

# Investigation of the Acoustic Performance of After Treatment Devices

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## ABSTRACT

Diesel engines produce harmful exhaust emissions and high exhaust noise levels. One way of mitigating both exhaust emissions and noise is via the use of after treatment devices such as Catalytic Converters (CC), Selective Catalytic Reducers (SCR), Diesel Oxidation Catalysts (DOC), and Diesel Particulate Filters (DPF). The objective of this investigation is to characterize and simulate the acoustic performance of different types of filters so that maximum benefit can be achieved. A number of after treatment device configurations for trucks were selected and measured. A measurement campaign was conducted to characterize the two-port transfer matrix of these devices. The simulation was performed using the two-port theory where the two-port models are limited to the plane wave range in the filter cavity. These models are implemented in SIDLAB Software for the simulation of low frequency sound propagation in ducts, and SIDLAB was used to predict the transfer matrix of the tested configurations. This paper presents guidelines for dividing these complicated systems into a number of simple 1D elements. Specifically, strategies for modeling the side inlet and outlet end caps are documented. The model takes about 15 minutes to set-up and 15 seconds to solve which demonstrates the power of using two-port techniques in modeling exhaust systems. The comparisons show good agreement between the measured and simulated transmission loss in the plane wave region.

## INTRODUCTION

Protection of the environment is a concern of global interest. It is universally acknowledged that the steady rise in all kinds

of pollution cannot continue. The pollution from internal combustion and diesel engine emissions is especially alarming, but exhaust emissions are not the only concern. Diesel engines are also notorious for their noise levels. Currently, trucks and heavy equipment must pass noise certifications in order to be admitted in many markets. Moreover, noise is a major factor influencing marketability and competitiveness.

One way of mitigating both exhaust emissions and noise is via the use of after treatment devices like catalytic converters and diesel particulate filters (DPF). The research proposed herein will focus on DPF units. DPF units are devices which remove from 50 to over 90 percent of diesel particulate matter from exhaust gases. Their use in both the United States and Europe will likely be mandated by 2013. DPF units are similar to catalytic converters, but differ by introducing a less direct path through the filter as shown in [Figure 1](#). Instead of a straight-through path, exhaust gases must penetrate through a porous cell wall before exiting the filter. A number of different filter materials have been used including ceramic and silicon carbide materials, fiber wound cartridges, knitted silica fiber coils, ceramic foam, wire mesh, and sintered metal structures. DPF units not only filter out particulate matter, but are also excellent noise filters due to the indirect air path plus the filter itself consists of sound absorbing materials.

The objective of this paper is to investigate several after treatment devices. The passive acoustic properties of three different units are measured and compared to the 1D simulations using two-port techniques. The acoustic two-port is measured at no flow in addition to 3 different flow

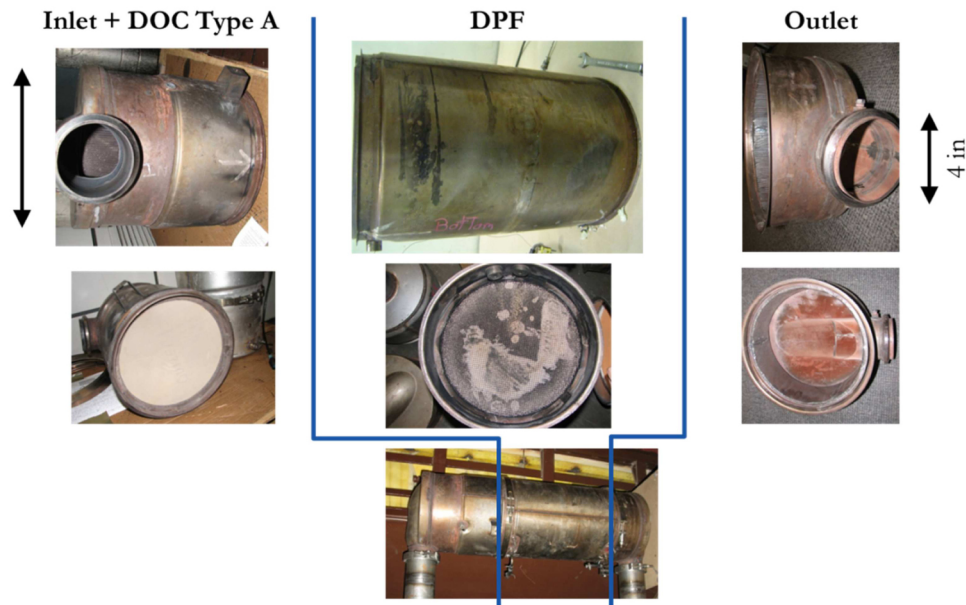


*Figure 1. The DPF unit with the DOC filter, inlet and outlet end caps.*



*Figure 2. The SCR unit with AMOX filter, inlet and outlet end caps.*

conditions. The permeability of the DPF walls was estimated from the measurement of the linear pressure drop across the filter.

## TESTED CONFIGURATIONS

Three units were tested in this paper. The first is a DPF unit which consists of a Diesel Oxidation Catalyst filter Type A and a Diesel Particulate Filter, both enclosed between side inlet and outlet end caps (Figure 1). The second unit is the same but with a different Diesel Oxidation Catalyst filter

Type B. The third is an SCR unit which consists of an Ammonia Oxidation Catalyst (AMOX) filter, and a Selective Catalytic Reducer (SCR) filter, both enclosed between side inlet and outlet end caps (Figure 2). The inlet diameter of all units is 4 inch and the cavity diameter is 12 inch.

Figure 3 shows how these units are divided into a number of two ports for the simulation in SIDLAB. The green dot is the inlet node, whereas the red dot is the outlet node. The side inlet and outlet end caps are divided into 3 pipes as shown in the figure. The blue dot indicates a closed pipe to simulate the

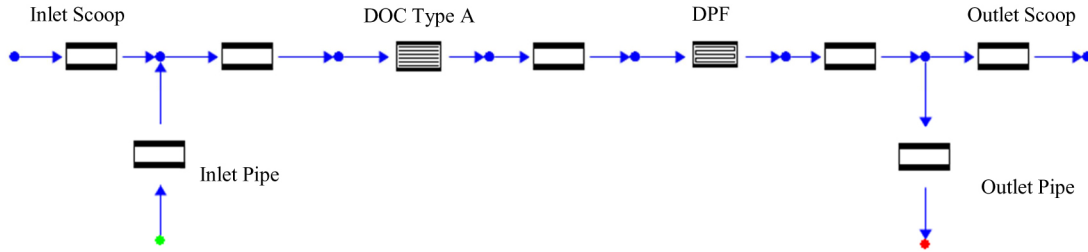


**Figure 3. The SIDLAB network of the tested units.**

quarter-wavelength resonator from both sides. Between the inlet and outlet end caps, there are two filters installed with a short empty pipe in-between.

## THEORETICAL MODEL

Duct systems or networks are often too complicated to enable direct solution of the governing equations. One method to describe the sound transmission along the system is called the building block method or two-port transfer matrix method. This method splits the system into several smaller duct parts (i.e. acoustic elements) in which the sound propagation is well defined. Plane waves are assumed to propagate between different elements and the sound field can be characterized by two state variables. One convenient choice is to use pressure and volume velocity. The sound propagation inside each element is analyzed separately and higher order modes can exist inside the element.

There exists a complex  $2 \times 2$  matrix  $\mathbf{T}$ , one for each frequency, which completely describes the sound transmission within this element. The pressure and volume velocity on each side of the element can be related with the following expression

$$\begin{bmatrix} p_1 \\ q_1 \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \cdot \begin{bmatrix} p_2 \\ U_2 \end{bmatrix} + \begin{bmatrix} p^s \\ q^s \end{bmatrix} \quad (1)$$

where  $p$  and  $q$  are the pressure and volume velocity, 1 refers to the inlet side and 2 refers to the outlet side,  $T_{ii}$  are the elements of the two-port transfer matrix,  $p^s$  is the source pressure and  $q^s$  is the source volume velocity.

After all the elements in a network are generated, they are connected to each other as defined by the network structure and the sound propagation in the complete duct system can be analyzed. If the elements are connected in cascade ("a chain"), the problem is simple and the transfer matrix for the system is the result of the successive multiplication of the transfer matrices of all elements. If the elements are connected in an arbitrary fashion, the analysis developed by Glav and Åbom [1] is used to set up a global network matrix. A code to analyse low frequency sound propagation in complex duct networks [3] called SIDLAB has been

developed jointly by some of the authors. It is based on the representation of a duct network as a network of two-ports. SIDLAB was used in this work for the 1D simulations.

## CATALYTIC CONVERTER

Catalytic converters have been a standard element in automobile exhaust system since the 90s. A catalytic converter is used to decrease the contents of harmful exhaust gases, mainly CO, HC, and NOx, from internal combustion engines. The key element in a typical catalytic converter is the honeycomb structure which consists of a large amount of parallel coated capillary pipes. The model used in SIDLAB Simulation is the one developed by Allam and Åbom [1]. The transfer matrix of a catalytic converter can be split into three different parts, the inlet cross section ( $T_{in}$ ), the narrow pipes with hard impermeable walls ( $T_p$ ), and the outlet cross section ( $T_{out}$ ), and is expressed as

$$T_{cc} = T_{in} T_p T_{out} \quad (2)$$

The inlet and outlet sections represent coupling two ports which are needed since the pressure and volume velocity are not continuous at a sudden area change with flow. The inlet and outlet two ports are obtained by applying the principle of conservation of energy and momentum, respectively. Since the mach number in the catalytic converter section is very small in practice (less than 0.1), these relations can be derived assuming incompressible mean flow. The resulting two ports are

$$T_{in} = \begin{bmatrix} 1 & Z_{in} M_{in} (1/m_{in}^2 - 1) \\ 0 & 1 \end{bmatrix} \quad (3)$$

$$T_{out} = \begin{bmatrix} 1 & 2Z_{out} M_{out} (1 - 1/m_{in}) \\ 0 & 1 \end{bmatrix} \quad (4)$$

where  $Z_i = \rho_i c_i / A_i$ ,  $M_i$  is the Mach number, and  $m_i$  is the percentage open area. The transfer matrix for the narrow pipe section can be calculated using the classical Kirchoff solution for narrow pipes