Recommendations for Mounting and Connecting InvenSense MEMS Microphones

INTRODUCTION

The InvenSense bottom-ported MEMS microphones are high-performance acoustic transducers featuring an extended wideband frequency response. Although the response of the microphone exhibits very little variation over its operating range, placement of the microphone inside a device case may introduce changes to this response. This application note provides mounting recommendations for minimizing the influence of packaging on the microphone performance in the final product. Electrical connections, codec interfaces, and performance aspects are described, as well.

This application note discusses the following:

- Mechanical design considerations: printed circuit board (PCB) mounting, use of gaskets and spacers, and avoiding resonances
- Electrical connections: analog connections, digital data format, and codec interfaces
- Application-enabling performance aspects

MECHANICAL DESIGN CONSIDERATIONS

The InvenSense bottom-ported MEMS microphones are designed to be reflow soldered directly onto a PCB. A hole in the PCB is required to admit the sound into the microphone package. In addition, the PCB with the microphone is placed in a housing that also must have an opening connecting the microphone to the outside environment.

The PCB, together with the housing, forms elements of an acoustic circuit that can affect the frequency response of the microphone. This application note provides recommendations to help ensure the best audio performance from the microphone.

SOUND PATH DESIGN

The microphone requires a path for the sound into the package through the bottom port. Due to the small size of the microphone packages and their related features, the exact geometry of the sound path does not significantly influence the response of the microphone. Because all dimensional references in acoustics are related to the wavelength of sound, the following formula for converting frequency to wavelength is useful:

$$\lambda = c/f$$

where:

λ is the wavelength, m.

c is the speed of sound, approximately 340 m/sec.

f is the frequency, Hz.

For example, at 10 kHz, the wavelength is 34 mm (see Figure 1).

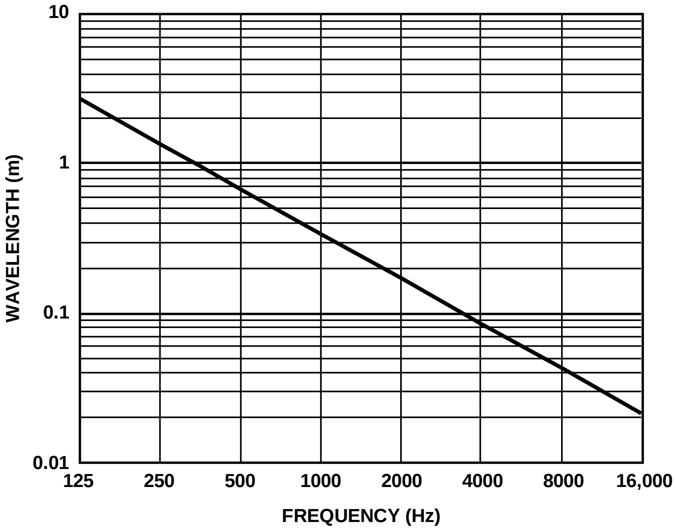

Figure 1. Wavelength of Sound vs. Frequency

PCB THICKNESS AND THE USE OF FLEXIBLE PCB

The performance of an InvenSense MEMS microphone is not affected by PCB thickness. The microphone can be mounted on a flexible PCB using the guidelines listed in the microphone data sheet available at www.invensense.com and in the AN-1068 Application Note. The flexible PCB with the microphone can be attached directly to the device housing with an adhesive layer. This mounting method offers a reliable seal around the sound port, while providing the shortest acoustic path for good sound quality.

PCB SOUND HOLE SIZE

The response of an InvenSense MEMS microphone is not affected by the PCB hole size, as long as the hole is not smaller than 0.25 mm (0.010 inch) in diameter. A 0.5 mm to 1 mm (0.020 inch to 0.040 inch) diameter for the hole is typical. Take care to align the hole in the microphone package with the hole in the PCB. The exact degree of the alignment does not affect the microphone performance, as long as the holes are not partially or completely blocked.

AVOIDING RESONANCES

One acoustical structure that can influence sound quality, even when its dimensions are much smaller than the wavelength, is a Helmholtz resonator. This resonator consists of a wide section forming an inner cavity and a narrow hole, or vent, to the outside. A Helmholtz resonator may be formed when, for example, a wide gasket is used between the microphone PCB and the device case (see Figure 2).

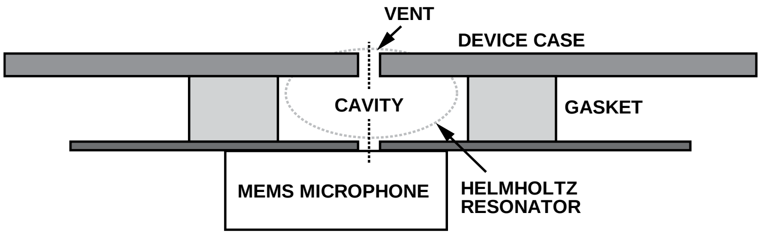

Figure 2. Helmholtz Resonator Example

This structure may result in a high-frequency response peak and should be avoided unless the product designer deliberately seeks such a peak. To avoid this resonance, the gasket should be as small as possible, or the board should be placed directly against the device case. When a longer acoustic path is required by industrial design constraints, the effective path diameter should be close in size or smaller than the device case opening (the vent, as shown in Figure 3). Multiple small holes can be used in place of a single vent in the device case.

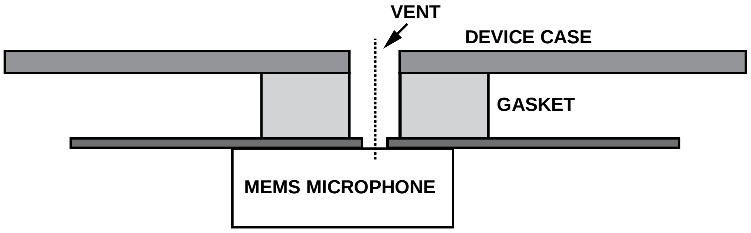

Figure 3. Recommended Gasket Design Example

A good seal between the device case and the gasket and between the PCB and the gasket is important. The influence of the stiffness of the gasket material on the overall microphone performance is negligible. Examples of gasket material include rubber, silicone, neoprene, or closed-cell foam.

To calculate the Helmholtz resonance frequency, the following formula can be used:

$$f_b = \frac{c \times D}{4\sqrt{\pi \times V \times (L + \sqrt{\pi} \times D/2)}}$$

where:

f_b is the resonance frequency, Hz.

c is the speed of sound, approximately 340 m/sec.

D is the vent diameter, mm.

V is the cavity volume, mm^3.

L is the vent length, mm.

The calculated resonance frequency can differ from the actual measurement results due to nonrigid gasket walls, leakages, and other imperfections. Use the previous formula for an estimate of where in the frequency domain the resonance is likely to be located rather than to establish an exact value.

ELECTRICAL CONNECTIONS—DIGITAL MEMS MICROPHONES WITH PDM OUTPUT

CODECS SUPPORTING PDM DATA FORMAT

InvenSense has multiple MEMS microphones with a pulse-density modulated (PDM) output that connect directly to codecs or ADCs with a dedicated PDM input. For the PDM format, a codec or processor typically provides the clock to the microphone, and up to two microphone data output signals can be connected on the same signal line that is connected to the input of the codec. See Figure 4 for an example connection and refer to the data sheets for more details on the PDM microphone interface.

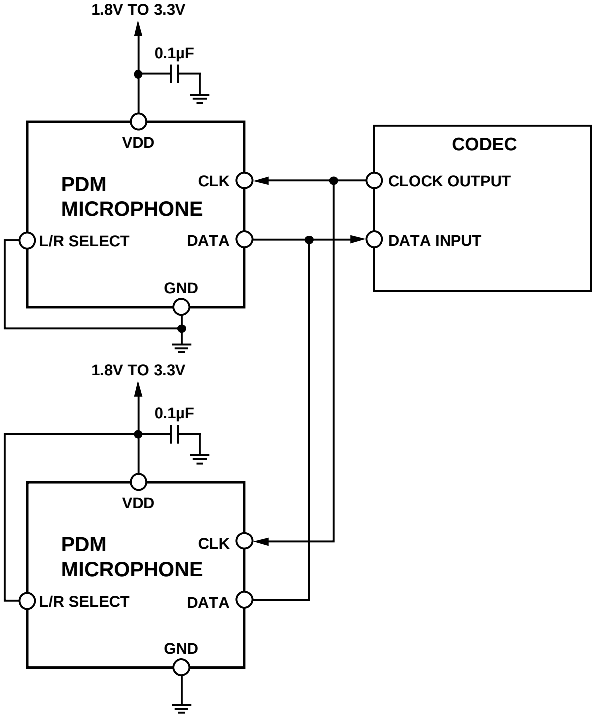

Figure 4. Codec Interface Block Diagram with Two PDM Microphones

CONNECTING TWO MICROPHONES TO A SINGLE DATA LINE

As shown in Figure 4, two microphones can be connected to a single DATA wire for stereo operation. This is possible because the DATA output is in high impedance mode during half of every clock cycle. The L/R SELECT pin controls assignment of the microphone to the left or right output channel (see

Table 1).

TABLE 1. L/R SELECT PIN ASSIGNMENT

L/R SELECT Connected To	Selected Mode
Logical low (GND)	Right microphone (DATA1)
Logical high (V_{DD})	Left microphone (DATA2)

The DATA1 output bit is valid when the clock is low. The DATA2 output bit is valid when the clock is high. This means that the right channel (DATA1) bit must be read on the low-to-high clock transition, and the left channel (DATA2) bit must be read on the high-to-low clock transition. See Figure 5 for a suggested two-microphone connection schematic. Depending on the distance between the two microphones and the length of the V_{DD} trace, a separate 0.1 µF V_{DD} bypass capacitor may be required per microphone.

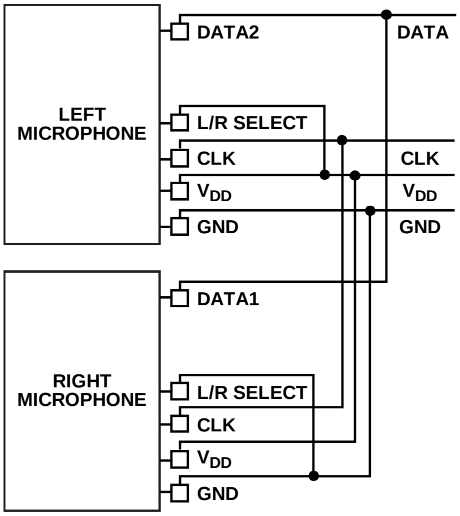

Figure 5. Two PDM Microphones Connected to a Single DATA Wire

WIRE LENGTH RECOMMENDATIONS

For out-of-product evaluations, a PDM microphone can be connected to a codec directly with wire lengths of up to 6 inches (15 cm). When longer wires are required, a 20 to 100 Ω (depending on the trace's characteristic impedance) source termination resistor is recommended on the clock output of the codec to minimize overshoot or ringing of the clock signal. In some cases, a clock buffer may be necessary to avoid performance degradation with excessively long wires. A schematic for a simple clock buffer is suggested in Figure 6. This design uses a 74LVC2T45 bidirectional level translator as a buffer for the clock and data signals between the microphone and codec.

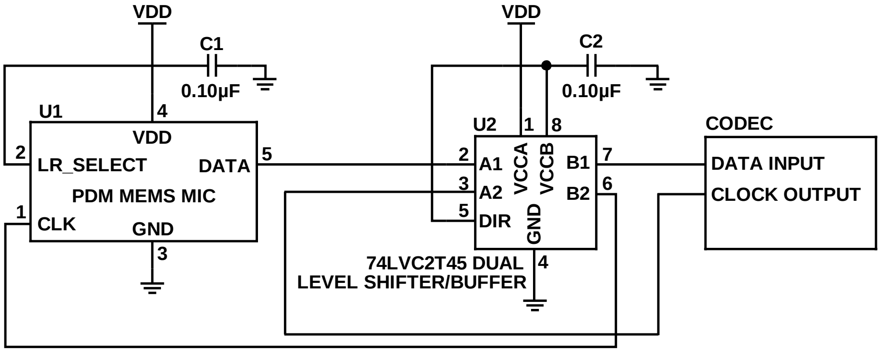

Figure 6. PDM Microphone Buffer Schematic Suggestion

ELECTRICAL CONNECTIONS—ANALOG MEMS MICROPHONES

CONNNECTING ANALOG MEMS MICROPHONES TO A CODEC OR AN OP AMP GAIN STAGE

An InvenSense MEMS microphone with analog outputs can be connected to a dedicated codec microphone input (see Figure 7) or to a high input impedance gain stage (see Figure 8). A 0.1 µF ceramic capacitor, placed close to the power supply pin of the microphone, is used for testing and is recommended to adequately decouple the microphone from noise on the power supply. A DC-blocking capacitor is required at the output of the microphone.

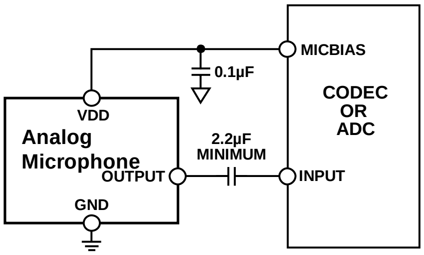

Figure 7. InvenSense MEMS Microphone Connected to a Codec or ADC Input

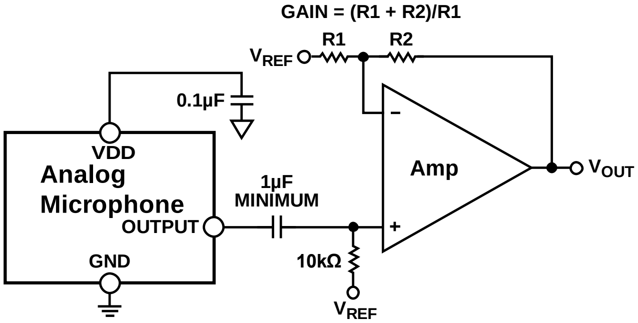

Figure 8. InvenSense MEMS Microphone Connected to an Op Amp Preamp Stage

CONNNECTING ANALOG OUTPUT MEMS MICROPHONES TO A DIFFERENTIAL INPUT

Routing low level, single-ended signals across circuit boards in the presence of electromagnetic interference may inject audible noise into the signal chain. The use of balanced signal paths, a simple solution that is often overlooked, may result in significant reduction in the noise pickup even when the microphone itself has a single-ended output.

The critical property of a balanced line is that both conductors have equal impedance with respect to ground[1]. This condition can be replicated by using a reference conductor terminated into appropriate impedance. For example, many InvenSense MEMS microphones have an output impedance of 200 Ω. A balanced signal path is created by adding a 200 Ω resistor at the ground reference point of the microphone and routing a reference trace in parallel with the signal (see Figure 9). While not creating perfect balanced-line conditions due to resistor value tolerances and other factors, this low cost circuit has been shown to reduce RFI noise in real-life applications.

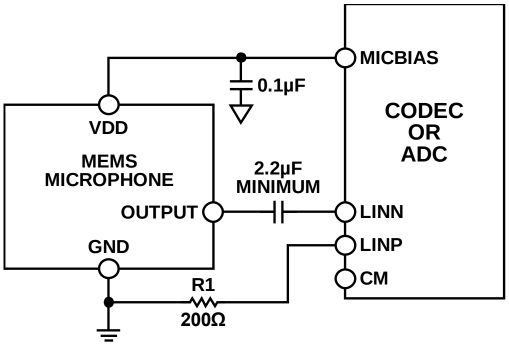

Figure 9. Connecting a Single-Ended Analog Output MEMS Microphone to a Differential Input

Note 1: Bill Whitlock, *Balanced Lines in Audio Systems: Fact, Fiction, and Transformers*, presented at the 97th Convention of the Audio Engineering Society, San Francisco, CA, 1994 November 10–13; revised 1995 March 9.

PERFORMANCE

LOW VIBRATION SENSITIVITY

The InvenSense MEMS microphones exhibit low vibration sensitivity due to very low surface density (mass per unit area) of the membrane. The surface density of a membrane is a product of the membrane's material density and thickness. The equivalent sound pressure that is generated by axial vibration is then

$$p_a = \rho \times t \times a$$

where:

p_a is the equivalent sound pressure, Pa.
ρ is the membrane material density, kg/m^3.
t is the membrane thickness, m.
a is the vibration acceleration, m/sec^2.

Due to a much lower surface density of a MEMS microphone membrane, the vibration signal generated by the MEMS micro-phone is significantly lower than that of a typical electret condenser microphone (ECM). Table 2 provides examples of axial vibration sensitivity of several types of microphones for reference. These calculated equivalent sound pressure levels are in excellent agreement with experimental data where available.

TABLE 2. VIBRATION SENSITIVITY OF VARIOUS CONDENSER MICROPHONES AND AXIAL ACCELERATION

Microphone, Membrane Material, Thickness	**SPL at 1 m/sec^2, dB**	**SPL at 1 *g*, dB**
Bruel & Kjaer ½" mic, metal, 4 µm	65	85
A Typical ECM, Mylar 10 µm	57	77
InvenSense MEMS, p-Si, 0.9 µm	40	60

The low mechanical vibration sensitivity of the MEMS microphones enables better performance in many applications. One particular application where low vibration sensitivity becomes critical is a microphone in a speakerphone with echo cancelling. A vibration signal picked up by a microphone can significantly impair the performance of an acoustic echo cancellation algorithm. This reduction in parasitic pickup applies to mechanical vibration only. When the vibration produces sound at the microphone location, the microphone pickup of that sound is determined by its acoustic sensitivity.

FREQUENCY MAGNITUDE AND PHASE RESPONSE REPEATIBILITY

The InvenSense MEMS microphones have a frequency response with low variability from part to part due to high repeatability of the semiconductor manufacturing process. This response consistency makes multi-microphone applications, such as beamforming, possible without additional testing and matching of microphones. Figure 10 illustrates an example of overlaid magnitude responses of 40 randomly selected ADMP421 microphones. Due to the minimum phase nature of these tiny MEMS microphones, their phase responses are directly related to the magnitude responses and, therefore, are tightly matched, as well (see Figure 11). Note that the responses are normalized at 1 kHz.

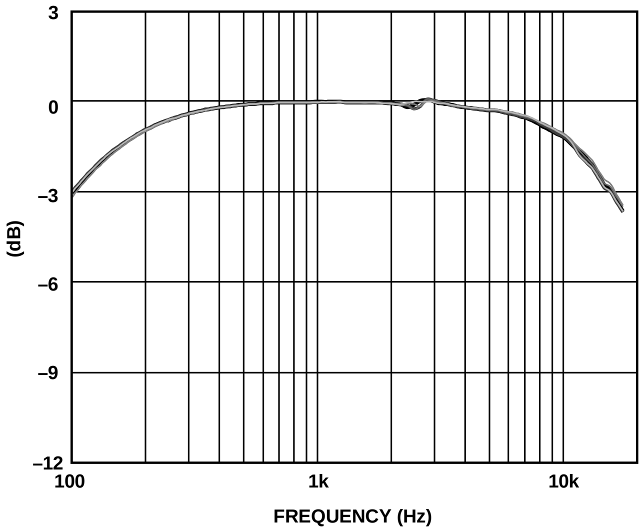

Figure 10. Magnitude Frequency Responses of Multiple ADMP421 Microphones

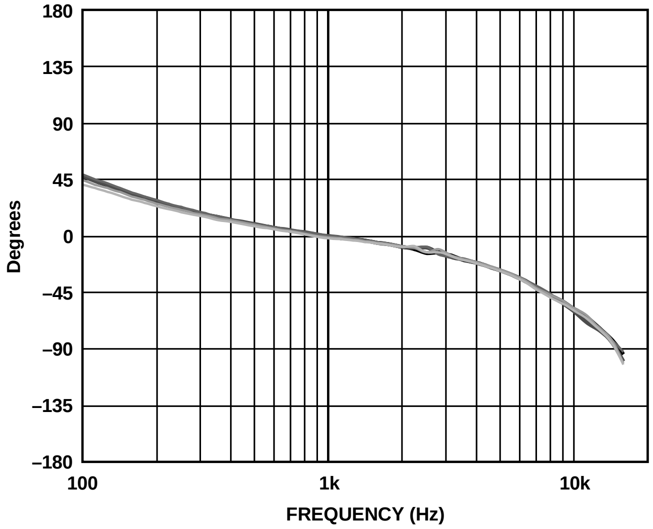

Figure 11. Phase Frequency Responses of Multiple ADMP421 Microphones

STABLE SENSITIVITY VS. TEMPERATURE

The sensitivity of the InvenSense MEMS microphones varies very little over temperature, a fraction of a decibel at most (see Figure 12). This improves performance of multi-microphone designs, especially in situations where temperature variations between microphones result from internal heat sources such as power supplies.

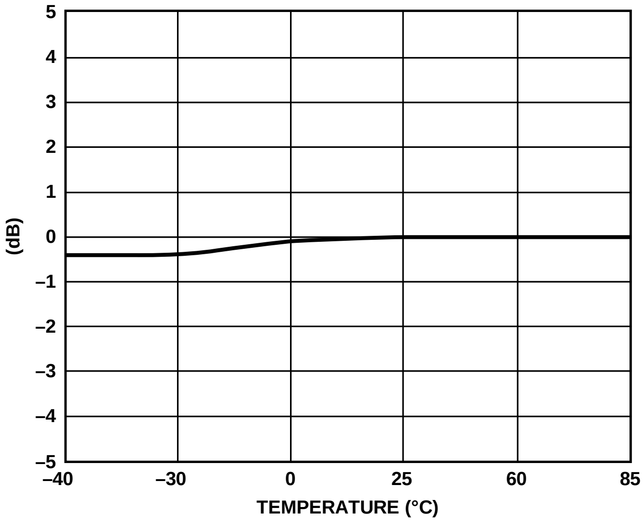

Figure 12. ADMP421 Sensitivity vs. Temperature (Typical)

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