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The Pure hearing aid from Sivantos, a division of Siemens, is a behind-the-ear model that features dual microphones for better directionality and a telecoil that lets telephones and facilities equipped with an induction loop such as churches and theaters beam sounds directly to the user's hearing aid.

Tech Advances Upgrade Hearing Aids

Thanks to advances in MEMS and signal processing, hearing aids can provide understandable speech and more natural, comfortable sounds to the hearing-impaired.

Technological developments in hearing aids (HAs) have always been driven by efforts to miniaturize hardware and give those with hearing problems—an estimated 35 million in the U.S.—the ability to better hear and understand the people and environment around them. Miniaturization lets engineers pack more amplification and signal processing power in small, wearable housings. It also lets hearing-impaired people use HAs small enough to go largely unnoticed.

Advancements in HAs have always been spurred by developments in electronics and MEMS and their manufacturing processes, and HAs are often the first commercial devices to make use of those developments. For example, the first consumer use of transistors was in a 1952 HA from Sonotone, according to John Dzarnoski, director of technology development at Starkey Hearing Technologies. It used a transistor and two vacuum tubes for amplification in a device that measured 3 × 2.75 × 0.5 in., small enough to fit in a shirt pocket.

"That is the story of hearing-aid development," explained Dzarnoski. "It uses new technologies ahead of other industries to build smaller, more capable devices. And that story continues on."

Here's a look at some of the other ways biomedical engineers are using new technologies to improve the lives of the hearing-impaired.

MICROPHONES

Two types of microphones are commonly used to pick up the sounds that will be amplified by HAs: electret and MEMS. Both have sensitivities of between −32 to −35 dB, according to Eric Branda, product manager for Sivantos Inc., the hearing-aid division of Siemens.

Electrets, long used in HAs, are electrostatic capacitor-based microphones. They measure about 3.6 × 2.5 × 1.27 mm and use a Teflon or polymer diaphragm. These diaphragms are sensitive to temperature, humidity, and aging, which can be a problem.

MEMS microphones are made of silicon using the processes similar to those that make ICs. Thus, they do not have the electrets' material-related problems. They are also smaller than electrets, measuring 3.2 × 2.5 × 1 mm, so engineers can fit several on a single HA.

Their downside is that HAs need a bandwidth of about 8,000 Hz to detect all the sounds needed for speech and normal environmental noises. MEMS microphones currently have a difficult task doing this, though they are fine for cell phones where their limited bandwidth is not a problem, said Dzarnoski.

The Insio in-the-ear hearing aid from Sivantos is said to be the first such device to employ wireless technology for exchanging data with another Insio in the user's other ear to synchronize settings and exchange audio signals. It can also be adjusted by the user through an iPhone or Android device.

Companies often place two microphones on HAs, especially behind-the-ear and in-the-ear types, so that the wearer will be able to tell what direction the sound is coming from (directionality). "Inputs from these microphones, both of which are omnidirectional, can be electronically manipulated or processed (after being converted to digital signals) to give users a sense of directionality," said Branda. "The inputs also help in identifying and tracking unwanted noise, letting the HA reduce amplification of those sounds." Directionality and selective amplification also helps users understand speech when it comes from behind them.

PROCESSING

Today's HAs have about the same processing power as a 386 chip and can handle about 5 million instructions per second, which is a lot of computational power to be running on a small battery, Dzarnoski pointed out.

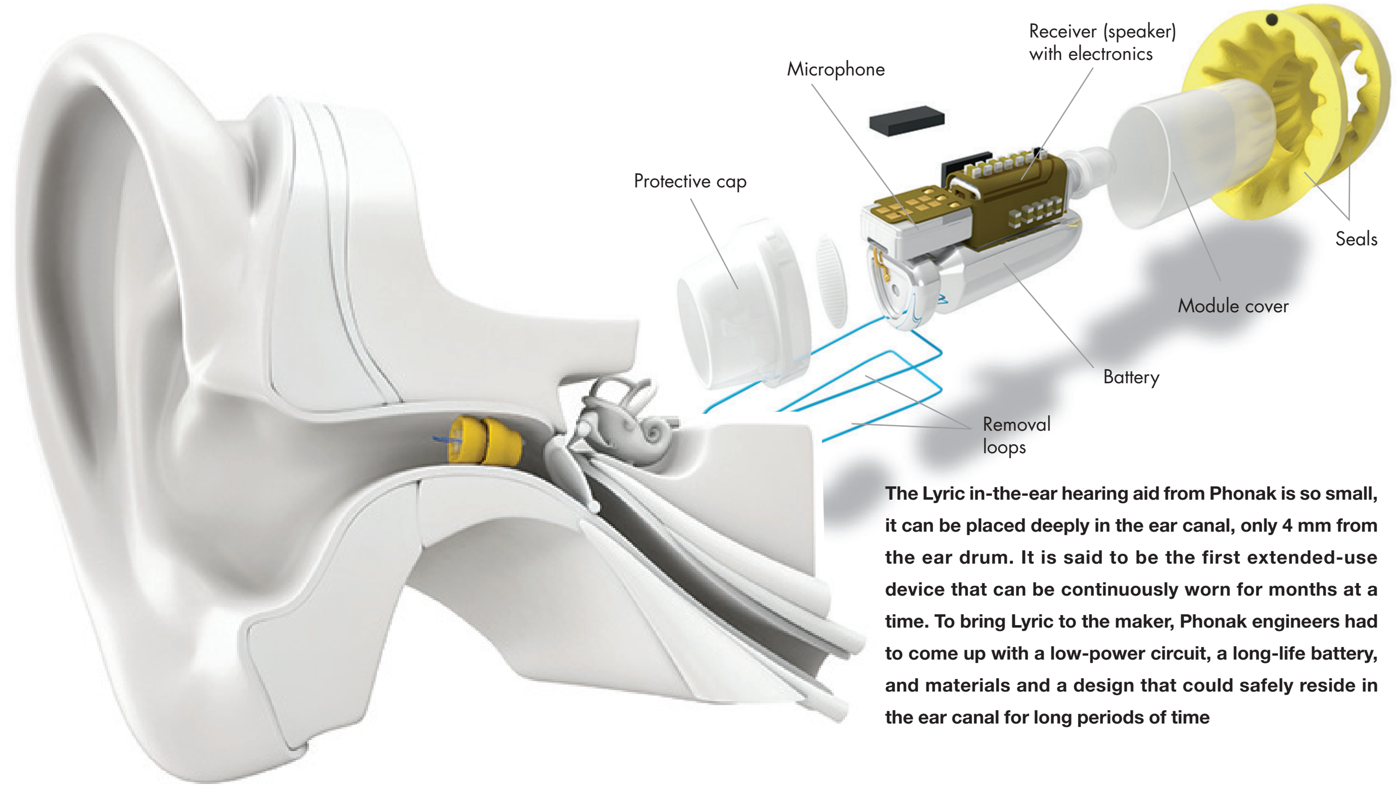
Some of that processing power goes to reduce or eliminate feedback. Feedback happens when sound from the speaker "leaks" back to the microphone and gets repeatedly amplified into a loud squeal. The approach taken by Starkey to reduce feedback is to decorrelate or change the output from the input by frequency shifting the output by 5 to 20 Hz. "A 20-Hz shift represents an aggressive feedback prevention scheme while a 5-Hz shift is used when listening to music," said Dzarnoski.

Digital processors also carry out sound compression, reducing the dynamic range of sounds so that it better matches the users hearing capability.

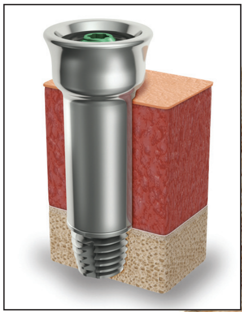
At Sivantos, some HAs use digital signal processing for SpeechFocus. It's a feature that selects the best directional pattern or amplification scheme for incoming microphone signals based on where a speaker is located. First it uses spectral analysis to recognize speech by its frequency spectrum. Then it boosts amplification to the microphone best positioned to pick up that sound.

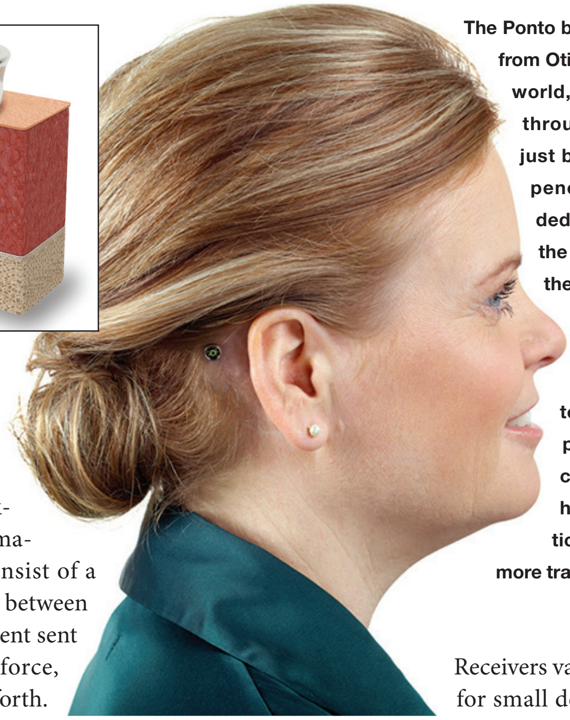
Sivantos and other HA manufacturers also use digital algorithms to reduce transient and impulsive noises, such as rustling paper or clanging dishes, without affecting speech signals. Sivantos' version, called Sound Smoothing, relies on spectral and temporal analysis to attenuate only the transient frequencies, usually high or low frequencies, within one millisecond of their onset.

One of the major goals HA designers have been working on for years is to use signal processing to let HA wearers hear and understand speech from one individual in a room full of peo-



The Lyric in-the-ear hearing aid from Phonak is so small, it can be placed deeply in the ear canal, only 4 mm from the ear drum. It is said to be the first extended-use device that can be continuously worn for months at a time. To bring Lyric to the maker, Phonak engineers had to come up with a low-power circuit, a long-life battery, and materials and a design that could safely reside in the ear canal for long periods of time ple talking, such as in a crowded restaurant or bar. "The ability of hearing aids to recognized unwanted sounds is still primitive, and the top complaint for years has been their inability to recognize speech in the presence of noise, even other speech," noted Dzarnoski.





The Ponto bone-anchored hearing aid (BAHA) from Oticon takes sound from the outside world, processes it, and then sends it through a titanium screw implanted just behind the user's ear. The screw penetrates the skin and is embedded in the user's skull. Users "hear" the sound through bone conduction, the same way you can hear yourself chewing or biting. Because using BAHAs involve surgery, the price for one can range from $15,000 to $25,000. They are an option for patients who have occluded ear canals or lack them entirely, or have some other physical restriction that prevents them from using more traditional hearing aids.

RECEIVERS

The receivers in HAs, or what those outside the industry might call speakers, are electro-acoustic balanced-armature magnetic transducers. They consist of a magnetic armature precisely centered between a pair of electromagnets. Electric current sent through the magnets' coils induces force, which moves the armature back and forth. This mechanical force is transferred to a membrane that converts the motion to air-pressure differences or sound, explained Branda.

Receivers vary in size from 1 × 2.5 × 5 mm for small devices and moderate amplification to 5 × 6 × 8 mm for larger, more powerful receivers. How much power the receivers require is a function of the amplification needed.

TYPES OF HEARING AIDS

THERE ARE FIVE basic types of hearing aids, and which ones patients choose depends on their level of hearing impairment, their physiology and health, and their lifestyle.

BEHIND-THE-EAR (BTE): These are the more traditional devices that consist of a durable plastic housing that rests behind the outer ear connected via a thin plastic tube that snakes into the ear canal. The tube carries sound from a receiver in the housing to the tympanic membrane in the ear, so there is no sound directionality. Its relatively large size lets it provide more amplification and larger batteries. As a result, it's well-suited for those with severe hearing loss. They are also able to contain more processing power. Therefore, audiologists, the medical professionals who fit patients with hearing aids, have more options in tailoring the sound. BTE units can have amplification or gains of 35 to 82 dB.

IN-THE EAR (ITE): These devices, which contain the microphone and speaker plus the battery and processor, fit into the ear. Their size accommodates two microphones for directionality, and larger batteries, making it easier to insert and remove for older persons whose hands aren't as nimble as they once were. ITE hearing aids provide 40 to 70 dB of gain.

IN-THE-CANAL (ITC): Smaller than ITE hearing aids, this fits directly into the canal. Being smaller makes it less noticeable, but it is only good for mild to moderate hearing loss. Users do, however, get better sound localization because the microphone takes advantage of the outer ear's sound-reflecting properties. ITC devices can amplify sound by approximately 35 to 50 dB.

COMPLETELY-IN-THE-CANAL (CIC): The smallest of all hearing aids, CIC versions are almost invisible to others. They are also more compatible with talking on the phone and, like ITC models, use the outer ear to reduce wind noise and help in sound localization. Its size limits battery capacity and how much amplification it can provide, but CIC devices do not need much amplification because they place the receiver so close to the tympanic membrane. They are uncomfortable for some patients due to their small ear canals and how deeply the HA must be inserted. It can also take several visits to the audiologist to get the device to remain comfortably in the ear.

BONE ANCHORED HEARING AIDS (BAHA): Some patients suffering hearing loss have an occluded or non-existing ear canal, or their ear canal secretes too much wax. For these people, traditional hearing aids aren't an option. To get around their limitations, engineers have developed a hearing aid that picks up and amplifies sound, then sends it to the patient's hearing centers in the brain using bone conduction though a titanium anchor inserted in the skull just behind the ear.

HA designers are coming up with smaller receivers, letting them fit in smaller housings that sit nearer to the ear drum. Some designers are also adding two or more receivers, each optimized for a specific range of frequencies. This is much like hi-fi speakers that contain tweeters for high frequencies and woofers for the low tones. Crossover circuitry routes the sounds to the proper receiver.

BATTERIES

Zinc-air batteries are the power source of choice for HAs based on their safety and energy densities. "Zinc-air batteries are very safe," says Dzarnoski, "And they will not get hot enough to burn a person even if the positive and negative side of the battery is shorted out."

They generate 1.35 to 1.45 V of electricity using metallic zinc and oxygen pulled from the air. These disc-shaped batteries have storage capacities that depend on how much zinc they contain. They range in size from 6 × 2 mm up to 11 × 5 mm and last from four to 10 days, depending on how much they are used and how much amplification is provided by the HA. They cost about $0.60 to $1.60 and are not rechargeable.

The Lyric, an in-the-canal HA from Phonak, uses extremely little power, thanks to ultra-low-power electronics and the fact it is so deep within the ear canal—the receiver is only 3 to 4 mm from the eardrum. It operates for months on a single battery. In fact, users can keep Lyric in their ear for up to six months before a technician removes and replaces it.

Sivantos, however, does make HAs that use rechargeable batteries, the only major HA maker to do so. "Rechargeable batteries hold less capacity than regular batteries," said Branda. "Only HAs that are sufficiently energy-efficient, such as some Sivantos makes, can use rechargeables and still last a full 16 hours before needing to be recharged."

PROTECTION

Biomedical engineers consider the ear canal a hostile environment when it comes to materials and electronics. "The ear canal is loaded with wax-generating glands that remove foreign material from the canal naturally," explained Dzarnoski. When hair follicles in the canal sense something in the canal, it stimulates pores to secrete a chemical that results in earwax. So putting a hearing aid in the canal can lead to excess wax creation, which plugs up ports and holes, and is somewhat corrosive.

In most cases, the tight plastic housing that goes in the canal keeps out most debris and wax. Some manufacturers, such as Starkey, add a screen over the microphone. When it gets clogged, it is replaced. Starkey also uses molecular vapor deposition to put a proprietary nanocoating called HydraShield on its housing and exposed components. The 100-nm thick layer makes oil and water bead up and run off the coated parts.

Sivantos makes a completely water- and dust-proof HA called Aquaris. It has been tested to IP68 standards and can be fully immersed in water. The technologies which make that possible include a bottle-housing concept, extra microphone and receiver protection, a waterproof battery door with a membrane seal, and acoustic vents.

THE WIRELESS ADVANTAGE

Designers are now taking advantage of wireless innovations to improve the usability and function of HAs. A common application lets HA wearers adjust the controls on their devices—while they are wearing them—from a smartphone or PDA. They can also key in various profiles, a group of settings for low-noise environments, speech in a noisy room, or for listening to music, among others.

Starkey has a similar feature called Geo Tagging. Wearers use their iPhone and an app to adjust their HA's controls for a particular setting, which could be a theater, classroom, or subway platform. The app stores the settings, as well as the GPS-derived latitude and longitude for the place. The next time the person goes to that place, the iPhone recognizes it from the GPS coordinates and automatically switches the settings to those saved for that location.

Wireless technology has also made it easier to use and wear binaural HAs in which users put a hearing aid in each ear. Just as natural hearing combines inputs from both ears and process it in the brain, outputs from one HAs gets sent to the other to maximize directionality and increase the ability to pull sound out of noise.

The main wireless platform used by HAs seems to be the Apple iPhone and its proprietary 2.4-GHz protocols, according to Dzarnoski. "Companies are building Android-based devices, but Android is not a single standard. There are many different types and versions," he said. "That means companies have to develop HA apps and systems for each one, making development more complex. Apple also forbids anyone from using its protocols with Android. But Apple does work with hearing-aid developers and iPhones seem to have the best functionality."

All of this technology does not come cheap. HAs cost from $2,500 to $7,000, depending on the level of technology, but this cost includes an audiologist who helps patients choose the proper device and helps fit and adjust it. Lyric, from Phonak, is sold as a subscription that costs about $2,400 per year, which includes up to seven replacements and visits with an audiologist. md