

MEMS Microphones, the Future for Hearing Aids

By Jerad Lewis and Dr. Brian Moss

Driven by aging populations and a pronounced increase in hearing loss, the market for hearing aids continues to grow, but their conspicuous size and short battery life turn many people off. As hearing loss becomes ever more common, people will look for smaller, more efficient, higher quality hearing aids. At the start of the hearing aid signal chain, microphones sense voices and other ambient sounds, so improved audio capture can lead to higher performance and lower power consumption throughout the signal chain.

Microphones are transducers that convert acoustical signals into electrical signals that can be processed by the hearing aid's audio signal chain. Many different types of technologies are used for this acoustic-to-electrical transduction, but condenser microphones have emerged as the smallest and most accurate. The diaphragm in condenser microphones moves in response to an acoustic signal. This motion causes a change in capacitance, which is then used to produce an electrical signal.

Electret condenser microphone (ECM) technology is the most widely used in hearing aids. ECMs implement a variable capacitor with one plate built from a material with a permanent electrical charge. ECMs are well established in today's hearing industry, but the technology behind these devices has remained relatively unchanged since the 1960s. Their performance, repeatability, and stability over temperature and other environmental conditions are not very good. Hearing aids, and other applications that value high performance and consistency, present an opportunity for a new microphone technology that improves on these shortcomings, allowing manufacturers to produce higher quality, more reliable devices.

Microelectromechanical systems (MEMS) technology is driving the next revolution in condenser microphones. MEMS microphones take advantage of the enormous advances made in silicon technology over the past decades—including ultrasmall fabrication geometries, excellent stability and repeatability, and low power consumption—all of which have become uncompromising requirements of the silicon industry. Until now, the power consumption and noise levels of MEMS microphones have been too high to make them appropriate for use in hearing aids, but new devices that meet these two key specifications are now enabling the next wave of innovation in hearing aid microphones.

MEMS Microphone Operation

Like ECMs, MEMS microphones operate as condenser microphones. MEMS microphones consist of a flexibly suspended diaphragm that is free to move above a fixed backplate, all fabricated on a silicon wafer. This structure forms a variable capacitor, with a fixed electrical charge applied between the diaphragm and backplate. An incoming sound pressure wave passing through holes in the backplate causes the diaphragm to move in proportion to the amplitude of the compression and rarefaction waves. This movement varies the distance between the diaphragm and the backplate, which

in turn varies the capacitance, as shown in Figure 1. Given a constant charge, this capacitance change is converted into an electrical signal.

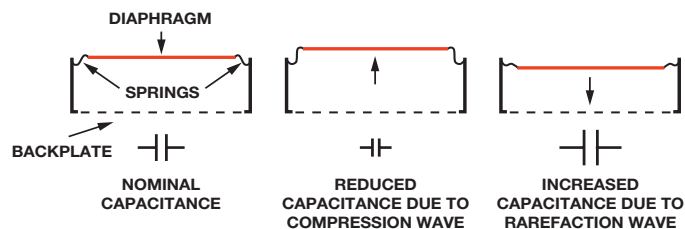


Figure 1. Capacitance of MEMS microphone varies with amplitude of acoustic wave.

The microphone sensor element is constructed on a silicon wafer using similar manufacturing processes to other integrated circuits (ICs). Unlike ECM manufacturing technologies, silicon manufacturing processes are very precise and highly repeatable. Each MEMS microphone element fabricated on a wafer will perform like every other element on that wafer—and like every element on different wafers produced across the many years of the product's lifetime.

Silicon fabrication uses a series of deposition and etching processes in a tightly controlled environment to create the collection of shapes in metal and polysilicon that form a MEMS microphone. The geometries involved in the construction of MEMS microphones are on the order of microns (μm). The holes in the backplate through which sound waves pass can be less than $10\ \mu\text{m}$ in diameter and the diaphragm thickness can be on the order of $1\ \mu\text{m}$. The gap between the diaphragm and the backplate is on the order of several microns. Figure 2 shows a SEM image of a typical MEMS microphone transducer element, looking at it from the top (diaphragm) side; Figure 3 shows the cross section through the middle of this microphone element. In this design, sound waves enter the microphone through the cavity in the bottom of the element and pass through the backplate holes to excite the diaphragm.

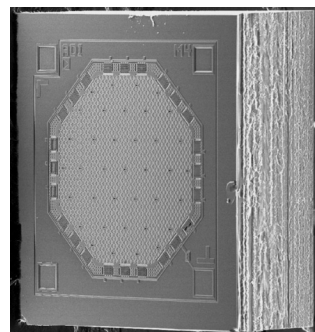


Figure 2. SEM image of MEMS microphone.

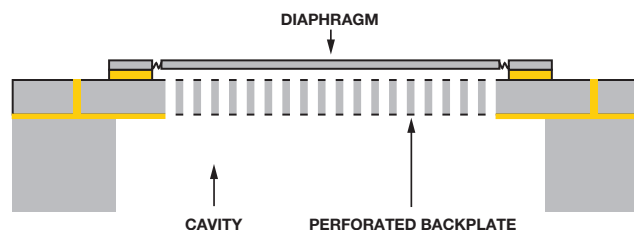


Figure 3. Cross section of a MEMS microphone.

Because the geometries are tightly controlled during the manufacturing process, the measured performance from microphone to microphone is highly repeatable. Another advantage of using MEMS technology to build microphones is that the diaphragm is extremely small, resulting in very low mass and making a MEMS microphone much less susceptible to vibration than an ECM, which has a much more massive diaphragm.

Evolution, Repeatability, and Stability

MEMS microphones have developed to the point where they are now the default choice for many audio capture applications that require small size and high performance, but most commercial grade microphones are unsuitable for the hearing aid industry, which requires significantly smaller parts with lower power consumption; better noise performance; and improved reliability, environmental stability, and device-to-device repeatability. MEMS microphones technology is now at the stage where all of these can be offered: ultrasmall packages, very low power consumption, and very low equivalent input noise.

Tight controls in the silicon manufacturing process make the stability and device-to-device performance variation of MEMS microphones significantly better than that of ECMs. Figure 4 shows the normalized frequency response of several MEMS microphones of the same model; Figure 5 shows the normalized frequency response of various ECMs. The frequency response of each MEMS microphone is nearly identical, while that of the ECMs shows significant device-to-device variation, especially at high and low frequencies.

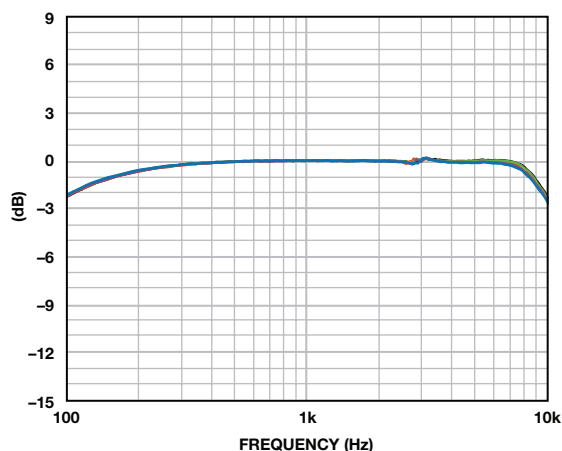


Figure 4. Frequency response of several MEMS microphones.

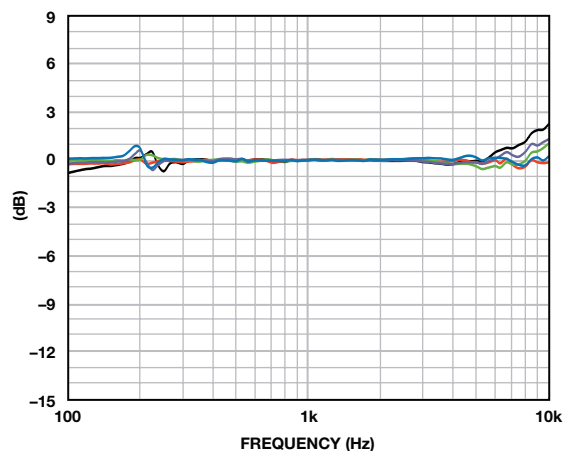
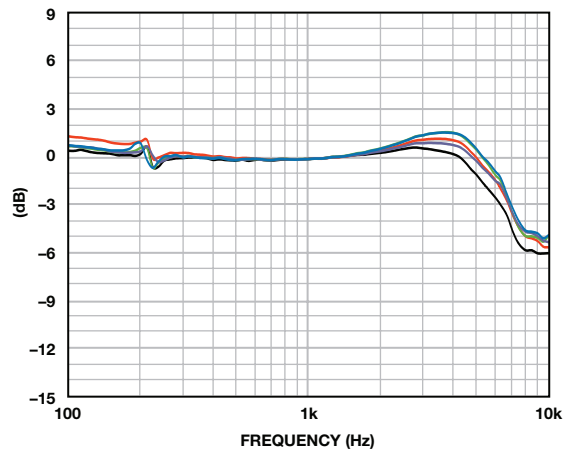
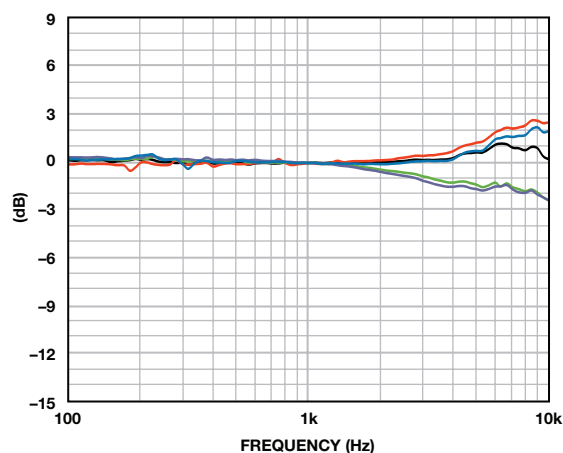


Figure 5. Frequency response of three sets of ECM microphones.

MEMS microphones also exhibit excellent stability across a wide temperature range. Figure 6 shows the change in sensitivity as the ambient temperature is varied between -40°C and $+85^{\circ}\text{C}$. The black line shows less than 0.5-dB variation over the temperature range for the MEMS microphone, while the ECMs show up to 8-dB variation over temperature.

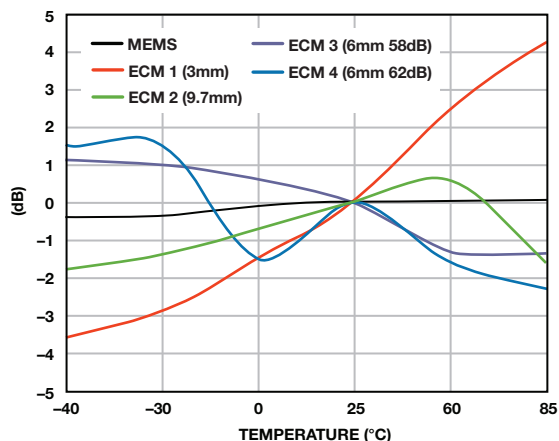


Figure 6. Sensitivity to vibration vs. temperature: MEMS vs. ECMs.

MEMS microphone designs also have significantly improved power supply rejection compared to ECMs, with a typical power supply rejection ratio (PSRR) of better than -50 dB. The output signal and the bias voltage (power) share a common pin on an ECM, so any ripple on the power supply appears directly on the output signal. The exceptional PSRR of MEMS microphones allows freedom in the audio circuit design that is not possible with ECMs. This can result in reduced component count and system cost.

In tiny, battery-powered applications like hearing aids, every microwatt of power is critical. Microphones cannot be power cycled to save power when the hearing aid is operating, so the microphone's active power consumption is of critical importance. Typical ECM microphones used in hearing aids can draw $35\ \mu\text{A}$ when powered at typical Zn-air battery voltages (0.9 V – 1.4 V). The current draw of MEMS microphones used in hearing aids can be less than half of that at the same voltages, enabling hearing aids to go longer between battery changes.

The latest generation of MEMS microphones has the excellent noise and power performance required by the hearing aid industry. Analog Devices has leveraged more than 20 years of experience in MEMS technology to build high-performance microphones that can be used in the hearing aid market. Typical omnidirectional MEMS microphones specify an equivalent input noise (EIN) of 27.5 dB SPL (A-weighted, 8 kHz bandwidth), which makes them suitable for hearing aid applications. The $\frac{1}{3}$ -octave EIN noise performance, typically used for specifying hearing aid microphones, is exceptionally good at low frequencies, as shown in Figure 7. This level of noise performance is achieved with only $17\ \mu\text{A}$ current draw at typical hearing aid battery voltages. The microphones are available in tiny packages with less than $7.5\ \text{mm}^3$ total volume, as shown in Figure 8.

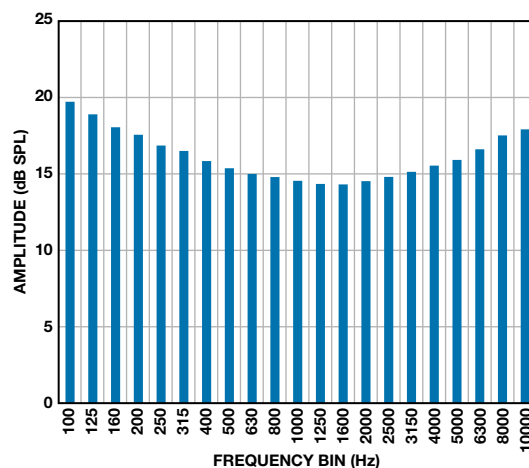


Figure 7. MEMS microphone $\frac{1}{3}$ -octave noise.

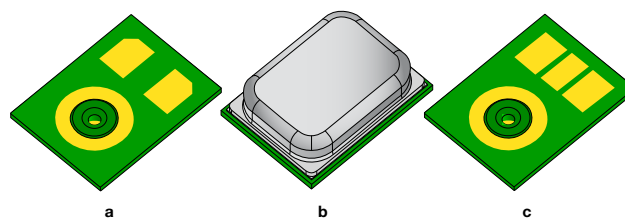


Figure 8. Omnidirectional MEMS microphones for hearing aids. a) bottom view. b) top view. c) bottom view of package that facilitates hand soldering.

Conclusion

New high-performance, low-power MEMS microphones demonstrate that they will be the next generation of microphone technology for hearing aids. MEMS microphones can compete in performance with many hearing aid ECMs and can surpass ECM technology in many areas, such as repeatability, stability, size, manufacturability, and power consumption. MEMS microphones are the future for hearing aids, and that future is here now.

Authors

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