LARGE AREA ASSISTIVE LISTENING SYSTEMS (ALS): REVIEW AND RECOMMENDATIONS

Final Report to United States Architectural and Transportation Barriers Compliance Board (U.S. Access Board)
December 1999

Matthew H. Bakke, Ph.D., CCC-A
Harry Levitt, Ph.D.
Mark Ross, Ph.D., CCC-A
Faye Erickson, MA, CCC-A

Lexington School for the Deaf/Center for the Deaf
Rehabilitation Engineering Research Center on Hearing Enhancement
30th Ave and 75th St.
Jackson Heights, NY 11370

LARGE AREA ASSISTIVE LISTENING SYSTEMS: REVIEW AND RECOMMENDATIONS

EXECUTIVE SUMMARY

The Rehabilitation Engineering Research Center at the Lexington School for the Deaf was charged with recommending performance standards for Assistive Listening Systems (ALS) to the Architectural and Transportation Barriers Compliance Board (the "Access" board). Included in this charge was the preparation of a "State of the Art" paper that would describe the current status and major issues presented by ALS. The recommended standards were to be based not only on the results of a study investigating listening performance under various acoustical conditions, but also to include other factors that affect the real-life use of these systems. In addition to the research study, three focus groups were conducted composed of consumers, and representatives from manufacturers, installers, movie and theater chains, and the national sound contractor's association. A detailed description of the entire project can be found in the accompanying paper; in this "executive summary", we will focus only on our final recommendations.

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.

<u>Receivers and Couplers: Recommendations</u>

- 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.

Acknowledgments:

This study is supported by the Rehabilitation Engineering Research Center (RERC) on Hearing Enhancement and Assistive Devices, funded by the National Institute on Disability and Rehabilitation Research (NIDRR), U.S. Department of Education, grant #H133E30015. The opinions contained in this presentation are those of the grantee and do not reflect those of the Department of Education.

Special thanks to the consumers, manufacturers, installers and distributors of Assistive Listening Systems for their contributions to this study. Also a special thank you to the staff at Lexington Research Division and Hackensack University Medical Center for their undying efforts in getting this study completed.

TABLE OF CONTENTS

LARGE AREA ASSISTIVE LISTENING SYSTEMS: REVIEW AND RECOMMENDATIONS

1. INTRODUCTION

Assistive listening systems (ALS) are designed to improve communication access for people with hearing loss. Signals generated by a loudspeaker or talker must often traverse a less than optimal acoustical space before being received by a listener. Though such acoustical conditions may be acceptable for people with normal hearing, this is not necessarily true for those with hearing loss. Because of the acoustical environment these people must expend a great deal of energy, with concomitant feelings of frustration and anger, in order to comprehend less than their basic auditory capabilities would otherwise have permitted.

This is a point worth emphasizing: an acoustical environment acceptable for normal hearing individuals may not be so for those with hearing impairments. Hearing-impaired people frequently exhibit an inordinate sensitivity to noise and reverberation (Ross l992; Nabalek l994). Because of the hearing loss, they have already lost much of the linguistic and acoustical redundancy ordinarily present in speech signals. In a sense, they are already holding on to speech comprehension by their finger tips; add a bit more noise and reverberation into the equation, and their understanding of speech may go from barely adequate to complete incomprehension. Assistive listening systems (ALS) help by bypassing the acoustical space between the sound source and the listener. They do this by utilizing electromagnetic, radio, or light waves to transmit the signal from the source (either a loudspeaker or a person talking) directly to the listener. In this way, the deleterious effects of noise and reverberation upon speech perception is eliminated or minimized.

Assistive listening systems are not a new development. Over 90 years ago, some Churches in Denmark were using wired systems that led from a microphone on the pulpit to earphones located at designated seats within the sanctuary. Fifty years ago almost all the Churches in the same country were using induction loop (IL) systems (Hermansen 1979). Twenty years ago in this country, one manufacturer reported that in the previous five years over 2000 AM radio ALS had been installed in various public places (Williams, personal correspondence). While for a number of technical and convenience reasons neither hard wire or AM radio systems are used very much nowadays, it is nevertheless instructive to note that the need and advantages of some kind of ALS has been apparent for many years (Ross l982). This was recognized almost 20 years ago by the Architectural and Transportation Barriers Compliance Board (the "Access" board) in their ruling that effective January 6th l981 all federally funded facilities must include listening systems in assembly areas to assist no fewer than two persons with hearing loss. Although we do not know how effectively this ruling was implemented in fact, it does testify to a long-standing national intent to improve "communication access" to persons with hearing loss, comparable to that provided for person's with physical handicaps

(Federal Register, Volume 42, Number 6, May 4th, l977).

It is apparent, however, that the recent resurgence of interest in ALS date from the passage of the Americans With Disability 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: 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 were 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: On the one hand, when "everything" works well, the ALS will substantially improve communication access. Instead of feeling frustrated, angry and isolated by a poor listening experience, hard of hearing people instead can relax, enjoy the performance, and continue their engagement in social/cultural activities. But, on the other hand, Murphy's law ("whatever can go wrong, will") describes too many real-life experiences. But 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 indeed occur to interfere with the realization of the full benefit of an ALS.

It was because of the persistent reports of problems by consumers that the Rehabilitation Engineering Research Center (RERC) of the Lexington Center received a grant to investigate and recommend ALS performance standards to the 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 to elicit their perspective 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 this report, we will (1) provide an overview of assistive listening systems, incorporating and summarizing the observations and suggestions made by the participants in all three meetings, (2) present the consensus recommendations regarding logistical, signage, receiver and coupling issues, (3) comment on the installation-related issues, (4) report the research study that was conducted by the RERC and, in conclusion, (5) present the recommended electroacoustic performance standards arrived at through both the research project and modifications suggested by focus group members.

2. BACKGROUND

Three types of ALS are in widespread use at the present time: Induction Loop (IL) systems, Frequency Modulated (FM) radio systems, and Infrared (IR) systems. Each offers the advantages of bridging the acoustical space between the source and the listener. Thus each can potentially offer advantages not possible when listening to a live voice or in the acoustic far field of a loudspeaker. Each, however, presents its own unique set of installation and user related concerns (Ross 1994). In this section, we will describe the systems, discuss standards and issues pertaining to each, and conclude with a direct comparison of the three systems.

2.1 Induction Loop (IL) Systems

2.1.1 General Description

In an IL system, the output from an amplifier is delivered to a loop of wire placed around the circumference of a designated "listening area". The audio signals from the sound source (usually a microphone, though other audio sources can be accommodated) are amplified and sent as an alternating electric current through the wire loop. This electrical current creates an electromagnetic field around the wire. This electromagnetic field - basically the original audio signals coded in a different form - can be accessed by someone wearing a hearing aid (or special IL receiver) switched to the telecoil position. The telecoil is an "induction" coil, one in which an electrical current is "induced" when it is placed within the electromagnetic field. In other words, the information coded in the electromagnetic field is converted to an electrical current. This electrical current is then amplified by the hearing aid and converted back into audio signals. The sequence goes as follows: audio input > amplifier > electrical current in wire loop > electromagnetic field around wire loop > induced electrical current in telecoil > audio output (see figure 1).

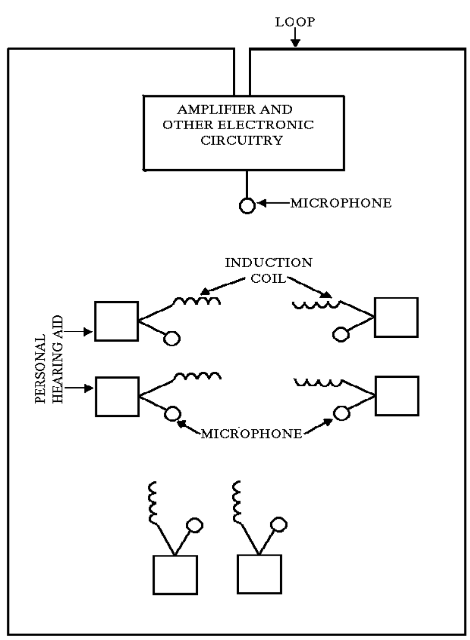

Figure 1. Schematic of an Induction Loop Installation

IL systems are the oldest - and least employed - of the existing ALS in this country (they are used much more often in European countries). The loop has to be physically placed around the listening area and secured so that it will stay in place. Once properly installed, and given that the listener's hearing aids include "T" coils, an IL system is undoubtedly the most convenient and possibly the most cost effective ALS. To hear the audio, all a person has to do is enter the looped area and switch his/her personal hearing aids to the telecoil position. As long as the person's hearing aids include "T" coils, he or she always has an assistive device "receiver" available. Wireless FM microphones can be integrated into the system and employed by talkers in order to provide instructional flexibility (see figure 2).

Figure 2. Oval window induction loop amplifier system , with wired and FM microphones

2.1.2 Standards

There are no national US standards that define the required performance of IL systems. The International Electrotechnical Commission (IEC) has developed pertinent standards for "Magnetic field strength in audio-frequency induction loops for hearing aid purposes" (IEC, 118-4, 1981). Suggested modifications to these standards have been made by Oval Window Audio, a manufacturer of audio loops in this country. Standards developed at the National Technical Institute for the Deaf (Johnstone 1997) are part of the NTS Uniform Fire Prevention and Building Code, Chapter 23 of the Laws of 1989 (Title 9, Subtitle S, Volume 9 Executive [B] of the "Official Compilation of the Codes, Rules and Regulations of the State of New York"). Each of these will be briefly reviewed. In ensuring that the prescribed magnetic field goals are achieved, the utilization of a "magnetic field-strength" meter is assumed (see figure 3).

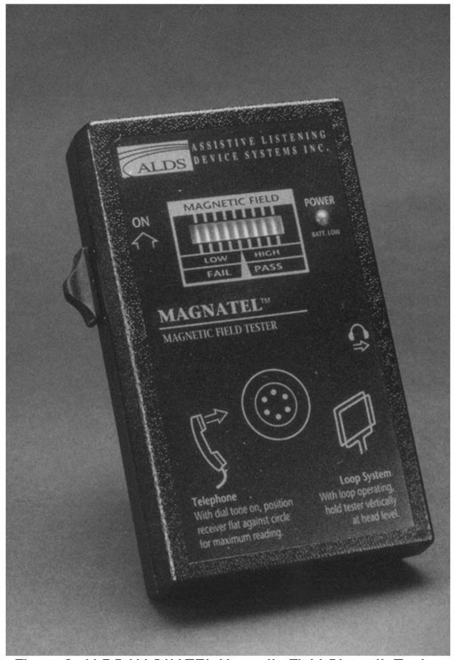

Figure 3. ALDS MAGNATEL Magnetic Field Strength Tester

2.1.2.1 Summary of IEC 118-4 (1981) Standards

With a source of 1000 Hz equal to the long-time average level of the speech signal applied to the input of the system, the resulting field strength within the loop shall average 100 mA/meter +/- 3 dB. This level should not go below 70 mA/meter or above 140 mA/meter. These values apply to the vertical component of the field strength inside the area enclosed by the loop, measured 1.2 meters above the floor. Allowing for the 12 dB peaks occurring in speech signals, peak field strength may reach 400 mA/meter. The frequency response shall be 100 Hz - 5 kHz +/- 3 dB. The document includes a statement that in schools for hearing-impaired children it may be desirable to boost the low frequencies to compensate for the decrement in the low frequency response often produced by the inductive process. The degree of such a boost, and whether and under what circumstances it should take place, is therefore a local option.

2.1.2.2 Additional Proposed Specifications (by Oval Window Audio)

1. Loop Wire Installation: In order to maximize signal strength and uniformity, the loop wire shall be installed either at floor or ceiling level. At least 80% of the installed loop should be free of the influences of metal, either in front of, or immediately behind the wire.

2. Field Strength: As per IEC 118-4, with the additional condition that the measurements be "A" weighted to disallow the influence of inaudible low frequency power line electrical noise.

3. Input Signal Compression: To compensate for fluctuating signal input levels, an automatic gain control, signal compression, and/or adjustable non-distorting peak limited must be employed at the input of the system (Recommended compression ratios: 4:1 for music, and up to 20:1 for speech).

4. Frequency Response: Frequency response measurements conducted with an "A" weighted field strength meter must be corrected to compensate for the substantial low frequency roll off characteristic of this weighting network.

5. Ambient Electrical Interference: Sources of electromagnetic radiation that may interfere with the proper functioning of an induction loop system include: faulty fluorescent lighting, light dimmers, electrical wiring, TV and computer monitors, surge protectors that are in close proximity to the loop system. An on-site evaluation of ambient electromagnetic noise should be performed before a loop is installed in order to identify and resolve electromagnetic interference. Ambient electromagnetic noise should not exceed 25 mA/meter or –12dB ("A" weighting) re: 100 mA/meter as measured at any seat within the looped area. If potential sources of noise cannot be reduced or eliminated, then the use of a loop must be ruled out.

6. Signal Spillover: When adjacent areas are equipped with an induction loop, signal spillover must not exceed 12.5 mA/meter, or –18 dB ("A" weighted) re: 100 mA/meter as measured at any location within an adjacent loop. Listening tests should also be performed to determine if signal spillover is audible.

7. System Signal-to-Noise: The electrical signal to noise ratio of the loop amplifier output (measured directly, not inductively) at 1000 HZ must be at least +30 dB at an output level sufficient to deliver mA/meter as per IEC 118-4 specifications.

8. Distortion: With an input signal of 1000 Hz and the system adjusted for an output of 100 mA/meter, harmonic distortion must not exceed 3%.

2.1.2.3 New York State Standards

Ambient electro-magnetic fields should not exceed 30 mA/meter; higher levels would preclude the installation of an IL in the particular location. In the event that adjacent areas were to be looped, magnetic field "spill-over" should not exceed 15 mA/meter. Given a 1000 Hz signal at a level equal to the long-time average level of speech, the *average* value of the magnetic field should be 100 mA/meter +/- 3 dB between 100 to 8000 Hz, with a *maximum* no greater than 400 mA/meter. This same signal should produce no more than 5% harmonic distortion and provide a signal to noise (ambient magnetic field) of at least 30 dB.

2.1.3 Receivers

The major advantage of IL systems is that they permit listeners whose hearing aids incorporate telecoils to use their own hearing aids as the receiver. All the person has to do is enter the field and switch the hearing aids to the telecoil position. Given an appropriately functioning telecoil (see *issues* below), wearers have the advantage of being able to utilize their own hearing aids that, presumably, provide an appropriate and individualized amplified frequency response. There are headsets and pocket receivers available that will detect and amplify an IL signal, but this defeats the major advantage of IL systems - their convenience to the user.

2.1.4 Issues

* Only about 30 percent of modern hearing aids in the United States include a telecoil (more than twice this number use telecoils in Europe, which may help explain the popularity of IL systems there). As useful as telecoils are, with the trend toward smaller and smaller hearing aids, it seems unlikely that this 30% figure will increase in the future. Given the potential advantages of telecoils, not only for IL systems and telephones, but for all other types of ALS as well, it is unfortunate that a higher percentage of hearing aids do not routinely incorporate them. However, unless there is a drastic change in the type of hearing aids used by hard of hearing people, it does not appear that the use and popularity of IL systems will significantly increase.

* Even when a hearing aid includes a telecoil, it is quite likely that its electroacoustic performance will not duplicate the hearing aid's microphone response (Rodriguez, Holmes & Gerhardt l985; Culpepper l986; Thibodeau & Abrahamson l988). However, recent developments in hearing aids suggest that this variable can be circumvented, either by programming the telecoil to match the microphone response (Davidson & Noe l994) or by using amplified telecoils (Noe, Davidson & Mishler 1997).

* Complicating telecoil usage is its physical orientation within the hearing aid. For optimal sensitivity to an IL system, the telecoil should be mounted perpendicular to the floor loop (or a neckloop). But since optimal sensitivity for detecting the electromagnetic field around a telephone occurs when the "T" coil is in the horizontal position, a positional compromise is often necessary (Preves, l994).

* The newest telecoil standards (revision of ANSI S3.22) provide for measurements in which the extent of any compromise can be determined. In this new standard, the high frequency average (HFA) gain in the microphone position of the hearing aid is explicitly compared to both simulated telephone and induction coil usage (Preves 1996). The differences are expressed as Simulated Telephone Sensitivity (STS). A zero figure means that at the same gain control setting, the high frequency average gain in the microphone position was equal to that obtained in the telecoil position. Usually, the STS is negative, indicating that the gain must be increased in the telecoil position to achieve the same results as in the microphone position. Preves (l996) points out that the STS can be

positive with the use of preamplified telecoils, and indeed this was found in the most recent study looking at ALS (Noe, Davidson & Mishler l998). However, it should be noted that even with an STS of zero there can still be significant differences in the frequency response between the telecoil and the microphone positions. That is, while equal high frequency *average* gain can be obtained at the microphone and telecoil positions, the *pattern* of gain may be quite different for the two conditions.

* The hearing aid microphone is usually disconnected when the telecoil is switched on. Since in some applications, it is desirable that the person be able to respond to audio signals (such as being able to hear side comments by one's partner during a lecture or stage performance), the optimal situation would be for the hearing aid to include an M/T position (both microphone and telecoil operative) and to do this without changing either the microphone or the telecoil frequency responses or output levels.

* The electromagnetic field is not confined within the looped area; some of the electromagnetic field "spills over" into adjacent vicinities. This is not a problem unless induction loops are also installed in the adjacent areas (vertical or horizontal), in which case listeners can be exposed to simultaneous audio signals from different sources. Also, the intensity of the signal within large looped areas can vary; the further from the wire, the weaker the signal. A great many creative loop configurations have been used in an attempt to circumvent these problems, with mixed results (Lederman & Hendricks l994).

* The "3-D" loop developed by the Oval Window company has minimized the effect of spillover and telecoil orientation. In the 3-D loop, four wires configured in a prescribed geometric pattern are embedded in a mat placed beneath carpeting. Reportedly, the resulting electromagnetic signal is not only contained within the looped area, but the "3-D" pattern of the electromagnetic field reduces the impact of the telecoil orientation upon the perceived signal. A limitation of the 3-D IL system is that the listening area must permit the installation of one or more rugs (see figure 4).

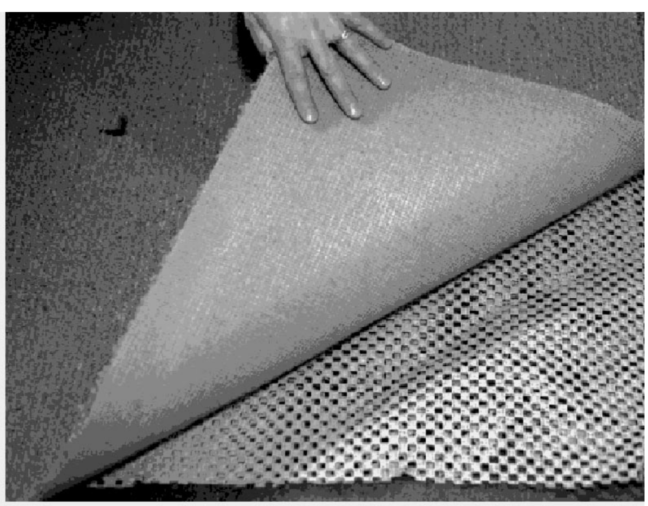

Figure 4. "3D" induction loop under mat

2.2 FM Radio Systems

2.2.1 General Description

There are two types of FM listening systems. One is a personal system, designed to be used by an individual on a one-to-one basis (Yuzon l994). The other, the type that concerns us in this paper, is meant to service one or more listeners in such large-area listening venues as auditoriums, classrooms, all types of theaters, and houses of worship (Ross l994). Both types are basically FM radios where the audio signal is "broadcast" to listeners wearing FM receivers tuned to the transmitting frequency. ALS can be a "stand-alone" device, or be integrated into an existing Public Address (PA) system (Compton l991). Of the three types of ALS described in this document, FM radio systems appear the easiest to install; generally, all that is required is a patch cord between an output from the PA amplifier ("line-out" or other audio output) and the input to the FM transmitter. Transmitters range in complexity from simple devices that include only basic interconnection and transmission capacities, to sophisticated devices that are capable of accepting a range of inputs from different sources and that incorporate many signal processing options (such as high frequency pre-emphasis, various compression options, etc.). Examples of commercially available large-area FM systems are displayed in figures 5, 6, 7, and 8.

Figure 5. DRAKE Audio Accent FM assistive listening system

Figure 6. Telex Sound-Mate FM assistive listening system

Figure 7. Phonic Ear Easy Listener FM assistive listening system

Figure 8. GENTNER FM assistive listening system

2.2.2 Standards

2.2.2.1 FCC Regulations

In 1982, the Federal Communications Commission authorized the use of frequencies within the 72-76 MHz band as the designated radio frequencies that could be used by people with hearing loss. This is non-exclusive, unlicenced band. Other users, such as pagers, emergency vehicles, etc. are also permitted to transmit radio signals on frequencies within this band. ALS manufacturers differ in how they allocate this band. For example: Phonic Ear makes 40 narrow-band (50 kHz) channels available; Gentner uses 37 narrow-band (50 kHz) channels; Telex, 16 narrow-band (50 kHz) channels; Drake, 10 wider (150 kHz) channels; Williams, 10 wide (200 kHz) or 40 narrow-band (50 kHz) channels, while Comtek employs 10 wide-bands (200 kHz) and narrow-band (50 kHz) channels both in the 72-76 MHZ and in the 216 to 217 MHZ bands. Some of the frequencies used by different manufacturers may be identical, while others may differ. The FCC also permits the use of the 216-217 MHz band as a low power radio source for auditory assistive devices and several manufacturers are now marketing large area transmitter using this higher frequency band. ALS in really large venues, such as football stadiums, can also employ one of the commercial FM frequencies as long as they meet the power requirements designated by the FCC.

In terms of the permitted maximum power of ALS, the FCC limits it to no more than 80 millivolts per meter at 3 meters. This can provide for an effective transmission range between 300 and 500 feet. Larger antennas can extend this range to l000 feet; however, the maximum strength cannot be exceeded regardless of antenna design. The 216-217 MHz band does permit higher signal strength and can provide greater operating distances. Within the transmission range, the field-strength of the transmitted radio signal should be adequate and equal at all seat locations within a venue. ALS are "low-power" devices that are not likely to interfere with other permitted user in the same channels (i.e. paging devices, emergency vehicles). No priority is given assistive listening devices. When interference occurs from other radio sources, the onus is on the ALS user to switch to another channel within the same frequency band.

2.2.2.2 New York State Standards

As far as can be determined, New York is the only state that has developed written standards for large area FM assistive listening systems. Enforcement of the standards is the option of the local building code inspectors (who have, literally, thousands of items to verify on a checklist code). Information and educational sessions can help ensure their understanding and compliance with the ALS standards (Johnstone l997). The New York State standards reflect the combined operation of *both* the transmitter and the receiver using various coupling options.

* Given an appropriate input signal to the transmitter (as specified by the transmitter's specifications), the frequency response at the output of the receiver and transducer should not vary more than +/- 5 dB over the frequency range 100 to 8000 Hz from the value at 1000 Hz. (Note: This appears to be an overstatement; it is unlikely that such transducers as miniature earphones, as well as silhouettes and neckloops working through hearing aids would be capable of meeting this standard at the higher frequencies).

* The minimal signal to noise ratio at the receiver's output should not be less than 35 dB. Harmonic distortion shall not be more than 10%. The minimum sensitivity of the receiver shall be no greater than 1 uV at 12 dB SINAD. The maximum RF signal generated by the transmitter shall not exceed 8000 uV/meter at 30 meters (which accords with the FCC regulations).

* When using a neckloop as a transducer, it should generate an average magnetic field strength of 150 mA/meter, with peaks no more than 600 mA/meter. Measurements shall be made in the center of the neckloop. If using a silhouette transducer, the average magnetic field strength should be 50 mA/meter, with peaks no more than 200 mA/meter. Measurements should be made at a distance 10 cm from the silhouette. (Note: 10 mm would appear to be a more realistic distance.) If using a miniature earphone as the output transducer, the output shall be at least 80 dB SPL and no more than 130 dB SPL.

* All systems must be capable of accepting input signals at line or microphone levels and must be capable of interfacing with existing PA systems.

2.2.3 Receivers

The receivers for FM assistive listening systems are basically FM radios "tuned" to the transmitting frequency. Most manufacturer supply a number of receivers that vary in complexity and secondary features, but all are designed to accord with the characteristics of their own transmitters. Companies that make 8, 10, 16, 37 or 40 wide or narrow band channels available in the transmitter also provide receivers that can detect any one or all of these channels. Channel selection is generally accomplished by a slide switch, push button, or wheel rotation. For some FM receivers, it is necessary to remove the back and "tune" a rotary wheel while listening to a test signal from the transmitter. This is not as "user friendly" as those receivers which permit pre-set channel changes by discrete switch adjustments.

Depending upon the specific transmitting frequency, it may be possible to interchange transmitters and receivers from different companies. Whenever, however, a receiver from one manufacturer is being employed in conjunction with the transmitter of a different manufacturer, complete compatibility may be questionable because of subtle differences in the RF and acoustic properties of the receivers. Engineers design receivers to conform to the electronic characteristics of their own transmitters.

Power to the FM receivers are supplied by disposable or rechargeable batteries. Battery life for the rechargeable batteries range from 6 to 10 hours (or up to 35 hours according to one report), while the life span of the disposable batteries (either 9 volt, AAA, or AA) vary from 18 to 70 hours depending upon volume setting and type of coupling. Convenient pocket recharging-carrying cases are available in which the receivers can be recharged while being stored. Unlike many personal FM receivers, those used with ALS generally do not include a warning light signal when the battery is weak.

The receivers come with a number of coupling options. While the ADA requires a set number of receivers in different venues, it does not stipulate the precise type or percentages of the different kinds of coupling alternatives. For people whose hearing aids contain "T" coils, the most convenient and desirable option is for them to plug a neckloop or silhouette inductor into the FM receiver, or to place electromagnetic headphones right over in-the-ear hearing aids. They are then able to take advantage of the "prescribed" characteristics of their own aids when listening through an ALS. Many BTE hearing aids can accept a direct audio input (DAI) from an FM (or IR) receiver through a wire connector. This will also permit users to benefit from the prescribed electroacoustic characteristics of their own hearing aids (keeping in mind, however, the possibility that either inductive or direct audio input coupling may not preserve the microphone response of a hearing aid).

People whose hearing aids do not include "T" coils can either remove their hearing aids and use earbuds or earphones, or place earphones right over the hearing aids (this will not work for people wearing behind-the-ear hearing aids). We cannot now predict whether such acoustical coupling will produce audible feedback or what acoustical changes this produces in the hearing aid's response. This topic has not been investigated with the current generation of miniature hearing aids. Consumers would have to try using an earphone with their own hearing aid in order to determine if acoustic feedback occurs. While it may be difficult at first for a venue to ensure the proper "mix" and number of coupling alternatives, with time and experience venues should soon learn what type of coupling arrangements their patrons prefer.

Some manufacturers of FM systems depict a user with a monaural earbud in their promotional material. Unfortunately, this depiction sends an implied message that monaural use of an ALS is the routine and desirable listening condition. This is inaccurate when it comes to people with normal hearing and even more inaccurate for people with hearing loss using an ALS. They need all the acoustical help they can get and, unless contraindicated by audiological findings, two-ear listening should be the routine in all ALS situations.

2.2.4 Issues

* While theoretically, an FM receiver from one manufacturer can be employed with a transmitter made by a different company, the reality is a bit more complex. As pointed out earlier, companies design their transmitters and receivers as a unit, to work together. Although several FM receivers can be tuned to any of the 10 wide or 40 narrow bands available, other factors, such as the selectivity and power of the FM receivers, may still affect the quality of the reception with different FM transmitters. The recommendation had been made that only standard transmitting frequencies with standardized electrical characteristics be used in all ALS. This would, theoretically, permit consumers to utilize their own personal FM receiver in any venue. However, this led to the objection that this requirement would stifle creativity and future developments. At the present time, it appears more feasible and realistic to stress flexibility in receiver options than to require standardized transmitter characteristics.

* FM systems are subject to interference from other radio sources. While using a frequency scanner can help select a "clean" frequency at the time of installation, there is no assurance that the channel would remain clean at a later time. If the transmitting frequency is changed, this requires that the tuning of the receivers be changed accordingly (not always possible or easy, see below). Wide-band receivers are more likely to pick up radio interference and cannot be used in as many adjacent venues (e.g. a multiplex theater complex) as narrow-band frequencies. On the other hand, the acoustical output from a wide-band receiver is somewhat superior to that emanating from a narrow-band receiver, but it is an open question whether this difference has any real-world significance for hard of hearing people. We know of no evidence that supports or refutes the listening advantages of either wide or narrow band channels for hard of hearing people.

* Many FM transmitters are capable of being adjusted to provide a range of pre-processing possibilities. This was one of the recurring issues discussed in the

manufacturer's focus group, and applies not just to FM systems but to IR and IL systems as well. The general recommendation was that the transmitted signal be "as pure" as possible, with processing used to maximize speech intelligibility (as opposed other types of sound stimuli such as orchestral music). However, because the dynamic range of some audio sources can exceed 80 dB, or far beyond the dynamic range of just about everybody with a significant hearing loss, it appears necessary to provide some compression in the transmitter to keep from overloading the system and to ensure at least some audibility for low-level input sounds.

* Given the range of possible pre-processing strategies and the different venues and populations that would be using the ALS, it is necessary to develop and support a rationale for selecting one particular strategy over another. At the present time, each manufacturer provides its own instructions to installers regarding the necessity for a particular processing strategy. Further complicating the situation, what may be suitable in one situation and for one type of listener may not be optimal in another venue for other types of listeners. Some FM transmitters include choices for different amounts of high pass filtering, single or multiple band transmission, high frequency pre-emphasis, and different parameters of compression and modes of output limiting. Whatever rationale is developed, it is likely that the final decision would be made "on site" by a trained installer (meeting, it is assumed, the output electroacoustic recommendations that will be presented below). An example of the processing choices that is available can be seen in figure 9.

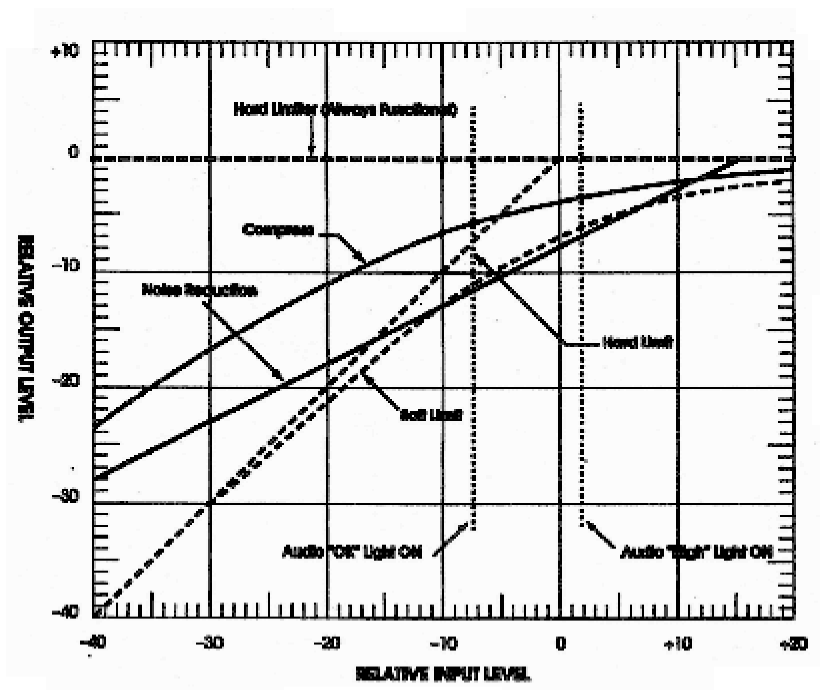

Figure 9. Audio processing possibilities with the Williams T-20 transmitter* used with permission

2.3 Infrared (IR) Systems

An IR system transmits audio signals via invisible infrared light waves. The frequency of infrared light falls somewhere between 700 nm and 1000+ nm; visible light waves fall between 400 and 700 nm. The specific bandwidth of the IR carrier varies among manufacturers; it may be as narrow as 50 nm wide, or considerably broader and perhaps be visible as a faint reddish glow (Laszlo l998). The audio signal, from any source, is used to frequency modulate an RF sub-carrier which in turn is impressed upon, and essentially amplitude modulates, the IR carrier. An FM/AM double modulation of the IR light wave is the result. Up to now, 95 kHz has been the RF sub-carrier most often used by manufacturers but this may now be changing (more on this below).

To achieve the best possible audio reception, the modulation characteristics of the RF carrier is typically +/- 50 kHz. IR systems are also frequently used with normal hearing people during events requiring simultaneous translation into several languages. In these instances, a number of other sub-carriers may be used, each narrower than the bandwidth used for people with hearing loss.

All IR systems are composed of three basic components: the transmitter (also called the modulator), the emitter and the IR receiver. The modulator processes the audio signal so that it can be transmitted via infrared light. This audio processing may include some kind of output limiting, companding (designed to control widely varying amplitude levels), high frequency pre-emphasis and/or high pass filtering. These appear to be similar pre-processing strategies that are used with large-area FM ALS. Examples of IR transmitter/emitters and receivers can be seen in figures 10, 11, 12, and 13.

Figure 10. Phonic Ear Star Sound PE 600 IR emitter/transmitter

Figure 11. Phonic Ear Star Sound PR IR emitter/transmitter with IR earphones

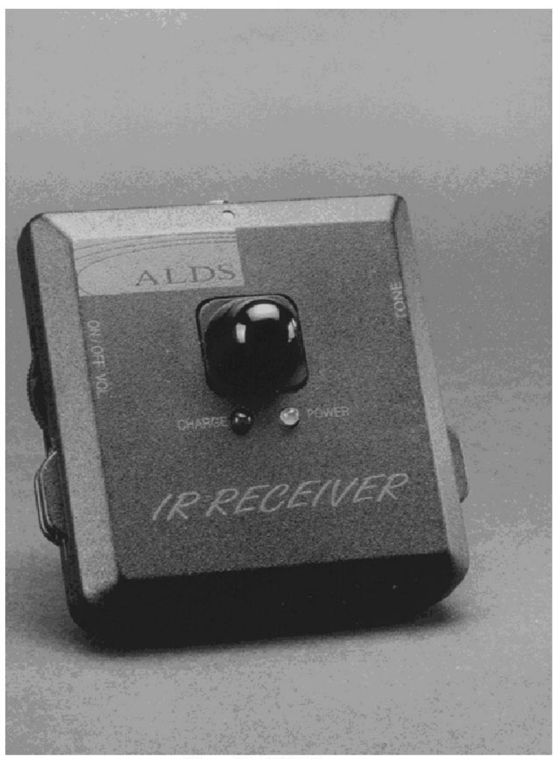

Figure 12. ALDS IR receiver

Figure 13. Sennheisser IR receiver (bottom unit is a TV IR emitter)

The signal from the modulator (transmitter) is delivered to emitters that actually produce the IR light waves (these two components may be contained within the same physical unit). The emitter is composed of a number of light emitting diodes (the "light bulbs" of an IR system). Until quite recently, the more diodes contained within an emitter, the more powerful the system. However, with the development of more powerful diodes, this is no longer necessarily true. Although these light waves are invisible to the human eye, they *are* light waves with certain definable characteristics. This fact may help us understand some of the issues related to IR systems, such as the effects of sunlight and incandescent light (these contain a great deal of infrared energy) and the impact that the color and texture of the wall surfaces have upon IR reflections. Ensuring the appropriate number and placement of emitters is the major challenge facing an installer of IR systems.

The third basic component is the IR receiver. The transparent lens found on every IR receiver contains the photo detector diode that detects the IR light wave. An optical filter on the lens reduces at least some of the light interference from extraneous sources. The IR receiver then demodulates the RF sub-carrier and the audio signal is retrieved and amplified. If the audio signal has been pre-processed in some fashion, such as providing high frequency pre-emphasis or sent through a companding circuit, then it is at this stage that individualized compensation can occur. One reason that the IR systems of different companies are not always compatible, even though they may use the same sub-carrier frequency, is because they may differ in the nature of their pre-processing strategies and compensatory receiver characteristics. While a signal may be received, and even understood, this incompatibility would reduce its clarity.

2.3.1 Standards

There are no standards that we are aware of that specifically cover the unique aspects of IR systems. The New York Standards, quoted in respect to IL and FM installations, do not provide this information; rather these standards basically focus on the electroacoustic output from the IR receivers. When the NYS standards were drafted in 1988-89, the manufacturers could not reach a consensus regarding minimum energy level of the IR light at a set distance from the emitters. Instead a general recommendation was made that the minimum light level must be sufficient so that receivers could produce the required output signal specifications (Johnstone 1999).

2.3.2 IR Receivers

A number of different types of IR receivers are used. In one of the most common, the sound tubes are placed in each ear and the unit itself dangles under the chin. Sometimes this is called a stethoset or stethophone receiver. The lens of the receiving diode usually faces forward, toward the presumed location of an emitter. In traversing the tubing leading from the receiver to the eartips, the frequency response of the acoustic signal may display several resonant peaks (Nabalek, Donahue, & Letowski 1986). Recently, however, receivers have been developed that locates the transducer at the earphone tips thus precluding the formation of resonant peaks. Some under-chin receivers include an output jack into which a neckloop can be plugged for inductive coupling to a hearing aid. However, these are generally designed for micro-mini plugs and will not accept the mini plug used with neck loops designed for body worn receivers. Some receivers include an environmental microphone to permit the direct audio reception of one's companions while using the IR receiver. Acoustical coupling through personal hearing aids is not feasible with this type of receiver.

Some IR receivers are built into headphones. In these instances, the receiving diode can be placed within an oblong lens on the top of the headband, for presumably 360 degree reception, or appear as a rounded protuberance on the surface of each earphone. The "best" position for receiving IR signals depend upon the relative positions of the emitter and the receiving diodes. Some IR headphones allow for possible acoustical coupling, in that they can be placed right over hearing aids (not the BTE type, however). As pointed out earlier, the incidence of acoustical coupling upon the production of acoustic feedback, or undesirable changes in the frequency response of the hearing aid, has not been determined with this type of acoustical coupling. Many hearing aid users prefer to remove the aids before placing the headphones on and listening through headphone alone.

Body IR receivers look like personal listening systems or FM receivers. They are distinguished from these by the presence of the visible translucent lens on the front surface (presumably facing the light source, i.e. the emitter). This type of receiver would not be too useful when the emitter is directly overhead, in a darkened theater for example. The other coupling choices - inductive, acoustical (headphones worn over personal hearing aids), or headphones or earbuds directly - are the same as that used with FM receivers. Some IR receivers include an environmental microphone and some do not. No IR receiver, as far as we know, provides a low battery light feature.

2.3.3 Issues

* Up to now, 95 kHz has been the sub-carrier most frequently used by manufacturers of IR systems. When stereo reception was desired, a sub-carrier of 250 kHz was simultaneously employed. These frequencies reflected an informal agreement among manufacturers rather than any national or international standards (Lieske 1994). Other frequencies are now being used as sub-carriers in ALS (300 kHz, 2.3 mHz and 2.8 mHz). One reason for switching to a higher sub-carrier frequency is because of the electromagnetic interference at 95 kHz produced by the newly introduced T-12 fluorescent ballasts. Since these are more energy efficient than the older type of ballast (type T-8), their use is likely to increase in the future. In other words, the pre-eminence of the 95 kHz sub-carrier is no longer assured. While it does not appear to be on its way out, it may be employed in fewer locations. Compatibility between venues has been an advantageous feature of IR but, with the introduction of different sub-carriers, this advantage can no longer be taken for granted.

* The frequency of the sub-carrier is not the only uncontrolled factor in IR systems. Unlike RF fields, the strength of the IR field is left up to the manufacturers and installers. To reduce the interference effect of ambient light, a manufacturer may increase the radiated IR light level and decrease the sensitivity of the IR receiver. Other manufacturers may radiate less light energy from their emitters and depend upon the sensitivity and electronics of the receivers to detect an adequate signal. These factors help explain the variation in performance of different IR receivers in a specific venue, even when they all use the same sub-carrier frequency.

* IR receiver diodes generally detect a broad bandwidth of light, extending over 500 nm. Every receiver uses filters built into the detector diode that is designed to accept the transmitter frequency and block the other IR light (Laszlo 1998). However, the filter characteristics cannot be too narrow, else slight transmitter "drifts", perhaps due to temperature effects may put the device outside the passband. This effect can be compensated for with more expensive electronics, but then the decision becomes a cost/benefit issue. The specific characteristics of these filters presumably differ among the receivers from different manufacturers and are another reason why, in spite of using the same sub-carrier frequency, some IR receivers are less compatible than others in the same location.

* IR light waves are considered "line of sight" transmission. That is, ordinarily the "eye" of the emitter should be facing the "eye" of the receiver, with no physical obstructions placed between these two devices. Turning one's back to the emitter, or placing an IR receiver in one's pocket, can either eliminate or distort the perceived audio signal. However, line of sight reception is affected by surface material (light surfaces reflect more light energy), the strength of the transmitted signal, and the geometric shape and number of listening levels (e.g. balconies) in the venue. In rooms with light covered surfaces, these reflections may enhance IR coverage by filling in gaps not covered by the primary signal. Conversely, with dark surface, or checkerboard patterns, may reduce or modify IR light reflections. Reportedly, a few recently introduced IR transmitters are capable of being employed in some outdoor venues (but not in direct sunlight).

* The emitters produce an ovoid IR light pattern that diminishes in strength following the inverse-square law. This means that a number of emitters must be used to ensure that all seats in a venue, such as in the corners or in the rear of the room, receive an "adequate" level of the light. Installers frequently "daisy-chain" emitters to guarantee that IR light is being directed at the audience from several directions. There are no standards which specify the radiated level of light required at seat locations. At least one manufacturer (Audex) makes a light meter available for installers. This particular lightmeter is designed only with the company's own products in mind, in that it reads only *relative* light intensity for determining whether the illumination levels are satisfactory. Installers also can, and usually do, listen through a receiver at various seat locations. This is a highly subjective judgment and offers hard of hearing listeners no assurance of adequate IR field strength at *all* seat locations in a venue. One of the recurring complaints made by the consumers in the focus group was the variations they experienced in IR field strength and the clarity of the IR signal in different venues and at different locations in the same venue.

3. MICROPHONE INPUTS

The quality of the signal received by users of an ALS system depends not only on the transmission characteristics to the receiver, but on the nature of the source. If the source is "live", then the quality of the signal at the microphone will affect the quality of the signal at all later stages in the transmission process. Questions and problems related to the appropriate type and placement of microphones in live performances was a recurring theme in both the consumer and manufacturer's focus groups.

3.1 Selecting the Appropriate Microphone

The selection of appropriate microphone types is crucial when they are to be the primary source of input into an ALS. In order to ensure adequate signal strength and maximum speech intelligibility, microphone specifications should meet or exceed the specifications of the rest of the system components. Poor quality microphones will limit the effectiveness of an ALS. To minimize background noise, it is desirable to utilize noise-suppressing directional microphones (such as those with a cardioid or hyper-cardioid pattern).

The most desirable situation is where ***all talkers*** have available a microphone in close proximity to their lips. If a situation, such as theatrical performances that require multiple microphones, then it's desirable to either utilize an automatic mixer (one that switches on only the microphone being spoken into) or for the microphone gain and activation to be controlled by a sound technician. In this latter instance, the sound technician can also control the relative level of the various sound signals in order to favor speech or lyrics and de-emphasize other competing stimuli such as background music. Currently, the provision of a separate wireless microphone for each performer is evidently practiced in only major theaters and then unpredictably. (Theaters do not publicize the details of their sound reproduction system, other than to indicate that one is available as required by the ADA).

3.2 Microphone Location

There are no standards for microphone placement in live performances. The actual location appears to be a pragmatic mix composed of production requirements, financial resources, physical limitations, and a sophisticated appreciation (or lack of it) of sound transmission and perception. In some theaters, there may be one or more microphones near the footlights or dangling from the ceiling. There may or may not be a sound technician controlling the signals. It is easier to control microphone positioning when only one talker is involved, but even so optimal microphone technique cannot be taken for granted (Ross 1991). If the person is using a podium microphone (as opposed to lapel or lavaliere microphones worn on the body), often he or she will move away from it as the lecture proceeds. In any large area listening situation, where only one talker is involved (a lecture, sermon, etc.) it would be desirable to provide speakers with the alternative of using a lapel or lavaliere microphone; this will give them freedom of movement around the podium without impacting upon the quality of sound reaching the microphone.

In situations other than theatrical performances where more than one microphone is required (i.e. panel discussions), then each participant should have a microphone close by. Optimally, these should be normal "off", and either be sound or switch activated. This is to prevent inadvertent vocalizations, or verbal "asides" made by one panel member to another, from being picked up and transmitted to the entire audience. In programs in which audience participation is expected (as in a large lecture), then a wireless FM microphone should be available for audience use.

3.3 Need for "Overriding" Principle

Because there are so many permutations regarding types and conditions of microphone usage, it would be helpful to have some overriding principle that can be applied generally, to all situations in which microphones are picking up "live" signals.

The principle used by the Lexington Rehabilitation Engineering Research Center (RERC) was to emphasize the integrity of the sound signal as it is delivered through earphones by focusing on defined electroacoustic products. This concept can be employed for both live and recorded transmissions. It gives installers and manufacturers wide latitude in how they reach these electroacoustic goals. The concept and the research project through which we arrived at our performance recommendations will be expanded upon at length in the last section of this paper.

4. COMPARISONS BETWEEN ALS

4.1 Research

There have been four published research studies that have examined the relative performance of different ALS compared to when the signals are delivered through a PA system. In the Bankoski & Ross (l984) study, nine hearing-impaired adults ages 48 to 84 years were administered a speech intelligibility test through a PA system in a large auditorium under two listening conditions: one in their usual mode (monaural or binaural) and one with each of two different FM systems. Their scores in the non ALS condition was compared to the scores obtained by 146 normal hearing college students in the same auditorium.

The results showed that the scores for the hard of hearing group, with either of the FM systems, were significantly higher than those obtained in their usual listening condition (an average of about 45% without an ALS and 70% with an ALS). The scores of the two different FM systems were essentially similar. What was interesting about these results was that with an ALS, the older hard of hearing subjects scored as well or better on speech perception measures than did the young normal hearing college students. The students achieved average scores of about 65% in the auditorium, which varied considerably depending upon their specific location in the auditorium, compared to an average of 90% with headphones in the clinic. What these results indicate is that even the normal hearing group could have used auditory assistance in this particular auditorium.

Three other studies compared the speech perception scores of different ALS to those obtained via a PA system. Nabelek, Donahue, and Letowski (1986) compared the performance of IL, FM, and IR systems to a PA system in a medium size classroom. There were four groups of subjects: 10 young adults with normal hearing, 10 hearing-impaired with mild-to-moderate hearing loss not using hearing aids, 9 elderly people with hearing loss "typical" of their age, and a group of 10 hearing aid users with moderate hearing loss. Speech perception scores were obtained under two S/N conditions (+8 dB and + 20 dB) with all listening systems.

The results showed that for both S/N conditions, the speech perception scores obtained with the IR, IL, and FM systems were superior to those achieved with the PA system (Nabelek, Donahue & Letowski l986). The differences between the scores with the PA system and the three ALS widened as the listening conditions became poorer.

Minor differences were found between the FM, IR and IL systems, but these were not considered to be clinically significant.

In a companion study, Nabalek and Donahue (1986) compared speech perception scores obtained with a PA system to those obtained with an FM and an IR system in a large auditorium. They reasoned that the results obtained in a classroom may not be applicable to a larger listening situation. Five groups of subjects were tested. In addition to the four types tested in the earlier study, they added a group of normal hearing non-native listeners. Two listening positions were selected, one representing a favorable seating location (10th row center) and a poor one (under a balcony overhang).

The results corroborate those obtained in the earlier study. Speech perception scores achieved with either the FM or the IR system were significantly higher than those attained with the PA system, while differences between the FM and IR system were minor and not clinically significant. The biggest differences were found with the hearing-impaired and non-native listener groups. The study did show that, as did Bankoski and Ross (1984), that the ability to comprehend speech by normal hearing people, particularly non-native normal hearing people, can be affected in large auditoriums but can be improved with an ALS. Even a "favorable" seating location is no guarantee of a superior speech perception. In this study, people in the "poorer" location did better while listening to the PA system than those in the "better" location. This fact helps explain the huge demand for IR receivers by normal hearing people in some legitimate theaters, as reported in the manufacturer's focus group. In other words, the quality of the acoustical conditions in large-area listening environments should be a universal concern, and not just something that affects only people with hearing loss.

In the most recent study, speech perception scores obtained with four types of ALSs were compared to scores achieved when no system was being used (Noe, Davidson, & Mishler 1997). The four systems were IR, IL, FM and an FM sound-field system (This latter is basically a PA system employed with an FM rather than a hard-wire microphone being used.) Two groups of subjects were tested: a group of 10 listeners with normal hearing and 18 listeners with sensorineural hearing loss, half of whose hearing losses included a central aging component. Testing took place in a medium-size classroom, with the understanding that this would be less of a listening challenge for the subjects than would occur in a larger venue. The hard of hearing listeners were tested using the ALS with earphones and coupled inductively (via a neckloop) to their ITE hearing aids. As in the previous studies, both the normal hearing and hearing-impaired groups benefitted from the use of an ALS (FM, IR, or IL). The only exception was the lack of improvement shown by the normal hearing subjects to the FM sound-field system (but these scores were already very high). Generally, the hearing-impaired subjects preferred the FM to the other ALS systems, though differences between them appear minor compared to when no ALS was being used.

One other purpose of the study was to compare ALS performance with and without inductive coupling for persons with hearing loss. The results showed poorer scores when the ALS was inductively coupled to personal hearing aids than when headphones were used with the ALS receivers. The investigators attribute this to the higher quality signal the ALS receiver delivered when coupled to a headset, as opposed to a neckloop/telecoil combination. They reiterate the point made many times by other investigators (and reviewed earlier in this paper) that telecoil performance with a neckloop is a significant factor that must be considered when inductively coupling an ALS to a hearing aid. The authors also point out that the use of an amplified telecoil provides a significant improvement in hearing aid performance compared to conventional telecoils. They point out the necessity to evaluate telecoil performance whenever an ALS is being coupled inductively to a personal hearing aid and the need to compare which option (unaided with headset or inductively with hearing aid) would provide a hard of hearing person with superior listening performance.

4.2 Functional Comparisons

The advantages, problems and limitations of IL systems were reviewed above, in the description and issues concerning such systems. While these systems have a continued contribution to make in providing auditory access for people with hearing loss, they rarely appear in direct competition with IR and FM systems in terms of new installations. Unless more hard of hearing people can be convinced (or their hearing aid dispensers) to include telecoils in their hearing aids, this situation is unlikely to change. This section, therefore, will concentrate on comparing the advantages and disadvantages of FM and IR systems.

It is easier to ensure that a transmitted signal is adequate and equal throughout any size venue, including outdoors, with an FM rather than an IR system. An FM transmitter can be hooked into the sound system and, in most instances, that appears to be the extent of the necessary "installation". FM systems, however, are susceptible to outside radio interference or may cause such interference to other nearby users of radio equipment. There appears to be an adequate number of channels available to ensure coverage in multiplex cinemas or multiple adjacent auditoriums. Since the FM transmission is not contained within the facility, an FM ALS is not appropriate if privacy is a concern.

An IR signal, on the other hand, stays contained within a facility, thus ensuring privacy. Any number of systems can be used in adjacent auditoriums without interference or spillover. Most venues with IR systems currently use the same sub-carrier (95 kHz), thus providing compatibility between different locations. However, this is an informal practice, and other sub-carrier frequencies can and are now being used in some places. The use of other and different sub-carrier frequencies would require either that receivers be designed only for particular transmitters, or that multiple-frequency IR receivers be deployed.

IR signals are affected by sunlight and, less severely, by fluorescent lights. It is possible to install more emitters in a facility, and overcome all but the most unfavorable natural or artificial light conditions (like direct sunlight). Ensuring adequate light coverage in a facility requires a skilled installer, a fair amount of "trial and error", and a willingness to verify the field strength at all likely seat positions in a facility. IR systems are considered "line of sight", in that the "eye" of the receiver must be in line with an emitter. However, because of the undefined light reflection patterns in different rooms, this may not be strictly applicable; in some rooms and at some use positions, strict "line of sight" reception is not necessary. Reception, therefore, may be uncertain and has to be empirically determined in each venue. Covering the light receiving diode with clothing (as in a pocket) or turning one's back to an emitter will most likely interfere with reception.

IR receivers tend to be simpler than FM receivers, though this may be less true as additional sub-carrier frequencies become used. In this case, multiple frequency IR receivers may become common. In some places and for some populations, this can be a problem; simpler is better. FM receivers vary from a fixed, single frequency reception to units with the capacity to detect many ALS channels. Both FM and IR receivers can be used with the same types of coupling possibilities, including personal hearing aids.

5. LOGISTICAL CONSIDERATIONS: RECOMMENDATIONS

5.1 Public Notification of Availability

People have to know that ALS are available *before* they attend a performance or lecture and where to get them once they enter the facility. While some of these suggestions are already in place (e.g. some newspaper advertisements, signage in facilities), their practice is not universal or standardized. We recommend that all venues providing ALS comply with the following:

★ Newspaper advertisements should include notification that the venue provides an ALS. This notification should be of the same order of visibility and location as information regarding other attributes of a performance ("Dolby Sound", etc.). Eventually, with public education, printing the international symbol of "communication access" would be sufficient (much like the CC symbol signified "closed captioning").

★ Recorded telephone information from movie houses and theaters should include a comment that ALS are available for people with hearing loss.

★ The "leader" preceding the show in movie houses should include information re: the availability and location of the assistive listening device receivers.

★ At the entrance to each venue, there should be clear and visible signs indicating that ALS are available and where the receivers can be obtained. Furthermore, the sign should identify specific frequency employed by the FM or IR system. This information would be valuable for consumers who desire to employ a personal receiver.

5.2 Distributing Receivers

★ The same individual in the same physical location in a venue should be responsible for both checking in and checking out of the receivers.

★ This individual should be trained to operate and troubleshoot the ALS receivers. Their responsibilities include:

- Inserting rechargeable batteries into battery recharger after each performance.

- Verifying that disposable batteries are functional prior to each performance.

- Performing a "listening test" on all receivers prior to checking them out.

- Assist listeners in selecting the appropriate coupling arrangement (headphones, neckloop, earbuds, etc.). Briefly instruct users in how to operate the receiver. A simple instructional card can be provided to consumers when necessary.

- Taking appropriate hygienic measures after receivers are returned (e.g. spraying or wiping foam cushions with an antiseptic solution and replacing disposable cushions).

6. RECEIVERS AND COUPLERS: RECOMMENDATIONS

When hard of hearing people use an ALS, they are not usually concerned with the characteristics of the installation and transmission process of the various systems. They expect, and rightly so, that when they obtain a receiver at some venue that the signal they perceive will be superior to that they could obtain unaided or with their own hearing aids. The nature, characteristics, and operation of ALS receivers proved to be a major concern in all the focus groups. The recommendations given below reflect the comments and suggestions made, but also represent our own best judgements:

- The ALS receiver should be capable of delivering speech at levels of 110 dB SPL, but not to exceed 120 dB SPL.

- Single-channel receivers with only a minimum of external controls should be available for use at locations catering to elderly people (such as nursing homes and senior centers).

- Discrete and highly visible controls should be included in receivers that can detect multiple channels or capable of other electroacoustic modifications (e.g. volume and tone controls).

- All receivers should include "low battery" warning lights, to give adequate battery life warning.

- 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.

- Coupling options should include headphones, earbuds, and neckloops. We recommend that one neckloop be available for every four air conduction type receivers.

- Headphones should be able to fit comfortably over in-the-ear hearing aids and permit users to either couple inductively or acoustically. Furthermore, the "bleed" from such receivers should not exceed the ambient noise at a seat adjacent to the user.

6.1 Universal Receiver: Recommendations

The need for a universal receiver was highlighted when it was suggested that standardized transmitting characteristics for both FM and IR ASL be required. This suggestion was not accepted. It was felt that mandating standardized transmitting characteristics to which all the manufacturers would adhere would stifle innovation and creative new developments. Nevertheless, consumers should have the option of purchasing a personal ALS receiver that can be used in any large venue they attend. If "universal access" cannot be obtained by standardizing transmission characteristics, then it should be sought by the development of a "universal" receiver. Such a device was available until quite recently, but is no longer being manufactured. This is an option that should now be resurrected and available to consumers. Many people prefer to purchase their own ALS receiver, one that they could use in any venue with any type of ALS. This is more than just a convenience; it provides these people with the security of knowing that their ALS receiver functions well and in accordance with their personal needs. We have already recommended, above, that venues note the transmitting frequencies of the ALS on their signage.

We recommend that the industry be encouraged to develop a "Universal Receiver", one that can be (1) tuned to any FM frequency used in ALS in the 72-75 MHz or 216-127 MHz range, either wide or narrow channel, (2) adjusted to detect any of the sub-carriers used with IR systems, and (3) include a telecoil for usage with IL systems.

Additional desirable features would be an environmental microphone and a "low battery" warning light.

7. INSTALLATION

The adequacy of the installation and the competency of the installers were a recurring theme in all the focus groups. Consumers complained of listening variations in different seating positions in the same venue, and of variations in the location at different times. Noise and interference appeared intermittently and unpredictably. For the most part, it did not appear that the equipment itself was responsible for these problems. Rather, it often appeared that the installer had either not installed the equipment correctly, or had not selected the appropriate ALS or characteristics for a particular venue. Perhaps occurring as frequently as poor installation, however, are the occasions when a proper installation is modified by local facility managers or personnel after the initial installation takes place. In these instances, even the best installation can be defeated. What is clear is that the best of intentions, the most sophisticated equipment and, sometimes, even an excellent installation, are not a sufficient guarantee of adequate performance in the ALS. Once the installation is made, local facility managers and personnel may modify it in some fashion for their own reasons, thus affecting the quality of the installation. Since it is impossible to control the actions of these people, in this report we can but focus on the adequacy of the initial installation, which means the competency of the people who perform this service.

People who install ALS range from trained sound engineers to a questionably competent on-site maintenance person. While the different ALS and venues will require different depths and ranges of competencies, all require some minimum of information if the system is to be installed correctly. Employees of a company selling ALS may be asked to install any one of the three technologies described below, and to do this in venues varying from large stadiums, various kinds of theaters and auditoriums, to public rooms in municipal facilities (courtrooms, legislative hearing rooms, etc.). The installer, then, must understand not only the specific requirements imposed by many different venues, but also know how to deal with variables introduced by live versus recorded performances, formal versus informal settings, and the listening needs exhibited by people with hearing loss. In the final analysis, it is the installer who determines whether an ALS will, at least initially, work well, equivocally, or not at all.

7.1 Characterizing Facilities

Recommendations regarding installers of ALS can be facilitated by characterizing the nature of the venues they work in. These can be divided into three levels. The first and most frequent one are the small sites, such as houses of worship, tour sites, funeral parlors, small museums, historic houses, and various kinds of social service agencies. These are facilities in which master electricians and sound engineers are rarely, if ever, employed. The second facility level are medium sites, consisting of such venues as motion picture theaters, courtrooms, museum auditoriums, hotel meeting and conference rooms, and lecture halls. These types of sites may have a technical person on staff to assist in the installation, but not one necessarily skilled in installing sound systems. The third level of sites will almost always have a trained person on staff, either a master electrician or sound engineer to either install, or to assist in the installation, of an ALS. These consist of large legitimate theaters, stadiums, and conference and concert centers. Ordinarily, a manufacturer will offer to send a member of their technical staff to such sites to assist in the installation.

From the comments we received, however, it appears that installation problems occur whether or not the facility has a trained person on staff. The training and skills necessary to install a PA system for normal hearing people, while undoubtedly very helpful, do not directly address the specific listening needs exhibited by people with hearing loss. In any venue, no matter what level, the person installing the ALS must understand both the sound transmission process of every technology as well as the receiver variables that affect people with hearing loss. What this observation suggests is that people who install, or maintain, ALS required specific training focused on the listening needs of hearing-impaired people.

7.2 Training Program: Recommendations

We recommend that training programs be offered to train ALS installers. Such training programs can be a combined effort of industry and the Lexington RERC. Participants could be people who are currently employed in installing ALS, who are on the staff of large facilities in which various kinds of ALS are employed, or those whose job activities may make them occasionally responsible for installing or advising the installation of an ALS (e.g. audiologists, hearing instrument specialists). The specific curriculum would be developed through consultation with active installers of ALS and manufacturers. We would assume that such a workshop would last at least two or three days. Participants would receive a certificate attesting to their completion of the course.

8. DEVELOPING ALS PERFORMANCE STANDARDS FOR PEOPLE WITH HEARING LOSS

8.1 Objective

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.

8.2 Method

8.2.1 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.

1. 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.

2. Moderate flat hearing loss: PTA is greater than 41 dB HL with threshold at 2000 Hz less than 55 dB HL.

3. Moderately-severe, gently sloping hearing loss: PTA is greater than 41 dB HL with threshold at 2000 Hz between 55 and 60 dB HL).

4. Moderate to severe flat hearing loss: PTA is greater than 41 dB HL with thresholds at 2000 Hz between 61 and 70 dB HL.

5. Moderate to severe sloping hearing loss: PTA is greater than 41 dB HL with thresholds at 2000 Hz greater than 70 dB HL.

6. Precipitous, high- frequency hearing loss: PTA is less than 41 d B HL with thresholds at 2000 Hz greater than 40 dB HL.

Figures 14 through 19 are group audiograms showing averaged thresholds (both ears) for each of the participants with hearing loss. All but three listeners who participated in the study had symmetrical hearing losses. In addition, data were collected for ten listeners without hearing loss.

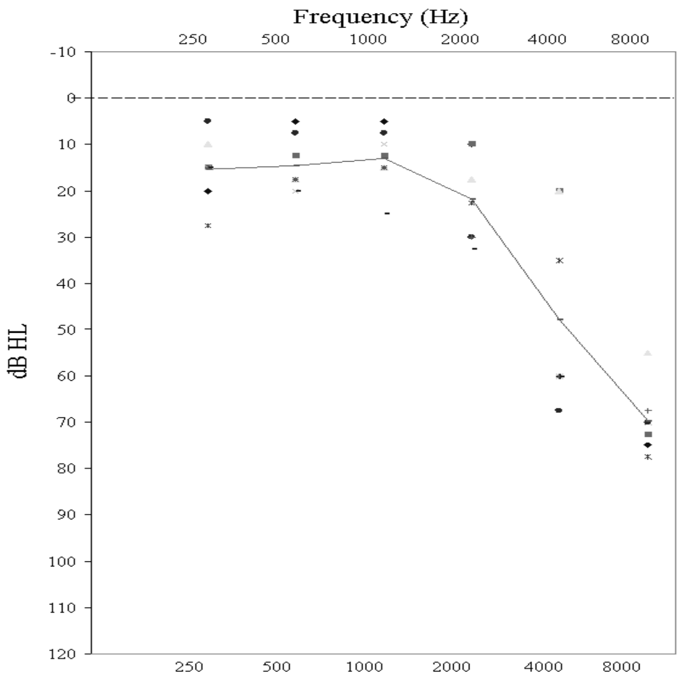

Figure 14. Group 1, (n=8). Very high frequency hearing loss (PTA < 41 with threshold at 2000 Hz < 40 dB HL).

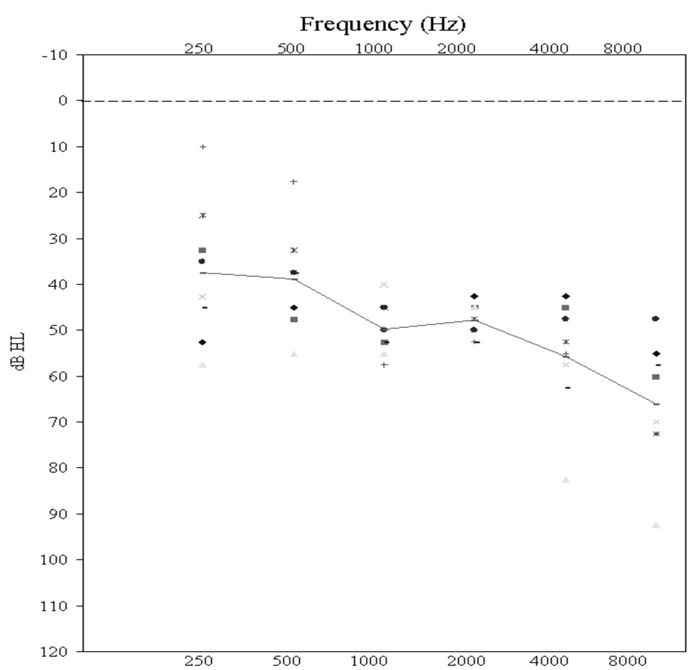

Figure 15. Group 2 (n=8). Moderately flat hearing loss (PTA > 41 with threshold at 2000 Hz < 55 dB HL).

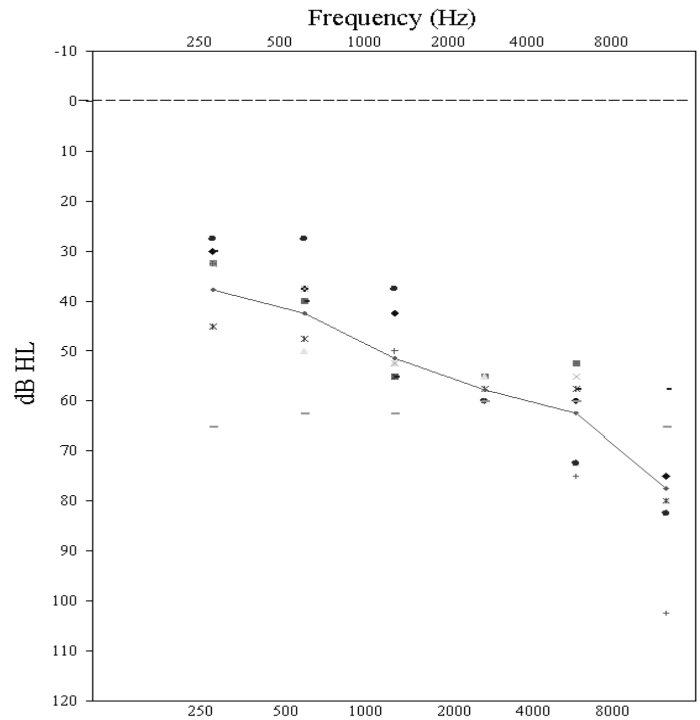

Figure 16. Group 3 (n=9). Moderately severe, gently sloping hearing loss (PTA > 41 with threshold at 2000 Hz between 55 and 60 dB HL).

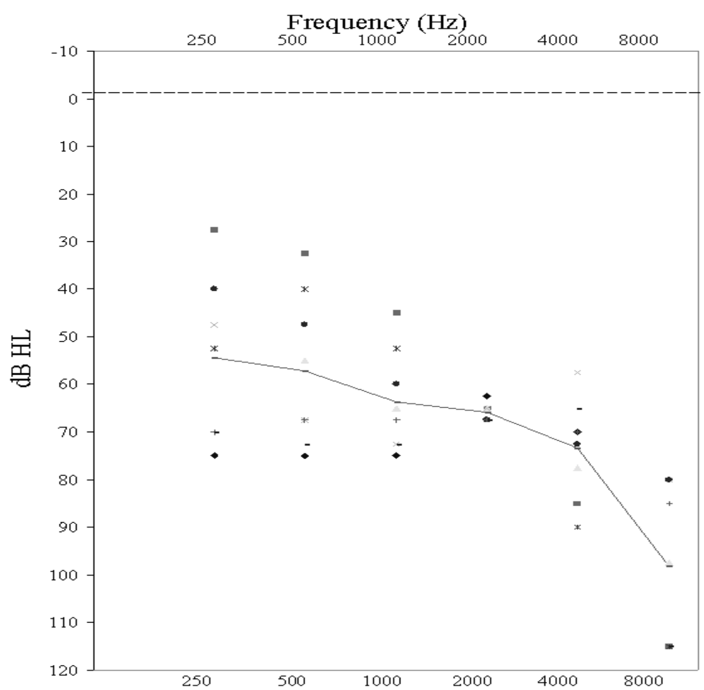

Figure 17. Group 4 (n=8). Moderate to severe flat hearing loss (PTA > 41 with threshold at 2000 Hz between 61 and 70 dB HL).

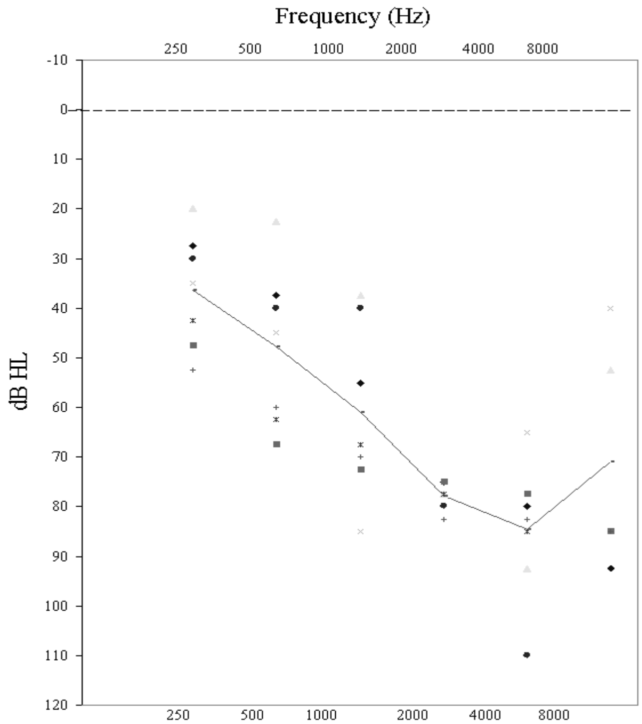

Figure 18. Group 5 (n=7). Moderate to severe sloping hearing loss (PTA > with threshold at 2000 Hz > 70 dB HL).

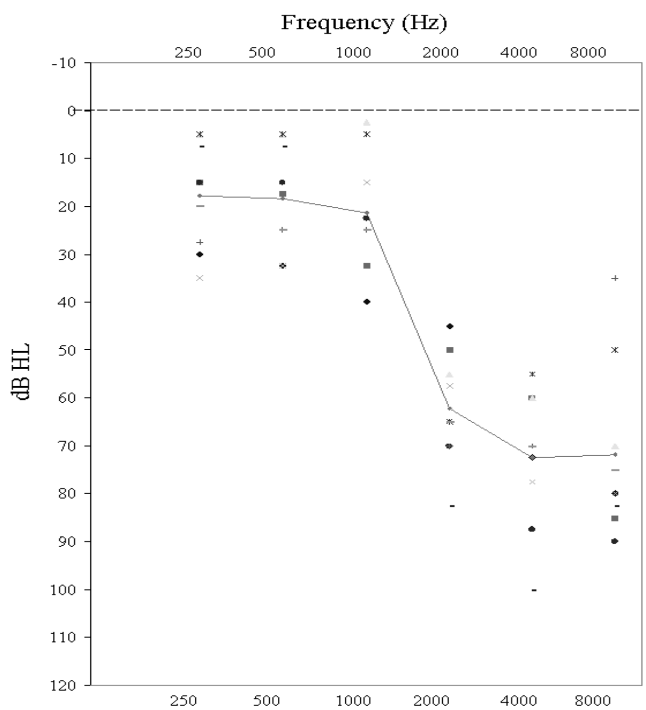

Figure 19. Group 6 (n=9). Precipitously high frequency hearing loss (PTA < 41 with threshold at 2000 Hz > 40 dB HL).

8.2.2 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. <u>Reverberation plus noise</u>.

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 redigitized and stored onto a computer disk for presentation during the experiment.

Figure 20 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.

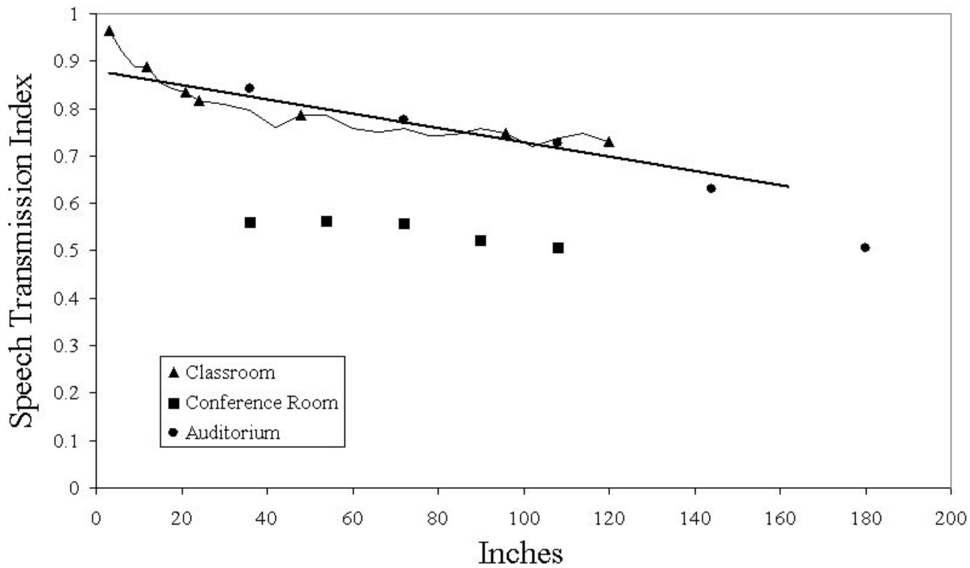

Figure 20. Speech Transmission Index (STI) as a function of speaker/listener (microphone) distance in the three recording environments for the reverberation plus noise condition.

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. Figure 21 shows the spectrum of the induction loop noise.

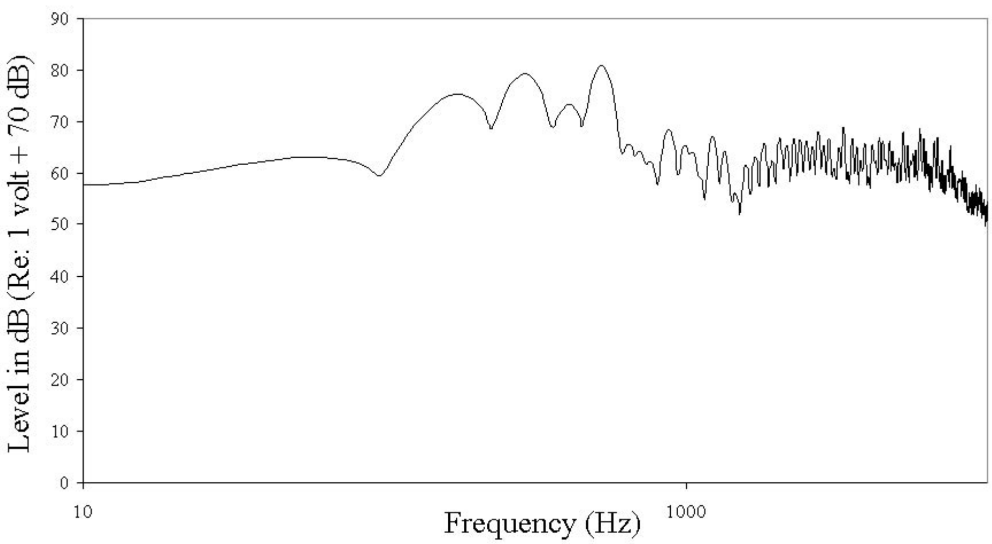

Figure 21. Spectrum of Teleloop noise.

The noise largely consists of a background "buzz " (see primary at 60 Hz with harmonics) and a high-frequency hiss. Also shown in Figures 22 and 23 are the composite spectra of the male and female voices, respectively, for the Lexington Sentences that were chosen.

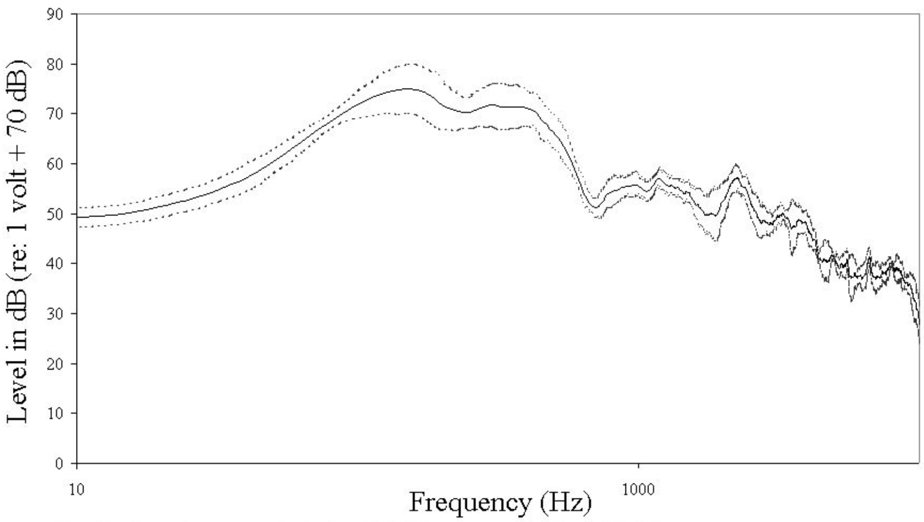

Figure 22. Composite spectrum of male voice. Dashed lines represent +/- 1 Standard Deviation.

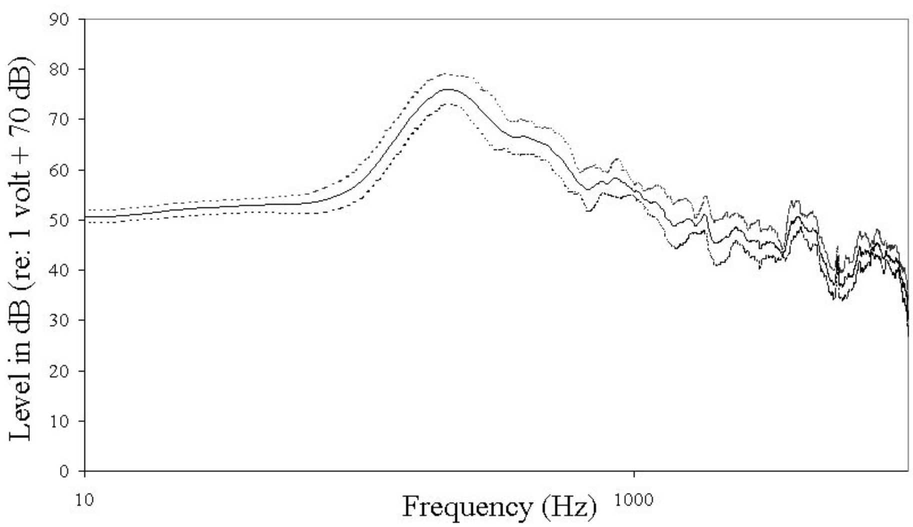

Figure 23. Composite spectrum of female voice. Dashed lines represent +/- 1 Standard Deviation.

3. Peak clipping

The signals were digitally and 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

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

8.2.3 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.

8.2.4 Procedure

To adjust to a comfortable listening level the listeners were instructed to indicate the level of the quiet, undistorted sentences that they felt they could listen to for a very long time. Listeners were instructed to judge the quality of the 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 where 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 subcondition recorded following the pretest phase.

8.3 Results and Discussion

Figure 24 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.

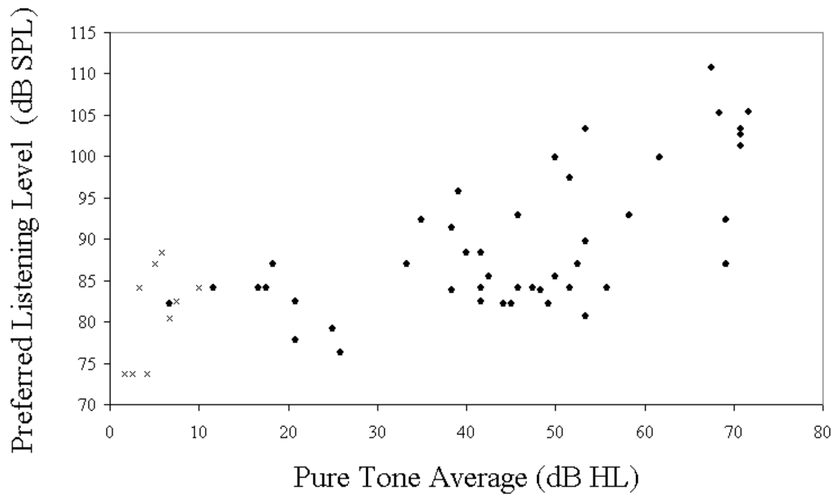

Figure 24. Subject-selected preferred listening levels as a function of 3-frequency pure tone average for the 59 listeners who participated in this study. The level of the signal was the same for both ears. The circles represent the combined pure tone averages (both ears) for each of the listeners with hearing loss. The X's represent the combined pure tone averages for each of the listeners without hearing loss.

For purposes of statistical data management the qualitative ratings were converted to numerical values. The excellent rating was converted to a score of 4, good was converted to 3, marginal was converted to 2, and unacceptable was converted to 1. Tables 1 through 5 show the median ratings for each of the five listening conditions. These median values were initially divided into groups according to degree and configuration of hearing loss. It is interesting to note that the median ratings cluster together regardless of the degree and configuration of hearing loss.

Table 1. Median listener ratings for the Auditorium condition

	Listener/Speaker Distance in Feet					
Groups	0	3	6	9	12	15
NO HL	4.00	2.88	2.38	2.13	1.88	1.38
1 very high frequency	3.75	3.00	2.63	2.75	2.13	1.38
2 moderate flat	3.25	3.00	2.38	2.25	1.50	1.13
3 moderate sloping	3.25	2.25	2.25	1.75	1.50	1.00
4 moderate-to-severe flat	3.88	2.88	2.38	2.63	2.00	1.25
5 moderate-to-severe sloping	3.75	3.00	2.50	2.50	2.00	1.50
6 Presbycusis	4.00	2.75	2.50	2.25	1.75	1.50

Table 2. Median listener ratings for the Conference Room condition

Groups	Listener/Speaker Distance in Feet: 0	3	4.5	6	7.5	9
NO HL	4.00	2.25	2.00	2.13	1.75	1.63
1 very high frequency	4.00	2.50	2.13	2.00	1.63	1.63
2 moderate flat	3.50	2.13	2.13	2.00	1.63	1.63
3 moderate sloping	3.50	2.25	2.00	2.00	1.75	1.75
4 moderate-sloping flat	4.00	2.25	2.25	1.88	1.75	2.00
5 moderate-severe sloping	4.00	2.75	2.25	2.25	2.50	2.00
6 Precipitous	4.00	2.75	2.75	2.50	2.25	2.25

Table 3. Median listener ratings for each of the six experimental groups for the Classroom condition.

Groups	Listener/Speaker Distance in Feet: 0	.25	1	2	4	8	10
No HL	4.00	3.38	3.125	3.00	2.63	2.5	2.00
1 very high frequency	4.00	3.50	3.00	3.13	2.50	2.38	2.25
2 moderate flat	3.75	3.25	3.38	3.00	2.50	2.38	1.63
3 moderate sloping	3.25	3.00	3.00	2.50	2.25	2.50	1.75
4 moderate-severe flat	4.00	3.50	3.00	2.75	2.75	2.25	2.00
5 moderate-severe sloping	3.75	2.75	3.25	3.00	2.25	2.25	1.50
6 Precipitous	3.75	3.50	3.25	3.00	2.75	2.50	2.25

Table 4. Median listener ratings for the FM Teleloop Noise condition

	Signal to Noise Ratio in dB						
Groups	quiet	30	24	18	12	6	0
No HL	4.00	3.00	2.75	2.25	1.5	1.00	1.00
1 very high frequency	4.00	3.63	2.88	3.00	2.63	1.50	1.25
2 moderate flat	3.75	3.50	3.50	3.50	2.50	1.88	1.37
2 moderate sloping	3.00	3.00	3.00	2.75	2.50	2.00	1.25
2 moderate-severe flat	4.00	3.75	3.75	3.00	2.50	2.00	1.25
3 moderate-severe sloping	3.00	3.00	3.00	3.00	3.00	2.50	2.50
4 Precipitous	3.50	3.25	3.00	3.00	2.75	2.75	2.00

Table 5. Median listener ratings for the Peak Clipping condition

	Clipping Levels re: Peak						
Groups	0	6	12	18	24	30	36
No HL	4.00	3.88	3.13	2.63	1.63	1.00	1.00
1 very high frequency	3.75	3.63	3.78	2.88	2.38	1.63	1.63
2 moderate flat	3.50	3.50	3.00	2.63	2.38	1.88	1.38
1 moderate sloping	3.00	3.25	3.00	2.50	2.25	2.25	1.75
1 moderate-severe flat	3.38	3.50	3.00	2.63	2.38	2.13	1.75
3 moderate-severe sloping	3.00	2.75	2.75	2.50	2.50	2.25	2.00
4 Precipitous	3.25	3.50	3.25	3.00	2.25	2.25	2.00

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 subcondition as good: marginal (2), marginal (2), marginal (2), and good (3). Tables 6 through 10 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.

Table 6. Seventy-fifth percentile ratings for the Auditorium condition. In parentheses following each subcondition 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 7. Seventy-fifth percentile ratings for the Classroom condition. In parentheses following each subcondition 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 8. Seventy-fifth percentile ratings for the Conference Room condition. In parentheses following the subcondition are the corresponding STI values.

Quiet	3 feet (.562)	4 ½ feet (.566)	6 feet (.561)	7 ½ feet (.523)	9 feet (.512)
3.50	***1.75***	***1.75***	***1.63***	***1.5***	***1.5***

Table 9. 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 10. 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 25 shows 75th percentile ratings as a function of the STI results from the reverberation plus noise conditions combined for the three different 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 .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 impairment.

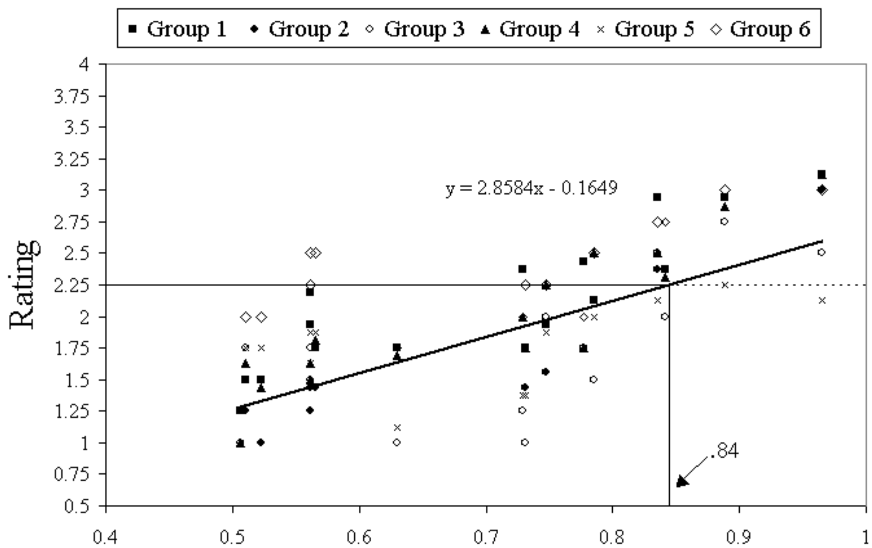

Figure 25. Seventy-fifth percentile ratings for each experimental group as a function of the speech transmission index. The diagonal line represents the best fit first order regression line to the data. Also shown is the equation that corresponds with the line and the STI value of .84 that results from the equation with 2.25 as the minium acceptable rating.

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 20).

8.4 Recommendations

1. The system must be capable of providing 110 dB SPL and not exceed 118 dB SPL with a dynamic range on the volume control of 50 dB.

2. The speech transmission index cannot be less than .84.

3. The signal-to-noise ratio for internally generated noise cannot be less than 18 dB.

4. The peak clipping levels down from the peak cannot be greater than 18 dB.

REFERENCES

Architectural and Transportation Barriers Compliance Board, Office of Technical Services, January 6, 1981 Ruling.

Bankoski, S. M. & Ross, M. (1984). FM systems' effect on speech discrimination in an auditorium. Hearing Instruments, 35(7), 8-12, 49.

Compton, C. L. (1991). Doorways to Independence. Washington, DC: Gallaudet University.

Culpepper, N. B. (1986). Performance variability of the hearing aid telecoil. Journal of the Academy of Rehabilitative Audiology, 19, 126-135.

Davidson, S. A. & Noe, C. M. (1994). Digitally programmable telecoil responses: Potential advantages for assistive listening device fittings. American Journal of Audiology, 3(2), 59-64.

Federal Register, May 4, 1977, Volume 42, No. 86.

Hermansen, H. (1979). A hearing aid may be only half the solution. Hearing Instruments, 30, 13-15.

Johnstone, C. (1997). Assistive Listening Devices (ALSs). NY: National Technical Institute for the Deaf.

Johnstone, C. (1999) Personal communication.

Laszlo, C. (1998) Personal Communication.

Lederman, N. & Hendricks, P. (1994). Induction Loop Assistive Listening Systems. In Communication Access for Persons with Hearing Loss, Ross, M. (Ed.), 19-40. Timonium, MD: York Press, Inc.

Lieske, M. (1994). Infrared Systems. In Communication Access for Persons with Hearing Loss, Ross, M. (Ed.), 41-50. Timonium, MD: York Press, Inc.

Nabelek, A. K. & Donahue, A. M. (1986). Comparison of amplification systems in an auditorium. Journal of the Acoustical Society of American, 79(6), 2078-2082.

Nabelek, A. K., Donahue, A. M., & Letowski, T. R. (1986). Comparison of amplification systems in a classroom. Journal of Rehabilitative Research and Development, 23(1), 41-52.

Nabelek, A. K. & Nabelek, I. V. (1994). Room acoustics and speech perception. In Handbook of Clinical Audiology, 4th Edition, Katz, J. (Ed.), 624-637. Baltimore, MD: Williams & Wilkins.

Noe, C. M., Davidson, S. A. & Mishler, P. J. (1997). The use of large group assistive listening devices with and without hearing aids in an adult classroom setting. American Journal of Audiology, 6(3), 48-63.

Preves, D. A. (1996). Revised ANSI standard for measurement of hearing instrument performance. The Hearing Journal, 49(10), 49-57.

Preves, D. A. (1994). A look at the telecoil - its development and potential. SHHH Journal, , 15(5), 7- 10.

Rodriguez, G. P., Holmes, A. E. & Gerhardt, K. J. (1985). Microphone vs. telecoil performance characteristics. Hearing Instruments, 36(9), 22-24, 57.

Ross, M. (1991). Microphone technique. Hearing Rehabilitation Quarterly, 16(4), 8-11.

Ross, M. (1982). Communication Access. In The Vanderbilt Hearing Aid Report: State of the art-research needs. Studebaker, G. A. & Bess, F. H. (Eds.). Upper Darby, PA: Monographs in Contemporary Audiology.

Ross, M. (1992). Room acoustics and speech perception. In FM Auditory Training Systems: Characteristics, Selection, and Use, Ross, M. (Ed.), 21-44. . Timonium, MD: York Press.

Ross, M. (1994) FM Large-Area listening Systems. In Communication Access for Persons with Hearing Loss, Ross, M. (Ed), 51-70. Timonium, MD: York Press, Inc.

Thibodeau, L. & Abrahamson, J. (1988). Effects of coupling hearing aids to FM systems via neck loops. Journal of the Academy of Rehabilitative Audiology, 21, 49-56.

Williams Sound Corp (1981) Personal Communication.

Yuzon, E. (1992). FM personal listening systems. In Communication Access for Persons with Hearing Loss, Ross, M. (Ed.) 73-102. Timonium, MD: York Press, Inc.