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Fly-Inspired Microphone for Directional Hearing Aids: Unusual Ears Lead to Smaller Microphone Technology

by Ronald Miles

Central to hearing aid design is the desire to reduce the unwanted sound that makes it maddeningly difficult to understand speech in noisy environments. The use of hearing aid microphones with the ability to reject sounds from specified directions can form a first line of defense against unwanted noises that compete with speech. Much of our work at the Thomas J. Watson School of Engineering and Applied Science at Binghamton University has focused on the creation of new miniature microphone technology that can address some of the technological challenges in hearing aids.

Directional hearing aids use a pair of nondirectional, independent microphones that process the signals to determine pressure differences and reduce the influence of unwanted sounds. Attempting to sort out differences in signals that are extremely similar (as when the microphones are placed close to each other) poses significant problems, especially at lower frequencies at which the wavelength of sound is huge relative to the spacing between the microphones. For this reason, there are practical limits on how small directional hearing aids can be; the microphones need to be spaced far enough apart to obtain a signal that isn''t buried in electronic noise.

An Unusual Ear

Our approach to directional microphone design is based on our earlier studies of the mechanisms of directional hearing in small animals, such as insects. In collaboration with neurobiologists Ron Hoy and Daniel Robert at Cornell University, we discovered an unusual ear in a small parasitic fly, *Ormia ochracea*. This fly is remarkably capable of localizing sound sources, even though its two ears are only about 200 microns apart. Behavioral studies have shown that the fly can detect changes in the orientation of a sound source that differ by as little as two degrees (Mason, Oshinsky, & Hoy, 2001).

To determine the direction of sound wave propagation, any animal that senses sound pressure (or any man-made acoustic pressure sensor) must detect differences in pressure in at least two points. The difference in the sound pressure that arrives at an animal''s ears is less in small animals with closely spaced ears than in large animals. Despite being small, some animals—like the fly we studied—depend on being able to localize sound sources to find mates, avoid predators, or, in the case of the fly, to locate a suitable host for its parasitic offspring.

When the female *Ormia* is ready to produce offspring, she must locate a cricket, which serves as a food source for her larvae. She does this by listening for their song. When she hears a cricket she flies to it and deposits her larvae, which ultimately consume the cricket. The remarkable ability of this animal to localize the sound of a singing cricket (not an easy task for humans) motivated us to study how the fly''s ears achieve this goal, given that they are so close together that the difference between the pressures at the ears is incredibly tiny. This tiny difference in pressure must be processed by the fly''s nervous system to determine the orientation of the cricket. This ability seemed particularly remarkable, given that the fly doesn''t have the extensive neural processing power of other auditory specialists, such as bats and owls.

Intertympanal Connection

During our study of the ears of *Ormia*, we discovered that rather than having a pair of ears that are as widely separated as possible, the fly has ears that are next to each other and connected by a structure we named the "intertympanal bridge." This mechanical connection causes the two eardrums to rock about a central pivot when sound comes from the side of the fly. This rocking, teeter-totter-like motion is a very sensitive response to the miniscule differences in pressure on the two eardrums. The mechanical connection between the eardrums causes the mechanical structure of the ears to concentrate on minute pressure differences.

Using the eardrums collectively to respond to pressure differences at the ears is an approach to localizing sound that is radically different from using a pair of completely isolated ears (again, like in bats, owls, and humans) and relying on considerable neural processing to determine the differences in the detected signals.

Converting Motion Into Sound

Nature has employed an effective eardrum-based method of detecting pressure differences in very small animals such as *Ormia*, and we believe the idea is worth investigating for application in man-made devices. We''ve designed and fabricated tiny microphone diaphragms that respond to pressure gradients by rotating about a central pivot (see Miles et al., 2009). The diaphragms are 2–3 mm long and 1 mm wide. Made out of silicon, they use the same sort of wafer processing methods as electronic integrated circuits.

When a sound wave causes the diaphragm to rock about its central pivot, the motion is converted into an electronic signal using an optical detection scheme as illustrated in Figure 1 [PDF]. This scheme consists of a microscopic laser, placed underneath the pressure-gradient sensing diaphragm, that shines light up toward an optical grating (actually a series of slits) on the diaphragm. Above this grating, a mirror reflects the light that passes through the grating. The light that reflects from the grating interferes with the light that reflects from the mirror in a way that depends strongly on the position of the diaphragm relative to the mirror. The interference of the reflected light is then picked up on photodiodes housed underneath the diaphragm.

Using this optical detection scheme with our *Ormia*-inspired rocking diaphragm, we have demonstrated that our microphone is able to detect sound with less influence from internal microphone noise than existing low-noise hearing aid microphones (Miles et al., 2009). We have achieved this result in spite of the fact that our microphone is considerably smaller than a pair of conventional microphones used in current directional hearing aids.

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