Hearing Aids: Cutting Edge Technology, In An Ultra Constrained Environment

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Agenda

> Starkey Laboratories, Inc.
> Hearing Aid (HA) Styles
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> Summary
Starkey Laboratories, Inc.

> Starkey is a world leader in the design, development and distribution of comprehensive hearing solutions.
  - Private Company
  - Founded: 1967 as Professional Hearing Aid Service
  - Owner: William Austin
  - Employees: >3,000
  - World headquarters are located in Minnesota, USA

> With 35 facilities in more than 24 countries around the globe, Starkey is an industry leader in hearing instrument manufacturing.

Starkey is the largest American owned and US based hearing technology company.

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**Hearing Aid Styles**

<table>
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<tr>
<th>Behind The Ear (BTE)</th>
<th>On The Ear (OTE)</th>
<th>Receiver-In-the-Canal (RIC)</th>
<th>In-The-Ear (ITE)</th>
<th>In-The-Canal (ITC)</th>
<th>Completely-In-The-Canal (CIC)</th>
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<td><img src="image" alt="BTE" /></td>
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**BTE instruments** have a plastic casing that rests behind the ear and houses the device’s technology. A clear plastic tube then directs amplified sound into an earmold inside the ear canal.

**OTE instruments** are soft, flexible earbuds and an extra-small casing, on-the-ear models are light and comfortable.

**Receiver-in-the-canal device** is small, discreet, and incredibly quick to fit; perfect for many first-time wearers.

**In-the-ear instruments** house their technology components in a custom-formed earmold that fits within the outer portion of the ear.

**In-the-canal instruments** are smaller still, featuring an earmold that fits down into the ear canal and a smaller portion that faces out into the outer ear.

**Completely-in-the-canal (CIC) devices** fit completely in the canal. Only the head of a tiny plastic line—with which you insert or remove the instrument—shows above the canal.
Hearing Aid Industry at a Glance

> Hearing is essential to fully enjoy and participate in life:
  - One in ten Americans — more than 31 million — experience some degree of hearing loss.
  - About 40% of hearing-impaired Americans are under the age of 65.
  - This makes hearing loss our third most prevalent chronic health condition, after arthritis and high blood pressure.
> Estimates place approximately 300 million people worldwide with hearing impairment.
> 90% of the worldwide production of hearing aids is controlled by 6 multi-national hearing aid conglomerates who market their hearing aids under approximately >2 dozen different brand names.
  - Starkey, Widex, Siemens, Phonak, Oticon and GN-Resound.
> More than 90 percent of all hearing aids sold are digital.
  - The incoming sound is separated into discreet bands or channels, each of which is processed independently.

Hearing Aid Market at a Glance

> According to the Hearing Industries Association (HIA), hearing aids dispensed in the United States during 2007 totaled 2.42 million units.
> BTEs now constitute 51.4% of the overall US market.
  - BTE market share is accelerating toward the levels seen in Europe
  - For example, BTE market penetration is estimated at 83% in France and 89% in Germany
> Worldwide, approximately 6-7 million hearing aid units are sold each year.
Wireless and Hearing Aids: Why?

- Programming of Digital Data
  - Optimizing signal processing parameters
  - Real-time audio response
- 1-way Data Control
  - Volume controls
  - Mode selections
- 1-way Streaming Audio
  - Television, radio, MP3, movie theaters, etc...
  - Classroom, Assisted Listening Devices
- 2-way Streaming Audio
  - Telephone conversations
- 2-way Eat-to-Ear (EtE):
  - Dual-Mic Directional Noise Reduction
  - Binaural Processing

What Does the End User Desire?

Which Wireless?

- Constraints to adding wireless into a HA:
  - Limited available area leads to a single chip small transceiver/antenna solution with minimal to no external components.
  - Limited power available, a wireless solution should consume no more than 1-2mA when operating.
  - HA solution needs to operate on a single 1.1v-1.3v battery for >40 hours
- Any wireless approach has additional limitations to reach the market applications:
  - Infrared (IR) Limited Range/Orientation
    - Line of sight
  - Magnetic (Near Field Comm) Limited Range
    - Energy dissipates at 1/r^3
  - Radio Frequency Small Antenna & Interferers
    - No frequency allocation exists for HAs to operate independently.
    - Which frequency space and protocol (no industry std. for 1mW operation)

Despite Limitations, Radio Frequency Meets the Broadest Consumer Needs
Adding Wireless: The Challenge

> **Constraints:**

- Packaging
  - Overall size of hybrid (CIC fit rate)
- Limited Data throughput
- Power consumption ≈1-2mA@1.1v
- Small Antenna Aperture
- Standard RF Issues
  - Link Integrity/Budget
  - Interference (ISM Band)
  - Human Body Shadowing
  - Changing Environment

> **Wireless Performance:**

- Most RF parameters are similar to off the shelf transceivers operating at 2.3v to 3.6v except for Tx power output.
  - Sensitivity ≈-95 to -100dBm
  - Image rejection
  - Digital interfaces

Adding Wireless: Defining a Path

> **High Efficiency – Minimize Power Consumption (1-2mA Tx and Rx)**

- Direct GMSK modulation
- Constant envelope for PA efficiency.
- Allows direct bit modulation of a VCO via a Gaussian filter
- Single conversion IF with direct analog demodulation

> **Optimized protocol for low overhead voice and data**

- Efficient Media Access Control
- 200Kbps for 2-way voice/audio applications

> **Sniff mode for lowest power consumption**

- Asynchronous Intermittent communication

> **Minimize Area**

- Single chip solution
- No/few off chip components

> **Link Budget – Link Integrity**

- Antenna Aperture (bigger is better) @900 MHz a wavelength is .33m
- The hybrid area (x,y) is less than .05λ (-25 to -30 dBi designs)
- Free space loss (3m) + loss through head can be ≈-50dB
- CRC, ACK, Forward Error Correction to improve link.
HA Antennas: A Crucial Element

> The antenna is a very crucial component in a wireless communication system. The purpose of an antenna:
> - Transform RF signals into electromagnetic waves, propagating into free space (transmit mode).
> - Transform electromagnetic waves into RF signals (receive mode).

> Two fundamental types of antennas
> - Single ended antennas:
>   > Usually matched to 50 ohm
>   > Needs a balun if the chip has a differential output
>   > Easy to measure the impedance with a network analyzer
>   > Possible to get good performance
> - Differential antennas:
>   > Can be matched directly to the impedance at the RF pins
>   > Can be used to reduce the number of external components
>   > Complicated to make good design, needs to be simulated
>   > Difficult to measure the impedance
>   > Possible to get good performance

Antenna Trades May Change Based on HA Type

Frequency of Operation Trades

> Factors
> - Antenna (gain, sensitivity to body effects etc.)
> - Sensitivity
> - Output power
> - Radio pollution (selectivity, blocking, IP3)
> - High frequency consumes more power

> Environment (obstructions, reflections, multipath fading)
> Lower frequency gives better range
>   > Reducing the frequency with a factor of two doubles the range

> Lower frequency requires a larger antenna
> - λ/4 at 433 MHz is 17.3 cm  (free space path loss @ 3m ≈ -35dB)
> - λ/4 at 915 MHz is 8.2 cm  (free space path loss @ 3m ≈ -41dB)
> - λ/4 at 2.4 GHz is 3.1 cm  (free space path loss @ 3m ≈ -50dB)

Global Coverage is a Necessity
HA Summary

> Wireless Challenges:
  - Low battery voltage 1.1v
  - Low system current consumption 1-2mA
  - Limited packaging space.
    - Can the entire solution (mic(s), real time audio processing, spkr/rcvr, wireless and battery) fit in >90% of the populations ear and operate for >40 hours?
    - Small aperture antenna
    - Few external components

HAs – A Challenging Design Space