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## A Review of Assistive Listening Device and Digital Wireless Technology for Hearing Instruments

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### Abstract

Assistive listening devices (ALDs) refer to various types of amplification equipment designed to improve the communication of individuals with hard of hearing to enhance the accessibility to speech signal when individual hearing instruments are not sufficient. There are many types of ALDs to overcome a triangle of speech to noise ratio (SNR) problems, noise, distance, and reverberation. ALDs vary in their internal electronic mechanisms ranging from simple hard-wire microphone-amplifier units to more sophisticated broadcasting systems. They usually use microphones to capture an audio source and broadcast it wirelessly over a frequency modulation (FM), infra-red, induction loop, or other transmission techniques. The seven types of ALDs are introduced including hardwire devices, FM sound system, infra-red sound system, induction loop system, telephone listening devices, television, and alert/alarm system. Further development of digital wireless technology in hearing instruments will make possible direct communication with ALDs without any accessories in the near future. There are two technology solutions for digital wireless hearing instruments improving SNR and convenience. One is near-field magnetic induction combined with Bluetooth radio frequency (RF) transmission or proprietary RF transmission and the other is proprietary RF transmission alone. Recently launched digital wireless hearing aid applying this new technology can communicate from the hearing instrument to personal computer, phones, Wi-Fi, alert systems, and ALDs via iPhone, iPad, and iPod. However, it comes with its own iOS application offering a range of features but there is no option for Android users as of this moment.

**Keywords:** Assistive listening devices, Bluetooth, Digital wireless technology, Near-field magnetic induction, Radio frequency

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## Introduction

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As hearing is not an all or nothing phenomenon, people show various degrees of hearing loss at varying frequencies in both ears. The implications of this fact are often overlooked for a variety of reasons that include a lack of understanding about modern technology that improves access to sound such as assistive listening devices (ALDs). ALDs are diverse types of amplification equipment designed to improve the communication of persons with hearing loss and to ensure optimal communication when individual hearing instruments are not sufficient. Since ALDs especially can increase effectiveness of the hearing aids and cochlear implants, they can make huge differences in alleviating the daily grind of hard of hearing (HOH) individuals and make hearing easier and therefore improve their life quality. Therefore, the potential advantages of all ALDs must be thoroughly discussed with the individuals with HOH in counseling. ALD technology continues to progress with the development of digital wireless technologies. More and more devices are becoming available and participate sufficiently in their daily lives, as advances in computer technology along with miniaturization and human engineering. In addition to analog wireless systems applied to present ALDs, digital wireless technology for hearing instruments continue to promise new ALDs and improvements of current devices including better interfaces to personal hearing aids in the future.

## Assistive Listening Device

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ALDs are used to improve hearing ability for people in a variety of situations such as classrooms, theaters, places of worship, and airports. They permit greater autonomy, alleviate the daily grind, and improve the life quality of the individuals with HOH. ALDs separate the sounds, particularly speech, that a person wants to hear from background noise and improve what is known as the 'speech to noise ratio (SNR)' rather than the 'signal to noise ratio'. As the primary purpose of ALDs is to accomplish better SNR in a variety of situations for the HOH, the method of improving SNR should be further discussed.

Noise, distance, and reverberation represent a triangle of problems in terms of SNR. The intelligibility of a signal is diminished when environmental noise and/or reverberation are existed. Less optimal listening environments also have been proven to debilitate the hearing difficulties especially for the individuals with HOH.[1,2](#)) It was also noted that SNR diminishes as the distance increases because sound intensity is significantly lessened with expanded distance. For optimal speech intelligibility, the listeners should be no more than 1.8 meters away from the signal of interest. Fickes[3](#)) reported that students at a distance of 1.8 meters from the signal of interest achieved speech recognition scores of 95% while scores dropped to 60% when they were seated 7.3 meters away. The SNR required by individuals with hearing impairment is about 15 dB in order to achieve the same level of understanding as people with normal hearing although the difference should be considered depending on the type and degree of hearing loss.[4](#))

When listening is challenging, ALDs improve SNR in three ways: minimizing background noise, reducing negative influences due to distance between the sound source and the deaf or HOH, and overriding poor acoustics such as reverberation. In hearing instruments, augmenting SNR can be achieved by means of directionality.[5](#)) By taking advantage of spatial separation of the reduced

speech signal resulted from distance and competing noise, directionality improves speech understanding in background noise. Directionality is most effective when the signal is near and facing hearing instrument users and the environment does not have a lot of reverberation. This is not always the case for the individual hearing instrument users whereas ALDs increase the access to speech signal in the midst of background noise and reverberant sound.[6,7](#)) Other than directionality, there are many types of ALDs to overcome a triangle of problems, noise, distance, and reverberation.

## Types of ALDs

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ALDs can be used in several public areas such as churches and theaters or with personal aids for individual use on telephone, small group activity, or television/radio connection. ALDs can also be utilized as simple alerting devices informing the individual with HOH of a knock at the door or the cry of a baby. ALDs vary in their internal electronic mechanisms ranging from simple hard-wire microphone-amplifier units to more sophisticated broadcasting systems. They usually use a microphone to capture an audio source and broadcast it wirelessly over a frequency modulation (FM) transmission, infra-red transmission, induction loop transmission, or other transmission techniques.[8](#))

### Hardwire devices

These devices require wires to connect with the microphone, amplifier, and receiver in the stethoscope earphone or ear-mold. When the device is used as a personal system, the amplifier is small and can be held in a hand or placed in a pocket. For this reason, the device is sometimes called "pocket talker." It is also called often "box hearing aid," as the device looks like a little box. The microphone can be mounted on the listeners as a part of system or can be given to the talkers in order to decrease the distance from the speaker's mouth to the microphone. These devices increase sound levels and reduce background noise for a listener and some have directional microphones that can be angled toward speakers or other sources such as televisions and audio systems. The devices are intended for personal user and for use by professionals or healthcare workers providing services to HOH people. For the public usage, the selected seats wired with the apparatus and some types of receiver such as a headset or a earphone can be set as well.

### FM sound system

Free-field wireless FM sound systems send the auditory message through FM radio waves from a wireless transmitter directly to a small receiver equipped to the listener with HOH. The wireless transmitters can drive the signal from the speaker's microphone or from the output of most common sound systems such as radio, television, and stereos. Receivers can be installed to hearing aids through direct audio input adaptors or via neck-loop or telecoil induction coupling called a silhouette inductor in order to convert the signal into magnetic signals that can be picked up directly by the telecoil. FM systems can also be coupled to personal hearing aids or cochlear implants via miniature adaptors or built into them. The systems are often used in classrooms, where the instructor wears a small microphone connected to a transmitter and the student wears the re-

ceiver, which is tuned to a specific frequency or channel. FM systems can transmit signals up to 300 feet and are able to be used in many public places such as an auditorium or a church. However, listeners in one room may listen to a different channel because radio signals can penetrate walls. Personal FM systems operate in the same way and can be used to help people with HOH at one-to-one conversations.<sup>9)</sup>

#### What is telecoil?

A telecoil, also called a t-coil, is a coil of wire that is equipped inside many hearing aids and cochlear implants to operate as miniature wireless receivers. It was originally designed to make sounds clearer to a listener over the telephone. The telecoil works by receiving an electromagnetic signal from the hearing loop and then turning it back into sound. This process eliminates distracting background noise and customizes or corrects sound feature that matches one's hearing loss pattern. For people with HOH who do not have a telecoil installed in hearing aids or cochlear implants, loop receivers with headsets can provide similar benefits but without customization. It also is used with other ALDs such as induction loop systems, FM systems, infra-red systems, and personal amplifiers.

#### Infra-red sound system

An infra-red system transmits the sound to the audience via invisible infra-red light waves. A transmitter converts sound into a light wave and beams it to individual wireless headset receivers. The receiver which is hooked to headphones or can be used with any hearing aid having a telephone switch decodes the infra-red signal back to sound. To convert the infra-red signal into a magnetic signal, which can be picked up through the telecoil, people whose hearing aids or cochlear implants have a telecoil may also wear a neck-loop or silhouette inductor. Unlike induction loop or FM systems, the infra-red signal vulnerable to natural light cannot pass through walls and thus is not interfered with other electromagnetic waves. Therefore, infra-red systems cannot be used in environments with many competing light sources like outdoors or in strongly lit rooms. Infra-red has the advantages to contain the signal within a room, to increase privacy of the signal information, to have an unlimited number of receivers, and to provide excellent sound quality.

#### Induction loop system

An induction loop system transmits sound via a loop of wire that setups around the area where a HOH person places. The electric current that flows through the loop creates an electromagnetic field that can be received and then amplified by a hearing aid furnished with a telecoil or telephone switch. For those who don't have hearing aids or cochlear implants with embedded telecoils, portable loop receivers are also available. Induction loop systems can be permanently installed in the large places such as auditorium or theaters. The portable loop systems can be ar-

ranged as needed. To pick up the signal, the listener must be wearing the receiver and be within or near the loop. Because the sound is picked up directly by the receiver, it is clear without competing background noise.

### Telephone listening devices

Telecommunication devices for the deaf (TDD) or teletype-writers have been used for many years as a method of typing messages for people with very limited or no usable hearing. However, these machines have almost become a thing of the past due to today's new electronic communication devices, such as personal computers (PCs) and cellular phones. Partially these systems are still being used which permit a TDD user to make calls to a standard telephone user and relays to the messages in the proper form and vice versa. Another system uses voice recognition software and an extensive library of video clips depicting sign language to translate a signer's words into text or computer-generated speech in real time. It is also able to translate spoken words back into sign language or text. For people with mild to moderate hearing loss, captioned telephones allow to carry on a spoken conversation, while providing a transcript of the other person's words on a readout panel or computer screen as back-up. In addition, telephone amplifiers such as specially manufactured telephone or its handset, or portable snap-on amplifiers can be utilized. Visual alerting devices hooked to lights and telephone ringer amplifiers can be used to help a HOH person know the telephone is ringing. The remote ringers can be placed throughout the house to increase the chance the HOH person hear the ringing telephone.

### Television

For watching television, wireless systems including FM, infra-red, and audio loop systems can be installed. Also, simple amplifiers with earphones or headphones can plug directly into the television. Another excellent option is closed captioning. The ability to read the spoken word greatly enhances understanding on this media because most programs include background music or noise which is easy to interfere amplified signals.

### Alert/alarm system

Alerting or alarm devices use sound, light, vibrations, or a combination of these techniques to let someone know when a particular occasion happens. The devices can change the sound signals to flashing lights, bed vibrators, horns, or a gentle shaking for clocks and wake-up alarm systems. Visual alert signalers can monitor a variety of household devices and other sounds, such as doorbells, smoke alarm, kitchen timers, and telephones. Also, remote receivers placed around the house can alert a person from any room. Portable vibrating pagers can monitor a baby's cry even with lighting up a picture to indicate if the baby sounds hungry, bored, or sleepy.

### Digital Wireless Technology for Hearing Instruments: Improved SNR and Convenience

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The advantages of digital wireless technology in hearing instruments fall into two broad categories, improved SNR and convenience. As mentioned above, SNR can be improved by reducing the three addressed problems, noise, distance, and reverberation. SNR can be further enhanced with digital wireless technology through developing sound processing algorithms such as directionality and feedback cancellation especially for bilaterally worn devices to share information. The development of microphone is another factor for improving SNR as several manufacturers of digital wireless hearing instrument systems offer enhanced microphone systems at present. For example, the ReSound Unite™ Mini Microphone (Bloomington, USA), which transmits sound and/or external audio sources directly to the hearing instruments of the listener. Streaming of sounds from other sources such as televisions and radios to iPads, MP3 players, and PCs also improves the SNR for the users.[10](#))

What is streaming?

Streaming technology refers for transferring data so that it can be processed as a steady and continuous method. The term 'stream' comes from the definition of a continuous natural flow of water, people, or things. Streaming technologies are becoming increasingly important with the growth of the internet because most users do not have fast enough access to download large multimedia files such as text, audio, still images, animation, video, or interactivity content forms. With streaming technology, the user can start displaying the data before the entire file has been transmitted.[11](#))

Convenience can be first obtained by facilitating operations of the hearing instruments with a method of a remote control or synchronizing volume control, and program choice settings between devices when worn bilaterally. Wireless exchange of information between bilaterally worn devices can be used to automatically select and align the microphone mode and noise reduction settings. This decreases the need for a user to recognize and manually select hearing instrument programs or features intended for particular listening situations. Interface technology adoption with other electronic devices such as cell phones, MP3 players, PCs, televisions, radios, or any audio source can also be another factor for pursuing convenience of digital wireless technology.

What is interface?

An interface technology means that two independent systems meet and act on or communicate with each other at a shared boundary across. This will let two separate components of a computer system exchange information without obstruction. Such exchange can be between software, computer hardware, peripheral devices, humans and combinations of

these. Some computer hardware devices such as a touchscreen can send and receive data through the interface, while others such as a mouse, microphone or joystick are one way only.[12](#))

## Two Technology Solutions for Digital Wireless Technologies

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There are two technology solutions for digital wireless hearing instruments. One is near-field magnetic induction (NFMI) combined with Bluetooth radio frequency (RF) or proprietary RF transmissions and the other is proprietary RF transmission alone.[13](#))

### NFMI combined with Bluetooth or proprietary RF

Most digital wireless hearing instrument systems use this method. The NFMI transmission systems are designed to communicate between a gateway device and the hearing instrument, while Bluetooth RF is adapted for transmission between a streamer and a gateway device.

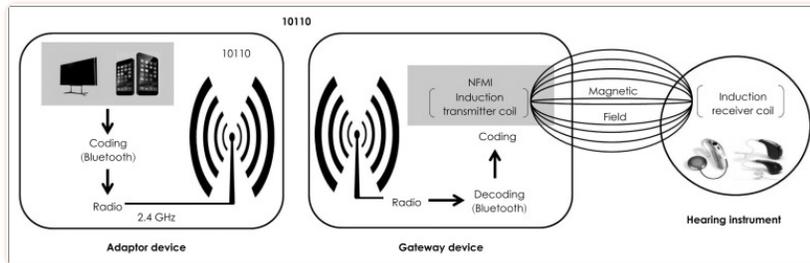
What is a gateway device?

The gateway is a relaying device that transmits the signal from the peripheral equipments including Bluetooth to the hearing instruments such as hearing aids or ALDs through the low-power RF technology or telecoil for reducing power consumption. Typically worn around the neck or used as a remote control, the gateway device needs to be within the 1-meter NFMI in order to pick up the signal.[13](#))

What is the Bluetooth?

First invented by a telecom vendor Ericsson in 1994, Bluetooth is a standard wireless technology for exchanging data such as sound or pictures over short distances. Eliminating problems of synchronization, it can connect several fixed and mobile devices. It uses ultra high frequency radio waves from 2.4 to 2.485 GHz license-free Industry Science Medical (ISM) band. Bluetooth is managed by the Special Interest Group. Bluetooth was named after 10th century Danish king 'Harald Bluetooth Gormsson' who united dissonant tribes into a single kingdom in Scandinavian peninsula. The implication is that Bluetooth does the same with wireless communications protocols among devices, uniting them into one universal standard. The Bluetooth logo (✪) was king's initial. The story tells that he was called the 'blue tooth' because his teeth were tinged blue all the time for enjoying blueberries.[14](#))

[Fig. 1](#) illustrates how a wireless hearing instrument system works based on NFMI. A sound source, such as a television or a cellular phone, is connected to an adaptor device which digitizes the signal and codes it into a language that can be understood by a radio. This language can be for Bluetooth communication or for a proprietary language. The radio then transmits the signal via a 2.4 GHz antenna to a radio in a gateway device. In the gateway device, a language is decoded and sent into the NFMI system which has an induction transmitter coil. This transmitter coil produces a magnetic field, which is picked up by an induction receiver coil in the hearing instruments such as hearing aids or cochlear implants. After being transmitted via the NFMI field, the signal is then manipulated by the hearing instrument and provided as sound to the user.



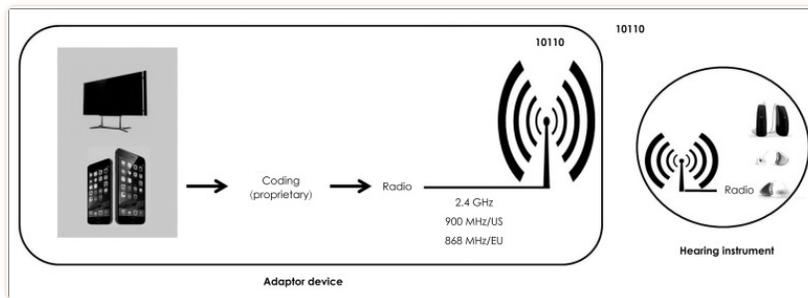
[Fig. 1](#)

Illustration of a digital wireless hearing instrument system according to near-field magnetic induction combined with Bluetooth radio frequency transmission system. NFMI: near-field magnetic induction.

NFMI is relatively easy to implement in hearing instruments because the technology is similar to the telecoil technology. Although using wireless features, the end user gets longer battery life as it works on a lower frequency, generally 10 to 14 MHz. However, the NFMI wireless hearing instrument systems have the disadvantage of a short transmission distance, which has a range of up to 1 meter. This means that a gateway device needs to be close by or worn on the body. Sound quality can be affected by the orientation of the gateway device, receiver coil, or any relay between components. Interference with magnetic sources such as cochlear implants or induction stoves also may be come across. The latency associated with Bluetooth audio transmission can degrade sound quality when the NFMI systems combine with Bluetooth for audio streaming.

### Proprietary RF systems

Proprietary RF transmission digital wireless systems which use RF for direct communication between the streamer device and the hearing instruments have been recently introduced. [Fig. 2](#) illustrates how a proprietary RF system works. A sound source, such as a television or a cell phone, is connected to an adaptor device similar to the NFMI system. The streamer digitizes the signal and codes it into a proprietary protocol. Currently, the RF transmission is either via the 2.4 GHz license free ISM band, 900 MHz band for US, or 868 MHz band for EU, transmitted directly to an antenna in the hearing instruments where the language is decoded back into a digitalized signal. The signal is manipulated by the hearing instrument and provided as an audio signal to the user.



[Fig. 2](#)

Illustration of a digital wireless hearing instrument system according to a proprietary RF transmission system.  
RF: radio frequency.

The advantage of proprietary RF systems is a long transmission range which gives a benefit of convenience to the user without a body-worn 'gateway' device for media connectivity. Also, these systems eliminate the delay in transmission of audio that is associated with Bluetooth, which gives improved sound quality. However, proprietary RF systems require a specially designed and efficient antenna, which can be packed into small hearing instruments. The higher power consumption relative to NFMI systems is a disadvantage. The signal should ensure stability to avoid interference and prohibit eavesdropping by any other wireless devices. This can be accomplished by transmitting data in exceedingly small amounts or packets at a time, by transmitting the data in very short time intervals across different channels which is called 'frequency hopping' technique, and by sending every data packet with an address, which means pairing between hearing instruments and the devices they communicate with.

## Conclusion

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The technology that the hearing instruments are connected directly to compatible electronic devices without the need for a hearing instrument accessory is just around the corner. This would make possible direct communication from the hearing instrument to PC, phones, Wi-Fi, alert systems, and ALDs. Actually, on March 5, 2014 in USA and on April 3, 2014 in UK launched a new hearing aid, LiNX (ReSound), that is compatible with iPhone, iPad and iPod touch.[15,16](#)) It was introduced that the hearing aid acts like a hybrid of hearing aids and stereo Bluetooth headphones working for picking up in-person conversations and surrounding sounds such as phone calls, music, navigations, or other audio which can be streamed directly. It comes with its own iOS application offering a range of features but there is no option for Android users as of this moment. In Korea, LiNX and Halo (Starkey) were also introduced on last April and July, respectively.[17,18](#)) These days expanding connectivity directly to the internet could provide the user more possibilities of improving the signal processing in their hearing instruments or logging into sound systems in theaters and in school. Perhaps in the near future, we could anticipate the pair of hearing instruments that we would be fit with the capacity to take phone calls through the hearing instruments, Skype with our children on our PC using our hearing instruments as the headset with still listening to worship services in the looped church via the built-in induction coil.

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