Auditory Access in Public Areas: Issues and Options

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Introduction

Assistive Listening Systems (ALS) are widely used in the United States to provide access for people with hearing loss to auditory information in public spaces such as theaters, auditoriums and lecture halls. Among the many effects of hearing loss is the increased need, relative to those with normal hearing, for a clear signal without interference from noise and reverberation. Many ALS are available to meet this need, and can be categorized according to the carrier that they use to move the signal from the microphone or other signal source to the receiver used by the listener. The most common carrier signals available on the market are FM radio (FM), Infrared light (IR) and Magnetic Induction, or "Induction Loop" (IL).

A recent resurgence of interest in ALS dates from the passage of the Americans with Disabilities Act in l990. Among the many provisions that can affect people with hearing loss, the law requires that any business (auditoriums, theaters, movie houses, etc.) with 50 or more fixed seats in an assembly area must make assistive listening devices available for at least 4% of the seating capacity (note that the law does not apply to houses of worship). Nothing in the law designates the type of ALS that should be provided in the different venues in which they can be used or the nature and adequacy of the receiving devices. Nor are installation or performance standards, at either the transmission or the receiving end, included in the implementing regulations. In taking advantage of the law, hard of hearing people often find themselves victims of uncertainty. When "everything works well," an ALS will substantially improve communication access. Instead of feeling frustrated, angry and isolated by a poor listening experience, hard of hearing people can relax, enjoy the performance, and continue their engagement in social/cultural activities. Unfortunately, Murphy's Law ("whatever can go wrong, will") describes too many real-life experiences. Even when things go right, hard of hearing people often report an underlying uncertainty, based on their own or other's prior experiences, that something will occur to interfere with the realization of the full benefit of an ALS.

We have identified four interdependent, dynamic factors that are necessary to achieve successful access to sound in public areas. They include:

1. Quality of the signal – Is the quality of the signal at the ear of the user sufficient for good auditory access?
2. Availability of the system – Is a working system available when needed?
3. Ease of Use – Is the system user-friendly?
4. Quality of the fitting – Does the listener have the appropriate technology, and is it correctly matched to his/her hearing needs?

This paper will report on empirical data related to the required signal quality of large area ALS as well as documented consumer concerns regarding public access. We will also share our clinical observations over many years at Gallaudet University regarding ease of use and methods to ensure quality of fitting. We will end with some recommendations regarding future research and development

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Quality of Signal: Developing ALS Performance Standards for People with Hearing Loss

This data comes from work conducted by the Rehabilitation Engineering Research Center on Hearing Enhancement (RERC-HE) at the Lexington Center for the Deaf in New York under a contract to the United States Architectural and Transportation Compliance Board (U.S. Access Board). As a consumer-driven project, the first step was to convene a consumer focus group, in which hard of hearing people discussed the problems they encountered with ALS and offered their perspectives on how the situation could be improved. Later a second focus group was convened, this one composed of the representatives from manufacturers, installers, and large-scale users of such systems (theaters and movie houses). Finally, a third meeting was held, attended by participants of both the previous groups, plus representatives from the National Systems Contractors Association (NSCA). In parallel with this series of focus groups, empirical data was collected to inform the U.S. Access Board on the aspects of signal clarity that needed to be addressed in any standards that might be proposed to ensure access to sound in public places in the United States.

The objective of this study was to establish guidelines for specifying the acceptable output characteristics of assistive listening devices for people with hearing loss. Fifty-nine adult listeners (49 with hearing loss and 10 without) listened binaurally to sentence materials that were subjected to three different types of distortion; reverberation and background noise, internally-generated induction loop noise, and peak clipping. The listeners provided ratings as to the quality of the materials presented. A minimally acceptable criterion was selected and results for the listeners with hearing loss were compared with that criterion to arrive at:

1. Minimally acceptable output and dynamic range levels,
2. Minimally acceptable Speech Transmission Index (STI) level,
3. Minimally acceptable signal-to-noise ratio for internally generated noise, and
4. Minimally acceptable peak clipping level.

Participants

Forty-nine adult listeners with sensorineural hearing loss participated in this study. They were divided into six groups according the degree and configuration of their hearing loss. The following is a list of criteria for inclusion in each group:

- Very high frequency hearing loss: the three-frequency pure tone average (PTA) is less than 41 dB HL with thresholds at 2000 Hz less than 40 dB HL.
- Moderate flat hearing loss: PTA is greater than 41 dB HL with threshold at 2000 Hz less than 55 dB HL.
- Moderately-severe, gently sloping hearing loss: PTA is greater than 41 dB HL with threshold at 2000 Hz between 55 and 60 dB HL.
- Moderate to severe flat hearing loss: PTA is greater than 41 dB HL with thresholds at 2000 Hz between 61 and 70 dB HL.
- Moderate to severe sloping hearing loss: PTA is greater than 41 dB HL with thresholds at 2000 Hz greater than 70 dB HL.
- Precipitous, high- frequency hearing loss: PTA is less than 41 d B HL with thresholds at 2000 Hz greater than 40 dB HL.

Stimuli

Six pairs of sentences (one male and one female talker) were selected from the corpus of the Lexington Dialogue Sentences. These materials were developed at Lexington specifically for evaluation of hearing aids. The six pairs of Lexington Dialogue Sentences selected were as follows:

1. I would like to try these shoes.
   What size shoes do you wear?
2. Where did you go to school?
   I went to school in New York City
3. That bookcase fits in nicely with your other furniture.
   I tried to find the perfect place for it.
4. Did you do anything special over the weekend?
   I went to the movies and read a lot.
5. The basket is on the table.
   It is filled with beautiful flowers.
6. Did you watch the movie on television last night?
   No, I watched a documentary instead.

The original sentences were subjected to three types of distortion created under either live or computer simulated listening conditions. Stimuli for the reverberation plus noise condition were recorded in three separate environments: a classroom, an auditorium, and a conference room. For the teleloop noise and peak clipping conditions digital signal processing techniques were used to simulate real-world listening conditions. The following is a brief description of how the three types of stimuli were prepared:

1. Reverberation Plus Noise

In three separate recording environments sentence materials were delivered from a B & K artificial mouth at successive distances from the recording microphone. The environments were selected to represent those where a person with hearing loss is likely to encounter an assistive listening system: a classroom, a conference room, and an auditorium. A high quality microphone attached to a sound level meter picked up the signals and delivered them to a digital audio tape recorder. Speech Transmission Index (STI) measurements were made immediately following the recording of each sentence pair at each microphone location. The recorded signals were then re-digitized and stored onto a computer disk for presentation during the experiment. Figure 1 shows the STI at each of the recording distances from the microphone.

Note that STI values for the conference room at equivalent distances to those for the other rooms were comparatively quite poor. This is because of the constant background noise created by the ventilation system in the conference room.

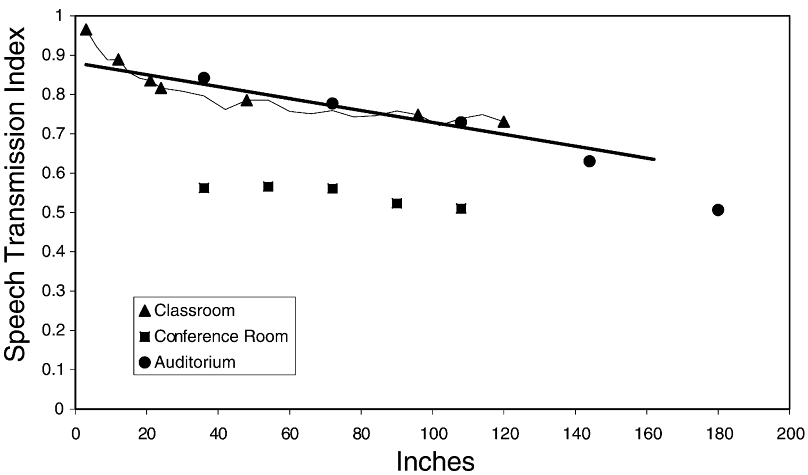

Figure 1. Speech Transmission Index (STI) as a function of speaker/listener (microphone) distance in the three recording environments for the reverberation plus noise condition.

2. Induction Loop Noise

A digital recording was made of the noise created by a poorly installed induction loop. This noise was digitally mixed with the original sentences at six signal to noise ratios ranging from 0 to 30 dB in 6 dB steps. The noise largely consists of a background "buzz" and a high-frequency hiss.

3. Peak Clipping

The signals were symmetrically clipped at six different levels down from the peak level.

The following outline summarizes the three listening conditions.

1. Reverberation and background noise – expressed as distance from the recording microphone. Also shown are the corresponding STI measurements.

A. Auditorium

Distance	*STI*
3 feet	0.842
6 feet	0.777
9 feet	0.729
12 feet	0.632
15 feet	0.506

B. Conference Room

Distance	*STI*
3 feet	0.562
3.5 feet	0.566
6 feet	0.561
7.5 feet	0.523
9 feet	0.512

C. Classroom

Distance	*STI*
3 inches	0.965
12 inches	0.889
24 inches	0.816
48 inches	0.785
96 inches	0.748
120 inches	0.731

2. Internally Generated Induction Loop Noise – expressed as signal to noise ratio of the RMS of speech to the RMS of noise

   0 dB
   6 dB
   12 dB
   18 dB
   24 dB
   30 dB

3. Peak clipping – expressed in level down from the peak amplitude

   6 dB
   12 dB
   18 dB
   24 dB
   30 dB
   36 dB

Apparatus

Listeners were seated in a sound treated booth wearing TDH 49 earphones mounted in MX 41AR cushions. Stimuli were delivered binaurally at a comfortable listening level. The level of the signal was the same for both ears. Signal delivery and data collection were controlled by a personal computer.

Procedure

To adjust to a comfortable listening level the listeners were instructed to indicate the level of quiet, undistorted sentences that they felt they could listen to for a very long time.

Listeners were instructed to judge the quality of the test sentences by selecting one of the following ratings.

1. Excellent
2. Good
   (I would purchase a ticket for a show)
3. Marginal
   (I may or may not purchase a ticket for a show)
4. Unacceptable
   (I would not purchase a ticket for a show)

Listeners were tested in five blocks of trials for each of the listening conditions. Sentences were always presented in female/male question/reply pairs. Pairs for each level of distortion were presented six times. The protocol consisted of a pretest phase in which sentence pairs were presented in two orders from greatest degradation to quiet and quiet to greatest degradation. Following the pretest phase, the remaining four pairs of sentences for each level of distortion were presented in random order. The final result for each listener represents an average of the four rating responses for each sub-condition recorded following the pretest phase.

Results and Discussion

Listening Level

Figure 2 shows the range of preferred listening levels selected by the listeners who participated in this study. The highest level of 111 dB SPL was selected by a listener with a moderate-to-severe flat hearing loss. The dB SPL values were referenced to the level of a 1000 Hz calibration tone whose RMS level is equivalent to the average RMS level of the sentences.

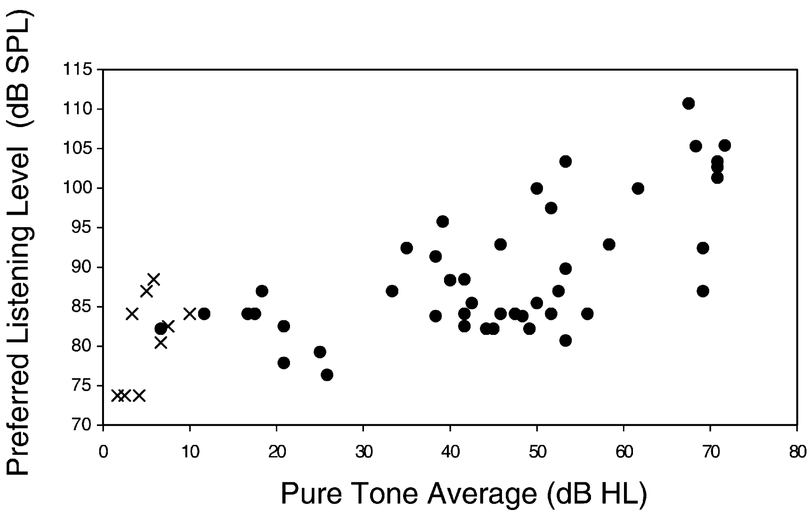

Figure 2. Subject-selected preferred listening levels as a function of 3-frequency pure tone average for the 59 listeners who participated in this study. The level of the signal was the same for both ears. The circles represent the combined pure tone averages (both ears) for each of the listeners with hearing loss. The X's represent the combined pure tone averages for each of the listeners without hearing loss.

Ratings

Because all of the groups rated the quality of the sentences similarly, recommendations stemming from this report are independent of degree of hearing impairment. Results, however, for the 10 listeners without hearing loss were excluded in arriving at the recommendations. Furthermore, in the interest of being more inclusive, the 75th percentile was chosen over the median (50th percentile). As opposed to an average (mean or median), which does not take into account those listeners with more strict listening criteria, the ratings for 75 percent of the listeners with hearing loss were considered in arriving at the recommendations.

A minimally acceptable rating of 2.25 was chosen. This value represents the average if a listener rated at least one of the four presentations for a particular sub-condition as good: marginal (2), marginal (2), marginal (2), and good (3). Tables 1 through 5 show the rating level above which 75 percent of the listeners' scores fell for each of the five listening conditions. Values that are below the minimal criterion of 2.25 are both italicized and highlighted. For the auditorium condition the microphone distance cannot be greater than 3 feet from the talker. For the classroom condition the microphone distance cannot be greater than 2 feet from the talker. For the conference room condition all of the microphone distances were judged to be unacceptable. For the induction loop condition the signal-to-noise ratio cannot be poorer than 18 dB. Finally, for the peak clipping condition the level of peak clipping down from the peak level cannot exceed 18 dB.

Figure 3 shows 75th percentile ratings as a function of the STI results from the reverberation plus noise conditions combined for the three different

Table 1. Seventy-fifth percentile ratings for the Auditorium condition. In parentheses following each sub-condition are the corresponding STI values.

Quiet	**3 feet (.842)**	**6 feet (.777)**	**9 feet (.729)**	**12 feet (.632)**	**15 feet (.506)**
3.25	2.25	***1.81***	***1.56***	***1.25***	***1.00***

Table 2. Seventy-fifth percentile ratings for the Classroom condition. In parentheses following each sub-condition are the corresponding STI values.

Quiet	**3 inches (.965)**	**1 foot (.889)**	**2 feet (.816)**	**4 feet (.785)**	**8 feet (.748)**	**10 feet (.731)**
3.25	2.75	2.75	2.5	***2.0***	***2.0***	***1.25***

Table 3. Seventy-fifth percentile ratings for the Conference Room condition. In parentheses following the sub-condition are the corresponding STI values.

Quiet	**3 feet (.562)**	**4 1/2 feet (.566)**	**6 feet (.561)**	**7 1/2 feet (.523)**	**9 feet (.512)**
3.50	***1.75***	***1.75***	***1.63***	***1.5***	***1.5***

Table 4. Seventy-fifth percentile ratings for the Induction Loop noise condition.

Quiet	**30 dB S/N**	**24 dB S/N**	**18 dB S/N**	**12 dB S/N**	**6 dB S/N**	**0 dB S/N**
3.13	3.00	2.88	2.63	***2.13***	***1.50***	***1.00***

Table 5. Seventy-fifth percentile ratings for the Peak Clipping condition.

Quiet	**6 dB**	**12 dB**	**18 dB**	**24 dB**	**30 dB**	**36 dB**
3.00	2.88	2.75	2.25	***1.75***	***1.50***	***1.00***

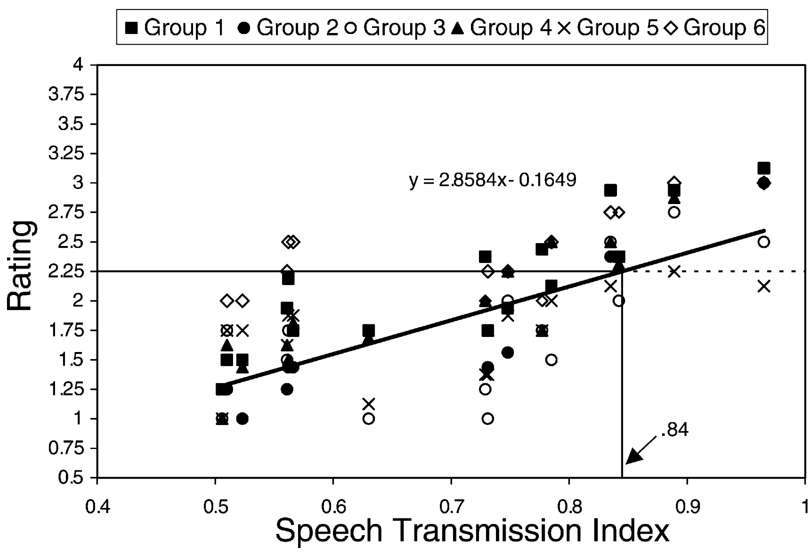

Figure 3. Seventy-fifth percentile ratings for each experimental group as a function of the speech transmission index. The diagonal line represents the best fit first order regression line to the data. Also shown is the equation that corresponds with the line and the STI value of .84 that results from the equation with 2.25 as the minimum acceptable rating.

environments. Also shown on this graph is the best fit, first order regression line to the data. For a minimally acceptable criterion of 2.25 the STI value cannot be less than 0.84. Note that with our criteria (a 2.25 rating for 75% of the listeners and an STI value of .84) only a few data points can be found in the unacceptable region. Note that these two data points (x's) are for Group 5 with the greatest degree of hearing loss.

The STI was chosen as the criterion metric over a simple distance measure because different STI values can be recorded at the same distance depending on the level of the background noise in the environment (See figure 1).

Documented User Concerns

In addition to the research (reported above) that led to the recommendations for signal clarity, a series of focus groups were convened in which hard of hearing people discussed the problems they encountered with ALS and offered their perspectives on how the situation could be improved. From these discussions four lists of consumer concerns were derived, organized into four categories: Concerns about signal quality (Electroacoustics), installation-related concerns, logistics-related concerns, and advertising/signage-related concerns. Table 6 lists the major concerns expressed by the participants:

Table 6. Major concerns of consumers related to ALS in Public Places

Signal Quality (Electroacoustics)	
• Availability of hearing aid coupling	• Telecoils in hearing aids vary significantly
• Microphone location in live performance	• Stereo sound with binaural BTE or ITE
• Need for universal plug on receivers to couple with users' equipment (e.g., neckloop)	• Bleed from headphones
• Wide dynamic range in movie sound tracks	• Variations in receivers under same listening conditions
Installation-related	
• ALDs unavailable in all movies of multiplex	• Dead spots for reception in theaters
• Variations: same systems/different theaters	• Appropriate use of FM vs. IR vs. Loop
• IR "hum" and reflections off metal objects	• FM interference
• "T" coil interference	• "Pass-around" microphone availability (for discussion situations)
Logistics-related	
• User-friendly receivers are desirable	• Monaural earbud should not be only option
• System check-out/check-in	• Personnel training for dispensers
• Adequate numbers of units for groups of hard of hearing people	• Reliability of system functioning
• Public education in use of device – Suggestion that a guide could be distributed with the units	• Hearing aid interfaces, e.g., neckloop/silhouette
Advertising/Signage-related	
• Inconsistent inclusion of ALD information in newspaper advertisements	• Need for more visible signage at the facilities
• Public media should present role models using ALDs (Public Education)	

Recommendations

Based upon these results, the following recommendations were made to the U.S. Access Board:

Electroacoustic Performance Standards: Recommendations

- That the speech signal meet or exceed a Speech Transmission Index (STI) of .84, measured at the earphones. (The STI is, in effect, a measure of reverberation and noise upon the integrity of the speech source; numbers lower than 1.0 reflect degrees of degradation of the originating signal).
- That the system produce a signal-to-noise (S/N) ratio of at least 18 dB measured at the earphones.
- That the receiver be capable of delivering a signal of at least 110 dB SPL and no greater than 118 dB SPL measured at the earphone output. Volume controls should be included with a range of at least 50 dB.
- That the peak clipping levels not exceed 18 dB down from the peak level of the signal.

Logistical Considerations: Recommendations

- Newspaper and other media advertisements should include information that the venue provides an ALS.
- Recorded telephone information should include a comment that the venue provides an ALS.
- Within each venue, there should be clear and visible signs that an ALS is available and exactly where the receivers can be obtained.
- At each venue, information regarding the frequency of the FM and IR (sub-carrier) transmissions should be clearly posted for those consumers who bring their own receivers.
- The same individual in the same physical location should be responsible for both the checking in and checking out of the receivers
- This individual should be trained to operate, troubleshoot, and maintain the receivers. See report for a full listing of this person's responsibilities.

Receivers and Couplers: Recommendations

- The output jack of all ALD receivers should accommodate a 1/8" (3.5mm) stereo plug using a TRS (tip, ring, sleeve) configuration, with the sleeve always carrying the ground. In mono systems the signal should be carried on the tip; in stereo systems, on the tip and the ring. This will permit the use of stereo earphones, direct audio input (DAI) cables, neckloops, cochlear implant patch cords, and silhouette inductors.
- Discrete and highly visible and easy to use controls should be included in receivers that have the capacity to detect multiple channels or be capable of other electroacoustic modifications (e.g. volume and tone controls).
- Single-channel receivers that contain only a minimum of external controls should be available for use at locations catering to elderly people (e.g. nursing homes, senior centers).
- Receivers should include "low battery" lights than signal limited remaining battery life.
- Coupling options should include headphone, earbuds, and neckloops. We suggest that at least one neckloop be available for every four air conduction type receivers.
- Headphones should fit comfortably over all types of in-the-ear hearing aids and permit users to couple either inductively or acoustically to receivers. Furthermore, the "bleed" should not exceed the ambient noise at seats adjacent to the user.
- It would be desirable for the industry to develop a "universal receiver", one that can be (1) tuned to any FM frequency used in ALS in the 72–75 MHz or the 216–217 MHz range, either wide or narrow band channels, (2) adjusted to detect any of the sub-carriers used with IR systems, and (3) include a telecoil for usage with IL systems. The rationale for this is to provide consumers with the option of purchasing a personal ALS receiver, one that could be used in any venue.

Installation: Recommendations

The adequacy of the installation and the competency of the installers were a recurring theme in all the focus groups. While the competencies required for selecting and installing the appropriate ALS will differ depending upon the specific type of venue, all require some minimum information if the appropriate system is to be selected and installed properly.

- We recommend that the Access Board sponsor workshops to train or update the training of ALS installers.

- Such training programs can be a joint effort of consumer organizations, professional groups, industry, and such agencies as the Lexington RERC.
- Training materials should be prepared independent of but also as a component of these training programs. Such material can consist of printed and video material, all suitable for dissemination on the internet.

Clinical Observations

Ease of Access/Use by Consumers

Each of the documented concerns above has been echoed in the Audiology Clinic at Gallaudet University, which serves patients with a wide range of hearing difficulties in the Washington, DC metropolitan area. For the past 20 years we have been heavily involved in work with hearing assistance technology. Based on the reports of our patients, we feel that the problems experienced by consumers can be boiled down to two issues: (1) Ease of access to assistive technology and (2) ease of use. To put a more human face on the problem, let's look at a sampling of common actual patient complaints is listed below:

- When I ask for a wireless receiver at the box office window, they have no idea what I'm talking about.
- When I obtain the receiver, the batteries are dead and/or the headphones are broken.
- Why can't I just use my own FM receiver or telecoil everywhere?
- In the theater, often one microphone picks up the signal while the actors' voices in the distance are inaudible.
- My pet peeve is being handed an under-the-chin IR receivers with no neckloop.
- Going to the movies is a hassle. First I have to borrow a device, and then I need to make sure it works. How it works is always different. And I have to write myself a mental note to get my ID back. It's easier to stay home like a hermit with a good book and a glass of wine.
- I wish I could listen to the sound system on an airplane with my hearing aid.

In addition, two additional rather disturbing comments continue to be made, even by long-time users of amplification: (1) Why didn't my audiologist recommend a telecoil?; (2) No one ever showed me how to use my telecoil with an ALD. I thought it was for the phone only!

Fitting Complexity

The frustration experienced by consumers is also experienced by the audiologists serving them. The current fitting process for providing auditory access in public (and private) places is intricate and can be time-consuming unless one has developed some expertise in this area. In order to provide consumers with appropriate technology and training, one must travel through a detailed needs assessment process that facilitates intimate knowledge of each patient's lifestyle. This is necessary because receptive communication needs, and the technology to meet those needs, may vary, depending on the setting. For example, a patient with a severe sensorineural hearing loss who uses behind-the-ear (BTE) hearing aids, might be a great candidate for BTE FM at home where he or she can use this technology to better hear the television or the conversation of a loved one while riding in the car. However, if this same person works in a secure environment such as would be the case in the defense industry or at the CIA or other government agency, then FM technology would not be permitted due to security reasons. In this case, infrared or even hardwired systems might be required. If this same individual desires access to a movie theater, the recommendation of a BTE FM system does not guarantee access since various types of systems may be installed. Figure 4 shows a schematic of how modern day systems for public auditory access can vary – and thus be incompatible.

All systems can be designed to provide acoustic or electrical input. Three types of transmission and reception modes are commonly available: FM, infrared (IR), and magnetic (loop). While all loop systems are compatible with each other, this is not the case with IR and FM systems. Wide band (WB) and narrowband (NB) FM systems are not compatible with each other. Each type of FM system can be broadcast on two different bands of the electromagnetic spectrum – 72–76 MHz or 216–217 MHz – and each of these bands can be divided up into various channels. A few years ago, 95 kHz was the de facto standard of transmission for IR systems. This is not the case today. While some systems do broadcast at 95 kHz, others use a combination of 95 KHz and 250 KHz (stereo systems) while newer systems use 2.3 and 2.8 MHz (stereo). The complexity of interfacing to a hear-

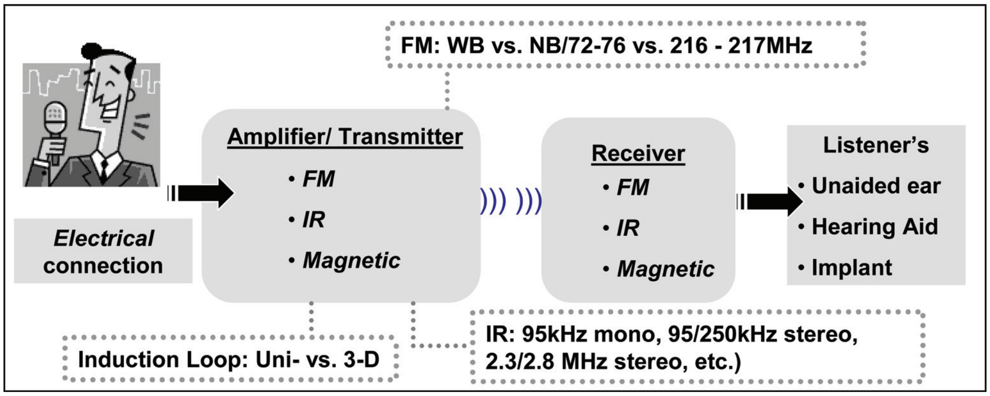

Figure 4. Transmission and reception options for large ALS.

ing assistance device can be daunting. For example, figure 5 before shows the "maze" of auditory options available to consumers.

For example, three friends decide to attend the opera at the Kennedy Center (acoustic input), which is equipped with an IR system. Each patron borrows an under-the-chin headset. Friend #1 removes her in-the-canal (ITC) hearing aids because the headset's built-in earbuds place too much pressure on them. Because she has a mild hearing loss, she simply turns up the IR headset to a comfortable level. Friend #2 plugs a neckloop into a jack in the under-the-chin headset and uses her ITE hearing aids set to the telecoil mode. Friend #3 also uses a neckloop, but with her behind-the-ear (BTE) hearing aids set to telecoil mode. By further examining the various permutations "fitting maze" one can appreciate the fitting frustration experienced not only by consumers but also by the audiologists who must recommend appropriate technology.

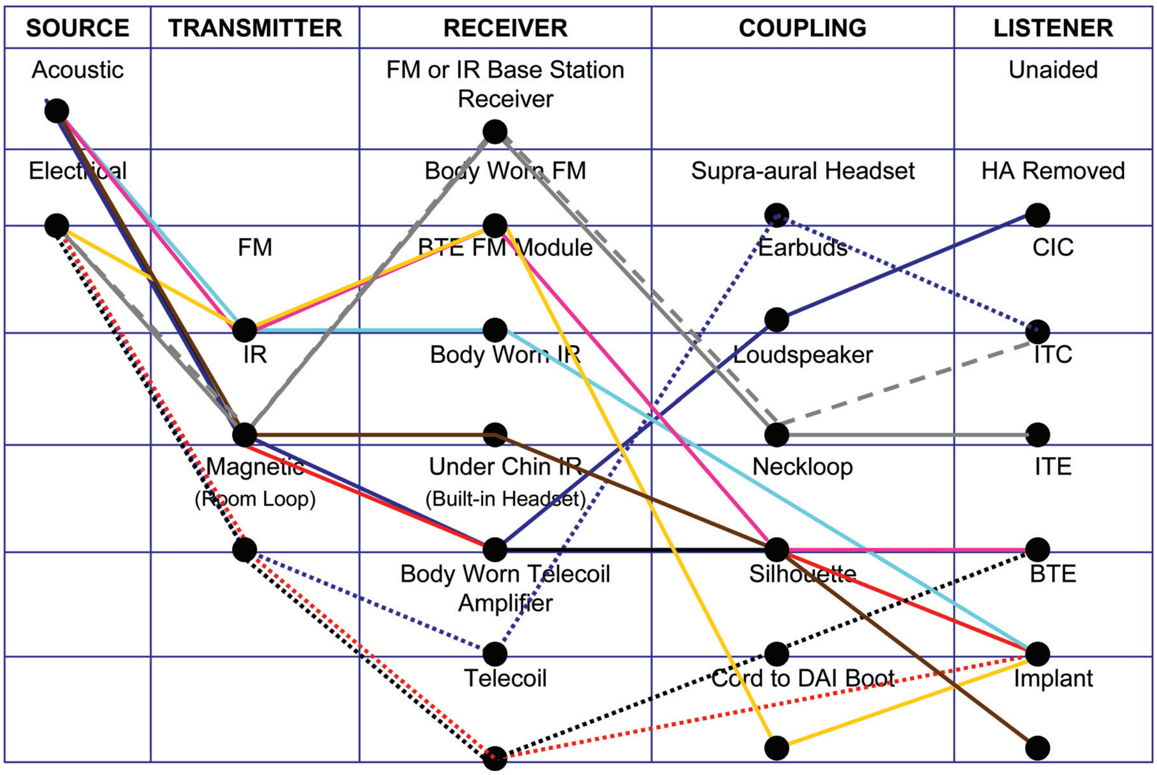

Figure 5. Interface options for auditory systems in public areas.

Recommendations for Simplification of the Fitting Process

Providing universal access to auditory systems in public areas is challenging for several reasons. First, the United States is a free-market economy. We cannot mandate the use of one particular technology, nor should we. Loop, FM, and IR systems all have their advantages and disadvantages. And companies representing these various technologies reserve the right to compete for a share of the market. However, we can, and should, mandate acoustical performance standards for all technologies. And, it would make sense for the industry to develop a "universal receiver" that can be either built into or externally interfaced to a hearing aid or headset (for those that do not use hearing aids). This would provide each consumer with access to any and all systems and would certainly simplify the fitting process. But until this happens, how do we navigate this "fitting maze" of options? Two approaches that have been used thus far, include pen and paper questionnaires and computerized needs assessment/selection tools.

In the 1980s, Vaughn and Lightfoot (1987) were the first to publish a questionnaire designed to help match a listener's receptive communication needs with the most appropriate hearing assistance technology. In 1989 and 2000, Compton expanded upon their questionnaire. In 1994, Grimes developed a clever two-page version of this questionnaire.

A high-tech approach to the problem of needs assessment was offered by Palmer and Garstecki (1990), who developed a software program that not only lead the user through a decision tree of options, but also suggested products designed to meet those needs. According to Palmer (2003), this product did not succeed because it did not have the necessary ongoing support to keep it up to date.

Currently, preparations are under way by the Rehabilitation Engineering Research Center on Hearing Enhancement to develop a new, web-based tool for needs assessment that could be used by consumers and/or audiologists. Since updating is critical, plans will be made to secure funding to update an sustain the product until such time that technology and standards are such that the needs assessment fitting process is significantly simplified.

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