Acoustic Design for MEMS Microphones

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Introduction

The high performance and small size of MEMS microphones makes them ideal for use in consumer products such as tablets, laptops, and smartphones. However, the sound inlet of the microphones used in these products is usually not in direct contact with the external environment. This makes it necessary to design an acoustic path from the external environment to allow sound to reach the microphone. The design of this acoustic path can have a considerable impact on the overall performance of the system.

All of the components between the external environment and the microphone membrane including the product housing, the acoustic gasket, the PCB, and the microphone act as a wave guide that shapes the overall frequency response. In addition, the materials used in the sound path can also affect the frequency response. Predicting exactly how an acoustic design will perform requires modeling the acoustic path and simulating its frequency response using a professional simulation tool such as COMSOL®. However, this article provides some basic guidelines for optimizing a microphone's acoustic path.

The Helmholtz resonance

A hollow cavity with a narrow sound inlet will resonate acoustically when excited. This is what produces sound when blowing across the top of an empty bottle. This type of structure is known as a Helmholtz resonator and is named for its inventor, Hermann von Helmholtz. Helmholtz used resonators with different resonant frequencies to identify the frequency components present in music and other complex sounds.

The center frequency of the Helmholtz resonance is given by the following equation:

$$f_H = \frac{c}{2\pi} \sqrt{\frac{A_H}{V_C L_H}}$$

where c is the speed of sound in air, A_H is the cross-sectional area of the sound inlet, L_H is the length of the inlet, and V_C is the volume of the cavity. This equation assumes a simple structure comprised of a tube with a uniform cross-sectional area connected to a cavity. The equations

describing the behavior of sound waves in the acoustic path of a microphone with varying cross-sectional areas and different materials are far more complex. This complexity makes it necessary to simulate the acoustic behavior of the entire sound path in order to accurately predict its overall performance.

For this article we have simulated the frequency response of different acoustic paths while varying the thickness and hole diameter of the gasket, the diameter of the holes in the product housing and PCB, bends in the acoustic path, and the acoustic impedance of the materials used. The simulator solves the acoustic equations at every discrete point of the model and at the end of the simulation it is possible to plot the collected data at any desired point. The results of these simulations allow designers to predict in general terms how changes to these parameters will affect the overall performance of an acoustic path.

The frequency response of the microphone

The response of a MEMS microphone at low frequencies is determined by the dimensions of the ventilation hole between the front and back sides of the sensor membrane and by the volume of its back chamber, while the high frequency response is determined by the Helmholtz resonance created by the front chamber of the microphone and its sound inlet.

The overall shape of the frequency response is generally the same for most MEMS microphones, with their sensitivity falling off at low frequencies and rising at higher frequencies due to the Helmholtz resonance. However, there are considerable differences in response between different MEMS microphones due to differences in sensor design, package size, and construction, especially at high frequencies. Most of ST's MEMS microphones have the sensor placed directly over the sound inlet in order to minimize the size of the front chamber and ensure excellent high frequency response.
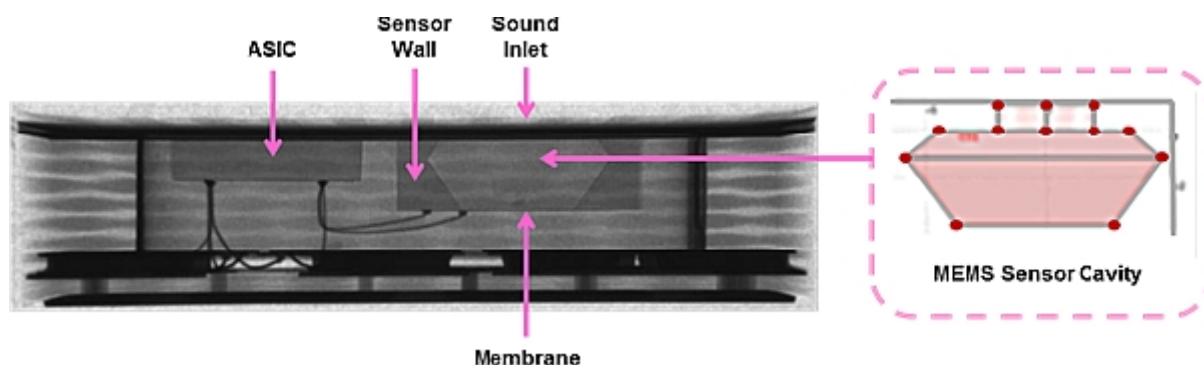

Figure 1 – An x-ray photograph of a ST MP34DT01 top-port microphone and its acoustic cavity

A simulation of the MP34DB01 microphone shows that its response is very flat at higher frequencies, with a typical rise in sensitivity of about +3dB at 20 kHz due to the very high center frequency of its Helmholtz resonance.

The effect of the gasket thickness on the frequency response

A gasket is needed to provide an airtight seal between the microphone sound inlet and the acoustic port in the product housing. When a gasket is placed over a microphone it changes the resonant frequency by increasing the effective length of the sound inlet leading to the front chamber of the microphone. The following simulations show how gasket thickness affects frequency response by placing a cylindrical tube with a fixed diameter (400µm) and varying lengths over a microphone sound inlet.
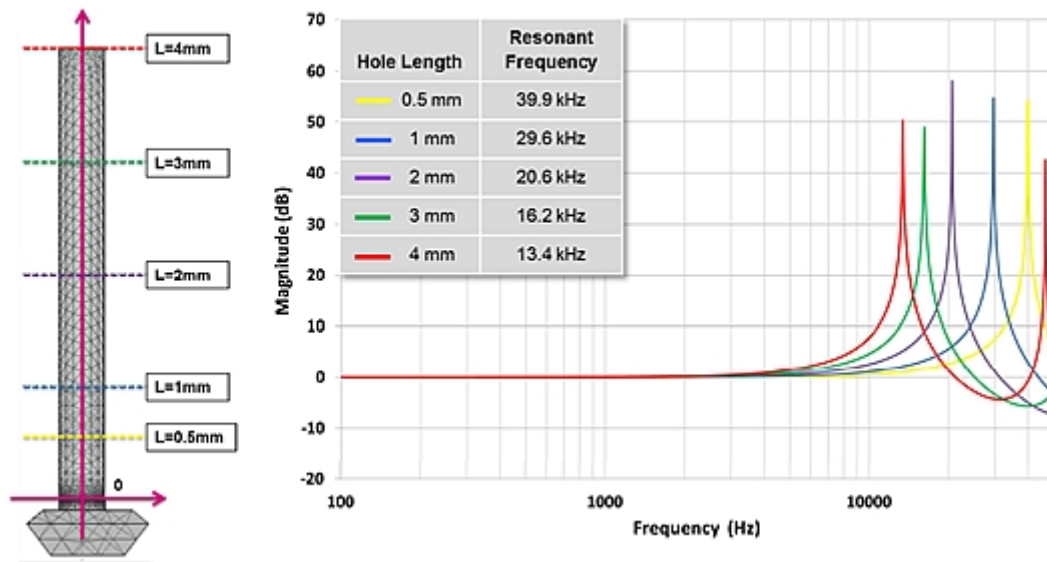

Figure 2 – MP34DT01 frequency response vs. gasket thickness

It's clear from these simulations that adding a gasket hurts the high frequency response. The addition of a gasket (and a PCB in the case of a bottom-port mic) increases the effective length of the sound inlet which lowers the resonant frequency and causes the sensitivity to rise at higher frequencies. Thicker gaskets increase the length of the resonator neck, resulting in a lower resonant frequency and poorer high frequency response.

The effect of the gasket hole diameter on the frequency response

The next set of simulations show the effect of a gasket with a fixed thickness (2mm) and varying hole diameters on the frequency response. Figure 3 shows the simulation results for different gasket hole diameters.
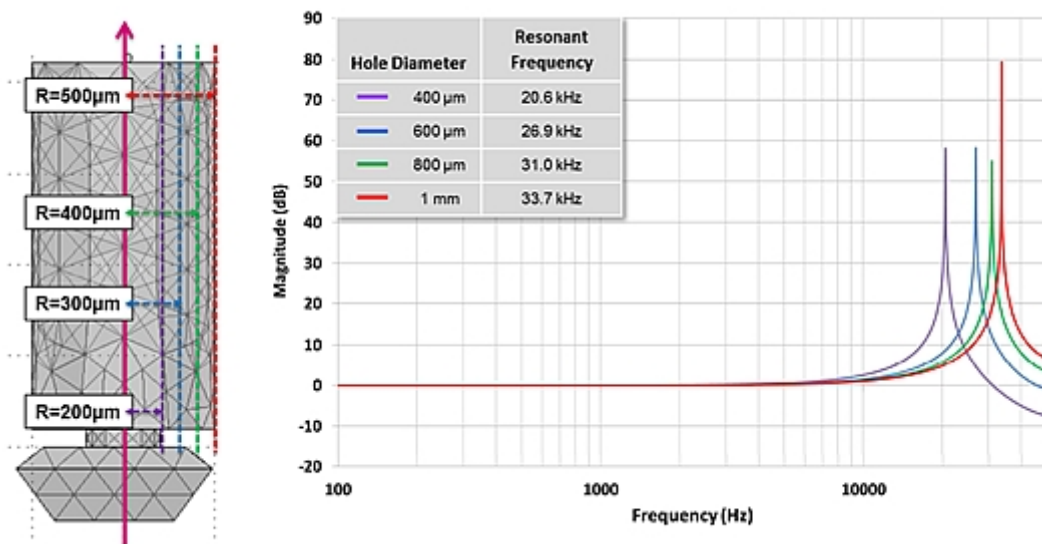
Figure 3 – MP34DT01 frequency response vs. gasket hole radius

These simulations show that increasing diameter of the hole in the gasket increase the resonant frequency, improving the overall frequency response.

The effect of different geometries on the frequency response

The results up to this point have been in line with what could be predicted by examining the equation for the Helmholtz resonant frequency. The next set simulations look at the effect of changing the shape of the microphone's acoustic path, which is not so easy to predict. The structure shown in Figure 4(a) is a simple acoustic path with a constant 4mm length and 600µm diameter that serves as a point of comparison for the other simulations. The other acoustic paths studied increase the complexity by adding cavities with different radiuses, lengths, and shapes that simulate variations in the widths and shapes of the holes in the product housing, the gasket, and the PCB.
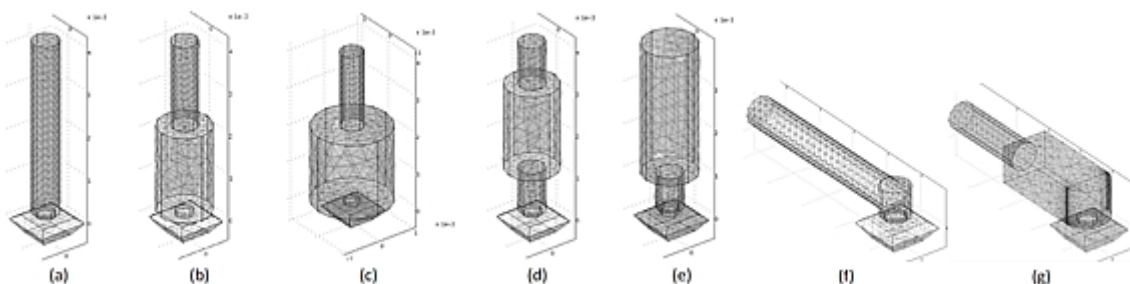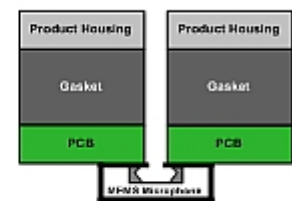

Figure 4 – Acoustic path shape variations

The structure in Figure 4(a) is a simple acoustic path with a constant 600µm diameter and 4mm length. This simulates having holes with the same diameter in the product housing, gasket, and PCB.
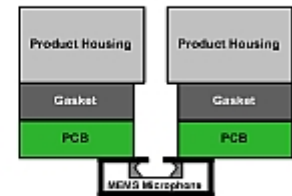
Resonant frequency = 16.6 kHz

The structure in Figure 4(b) doubles the diameter of the acoustic path close to the microphone sound inlet. This simulates the use of a 600µm hole in the exterior housing of the product and a 1.2mm hole in the gasket and the PCB.
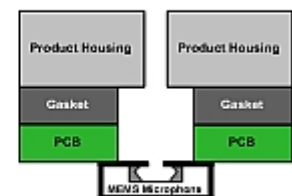
Resonant frequency = 11.6 kHz

Conclusion: Increasing the diameter of the sound path in front of the microphone sound inlet hurts the high frequency response.

The structure in Figure 4(c) is the same as the structure in Figure 4(b) except that the diameter of the holes in the gasket and the PCB has been increased from 1.2mm to 2mm.
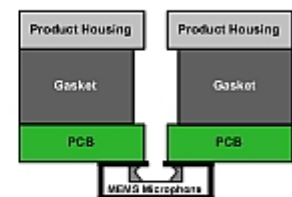
Resonant frequency = 7.5 kHz

Conclusion: A further widening of the acoustic path adjacent to the microphone hurts the high frequency response even more.

The structure in Figure 4(d) doubles the diameter of the acoustic path at its center, simulating the use of a 600µm holes in the product housing and the PCB and a gasket with a 1.2mm hole.
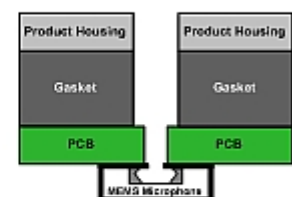
Resonant frequency = 14.6 kHz

Conclusion: This change lowers the resonant frequency and increases the magnitude of the resonance relative to the structure in Figure 4(a) but it is better than the structure in Figure 4(b).

The structure in Figure 4(e) doubles the diameter of the acoustic path at its entrance, simulating 1.2mm holes in both the product housing and the gasket and a 600µm hole in the PCB.

Resonant frequency = 22.7 kHz

Conclusion: Increasing the diameter at the entrance of the acoustic path increases the resonant frequency significantly. It also increases the magnitude of the response at the resonant frequency but the overall impact on frequency response is very positive.

The sound path in Figure 4(f) is the same as the structure shown in Figure 4(a) except that a 90° bend has been added.

Resonant frequency = 15.6 kHz

Conclusion: Adding a 90° bend in the acoustic path does not appear to have a large effect on the frequency response.
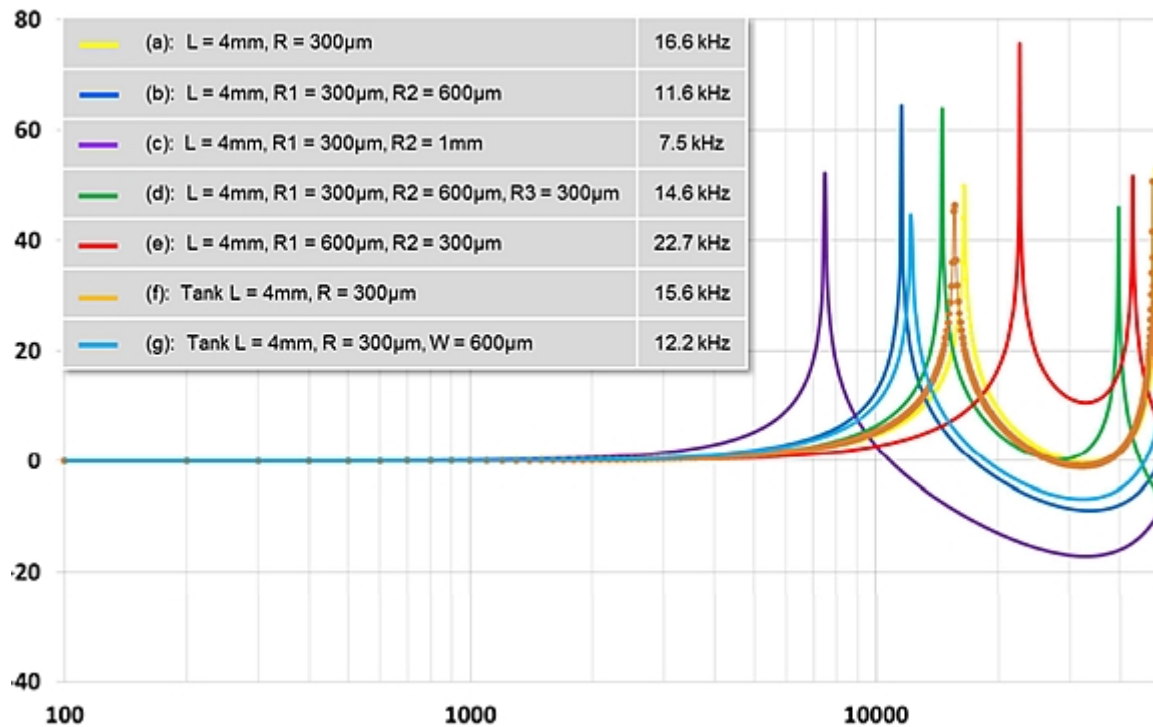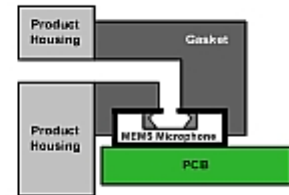

(a): L = 4mm, R = 300µm	16.6 kHz
(b): L = 4mm, R1 = 300µm, R2 = 600µm	11.6 kHz
(c): L = 4mm, R1 = 300µm, R2 = 1mm	7.5 kHz
(d): L = 4mm, R1 = 300µm, R2 = 600µm, R3 = 300µm	14.6 kHz
(e): L = 4mm, R1 = 600µm, R2 = 300µm	22.7 kHz
(f): Tank L = 4mm, R = 300µm	15.6 kHz
(g): Tank L = 4mm, R = 300µm, W = 600µm	12.2 kHz

Figure 5 – MP34DB01 frequency response with different acoustic port shapes

The effect of different materials on the frequency response

The effect of different materials on the frequency response

The simulations performed up to this point have focused on the effect of the sound path geometry on frequency response and have used sound-hard boundary conditions for all of the surfaces. The next set of simulations examines how the acoustic impedance of the gasket affects the frequency response. The correct acoustic impedances were used for the materials used for the inlet (yellow), sensor body (pink), and sensor membrane (green) surfaces while the acoustic impedance of the blue surface was varied. The acoustic impedance of a material is the product of its density and the speed of sound in that material ($Z = \rho \cdot c$). Gaskets are usually made from rubber or other elastomeric materials, while typical housing materials include plastic, aluminum, and steel.
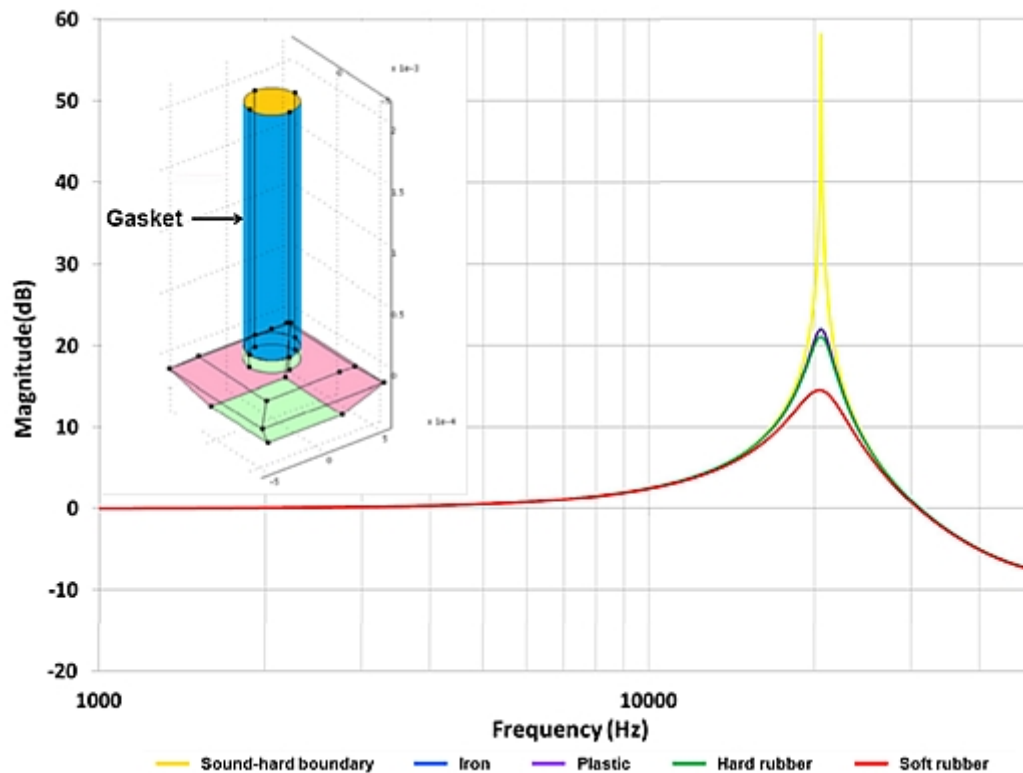
Figure 6 – The effect of gasket material on the magnitude of the resonant peak

The results in figure 6 show that the acoustic impedance of the gasket did not affect the resonant frequency which is determined by the geometry of the acoustic path, but it did affect the Q of the resonant response. Although the acoustic path continues to resonate, softer gasket materials damp the resonance and reduce its impact near the resonant frequency. Even using iron surface material for the sound inlet reduced the peak magnitude of the response significantly from the results obtained with sound-hard boundary conditions, showing that using sound-hard boundary conditions gives unrealistically severe results.

Case study – Analysis of the full acoustic path of a tablet with a bottom-port microphone

As a case study we have modeled the acoustic path for a bottom-port microphone in a tablet. In this example the bottom port microphone is mounted on a PCB and a soft rubber gasket is used to provide the seal between the PCB and the product housing.

The materials used for this simulation are those typically found in consumer electronics: the printed circuit board is FR4, the gasket is made with a soft rubber, and the case material is aluminum.
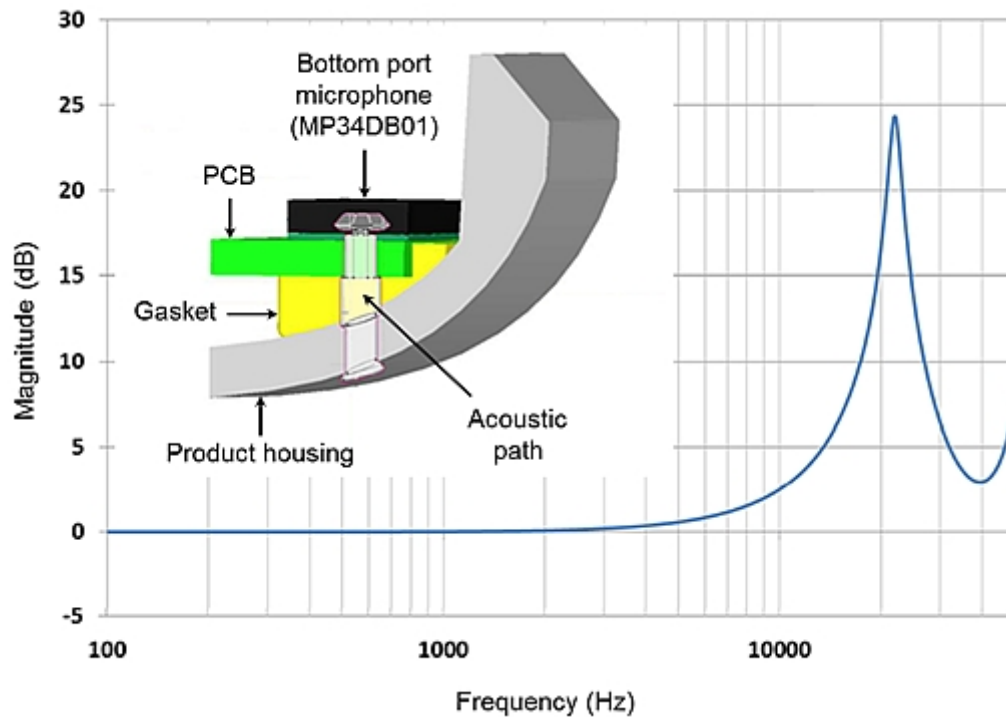
Figure 7 – Tablet microphone acoustic path simulation results

Figure 7 shows the frequency response for the microphone acoustic path with a resonant peak at about 21.6 kHz. The maximum pressure at the resonant frequency is at the MEMS membrane.

Summary

The following guidelines will help optimize the frequency response of a microphone's acoustic path:

- Keep the acoustic path as short and as wide as possible. Widening the sound path at the exterior end will help the frequency response but widening it next to the microphone will hurt the response.
- Try to eliminate any cavities in the acoustic path. If a cavity is unavoidable then it should not be directly adjacent to the microphone sound inlet.
- Bends in the acoustic path do not seem to have a major effect on the frequency response.
- Softer gasket materials damp the resonance and may improve the frequency response.