(Apparent) Sound Speed Variations in Close Proximity to Porous Absorbers

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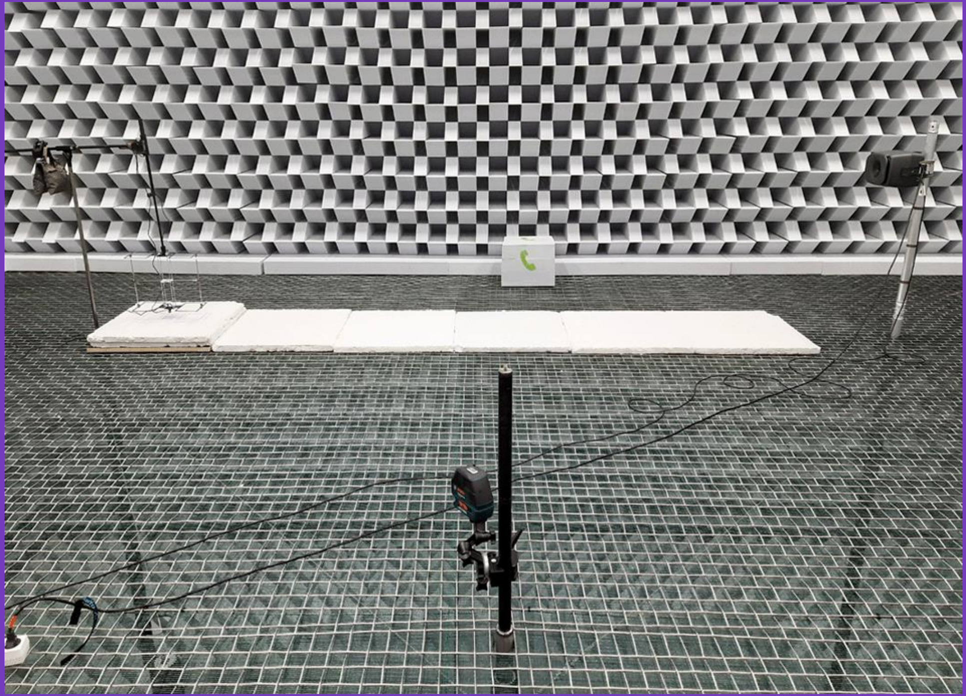
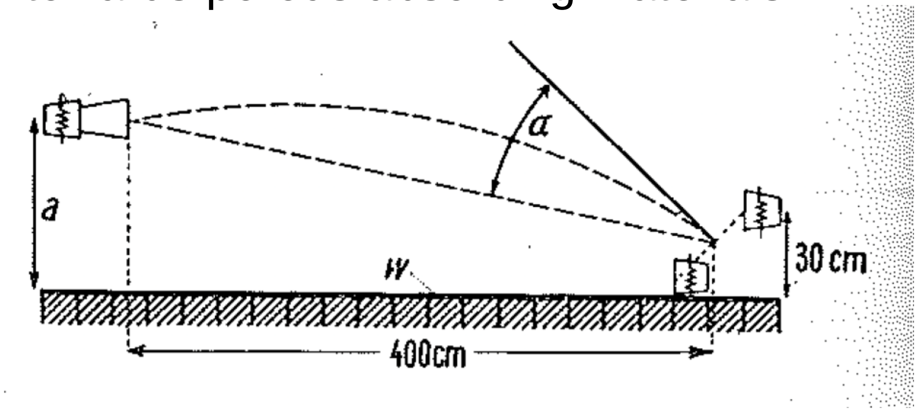
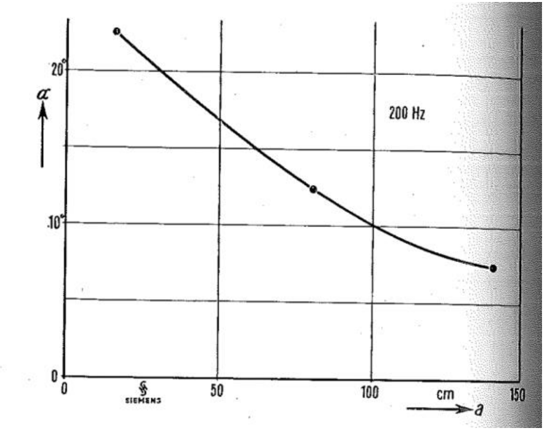


Motivation

- In the 1930s, a research findings revealed sound wave bending towards porous absorbing materials[1].

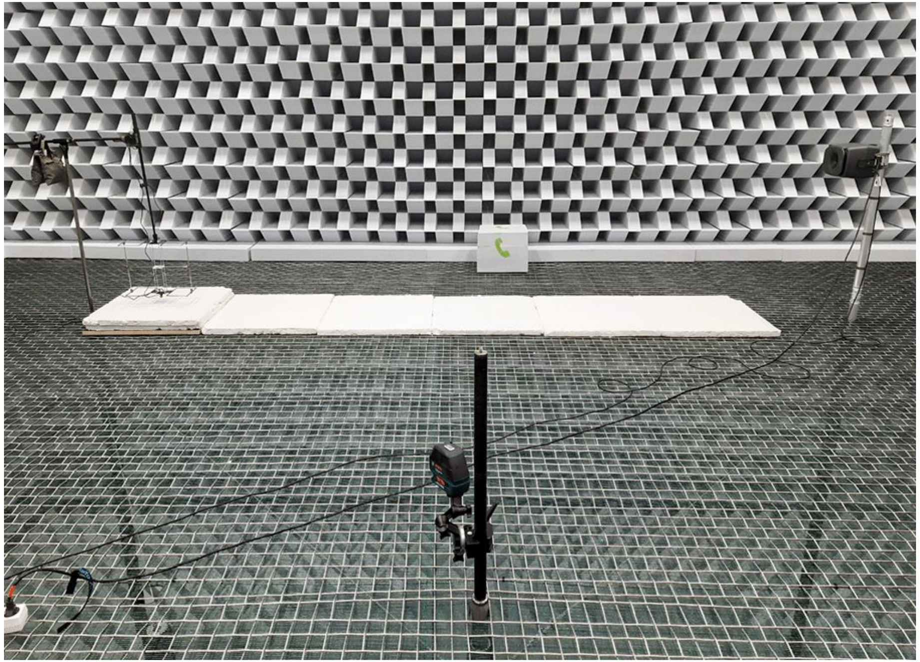


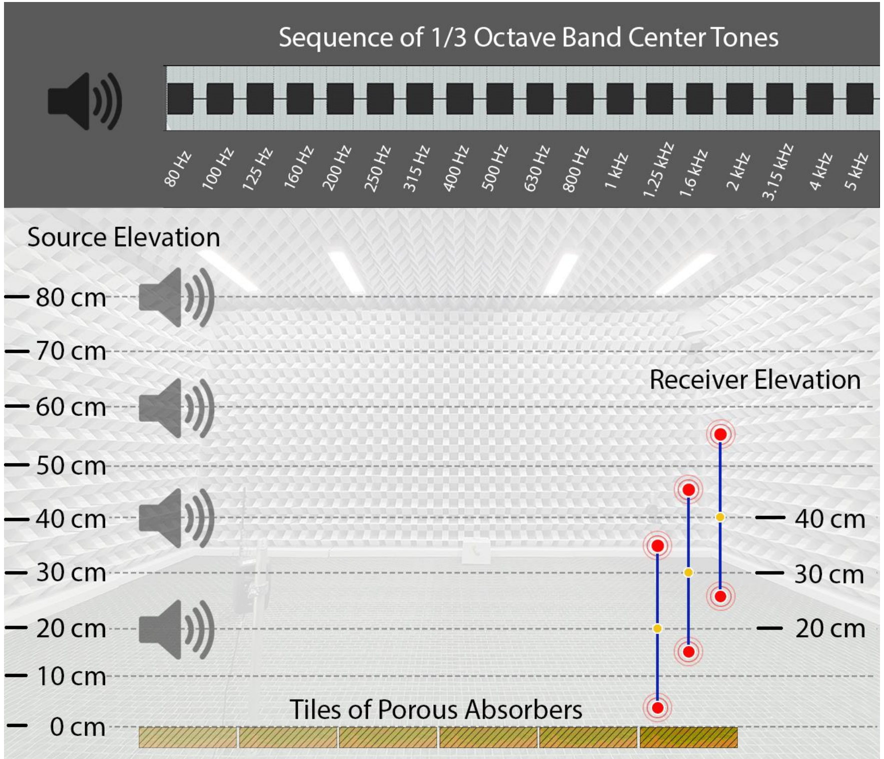


- Bedell referred to the same effect to explain why the pressure of sound waves propagating along an absorbent surface decreases faster with increasing distance from the source than the theoretical contours for a free field would predict [2].

[1] W. Janowsky and F. Spandöck, "Aufbau und untersuchungend eines schallged ämpften raumes," Akust. Z 2, 322–331 (1937).
[2] E. Bedell, "Some data on a room designed for free field measure-ments," The Journal of the Acoustical Society of America 8(2), 118–125 (1936).

Replication of the 100-year old study





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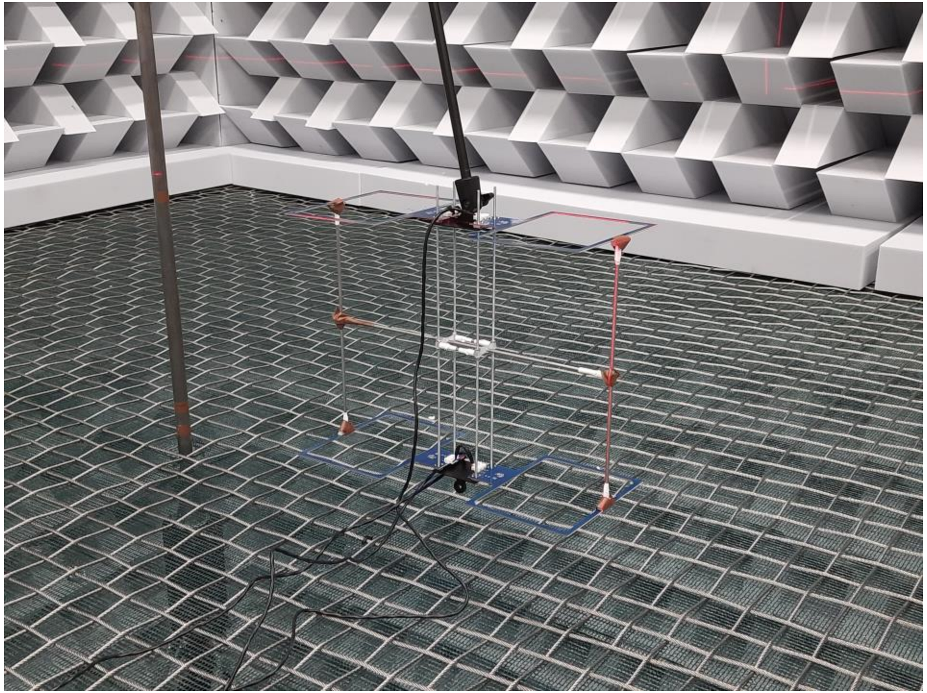
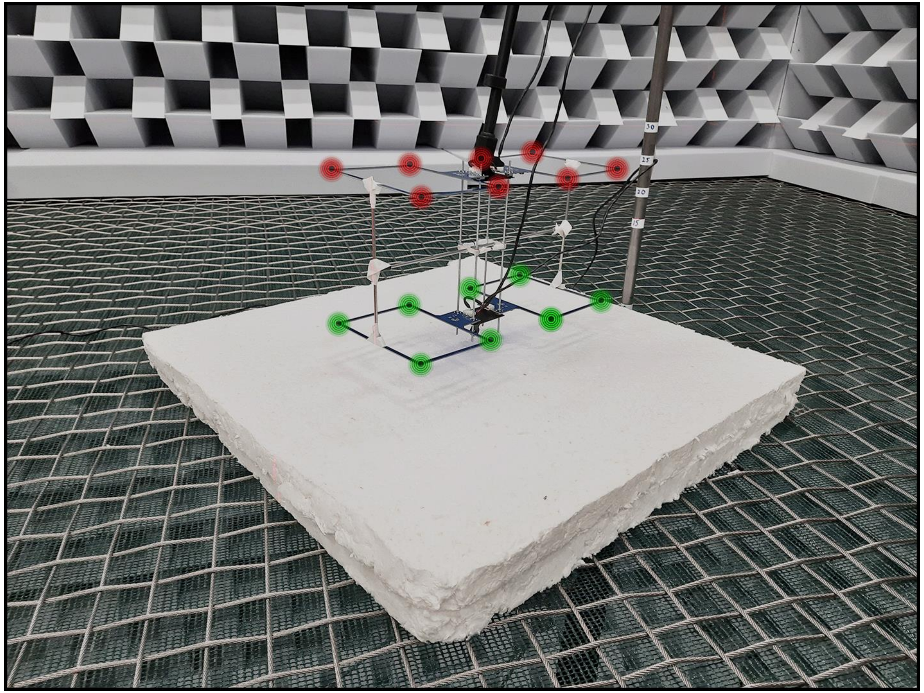
Microphone grid (UMIK-X, 16 mems)

Free field

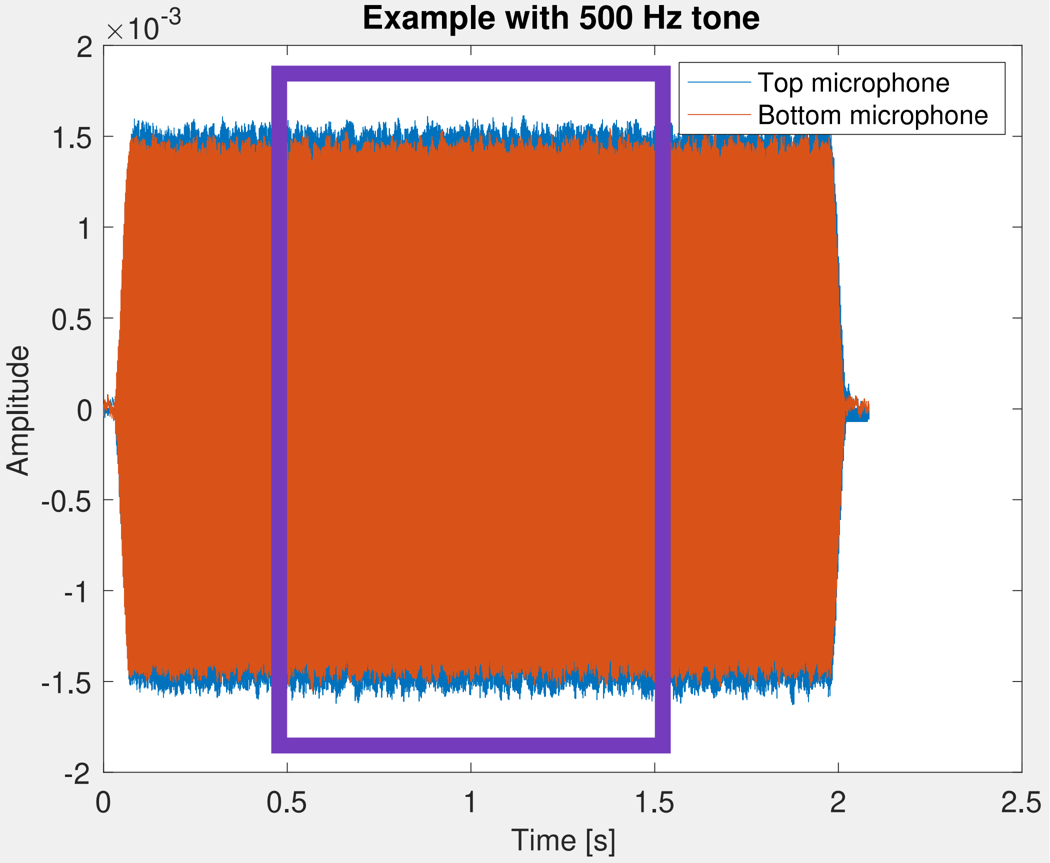


Above porous material



Analysis method

1. **Window each tone and take 1 s of signals [0.5 s…1.5s]**



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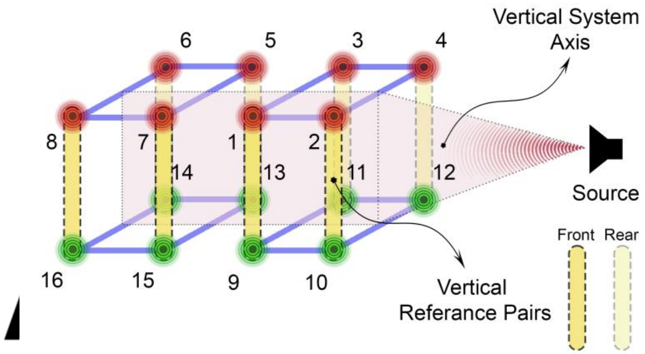
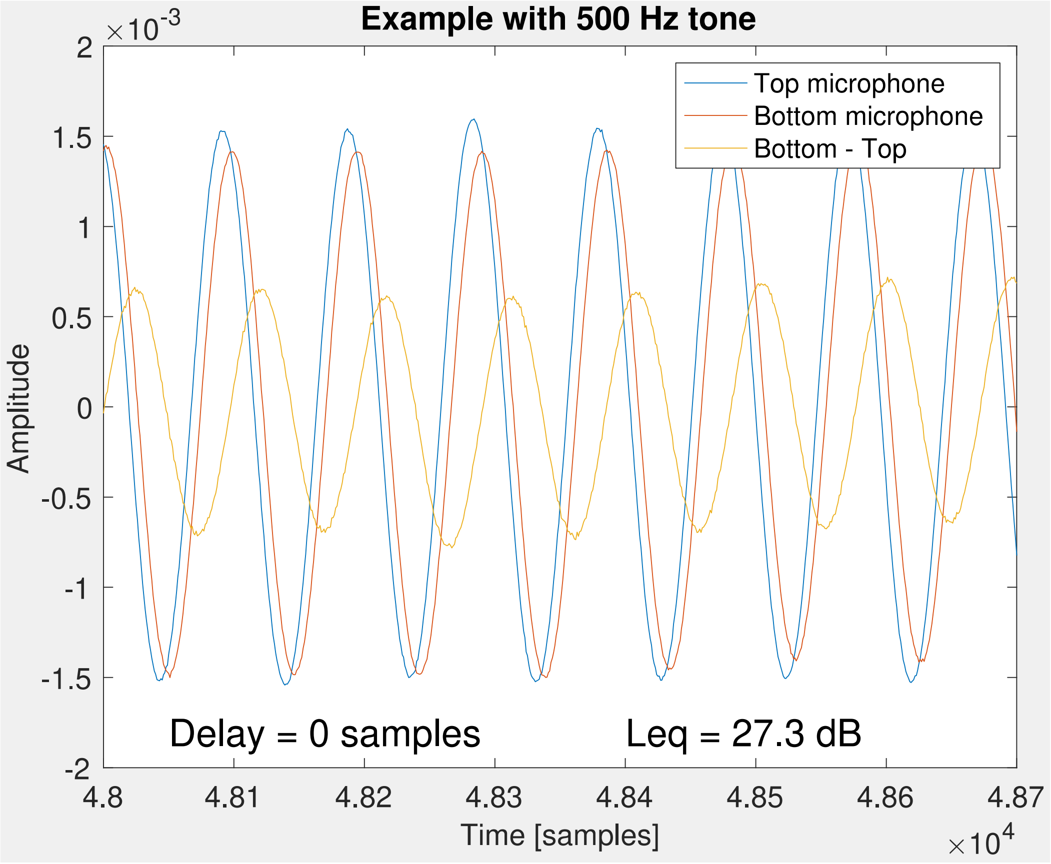
Analysis method

1. Window each tone
2. ***L*$_{eq}$(Bottom – top mics)**
3. **Delay top [0:1:20]**
4. **Find min(*L*$_{eq}$)**





Analysis method

1. Window each tone
2. *L_{eq}*(Bottom – top mics)
3. Delay top [0:1:20]
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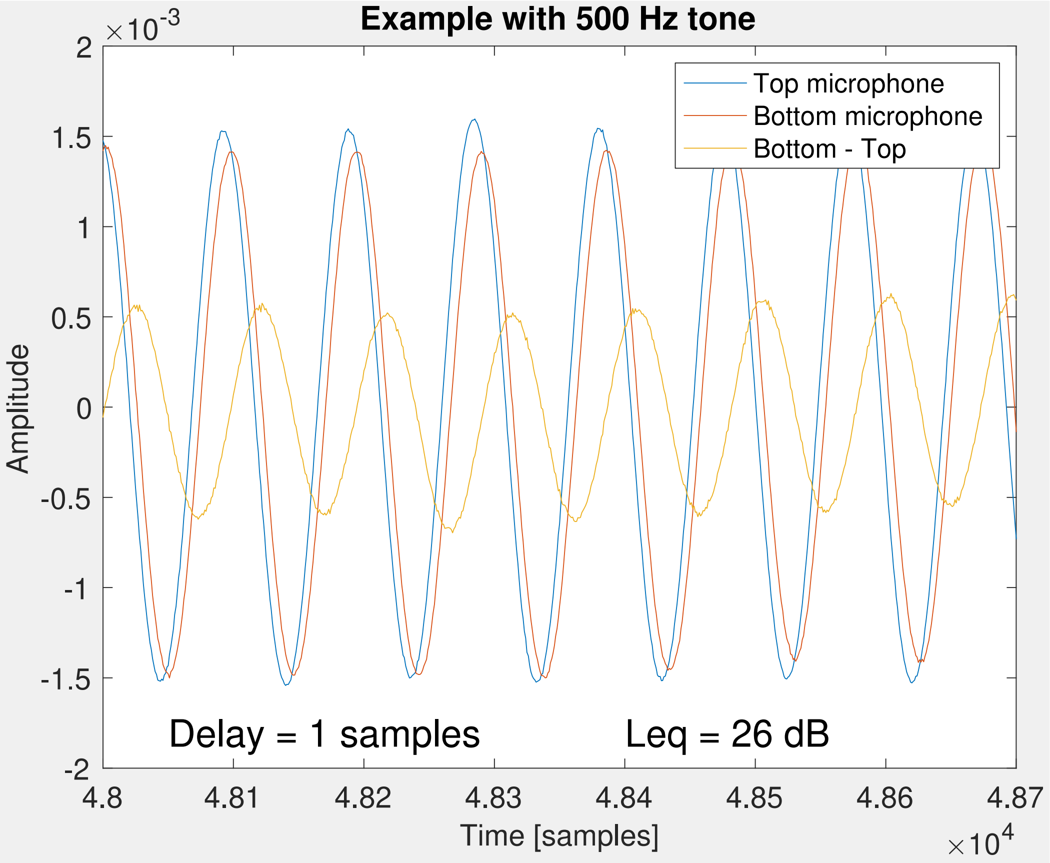

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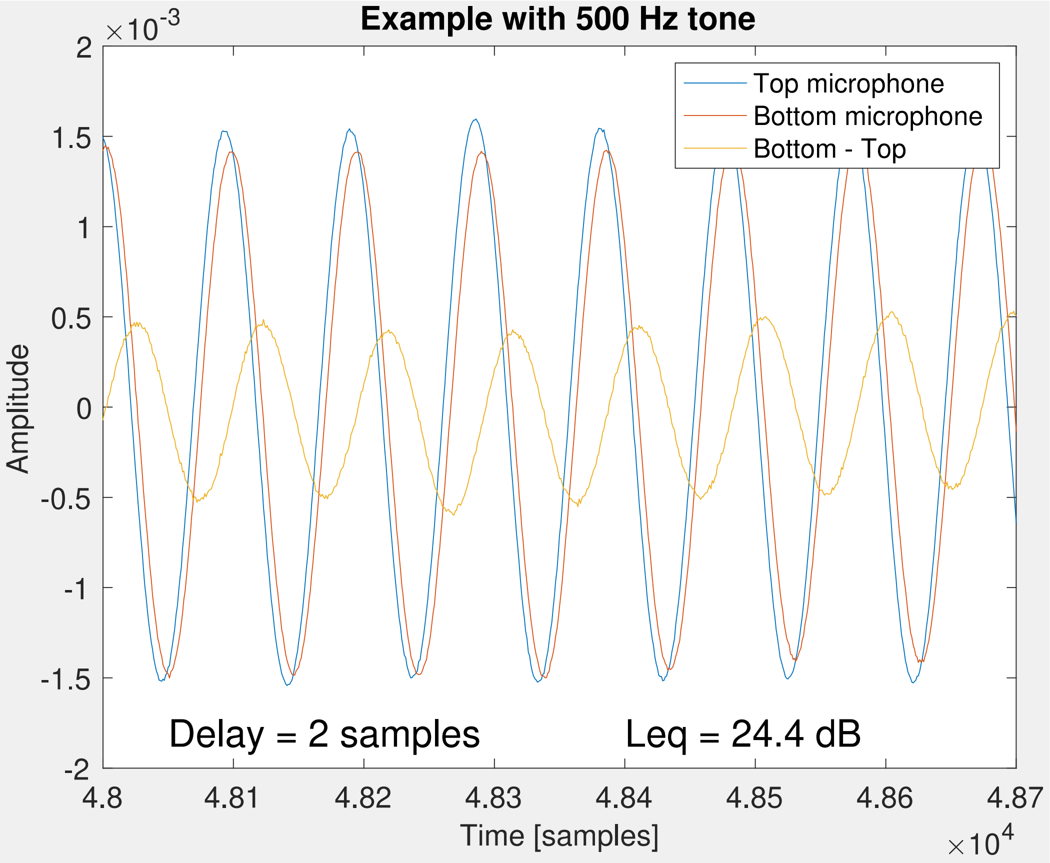

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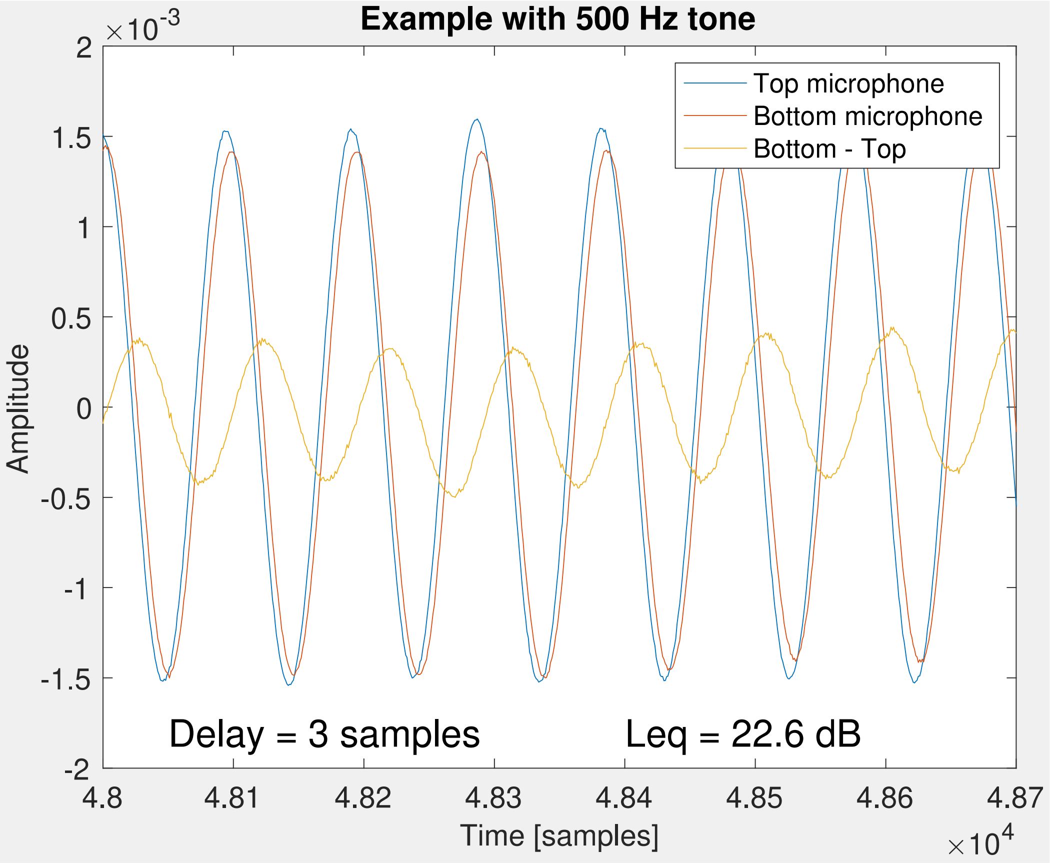

Analysis method

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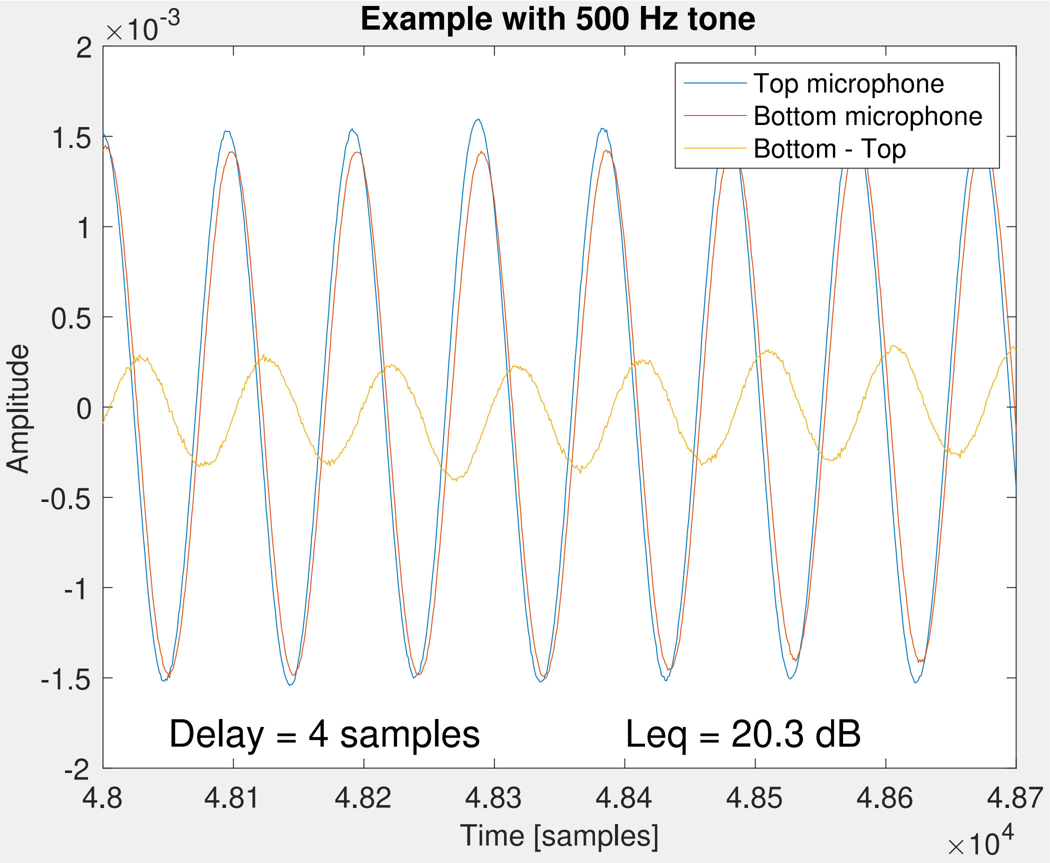

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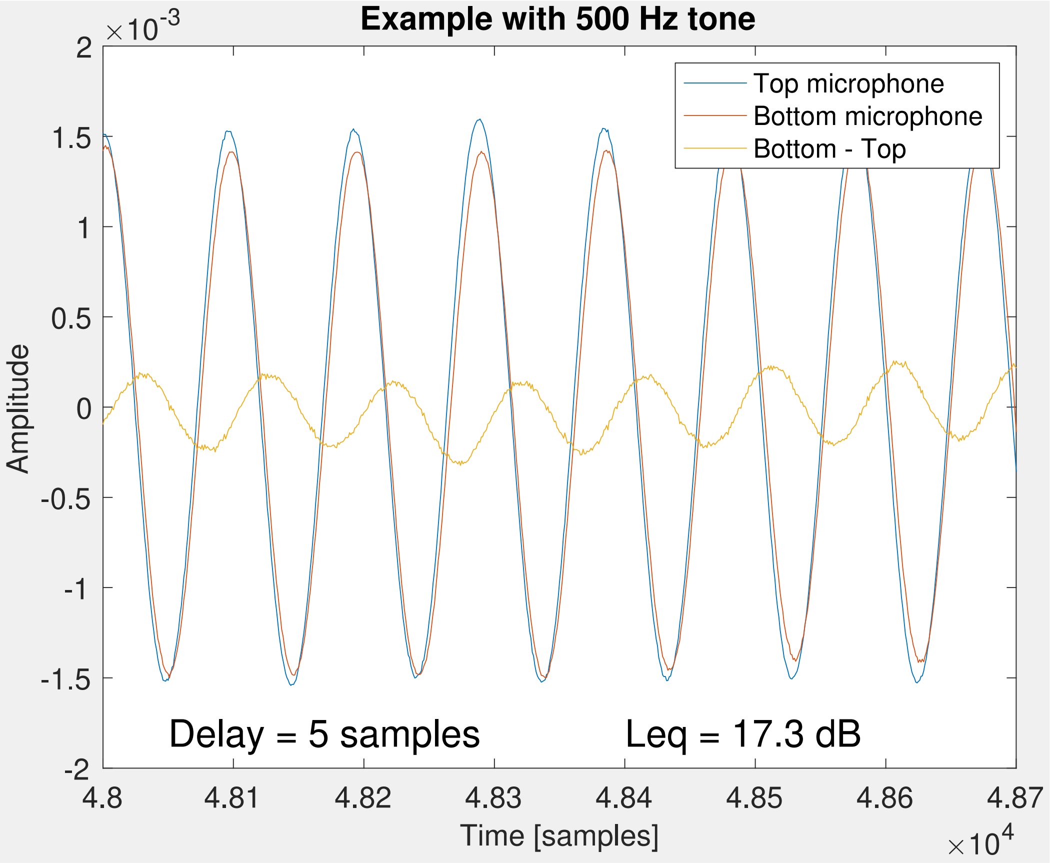

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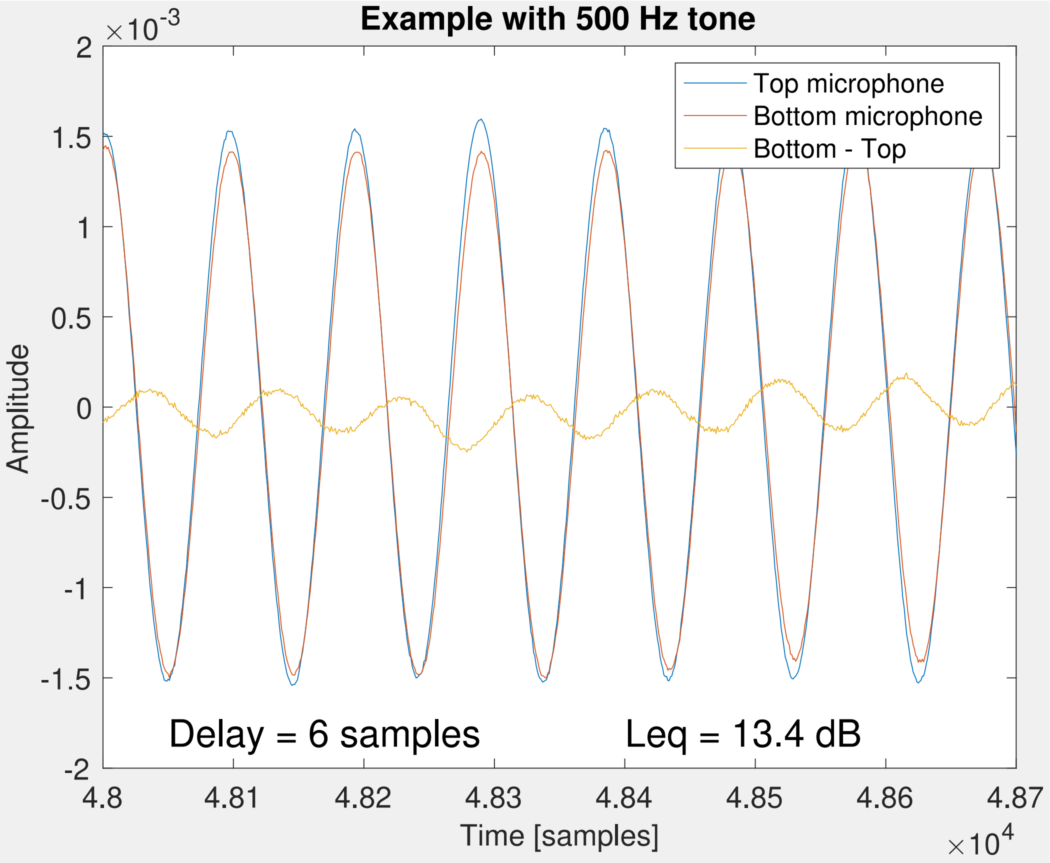

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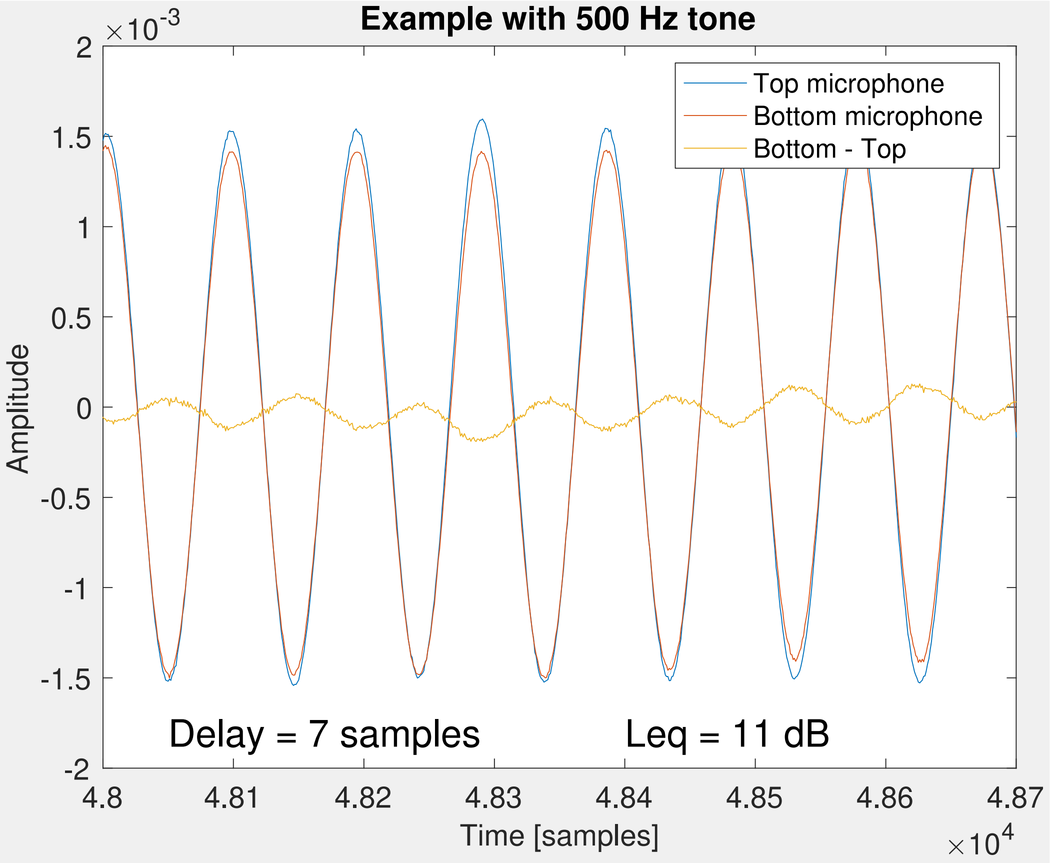

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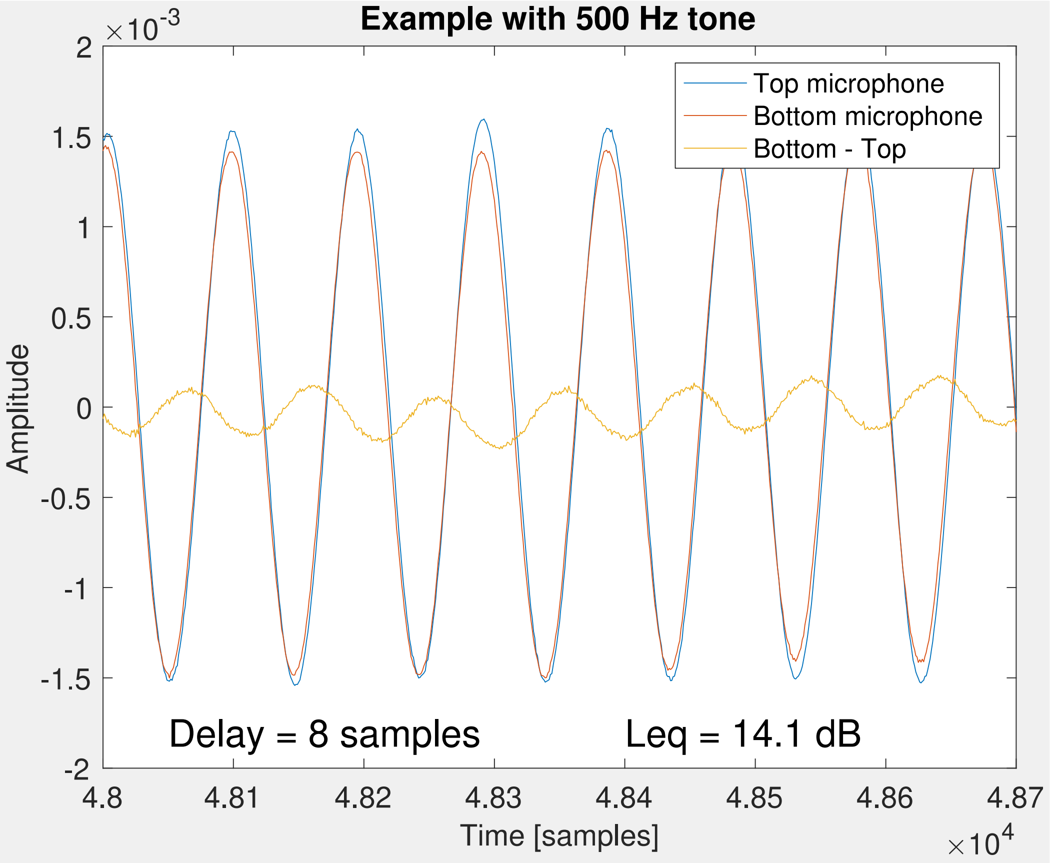

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Analysis method

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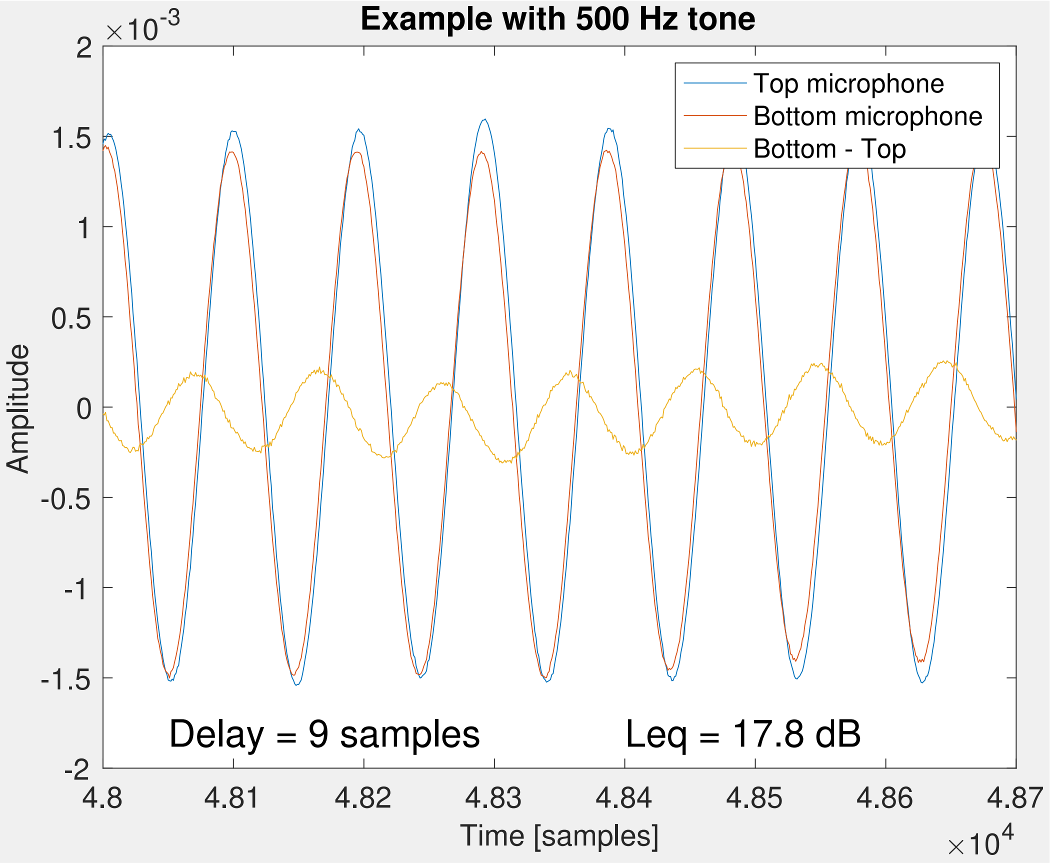

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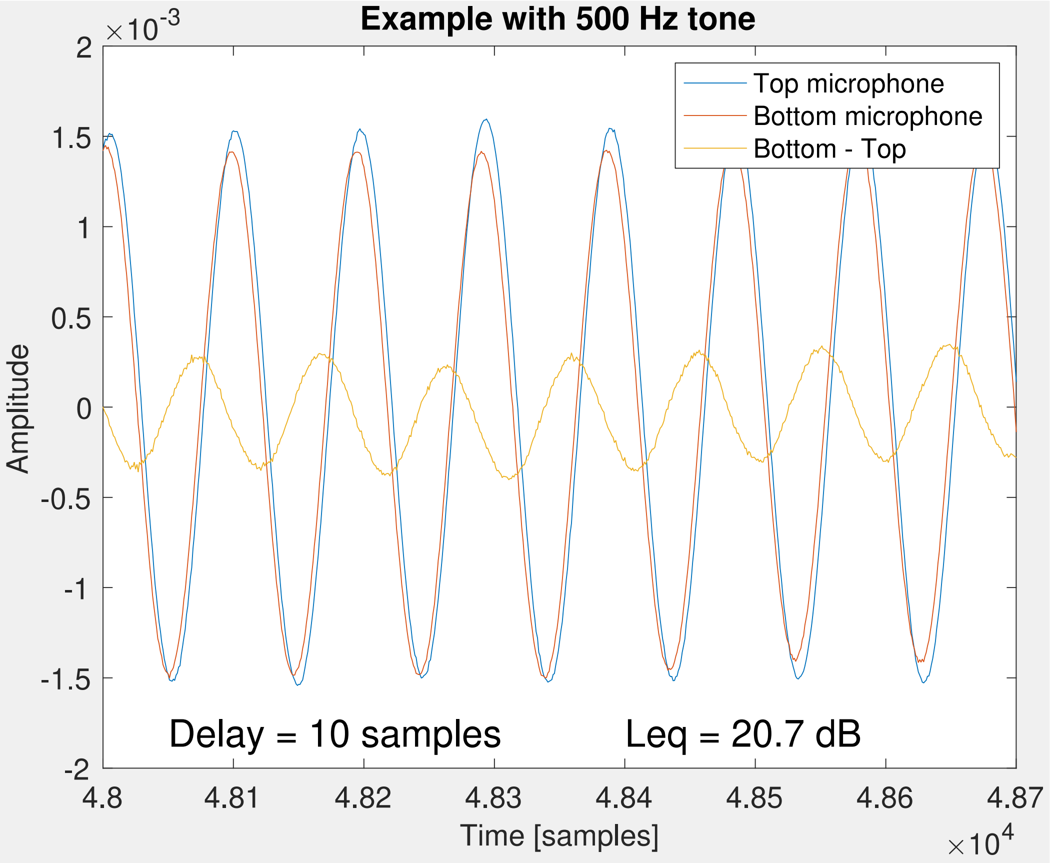

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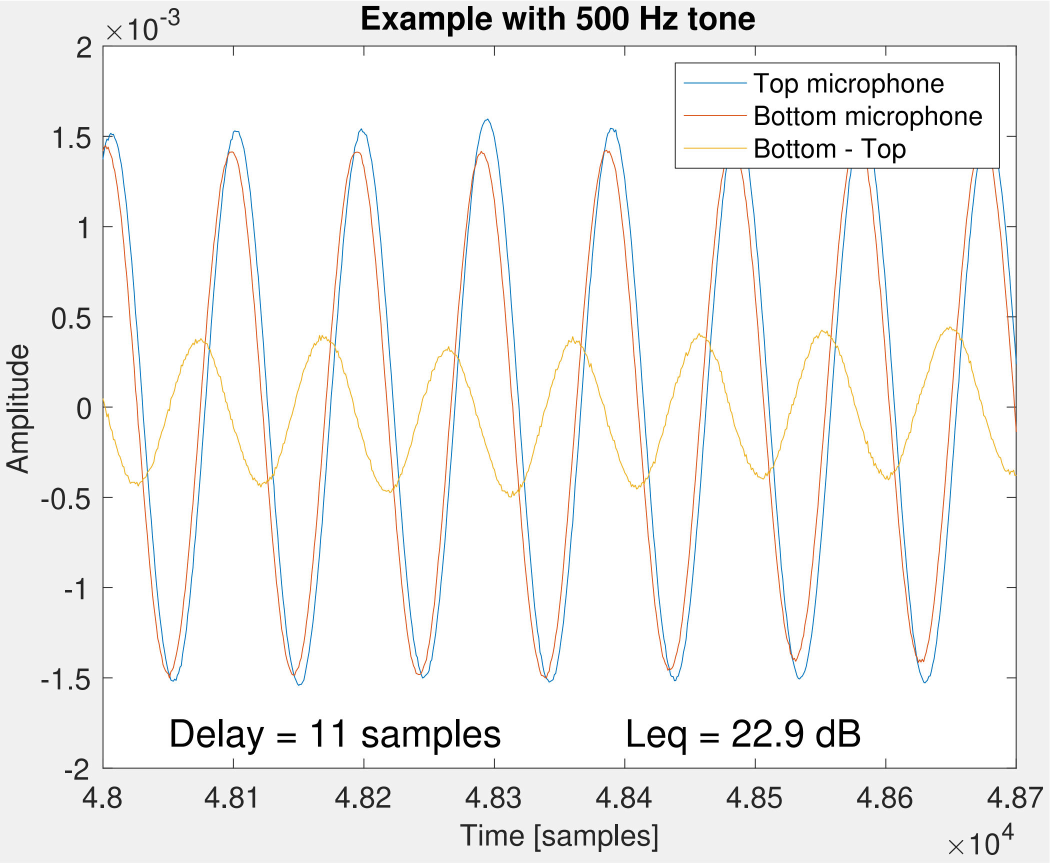

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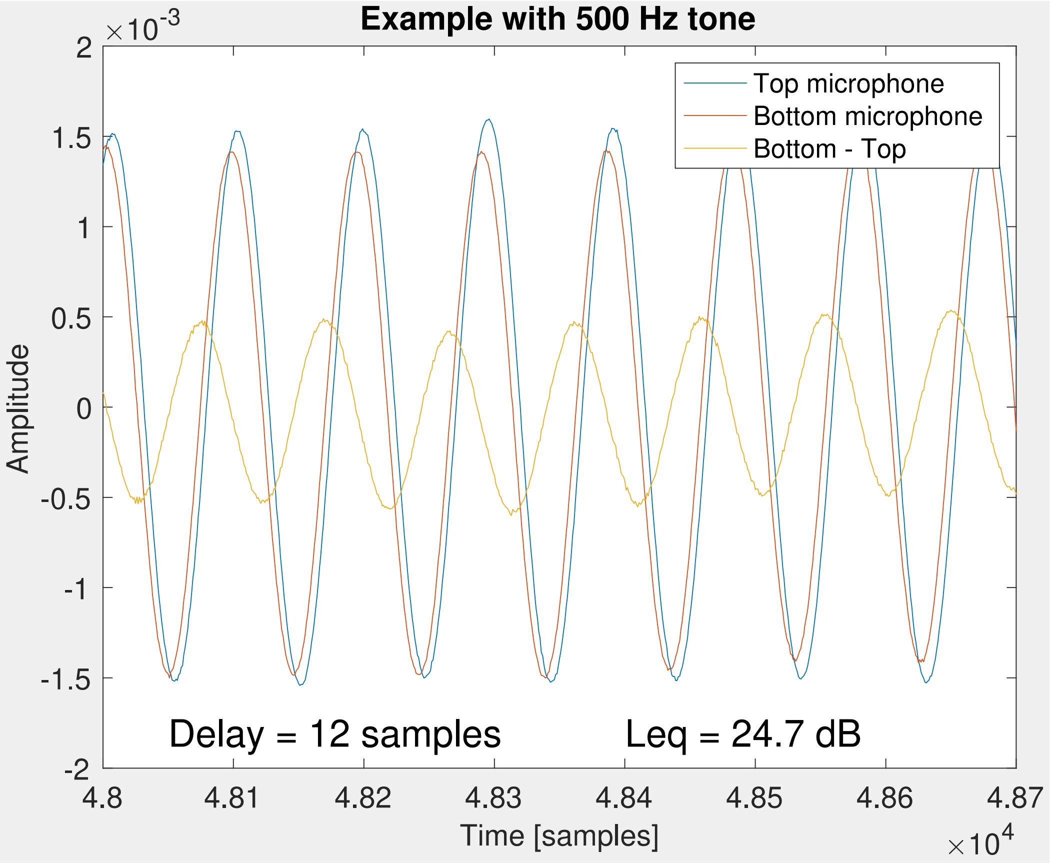

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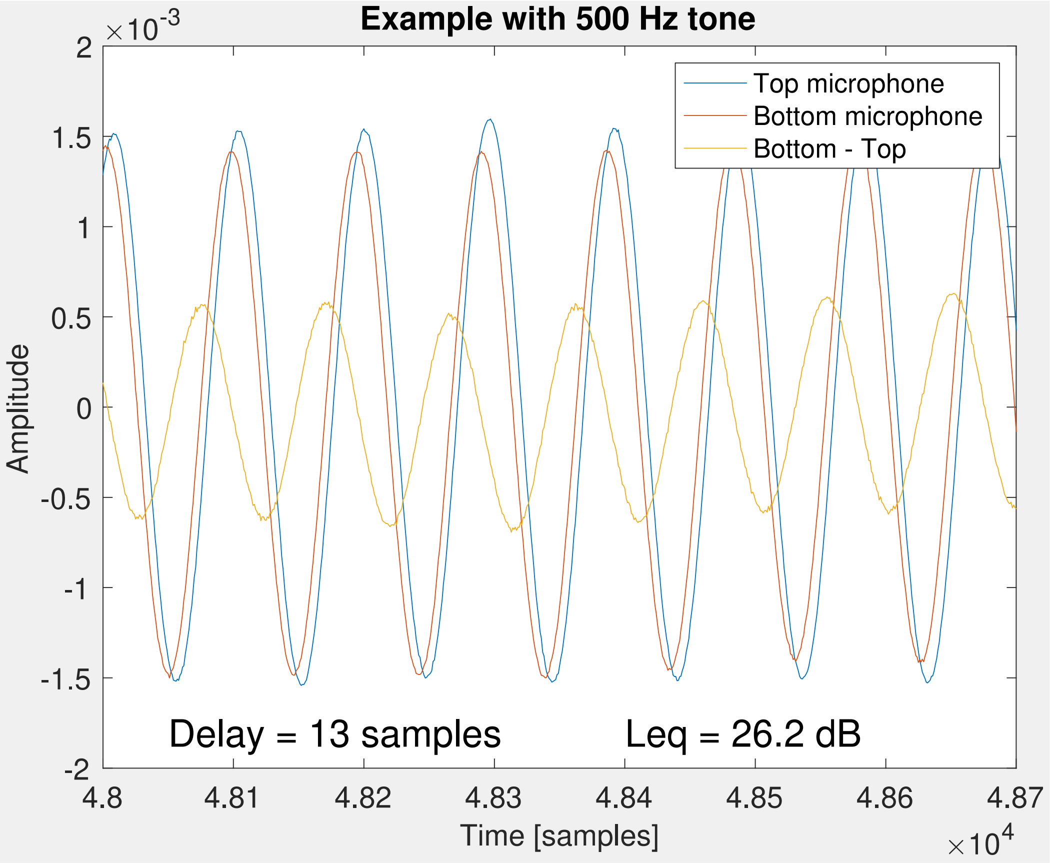
Analysis method

1. Window each tone
2. ***L*_eq(Bottom – top mics)**
3. **Delay top [0:1:20]**
4. **Find min(*L*_eq)**



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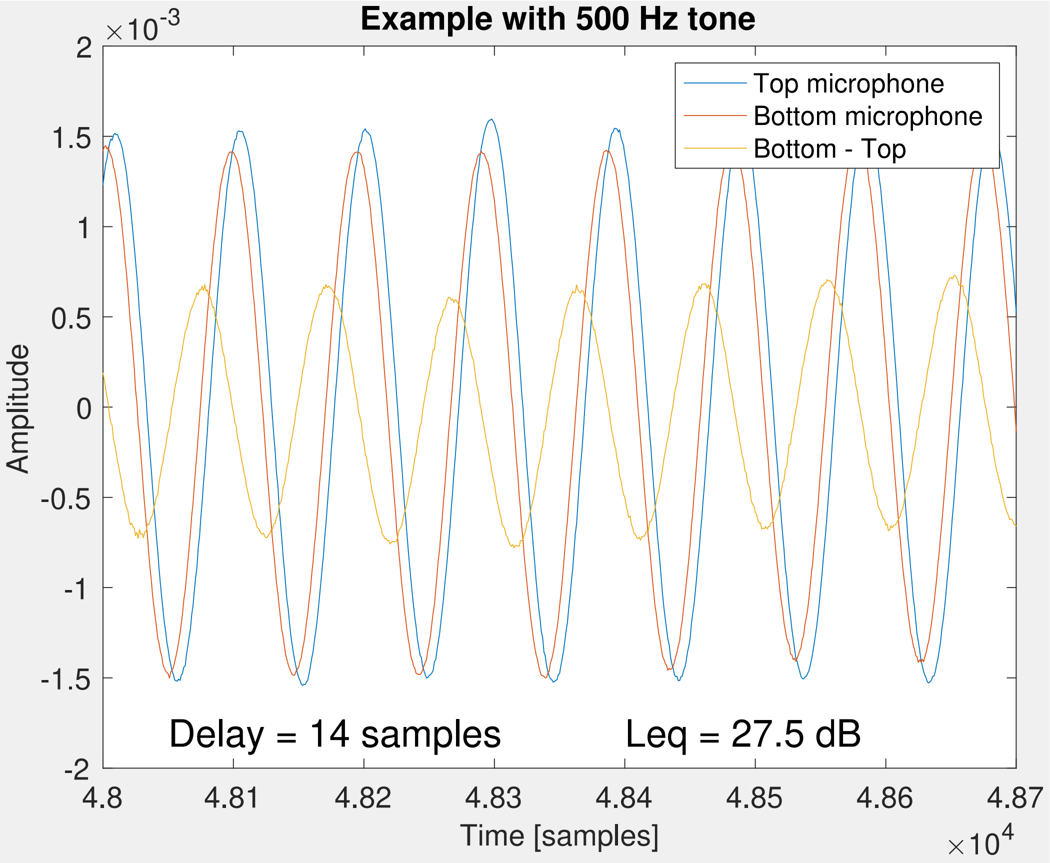

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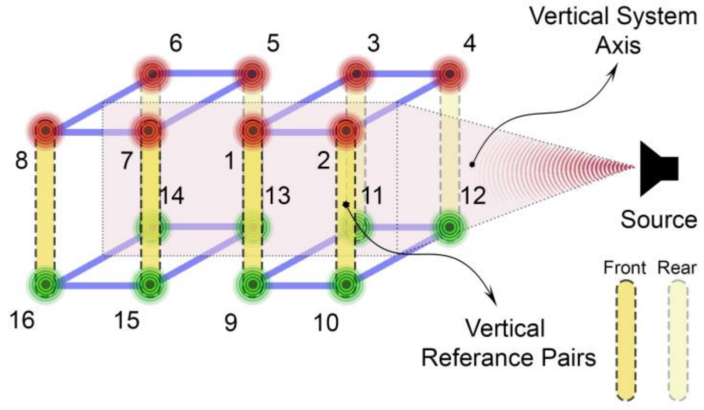

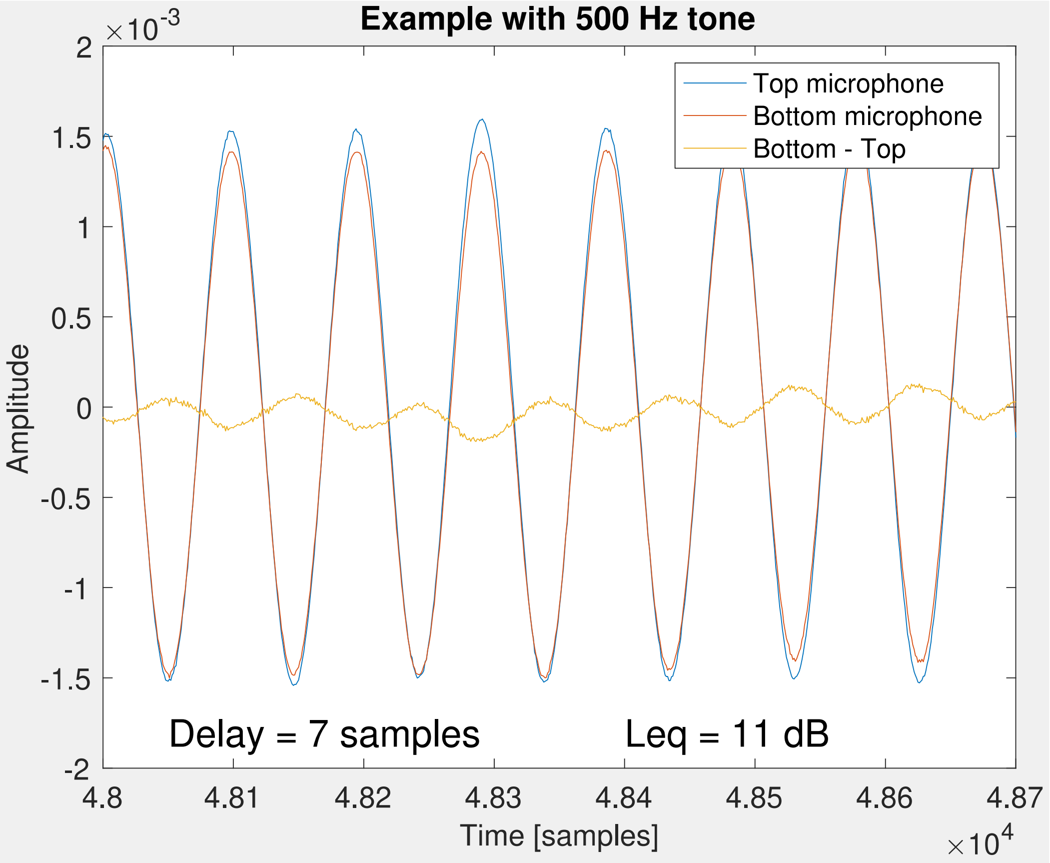

5. **Repeat for all 8 mic pairs**
6. **Mean of 4 median values**
7. **Repeat for all tones**

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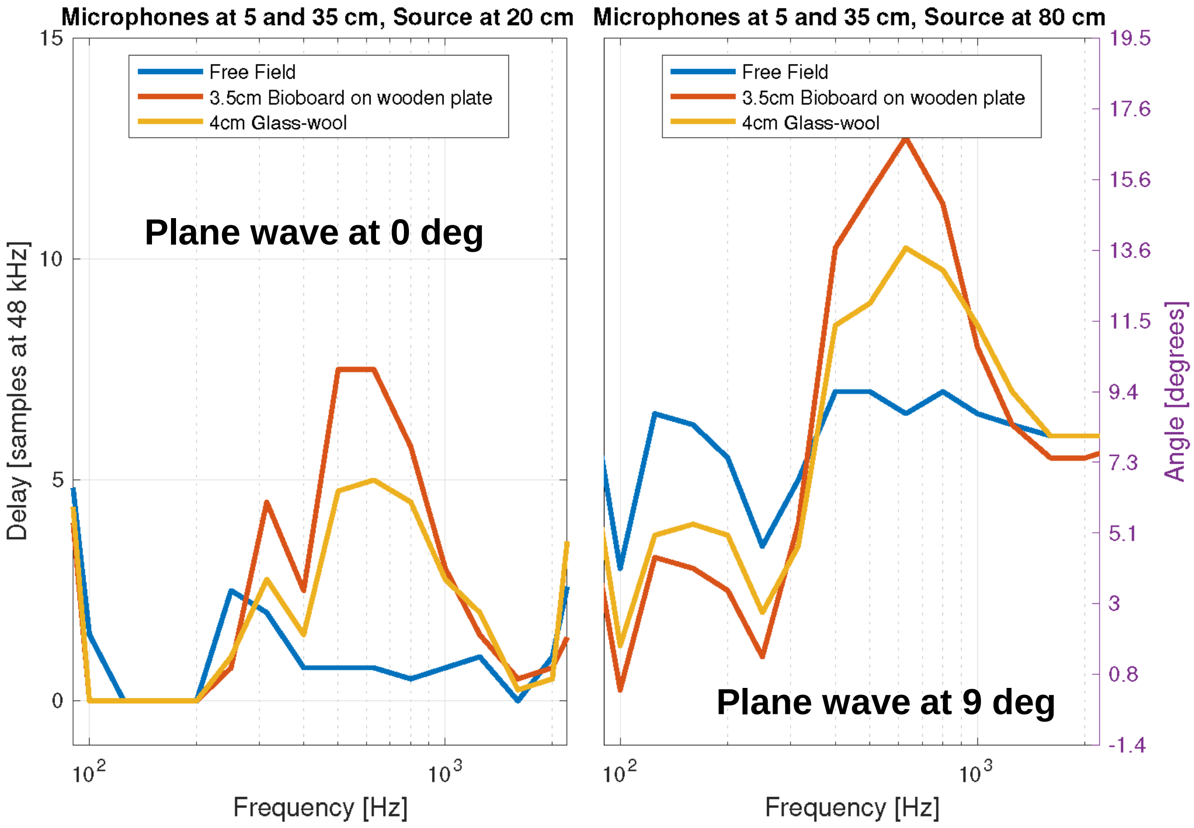
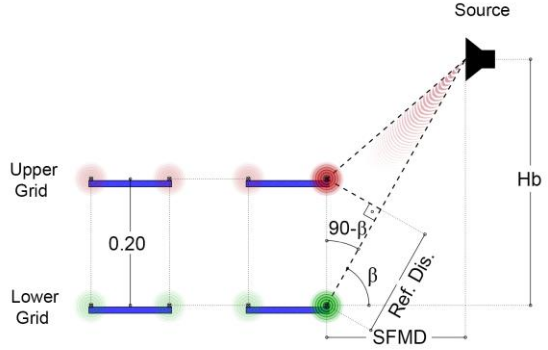
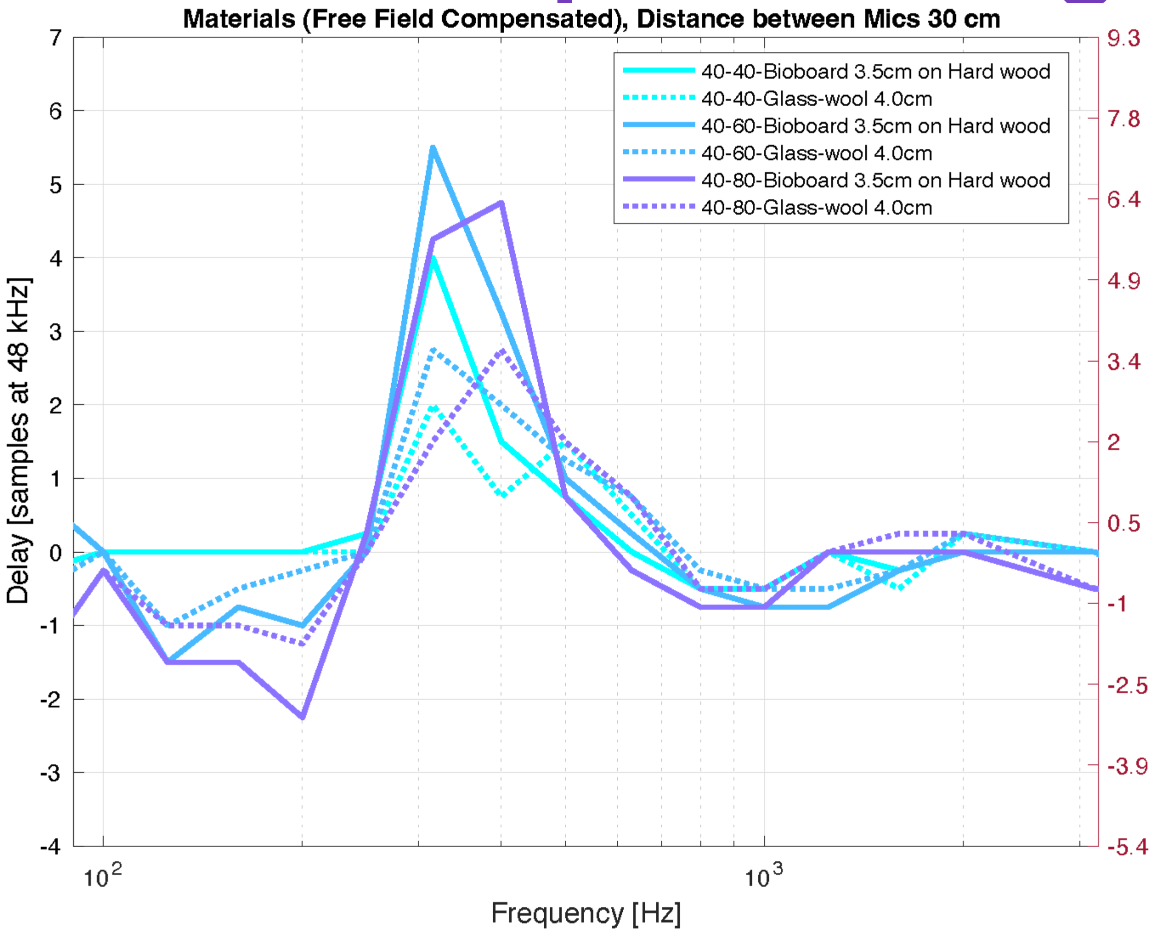
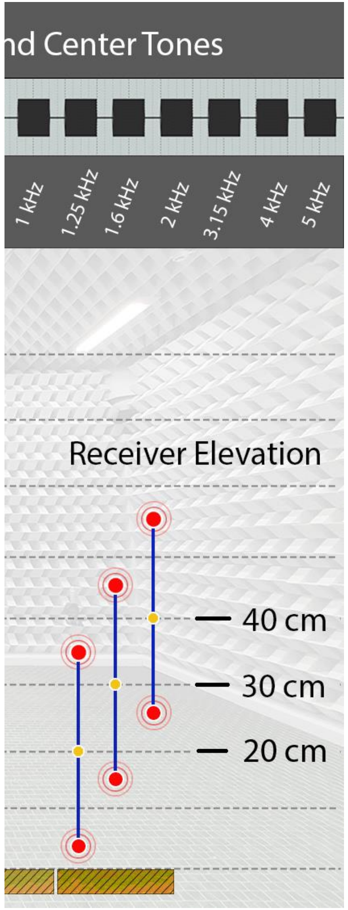
Results: one example





Results II: Microphone heights





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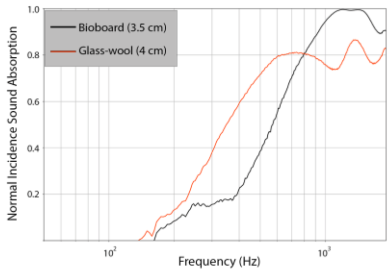
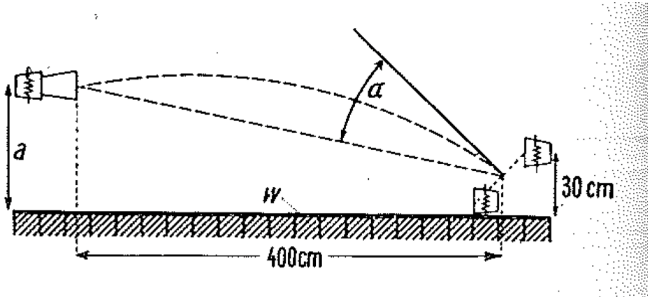
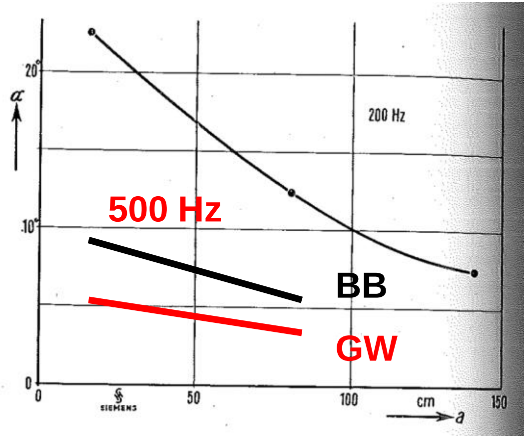
Conclusions (FA 2023 paper)

1. **Sound waves bend at certain frequency range, here 300 – 1200 Hz for sound at low grazing angle**

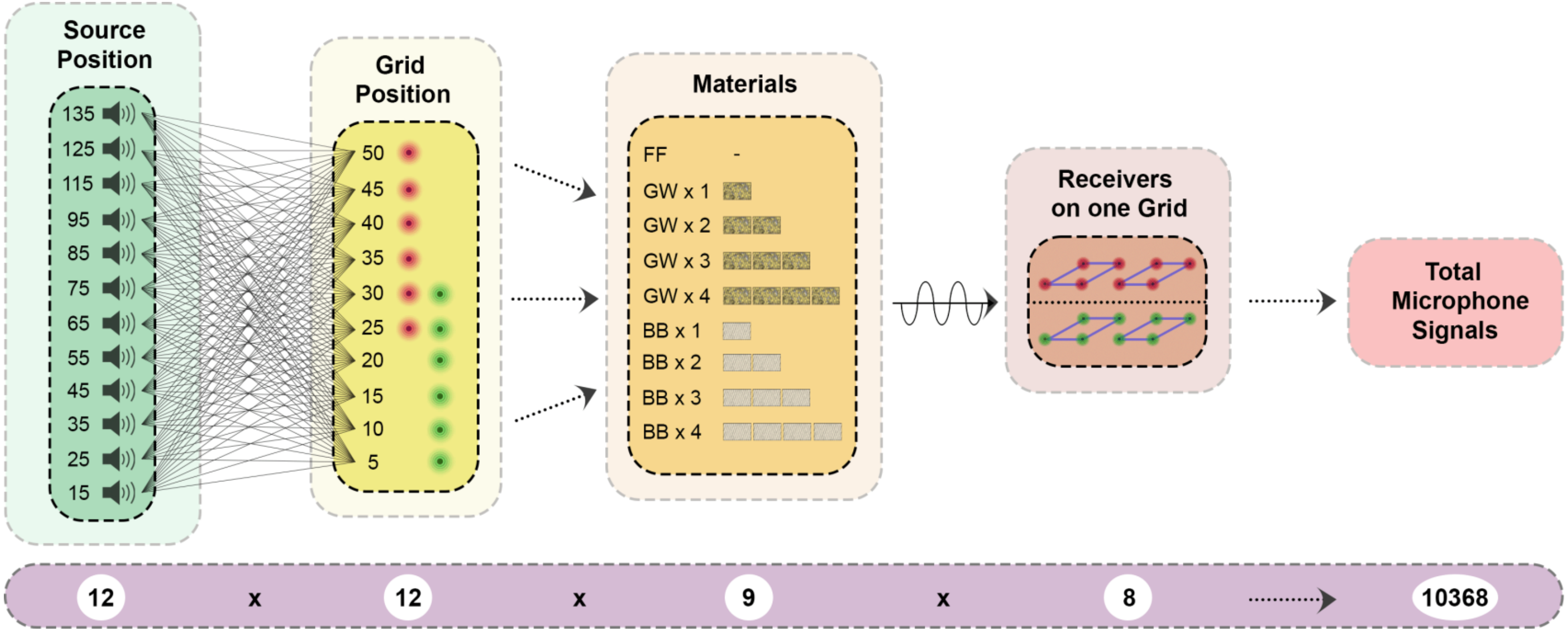


2. **Material affects to speed of sound up to 30 cm**
   - Depends on the frequency
   - Depends on the material
3. **Results differ significantly from Spändock & Janowsky (1937)**
   - From 0 to 9 deg grazing angles no large difference
   - Less bending than shown earlier





A new set of measurements



Speed of sound analysis based on cross-correlation of impulses

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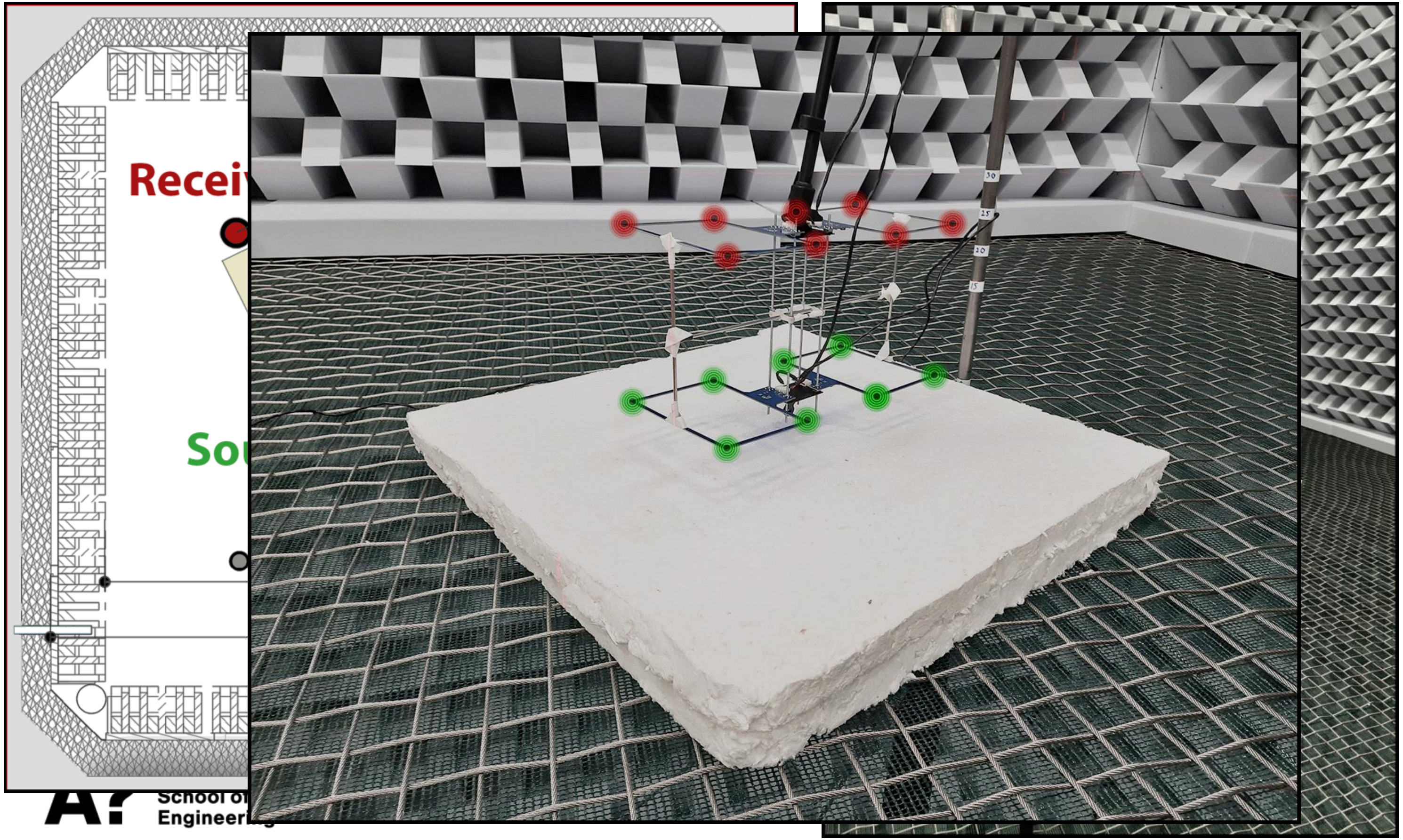
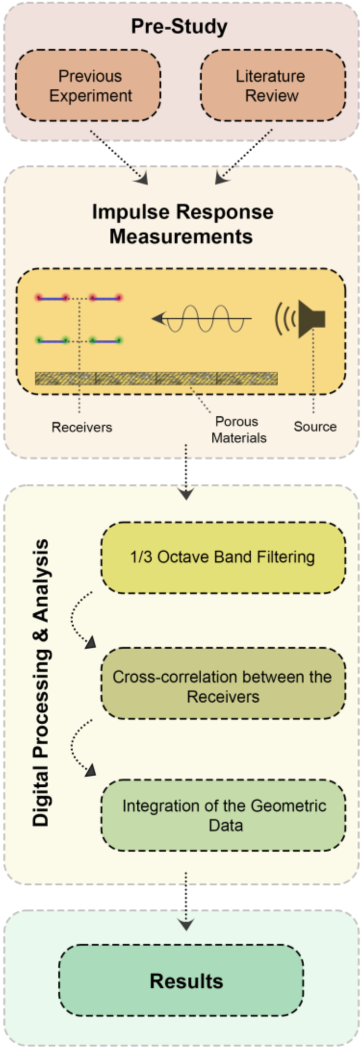
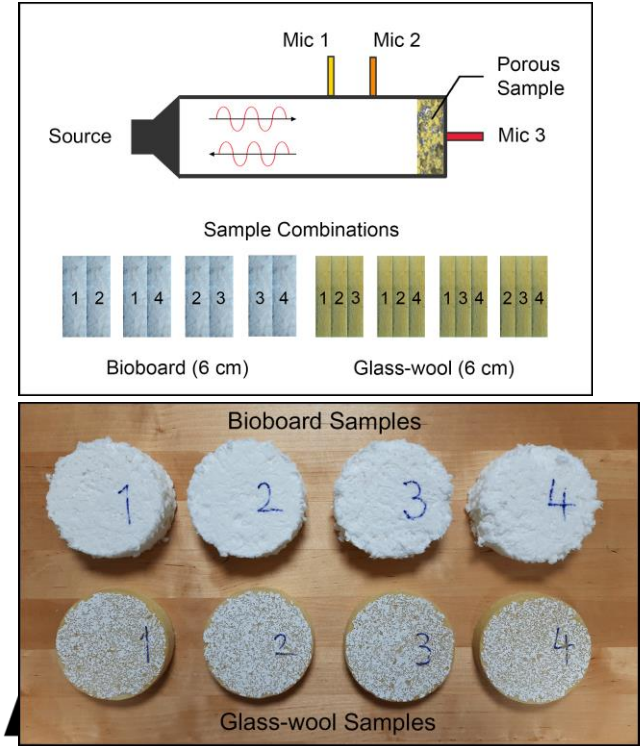
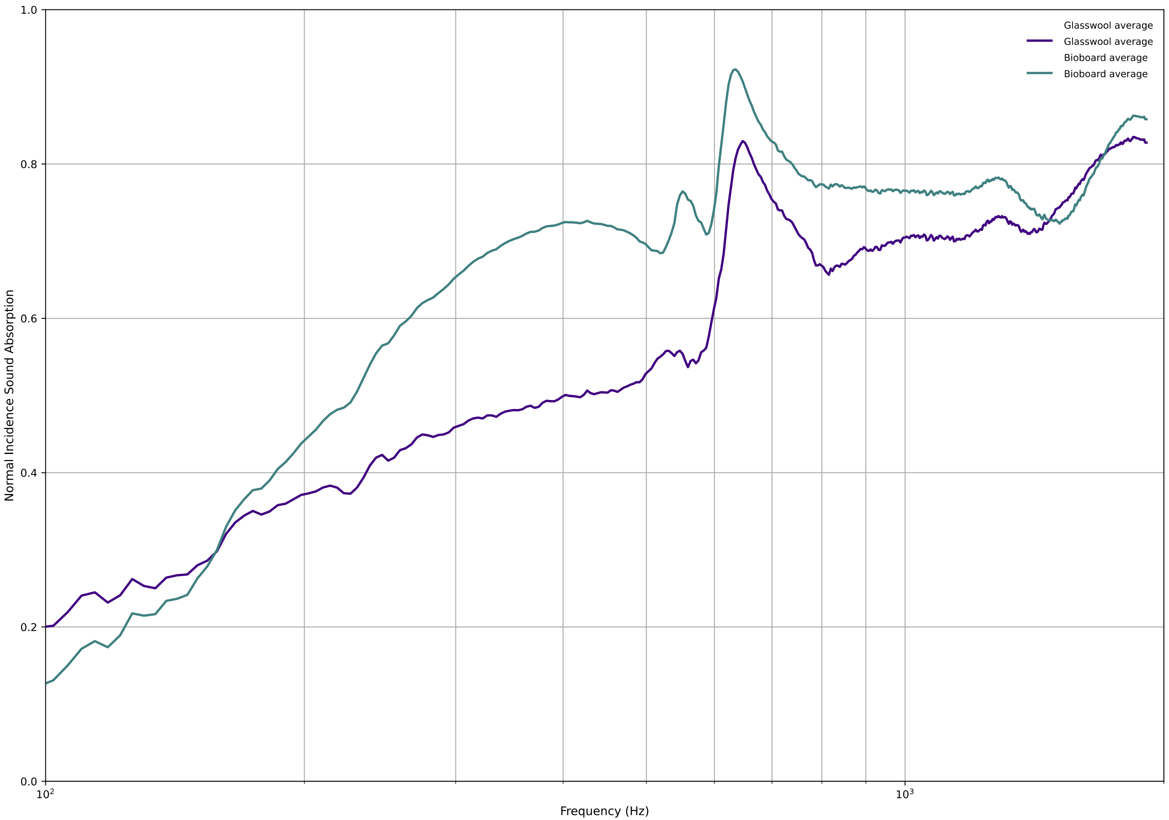
A new set of measurements





Two materials thickness 6 cm

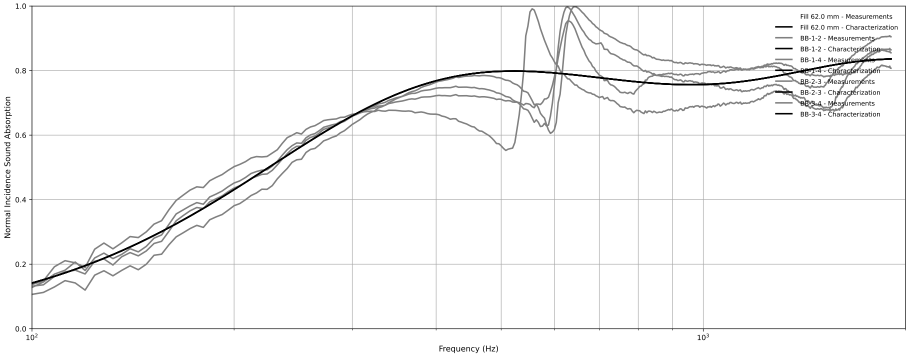




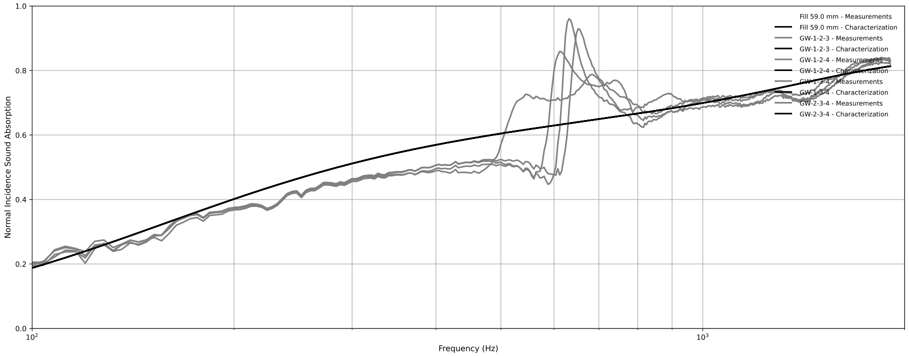
Characterization

Material	sigma (N.s.m-4)	phi	alphainf	lcv (mum)	lct (mum)	k'0 (1e-10 m2)
Bioboard	29600	0.97	1.28	20	169	30
Glasswoll	63200	0.97	1.4	24	38	15

Bioboard



Glasswool



Analysis method: cross-correlation

Delay between two microphones

$$\text{delay} = \tau + c$$

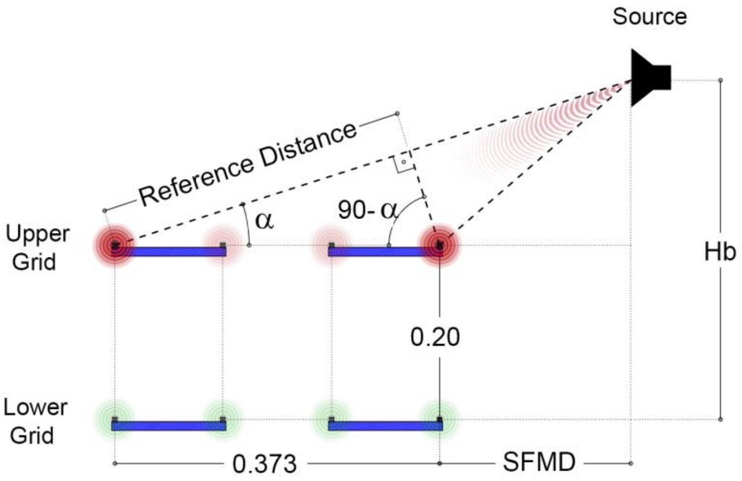
Delay obtained with cross-correlation

$$R(n) = h_1(t)h_2(t+n) = \mathcal{F}^{-1}\{H_1(\omega)\,H_2(\omega)^*\}$$

$$\tau = \operatorname{argmax} R(n)$$

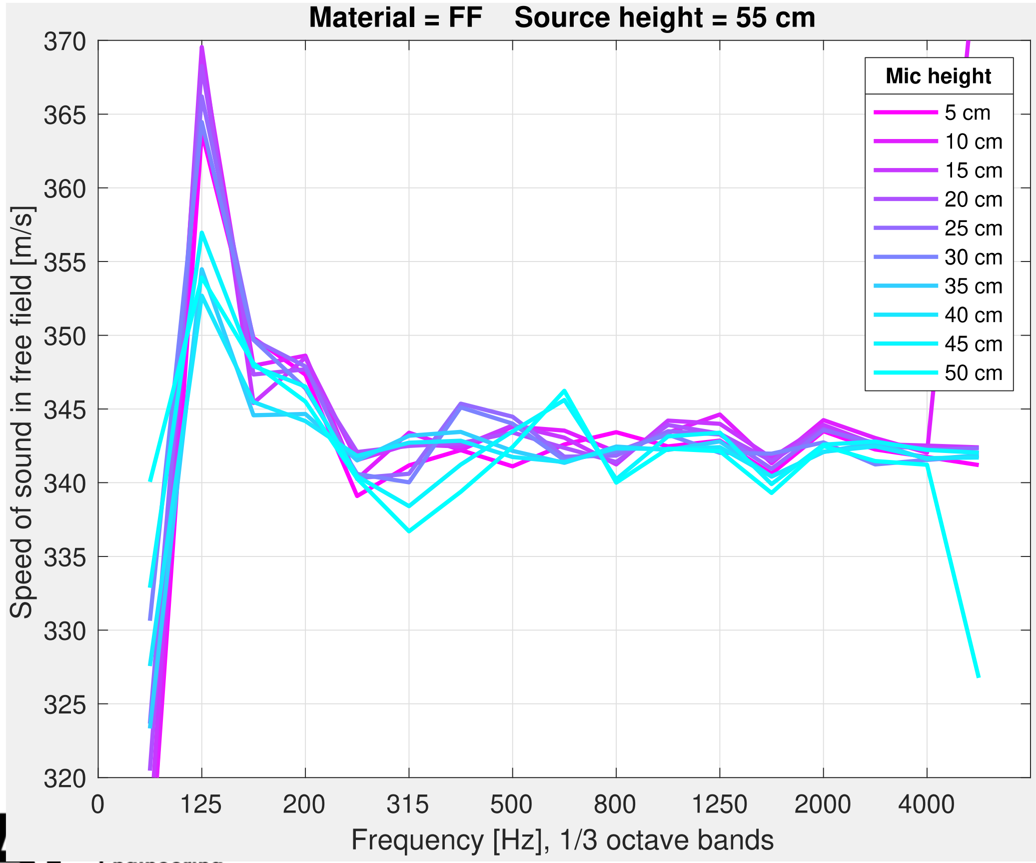
Subsample accuracy with

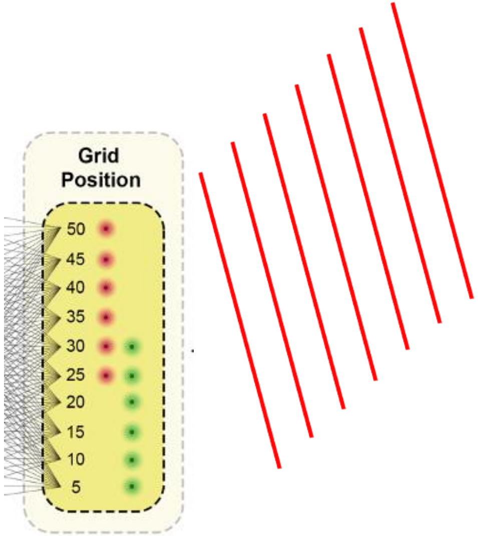
$$c = \frac{\ln R(\tau+1) - \ln R(\tau-1)}{4\ln R(\tau) - 2\ln R(\tau-1) - 2\ln R(\tau+1)}$$

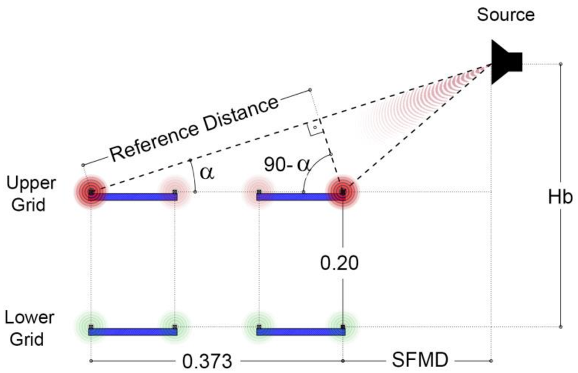


$$\text{Reference distance} = 0.373 * \cos(\tan^{-1}\frac{\text{Hb} - 0.2}{0.373 + \text{SFMD}})$$

Results, grazing angle 15.4°, free field







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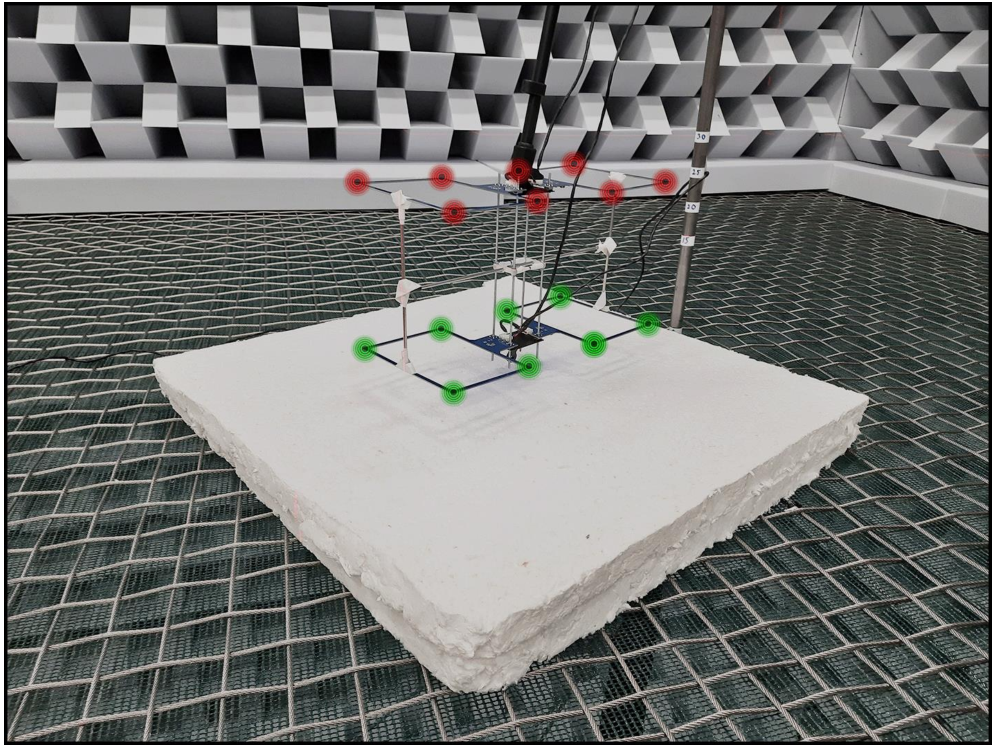
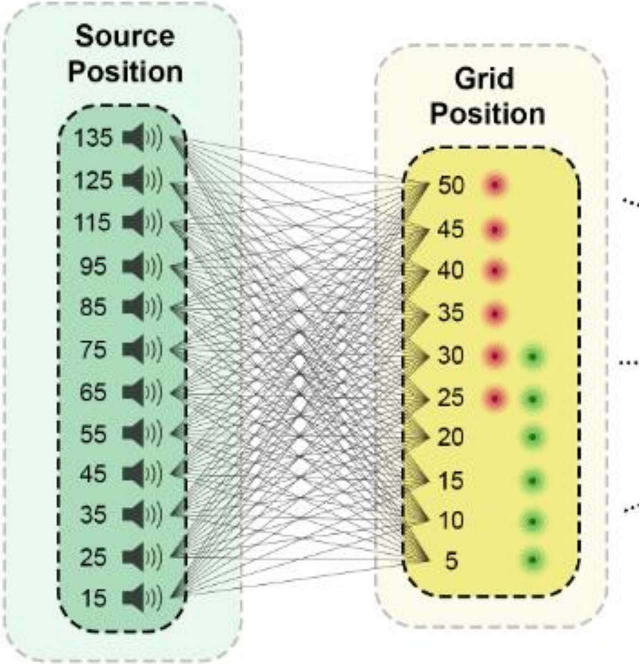
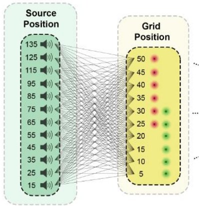
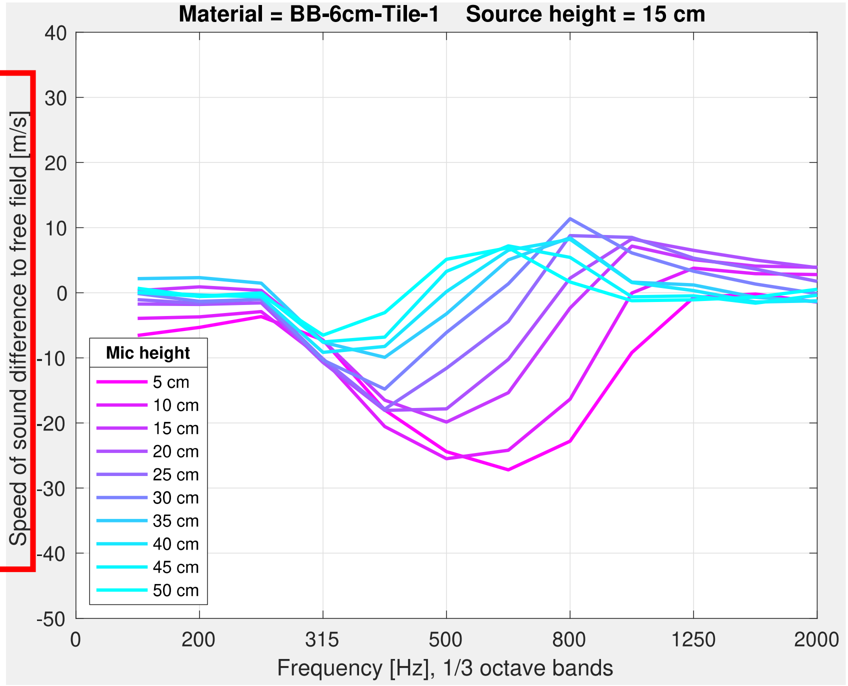
Results, (on absorption – free field)

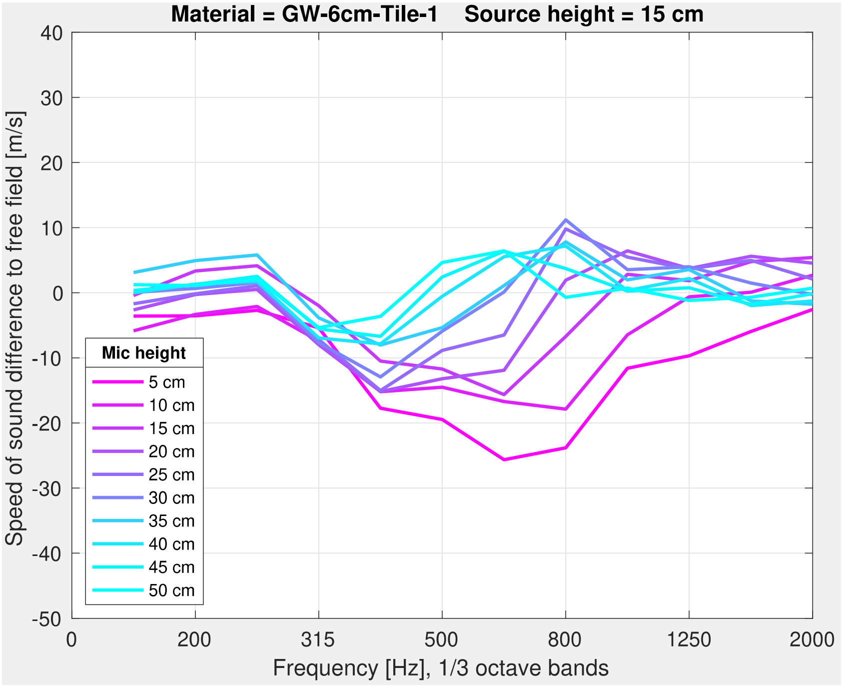




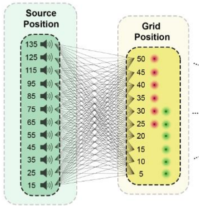
Results, grazing angle 4.3°

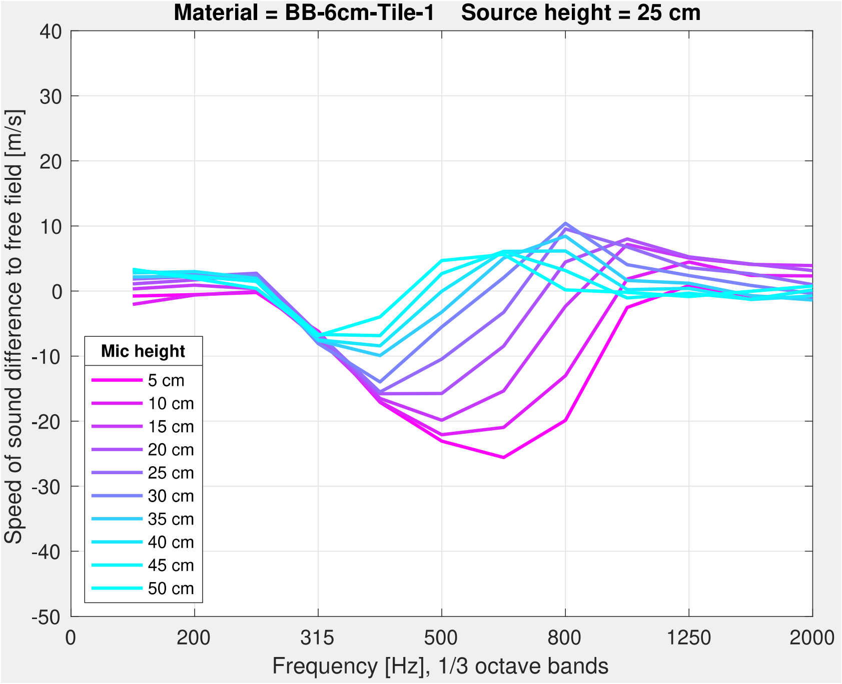


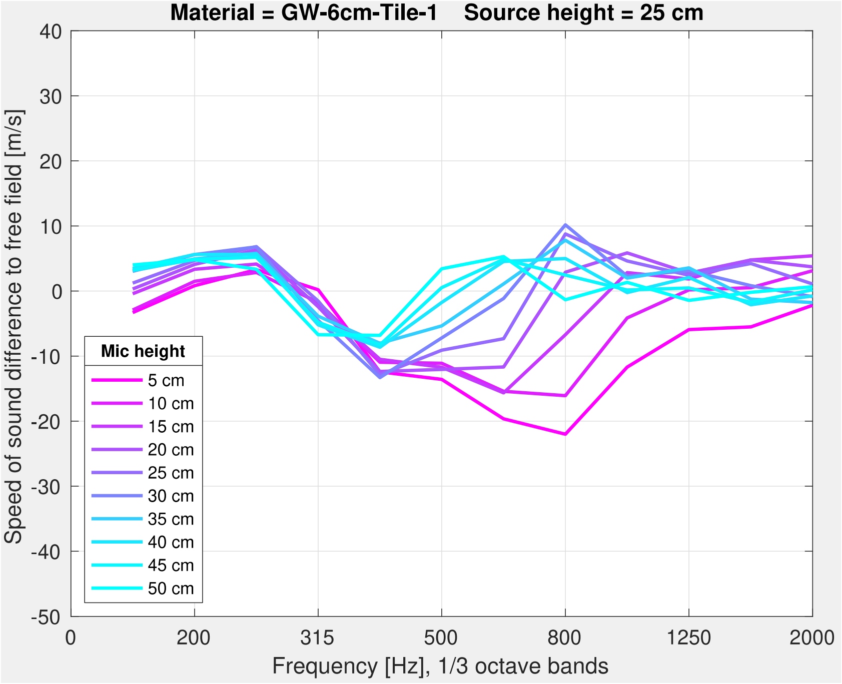




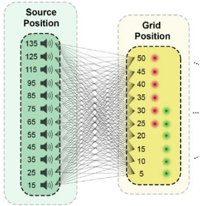
Results, grazing angle 7.1°

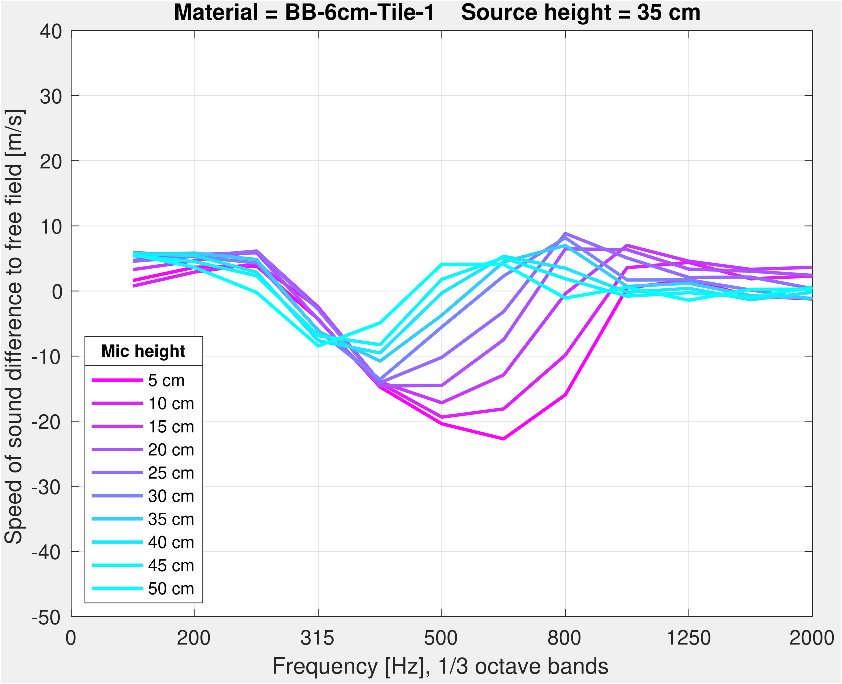


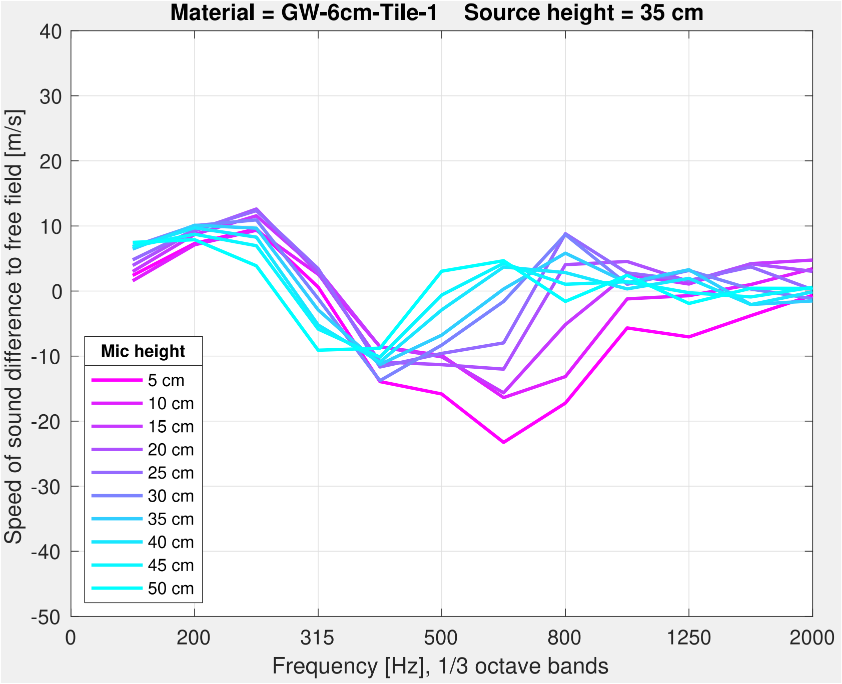




Results, grazing angle 9.9°







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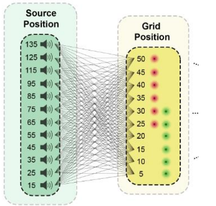
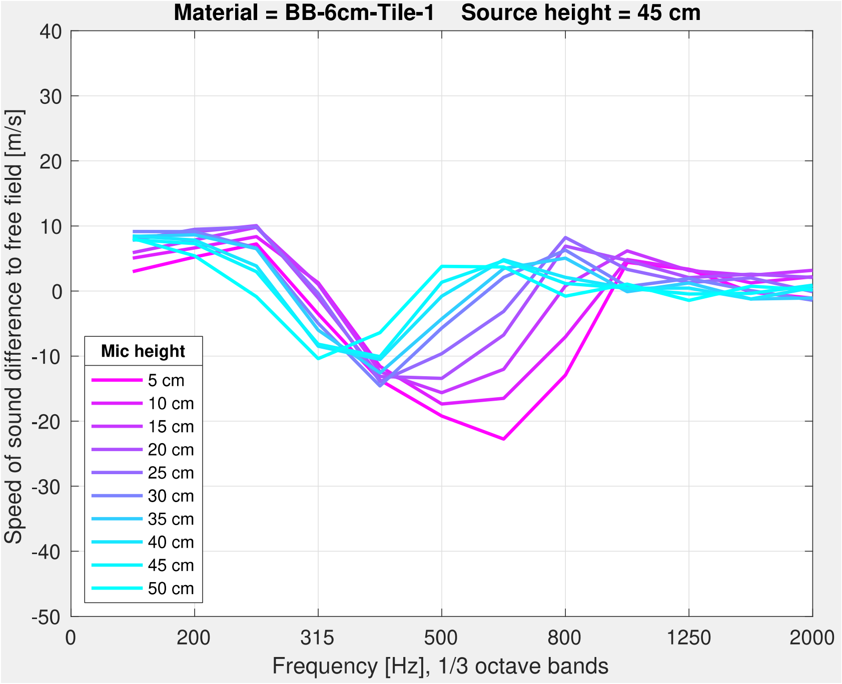
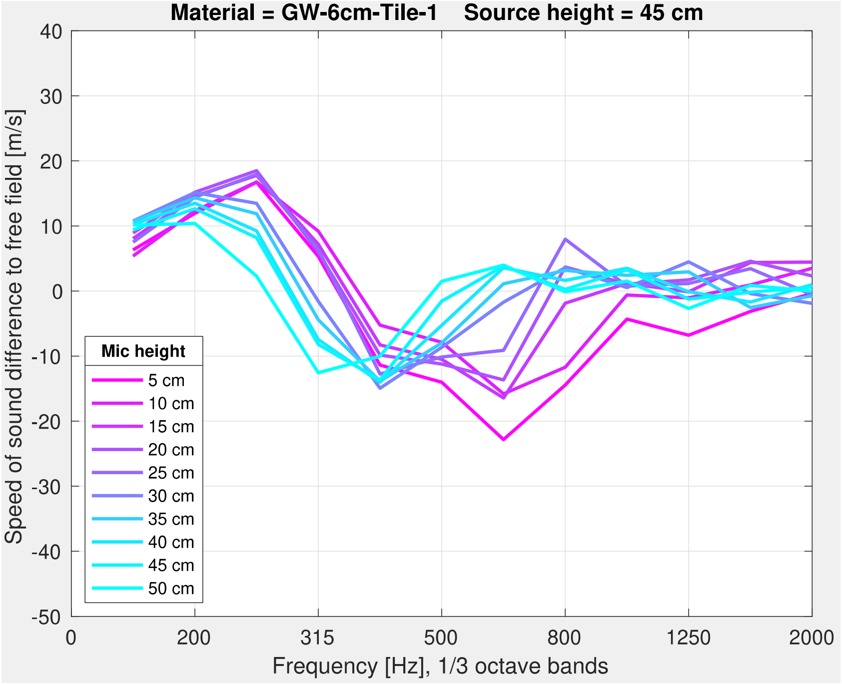
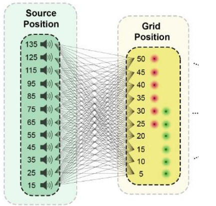
Results, grazing angle 12.7°

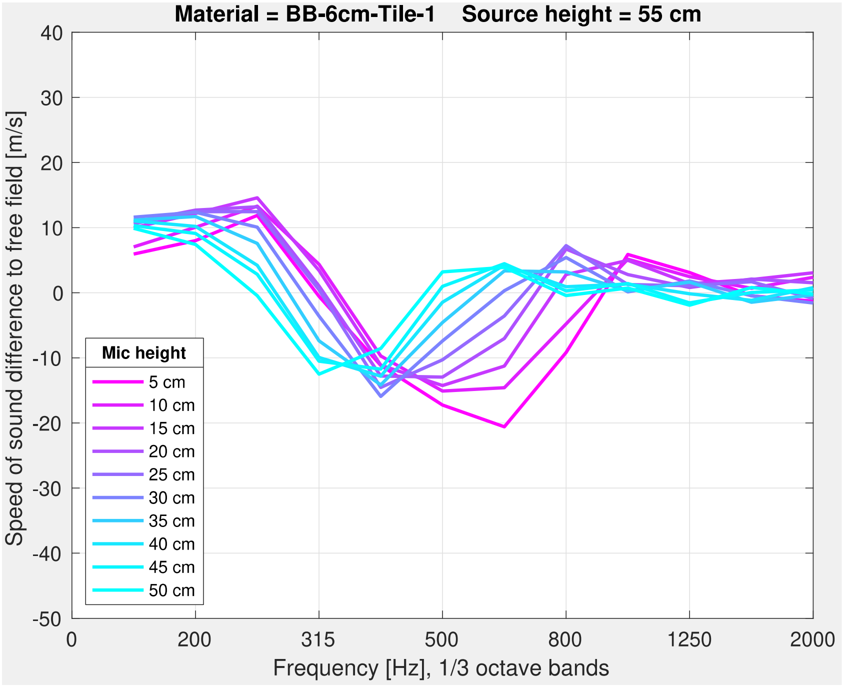


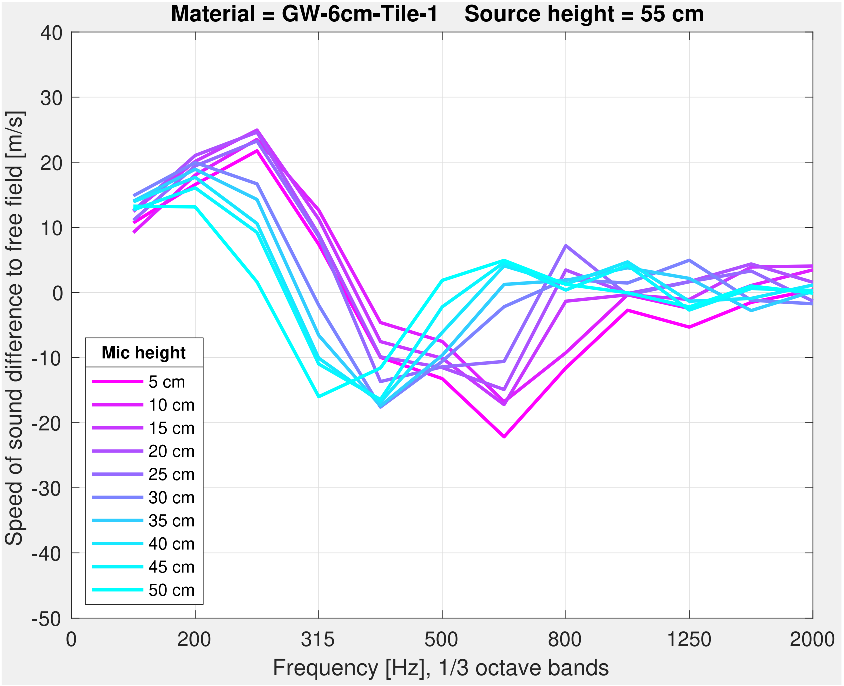




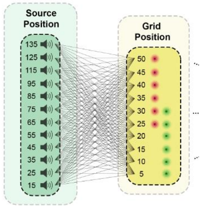
Results, grazing angle 15.4°

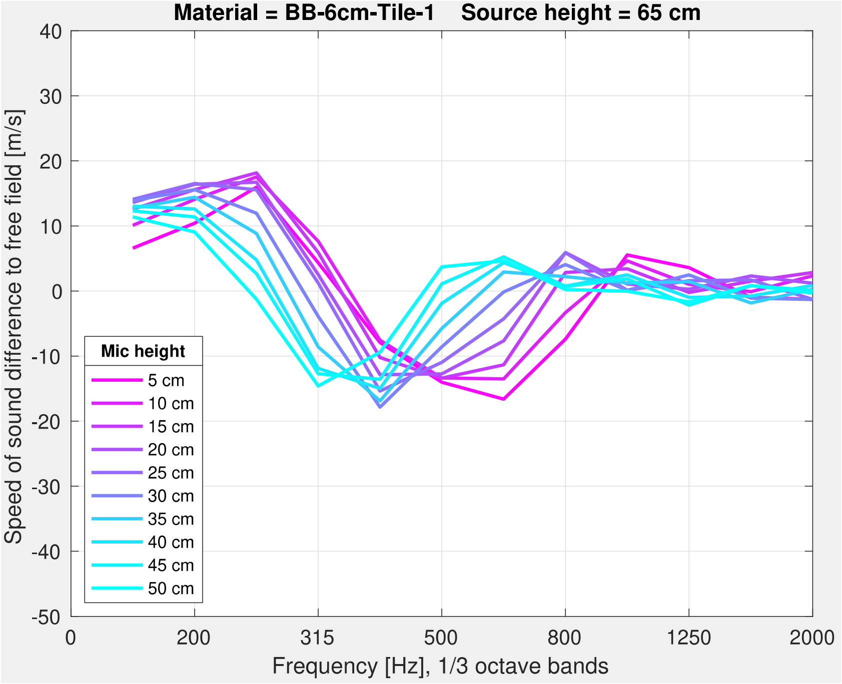


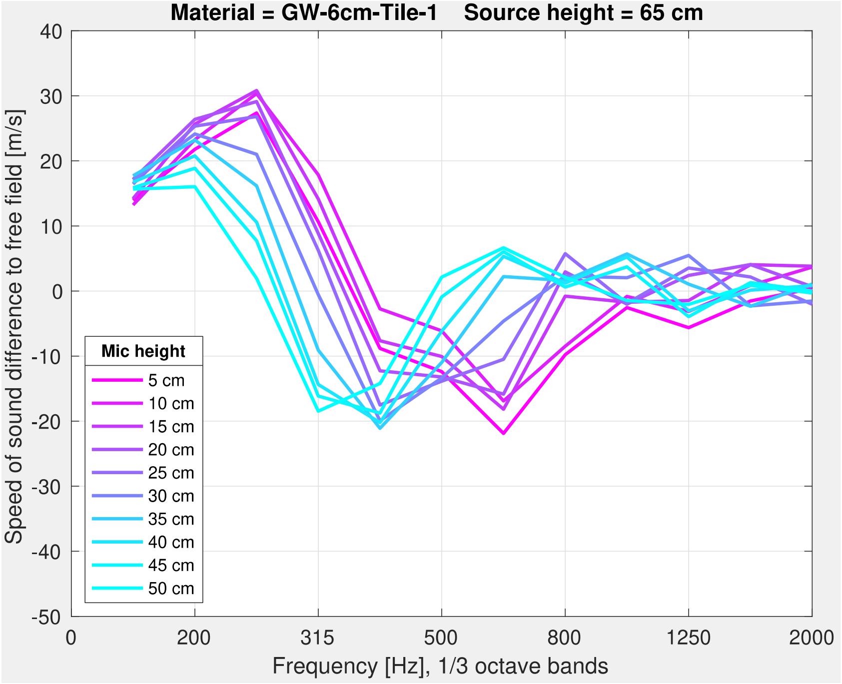




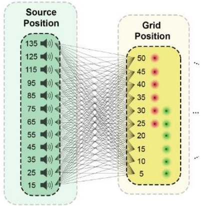
Results, grazing angle 18.0°

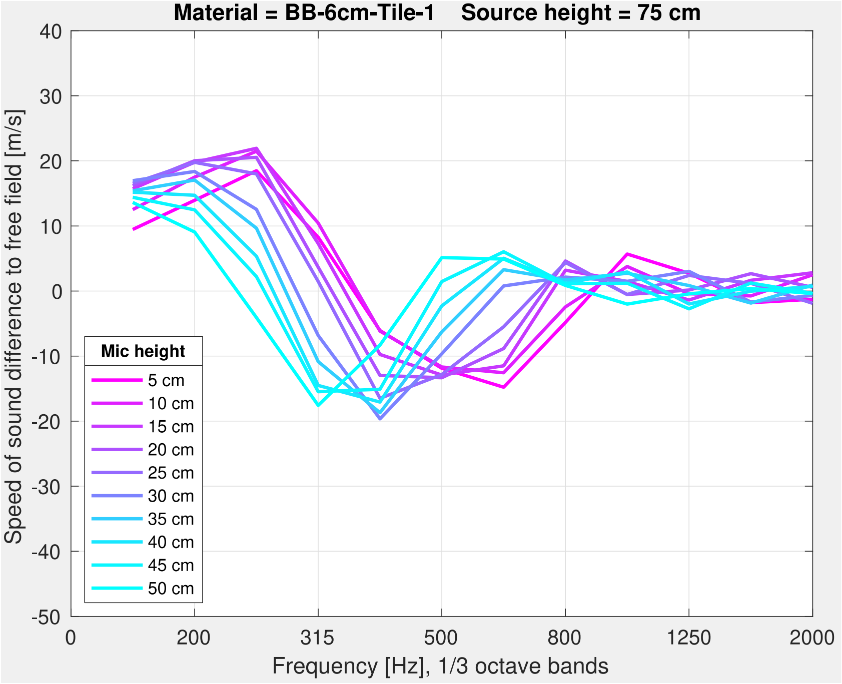


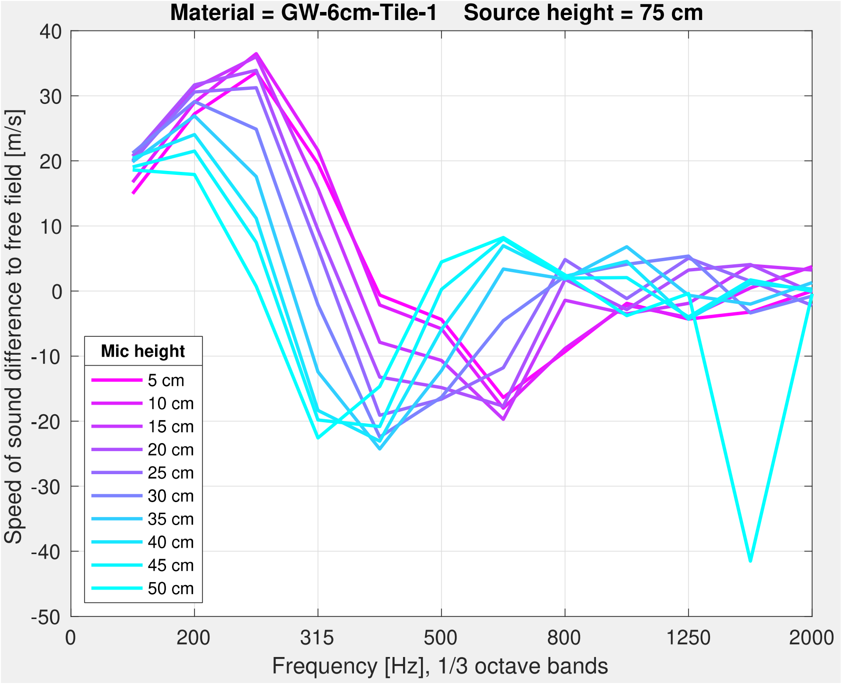




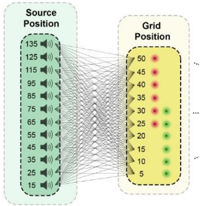
Results, grazing angle 20.6°

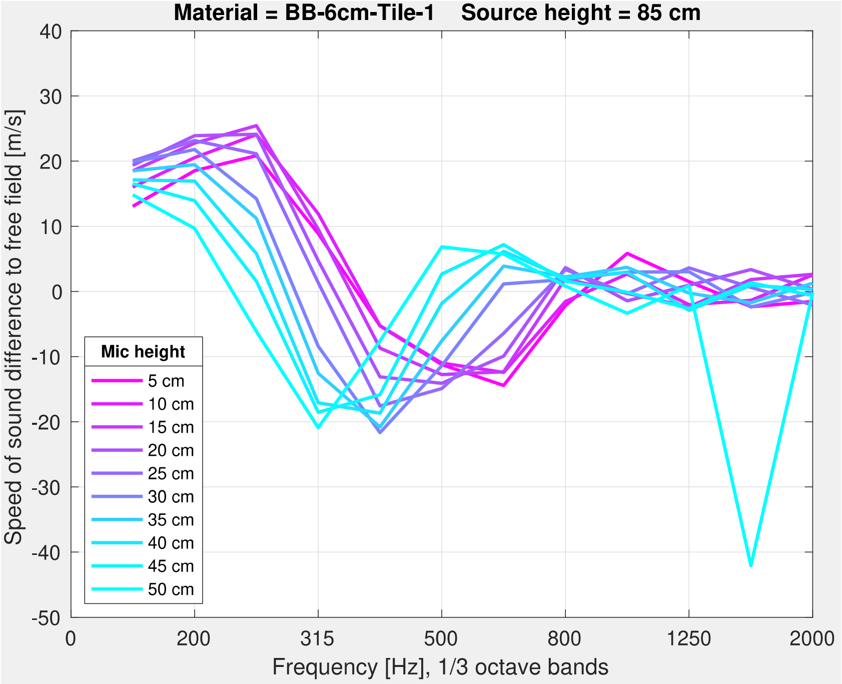


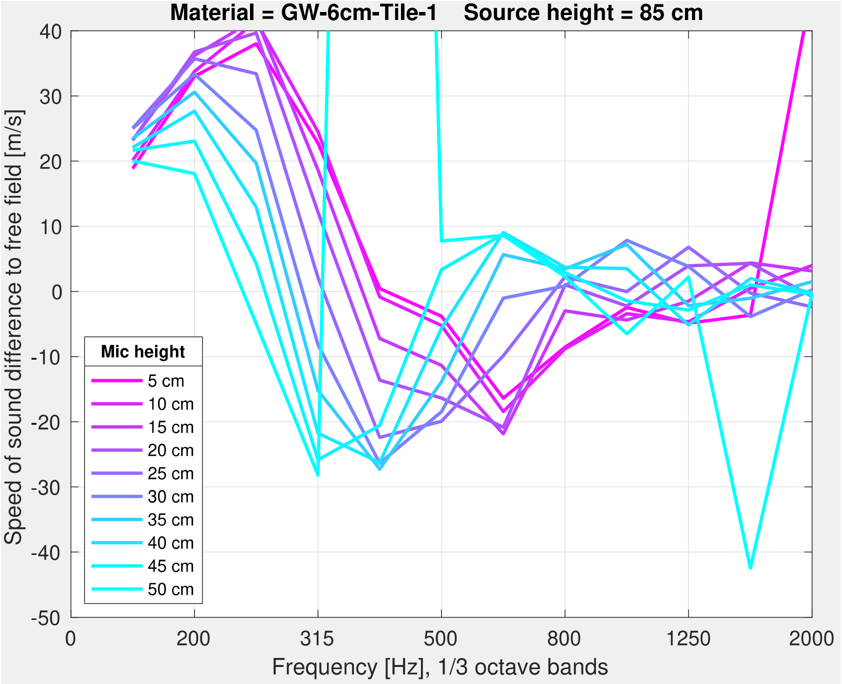




Results, grazing angle 23.0°







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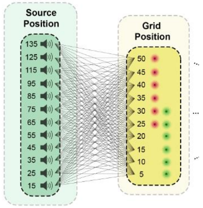
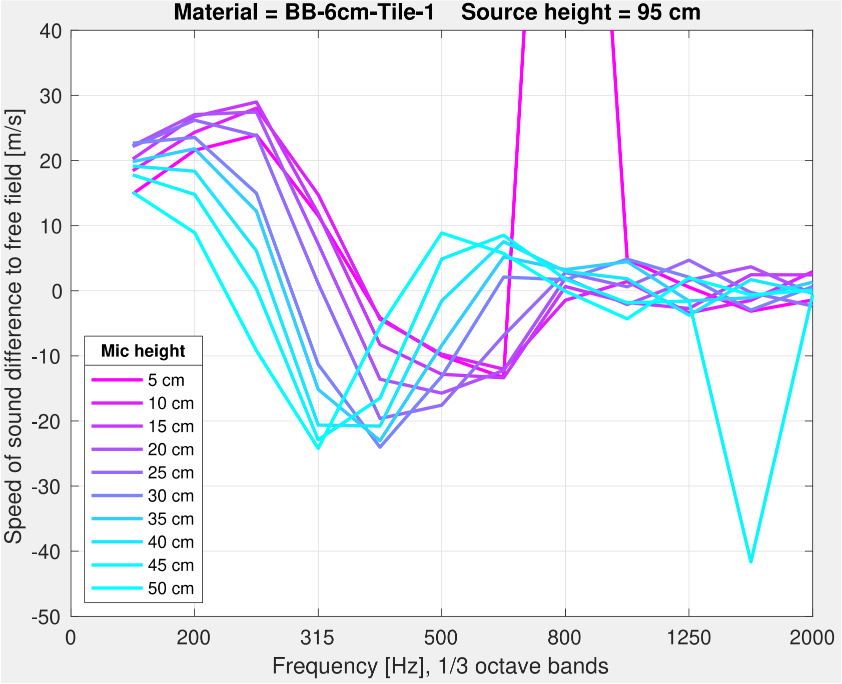
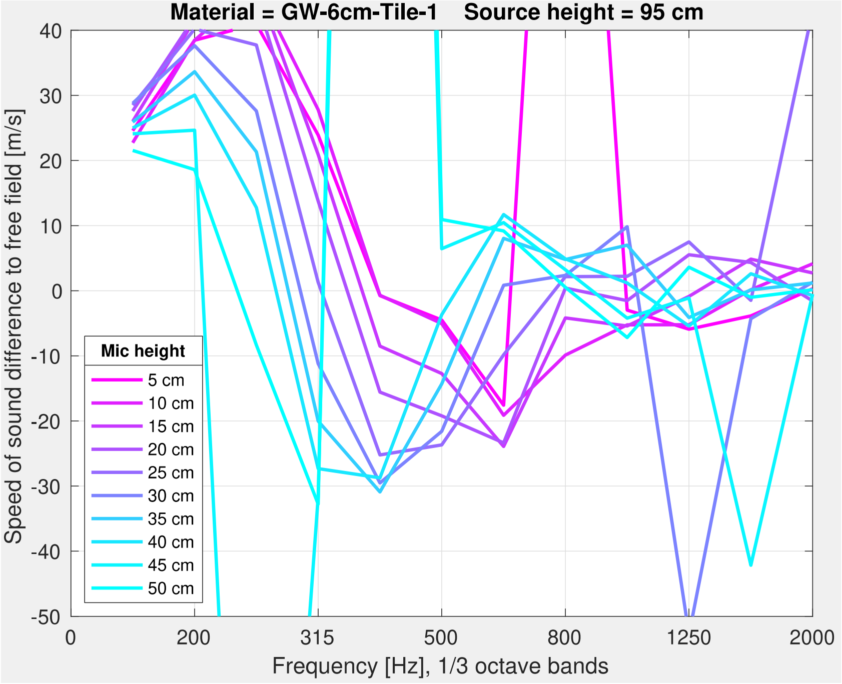
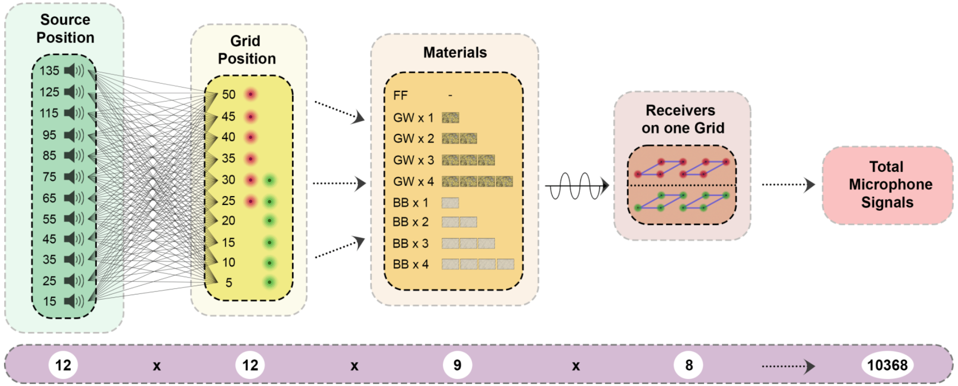
Results, grazing angle 25.4°

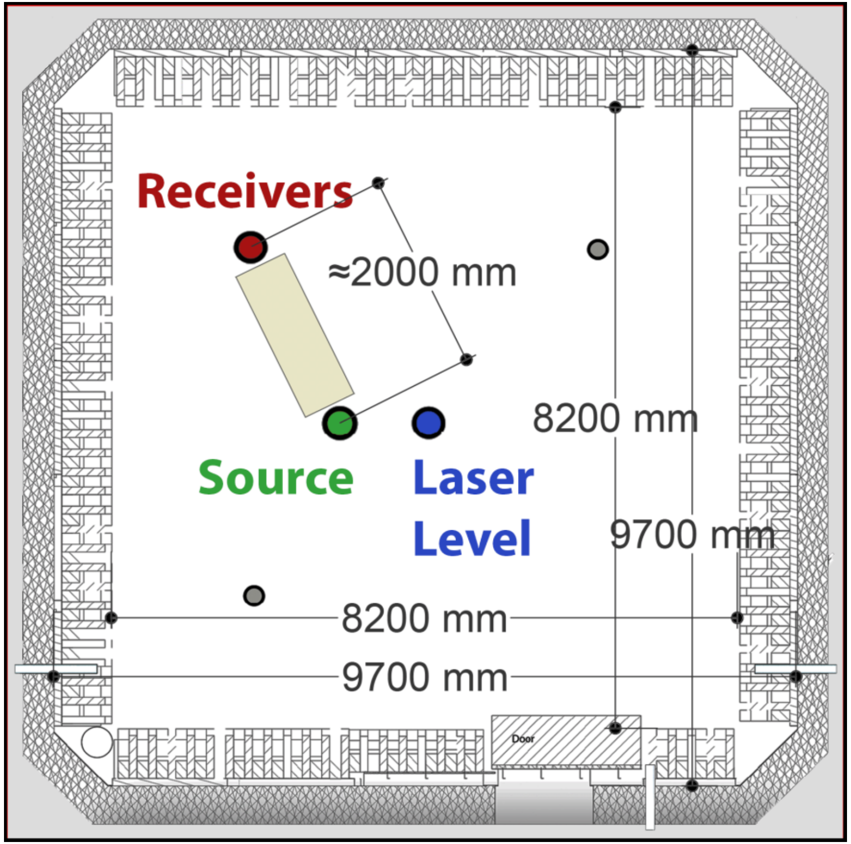




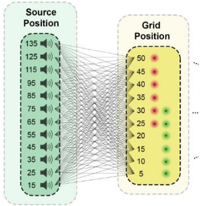


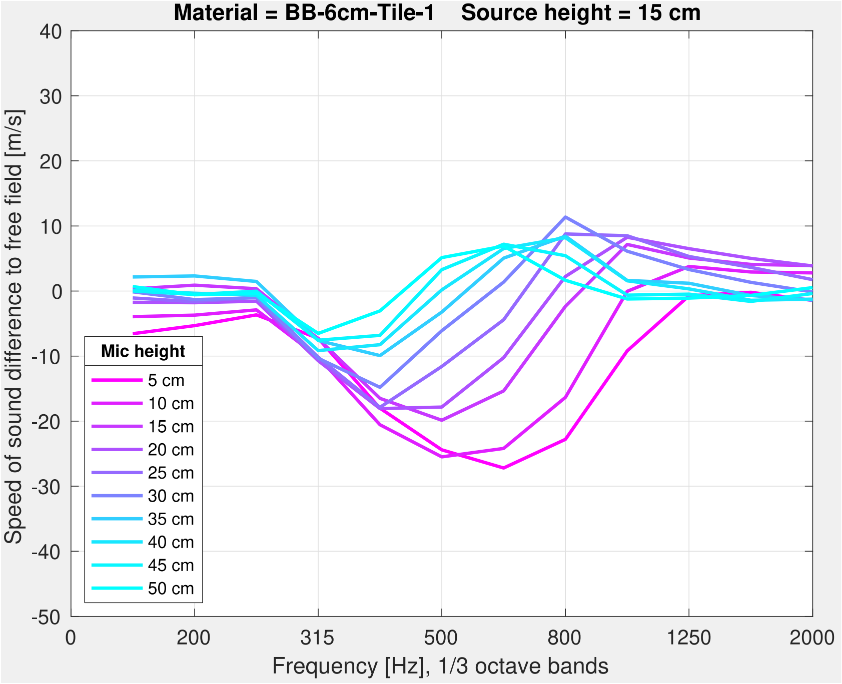
Effect of number of tiles on the path

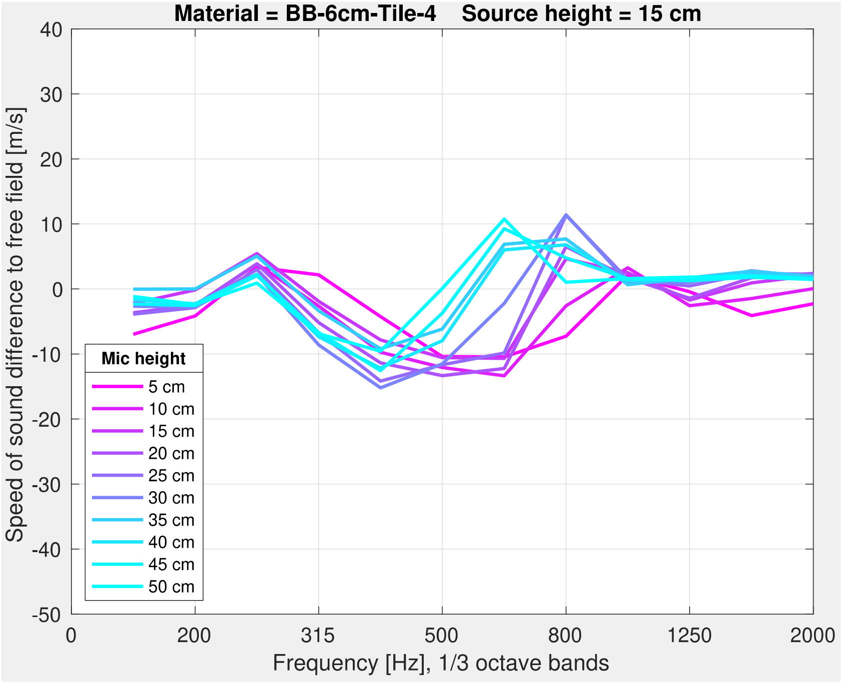




Results, grazing angle 4.3°







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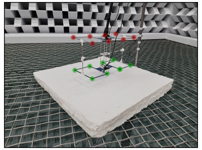
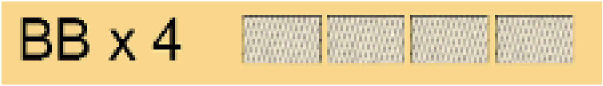
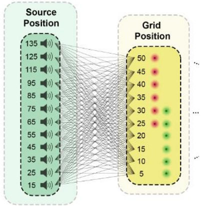
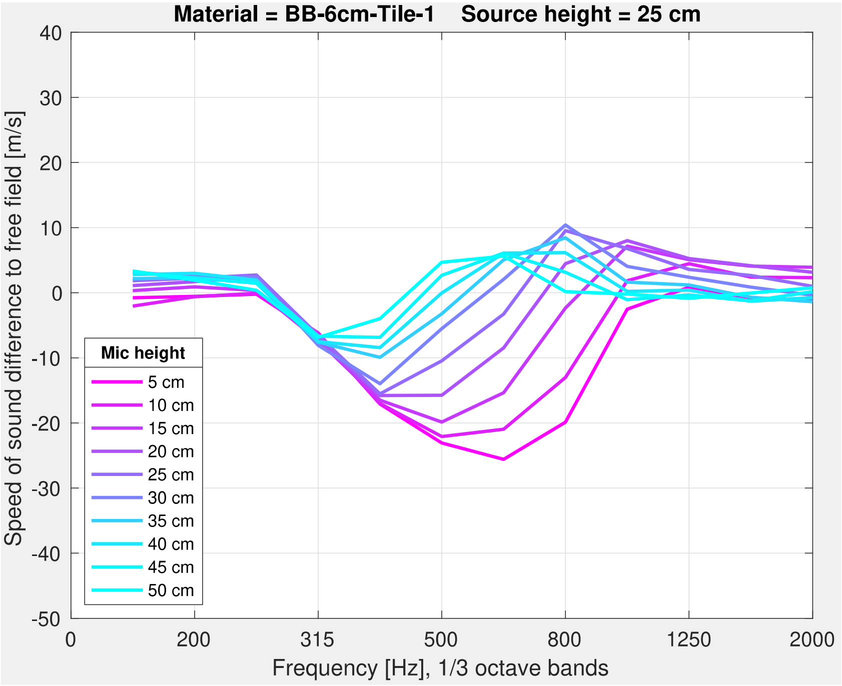
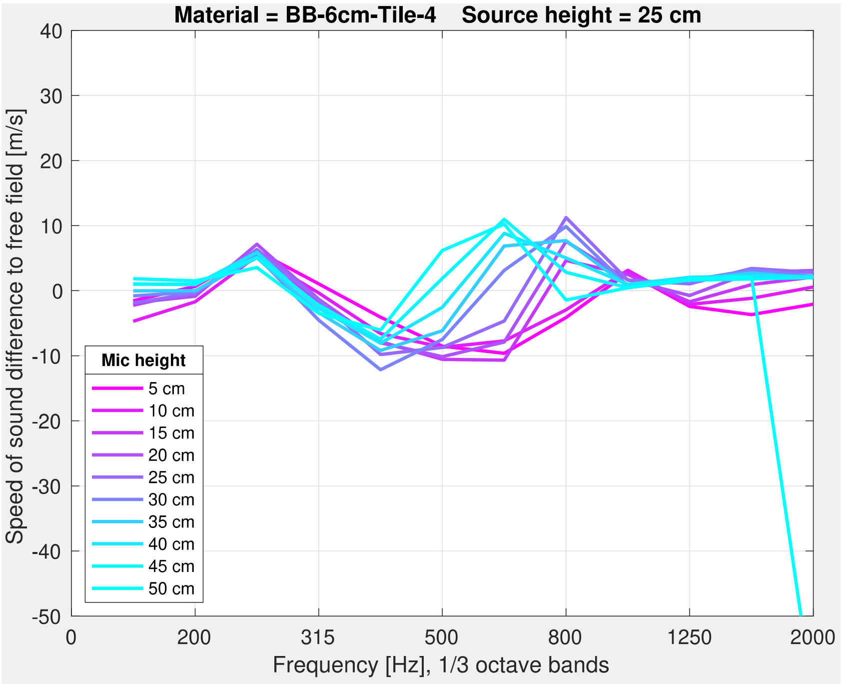




Results, grazing angle 7.1°







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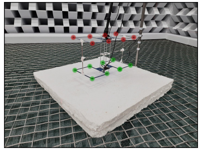
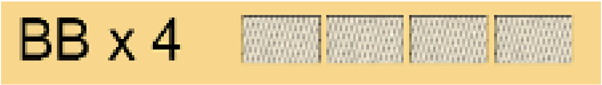
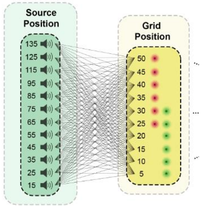
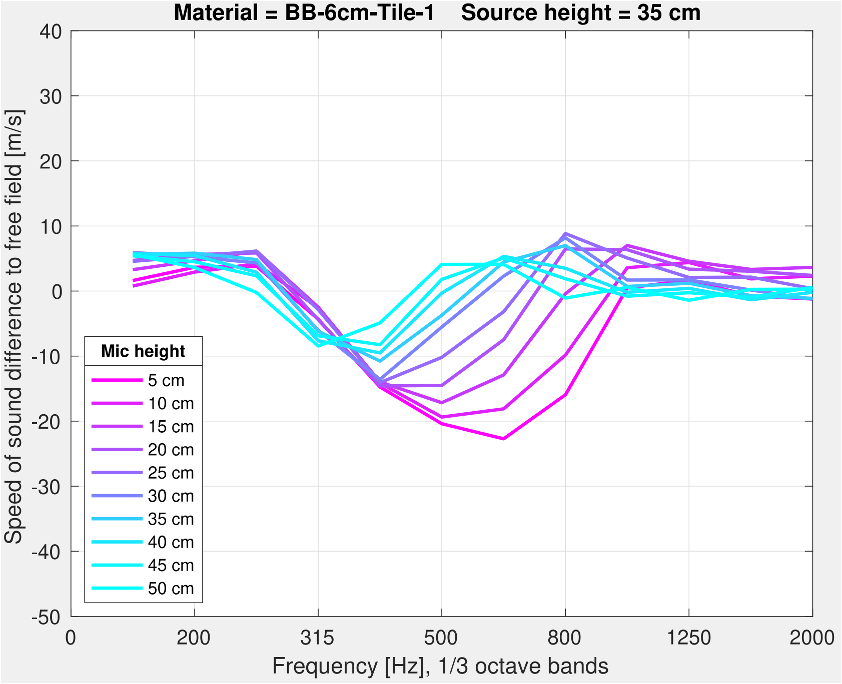
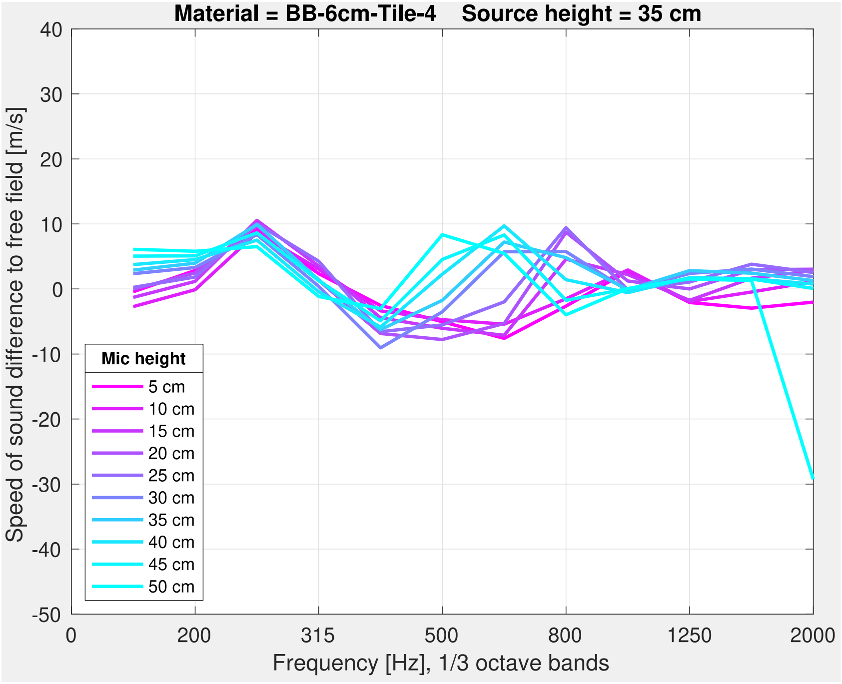




Results, grazing angle 9.9°







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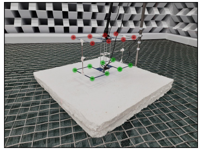
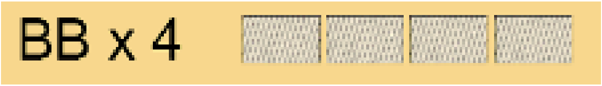
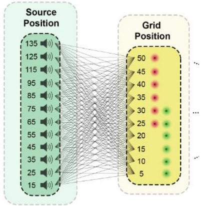
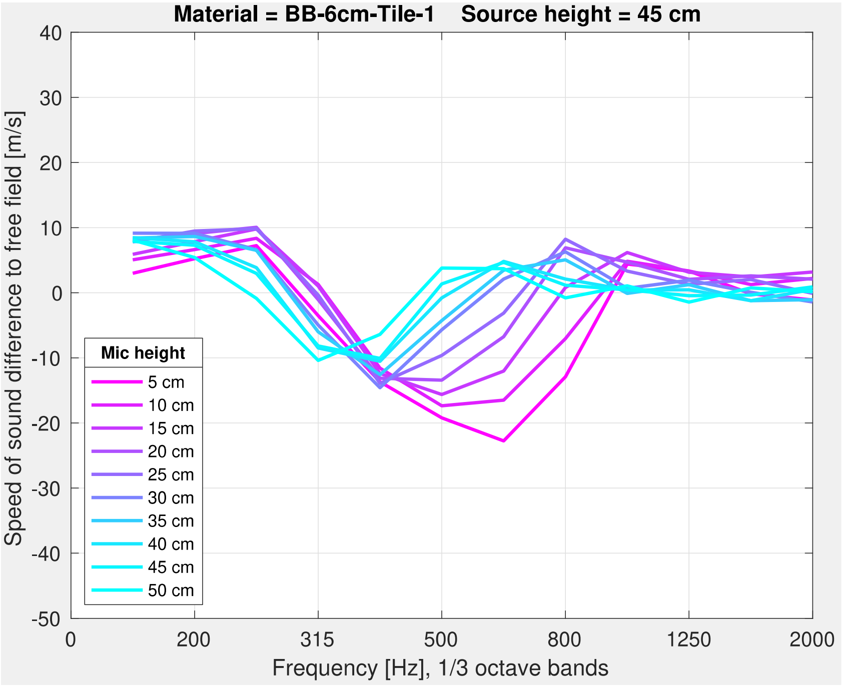
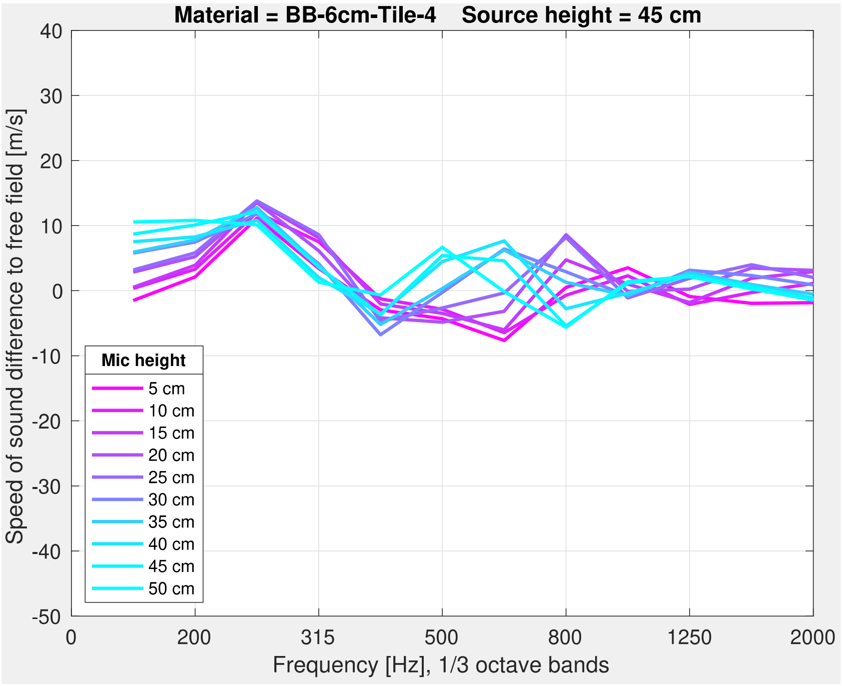




Results, grazing angle 12.7°







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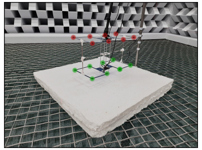
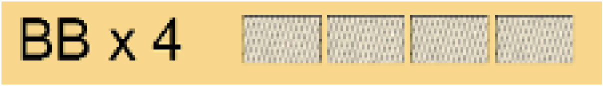
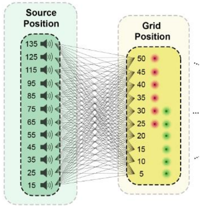
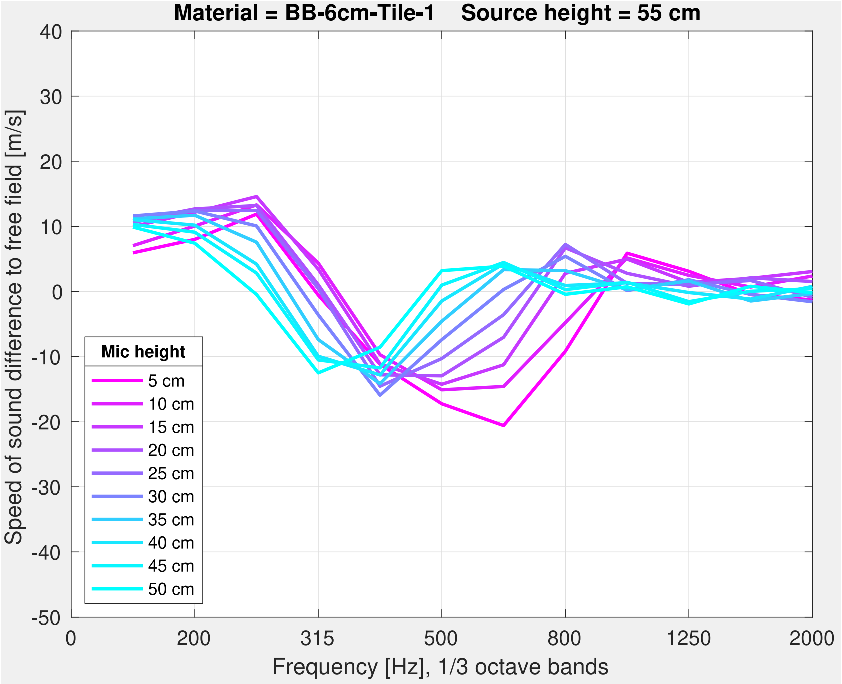
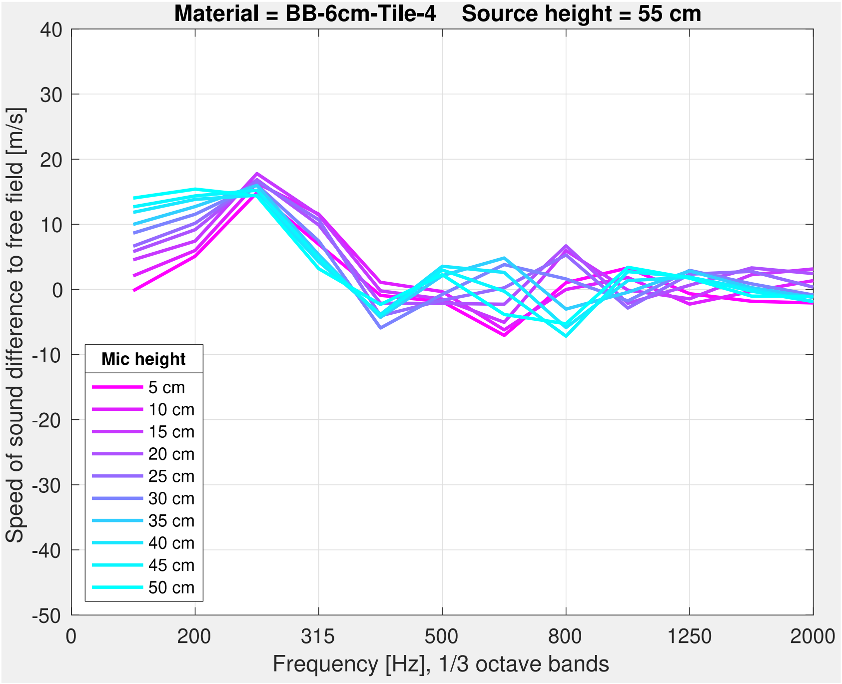




Results, grazing angle 15.4°







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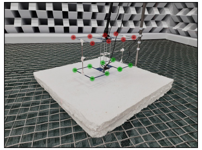
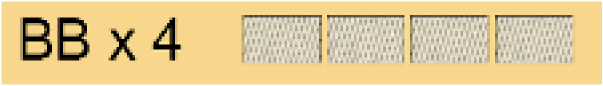
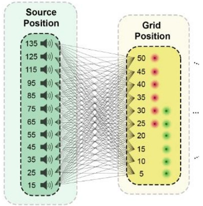
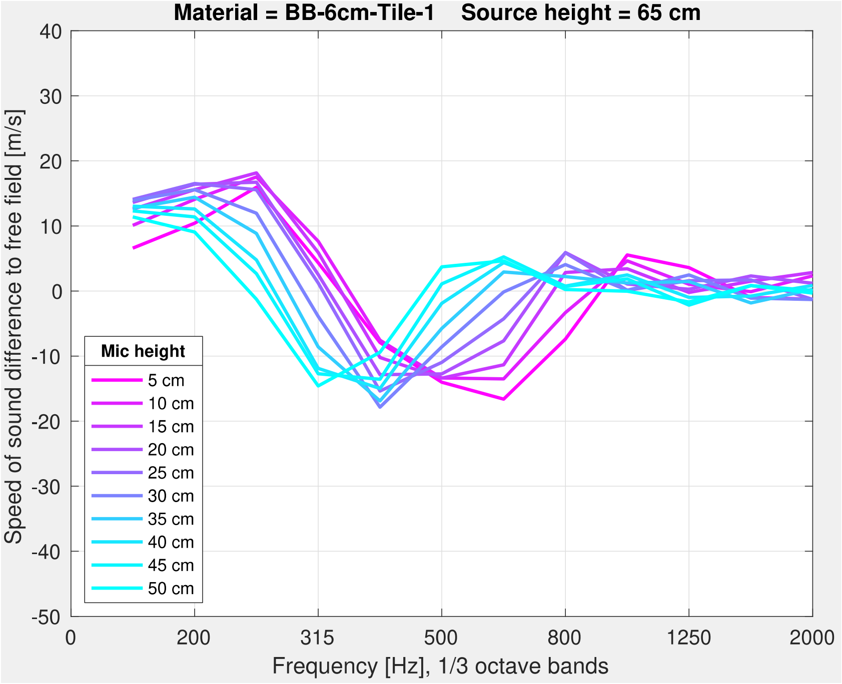
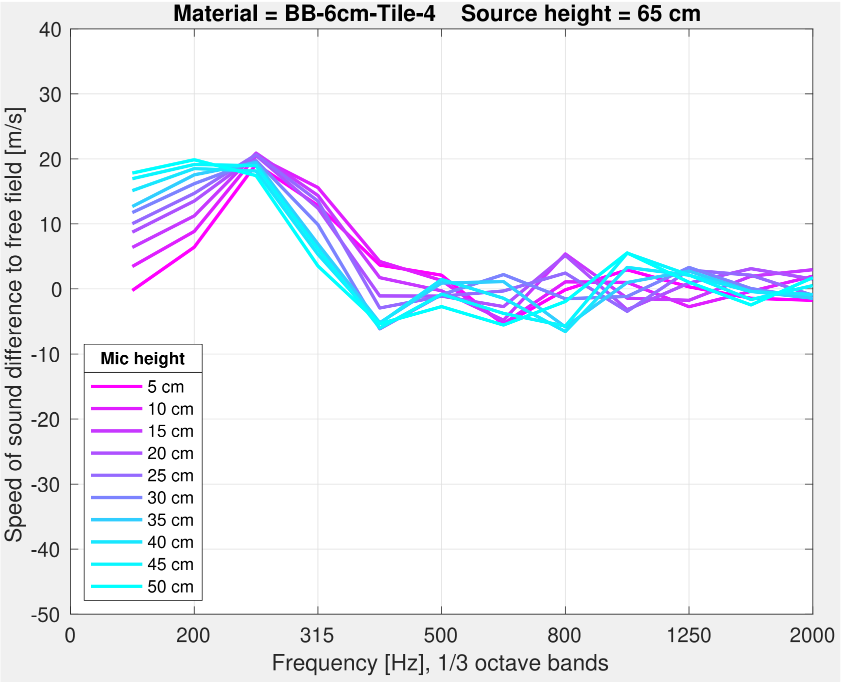




Results, grazing angle 18.0°







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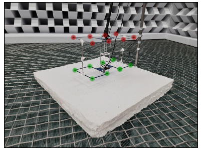
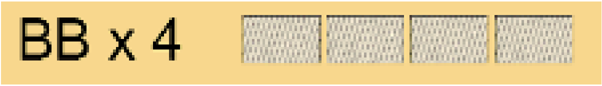
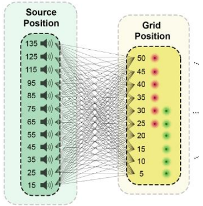
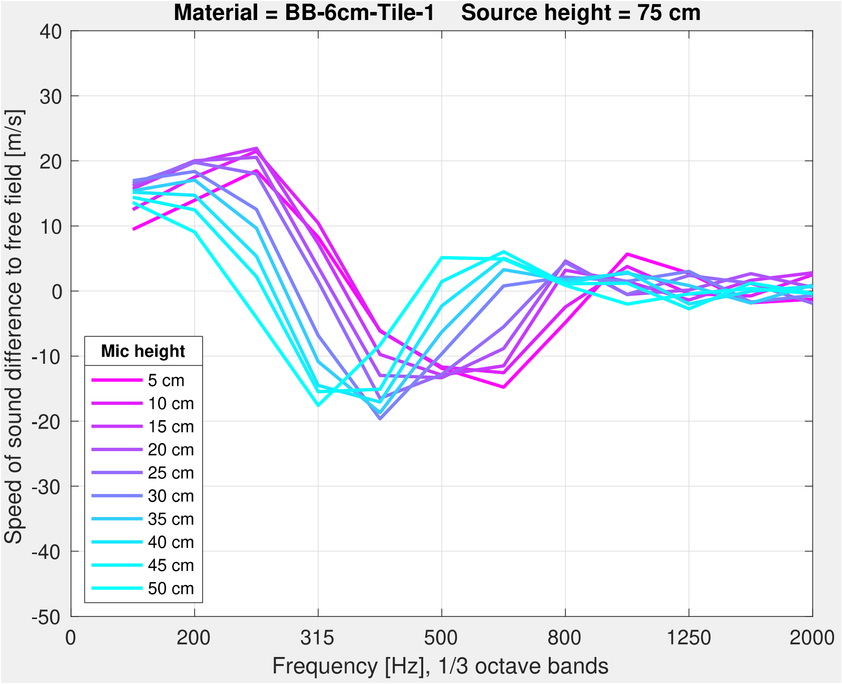
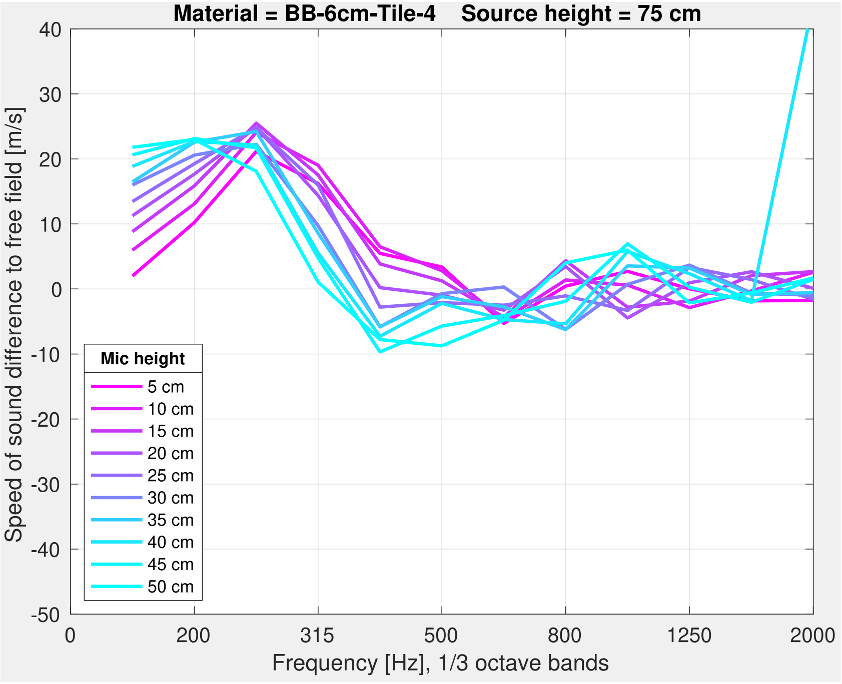




Results, grazing angle 20.6°







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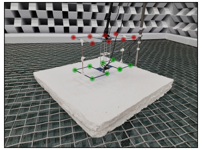
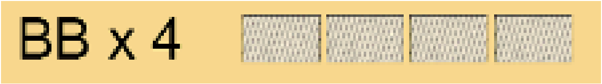
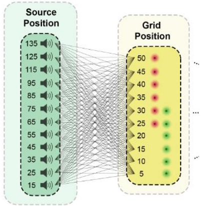
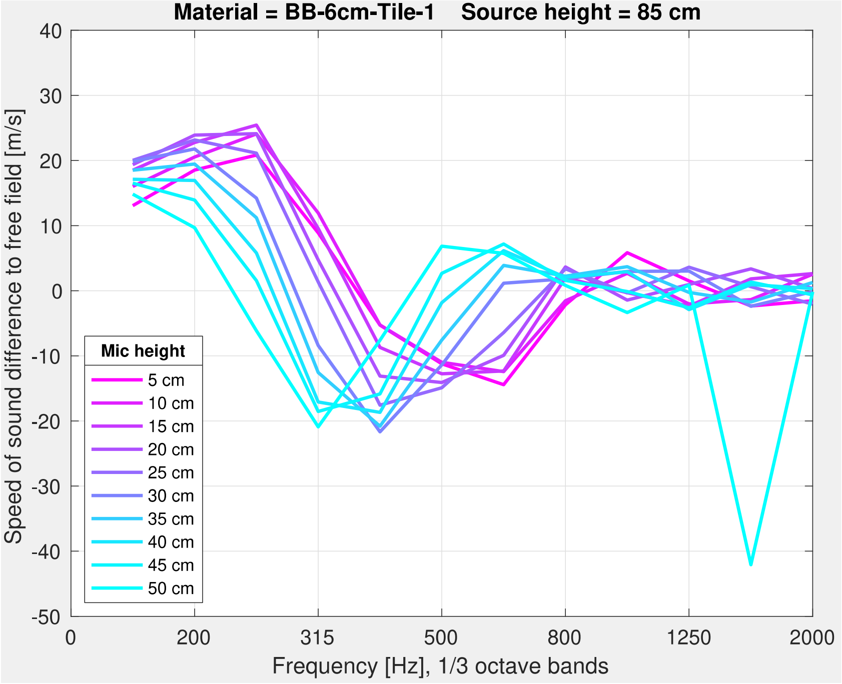
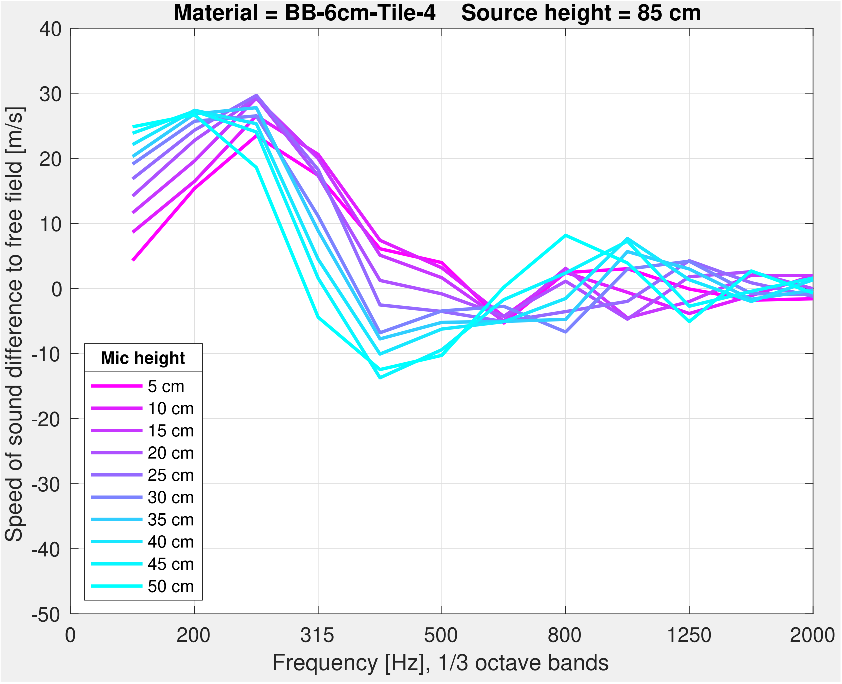




Results, grazing angle 23.0°







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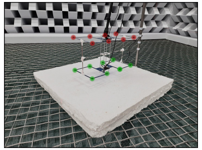
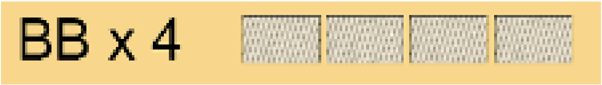
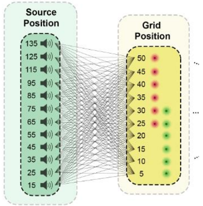
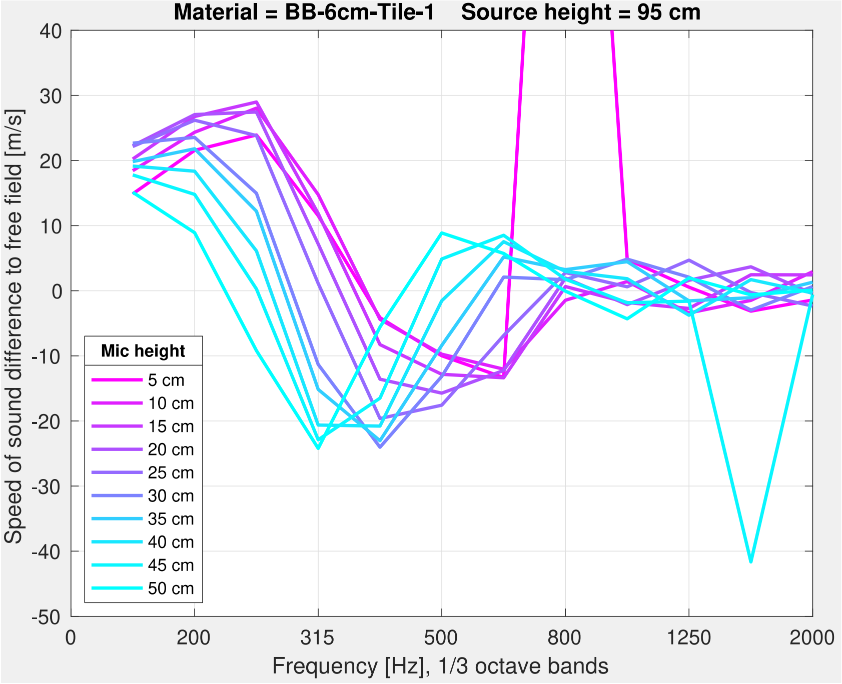
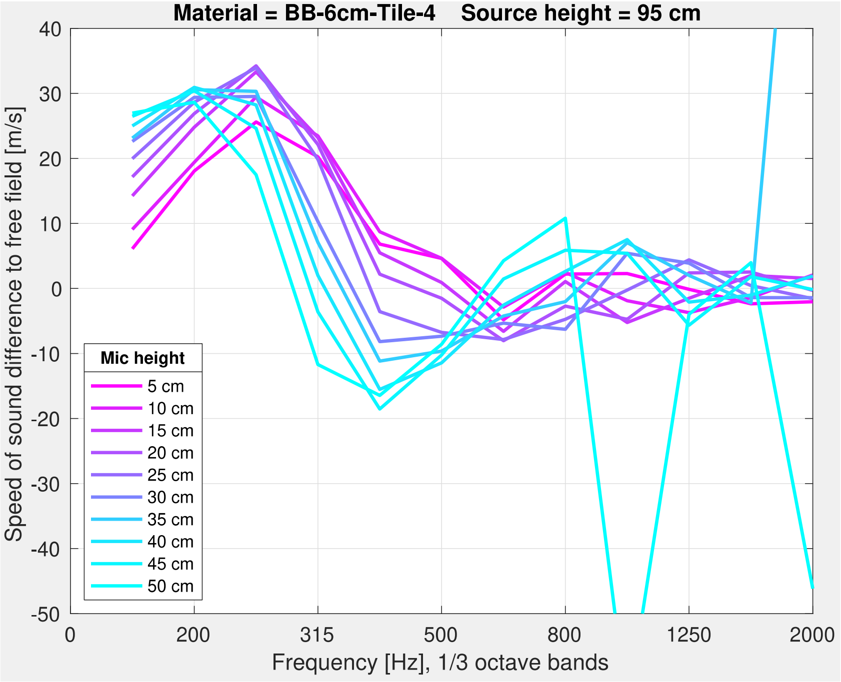




Results, grazing angle 25.4°







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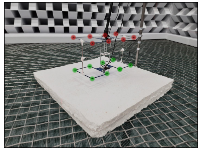
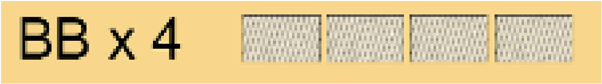
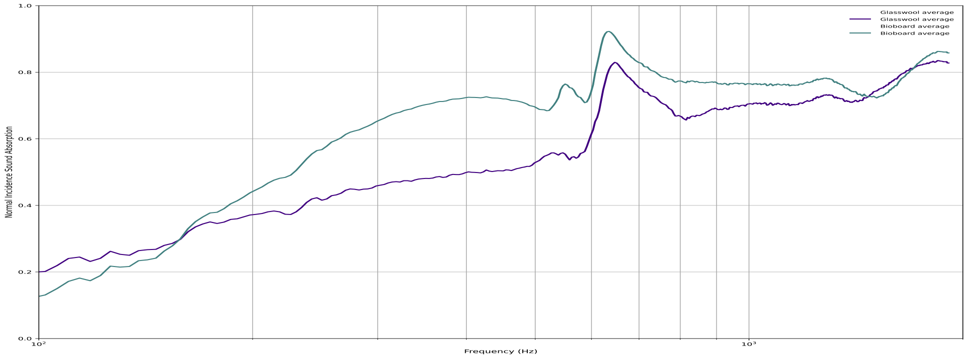




Conclusions (SAPEM 2023)

1. **Apparent Speed of Sound is lower at certain frequency range, here 300 – 1200 Hz for sound at grazing angles up to 25°**
2. **Material affects to speed of sound up to 30 cm**
   - Depends on the frequency
     - The frequency range is widest at high grazing angle
   - Depends on the material
3. **The effect is smaller when the whole path is covered with absorption material**



Thank your for attention!

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