# Practical Single MPP Absorber

**Dah-You Maa**[†]

*Institute of Acoustics CAS, POB 2712, Beijing 100080, China*

(Received 8 September 2006; accepted 15 January 2007)

The construction and properties of microperforated panel (MPP) absorbers are discussed. MPP is a plate perforated with numerous sub-millimeter orifices forming a resonant sound absorber with a cavity behind. It has been shown that low values of the perforate constant $k$ and the orifice diameter $d$ are essential for the MPP to have high absorption over a wide frequency band. To find the exact absorption limits, one can assume for that $k = 1$ as a start, because both specific resistance and wide frequency bands of absorption require $k$ to be one or less. The orifice diameter $d$ is chosen as 0.1 mm, so that the peak absorption coefficient (resonance absorption) is at 1000 Hz, and the higher sound frequencies may be included in the absorption region. Is it possible for a single MPP to cover the whole absorption region required in practice? The half-absorption limit and 0.5 absorption coefficient limit were used as criteria for comparison with different load resistances. MPP absorbers designed for use typically absorb sound over approximately two octaves, and the new absorbers with low values of $k$ and $d$ are found to be better for $r = 1$ (relative acoustical resistance equal to the characteristic impedance $\rho c$ in air), over about 2.5 octaves. This increases to around 3 octaves for $r = 2$ or 3. In addition, the MPP in a reverberant sound field will absorb over a wider frequency ranges due to increased high frequency absorption. If the increase in range is enough, the absorption region will join forces with the secondary absorption regions, due to the multi-resonance property of the resonance structure, to form a continuous absorption region. The design of a single MPP absorber is given and its realisation is discussed.

[†] Honorary Fellow of the International Institute of Acoustics and Vibration (IIAV)

## 1. INTRODUCTION

A microperforated panel (MPP) absorber is made of thin sheet metal drilled or punched with tens of thousands of minute orifices of sub-millimetre diameter with a cavity behind and is used to absorb sound without using any porous, fibrous absorbing materials. Such absorbers have been found to be good, and better than any other resonant absorber, but the frequency range is not quite enough for a practical applications. Further development has been made to extend the absorption frequency range by using a double resonator; two similar MPP sheets with individual cavities in tandem are used. The results were satisfactory. Theory was developed in 1975,[1] and simplified later,[2] to allow MPP absorber properties to be precisely predicted. Both structure and absorption characteristics can be exactly predicted from given values of the relative load resistance $r$ and perforate constant $k = d(\omega\rho/4\eta)^{1/2}$, where $d$ is the diameter of orifice, and the resonant angular frequency is $\omega = 2\pi f$. MPP absorbers have sufficient acoustic resistance in themselves and low mass reactance suitable for a wide frequency band absorber without any fibrous and porous absorbing material. The panels can be made with any material suitable for the application and environment, and are easy to prepare and to design exactly according to the requirements. It has been applied successfully ever since with important progress of the technology and public interest.[3]

Is it possible to design a practical single MPP absorber to cover the whole frequency range of interest in noise control? A rough estimate has been made[4] that this is possible provided low values of $k$ and $d$ are used. The purpose of the present investigation is to find whether the estimation can be realised by taking $k = 1$, and $d = 0.1$ mm as a start and to find the exact requirements for a practical single MPP absorber. Realisation of the single MPP absorber is considered.

## 2. THE MPP ABSORBER[1]

The MPP absorber and its equivalent circuit are shown in Fig. 1. The absorption coefficient of the MPP absorber at normal incidence is

$$\alpha = \frac{4r}{(1+r)^2 + [\omega m - \cot(\omega D/c)]^2}, \tag{1}$$

where the relative impedance $r + j\omega m$ of the MPP is the ratio of the specific acoustic impedance per unit area $Z = R + j\omega M$ divided by the characteristic impedance $\rho c$ in air ($\rho$ being the density and $c$ the sound velocity in air), and may be found as

$$r = \frac{32\eta}{\sigma\rho c}\frac{t}{d^2}k_r; \quad k_r = \left(1 + \frac{k^2}{32}\right)^{1/2} + \frac{\sqrt{2}}{32}\frac{kd}{t}; \tag{2}$$

$$\omega m = \frac{\omega t}{\sigma c}k_m; \quad k_m = 1 + \left(9 + \frac{k^2}{2}\right)^{-1/2} + 0.85\frac{d}{t}, \tag{3}$$

or

$$\omega m = \frac{1}{8}\frac{k_m}{k_r} r k^2, \tag{4}$$

and

$$k = d\sqrt{\omega\rho/\eta} = 10d\sqrt{f}, \tag{5}$$

as the value of viscosity is substituted.

The constants are: the thickness of the panel $t$, the diameter of the orifice $d$, the sound frequency $f$, the depth of the cavity behind the panel $D$, the coefficient of viscosity $\eta$ in air, $1.8 \times 10^{-5}$ kg/ms, and the porosity $\sigma$ on the panel, all in SI units.

The maximum value of the absorption coefficient is given by

$$\alpha_0 = \frac{4r}{(1+r)^2}, \tag{6}$$

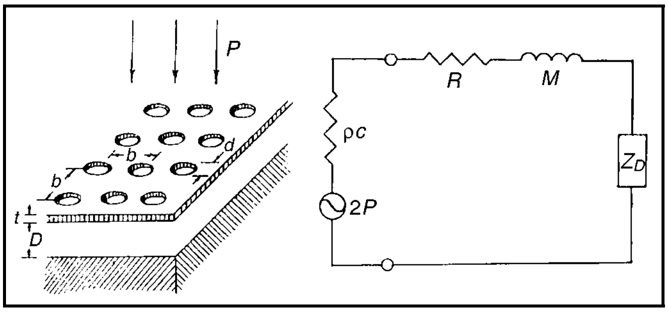

**Figure 1.** The MPP absorber and its equivalent circuit.

at the resonance angular frequency $\omega_0$ satisfying

$$\omega_0 m - \cot(\omega_0 D/c) = 0\,, \tag{7}$$

or the non-dimensional frequency

$$\omega_0 D/c = \cot^{-1}\omega_0 m\,. \tag{8}$$

## 3. HALF ABSORPTION AND 0.5 ABSORPTION LIMITS

The absorption coefficient is half the maximum value when

$$\omega m - \cot(\omega D/c) = \pm(1+r)\,. \tag{9}$$

This relation is shown in Fig. 2; the $\omega m$ curve is a straight line with a slope $g$. The perforate constant $k = d\sqrt{\omega\rho/4\eta}$ is equal to one. The vertical distance between the line of $\omega m$ and the cotangent curve $\cot\omega D/c$ is $1+r$ at the frequency limits.

The limit frequencies satisfy

$$\begin{aligned}\frac{\omega D}{c} &= \cot^{-1}[\pm(1+r)+\omega_1 m]\\ &= \cot^{-1}[\pm(1+r)] - \frac{\omega_1 m}{1+\dfrac{g}{1+(1+r)^2}},\end{aligned} \tag{10}$$

according to the approximate equation[5] of arc-cotangent, provided that $\omega_1 m = g\cot(\omega_1 D/c)$ is small compared to $1+r$, where $g = \omega m/(\omega D/c) = mc/D$, is nearly a constant. The rearrangement of Eq. (10) gives

$$\frac{\omega_1 D}{c} = \frac{\cot^{-1}(1+r)}{1+\dfrac{g}{1+(1+r)^2}}. \tag{11}$$

Similarly one may find for the upper frequency limit[5]

$$\frac{\omega_2 D}{c} = \frac{\cot^{-1}\{-(1+r)\}}{1+\dfrac{g}{1+(1+r)^2}} = \frac{\pi-\cot^{-1}(1+r)}{1+\dfrac{g}{1+(1+r)^2}}. \tag{12}$$

$\omega m$ must be small compared to $1+r$ at both the high and low frequency limits. From these, the half-width of the absorption curve is rather complicated, but the frequency interval is simple,

$$\omega_2/\omega_1 = f_2/f_1 = \pi/\cot^{-1}(1+r) - 1\,, \tag{13}$$

and depends on the resistance $r$ alone. In Eq. (4) the ratio $k_m/k_r$ is nearly a constant 2, when $k=1$. Thus, $\omega m$ increases proportionally with $r$ and the half-absorption frequency interval may reaches a very great value for large values of $r$, but the absorption coefficient may be too low to be meaningful.

Taking 0.5 of the sound absorption coefficient as the lower limit is another way to define the effective absorption region. Set 0.5 for $\alpha$ in Eq. (1), the non-dimensional frequency for the absorption coefficient above 0.5 is obtained:

$$\frac{\omega D}{c} = \cot^{-1}[\pm\{8r-(1+r)^2\}^{1/2}+\omega m]\,. \tag{14}$$

Similar to Eq. (6), with $\pm\{8r-(1+r)^2\}^{1/2}$ in the place of $\pm(1+r)$, one may find the lower and higher frequency limits

$$\frac{\omega_1 D}{c} = \frac{\cot^{-1}[8r-(1+r)^2]^{1/2}}{1+\dfrac{g}{1+8r-(1+r)^2}}; \tag{15}$$

$$\frac{\omega_2 D}{c} = \frac{\pi-\cot^{-1}[8r-(1+r)^2]^{1/2}}{1+\dfrac{g}{1+8r-(1+r)^2}}, \tag{16}$$

similar to the above half-absorption system. Also the frequency interval

$$\omega_2/\omega_1 = f_2/f_1 = \pi/\cot^{-1}[8r-(1+r)^2]^{1/2} - 1\,, \tag{17}$$

with $[8r-(1+r)^2]^{1/2}$ takes the place of $1+r$ in the half-absorption system. The same replacement should occur in Fig. 2. for absorption coefficient 0.5 as the lower limit. The results of these two schemes are compared in Table 1.

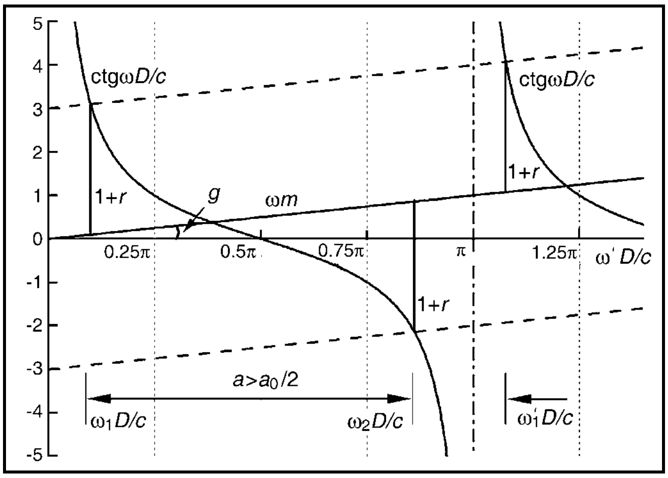

**Figure 2.** Absorption region for half absorption limit of MPP absorber.

**Table 1.** Comparison of half absorption and 0.5 absorption systems, $k=1$, $d=0.1$ mm.

| $r$ | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $\omega m$ | 0.25 | 0.50 | 0.75 | 1 | 1.25 |
| $g$ | 0.188 | 0.452 | 0.677 | 0.785 | 0.675 |
| Resonance frequency $\omega_0 D/c$ | 1.136 | 1.107 | 0.9273 | 0.785 | 0.675 |
| Cavity depth $D/\lambda$ | 0.21 | 0.175 | 0.148 | 0.125 | 0.097 |
| $a_0/2$ interval $f_2/f_1$ | 5.78 | 8.76 | 11.82 | 14.91 | 18.02 |
| System lower limit $f_1$ | 393 | 278 | 254 | 240 | 233 |
| Higher limit $f_2$ | 2273 | 2436 | 3003 | 3575 | 4200 |
| $a=0.5$ interval $f_2/f_1$ | 5.78 | 7.69 | 8.24 | 7.69 | 5.78 |
| System lower limit $f_1$ | 393 | 309 | 341 | 397 | 501 |
| Higher limit $f_2$ | 2273 | 2376 | 2810 | 3054 | 2893 |

The change of $\omega_0 D/c$ for different load resistances does not depend on the frequency, which is constant but only on the cavity depth $D$. When $\omega m$ is negligibly small, the resonance cavity is a quarter wavelength deep, $D/\lambda = 0.25$, which is reduced due to larger values of $\omega m$, as given by the value of $D/\lambda$ in the table, $\lambda$ being the wavelength. The half-absorption frequency interval for $r = 1$ is the same in the half absorption and 0.5 absorption coefficient systems. For $k = 2$, the frequency interval in the half absorption system is slightly larger than in the 0.5 absorption system. They may be used equally well. But when $r$ is to three or more, the half absorption interval becomes quite large, and the low absorption coefficient contained in the half absorption system will limit its usefulness.

In the $\alpha = 0.5$ system in Table 1, however, the advantage is apparent; it shows exactly the useful frequency ranges for different load resistances $r$. The choice of 1000 Hz as the resonance frequency has the advantage of pushing the response beyond 2000 Hz, which is desired for a practical absorber but impossible in an ordinary MPP. The lower frequency limit may be too high when the resonance frequency is 1000 Hz. This may be changed by choosing lower frequencies for resonance, e.g. 500 or 700 Hz if necessary. It is seen that when the MPP is designed with $r = 1$ (the specific acoustical resistance of the panel is equal to $\rho c$ in the air) which has highest resonance absorption coefficient $\alpha_0 = 1$. This is used in general applications, but not in the wide band absorber, where the frequency ratio is only 5.78, an interval of 2.53 octaves. The design with $r = 2$ gives a reduced resonance absorption of $\alpha_0 = 0.89$, but a much larger frequency ratio 7.69 (2.94 octaves). And the design with $r = 3$ reduces the resonance absorption further to $\alpha_0 = 0.75$, but raises the frequency ratio to 8.24 (3.04 octaves), which is about the best frequency ratio that the MPP can have. The difference between the last two designs is rather slight (0.1 octave), any value between 2 and 3 for $r$ will be good enough so far as wide band absorption is concerned. Besides, in the $r = 2$ design, the resonant absorption as well as the average absorption in the band is large. This means that the $r = 2$ design is better than it seems. The maximum and average absorption for the $r = 4$ and $r = 5$ designs are low.

It is interesting to note that in any system (electrical, for instance), the load impedance must match the system to have best efficiency. But in the MPP absorber, matching, although it produces a large resonant absorption coefficient, causes the worst transmission (least absorption frequency interval), affecting practically all the MPP absorbers designed previously.

## 4. PROPERTIES OF THE ABSORPTION CURVES

The properties of the absorption curves for different values of $r$, shown in Fig. 3, may be found also from the low absorption limit frequencies in both the half absorption and 0.5 absorption systems.

*Asymmetrical curves of absorption*. From Eq. (10) of the half absorption and corresponding equation of 0.5 absorption, it can be seen that the frequency curves are symmetrical with respect to the resonance frequency, provided that $\omega m$ is large compared to $1 + r$. On the other hand, they are asymmetrical when $1 + r$ is much larger, as in the present case. The asymmetry is evident in Table 1. Take the ratio $(f_2 – f_0)/(f_0 - f_1)$ e.g., it is found 1.3, 1.33, 1.42, 1.5, and 1.6 for $r$ equal to 1, 2, through 5 respectively, the asymmetry increases with $r$.

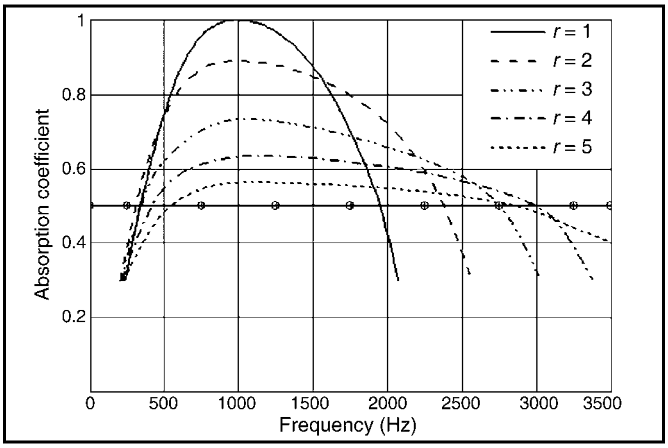

**Figure 3.** Absorption curves for different values of load resistances.

The lower limit for the 0.5 absorption limit is the line $\alpha = 0.5$, the same for all $r$ values. The absorption regions have the same base and tops at the resonance frequency, with $\alpha_0 = 4r/(1 + r)^2$, gradually descending with increasing $r$. The curves for different load resistances are quite similar in bell-like shapes, round at the top, gradually separating toward the skirt, and with distance $R = \{8r – (1 + r)^2\}^{1/2}$ between the lines $\omega m$ and $\omega D/c$ in Fig. 1. The set of curves is equivalent to a single fixed curve, gradually descending and broadening with the decreasing resonance absorption, for $r = 1$, $R$ is 2, the same as $1 + r$ of the first curve. The value of the frequency separation is the least, and the value of arc-cotangent is the largest. The second curve has $R$ equal to $\sqrt{7}$, larger than the first curve, with a larger separation of two non-dimensional frequencies. The distance $R$ for $r = 3$ is $\sqrt{8}$, and that for $r = 4$ is back to $\sqrt{7}$, the same as $r = 2$. The differences are only minor, but the high frequency absorptions are shifting gradually toward higher frequencies. The absorption regions of the three curves are equal, but shifting to higher frequency for higher $r$, nearly 0.6 octave for the largest. Thus the absorption curves are gradually becoming more and more asymmetrical with respect to the resonance frequency.

*More asymmetry at random incidence*. The data discussed in the above section are for normal incidence. When the MPP is used in reverberant spaces, the random absorption shall be the average of absorption for all directions of incidence, the maximum absorption shall be reduced, and the direction of 45 degrees to the normal shall be emphasised. Thus, the absorption region is enlarged, especially the high-frequency absorption region shifts to higher frequencies with some shift of the lower frequency absorption region.[6] Table 2 summarises the results of measurements on the same MPP in a resonance tube and in a reverberation chamber with a backing cavity of 50 mm.

**Table 2.** Results of measurements on the same MPP with cavity.

| Measurements | $f_0$ | $\alpha_0$ | $f_1$ | $f_2$ | $\Delta f$ | $f_2/f_1$ | $f_0 - f_1$ | $f_2 - f_0$ | $\frac{f_2 - f_0}{f_0 - f_1}$ |
|---|---|---|---|---|---|---|---|---|---|
| Tube | 435 | 0.95 | 270 | 730 | 460 | 1.4 octave | 165 | 295 | 1.79 |
| Chamber | 630 | 0.63 | 305 | 1500 | 1195 | 2.3 octave | 325 | 870 | 3.28 |

Between the tube and chamber measurements, the maximum absorption $\alpha_0$ is reduced by nearly one third, and the frequency is shifted from 435 to 630 Hz, a factor of about

1.45 times. The range of the entire absorption region is broadened from 460 to 1195, about 2.6 times. The high frequency absorption region $f_2-f_0$ is broadened more, from 295 to 870 Hz, 2.95 times, with the upper limit $f_2$ shifted from 730 to 1500 Hz, more than two times. While the lower frequency absorption region only doubles, the lower limit frequency $f_1$ is only shifted up by 35 Hz, some 30 %. Roughly speaking, the higher frequency region becomes three times, the lower frequency region only doubles. The whole absorption region becomes two and half times when the MPP works in the reverberation chamber. In these changes, the higher frequency, $f_2$, shifts by 770 Hz to a higher frequency, while the lower frequency, $f_1$, moves by 35 Hz. The high frequency absorption region shifts with an expansion.

Besides, the shifting of high-frequency absorption regions toward a higher frequency, if the shift is great enough it, makes it able to join forces with secondary absorption regions due to the multiple-branch property of the cotangent function. See Fig. 4.[7] This is more important than the broadening of the principal absorptive band. The absorption extends naturally far into the next octaves to form a really wide band absorber. The effect becomes important when $k$ is about one, it is more pronounced when $k$ is much smaller.

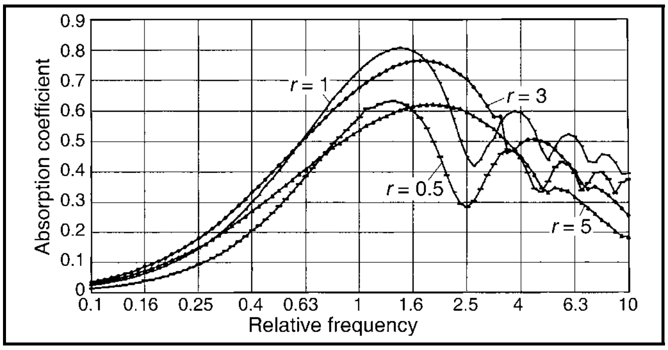

**Figure 4.** Continuous absorption region: in reverberant space, $k = 1$.

## 5. DESIGN PARAMETERS OF PRACTICAL MPP ABSORBERS

The important parameters of the MPP are $k$, $d$ (or $f_0$), and $r$. $k = 1$ is necessary, $r = 2$ or 3 has been found to be good. The terms ($d$, $f_0$), are related when $k$ is a constant. The choice of (0.1 mm, 1000 Hz) is good for high frequency absorption, but does not have enough low frequency absorption, and the use of a MPP absorber in reverberant spaces makes it worse for low frequencies; $d$ should be larger, or $f_0$ lower. But (0.2 mm, 250 Hz) is too much; the region for high frequency absorption cannot get in touch with the secondary absorption regions. A good compromise is (1.4 mm, 500 Hz), the frequencies of the absorption region are high enough to reach the secondary absorption regions when the MPP is used in a reverberant field, and yet low enough for low frequency absorption. The other constants are determined by these, resistance and mass reactance are determined by mainly the $t$ and $d$ of the panel. The most important effect is the load resistance. The formula for the resistance may be simplified as

$$r = \frac{32\eta t}{\sigma\rho_0 c d^2} k_r, k_r = \left[1 + \frac{k^2}{32}\right]^{1/2} + \frac{\sqrt{2}}{32} k \frac{d}{t}. \qquad (18)$$

At $k = 1$, the correction factor $k_r$ is 1.03 or less. $d$ is chosen as 1.4, and $t$, the thickness of the panel, may be 0.2 or $0.3 \times 10^{-3}$ m, or even greater. Thus the resistance $r$ is about 2 to 3. The divisor is $\sigma$, meaning that the porosity should be around one percent to get the required $r$, nearly a million minute orifices per square metre.

## 6. REALISATION OF THE PRACTICAL MPP ABSORBER

The most important problem is to make approximately a million minute holes on a square metre of the specimen, or a hundred in a square centimetre to realise the broad absorption limits. It is no problem is in principle, but new technology is needed.

1) To make the minute orifices on a sheet of metal by pressing the pointed end of a drill or punch on the metal to make a dent, but not completely through, until only until a small hole appears at the tip. It depends on experience to make the size of the hole correct. Automatic mechanical means is needed.

2) Making a hole in a plastic film is possible with a hot needle. But also not completely through, only pricking with the tip to get the right size.

3) Noise control using fabric has a long history. Long before any functional sound absorber was developed, fabric and draperies were used to reduce noise. Even layers of cloth have been used to make a dead end in a room. It was found to be very effective. In a piece of cloth, there are minute holes between threads; some holes may be even smaller than 0.1 mm, with the threads, thin or coarse, serving as "land." The only trouble is that the porosity is usually too large. There might be a kind of fabric which would satisfy the requirements for an MPP, naturally or fabricated. Fabric may be good a MPP material; no drilling is necessary.

## 7. CONCLUSION

The problem of a MPP absorber with a single panel suitable for general noise control has been considered. The adequate sound absorption in a broad frequency band is taken as essential, and the sound absorption coefficient 0.5 is taken as the lower limit of absorption for comparison. Any other limit may be used and solved with the same method as in the present article.

It is concluded that a design of a MPP absorber is among the best, with a perforate constant of one, orifice diameter 0.14 mm, resonance frequency 500 Hz, and load resistance between 2 and 3.

This reduces the problem to the making of millions of minute holes with a diameter of 0.1 or 0.14 mm on thin materials. Fabrication is possible, but new fabrication technologies are required. Fabric seems to be the desired material, with natural minute holes.

## REFERENCES

[1] Maa, D.-Y. Theory and design of microperforated panel sound-absorbing, Construction, Scientia Sinica XVIII, 55-71, (1957).

[2] Maa, D.-Y. Potential of microperforated panel absorbers, *J. Acoust. Soc. Am.*, **104**, 2861-2866, (2000).

[3] Fuchs, H. V. and Zha, X. Micro-perforated structures as sound absorbers – a review and outlook, *Acta Acustica united with Acustica*, **92**, 139-146, (2006).

[4] Maa, D.-Y. Absorption limit of MPP, *Acta Acustica* (in Chinese), **28** (6), 561-562, (2003).

[5] Dwight, H. B. Tables of integrals, 512.4 MACMILLAN, (1934).

[6] Nocke, C., Liu, K., and Maa, D.-Y. Statistical absorption coefficient of microperforated panel absorbers, *Chinese Journal of Acoustics*, **19**, 97-104, (2000).

[7] Maa, D.-Y. and Liu, K. Sound absorption characteristics of microperforated absorber for random incidence, *Chinese Journal of Acoustics*, **19**, 289-298, (2000).