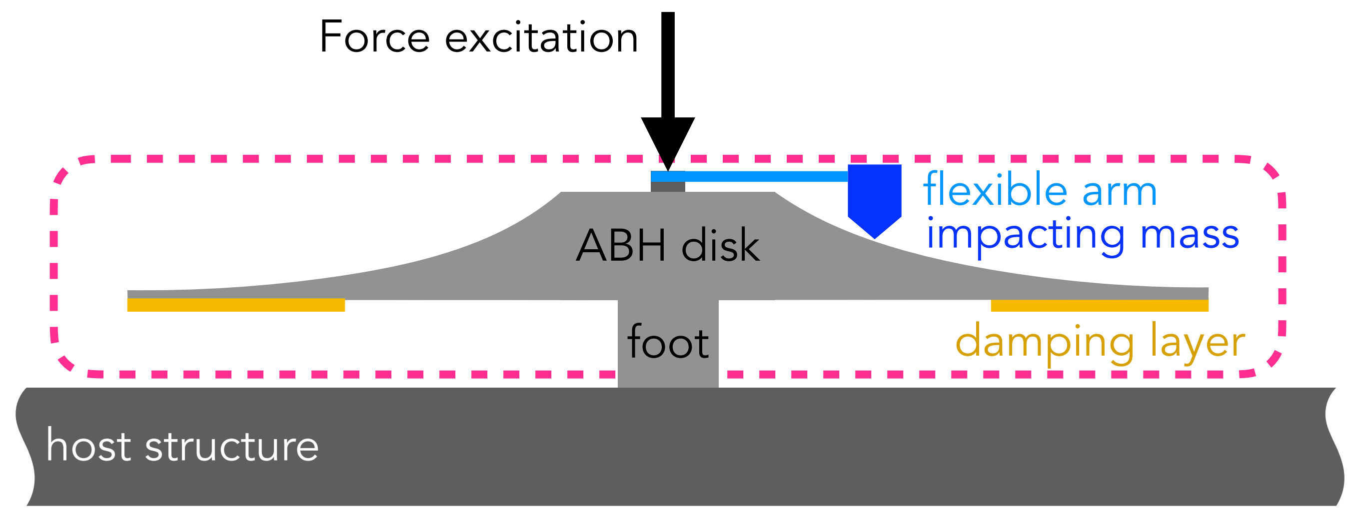
Conceptual design of a VI-ABH attenuator

Academic design

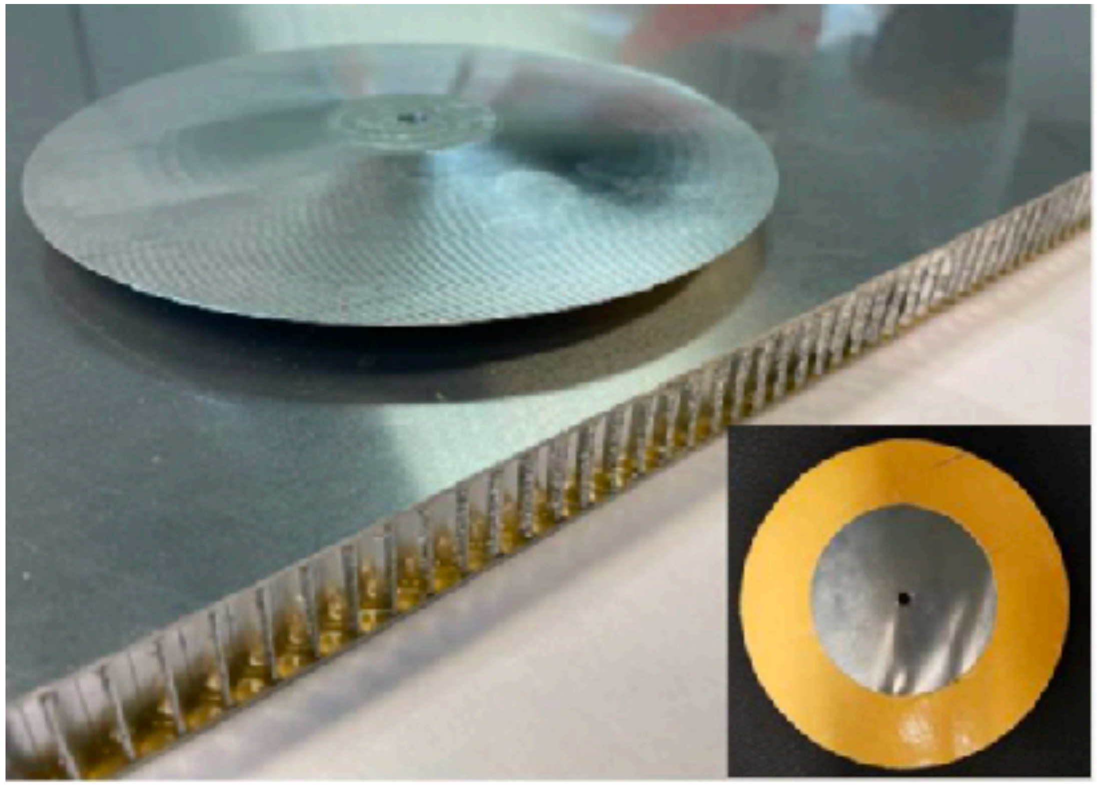


More applicable design

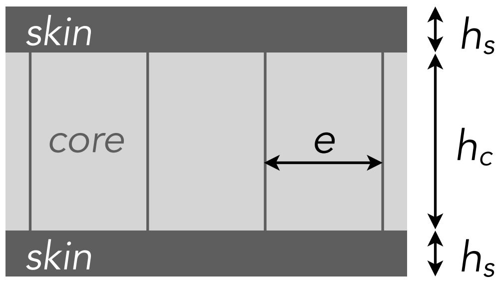
- Attached attenuator seen as a **decoupling device**
- insertion of a **resonant Vibro-Impactor**



Preliminar sizing of the attenuator

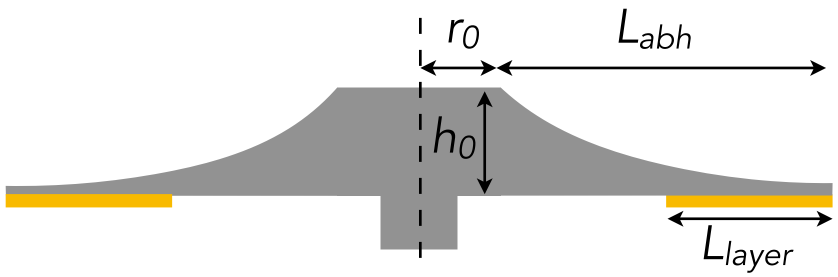


Honeycomb panel sizes



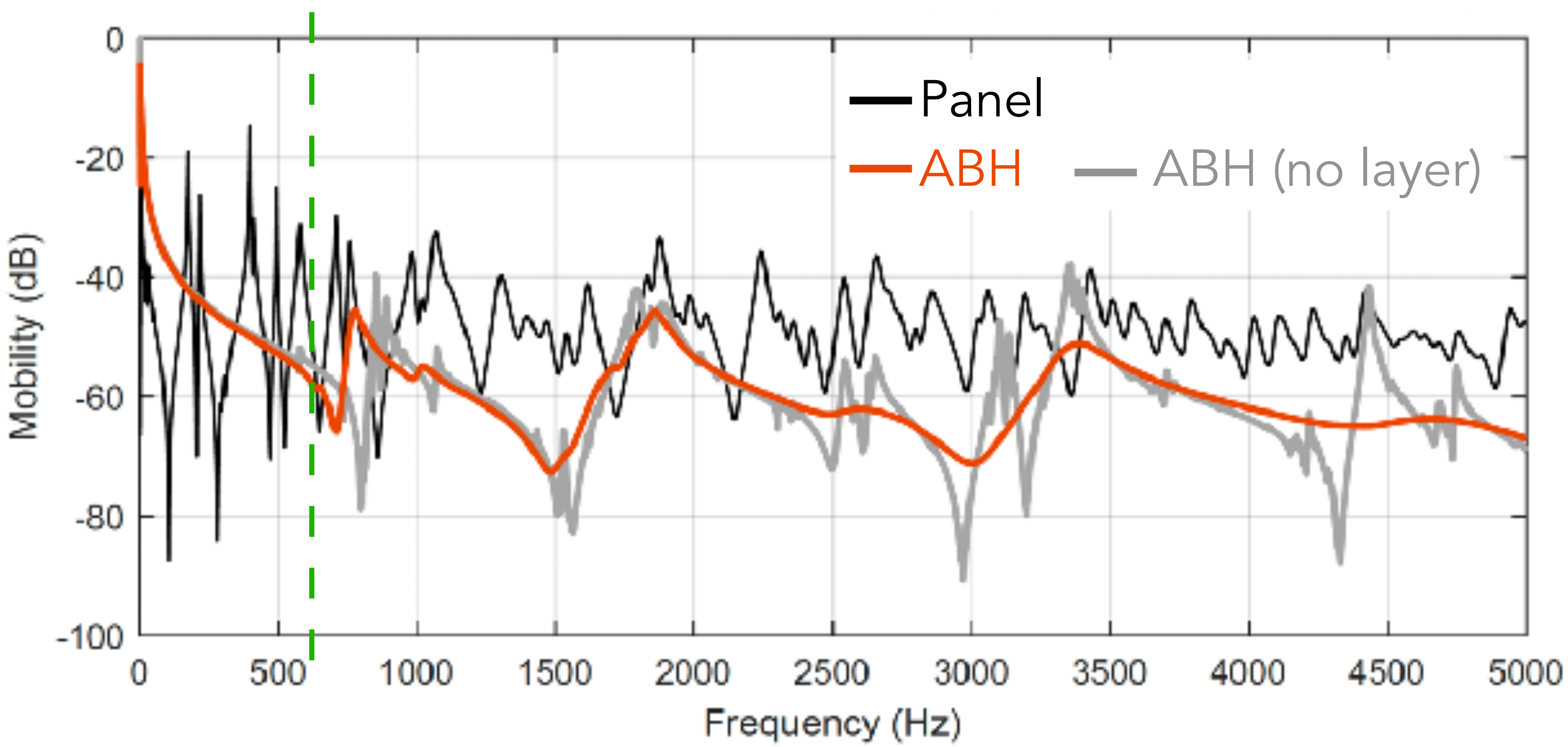
param.	[mm]
h_s	1
h_c	17.5
e	3
panel size	600x800

ABH attenuator sizes



param.	[mm]
h_0	4
r_0	20
L_{abh}	60
L_{layer}	30

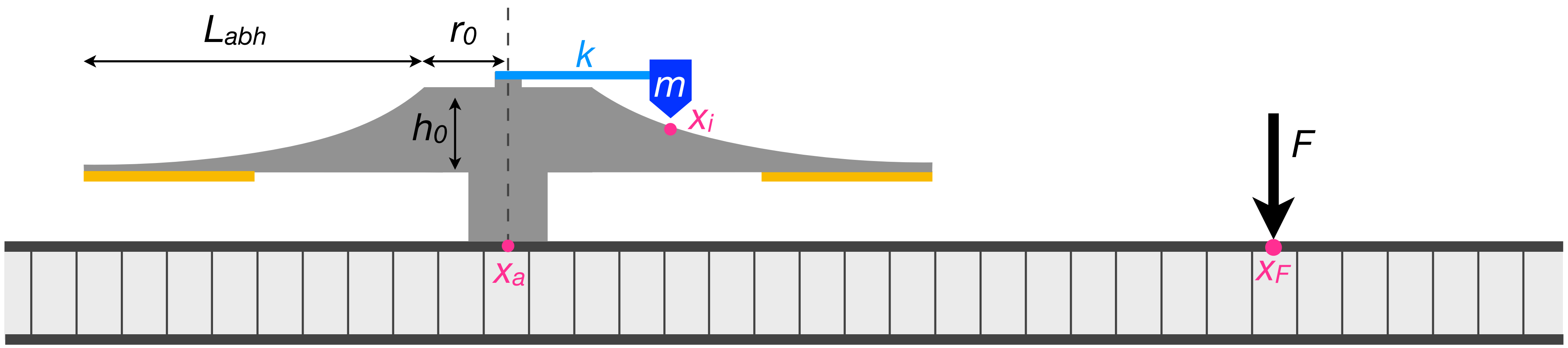
ABH threshold : f_{ABH} ~ 600Hz



Good impedance matching

Good mechanical coupling

Model of a VI-ABH attached attenuator



1 - Motion equations

structure : $\mathscr{L}\{u(x,t)\} = F(t)\delta(x - x_F) - k(u(x_i,t) - v) - f_{VI}(t)\delta(x - x_i)$

VI mass : $m\ddot{v}(t) = k\left(u(x_i,t) - v(t)\right) + f_{VI}(t)$

2 - Modal expansion principle

$$u(x,t) = \sum_{k=1}^{K} \phi_k(x)\,.\,q_k(t)$$

3 - Projection of motion equation on mode ϕ_k

$$\ddot{q}_k + 2\xi_k\omega_k\dot{q}_k + \omega_k^2 q_k = F\phi_k(x_F) - f_{VI}\phi_k(x_i) - k\left(u(x_i) - v\right)\phi_k(x_i)$$

<u>Step 1 :</u> FE calculation of the modal basis

COMSOL

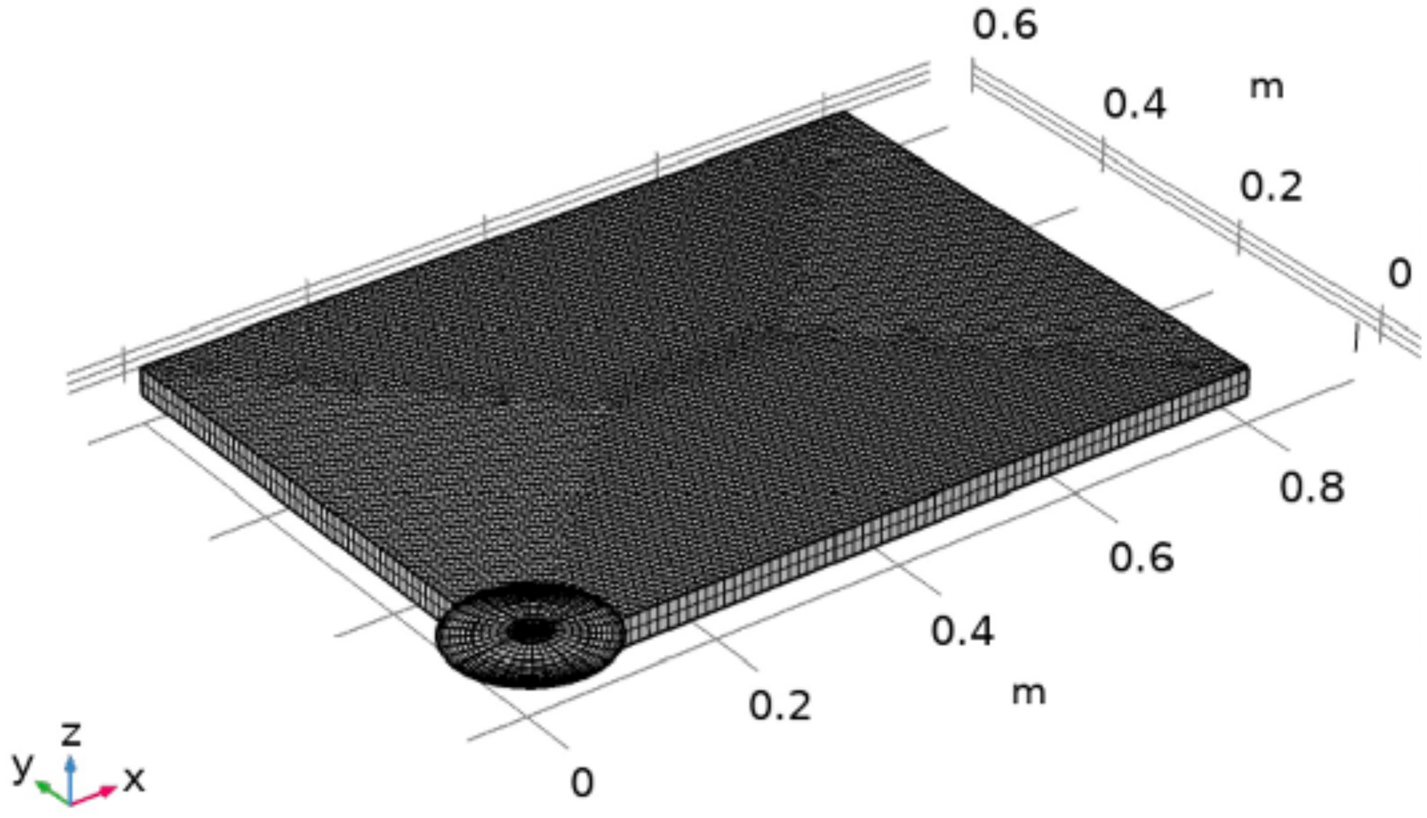
3D structural dynamics package

<u>Step 2 :</u> Time integration of the solution

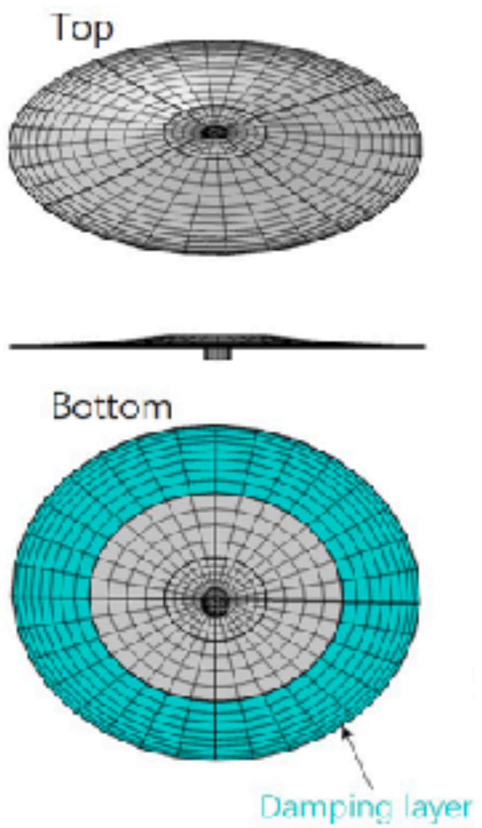
- two-order non conditional scheme
- implicit scheme (Newton-Raphson procedure)

FE model for modal basis calculation

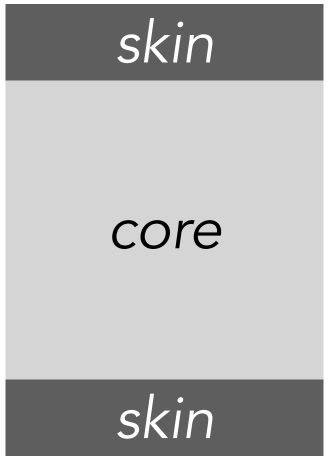
Assembled structure



ABH attenuator



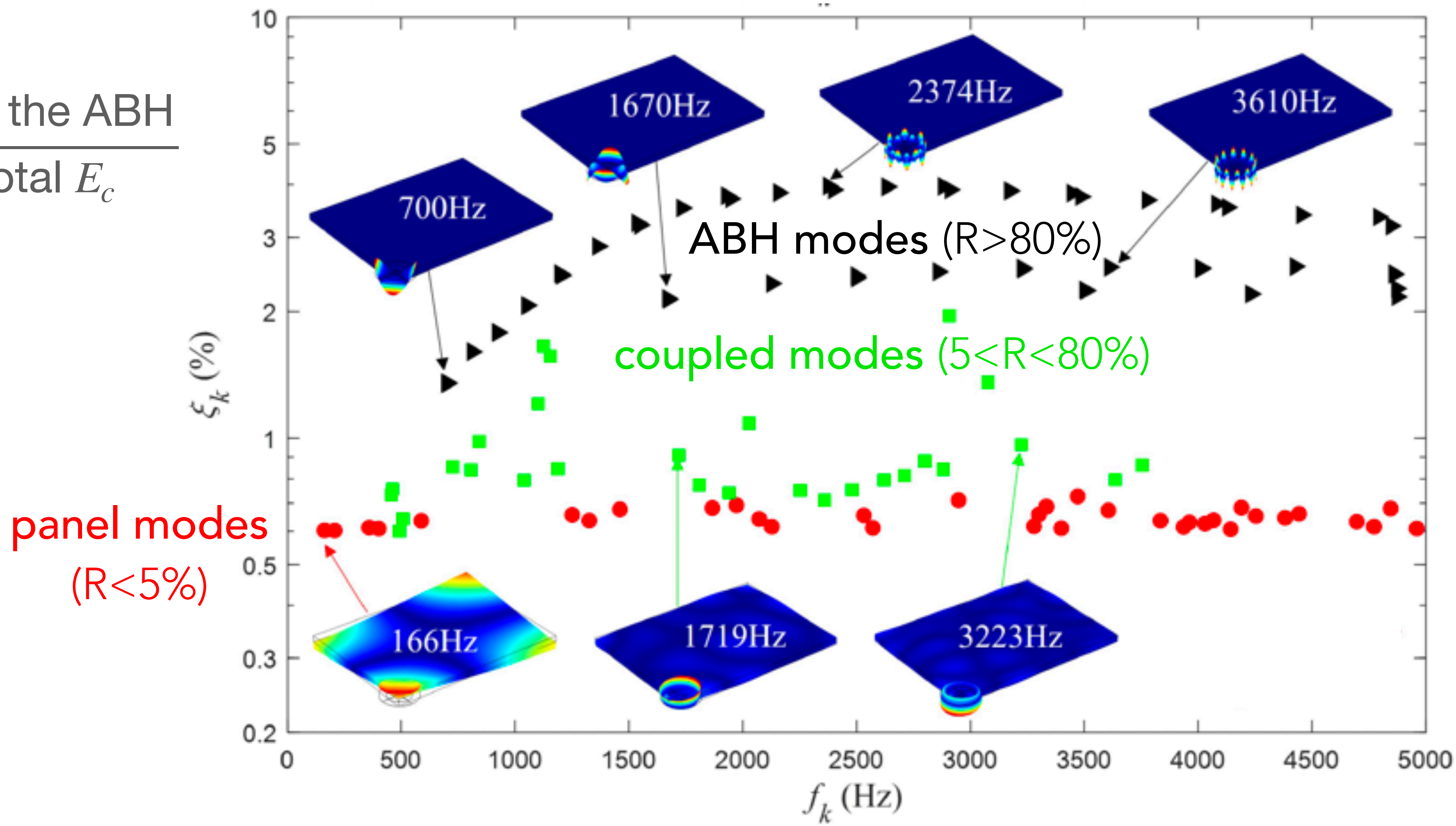
Homogenization of the honeycomb panel (Reissner theory)



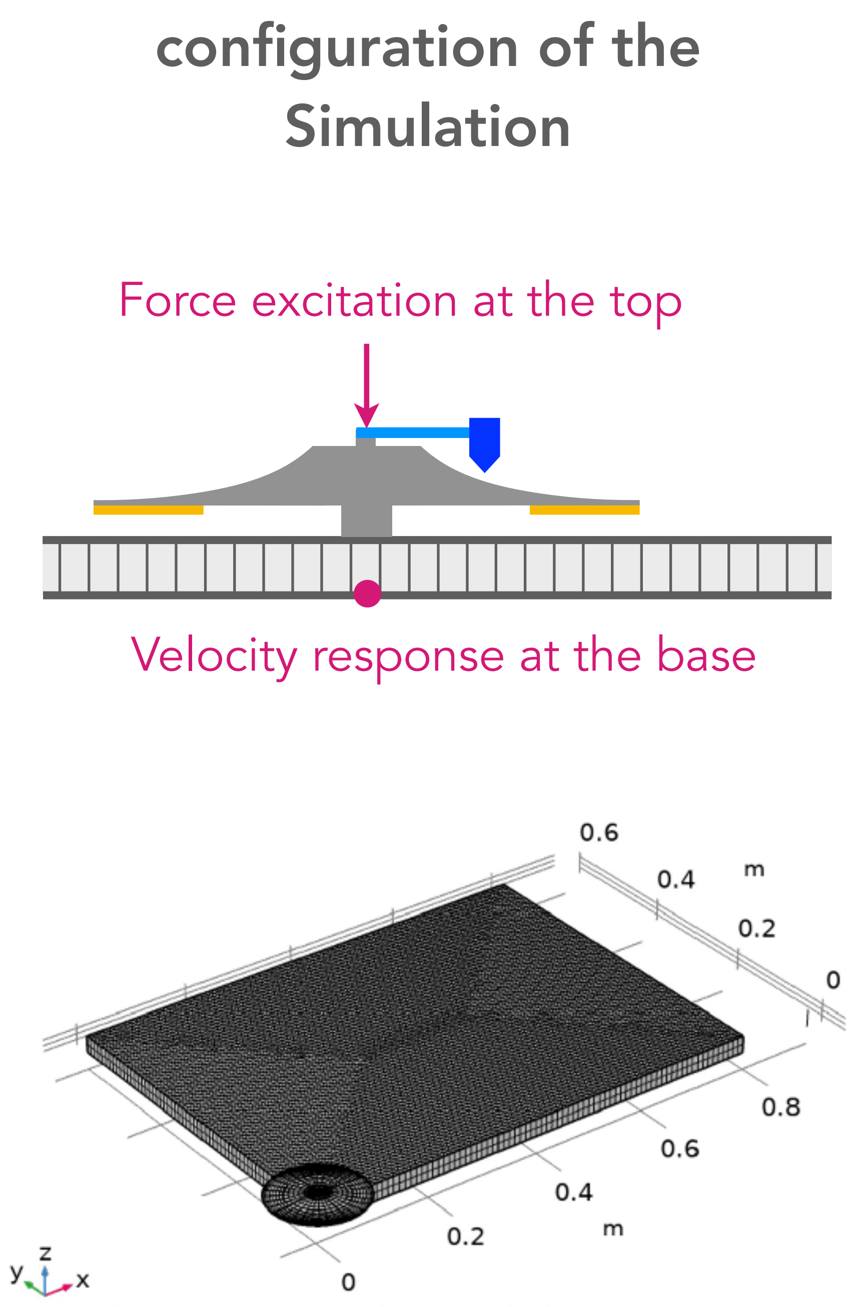
thickness	$h_{eq} = \sqrt{3}\left(h_s + h_c\right)$
Yong modulus	$E_{eq} = \dfrac{2E_s h_s}{t_{eq}}$
Poisson ratio	$\mu_{eq} = \mu_s$
density	$\rho_{eq} = \dfrac{\rho_c h_c + 2\rho_s h_s}{t_{eq}} k$

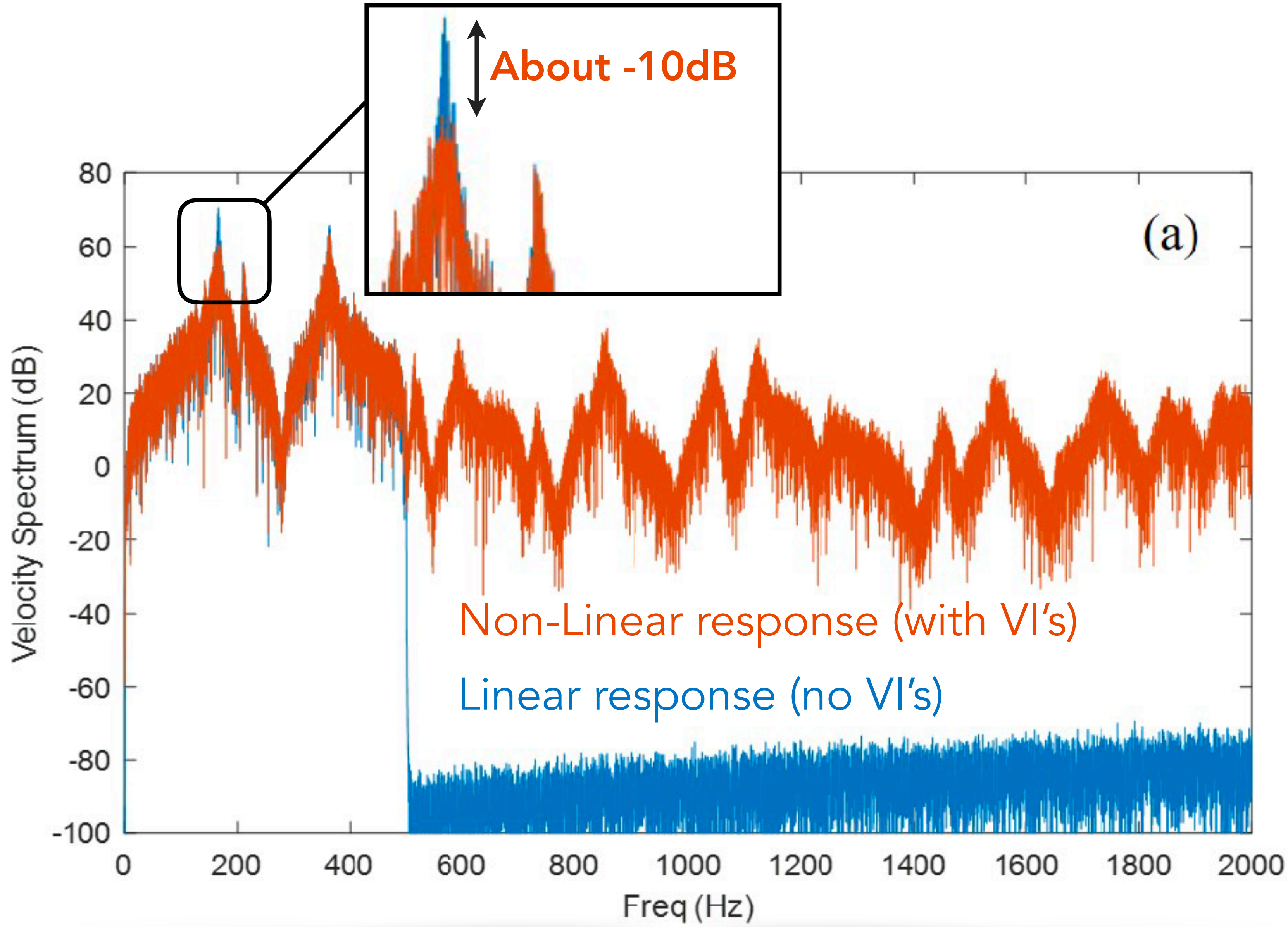
Modal analysis of the complete structure

$$R = \frac{E_c \text{ in the ABH}}{\text{Total } E_c}$$



Typical response to a [0-500]Hz noise



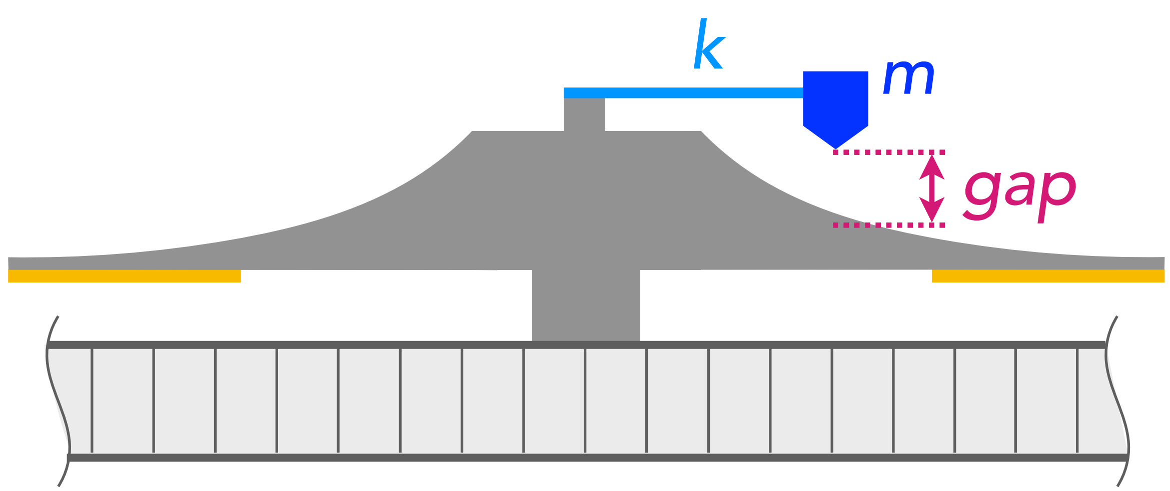


Post-processing : attenuation indicator (ref = panel only)

$$I = 10\log_{10}\left(\frac{\int_{f_{min}}^{f_{max}} v_c^2 df}{\int_{f_{min}}^{f_{max}} v_{ref}^2 df}\right)$$

- → Around a resonance peak at ω_k
- → At Low Frequencies [0-500] Hz
- → At High Frequencies [500-5k] Hz

Detailed design of the attenuator



What is the best f_{VI} ?

$$f_{VI} = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \simeq \frac{1}{2} f_{mode}$$

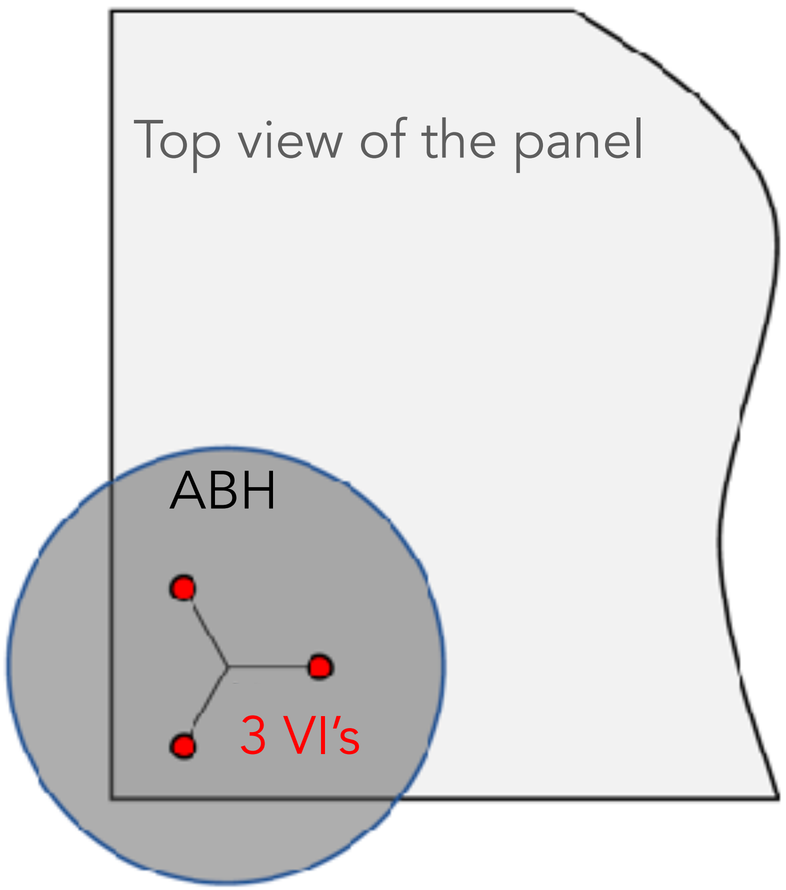
Mass dependency of the energy transfer

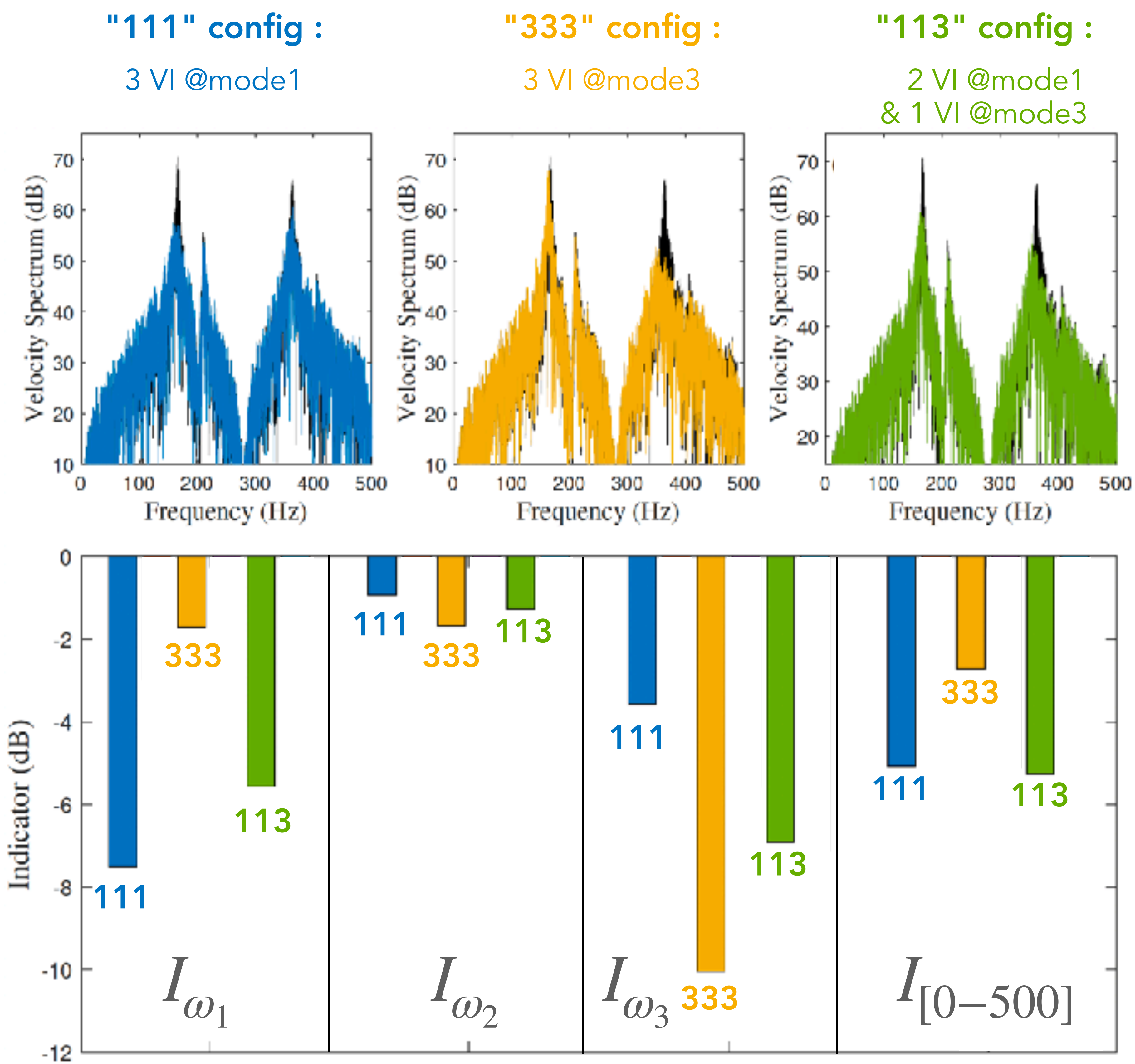
- Energy Transfer is enhanced as mass increases
- Only few grams lead to significant attenuation

Gap between VI mass & ABH ?

Grazing contact
(no gap, no prestress)

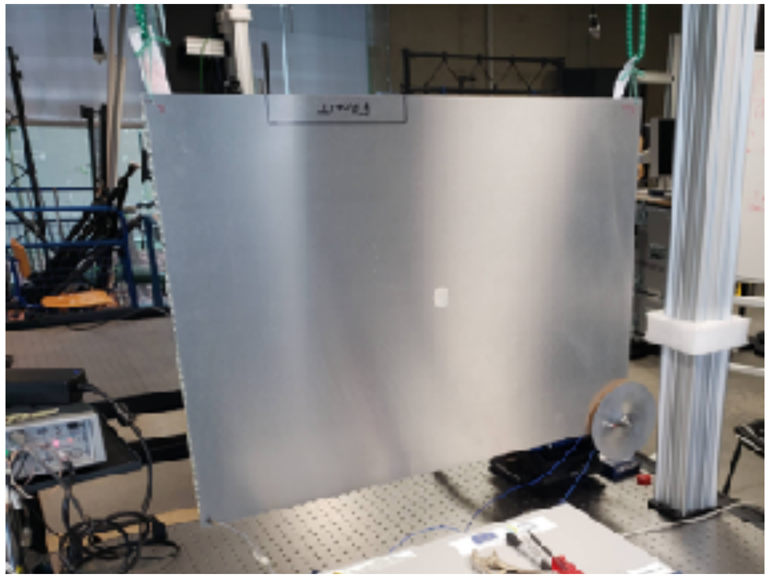
VI tuning for multi-mode attenuation



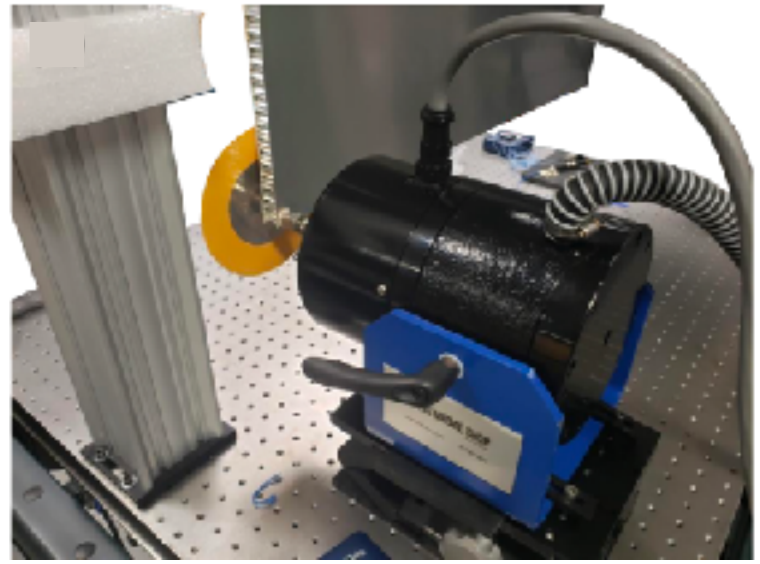


Analysis of an experimental demonstrator

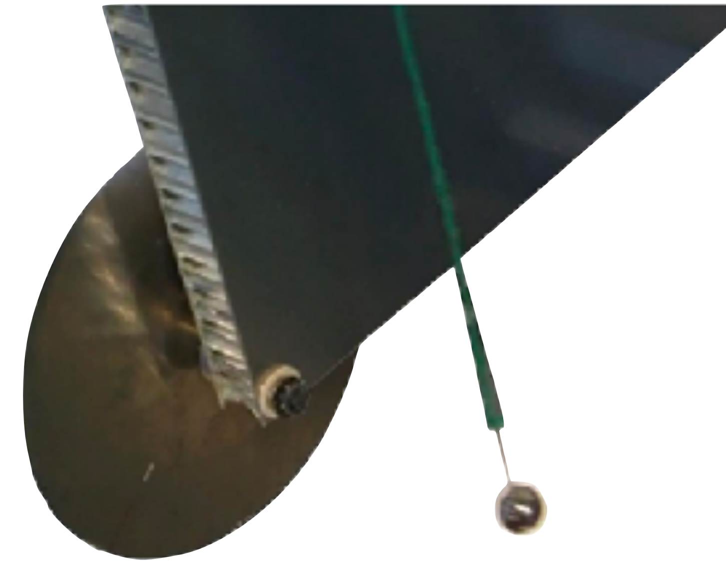
Experimental setup



Demonstrator settings
- Suspended free-free panel
- ABH attenuator at a corner

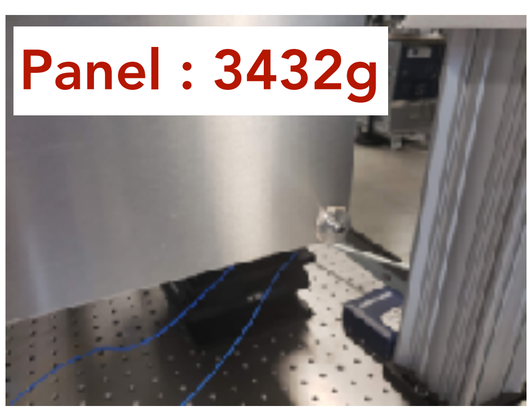


Forced vibration settings
- co-localised shaker excitation
- [0-5k]Hz or [0-500]Hz noise

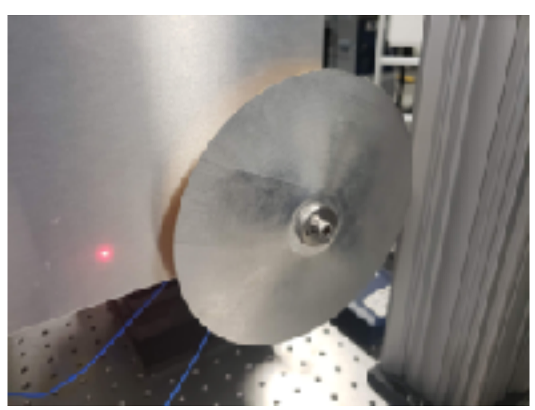


Shock response settings
- Released marble impact
- Acceleration peak about 500g

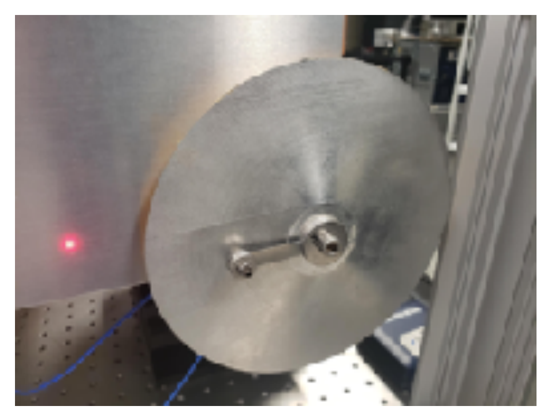
Attenuator configurations under study



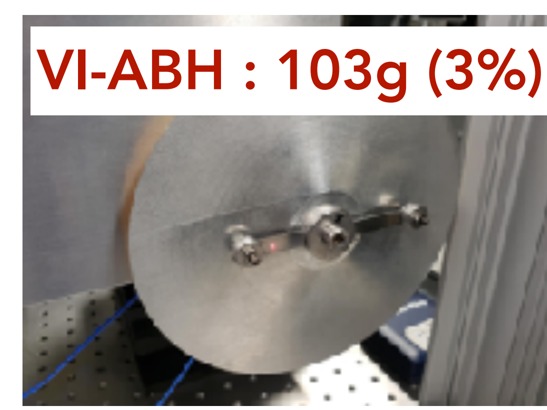
Panel only
(reference config.)



Linear ABH



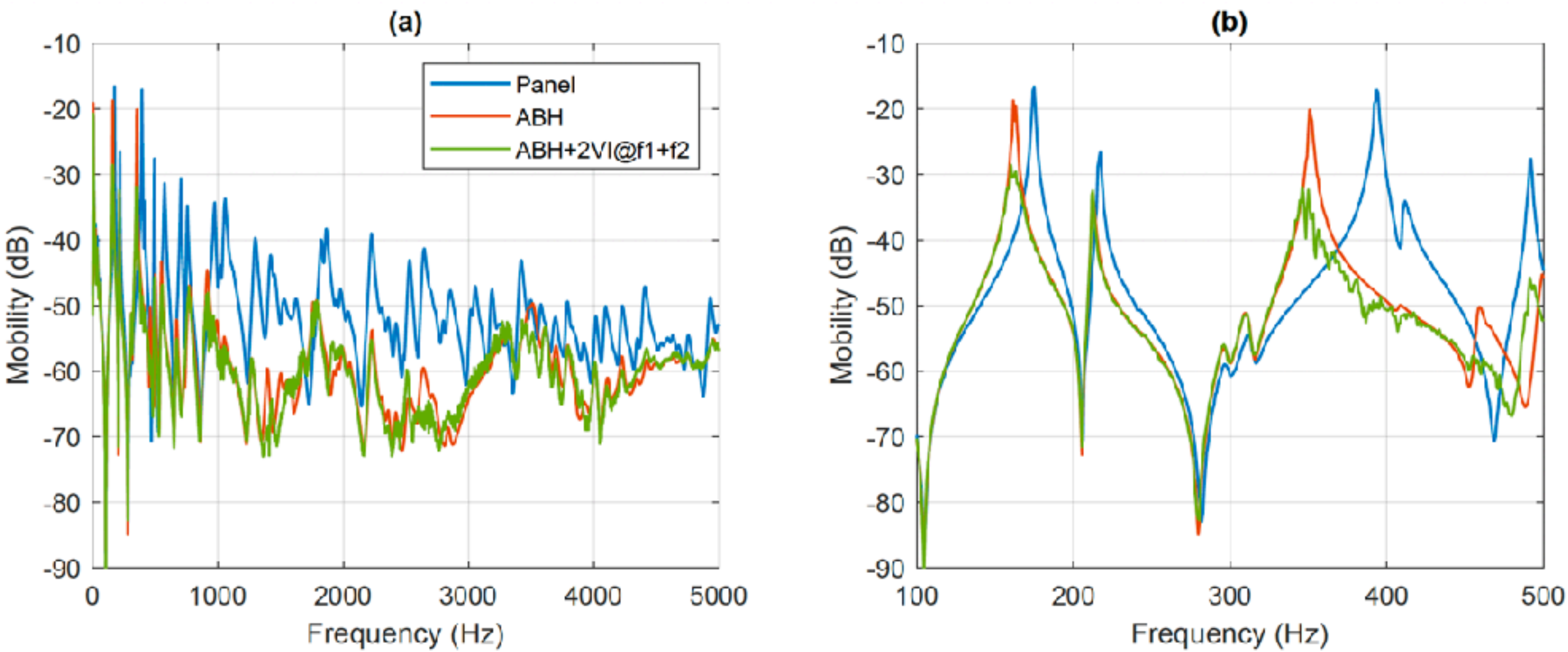
VI-ABH - 1VI@mode1



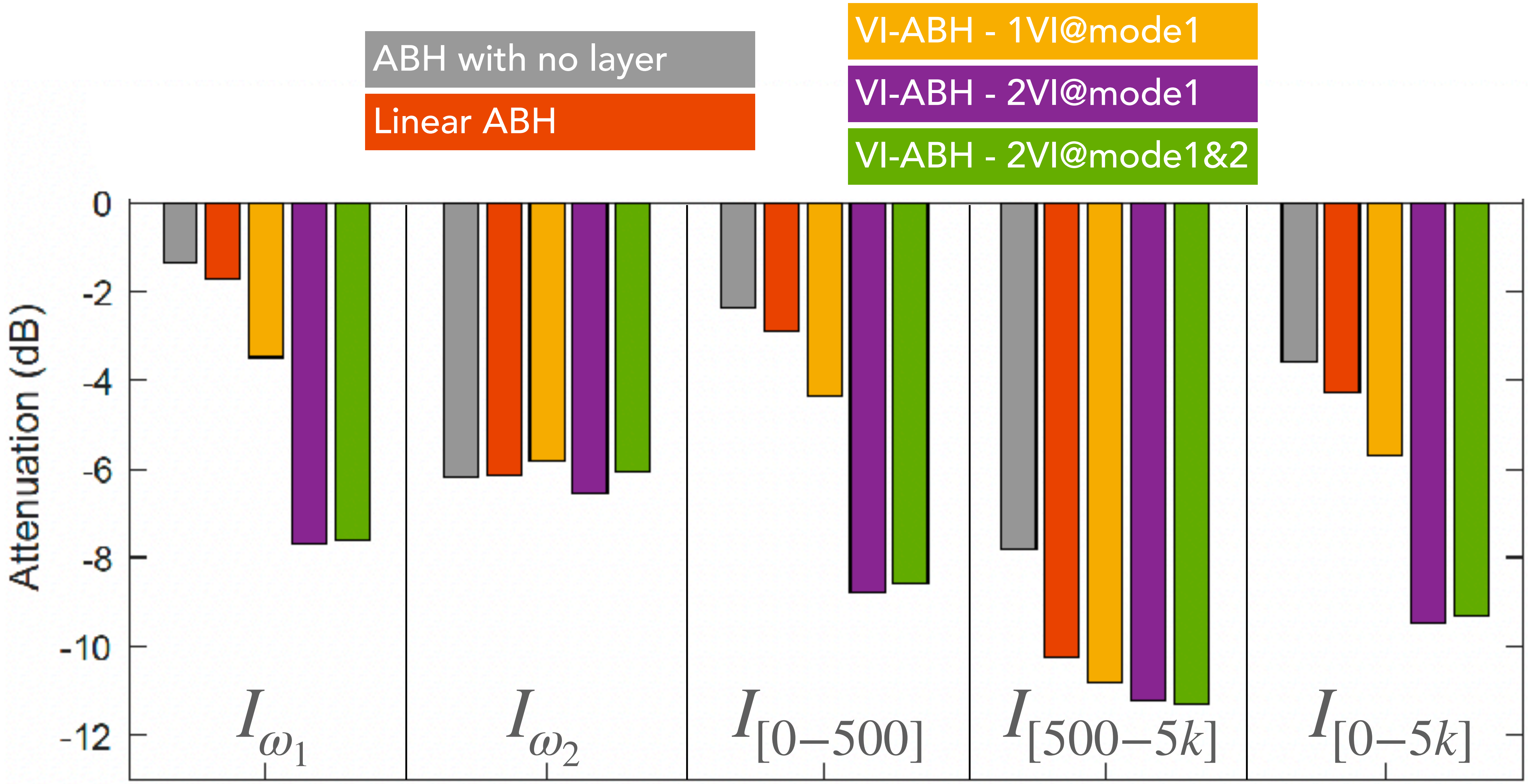
VI-ABH - 2VI@mode1

VI-ABH - 2VI@mode1&2

Attenuation due to ABH vs VI-ABH effects



Synthesis of the performances in forced regime



Post-processing : attenuation indicator (ref. : panel only)

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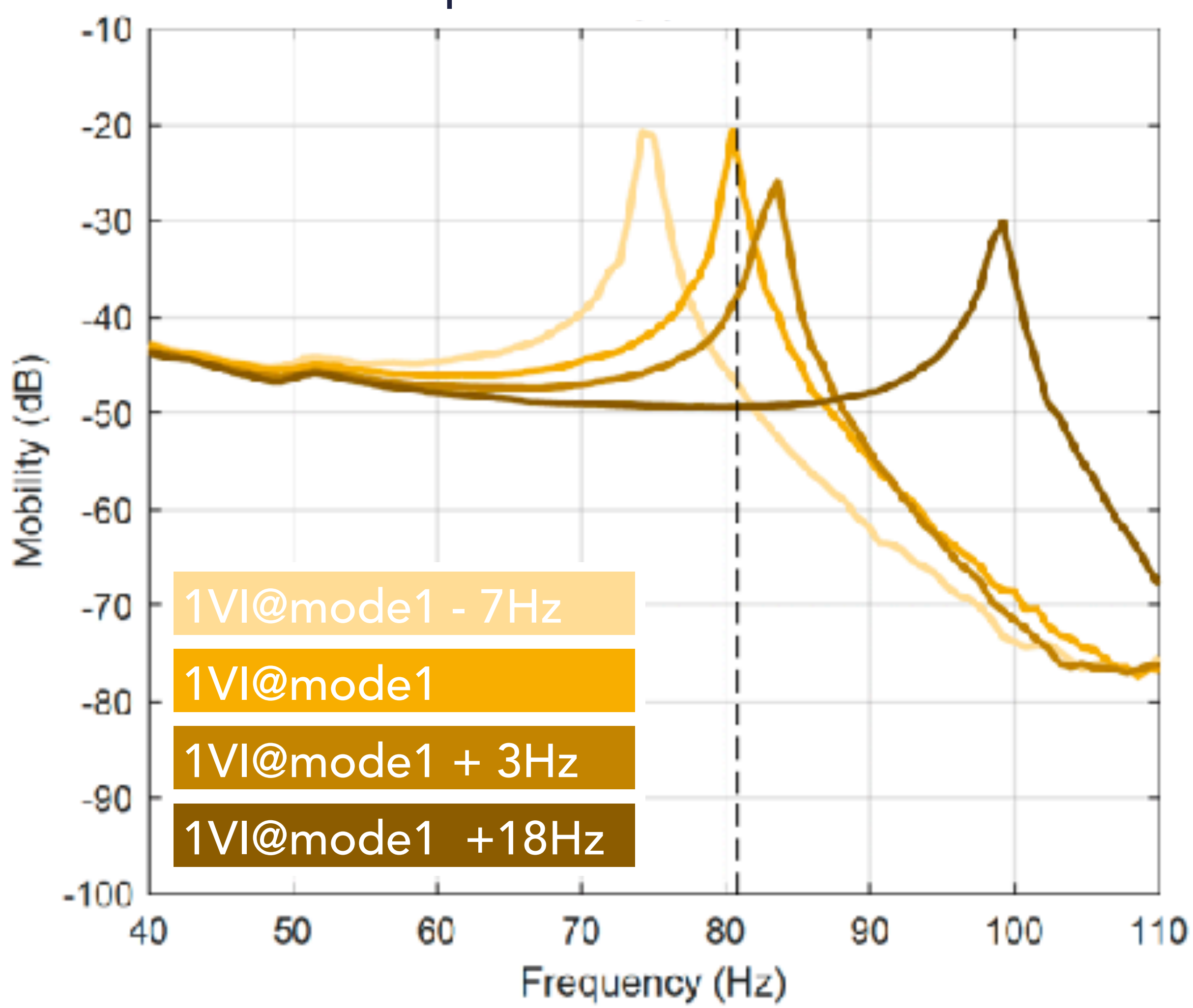
→ Around a resonance peak at ω_k

→ At Low Frequencies [0-500] Hz

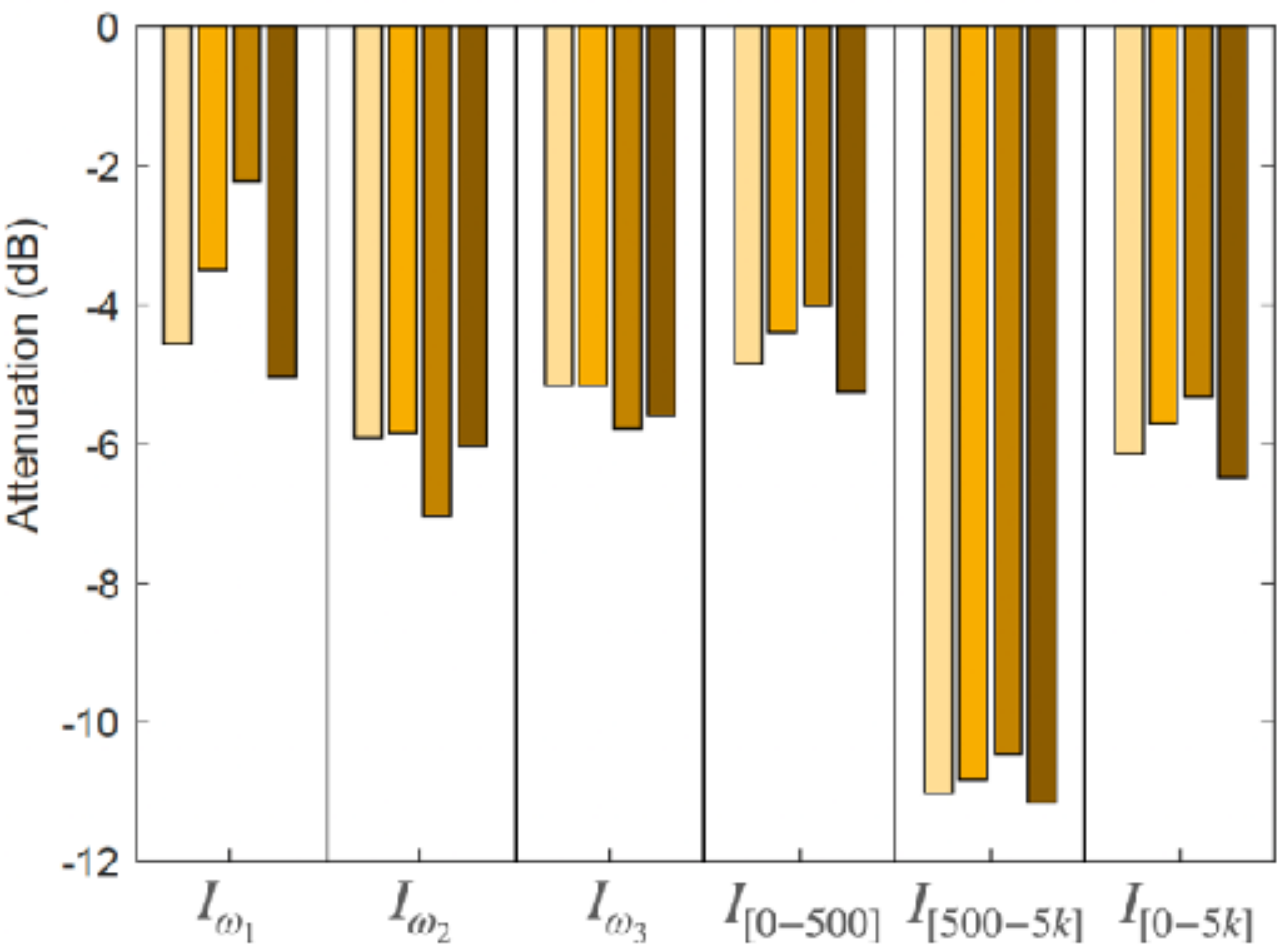
→ At High Frequencies [500-5k] Hz

Robustness to tuning accuracy

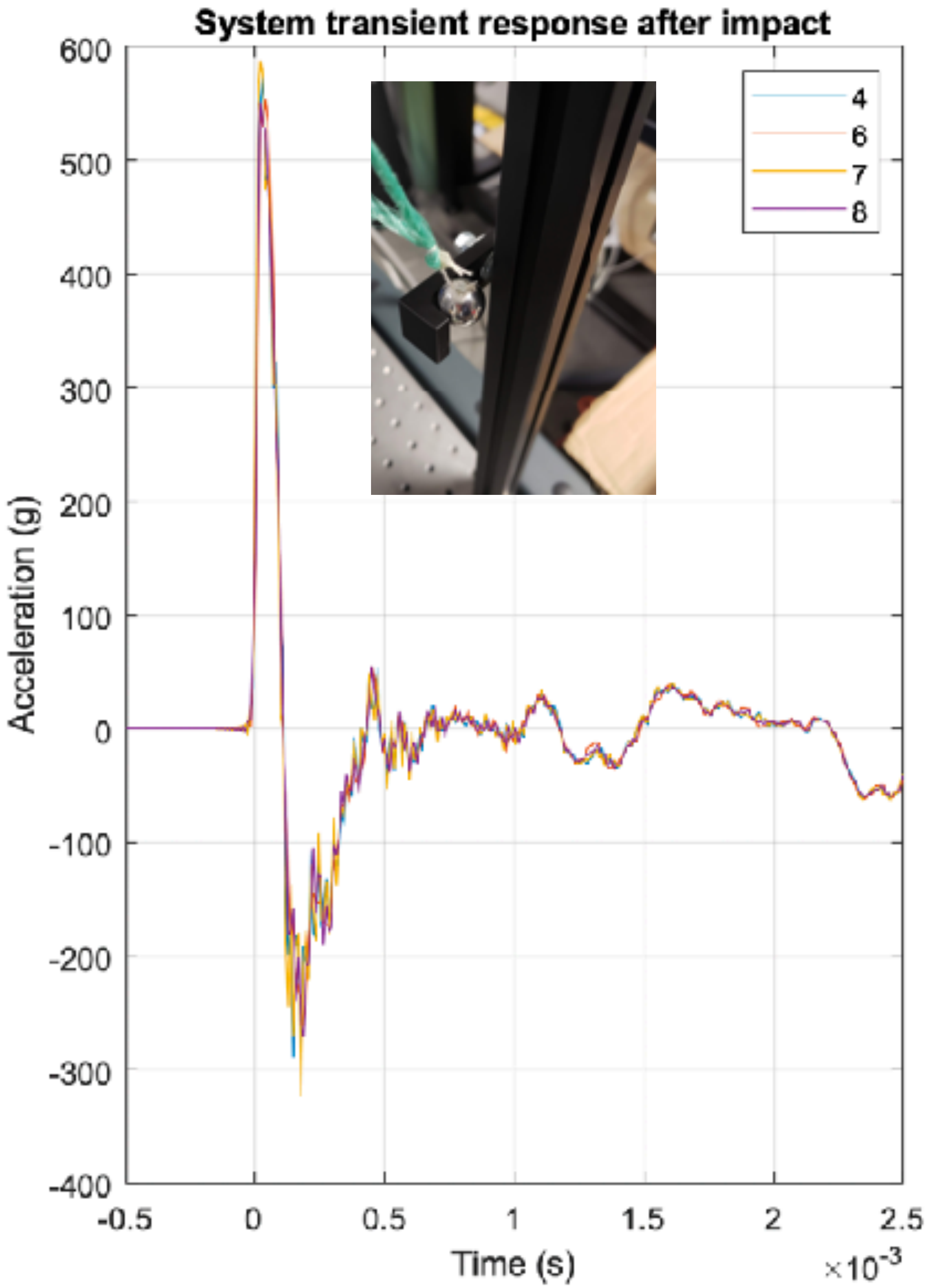
Linear response of the VI device

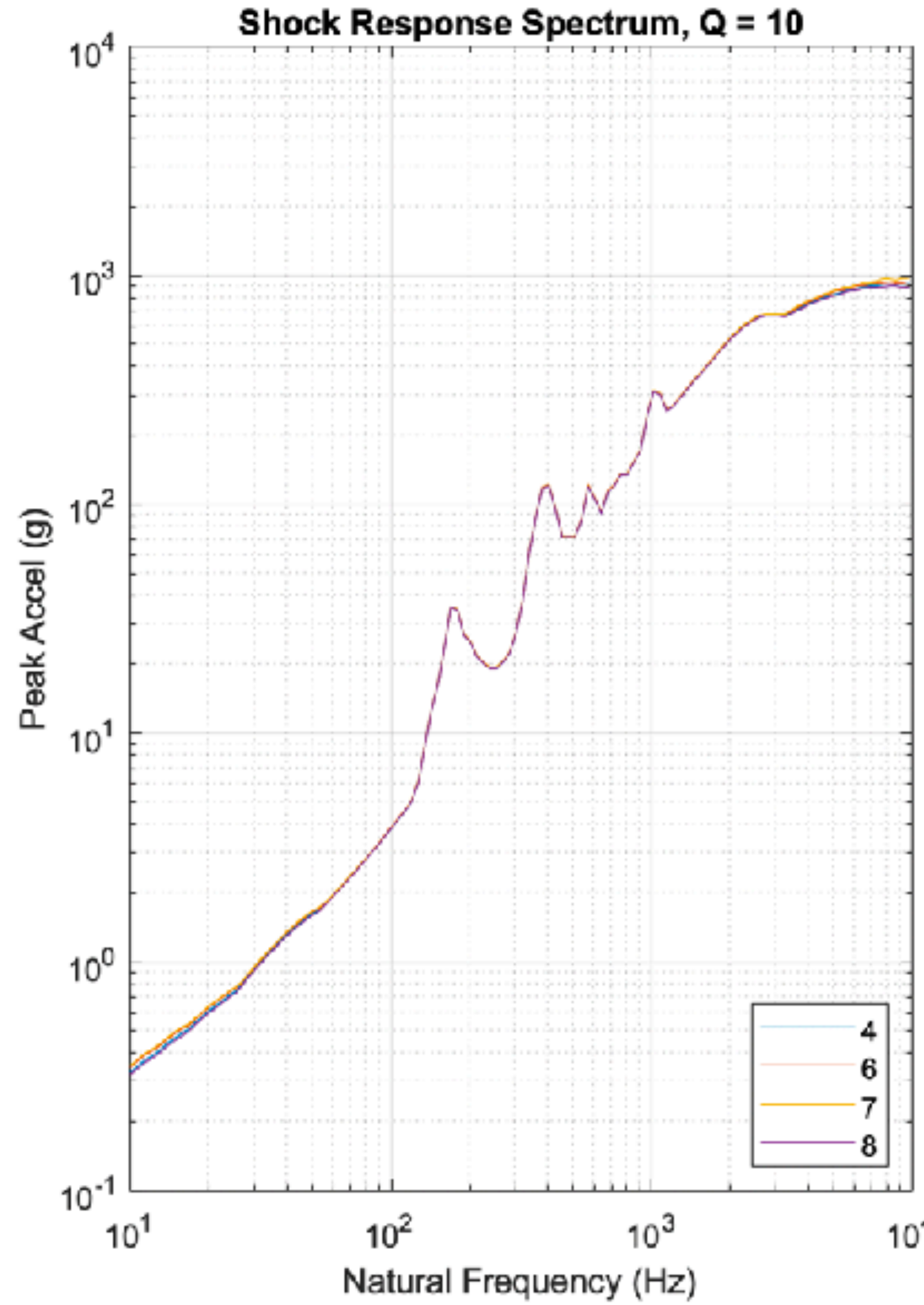


Efficiency indicators

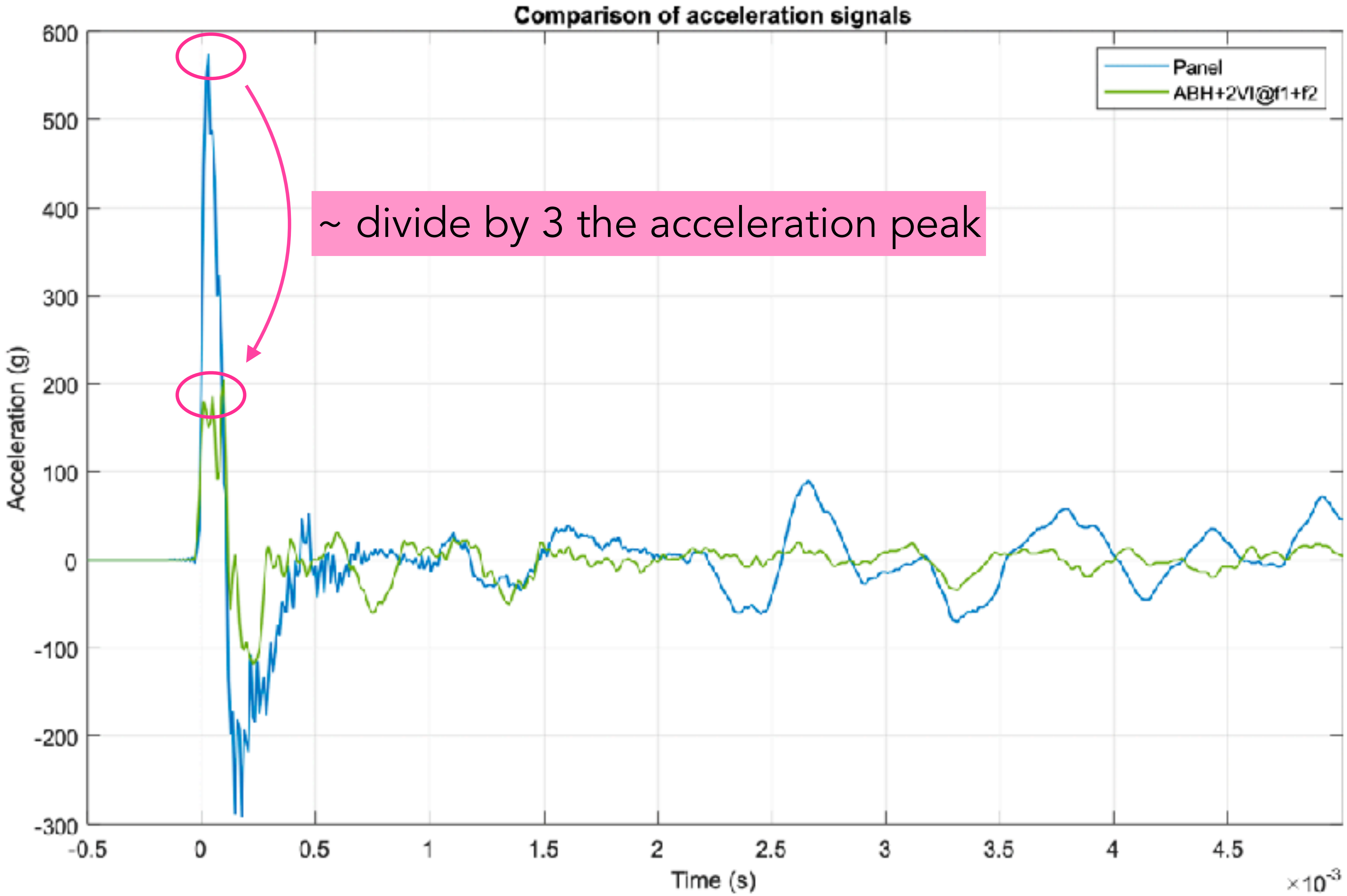


Typical shock response (reference panel)

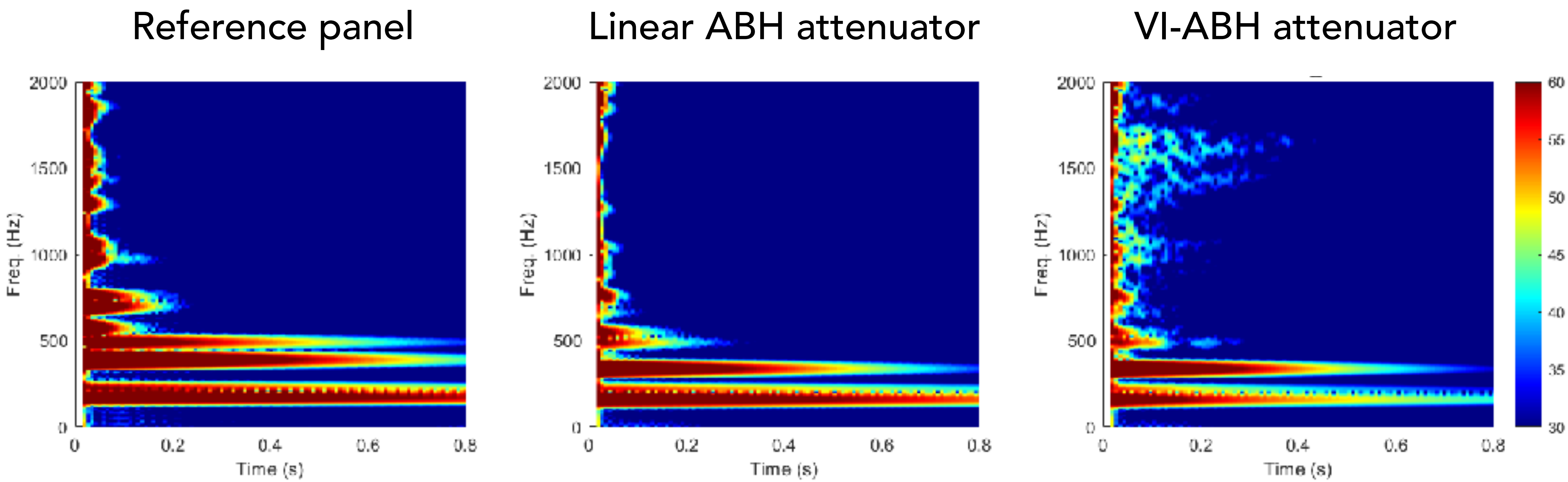




Time response w/wo VI-ABH attenuator



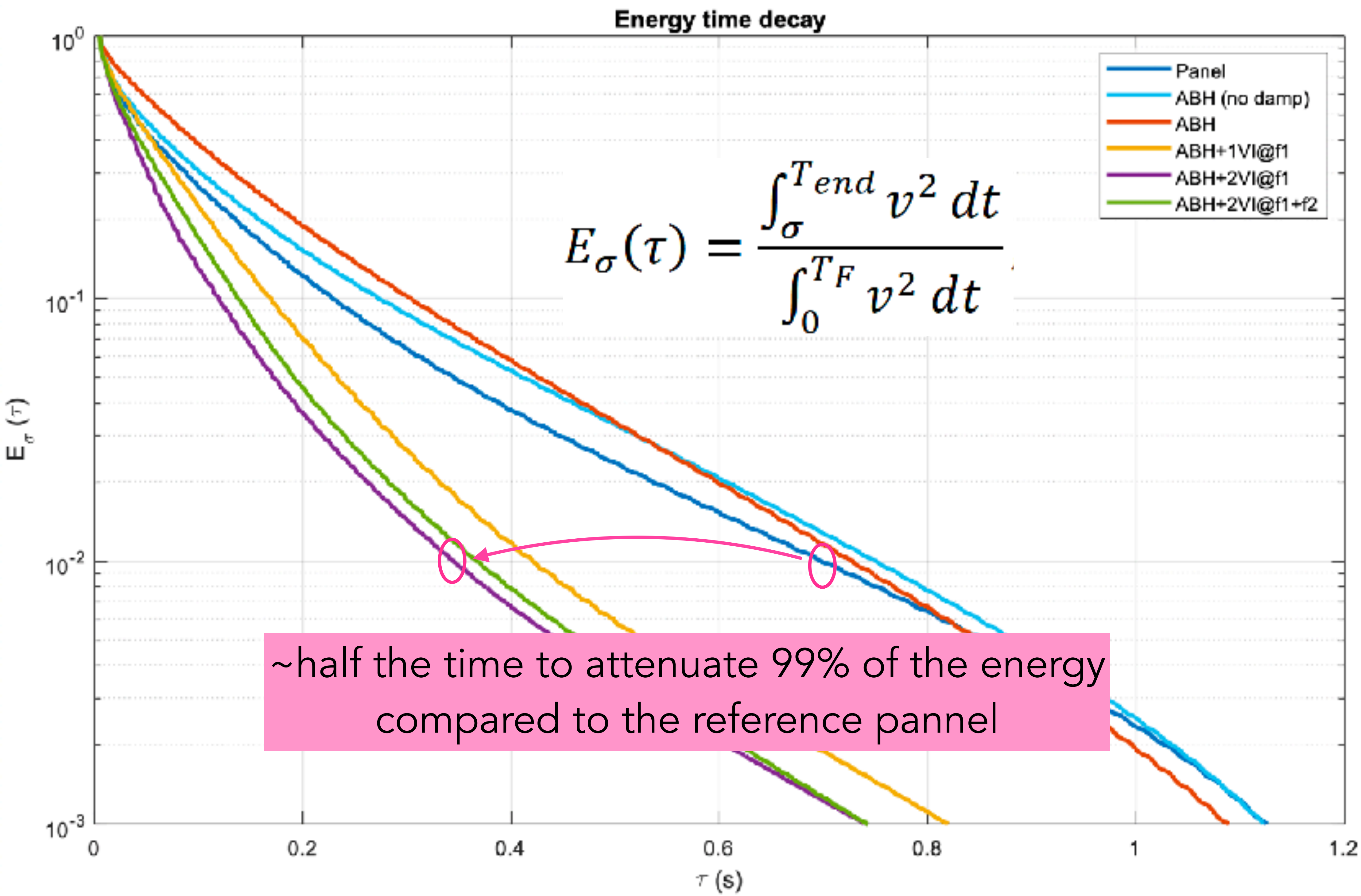
Spectrogram of the shock responses



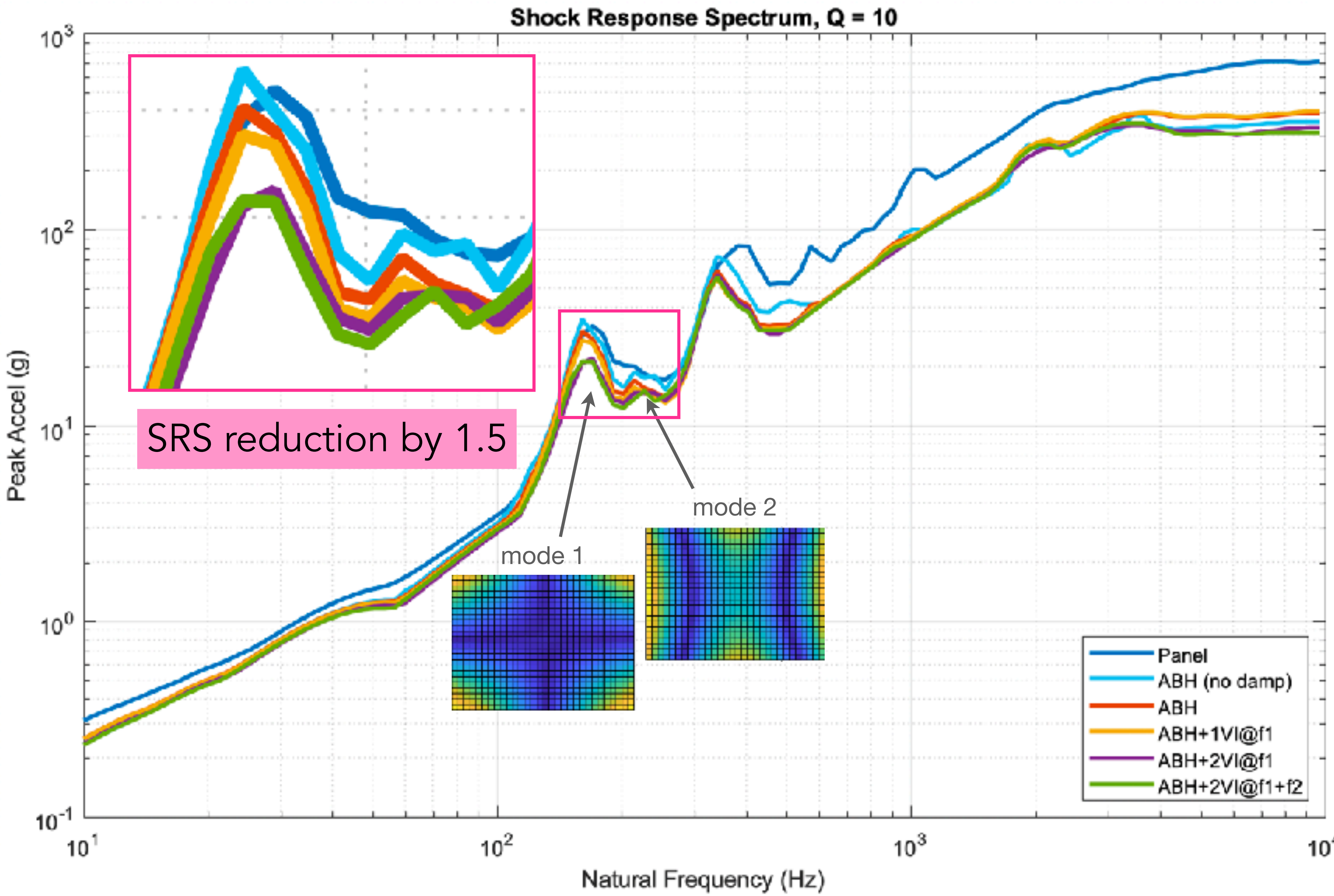
HF modes attenuation due to ABH effect

LF added attenuation due to VI's energy transfer

Energy decays analysis



SRS analysis for all tested configurations



General conclusions

- A new type of vibration attenuator is proposed based on the VI-ABH principle
  - TRL_end = TRL_start + 1
- Numerical modeling provides guides lines to reach the optimal design :
  - The design involves 3 main parameters :
    - h_0 drives the mechanical impedance match
    - L_{abh} drives the ABH threshold frequency
    - f_{VI} drives the attenuation efficiency for LF modes
  - The attenuator mass is <5% of the host structure
  - Main design challenge : ensuring a grazing contact of the VI
- Performances of an experimental proof of concept in lab conditions :
  - About -8dB broadband in acceleration spectra
  - Reduction by 1.5 of the SRS at selected panel modes
  - Reduction by 2 of the time to attenuate 99% of the shock energy
  - Quite good robustness to VI mistuning

Some perspectives

- VI-ABH attenuator is searching for an industrial application context !

- Improve the geometrical & mechanical design
  - Use of space qualified material for the damping layer
  - Enhance the mechanical strength for addressing high level shocks
  - Improve compacity & consider space requirements

- Think about other non-linear ABH designs …

Some perspectives

- VI-ABH attenuator is searching for an industrial application context !
- Improve the geometrical & mechanical design
  - Use of space qualified material for the damping layer
  - Enhance the mechanical strength for addressing high level shocks
  - Improve compacity & consider space requirements
- Think about other non-linear ABH designs …

Thank's for your attention

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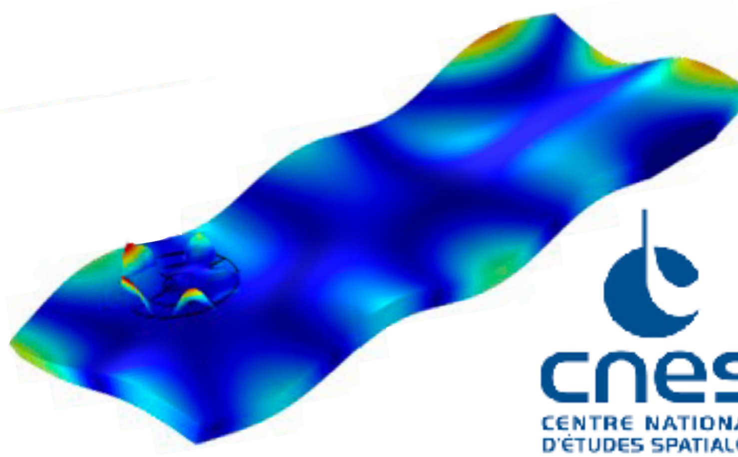

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