

Determination of Transmission and Insertion Loss for the General Multi-Inlet Multi-Outlet Case

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ABSTRACT

Prior research on assessing multiple inlet and outlet mufflers is limited, and only recently have researchers begun to consider suitable metrics for multiple inlet and outlet mufflers. In this paper, transmission loss and insertion loss are defined for multiple inlet and outlet mufflers using a superposition method that can be extended to any m -inlet n -outlet muffler. Transmission loss is determined assuming that the sources and terminations are anechoic. On the other hand, insertion loss considers reflections. For both metrics, the amplitude and phase relationship between the sources should be known a priori. This paper explains both metrics, and measurement of transmission and insertion loss are demonstrated for a 2-inlet 2-outlet muffler with good agreement.

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INTRODUCTION

Most prior muffler research has been dedicated to the single-inlet and single-outlet (SISO) case. Transmission and insertion loss are the two metrics most commonly used to evaluate the performance of a muffler system. For a SISO muffler, transmission loss is defined as the logarithmic ratio between incident and transmitted sound powers, under the assumption that both the source and termination are anechoic. This eliminates the influence of reflections from the source and termination, thus making transmission loss an attribute of the muffler itself [1]. Transmission loss can be readily calculated from the transfer matrix below the plane wave cut-off frequency.

Insertion loss, on the other hand, is defined as the difference between the sound pressure levels with and without the muffler installed. Insertion loss is an evaluation of the muffler in a specific source and termination combination and is most easily measured. However, calculation is problematic. Reflections from the source and termination must be taken into consideration meaning that the source and termination impedances must be known to calculate insertion loss [2].

Multi-inlet and multi-outlet (MIMO) mufflers have been investigated in generally two ways. Selamat and Ji [3] and Denia et al. [4] investigated the transmission loss of circular expansion chambers using a mode-matching approach and developed analytical solutions for pre-defined configurations. The solutions from a mode-matching approach are for certain configurations and cannot be easily extended

to the general case. Another approach by Jiang [5] and Mimani and Munjal [6] is based on an impedance matrix, which is obtained by either plane wave analysis or the boundary or finite element method. In both approaches, it is noted that transmission loss and insertion loss for MIMO mufflers are dependent on the amplitude and phase relationship between the sources, which can be dealt with by using complex ratios between each source and a reference source.

In this work, the definitions for transmission loss and insertion loss are extended to the MIMO case using a different approach based on transfer matrix theory and superposition. A MIMO muffler is considered as several SISO mufflers, and transfer matrix theory is used to characterize each. Results are combined using a superposition approach assuming that the phasing between sources is known. The approach is validated using an experimental 2-inlet 2-outlet muffler.

SOURCE MODEL

For MIMO mufflers, the amplitude and phase relationship between sources and the source impedance must be taken into consideration when defining transmission and insertion loss. In this work, a circuit analogy model [1] is used to describe the sources. The sound source is modeled as a pressure source (analogous to a voltage source) and source impedance (z_s) in series with the acoustic load impedance (z_L) (Fig.1). It is assumed that the particle velocity (analogous to electrical current) is continuous at the source-load interface.

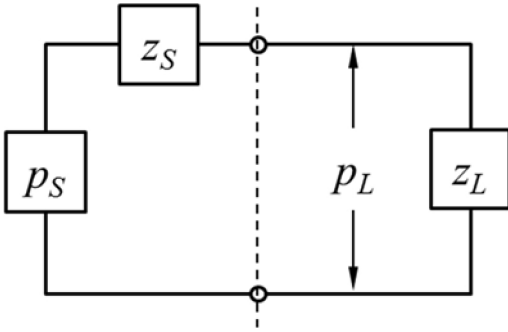


Figure 1. Schematic showing circuit analogy for acoustic sources.

From this model, it can be observed that

$$\frac{p_S}{z_S + z_L} = \frac{p_L}{z_L} \quad (1)$$

where p_S and z_S are the source strength and impedance respectively. p_L and z_L are the respective load sound pressure and impedance. To use this model, the interface between the sound source and load must be assumed. p_L and z_L can be determined indirectly from measurement by performing wave decomposition downstream of the source using the two-microphone method [7].

As there are two unknowns (p_S and z_S) in Eqn.1, at least two equations should be obtained from two different working conditions of the system (i.e., acoustic loads). The set of equations can be represented as

$$\begin{bmatrix} z_L^{(1)} & -p_L^{(1)} \\ z_L^{(2)} & -p_L^{(2)} \end{bmatrix} \begin{Bmatrix} p_S \\ z_S \end{Bmatrix} = \begin{Bmatrix} z_L^{(1)} p_L^{(1)} \\ z_L^{(2)} p_L^{(2)} \end{Bmatrix} \quad (2)$$

where the superscript indicate the respective load. For higher accuracy, more than two loads can be used and the source properties can be solved using a least-square method [8].

TRANSMISSION LOSS

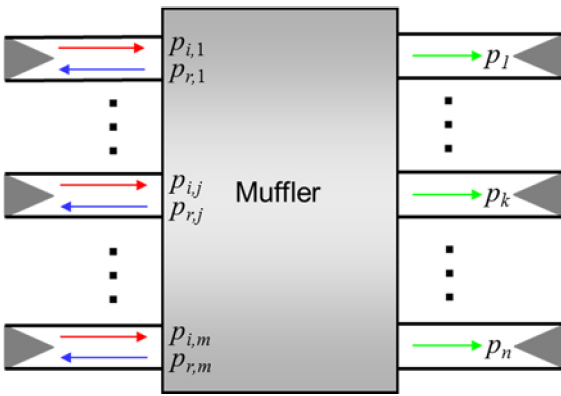


Figure 2. m-inlet n-outlet muffler with anechoic sources and terminations.

The definition of transmission loss for MIMO mufflers is a straight forward extension from the SISO case. As Fig. 2 shows, the sound

pressures inside Inlet j are decomposed into incident and reflected waves $p_{i,j}$ and $p_{r,j}$ respectively. Under the assumption that all the sources and terminations are anechoic, the transmission loss is defined as the ratio between the summation of incident sound power in the inlets and the summation of transmitted sound power in the outlets where s_j and s_k are cross-sectional area of inlets and outlets. Accordingly,

$$TL = 10 \log_{10} \frac{\sum_j W_{j,incident}}{\sum_k W_{k,transmitted}} = 10 \log_{10} \frac{\sum_j |p_{i,j}|^2 s_j}{\sum_k |p_{t,k}|^2 s_k} \quad (3)$$

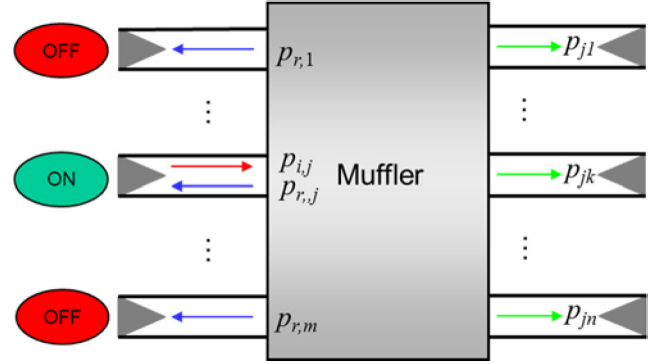


Figure 3. Superposition model for transmission loss calculation.

To calculate $p_{i,j}$ and $p_{r,j}$, a superposition model can be used. First assume only one source (j) is active (Fig. 3), the transmitted sound pressure at Outlet k can be calculated using transfer matrix between Inlet j and Outlet k and the circuit analogy source model. Hence,

$$\begin{Bmatrix} p_{Lj} \\ v_{Lj} \end{Bmatrix} = \begin{bmatrix} A_{jk}^a & B_{jk}^a \\ C_{jk}^a & D_{jk}^a \end{bmatrix} \begin{Bmatrix} p_{jk} \\ v_{jk} \end{Bmatrix} \quad (4)$$

The load sound pressure and particle velocity can be expressed as

$$p_{Lj} = p_{i,j} + p_{r,j} \quad (5)$$

and

$$v_{L,j} = \frac{p_{i,j} - p_{r,j}}{z_c} \quad (6)$$

where z_c is characteristic impedance, and the superscript a indicates the transfer matrix is obtained with anechoic boundary conditions applied to all inlets and outlets other than Inlet j and Outlet k . From the circuit analogy in Fig. 1,

$$\frac{p_{sj} - p_{Lj}}{v_{Lj}} = z_c \quad (7)$$

Since outlets are assumed anechoic,

$$\frac{p_{jk}}{v_{jk}} = z_c \quad (8)$$