

Enhancing the Performance of Microperforated Panel Absorbers by Designing Custom Backings

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ABSTRACT

Micro-perforated (MPP) panels are acoustic absorbers that are non-combustible, acoustically tunable, lightweight, and environmentally friendly. In most cases, they are spaced from a wall, and that spacing determines the frequency range where the absorber performs well. The absorption is maximized when the particle velocity in the perforations is high. Accordingly, the absorber performs best when positioned approximately a quarter acoustic wavelength from the wall, and larger cavity depths improve the low frequency absorption. At multiples of one half acoustic wavelength, the absorption is minimal. Additionally, the absorption is minimal at low frequencies due to the limited cavity depth behind the MPP. By partitioning the backing cavity, the cavity depth can be strategically increased and varied. This will improve the absorption at low frequencies and can provide absorption over a wide frequency range. In this work, backing substrates have been developed to enhance the absorption performance. Maa's model is first reviewed. Then, different MPP and backing substrate combinations are analyzed using Maa's theory and the boundary element method. The broadband absorptive behavior is validated via measurement in a square impedance tube. Measured results agree reasonably well with analysis.

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INTRODUCTION

Micro-perforated panel (MPP) absorbers are a promising complement for traditional sound absorbing materials like fibers and foams since they are light weight, nonflammable, cleanable, durable, and fiber free. Because of these advantages, MPP absorbers have been utilized in mufflers [1-2], HVAC ducts [3], building interiors [4], engine enclosures [5], and noise barriers [6-7].

MPP absorbers are normally manufactured from steel, aluminum or plastic and have uniformly distributed sub-millimeter sized holes and low porosity (typically under 5%). The first generation MPP absorbers were metal panels with circular perforations. In order to reduce the manufacturing cost, slit-shaped perforations have become common recently. Slits are pressed or cut into the metal instead of by laser or chemical reaction.

MPP absorbers are most often spaced from a rigid wall. In fact, it is best to think of the absorber as a system consisting of both the panel and backing cavity. Air oscillates back and forth in the perforations. Since the perforations are small, the acoustic resistance is high. Accordingly, frictional losses are

greatest when the particle velocity in the pores is maximized. This roughly corresponds to spacing the panels a quarter acoustic wavelength from the wall. Hence, larger cavity depths are required to extend absorption to lower frequencies.

Whereas foams and fibers provide excellent broadband absorption above a certain frequency, the frequency range that MPP absorbers perform acceptably in is banded and much narrower due to the sound absorbing mechanism. Absorption is minimal when the particle velocity in the perforations is low. Accordingly, the spacing from the wall controls the frequencies of effectiveness and the absorption is

greatest when the MPP is approximately $\frac{1}{4}\lambda$, $\frac{3}{4}\lambda$, $\frac{5}{4}\lambda$... away from the wall where λ is the acoustic wavelength. Absorption is low in frequency ranges corresponding roughly to multiples of a half acoustic wavelength.

Moreover, MPP absorbers generally do not perform as well as a fiber or foam even at the frequencies they are designed for. Yairi et al. [8], Toyoda and Takahashi [9], and Liu et al. [10] demonstrated that performance is comparable to traditional absorbing materials only when the backing

cavity is partitioned. Probably, the most common partitioning used has been a honeycomb. In most cases, no effort has been made to vary the cavity depth.

Liu and Herrin [11] used boundary element simulation to investigate the reason for improved performance with partitioning. The study indicated that partitioning disrupts wave propagation behind the MPP and forces the MPP to behave like a traditional local reacting absorber. It was shown that acoustic waves that propagated normal to the panel were attenuated equally well with or without a partitioned substrate. The sound pressure due to grazing waves (propagating parallel to the MPP absorber) was essentially unaffected if partitioning was not used.

Efforts have been aimed at improving the broadband absorption of MPP absorbers. For example, double [12,13,14] or multi-layer [15] MPP absorbers have been suggested. Though the absorptive performance is improved, multi-layer MPP absorbers effectively double the materials cost and are more difficult to install. Additionally, partitioning should be installed between the layers to improve their effectiveness.

Others have considered varying the cavity depth. For example, Jiang [16] and Liu et al. [10] investigated using a triangular prism backed cavity. Sum [17] recommended a parallel stepped configuration. However, these approaches do not lend themselves to typical box-shaped enclosures.

The work in this paper focuses on improving single-layer MPP absorbers by developing a partitioned backing. The backing is designed so that cavity depth is increased which provides lower frequency absorption without adding additional volume. Moreover, the cavity depth is varied so that broadband frequency absorption is achieved. The normal incidence sound absorption of the newly designed backings was measured using a square impedance tube. Diffuse incidence absorption was measured using a reverberation chamber.

Two design concepts are considered in this paper. They include two-channel and three-channel arrangements as shown in Figure 1. By wrapping one channel around the others, the length of a single channel can be increased by well over 50%. In doing so, the low frequency absorption will be improved. Moreover, the lengths of channels can be varied to create a broadband absorber. The newly created backings are called a folded two-channel and folded three-channel. These ideas are similar to those proposed by Wirt [18] for ordinary perforated panels.

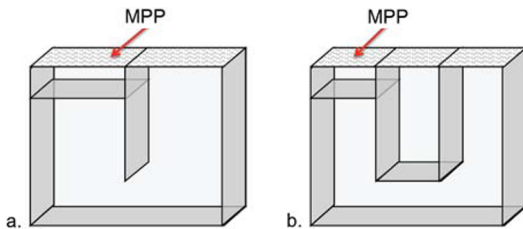


Figure 1. Schematics showing the folded a) two-channel and b) three-channel design concepts.

REVIEW OF MAA'S MODEL AND EQUIVALENT PARAMETERS

Maa's Model

As with other perforates, researchers have generally assumed that acoustic particle velocity is continuous due to the small thickness. Accordingly, Maa [19-20] modeled the MPP as a transfer impedance and expressed the impedance as:

$$Z_{tr} = \frac{32\eta t}{\sigma\rho_0 c d^2} \left(\sqrt{1 + \frac{\beta^2}{32}} + \frac{\sqrt{2}\beta d}{32t} \right) + \frac{j\omega t}{\sigma c} \left(1 + \frac{1}{\sqrt{9 + \frac{\beta^2}{2}}} + \frac{0.85d}{t} \right) \quad (1)$$

where η is the dynamic viscosity of air, t is the thickness of the MPP, σ is the porosity, ρ_0 is the density of the air, c is the speed of sound, d is the single hole diameter, ω is the angular frequency, and

$$\beta = d \left(\frac{\rho_0 \omega}{4\eta} \right)^{\frac{1}{2}} \quad (2)$$

is the perforate constant. For MPP absorbers with rectangular perforations, Maa [21] proposed a modified model, which is similar to the circular perforation MPP model and is expressed as

$$Z_{tr} = \frac{12\eta t}{\sigma\rho_0 c d^2} \left(\sqrt{1 + \frac{\beta^2}{18}} + \frac{\sqrt{2}\beta d}{12t} \right) + \frac{j\omega t}{\sigma c} \left(\left(1 + \frac{1}{\sqrt{25 + 2\beta^2}} \right) + \frac{1}{2} F(e) \frac{d}{t} \right) \quad (3)$$

where $e = \left(1 - \frac{d^2}{4l^2} \right)^{\frac{1}{2}}$ is the eccentricity of the ellipse and $F(e)$ is the incomplete elliptic integral of the first kind which is expressed as

$$F(e) = \int_0^{\frac{\pi}{2}} \frac{d\theta}{\sqrt{1 - e^2 \sin^2 \theta}} \quad (4)$$

The impedance at the surface of a conventional MPP absorber is expressed as

$$Z = Z_{tr} - j \cot\left(\frac{\omega D}{c}\right) \quad (5)$$

where D is the air cavity depth behind the MPP. It can be observed that the porosity, thickness, hole diameter, and the cavity depth govern the performance of the MPP absorber. The effect of varying the cavity depth is shown in Figure 2.

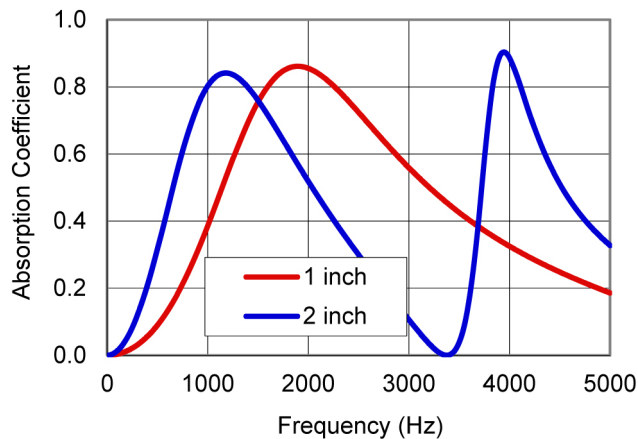


Figure 2. Typical absorption coefficients for a MPP absorber with different cavity depths.

Notice that an extremely low absorption band cannot be avoided when the cavity depth is approximately half of an acoustic wavelength. Moreover, increasing the cavity depth lowers the frequency of the high absorption band.

Equivalent Parameters Based on Maa's Model

At first glance, Maa's model seems difficult to apply to less expensive second-generation MPP absorbers where slits are pressed or cut into metal. Although the sound absorbing mechanism is the same, Maa's equations cannot be applied directly due to the slit being irregular in shape (i.e., not circular or elliptical). Moreover, the slit is often pressed through the material at an angle and the dimensions of the slit are not consistent through the thickness.

However, Liu et al. [22] used a nonlinear least-square data-fitting algorithm to estimate equivalent parameters (usually porosity and hole size) from the measured absorption. The absorption of a sample with a given cavity depth is first measured and then a least-square data fitting algorithm is used to select a porosity and hole diameter that minimizes the error. The algorithm has been used to investigate the effect of manufacturing variability and dust

contamination. In the current effort, the method was used to determine the equivalent porosity and hole size of a MPP with slit perforations so that Maa's theory could be used for the simulation models.

The sound absorption of an MPP sample was measured using ASTM E1050 [23] with a two-inch cavity behind it. Maa's model was then fitted to the measured data from 200 to 1500 Hz. The fitted equivalent hole size and porosity were 0.26 mm and 8% respectively. The fitted and measured absorption are compared in Figure 3.

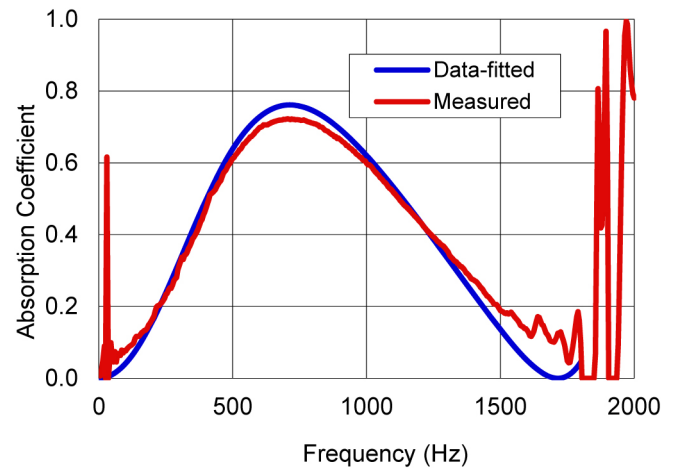


Figure 3. The fitted and measured absorption of a selected MPP with a backing cavity depth of 51 mm.

SIMULATION

Plane Wave Model for Parallel Cavities

Using the electrical analogy, the MPP can be modeled as being in series with the impedance of the backing cavity. The MPP is both resistive and reactive whereas the backing air cavity is purely reactive. Figure 4a illustrates the analogous electrical circuit.

In a similar manner, consider the case where the cavity is partitioned into a series of channels with varying depths as shown in Figure 4b. It can be assumed that the sound pressure is constant on the front surface of the MPP. In that case, the combined transfer impedance and reactance for each channel may be considered in parallel with its neighbor as shown in Figure 4b.