AN-1003
APPLICATION NOTE

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Recommendations for Mounting and Connecting Analog Devices, Inc., Bottom-Ported MEMS Microphones

by Alex Khenkin

INTRODUCTION

Analog Devices bottom-ported MEMS microphones are high performance acoustic transducers featuring an extended wideband frequency response. While the microphone's response 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.

TABLE OF CONTENTS

REVISION HISTORY

11/10—Rev.0 to Rev. A

Changes to Product Title and Introduction Section 1
Changes to Mechanical Design Considerations Section, Sound Path Design Section, PCB Thickness and the Use of Flexible PCB Section, and the PCB Sound Hole Size Section 3
Changes to Avoiding Resonances Section 4
Changed Electrical Connections Section to Electrical Connections: Digital MEMS Microphones with PDM Output Section 5
Deleted Evaluation Board Section, Figure 6, Figure 7, and Table 1; Renumbered Sequentially 5
Changes to Connecting Two Microphones to a Single Data Line Section 5
Added Power Savings When Disabling One Microphone in a Multimicrophone Application Section and the Sleep Mode Section 6
Deleted PCB Land Pattern Layout Section and Figure 10 6
Added Electrical Connections: Analog MEMS Microphone Section and Figure 10 7
Changes to Low Vibration Sensitivity Section, Extended Frequency Response Section, Frequency Magnitude and Phase Response Repeatibility Section, and Figure 11 8
Added Figure 12 8
Added Stable Sensitivity vs. Temperature Section and Figure 13 9

4/10—Revision 0: Initial Version

MECHANICAL DESIGN CONSIDERATIONS

Analog Devices 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 flat frequency response of Analog Devices MEMS microphones, as well as 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).

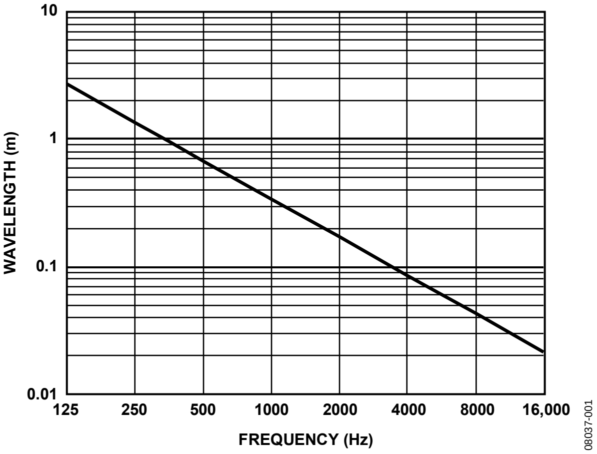

Figure 1. Wavelength of Sound vs. Frequency

PCB THICKNESS AND THE USE OF FLEXIBLE PCB

The performance of an Analog Devices 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.analog.com/mic 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 Analog Devices 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 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).

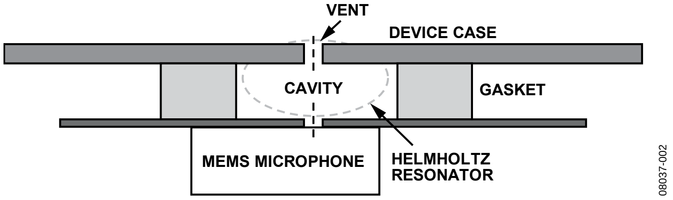

Figure 2. Helmholtz Resonator Example

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 (vent), see Figure 3. Multiple small holes can be used in place of a single vent in the device case.

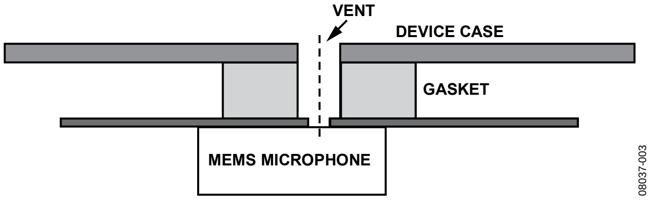

Figure 3. Recommended Gasket Design Example

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

ANALOG DEVICES CODECS SUPPORTING PDM DATA FORMAT

The ADMP421 output data is in pulse density modulated (PDM) digital format. The Analog Devices ADAU1361 and ADAU1761 codecs feature digital microphone inputs that support the PDM format. See Figure 4 and refer to their respective data sheets for more details on digital microphone interface.

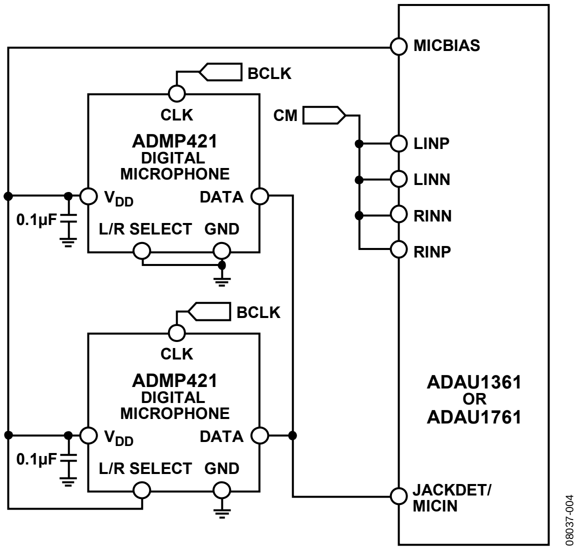

Figure 4. ADAU1361 and ADAU1761 Interface Block Diagram with Two ADMP421 Microphones

When using the ADMP421 connected to the JACKDET/MICIN pin, the JDFUNC Bits[1:0] in Register R2 (Address 0x4008) must be set to enable the microphone input and disable the jack detection function. The ADAU1361 must operate in master mode and source BCLK to the input clock of the digital microphones.

The digital microphone signal bypasses record path mixers and ADCs and is routed directly into the decimation filters. The digital microphone and ADCs share decimation filters and, therefore, both cannot be used simultaneously. The digital microphone input select bit, INSEL, can be set in Register R19 (ADC control register, Address 0x4019).

Figure 5 depicts the digital microphone signal routing. In addition, for the ADAU1761, the DSPRUN bit must also be asserted in Register R62 (DSP run register, Address 0x40F6) for digital microphone operation.

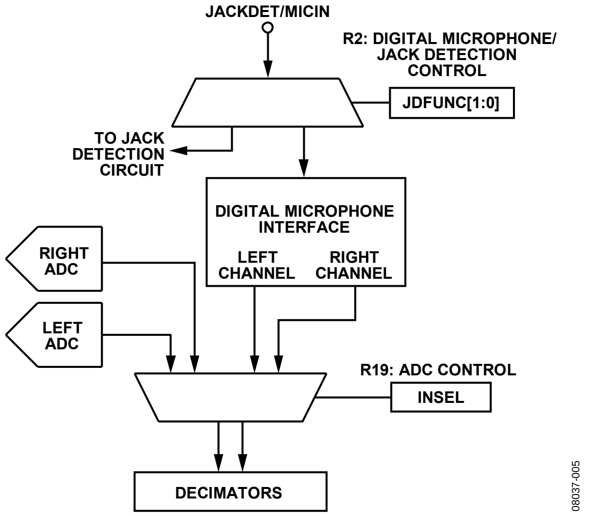

Figure 5. Digital Microphone Signal Routing Block Diagram

CONNECTING TWO MICROPHONES TO A SINGLE DATA LINE

As illustrated 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 left or right output channel, as described in 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 6 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.

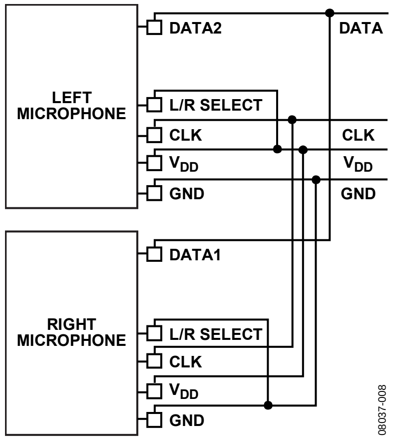

Figure 6. Two ADMP421 Microphones Connected to a Single DATA Wire

POWER SAVINGS WHEN DISABLING ONE MICROPHONE IN A MULTIMICROPHONE APPLICATION

The ADMP421 has a unique power-saving feature when used in systems where two or more microphones share the same clock and/or data lines. The microphone is designed to present high impedance on both the clock and data pins when the power supply (V_{DD}) pin is at 0 V or floating. This disabled microphone presents no load to, and consumes no power from, other active microphones.

SLEEP MODE

When the clock is turned off, or the clock frequency falls below 1 kHz, the microphone enters into sleep mode. In this mode, the microphone data output is in a high impedance state. The current consumption in sleep mode is less than 50 µA.

WIRE LENGTH RECOMMENDATIONS

For out-of-product evaluations, the ADMP421 can be connected to a codec directly with the wire lengths up to 6 inches (15 cm). When longer wires are required, a 100 Ω 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 7.

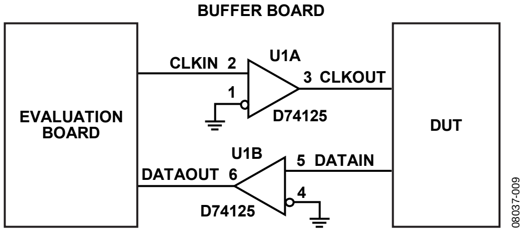

Figure 7. ADMP421 Buffer Schematic Suggestion

ELECTRICAL CONNECTIONS: ANALOG MEMS MICROPHONES

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

An Analog Devices MEMS microphone with analog outputs can be connected to a dedicated codec microphone input (see Figure 8) or to a high input impedance gain stage (see Figure 9). A 0.1 µF ceramic capacitor placed close to the microphone's power supply pin 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.

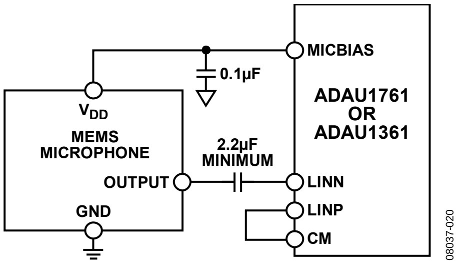

Figure 8. Analog Devices MEMS Microphone Connected to the Analog Devices ADAU1761 or ADAU1361 Codec

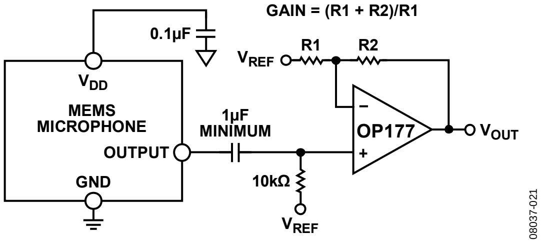

Figure 9. Analog Devices MEMS Microphone Connected to the OP177 Op Amp

CONNNECTING ANALOG OUTPUT MEMS MICROPHONES TO A DIFFERENTIAL INPUT

Routing low level single-ended signals across circuit boards in a 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, an Analog Devices MEMS microphone has an output impedance of 200 Ω. A balanced signal path is created by adding a 200 Ω resistor at the microphone's ground reference point and routing a reference trace in parallel with the signal (see Figure 10). 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.

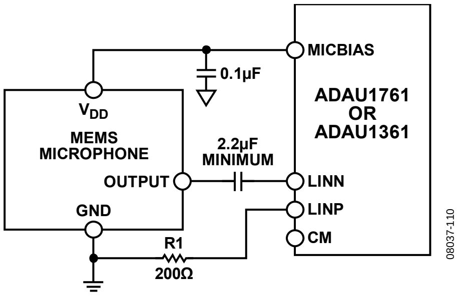

Figure 10. Connecting a Single-Ended Analog Output MEMS Microphone to a Differential Input

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[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

Analog Devices 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 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 microphone 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
Analog Devices 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.

EXTENDED FREQUENCY RESPONSE

Analog Devices MEMS microphones feature uniform extended frequency response, making them an excellent choice for applications such as wideband speech and music capture. Unlike when using microphones with high frequency resonance peaks, adding acoustically resistive material to the microphone port does not improve the response and is not required. In general, additional signal processing, such as low-pass or notch filters, is also unnecessary.

FREQUENCY MAGNITUDE AND PHASE RESPONSE REPEATIBILITY

Analog Devices 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 multimicrophone applications, such as beamforming, possible without additional testing and matching of microphones. Figure 11 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 12). Note that the responses are normalized at 1 kHz.

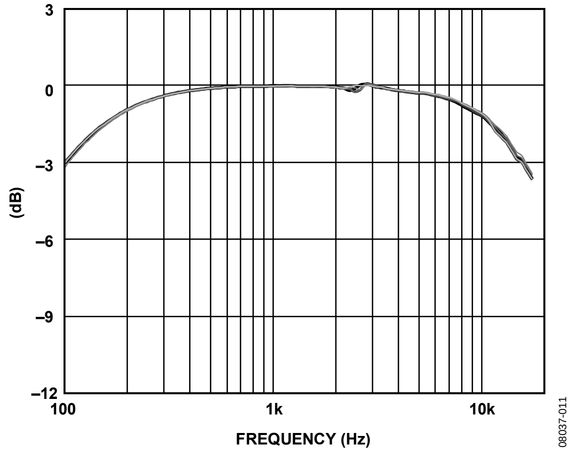

Figure 11. Magnitude Frequency Responses of Multiple ADMP421 Microphones

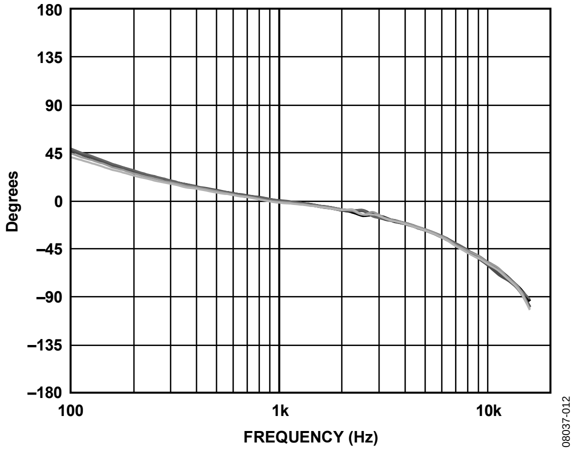

Figure 12. Phase Frequency Responses of Multiple ADMP421 Microphones

STABLE SENSITIVITY VS. TEMPERATURE

The sensitivity of Analog Devices MEMS microphones varies very little over temperature, a fraction of a decibel at most (see Figure 13). This improves performance of multimicrophone designs, especially in situations where temperature variations between microphones result from internal heat sources such as power supplies.

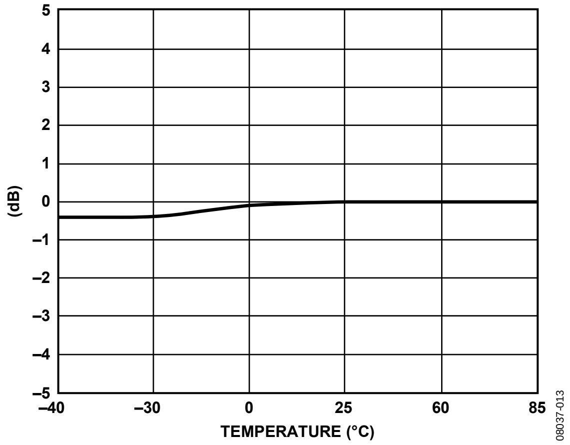

Figure 13. ADMP421 Sensitivity vs. Temperature (Typical)

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