how it works

INVENTIVE DESIGN AND ATTENTION TO MANUFACTURING HAVE MADE DISPOSABLE HEARING AIDS A REALITY

Hear today, gone tomorrow

By Joseph Ogando, Design News *Magazine*

CONSUMERS REALLY LIKE the convenience of products that lead short but useful lives. Think of all those disposable razors and contact lenses. Now, even hearing aids have joined the growing ranks of throwaway goods. Songbird Hearing Inc, a spin-off of Sarnoff Corp, has come out with a digital hearing aid that lasts for almost two-and-a-half months. Once it quits, the patient tosses it in the trash and reaches for a new one.

Don't worry if you see this hearing aid in the trash. Low-cost electronics-design and manufacturing techniques have resulted in the first disposable digital hearing aid.

At first glance, hearing aids might seem like an unlikely candidate for disposability. Audiologists usually have to customize high-quality models to fit individual ear canals and to tune the acoustic circuitry to match the patient's hearing loss. And the increasingly sophisticated electronics and inefficient hand assembly methods that prevail in the hearing-aid industry further drive up costs. Taken together, these factors push prices for the top-quality digital models to more than $1800—with some models reaching more than $4000. Yet Songbird engineers managed to design away so much cost that their disposable model sells for just $79.

Though disposable, the Songbird nevertheless shares the same basic electro-acoustic features as a conventional digital hearing aid, according to Walter Sjursen, Songbird's director of electro-acoustic research. It contains a microphone to pick up sound. An IC, the digital brain of the hearing aid, converts the microphone's analog signal to a digital one and then processes that signal, filtering out noise and boosting specific sound frequencies. That digital signal then goes to a receiver, which broadcasts the sound into a patient's ear. A polycarbonate shell that fits entirely within the ear canal houses all the electronics. Unlike conventional high-end hearing aids, however, the Songbird runs on a nonreplaceable battery. And it comes in 40 stock versions to cover the differing physical and auditory requirements of people with mild to moderate hearing loss.

To transform an expensive, custom product into a low-cost, mass-manufactured one, Songbird's engineering team began with a blank page and designed nearly every component from scratch. "When the project first started, none of us came from the hearing-aid industry, so we weren't constrained by existing design strategies," says Reuben Zielinski, Songbird's director of engineering. Without preconceived ideas about hearing-aid construction, they produced a design with two goals in mind: Nearly every component had to promote automated assembly to remove cost, and the hearing aid had to offer superior sound quality without all of the custom fitting and tuning procedures.

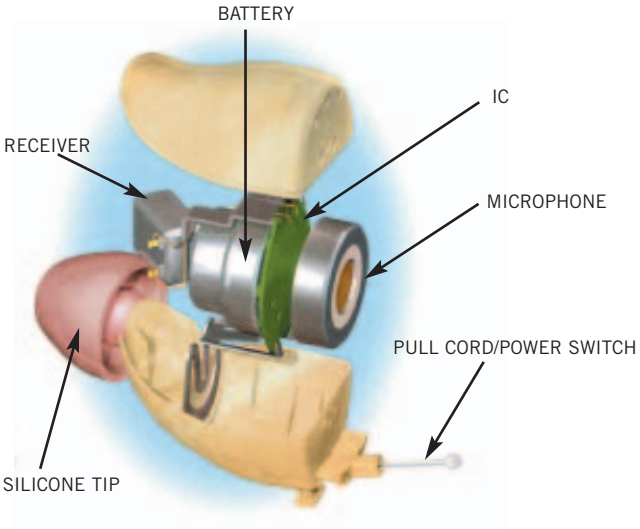
DISPOSABILITY CHANGES EVERYTHING

One thing that Songbird broadcasts loud and clear is just how much disposability matters. For the consumer, disposability does away with the need to change tiny batteries, which can frustrate even the nimble-fingered and can really trouble older wearers. Disposability also promises to save money for some patients. A five-year supply of Songbird hearing aids costs about $2050, or a few hundred more than cheapest digital hearing aids. "But many of the low-end dig-

ital models won't really last five years," Zielinski says.

And even in those cases where Songbird hearing aids do cost more to use, they offer other benefits. Because patients change hearing aids every 70 days or so, it's relatively easy to keep pace with changes in the patient's hearing over time. Songbird's from-stock-to-ear approach also offers instant gratification, allowing patients to leave an audiologist's office with new hearing aids on the same day as their initial appointments. These ease-of-use factors together could help hearing-aid use become more widespread among Songbird's target market—aging Baby Boomers who currently avoid hearing aids. Zielinski calls them "green-bar guys" because they just keep cranking up their television volumes and otherwise ignore their hearing problems.

As much as disposability matters to consumers, it also benefits the engineers who developed the Songbird—by freeing them from design restrictions. "Disposability gave us the flexibility to do all sorts of things we couldn't have done otherwise," says Zielinski, explaining that the short life cycle not only had a positive effect on the mechanical design of the hearing aid, but also contributed to the overall sound quality. Nowhere is relationship more apparent that in the Songbird's microphone. It features a 4-mm diaphragm that's roughly seven times larger than conventional designs. Supersizing the microphone seems to buck the industry's trend toward electronics miniaturization. "But we knew that a larger diaphragm would significantly reduce noise and improve sound quality," notes Sjursen. Songbird engineers would have had a tough time squeezing the larger microphone into the shell—except for the fact that that disposable device didn't need a battery door. As Sjursen explains, conventional in-the-canal designs tend to locate the door and related fastening hardware on the faceplate, or the outward facing surface of the shell. "Without the need for a battery door, our entire faceplate is taken up by the microphone," he says.



To keep manufacturing costs low, Songbird engineers constructed a hearing aid from subassemblies that lend themselves to automated manufacturing.

DESIGNING AWAY COST

Though disposability opened design possibilities, it also imposed strict curbs on manufacturing costs to meet the $79 price target. To keep costs low, Songbird engineers started by integrating what normally would be many stand-alone components in just a few subassemblies. Robots drop these assemblies into the hearing aid's two-piece plastic shell, which itself snaps together in an automated process. "Our design does away with nearly all manual-assembly operations," says Zielinski, who adds that many conventional hearing aids are currently hand-wired under a microscope.

Songbird's assembly-friendly design strategies really shine in the design and packaging of the hearing aid's electronic components. The microphone, for example, doesn't arrive on Songbird's produc-

FINDING A GOOD FIT

One big hurdle for Songbird has been finding ways to make a mass-manufactured product that matches a range of individual ear canals and hearing-loss characteristics. To make sure the hearing aids fit properly, the engineering team worked with audiologists early in the design process to make hundreds of impressions of ear canals. This ergonomic work resulted in a dual-durometer silicone tip in which a soft mushroom-shaped exterior, 10 Shore C, seals off against the ear canal and a slightly harder stem, 45 Shore C, provides some structure. The ergonomic research also revealed that just a handful of tip sizes–8, 9, 10, and 11 mm–enable the disposable hearing aids to fit most adult ears, according to Reuben Zielinski, Songbird's director of engineering.

And fit has implications that go beyond comfort. Feedback can result if the hearing aid doesn't seal off the ear canal. And, according to Walter Sjursen, who leads the company's acoustic-engineering efforts, fit is also an important element in the functioning of the hearing aid as an acoustic system. Because Songbird's hearing aid sits relatively deep in the ear canal, for example, it needs to provide less gain. "We actually started with the outside shape of the hearing aid because it influences the design of the electronics," he says.

Songbird also differs from conventional hearing aids when it comes to providing auditory match with individual patients needs. Rather than custom-programming hearing aids to each patient's hearing loss, the Songbird comes in 10 "acoustic formats." Each offers different amplification characteristics, boosting certain frequencies more than others to address different types of hearing loss. "The formats get very close but don't provide a perfect match to the patient's hearing loss," Zielinski concedes. Then again, current audiology testing techniques can also fall short of a perfect match. "The error rates in many hearing tests are on the order of 2.5 dB," he says.

tion floor as a separate component but instead mounts in a through-hole on the same pc board that holds the hearing aid's digital chip. A round metal can encapsulates both the microphone and the board, forming a module that fulfills two important functions. "The circular shape lends itself to robotic pick-and-place assembly," Zielinski says. And, in a clever design twist, the metal can extends over the board to provide EMI shielding on the top and the sides of the 12-mil-thick board, eliminating an expensive metallizing process. The Songbird's zinc-air battery, meanwhile, shields the bottom of the board.

And that's not all the battery does for component integration. Songbird engineers also use the battery as part of a gambit to eliminate the need for a separate microswitch to turn the hearing aid on and off. Instead, the contact for switching is soldered directly onto the IC and makes contact with the battery. "That [approach] costs us pennies rather than $10 or $12 for a microswitch," Zielinski says. The company has also integrated the on/off "switch" with the pull cord that helps patients remove their hearing aids. "Usually, on/off switch and pull cord are separate components, but, for us, they are one and the same," Sjursen says.

CUSTOM COMPONENTS

If all the function integration work that Songbird performed has a downside, it's the degree to which the company had to come up with its own components—even for ones that users can select from a catalog. And, because nearly every aspect is custom, Songbird worked closely with its suppliers, including Texas Instruments for the IC, Energizer for the battery, and Star Micronics for the receiver. "We cared a lot more about our partners' ability to support high-volume manufacturing than their experience making hearing aids," Zielinski notes.

Even the interconnect that links the microphone to the receiver had to be tailor-made for this application. "We couldn't find an off-the-shelf interconnect that had the right balance of flexibility and rigidity," says Zielinski. Created through a series of stamping, encapsulation, and forming steps, the interconnect has to flex to fit within the shell and has to bend under the load of soldering equipment while it's spot welded to terminals on the receiver. "But it also has to be rigid enough for our pick and place tools to locate it properly," Zielinski adds.

The Songbird's battery, too, required lots of custom engineering to get the right energy density and shape. "There are plenty of batteries out there, but they were either too large and powerful or too small and underpowered for our needs," Sjursen recalls. So Songbird and Energizer engineers worked together, trading Pro/Engineer files over the Internet, to come up with a battery that fits the hearing-aid shell without sacrificing battery life. Sjursen helped the battery-design process along by optimizing the hearing aid's electronics—particularly the impedance of the receiver—for a low current draw. "There was a big push for ultralow power," he says, adding that the Songbird draws between one-tenth and one-fifth of the current requirements of a conventional digital hearing aid.

So pervasive is the Songbird's custom components that the Songbird contains only two off-the-shelf products: a couple of capacitors, or bypass filters, that go on the pc board in the microphone assembly. And even these parts required some engineering consideration. To work around a height constraint on the microphone assembly and save some money, Songbird engineers used low-profile ceramic capacitors (0402) in place of taller tantalum models (0603). Sjursen points out that the tantalum may do a better job of filtering electrical noise, "but they were unnecessary in our case because we optimized the IC to minimize the amount of noise reflected onto the battery line."

Songbird's electronics and mechanical design choices together add up to a total reliance on automated assembly. A collection of servocam robots install the hearing aid's electronic subassemblies, and a six-axis articulated arm robot snaps the shell together. Only the silicone tip and one end of the interconnect are installed by hand, Zielinski reports. "We have designs to automate these steps too, but we use the manual operations as an opportunity to add quality inspections."

If the key to low-cost manufacturing is high production volume, all of Songbird's automation has paid off. Zielinski reports that the company's production line can now make 5 million hearing aids each year. "That's double the rest of the world's capacity, he says."□

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