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Introduction to Hearing Aids and Important Design Considerations

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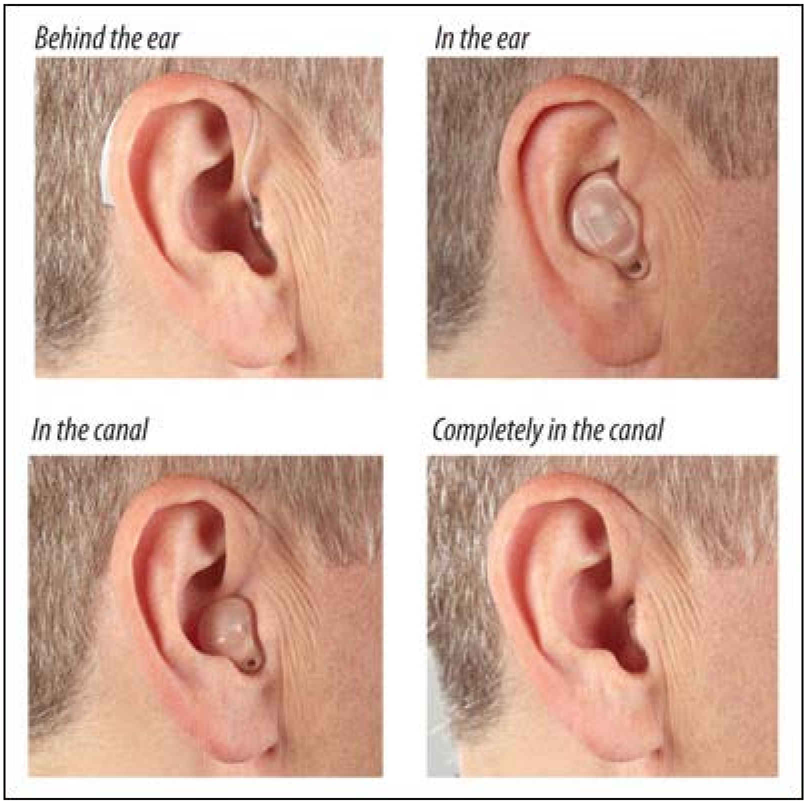
Abstract: This application note introduces the styles of hearing aids, including behind the ear (BTE), in the ear (ITE), in the canal (ITC), and completely in the canal (CIC), as well as a brief summary of both analog and digital hearing aid technologies. Also discussed is the importance of the audio-processing path, the functions of electrical components, and some critical elements that designers must consider when selecting products.

Overview

An electronic hearing aid is a small device placed in or around the ear to improve the hearing of those with hearing loss. The basic components of a hearing aid are a microphone, signal conditioning, a receiver also known as a speaker, and a battery. The microphone converts the sound into an electric signal. The signal then undergoes conditioning that can be as simple as amplifying all of the sound equally, to more advanced equalization involving a digital signal processor. The receiver converts the electronic signal back to sound, and the battery powers the electronics.

Styles

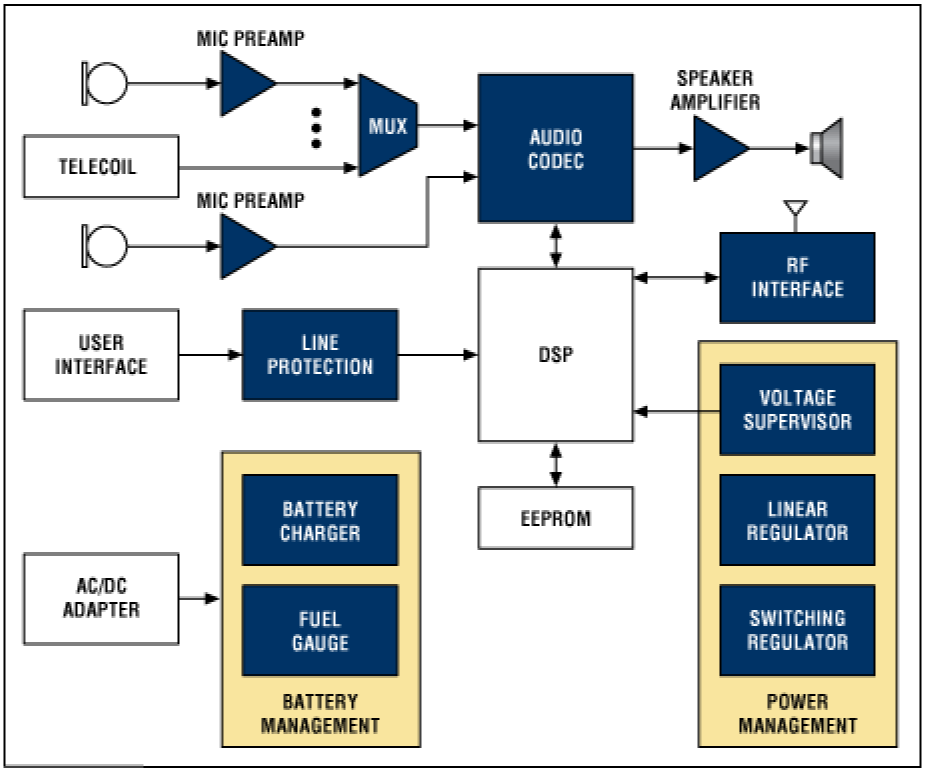
There are four main styles of hearing aids on the market today. From largest to smallest, they are behind the ear (BTE), in the ear (ITE), in the canal (ITC), and completely in the canal (CIC). The BTE style sits behind the ear with a clear tube going to an earmold in the ear to deliver the sound. A variation on this style is called an open-fit-behind-the-ear (OTE) where the earmold is replaced by a small tip, resulting in a more open feeling. Other variations include replacing the tube with wires and moving the receiver from the behind the ear to inside the ear. The ITE style moves the hearing aid into the outer ear, where it becomes a single unit with the earmold. This style fills up most of the outer ear and appears as a solid mass. The ITC style moves some of the hearing aid into the ear canal and reduces the space taken up in the outer ear, but is still plainly visible. The CIC style is the smallest of them all, as it fits completely inside the ear canal, thus nearly disappearing from view.



Behind the ear (BTE), in the ear (ITE), in the canal (ITC), and completely in the canal (CIC). Photos courtesy of Starkey Laboratories, Inc.

Technology Types

The two basic types of technology for hearing aids are analog and digital. The first to exist, analog hearing aids process electrical sound in the analog domain; the more recent digital hearing aids process electrical sound in the digital domain. The earliest analog hearing aids simply amplified both speech and noise, and were ordered after testing to determine the particular frequency response needed by the patient. Newer analog hearing aids can be programmed during the fitting process, and some have multiple listening profiles that the patient can select with a button on the hearing aid. Digital hearing aids are also programmable during the fitting process and have multiple listening profiles that are selectable by the patient. The digitization of sound allows more advanced signal processing such as noise reduction, filtering, and acoustic feedback (ringing) control. The vast majority of hearing aids sold today are digital because of their increased performance and flexibility over the analog versions.



Digital hearing aid functional block diagram. For a list of Maxim's recommended solutions for hearing aid designs, please go to www.maximintegrated.com/hearing.

Features

There are many features available for today's hearing aids, including volume control, remote control, telecoil, direct audio input, FM reception, Bluetooth® capabilities, directional microphone, compression, clipping, frequency shifting, wind-noise management, data logging, self-learning, moisture resistance, and earmold venting. Some of these features require external area to implement and become more difficult to include as the size of hearing aids shrinks, while other features can be implemented in all hearing aids.

Volume control is performed manually with buttons or a rotary dial on the hearing aid. A remote control eliminates the need for buttons and dials on the hearing aid and can be used to control all the features of the hearing aid. A telecoil is an alternate input other than the microphone, and it originally picked up the magnetic signal generated by older telephones with speakers driven by magnetic coils so that listeners could hear better when talking on the telephone. Today's telephones and other alternate listening devices build-in this capability in order to work with a telecoil and specifically indicate that they are hearing aid compatible. Direct audio input and FM reception are other ways to input sound or speech into the hearing aid, the first using a wired connector as an input, and the other an FM radio receiver. An emerging trend is to include Bluetooth capability to receive sound from a cell phone or music player. The Bluetooth device can either be integral to the hearing aid or an add-on device through the telecoil or FM input.

A hearing aid with directional microphones uses two or more microphones to receive sound from multiple directions. This improves the signal-to-noise ratio (SNR) of speech when heard in a noisy environment, and enhances the quality of speech further when used with digital signal processing. Compression and clipping both increase listening comfort by reducing portions of the sound that are too loud but, in some cases, just clip or limit the sound. Frequency shifting uses digital signal processing to shift speech to a lower frequency, which is helpful for people with high-frequency hearing loss. Wind-noise management detects wind and eliminates the feedback that would otherwise cause ringing sounds to be heard by the hearing aid wearer.

Data logging records the listening environment and how the hearing aid is used. A hearing professional can use this information to fine-tune hearing aid performance. Self-learning uses the data logs and fine-tunes the performance on its own over time. Moisture resistance helps reduce repairs due to exposure to moisture, and earmold vents provide additional comfort by reducing the closed-in sensation felt when wearing an earmold type of hearing aid.

General Requirements

The critical components of a hearing aid design are in the audio-processing path. The one or more microphones and the receiver are chosen in conjunction with the preamplifiers (if required) and the speaker amplifiers. Class D amplifiers are used in modern hearing aids due to their low-power operation, low distortion, and small size as compared to Class A and B amplifier. Whether the audio bandwidth is 20kHz or limited to 8kHz, the audio codec should have a high SNR to preserve and reproduce sounds accurately.

The heart of the system is the digital signal processor (DSP), which is where all of the benefits of a digital hearing aid are implemented. The DSP implementation is manufacturer dependent. In general, it performs compression/expansion by band, positive feedback reduction, noise reduction, and speech enhancement. It also processes directional information and can generate its own signals to help improve fitting a hearing aid to a patient.

Power and Battery Management

Some hearing aids are beginning to use rechargeable single-cell lithium-ion (Li+) batteries, but most hearing aids are still powered by primary zinc-air batteries. There are five main sizes of zinc-air batteries used, depending on the hearing aid style or size, the power consumption of the circuitry, and the battery-life requirements. **Table 1** compares the capacity and size of the five most common zinc-air batteries, and includes their color codes for easy selection and the styles of hearing aid in which they are usually used.

Zinc-air batteries start at 1.4V and are used down to about 1.0V or lower before requiring replacement. When used for 16 hours per day, battery life ranges from a couple of days to a few weeks, depending on the battery capacity and hearing aid design. The most power-efficient design runs directly off of a single battery, but a switching regulator can be used to boost the voltage to fit design needs, whether 1.8V or 3.0V. The power dissipation is targeted to be 1mW to 10mW when running off of zinc-air batteries. Hearing aids that use rechargeable Li+ batteries may require a linear or switching regulator to step the battery voltage down if the circuitry cannot run directly from the typical 4.2V, single-cell Li+ battery's fully charged voltage. Alternatively, the battery charger can limit the charging to a lower end voltage such as 3.3V, depending on the circuitry requirements. An accurate fuel gauge is critical to provide warning before the battery is depleted so that the patient is not left with a nonfunctioning hearing aid.

Table 1. Zinc-Air Battery Comparison.

Type	Capacity (mAh)	Size (d x h, mm)	Color Code	Style Usage
675	540 to 640	11.6 x 5.4	Blue	BTE (high power), cochlear implants
13	230 to 285	7.9 x 5.4	Gold	BTE, ITE
312	120 to 160	7.9 x 3.6	Burgundy	miniBTE, ITE, ITC
10	60 to 90	5.8 x 3.6	Yellow	ITC, CIC
5	30 to 40	5.8 x 2.1	Red	CIC

Electrostatic Discharge

All hearing aids must pass IEC 61000-4-2 electrostatic discharge (ESD) requirements. Using electronics with built-in protection or adding ESD line protectors to exposed traces can help meet these requirements.

Related Parts		
DS2745	Low-Cost I²C Battery Monitor	Free Samples
DS2756	High-Accuracy Battery Fuel Gauge with Programmable Suspend Mode	Free Samples
DS2780	Stand-Alone Fuel Gauge IC	Free Samples
DS2782	Stand-Alone Fuel Gauge IC	Free Samples
MAX13202E	2-/4-/6-/8-Channel ±30kV ESD Protectors in µDFN	Free Samples
MAX13204E	2-/4-/6-/8-Channel ±30kV ESD Protectors in µDFN	Free Samples
MAX13206E	2-/4-/6-/8-Channel ±30kV ESD Protectors in µDFN	Free Samples
MAX13208E	2-/4-/6-/8-Channel ±30kV ESD Protectors in µDFN	Free Samples
MAX1471	315MHz/434MHz Low-Power, 3V/5V ASK/FSK Superheterodyne Receiver	Free Samples
MAX1472	300MHz-to-450MHz Low-Power, Crystal-Based ASK Transmitter	Free Samples
MAX1473	315MHz/433MHz ASK Superheterodyne Receiver with Extended Dynamic Range	Free Samples
MAX1479	300MHz to 450MHz Low-Power, Crystal-Based +10dBm ASK/FSK Transmitter	Free Samples
MAX1551	SOT23, Dual-Input, USB/AC Adapter, 1-Cell Li+ Battery Chargers	Free Samples
MAX1555	SOT23, Dual-Input, USB/AC Adapter, 1-Cell Li+ Battery	Free Samples

	Chargers	
MAX16056	125nA Supervisory Circuits with Capacitor-Adjustable Reset and Watchdog Timeouts	Free Samples
MAX16059	125nA Supervisory Circuits with Capacitor-Adjustable Reset and Watchdog Timeouts	Free Samples
MAX16060	1% Accurate, Quad-/Hex-/Octal-Voltage µP Supervisors	Free Samples
MAX16062	1% Accurate, Quad-/Hex-/Octal-Voltage µP Supervisors	Free Samples
MAX16072	µP Supervisory Circuits in 4-Bump (1mm x 1mm) Chip-Scale Package	Free Samples
MAX16074	µP Supervisory Circuits in 4-Bump (1mm x 1mm) Chip-Scale Package	
MAX17043	Compact, Low-Cost 1S/2S Fuel Gauges with Low-Battery Alert	Free Samples
MAX1722	1.5µA I_Q, Step-Up DC-DC Converters in Thin SOT23-5	
MAX1724	1.5µA I_Q, Step-Up DC-DC Converters in Thin SOT23-5	Free Samples
MAX1736	SOT23, Single-Cell Li+ Battery Charger for Current-Limited Supply	Free Samples
MAX1811	USB-Powered Li+ Charger	Free Samples
MAX1832	High-Efficiency Step-Up Converters with Reverse Battery Protection	
MAX1835	High-Efficiency Step-Up Converters with Reverse Battery Protection	
MAX1947	Low Input/Output Voltage Step-Up DC-DC Converter with Active-Low RESET	Free Samples
MAX2830	2.4GHz to 2.5GHz 802.11g/b RF Transceiver with PA and Rx/Tx/Diversity Switch	
MAX2900	200mW Single-Chip Transmitter ICs for 868MHz/915MHz ISM Bands	Free Samples
MAX2904	200mW Single-Chip Transmitter ICs for 868MHz/915MHz ISM Bands	Free Samples
MAX3202E	Low-Capacitance, 2/3/4/6-Channel, ±15kV ESD-Protection Arrays for High-Speed Data Interfaces	Free Samples
MAX3204E	Low-Capacitance, 2/3/4/6-Channel, ±15kV ESD-Protection Arrays for High-Speed Data Interfaces	Free Samples
MAX3206E	Low-Capacitance, 2/3/4/6-Channel, ±15kV ESD-Protection Arrays for High-Speed Data Interfaces	Free Samples
MAX4060	Differential Microphone Preamplifiers with Internal Bias and Complete Shutdown	

MAX4062	Differential Microphone Preamplifiers with Internal Bias and Complete Shutdown	Free Samples
MAX6381	SC70/µDFN, Single/Dual Low-Voltage, Low-Power µP Reset Circuits	Free Samples
MAX6390	SC70/µDFN, Single/Dual Low-Voltage, Low-Power µP Reset Circuits	Free Samples
MAX6443	µP Reset Circuits with Long Manual Reset Setup Period	Free Samples
MAX6452	µP Reset Circuits with Long Manual Reset Setup Period	Free Samples
MAX6469	300mA LDO Linear Regulators with Internal Microprocessor Reset Circuit	Free Samples
MAX6484	300mA LDO Linear Regulators with Internal Microprocessor Reset Circuit	
MAX7030	Low-Cost, 315MHz and 433.92MHz ASK Transceiver with Fractional-N PLL	Free Samples
MAX7031	Low-Cost, 308MHz, 315MHz, and 433.92MHz FSK Transceiver with Fractional-N PLL	Free Samples
MAX7032	Low-Cost, Crystal-Based, Programmable, ASK/FSK Transceiver with Fractional-N PLL	Free Samples
MAX7042	308MHz/315MHz/418MHz/433.92MHz Low-Power, FSK Superheterodyne Receiver	Free Samples
MAX7057	300MHz to 450MHz Frequency-Programmable ASK/FSK Transmitter	Free Samples
MAX8569	200mA Step-Up Converters in 6-Pin SOT23 and TDFN	Free Samples
MAX8606	USB/AC Adapter, Li+ Linear Battery Charger with Integrated 50m Ohm Battery Switch in TDFN	Free Samples
MAX8625	High-Efficiency, Seamless Transition, Step-Up/Down DC-DC Converter	Free Samples
MAX8860	Low-Dropout, 300mA Linear Regulator in µMAX	Free Samples
MAX8900A	1.2A Switch-Mode Li+ Chargers with ±22V Input Rating and JEITA Battery Temperature Monitoring	
MAX8900B	1.2A Switch-Mode Li+ Chargers with ±22V Input Rating and JEITA Battery Temperature Monitoring	
MAX8902A	Low-Noise 500mA LDO Regulators in a 2mm x 2mm TDFN Package	Free Samples
MAX8902B	Low-Noise 500mA LDO Regulators in a 2mm x 2mm TDFN Package	Free Samples
MAX9700	1.2W, Low-EMI, Filterless, Class D Audio Amplifier	Free Samples

MAX9718	Low-Cost, Mono/Stereo, 1.4W Differential Audio Power Amplifiers	Free Samples
MAX9719	Low-Cost, Mono/Stereo, 1.4W Differential Audio Power Amplifiers	Free Samples
MAX9812	Tiny, Low-Cost, Single/Dual-Input, Fixed-Gain Microphone Amplifiers with Integrated Bias	Free Samples
MAX9813	Tiny, Low-Cost, Single/Dual-Input, Fixed-Gain Microphone Amplifiers with Integrated Bias	Free Samples
MAX9856	Low-Power Audio CODEC with DirectDrive Headphone Amplifiers	Free Samples
MAX9860	16-Bit Mono Audio Voice Codec	Free Samples
MAX9867	Low-Power, Stereo Audio Codec	Free Samples

More Information
For Technical Support: http://www.maximintegrated.com/support
For Samples: http://www.maximintegrated.com/samples
Other Questions and Comments: http://www.maximintegrated.com/contact

Application Note 4691: http://www.maximintegrated.com/an4691
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