ADA Accessibility Guidelines for Buildings and Facilities (ADAAG)

ASSISTIVE LISTENING SYSTEMS

BULLETIN #9B: FOR INSTALLERS

How do assistive listening systems (ALS) interface with public address (PA) systems?

Public address systems are, in fact, assistive listening systems. They are designed to help people hear across a distance. In a PA system, the sound is picked up at a microphone and delivered through speakers that bring the amplified sound closer to listeners in an audience.
For many people and in many circumstances, a loudspeaker may provide enough gain in volume for adequate speech perception. But no matter how well placed the loudspeaker(s), perception of air-borne speech signals will be difficult for people with hearing loss unless background noise and reverberation can be carefully controlled.

The same microphone pick-up used in the PA system can also serve an assistive listening system (ALS or ALD). By bridging the acoustical space between the source and the listener, an ALS circumvents the effects of distance (drop in volume), background noise (competing sound), and reverberation (reflecting sound that blurs the desired signal).

The sound signals delivered by the ALS do not travel through acoustical space before arriving at listeners' ears. Thus, they are not weakened by distance or degraded by noise and reverberation during the transmission process. Instead, signals are transmitted via electromagnetic, radio, or light waves to specialized receivers used by listeners.

An ALS eliminates the last acoustical leg of the signal transmission path, providing listeners with hearing disabilities with a parallel transmission path that short cuts the usual delivery process.

What are the benefits of bridging acoustical space?

It is necessary here to emphasize the distinction between audibility and comprehension.

Certainly, the signals delivered by loudspeakers can ensure audibility for almost everyone. For a hearing-impaired person, however, loudness is just one part of the listening equation. Of course, the signal must be audible to listeners with and without hearing aids in order to understand it. But, for most people with hearing loss, the comprehension of verbal messages takes more than audibility.

Comprehension also depends upon the nature of the hearing loss and on the acoustical properties of the space. In the most common type of problem, particularly affecting older persons, hearing acuity is poorer at the higher frequencies than the lower. However, the acoustical characteristics of speech that allow listeners to distinguish between speech sounds occur largely in the higher frequencies. Thus, the common complaint of people with hearing loss, "I can hear but I don't understand": they can "hear" the low frequency components of speech signals, and thus know someone is talking, but cannot "understand" because the higher frequencies that carry the sounds necessary for differentiation between letters and sounds are being filtered out by their hearing loss. Increasing loudness, by itself, will not measurably improve this situation.

In addition to the filtering impact of the hearing loss, the nature of many hearing problems is that the analytic powers of the cochlea are also compromised. Thus, people may have difficulty resolving the separate components of complex acoustic signals (as in a piano chord) or discriminating fine temporal differences within speech sounds. For example, the distinction between such voiced and voiceless sounds as /p/ and /b/ or /t/ and /d/ depend as much on detecting timing differences as it does upon hearing the voiced components. Beyond a pure sensitivity loss, then, and depending upon the specific site and type of damage to the cochlea and the higher auditory pathways, other psychoacoustic abnormalities may co-exist with diminished hearing thresholds and interfere with speech perception.

Additionally, these auditory pathologies interact with external acoustic conditions in such a way as to produce a disproportionate effect upon speech perception. In an optimal acoustical situation, that is, in quiet, a hearing person can achieve speech perception scores of 96% while a listener with a hearing disability can obtain no more than an 84% score. If a moderate degree of noise and/or reverberation is introduced into the room, scores will drop: to 88% – a slight decline – for the listener with normal hearing but to 40% – a precipitate and overwhelming change – for the person with hearing loss.

Increasing the loudness of the signal will not remedy this situation because greater signal volume also produces higher levels of background noise and reverberation. What needs to be increased to improve speech perception is the signal-to-noise (S/N) ratio.

Studies show that increasing signal volume relative to background noise and reverberation can compensate to some degree for the disproportionate effect of noise and reverberation on speech perception by people with hearing loss. By delivering an amplified signal directly to the ear, signal volumes can be increased even though noise levels in the room remain the same.

In effect, what we're doing with an ALS is attempting to replicate a perfect listening situation for the person with a hearing disability, the one in which (in the example above) a score of 84% was achieved. While we can't always provide the perfect signal, we can, through an ALS, significantly improve its quality over that which would be received via the loudspeaker system.

What ALSs do for people with hearing loss, then, is to permit them to function to the limits of their residual hearing capacities. They do more than this, however. Often people with hearing disabilities are able, with a great deal of effort, and by expending a great deal of energy, to understand speech signals in large-area listening venues. They can get the message, but in doing so they have to focus so intently on receiving the message that they have difficulty attending to what is being said. Unlike people with normal hearing, they can't really relax and enjoy the listening experience. ALSs can optimize the listening experience and minimize the stress of concentration.

How many people in our society can benefit from an ALS?

The statistics regarding the number of people with hearing loss in our society vary depending upon the source and the criterion used to define hearing loss. Most sources give this number as between 24 and 28 million people, or about 10 percent of the population. Hearing-impairment increases with age; it is estimated that the majority of people over the age of 65 have some degree of hearing loss. Additionally, noise-induced hearing loss is increasing steadily.

Due to the increased longevity and the aging of our population, the total number (and the percentage) of people with hearing loss is likely to be substantial in the future. Most of these people would be able to benefit from an ALS. Some will benefit more than others, but everyone can obtain some advantages from using an ALS, in comprehension and in the effort they have to make in order to comprehend.

Because ALSs work by improving the signal-to-noise ratio, they are most often used by people who have mild to moderate hearing loss. They can also provide direct audio input to listeners who have cochlear implants. However, ALS may not provide effective communications for people who rely on captioning or ASL (American Sign Language) interpreting. For more information on effective communications, see the *Fact Sheet on Effective Communications* published by Adaptive Environments, Inc. at **www.adaptenv.org/neada/fact2.asp**.

What are the statutory requirements for ALS for specific venues?

The Americans with Disabilities Act of 1990 (ADA) requires that buildings and facilities be accessible to and usable by people with disabilities. This includes communications access for people with hearing loss.

The ADA Accessibility Guidelines (ADAAG), adopted as the ADA standards for accessible design by the Department of Justice (DOJ) in 1991, require that certain newly constructed and altered assembly facilities where audible communications are integral to the use of the space, be designed and constructed to include assistive listening systems.

In addition, DOJ regulations implementing title II (covering the public sector) and title III (covering the private sector) of the ADA include requirements for effective communication with people with disabilities that may require the installation of fixed or portable ALSs in existing assembly facilities.

The ADA does not cover private clubs and entities that are operated and controlled by religious organizations. However, many houses of worship make ALSs available to their congregants, not as a matter of law but as a service, and club facilities used by other organizations must support ALSs required for meetings and performances.

What types of systems are available?

There are three types of large area ALSs:

Induction Loop

In the first type, the induction loop (IL) system, a loop of wire encircles the listening area or is embedded in a mat placed under a rug. This loop of wire is connected to the amplifier output of a public address (PA) system instead of, or in addition to, the usual loudspeaker (input is through the microphone serving the PA system).

The IL system produces an electromagnetic field around the wire that can be picked up by a telecoil in a hearing aid. About 30% of hearing aids include T- coils, which also facilitate telephone communication. When the electromagnetic field emanating from the wire loop intersects these coils, it "induces" an alternating electrical current in the coil. This electrical current is then processed by the hearing aid in the same way a microphone processes acoustical signals.

The major advantage of IL systems is that listeners whose hearing aids include T- coils always have an ALS receiver with them.

Facilities that provide an IL system must also provide telecoil receivers for people who do not use hearing aids or who wear hearing aids that do not have telecoils. These special receivers come in various shapes and sizes, but all contain a wire coil to detect the electromagnetic field and an amplifier to increase the signal level.

Disadvantages of IL systems can include spill-over of the magnetic field into adjacent areas (both horizontally and vertically), susceptibility to stray electromagnetic fields, variations in the electromagnetic field within the loop, and issues related to the quality and physical orientation of the telecoils. With a proper installation and appropriate hearing aids, these problems can be minimized and often eliminated.

FM

The second type is the FM system.

An FM assistive listening system is simply a variation on the commercial FM radio. The signals are broadcast by FM transmitters and picked up by listeners using a receiver tuned to the transmitting frequency. FM receivers must be made available by the facilities that use FM-based ALSs. The FCC has reserved the non-commercial 72MHz to 75MHz and the 216 MHz to 217 MHz bands for auditory assistance devices. The lower band is a non-exclusive band, which means that interference from other users in the same frequencies may occur (such as from emergency vehicles of various kinds). The effective range of the lower FM band is a radius of about 300 to 500 feet, given the power limits set by the FCC (80 millivolts per meter at 3 meters). The effective transmitting range of the 216-217 MHz band is approximately twice that of the lower band.

There are several disadvantages of FM systems.

The first is that privacy is not possible. The FM signals do not stay contained within the four walls of the enclosure. If privacy is a consideration, then an FM system is not appropriate for that facility. Different rooms can broadcast at different frequencies to receivers tuned to those frequencies, making FM systems useful in school classrooms and multiplex cinemas. But they should not be used in courtrooms where confidentiality is an issue.

The second potential problem is the flip side of the first: radio signals originating outside of the facility can enter the facility and interfere with reception. One cannot prevent occasional interference, as when some emergency vehicle in the area transmits on the same frequency used in the venue. However, persistent interference can usually be overcome by selecting alternate frequencies within the permitted bands. On the up side, it is relatively easy with an FM system to ensure adequate signal strength at all seat locations, even in the largest venues.

Infrared

The third type of ALS is the infrared (IR) light system.

In an IR system, audio signals from any source are conveyed to listeners via infrared light waves (using light-emitting diodes) invisible to the human eye. The light waves are picked up by a photo detector diode contained within the optical bubble found on every IR receiver. The receiver then extracts the audio information from the IR signal and delivers an amplified version to the ears of a listener.

Ordinarily, strict line-of-sight is necessary between an IR emitter and the transparent lens on the receiver, but this can be modified in rooms with light-colored surfaces (the IR waves are reflected off them) or by adding additional emitters.

Since IR systems are light waves, they exhibit the advantages and disadvantages of light waves. The IR signals are contained within a room, thus ensuring privacy, and adjacent rooms in a facility can use IR systems without fear of inter-room interference. They are also not as subject to radio or electromagnetic interference as are FM systems. However, outdoor use is problematic because of the effect of sunlight (which contains a great deal of infrared energy) and it is more difficult to cover the largest venues with IR systems than with an FM system.

All IR systems require a radio frequency (RF) sub-carrier as an intervening step between the audio and the light waves. That is, the audio signals first modulate the RF sub-carrier, which in turn modulates the IR light signals. Until now, 95 kHz has been the unofficial RF sub-carrier, permitting a person to use the same IR receiver in different venues.

Compatibility between venues has always been a major advantage of IR systems. The situation may now be changing because of the electromagnetic interference at this frequency produced by newer, more energy efficient, fluorescent lights. Because of this, some facilities are or may be switching to different sub-carrier frequencies (250 kHz, 2.3 MHz) with their IR systems. This will not be a problem for consumers as long as the facility provides them with compatible IR receivers. However, switching sub-carrier frequencies may affect those consumers who have, or desire to purchase a personal IR receiver, since no commercially available IR receivers are able to detect all the possible sub-carrier frequencies.

What principles govern the selection of ALSs for specific venues?

It is always a good idea for the installer (or the equipment distributor) to consult with the provider prior to the selection and installation of an ALS. Whenever possible, a preliminary visit to the facility is advisable. At the least, the installer should obtain a detailed description of the facility, its operation, and its unique needs prior to decision-making. Below are just some of the considerations that should be jointly considered:

- Is privacy a major consideration? Is it necessary that the events taking place within a facility not be accessible to people outside the enclosure? If so, then an IR system must be employed. There are really no other alternatives for facilities such as courtrooms, confidential meeting venues, and even musical performance facilities where "bootlegging" a recording may be attempted.

- Is this an outdoor facility (an amphitheater with lawn seating or a racetrack, for example)? In this case, an FM system would be the appropriate choice.

- Is this a large indoor facility, such as a concert hall or auditorium with balconies, overhangs, and other nooks and crannies? While a skilled person can satisfactorily install an IR system in such locations (and it should not be ruled out), it is easier to ensure adequate signal strength at all seat locations with an

FM system. However, this choice will be influenced by the possible presence of electromagnetic interference from outside sources, requiring shielding, or the possibility of interfering with nearby external users of radio systems, such as hospitals and public safety organizations.

- Are a large number of simultaneous events going to be taking place in adjoining facilities? While there are a sufficient number of potential FM carrier frequencies available to ensure non-interference between rooms, and thus an FM system is a possibility, it may then be necessary to provide FM receivers that can be tuned to all the possible frequencies or to match supplies of receivers to particular rooms. How will the audience respond to the necessity to change frequencies? Will it cause difficulties if someone in one room can "tune in" to events in a different room? If these possibilities may turn into future problems, then an IR system is advisable. IR systems can be installed in every room in a facility with no interference between rooms. Furthermore, the same IR receiver can be used in every room.

- Is it going to be necessary to use the same system alternately in a number of different rooms (such as in a community center, switching from one activity room to another)? Ordinarily, FM systems are somewhat more flexible and can be used both indoors and out (as in a tour group). However, some IR systems are also relatively easy to deploy, and portable units will work well in the smaller activity rooms, though they will not operate as effectively outdoors.
- Is there a possibility of radio interference within the auditory assistance FM frequencies (72-75 MHz and 216-217 MHz bands)? This can be determined by using a frequency scanner to determine the possibility of interference prior to the installation. If the interference is likely to persist, and this is not amenable to a change in carrier frequency (which most problems would be) or shielding, then an IR system would be the best bet.
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Except for a few specialized locations (like schools for the deaf), IL systems are rarely used in large listening venues in the U.S. This is ironic, since of all the ALSs, they are probably -- from the viewpoint of the facility -- the simplest system to provide. The IL receiver is simply the telecoil in the person's own hearing aid, thus relieving the facility of the necessity to supply and care for a large number of receivers. Specialized IL receivers with telecoils are available for people who wear hearing aids without telecoils (and for those with mild hearing loss who wear no hearing aids at all).

What do I need to know about ALS performance?

The following recommended electroacoustic performance standards reflect the results of a research project completed at the Lexington Center's Rehabilitation Engineering Research Center (RERC) in 1998 and 1999. In conducting this study, the RERC researchers opted to focus on the last stages of the transmission process, i.e., the signals actually being delivered to the earphones through ALSs. By comparing the input to the output, all the factors that ALSs can impose upon an audio signal would be subsumed. The complete project, as well as the background state of the art paper can be accessed on the Lexington Center website at **www.hearingresearch.org**.

The primary metric used to define the quality of the output signal was the Speech Transmission Index (STI). Basically, the STI compares the integrity of an audio signal at two different points in the transmission process, e.g., at a talker's lips or loudspeaker compared to the same signal being delivered through the earphones. It does this by measuring the fill between adjacent peaks in a simulated or actual speech envelope. This fill represents the addition of noise and reverberation to the primary signal. The more the fill, the lower the STI. An STI of 1.0 represents the source signal; anything less reflects the amount of noise and reverberation added to the primary signal.

Measuring the STI

RERC engineers developed a simplified software version of the basic STI calculation. This software, available on-line from the Lexington RERC, can be used to measure the STI with input from either a live microphone or an audio track. With live microphones, a test loudspeaker is placed at the location of the talker. The output signal from the STI measurement system is broadcast from the test loudspeaker, picked up by the microphone, and passed through the ALS for measurement. When an audio track is the source (such as in a movie), the line output of the STI measurement system replaces the audio track. In either case, the output of the ALS is monitored either by means of a line output from the ALS, or via earphones through a coupler of some kind (e.g., Zwislocki coupler). The output from the ALS is connected to the STI measurement system through the line input port of the computer's sound card. The person testing the system can then run the software and in about three minutes the STI measurement is complete. It is important to note that the recommended STI is applicable in any type of listening situation. It can be employed in the absence of a sound system simply by comparing the signal at a talker's mouth (the input) to that picked up at any point in an enclosure (the output).

Obtaining the software

Detailed information about the Speech Transmission Index Software, including system requirements and equipment setup, may be found at the following website: **www.hearingresearch.org/STIinfo.htm**. The software itself may be downloaded from **hearingresearch.org/stidownload.htm** or ordered on CD-ROM from **hearingresearch.org/STI.htm**.

Electroacoustic targets

These targets apply in all seating locations in every venue employing an ALS.

- A minimum STI of .84 is recommended with any ALS in any large-area listening situation. All facilities should strive to exceed this minimal figure, in this and in all of the other electroacoustic recommendations given below.

- A minimum signal-to-noise ratio of 18 dB is recommended. This result is also based on the results obtained in the listening project conducted with hearing-impaired listeners. When the system is being used with hearing-impaired children, it is recommended that the S/N be increased to 25 dB, to reflect the fact that children in the process of learning auditory language require greater signal saliency than adults who use the sound to recognize a previously learned language system.
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- The system must be capable of providing at least 110 SPL output, but not exceed an output of 118 dB SPL. The assumption here is that people who require greater signal levels would be employing some kind of external coupling to personal hearing aids (acoustical, inductive, or direct audio input).
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Are all the possible transmission variables subsumed under these electroacoustic targets?

Yes. By measuring the signal at the last stage in the transmission process, i.e., the headphones, all the variables and factors that can reduce signal quality would be included. For signals originating from microphones, this would include the microphone position relative to the talker, the type of microphone, and room acoustics as well as any signal degradation occurring between the source and the headphones. When any of the electroacoustic targets are not met, the installer must troubleshoot the system, locate the source of the problem, and correct the situation. It is impossible to predict and anticipate all the factors that may affect signal quality, and there is no desire to dictate the details of an ALS installation to the professionals who install them. By focusing only upon the electroacoustic targets, installers would then be able to utilize their own skills and creativity in ensuring that these criteria are being met. In some instances, because of a clearly inadequate system, it may be impossible to achieve the desired targets. In such a situation, it would be incumbent upon the installer to recommend a higher quality ALS; one with which the electroacoustic targets can be met.

What types of pre-processing strategies are desirable?

This is a very difficult question to answer specifically. A number of the participants in the RERC's focus groups suggested that the transmitted signal be as transparent as possible, with any signal processing strategies accomplished at the personal receiver level. However, other participants pointed out that certain pre-processing strategies may be inevitable, given the need to compensate for wide input signal variations and to provide additional high frequency emphasis when transmitting speech signals. This issue was left unresolved. The danger of being too specific in recommending certain pre-processing strategies is that it may inhibit future product development by manufacturers trying to improve their products. As long as the electroacoustic targets are met (or exceeded), installers can exercise a wide range of pre-processing strategies to obtain the desired targets.

What types of receivers and coupling arrangements are available?

Radio frequency FM receivers are about the size of a pack of cigarettes and feed either headsets, earphones, or earbuds. All include on/off switches and volume controls. The receivers may be worn hung around the neck, clipped to a belt or placed in a pocket.

People who use hearing aids may prefer to use a neckloop or silhouette instead of headphones or earbuds. A neckloop operates on the same principle as the large-area IL system; it fits around the neck rather than around a room. Neckloops and silhouette inductors are plugged into the receiver earphone jack and transmit an electromagnetic field to a hearing aid telecoil. For the individuals involved, inductive coupling is a convenient way to use an ALS receiver, since it enables them to continue to use their personal hearing aids. However, only about 30% of modern hearing aids include telecoils, mainly because of size restrictions (they won't fit into the smallest hearing aids).

Other hearing aid (behind-the-ear type) or cochlear implant users may prefer to directly connect the ALS receiver to their personal listening devices through a wire cord. In these instances, users would ordinarily supply their own patch cords.

IR body pack receivers are similar to FM receivers and employ the same coupling arrangements (headphones, earbuds, neckloops, patchcords). The major difference is that every IR receiver has an optical bubble which collects the IR light wave for processing by a photo-optical circuit. IR receivers are also available in forms not available with FM receivers, such as under-the-chin stethoscope units and self-contained headphones. Stethoscope units place the electronics, volume control and optical bubble in a single unit that dangles from a user's ears. Some of these units also include an output jack for insertion of a neckloop.

Is it possible or desirable to mix and match transmitters from one company to the receivers of another?

Yes, it is possible, as long as both transmitter and receiver function at the same frequencies (FM or IR). Generally, however, it is not desirable. Even though the same frequencies are being used, there are issues of receiver sensitivity and bandwidth that can affect the quality of the received signal. It is advisable, therefore, to use receivers and transmitters from the same company to preclude possible problems. On the other hand, many consumers have purchased IR receivers that use the 95 kHz sub-carrier and find themselves able to use the same receiver in a number of different venues that employ this frequency (which up to now has been a kind of de facto universal standard).

How many receivers should be made available?
The number of receivers should be equal to at least four percent of the total number of seats available, with a minimum of two in any facility with fixed seating of 50 or more.

What possible problems should I be aware of?

There are two types of problems to be considered, one connected with proper installation and the other with maintenance.

The presence of interfering radio signals, in the event of an FM installation, or interference from fluorescent ballasts with an IR installation, are examples of the first type of problem apparent at the time the ALS is being installed. In some locations, it may be desirable to monitor the presence of potential radio interference for some period of time, and to do this throughout the facility, before making an FM installation.

A frequency scanner would be a useful device to employ. These problems can be managed before the system is put into operation. When extraneous radio signals of particular frequencies are found to occur often, the installer has the option of shifting to another radio frequency. Inductive loop systems need to be carefully checked to see that the field covers all seating locations equally well.

The second type of problem is one that often bedevils installers (as well as providers and consumers). Some period after making what they believed to be an excellent installation, they may get calls from an irate provider who reports that their patrons are complaining of poor or non-existent reception. After visiting the facility and troubleshooting the problem, the installer may find:

- IR emitters moved from their previous location because some maintenance person or stage designer felt that they were intrusive in a particular location.
- Scenery, curtains, or some other fixture placed between the audience and an emitter and thus "shadowing" some of the IR light waves.
- Transmitter system settings modified from the original ones (e.g., VU meter readings below optimum level).
- Radio or electromagnetic interference from an adjacent facility, or from within the facility, not present during original installation.
- Maintenance problems with the receivers (dead batteries, broken cords, poor connectors, etc.).
- Some change in microphone usage (i.e., number, location, type) which severely affects the quality of the signals reaching the microphones.

The solutions in these examples are obvious. Facility personnel must be trained to understand that the ALS installation is a permanent addition to the venue, not to be tampered with for any reason, and how it works with the basic sound system.

The quality of an ALS installation can be compromised at any point in the transmission path by what may appear to be a simple adjustment or change of some kind. When problems occur subsequent to the original installation and the problems rectified, the technician should retest the system to ensure that the electroacoustic targets are once again being met.

The Rehabilitation Engineering Research Center on Hearing Enhancement, website **www.hearingresearch.org**, has a great deal of useful information on assistive listening systems. Other resources include the technical assistance center at Gallaudet University, **www.tap.gallaudet.edu**, and the Access Board, **www.access-board.gov**. The Access Board also provides a toll-free technical assistance number at 1-800 872-2253 (V) or l-800 993-2822 (TTY).

Bulletin #9B **November 2001**

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Related Bulletins on Assistive Listening Systems:

- **Bulletin 9A: For Consumers**
- **Bulletin 9C: For Providers**