Design of Double Tuned Helmholtz Resonators

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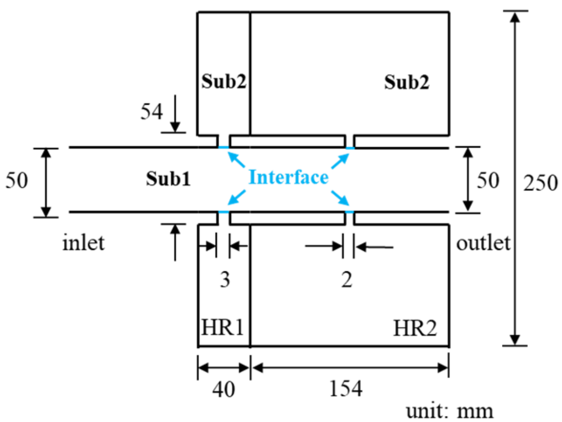
Introduction

Design of DTHR

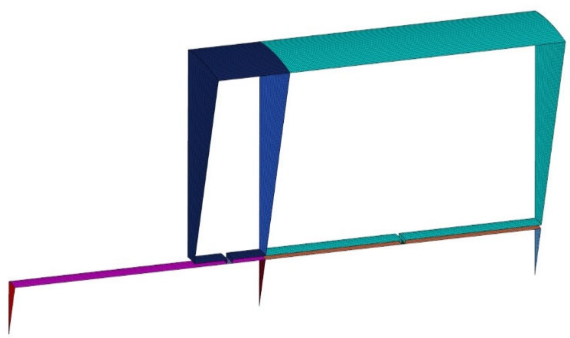
- Helmholtz resonators are often used in the design of vehicle mufflers to target tonal noise at a few specific low frequencies generated by the engine.
- One way to increase the bandwidth of the resonance peak is to connect two Helmholtz resonators with two different natural frequencies in series. The two HRs then form a double-tuned Helmholtz resonator (DTHR).
- The performance of a double-tuned Helmholtz resonator (DTHR) created by punching small slots into a thin-walled tube is investigated.

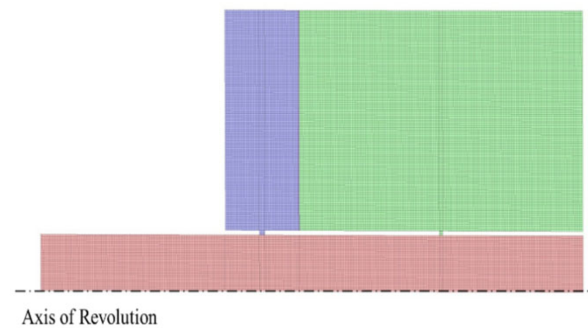
Numerical Simulation BEM and FEM

Design of DTHR



Side View


BEM mesh

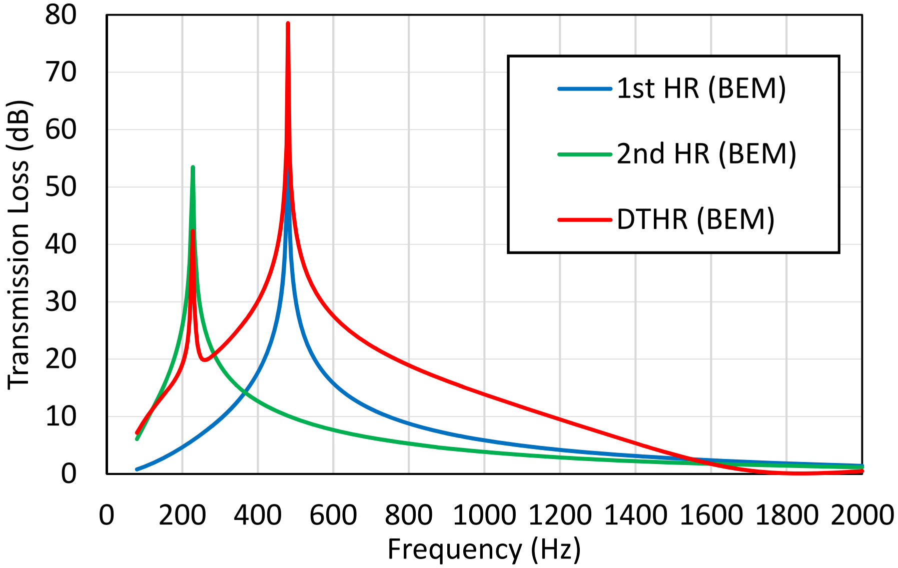


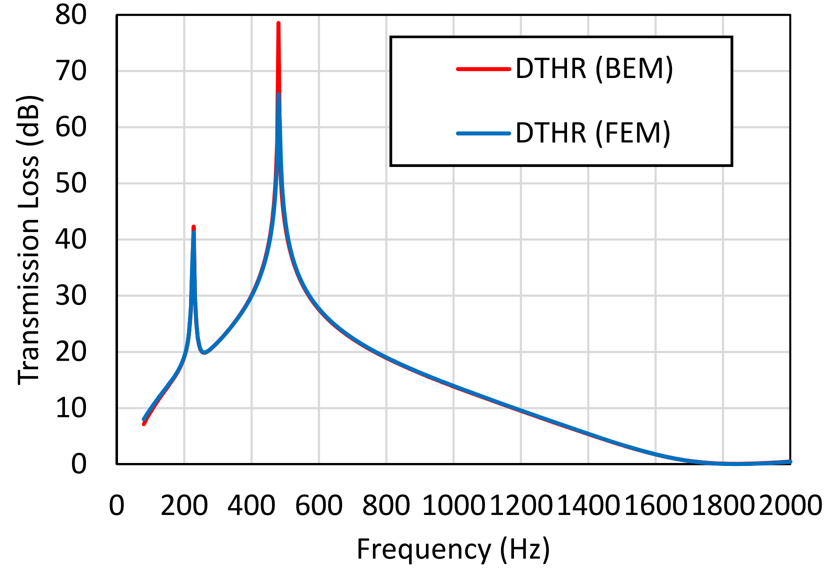
FEM mesh

- The temperature is set at 400 ℃ for all test cases in this paper.
- Either the BEM or the FEM can be used to model a DTHR.
- Simulation used to estimate possible range of the end correction factor.

Numerical Simulation BEM and FEM

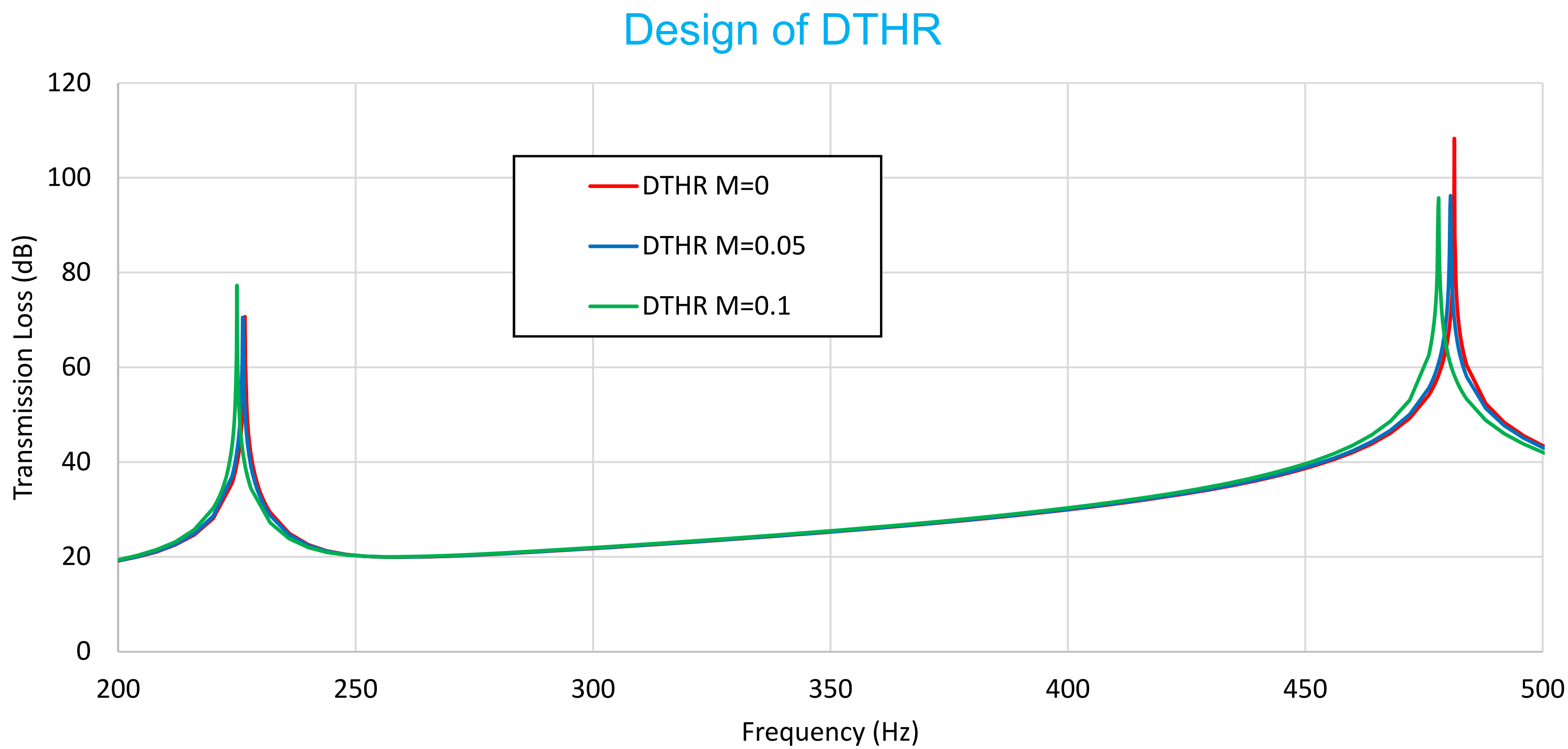
Design of DTHR





A well-tuned slot DTHR preserves the individual resonances while maintaining good performance between the two peaks.

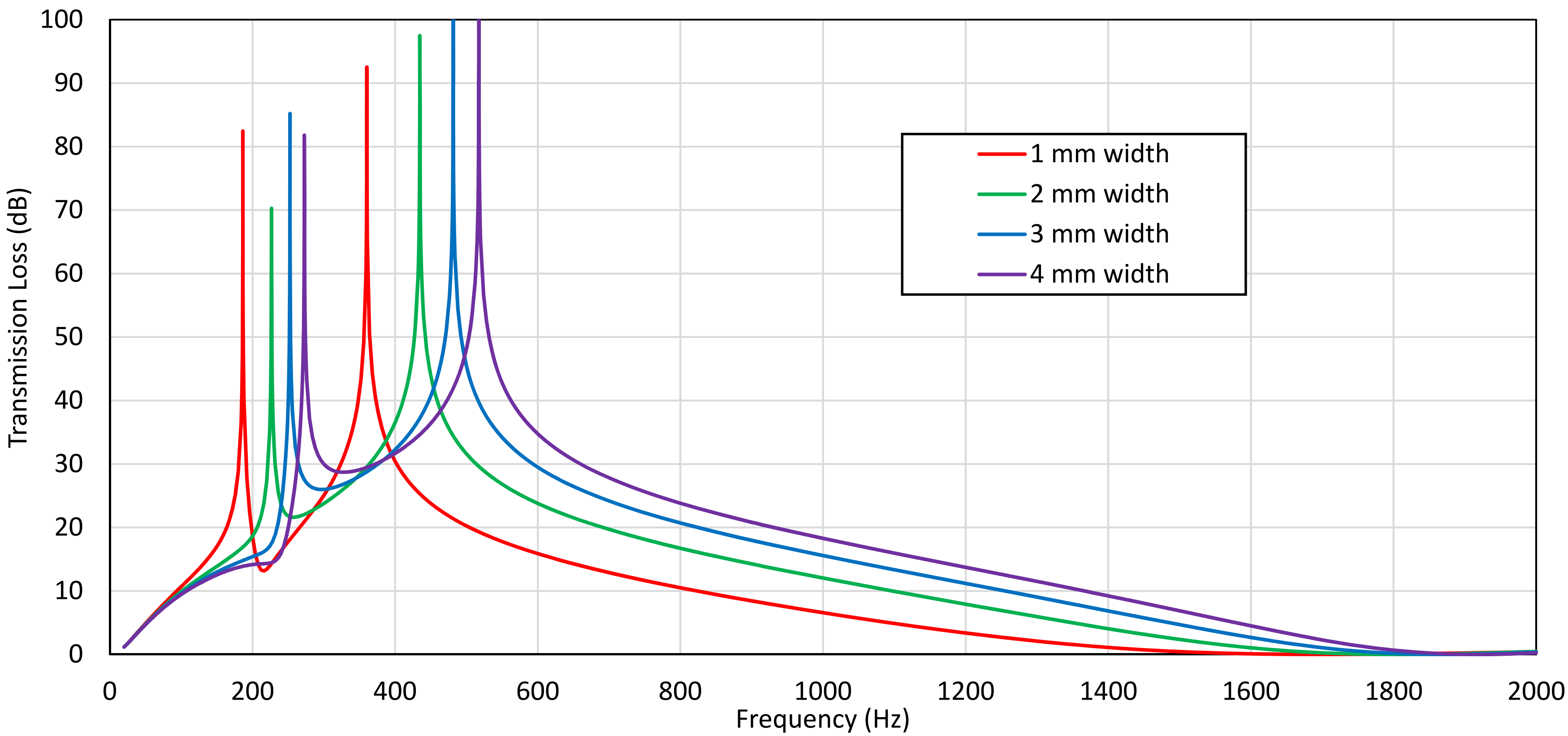
Numerical Simulation Effect of Mean Flow



There is little effect on TL results with or without mean flow.

Numerical Simulation Effect of Slot Width

Design of DTHR



Effect of Slot Width

Design of DTHR

- The natural frequency f_n (in Hz) of a short-neck Helmholtz resonator modeled by the spring-mass approximation can be estimated by

$$f_n = \frac{c}{2\pi}\sqrt{\frac{S_b}{l'V}}$$

where l' is the so-called *effective neck length*.

- Convert the slot opening area to an equivalent circular hole with an equivalent radius a_e or directly use the slot width w:

$$l' = l + \alpha a_e$$

$$l' = l + \beta w$$

where α and β are end correction coefficients to be determined from the numerical results.

Effect of Slot Width

Design of DTHR

End Correction coefficients of HR1

w (mm)	HR1 Peak Frequency (Hz)	a_e (mm)	α	β
1	360.3	7.2	0.3614	2.6021
2	434.6	10.2	0.4248	2.1665
3	481.4	12.5	0.4596	1.915
4	517.4	14.4	0.4808	1.7309

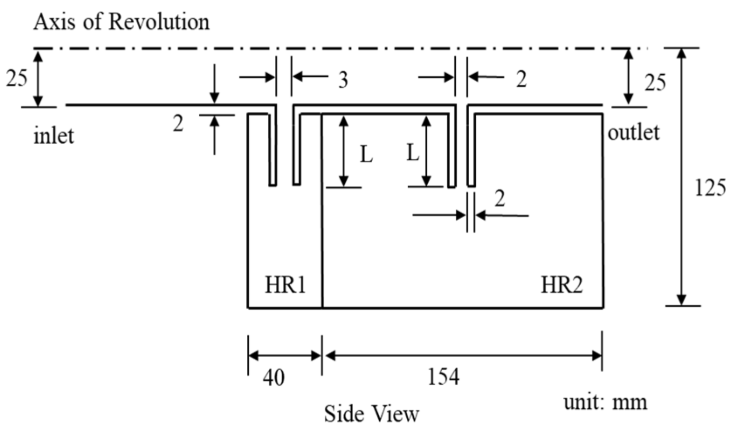
End Correction coefficients of HR2

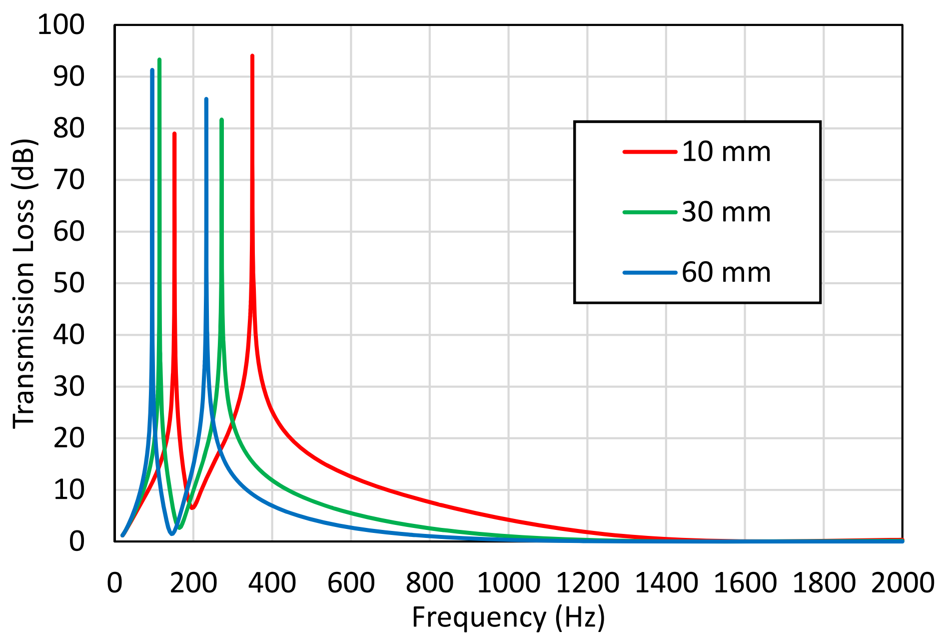
w (mm)	HR2 Peak Frequency (Hz)	a_e (mm)	α	β
1	186.5	7.2	0.3419	2.4617
2	226.7	10.2	0.3966	2.0227
3	252.5	12.5	0.425	1.7708
4	272.7	14.4	0.4406	1.5862

- The recovered α values range from 0.34 to 0.48 and β values range from 1.586 to 2.60.
- The larger the equivalent radius, the larger the α end correction coefficient will be.
- The larger the slot width, the smaller the β end correction coefficient will be.

Effect of Additional Slot Length

Design of DTHR

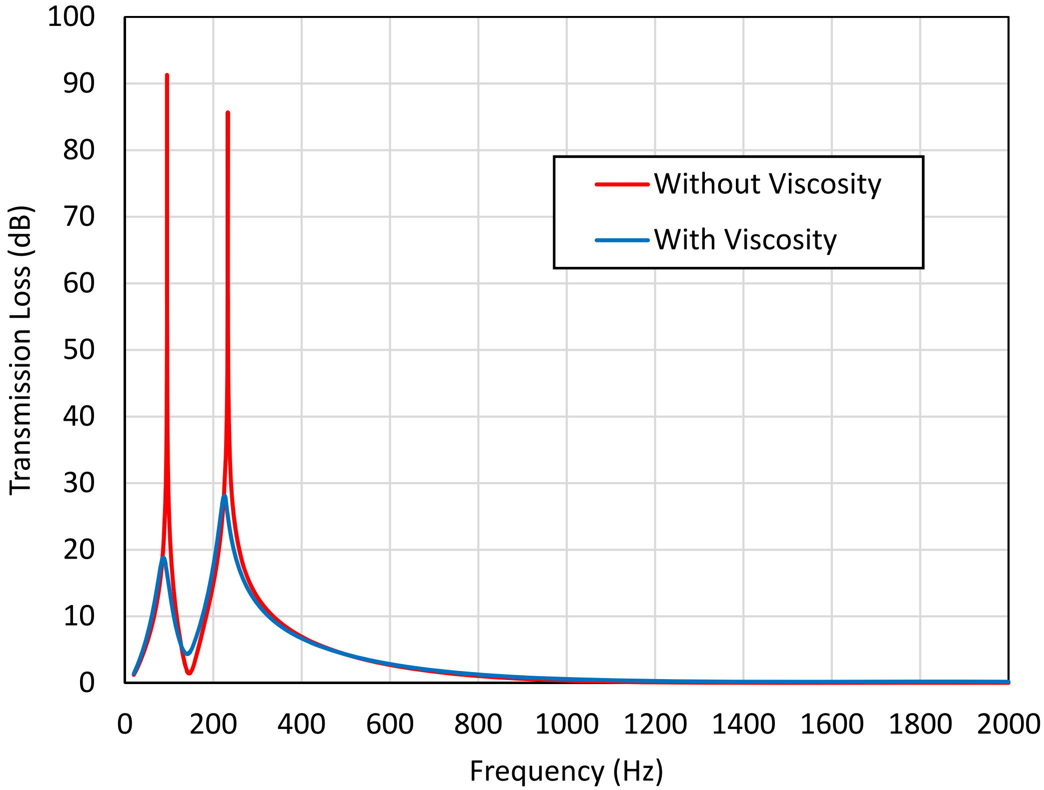




- If the target frequency is lower than what adjusting the slot width can achieve, an additional neck can be added to the slot design.
- An added neck may create a dip in TL between the two peaks when compared to the original performance without a neck.

Effects of Additional Neck Length

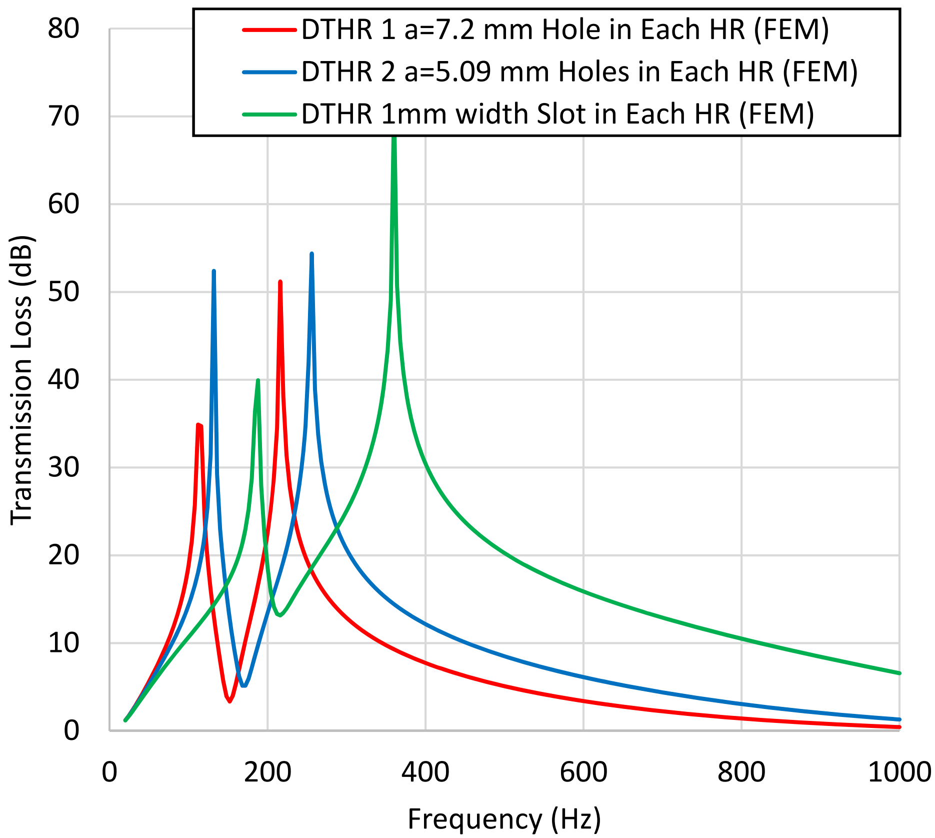
Design of DTHR



- When sound waves pass through a very narrow and long neck, fluid viscosity may have to be considered in numerical modeling.
- The peak frequencies remain the same for this case, but fluid viscosity does lower the two theoretically infinite sharp peaks.
- Viscosity does not change the TL in 1/3 octave bands.

Slot versus Hole DTHR Same Open Area

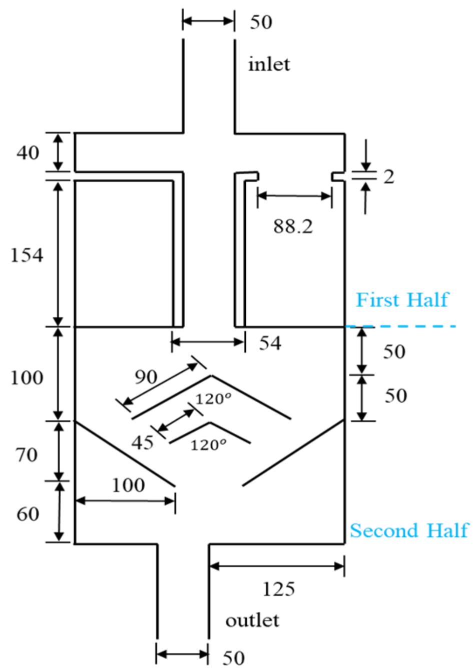
Design of DTHR



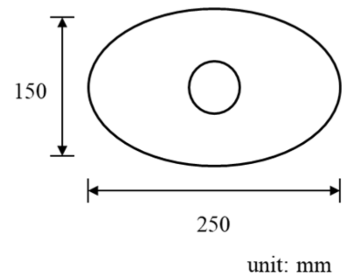
- The equivalent neck opening area alone is insufficient to determine the performance.

Case Study: Base

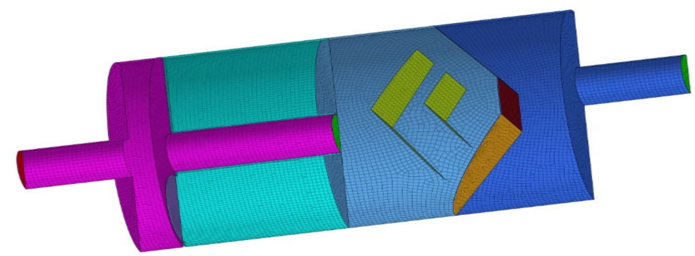
Design of DTHR



Side View



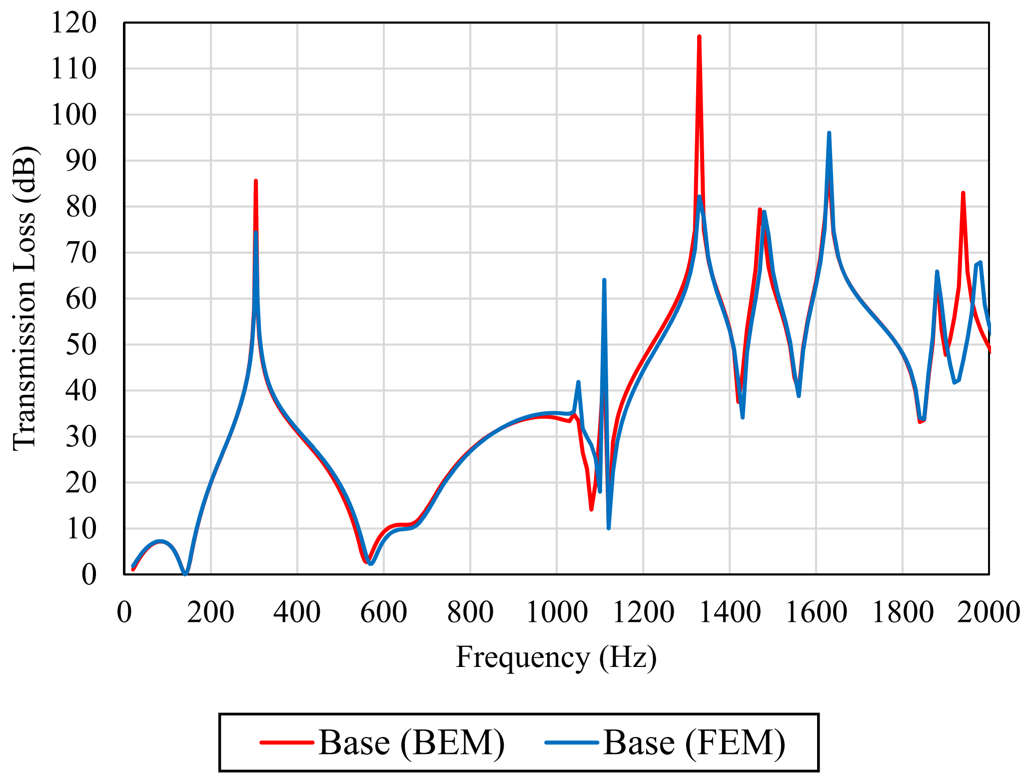
Top View



- The first half includes a resonator with an 88.2 mm diameter hole targeting the 300 Hz, along with a short expansion chamber placed in front of the resonator.
- Propose a few possible internal modifications within the same limitations of the exterior dimensions.

Case Study: Base

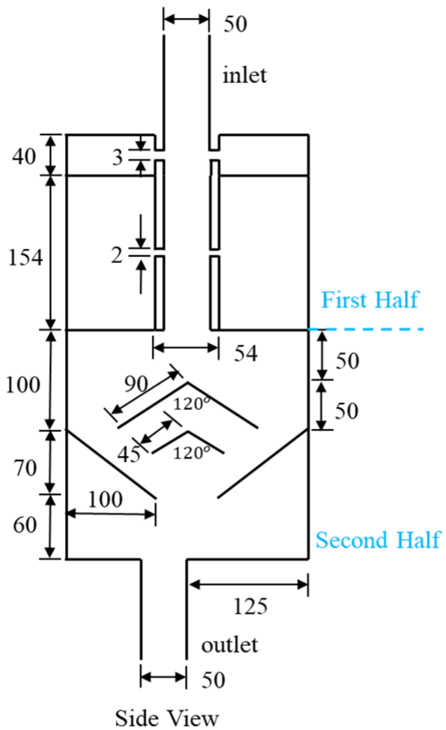
Design of DTHR

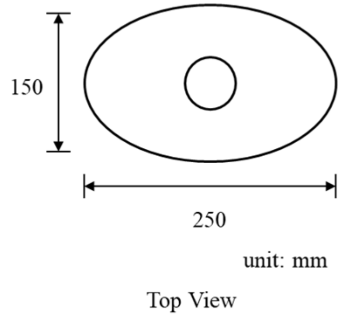


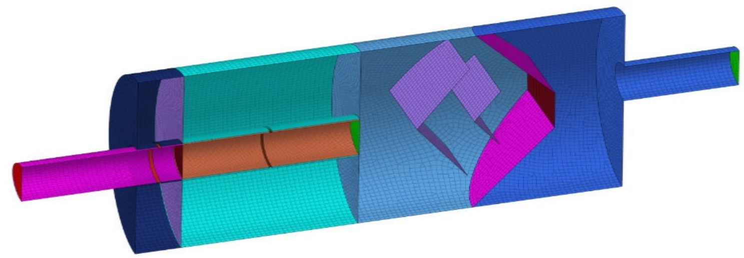
- The resonator does meet the 300 Hz performance target, but it has a low point around 600 Hz.
- The correction factor needed for the analytical formula to produce the 300 Hz target frequency is 2.4*a* instead of the conventional 1.7*a*.

Design Modification 1 DTHR

Design of DTHR



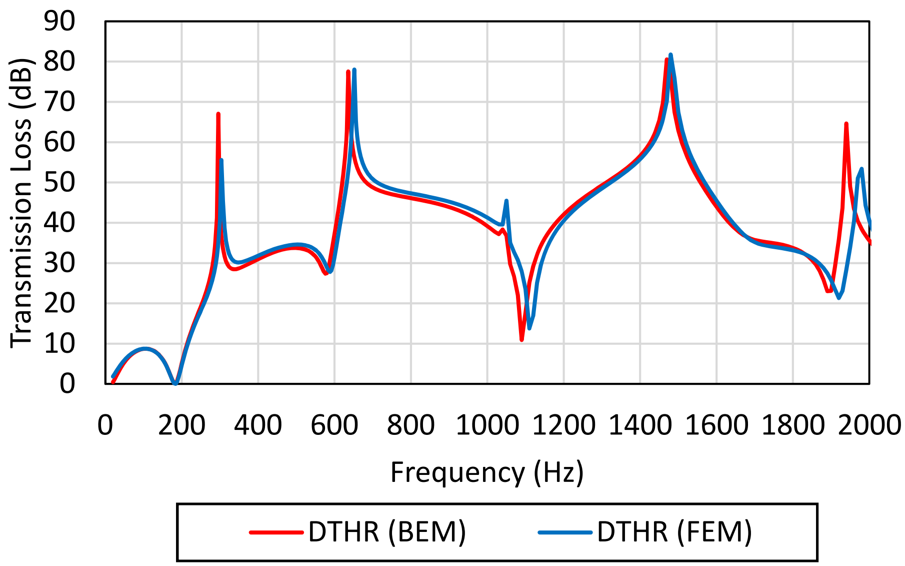


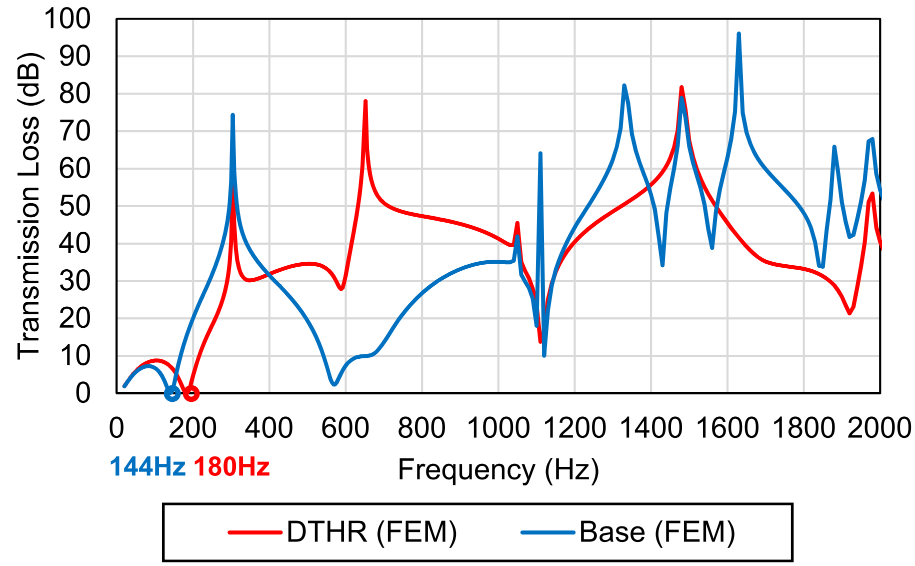


To improve the 600 Hz performance while maintaining the performance peak at the 300 Hz, the first half in the baseline design is replaced by a DTHR design.

Design Modification 1 DTHR

Design of DTHR

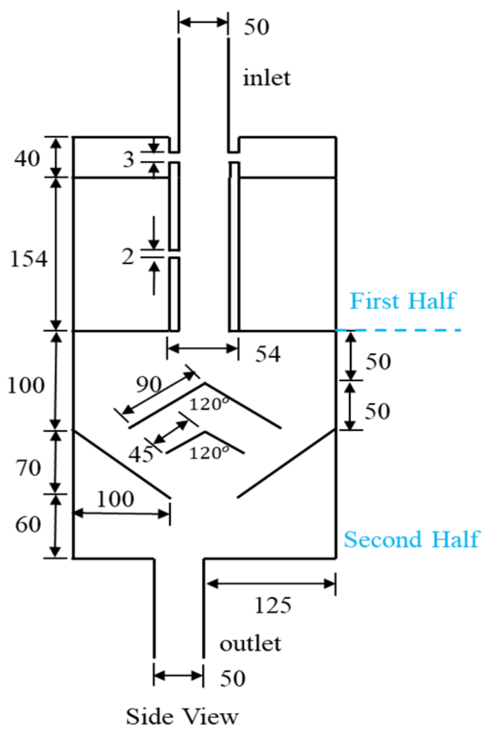


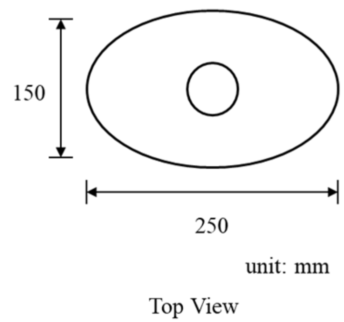


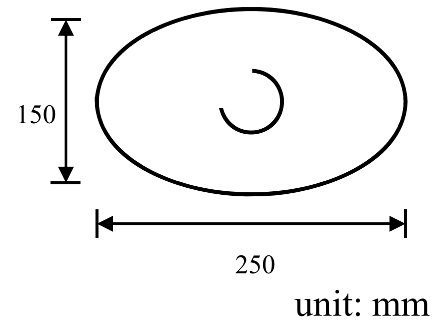
- The DTHR does hit the target frequencies at both 300 Hz and 600 Hz.
- The DTHR design has a much better overall performance under 1000 Hz when compared to the baseline design.
- Both the baseline and the DTHR design still have a performance dip at 144 Hz and 180 Hz, respectively.

Design Modification 2 DTHR with Quarter Slot

Design of DTHR



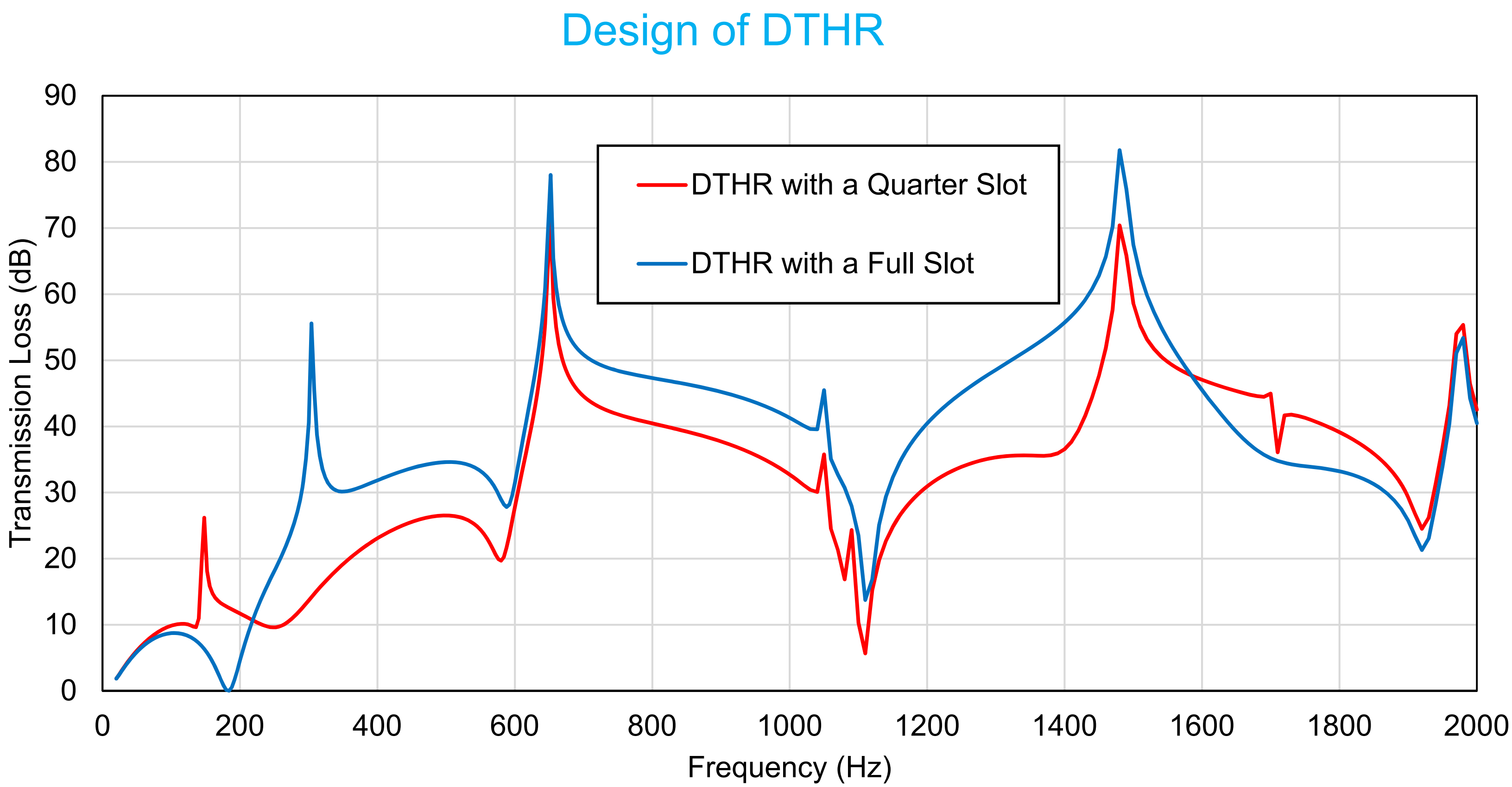




Quarter opening for HR2

To improve the low-frequency performance, the length of the 2 mm slot in HR2 from a full circumferential slot is reduced to only a quarter slot around the circumference.

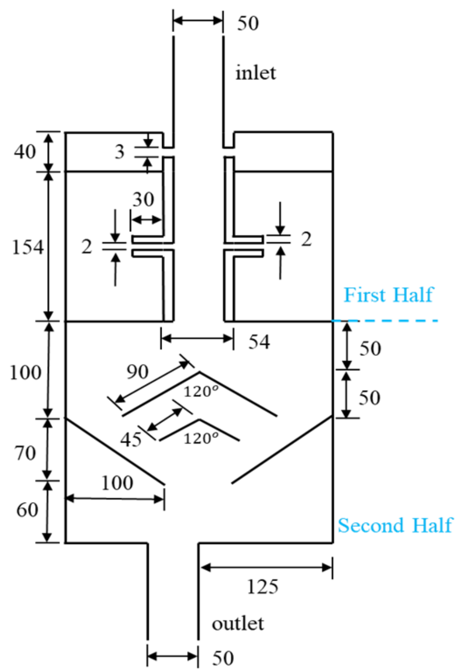
Design Modification 2 DTHR with Quarter Slot



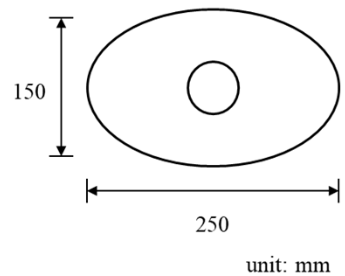
The modified quarter slot design can improve the low-frequency performance while keeping the overall performance between 300 Hz and 1000 Hz above 15 dB.

Design Modification 3 DTHR with Added Neck

Design of DTHR



Side View

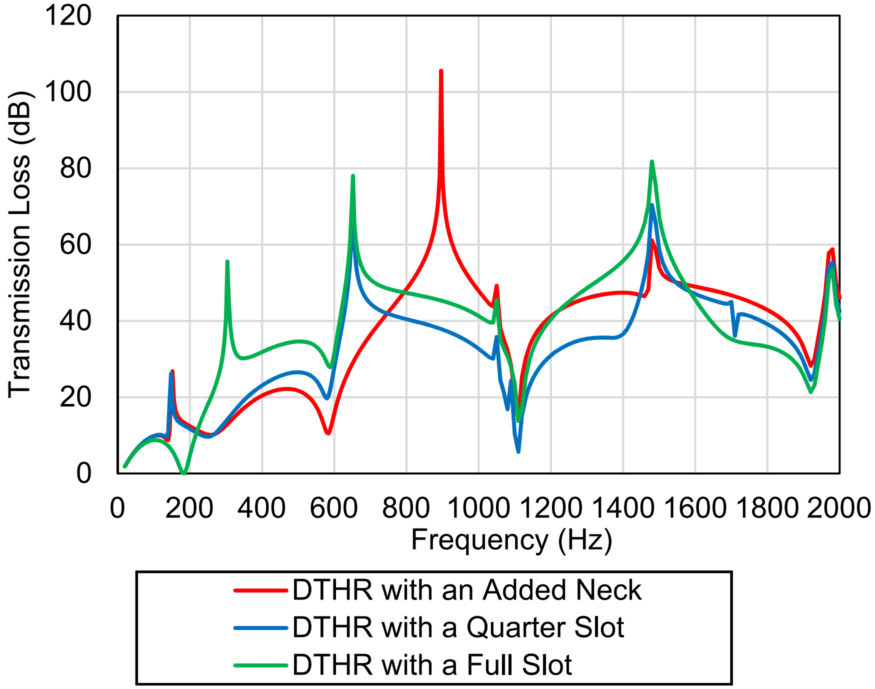


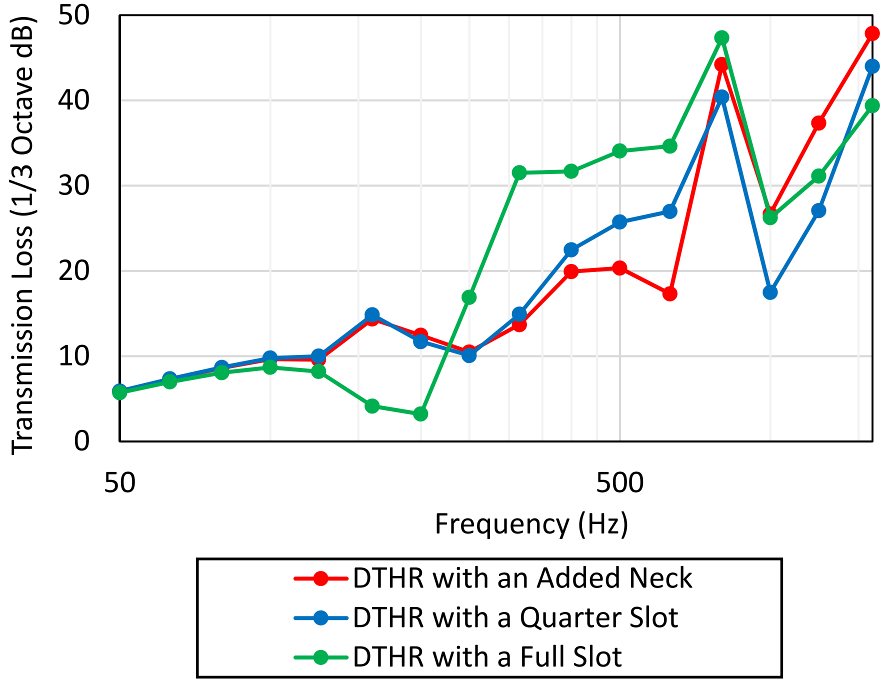
Top View

We add a 30 mm neck in HR2.

Design Modification 3 DTHR with Added Neck

Design of DTHR





The quarter slot design has better TL performance than adding neck length under 1000 Hz.

Summary

Design of DTHR

- DTHR provides good broadband attenuation at the low frequencies.
- DTHR can be tuned by changing the slot length, slot width, or the slot arc angle.