AN5522

Application note

Ultrasound behavior and guidelines of analog MEMS microphone IMP23ABSU

Introduction

The purpose of this application note is to help the user to design an industrial ultrasound microphone system with ST's IMP23ABSU MEMS analog microphone, outlining the guidelines for handling the microphone and for hardware integration.

This document does not modify the content of the official datasheet. Please refer to the datasheet for parameter specifications.

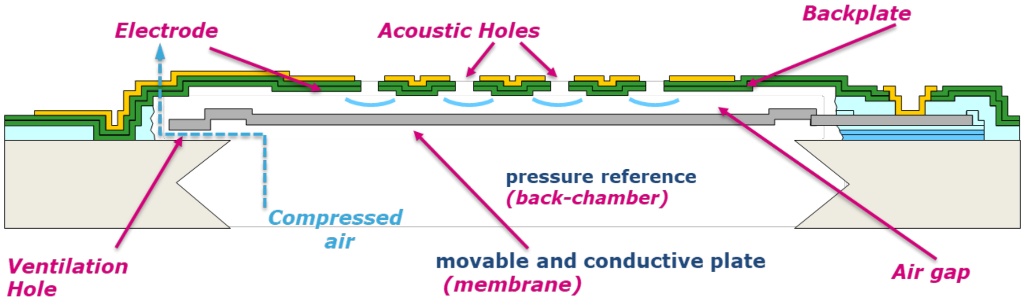
1 Overview of ST MEMS microphones

This section introduces the current state-of-the-art MEMS microphone mechanical structure to help and guide testing in the ultrasound frequency range and designing suitable hardware ultrasonic systems.

1.1 Mechanical structure of MEMS microphones

As a standalone object, the MEMS microphone is composed of a parallel plate capacitor (plates named “membrane” and “backplate”), whose capacitive change is caused by sound, passing through the acoustic holes in the fixed backplate, that moves the membrane. The ventilation hole allows static pressure equalization between the microphone and the ambient environment. There is no membrane deflection due to static pressure.

Figure 1. Section of the MEMS microphone parallel plate capacitor structure

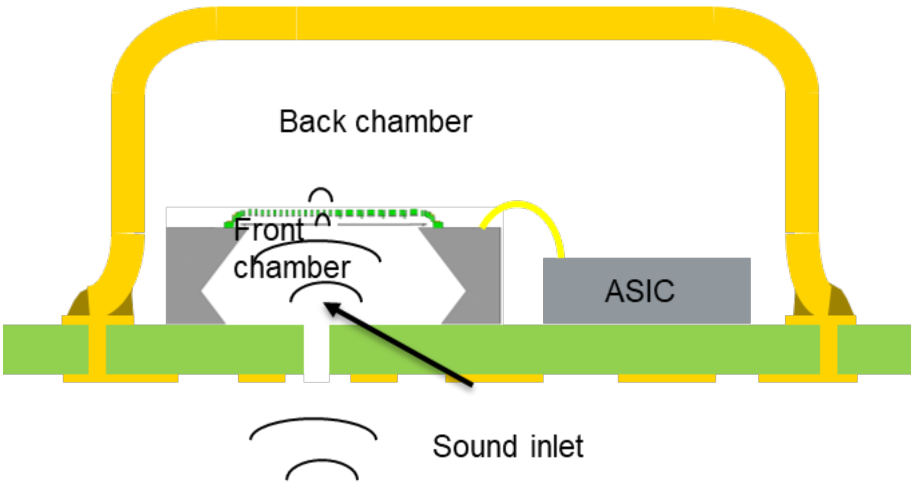


For a more detailed explanation on MEMS microphone structure and main parameters, refer to *AN4426: Tutorial for MEMS microphones* on www.st.com.

1.2 Helmholtz frequency

The MEMS microphone is inserted in a properly designed package, creating a front chamber and a back chamber, that determines the frequency response behavior of the microphone. The substrate thickness is chosen to optimize the trade-off between robustness and the minimum impact on the Helmholtz frequency. The IMP23ABSU device components are assembled in a metal package as shown in Figure 2.

Figure 2. MEMS microphone inserted into a standard metal package



Helmholtz resonance is the phenomenon of air resonance in a cavity, such as when one blows across the top of an empty bottle. The name comes from a device created in the 1850s by Hermann Von Helmholtz, the "Helmholtz resonator", which he, the author of the classic study of acoustic science, used to identify the various frequencies or musical pitches present in music and other complex sounds. If the volume of the MEMS cavity is greater than the neck, the resonator corresponds exactly to a Helmholtz resonator. More commonly this condition is not respected since the volume of the MEMS cavity is smaller than the entire volume created by the gasket cavity. Hence, since the equations regulating the behavior of a stationary wave inside an acoustic cavity are complex and depend on the geometry of every involved acoustic cavity, the use of a simulating tool like COMSOL® is mandatory.

For further details on the COMSOL® tool for MEMS microphone gasket simulation, refer to paragraph 1.2 of *AN4427: Gasket design for optimal acoustic performance in MEMS microphones*, available on www.st.com.

2 Ultrasound capability of analog microphones

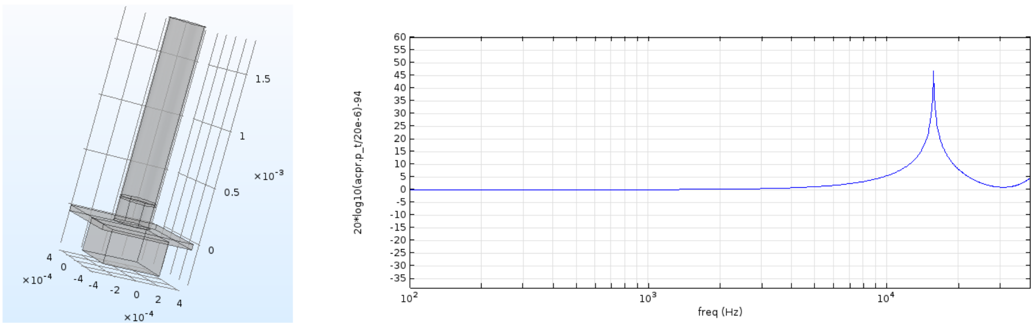
Standard MEMS microphones are intended to operate in the audio bandwidth which is defined between 20 Hz (lower audio band limit) and 20 kHz (upper audio band limit). This section explains the theoretical study of the behavior of ST analog MEMS microphones in the ultrasound band, i.e. from 20 kHz to 80 kHz. The standard audio band must, however, be considered on the whole because all the frequency response values are normalized as standard procedure to the 1 kHz 94 dBSPL Sensitivity value.

2.1 Theoretical ultrasound behavior simulation

As noted in the previous sections, in order to determine the best practices for gasket design, simulation experiments have been performed using the COMSOL® tool. The method consists of simulating the effect of defined geometries placed close to the sound inlet of the microphone. These simulations have been performed, checking how such geometries can modify the frequency response of the ST bottom port analog MEMS microphone IMP23ABSU. The purpose is to study the ultrasound behavior of the microphone's mechanical system. As a general consideration, low-frequency behavior depends on the ventilation hole and the back-chamber dimension while the high-frequency response depends on the geometry of the front chamber only.

The first simulation consists of the calculation of the frequency response of the acoustic system defined by the combination of the MEMS microphone front chamber, the substrate inlet and a cylindrical tube with fixed radius (250 µm) and 1.5 mm length (plus 0.1 mm solder paste thickness). This geometry simulates a standard PCB inlet structure.

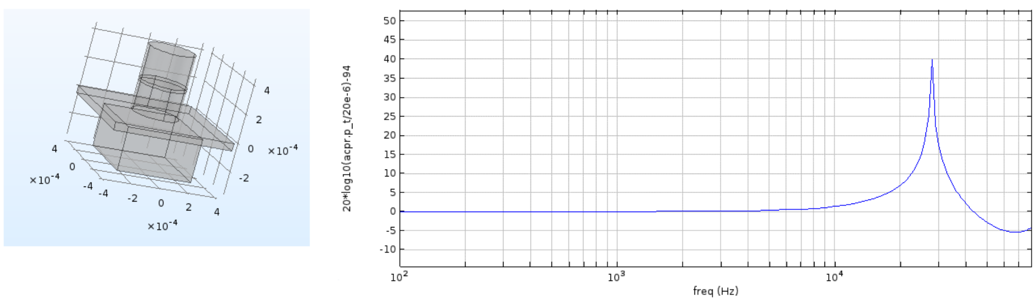
Figure 3. Simulation of MEMS microphone - thick, standard board application



Since the resonance frequency of the system is close to 15 kHz and the 3 dB flatness is up to 17 kHz, a gasket based on a standard PCB is good for voice band related applications.

The second simulation consists of the calculation of the frequency response of the acoustic system defined by the combination of the MEMS microphone front chamber, the substrate inlet and a cylindrical tube with fixed radius (250 µm) and 0.3 mm length (plus 0.1 mm solder paste thickness). This geometry simulates a flex PCB inlet structure and is close to the limit of the pure free field, i.e. the bare device without an additional gasket.

Figure 4. Simulation of MEMS microphone - thin, flex board application



Since the resonance frequency of the system is close to 30 kHz and the 3 dB flatness is up to 15 kHz, a gasket based on a thin PCB is good for general audio band related applications that extend to the near ultrasound field.

The results of these two use-case simulations demonstrate that the second case, the flex PCB, is the one to be preferred for having a flat frequency response across the widest part of the audio and near-ultrasound spectrum.

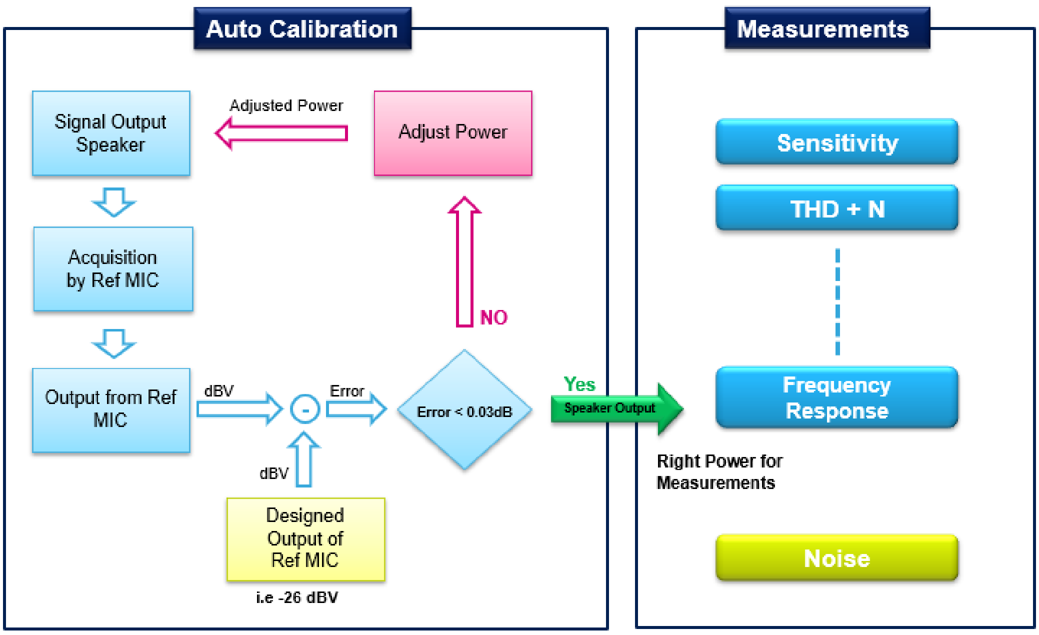
For further details on MEMS microphone gasket design and optimization, refer to *AN4427: Gasket design for optimal acoustic performance in MEMS microphones* on www.st.com.

2.2 Experimental results

2.2.1 Ultrasound test setup

The standard free-field setup for audio measurements is composed of an anechoic chamber, a loudspeaker (a woofer, a tweeter or a coaxial speaker, depending on the frequency range of interest), a reference microphone, an acquisition system and a device under test (DUT). The setup should be thermally controlled and the audio field must be equalized (typically at 94 dBSPL). The standard procedure for the system equalization is depicted in the following figure.

Figure 5. **Flowchart of the tester equalization procedure**



The frequency response of a microphone DUT defines its reaction to the acoustical stimuli at different frequencies and it is typically normalized with respect to 1 kHz, 94 dBSPL. To minimize any effect due to misalignment between the reference microphone, the DUT and the acoustic source, amplified by the small acoustic ultrasound wavelengths, the substitution method for the measurement has been preferred. The detailed composition of the measurement setup is the following:

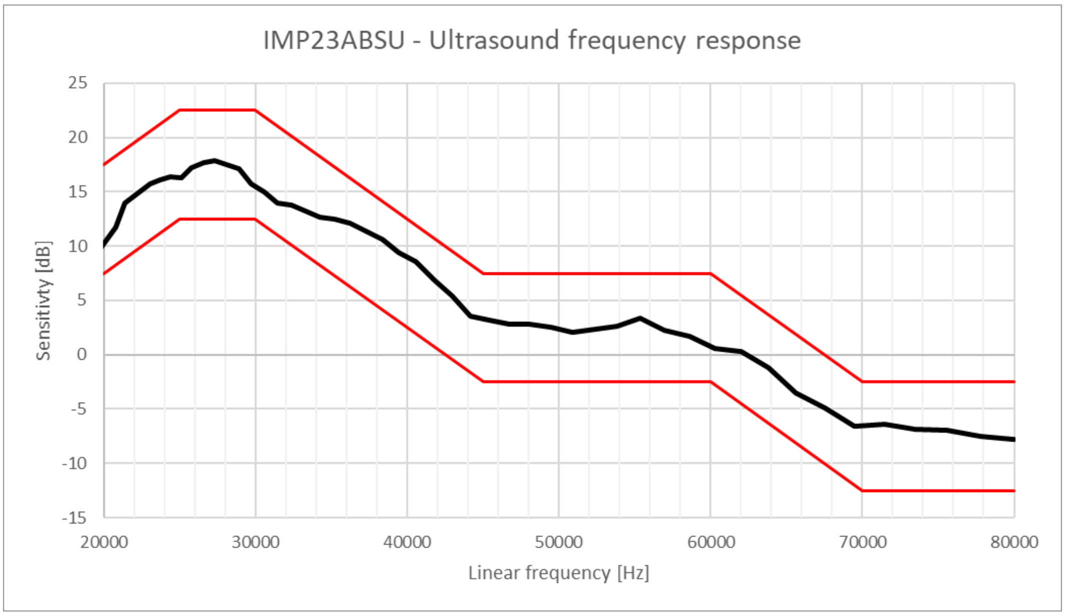
- Reference microphone: GRAS 46BD
- Loudspeaker: L400 Ultrasound Speaker - Pettersson Elektronik AB
- Acquisition system: analog input module from Audio Precision APx525

For further details, refer to the available literature: *Calibration of the pressure sensitivity of microphones by a free-field method at frequencies up to 80 kHz*, A. J. Zuckerwar, G. C. Herring, B. R. Elbing, The Journal of the Acoustical Society of America 119(1):320-9, January 2006)

2.2.2 Ultrasound test results

Experimental tests have been performed on N.100 samples on the flex PCB simulated in Section 2.1 Theoretical ultrasound behavior simulation and described in Section 3.2 ST reference design guidelines and have been submitted to the R&R process. The average ultrasound frequency response has been recorded and the following graph has been added to the IMP23ABSU datasheet.

Figure 6. Average IMP23ABSU ultrasound frequency response



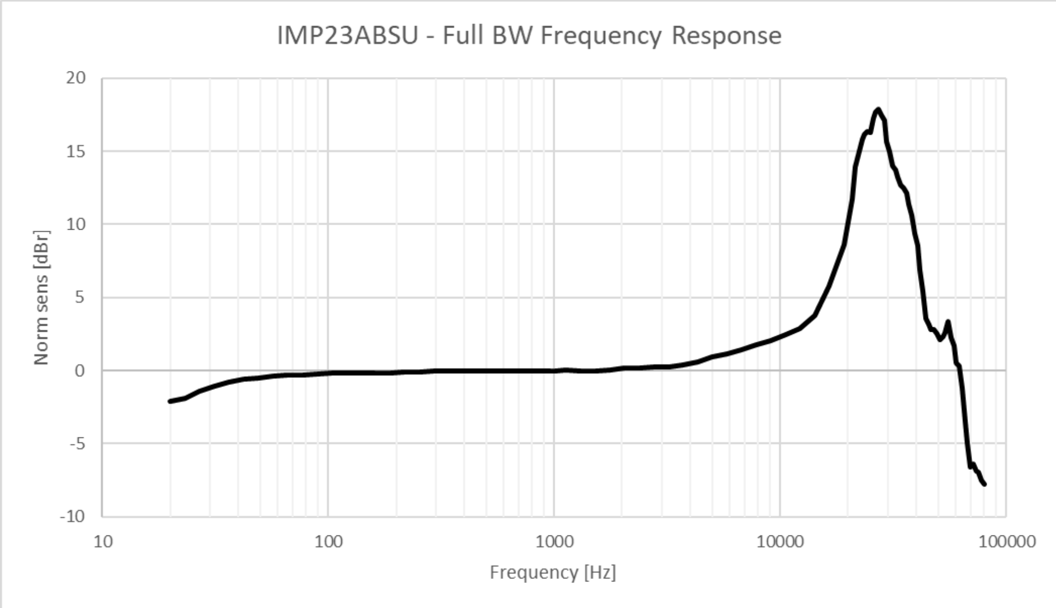
The punctual limits of the ultrasound frequency response can be inferred from the average behavior and the standard deviation of the measurements on characterization samples. The results are shown in the following table.

Table 1. Ultrasound frequency response limits and typical values for IMP23ABSU normalized sensitivity

Frequency [Hz]	Min.	Typ.	Max.
20000	7.5	12.5	17.5
25000	12.5	17.5	22.5
30000	12.5	17.5	22.5
45000	-2.5	2.5	7.5
60000	-2.5	2.5	7.5
70000	-12.5	-7.5	-2.5
80000	-12.5	-7.5	-2.5

The repeatability and reproducibility of these results can help the application developer to consider these values as the typical microphone behavior in the ultrasound frequency spectrum and to add them in their equalization procedure (real-time or post-processing software procedures). The low-pass filtering effect above 50 kHz (which differs from the flex PCB gasket simulation results) is due to internal electronics filtering and it is fully repeatable.

Figure 7. Full 20 Hz-80 kHz frequency response band normalized with respect to the 1 kHz 94 dBSPL sensitivity, in logarithmic scale



3 Ultrasound applications

3.1 Overview of ultrasound applications

This section describes some MEMS sensor application families that involve ultrasonic analysis and data collection.

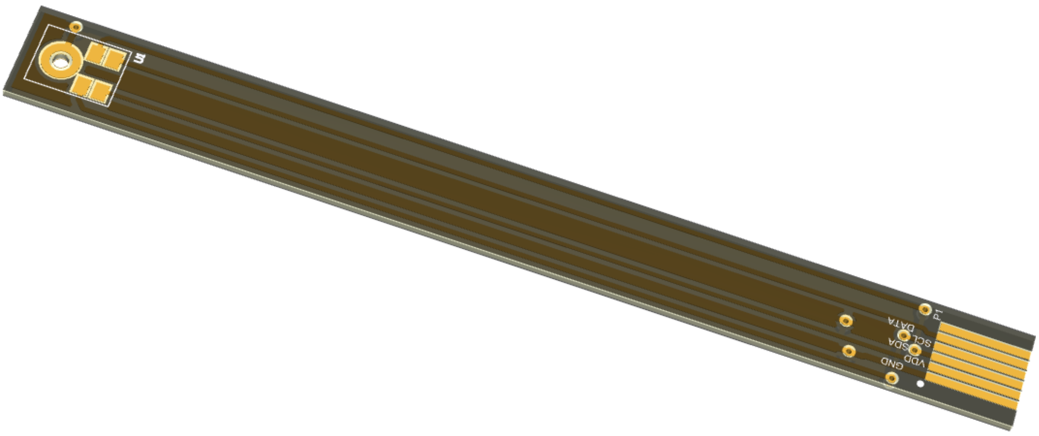
- **Industrial applications**
  - A broad segment for ultrasound microphone applications is the industrial-related **predictive maintenance** field. Most machine failures can be discovered early, making them treatable issues instead of replaceable downtime issues. Excessive vibration, especially in the ultrasonic range, and temperature increases are indicators of mechanical failure on the horizon, but we also know that microscopic changes in friction forces, detectable early with ultrasound, provide a bigger window of opportunity for scheduled maintenance.
  - Another important application field is **air/gas leakage detection**. When a tube containing fluid starts to leak, it emits an ultrasound characteristic pattern which depends on the diameter of the leakage hole and on the pressure of the fluid inside the tube.
- **Telecommunications**
  - **Partial electrostatic discharge** is another possible application sector. It has been proven that defects on high-voltage cables can produce an electrical discharge that can be detected from the acoustical effect that it generates while breaking the air dielectric.
  - Another important application area related to **telecommunications** is **data transmission via ultrasound**. For example, Google Chromecast broadcasts data packets in the near ultrasound BW so Android devices can detect if a Chromecast device is in the room and pair to it.
- **Personal electronics**
  - A general application involving ultrasound detection in **personal electronics** is the acquisition of **ultrasound signals from pets**. For example, in particular cases it has been proven that animals such as guinea pigs emit a characteristic ultrasound pattern during their birth. Another application is related to the “bat detector”. Bats localize objects in space emitting ultrasound signals (up to 200 kHz), and ultrasound microphones can be used to hear the reflected and transmitted signal, detecting in this way a bat’s presence.
  - Finally, an innovative application includes proximity and smart pen detection. Ultrasound signals can be used for proximity/occupancy detection and smart pen detection in tablets.

The research field of ultrasound applications is broad and the related market is currently under definition and expansion.

3.2 ST reference design guidelines

As pointed out throughout this application note, in the ultrasound range [20 Hz-80 kHz] the DUT must be as close as possible to the free-field environment, meaning that the acoustical path between the sound inlet and the outer environment must be minimized. For this reason, the recommendation for using ST MEMS microphone IMP23ABSU is to solder the devices on flex PCBs of thickness 250 µm, which is the current standard for microphone modules on smartphone platforms. The proposed ultrasound adapter should be a flex printed circuit board like the following.

Figure 8. Reference design adapter for IMP23ABSU ultrasound applications



Our recommendation is to keep the microphone distant from the other application components and to keep the microphone gasket unsealed with respect to the ultrasound vibrating object to be detected.

Revision history

Table 2. **Document revision history**

Date	Version	Changes
31-Aug-2020	1	Initial release
16-Sep-2020	2	Minor textual updates

Contents

List of figures