Numerical Studies on Double Expansion Chamber Mufflers with Acoustic Black Hole Modification

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INTRODUCTION: Mufflers are used for reducing exhaust noise from automotive engines. Double expansion chamber(DEC) muffler is one design to improve noise reduction of the muffler. However, the double expansion chamber muffler takes more space and has significant decrease of Transmission Loss(TL) at specific frequencies corresponding to resonance frequencies. To eliminate the decrease of TL, Acoustic Black Hole Modification is applied DEC Mufflers. Excellent results are obtained using the ***Acoustics Module of COMSOL Multiphysics®.***

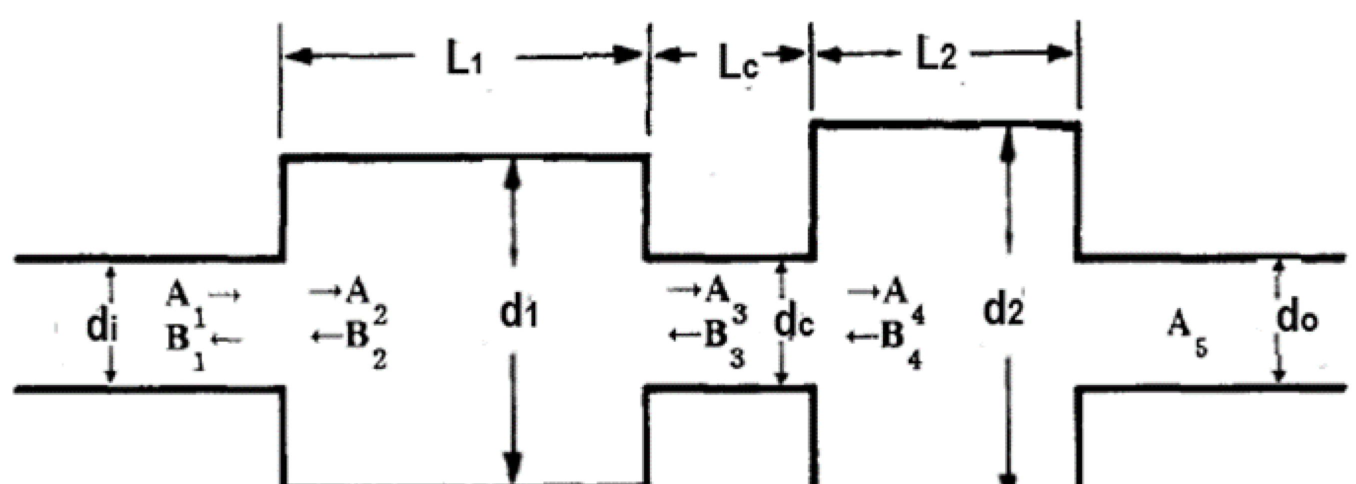

Figure 1. Schematic of a Double Expansion Chamber muffler

Acoustics Black Hole(ABH) Modification: For a give length of ABH at low frequency, when sound propagates through ABH area, most sound being reflected due to high reflection coefficient (near to 1).

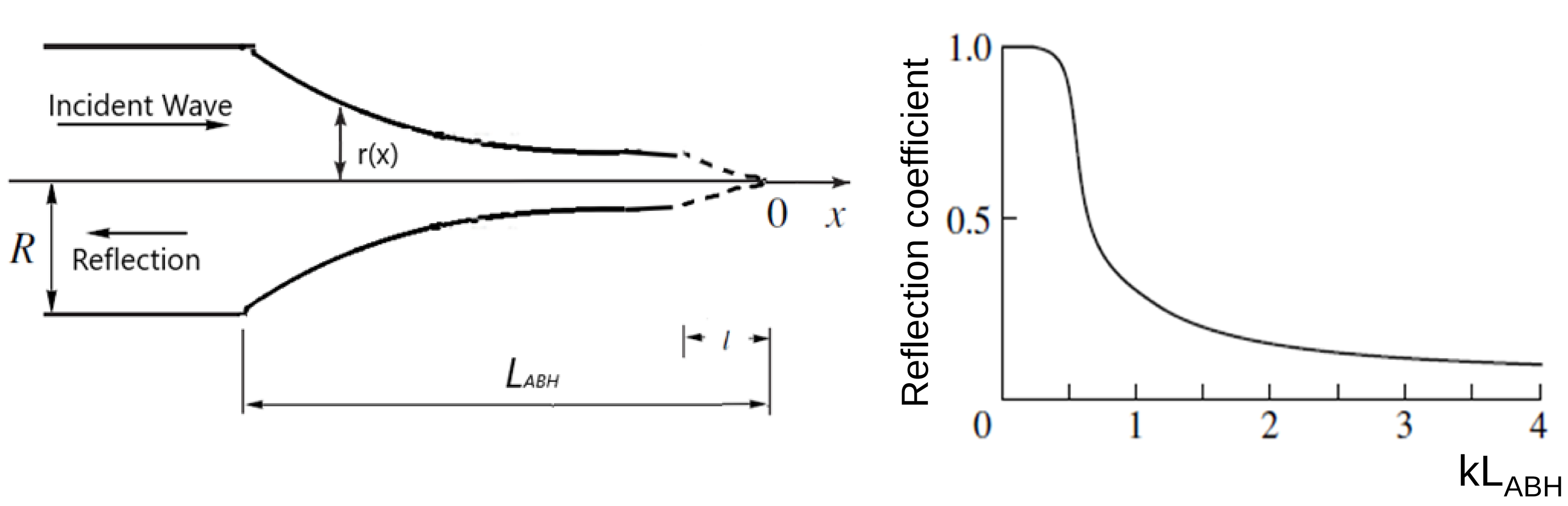

Figure 2. Reflection of sound from an ABH termination in ducts.

Mathematical Equations: Transmission Loss of Double Expansion Chamber Muffler with unequal sized chambers is

$$\boldsymbol{TL} = 10\,log_{10}\left(\left[Re\left({}^{A_1}\!/_{A_5}\right)^2 + Im\left({}^{A_1}\!/_{A_5}\right)^2\right]\right)$$

Where

$$\begin{aligned} {}^{A_1}\!/_{A_5} &= \frac{1}{16 m_d n_d}\{[(C_1 + C_2 - C_3)cos\,k(L_1 + L_c + L_2) \\ &+ (-C_4 - C_5 + C_3)cos\,k(L_1 + L_c - L_2) + (C_6 - C_7 + C_8)cos\,k(L_1 - L_c + L_2) \\ &+ (-C_6 + C_7 - C_9)cos\,k(L_1 - L_c - L_2)] \\ &+ i\,[(C_1 + C_2 + C_3)sin\,k(L_1 + L_c + L_2) + (-C_4 - C_5 - C_3)sin\,k(L_1 + L_c - L_2) \\ &+ (C_6 - C_7 - C_8)sin\,k(L_1 - L_c + L_2) + (-C_6 + C_7 - C_9)sin\,k(L_1 - L_c - L_2)]\} \end{aligned}$$

$$\begin{aligned} C_1 &= 2(m_d + 1)(n_d + 1)^2, \\ C_2 &= (m_d + 1)(m_d - 1)(n_d + 1)^2, \\ C_3 &= (m_d + 1)(m_d - 1)(n_d + 1)(n_d - 1), \\ C_4 &= 2(m_d + 1)(n_d - 1)^2, \\ C_5 &= (m_d + 1)(m_d - 1)(n_d - 1)^2, \\ C_6 &= 2(m_d + 1)(n_d + 1)(n_d - 1), \\ C_7 &= (m_d + 1)^2(n_d + 1)(n_d - 1), \\ C_8 &= (m_d - 1)^2(n_d - 1)^2, \\ C_9 &= (m_d - 1)^2(n_d + 1)^2. \end{aligned}$$

$$m_d = {}^{d_1^2}\!/_{d_i^2}, \; n_d = {}^{d_2^2}\!/_{d_c^2}$$

RESULTS: For this case, ***L1=Lc=12 in, L2=24 in, m=16*** as defined in Figure 1, a very good agreement can be observed in comparison of the mathematical calculation and numerical analysis of unmodified DEC muffler with unequal sized chambers as shown in Figure 4. which indicates that the numerical code and simulation model are valid. The numerical results in figure 5 shows DEC muffler with ABH can fully eliminate the decrease of TL at des circle location.

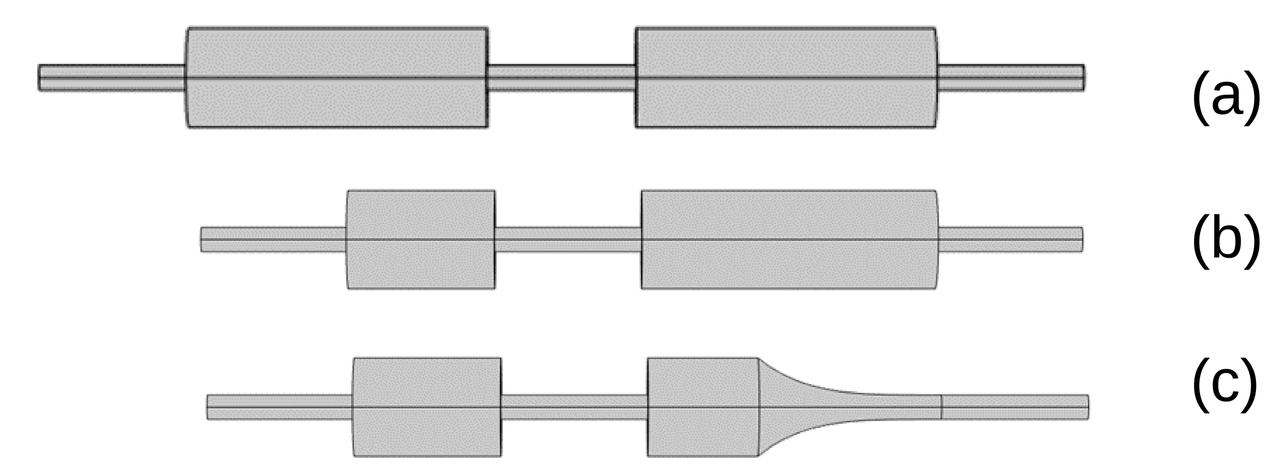

Figure 3. Illustration of the DEC muffler (a) with equal sized muffler and unequal size muffler (b) without ABH modification and (c) with ABH modification.

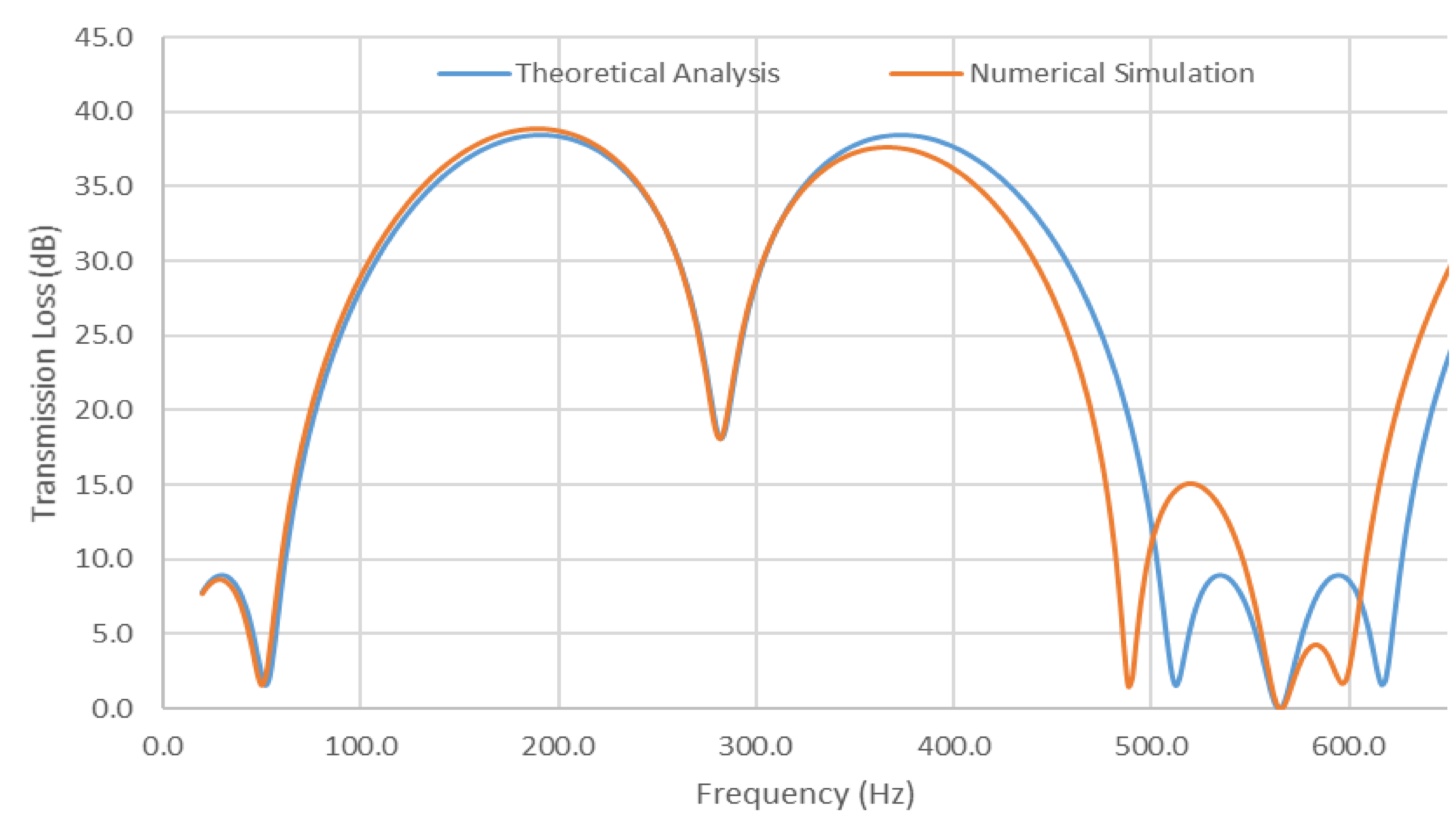

Figure 4. The comparison of the theoretical analysis and simulation results of the unmodified DEC muffler with unequal size chambers

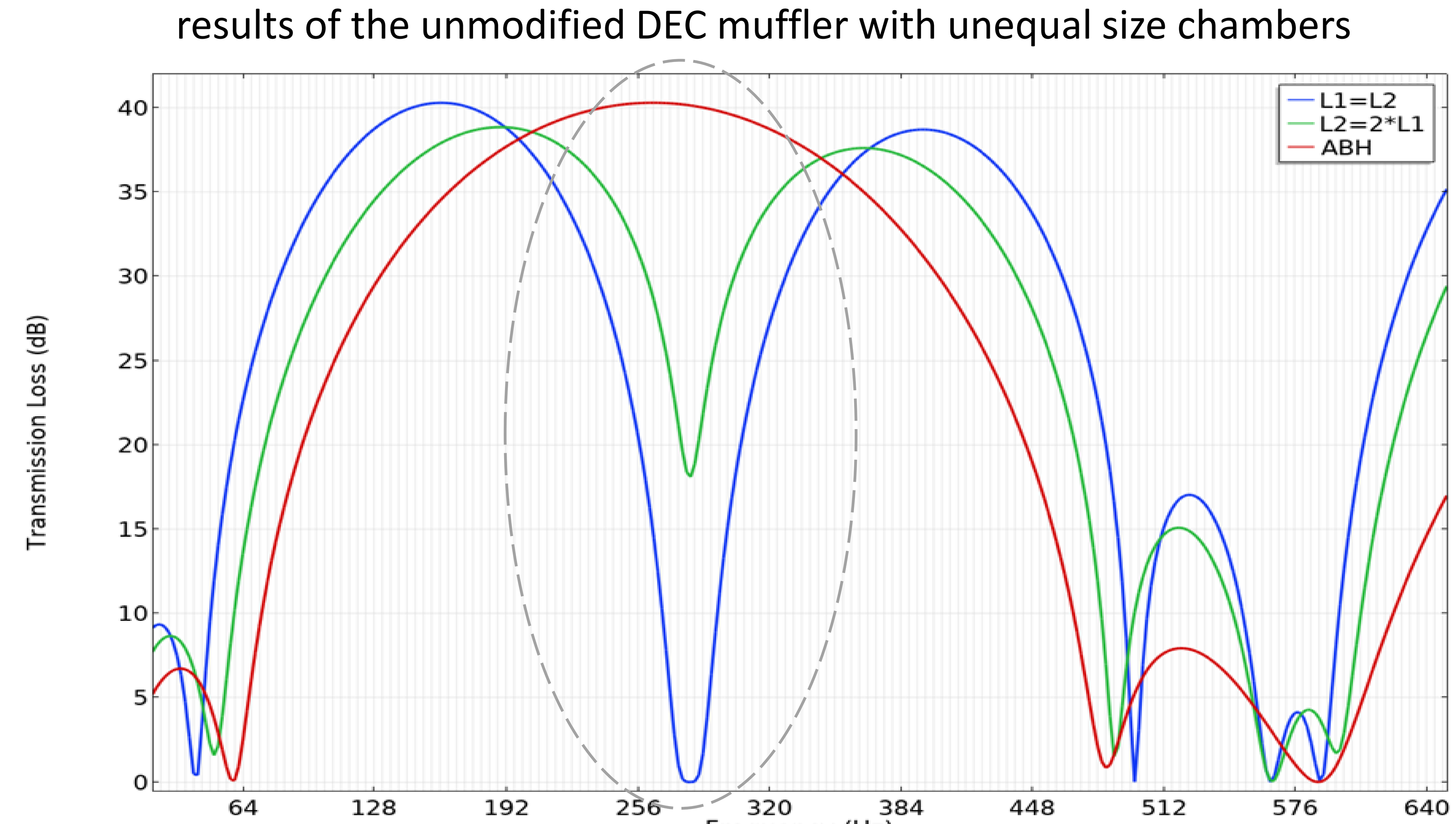

Figure 5. The simulation results of TL of DEC muffler with unequal size chambers without ABH modification (green), with ABH modification (red), and the DEC muffler with equal size chambers(blue).

CONCLUSIONS: The modified DEC muffler with ABH can fully eliminate the decrease of TL corresponding to the resonance frequencies. ABH modified chamber is about one-half volume of the original unmodified one.

REFERENCES:

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2. J.S. Lamancusa, "The Transmission Loss of Double Expansion Chamber Mufflers with Unequal Size Chambers", Applied Acoustics, 24, 15-32, (1987).
3. C. Zhao and M.G. Prasad, Studies on a Modified Simple Expansion Chamber Muffler using Acoustic Black Hole, Noise-Con 2019, San Diego, CA, (2019).