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Rechargeable Silver-Zinc Batteries Will Soon Become the New Standard for Hearing Aids

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Overview

Unlike many other modern portable electronic devices that are powered by rechargeable batteries, hearing aids still primarily use disposable batteries which require frequent replacement. Depending upon the severity of hearing loss and the frequency of use, today's hearing aid batteries last 3-14 days. With the rapid penetration of wireless communications and device connectivity technology into new hearing aids, the frequency of battery replacement will become significantly greater in the coming years.

The obvious solution to the problem is switching to rechargeable batteries. Until recently, rechargeable hearing aid batteries were only available using nickel metal hydride technology which is unable to provide enough energy to last a full day even for many hearing aids – even those without wireless communications capability. Increased battery energy, however, can be achieved by using more advanced technology, such as silver-zinc chemistry. In this white paper, the authors state their case for why ZPower silver-zinc batteries will become the next standard for hearing aids.

Zinc-Air Disposable Batteries Are Today's Standard

Zinc-air batteries possess the highest energy density amongst all commercially available battery systems today. The primary reason for its advantage stems from having to carry only one of its active materials, zinc, while the other, oxygen, comes from the atmosphere. Almost all of the internal volume of a zinc-air cell is occupied by metallic zinc with holes in the cell's exterior allowing for the influx of air. Due to practical limitations in the rate of air transport into the cell, zinc-air batteries are generally capable of sustaining only low levels of electrical current without significant loss in their energy capacity. Performance is also adversely affected by external conditions like temperature, humidity and altitude. Zinc-air cells have an adhesive tab covering the holes which when removed causes the cell to fully activate within several minutes. Once activated, the cell has a short window of use spanning several days to weeks before becoming inactive.

Zinc-air batteries come in four different sizes in order to fit the various types of hearing aids. The smallest, size 10, is designed to power most in-the-ear models. The next two in order of increasing size, 312 and 13, power most of the behind-the-ear models. For high power hearing aids, the largest size 675 is preferred.

Figure 1 Four sizes of hearing aid batteries

The life of a battery can vary greatly and is determined primarily by the individual's hearing loss, their daily usage, and hearing aid features. For example, users who wear their hearing aids continuously while awake will replace batteries more frequently than those that occasionally wear their aids. Features within hearing aids, like noise suppression and FM looping, require additional energy to operate, thereby decreasing battery life. The following table published by Rayovac lists the expected ranges of life by battery size.

BATTERY SIZE	LIFE EXPECTANCY
10	3-10 days
312	3-12 days
13	6-14 days
675	9-20 days

Figure 2: Hearing aid battery life expectancy (Source: Rayovac, June 2013, HearingReview.com)

What are the Wireless Technology Alternatives in Use Today?

Wireless technologies in the form of the telecoil have been used in hearing aids for a number of years. A telecoil is a small copper receiver that picks up electromagnetic waves transmitted by telephones and hearing loops installed in buildings like theaters and churches. When switched on, telecoils offer all wearers within range of the transmitting source greater hearing clarity during phone calls and in public venues involving lectures, concerts, or movies. Telecoils consume very little power, so battery life is not greatly impacted.

The latest wireless technologies gaining rapid penetration within manufacturer's new hearing aids are near-field magnetic induction (NFMI) and radio frequency (RF) that enable direct connection to cell phones, MP3 players, and other electronic devices. The Hearing Industries Association (HIA) reported that hearing aids containing these new wireless technologies constituted 70% of U.S. sales for the first quarter of 2013. The following table compares NFMI and RF.

COMPARISON OF WIRELESS TECHNOLOGIES

	NFMI	RF
Advantages	• Lower power consumption • Signal easily propagates through and around the human head and body enabling ear-to-ear communication • Signal easily propagates through and around the human head and body enabling ear-to-ear communication	• Long range of approximately 7-9 meters (23-30 feet) • Relay device not required for far-field wireless communication • Low transmission delay from far-field sound sources
Disadvantages	• Limited transmission range or approximately 60-90 cm (2-3 feet) • Requires a relay device for far-field wireless communication • Transmission delay when receiving sound from far-field sources via a relay device	• Higher power consumption • 2.4 GHz signal does not propagate well around the human head and body • Sub 1GHz require larger antennas • Only a few frequency bands are available for world-wide license-free use

Source: ON Semiconductor

Implementing these new wireless technologies has been and continues to be a challenge for manufacturers due primarily to the relatively high power requirements for streaming data. Continuous streaming, as would occur while listening to music via a Bluetooth connection, consumes far more energy than hearing amplification, resulting in significantly shortened battery life. Until recently, manufacturers addressed this issue by using an intermediary or gateway device that acts as a bridge or relay between the hearing aids and portable electronics. These intermediary devices vary in size from a small MP3 player to a cell phone and are worn around the neck or carried in a pocket. The key requirement is that they are located within a short distance of the head in order to minimize the power drain on the hearing aid batteries. The bridge device is powered by a rechargeable battery that is large enough to handle the streaming between itself and the electronics which may be several meters away from the wearer.

Figure 3: Intermediary devices from the major hearing aid manufacturers. (Source: company websites)

Ultimately, wearers desire their hearing aids connect directly to their smartphone (e.g. made for iPhone designation) or music player, like a Bluetooth earpiece, without the intermediary device. This approach, used by Resound in LiNX and Starkey in HALO models, requires equipping hearing aids with Bluetooth radios which significantly increases power demand upon the battery. Hearing aid manufacturers continue to work on ways to lower the power demand for streaming.

Direct Approach – Near Future

- Hearing aids communicate directly with wireless device
- Wireless device connects to TV/Stereo, smart phone, MP3 player
- Wearer must remain within range of wireless device

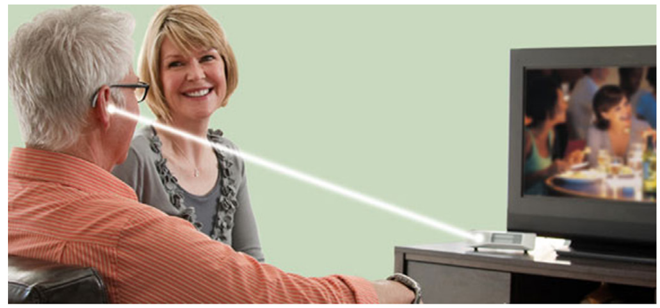

Figure 4

What is Wireless Communications Impact on Battery Life?

Hearing aid manufacturers frequently publish the expected battery life for each of their models.

Widex published a report on battery consumption in premium, wireless hearing aid products from itself and its five major competitors. Figures 5 and 6 show current consumption and calculated battery life for each hearing aid when streaming is inactive and active. The variation between manufacturers is primarily due to the type of wireless technologies they've selected. RF technologies, such as Bluetooth, cause the largest increases in current draw and decreases in battery life. Based upon this data, one assumes manufacturers B, C, and E are deploying RF-based systems in their hearing aids while Widex, A, and D use NFMI technology in their hearing aids.

ZPower measured hearing aid battery life using industry standard tests with and without streaming. Testing occurred under a simulated hearing aid load for 12 hours each day with Bluetooth streaming active every 15 minutes of each hour. This regimen was repeated daily until the batteries were depleted. Results, shown in Figure 7, are the average lives for both size 312 and 13 zinc-air batteries from a leading manufacturer with and without streaming active.

Results show wireless streaming causes a significant decrease in battery life – over 50% decline for size 312 batteries and about 25% decline for size 13. These results are consistent with those measured by Widex and support the general view that battery consumption will increase greatly with wireless streaming.

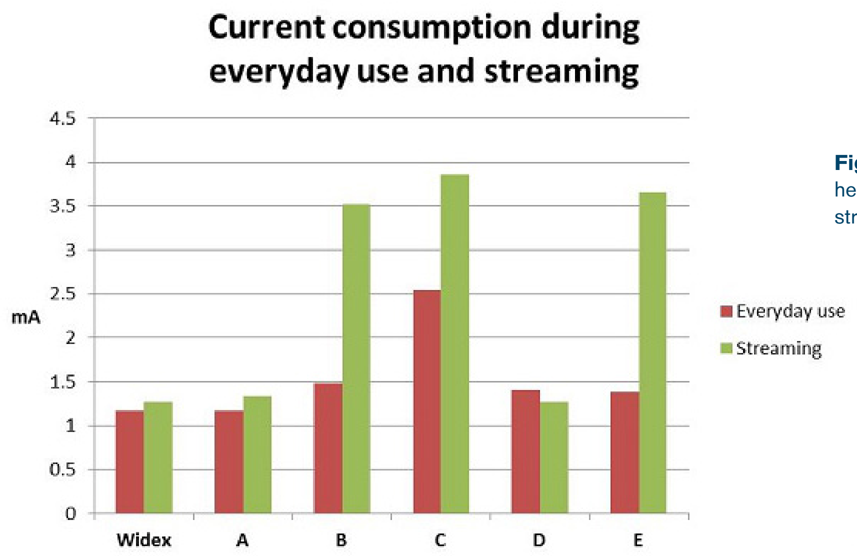

Figure 5: Measured current consumption of six hearing aids during simulated everyday use and streaming.

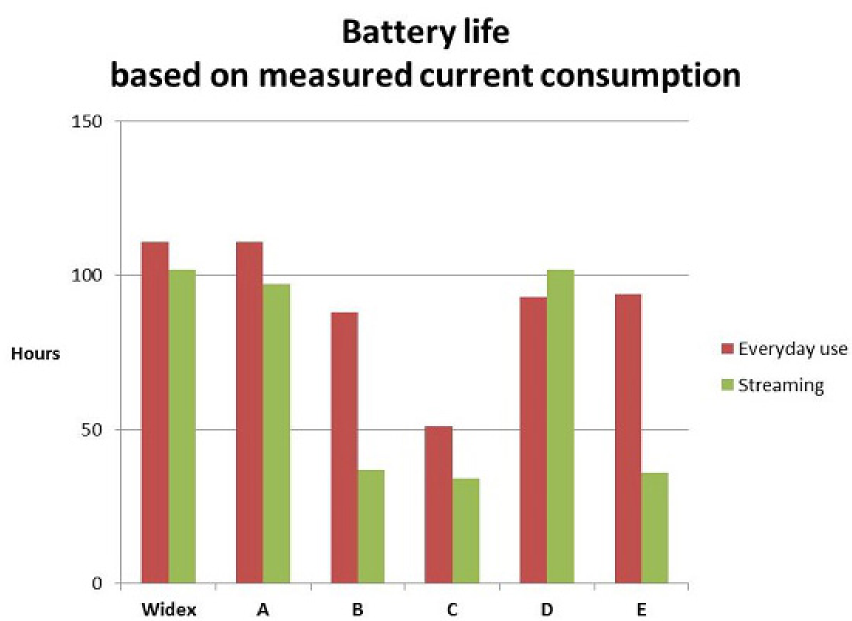

Figure 6: Battery life (hours of use) of six hearing aids during simulated everyday use and streaming based on measured current consumption. The calculations are based on an expected battery capacity of 130 mAh

Source: Joergensen, H.S., Baekgaard, L., and Bendtsen, B. (2013, June). Battery consumption in wireless hearing aid products – Datasheet vs. real-world performance. AudiologyOnline, Article #11899. Retrieved from **http://www.audiologyonline.com/**

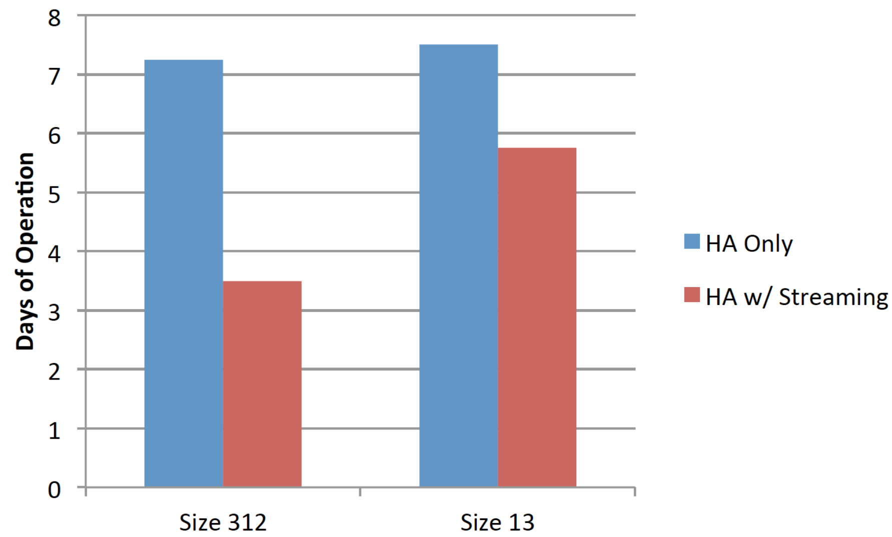

Figure 7: Zinc-air battery life measured using IEC standard tests without and with wireless streaming active.

What Are the Alternatives to More Frequent Battery Replacement?

The two alternatives to address the increasing frequency of battery replacement are 1) increase the energy content of disposable batteries or 2) switch to rechargeable batteries. Increasing disposable battery energy content can be accomplished by either discovery of new higher energy technologies than zinc-air or by making zinc-air batteries larger in size. We currently don't have a better disposable battery alternative to mature zinc-air technology, so increasing battery size is the only viable option at this time. This would mean the highly undesirable outcome of enlarged hearing aid designs to accommodate these bigger batteries.

The other alternative is to use rechargeable batteries, provided they can last through a full day of wear and be recharged overnight. Rechargeable batteries using older nickel metal hydride chemistry have been available on the market for several years from Siemens, Hansaton, and Power One. Unfortunately, nickel metal hydride doesn't pack enough energy to power many current hearing aids an entire day. With the additional energy required for wireless streaming, nickel metal hydride simply isn't a suitable option for the future. This leaves then only silver-zinc and lithium-ion as possible candidates for rechargeable batteries in hearing aids.

Non-rechargeable silver-zinc, also known as silver oxide, hearing aid batteries have been on the market for many years. Silver oxide batteries, unlike zinc-air, are completely sealed and don't rely upon air to operate. They don't last as long as zinc-air and are more expensive, so they see limited use in hearing aids.

Lithium-ion technology saw its first use in the early 1990s by Sony in camcorders, and dominates the portable electronics market today. Nevertheless, it has not gained favor by hearing aid manufacturers for reasons including low energy density, high voltage, and safety. No battery manufacturer today commercially offers a lithium-ion hearing aid battery. The authors have heard reports, however, of prototype size lithium-ion cells being produced and tested.

Silver-Zinc Batteries Available and Ready for Use?

ZPower began development of silver-zinc hearing aid batteries in 2007 at the request of several hearing aid manufacturers. Even back then, hearing aid manufacturers recognized the shortcomings of nickel metal hydride and lithium-ion technologies and were seeking alternatives. The primary advantages of silver-zinc are 1) high energy density, 2) cell potential less than 2 volts, 3) safe, water based chemistry similar to zinc-air, 4) easily scalable to existing hearing aid battery sizes, and 5) recyclable.

Large format silver-zinc batteries have been used for military and aerospace applications such as submersible vehicles, missiles, torpedoes, and space vehicles for several decades. Due to its high energy content and non-flammable chemistry, it has seen extensive use in critical applications. ZPower has made significant improvements to silver-zinc technology to make it suitable for use in hearing aids. The current product reflects the seven years of development and testing it took to bring it to market. Key product specifications that ZPower successfully designed to were:

- Operate 18–36 hours per day on a single charge in all battery sizes
- Recharge time of six hours or less
- Support advanced hearing aid features
- One year between replacements

In addition to providing a superior silver-zinc battery, ZPower also offers advanced charge and control software and an ASIC regulator to increase battery life and capacity. The software's algorithms keep the battery at peak performance and overcome the capacity decline during aging as seen in lithium-ion. The ASIC regulator increases the battery's effective capacity by 20% and provides an output potential to the hearing aid's DSP that matches zinc-air. The ASIC regulator is not necessary with hearing aids, such as those available from Starkey, using DSPs that can accept silver-zinc's potential of 1.85V.

Roadblocks for Implementing Lithium-ion

Energy content is probably the single, most important parameter when comparing rechargeable battery technologies.

In hearing aids, the key system components (DSP, receiver, microphone, etc.) are all optimized around the nominal zinc-air voltage of 1.2V. Because of lithium-ion's higher nominal voltage of 3.7V, some form of voltage regulation is necessary for hearing aids. Linear regulation is the simplest and smallest approach but is too inefficient to be used with lithium-ion (<33% efficiency). As a result, a switching DC-DC converter must be utilized to efficiently lower the voltage to work with the hearing aid electronics. Currently, there are no off-the-shelf products that meet the hearing aid manufacturer's requirements for size, EMI and efficiency. Due to the small form factor requirements for hearing aids, OEMs would need a DC-DC converter's footprint to be less than 2.5mm2 (~1.5mm x ~1.5mm). Off the shelf DC-DC converters are several times larger and impractical for usage in a hearing aid. Due to the inductive nature of the receiver and telecoil, the EMI of the DC-DC converter must also be optimized for the hearing aid application. Existing DC-DC converters are not optimized for efficiency around 1-3mA, typical hearing aid loads. To be practical, a DC-DC converter would need to be 90+% efficient, fit within the design envelope and have low EMI. To accomplish this requires a custom design from a silicon manufacturer with expertise in low voltage DC-DC converters.

Lithium-ion also requires additional electronic components for charge control and safety protection. The total space occupied by all electronic components required for lithium-ion is about 3X that needed for silver-zinc with cost being greater as well.

Silver-zinc chemistry also has advantages over lithium-ion in the following areas:

- Battery and hearing aid corrosion – the higher lithium-ion cell voltage drives corrosion faster inside a hearing aid than silver-zinc. This is a valid concern since the hearing aid is regularly exposed to a warm, salty environment behind the patient's ear (wearer's sweat & cerumen)
- Gassing – any internal gassing is an irreversible reaction in lithium-ion while silver-zinc has a slow rate of recombination that can reverse gassing from minor over-charging. For lithium-ion, any release of electrolyte can result in extremely high temperatures. This is not a risk for silver-zinc.
- Short circuits – internal short circuits for lithium-ion can result in extremely high temperatures which could burn patient's skin (>100°C). Preventing external short circuits requires an added protection IC for lithium-ion. The higher impedance of the silver-zinc cell design limits this temperature rise.
- Over-discharge – discharging lithium-ion below 3.0V can result in plating out lithium which is a safety concern. Additional circuitry to prevent over-discharge is required but can't completely remove a current drain from the battery. Silver-zinc batteries can be over-discharged below 100mV and be recovered to normal operation a limited number of times before performance degradation is noticeable.
- Personal Safety – accidental swallowing of hearing aid batteries by children would be significantly more harmful with lithium-ion due to its 3.7 V potential which can cause extensive tissue damage in a short amount of time. Most likely will require sealing the battery in the hearing aid and factory replacement with no ability to swap out with zinc-air batteries.
- Recycling – over 95% of the silver-zinc battery elements can be recycled and reused to make new silver-zinc batteries. The silver content of the battery makes this economically attractive. Lithium-ion batteries are "down cycled" and materials are a lower grade than required for batteries. The value of the lithium-ion materials is not significant enough to pay for the recycling process.

Summary

For the hearing aid application, a rechargeable battery must meet strict form factor requirements and be capable of delivering a full day of hearing instrument usage. Lithium-ion batteries do not scale down well into hearing aid sizes compared to the silver-zinc technology. Despite different creative design approaches, lithium-ion batteries offer significantly less capacity than silver-zinc. Additionally, known safety issues with lithium-ion require extra safety devices which make its application more complicated and more space hungry. In this industry, mature technologies in other markets don't necessarily translate well into hearing aid designs.

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