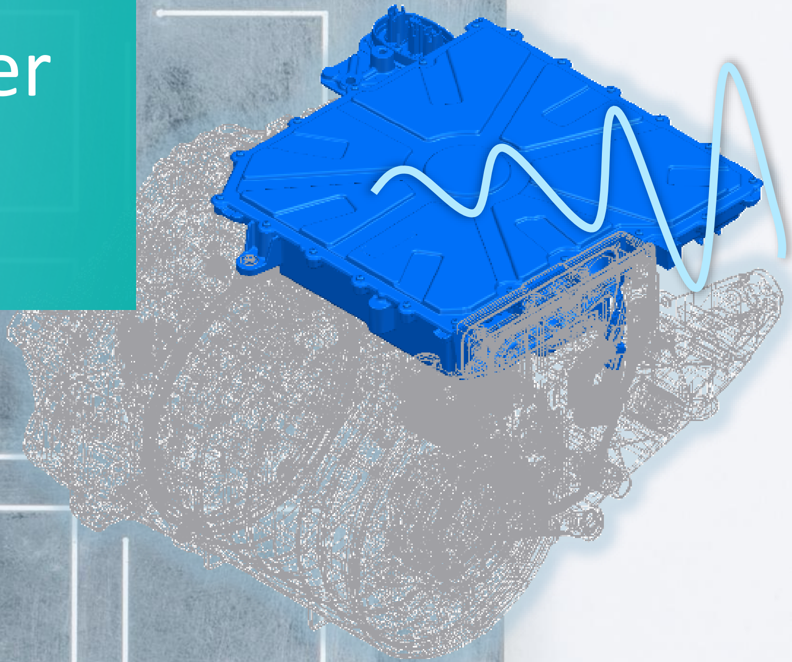
» Noise and vibration reduction with vibroacoustic metamaterials on a cover for power electronics of an electric powertrain «



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[1] Fraunhofer Institute for Structural Durability and Systems Reliability LBF
[2] Institute for Automotive Engineering (ika), RWTH Aachen University
[3] Mercedes-Benz Group AG

Outline

1 Motivation

2 What are Vibroacoustic Metamaterials?

3 Cover for power electronics with VAMM

  - open -

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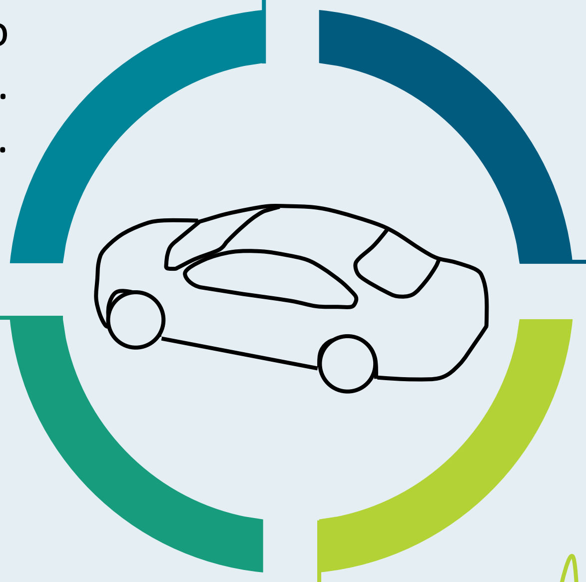
Motivation

Challenges in automotive design

Light weight structures are necessary to reduce CO_2 emissions and to enlarge range of EVs. Those structures are more prone to vibration.



The interior noise level is one of the most essential quality criteria which is perceptible by the customer.

Due to the electrification of vehicles there is no masking of the combustion engine anymore.

Conventional NVH measures are heavy and reach their limits.

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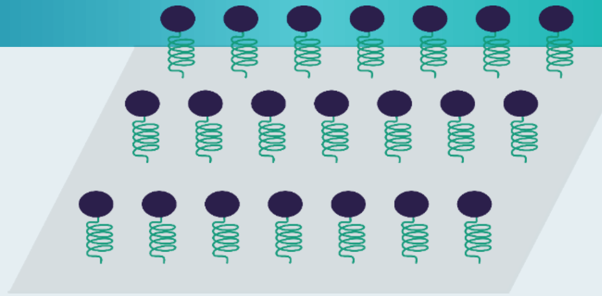
Motivation

Challenges in automotive design

» Vibroacoustic Metamaterials «

… as a novel and light weight NVH measure



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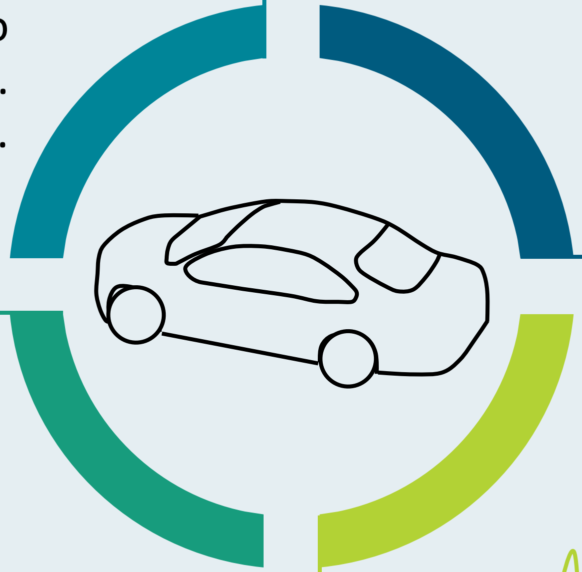

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 30.08.2023 - open -

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Outline

Metamaterials

- Artificial materials/structures which feature a behavior that differs from the usual in nature.
- First implemented in electromagnetics (negative permittivity and permeability) and optics (negative refractive index).
- Analogies in wave behavior have been transferred to research on vibroacoustic metamaterials.

since 1968
Electromagnetic and optical Metamaterials

since ca. 2005
Vibroacoustic Metamaterials

source: [1]

source: [2]

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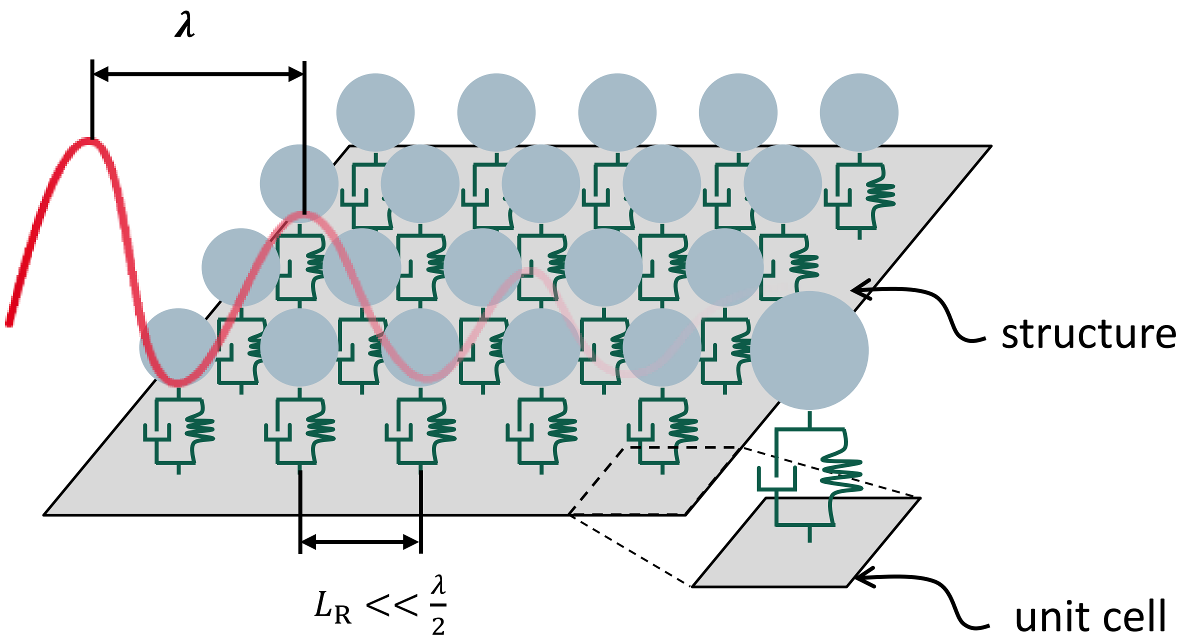
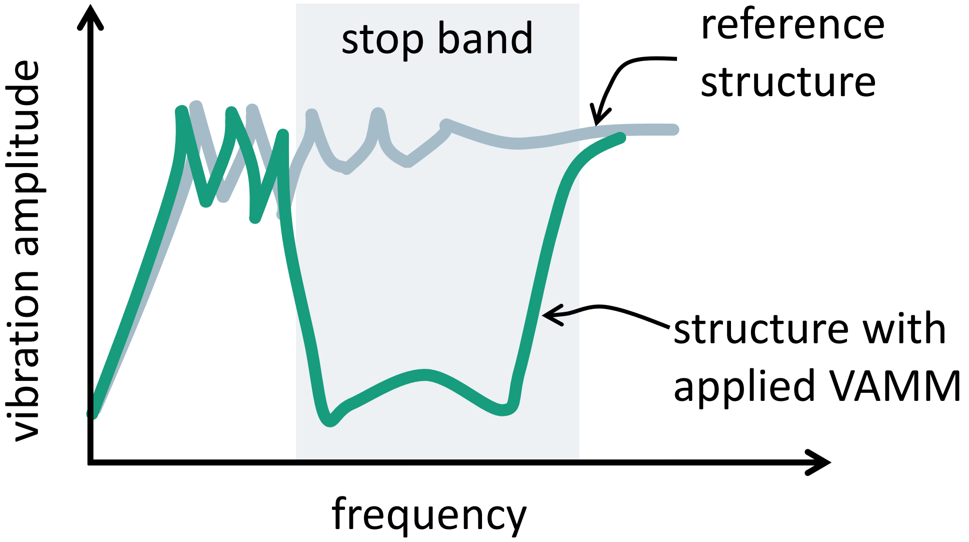
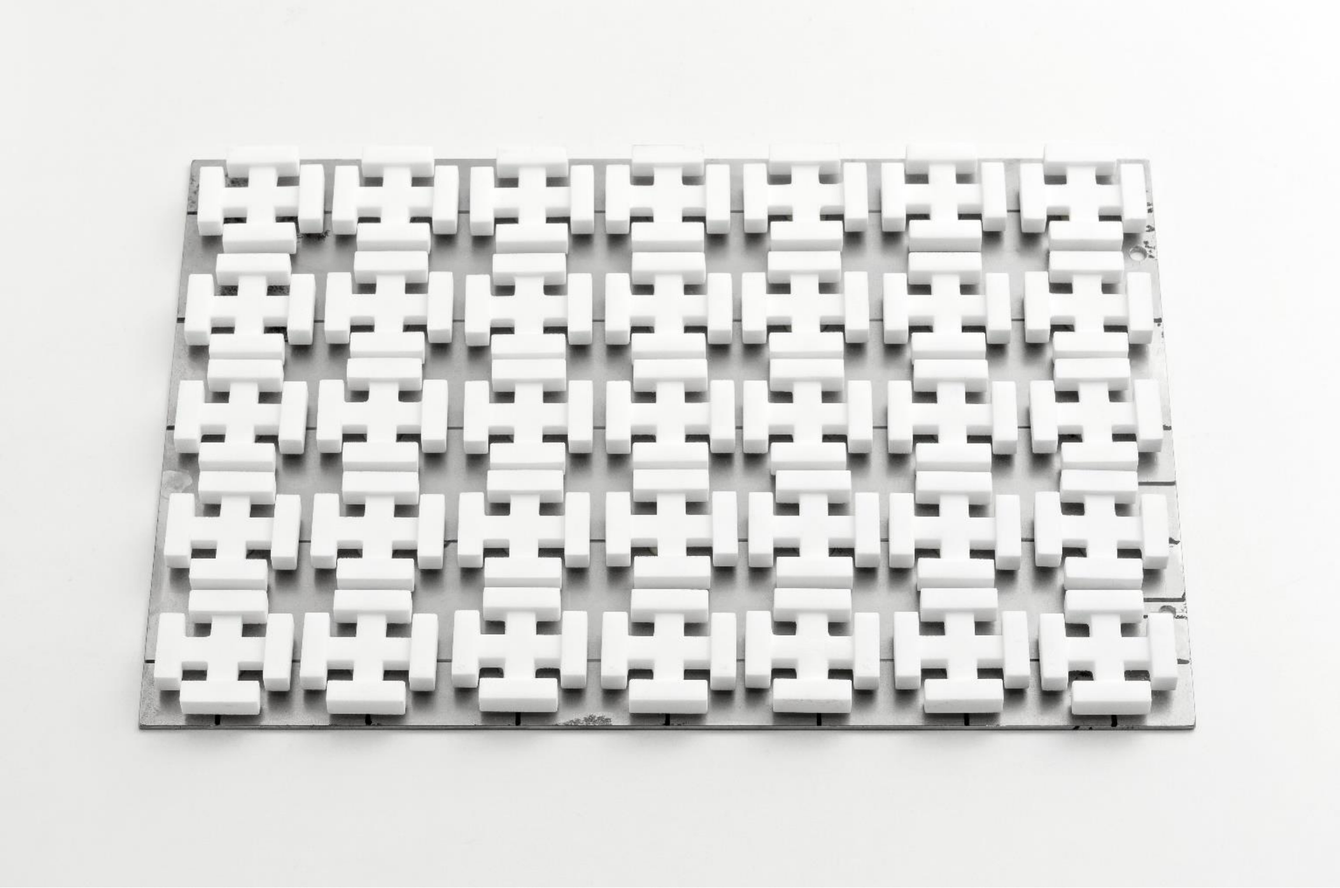
Vibroacoustic Metamaterials

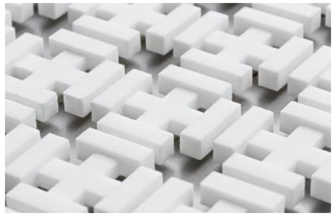


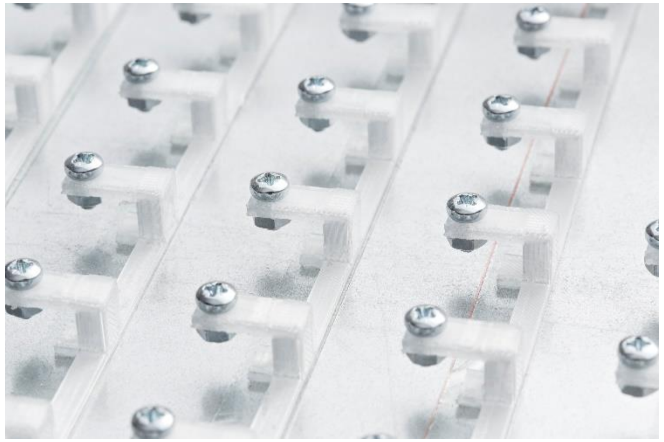


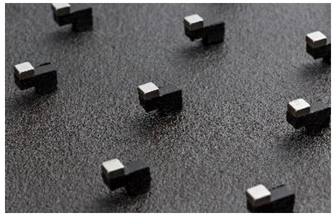
- VAMMs consists of an array of single mass oscillators
- Resonator array leads to effective negative mass in certain frequency-range = **„stop band“**

Vibroacoustic Metamaterials

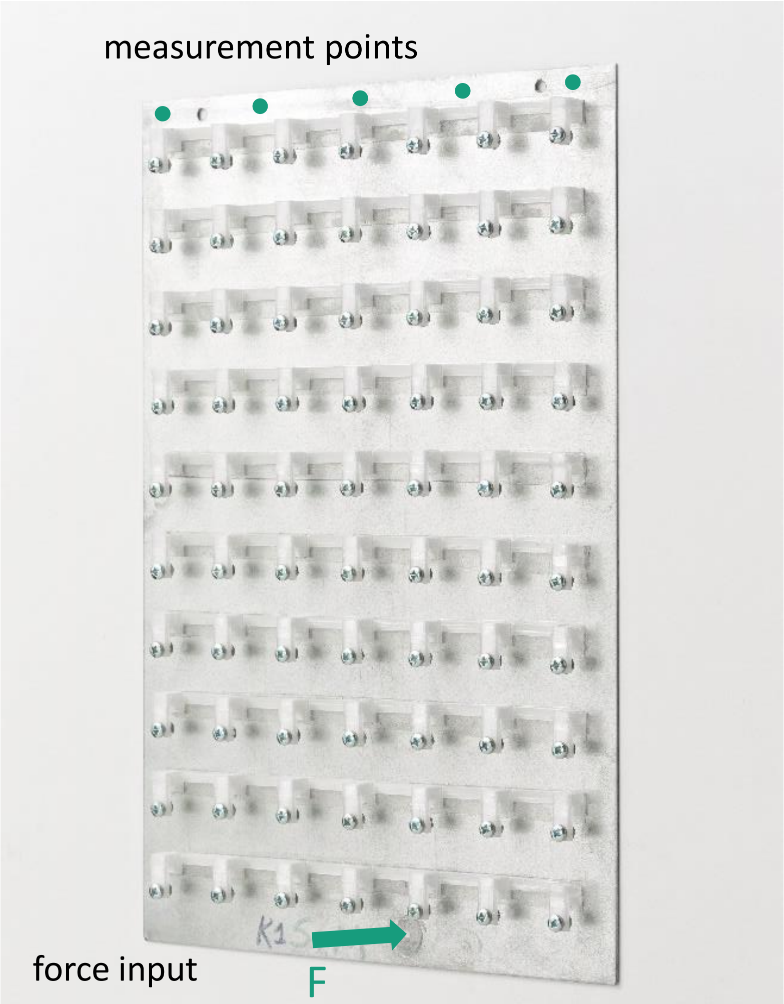


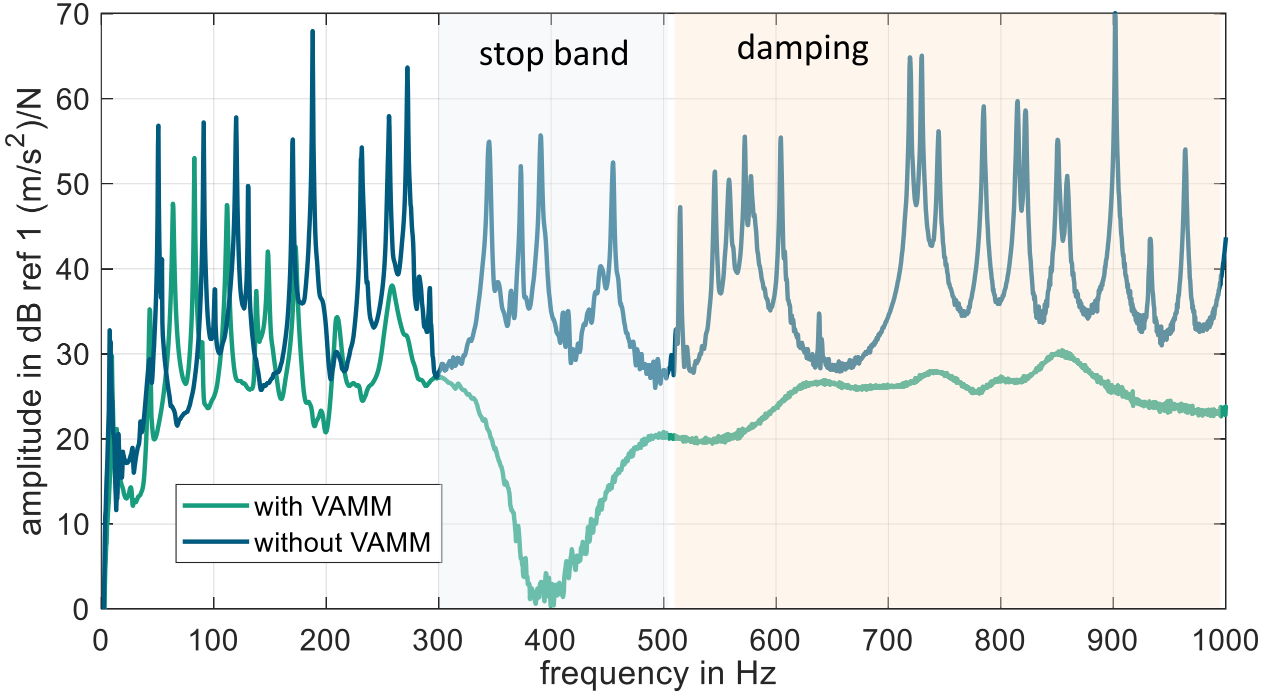






Vibroacoustic Metamaterials





- 0.7 mm steel plate
- Stop band frequency range: 300 – 500 Hz
- Effective damping above the stop band

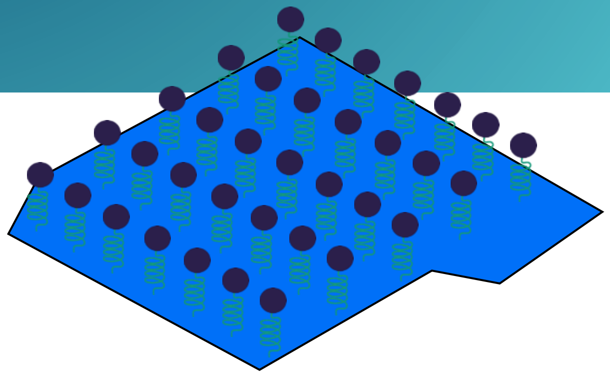
Outline

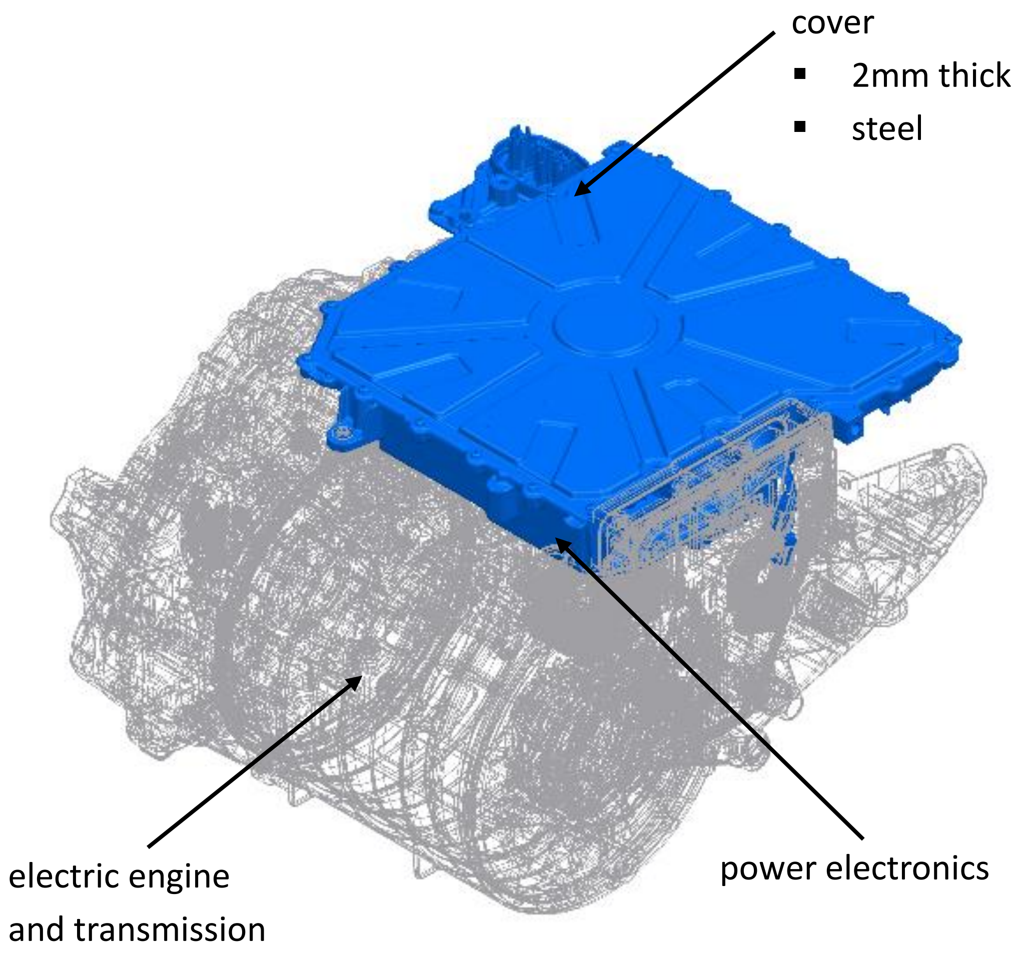
Cover of power electronics

Challenge

Challenge

- Large sound emission in the frequency range of 400 to 1500 Hz
- Small/no design space available
- No addition of mass





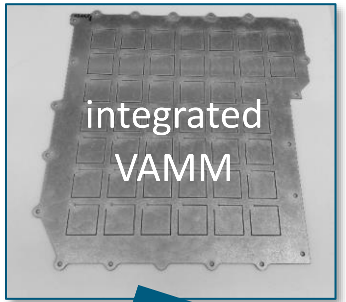
Cover of power electronics

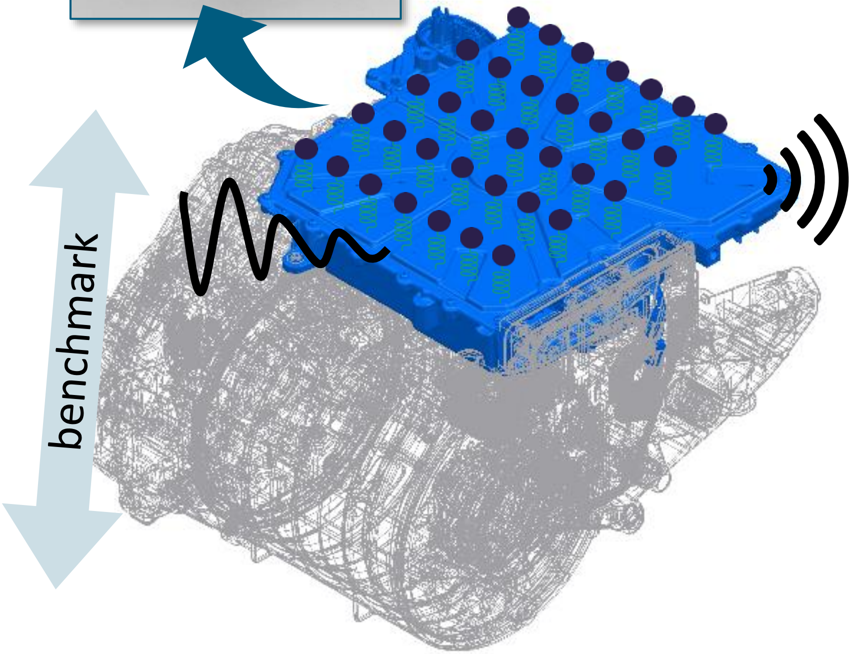
Aim of work

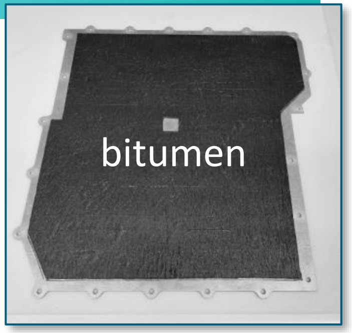
Aim

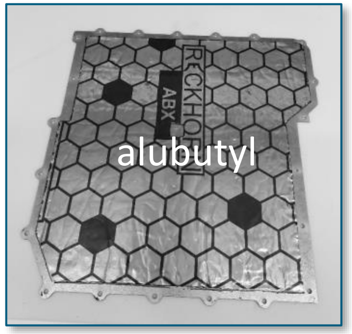
1. Design of integrated VAMM
2. Test and benchmark against conventional measures for noise and vibration reduction such as
   - Bitumen
   - Alubutyl
   - Larger wall thickness
   - Bondal ®

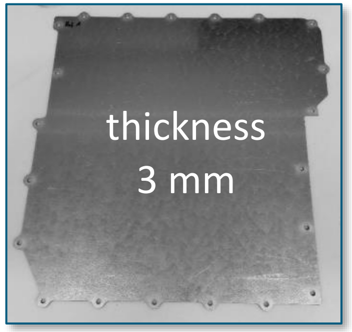
In terms of
- Structural dynamic behavior
- Acoustic emission





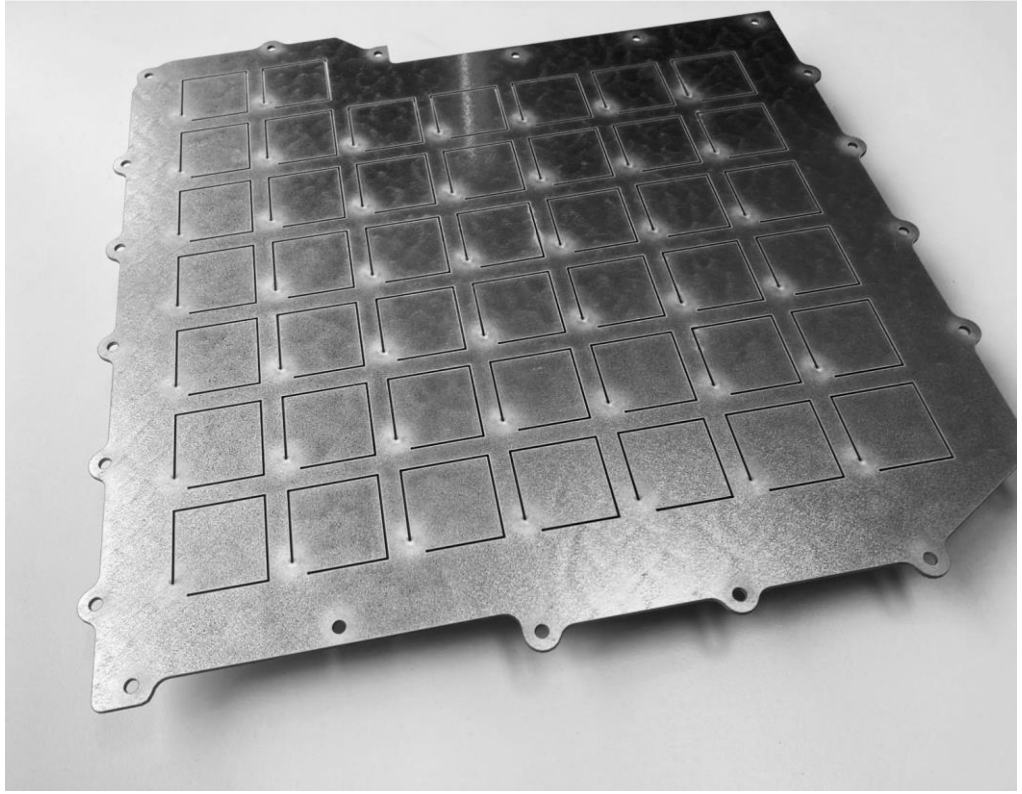


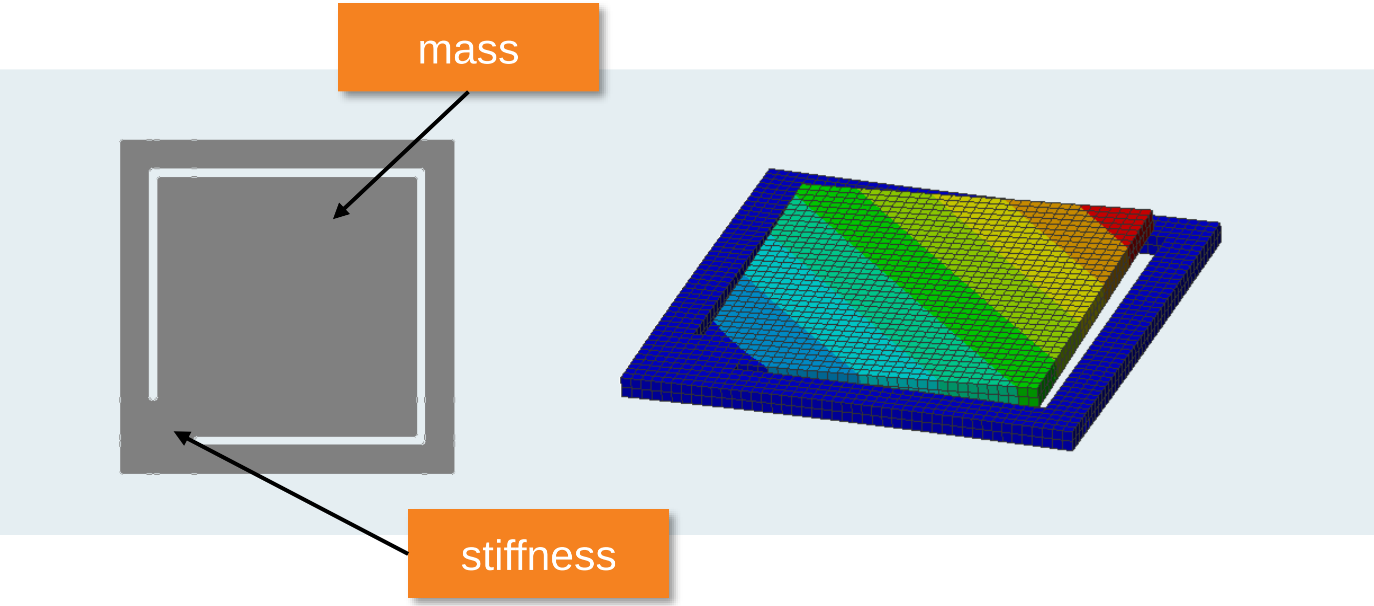




Cover of power electronics

Numerical design

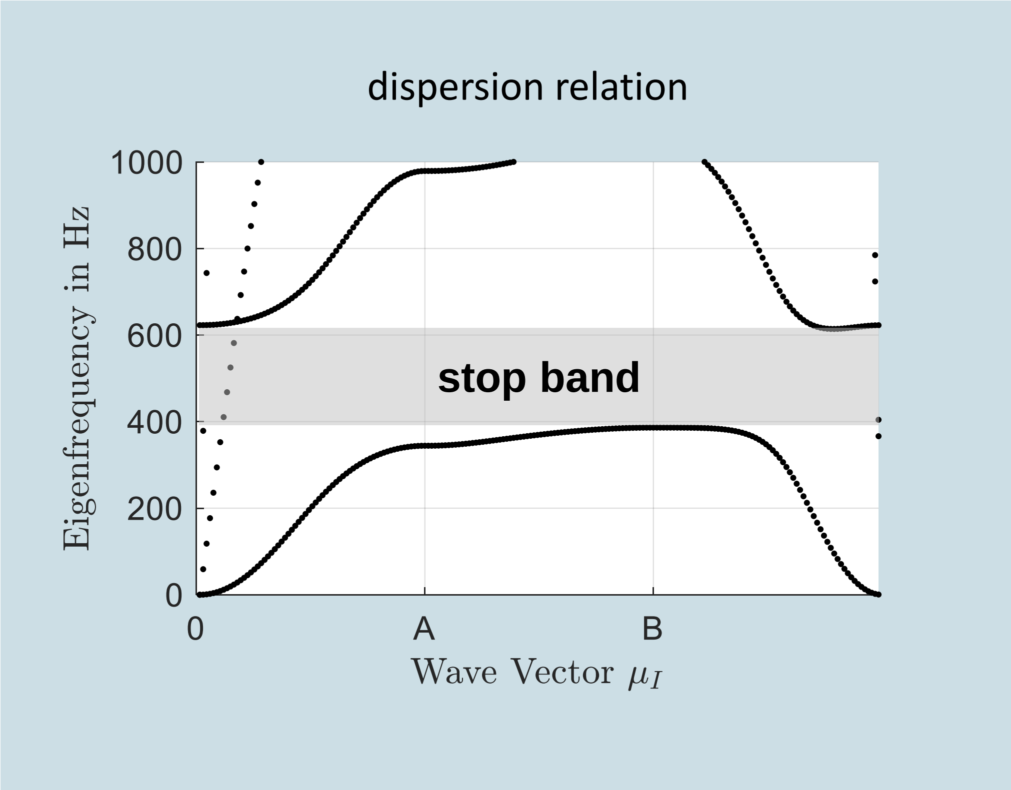


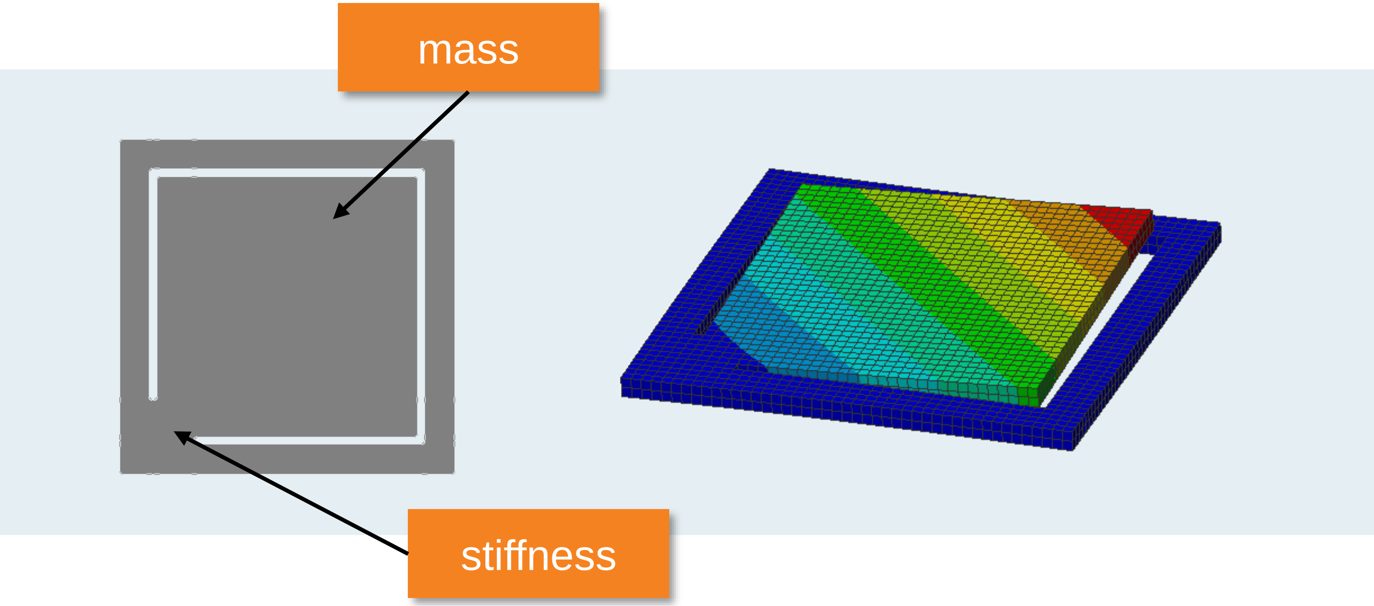


- Resonators are cut into the cover
- Space- and weight-neutral integration (3% mass reduction)
- Damping and sealing through:
  - Version 1: application of PVC film
  - Version 2: gaps filled with viscoelastic material (silicone)

Cover of power electronics

Numerical design





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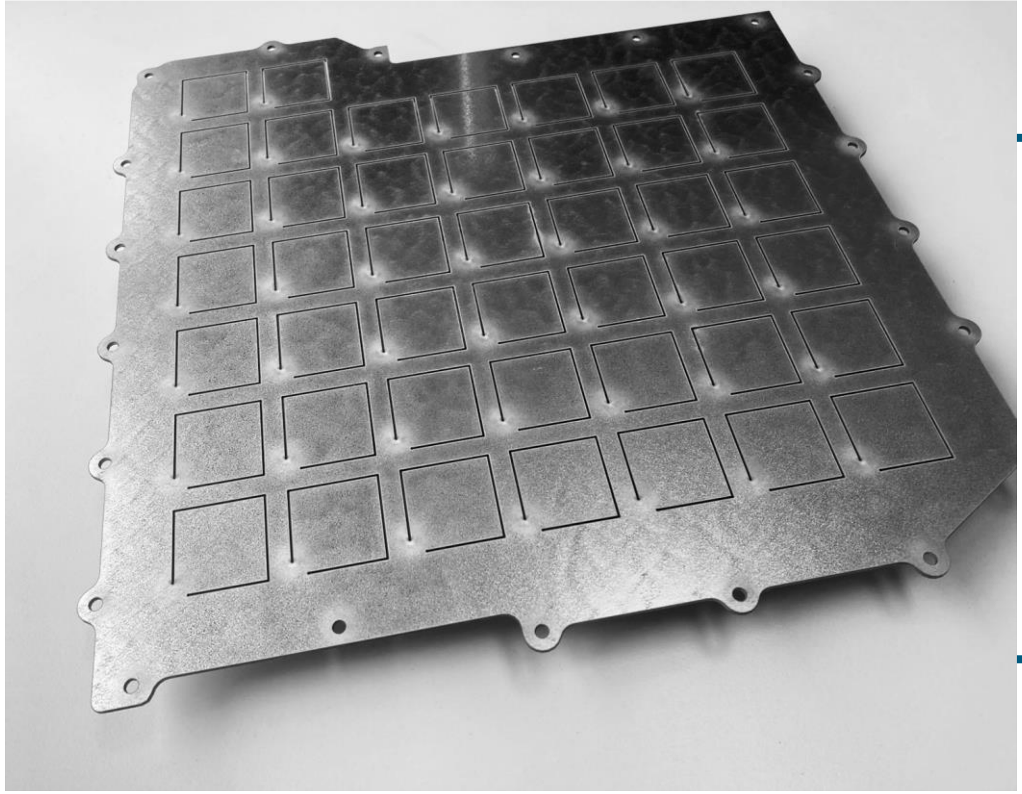
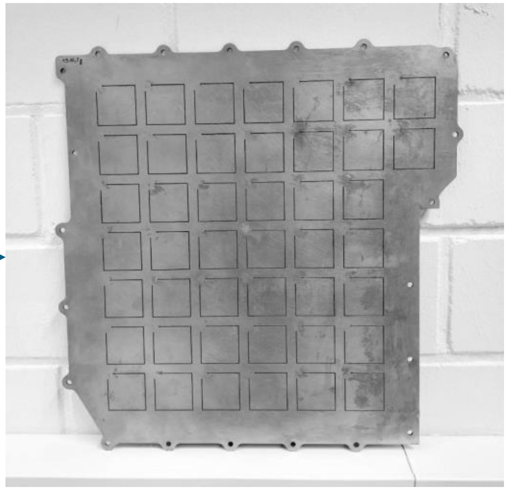
Cover of power electronics

Damping mechanisms



PVC film

- Sealing and damping with added PVC-film
- 0.1 mm thick



Silicone

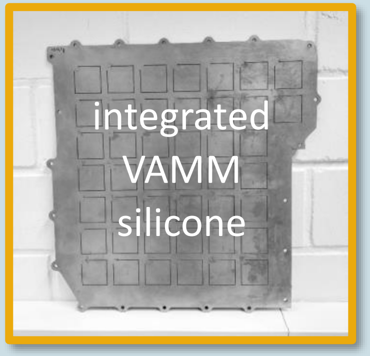
- Gaps filled with silicone

Cover of power electronics

Scope

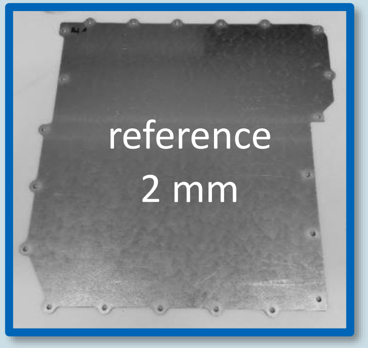
- 3% mass

-3% mass

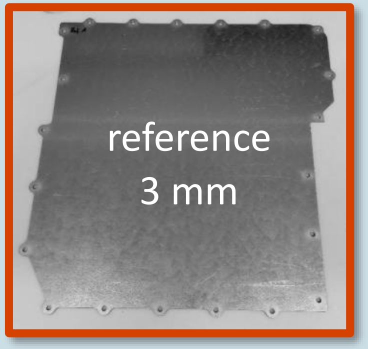


-3% mass

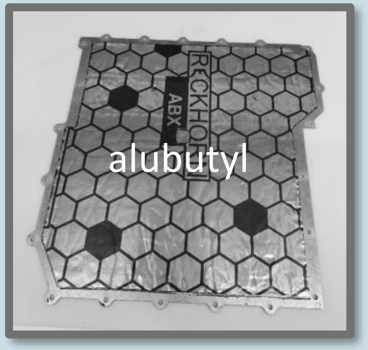
comparison



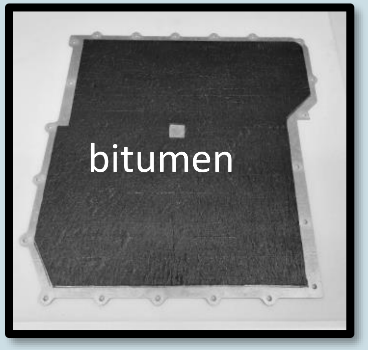
baseline



+50% mass



+19% mass

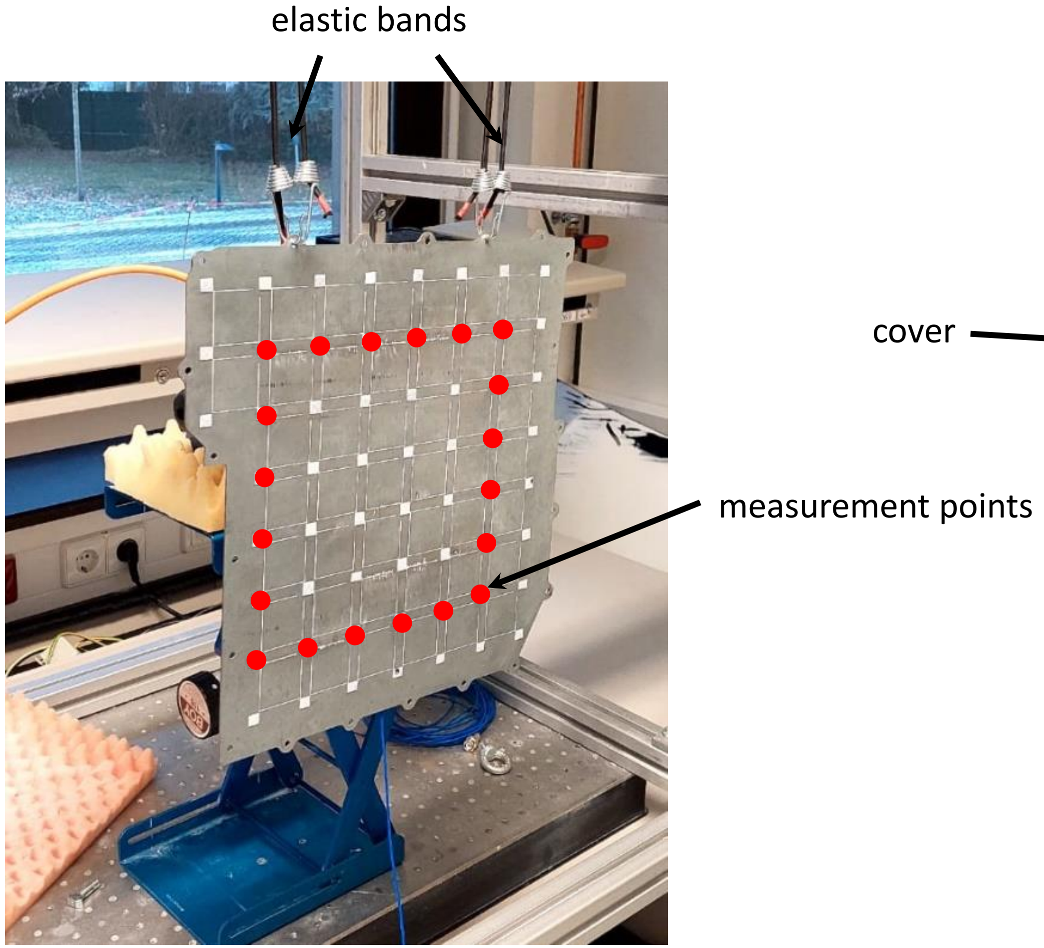


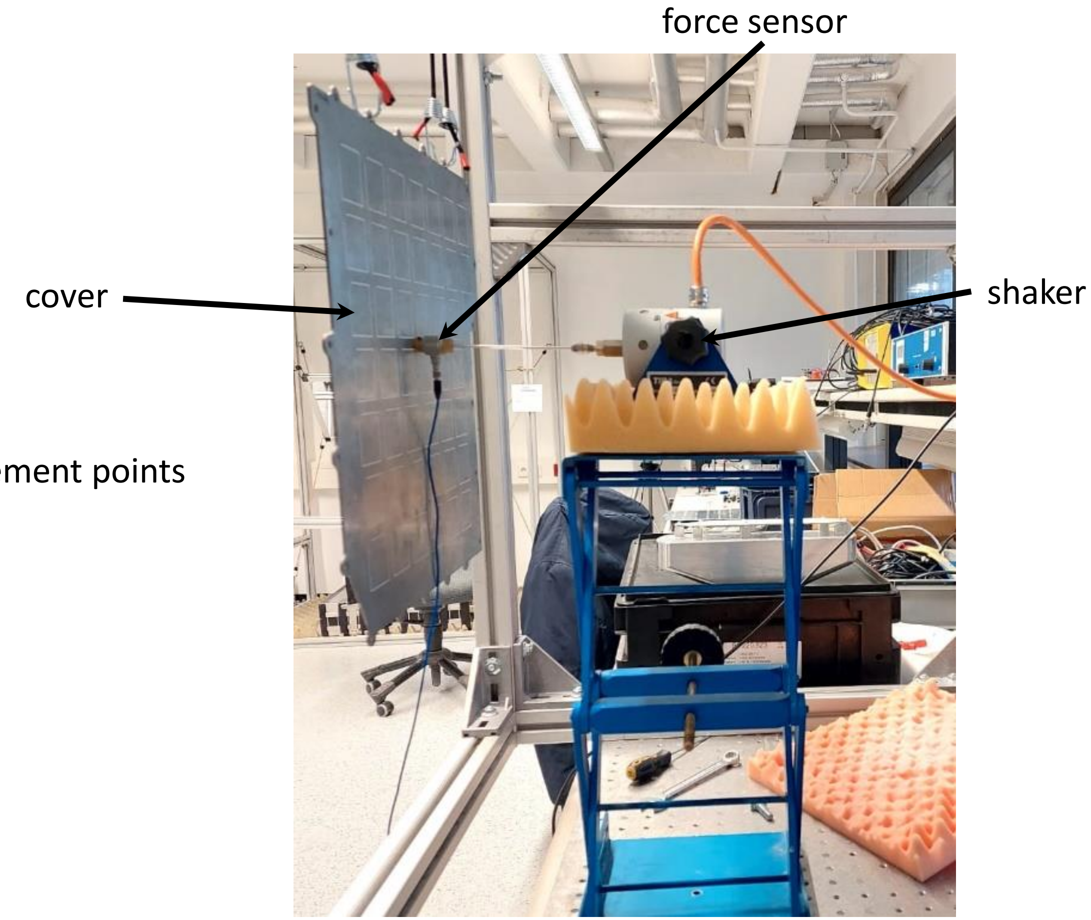
+27% mass

-2% mass

Cover of power electronics

Structural dynamic measurements





Cover of power electronics

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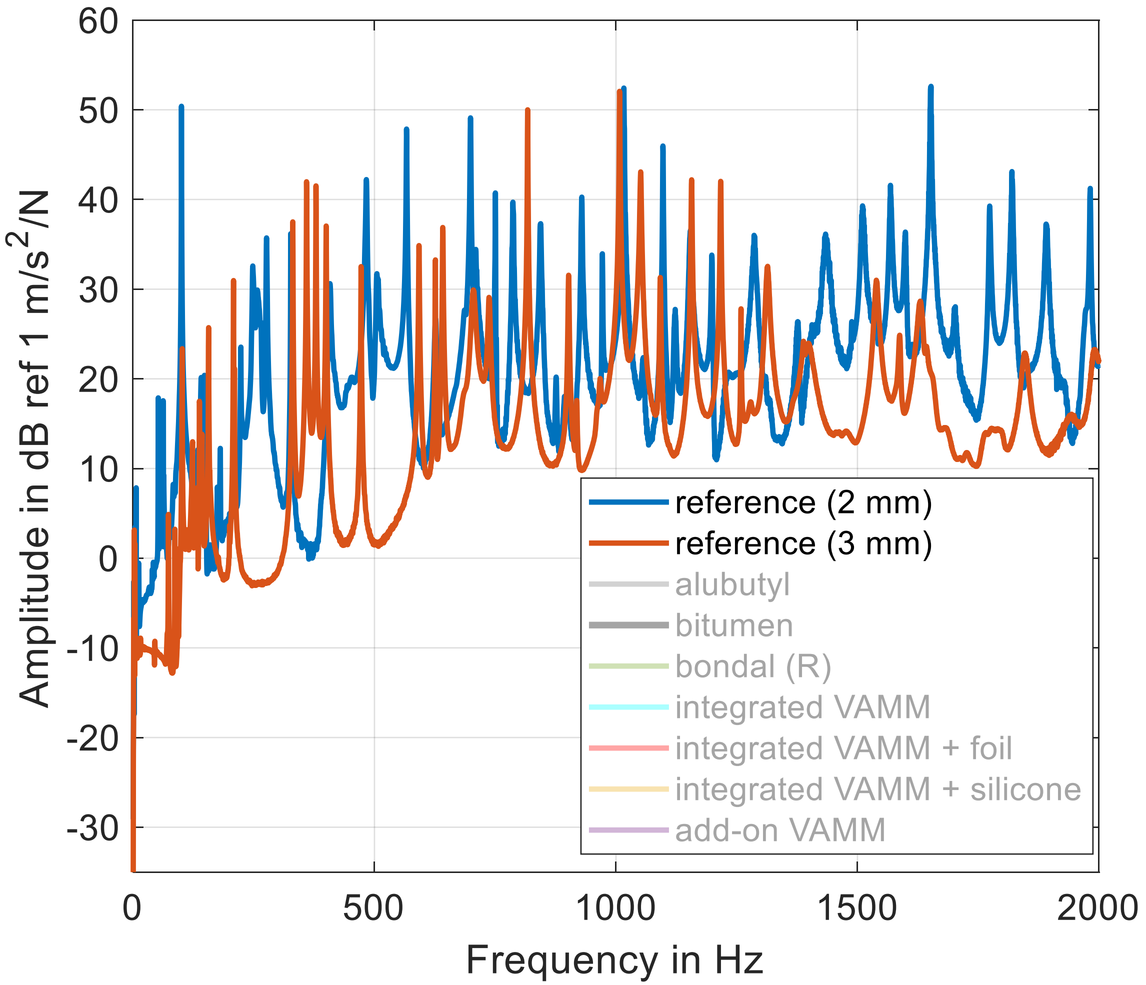

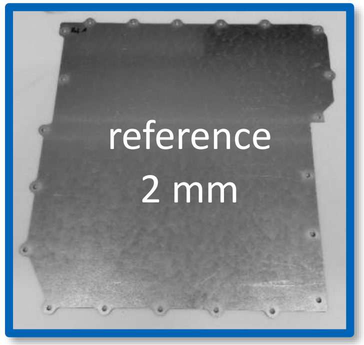

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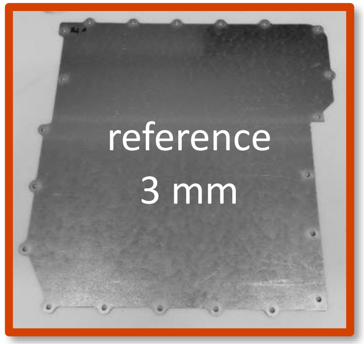

+50% mass

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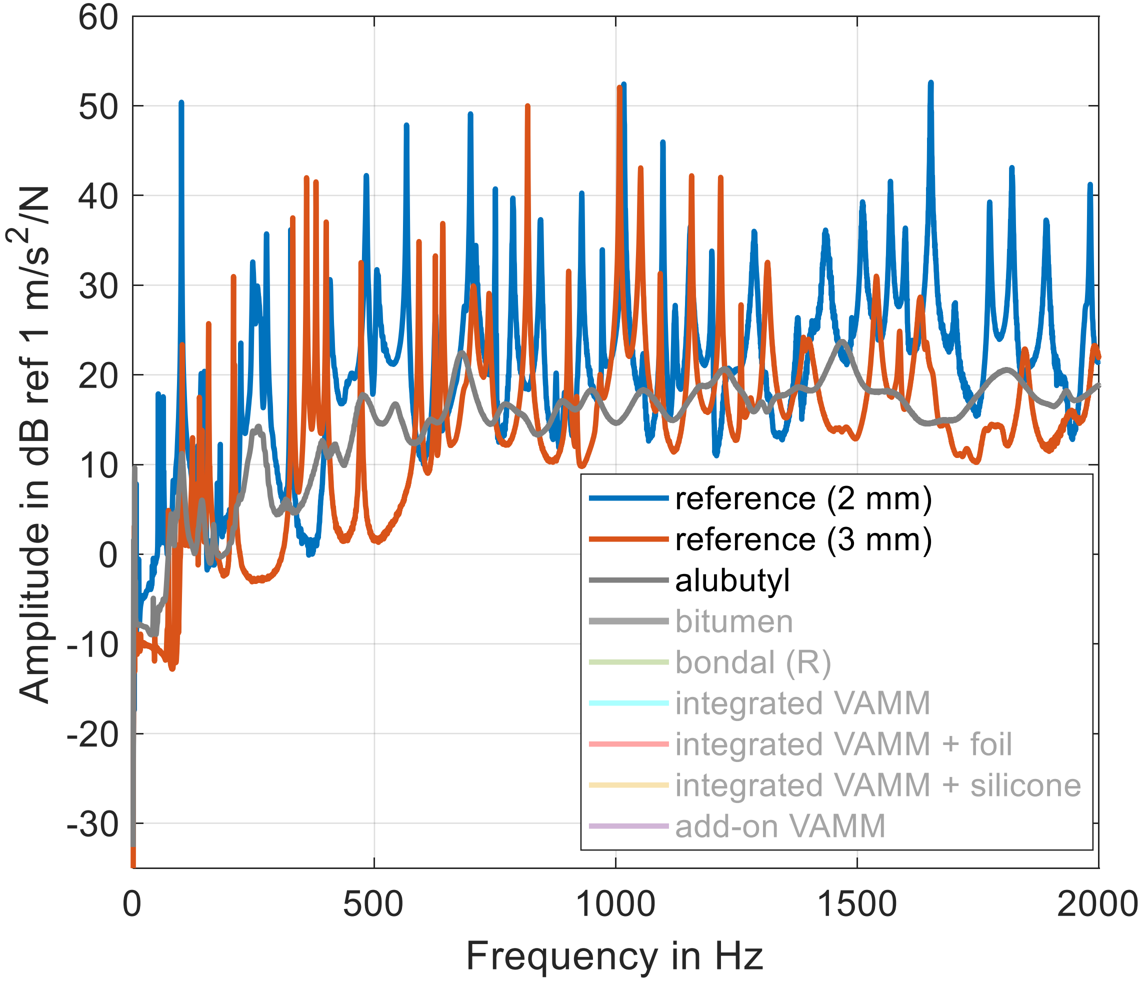
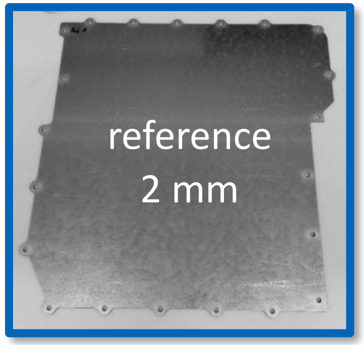
Cover of power electronics
Structural dynamic measurements





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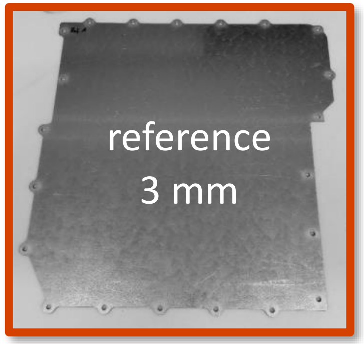

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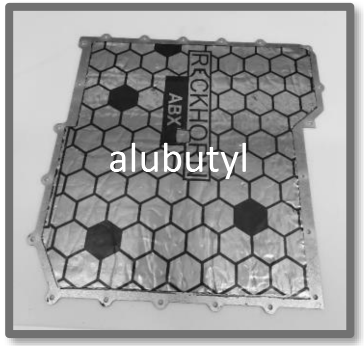

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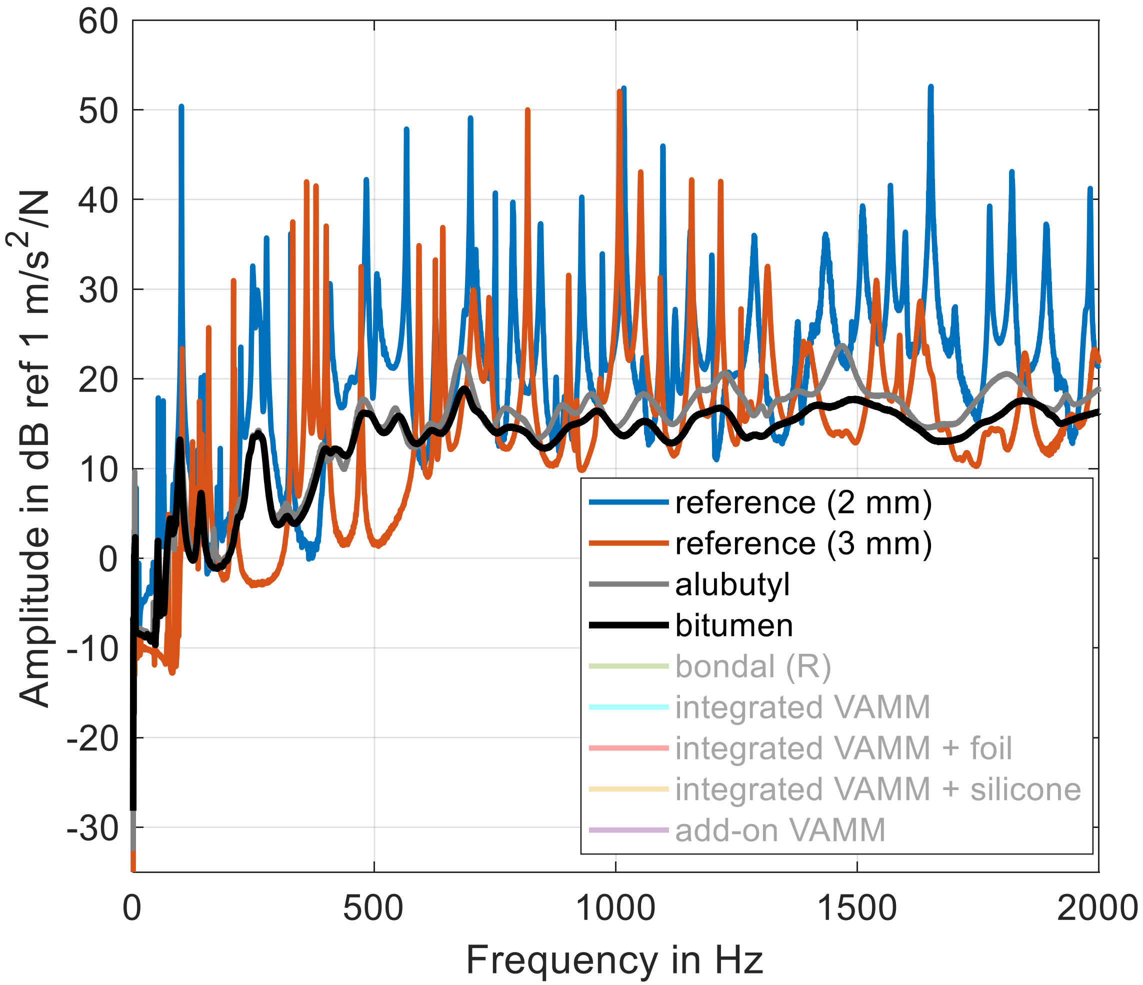
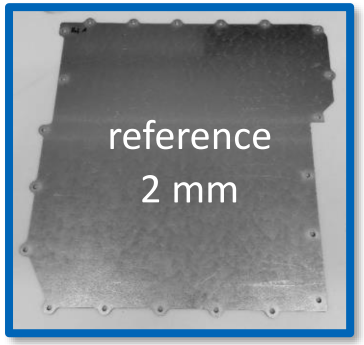
Cover of power electronics

Structural dynamic measurements





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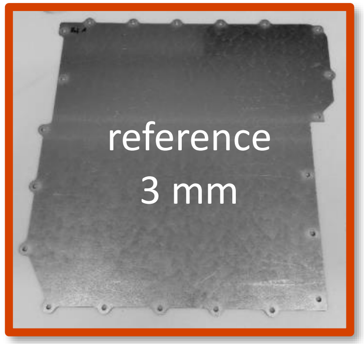

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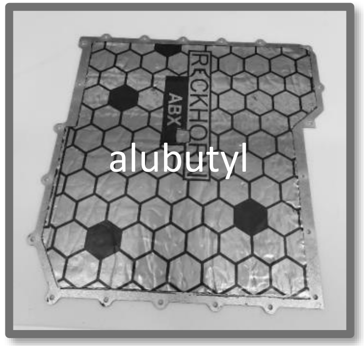

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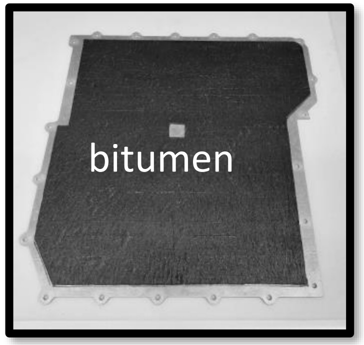
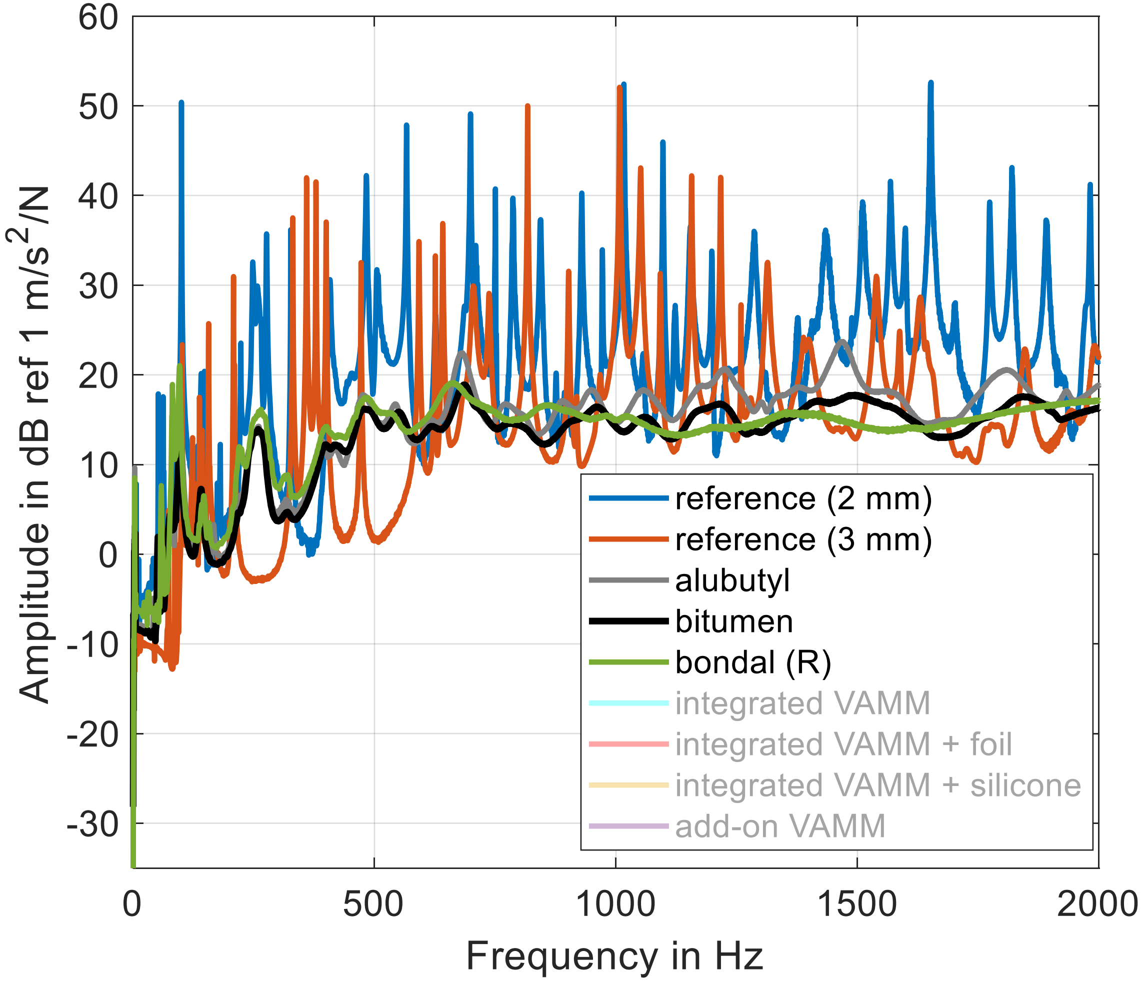
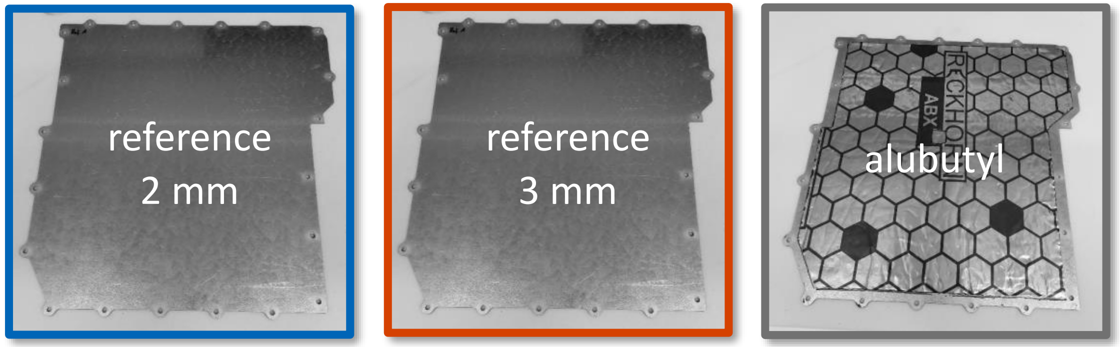


+27% mass

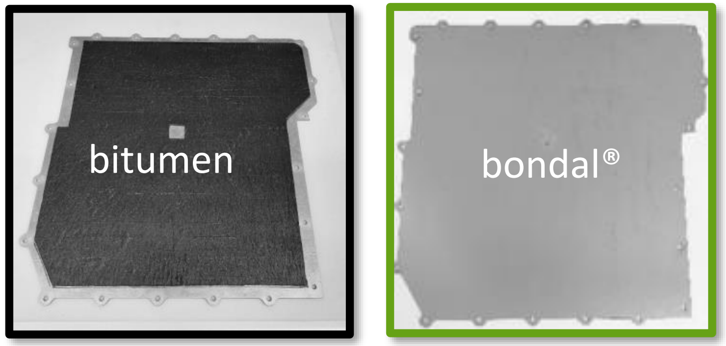
Cover of power electronics

Structural dynamic measurements





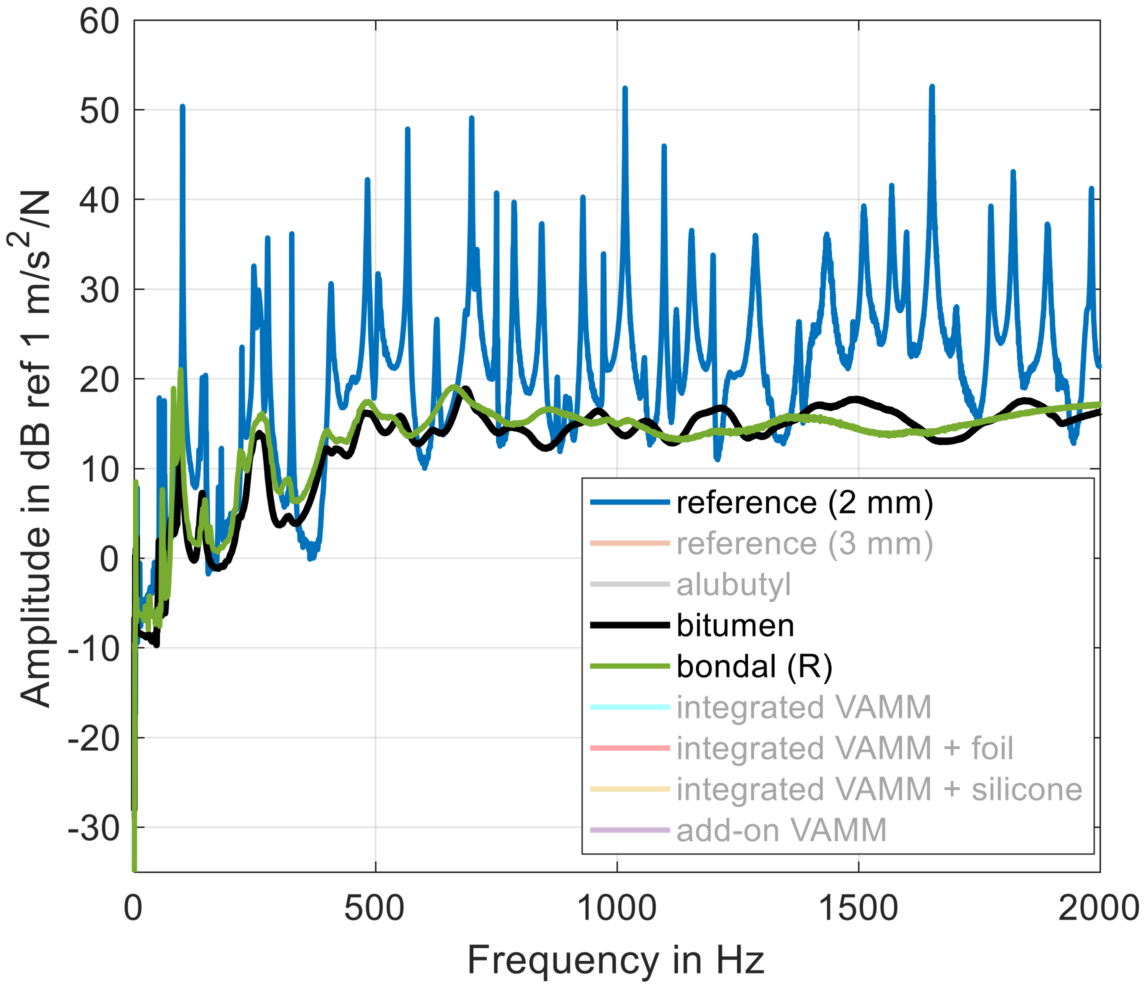
baseline **+50% mass** **+19% mass**

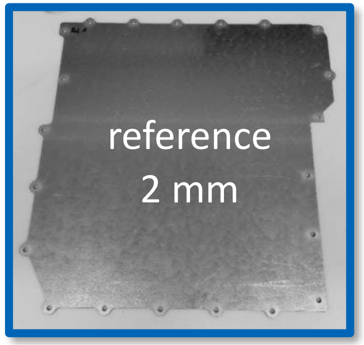


+27% mass **-2% mass**

Cover of power electronics

Structural dynamic measurements





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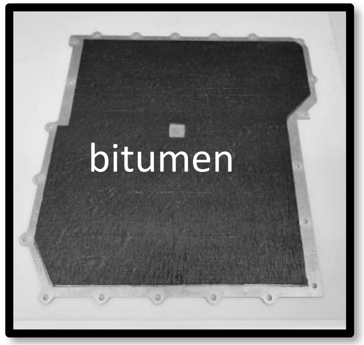
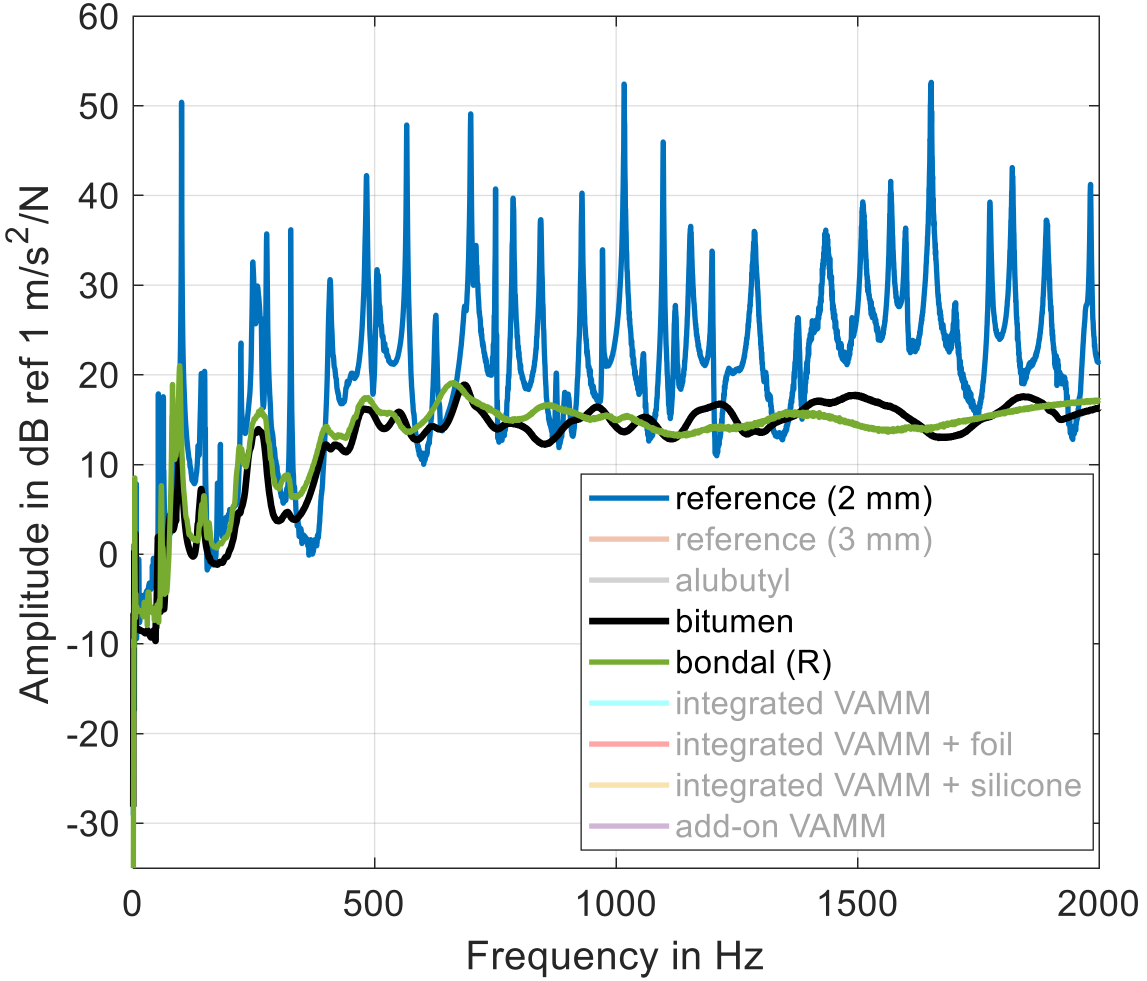


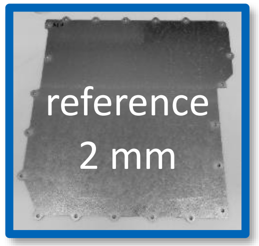
+27% mass

-2% mass

Cover of power electronics

Structural dynamic measurements





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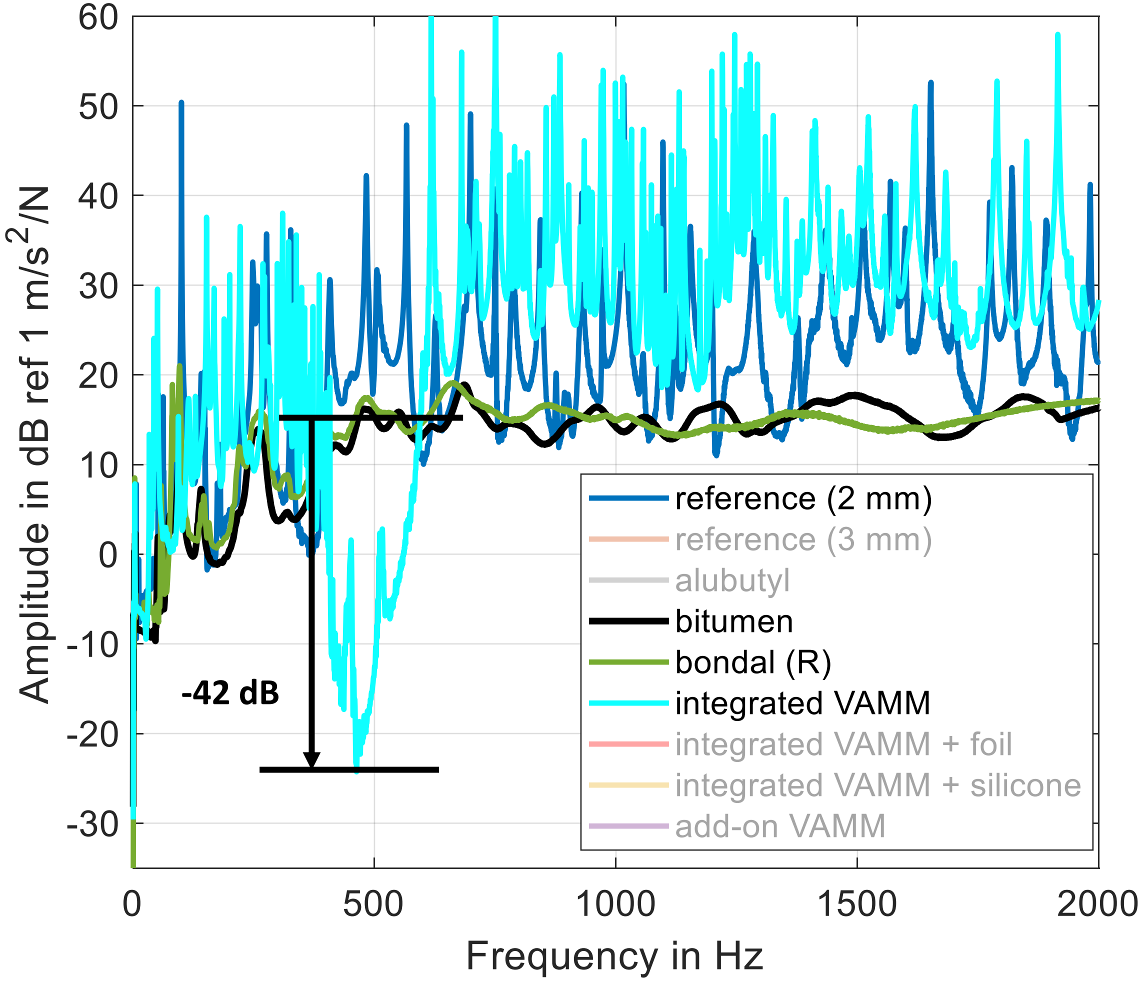
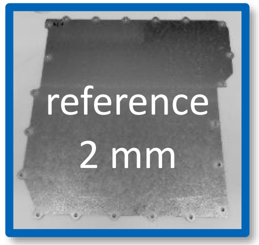
Cover of power electronics

Structural dynamic measurements





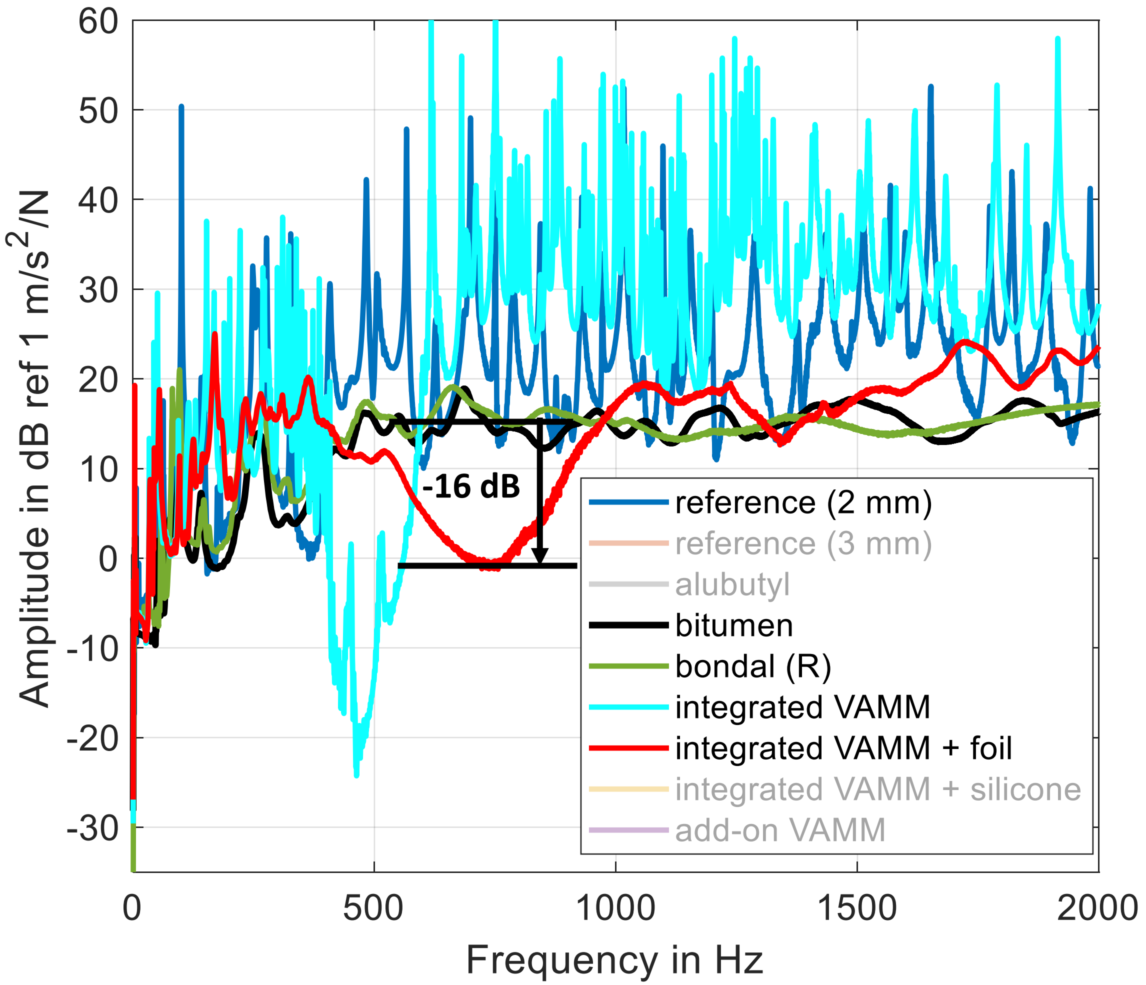
-3 % mass

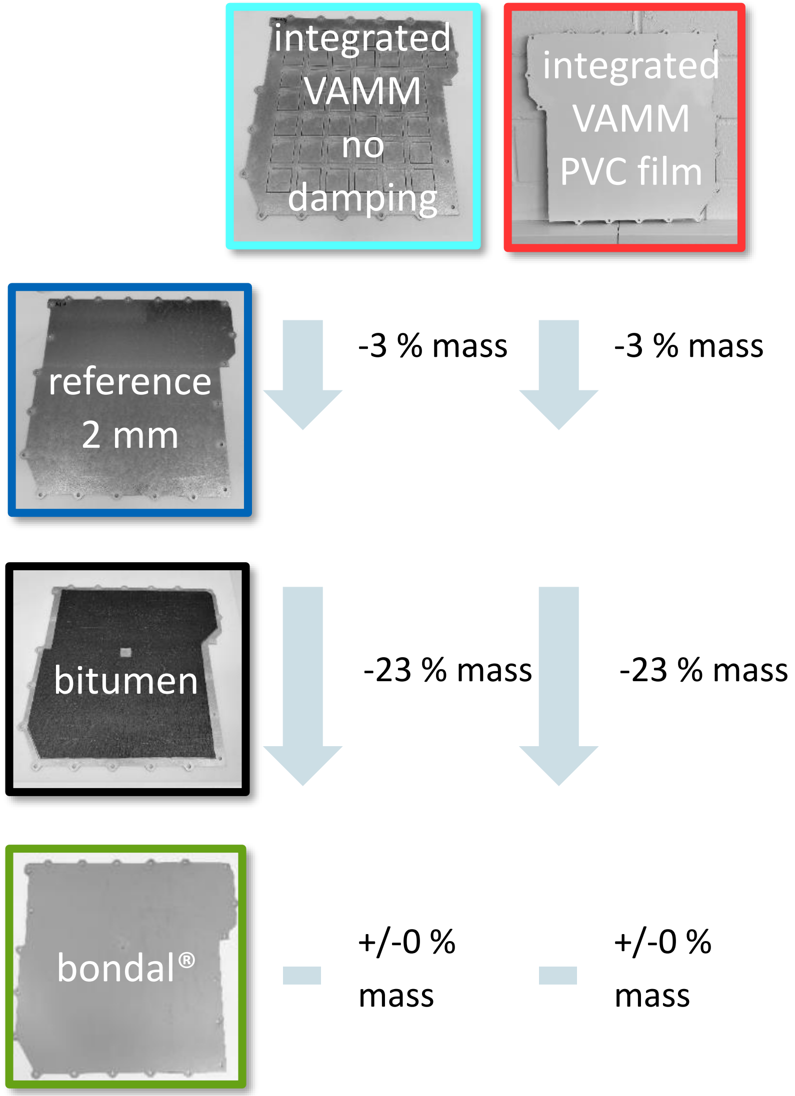
-23 % mass

+/-0 % mass

Cover of power electronics

Structural dynamic measurements





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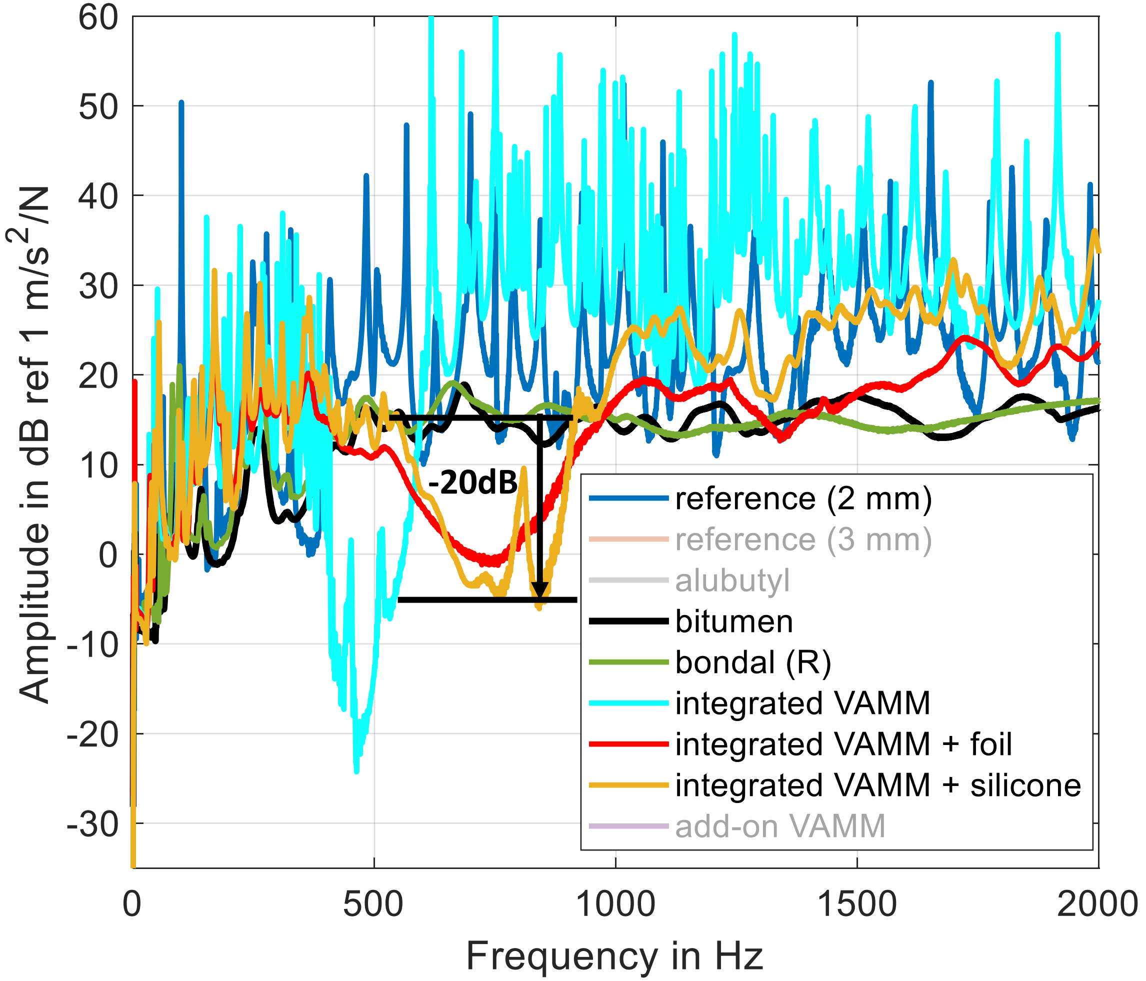
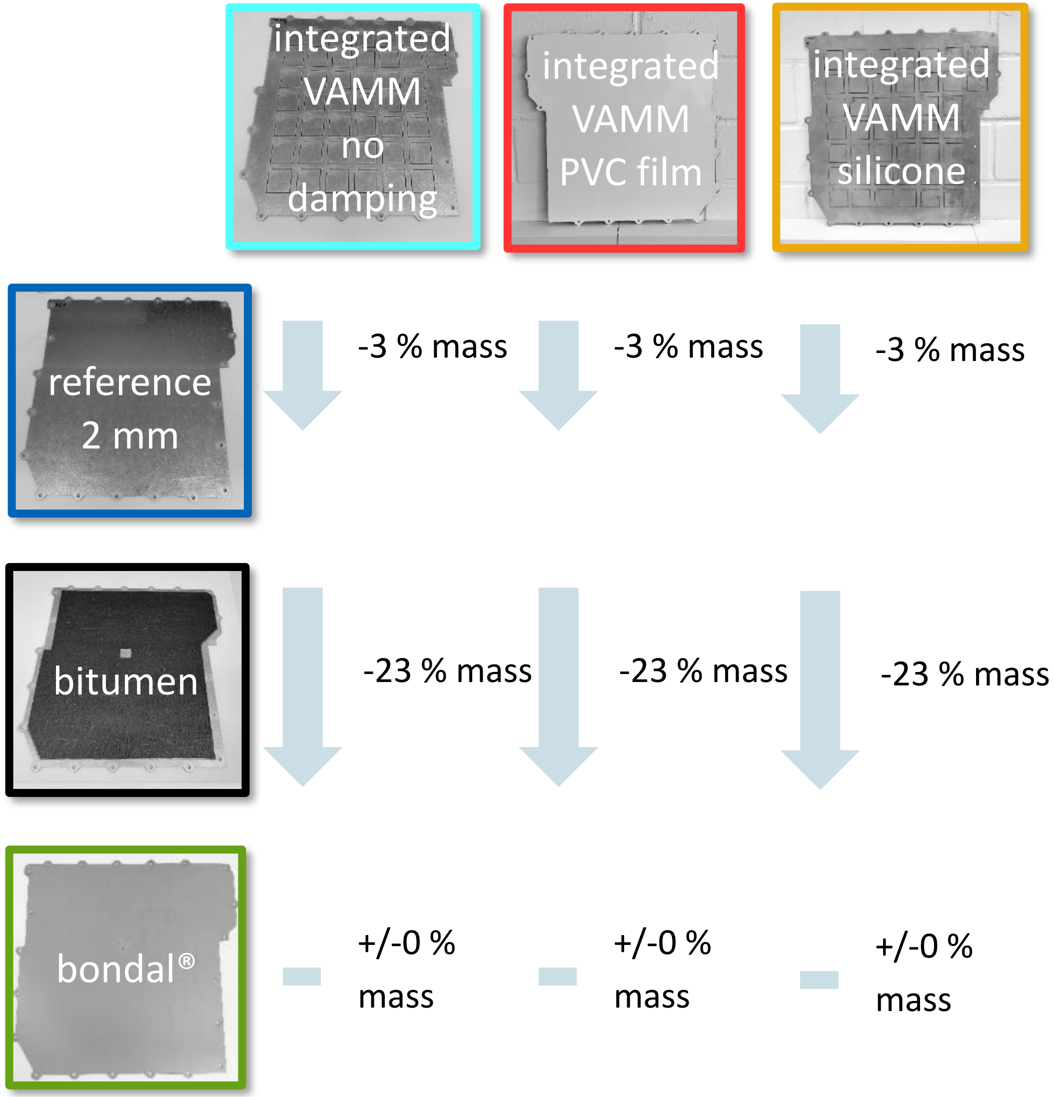
Cover of power electronics

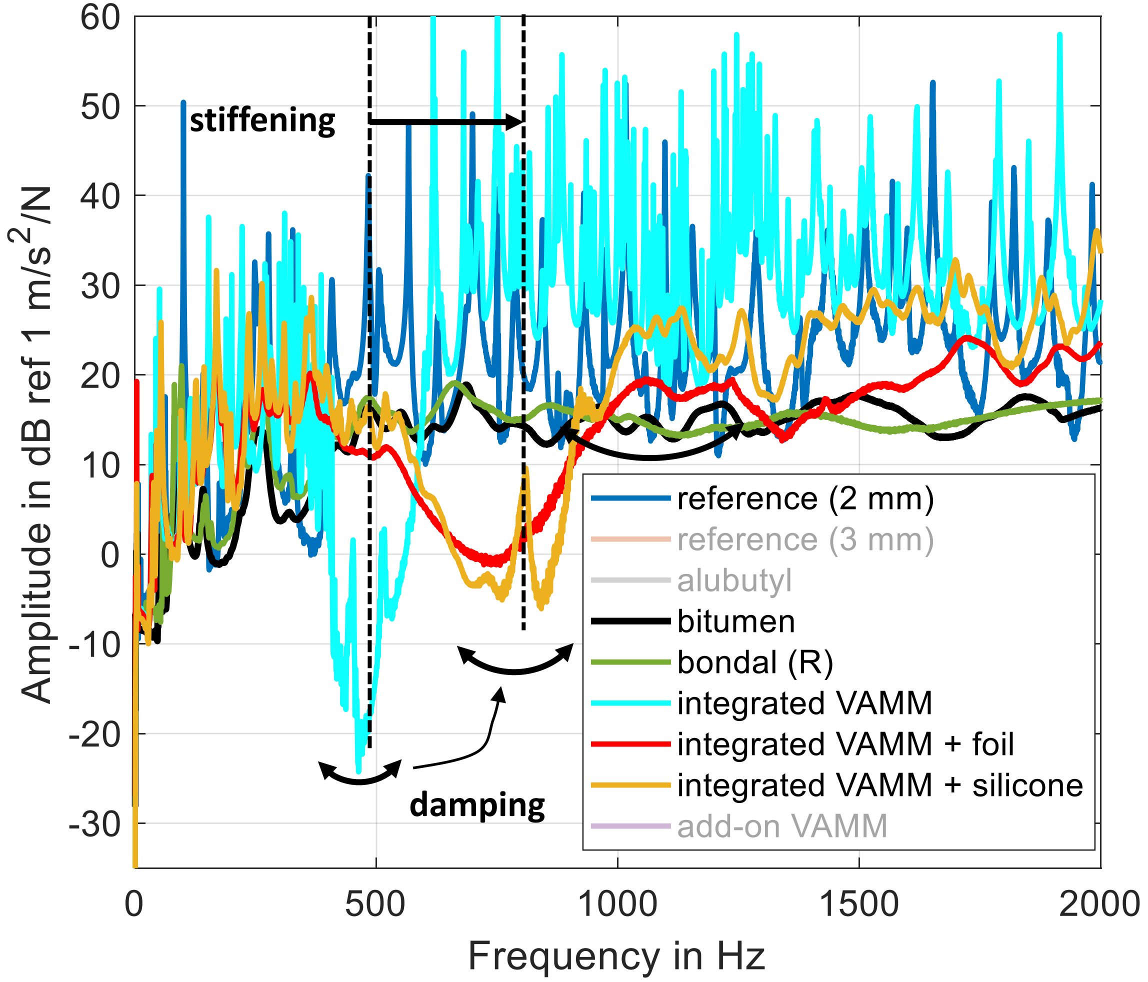
Structural dynamic measurements

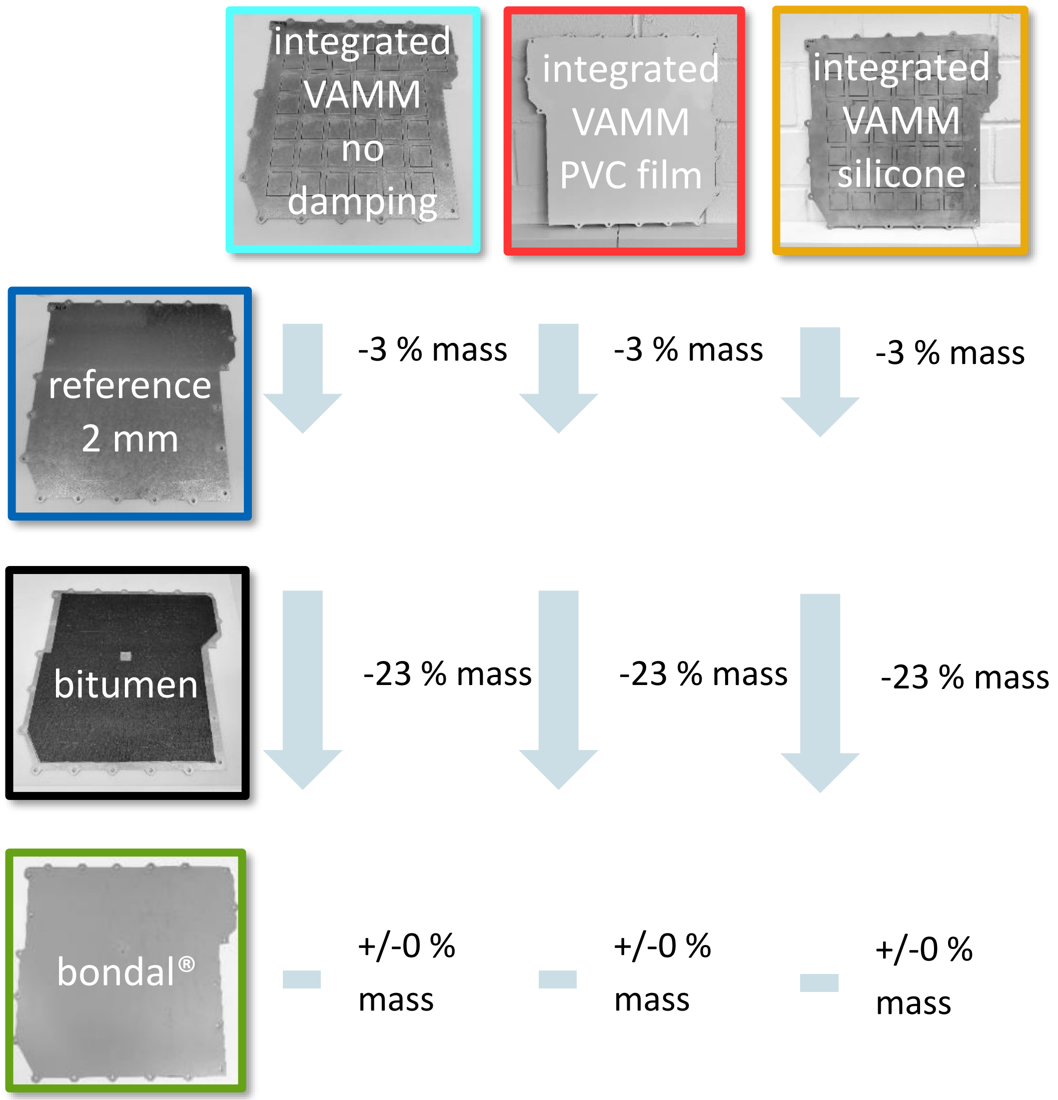




Cover of power electronics

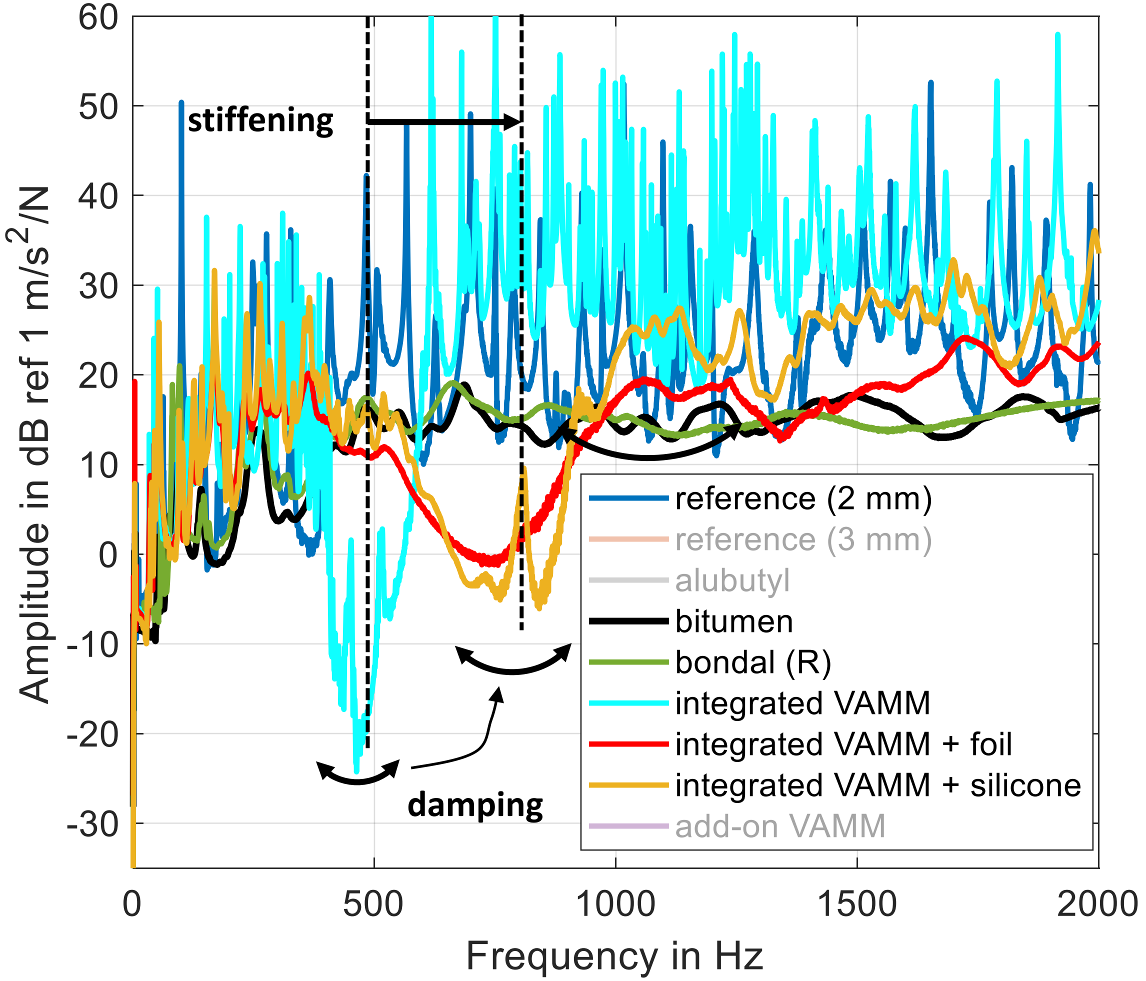
Structural dynamic measurements

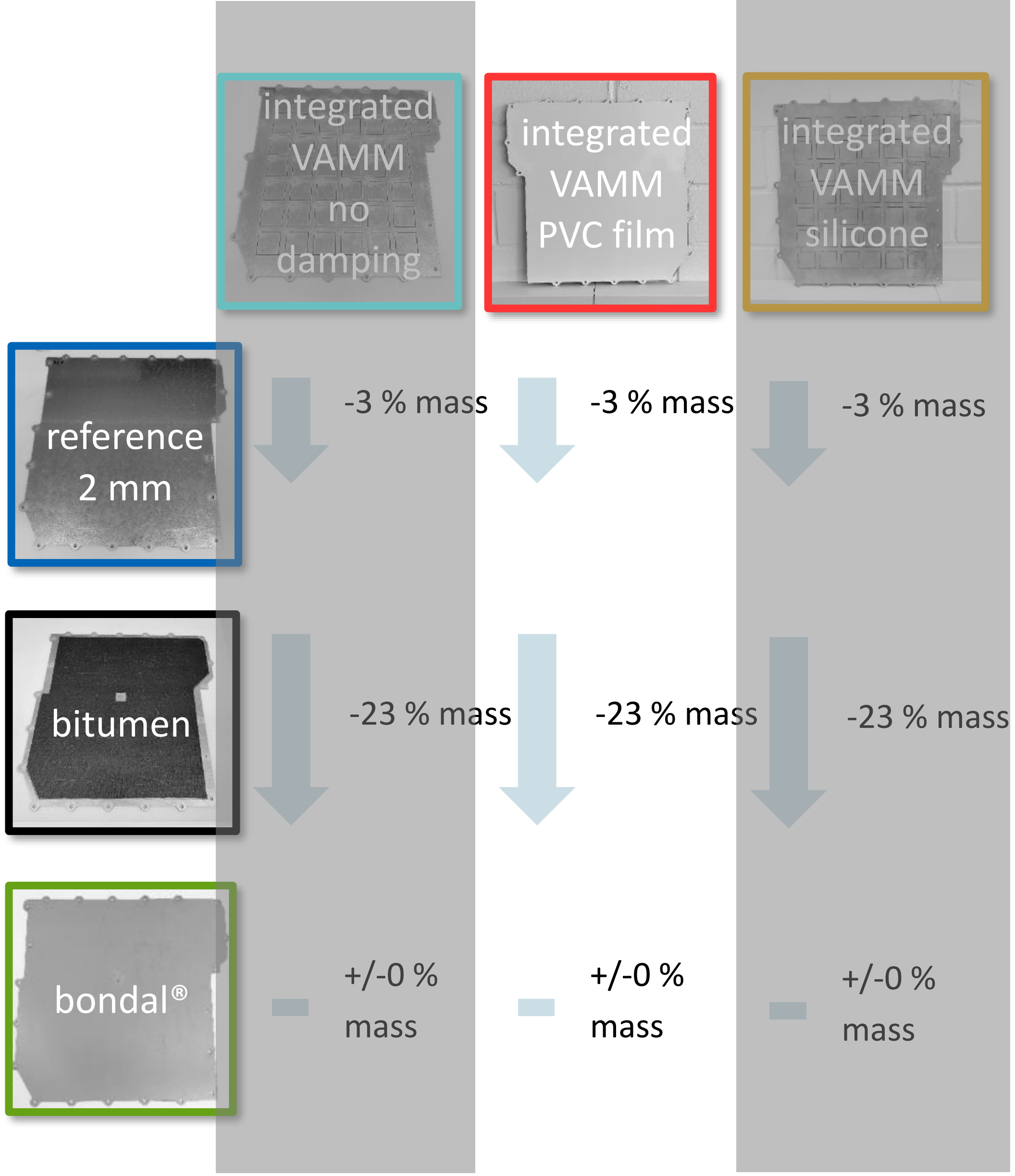




Cover of power electronics

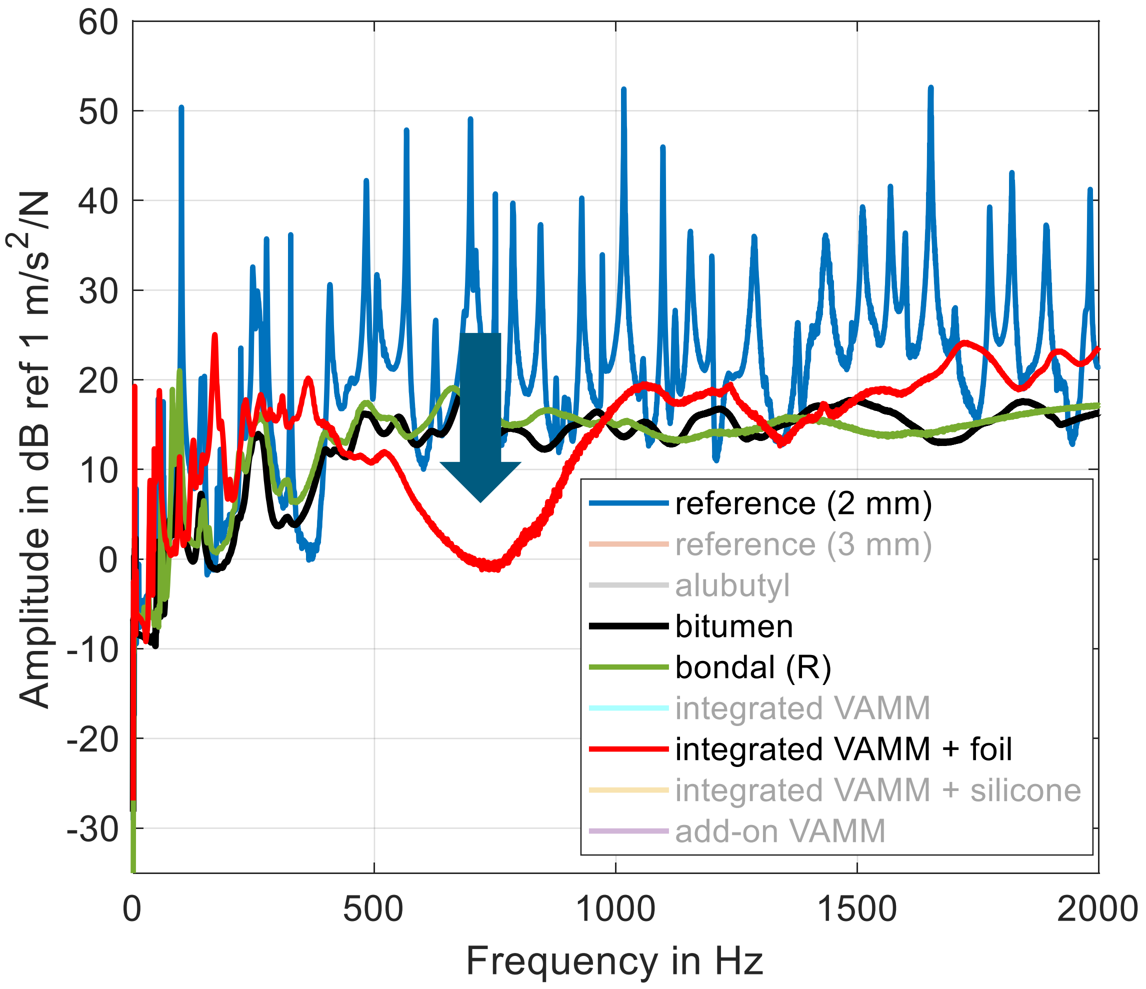
Structural dynamic measurements

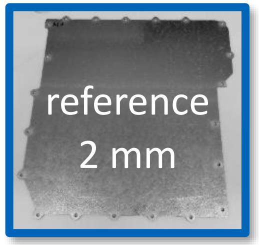




Cover of power electronics

Structural dynamic measurements





VAMM vs. reference

- 3% lighter
- -50 dB within stop band
- -15 … -25 dB outside stop band

VAMM vs. bitumen

- 23% lighter
- -19 dB within stop band
- Outside stop band comparable

VAMM vs. bondal®

- About same weight
- -19 dB within stop band
- Outside stop band comparable

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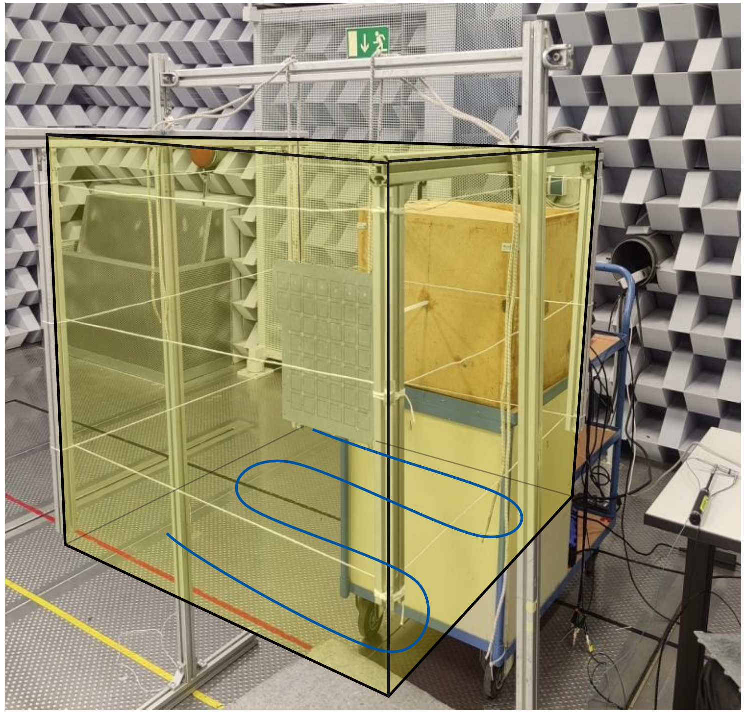
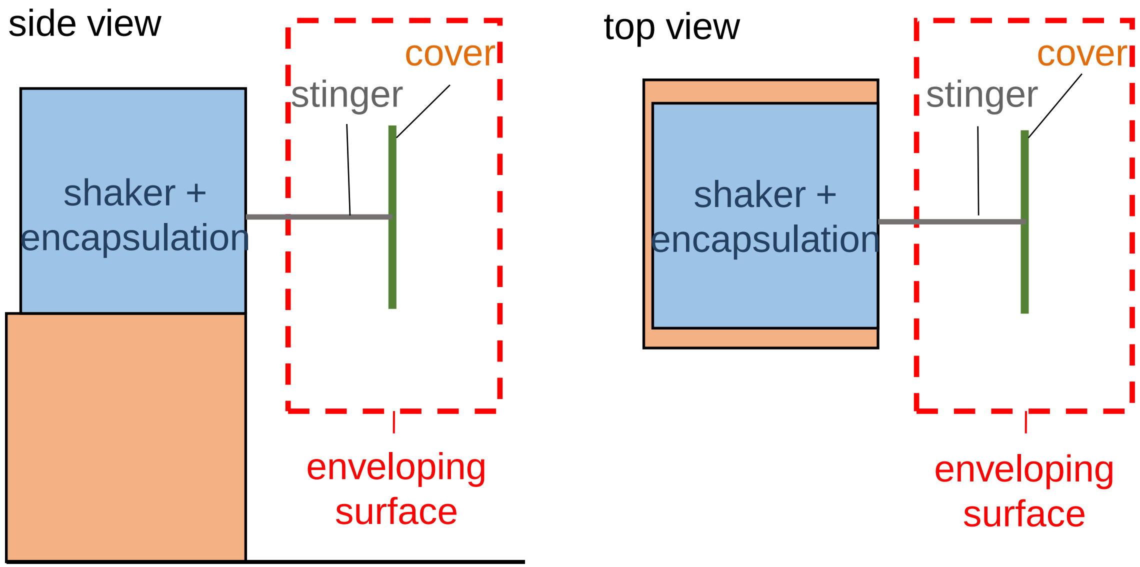
Cover of power electronics

Acoustic measurements



Radiation efficiency:

$$\Delta L_W = 10\log_{10}\frac{P_W}{P_{in}} - 10\log_{10}\frac{P_{W,reference}}{P_{in,reference}}$$



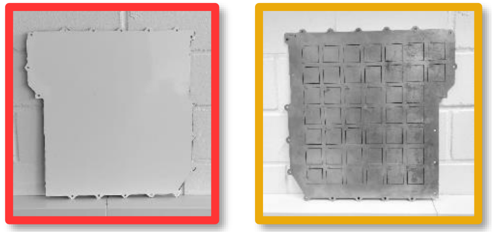
- Envelope surface: 5.53 m²
- Constant acceleration input: 2m/s²
- Measurement with sound intensity probe

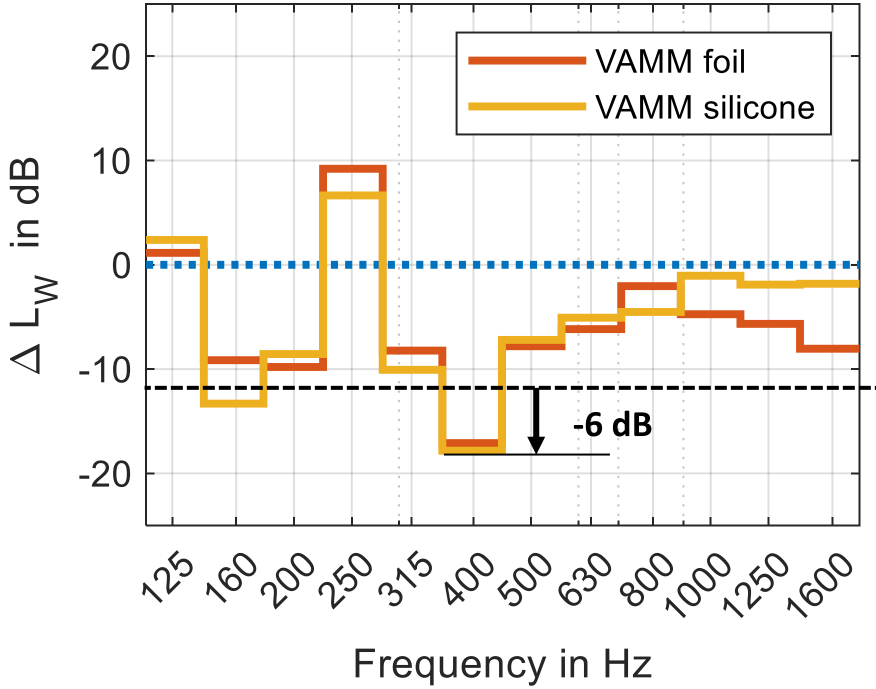
Cover of power electronics

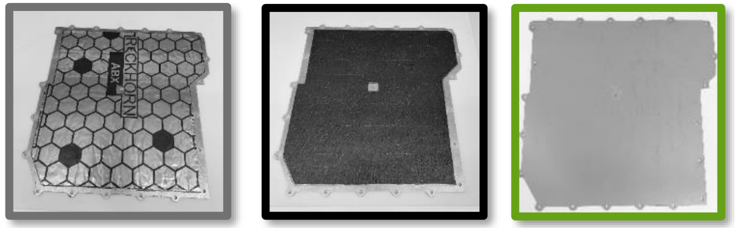
Acoustic measurements

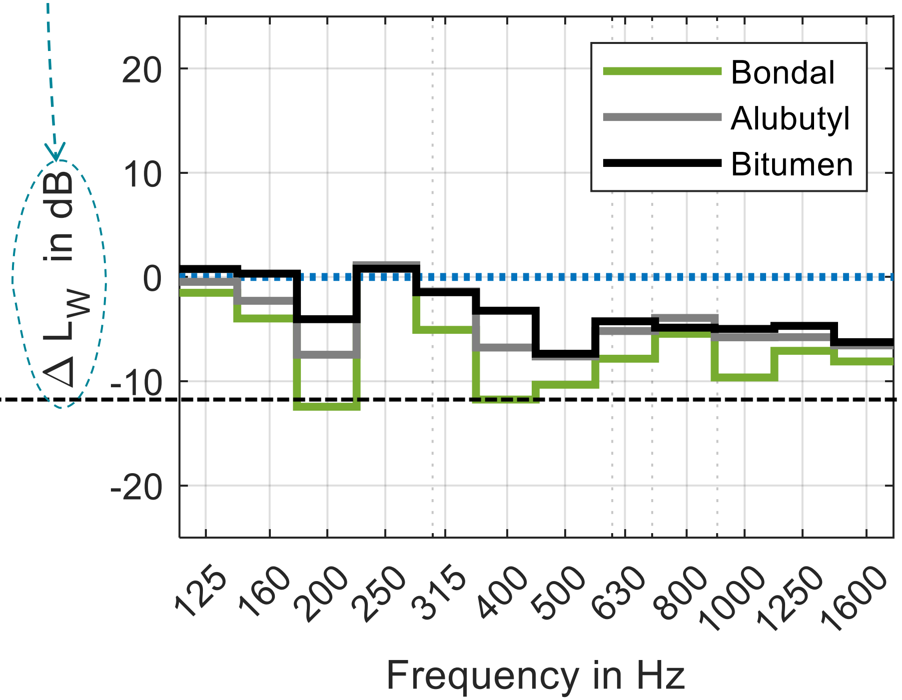
Radiation efficiency:

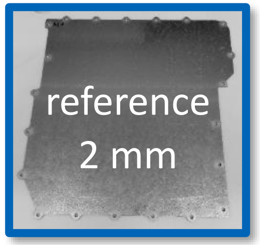
$$\Delta L_W = 10\log_{10}\frac{P_W}{P_{in}} - 10\log_{10}\frac{P_{W,reference}}{P_{in,reference}}$$











Cover of power electronics

Summary and conclusion

Summary

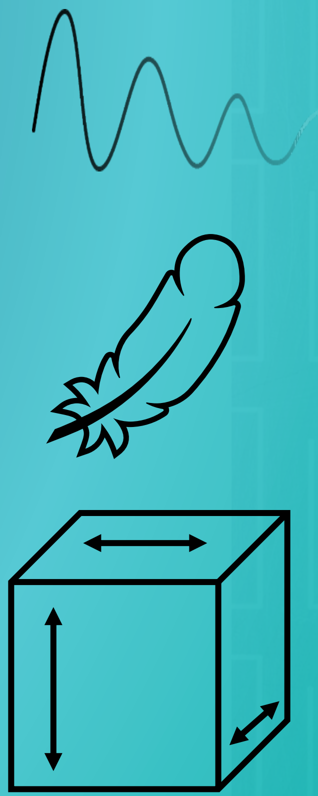
- Development of a cover with integrated VAMM
- Benchmarking against conventional measures in terms of:
  - Structural dynamics and
  - Acoustics

Conclusion

- Larger vibration and noise reduction with VAMM than with bondal® and bitumen within the stop band
- Lighter than reference cover and cover with bitumen
- Comparable performance outside stop band range
- No additional mass
- Space-neutral integration possible

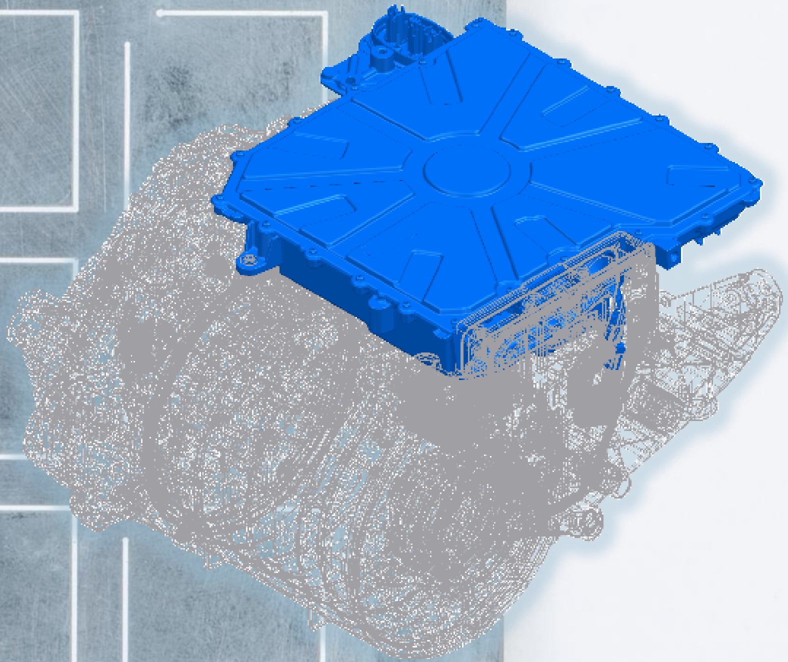
Outlook

- Test of the developed covers in a test vehicle



   Fraunhofer LBF

Thank you for your attention!



Sources

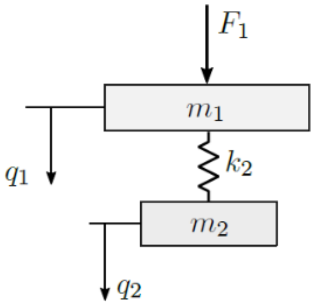
[1] Marnett, L. (2008). *Biochemistry: Divergence from the superfamily. Nature, 455, 300-301.*

[2] *The original cloaking device designed to bend microwaves around an object placed at its center.* Duke University. https://stories.duke.edu/beyond-materials-from-invisibility-cloaks-to-satellite-communications. Duke University, 2020 (visited at 02.11.2020)

Vibroacoustic Metamaterials

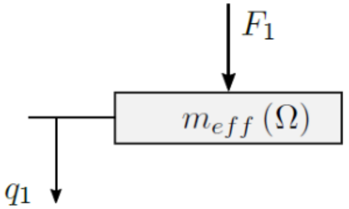
Negative effective mass

two degree of freedom system



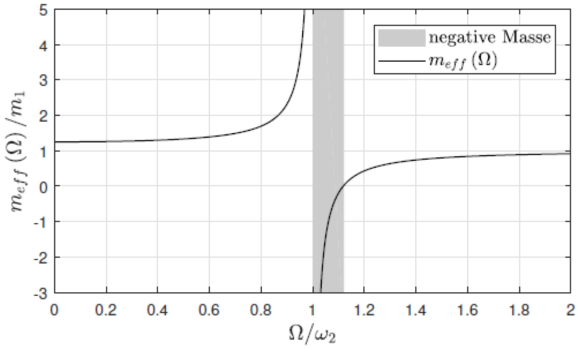
$$\omega_2 = \sqrt{k_2/m_2}$$

homogenized model



$$m_{eff} = \frac{\hat{F}_1}{\ddot{\hat{q}}_1} = \cdots = m_1 + \frac{m_2}{1 - \Omega^2/\omega_2^2}$$

region of negative mass



$$\Omega/\omega_2 \in \left[1, \sqrt{m_2/m_1 + 1}\right]$$

Region of negative mass **above the resonance frequency**

Vibroacoustic Metamaterials