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STAKEHOLDER FORUM
ON
HEARING ENHANCEMENT

Proceedings from the Stakeholder Forum on Hearing Enhancement

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Acknowledgement

"Coming together is a beginning, staying together is progress, and working together is success."
-- Henry Ford

On behalf of the Rehabilitation Engineering Research Center on Technology Transfer (T^2RERC) I would like to acknowledge and thank a number of people and organizations who are helping to make the Project on Hearing Enhancement a success.

First, I want to thank our sponsor, the National Institute on Disability and Rehabilitation Research of the U.S. Department of Education. Without their support, this valuable research would not have been possible.

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Of course without the participation of many consumers, clinicians, researchers, businesses and government, the Forum and overall Project could not be successful. Thank you to everyone who participated in our initial telephone interviews, panels and the Forum itself.

I would like to thank our partners from the Research Triangle Institute, for providing valuable insights and assistance on technology transfer; AZtech for developing the industry profile, and the Western New York Independent Living Center for bringing the consumer's perspective to this Project.

Finally, I would like to give my thanks to the staff at the T^2RERC whose hard work, team effort, patience and humor have sustained this Project from the very beginning.

Sincerely,
Dr. Stephen Bauer
Demand-Pull Project Director &
Co-Director of the T^2RERC

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Executive Summary

In November 1999 the Rehabilitation Engineering Research Center on Technology Transfer (T RERC), partnered with the RERC on Hearing Enhancement to begin the Demand-Pull Project on Hearing Enhancement.

The goal of this Project is to identify unmet needs in the hearing aid and assistive listening system industry and to facilitate the transfer of technology from Federal Labs, research institutions and other advanced technology developers to meet these needs.

The Project focused on four technology areas: earmold technology, infrared and inductive loop technology, FM and related technology and microphone technology. Technology needs identified within these four areas represent important and unmet customer concerns having a significant business potential for manufacturers. Further, technology solutions required to address these needs are likely to be beyond current industry capabilities or resources.

The Project depends upon the participation of a wide variety of disability specific stakeholders. In the case of the Hearing Enhancement Project these include product end-users (consumers), referral sources (clinicians), evaluators of existing or developing technologies (clinical researchers), producers of technology for commercial application (manufacturers), innovators of new technology (Federal Laboratory Consortium scientists), as well as representatives from various governmental agencies.

Full stakeholder participation helps to ensure that: unmet needs of consumers and manufacturers are clearly identified; the technological state-of-the-practice for current products is well characterized; and reasonable design and performance parameters are established for both short-term and long-term technology solutions. All stakeholders benefit from this process. Product customers shape the design and performance characteristics of next generation products. Scientist, engineers and clinicians become aware of research needs and transfer opportunities. Product manufacturers are introduced to business opportunities and advanced technology solutions.

Further details on the steps and process of the Hearing Enhancement Project can be found in the Project Description of these Proceedings.

Project Description

Introduction

The T^{2}RERC's Demand Pull Project focuses on the transfer of emerging technologies, R&D capabilities, or design expertise from Federal Labs, advanced technology manufacturers, and researchers (referred to as "technology developers") to assistive technology manufacturers (referred to as "technology consumers").

The T^{2}RERC Project uses a five-step process:

1) Select the Industry Segment

Each year, the T^{2}RERC in partnership with a sister RERC begins a new demand-pull Technology Transfer Project that targets a distinct assistive technology industry segment. The partner RERC plays a key role in selecting the industry segment and in the identification of candidate technology needs.

2) Identify Technology Needs

Selection of specific technology needs relies upon the triangulation of information obtained from product end-users, technical and clinical experts and manufacturers. Consumer panels are used to obtain end user information. Interviews are used to obtain information from technical experts, clinical experts and manufacturers. The T^{2}RERC works with interviewees to protect intellectual property and business interests. The T^{2}RERC develops white papers and an industry specific profile to compliment and expand upon the information derived from the interviews and panels. A white paper is written for each distinct technology area. A white paper includes information on unmet customer needs; market information; business opportunities; and technology state-of-the-practice for products now in the market. The industry profile provides details about relevant manufacturers and products, it also identifies the overall market size, distribution channels, reimbursement issues, trade shows, and conferences for the targeted market segments. The partner RERC reviews and validates the white papers and industry profiles.

3) Validate Technology Needs

A stakeholder forum is convened to provide additional focus and detail for the technology needs identified. Forum participants include: market, research and technical experts; advanced technology developers from related industry segments; product customers (e.g. end-users, clinicians, therapists, equipment vendors and service technicians); and private and public resource providers (e.g. representatives from federal agencies and national associations). Prior to the Forum, all participants receive the industry overview and "white papers" that provide market and technical background on the technology areas to be discussed.

The purpose of the Forum is to:

1. Clarify and validate the existence of significant customer needs not addressed by current technology.

2. Validate that the unmet customer needs represent a significant business opportunity.

3. Validate that significant technical innovation is required to meet these customer needs.

4. Validate that the technical innovation cannot easily take place within the industry segment.

5. Establish design and performance targets for the technical innovation.

6. Identify barriers that might prevent the successful development or transfer of the technical innovation.

Stakeholder Forum outcomes and all prior work are used to generate problem statements that summarize customer needs, business opportunities, and technical needs and specifications.

4) Locate Technology Solutions

A web site is developed to disseminate problem statements and promote the technology transfer project to Federal Laboratories, advanced technology manufacturers, research institutions and other technology developers. Additional project promotion is accomplished through the T^2RERC and partner RERC web sites; press releases; articles in journals, newsletters and trade publications; and presentations at trade shows and conferences. Technology developers are identified and contacted through phone, email and mail correspondence.

Technology developers submit [most] technology proposals through the project web site. Initially, all submitted solutions are non-proprietary. To confirm that technology proposals address customer needs, manufacturer needs and are also technically feasible the T^2RERC and partner RERC review the technology proposals. External technical or industry experts may be used as part of this review. Proprietary information may be requested from the technology developer. In such cases, mechanisms to protect intellectual property are worked out between the technology developer and the T^2RERC. For promising technology proposals, disclosure agreements are negotiated between the T^2RERC and these technology developers. These agreements allow the T^2RERC to act as an agent of the technology developer when approaching manufacturers.

5) Transfer the Technology Solution

The T^2RERC, prepares a commercialization package. The commercialization package summarizes how the technology meets end-user needs and presents a business opportunity for product manufacturers. The package also outlines the technical specifications of the proposed technology and proposed business plan for the technology transfer.

A marketing plan is developed that identifies target manufacturers and the strategy that will be employed to contact and present the commercialization package to these manufacturers.

The technology transfer is completed through mechanisms such as licensing the technology directly to a manufacturer; establishment of a research and development agreement between manufacturers; or a cooperative research and development agreement (CRADA) between a federal lab and a manufacturer.

Technology Transfer activities of the T^2RERC are funded by a grant from the National Institute of Disability and Rehabilitation Research. The T^2RERC receives no financial benefits from technologies transferred under this project.

Stakeholder Forum Protocols

The Stakeholder Forum discussions were based upon the information contained in four White Papers disseminated to participants prior to the meeting. Each of the White Papers was developed into a topic area for group discussion. Participants were organized into two sets of four groups based on their expertise or area of interest.

On the first day everyone was divided into their assigned groups and participated in focus group discussions on one of the four topic areas. The following morning each person participated in a second topic area. This method allowed everyone to be involved in two of the four topic areas and increased the number of people involved in creating the problem statements.

Participants in the discussions represented all stakeholder groups identified in the project outline. A heterogeneous group brings a greater variety of perspectives to the discussion. This method has proven to be extremely useful when evaluating the reality of products in the market and how they interact with the user and their environment. The method is also helpful when evaluating issues that are important to product design, development, manufacture and distribution.

Four moderators lead the four sessions. Each moderator was responsible for their topic area on both days of the Forum. Moderators led each group with a script developed from the White Papers as well as additional information gathered during the project's earlier interview phase. A team of technical support personnel who had been involved in the initial research of material for the White Papers was also available to clarify key issues within the group's discussion. As well, T^2RERC staff acted as transcribers to document relevant issues from each session. To ensure accuracy of the documentation, each group reviewed the transcript before the session was completed. All group discussions were made fully accessible to participants with hearing impairments by using real time transcription and captioning; recording statement summaries on flip charts; and providing infrared listening systems for all groups.

Participants were informed of the process that would be followed during each of the three-hour discussion groups. Each moderator followed a common protocol outline but they were given an flexibility to adapt their interview techniques to suit their personal style, and more importantly to adapt to the dynamics of the group itself. This is in keeping with the focus group philosophy of creating an open environment for discussion with the freedom to react to what the group has experienced rather than responding to questions identified by researchers. The moderator's role was to ensure that the discussions remain relevant to the topic area with the ultimate goal of identifying technical barriers to the development of "next generation" hearing technology.

The protocols developed for group discussion included six steps:

1. Establish a common knowledge base for all participants. Issues discussed include personal experiences with products and technologies; human factors; environmental factors; safety; service; maintenance and other product related issues.

2. Identify current technologies that pertain to the topic area and discuss their limitations and advantages. For example, "What types of hearing aids and assistive listening systems are on the market?," and identify their benefits and/or limitations as they relate to the experiences in the discussion section above.

3. Converge on top technologies meeting important end-user needs and addressing current industry limitations.

4. Identify specific design or consumer requirements to achieve the "ideal" product. Each participant was encouraged to develop criteria or design specifications of the perfect product (ideal) without limitation of current technologies used in the industry.

5. Identify and define the technical barriers that currently constrain developing the ideal device.

6. Review notes from discussion to ensure participants agreed with conclusions.

On the final afternoon representatives from each discussion group presented the results of their group to the full delegation of Forum attendees. Attendees were given the opportunity to contribute to the report if they had additional information or comments that needed to be included.

The reports from each topic area were collected by the T^{2}RERC and were used as the basis for writing the problem statements found within this publication

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Hearing Industry Summary

This document is a brief summary of the hearing aid and assistive listening system market in the United States. It is intended to provide the reader with a basic understanding of the current and potential future market size, the hearing enhancement technologies currently available, and reimbursement sources.

Hearing Enhancement Technology Market Size and Users

Technologies presently exist that could improve the quality of sound for up to 95% of the estimated 20+ million people in the United States who experience some form of hearing loss. This "Treatable Population" of over 19 million people can be further divided into those who can be treated through medical intervention and those who can benefit from an assistive device as seen in **Figure 1**.

Figure 1

Treatable Population*

- 5% - 10% can be helped medically or surgically. (This would include cochlear implants.)
- The remaining 90% - 95% can significantly correct their hearing loss with hearing aids. Hearing aids can not totally restore hearing, but they can make a big difference in improving the quality of life for people with hearing loss.

*Source: Better Hearing Institute (1999). Number of Persons Using Hearing Devices by Age of Person and Type of Device. (online). Available: http://www.betterheading.org/faq.htm (June 2, 2000).

Unfortunately approximately 80% of people who experience non-medically correctable hearing loss choose not to make use of available technologies. Reasons for low usage seem to rest primarily on cost factors. Other factors include a lack of understanding of hearing aid and assistive listening technologies, the societal stigma associated with hearing aids, and dissatisfaction with previously used technologies.

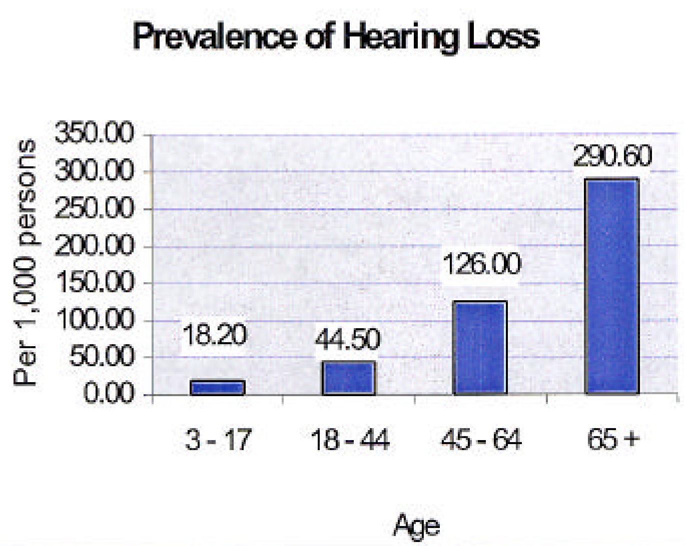
In 1999 the penetrated hearing aid market size was estimated to be only 1,900,000 units sold in the United States. This number can be broken down into types of hearing aids as follows: Behind-the-Ear (372,400 units), In-the-Ear (893,000 units), Completely-In-the-Canal (195,700), In-the-Canal (385,700), Body Aids, Eyeglasses, and others (53,200) (Hearing Industries Association, 1999).

This still leaves more than 16 million people with substantially correctable hearing loss who are not using hearing aids as a means of addressing their hearing loss.

According to the 1990-91 National Health Survey on the Prevalence and Characteristics of Persons with Hearing Trouble, 3.6 million people, or 18% of those who identified themselves as having hearing problems, use hearing aids (over the age of three and non-institutionalized). Use of hearing aids is highest among those 18 years of age and older. People whose hearing loss became significant after the age of 19 are most likely to use hearing aids.

The largest percentage of persons with hearing loss was reported in the 65 year and older age group. Age related hearing loss occurs exponentially with advancing years, rising sharply around age 55 (see Figure 2). This group increased by 24.8% from 1971 to 1991. This corresponds with the overall aging of America. Therefore, it is assumed that the largest increase in the hearing market will come from the increasing elderly population. The 1990 Census indicates that 13% of the population was over age 65, and projections indicate this figure will double over the next three decades as baby boomers enter their senior years.

Figure 2



There are three types of hearing loss: conductive, sensorineural, and mixed.

- *Conductive* hearing loss can occur if the structures of the outer or middle ear do not work correctly. Conductive loss is more likely to respond to medical or surgical treatment.
- *Sensorineural* hearing loss (nonprofessionals sometimes call this nerve deafness) can occur if inner ear structures do not work correctly. Sensorineural hearing loss is more likely to be permanent. See Figure 3 for common causes.
- *Mixed hearing loss* involves both conductive as well as sensorineural components.

TYPES OF HEARING LOSS

Figure 3

Common Sound Levels
Continued exposure to sound levels louder than 90 decibels will, eventually, cause loss of hearing.

Sound Level (decibels)	Common Sounds
30	Whisper
50	Rainfall, Refrigerator
60	Normal Conversation
70	Hair Dryer, Heavy Traffic
80	Alarm Clock, Subway
90	Electric Razor, Lawnmower
100	Chainsaw
110	Power Saw, Rock Concert
120	Jet Taking Off, Thunder
130	Jack Hammer
140	Shotgun
180	Rocket Launching Pad

Hearing Enhancement Technologies Currently Available

Without surgical or medical treatment to adjust a person's ability to hear, people with conductive and/or sensorineural hearing loss have the option of using a variety of technologies. These technologies have been categorized into two areas: hearing aids and assistive listening systems.

Hearing Aids

Hearing aids are amplification devices that compensate for partial hearing loss. The individual must have some residual hearing in order to benefit from a hearing aid. Hearing aids come in many styles and use several types of technologies. Regardless of the appearance or inner-workings of the aid, the intention is to amplify sound in order to compensate for poor hearing and help the user to function better in daily communication situations. Hearing aids do not restore normal hearing.

The hearing aid that best fits the user will depend upon many factors, including the degree of hearing loss and the daily listening situations to which the user is exposed. The best way to determine the optimal hearing aid user fit is to have a hearing test done by a licensed audiologist, who will discuss the available options.

Types of Hearing Aids (American Speech Language Hearing Association, 1997)

In-the-Ear (ITE): all parts of the aid are contained in the outer part of the ear. Offers easy positioning and adjustment by user. Generally, for mild to moderate hearing loss.
Completely-in-the-Canal (CIC): entire aid is inside the ear canal; smallest, least visible hearing device.
In-the-Canal (ITC): aid contained in a tiny case that fits partially in the ear canal.
Behind-the-Ear (BTE): all parts are in a small plastic case that sits behind the ear; case is connected to earmold by a piece of clear tubing. Used for severe to profound hearing loss, as well as by people who may encounter difficulties with manipulation.
Eyeglass Aids: aid parts contained inside the frame of eyeglasses in the earpieces; clear plastic tubing connects hearing aid to earmolds. Rarely used today.
Body Hearing Aids: Microphone, amplifier, and batteries are combined into a small rectangular case, which the user carries; cord connecting case to receiver runs along neck; receiver snaps into earmold. Used for most severe hearing loss. Rarely used today.

Technologies of Hearing Aids

Analog: Sound pressure waves are transformed into an electrical signal by a microphone. These electrical signals are then filtered and transformed by electronic circuitry. The transformed signals are then amplified and presented to the impaired ear by a speaker.

Digital (DSP- Digital Signal Processing): Different from analog in the way it "recognizes" noise and separates it from speech. In digital technology, the electrical waveform is converted into a digital code of a series of zeros and ones. This digital signal is then filtered and transformed by microcomputer and digital signal processing electronics. The transformed signal is then amplified and presented to the impaired ear by a speaker. Digital hearing aids are generally more flexible than analog hearing aids in their ability to give a customized response.

Hybrid (digital controlled analog hearing aid): More common than purely digital hearing aids. A hybrid hearing aid uses digital electronics to control the characteristics of the analog signal processing. A computer is used to program the hearing aid parameters.

Advantages of DSP capable hearing aids may include: Adaptive Signal Processing:

- Automatically adjusts the amount of amplification (gain) hearing aid provides according to the loudness of the sound reaching its microphone.

- Multi-Channel Capability: The amount of gain a hearing aid provides at each pitch or frequency is called its frequency response. Frequency response can be divided into two or more channels of control, allowing the hearing aid to respond differently to low and high-pitched sounds.
- Multi-Memory Capability: Hearing aids can store more than one programmed set of frequency responses. This allows the user to select the program that responds best in the hearing environment.
- Multi-Microphone Capability: Two separate microphones allow the hearing aid to either pick up sound from a broad or narrow view. (Much like a wide angle vs. zoom lens.)

Assistive Listening Systems

Assistive Listening Systems (ALSs), also known as Assistive Listening Devices (ALDs), are amplification systems designed specifically to help people, both hearing and hard-of-hearing, to hear better. ALSs are used to amplify desirable sounds and to reduce undesirable sounds in the environment. ALSs can be used in combination with hearing aids, or by themselves, to overcome background noises and to "reduce" the distance from the sound source.

There are several types of ALSs currently available, including infrared systems, FM systems, loop systems, and personal amplified systems. Although the various types of ALSs use different technologies, they all pick up sound from the source and deliver it directly to the user wearing a receiver.

ALSs are used to enhance sound in large public facilities or in-group situations. The Americans with Disabilities Act requires that ALSs be available at public places, such as courtrooms, schools, theatres, and concert halls. They can also be used by individuals to improve the sounds of television, radio, and conversations. Additionally, many of these technologies can be used for education, public displays (museums, galleries), talking signs, library access, kiosks, etc., in order to separate the signal source from noise, allowing multiple signals to be heard distinctly and clearly.

Types of Large Area Assistive Listening Systems

Conventional Induction Loop Systems (Architectural and Transportation Barriers Compliance Board, 1999): This technology converts the input sound signal to electromagnetic waves that radiate from wire loops placed around the listening area. The wire loop must be placed around the room and the user must remain within the loop in order to stay within the electromagnetic field necessary to receive transmission.

To use an Inductive Loop System, a person speaks into a microphone that is connected to an amplifier. The acoustic energy of the person's voice is changed to electrical signal by the microphone. The electrical energy is sent to the amplifier. The amplified electrical signal is sent through a loop of wire placed around the room. This coil of wire changes the electrical energy to electromagnetic energy. The electromagnetic energy is picked up by the hearing aid telecoil. The hearing aid telecoil changes the electromagnetic signal to an electrical one, which travels through the hearing aid to the hearing aid's receiver (loudspeaker). The hearing aid loudspeaker changes the electrical signal to an acoustic signal (sound) that is delivered to the ear.

3-D Loop Systems (Architectural and Transportation Barriers Compliance Board, 1999) similar to conventional inductive loop systems: An individual's voice is transmitted from the microphone to a 3-D loop processor box. The system's processor transmits the voice signal to the listener's telecoil (or receiver) by means of special "loop mats" that are placed beneath the room's carpet. Reception is not significantly affected by the orientation of the telecoil.

FM Systems (Architectural and Transportation Barriers Compliance Board, 1999): Radio Frequency Modulated (FM) systems transmit sounds via radio waves. There are two kinds of FM transmissions, wide band and narrow band. Ten wide band frequencies can be used for FM transmission. Forty narrow band frequencies are available in the 72-76 MHz band and the 216-217 MHz band. These frequencies are not reserved for hearing aid transmission, making them susceptible to interference.

With a FM System, the person speaks into a microphone. The microphone then changes the acoustic energy of the person's voice into an electrical signal that enters the person's body worn transmitter. The transmitter modulates the electrical signal into a radio wave that is sent through the air to the receiver. The receiver, worn by the listener, picks up the radio waves and changes (demodulates) them back into an electrical signal. The electrical signal is sent to the coupling system worn by the listener.

Infra-Red (IR) Systems (Architectural and Transportation Barriers Compliance Board, 1999): Light waves are used to transmit audio signals by converting them to "invisible to the human eye" light waves, at a wavelength below red light. These waves are picked up by special receivers, which change the signal back to audio. Receiver must be within direct line of sight with the light beam from the transmitter.

Personal Assistive Listening Systems

The following devices are intended for use by a single listener:

Pocketalker: The most common type of device used by an individual is the Pocketalker. This device consists of a small processor about the size of a hand-held radio, a microphone and output device, which both connect by wire to the processor. The person talking speaks into the microphone, and the person with the hearing loss uses the output device to improve speech comprehension of the speaker. The output device can be headphones, earphones, or a wire with a jack that plugs directly into a hearing aid.

Personal FM Systems: Personal FM systems are also popular devices used by a single listener. These devices are more flexible than the Pocketalker, in that they are wireless. Acting much like a radio station, this device has a transmitter that accepts microphone input, and transmits the electronic equivalent of the sound into the air. The receiver grabs the electronic signal and provides the acoustic equivalent to the listener. The speaker wears a compact transmitter and microphone and listeners use portable receivers and earphones.

Wireless Headphones: One technology that many users have found especially useful for television listening is wireless headphones. Available in both FM and Infrared, the input can be through an audio jack plug on the TV, or through a microphone placed near the TV speaker.

Sources of Financial Aid for Hearing Care Technologies

There are a number of options for reimbursement of hearing enhancement technologies. Programs that support these devices include Medicaid (not Medicare), Private Insurance, Community Service Programs, the Department of Veterans Affairs, and others. Assistive Listening Devices, however, are not normally covered by third party reimbursement. Health plans may limit coverage to diagnostic audiology services only, or they may limit coverage to illness/accident-related hearing disorders, excluding hearing services related to congenital causes. Hearing aids are not frequently covered by private health plans, though some benefit packages may include such items. Audiological services delivered to inpatients are routinely included in basic hospital coverage.

Reimbursement for services may be restricted to certain provider settings (hospitals or clinics), or to licensed practitioners. In addition, a primary care physician may have to refer the patient, or "prescribe," audiological treatment. Nearly all insurers will cover audiological diagnostic services when required by a physician to establish a diagnosis. Some companies cover audiologic services and hearing aids when the hearing loss results from illness or injury, but most insurers specifically exclude hearing aid coverage. Recently though, some of the Medicare HMOs have been including a hearing aid benefit in their Medicare plans (American Speech Language Hearing Association, 2000).

Medicaid

Medicaid is a joint state and federally funded program, which provides services on a state-by-state basis to financially needy individuals. It may cover any service fees (health care provider visits), hearing aid at invoice cost (only basic, analog hearing aids), and sometimes an allowance for other equipment.

- Eligibility is based on financial need and medical necessity (as determined by health care provider).
- Medicaid HMO plans which provide hearing plans include MediService, Community Care, and Partners.
- Individual states are permitted to offer the following types of optional services, provided they are specified in that state's approved Medicaid plan: clinical services; treatment for speech, hearing, and language disorders; other diagnostic, screening, and rehabilitative services; and any other type of medical or remedial care recognized under state law and approved by the Secretary of Health and Human Services.

Medicare

Medicare specifically excludes hearing aid coverage. An initial diagnostic visit may be covered if it is determined a patient does not need a hearing aid (or it is not reported that a hearing aid is needed). Individuals must meet standard qualifications for Medicare program.

Rehabilitation Services Administration (Vocational Rehabilitation)

State-federal program authorized by the Rehabilitation Act of 1973, which provides services for individuals with disabilities in order to assist them in obtaining employment. Approximately 7.3% of the rehabilitation services provided by VR in 1998 were devoted to qualified, hard-of-hearing individuals (U.S. Department of Education, 1991). Individuals must meet eligibility requirements to participate in VR program.

U.S. Veterans Administration

Veterans must contact a VA medical facility near their home. All World War I Veterans are eligible to receive free hearing aids. Other veterans can receive free hearing aids if their hearing loss is at least 50% service-related. The Veterans Health Care Act provides free TeleCaption decoders to veterans who have a profound hearing loss that is service-related. The VA will also provide TTYs and telephone amplification devices to veterans with service-related hearing loss. Some assistive devices may also be reimbursable (Gallaudet University, 1999).

- VA will pay for hearing aids, batteries and repairs - classified under Audiology and Prosthetics & Sensory Aids.

Private Insurance

Private insurance hearing coverage is limited and varies among companies and individual policies.

Civic & Service Organizations (Gallaudet University, 1999)

Many community service organizations receive charitable donations to purchase hearing aids and other devices for low-income individuals who are deaf or hard-of-hearing. Community clubs often recondition hearing aids and donate them to needy individuals.

Local Agencies & Programs (Gallaudet University, 1999)

Local agencies sometimes receive donations or private funds to assist with various needs. Speech and hearing centers may provide hearing aids at a reduced rate for clients who have used their services for audiological assessment. Some areas have hearing aid banks that distribute reconditioned hearing aids to individuals ineligible for financial assistance. These banks are often affiliated with local service organizations.

Additional Funding Sources

Although there are limited additional sources of funding available, some do exist. In some cases, for example, people have been able to convince an individual company (i.e., in the case of an employee funded medical plan) to reimburse an employee for their own, or a family member's, hearing aid expense (Hearing Industries Association, 1999).

- Trade-ins: If a hearing aid purchaser already has a hearing aid, it may be possible to receive a trade-in value on the old hearing aid when purchasing a new hearing aid. Although not common, this option does exist. This trade-in value is determined by the hearing aid dispenser on an individual basis.
- Leasing: There has been a trend in recent years of hearing aid dispensers offering patients the option of leasing, rather than buying, a hearing aid. This not only allows payments to be spread out over the useful life of the aid, but also permits the user to update technology without worrying about a huge lump sum payment. The terms and conditions of this arrangement must be worked out with the hearing aid dispenser on an individual basis.
- HEAR NOW (Gallaudet University, 1999): This unique national program provides assistance to individuals and families with limited financial resources. HEAR NOW maintains the National Hearing Aid Bank, which provides new and reconditioned hearing aids to people who are deaf and hard-of-hearing who cannot otherwise afford them. These hearing aids are distributed through hearing health care providers in communities nationwide. HEAR NOW also has a Cochlear Implant Program that raises funds to provide cochlear implants and related services to both adults and children.

ADA Compliance Reimbursement

The ADA requires, "No person shall be discriminated against on the basis of disability in the full and equal enjoyment of the goods, facilities, privileges, advantages, and accommodations of any place or public accommodation." The Architectural and Transportation Barriers Compliance Board (also known as the Access Board) states that FM, infrared and induction loop assistive listening systems are acceptable for meeting the requirements of the ADA.

The 1990 amendment to the Americans with Disabilities Act permits eligible small businesses to receive a tax credit for certain costs of compliance with the ADA. An eligible small business is one whose gross receipts do not exceed $1,000,000 or whose workforce does not consist of more than 30 full-time workers. Qualifying businesses may claim a credit of up to 50% of eligible access expenditures that are between $250 and $10,250. Examples of eligible access expenditures include the necessary and reasonable costs of removing architectural, physical, communications, and transportation barriers; providing readers, interpreters, and other auxiliary aids; and acquiring or modifying equipment or devices. Assistive listening devices may fall under this reimbursement category (The US Equal Employment Opportunity Commission, 1990).

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Overview of Technologies

The Forum on Hearing Enhancement has focused on earmold technology, inductive loop systems, infrared systems, FM systems and microphone technology. These technologies were familiar to end-users, clinicians, researchers, manufacturers and other Forum participants – providing common ground for a lively, inclusive discussion. Many recommendations for technology specific refinements and innovations have been put forward.

Immediately following this introduction are comments from Dr. Charles Laszlo and Dr. Mark Ross. I want to thank each of these gentlemen for giving of their time and sharing their important insights.

Readers are encouraged to consider the overall system concept. New, innovative or revolutionary approaches that are independent of the technologies under consideration might provide the superior solution. Dr. Laszlo's comments introducing this section of the Proceedings are particularly relevant.

For each technology area there are three distinct sections: the White Paper, Forum Data, and one or more Problem Statements. There is one exception in that a single White Paper was written for Infrared and Inductive Loop Systems. A description of each section follows.

White Papers include information on unmet customer needs, market information, business opportunities, and technology state-of-the-practice for products now in the market. White Papers compliment the Industry Summary. The White Papers were provided to all participants prior to the Forum in order to establish a common knowledge base.

Forum Data is a summary of the statements obtained from group participants. Forum Data includes: priority customer needs; technology "state-of-the-practice" for products currently in the marketplace; requirements and performance specifications for sought-after technology and barriers that might prevent the development or transfer of the sought-after technology. Forum Data was derived from group transcripts, observer notes, and group summaries developed by the participants. Comments are logically grouped and paraphrased. Care has been taken to avoid distortion while providing information in a format that is clear, concise and unambiguous. A more complete description of Forum Protocols can be found in the Pre-Forum section of these Proceedings.

Problem Statements provide a brief introduction to the market and customer needs, the state-of-the-practice for technology in the marketplace and technology requirements. Problem statements have been internally and externally reviewed prior to publication. Technology requirements are disseminated to technology developers in the public (Federal Laboratories, Research Universities) and private (advanced technology manufacturers) sectors. The primary vehicles for dissemination include: the T^{2}RERC website (cosmos.buffalo.edu/hearing), Federal Laboratory Locator Service, Federal Laboratory website (www.federallabs.org), Federal Laboratory newsletter (FLC NEWSLink) and NASA Technical Briefs (Readers Forum).

Post Forum Comments

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The proper way to look at the classification of assistive listening device technologies

At the Forum we have examined existing assistive listening devices divided into FM, infrared and loop categories. I wish to submit that such a categorization is based on only one aspect of assistive device technologies, and that due to the shortage of time we did not have the opportunity to fully synthesise our views on the "common" problems.

The main purpose of assistive listening devices is to deliver "clear speech". Clear speech may be defined as speech delivered to the hard of hearing listener from the speaker's mouth, or from a TV or other sound system, without any distortion by echoes, corruption by noise, or modification by acoustical conditions. The general scheme for all assistive listening devices is shown in the attached diagram.

As illustrated, the existing technologies (FM, infrared, inductive) differ only in the method by which the signal is transmitted non-acoustically. They all share the common components required to convert the acoustical signal to a high-quality electrical signal, and on the other end, to deliver the signal in the most appropriate form to the hard of hearing listener.

Any analysis or comparison of the different technologies available today, and the evaluation of technologies that may become available in the future, must be considered in this general framework. Some problems, such as microphone arrangements and signal acquisition are common to all system, while other matters, such as privacy, depend on the transmission method (FM, infrared, inductive) used.

It became apparent at the verbal presentation of the summary reports at the Forum, that this essential distinction was somewhat lost. For example, specific recommendations were made for improved microphone arrangements for FM systems, but not for infrared or loop systems. Yet, the microphone issue is common for all system, whatever transmission methods they may use.

I would recommend that in the preparation of the final report the common issues, and the issues specific to each of the transmission methods, be clearly separated. The scheme illustrated provides the correct framework for presenting the existing obstacles and the technological needs in this area.

A view on accessibility for hard of hearing people

A major concern of people with disabilities is accessibility, but this term has different meaning to people with different disabilities. For example, people in wheelchairs are concerned with mechanical accessibility to places and services so that they can get access to buildings, enter rooms, use bathrooms, reach telephones, and so on. Hard of hearing people define accessibility in terms of their ability to communicate and to understand verbal communication. In this context signs and written instructions, quiet acoustical surroundings, good lighting to aid speech reading, and assistive listening devices are important.

In the US and Canada the fight for such hearing or communication accessibility has been a major focus for hard of hearing people, and some spectacular results have been achieved. For example, and we now have laws that require telephones to be hearing aid compatible. Such laws have a profound impact. Hard of hearing people can now reasonable expect that eventually all telephones will be accessible to them. The responsibility to provide such telephones is not the responsibility of the individual hard of hearing person; he or she has to do nothing. The responsibility has been passed on to the manufacturers and suppliers of telephones to ensure that hearing aid compatibility exists. Naturally, the hard of hearing person still has the responsibility to obtain a suitable hearing aid equipped with a T-switch in order to take advantage of the capabilities of hearing aid compatible telephones. If the hard of hearing person decides to use a hearing aid without the T-switch, then we expect that he or she is prepared to bear the consequences.

The decision to introduce laws that require that public utilities supply the means of access through the hearing aid compatible telephone is an act by society to provide the means of communication for hard of hearing people. It seems to be obvious that such societal action with respect to telephone accessibility cannot succeed without hard of hearing people taking the responsibility to ensure that they take advantage of what is made available to them. In other words, they must decide to purchase the right kind of hearing aid.

Another major aspect of accessibility for hard of hearing people is the ability to hear, communicate, and participate in those aspects of life where live speech, verbal presentation, face-to-face communication, and interaction are essential. Unfortunately, in many everyday environments it is difficult, and often impossible, for hard of hearing people to communicate effectively. For this reason hard of hearing consumer organizations are exerting a great deal of pressure on governments, schools, churches, health care institutions, entertainment facilities, and on businesses to provide hearing-accessible environments.

Among the factors that help to create such accessible environments the acoustics of rooms is obviously very important. The creation of good acoustical environments is difficult, but nevertheless it should be a major concern in the architectural and engineering design of buildings. Not much can be expected in the improvement of existing buildings, and so in general we must continue to cope with generally poor acoustical environments.

This is one of the reasons why assistive listening devices and systems are gaining popularity. Specifically, under certain circumstances, such devices can overcome the barriers created by poor acoustical conditions. Thus, the demand for better accessibility is closely linked to the performance and availability of assistive listening devices. It is significant that at present the tendency is to judge accessibility in terms of what facilities are provided by others. For example, we consider a movie theatre or similar public place hearing-accessible if a suitable infrared, FM, or loop system is provided.

In general, hard of hearing people expect that accessible public places provide both the transmitters and the receivers for infrared and FM systems. From the provider's point of view, making available the transmitter part of the system requires a one-time installation. For example, to set up the equipment for the transmitting part of an infrared system in a meeting hall, it is necessary to install a bank of microphones, a microphone selector, an amplifier, and the infrared panels, and to establish cable connections to all these parts. The financial investment in such a system may be quite substantial. However, microphones and other components of the system often exist as part of the public address system, and so costs can be kept within reasonable limits. The important point is that the provider has to be concerned about the system only once. They have to make a capital investment, and apart from some occasional maintenance, have very little to do with the transmitting part of the system afterwards.

The receiver part, however, is another matter. To make these available requires a substantial on-going operational effort. To use our example of the infrared system, the operator of the meeting hall must ensure that there are a sufficient number of receivers, neck loops, silhouettes, and earphones available. The operator must also have staff to ensure that the batteries are charged and that the receivers are working well, that the receivers are handed out and collected(!) after use, that their operation is explained to hard of hearing people, and that assistance is given to those who run into trouble with the equipment. To ensure that all is running smoothly requires careful organization and specially trained people. This is very costly and troublesome for most operators.

Not surprisingly, experience has shown that while institutions are prepared to supply the installations that involve the transmitting equipment, many are reluctant to commit themselves to the related facilities and personnel required by the operational management of the receivers.

It is not difficult to appreciate the problem. Hard of hearing people are often frustrated by not being able to use an assistive listening device which has been provided for them. They commonly encounter inoperative receivers, discharged batteries, unfamiliar equipment, and lack of help! Thus, hard of hearing people feel that the many institutions and commercial establishments are insensitive and are not interested in providing proper accessibility, while on the other hand, management of facilities often conclude that hard of hearing people are not appreciative of their efforts and make unreasonable demands. Stories of unhappy experiences of operators are abound, and these negatively influence the motivation of managers to install systems for hard of hearing people. It is truly a sad situation when goodwill and effort results in frustration and bad feelings on both sides!

In view of these experiences it seems reasonable to believe that hard of hearing people would enjoy much greater accessibility and satisfaction if they would own and could use their own receivers no matter where they go! Firstly, many more public and private establishments would be equipped with transmitters if management did not have to worry about receivers. Secondly, users themselves would ensure that the equipment is working well with fresh batteries installed, and would of course know how to use the receivers with or without their hearing aid.

But is this a feasible proposition? The answer is yes, it is, provided some conditions are met.

The first condition is that both transmitters and receivers must be made to conform to standards so that all of the user-owned receivers will work with any infrared, FM or loop installation. While such standards do not exist at present, they would be in the best interests of all parties.

The second condition is that the receivers must be simple to operate. At present some receivers have too many adjustments, dials and buttons, making them difficult and confusing to operate. However, operational simplicity could be achieved with the increasing use of microelectronics and careful design.

The third condition is reliability and robustness. There are no technical or manufacturing reasons why receivers could not be made reliable. Equipment already on the market seldom requires repairs, and the electronics are already very robust. With simplification most controls could be eliminated, allowing the introduction of "unbreakable" designs.

The fourth condition is low cost. Receivers, some of which are quite expensive at present, could be made generally affordable with economies of scale brought about by a large market. This large market would be created if millions of hard of hearing people would begin buying their own equipment!

The fifth condition depends on the four previous ones and is perhaps the most important. This condition is the interest and willingness of hard of hearing individuals to actively accept more responsibility for accessibility. If hard of hearing people could be assured that a standardised system widely supported and serviced by businesses, institutions, and governments is in place, it would then become possible for them to accept this responsibility through the "ownership" of their receivers.

Due to the shortage of time, there was no opportunity to discuss this matter at the Forum. Nevertheless, I believe that this is an important, and possibly decisive, consideration and should be included in a "demand-pull" examination of the assistive listening device field.

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One of the biggest problems faced by people with hearing loss was exemplified several times during our meeting, and that is hearing the other people around a banquet table in a large room. This would be exacerbated in some social event (weddings, parties, etc.) in which a band was playing.

What I think would help tremendously are small (one to two inches) FM mike/ transmitters, limited range (10-15 feet), each with a different numbered frequency, and each worn by a different person around a banquet table (maybe eight or ten of them). They would transmit to a mixer (I visualize a rectangular, battery powered unit, about 10 inches long) that would retransmit the signal to a personal receiver worn by the hearing-impaired person. The mixer would contain on/off switches (with a light) for each numbered frequency. That way, the listener could control which mike to activate. If two or three people were engaged in a conversation, this would also work, as long as one person talked at a time.

Many people with hearing loss would be reluctant to take advantage of such a device, but still others would. We can never bat a 1000. I'd like to think that it was at least available (if technically feasible) if someone wanted to take advantage of it.

TECHNOLOGY AREA

Researchers, manufacturers and end-users identified earmold materials, fitting and production as technology areas that could benefit from technological innovation and refinement. They believed that development of improved earmold technology would meet important user needs and represent significant business opportunities.

THE NEED

It is estimated that more than 20 million people in the United States experience some form of hearing loss. Yet, according to research reported by Dr. Sergei Kochkin, only 21% to 22% of the people use hearing devices (Kochkin, 1997b). Further research indicates the reasons that people who experience hearing loss chose not to use the available technology include: hearing aids do not perform in noisy situations (7.1 million), provide too much whistle or feedback (6.4 million), do not work well (4.8 million), work only in limited situations (4.3 million), have poor sound quality (3.9 million), break down too much (3.4 million), cannot be used on the telephone (3.1 million), and negative experiences of friends (3.9 million) (Kochkin, 1997a).

As previously mentioned, a common annoyance is the presence of feedback (6.4 million) experienced by the hearing aid user. There are two types of acoustic feedback: (1) produced internally from the hearing aid, indicating a need for repair; and (2) the more common cause, externally produced feedback due to leakage of amplified sound, that radiates from the speaker and then is picked up by the microphone and re-amplified. In many cases, the feedback can be addressed by either repositioning the hearing aid or by reshaping the earmold so that its fit conforms more closely to the shape of the ear canal (Smedley & Schow, 1998; Sweetow, 1998).

The earmold provides several basic functions. First, it couples the hearing aid with the user's ear. It channels the sound from the hearing aid, through the ear canal, to the eardrum. The earmold also helps to secure the hearing aid in place. The challenge is to provide the user with a secure fit. Yet the tighter the fit, the more uncomfortable the device is to wear. A well-fitted earmold directs sound from the hearing aid to the ear without feedback, thus allowing the user to hear comfortably (Lachapelle, 1999). Earmolds are required for all hearing aids, and since the anatomical structure of the ear varies from person to person, the majority (80%) of all earmolds are custom-made.

An earmold is also used to protect hearing in environments with loud noise. For example, the earmold can be used in recreational settings such as car racing, hunting, and for fans of sports or music during games and concerts. It also provides hearing protection for industrial workers such as carpenters, factory workers, machinists, and others (Earmold Design, 2000).

The use of earmolds for Assistive Listening Devices (ALD) is less common; however, in those situations where earmolds are appropriate, the general characteristics do not vary from those of a hearing aid. Only 5% of the people who experience hearing loss use ALDs (National Center for Health Statistics, 1997).

BASIS FOR DISCUSSION

There is a need to improve the comfort of earmolds while maintaining the secure fit necessary for proper hearing aid function, including the reduction of acoustic feedback.

Chewing, yawning, and other facial movements change the geometry of the ear canal structure. As the anatomic structure changes, the fit of the earmold is affected causing an increase in acoustic feedback. The hearing instrument may dislodge from the ear if the ear canal's shape is changed.

Feedback occurs when the hearing aid does not fit properly and the output signal leaks around the earmold, is received by the hearing aid microphone, and is amplified. Other causes of feedback include the vents that are drilled into them. Vents are used to reduce the "plugged up" feeling experienced when the user speaks. However, the vent also provides an opening for the sound to create feedback within the hearing aid. At high amplification the output signal can again be picked up by the hearing aid microphone and be amplified. Users who experience significant feedback will adjust the hearing instrument's gain, or will turn it off completely. In the worst case situation, the hearing aid user will stop wearing the device all together.

Issues that relate to hearing aids are equivalent to the issues for earmolds used for hearing protection. The overall fit and comfort are critical in the success of providing protection to the hearing of the user in environments with sustained high noise levels.

STATEMENT OF THE PROBLEM

The earmold is an important link in fitting a hearing aid system and must meet multiple requirements. The earmold must:

- Provide a satisfactory acoustic seal.
- Acoustically couple the hearing aid to the ear.
- Retain the hearing aid on the pinna (auricle).
- The earmold must be better integrated into the overall design and performance of the hearing aid.
- Be comfortable to wear for an extended period.
- Be aesthetically acceptable to the user.
- Be of a style that the user can physically handle.

Failure to meet any of these requirements will increase the likelihood of product abandonment by the user. Therefore, Stakeholders desire improvements in the fitting, production, comfort and performance of earmolds as they are used for hearing aids or as hearing protection devices.

CURRENT SOLUTIONS

Custom modification of the earmold aids in the overall fit (comfort & security) and minimizes acoustic feedback. These custom designs are handmade which is time consuming and costly. Yet, the time taken to properly fit the ear canal in the beginning may reduce the need for modification to the earmold shell later.

There are a number of options in the type of materials used to create the earmold. Proper selection of the material is critical to improve the overall fit and comfort to the user. Some materials may cause allergic reactions for the user, some provide options in colors, while others are simply more comfortable for the user (individual perception). Material characteristics or properties may change over time and become hard, or may experience shrinkage causing poor fit or discomfort to the user. hearing aid. Three of the most common options include; venting, dampers and horn effects. Each will affect different portions of the hearing aid response curve (Microsonic, 2000a).

Venting is an opening that is drilled into the earmold to release low frequency sound. This reduces the "plugged feeling" experienced by the hearing aid user while speaking, described as "talking inside a barrel." This sensation is called the *occlusion effect.*

Dampers are materials that are used to alter the frequency and decrease unwanted peaks of sound waves. Common materials used include wool, plastic and metal, which fit inside the earmold tubing.

The *horn effect* is provided when the bore of the earmold increases as it goes deeper into the ear canal. It increases and extends the high frequency sound waves. A *reverse horn effect* is achieved by adapting the earmold to gradually narrow towards the inner portion of the ear canal

Additional adjustments to the earmold can be made by buffing and shaping the product for a better fit. However, this is a "hit and miss" approach. Another method of securing the earmold in the ear canal is to wrap the shell with a flexible material that will provide a temporary solution to the problem.

Health care professionals must evaluate each person individually as to the material and style selection of earmolds to best meet their needs and to ensure the highest success rate with the hearing aid. Issues to consider include:

- whether the user is active or sedentary in their lifestyle,
- user dexterity (for example, the persons ability to handle hearing aid insertion, daily care, and cleaning of the earmold),
- the anatomy of the individual's ear and the affect it has on the choice of material or style of hearing aids that are to be used (anatomic considerations when choosing a hearing aid include: a deformed outer ear, the depth of the concha, whether ear canal is of sufficient diameter and whether there is a sharp enough bend to hold the hearing aid),
- growth changes, (in particular children),
- changes in morphology of the ear canal as it slowly adapts to the continuous pressure of the device (continuous pressure may cause the area to expand slightly),
- amplification objectives of the fitting,
- toxicity or allergies to plastics,
- appearance -- color selection, hearing aid style and earmold design options, and
- the number of modifications that ma be required after delivery of the device (Microsonic, 2000b).

Each manufacturer offers a variety of materials to be used with earmolds to meet the specific needs of each client. Choosing the correct material for earmolds is as important as determining the earmold style and acoustics. Some of the generic varieties include:

- *Acrylic* is used to create hard custom earmolds, used with mild to severe hearing losses. Most earmold styles can be made with acrylic and are available in a range of color options.

- *Polyethylene* is a semi-rigid material and is hypoallergenic. It is used for mild to severe hearing losses. Polyethylene is not as durable as other materials and should be handled with care. The color selection is limited to white.

- *Silicone* is a flexible inert material that is useful when fitting client's with allergy problems (although the hypoallergenic feature is not available if produced in any color other than beige or clear). There is little to no shrinkage with silicone and can therefore be used when fitting high-power hearing aids.

- *Lucite* is a clear synthetic plastic resin that is rigid at all temperatures. It is useful for mild to moderate hearing losses. It does not shrink over time, is easy to grind and buff, but is not recommended for children.

- *Poly Vinyls* (Polymerized vinyl) provide a soft, comfortable fit with a superior acoustic seal. The texture of the material provides a rich mellow sound quality that preserves the harmonic and resonant characteristics of the ear canal.

ISSUES TO CONSIDER

- Are new materials available to provide the comfort and snug fit needed to produce the highest level of speech recognition while reducing acoustic feedback?

- What methods of making an impression of the ear canal could be improved to create a better earmold?

- Is there a better way to measure the internal cavity of the ear canal that could be transmitted to a computer program that fabricates the earmold?

- What type of adjustments should be available to the earmold once a client has been fitted with the hearing aid?

- What physical characteristics in the materials used for making earmolds would enhance the ability to make alterations once the mold has been created?

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DATA: EARMOLDS

The following is the raw data collected during the stakeholder forum. It reflects the comments and needs as expressed by the forum participants.

1. Needs (unmet needs of consumers, clinicians, etc.)

- Measurement process needs to be more comfortable for the client by reducing the time that the impression material is in place.
- Earmolds need to be flexible to accommodate changes in head position (tilting the head or when bending over; sitting upright or slouching), and jaw positions or movement (when talking, eating, or laughing).
- Earmold materials need to remain comfortable and unaffected by prolonged contact with the skin, skin oils, or earwax.
- Earmold material needs to remain flexible without hardening over time.
- Need earmolds that are easy to insert into the ear canal.
- Need to reduce/eliminate feedback.
- Need to provide the same quality of sound as a person that doesn't use a hearing aid.
- Need to improve earmold aesthetics by making them less obvious (e.g. smaller earmolds, materials that are clear and will more closely match the wearer's skin color)

Note: smaller earmolds will impact other aspects of the hearing aid that are more important to the user. For example, sound quality, keeping the hearing aid securely in place, and placement of electronic components within the hearing aid).

- Need to create an earmold that is disposable and low cost.
- Need to eliminate the need for earmolds all together.
- Need ear-hook dampers that do not clog, or are self-cleaning.
- Need to identify a method that accurately measures the shape of the ear canal without the use of casting materials.
- Need to measure points of increased pressure within the ear canal, or areas that cause skin irritation. Allow measurements to be taken at different parts of the ear.
- Need to improve the measurement process (more accurate) with standardized methods to reduce the chance of error during the initial casting of the mold, or when replacement earmolds are required.
- Need 3-D image of the ear canal. Images kept in an electronic file could be maintained indefinitely, unlike earmold impressions that are kept for a short period of time.
- Need casting materials that are comfortable to the client, yet is flexible enough to register accurate impressions and will not shrink between the times the impression is taken and the earmold are cast.
- Need casting material that remain fluid until it comes in contact with the ear canal where is sets quickly to reduce the chance of the material leaking out of the canal.
- Need earmolds that accurately fit within the ear canal and conform to changes within the ear throughout the day -- depending on the time of day and on jaw and body movements.

- Need earmold material that is biocompatible with the ear environment over a long period of time. The ear recognizes an earmold as a foreign object and tries to eject it by increasing the amount of earwax and skin oils.
- Need earmold material that is stable for a long period of time; maintain its shape and hardness; does not absorb skin oils, earwax or water; and is non-irritating, non-allergenic, and resists bacteria.
- Need tubing materials that is compatible with the earmold and will not change color, shrink or deteriorate.
- Need to create same day production of the earmold to reduce impact caused by shrinkage that occurs between the time when the measurements are taken and the earmold is produced.
- Need to train technicians so that they employ consistent fitting methods - reduce irregular fittings regardless of the manufacturer.
- Need manufacturers to agree on consistent methods of production, and materials used for creating impressions and for the earmolds themselves.
- Need better communication between the clinician and consumer so they have realistic expectations of the process and end results of using a hearing aid.
- Need to work with other industries to increase the size of the market to increase the value of committing research and development efforts. The hearing industry itself is too small to justify large investments of time and resources.

2. State-of-the-Practice (current technology, strengths, weaknesses, etc.)

- Technology for the hearing industry has been transferred from the dental industry, however material requirements for dental and hearing applications differ. Earmold material (1) must be flexible and accommodate changes in the ear canal throughout the day. For example, after being worn a few hours, the earmold will cause the ear canal to stretch. (2) The ear canal is flexible, warm and moist and has many sharp angles and changes of direction. This same flexible material must provide a snug secure fit without causing irritation. (3) Creating the earmold shape depends upon measurements where the clinician cannot see the actual anatomy where the product will be used.
- Impressions are a static measurement (snapshot) while the ear canal constantly changes in response to such factors as head position, jaw movement, time of day when the impression is made, posture and whether the person was wearing a hearing aid just prior to the measurements being taken. Changing the position of the jaw can cause a variance in canal diameter of more than 30% depending upon whether the mouth is opened or closed. It is best to make more than one impression.
- Casting material and impression making technique differs somewhat between clinicians and from client to client. A technician's technique for making earmolds from these impressions depends upon who provides their training. "This process [from making the impression to a finished earmold] is considered by industry insiders as an "art form" rather than a science which cannot be repeated consistently. Ten impressions [for the same client] made by ten clinicians would yield ten very different earmolds.

- Casting material shrinks as it hardens. The length of time between when the impression is made by the clinician versus when the earmold is produced by the technician will vary greatly by days. The amount of shrinkage depends upon the time difference between measurement and production. For this reason, it is unreasonable for the manufacturers to keep impressions for an extended period of time and new impressions must be taken each time the earmold is reproduced.
- Earmold material differs between manufacturers, with client needs, and with the type of the hearing loss. Silicone, acrylics and polymers are examples of earmold materials used today. The clinician may also prefer one material or another based upon their ability to customize the earmold's shape after it has been cast.
- The body considers the earmold as a foreign body within the ear canal and tries to remove it by increasing the production of oils or wax. In addition, skin sensitivity is heightened with a foreign body in place. Improper measurements (or earmolds that change physical characteristics over time) may cause irritation and soreness that may result in the hearing aid not being used.
- Earmolds have an average lifespan of about two years. (Earmold lifespan among forum participants ranged from three months to thirteen years.) Earmold lifespan is dependent upon changes to the ear canal (e.g. canal growth in a young child); by the materials used (e.g. polymers have a relatively short lifespan and quickly discolor from skin oils and earwax); by how well the earmold is maintained (cleaning), and by changes to client's audiogram (requiring a different earmold).

3. Needed Technology (refinements, innovations, etc.)

- Automate and standardize the process by which earmolds are produced. Eliminate variability in methods and materials starting with the fitting process through to the finished product. Eliminate the "art" of creating an earmold.
- Computerized measurement of the ear canal. Create 3-D image and measurements (e.g. by using lasers, MRI or CAT scan etc.) that can be transformed into a mathematical representation of the ear canal and used to produce the earmold. This will ensure consistency in measurements, eliminate errors caused by shrinkage, and provide a permanent record of the impression to be kept on file.
- Rapid production of the earmold and hearing aid. One-day turn around from measurement to use is ideal.
- Earmold material
  - Flexibility to adapt to dimensional changes within the ear (e.g. due to head position or movement)
  - Long-term stability
  - Not susceptible to oils and wax
  - Will not shrink over time
  - Does not induce increased oil and wax production
  - Easy to clean
  - Provide "self-disinfecting" characteristics when in contact with open sores

- Specific earmold design suggestions included:
    - o Surround the earmold with a gel-like material that will “flex” with changes that might occur within the ear canal while maintaining a secure fit.
    - o A reverse thermal gel that hardens in the ear canal at body temperature (while remaining pliable for comfort) and softens at room temperature (for easy insertion).
    - o A “pneumatic earmold” that can be “pumped up” to provide a secure fit and deflated for insertion or removal.
    - o Prefabricate earmolds in standard sizes and shapes. Each earmold fits a certain range of (ear canal) sizes and shapes. This technology will enhance the development of disposable earmolds that are less expensive to purchase and reduces the need for technician related fittings after the initial measurements have been made.
- An earmold that has similar properties/characteristics of a contact lens on the eye.
    - o An open earmold.
    - o Material that has a "chameleon-like" ability to adapt to match the wearer's skin color -- similar to technology used with photo-gray eye lenses.

4. Barriers (to obtaining technology, to developing technology, etc.)

- The hearing aid market is not large enough to encourage investment in research and development efforts.
- Creating an "electronic" or 3-D image of the ear canal is difficult because of hair, wax or other debris that may be a temporary affect the shape and size of the ear canal.
- Participants are not aware of any materials suitable for making ear canal impressions that will not shrink.
- Participants are not aware of any materials suitable for making earmolds that have all of the desired characteristics.

Earmolds Problem Statements

Problem Statement - Earmolds
Manufacturers, researchers and clinicians have identified **computerized ear canal measurement** (e.g. 3D laser scanning), **automated earmold production** (e.g. one-day turnaround, computer automated), **earmold materials** (e.g. reverse thermal gels) and **designs** (multi-material, pneumatic, etc.) as addressing high-priority needs for persons with hearing impairments, clinicians and production technicians. Technology solutions represent good business opportunities for manufacturers.

MARKET
It is estimated that more than 20 million people in the United States experience some form of hearing loss. However, according to the 1990-91 National Health Survey, only 18% of those who identified themselves as having hearing problems use hearing aids (over the age of three and non-institutionalized). The reasons people who experience hearing loss but chose not to use the available technologies include: "hearing aids do not perform in noisy situations" (7.1 million), "provide too much whistle or feedback" (6.4 million), "do not work well" (4.8 million) or "work only in limited situations" (4.3 million), "have poor sound quality" (3.9 million), "break down too much" (3.4 million), "can not be used on the telephone" (3.1 million), and "negative experiences of friends" (3.9 million) (Kochkin, 1997).

The earmold provides several basic functions. First, it couples the hearing aid with the user's ear. It channels the sound from the hearing aid, through the ear canal, to the eardrum. The earmold also helps to secure the hearing aid in place. The challenge is to provide the user with a secure fit. Yet the tighter the fit, the more uncomfortable the device is to wear. A well-fitted earmold directs sound from the hearing aid to the ear without feedback, thus allowing the user to hear comfortably (Lachapelle, 1999). Earmolds are required for all hearing aids, and since the anatomical structure of the ear varies from person to person, the majority (80%) of all earmolds are custom-made.

Feedback is experienced by 6.4 million hearing aid users. There are two types of acoustic feedback: (1) produced internally from the hearing aid, indicating a need for repair; and (2) the more common cause, externally produced feedback due to leakage of amplified sound, that radiates from the speaker and then is picked up by the microphone and re-amplified. In many cases, the feedback can be addressed by either repositioning the hearing aid or by reshaping the earmold so that its fit conforms more closely to the shape of the ear canal (Smedley & Schow, 1998; Sweetow, 1998).

Feedback occurs when the hearing aid does not fit properly and the output signal leaks around the earmold, is received by the hearing aid microphone, and is amplified. Other causes of feedback include the vents that are drilled into them. Vents are used to reduce the "plugged up" feeling experienced when the user speaks. However, the vent also provides an opening for the sound to create feedback within the hearing aid. At high amplification the output signal can again be picked up by the hearing aid microphone and be amplified. Users who experience significant feedback will adjust the hearing instrument's gain, or will turn it off completely. In the worst-case situation, the hearing aid user will stop wearing the device all together.

There is a need to improve the comfort of earmolds while maintaining the secure fit necessary for proper hearing aid function, including the reduction of acoustic feedback. Chewing, yawning, and other facial movements change the geometry of the ear canal structure. As the anatomic structure changes, the fit of the earmold is affected causing an increase in acoustic feedback. The hearing instrument may dislodge from the ear if the ear canal's shape is changed.

CURRENT TECHNOLOGY

Health care professionals must evaluate each person individually as to the material and style selection of earmolds to best meet their needs and to ensure the highest success rate with the hearing aid. Issues to consider include:

- whether the user is active or sedentary in their lifestyle,
- user dexterity (for example, the persons ability to handle hearing aid insertion, daily care, and cleaning of the earmold),
- the anatomy of the individual's ear and the affect it has on the choice of material or style of hearing aids that are to be used (anatomic considerations when choosing a hearing aid include: a deformed outer ear, the depth of the concha, whether ear canal is of sufficient diameter and whether there is a sharp enough bend to hold the hearing aid),
- growth changes, (in particular children),
- changes in morphology of the ear canal as it slowly adapts to the continuous pressure of the device (continuous pressure may cause the area to expand slightly),
- amplification objectives of the fitting,
- toxicity or allergies to plastics,
- appearance -- color selection, hearing aid style and earmold design options, and
- the number of modifications that may be required after delivery of the device (Microsonic, 2000b).

Custom modification of the earmold aids in the overall fit (comfort & security) and minimizes acoustic feedback. These custom designs are handmade which is time consuming and costly. Yet, the time taken to properly fit the ear canal in the beginning may reduce the need for modification to the earmold shell later.

Technology for the hearing industry has been transferred from the dental industry, however material requirements for dental and hearing applications differ. Earmold material (1) must be flexible and accommodate changes in the ear canal throughout the day. For example, after being worn a few hours, the earmold will cause the ear canal to stretch. (2) The ear canal is flexible, warm and moist and has many sharp angles and changes of direction. This same flexible material must provide a snug secure fit without causing irritation. (3) Creating the earmold shape depends upon measurements where the clinician cannot see the actual anatomy where the product will be used.

Impressions are a static measurement (snapshot) while the ear canal constantly changes in response to such factors as head position, jaw movement, time of day when the impression is made, posture and whether the person was wearing a hearing aid just prior to the measurements being taken. Changing the position of the jaw can cause a variance in canal diameter of more than 30%

depending on whether the mouth is opened or closed. It is best to make more than one impression.

Casting materials and impression making techniques differ somewhat between clinicians and from client to client. The technician's techniques for making earmolds from these impressions depend upon their training. "This process [from making the impression to a finished earmold] is considered by industry insiders as an "art form" rather than a science which cannot be repeated consistently. [For example,] ten impressions [for the same client] made by ten clinicians would yield ten very different earmolds" (Stakeholder Forum Participant, 2000).

Casting material shrinks as it hardens. The length of time between when the impression is made by the clinician versus when the earmold is produced by the technician will vary greatly by days. The amount of shrinkage depends upon the time difference between measurement and production. For this reason, it is unreasonable for the manufacturers to keep impressions for an extended period of time and new impressions must be taken each time the earmold is reproduced.

There are a number of options in the type of materials used to create the earmold, which differ between manufacturers, with client needs, and with the type of the hearing loss. The clinician may also prefer one material or another based upon their ability to customize the earmold's shape after it has been cast.

Proper selection of the earmold material is critical to improve the overall fit and comfort to the user. Silicone, acrylics and polymers are examples of earmold materials used today. Some materials may cause allergic reactions for the user, some provide options in colors, while others are simply more comfortable for the user (individual perception). Material characteristics or properties may change over time and become hard, or may experience shrinkage causing poor fit or discomfort to the user.

Acoustic modifications of the earmold can significantly enhance the sound characteristics of a hearing aid. Three of the most common options include; venting, dampers and horn effects. Each will affect different portions of the hearing aid response curve.

Venting is an opening that is drilled into the earmold to release low frequency sound. This reduces the "plugged feeling" experienced by the hearing aid user while speaking, described as "talking inside a barrel." This sensation is called the *occlusion effect*.

Dampers are materials that are used to alter the frequency and decrease unwanted peaks of sound waves. Common materials used include wool, plastic and metal, which fit inside the earmold tubing.

The ***horn effect*** is provided when the bore of the earmold increases as it goes deeper into the ear canal. It increases and extends the high frequency sound waves. A *reverse horn effect* is achieved by adapting the earmold to gradually narrow towards the inner portion of the ear canal (Microsonic, 2000a).

The body considers the earmold as a foreign body within the ear canal and tries to remove it by increasing the production of oils or wax. In addition, skin sensitivity is heightened with a foreign body in place. Improper measurements (or earmolds that change physical characteristics, such as hardening, over time) may cause irritation and soreness that may result in the hearing aid not being used.

Earmolds have an average lifespan of about two years but lifespan is dependent upon changes to the ear canal (e.g. canal growth in a young child); by the materials used (e.g. polymers have a relatively short lifespan and quickly discolor from skin oils and earwax); by how well the earmold is maintained (cleaning), and by changes to client's audiogram (requiring a different earmold).

TECHNOLOGY REQUIREMENTS

Manufacturers, researchers and clinicians have identified **computerized ear canal measurement** (e.g. 3D laser scanning) as an improved method by which to perform accurate, consistent and repeatable ear canal measurements without the use of casting materials. There is a current need for **improved casting materials** that are quick setting, comfortable to the client and do not shrink. Consistent and rapid **earmold production** is highly desirable. **Earmolds materials and designs** must be biocompatible, fit accurately and comfortably, adapt to ear canal changes throughout the day and remain stable over long periods of time. Low cost, disposable earmolds are desirable. Earmolds must be aesthetically acceptable (e.g. smaller, skin colored, etc.). Technology solutions address important user needs and represent significant business opportunities for manufacturers.

Computerized Ear Canal Measurement - Create 3-D images and measurements (e.g. by using lasers, MRI or CAT scan etc.) that can be transformed into a mathematical representation of the ear canal and used to produce the earmold. This will ensure consistency in measurements, eliminate errors caused by shrinkage, and provide a permanent record of the impression to be kept on file. Issues to be addressed include transient changes to ear canal geometry (due to jaw position, posture, swelling, etc.); hair, wax and other debris in the ear canal; and variations in surface conformity (e.g. skin over bone versus skin over soft tissue); points of increased pressure within the ear canal, or areas that cause skin irritation.

Improved Casting Material – Although Computerized Ear Canal Measurement is the ideal, there remains a current need for an improved casting material that is comfortable to the client, non-irritating, and non-allergenic; remains fluid until it comes in contact with the ear canal; sets quickly once in contact with the ear canal and does not shrink thereafter.

Automated Earmold Production - Eliminate variability in methods and materials starting with the fitting process through to the finished product. Eliminate the "art" of creating an earmold. A one-day turn around from measurement to use would be ideal.

EARMOLD MATERIALS AND DESIGN:

- Should adapt to changes within the ear (e.g. due to head position, jaw movement, swelling, etc.) while maintaining a comfortable, secure fit.
- Should be easy to clean (quick; safe and easy to use cleaning solutions etc.).
- Should be aesthetically attractive in color and appearance.
- Should use tubing materials that are compatible with the earmold and will not change color, shrink or deteriorate.

- Should use ear-hook dampers that do not clog, or are self-cleaning
- Should be easy to insert into the ear canal.
- Should be non-irritating and non-allergenic.
- Should NOT harden, become less flexible, or generally change its physical characteristics over time.
- Should NOT shrink over time.
- Should NOT foster the buildup of bacteria; "self-disinfecting" when in contact with open sores.
- Should NOT absorb or be damaged by ear canal acidity, water, salt, oil, wax, etc.
- Should NOT induce increased oil and wax production.

Suggested Designs:

- ***Develop a compound earmold with a gel-like material surrounding the earmold core*** that will flex and conform to changes in the ear canal (material might be contained within sleeves or compartments).
- ***Reverse thermal gel*** that conforms to shape and hardens within the ear canal at body temperature (while remaining pliable) and softens at room temperature (for easy insertion).
- "***Pneumatic earmold***" that can be "pumped up" to provide a secure fit and deflated for insertion or removal.
- ***Pre-fabricated earmolds in standard sizes and shapes***. Each earmold fits a certain range of (ear canal) sizes and shapes. This technology will enhance the development of disposable earmolds that are less expensive to purchase and reduce the need for fitting adjustments after initial measurements have been made.
- Earmold with ***properties/characteristics of eye contact lens***.
- "***Chameleon-like***" material that adapts to match the wearer's skin color -- similar to material used with photo-gray eye lenses.
- An *open earmold* (with digital signal processing).

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TECHNOLOGY AREA

Clinicians, researchers and manufacturers identified FM Systems as an area that would benefit from new and innovative technology. They believed that improvement in FM system technology would help in developing better assistive hearing products that would meet significant end-user needs, and create significant business opportunities. FM based ALS include personal FM systems, large area FM systems, and FM sound-field classroom-systems.

THE NEED

Hearing aids provide user-customized processing of sound signals picked up by the hearing aid's microphones, telecoil or FM receiver (either in-built or an accessory to the hearing aid). Modern hearing aids use signal processing to make speech more understandable for hearing impaired persons (e.g., algorithms to remove certain undesirable sounds, compression or amplification of the certain frequency sound signal, etc.).

Assistive Listening Systems (ALS) are typically used to amplify selected sound signals, to overcome background noises, enhance sound in large public venues or to improve one-to-one conversations. An ALS reduces the acoustical space between a remote sound source and the listener. Many ALS are currently available, including (but not limited to) infrared systems, FM systems, and inductive loop systems. Each of these ALS transmits a relatively noise-free signal from a remote sound source directly to the receivers of one or more users wearing an appropriate receiver.

ALS can be used in combination with hearing aids, or by themselves. In many cases, use of an ALS in conjunction with a hearing aid provides the user with the optimal sound clarity and comprehension. ALS also includes such devices as amplified doorbells, phones and alarm clocks.

Binaural hearing aids currently refers to the use of hearing aids in both ears where each hearing aid processes its sound signal independently. The user's residual ability to process binaural sound cues (e.g. head shadow, phase and timing) may or may not be significant. A communication link between these hearing aids would permit true binaural processing by the hearing aids themselves. In order to be accepted, this communication link should be wireless (Kompis, Feuz, Valentini, & Pelizzone, 2000)

It is estimated that there are more than 20 million people in the U.S. who experience some form of hearing loss.[*] Hearing aids or assistive listening systems can aid about ninety to ninety-five percent of this population. A large majority of these people (approximately eighty-percent) have chosen not to make use of available technologies. This leaves more than 16 million people with substantially correctable hearing loss who are not seeking treatment, or addressing their hearing loss by other means.

According to the 1990-91 National Health Survey study, 3.6 million people who identified themselves as having hearing problems used hearing aids.[*] Use of hearing aids is highest among the 18 years of age and older groups whose hearing loss became significant after the age of 19. In 1999, hearing aid sales in the United States were

[*] The study included non-institutionalized persons over the age of three.

estimated at 1.9 million units.** The hearing aid industry accounted for $1 billion in revenue in 1993 and is currently estimated at $1.43 billion (5.2% compound growth rate)(Frost & Sullivan, 1994).

Assistive Listening Systems have general market potential beyond the needs of people with hearing impairments. For the hearing impairment market, an Advance Data Reports from the National Center for Health Statistics reported that in the U.S., approximately 874,000 persons who are `hard of hearing' use amplified telephones, ALS, and other hearing technologies (not including hearing aids) (National Center for Health Statistics, 1997). This figure represents less than 5% of the population who could benefit from such technology. ALS are used as private, noise free communication channels. For example, IR or FM listening systems are already common in schools and museums. The potential ALS market is broader than the hearing aid market because of general market ALS applications for the non-hearing impaired (e.g. guided tours through a museum exhibit) and for persons with non-hearing disabilities (e.g. blindness).

The Americans with Disabilities Act (ADA) and the Telecommunications Act have increased the popularity and availability of assistive technologies for employment, education, and access to buildings, transportation and telecommunications. The ADA requires that any business (auditoriums, theaters, etc) with 50 or more fixed seats in an assembly area must make ALS available for at least 4% of the seating capacity (Bakke, Levitt, Ross, & Erickson, 1999). In practice, many ALS are "provided upon request," rather than being permanently installed. However, an ALS that is not permanently installed may or may not be available to the user in a timely fashion. In addition, ALS equipment may not be installed or maintained (e.g., batteries uncharged, incomplete systems) properly.

BASIS FOR DISCUSSION

Assistive Listening Systems bring a remote - essentially noise free - sound signal directly to the hearing impaired listener across the intervening reverberant and noise filled acoustic space. ALS extend the hearing range of these individuals.

Directional hearing aids attenuate peripheral sounds and focus on sounds directly in front of the listener. These devices provide better understanding of speech in noise when the speaker is close by but provide little benefit when the speaker is distant. Used in conjunction with hearing aids, wearable and hand-held "directional beam-forming microphone arrays" further improve the perception of close by speakers.

ALS are typically classified by the technology that provides the wireless link between a distant transmitter and body worn receiver. The three most common technologies use infrared light, an electromagnetic field and radio waves to establish this link.

This discussion focuses on systems using FM (frequency modulated) radio waves. Some hearing aids already use in-built or

** Report published by the Hearing Industries Association Statistical Report, ending December 31, 1999. Numbers were based upon data supplied by 37 companies that agreed to participate in the report. Within this number the total number of hearing aids can be further broken down to: Behind-the-Ear (372,000 units), Completely-In-the-Canal (195,700), In-the-Canal (385,700), Body Aids, Eyeglasses, and others (53,200). Exports from the USA were estimated at 500,000 for this same time-period.

external FM receivers that can be coupled to ALS as well as hand-held and wearable directional microphones (Avrsono Company, 2000; Phonak, 2000). An FM communication link between hearing aids would support advanced binaural processing. Small area ALS might use short-range FM remote microphones.

Improvements to and application extensions of FM technology will provide important benefits for end-users and significant business opportunities to manufacturers.

CURRENT TECHNOLOGY

The following discussion relates primarily to FM personal systems, large area systems and sound field systems. The sound input of a personal or large area FM ALS is frequency modulated and transmitted. Transmissions typically use non-overlapping 50 kHz bands (referred to as `narrow band transmission'), or 150 kHz / 200 kHz bands (referred to as `broad band transmission') in two portions of the frequency spectrum - 72 MHz to 75 MHz and 216 MHz to 217 MHz. Federal Communication Commission regulations limit the permitted maximum power of the transmitted signal. The typical range (transmitter to receiver) for FM ALS is approximately 300 to 500 feet (at 72 MHz to 75 MHz). Range can be increased by using a larger antenna or by transmitting at higher frequencies (216 MHz to 217 MHz).

The portion of the frequency spectrum employed by FM ALS is non-exclusive and unlicensed. These systems are therefore subject to interference from other radio transmissions (e.g. pagers, emergency vehicles, etc.). Some FM ALS can transmit and receive in a number of frequency bands (as many as 50 narrow bands or 10 wide bands). Because these bands are non-overlapping - simultaneous, non-interfering communication can take place within the same environment. If an extraneous radio signal causes interference, the transmission frequency of the FM ALS can be changed (e.g. to the frequency of another narrow band). The listener then manually changes their receiver to match this frequency.

Large Area FM Assistive Listening Systems

A large area FM ALS is most commonly used for single input, multiple listener environments such as conference and classrooms, churches, nursing homes, theaters, and courtrooms. The most common input device is a single microphone, but multiple microphone positions and alternative sound sources such as tape machines and audio-mixing equipment may also be interfaced to the system.

Many large area FM ALSs can provide a range of input pre-processing options. It is unclear whether such preprocessing, coupled with the customized signal processing provided by each listeners' hearing aid will generally improve signal clarity or speech comprehension. The dynamic range of input signals can be quite large and some form of input compression will often be necessary to avoid saturating the output signal while still maintaining audibility at low input levels.

Various options are available by which to interface the FM receiver to the listener's hearing aid. Hearing aids with T-coils, neck-loops or silhouette inductors can be plugged into the FM receiver. For hearing aids lacking a T-coil, earphones can be employed - earphones probably won't comfortably fit over a BTE (behind-the-ear) hearing aid. Some hearing aids will also accept direct audio inputs (DAI).
FM ALS portable receivers can use rechargeable batteries (typically 6-10 hours

of continuous use between charges) or disposable batteries (typically 18-70 hours between replacement). The systems require administration - batteries must be charged or replaced and receiver hygiene maintained.

Personal FM Systems
These wireless communication devices act much like a radio station. FM systems have a transmitter that accepts microphone input and transmits the FM equivalent signal. The FM signal is picked up by a receiver antenna, amplified, and transformed back into a sound signal. The speaker wears a compact transmitter and microphone while the listener wears portable receivers and earphones.

Wireless Headphones
There is no physical connection between the transmitter and the receiver in the headphone. Available in both FM and Infrared, the input can be through an audio jack plug on the TV, or through a microphone placed near the TV speaker. This system is gaining acceptance for home entertainment (e.g., TV, music, etc.) where a person needs a volume level that would disturb others.

FM Sound-Field Systems
These devices are essentially Public Address (P.A.) systems whose input device is a wireless microphone. The speaker talks into the FM microphone/transmitter that transforms and broadcasts the signal to an FM receiver/amplifier connected to, or physically located within, a loudspeaker. This system amplifies the speaker's voice to the point that the level of his or her speech is clearly audible above the backgrounds sounds.

Hearing aids that communicate sound information from one hearing aid to the other via wireless, amplitude modulated (AM) carrier appeared briefly in the marketplace. Some BTE hearing aids now employ built-in or external FM receivers.

STATEMENT OF THE PROBLEM
The following discussion is based upon issues raised during interviews and panels involving researchers, manufacturers and end-users.

- FM ALS transmissions are subject to radio interference and electromagnetic noise. FM (or related wireless) ALS having improved robustness to radio interference and electromagnetic noise are needed. In addition, FM ALS transmissions can spill over into adjacent environments and can easily be intercepted by anyone having an appropriate receiver. FM (or related wireless) ALS supporting private and secure communication with FM systems are needed. The performance of FM ALS receivers can vary with antenna orientation, the wearers body orientation, and environmental factors.

- FM ALS that automatically switch transmission frequencies are desired. Manual switching between transmission frequencies is a simple, low cost approach but is not user-friendly. Manual switching can be difficult for persons having low manual dexterity. In general, when manually switching frequencies, the continuity of communication can be broken and important information lost.

- FM ALS are limited in situations where a person is trying to listen to one voice in a crowd. FM ALS supporting multi-input, multi-listener communication are needed. Such systems would have many applications in small group settings such as meetings, banquets and family dinners. In one possible scenario, each speaker could have a short-range, remote FM microphone (each its own frequency band). Each listener could have a small mixer, receiver with numbers and activity lights corresponding to each of the FM microphones. The listener selects the microphone that he/she wanted to "hear" by flipping a switch (the corresponding light would then come on). The selected transmission would be rebroadcast on the listener's private frequency and picked up by their built-in or external FM receiver. Many other scenarios are of course possible.

- FM receivers need to be simple, with very few visible controls, otherwise people may get intimidated by them. The cosmetic qualities of the technology need to be unobtrusive to be accepted by the user and non-user alike, in order to avoid stigma and abandonment.

- The brain can best process the speech signals when it is provided with binaural cues (head shadowing, time delays, and phase differences) in the differing sound signals received by each ear. Binaural hearing aids refer to the use of hearing aids in both ears where each hearing aid processes its sound signal independently. The user's residual ability to process binaural sound cues (e.g. head shadow, phase and timing) may or may not be significant. A communication link between these hearing aids would permit true binaural processing by the hearing aids themselves. This communication link should be wireless, interference-free, and have low power requirements. Hearing aid batteries currently supply approximately 2 mw of power.

ISSUES TO CONSIDER

The following are issues to consider when developing new and/or improved FM Technologies.

The Need

- What are the important, unmet (or poorly met) user needs related to FM Assistive Listening Systems?

- What populations or demographics (e.g., degree of hearing loss, characteristics of hearing loss, cause of hearing loss, age, etc.) are most affected by these needs/problems?

- In which environments and for which activities is this need or problem most significant?

- What accommodations (or behavioral changes) do hearing impaired persons make in order to function in these environments and accomplish these activities?

State-of-the-Practice

- What FM assistive listening products are used by, or prescribed for, hearing impaired persons in order to address these problems or needs?

- What are the strengths (e.g., performance, cost, etc.) of these products?

- What are the weaknesses (e.g., performance, cost, etc.) of these products?

Future Technology and Products

- What significant technical improvements are needed?

- What technical barriers (e.g. environmental factors, power consumption, size, etc.) must be overcome in order to achieve these technical improvements?

- What breakthrough technologies (not present in current products) might better address the identified needs and problems?

- What technical barriers (e.g. environmental factors, power consumption, size, etc.) must be overcome in order to achieve these technical breakthroughs?

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FM Systems Forum Data

Wireless FM Systems - Personal FM Systems

The following is the raw data collected during the stakeholder forum. It reflects the comments and needs as expressed by the forum participants.

1. Priority Customer Needs

- Ease of use
- Need standardization so that receiver and transmitter match
- Need predictable level and quality of signal Need to be able to use in public areas like tour buses, museums, stadiums, crowds and churches
- Need training for users/operators of the transmitters
- Need to benefit people with any degree of hearing loss
- Need to be used in language translators, theatre, sporting events, classrooms, museums, tours

2. State of Existing Technologies

- FM systems are single speaker/single listener and single speaker/multi listener.
- No multi speaker/multi listener systems are available.
- Both transmitter and receiver can be mobile.
- Transmitter worn by speaker and speaker can move around.
- Transmitter/Microphone must be near the sound source (e.g. speaker's mouth).
- Personal FMs improves SNR and shortens acoustical pathway between speaker and listener).
- FMs are compatible with other devices (e.g. place transmitter microphone near TV or Radio)
- FMs does not require line of sight between transmitter and receiver (i.e. FM transmission is Omni directional-360 degrees).
- Sound quality is dependent upon the frequency response of the transmitter microphone.
- FMs use frequency bands within the 72-76 MHz range and the 216 MHz-217 MHzfrequency range.
- FMs use "narrow band" (typically 50 KHz) or "wideband" (typically 150 or 200
- KHz) transmission.
- It is often difficult for the user to select the correct frequency for FM systems having
- multiple frequency channels
- FMs are susceptible to interference from other FM radio sources (such as pagers and emergency vehicles) especially at lower (non dedicated) frequencies (72 -76MHz)
- FM systems can be used in most environments (e.g. classrooms, museums.....).
- FM system can't be used in certain environments (e.g. industry, hospitals, airplanes where Personal FMs interferes with electronic equipment)
- Susceptible to electromagnetic field interference (e.g. lighting, motors, computers, lightning, power strips,etc);
- The acoustic quality of narrow band transmission is typically not as good as the acoustic quality of wide band transmission.

- FMs are subject to signal drift (generally a low frequency system problem)
- For transmitters using low frequencies (72-76 MHz) narrow transmission bandwidth (10 KHz) limits signal quality and dynamic range. (e,g, limits sound quality)
- No guarantee that you are tuned in (e.g. FM receivers don't signal the user when the transmission carrier is lost or the carrier frequency band has been switched at the transmitter.)
- FM systems provide a personal communication channel between the speaker and the listener.
- Concerns for privacy and security (i.e. any receiver tuned to the transmitter frequency can "listen in." Also the FM signal can not be easily confined to the "room.")
- Small FM receiver is an accessory to some Hearing aids (e.g. FM boot)
- Small FM receiver is built into some BTE hearing aids
- Custom fit - mechanically and acoustically (e.g. Hearing aids response to a signal from the FM receiver is similar to the response directly from the hearing aid microphone.)
- FM receivers are cosmetically acceptable (Receiver is small and inconspicuous. Accepted by children in school environments)
- Effort to standardize different makes of Hearing Aids to accommodate modular FM receiver (FM boot).
- Some difficulty achieving full compatibility between standardized FM receivers and HA processing capabilities (which may differ across brands and models)
- FM transmitter too large (may interfere with vigorous physical activities like dancing, aerobics, etc)
- Receiver antenna is too long (strange looking on boot).
- Limited battery power (i.e. number of hours between charges).
- The FM (built in or boot) receiver does not require a separate power source (draws power from the battery hearing aids battery.)
- FM receiver decreases hearing aids battery life (i.e. time between replacements)
- Transmitter not powerful enough (range is limited)
- Battery life on transmitter is too short
- Increasing transmission power (range) decreases the time between charge.
- No low battery power indicator
- No automatic receiver on/off (e.g. power consumption continues when there is no carrier frequency detected)
- High system cost
- Transmitter and receiver easily lost. Small and delicate antenna
- Multi-path problems can cause drop out (e.g. building structural elements interfere with the direct transmission path. Transmission signal reaches the receiver by multiple paths and "sums" destructively.)
- FM-boot only fits on BTE
- General problem for smaller HA to accommodate FM receivers.

3. Ideal Technology Requirements

- Ideal system should have a transmitter, a body-worn repeater and a wireless link to a HA receiver
- Transmission protocol should not be limited to FM
- Should consider using universally accepted wireless standard (e.g. consider spread spectrum, ultra-wide band, frequency coding phase shift keying, blue tooth.)
- Frequency agile (has capability to automatically "scan" and " lock onto" the carrier frequency)
- Supports bi-directional handshaking between receiver and transmitter.
- Handshaking might be all wireless or mixed (e.g. part wireless and part acoustic).
- Bi-directional handshaking might support channel switching, notification of poor signal reception, low battery indicator, etc.
- Guaranteed privacy and security
- Adjustable transmission range 0 - 40m indoors
- Improved Digital Signal Processing hardware and software is needed to support advanced communication protocols (e.g. spread spectrum)
- Clear transmission (i.e. good dynamic range, high signal to noise ratio, etc.)
- FM transmitter, microphone and receiver do not introduce unintended signal distortion(It should be noted that signal distortion is sometimes intentional - for example signal compression is sometimes built in at the transmitter.)
- Legislative action may be required for frequency spectrum allocation (i.e. the current allocation at 72 - 76 MHz may not be suitable for some advanced wireless communication protocols.)
- Transmitter should be size of fountain pen to size of cigarette pack
- Transmitter should weigh 4-5 ounces
- Backward compatible - works with existing hearing aids (e.g. a wireless communication accessory could replace the current FM - boot in a one to one fashion.)
- Handle both analog and digital.

a. Transmitter Controls

- Watertight (e.g. sealed membrane on/off switch)
- Larger (e.g. requires low precision)
- Tactile (e.g. switch location and function identifiable by touch.)
- Up/ Down switch to select transmission frequency.
- Stand-by feature (e.g. use input threshold detector to place transmitter on low - power stand-by when the input signal is below a threshold. This may require signal processing to account for voice loudness and the varying sound environment.)
- Feedback to user when transmitter active (e.g. LED or blinking LED)
- Transmitter can be "plugged" into a wide array of consumer and telecom devices (telephone, alert systems, home environment, computers, mixers, etc.)

b. Transmitter Microphone

- Processing of microphone signal adapts in response to environmental variable (e.g. signal strength, environmental noise characteristics, reverberation)
- Water resistant, wind resistant (Disposable windscreen), shock resistant
- Flexibility - microphone can be detached from the transmitter
- Ability to switch (swap transmitter microphones with differing functional characteristics.)
- Low sensitivity to vibration (does not pick up vibration noise.)
- Minimal internal mic noise
- Microphone and transmitter share same power source.
- Microphone located at one end of transmitter.
- Microphone should be highly directional and capable of picking up sound signal (voice) at 8 to 10 feet in a noisy environment.
- Microphone should have a directivity pattern of 20 - 40 degrees
- Size of microphone and transmitter should have a total size of 1" to length of pen.
- Microphone (even if swappable) and transmitter should form an integral unit
- Mute option, controlled at transmitter (i.e. transmission carrier maintained, but no sound signal transmitted)
- Microphone should be able to pick up speech in noise (Sensitivity without saturation)
- Microphone should be able to pick up speech in quiet (i.e. Sensitivity should allow microphone to pick up quiet voice in quiet environment.)
- Switch able between omni directional and directional microphone.
- Smart mike system should be considered (Multi microphone array beam forming microphone that adapts to sound environment, locates and tracks sound sources.)
- Life of battery 15 to 20 hrs for the transmitter
- Power level indicator.

c. Transmitter Antenna

- Antenna inside transmitter, never breaks
- Omni directional transmission.
- Optional external antenna jack for 4" external antenna (increase transmission range)
- Replaceable
- Antenna can "fold out" from transmitter allowing transmitter to be "stood up" on table.

d. Body worn Repeater

- Work with or w/o hearing aids (can be interfaced with HA, used with headphones etc)
- Should have 3.5 mm jack (i.e. for D.A.I or inductive neck loop).
- Support wireless transmission to hearing aid. (i.e. F.M. or other wireless protocols).
- Repeater should accept wireless data i/p (non analog signals from computer, etc.)
- Repeater can interface to "other" electronic devices (e.g. tape recorders, public address systems, mixers etc)
- Receive all available frequencies (Works across all allocated frequency ranges.)
- Tunable by user (user can select carrier frequency)

- Repeater should be able to communicate to the HA (e.g. T-Coil, D.A.I, F.M - boot).
- Repeater should be able to handshake bi-directionally with any wireless transmitter.
- Should have user selectable volume Control
- Watertight (e.g. sealed membrane on/off switch)
- Batteries of the control should last 3-4 weeks at 8-10 hours of continuous use
- Repeater battery (rechargeable or disposable) should be recyclable.
- Disposable batteries should have 40 hrs life minimum.
- Battery level indicator
- Feedback to user on loss of transmitter signal.
- Display Transmitter Carrier Detection
- Repeater should have up/down switch, to select initial transmitter frequency
- When turned on receiver should select last transmitter frequency used when turned off.
- Size-6"x3/o"x'/4"
- Same antenna characteristics as transmitter (e.g. omni- directional transmission for handshaking, same range as transmitter.)
- Repeater should have on/off indicator (e.g. LED)
- Adjustable according to individual requirements
- Active Tone Control, Active high frequency gain

e. Hearing Aid Receiver

- Ideally a wireless receiver should be built in to the (BTE) hearing aid.
- A receiver accessory to the HA (e.g. wireless or FM - boot) is less optimal.
- Receiver should be durable (unbreakable)
- Cosmetically appealing with small size, small antenna and light weight
- Additional weight for receiver should be about the same as a current FM boot accessory
- Smart signal selection capabilities to pick up and lock on to the wireless signal from the repeater (e.g. strongest FM signal)
- Manual signal selection capabilities (e.g. user presses a push button to manually select and lock onto a signal in multi-channel environments such as theatres)
- Antenna should be inside receiver.
- Wireless receiver should be affordable
- Easy to use manual on/off switch
- For receiver boot accessory - electronic interface to HA must be reliable (e.g. Durable, waterproof, etc)
- No visual indicator (e.g. power level, signal detect, etc) needed on HA
- Low battery indicator (e.g. beep, vibrate)
- BTE receiver should have wireless communication link with repeater.
- No bi-directional communication from HA receiver to repeater (e.g. to control or notify repeater)
- Moisture Resistant
- Wireless receiver powered off of HA battery.
- Receiver battery should source > 3-4 mA current.
- Receiver battery should be easily replaceable.

- Rechargeable BTE battery with life of 12 hrs per charge. Compatibility with existing BTE's (backward compatible)
- Explore new/ larger markets (e.g. communication between coach and players)

f. Barriers to realizing technology

- Cost (hearing aid w/built-in receiver are now $500-3000 dollars adding an FM or wireless receiver might raise HA cost to $3000 - 4000 dollars)
- Miniaturization (e.g. general problem for some wireless protocols such as spread spectrum which require significant electronics.)

Problem Statement - Wireless and FM Systems
Manufacturers, researchers, consumers and other stakeholders have identified a "universal" **Personal Communication System** as a high priority technology need. As defined, the system is extremely flexible. It can benefit people with any degree of hearing loss (from persons with no hearing loss to persons with severe hearing impairments) across a wide range of applications and environments. For example - the ***Portable Transmitter*** and ***Portable Repeater*** would be extremely useful devices even if purchased separately. As with any body-worn device, the manufactured product must pay careful attention to cosmetic issues (size, weight, appearance, etc.) and cost. Enhanced technologies for **portable transmitters, repeaters, and receivers** were identified as critical for improving FM systems.

Universal solutions in the field of FM ALS will have broad applications in consumer products such as cell phones, stereos, televisions, audio mixers and computers. By addressing important, unmet needs of people both with and without hearing impairments, these technology solutions represent a **significant business opportunity**.

MARKET
It is estimated that more than 20 million people in the United States experience some form of hearing loss. Ninety to ninety-five percent of these people could benefit from hearing aids and assistive listening systems. A large majority of the people who would benefit from these devices (approximately 80%) have chosen not to use them. This leaves more than 16 million people with substantially correctable hearing loss who are not currently using assistive devices. Many of the people in this population choose not to use the devices because they are not satisfied with the performance of products currently available or are reluctant to wear an obtrusive device they feel is stigmatizing.

Assistive Listening Systems (ALS) bring a remote (essentially 'noise free') sound into the direct-proximity of the user's ear in order to amplify a selected sound source, overcome background noise, enhance listening in large public venues, and improve one-to-one conversations. Used in combination with hearing aids an ALS can provide optimal sound clarity and speech comprehension. ALS are categorized by the wireless communication protocol used to link the remote sound source and the body-worn receiver. Common ALS include frequency modulated (FM), infrared (IR), and inductive loop (IL) systems. The receiver can be directly associated with the hearing aid (inbuilt FM receiver, FM-boot, telecoil). Alternatively, some IR and FM receivers retransmit the signal via an inductive neck loop to be picked up by the hearing aid telecoil.

According to the Hearing Aid Compatibility Act of 1988, all telephones sold in the US should be compatible with standard hearing aid telecoils. However, it is estimated that only 30% of modern hearing aids in the US actually incorporate a telecoil. (A telecoil is an induction coil placed in a hearing aid that is designed to pick up fluctuating magnetic fields produced by coils in the telephone hand set, so that these signals can be amplified without interference.)(Self Help for Hard of Hearing, 1999) Persons with greater hearing loss often have BTE hearing aids with T-coils, while persons with less severe hearing loss often have smaller ITC and CIC hearing aids that lack T-coils. As a consequence, persons with more severe hearing loss are more likely to benefit from inductive loop systems.

The Americans with Disabilities Act (ADA) and the Telecommunications Act have increased the popularity and availability of assistive technologies for employment, education, and access to buildings, transportation and telecommunications. The ADA requires that any business (auditoriums, theaters, etc.) with 50 or more fixed seats in an assembly area must make ALS available for at least 4% of the seating capacity.(The US Equal Employment Opportunity Commission, 1990) The market potential for assistive listening systems is much broader than the hearing aid market. People without hearing impairments are currently using ALS for museum tours, nature walks, improved listening at philharmonic concerts, and other "enhanced listening experiences". Additionally, FM technology used for high quality public address systems and for a multi-channel, multi-media entertainment venue poses a huge market opportunity for anyone able to develop these technologies.

CURRENT TECHNOLOGY

FM systems provide a personal communication channel between the speaker and the listener that shortens the "acoustical pathway" between speaker and listener and improves the signal-to-noise ratio. Personal FM systems are available for one-on-one (single speaker / single listener) communication and wide area FM systems are available for one-to-many (single speaker / many listeners) communication. Systems are currently not available for many-to-many (natural, small group) communication. FM systems are used in most environments (e.g. classrooms, museums etc.) generally excepting those environments where they can interfere with electronic or telecommunications equipment (e.g. hospitals, airplanes).

FM systems transmit in two, non-reserved portions of the frequency spectrum - 72 MHz to 75 MHz and 216 MHz to 217 MHz. FM systems are susceptible to interference from other radio sources (e.g. pagers, emergency vehicles) especially at lower frequencies (72 MHz –76 MHz) and electromagnetic interference (e.g. motors, computers, lightning controls, power strips, etc). Building structural elements can cause multi-path interference and signal dropout. FM systems typically use non-overlapping 50 kHz bands (referred to as 'narrow band transmission'), or 150 kHz / 200 kHz bands (referred to as 'broad band transmission'). Federal Communication Commission regulations limit the permitted maximum power of the transmitted signal. FM system transmitters are generally omni-directional and have a typical range of 300 to 500 feet (at 72 MHz to 75 MHz). Range can be increased by using a larger antenna or by transmitting at higher frequencies (216 MHz to 217 MHz). Some FM systems are multi-frequency with as many as 50 narrow band channels or 10 wide band channels. Multi-frequency systems support simultaneous, non-interfering communication within the same environment.

FM transmissions cannot easily be confined to a "room" and anyone with an appropriate receiver can "listen in."

Large Area FM Systems are used to enhance one-to-many communication. The most common input device is a single microphone, but multiple microphones, remote microphones and alternative sound sources (e.g. tape machines, audio-mixing tables, etc.) may also provide the input. Many large area FM systems provide a range of input pre-processing options. It is unclear whether such preprocessing, coupled with the customized signal processing provided by each listeners' hearing aid will generally improve signal clarity or speech comprehension. The dynamic range of input signals can be quite large and some form of input compression will often be necessary to avoid saturating signal output while still maintaining audibility at low input levels.

Personal FM systems are used to enhance one-to-one communication. The speaker wears a microphone and portable FM transmitter while the listener wears a portable receiver. Both the speaker and listener can move about.

Sound-Field Systems are essentially a Public Address system whose input device is a wireless microphone. The speaker talks into the FM microphone/transmitter that transforms and broadcasts the signal to an FM receiver/amplifier connected to, or physically located within, a loudspeaker. This system is used to amplify the speaker's voice so that it is clearly audible above background noise.

Wireless headphones (FM or IR) are gaining acceptance for home entertainment (e.g., TV, music, etc.) where a person needs a volume level that would disturb others. The transmitter receives its input from an audio jack (television, radio, etc.) or from a microphone placed near the sound source. The receiver is built into the headphone.

FM hearing aid receivers are built into or an accessory (e.g. FM-boot) to larger hearing aids (e.g. "behind-the-ear" BTE) but are not accommodated by smaller aids (e.g. "in-the-canal" ITC and "completely-in-the-canal" CIC). FM hearing aid receivers are generally small and inconspicuous with the possible exception of the antenna. There has been some discussion about adopting a standard modular FM receiver (FM boot) but it may be difficult to make these receivers fully compatible across makes and models of hearing aids. FM hearing aid receivers (built in or boot) draw power from the hearing aid battery, decreasing battery life.

Portable FM Transmitters currently have an in-built microphone. There is also a provision to have an external audio line input. The antenna is built into the transmitter (e.g. the stand is also an antenna on some transmitters). Most portable transmitters are capable of channel adjustments. The range of portable transmitters is generally up to 100ft. While some small FM transmitters exist (down to 3.5 oz), many of current transmitters are too large to be used while performing severe physical activities like dancing, aerobics, etc. Portable FM transmitters generally use rechargeable batteries (6-10 hrs of continuous use between charges typical or disposable batteries (15-60 hours between replacement is typical).

Portable FM receivers are completely separate from the hearing aid. These receivers (commonly) support headphones and inductive neck loops, silhouettes or DAI connections for hearing aid users. Multi-frequency receivers don't signal the user when the transmission is lost or the carrier frequency has been switched at the transmitter. The receivers also do not go to "low-power standby" if the carrier frequency is not detected. Frequency selection is manual and users often find it difficult to select the correct frequency. Portable FM receivers generally use rechargeable batteries (6-10 hours of continuous use between charges typical) or disposable batteries (18-70 hours between replacement typical). The systems require administration – batteries must be charged or replaced and receiver hygiene maintained (especially for large area system receivers).

Hearing Aids with a bi-directional communication link and appropriate processing capabilities can act together as beam-forming microphone arrays. **Binaural hearing aids** use the increased separation between microphones, head shadow effects and time and phase delays to mimic the capabilities of an intact hearing system. Binaural processing requires a bi-directional communication link between the two hearing aids. A product appeared briefly on the market that employed an AM wireless link between the two hearing aids. An advanced binaural hearing aid prototype was recently developed that hard-wired the two "hearing aids" to an external digital signal-processing unit. It was reported that this prototype provided 17 dB of directional gain.(Kompis, 2000)

TECHNOLOGY REQUIREMENTS

Users, manufacturers, clinicians, researchers, and other stakeholders have identified technology that will significantly improve the performance of ALS and expand the market for FM ALS and related technology. Technology currently needed includes:

- Standardized personal communication systems
- Portable transmitters
- Portable repeaters
- Portable receivers

The specific performance features for these technologies are listed below. Final product manufacturers and consumers are keenly interested in technologies that meet these needs. Both component and system solutions that enhance the lives of people with and without hearing disabilities present a **significant business opportunity**.*

Personal Communication System.*

- Should consist of a ***Transmitter***, a ***Body-Worn Repeater*** and a ***Hearing Aid Receiver***.

* Note: Technology developers who are interested in FM solutions may also want to refer to the Infrared and Inductive Loop Problem Statements. There may be opportunities to combine the technologies and leverage a multi-system solution for an expanded market share. New, innovative or revoluntionary approaches that are independent of the technologies under consideration might provide the superior solution. Dr. Laszlo's comments introducing this section of the Proceedings are particularly relevant.

- Should have components that can be used separately or as part of the system.
- Should have components that are not be obtrusive (should be small and/or cosmetically attractive)
- Should benefit people with any degree of hearing loss (from no hearing loss to severe hearing impairments).
- Should guarantee privacy and security.
- Should provide a clear, undistorted sound (e.g. consider a person with unimpaired hearing at a cello concert.).
- Communication protocols other than FM should be considered - including universally accepted wireless standards.

Portable Transmitter

Critical Features

- Should have bi-directional wireless link between ***Transmitter*** and ***Repeater***.
- Should have adjustable transmission range of 0 – 40 meters between ***Transmitter*** and ***Repeater***.
- Should accept input from a wide array of consumer and telecom devices (telephones; alert systems; doorbells; television, radio, computer audio jack; audio mixers, etc.).

Value-Added Features

- Should be size of fountain pen to size of cigarette pack and weigh 4-5 ounces.
- Should have controls that: are large (require low precision); provide tactile feedback (switch function identifiable by touch); watertight (e.g. sealed membrane)
- Should have "UP / DOWN switch" for manual frequency selection.
- Should provide feedback (e.g. steady or blinking LED) when active.
- Should have mute option (carrier maintained but no sound signal transmitted).
- Should have unbreakable antenna that is inside of the transmitter or can be "folded out" so the transmitter can be "stood up on the table."
- Should have jack for optional 4" external antenna (increase range).
- Should have 15 to 20 hours between battery recharge.
- Should have power level indicator.
- Should have automatic power down when not in use.

Portable Repeater

Critical Features

- Should have the same communication capabilities as the ***Transmitter*** (e.g. omni-directional transmission, bi-directional handshaking with transmitter, range, etc.).
- Should work with all Personal and Large Area FM ***Transmitters*** already in the market (Note: Repeater would not use bi-directional capability in this case.)
- Should work with all hearing aids (interface through ***FM Receivers***, T-coils or DAI) already in the market.
- Should accept microphone input.
- Should have universal input capabilities (e.g. computers, television, radio, etc.)
- Should have universal output capabilities (e.g. headphones, tape recorders, public address systems, audio mixers, headphones etc.)

Value-Added Features

- Should be frequency agile (automatically "scan" and " lock onto" the ***Transmitter*** frequency)

- Should select "last ***Transmitter*** frequency used" when turned ON.
- Should provide feedback to the user when the ***Transmitter*** carrier is detected or lost.
- Should have manual UP/DOWN switch for ***Transmitter*** frequency selection (e.g. for multi-frequency environments such as theatres).
- Should have manual volume control.
- Should have active tone control and active high frequency gain.
- Should have ON/OFF indicator (e.g. LED)
- Should have power level indicator.
- Should have batteries that last 3-4 weeks at 8-10 hours of continuous use OR disposable batteries with a minimum operating life of 40 hours. Batteries should be recyclable.
- Should be watertight (e.g. sealed membrane switches)
- Should be about the same size as the Personal FM System ***Transmitter***.
- Should have a microphone that is detachable from the ***Transmitter***; is "swappable" – you can switch between microphones with different functional characteristics; and can be nested into one end of the transmitter. This microphone should pick up speech in noise (sensitivity without saturation) and quiet speech in a quiet environment; be highly directional - capable of picking up sound signal (voice) at 8 to 10 feet in a noisy environment (a directivity pattern of 20 – 40 degrees); and "switchable" between omni-directional and directional modes. Advanced characteristics (adapts directional response in noise, orients to speaker, etc.) should be considered. Microphone should be durable (water, wind - disposable wind screen, and shock resistant) with low sensitivity to vibration

Receiver

Critical Features

- Should have one-way wireless link from ***Repeater*** to Hearing Aid ***Receiver*** - link through inductive loop or DAI is less ideal.
- Should pick up and lock onto the ***Repeater*** signal (e.g. smart signal detection, select strongest signal, etc.)
- Should be built into Hearing Aid - accessory similar to a FM boot is less ideal.

Value-Added Features

- Should weigh about the same as an FM boot (if integral to the hearing aid)
- Should have reliable electronic interface between ***Receiver*** (FM boot like accessory) and Hearing Aid (e.g. durable, waterproof, etc).
- Should have internal antenna.
- Should NOT have visual indicators (e.g. power level, signal detect, etc).
- Should have non-visual, low battery indicator (e.g. tone, vibrate)
- Should have easy to use, manual ON/OFF switch.
- Should be powered off of hearing aid battery.
- Should have battery that sources > 3-4 milliamps current.
- Should have battery that is easy to replace.
- Should be rechargeable battery with 12 hours time-between-recharge

- Should be moisture resistant and durable (unbreakable)
- Should use **batteries** with reduced size, increased time between recharge, increased capacity, reasonable cost etc.

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Infrared & Inductive Loop Systems White Paper

TECHNOLOGY AREA

Infrared and Inductive Loop Assistive Listening Systems were identified by researchers, manufacturers and end-users as technology areas that could benefit from technological innovation and refinement. They believed that the development of improved infrared and inductive loop systems would meet important user needs and represent significant business opportunities for this industry segment.

THE NEED

The general function of hearing aids is to pick up sound from the environment with a microphone, process this sound (e.g., compress, expand, amplify, filter, etc.) and deliver it to the user's ear through a speaker and earmold. Advanced hearing aids use signal processing algorithms (to remove certain types of undesirable sound) and directional microphones, which are somewhat more sensitive to sound sources in front of the user than to their sides or back. However, even advanced hearing aids provide limited benefit for users trying to pick up a remote sound source in a noisy or reverberant environment. Hearing aids can be fitted with a telecoil (T-coil) capable of picking up an electromagnetic signal. T-coils were designed to facilitate telephone conversation by picking up the electromagnetic fields produced by the speaker diaphragm coil in phone handsets. T-coils can also be the receiver for inductive loop Assistive Listening Systems (described below). Unfortunately, it is estimated that only 30% of modern hearing aids sold in the U.S. incorporate a telecoil (Self Help for Hard of Hearing, 1999b).

The general function of Assistive Listening Systems (ALS) is to bring a remote (essentially `noise free') sound signal into the direct-proximity of the user's ear. A television (e.g. with audio jack) or remote microphone might be the source for such sound signals. ALS's process the remote signal and then transmit this signal via a wireless link. These wireless links commonly use infrared light (`invisible light' whose wavelength is `longer than' the red light that we can see), inductive (electromagnetic) fields or frequency modulated (FM) radio waves. The receiver for the wireless link can be part of the hearing aid (e.g. built-in FM receivers or T-coils that pick up inductive transmissions) or a hearing aid accessory (e.g. an external FM receiver) (Avrsono Company, 2000; Phonak, 2000). Alternatively, the receivers can be completely separate from the hearing aid. In some cases, users wear a FM or IR receiver whose sound output is through headphones or earphones. Other FM or IR receivers process and retransmit the signal via an inductive neck loop whose signal is picked up by the hearing aid T-coil. Large assistive listening system can receive inputs from a number of remote sources (e.g., multiple microphones, sound systems, sound mixing tables, etc.).

Many people appear to be unaware that Assistive Listening Systems are available or may not understand that they can be used in conjunction with hearing aids to increase communication clarity (Self Help for Hard of Hearing, 1999a). Audiologists and hearing aid dispensers could have a important role educating their patients about ALS technology, its appropriate use and availability.

It is estimated that more than 20 million people in the United States experience some form of hearing loss. Ninety to ninety-five percent of these persons could benefit from hearing aids and Assistive Listening Systems. A large majority of these people (approximately eighty-percent) have chosen not to make use of available technologies. This leaves more than 16 million people with substantially correctable hearing loss who are not seeking treatment, or addressing their hearing loss by other means.

According to the 1990-91 National Health Survey study, 3.6 million people (eighteen percent) who identified themselves as having hearing problems use hearing aids.[*] Use of hearing aids is highest among the 18 years of age and older groups whose hearing loss became significant after the age of 19. In 1999, hearing aid sales in the United States were estimated at 1.9 million units.[**] Revenue from hearing aid sales reached $1 billion in 1993 and is currently estimated to be $1.43 billion (5.2% compound growth rate)(Frost & Sullivan, 1994). The USA presently generates 39.3% of hearing aid sales, Europe has 34.5%, the Pacific Rim has 14.3%, while the rest of the world accounts for 12.1% of all revenue.

Assistive Listening Systems have general market potential beyond the needs of people with hearing disability. For the hearings impaired market, an Advance Data Report from the National Center for Health Statistics reported that in the U.S., approximately 874,000 persons who are `hard of hearing' use amplified telephones, ALSs, and other hearing technologies (not including hearing aids)(National Center for Health Statistics, 1997). This figure represents less than 5% of those persons who could benefit from such technologies. ALS are used as private, noise free communication channels. For example, infrared and FM Assistive Listening Systems are common in educational settings, museums, conference rooms and many other settings. ALS also have great potential for people who are blind.

The United States population is aging, with more people living into their 70's and 80's. All of these persons are potential consumers of assistive hearing technology. The aged population is expected to grow until the year 2036 when this population is expected to reach its maximum level. The world population is also following a similar growth trend.

The Americans with Disabilities Act (ADA) has increased the availability of assistive listening technologies for employment, education, and access to public buildings and transportation. ALS can be permanently installed or set up on request - although this last option does not ensure timely access. Of course, the assistive listening system must

[*] The study included non-institutionalized persons over the age of three.

[**] Report published by the Hearing Industries Association Statistical Report, ending December 31, 1999. Numbers were based upon data supplied by 37 companies that agreed to participate in the report. Within this number the total number of hearing aids can be further broken down to: Behind-the-Ear (372,000 units), In-the-Ear (893,000 units), Completely-In-the-Canal (195,700), In-the-Canal (385,700), Body Aids, Eyeglasses, and others (53,200). Exports from the USA were estimated at 500,000 for this same time-period.

also be properly maintained (e.g., receiver batteries charged) in order to serve the user's needs.

BASIS FOR DISCUSSION
Assistive listening systems bring a remote - essentially noise free - sound signal directly to the hearing impaired listener across the intervening reverberant and noise filled acoustic space. Assistive listening systems extend the hearing range of these individuals.

Directional hearing aids attenuate peripheral sounds and focus on sounds directly in front of the listener. These devices provide better understanding of speech in noise when the speaker is close by but provide little benefit when the speaker is distant. Used in conjunction with hearing aids, wearable and hand-held "directional beam-forming microphone arrays" further improve the perception of close by speakers.

Assistive Listening Systems are classified by the wireless link between a distant transmitter and body worn receiver. The three most common technologies use infrared light, inductive (electromagnetic) fields and radio waves to establish this link.

This discussion focuses on systems using infrared (IR) and inductive loop (IL) technologies. Inductive loop systems have been in place for many years. The IL transmitter is commonly a loop of wire around a listening area. The IL receiver is a coil of wire -- often inside the hearing aid itself (telecoils or T-coils). The great benefit of IL systems is that a hearing aid user does not require a separate receiver. Unfortunately, most hearing aids in the U.S. are not equipped with telecoils. In addition, the telecoil orientation with respect to the inductive field may impact the quality of signal reception.

Infrared systems use an infrared `heat source' as their transmitter. Receivers must generally be in line of-sight to this transmitter. This feature provides a great benefit -- there is no spillover of communication between infrared systems in adjacent rooms. Infrared assistive listening systems are generally used indoors where sunlight cannot interfere with reception.

Improvements to and application extensions of inductive loop and infrared assistive listening technology will provide important benefits for end-users and significant business opportunities to manufacturers.

CURRENT TECHNOLOGY
Most ALS have a single sound source (e.g. public address system, TV audio output jack, etc.) and one or more listeners. For some systems, the user can switch between sound sources (e.g. multiple microphones) or mix signals from different sources. With the exception of gain control (roughly equal amplification across all frequencies) and signal compression (wide input signal excursions are kept within some dynamic range) most ALS do not further process the sound signal.[***] Typical environments for ALS include service counters, conference rooms, auditoriums, classrooms, courtrooms, churches and temples, theaters, museums, arenas and sport stadiums, retirement and nursing homes and hospitals. The following sections discuss conventional inductive loop, 3-D inductive loop and

[***] The general assumption appears to be that sound processing is more appropriately carried out by the individual's hearing aid.

infrared Assistive Listening Systems in more detail.

Conventional Induction Loop Systems (Architectural and Transportation Barriers Compliance Board, 1999; Bakke, Levitt, Ross, & Erickson, 1999)
This technology converts the acoustic signal into electromagnetic fields produced as electric current which passes through a wire loop placed around a listening area. In general, the user must remain within the loop area in order to receive the transmission. The inductive loop ALS can be permanently installed or installed on an as-needed basis. Portable inductive loop systems are available for use with small groups of listeners and can be stored in a carrying case and set up as needed.
For a typical system, a speaker talks into a microphone connected to a loop amplifier. The acoustic energy of the speaker's voice is changed to an amplified alternating electrical current that is sent through a loop of wire placed around the reception area (e.g., home, conference and class rooms, churches, nursing homes, theaters, courtrooms, etc.). As electrical current passes through the wire loop the electrical energy is transformed into electromagnetic energy. The electromagnetic field "induces" a corresponding electrical current in the hearing aid telecoil (essentially another loop of wire). This electrical current `travels through' the hearing aid to the hearing aid's speaker. The speaker transforms the electrical signal back into an acoustic signal (sound) that is delivered to the ear.

Microphones are the most common input device for inductive loop systems but these systems may also receive their input from other sources (e.g., a television's SCART connection, sound systems, special doorbells, telephone ringers, etc.). In large halls, there may be multiple microphone positions, along with alternative sound sources such as tape machines and audio-mixing equipment interfaced to the system. Pocket, hand-held, and ear level (similar in form to a hearing aid) inductive receivers are available. These devices output the sound signal through headphones (with or without a hearing aid in place) or earphones.

Permanent installation of the inductive loop wire often requires grooving the floor for cable placement. This may be difficult, costly or impractical (e.g. historical sites, vinyl floor covering, etc.). To solve this problem, a flat insulated cable with adhesive backing has been developed. A plastic (PVC) cap can be placed over the cable for increased protection and durability.

3D Induction Loop Systems (Frost & Sullivan, 1994; National Center for Health Statistics, 1997)
The 3D inductive loop systems use a special "loop processor" and "loop mats" rather than a single loop enclosing the reception area. The electromagnetic fields produced by a 3D-loop system substantially reduce the orientation dependent sensitivity of a standard telecoil receiver. Field spill-over for a 3D-loop system is also substantially reduced relative to the conventional inductive loop system. Installing loop mats six feet apart essentially eliminates the

spillover effects. 3D-loop systems are much less common and generally more difficult to install than conventional loop systems.

Infra-Red (IR) Systems (Frost & Sullivan, 1994; National Center for Health Statistics, 1997)
This technology converts the acoustic signal into infrared light radiated from infrared emitters focused onto the listening area. Infrared light has a `longer wavelength' than red light (wavelength determines the perceived color) and is invisible to human eyes. The infrared light signal will reflect well from many but not all surfaces. Depending upon the environment then, the user (actually their infrared receiver) may or may not need to be in the "line-of-sight" to the emitter. Infrared ALS can be permanently installed or installed on an as-needed basis. Portable infrared systems are available for use with small groups of listeners and can be stored in a carrying case and set up as needed. Infrared transmitters for in-home use can be plugged into the audio jack of a television or stereo.

For a typical system, the speaker talks into a microphone transforming the acoustic signal into an electrical signal. The electrical signal may be processed (e.g., input signal compression) before driving an infrared emitter. For large venues, infrared ALS employ large emitter (heater) panels. The infrared signal is picked up by the infrared receiver and converted back into an electrical signal. The transmitted infrared signal is typically frequency modulated (FM). This electrical signal drives headphones or earphone speakers. Alternatively, the electrical signal can be retransmitted via an inductive neck loop to be picked up by a hearing aid T-coil or provided as a direct audio input (DAI) to the hearing aid.

Infrared transmissions do not travel through walls or other solid surfaces. There is no signal spill-over and privacy is ensured. Some infrared systems use multi-frequency receivers that support independent, non-interfering communication channels. This is useful (for example) with multilingual translation and multilingual environments. Infrared wireless headphones are especially useful for television listening. Sound input to an in-home infrared transmitter from the audio jack plug on the TV, or a microphone placed near the TV speaker.

STATEMENT OF PROBLEM
The following discussion is based upon issues raised during interviews and panels involving researchers, manufacturers and end-users.

Induction Loop Systems

- For conventional inductive loop systems, the orientation of the electromagnetic field is dependent upon ones position relative to the loop. In the center of the loop, the field is perpendicular to the plane in which the loop lies. As one moves about the looped region, the field orientation changes somewhat. A telecoil picks up the signal best when the local electromagnetic field is perpendicular to the plane in which the telecoil lies. The user must reposition their head (and maintain this position) in order to orient the hearing aid telecoil for optimal reception.

- The electromagnetic field produced by a conventional loop system spreads somewhat beyond the region enclosed by the loop. This is problematic when adjacent regions are "looped." In such cases, users may pick up signals from adjacent looped regions.

- In principle, inductive loop systems have significant advantages over infrared and FM Assistive Listening Systems. These advantages include convenience for hearing aid users with built-in telecoil receivers, elimination of the cost for separate receiver units, and decreased system maintenance (e.g. charging receiver batteries). Unfortunately, it is estimated that only 30% of modern U.S. hearing aids are fitted with telecoils -though in many European countries, the percentage is much higher. For general applications, separate receiver units must be purchased and maintained. Inductive (telecoil) receivers are also susceptible to interference from ambient electromagnetic fields (e.g., fluorescent light fixtures, power cables, electric motors, etc.). Building structural elements (e.g., steel girders) and environmental objects (e.g., steel seats) can affect the shape, strength and local orientation of the electromagnetic field.

- 3D-loop systems are much less common and generally more difficult to install than conventional loop systems.

Infra-Red (IR) Systems

Infrared ALS generally cannot be used in direct sunlight and are subject to interference from fluorescent lighting. Infrared receivers are required for everyone and these receivers require administration and maintenance. Infrared systems that use neck loops are also subject to electromagnetic interference. Portable infrared transmitters are available that can run for hours between battery charges.

ISSUES TO CONSIDER

The Need

- What are the important, unmet (or poorly met) user needs related to infrared and inductive loop Assistive Listening Systems?

- What populations or demographics (e.g., degree of hearing loss, characteristics of hearing loss, cause of hearing loss, age, etc.) are most affected by these needs/problems?

- In which environments and for which activities is this need or problem most significant?

- What accommodations (or behavioral changes) do hearing impaired persons make in order to function in these environments and accomplish these activities?

State-of-the-Practice

- What infrared and inductive loop products are used by, or prescribed for, hearing impaired persons in order to address these problems or needs?

- What are the strengths (e.g., performance, cost, etc.) of these products?

- What are the weaknesses (e.g., performance, cost, etc.) of these products?

Future Technology and Products

- What significant technical improvements are needed?
- What technical barriers (e.g. environmental factors, power consumption, size, etc.) must be overcome in order to achieve these technical improvements?
- What breakthrough technologies (not present in current products) might better address the identified needs and problems?
- What technical barriers (e.g. environmental factors, power consumption, size, etc.) must be overcome in order to achieve these technical breakthroughs?

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Infrared Forum Data

DATA: INFRARED SYSTEM

The following is the raw data collected during the stakeholder forum. It reflects the comments and needs as expressed by the forum participants.

1. **Needs (unmet needs of customers, clinicians, etc.)**
   - Need to be able to have private small group conversation.
   - Need infrared system for everyday, free-flowing multi-speaker, multi-listener environments (i.e. social events, family situations, public meetings, group dinner conversations, etc.)
   - Need privacy in multi-speaker, multi-listener situations (i.e. eliminate "bill boarding" effect)
   - In multi-speaker, multi-listener situations, need to quickly know who is speaking without having to look around room
   - Need to be able to communicate one-to-one in a noise free Bell Jar (i.e. isolate the listener and the speaker in a "noise free cone")
   - Need a convenient way to maintain the power supply.
   - Infrared system applications (e.g. courtrooms, cinema, live theatre, guided tours, self-guided tours, signage, etc.)
   - Infrared systems can be used in aircraft, hospitals and other environments where FM systems can't be used.
   - Need to be able to use Infrared systems outdoors.
   - Infrared systems can be used for enclosed situations (such as depositions, etc.) where you need privacy.
   - IR systems need to look more natural (e.g. part of eye glasses, piece of jewelry, etc.)
   - IR systems should be able to receive multiple frequencies so that receiver can be used in "different areas."
   - IR receivers need to have a simple "switch" for user to select frequency – needs to be very easy to find right frequency.
   - A "switch" to select frequencies would be a lot better than a tuner.
   - If you build a smaller receiver - people will by it. Receiver controls cannot be miniature - otherwise elderly persons will not be able to use the device.

2. **State-of-the-Practice (current technology, strengths, weaknesses, etc.)**
   - Standards for infrared transmissions are no longer followed.
   - Single speaker / multi-listener systems require a powerful wide-pattern infrared transmitters - especially outdoors.
   - Infrared systems cannot (practically) be used outdoors in daylight (note: Talking Signs, Talking Lights and military infrared systems were noted for improved daylight capabilities).
   - Single-speaker / multi-listener infrared systems are generally simple to set up.

- Multi-speaker / multi-listener infrared systems are complicated to set up - lots of microphones and wires.
- Infrared receivers generally need to be in the line-of-sight of the IR transmitters (e.g. outdoors).
- Infrared transmitters are often not placed in the best location (i.e. leave reception "dead spots" in the environment)
- Extra infrared transmitters are sometimes required in order to eliminate reception dead spots.
- Most infrared systems (excepting portable / body worn transmitters and receivers) require an AC power supply.
- Portable infrared transmitters use a single diode and are very directional.
- Portable infrared transmitters work well for one-on-one communication in loud environments.
- Portable infrared transmitters are battery powered.
- Infrared systems (generally) require a line-of-sight between the transmitter and receiver. When people are moving around, changing their position and orientation - maintaining the signal path can be difficult.
- Infrared transmitter and receiver diodes can be scratched (note: some participants said that this wasn't a problem because protective coatings and covers are available).
- Infrared light is reflected by many surfaces.
- Surface reflection (of infrared light) can be an advantage – provided that the ambient infrared light is not to strong, infrared reflection can reduce the need for line-of-sight between transmitter and receiver.
- Line-of-sight requirements between the transmitter and receiver can be advantage – improve privacy.
- Infrared systems (within infrared opaque "walls") are secure/private – no one can listen outside the room in which infrared system is being used.
- Infrared systems (within infrared opaque "walls") don't have spillover problem – systems can be used in adjacent rooms.
- Infrared systems used at night (without intervening barriers) can interfere with the signal of nearby transmitters – signals carry a lot farther at night.
- Infrared systems are (relatively) more secure/private than FM systems (any tuned FM receiver can pick up signal) and inductive loop systems (any T-coil receiver can pick up inductive signal in looped or spillover region).
- Infrared systems are immune to electromagnetic and inductive interference that affect FM and inductive loop systems.
- Fluorescent ballast frequencies are at 45 kHz and 120 kHz. As a result of Federal mandates, 120 kHz ballasts will be phasing out in next ten years.
- Fluorescent lighting produces infrared noise (first harmonic of 45 kHz ballast frequency) for infrared systems (i.e. those infrared systems using 95 kHz carrier frequency)

- Fluorescent lights can be covered with an infrared absorbing material that is transparent to visible light.
- Several multi-channel (multi-frequency) infrared systems are readily available, but they are very expensive.
- Infrared systems use commercially available “off-the-shelf” components (designed for different applications) that have sub-optimal performance.
- Infrared receivers now use broadly tuned diodes. Broadly tuned receiver diode is more subject to infrared interference.
- Strong infrared transmitters can interfere with the infrared receiver of other electronic devices such as the Sony large screen video projector or TV remote control.
- Infrared transmitters are available that can be connected directly to televisions and radios (phono output jack).
- Infrared systems for in-home applications are generally inexpensive.
- Audio quality for infrared listening systems is generally very good.
- Transmission overlap (e.g. from two or more transmitters positioned too closely) can cause signal distortion.
- Transmission multi-path interference (signal travels two or more paths of different length to receiver) can cause signal distortion.
- Infrared systems for large area applications use a single transmitter panel with lots of diodes OR a number of smaller panels in multiple locations. The second approach works well if you don’t have a lot of multi-path distortion.
- Infrared systems can be used in environments (e.g. hospitals, airplanes) for which FM systems are unsuitable (e.g. electromagnetic interference sensitive environments).
- Disney World has infrared transmitters all over the park IR that use the same transmission frequency. These transmitters don’t interfere (probably because transmission power dies-off in the intervening space).
- Universal infrared / FM receiver was in the market. Participants felt that its FM receiver didn’t work well and that its “active microphone” was difficult to use when two or more persons were talking. Product was also considered to be too expensive.
- Evolution of infrared systems has been influenced by the development of television remote controls.
- Multi-channel (multi-frequency) infrared systems are used for multi-language transmissions (e.g. United Nations).
- Many infrared systems for the classroom applications have a problem – the teacher is stuck near (connected by a wire to) the transmitter.
- JVC has a wireless system that is suitable for classroom applications. The speaker carries a portable, short-range infrared transmitter and can move anywhere within the room. Receivers are in each corner of the room. They feed the signal to a powerful infrared transmitter (using a different frequency). Listeners all have portable receivers. *System works very well. Problem – a two-channel system costs about $2000 and has to be installed.*
- A blind person can record with hand-held infrared receiver from Talking Signs.

- Seaworld uses infrared systems whose receivers are (apparently) undamaged by the salt air.

3. Needed Technology (refinements, innovations, etc.)

- Specialized components (e.g. narrow spectrum receiver diodes) are needed in order to achieve optimal system performance (e.g. immunity to infrared interference).
- Need special purpose modulator integrated circuit for infrared transmitter (FM modulators are now used for IR systems).
- Infrared systems should be immune to interference (eliminated or greatly reduced) from the infrared emissions of fluorescent lighting systems. (Note: a number of remedies were suggested including "narrowly-tuned transmitter and receiver diodes," improved noise filtering, used of a different infrared carrier frequency and having the fluorescent lighting industry adopt a new ballast frequency standard.)
- Infrared transmitters for systems used on aircraft should have a relatively short range (i.e. enable one-on-one communication without interfering with other users.)
- Infrared systems (for one-on-one and small group discussion) should have the ability to isolate the speaker and listener in a "noise free cone" (imagine speaker and listener in a Bell Jar – ability to capture input "properly.")
- Infrared systems (for one-on-one and small group discussion) should eliminate "bill boarding" effect (e.g. persons at nearby "tables" listening in on conversations). Some participants suggested that a tightly directed (narrow) transmission would not provide sufficient privacy – persons at a nearby table might still pick up the signal.
- Infrared systems should use carrier frequency that will not be interfered with (e.g. increasing carrier frequency from 95 kHz to 2.3 MHz)
- Receivers should work for all (makes and models) of transmitters.
- Infrared receivers should be multi-frequency (e.g. readily identify and receive transmissions for some set of predefined frequencies).
- Users should be able to select from among different transmitter frequencies.
- Infrared receivers should be able to detect and lock onto the transmitter frequency.
- Infrared receiver (for multi-speaker systems) should indicate who is speaking – user should not have to look around to see who is speaking.
- A Universal FM / infrared receiver should be developed (i.e. need to minimize equipment - people with a profound hearing loss are required to carry a lot of equipment.)
- Infrared transmitters should have signage (e.g. ON/OFF sign) indicating when system is on (Note: This is important for users – if the system is "ON" and nothing is being received then there is a problem.)
- Infrared systems should function in daylight (note: typically it is not practical to use infrared systems outdoors because of the infrared energy in sunlight. Participants believed this was primarily a receiver problem. For this reason FM and inductive loop systems are more commonly used outdoors.)

- Infrared systems should be developed for use in and around water - in swimming or water aerobics classes you can't hear the instructor.
- Infrared systems have many potential (unrealized) applications (e.g. cinema, live theater, etc.); where privacy or signal spillover is a concern (e.g. court depositions, banking, etc.); where FM and infrared loop systems are precluded (e.g. hospitals, airlines).
- Infrared systems for multi-speaker / multi-listener applications (e.g. for business meetings, small group social gatherings) should be less complex (currently these systems use lots of microphones and wires. System setup impacts performance.)
- Receivers for multi-speaker / multi-listener infrared systems should indicate who is speaking (e.g. visual indicator).
- Infrared transmitters and receivers should be compatible with other electronic devices (e.g. connect infrared transmitter to TV or radio, connect receiver to tape recorder).
- Microphone should provide a low noise input to the infrared transmitter (i.e. signal quality at the receiver is limited by the input quality)
- Infrared receivers should be simple (easy to use) in order to be accepted by elderly users.
- More powerful transmitter diodes should be found for large-area infrared systems.
- Highly tuned diodes should be found for infrared receivers.
- Listening systems built around the Blue Tooth Standard (a multi-channel spread spectrum wireless communication standard) may provide the same security as an infrared system (plus additional benefits)
- Portable (body-worn) transmitters and receivers need to be smaller and lighter - current units are bulky, unaesthetic and interfere with vigorous physical activity.
- Body worn transmitter diodes should have low power consumption.
- Smaller batteries should be used for body worn transmitters and receivers.
- Infrared systems should address "listening enhancement" for persons with or without hearing impairment (e.g. at philharmonic concerts, many infrared receivers are used by persons with normal hearing in order to better enjoy the music. Defined in this way, the market for infrared systems may be much larger).
- Infrared transmitters, receivers and controls need to be standardized and universally compatible (i.e. user should be able to take their receiver anyplace and have it work with any receiver. Currently, receivers are matched to specific transmitters).
- Infrared receivers should come down in cost and be owned by individual users (note: some participants commented that the private sector doesn't purchase glasses for people, why should they be required to provide people with receivers?)
- The user should take their infrared receivers with them from place to place (more convenient than having a receiver provided to the user at each location).
- Infrared systems should not interfere with other devices/products using infrared communication (e.g. television remote controls).

- Some participants believed that the infrared receiver should only have an ON and OFF control but not have a volume control (it was suggested that volume could be preset by an audiologist).
- Some participants believed that users should control volume with a credit-card sized remote control.
- Crossover markets should be identified for the batteries used in portable infrared transmitters and receivers (drive down costs through economies of scale).
- New markets (e.g. cinema, public address, theatre, secure, private, tours, etc.) should be identified for infrared listening systems.
- Televisions are always on at bars - it should be possible to have inexpensive receivers to listen to the television even though the sound is turned off (can also be done on planes).
- Infrared receivers should be compatible with headphones and also interface with hearing aids through a DAI or inductive neck loop.
- Comfort, convenience, and aesthetics should be considered in the design of infrared receivers (e.g. keeping wire untangled, integrating the receiver into jewelry (e.g. cufflinks) and headphones).
- Infrared receivers should be smaller and more attractive - currently "big black box hanging from your neck"
- Infrared system manufacturers should work with the lighting products industry in a collaborative and cooperative fashion (currently not happening)
- Consortium of relevant manufacturers (fluorescent lighting, computer, infrared listening systems, … all stakeholders in technology) should define carrier frequencies for infrared systems.
- Infrared system manufacturers should (work to) get reserved carrier frequencies for infrared listening systems.
- Infrared receivers should be incorporated into cell phones - you wouldn't need a separate infrared receiver (problem - interface with hearing aid would require an inductive loop or alternative)
- Waterproof infrared receivers should be developed for in-water applications (e.g. swimming, water aerobics, etc.)
- Infrared receivers should have adjustable range of reception. Short range would be very useful for small group communication. Long range would enable the user to hear someone speaking across the room.
- Improved battery technology is needed for infrared transmitters and receivers – reduced size, increased time between recharge, increased capacity, etc.
- Infrared receiver should be "immune" to light pulses (e.g. camera flashes, strobe lights, etc.).
- Infrared receiver should employ improved signal processing and filter techniques (e.g. improve sensitivity, decrease interference from sunlight, immunity to "light pulses," etc.)

- Infrared systems for multi-speaker / multi-listener applications should take a multi-frequency approach or an approach based on controlling the signal path (i.e. directionality and range)
- There should be a more natural way to "aim" the infrared receiver (e.g. attached to eyeglasses, or a piece of [head worn] jewelry).
- Infrared system should have "front-end circuit" that reduces the effects of sunlight and allows the use of infrared systems outdoors in daylight (participants referenced Talking Signs).
- Portable infrared transmitters should limit the amount of infrared energy transmitted to just what is necessary - use a "smart diode" (Talking Signs referenced).
- Receiver controls should be large and easy to use (very important for elderly users.)
- Sound leakage from the receiver should be minimized.
- Infrared systems for "broad-daylight" applications - may not be needed if alternative communication link is acceptable.

4. Barriers (to obtaining technology, to developing technology, etc.)

- Many businesses object to the operational procedure and cost of setting up assistive listening systems (setting up systems that may only be used by one individual in a movie theatre cuts into profits).
- System performance is dependent upon proper installation and maintenance. Users are at the mercy of the public facilities.
- Public perception and acceptance - some theatre owners would like "hard of hearing" individuals to be issued cards so that only hard of hearing persons would get the reserved seating.
- System cost could be prohibitive if off-the-shelf components aren't used.
- ADA- 4% of the audience must have receivers available. This can be ambiguous.
- Diode shot noise – receiver technology (e.g. Talking Signs) may be reaching theoretical limit without chilling the junction or finding alternative diode materials.
- Reduced receiver size, increased power consumption, etc. requires improved battery technology (e.g. don't want to shorten battery life, don't want to shorten time between recharging, don't want to dramatically increase battery cost).
- Social stigma – some hearing impaired individuals won't wear infrared receivers because they don't want others to see the device. Receivers must be cosmetically acceptable.
- Insurance companies often do not cover assistive listening systems - making them unaffordable for many people.
- Many innovations require that communication standards and protocols be defined and implemented in products. Lack of these standards and protocols is inhibiting technology development.
- Owning multiple assistive listening systems can be expensive. A large portion of the assistive listening market are elderly and on fixed incomes. They cannot afford multiple systems.

5. Technology Sources (what technology, where found, etc.)

- Military - has a lot of diode technology that would be beneficial to this technology… they have diodes that can transmit over 3 miles in the sunlight (Technology exists but it is classified and it costs a lot).
- Department of Defense agency is interested in transferring "narrowly-tuned diodes" into the private commercial sector. Diode technology does not require further development costs from infrared system manufacturer.
- Talking Signs – infrared system for the blind. Talking Signs has an advanced front-end circuit that reduces the effects of sunlight (allows use outdoors in daylight except when receiver is aimed directly at sun) and smart transmitter diode. Hear and record information from Talking Signs transmitter with hand-held receiver.
- Batteries can be recharged through telemetry - a "plastic gun" held in front of the device and it recharges your battery.
- Department of Defense wants to transfer photonics technologies in order to drive down costs with only in-kind investment by manufacturer. Technologies available include smart diodes, advanced transmission technologies and batteries.
- The best battery technology is a dry lithium polymer – but this technology is not being released to the private sector yet (military applications only). Lithium polymer technologies with electrolytes are already in the market that are much better than the battery technologies now being used in assistive listening systems

Inductive Loop Forum Data

Data: Inductive Loop Technology

The following is the raw data collected during the stakeholder forum. It reflects the comments and needs as expressed by the forum participants.

1. **NEEDS (unmet needs of customers, clinicians, etc.)**
   - Need simple control to turn T-coil on/off - nothing more than T-switch
   - Need T-coil receivers in smaller (ITE, ITC, CIC) hearing aids.
   - Need T-coil receivers in hearing aids for persons with mild to moderate hearing loss.
   - Need "walkman style" IR or FM receiver that interfaces to the hearing aid with silhouette, neck loop or DAI.
   - Need receivers (of all types – IL, IR, FM) to be small and lightweight.
   - Need receivers (of all types – IL, IR, FM) to be comfortable when the user is physically active (e.g. dancing, aerobics, etc.)
   - Need IL systems (portable and permanent) that are easy for non-technical people to use (setup, install, and operate).
   - Need simple instructions for setup, installation and operation (e.g. many people don't read or understand instructions) for IL systems.
   - Need good sound quality (from hearing aid) from anywhere within the looped area.
   - Need to install inductive loop systems properly.
   - Need to follow standards for field strength when setting up or installing IL systems.
   - Need to check IL systems regularly (field strength, connections, wire fraying, etc.).
   - Need more durable IL systems (portable and permanent).
   - Need affordable Inductive loop systems for small organizations and community groups, community groups.
   - Many applications for inductive loop systems (e.g. service counters, cars, home environments, ticket windows, taxis, elevators, etc.) have not been explored (a few exceptions were cited).

2. **State-of-the-Practice (current technology, strengths, weaknesses, etc.)**
   - IL systems are very useful for large meetings (e.g. church)
   - IL systems do not support multiple communication channels (e.g. like multi-frequency FM systems).
   - IL systems are low cost relative to FM and IR based systems
   - IL systems (permanently installed, not portable) can be designed to have very little signal spillover (2 to 3 meters outside of the loop).
   - Lack of confidentiality – no practical way of completely eliminating all inductive field spillover (there is "a way" to stop spillover however, it is not cost effective)
   - Sound level (from hearing aid) varies directly with inductive field strength.
   - Inductive field strength (as received at T-coil) is not always uniform within looped area.

- IL systems (properly designed and installed) have fairly uniform field strength within the looped area. Your position within the loop should not affect signal strength.
- Inductive loop systems are unobtrusive and cost effective relative to infrared and FM systems – even if you need a separate receiver.
- Portable IL systems seem to take longer to set up than portable IR or FM systems.
- IL systems need to be customized for each location and application.
- Performance is susceptible to changes in the environment – inductive loop systems are more affected by what "other people" have done to the environment (changes to lighting, furnishings, room dimensions, etc.) then are IR and FM systems.
- Structural beams (in buildings) can distort the inductive field, generally not a problem for IL systems that are properly designed and installed.
- Some inductive systems use "3D mats" rather than loops. These systems produce more complex (3-dimensional) inductive fields. For these systems, head (T-coil) orientation is much less critical to signal reception.
- 3D mats cause sound distortion effects. Persons with normal hearing are not satisfied with the sound quality of IL systems using 3D mats.
- T-coils in hearing aids are an inherently small and portable receiver.
- Many hearing aids (BTE and others) already have built-in inductive receivers (T-coils).
- Most hearing aids (especially smaller devices) lack a receiver (T-coil).
- Some BTE hearing aids have 3-position T-switches (settings: hearing aid microphone only; T-coil only; both)
- Hearing aids are generally designed to respond to microphone-generated signals. T-coil generated signal differs from the microphone signal. This problem can be addressed by a multi-memory type approach (i.e. T-switch setting selects processing mode for microphone or T-coil).
- Voices simultaneously picked up through the hearing aid microphone and hearing and T-coil (from a neck loop, silhouette or phone handset) are difficult to comprehend.
- You can't use your hearing aid T-coil to listen to a phone while inside an active loop.
- It is difficult (coil size, orientation) put receivers (T-coils) into smaller (ITE, ITC, CIC) hearing aids.
- Receiver (T-coil) sensitivity is dependent upon its size. For hearing aids with built in T-coils, the size of the receiver is limited by the size of the hearing aid.
- Receiver (T-coil) orientation (head orientation) relative to the inductive field affects signal reception. The head position effect is a receiver (T-coil) issue, not a loop issue.
- T-coils pick up any magnetic field "in the room" (receivers are not tuned).
- Using T-coil near a computer can be problematic.
- T-coils receive their input from telephone handsets, silhouette and neck loops for FM and infrared (IR) receivers.
- Many newer telephones seem to provide poor signal quality to the T-coil.
- Basic inductive loop receiver (a hearing aid with a T-coil and without a microphone) sells for about 82 pounds in England. A separate inductive loop receiver is less expensive than an infrared or FM receiver.

- Inductive receivers are very cheap – a hand held receiver can be built for $25.
- FM and IR receivers with inductive neck loops are too large and are uncomfortable during vigorous physical activity (e.g. dancing, aerobics, etc.)
- Silhouettes (small induction coils) are less obtrusive than a neck loop and generate a very high field.
- IL systems are simple to maintain (e.g. permanent loops are very durable when properly installed, no maintenance for T-coil receivers)
- IL systems (permanent or portable) are often poorly installed - need to calculate loop area, measure and calculate field strength, know applicable standards, and check what the field strength should be.
- Wires becoming frayed or disconnected is a common problem for portable IL systems.
- Poor IL system performance is often due to poor installation.
- Sound contractors often improperly install IL systems.
- It isn't necessary to hire a professional installer - a person can be trained (in one-half hour) on how to "double check the loop system." The main concern is field strength.
- Need to properly match amplifier to loop.
- Inappropriate amplifiers are often purchased separately and used to drive the inductive loop.
- Amplifiers used to drive inductive loops often do not meet standards.
- Amplifiers selected to drive the inductive loop (e.g. audio amplifiers) are often inappropriate.
- Manufacturers sometimes make inaccurate performance claims for their amplifiers.
- There aren't many amplifier manufacturers. Limited choice of amplifier performance and features.
- Persons with severe hearing loss often have higher quality hearing aids with T-coils.
- Persons with greater hearing loss often have BTE hearing aids with T-coils. Persons with less severe hearing loss often use smaller ITE or CIC hearing aids that lack T-coils. Therefore, persons with more severe hearing loss are more likely to use and benefit from inductive loop systems.
- Most hearing aids being used in the United States lack T-coils (perhaps 30% of U.S. hearing aids have T-coils)
- Many public venues (e.g. auditoriums) that adhere to ADA regulations only loop certain sections. Hearing impaired individuals may feel separate (different) from other individuals.
- Entire looped area is hearing accessible.
- Segregation – when only a portion of a "room" is looped, persons using inductive loop systems may feel segregated and isolated.
- Building power lines can generate interference. However, when power lines are properly installed there should be almost no interference.
- Power lines operate at 60 Hz. Power line harmonics (i.e. 120 Hz, 240 Hz) are picked up by inductive receiver (T-coil)
- Lighting controls can cause interference (e.g. Scars/ lighting controls).

- If inductive loop systems did not exist, who would be affected? Environments or situations where you can't (conveniently) issue IR or FM receivers to people (e.g. ticket windows, answering machines, bus/cab, etc.)
- IL systems are not the best choice for "tour guide situations" (e.g. museum displays, self-guided tours, etc.). FM or IR based ALS are currently more suitable for these applications.
- Small inductive loops systems are available for service counters and teller windows (e.g. Audi product)
- IR systems are making big inroads on IL markets in Europe.
- Inductive loops could be installed in swimming pools (and other wet environments) but receivers (hearing aid T-coils) are not waterproof.
- IL systems are great for educational facilities and auditoriums where there might only be one or two hearing aid users - very cost effective.
- Talking Lights – new technology that replaces the standard fluorescent ballast with "special" ballast. Talking Lights eliminates the infrared interference problem of fluorescent lighting. May be "perfect solution" where fluorescent lighting is already installed. Concern was raised that lights are turned off for presentations – suggestion made that projector itself could be used as a Talking Light. System is not affected by broad daylight, as long as fluorescent lights are on. Talking Lights uses the 60 Hz AC power supply as a system clock.
- Metal cage problem – buildings constructed in the United States have far more metal than those in the United Kingdom. Solution - use different loops designs for different installations – Amptronics
- International standards specify the basic setup/installation requirements for IL systems - not highly technical.

3. Needed Technology (refinements, innovations, etc.)

- Receiver (T-coil) should fit (with proper orientation) into smaller (ITE, ITC, CIC) hearing aids.
- Receiver (T-coil) performance should not be sensitive to its orientation relative to the inductive field (e.g. 3D T-coil receiver. Two or three coils "combined into one." Practically, you should be able to get away with two coils – one flat, one vertical. Use microprocessor to process signals from multiple coils.)
- Improve receiver sensitivity by increasing coil size (e.g. by embedding in hearing aid body), perhaps change core material
- Smaller hearing aids should incorporate T-coils with 3 settings (T-coil, microphone, both).
- Hearing aids should have receivers (T-coils) that can be tuned to specific inductive loops. This would allow a number of loops to be run in the same area - analogous to FM systems with multiple, selectable frequencies).
- Receivers (T-coils in hearing aids or separate units) should have the ability to distinguish frequency.

- Receivers (T-coils) should sense field strength and normalize received signal appropriately (perhaps a reference signal could be transmitted from inductive loop).
- Common inductive noise (e.g. 60 Hz and harmonics) should be filtered out at the receiver (T-coil) level (e.g. filtering out 60 Hz hum is not difficult – practical solution can be found on Motorola website).
- Receiver should be shielded from high frequency interference.
- Hearing aids with programmable T-coils characteristics.
- Inductive loops (mats, or equivalent) should be simple and foolproof for non-technical users (e.g. drop "loop" onto floor; plug it into the amplifier; system senses and auto-adjusts field strength).
- Portable inductive loop systems should be prefabricated, reliable and have predictable performance
- Inductive loop systems (permanent and portable) should have a modular design to allow for easy expansion.
- Should take advantage of signal spillover to configure for larger environments (note: good performance with the spillover signal may require a more advanced receiver).
- Should integrate field strength meter into the inductive loop system; provide feedback to the loop amplifier to auto-adjust field strength.
- IL amplifiers should self-adjust based upon loop impedance.
- IL systems should have general-purpose amplifier plus a separate loop driver unit.
- Loop driver unit could be an intelligent adaptor for general-purpose amplifiers.
- IL systems should produce high quality sound (i.e. no distortion, as perceived by hearing aid user or non-hearing impaired person using headphones)
- A room's size, shape and architectural features should be the criteria for the proper design and installation IL system—not a limitation.
- Increase demand for advanced inductive loop systems. Make sure these systems accommodate the needs of persons with and without hearing impairments (e.g. good sound quality is necessary if a person with unimpaired hearing is listening to the philharmonic orchestra).
- Audiologists should be educated to the benefits of the IL and so they can prescribe / recommend hearing with T-coils to their patients.

4. Barriers (to obtaining technology, to developing technology, etc.)

- Lack of T-coils in majority of hearing aids sold in United States
- Lack of consumer understanding / education. Consumers don't understand the concept or benefits of inductive loops and T-coils. They therefore don't demand T-coils when purchasing their hearing aids.
- Audiologists (appear to) have a perception that T-coils are expensive and that IL systems are not effective or readily available. For this reason they do not recommend T-coils to their clients. Actually, T-coils in BTE are inexpensive and IL systems are available and cost effective in some areas.
- Many audiologists don't even try to sell BTE hearing aids with T-coils.

- Lack of consumer confidence in T-coil performance. Unpredictable performance. (Note: T-coils are mostly present in the hearing aids of persons with severe hearing impairments. Performance expectations may be unrealistic. T-coil performance is dependent upon the quality of IL system installation, telephone quality and many other factors.)
- Segregation – persons using T-coils need to sit in looped region. Within this region, they must sit in a location where they get the best reception. This may not be where they would prefer to sit.
- Inductive loops are not common (e.g. through the community) – until that changes will be difficult to sell hearing aids with T-coils.
- Lack signage on buildings indicating when an IL system is installed and accessed.
- Lack signage on telephones indicating when they are T-coil compatible.
- Lack information / signage at the point of sale indicating when phone is T-coil compatible.
- 3D T-coils require three loops and these loops must be smaller in order to fit in the same hearing aid volume. You need more amplification to pick up signal and therefore more power to provide the amplification.
- Incorporating 3D T-coils into hearing aids increases their cost (note: most participants thought that the cost impact would be very minor).
- Reducing T-coil size (for smaller hearing aids) reduces its sensitivity to the signal and increases its sensitivity to electromagnetic interference / noise.
- T-coil "is not going to fit as hearing aids get smaller and smaller.".
- Hearing aid speaker produces a field that can be picked up by the hearing aid T-coil.
- Initial installation of IL systems is labor intensive and costly.
- IL system installers are not always competent.
- Difficult to get correct match between amplifier and loop - requires highly knowledgeable person to do that.
- Difficult to set up portable loops correctly. Need to know the size of looped area and use the right amplifier size. Need high level of technical skill - requires appropriate technology, tools, and expertise.
- Power wiring layout in new buildings makes no allowance for the future installation of inductive loops. Significant source of interference.

5. Technology Sources (what technology, where found, etc.)

- An application for those who don't need or wear hearing aids (receiver in the shape of the T Coil.) –[used by secret service and news anchors].

Infrared Systems Problem Statements

Problem Statement - Infrared Systems
Manufacturers, researchers, clinicians and other stakeholders have identified technology needs in the field of Infrared Assistive Listening Systems (ALS). High priority technology needs include systems for **small group communication**, **portable receivers**, and **portable transmitters**. Component technologies for **narrow spectrum IR Diodes**, **low power transmitter/emitter diodes**, **environmentally sensitive "smart" diodes,** and an **improved modulator circuit** were identified as critical for improving infrared systems.

By addressing important, unmet needs of people both with and without hearing impairments, these technology solutions represent a **significant business opportunity**.

MARKET
It is estimated that more than 20 million people in the United States experience some form of hearing loss. Ninety to ninety-five percent of these people could benefit from hearing aids and assistive listening systems. A large majority of the people who would benefit from these devices (approximately 80%) have chosen not to use them. This leaves more than 16 million people with substantially correctable hearing loss who are not currently using assistive devices. Many of the people in this population choose not to use the devices because they are not satisfied with the performance of products currently available or are reluctant to wear an obtrusive device they feel is stigmatizing.

Assistive Listening Systems (ALS) bring a remote (essentially 'noise free') sound into the direct-proximity of the user's ear in order to amplify a selected sound source, overcome background noise, enhance listening in large public venues, and improve one-to-one conversations. Used in combination with hearing aids an ALS can provide optimal sound clarity and speech comprehension. ALS are categorized by the wireless communication protocol used to link the remote sound source and the body-worn receiver. Common ALS include frequency modulated (FM), infrared (IR), and inductive loop (IL) systems. The receiver can be directly associated with the hearing aid (built-in FM receiver, FM-boot, telecoil). Alternatively, some IR and FM receivers retransmit the signal via an inductive neck loop to be picked up by the hearing aid telecoil.

According to the Hearing Aid Compatibility Act of 1988, all telephones sold in the US should be compatible with standard hearing aid telecoils. However, it is estimated that only 30% of modern hearing aids in the US actually incorporate a telecoil. (A telecoil is an induction coil placed in a hearing aid that is designed to pick up fluctuating magnetic fields produced by coils in the telephone hand set, so that these signals can be amplified without interference.)(Self Help for Hard of Hearing, 1999) Persons with greater hearing loss often have BTE hearing aids with T-coils, while persons with less severe hearing loss often have smaller ITC and CIC hearing aids that lack T-coils. As a consequence, persons with more severe hearing loss are more likely to benefit from inductive loop systems.

The Americans with Disabilities Act (ADA) and the Telecommunications Act have increased the popularity and availability of assistive technologies for employment, education, and access to buildings, transportation and telecommunications. The ADA requires that any business (auditoriums, theaters, etc.) with 50 or more fixed seats in an assembly area must make ALS available for at least 4% of the seating capacity.(The US Equal Employment Opportunity Commission, 1990) The market potential for assistive listening systems is much broader than the hearing aid market. People without hearing impairments are currently using ALS for museum tours, nature walks, improved listening at philharmonic concerts, and other "enhanced listening experiences". Additionally, infrared technology used for high quality public address systems and for a multi-channel, multi-media entertainment venue poses a huge market opportunity for anyone able to develop these technologies.

CURRENT TECHNOLOGY

Infrared (IR) systems provide a personal communication channel between the speaker and the listener that shortens the "acoustical pathway" between speaker and listener and improves the signal-to-noise ratio. Wide area IR systems are available for one-to-many (single sound source / many listeners) communication. Personal IR systems are available for one-on-one (single speaker / single listener) communication. IR systems for many-to-many (natural, small group) communication are currently not available.

The basic IR system is composed of 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. The signal from the modulator (transmitter) is delivered to emitters composed of one or more infrared diodes that produce the IR light waves. The transparent lens found on every IR receiver contains an infrared photo diode that detects the IR light wave. The IR receiver then demodulates the RF sub-carrier and the audio signal is retrieved and amplified.(Bakke, Levitt, Ross, & Erickson, 1999) Infrared systems use commercially available "off-the-shelf" components that are designed for other applications (e.g. FM radio electronics) and may have sub-optimal performance.

Most infrared systems have operated at 95 kHz and 250 kHz (with stereo reception) sub-carriers. More recently, 300 kHz, 2.3 MHz and 2.8MHz sub-carriers have been employed. Infrared systems cannot generally be used in direct sunlight (infrared "noise" overpowers the transmitted "signal"). Fluorescent lighting produces infrared noise (harmonics from fluorescent lighting with T-12 ballasts) that interferes with 95 kHz infrared systems (providing impetus for other sub-carrier frequencies to be used). Fluorescent lights are sometimes covered with an infrared absorbing material that is transparent to visible light. Infrared receivers use broad-spectrum diodes with pass band filters that are more subject to infrared interference (than narrow-spectrum diodes). Narrowly tuned diodes would benefit system design by reducing interference - provided that transmitters will not drift outside the pass band during normal operation. Strong infrared transmitters can interfere with the infrared receivers of other electronic devices, such as large screen video projectors or TV remote controls. Signal overlap between nearby infrared transmitters can cause interference that is worse at night when the infrared signals carry farther.

Infrared systems generally require line-of-sight between transmitter and receiver. It can be difficult maintaining the signal path when people change their position and orientation relative to the transmitter (e.g. people moving about at an outdoor conference). Many surfaces reflect infrared light and for indoor applications it is generally not necessary to maintain direct line-of-sight between transmitter and receiver. Infrared opaque "walls," make infrared systems relatively secure and private. In contrast, FM and inductive systems lack privacy and security because their transmissions cannot easily be contained within a confined region. Infrared receivers are immune to electromagnetic and inductive interference that effect FM and inductive loop systems. Infrared systems can be used in electromagnetic sensitive environments (e.g. hospitals, airplanes) for which FM systems are unsuitable.

Wide area infrared transmitters are relatively simple to set up and use in meeting rooms, conference halls etc. A microphone is the most common input device but large halls often have multiple microphone positions, or alternative sound sources such as tape machines and audio-mixing equipment interfaced to the main transmitter (emitter) panel. Multi-microphone systems are somewhat more complicated to set up (wires and microphones) and use. Emitter panels can be permanently installed or portable and generally have an ovoid transmission pattern. Coverage depends on the size and shape of the "room." If one panel is not sufficient then repeater panels are used to increase the coverage area. Multi-channel (each channel a different frequency) infrared systems (e.g. for multi-language translation) are readily available but expensive. Small infrared systems for in-home applications are generally inexpensive. Most wide area infrared systems require an AC power supply.

Portable (body worn) IR transmitters are available with sound field systems and wide area systems. The speaker can move freely about some local area where a receiver picks up the signal that is then output through speakers (sound field system) or relayed to a more powerful infrared emitter and retransmitted on a different frequency (wide area system).

Portable IR transmitters are also used with personal communication systems for one-on-one communication in loud environments. Body-worn transmitters are generally powered by a rechargeable battery with between 2-20 hours of use between charges(depending on battery type).

Infrared receivers are available in stethophone, headphone and body worn variations.

Stethophone receivers hang below the user's chin, the lens of the receiver diode faces forward and sound is output through the ear buds or an inductive loop. Body worn receivers are similar in size and appearance to body-worn FM receivers except for the forward facing diode lens, sound output is through headphones, ear buds or an inductive loop. These receivers sometimes include jacks for environmental microphones (for communication in the immediate area) but generally lack low power indicators. Body-worn transmitters are generally powered by a rechargeable battery with between 2-20 hours of use between charges (depending on battery type).

Wireless headphones (FM or IR) are gaining acceptance for home entertainment (e.g., TV, music, etc.) where a person needs a volume level that would disturb others. The transmitter receives its input from an audio jack (television, radio, etc.) or from a microphone placed near the sound source. The receiver can be located at the top of the headphones with approximate omni-directional reception or on the headphones themselves. Headphones (for all receiver types) can be worn over all but behind-the-ear (BTE) hearing aids. Universal infrared/FM receivers were on the market that (in principle) eliminated the need for multiple receivers, however FM receiver and "active microphone" performance were not considered to be acceptable.*

Infrared systems from different manufacturers (even using the same sub-frequency carrier) are often not completely compatible due to differences in transmitter signal pre-processing (e.g. high frequency emphasis) and receiver signal post-processing and sensitivity. IR system standards (e.g. light level) are generally lacking. Setting up or installing an IR system may be straightforward but obtaining uniform and consistent signal strength is not (installers usually move about the reception area to evaluate reception quality).

Technology is currently under development in other industry sectors that may be applied to the assistive listening field. This includes technology developed for the military and systems developed for the blind. The Department of Defense (DOD) has developed **high power diodes** that can transmit over three miles in sunlight. DOD is also interested in transferring

* Comments from participants at the Stakeholders Forum on Hearing Enhancement, New York, NY, June 24th and 25th, 2000.

narrowly tuned diodes to the private sector. Other DOD-developed technologies include phototonics, smart diodes, advanced transmission technologies, dry lithium polymer and other battery innovations.

Talking Signs is an infrared system for the blind that uses an advanced front-end receiver circuit to reduce interference from sunlight while the transmitter has a smart power-saving diode. Another technology with good potential for ALS applications is telemetry recharging. A "plastic gun" recharges the battery without removing it.

TECHNOLOGY REQUIREMENTS
Users, manufacturers, clinicians, researchers, and other stakeholders have identified technology that will significantly improve the performance of ALS and expand the market for infrared ALS and related technology. Technology currently needed includes:

- IR systems for "natural" or small group communication
- A "universal" portable receiver
- A "universal" portable transmitter
- Narrow-spectrum IR diodes for portable receivers
- Low power IR diodes for transmitter/emitter
- Smart transmitter diodes that adjust power in a response to the environment
- An improved IR modulator circuit
- Improved batteries

The specific performance features for these technologies are listed below.

Final product manufacturers and consumers are keenly interested in technologies that meet these needs. Both component and system solutions that enhance the lives of people with and without hearing disabilities present a significant business opportunity.[**]

Infrared System for "Natural" Small Group Communication
- Consists of ***Receivers*** and ***Transmitters***.
- Should use multi-frequency or signal path (range and direction) approach.
- Should isolate the speaker(s) and listener(s) in a "noise free cone" (imagine the speaker and listener in a Bell Jar – ability to capture input "properly.")
- Should eliminate "bill boarding" effect (e.g. prevent persons at nearby "tables" from listening in on conversations).
- Should be easy to use (e.g. portable, natural, little or no setup of transmitters, wires and microphones)

[**] Note: Technology developers who are interested in Infrared Technology solutions may also want to refer to the FM and Inductive Loop Problem Statements. There may be opportunities to combine the technologies and leverage a multi-system solution for an expanded market share. New, innovative or revoluntionary approaches that are independent of the technologies under consideration might provide the superior solution. Dr. Laszlo's comments introducing this section of the Proceedings are particularly relevant.

(Note: a **System for Natural, Small Group Communication** is essentially a combination of the characteristics found with the **"Universal" Receiver** and **"Universal" IR Transmitter** below.)

"Universal" Portable Receiver

- Should be priced so that individual users can own them (increased user convenience)
- Should be universally compatible (work with) any infrared transmitter.
- Should be multi-frequency (e.g. readily identify and receive transmissions for some set of predefined frequencies).
- Should detect and lock onto transmitter frequency (e.g. useful when changing environments; for small group communication systems)
- Should indicate who is speaking (user should not have to look around to see who is speaking, perhaps a visual display might indicate who is speaking).
- Should have a more natural way to "aim" the receiver (e.g. for small group communication, attached to eyeglasses, or a piece of [head worn] jewelry).
- Should have adjustable reception range (short range would help prevent billboarding during small group communication; long range would enable the user to hear someone speaking across the room).
- Should have user frequency selection capability (e.g. select among multiple channels carrying different languages).
- Should be compatible with other electronic devices (e.g. connect receiver to a tape recorder).
- Should support headphones, DAI, and inductive loop (universal output for persons with and without hearing aids).
- Should integrate FM and IR receivers (minimize equipment carried by persons with profound hearing loss).

[Note: please refer to problem statement on **FM Systems** for details on desirable FM receiver characteristics.]

- Should be immune (eliminated or greatly reduced) to infrared interference from sunlight, fluorescent lighting and bulb flashes.
- Should use **narrowly tuned (narrow spectrum) diodes** to reduce IR interference (e.g. sunlight, fluorescent lights, "flash bulbs)
- Should employ a **"front-end circuit" that reduces the effects of sunlight** (Talking Signs referenced)
- Should minimize sound leakage (i.e. don't annoy nearby listeners that do not have hearing impairments).
- Should be comfortable, convenient, and attractive (e.g. keep wires untangled, integrate receiver into jewelry (cufflinks, etc.) or headphones).
- Should be unobtrusive (currently "big black box hanging from your neck")
- Should have large and easy to use controls (ON/OFF, volume, etc.; especially important for elderly users.)

[Note: it was suggested that volume should not be under user control but rather could be preset by an audiologist. This suggestion is not compatible with universal use by persons with - and without impairments. It was also suggested that a separate credit card sized remote control could be employed.]

Infrared Transmitters (for both ***Portable and Wide Area Transmitters***)

- Should use a carrier frequency that fluorescent lighting will not interfere with (e.g. shift sub-carrier frequency away from 95 kHz)
- Should not interfere with other infrared devices (e.g. IR remote controls).
- Should have **improved modulator circuit** (e.g. FM modulators circuits now used)
- Should be compatible with other electronic devices (e.g. TV, radio audio output).
- Microphone should provide low noise input to the transmitter (i.e. signal quality at the receiver is limited by the signal quality from the transmitter.)

"Universal" Portable Infrared Transmitter (Emitter)

- Should use **diodes with lower power consumption**
- Should use **"smart diodes" that limit infrared energy to "just what is necessary"** for the environment (Talking Signs referenced)
- Should be smaller and lighter (current units are bulky, unaesthetic and interfere with vigorous physical activity)
- Should have short-range transmitters on aircraft (i.e. enable one-on-one communication without interfering with other users.).
- Should use **batteries** with reduced size, increased time between recharge, increased capacity, reasonable cost etc.

Wide Area Transmitter (Emitter)

- Should use more-powerful diodes
- Should have ON/OFF signage on (important for users – if the system is "ON" and nothing is received, users know there is a problem.)

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Inductive Loop Systems Problem Statements

Problem Statement - Inductive Loop Systems
Manufacturers, researchers, clinicians and other stakeholders have identified technology needs in the field of Inductive Loop Assistive Listening Systems (ALS). High priority technology needs include **prefabricated modular loops**, **advanced receivers employing 3-dimensional telecoils** and **intelligent loop amplifiers.**

By addressing important, unmet needs of persons with and without hearing impairments, these technology solutions represent a **significant business opportunity**.

MARKET
It is estimated that more than 20 million people in the United States experience some form of hearing loss. Ninety to ninety-five percent of these people could benefit from hearing aids and assistive listening systems. A large majority of the people who would benefit from these devices (approximately 80%) have chosen not to use them. This leaves more than 16 million people with substantially correctable hearing loss who are not currently using assistive devices. Many of the people in this population choose not to use the devices because they are not satisfied with the performance of products currently available or are reluctant to wear an obtrusive device they feel is stigmatizing.

Assistive Listening Systems (ALS) bring a remote (essentially 'noise free') sound into the direct-proximity of the user's ear in order to amplify a selected sound source, overcome background noise, enhance listening in large public venues, and improve one-to-one conversations. Used in combination with hearing aids an ALS can provide optimal sound clarity and speech comprehension. ALS are categorized by the wireless communication protocol used to link the remote sound source and the body-worn receiver. Common ALS include frequency modulated (FM), infrared (IR), and inductive loop (IL) systems. The receiver can be directly associated with the hearing aid (inbuilt FM receiver, FM-boot, telecoil). Alternatively, some IR and FM receivers retransmit the signal via an inductive neck loop to be picked up by the hearing aid telecoil.

According to the Hearing Aid Compatibility Act of 1988, all telephones sold in the US should be compatible with standard hearing aid telecoils. However, it is estimated that only 30% of modern hearing aids in the US actually incorporate a telecoil.(National Center for Health Statistics, 1997) (A telecoil is an induction coil placed in a hearing aid that is designed to pick up fluctuating magnetic fields produced by coils in the telephone hand set, so that these signals can be amplified without interference.(Self Help for Hard of Hearing, 1999)). Persons with greater hearing loss often have BTE hearing aids with T-coils, while persons with less severe hearing loss often have smaller ITC and CIC hearing aids that lack T-coils. As a consequence, persons with more severe hearing loss are more likely to benefit from inductive loop systems.

The Americans with Disabilities Act (ADA) and the Telecommunications Act have increased the popularity and availability of assistive technologies for employment, education, and access to buildings, transportation and telecommunications. The ADA requires that any business (auditoriums, theaters, etc.) with 50 or more fixed seats in an assembly area must make ALS available for at least 4% of the seating capacity (The US Equal Employment Opportunity Commission, 1990). The market potential for assistive listening systems is much broader than the hearing aid market. People without hearing impairments are currently using ALS for museum tours, nature walks, improved listening at philharmonic concerts, and other "enhanced listening experiences". Additionally, inductive loop technology used for high quality public address systems and for multi-channel, a multi-media entertainment venue poses a huge market opportunity for anyone able to develop these technologies.

CURRENT TECHNOLOGY

A generic inductive loop system consists of microphone, loop amplifier, wire loop and inductive receiver. A speaker talks into the microphone connected to the loop amplifier. The amplifier drives current into the wire loop wire placed around the reception area producing a time varying electromagnetic field. The electromagnetic field induces a current in the telecoil and the hearing aid transforms this signal into an acoustic output that is delivered to the ear. A microphone is the most common input device - but IL systems may also get their input from other sources (e.g. television SCART connection, special doorbells, telephone ringers, etc.) Large halls often have multiple microphone positions, and alternative sound sources such as tape machines and audio-mixing equipment interfaced to the system.

When properly installed, inductive loops systems are durable and simple to maintain. Common installation problems include the improper measurement of the loop area, incorrect measurement or calculation of field strength, and lack of knowledge of applicable standards. System performance is susceptible to changes in the environment (e.g. lighting, furnishings, room dimensions, etc.). Permanently installed inductive loops often require grooving the floor for cable placement and in some cases (e.g. historical sites, vinyl floor covering, etc.) this may be difficult, costly or impractical. To solve this problem, a flat insulated cable with adhesive backing has been developed and a plastic PVC cap can be placed over the cable for increased protection and durability.

Portable inductive loop systems are available for use with small groups of listeners and can be stored in a carrying case and set up as needed. **Loop amplifiers** must be properly matched to the load requirements of the inductive loop. Use of inappropriate amplifiers to drive the inductive loop results in poor performance and user dissatisfaction. For all practical inductive loop systems the inductive field can be picked up outside the looped area (a distance of perhaps 2 or 3 meters for a conventional loop). This effect is referred to as "signal spillover."

The **3D inductive loop systems** use a special "loop processor" and "loop mats" rather than a single loop enclosing the reception area. The fields produced by a 3D-loop system substantially reduce the orientation dependency of a standard telecoil receiver. Field spillover for a 3D loop system is also substantially reduced relative to a conventional inductive loop system. Installing loop mats six feet apart essentially eliminates spillover. However, 3D mats may create distortion effects and cause dissatisfaction for persons with normal hearing. 3D-loop systems are much less common and generally more difficult to install than conventional loop systems.

The most common **inductive receiver** is the **hearing aid telecoil**. Built into a hearing aid, a telecoil is an inherently small and portable receiver. The sound level output from the hearing aid is dependent upon the field strength within the loop and the orientation of the receiver coil relative to the field. If the loop has been properly designed and installed, field strength should not vary greatly with the user's location within the loop. In principle, a field orthogonal to the coil plane will produce the largest signal (induced current) and a field parallel to the coil plane will produce no signal. Inductive receivers are not "tuned" - that is they do not support multiple communication channels and pick up "noise" from any magnetic field "in the room." The user must remain within the looped area in order to receive transmission. Voices simultaneously picked up through a hearing aid microphone and telecoil are sometimes difficult to comprehend. BTE hearing aids with 3-position T-switches (microphone only, T-coil only or both) mitigate this problem. **Pocket, hand-held and ear level** (similar in form to a hearing aid) receivers are also available. Sound from these devices is output through headphones (with or without a hearing aid in place) or earphones.

TECHNOLOGY REQUIREMENTS
Users, manufacturers, clinicians, researchers, and other stakeholders have identified technology that will significantly improve the performance of ALS and expand the market for inductive loop ALS and related technology. Technology currently needed includes:

- **Prefabricated modular loops** (or mats)
- **Advanced receivers employing 3-dimensional telecoils** (or the equivalent)
- **Intelligent loop amplifiers** (or driver/adaptors for general purpose amplifiers)

The specific performance features for these technologies are listed below. Final product manufacturers and consumers are keenly interested in technologies that meet these needs. Both component and system solutions that enhance the lives of people with and without hearing disabilities present a

significant business opportunity.*

Inductive Loop System (**Loop** or analog, **Amplifier** and **Receiver**)

- Should be simple and foolproof for non-technical persons to install and operate (e.g. drop "loop" or "mat" onto floor; plug it into the amplifier; system senses and auto-adjusts field strength).
- Should produce high quality, undistorted sound from anywhere within the looped area (as perceived by a hearing aid user or non-hearing impaired person using a body-worn receiver and headphones).
- Should allow user to receive and select from a number of loops running in the same area (analogous to FM systems with multiple, selectable frequencies).
- Should have reliable and predictable performance.
- Might take advantage of signal spillover to configure for larger environments.
- Should be affordable for individuals, small businesses, organizations and community groups.

Loop (or analog)

- Should be prefabricated.
- Should be modular to allow for easy expansion.
- Should not be limited (in its applications) by room size, shape, architecture, etc.
- Should be durable.

Amplifier

- Should have an intelligent driver/adaptor for general-purpose amplifiers.
- Should have field strength meter integrated into the inductive loop system that provides feedback to the amplifier (driver/adaptor).
- Should auto-adjust output based upon field strength.
- Should have tunable "frequency" (see **Receivers** below).
- Should imbed a "signal strength" reference signal (see **Receivers** below).

[Note: a "signal strength" reference signal might simplify the design of an "orientation insensitive" **Receiver**.]

Receivers (Hearing Aid and Body Worn)

- Should not be sensitive to the orientation of the inductive field (e.g. "3-dimensional" receiver that uses a microprocessor to process signals from two or three coils.)
- Should have the ability to distinguish loops by their "frequency."
- Should be able to tune into specific inductive loops.
- Should sense field strength and normalize sound output accordingly (e.g. a standard "amplitude" reference signal could be transmitted from the inductive loop).
- Should filter out common inductive noise (e.g. power - 60 Hz and harmonics).

* Note: Technology developers who are interested in Inductive Loop Technology solutions may also want to refer to the FM and Infrared Problem Statements. There may be opportunities to combine the technologies and leverage a multi-system solution for an expanded market share. New, innovative or revoluntionary approaches that are independent of the technologies under consideration might provide the superior solution. Dr. Laszlo's comments introducing this section of the Proceedings are particularly relevant.

- Should be shielded from high frequency interference.

Hearing Aid Receivers

- Should have programmable hearing aids with tunable receivers.
- Should fit in smaller hearing aids (ITE, ITC, CIC) used by persons with mild to moderate hearing loss.
- Should have improved sensitivity (e.g. increase coil size by embedding in hearing aid shell, changing core material, etc.).
- Should not significantly increase power consumption.
- Should have 3 settings (T-coil, microphone, both) for smaller hearing aids.
- Should have simple, easy to use T-coil controls.

Body Worn Receivers

- Should be "walkman style" and interface with (smaller) hearing aids by DAI.
- Should support headphones (or equivalent) for non-hearing impaired individuals.
- Should be comfortable (small size, reasonable weight, etc.) for when the user is physically active (e.g. dancing, aerobics, etc.)

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TECHNOLOGY AREA

Clinicians, researchers, consumers and manufacturers all identified microphone technology as an area that could benefit from the development and application of new and innovative technology. Improved microphone technology underlies the development of improved hearing aids and assistive listening systems. Advancements to these systems would meet significant end users needs and represent significant business opportunities.

THE NEED

Most people rely upon hearing for communication, social participation and personal safety in their work, recreational, and daily living environments. A person's ability to hear is often reduced by trauma, drugs, disease, or the cumulative effects of aging. Diminished and uncorrected hearing can lead to social isolation, difficulty functioning within the workplace, increased risk to personal safety and a general reduction of a person's perceived quality of life. Assistive technology for hearing including (but not limited to) hearing aids and assistive listening systems, are an effective and enabling intervention for many of these persons.

Hearing and understanding speech accompanied by noise and reverberation is the principle concern of persons with hearing impairments, along with hearing local sound sources in background noise and hearing remote sound sources generally. Hearing aids; wearable, hand-held and remote FM microphones; and assistive listening systems are the principal interventions by which the comprehension of speech is improved. Microphones are an essential component of all hearing aids and most assistive listening systems.

According to the 1990-91 National Health Survey study, 3.6 million people self-identified as having hearing problems use hearing aids. Another 847,000 people use assistive listening systems other than these hearing aids (National Center for Health Statistics, 1997). An additional 16,000,000+ people in the United States could benefit from the use of a hearing aid or assistive listening devices. Hearing aids range from $800 to $1000 for Behind the Ear (BTE) models to $1200 to $2000 for completely in the ear canal models. In recent interviews, consumers stated that the hearing aids they use need better directionality. They said that their hearing aids are unable to narrow their focus to the source of the desired sound. The technology today to help people hear is not sufficient, and many people who are hearing impaired refuse to even use the current devices on the market (Frost & Sullivan, 1994).

The United States population is aging with more people living well beyond age 65, into their 70's and 80's. All of these persons are potential consumers of hearing technology now and into the future. The aged population is expected to grow until the year 2036 when this population is expected to reach its maximum level. The world population is also following a similar growth trend.

The Americans with Disabilities Act (ADA) has increased the availability of Assistive Listening Systems (ALS's) for employment, education, and access to public buildings and transportation. ALS's can be permanently installed or set up upon request, although timely access to the ALS is not assured in the latter case. Of course, the assistive listening system must also be properly maintained (e.g. receiver batteries charged) in order to serve the user's needs.

BASIS FOR DISCUSSION

Significant progress is being made improving the consumer's listening experience in noisy environments through the use of directional hearing aids, handheld and wearable microphones and assistive listening systems.

Consumers are significantly more satisfied with directional hearing aids when compared to high performance non-directional hearing aids in listening environments such as restaurants, cars, concerts, movies, and church. The directional microphones available on many of today's advanced instruments allows the hearing aid to attenuate peripheral sounds and focus on sounds directly in front of the listener. This permits better speech comprehension despite the noise. In one-on-one conversations, directional microphones result in better speech comprehension in noisy environments (Center for Hearing Aid Research & Technical Training, 1999).

Wearable and hand-held "directional beam-forming microphone arrays" demonstrate superior directional performance relative to hearing aid directional microphones. These microphones, used in conjunction with hearing aids, have great potential to improve the listening experience of hearing impaired individuals (Andrea Electronics, 2000; Starkey Laboratories, 1999).

Assistive Listening Systems bring a remote - essentially noise free - sound signal directly to the hearing impaired listener across the intervening reverberant and noise filled acoustic space. ALS's extend the hearing range of these individuals.

Microphone improvements in hearing aids, wearable and hand-held devices, and ALS's will provide important benefits to end-users and business opportunities to manufacturers.

CURRENT TECHNOLOGY

A microphone is a device that transforms sound into an electrical signal. Almost all microphones have a diaphragm that moves when struck by sound waves. Microphones differ primarily in the means by which this diaphragm movement is transformed into an electrical signal. Here are three of the many microphone technologies (Elsea, 2000b; Tan, 1996).

In **dynamic microphones** the diaphragm is connected to a coil of wire placed in a magnetic field. When the diaphragm is struck by sound waves, coil movement in the magnetic field generates an electric current. For condenser microphones, the diaphragm is separated from a back-plate forming a capacitor (a charge storage device). A static charge is placed upon either the diaphragm or back-plate. When struck by a sound wave, the separation between the diaphragm and back-plate changes the capacitor's ability to store charge and an electric current is generated. Condenser microphones require a battery or external power source to maintain the charge on the diaphragm or back plate. Condenser microphones produce a very small signal that must be amplified. Any electrical noise produced by or picked up by the microphone is also amplified.

Electret microphones, a common variant of the condenser microphone, use an 'electret' material for the diaphragm or back plane. This electret material (e.g. plastic, silicon dioxide, teflon) has a permanently embedded static charge that eliminates the need for an external battery or power supply (Elsea, 2000b).

An important characteristic of microphones is their directional (polar) response. Here are several of the most important response patterns and ways in which these responses might be obtained.

- **Omnidirectional** microphones respond equally to sounds coming from any direction. The back of the diaphragm for an omnidirectional microphone is enclosed. Sound from any direction striking the microphone creates a pressure gradient across the diaphragm. This pressure gradient then causes diaphragm displacement.
- **Bi-directional** microphones respond strongly to sounds from the front or rear of the microphone but do not respond to sound from the sides. The back and front of the diaphragm for a bi-directional microphone is open. Sound striking the front or rear of the microphone creates a pressure gradient across the diaphragm - displacing it. A sound striking from the front causes a positive displacement while sounds striking from the rear cause a negative displacement. Sound from the side of the microphone places equal pressure on the front and back of the diaphragm - no displacement takes place.
- **Cardioid** microphones respond most strongly to sounds from the front of the microphone. Sounds from the back of the microphone are reduced (not eliminated). The directional response varies sharply with the sound frequency. Cardioid microphones often respond strongly at low frequencies when the sound source is close to the microphone. This is known as the "proximity effect." In principle a cardioid microphone response can be obtained by adding responses from properly matched omnidirectional and bi-directional microphones.
- **Super-cardioid** and **hyper-cardioid** microphones have a tighter forward directional response than a cardioid microphone but are increasingly responsive to sound from the rear of the microphone.

In practice, a **practical cardioid microphone** response is commonly obtained by the clever use of acoustic delays. Roughly - consider a diaphragm placed at the front of a short tube (Elsea, 2000a). Sound from in front of the microphone strikes the front of the diaphragm but must go up the length of the tube and back before it strikes the rear of the diaphragm. This arrival delay produces a pressure gradient and diaphragm displacement. The extra time needed to go up the length of the tube and back is the acoustic delay. In contrast, a sound from the rear of the microphone travels down the inside and outside of tube simultaneously and strikes the front and rear of the diaphragm nearly simultaneously. Only a small pressure gradient is produced with little displacement. This simple approach will only work well for a narrow range of frequencies. In order to spread the directional effect across a wider frequency range, real microphones generally provide many delay paths (with differing acoustic delays).

A **noise-canceling microphone** generally refers to a combination of a directional and omnidirectional microphone. When the desired signal-in-noise strikes the noise-canceling microphone, the directional microphone captures the sound of interest strongly and the surrounding noise less strongly (assuming the microphone is pointed at the sound source) whereas the omnidirectional microphone captures the sound of interest and surrounding noise equally. Roughly - subtracting the omnidirectional response from the directional response enhances the signal strength relative to the noise strength (signal-to-noise ratio). Signal processing hardware and algorithms may be employed to enhance this effect.

Recently **beam-forming microphone arrays** have been employed to separate a sound signal from noise. Roughly, an array of microphones is placed in a plane, each microphone apart from the others. A sound wave strikes the array. If its direction of movement is perpendicular to the plane in which the array lies, it arrives at each microphone at about the same time (in phase). If its direction of movement is not perpendicular to the plane, it strikes each microphone at a slightly different time (out of phase). This effect varies with the sound frequency and the angle at which the sound wave strikes the array. In addition, the speech and noise around us is a complex mix of frequencies. By application of powerful signal processing hardware and algorithms, this phase information can be used to accept sound coming from one direction but reject (significantly attenuate) sound coming from other directions.

A **wireless remote microphone** is essentially a microphone connected to a wireless (typically) FM transmitter. The microphone transmitter can be in the microphone body or in a separate `box' often carried in a pocket or clipped to a belt Lavalier microphones (interviewer's collar pin) are a common example. Each wireless microphone usually transmits on a single unique frequency. A `true diversity' wireless system has two antennas on the receiver. When the signal strength at the two antennas differs, the receiver uses the stronger signal. True diversity systems are typically less sensitive to radio interference and blockage than single antenna systems.

Hearing Aid Microphones

Digital microphones and digital noise reduction algorithms are two approaches used in hearing aid technology to distinguish speech from noise. Directional microphones actually improve the user's ability to perceive speech in noise. Digital noise reduction improves the user's hearing comfort in noise but does not generally improve their ability to perceive speech.

Conventional directional hearing aid microphones use a single microphone with two ports and acoustic delays. They are only available on BTE (behind-the-ear) hearing aids and often cannot be switched between directional and omnidirectional response patterns.

Newer directional hearing aid microphones use two microphones (two omni-directional microphones plus beam-forming electronics or a directional plus omnidirectional microphone). Each microphone has its own port (Gennum Corporation, 2000). These dual port microphones available for both BTE and ITE (in-the-ear) hearing aids, can support a wide range of directivity patterns (e.g. cardioid to hypercardioid) and can typically be switched between directional and omnidirectional response patterns (Etymotic Research, 2000b). Generally, directional microphones are less sensitive at low frequencies with further sensitivity reduction with small microphone separation. Some directional microphones provide more than four decibels improvement in AI-DI (Orientation-Index-Weighted-Directivity Index) (Etymotic Research, 2000a).

Hand Held and Wearable Microphones

The directional sensitivity of wearable beam-forming microphone arrays is (typically) much better than that of directional hearing aid microphones. The signal processing hardware and algorithms used by these microphones currently cannot be implemented at ear level (within a hearing aid). Instead, hand-held or wearable (e.g. pendant) beam-forming microphone arrays are coupled to the user's hearing aid by an inductive or FM wireless link.

Hand-held, desktop and wearable beam-forming microphone arrays often have advanced features such as user adjustable beam patterns; automatically changing the directional response from speaker to speaker; or automatically changing directional sensitivity in response to the noise characteristics of the environment. Hearing Aids can be linked by wire or wireless means, and act as a beam forming array themselves (Kompis, 2000).

Assistive Listening Systems

The purpose of many ALS's is to bring a remote -- and essentially `noise free' -sound signal into the direct-proximity of the user's ear. ALS's process and then transmit the remote signal via a wireless link typically infrared light, inductive (electromagnetic) fields, or FM radio waves. There are a number of ways that a user can receive these transmissions. The receiver can be part of the hearing aid (e.g. built-in FM receivers or telecoils that pick up inductive transmissions), or a hearing aid accessory (e.g. an accessory FM receiver). In some cases, users wear an FM or IR receiver that outputs sound through headphones or ear buds. Other systems use FM or IR receivers, which then process and retransmit the signal via an inductive neck loop to be picked up by the hearing aid T-coil (Bakke, Levitt, Ross, & Erickson, 1999).

Beam-forming microphone arrays have good applications in meetings and small group settings in which the conversation jumps from one distinct speaker to another. These microphones can be integrated into ALS's -- eliminating the need to pass around a single microphone from speaker to speaker. Because of their superior directional performance and ability to eliminate extraneous noise, these microphones are components in high-performance, PC-based voice recognition systems.

Various other types of microphones are used in ALS's. The most appropriate microphone is determined by the communication needs, the assistive listening system technology and the environment of use. They include:

- **Boom** - head-worn microphone worn close to mouth. Because the microphone is mounted on a headband, movement of the head does not affect loudness of sound going into the microphone.
- **Collar** - microphone is held in front of the user's lips by a bendable snake-like wire that wraps around the user's neck. Often used in classroom teaching.
- **Directional Lapel** - picks up sound mostly from in front of the microphone. This microphone is useful in noisy listening environments.
- **Omni-directional Lapel** - picks up sounds all around the microphone (although the body is in the way of the microphone). Worn 4-10 inches from lip. Used in classroom teaching.
- **Omni-directionaVPZM** - the microphone is placed on a hard, flat surface (table) and picks up sounds from a 360° azimuth. Good for situations where you have listeners seated around a table. To work best, the room must be quiet and speakers must avoid generating additional noise.
- **Voice Activated Microphones**- activated only when person speaks. May work well in noisy situations. Usually part of a boom headset.

STATEMENT OF PROBLEM

The following issues were raised during interviews and panels involving researchers, manufacturers and end-users.

- High performance hearing aids with directional microphones need to available at a reasonable price for persons with mild to moderate hearing loss.
- Superior directional microphone technology exists in research literature and military but has not been transferred to the hearing aid and assistive listening device industry.
- Assistive listening systems for small group settings currently use a single microphone (e.g. passed around) or multiple microphones (e.g. one selected to be active at a time, voice activated). With an adaptive beam-forming microphone array that automatically switches from speaker to speaker, these small group ALS's could become true multi-speaker systems.
- The "tunnel of sensitivity" for directional hearing aid microphones changes as the user moves his head. To be most effective the sound source or speaker must be directly in front of the user and the user's head must be still. Highly directional hearing aids may not work well when the conversation is jumping rapidly from speaker to speaker (e.g., social gathering), or when the environment is providing important safety or navigation cues (e.g., crossing an intersection). Manually switching the hearing aid from directional to non-directional mode is the best solution currently available.
- A wireless link between hearing aids, or between the hearing aids and an external processor, would support advanced binaural processing. This approach has been explored with hearing aids and hard-wired connections. Improved directionality was demonstrated but the hard-wire connection is cumbersome and unacceptable to the end-users.
- Increasing the geometry and number of microphones in wearable or hand-held beam forming directional arrays improves directional performance. Increasing the size or weight of a

wearable (e.g. necklace, headband, or eyeglass frame) or hand-held device is likely to be burdensome and unacceptable to end-users.

- Microphones often have unpredictable directional performance. Manufacturing tolerances need to be improved so that a uniform directional response is obtained from microphone to microphone.
- Dual directional microphones have great value but there is still a need for improved performance for single directional microphones.
- Microphone improvements may require an increase in cost, size or power consumption - but those changes would prevent them from being incorporated into the hearing aid.
- How can microphones be reduced in size, yet demonstrate good sensitivity (especially at low frequencies)?

ISSUES TO CONSIDER

The Need

1. What are the important, unmet (or poorly met) user needs related to microphones in hearing aids; wearable and hand-held devices; or assistive listening systems?

2. What populations or demographics (e.g., degree of hearing loss, characteristics of hearing loss, cause of hearing loss, age, etc.) are most affected by these needs/problems?

3. In which environments and for which activities is this need or problem most significant?

4. What accommodations (or behavioral changes) do hearing impaired persons make in order to function in these environments and accomplish these activities?

State-of-the-Practice

5. What hearing and assistive listening products are used by, or prescribed for, hearing impaired persons' in order to address these problems or needs?

6. What are the strengths (e.g., performance, cost, etc.) of these products?

7. What are the weaknesses (e.g., performance, cost, etc.) of these products?

Future Technology and Products

8. What significant technical improvements are needed?

9. What technical barriers (e.g., environmental factors, power consumption, size, etc.) must be overcome in order to achieve these technical improvements?

10. What breakthrough technologies (not present in current products) might better address the identified needs and problems?

11. What technical barriers (e.g., environmental factors, power consumption, size, etc.) must be overcome in order to achieve these technical breakthroughs?

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Microphones Forum Data

Microphones Forum Data

The following is the raw data collected during the stakeholder forum. It reflects the comments and needs as expressed by the forum participants.

1. Needs (unmet needs of customers, clinicians, etc.)

- Need to improve ability to hear speech in noise (e.g. a hearing aid user participating in the Forum could not hear across the lunch table).
- Need to improve ability to hear non-speech sounds in noise (e.g. ability to hear a flute in an orchestral piece).
- Need to improve ability to hear speech at a distance (e.g. listening to a person some distance away is a problem even in a quiet environment).
- Need hearing technologies to incorporate wireless standards.
- Need microphones to have good directional performance at low frequencies.
- Need adaptive microphones (e.g. self-orienting, track speakers, switch speakers) for small group (e.g. business meetings) and classroom situations.
- Need hearing aid microphones with better directionality so the user can focus (their hearing) on the person they are listening to.
- Need hearing aid microphones whose directionality (e.g. directional, omni-directional) can be changed for different environments.
- Need hearing aid microphones whose directionality is easy for the user to control.
- Need a quick and easy means for hearing aid users to switch their microphones between omni-directional and directional modes (e.g. a hearing aid user can miss the beginning of conversations when they can't switch from omni-directional to directional mode quickly enough).
- Need lower "self-noise" (e.g. amplified noise of rustling clothes) for persons with mild hearing losses.
- Need binaural hearing aids.
- Need improved cosmetics for body worn microphones (e.g. look like jewelry, part of clothing or eyeglasses - does not look unnatural).
- Need microphones (e.g. body worn, desk top) that can lock onto and track sound source (e.g. speaker).
- Need body worn microphones (e.g. body worn microphone arrays) to look "cool."
- Need system for small group communication (people engaged in natural conversation - table of eight in a restaurant, business meeting, etc.).
- Need system for small group communication that does not require a microphone to be passed about.
- Need microphones (in hearing aids, in personal FM systems, etc.) that can "pick up" and orient toward new speakers engaged in natural conversation (e.g. small groups conversation at the dinner table or at a cocktail party).
- Need improved microphone positioning (relative to speaker or speakers mouth) to ensure good sound pickup.

- Need reimbursement policy to support the purchase of advanced hearing aid technology (for persons with all degrees of hearing disability).
- Need to educate persons with hearing disabilities on the benefits of hearing aids and assistive listening systems (e.g. only 20% of people who should use hearing aids are actually using hearing aids).
- Need improved hearing evaluation and hearing aid fitting.
- Need standard procedures/tests for evaluating all microphones in order to compare their performance.
- Need education on different microphones and listening systems and how each are suitable for different applications and sound environments
- Need to better educate consumers, middlemen, audiologists, and manufacturers about microphones (types, uses, applications, etc.) used in hearing aids, ALS, etc.
- Need to better educate consumers about the performance/possible problems of microphones in hearing aids, assistive listening systems, etc.

2. State-of-the-Practice (current technology, strengths, weaknesses, etc.)

- Microphones (generally) have fixed performance characteristics that are not suitable for all environments and activities.
- Omni-directional microphones - receive sound equally from all directions.
- Directional microphones (all sorts) emphasize sound from the direction they are being "pointed."
- All directional microphones make the user seem closer to the sound source than he or she really is – "reduce the acoustic distance."
- Directional microphones include "cardioid family" microphones and beam forming microphone arrays.
- Directivity index is a measure of how directional a microphone is. Consider a cardioid microphone with a directivity index of 4.7 dB. If we spoke into this microphone at a distance of 5 feet in a reverberant environment, a directivity index of 25dB is needed in order to "sound" as if we were 1 foot away from the same microphone.
- While many microphones are available having a wide range of directional responses - not all are appropriate for hearing technology because of size, cost, power consumption, processing requirements, etc.
- Noise is not equal. Noise from speech babble is worse than machine hum.
- Most noise reduction techniques work well only for environments with few or stationary (unchanging) noise sources.
- Persons with hearing impairments often must "cuddle up" to the speaker in order to communicate.
- Higher reimbursement rates are now directed toward hearing technology for persons with severe hearing disabilities - a small market segment.
- As long as the hearing aid market remains small, research and development costs will remain a barrier.

Beam forming microphones

- Directional microphones (e.g. some body worn beam forming microphone arrays) can currently achieve directivity index of 12 dB.
- Beam forming microphone arrays are now used in hearing aids, hand-held batons, body worn, eyeglasses, table top, etc.
- Adaptive beam forming microphones arrays (desktop, wearable) automatically change their directional response (e.g. alter directivity with changes in environmental noise, track speaker, switch to a new speaker).
- Beam forming microphone array has been placed on an eyeglass frame (NIH sponsored research with four microphones on the frame).
- Microphone technology will be increasingly dependent upon digital signal processing.
- Wyn Suede carried out important research on beam forming microphones.

Hearing aids

- Hearing aids microphones (generally) have poor directional performance at low frequencies because of the small separation between hearing aid microphones.
- Directional hearing aids - must face the speaker (sound source). Decreased ability to locate new speakers (sound sources).
- Directional hearing aids sometimes have a single microphone with two "ports."
- Directional hearing aids with two microphones and digital signal processing (beam forming) - provide limited improvement (reduce background noise less than 5 dB).
- Directional hearing aids have an effective hearing range of six feet or less.
- Some hearing aids can be manually switched between directional and omni-directional modes.
- Some hearing aids automatically switch between directional and omni-directional modes in response to the environment (more convenient than manual).
- Some hearing aids have dual microphones - directional response is obtained with beam forming techniques.
- Some hearing aids (ITE, BTE) with dual microphones (beam forming) can be switched between cardioid to hyper-cardiod beam patterns.
- Hearing aids generally use 1.1volt zinc-air batteries.
- Battery state-of-the-art is much more advanced than the battery technology employed in hearing aids.

Binaural hearing aids

- Of persons wearing hearing aids, 53-56% have two aids (Hearing Journal cited).
- CRoS hearing aids (a hearing aid with a microphone on opposite side of persons head) are useful when riding in a car.
- BiCRoS hearing aids could be adapted to do binaural processing.
- CRoS hearing aids with additional microphones are being looked at.

- Binaural hearing aids have been attempted. Two hearing aids hard-wired to an external digital signal-processing unit (a prototype device). Two hearing aids linked by an AM wireless link (Telex product no longer on market).
- Early binaural hearing aids (wired and wireless) were oversimplified.

Small group

- Systems for small group communication require that the microphone be passed around (single-microphone system) OR that everyone has their own microphone (multi-microphone system).
- Systems that provide poor sound quality to the listener are worse than having no system at all.
- People are intimidated (uncomfortable, unaccustomed to) speaking into microphones. As a result they speak too loudly, too softly or position themselves too far or too close to the microphone.
- Sound amplification systems (e.g. public address systems in schools, trains, and airlines) often have poor sound quality and provide little benefit to hearing-impaired individuals.
- Sound amplification system performance (often) depends upon the user speaking directly into the microphone.
- Remote microphone – most commonly a microphone with an FM transmitter.
- Systems with a single microphone -cumbersome or impossible to pass a microphone from speaker to speaker.
- Systems with a single microphone -listeners miss the beginnings of conversation as the microphone is passed from speaker to speaker.
- Assistive listening systems (FM, infrared, inductive loop) often have multiple microphones connected to a single transmitter.
- Systems with multiple microphones are difficult to set up properly - cumbersome or impossible to place a microphone in front of each speaker.
- Systems with multiple microphones - difficult to identify and orient toward the current speaker.
- Multi-microphone systems have been built into rooms - with automatic switching (pick up new speaker) and mixing (get input from correct microphone). These systems have good reception and signal to noise performance (reference Shure's Intellimix).

Public policy

- ADA standards have not been established for many difficult hearing environments.

Related technology

- Parabolic microphones with humans to "aim" them constitute a highly directional microphone system.
- Personal Digital Assistant (PDA's) are sometimes used to beam text based communication to another person (e.g. friends communicating at bars).

- "Blue Tooth" - named after a King of Denmark who had blue teeth - is an international wireless communication standard being developed to support communications between electronic devices such as TV, cell phone, and computers.
- Microphones for cochlear implants with signal processing.
- Laser pointer microphone picks up whatever you are aiming at (20 degree azimuth).
- Baton microphones.
- Sound recording industry often employs several microphones (of various sorts) and brings sound signals together through a mixer.
- Remote microphones with FM transmitters are used in professional music and theater.
- Teleconferencing employs various types of microphones.

3. Needed Technology (refinements, innovations, etc.)

- Natural hearing systems should be studied and modeled (e.g. a small bird in Australia is able to localize very low frequency-the acoustical path in its skull does something to create the delay)
- Microphones should be highly directional across all speech frequencies (200 Hz to 7 kHz).
- Microphones should have increased directionality (higher directivity index).
- Microphones should reduce "wind" and "outdoor" noise.
- Microphones should work in very complex acoustic environments where the sound sources (voices) may be physically moving about.
- Microphones should improve the speech in noise ratio.
- Microphones should have wide dynamic range.
- Microphones should have a linear response to sound signals over entire auditory frequency range.
- Microphones should provide hearing-at-a-distance (analogous to depth-of-focus for a light microscope) especially in difficult acoustic environments.
- Microphone sensitivity should adjust to the environment (high sensitivity for quiet conversations in quiet environments, lower sensitivity for loud conversations in noisy environments).
- High research and development costs for improved technologies.
- Cost (e.g., R&D, production, price reimbursement issues)
- Highly directional microphones (hearing aid, hand held or wearable) are hard to aim (e.g. locating a new speaker).

Beam forming microphones

- Beam forming microphone arrays (e.g. desktop microphones) should provide orientation cues (e.g. N S E W lights on beam forming device – indicating direction of speaker).
- Beam forming microphone arrays (e.g. desktop microphones) should be adaptive (e.g. track moving speaker, pick out and orient toward new speaker, change directional performance in response to environmental cues).

- Adaptive filtering should identify and eliminate steady state noise such as wind noise and fan hum.
- Beam forming microphone arrays should be employed in hearing aids, "optional attachment around the ear," body wearable, hand held, and table top devices.
- Beam forming microphone arrays (with necessary processing) should be small and inexpensive.
- Beam forming microphone arrays should work in difficult listening environments (e.g. many sound sources, noise from all directions)
- Beam forming microphone arrays should work in real time (fast response, no processing delay).
- Beam forming microphone arrays (two or more microphones) should not generate more noise than single microphone (24 dB – 27 dB with a filter band up to 10 kHz).
- Beam forming microphone arrays directionality should adapt in response to environment factors (e.g. level, orientation and type of noise, multiple speakers, etc.)
- Beam forming microphone arrays should orient to new speakers or track moving speaker.
- Beam forming microphone arrays should sense noise from all sources and directions and change their performance based upon this information.
- Beam forming microphone arrays should pick up orienting cues. (Microphone anticipates who you want to hear, not who you are currently "pointing at.").
- Beam forming microphone arrays should have user selectable steering modes (user needs to know which modes will work in each environment)
- For persons with intact hearing, the brain automatically orients the eyes to the sound source. For a adaptive microphone system (orienting to a sound source), the brain can't (directly) fulfill this function and the user may not be able to physically re-orient to new speakers fast enough.
- Beam forming microphone performance depends upon the placement and separation of the microphones. The size and form of the hearing aid, hand held or body worn device will impact microphone performance. Increased a devices size or changing its shape may not be acceptable to users.

Hearing aids

- Directional hearing aids (using two or more microphones) should employ improved digital signal processing schemes.
- Hearing aid microphone directionality should be user and/or automatically controlled.
- Directional hearing aids should have an improved user interface to control microphone directionality (e.g. omni-directional, directional or degree of directivity).
- Hearing aid microphones should be weather proof, durable, smaller, and less expensive.
- Hearing aid microphones should employ adaptable beam steering that fits the acoustic environment (e.g. kids sitting to the driver's right or in the back seat of a car)

- Hearing aids with improved microphone performance (e.g. advanced beam forming with powerful digital signal processing) should not increase power consumption (work with standard hearing aid batteries).
- Hearing aids should have higher gain settings without feedback (through hearing aid microphones).
- Hearing aid function should be "matched" to residual cochlear function.
- Remote microphones should have a wireless link directly to a hearing aid receiver.
- As hearing aid capabilities become more complex it may become more difficult to properly fit the hearing aid to the client.
- Hearing aid feedback is still a problem due to poor earmold fitting.
- Hearing aid feedback is still a problem because of the small physical separation between hearing aid speaker and microphone (e.g. for ITE aids).
- Tiny market for hearing aids.
- Adding hardware to increase processing power also increases power consumption and decreases battery life (or time-between-recharge).
- Increasing battery size (to provide additional power) is precluded for small hearing aids.

Binaural hearing aids

- BiCRoS hearing aids should perform true binaural processing.
- Binaural hearing aids should have a wireless bi-directional communication link.
- Binaural hearing aids should employ binaural processing (i.e. hardware/algorithms that take advantage of head-shadow effects, signal time delays, etc.).
- Binaural hearing aids should do beam forming with the microphones from both hearing aids (sound received at both hearing aids with wireless connection and true binaural processing).
- There is an incomplete understanding of how impaired ears function. For example, how do impaired ears process binaural cues?
- Research is needed on binaural "stereo sound" pickup and processing by persons with and without intact hearing.
- Binaural processing by the brain is not fully understood in intact hearing systems (e.g. how is a voice picked out and focused upon at a cocktail party?).
- Binaural hearing aids may not be accepted if people perceive that their hearing is worse if they use two hearing aids.

Body worn microphones

- Wearable beam forming microphone arrays (e.g. microphones spread over surface of necklace or eyeglasses) should have a wireless link to the hearing aids.
- Wearable beam forming microphone arrays (e.g. microphones spread over surface of necklace or eyeglasses) should be adaptive (e.g. change directional performance in response to environmental cues).

- Body worn microphones (e.g. eyeglass microphone arrays, body worn microphones, etc) must have acceptable size, weight and appearance.
- Hand held or wearable beam forming microphones may not be accepted because of added expense, complexity (another thing to carry around) or appearance (odd looking).
- Hand held or wearable beam forming microphones may not be accepted if people perceive that their hearing is worse if they use additional devices.
- Hand held microphones with laser pointing might be socially unacceptable (annoy other persons).

Systems for small group communication

- Everyone should be able to communicate with a hearing aid user via common telecommunication devices (phones, pagers, etc.).
- Telecommunication devices (cell phones, pagers, etc.) should act as receivers and be interfaced to hearing aids via neck loops and DAI.
- Hearing aids should be equipped with a receiver (in-built or accessory) and receive wireless communication directly.
- Wireless communication devices that now support data communication (e.g. Palm Pilot) should incorporate microphones and support voice communication.
- New concept for assistive listening system - microphone transmitter broadcasts on some frequency; press “frequency select” button on cell phone (pager or similar device) to select among transmission frequencies; cell phone interfaced to hearing aids via neck loop, DAI or headphones.
- Systems for small group communication should provide orientation cues (e.g. N-S-E-W lights on beam forming device – indicating direction of speaker).
- In order for systems to work all hearing aid users must have appropriate receivers and all non-hearing impaired must have appropriate transmitters.
- Complex systems tend to be larger and may not be accepted by users (e.g. impede physical activities, poor aesthetics)
- Systems may not be socially acceptable. How do friends, peers and coworkers view the person using the system? Will people be willing to carry and use cell phones (related devices, remote microphones and transmitters, etc.) in order to communicate with persons with hearing impairments?
- Power consumption - adding a receiver and processing hardware to hearing aids increases power consumption and decreases battery life (or time between recharge).
- Systems that require additional hardware have increased associated costs.
- Classroom situations are complex. It is currently not practical for each student and teacher to have a separate microphone.
- Complex systems (many components, wires, require careful setup, sensitive to environmental factors) are not accepted in many situations (e.g. classrooms, cocktail parties, etc).

Other Issues

- Worldwide performance standards should be established for hearing aids.
- Marketing should be employed to improve consumer awareness of advanced hearing technology.
- In-the-ear receiver that resembles accepted technology (e.g. like Back Street Boys' ear receivers).
- Designer colors for teenagers.
- It is not true Bell array built into ceiling, 1980's – complex mixer system – did not work.

Problem Statement – Microphone Technology
Manufacturers, researchers, and clinicians have identified beam-forming microphone arrays for body worn, tabletop, binaural hearing aid and directional hearing aid microphones as the critical technology. These technologies address important, unmet needs of persons with hearing impairments and represent good business opportunities for manufacturers.

MARKET
Most people rely upon hearing for communication, social participation and personal safety in their work, recreational, and daily living environments. A person's ability to hear is often reduced by trauma, drugs, disease, or the cumulative effects of aging. Diminished and uncorrected hearing can lead to social isolation, difficulty functioning within the workplace, increased risk to personal safety and a general reduction of a person's perceived quality of life. Assistive technology for hearing including (but not limited to) hearing aids and assistive listening systems, are an effective and enabling intervention for many of these persons. However, it is the microphone(s) contained within these hearing systems that translate sound into an electrical signal that is re-translated back to sound for the wearer to hear.

It is estimated that more than 20 million people in the United States experience some form of hearing loss. However, according to the 1990-91 National Health Survey, only 18% of those who identified themselves as having hearing problems use hearing aids (over the age of three and non-institutionalized). The reasons people who experience hearing loss but chose not to use the available technologies include: "hearing aids do not perform in noisy situations" (7.1 million), "provide too much whistle or feedback" (6.4 million), "do not work well" (4.8 million) or "work only in limited situations" (4.3 million), "have poor sound quality" (3.9 million), "break down too much" (3.4 million), "can not be used on the telephone" (3.1 million), and "negative experiences of friends" (3.9 million) (Kochkin, 1997).

Hearing and understanding speech accompanied by noise and reverberation is the principle concern of persons with hearing impairments, along with hearing local sound sources in background noise (such as differentiating voices in a crowded room in order to participate in a conversation), and hearing remote sound sources in general (for example, hearing a doorbell or telephone ring, or the sirens on an emergency vehicle). Hearing aids; body worn, hand-held, and remote FM microphones; and assistive listening systems are the principal interventions by which the comprehension of sound is improved. Microphones are an essential component of all hearing aids and most assistive listening systems.

According to the Advance Data Report (National Center for Health Statistics, 1997) there are approximately 874,000 people in the US who are hard-of-hearing and who use assistive hearing devices; this is less than 5% of the potential hard-of-hearing market segment. This leaves more than 16 million people who have substantially correctable hearing loss but whose needs are not being met by the current technologies available to them.

CURRENT TECHNOLOGY

Recently, beam forming microphone arrays have been employed in hearing aids, hand held batons, body worn, eyeglass frames (NIH sponsored research which resulted in a design with four microphones on the frame), and table top systems. The performance of beam-forming microphone array depends upon the placement and spacing of these microphones on a hearing aid, body worn or other device. Some of these microphones can adaptively change their directional response (narrow the directional response in the presence of noise, track a moving speaker, switch to new speaker). For persons with intact hearing, the brain quickly orients the person's eyes to the sound source. For adaptive microphones that orient to new speakers the brain can't (directly) fulfill this function.

In one-on-one conversations, hearing aids with directional microphones result in better speech comprehension in noisy environments (Trine, 1999). But, the user must face the speaker (sound source) and this may decrease the ability to locate new speakers. Conventional directional hearing aids use a single microphone with two ports and acoustic delays. They are only available on BTE (behind-the-ear) hearing aids and often cannot be switched between directional and omni-directional response patterns.

Newer directional hearing aids use two microphones (two omni-directional or a directional plus omni-directional microphone) each with its own port plus digital signal processing (Bakke, Levitt, Ross, & Erickson, 1999). These dual port microphones are available for both BTE and ITE (in-the-ear) hearing aids. They support a wide range of directivity patterns (e.g. cardioid to hyper-cardioid) and generally can be switched (manually or automatically) between directional and omni-directional modes (Etymotic Research, 2000b). The small physical separation between microphones on hearing aids reduces their performance at low frequencies. Directional microphones on hearing aids can provide 4 to 5 decibels improvement (AI-DI, Orientation-Index-Weighted-Directivity Index) and have an effective hearing range of six feet or less (Etymotic Research, 2000a).

Hearing Aids can be linked by wire or wireless means and can act as a beam-forming microphone array themselves. Binaural hearing aids use the increased separation between microphones, head shadow effects and time and phase delays to mimic the capabilities of an intact hearing system. Binaural processing requires a bi-directional communication link between the two hearing aids.

The directional performance of hand-held and wearable microphone arrays is (typically) much better than that of directional hearing aid microphones. Some of these devices achieve a directivity index of about 12dB. The signal processing hardware used by these microphones cannot currently be implemented at ear level (within a hearing aid). Instead, hand-held or wearable (e.g. pendant) beam-forming microphone arrays are coupled to the user's hearing aid by an inductive or

FM wireless link. Used in conjunction with hearing aids, wearable and hand-held beam-forming microphone arrays have great potential to improve the listening experience of hearing impaired individuals (Andrea Electronics, 2000; Trine, 1999). Assistive Listening Systems (ALS) bring a remote (essentially 'noise free') sound into the direct-proximity of the user's ear in order to amplify a selected sound source, overcome background noise, enhance listening in large public venues, and improve one-to-one conversations. Used in combination with hearing aids an ALS can provide optimal sound clarity and speech comprehension. ALS are categorized by the wireless communication protocol used to link the remote sound source and the body-worn receiver. Common ALS include frequency modulated (FM), infrared (IR), and inductive loop (IL) systems. The receiver can be directly associated with the hearing aid (inbuilt FM receiver, FM-boot, telecoil). Alternatively, some IR and FM receivers retransmit the signal via an inductive neck loop to be picked up by the hearing aid telecoil (Bakke et al., 1999).

Systems for small group communication require that the microphone be passed around (single-microphone system) OR that everyone has their own microphone (multi-microphone system). For single-microphone systems it is often difficult or impossible to pass the microphone. Listeners often miss the start of the conversation as the microphone is passed to the next speaker. Multi-microphone systems are difficult to set up properly; they are cumbersome or impossible to place a microphone in front of every speaker. People are often intimidated (unfamiliar, uncomfortable) speaking into the microphone. As a result they speak too loudly or softly, or position themselves too close to or far from the microphone. It is often difficult for the listener to identify and orient toward the current speaker.

Some desktop microphone arrays have advanced features such as the ability to track a moving speaker or locate and orient toward a new speaker. These microphones are sometimes used in conjunction with high-performance, PC-based voice recognition systems. Desktop microphone arrays have good potential for small group communication in which the conversation jumps from one speaker to another. These microphones could be integrated into assistive listening systems - eliminating the need to pass around a single microphone from speaker to speaker and much easier to set up than a multi-microphone system.

TECHNOLOGY REQUIREMENTS

Persons with hearing impairments need an improved ability to hear speech in noise and non-speech sounds in noise (e.g. flute in an orchestral piece). Technology solutions must work in complex acoustic environments with reverberation, multiple sound sources that may be moving about and complex noise sources. To be accepted by end-users, a market product must be aesthetically pleasing (e.g. look like jewelry, part of clothing or eyeglasses - does not look unnatural, look "cool", etc.). Manufacturers and researchers have identified beam forming microphone arrays as the critical technology for body worn, table top, binaural hearing aid and directional hearing aid microphones. Many of the capabilities identified for beam forming microphone arrays apply across these applications.

Beam Forming Microphone Arrays

- Should work in difficult listening environments (e.g. many sound sources, noise from all directions). Should sense noise from all sources and directions and adaptively change directional performance in response.
- Should adjust sensitivity in response to the environment (high sensitivity for quiet conversations in quiet environments, lower sensitivity for loud conversations in noisy environments).
- Should identify and eliminate common noise (adaptive filtering for wind, self-noise, outdoor, fan hum, etc.).
- Should pick up orienting cues (microphone anticipates who you want to hear, not who you are currently "pointing at.").
- Should orient to new speakers or track moving speakers.
- Should provide hearing-at-a-distance (analogous to depth-of-focus for a light microscope) especially in difficult acoustic environments (e.g. listening to a person some distance away is a problem even in a quiet environment).
- Should work in real time (fast response, no processing delay).
- Should be highly directional across all speech frequencies (200 Hz to 7 kHz).
- Should have wide dynamic range.
- Should have a linear response to sound signals over entire auditory frequency range.
- Should not generate more noise than a single microphone (24 dB – 27 dB with a filter band up to 10 kHz).
- Should (with necessary processing hardware) be small and inexpensive.

Binaural Hearing Aids

- Should do beam forming with the microphones from both hearing aids.
- Should have a wireless bi-directional communication link.
- Should employ binaural processing (hardware/algorithms that take advantage of head-shadow effects, phase and time delays, etc.).

Table Top Microphones

- Should provide orientation cues (e.g. N S E W lights indicating direction of speaker).
- Should be adaptive (e.g. track moving speaker, pick out and orient toward new speaker, change directional performance in response to environmental cues).

Body Worn Microphones

- Should have a wireless link to the hearing aids.
- Should be adaptive (e.g. change directional performance in response to environment).
- Should have user selectable beam steering modes (user needs to know which modes will work in each environment).
- Should have acceptable size, weight and appearance (e.g. microphones spread over surface of necklace or eyeglasses)

Directional Hearing Aids

- Should employ adaptable beam steering that fits the acoustic environment (e.g. kids sitting to the driver's right or in the back seat of a car)Should employ advanced beam forming that does not increase power consumption (work with standard hearing aid batteries).

- Should have higher gain settings without feedback (through hearing aid microphones).
- Should have microphone directionality that is user and/or automatically controlled.
- Should have an improved user interface to control microphone directionality.

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Technology Transfer

Locate Technology Solutions

Outcomes from the Stakeholder Forum and all prior work were used to generate problem statements. Problem statements outline the need for technology; technology state-of-the-practice for products currently in the market; specifications and parameters for the 'ideal technology solution;' and barriers/impediments that must be overcome to achieve this ideal technology.

T2 RERC is disseminating the problem statements to Federal Laboratories, advanced technology manufacturers, research institutions and other technology developers. Proposed technology solutions are submitted to T^2RERC. Initially, all submitted technology solutions are non-proprietary.

T2 RERC and the partner RERC screen proposed technology solutions. Technical and industry experts review appropriate technology solutions to confirm that these solutions address the problem and are technically feasible. Following the initial review, proprietary information may be requested from the technology developer. The protection of intellectual property is the responsibility of all parties involved in this exchange.

Transfer the Technology Solution

The T2 RERC will prepare a commercialization package that summarizes the end-user needs being met, market opportunity, technical solutions, and the business plan for transferring the technology to market. A marketing plan will be developed to contact and present the commercialization package to targeted manufacturers.

The transfer of technology can be completed through mechanisms such as direct licensing of technology to a manufacturer; or a cooperative research and development agreement (CRADA) between a federal lab and a manufacturer.

We expect to continue disseminating the problem statements indefinitely, or at least until an appropriate solution is identified and transferred. Anyone who has potential solutions to the problem statements developed from this project is encouraged to submit them to T^2RERC via the Internet at (http://cosmos.buffalo.edu/hearing).

The purpose of this endeavor is to match new technologies or those that were originally used for other applications, with manufacturers who can bring the technology to market. The end result will be new and improved assistive technology devices that will enhance the quality of life for persons with disabilities.

Appendix A. Project Staffing

A. ROLES AND STRUCTURE OF THE T^2 RERC

The project staff of the T^2 RERC are from four organizations: the Center for Assistive Technology, University at Buffalo (administrative and technical staff), the Independent Living Center of Western New York (consumer staff), AZtech Inc (marketing staff), and Research Triangle Institute (technology transfer staff). The project staff has the full range of technical, marketing and consumer expertise required by the Tech Transfer RERC. Project activity is concentrated at the Center for Assistive Technology, although staff draws upon resources from their home organizations. Project staff work in cross-functional teams to ensure that all perspectives are represented in each activity.

CENTER FOR ASSISITIVE TECHNOLOGY

The Center for Assistive Technology (CAT), University at Buffalo, conducts research, education, service and policy projects addressing assistive technology for people with disabilities. The CAT staff provides support to the T^2 RERC, either directly as employees or indirectly as consultants.

Core CAT staff provide administrative support. Researchers participate in project design, data analysis and publications. Educators provide their knowledge of the state of the science and practice, and integrate research and service findings into their coursework. Service providers contribute their expertise on service delivery, assistive device applications, and policy issues. Consumers advise the CAT on all projects, and participate as staff, students and consumers. The CAT's research, education, and community service is to increase knowledge about assistive devices for persons with disabilities. The Center works in four related areas: 1 . Research and development of assistive devices for education, employment, leisure, and daily living. 2. Education for students professionals and consumers. 3. Assistive device service provision. 4. Dissemination of information about Assistive Technology.

AZTECH

AZtech is one of four organizations in partnership with the T^2 RERC. AZtech provides market research for companies in the field of assistive technology for persons with disabilities and the elderly. It also makes significant contribution to development of new technologies through its technology transfer program. AZtech has extensive resources, knowledge and experience in the assistive technology industry. Staff from AZtech provides the T^2RERC with marketing and try analysis for the negotiation and execution of sales agreements, license and other contracts needed to accomplish a successful transfer.

INDEPENDENT LIVING CENTER OF WESTERN NEW YORK (ILC)

The ILC of Western New York is the consumer voice for T^2 RERC. It has the ability to bring consumers, (consumer) family members and friends, clinicians and product experts to participate in research performed for all of the center's programs.

Their national network of agencies has been a major resource in the work of the T^2 RERC, and in particular bringing together consumer representatives for the work of the demand pull project.

RESEARCH TRIANGLE INSTITUTE

Research Triangle Institute is an independent research institute that serves government and industry clients in the U.S. and abroad. With a staff of 1,450 people, RTI conducts research in public health and medicine, environmental protection, advanced technologies, and public policy. Scientific disciplines at RTI include social sciences, applied statistics, environmental sciences, electronics, physical sciences, chemistry, and life sciences. RTI was established in 1958 as the initial R&D center in the Research Triangle Park. The Center for Technology Applications at the Research Triangle Institute

(RTI) brings to the T^2RERC a history of successful technology transfer and over thirty years of technology management services. Since 1966, RTI has helped NASA and other federal agencies transfer its technologies to the commercial and public sectors. One approach that RTI uses to transfer technologies is driven by customer needs. In this approach, RTI works with national agencies to synthesize technical requirements from consumers and clinicians, assess possible solutions and support technology development, and commercialization partnerships with industry. The goal for RTI in working with the T^2RERC is to disseminate problem statements developed from the Stakeholder Forum to technology developers and to facilitate commercialization between researchers and manufacturers.

RERC ON HEARING ENHANCEMENT
The Lexington School for the Deaf/Center for the Deal

The Rehabilitation Engineering Research Center (RERC) on Hearing Enhancement is a national project. The objective of the project is to conduct research programs that promote technological solutions to problems confronting people who are deaf or hard of hearing.

The RERC on Hearing Enhancement addresses accessibility problems of deaf and hard-of-hearing individuals by developing and evaluating cost-effective technological aids for the various groups of people with hearing loss according to their needs (e.g. people with moderate hearing losses, people with severe or profound hearing losses, young children, older adults and people with both vision and hearing loss).

Specific Objectives of the Lexington RERC are:

- to develop and evaluate technological solutions to problems confronting people with hearing loss.
- to develop systems for the exchange of technical and engineering information
- to improve the distribution of assistive devices and equipment to individuals with hearing loss
- to provide training in rehabilitation engineering research
- to develop training materials explaining the use of new technology for service providers and consumers with various types of impairments.

- to evaluate its own products and those of other Centers, and to develop cooperative arrangements with the private sector.

B. PROJECT STAFFING

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C. PROJECT SPONSORS

NATIONAL INSTITUTE ON DISABILITY AND REHABILITATION RESEARCH (NIDRR), U.S. DEPARTMENT OF EDUCATION

"The NIDRR mission is manifold: to provide for research and demonstration projects, training, and related activities; to maximize the full inclusion and integration into society, employment, independent living, of individuals with disabilities and to provide support to their families; to increase the economic and social self-sufficiency of individuals with disabilities of all ages, and to improve the effectiveness of services authorized under the Rehabilitation Act."

Katherine Seelman
Director, NIDRR

The NIDRR is the federal government's single largest funding source for assistive technology research and development programs. These programs include fifteen Rehabilitation Engineering Research Centers, each focused on a particular assistive technology industry or research topic.

NORTHEAST REGION OF THE FEDERAL LABORATORY CONSORTIUM

The *Federal/ Laboratory Consortium* (FLC) represents the resources of all of the Federal laboratories. In partnership with the T^2 RERC, the FLC is seeking ways to integrate their laboratories' technologies with the needs identified by consumers, manufacturers, and researchers in the assistive technology industry.

Appendix B. Stakeholder Forum Attendees

STAKE HOLDER FORUM ON HEARING ENHANCEMENT
Attendee - Contact Information
Attendees at the Forum were selected as representatives from one of five stakeholder groups identified by the T^2 RERC in the development of the Demand-Pull Project.

The categories are defined as:

1. Technical Experts: Persons who have performed extensive research in the areas of hearing aids and assistive listening products. The research performed by Technical Experts is directed towards the technical development or enhancement of products. The RERC on Hearing Enhancement was a major resource in this category, as well as representation from clinicians and technicians from health care suppliers and medical facilities.

2. Technology Producers: Innovators of core technologies that are incorporated into the design of hearing aids and assistive listening products. Participants in this category represent a company, a research facility, or individual innovator.

3. Technology Consumers: Also known as Product Producers, are companies that acquire technology for inclusion in the manufacture of hearing aids and assistive listening products. Many manufacturers who participated in this Forum played a dual role as Technology Consumer and Technology Producer.

4. Product Consumers: People that use hearing aids and assistive listening products in their day to day life. Many participants were people that use hearing aids, as well as clinicians that prescribe hearing aid products.

5. Resource Providers: Resources to the industry as third party reimbursement suppliers, government agencies involved in products for persons with disabilities, community service suppliers and national agencies.

6. While some attendees could be placed into one or more category, they have, for the purposes of the Project, been designated into a single classification listed below.

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Ron Bloomgren	Russ Thoma
Vasant Kolpe	Charles Beaty
Robert Belenger	Bob Oliviera
Steve Leeb	Matt Bakke
Richard Carmen	Neil Lupton
Melanie Hezfeld	Frank Corso
Warren Hanna	Paula Bonillas
Michael Valente	Maragaret McNamara
William McConeghey	Martin Goldstein
Ronald Vickery	Florence Steiger
Gladys Challenor	Lois O’Neill

FM Systems Technology Group

Friday	Saturday
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Stephen Thomspson	Steve Armstrong
Charles Lazlo	Gendel
Carl Sandrock	Stephanie Davidson
Tim Vear	Bill Crandall
Victor Nedzelnitsky	Al Loghi
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Douglas Jones	Anita Haravon
Linda Kozma-Spytek	Melanie Hezfield
Arthur Boothroyd	Warren Hanna
Mark Ross	Carolyn Musket
David Baquis	Larry Humes
Bill Mann	Fred Palm
Dorry Tooker	Jeanne Stiernberg
Greg Flamme	Ronald Rau
Ted Simons	Alice Dungan
Rainy Dae Vessel	George DeVilbiss
Martin Goldstein	Ronald Vickery
	Brian Logue

Microphone Technology Group

Friday	Saturday
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Bill Crandall	Harry Levitt
Mauro Caputi	Richard Carmen
Al Longhi	Bill Mann
Neil Lupton	Dorry Tooker
Anita Haravon	Chas Johnstone
David Kirkwood	Ted Simons
Paula Bonillas	Inge Goldstein
Carolyn Musket	
Tom Lane	
Fred Palm	
George DeVibiss	
Alford Wolf	
Ronald Rau	
Florence Steiger	

Microphone Technology Group

Friday	Saturday
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Matt Bakke	Carl Sandrock
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Larry Humes	Robert Belenger
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Alice Dungan	Greg Flamme
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	Rainy Dae Vessel
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	William McConeghey
	Gladys Challenor

EVALUATION OF STAKEHOLDER FORUM ON HEARING ENHANCEMENT

Table of Contents

Introduction

This is a report of the evaluation of the Stakeholder Forum on Hearing Enhancement and Assistive Listening systems. The Forum evaluation is an integral part of the ongoing evaluation of the Demand-Pull model of technology transfer. The report presents the background, methods and results related to the evaluation of the Forum conducted on-site.

Background

The Demand-Pull Model and its Best Practices

Demand-Pull is one of the two approaches to technology transfer implemented and tested by T²RERC. An earlier section of this document described the Demand-Pull project's protocols. The methods under these protocols as well as the theoretical framework that drives them are drawn from best practices in industry and marketing research fields. Among such practices are: use of Kano Model for collecting and using primary market data; Quality Function Deployment for product planning; Structured focus groups and surveys as data gathering tools; and an array of subordinate tasks and practices ranging from sampling and recruiting to managing communication with and among stakeholders at significant project stages. The specific practices under the Demand-Pull model represent applications of these best practices to our project's context in a way that addresses specific disability issues and stakeholder characteristics. As we implement our project to transfer technology, our evaluation efforts focus on field-testing and validating our best practices. The validated practices are duly incorporated into the model and contribute to its ongoing refinement.

The Forum – why, what and how

Purpose: The Demand-Pull activities that preceded the Forum [see project description, p. ---] identified (a) current needs in hearing enhancement technology and (b) the relevant market and industry information, which were documented in *White papers* and an *industry profile.* The purpose of the Forum was to have this previously identified information *validated* by a larger stakeholder expert group interacting in formal, moderated discussion sessions. The stakeholders brought their multiple perspectives to *systematically* address and discuss issues surrounding current hearing technologies, and came to a consensus about valid *technology needs* expected to advance the state of the practice regarding hearing enhancement products.

Significance: The Stakeholder Forum is a significant step in our Demand-Pull process of technology transfer, since it generates, validates and converges information relevant to significant technology needs. After the Forum, we develop them into statements of problems in need of technical solutions. These problem statements not only indicate current limitations in the features and functions of products (hearing enhancement, in this case), but also point to business opportunities for advanced technology solutions. In addition, they establish design and performance for these solutions and the technical specifications needed to improve the products. In a later step, [see project description, p.---] other stakeholders – advanced technology developers – respond by proposing technology *solutions* to the stated problems in lieu of improving the products.

The importance of the Forum's outcomes to the transfer process is evident. And hence the importance of ensuring the quality of the problem statements resulting from the Forum, making sure that they represent significant needs of the hearing enhancement industry. Our on-site forum evaluation constitutes our effort to achieve this by ensuring the quality of the *inputs* as well as the *processes* that produced these Forum outcomes.

Prodedures: Before the Forum:
We began our systematic approach to quality assurance far in advance of the Forum itself. During the months *prior* to the Forum, manufacturing, research, clinical and consumer experts on hearing enhancement provided input through interview sessions conducted by the T^2RERC. These sessions explored the current status of product features and functions and on the capabilities of their underlying technologies. Analysis of this information, along with a literature review, allowed us to identify about twelve potential topics in need of further exploration. Then, working with our partner RERC on Hearing Technology at Lexington Center in New York City, we selected the four Technology Areas deemed most important for making significant advancements in the state of the technology underlying hearing enhancement devices. The RERC on Hearing then helped us develop the "white-papers" for each Technology Area, which presented the current state of knowledge and practice for the specific Technology Areas. All Forum participants received the white papers in advance so they arrived with the same current knowledge about each Technology Area.

Procedures: At the Forum:
Participation in the Forum was strictly by invitation. The Forum brought together 62 stakeholders–each one expert in an aspect unique to Hearing Assistive Technology. This diverse group of stakeholders included – advanced technology developers, consumers, nationally and internationally known researchers, hearing enhancement product manufacturers, clinical and technical experts, and experts in third party reimbursement. They brought specific knowledge about hearing aid technology and assistive listening systems, their underlying technologies, or their application and use.

We designed the Forum in the basic mold of our previous Forum on Wheeled Mobility, with refinements from evaluations of that forum. Trained moderators from the T^2RERC led structured discussions among the participants, and their varied perspectives generated the consensus statements needed to create *problem statements*, the intended outcomes of the Forum. The Four Technology Areas on which the discussions concentrated were:

- Earmolds
- Infrared and Inductive Loop Systems
- FM and Related Technology
- Microphone Technology

We conducted the four sessions simultaneously each day, corresponding to the four Technology Areas. Thus there were two sessions for each Area, one on each day. Participants took part in two different sessions, one on each day, depending on their expertise and interest. The interactions were highly structured, with moderators using pre-prepared scripts to guide the discussions. A scribe recorded notes on a personal computer for reference and display, another recorded points on a flipchart and a technical consultant aided the moderator. To ensure that our participants with hearing-impairments could fully engage in the discussions, each room had a CART system for real-time captioning and an assistive listening system with microphones for each participant. The room layouts ensured that there were no visual barriers between speakers. For each Technology Area, the consensus that emerged from the discussions of the two sessions were systematically merged, summarized and reported at a general session at the end of the Forum.

Evaluation Methodology:

Purpose:

As mentioned earlier, validation of the Demand-Pull model of technology transfer provides the broader context for the Forum's evaluation. Quality assurance is vital for ongoing refinement and consolidation of best practices under the model. Since the Stakeholder Forum processes represent our current understanding of best practices tested in actual use, assuring the quality of its inputs, process and outcomes, and observing these best practices in action, are integral parts of our Forum activity. It supports the ongoing improvement of both the Forum and the Demand-Pull model's cycle of operations.

Thus, the purpose of the Forum evaluation was to:

- Evaluate Forum inputs and structure and support ongoing planning of future Forums and related model activities;
- Evaluate Forum processes and support its monitoring and on-site improvement.
- Evaluate, screen and incorporate both tested and newly identified best practices.

Best practices in focus: what was different this year

The evaluation focused on the validity of both input-related and process-related best practices. Such practices involved the development of the white papers, the selection and recruitment of the participant sample, selection and training of the moderators, forum structure and organization involving staff, logistical and technical support, and on-site environmental adaptations. A special set of these best practices represented improvements incorporated from valuable participant suggestions from last year's forum. These included: (a) Improved Session formats -We maintained and strengthened our structured format for the sessions. In particular we refined and brought scripts to a more standardized form, and trained the moderators in their use. (b) Enabling Consumer to participate more effectively: In the interest of drawing their best contributions, we included a pre-training session for our consumer participants using a format that simulated the sessions. (c) Raising consumer sample quality: We expanded our consumer recruitment efforts to include participants who were not only "information-rich" (expert) consumers, but also articulate contributors. (d) Raising stakeholder interaction effectiveness: We strove for better technical/laymen communication both by training our moderators and by appropriate room lay out at the sessions (e) More accessible forum environment: We selected a better venue for this year's Forum. We had all meeting rooms on a single floor potentially more accessible to participants and staff alike.

Procedures for collecting, analyzing and using information

We obtained information about the quality of our best practices from two sources. *Internally,* our project staff gave us their self-evaluative perceptions and judgements of the forum performance. Our *external* source was our participating stakeholders. They judged the validity of the Forum sessions they attended and reported their satisfaction levels about them. They also judged the quality of the Forum as a whole at the end. Additionally, a team of two evaluators made formal, on-site observations of the Forum in session for process monitoring. All evaluative information was gathered both by formal and informal modes as described in the next section.

We carried the on-site evaluator observations back and forth between live sessions, reinforcing their strengths and correcting process errors. Also, we analyzed stakeholder responses and comments at the end of the day and fed them back to the moderating teams immediately, enabling them to modify their second day sessions in accordance with the needs perceived on the first day. The participants' insights into our strengths and weaknesses *during* the Forum, as well as our on-site observations enabled us to monitor the processes, improve them while they were still being conducted, and keep them appropriately focussed and directed.

In addition to guiding on-site modifications in our on site processes, systematic triangulation between the foregoing sets of data also helped us identify improvements for future events and the relevant demand-pull steps.

Instruments

Surveys during and at the close of the Forum: Participant stakeholders evaluated the quality of each individual session against their own expectations, using a survey form. They expressed their satisfaction levels about the session they attended by answering questions on a 5 point rating scale about various session aspects. They evaluated the session for *content* (topics relevant? discussions deep enough?), *purpose* (achieved?) and *personal satisfaction* (felt comfortable? able to contribute?). Participants also responded to open-ended questions, making additional evaluative comments. **Fig.1** presents this survey and its items.

Our participating stakeholders also made final evaluations of the Forum using a separate survey at the conclusion [see **Fig.2**]. They rated Forum organization, the quality and appropriateness of the white papers and the accessibility of venue each on a 5 point rating scale. Besides, they indicated the extent to which the Forum met our expectations for them by way of: exposing them to the state-of-the-art technology; facilitating networking, partnerships and collaborations; indicating untapped business opportunities; enabling them to shape the future of the hearing aid and assistive listening industries.

Formal On-site Observation Checklist: Our "on-site" evaluation is an important part of the Forum. The team of two evaluators made direct observation of the interactions at every session, circulating from room to room, and recording the unique features of each session. We used a formal *checklist* [See **Fig. 3**] to observe what styles the moderators used, the way they used the audio-visual aids, and how effectively their team coordinated its roles to monitor discussions, clarify technical content and summarize key points.

Informal On-site Observations: In addition to the formal observation by the evaluation team, there were also informal observations reported by the organizers. The spontaneous comments they captured from the stakeholders outside the sessions corroborated or clarified information that came from the other sources.

Formal Self-evaluative feedback: Critical comments from project staff, including the moderators, scribes, evaluators and on-site technical team, also served to clarify or enhance the information collected from other sources regarding Forum effectiveness.

Results – what we found and how we used it

Analyses of the foregoing information revealed that the Forum was a success, an experience considered gratifying by participants and hosts alike. The results are detailed below.

Stakeholders Evaluate Forum Sessions:

In all, 52- 57 participants consistently filled out the evaluation forms expressing their satisfaction levels about the session they attended and making additional comments. Overall perceptions were very positive about all sessions. **Table 1** summarizes and compares the ratings across the four sessions. On the whole, moderators got higher average ratings than last year – ranging from 4.1 to 4.5 [compared to 3.8 to 4.2 from last year]. However, individual evaluations varied due to participant mix and differences in moderator styles. They ranged from reasonably satisfactory (3.4 points on a 5 point scale) to highly satisfactory (4.9 points). Two moderators scored higher ratings the second day, and the other two scored higher on the first day.

Table 2 lists and groups open stakeholder comments on the quality of each session. They revealed satisfaction about most of the aspects, in particular our improved practices that related to: our structured and standardized session formats, and moderator quality; level of expertise and participation of the participating consumers; quality of participating stakeholders and contributions.

Stakeholders Evaluate Forum Performance

On the End-of-the-Forum survey, participant evaluations of the organization of the Forum were higher than last year. **Table 3** summarizes the ratings on this survey. Rating averages were 4.7 points (vs. 4.1 last year) for adequacy of the facilities; 4.8 points (vs. 4.0 last year) for accessibility of the facilities; and 4.6 points (vs. 4.2 last year) for background information provided by the white papers.

The perceived effectiveness of white papers by the stakeholders is noteworthy. White papers represent significant *intermediary* outcomes in the Demand-pull process and feed as major *input* for the Forum discussions. It is also worth noting that accessibility arrangements were acceptable. This was one of the improvements we made from our last year's feedback, incorporated into this year's Forum. Our selection of venue with all meeting rooms on a single floor did in fact make a big difference in accessibility also for our own project staff with functional limitations.

The table shows also that perceptions of the stakeholder groups this year were not much different from those of last year's regarding the benefits they took away with them. Different stakeholder groups valued different aspects of the forum as its strength, but the opportunity to network with and learn about the ideas of other stakeholder groups was upheld as the Forum's strength by all groups. Thirty-nine (39) out of the 45 survey responses (about 87%) indicated this as a benefit from the Forum. Networking and quality of the interactions also made a repeated appearance in the open-ended comments participants made pointing to forum strengths.

Next in order to networking was "exposure to new or innovative technology" acknowledged as a benefit by thirty (or two-thirds) participants. In terms of proportions, this included most (10 out of 12) *technology producers*, over half (12 out of 19) of *customers*, so also (6 out of 11) of *manufacturers* and 2 out of the 3 attending *resource providers*. Being able to identify direction for new product development (58%), being able to identify need for new technology (50%) and being able to identify new business opportunities (one-third) were next in that order.

Stakeholder comments presented in **Table 4** corroborate the above results.

<u>Informal Stakeholder Evaluations:</u>
Participant comments gathered during informal interactions with them described the various activities of the Forum with remarks such as: "the most focused meeting, with the clearest objectives", "the most constructive group meeting [he] had ever participated in," "the mix of stakeholders provided a level of insight not previously encountered", 'the sessions were illuminating". The perception on the whole was that the entire program was well run and in a professional manner. Most of the specific comments mentioned as **"**strengths" of the Forum reflected our best practices improved from last year, reinforcing our decision to incorporate them. On the other hand, we derived "lessons" from this year's experience in the constructive suggestions some participant s made about our practices.

<u>In-house Input – Self-study comments</u>

Self-evaluative feedback from project staff, including the moderators, scribes, evaluators and on-site technical team, also pointed to a high level of satisfaction on everyone's part. These comments were re-grouped under the following categories: Pre-Forum activities and Consumer recruitment; Locale of Event; On-site Project support; Forum organization and coordination; Registration of participants; Use of AV aids; Breakout sessions – structure and interactions; and Reporting Session. The "strengths" under each category reinforced both features that we maintained and those we improved from last year. At the same time, we acknowledge and appreciate several constructive comments related to improving the process further. These "lessons" related to: early consumer recruitment; early dispatch of white papers to participants; better attendance keeping; optimal room and group size; improved survey administration; effective flip-chart work; better

collaboration with partner RERC; reschedule for more time at sessions as well as for report preparation; and participant cost reimbursement policies.
Most of the findings discussed so far were corroborated and complimented by our on-site process observations. For example, bringing scripts to a more standardized form helped our two new moderators –one a stronger subject matter expert and the other a more experienced facilitator- to be on track at various points. Having all meeting rooms on a single floor made a big difference in accessibility. The quality of interactions in sessions revealed the quality of the participant mix we were able to achieve in the sample.

Final Considerations

Formal feedback about the Forum processes from staff and participants alike helped us make on-site improvements to raise the performance level of the sessions and of the Forum as a whole. Moderators made the appropriate changes from one session to the next, and we controlled, monitored and made better use of audio-visual resources.

On the other hand, all end-of-the process feedback was recorded as "lessons" for future events and will be used in our ongoing planning.

Back at the T^2RERC, *problem statements* are now in development, using the rich material generated at the Forum. As the old adage goes, "the proof of the pudding is in the eating." Current perceptions by the staff and the participants about Forum effectiveness need corroboration from evaluations of the outcomes from the Forum and their value to the stakeholders.

We conclude by acknowledging our gratitude to our project sponsor, the National Institute on Disability and Rehabilitation Research (NIDRR), our partner RERC on Hearing Technology at the Lexington Center in Queens, NY, our co-sponsor the North East Region of the Federal Laboratory Consortium, the Research Triangle Institute (RTI) that provided us expertise on tech transfer from the federal labs, and, in a very special way, all of the stakeholders who participated in the Forum.

Figure 1 - Stakeholder Survey about Breakout Sessions

Date: (Check one) [ ] Friday, June 9, 2000 [ ] Saturday, June 10, 2000

Groups Participated In: (Check one)
[ ] Earmold Related Technology
[ ] Infrared and Inductive Loop Technology
[ ] FM and Related Technology
[ ] Microphone Technology

Background: (Check one) [ ] End User [ ] Clinician [ ] Other

INSTRUCTIONS: Please take a few minutes to answer the following questions about the group activity in which you just participated. Your perceptions and suggestions will help us make this Forum better.

		Strongly Agree				Strongly Disagree
1	The Group Session was well organized and run	**5**	**4**	**3**	**2**	**1**
2	The content of the group discussion was relevant to me	**5**	**4**	**3**	**2**	**1**
3	Discussion addressed most important aspects of topic	**5**	**4**	**3**	**2**	**1**
4	Discussion went into sufficient depth	**5**	**4**	**3**	**2**	**1**
5	Moderator's instructions were direct, simple and clear	**5**	**4**	**3**	**2**	**1**
6	The purpose of the group session was clear	**5**	**4**	**3**	**2**	**1**
7	Discussion achieved the purpose	**5**	**4**	**3**	**2**	**1**
8	I felt comfortable participating in the group discussion	**5**	**4**	**3**	**2**	**1**
9	I felt I made useful and relevant contributions	**5**	**4**	**3**	**2**	**1**

10. What aspect of the group needs to be improved?

11. What aspect of the group was most helpful?

Figure 2 - Stakeholder Survey about Forum

Date: (Check one) [ ] Friday, June 9, 2000 [ ] Saturday, June 10, 2000

Groups Participated In: (*Check all that apply)*
[ ] Earmold Related Technology
[ ] Infrared and Inductive Loop Technology
[ ] FM and Related Technology
[ ] Microphone Technology

Background: (Check one) [ ] End User [ ] Clinician [ ] Other

Instructions: Please take a few minutes to answer the following questions about the group activity in which you just participated. Your perceptions and suggestions will help us make this Forum better.

		Strongly Agree				**Strongly Disagree**
1	The Facilities were adequate for the purpose of the Forum	**5**	**4**	**3**	**2**	**1**
2	The facilities were accessible	**5**	**4**	**3**	**2**	**1**
3	The White Papers provided an appropriate background for the Forum	**5**	**4**	**3**	**2**	**1**

4. The value of the Forum to you: (check all that apply)

[ ] Helped you identify new business opportunities
[ ] Exposed you to new or innovative technology
[ ] Helped you identify direction for new product development
[ ] Helped you identify a need(s) for new technology
[ ] Gave you an opportunity to network with manufacturers, researchers, clinicians & others

5. What aspect of the Forum needs to be improved?

6. What aspect of the Forum was most useful?

Figure 3 - Checklist for observing Breakout Sessions

Topic: --

Friday am [ ] Saturday am [ ]

Friday pm [ ] Saturday pm [ ]

Moderator Posture	**Before Break**	**After Break**
1. Positioned adequately in line of vision of the consumers? (Visible, audibly accessible)		
2. Non-intimidating, friendly		
3. Uses short, understandable phrases to capture points		
4. Is objective – brings group to the point		
5. Follows script		
6. Encourages everyone's participation		
7. Is consumer sensitive – facilitates understanding of technical jargon		
8. Is effective hearing is taking place ?[*moderator is not having to repeat*]		
9. Is the pace suitable [*slow enough]* for real time captioning by scribe and hearing aid users?		
10. Using clear (*non-sloppy, loud, articulated, paused)* speech, to benefit consumer-participants?		
11. Is moderator (and others) using Assistive LisSystems effectively? [*holding mike properly,…]*		
12. Facilitates visual contact-[*not cover lips, hold things in mouth….]?*		
13. Gets consumer's attention before talking, in one-on-one situations?		
14. Gets people to talk one at a time [prevents cross-talk]		

Use of space/ Environment	Before Break	After Break
1. Adequate room space for AV aids [easel, computer, screen] use?		
2. Free from specific barriers such as obstructed sight lines		
3. Free from barriers to use of individual auditory (hearing aid) ?		
4. Free from background noise and interference?		

Use of AV aids

Flipcharts:

1. Sufficient number of flipcharts?		
2. Flipcharts ideally positioned?		
3. Use of flipcharts coordinated by moderator?		
4. Flipchart writing is “notes” rather than “transcripts”?		
5. Notes organized? [points are numbered, placed in some categories]		
6. Writing legible? – All CAPITALS for example?		
7. Markers/pens efficiently used? [contrasting color, for ex.]		

Wall Displays:

1. Sufficient wall space for notes display?		
2. Displays ideally [accessibly] positioned?		
3. Displays organized? [Ex. Divide walls up in categories *consumer needs, technical status, barrier* to hang up notes]		

Computers:

1. Computer efficiently used –Ex. Having two computers - one to take down notes, the other for display?		

Note any Creative use of AV aids, space…etc. [*Ex. as a display of illustrations on computer for reference during discussion;*] and pass it on to other groups at break.

Before break:	After break:

Special features:[team work, special techniques, ….]

Table 1 - Stakeholder Ratings of Hearing Enhancement Forum Sessions

Total number of surveys received (all four topics)
Friday - 53
Saturday - 52

		Earmold Tech.		FM & Related Technology		Infrared/Inductive Loops			Microphone Technology	
		Friday	Saturday	Friday	Saturday	Friday	Saturday		Friday	Saturday
		Mean (n=12)	Mean (n=13)	Mean (n=12)	Mean (n=15)	Mean (n=16)	Mean (n=9 or 8)	Median	Mean (n=13)	Mean (n=15)
1	The group sessions was well organized and run	4.8	4.7	3.7	4.5	3.8	4.6	5	4.5	3.9
2	The content of the group discussion was relevant to me	4.6	3.5	4.2	4.5	3.8	4.3	4	4.3	4.1
3	Discussion addressed most important aspects of topic	4.6	4.5	3.7	4.4	4.1	4.9	5	4.4	3.5
4	Discussion went into sufficient depth	4.8	4.6	3.8	4.2	4.3	4.3	4	4.2	3.9
5	Moderator's instructions were direct, simple and clear	4.8	4.6	3.8	4.6	4.0	4.6	5	4.5	4.5

Table 1 - Stakeholder Ratings of Hearing Enhancement Forum Sessions (continued)

		Earmold Technology		**FM & Related Technology**		**Infrared/Inductive Loop Systems**			**Microphone Technology**	
		Friday	**Saturday**	**Friday**	**Saturday**	**Friday**	**Saturday**		**Friday**	**Saturday**
		Mean (n=12)	**Mean (n=13)**	**Mean (n=12)**	**Mean (n=15)**	**Mean (n=16)**	**Mean (n=9 or 8)**	**Median**	**Mean (n=13)**	**Mean (n=15)**
6	The purpose of the group session was clear	4.7	4.4	3.8	4.5	4.1	4.6	5	4.4	3.9
7	Discussion achieved the purpose	4.7	4.1	3.8	4.1	3.8	4.5	5	4.2	3.6
8	I felt comfortable participating in the group discussion	4.9	4.0	3.9	4.1	4.5	4.2	5	4.2	3.8
9	I felt that I made useful and relevant contributions	4.3	3.7	3.9	3.7	3.8	3.9	4	3.6	3.4

Table 2 - Stakeholder Comments on the Breakout Sessions

Code: C= consumer comment; M =manufacturer comment; TP= tech producer comment; RP= resource provider comment]

Group: Earmold Technology- Session 1:
(Friday afternoon - n=12)

Which aspects of the forum need to be improved?	**Which aspects of the Forum were most useful or well done?**
• Most of us users need to have a short course or reading in more depth so we can participate better. It is difficult to solve problems on the spur of the moment **[c]** • More consumers. I have known people who have extreme difficulty with ear-molds even when going to different audiologists. **[c]** • Perhaps less time spent on personal issues of consumers which were not specific to earmold technology. **[RP]** • Done well **[RP]** • Two coffee breaks to break into shorter sessions (perhaps by subject area such as needs, tech, etc.) [**TP]** • Implementation (?) of ideas. [**M]** • Seem to work correctly **[M]** • None **[M]** • We need to think outside the box a bit more **[M]**	• The interchange between various technologies.**[c]** • Interactions with professionals and consumers.**[c]** • The friendly, cooperative attitude of <u>all</u> involved.**[c]** • Conclusions [**RP]** • Good moderator **[RP]** • Diversity of input and quality of people in group. [**TP]** • Free discussion of thoughts **[M]** • The variety of aspects **[M]** • Group interaction [**M**] • Discussion of Barriers. **[M]**

Table 2 - Stakeholder Comments on the Breakout Sessions (continued)

Group: Earmold Technology - Session 2:
(Saturday morning - n=13)

Which aspects of the forum need to be improved?	Which aspects of the Forum were most useful or well done?
• Note- total consumers 4, all blank .**[C]** • Very well run. Ideas flowed and were kept in reasonable bounds.[**M]** • THAT SURE – I believe this session was very informative. A deeper appreciation of a hearing disability is very important. If you are not with the disability you can not truly know.[**M]** • Diversity of group was both the strength and weakness – In-depth technical issues not addressed – but consumers brought personal experience .[**M]**	• note-4 blanks .**[C]** • It seems to me that discussions in this session that approached blue sky suffered from a focus on cost. Costs of development of significant technology breakthroughs might be high but ultimately could result in a much larger user group, thereby lowering product cost significantly. Eg., calculators from $895.00 to $8.95 in a matter of 6-12 months. Point is, we should think in terms of what's possible and then try to accomplish it. If hearing aid/ALS systems manufacturers are in the business to help people (as some said they were), they might want to put their money where their mouth is, and benefit financially a bit later than tomorrow or next week.(I was disturbed by some of the negativism).[**RP]** • I enjoyed Brian's style – gave the group opportunity to develop <u>its</u> style – while moderating only as needed – feel it was very constructive, open. [**RP]** • Thorough detailed discussion of details.[**TP]**

Table 2 - Stakeholder Comments on the Breakout Sessions (continued)

Group: Earmold Technology - Session 2:
(Saturday morning - n=13)

Which aspects of the forum need to be improved?	Which aspects of the Forum were most useful or well done?
	• Facilitator was superb – he knew enough of subject to lead meaningful discuss.[**M]** • Good brainstorming techniques. Focus was on the problem aspects of users. Focus of discussion – consumers' daily experienced problems and frustrations, review of manufacturer's ability to focus on designs of product without creating dissatisfaction with consumers but reviewing needs, along with outside groups that cn interact as possible. The mix set up for the disabilities was great. .[**M]**

Table 2 - Stakeholder Comments on the Breakout Sessions (continued)

Group: FM and Related Technology – Session 1:
(Friday afternoon - n=13)

Which aspects of the forum need to be improved?	Which aspects of the Forum were most useful or well done?
• Room moderator to point and select only one speaker at a time. Doug can't see hands raised so everyone spoke at same time, thus making it physically uncomfortable for the hearing impaired person. [**C]** • Initial focus needs to be clarified more. A little more explanation of process would be good. [**C**] • Clarify goals and objectives beforehand (explain the rules of the game) [**C**] • Assistive Technology failed – may be that proves the point of holding the session.[**RP**] • It was too controlled without knowing the sequence to be discussed. Why did that have to be hidden? **[RP**] • Note taking-perhaps display notes from computer using LCD [**TP]** • Methods for guiding discussions in which several separate yet relevant directions arise**.** [**TP]** • Better vision of boards/writing, more time,.. [**TP]** • The session ended up being a focus group for the design of a specific product. I thought we were to identify directions for longer term technology research. [**M**] • Appreciation for needs for speech understanding with respect to hearing in noise and level of hearing loss (i.e., speaker placement, spatial selectivity, AI-DI etc.) [**M**] • Tighter focus and group members knowledgeable about the subject. [**M**]	• Worked together to achieve a goal and respected peers input. [**C**] • A great diverse group. [**C**] • Good moderation. Great participants! [**C**] • Very good group assembled for discussion [**RP**] • Referring to existing technology in discussions to clarify what is on the market and how it is used [**RP**] • Skill of moderator [**TP]** • Comments of technically knowledgeable consumers [**TP]** • Diversity of attendees [**TP]** • Balance of interests and points of view : users, clinicians, engineers/manufacturers/ designers, researchers. Good exchanges of ideas. [**TP]** • Different viewpoints. Range of expertise. . [**M**]

Table 2 - Stakeholder Comments on the Breakout Sessions (continued)

Group: FM and Related Technology – Session 2:
(Saturday morning n=13)

Which aspects of the forum need to be improved?	Which aspects of the Forum were most useful or well done?
• More focused. [**C**] • Review of key points after each topic area to summarize for the group before moving on. [**C**] • Need more information or more people to share [**C**] • Things needed to move more expeditiously [**C**] • Although consumer (end-user) input was helpful – the end-user group needed more diversity –e.g., parents of children, younger adults, individuals with mild-to-moderate loss. Marketing individuals would also add another perspective. [**TP**] • It was good as is [**TP**] • Need manufacturers to give “reality check” on suggestions. Also, if there are technical considerations in specific areas, the right people. [**TP**] • Clarifying purpose [**TP**] • None [**M**] • People did not have an understanding of current technology. Hard to stay on task, but Doug brought them back on track. [**M**]	• The exchange of ideas [**C**] • All [**C**] • The manufacturers, the researchers and the users were able to agree or disagree with each other [**C**] • Ideas from technical people [**C**] • Engineers’ comments!! [**RP**] • Ability to talk with people from a variety of backgrounds [**TP**] • The expertise level of several of the participants [**TP**] • Broad representation. [**TP**] • The interchanges from different perspectives. [**TP**] • All [**M**] • Listing of ideal features [**M**]

Table 2 - Stakeholder Comments on the Breakout Sessions (continued)

Group: Infrared and Inductive Loop Technology - Session 1
(Friday afternoon - n=16)

Which aspects of the forum need to be improved?	Which aspects of the Forum were most useful or well done?
• The groups were probably too large, the continuity of knowledge across participants was so broad that communication was limited. The moderator's poor knowledge of the subject made it impossible to avoid entirely new subjects and/or orthogonal domains. The areas were too broad [**C**] • Think of none [**C**] • It was repetitive [**C**] • I honestly though the group was excellent [**C**] • Two topics were too much to cover in one session. Moderator was pressured at times short with participants. [**RP**] • Repetitive questions and topics [**TP**] • Would have been more helpful if leader was more "tech-savey". More industry needed!! [**TP**] • Next time try to involve DOD agencies that distribute SBIR grants, they may be able to provide(?)[**TP**] • The moderator was not adequately knowledgeable about the subject area – and therefore could not adequately facilitate discussion. [**TP**] • Better moderation [**TP**] • I like having end-users participate, but only a relatively small segment was represented –generally older adults with severe hearing loss. A broader range would be very helpful – some younger, some parents of h-I children. Some with less severe losses. [**TP**] • 1. Deeper understanding of topic by moderator. 2. Improved note taking by large sheet recorder. The first but not the second had problem catching what was said. [**M**] • bios of participating people so everyone knows who is who and what are people's strengths. [**M**] • Narrow the topics so they can be covered better. [**M**] • Discussions can be circular without developing [**M**]	• Contacts with professionals with related interests. [**C**] • Learning about developments in other technological areas. [**C**] • Discussion [**C**] • People contributed freely. [**C**] • Many sources of information gave me a lot of different aspects and ways of looking at overcoming various problems. [**C**] • Better understanding of current status of IR/IL technology. [**RP**] • Discussion of pluses and minuses of system [**TP**] • The broad representation . people who hve "been there" with the problems. [**TP**] • The expertise of the group members [**TP**] • Variety of people – diverse backgrounds; ability to look at problem from a variety of experts. [**TP**] • Clarification of strengths and weaknesses of IR and IL /T-coil systems. [**M**] • Unsure **[M]**

Table 2 - Stakeholder Comments on the Breakout Sessions (continued)

Group: Infrared and Inductive Loop Technology - Session 1
(Saturday morning n=9)

Which aspects of the forum need to be improved?	Which aspects of the Forum were most useful or well done?
• Better communication of technical terms needed. [**C**]. • It seems that the end-users were not representative of the majority of hearing-impaired users. Seemed to be more hearing-impaired –representing an extreme. [**TP**] • Participants being able to contribute through keyboard input **[TP]** • Higher level of technical discussion required **[M]**	• Hearing other people talk about experiences; Learning about the new technology that we can expect to see in the future.**[C]** • Excellent facilitator!! [**TP]** • Skill of moderator **[TP]** • It was very well done! **[M]** • Diverse perspectives **[M]**

Group: Microphone Technology - Session 1:
(Friday afternoon n=13)

Which aspects of the forum need to be improved?	Which aspects of the Forum were most useful or well done?
• Greater explanation of concepts and technical terms (technicians talked to each other) **.[C]** • More people in different group. **.[C]** • I think the level used should have been more qualified .[**C]** • Microphones are very technical. A representative at a microphone manufacturer/developer could have added greatly. [**M**]. • Clear definition of microphone – uses, etc. • Note: no comments from **TP**s-tech producers	• Identification of problem**.[C]** • Varied backgrounds meshed well i.e., end-users well versed in problems, manufacturers/industry people can find solutions, researches are familiar with what's being/been done. **.[C]** • I think what most helpful was the opinion from the manufacturers, research technology and the hearing impaired. We can tell the post and negative impact about the hearing aids to them. [??]**.[C]** • We were able to agree and disagree about the microphone technology. Everybody was able to share their opinion at the meeting. • Content was interesting to me. [**RP**] • Consumer perspectives [**M**].

Table 2 - Stakeholder Comments on the Breakout Sessions (continued)

Group: Microphone Technology Session 2:
(Saturday morning - n=15)

Which aspects of the forum need to be improved?	Which aspects of the Forum were most useful or well done?
• Better listening systems – otherwise much improved over yesterday.[**C**] • This session was good. Could have included a little more input from consumers.[**C**] • Technological information and end user experience need to be blended .[**C**] • No comments .[**C**] • The structure used to divide the topic into manageable sections was not very facile. But I can't think of a better approach. .[**C**] • More control over the topic. There were many cases whre the same word was used to represent many different things. .[**C**] • Give me a handout of facilitator questions [**RP]** • Repeat attendance three time (year to year) could improve knowledge base**.[TP]** • Leader should have kept us slightly more focused**. .[TP]** • Too much emphasis on high tech microphones without understanding needs for audibility, speech-to-noise requirements as a function of hearing loss. Much of this was covered in the FM related technology session anyway. .[**M]** • The techies dominated and talked over our the heads of the consumers and others. .[**M]**	• Good free-flowing discussion.[**C**] • I came in with only a small understanding of microphones, was exposed to post graduate information and I now hope to retain at least a high school level. .[**C**] • Participants teaching main cocepts about acoustics, filtering, dynamic range, etc. [**RP]** • The facilitator –otherwise we might have wandered off the subject matter. **.[TP]** • Consumer comments, and discussion of existing technology in aids **.[TP]** • The input from end-users in the group was extremely helpful.[**M]**

Table 3 - Stakeholder Ratings of Overall Forum Performance

	"End-of-the-Forum Responses; N=36					"Early Responses"**; N=9				
	Customers n=13	*Technology Producers n=12*	*Manu-facturers n=9*	*Resource Providers n=2*	**Total N=36**	*Customers n=6*	*Manu-facturers n=2*	*Resource Providers n=1*	**Total N=9**	**All N=45**
A. Participation	**# of people**	**# of people**	**# of people**	**# of people**	**# of people**	**# of people**	**# of people**	**# of people**	**# of people**	**# of people**
Participated in Ear mold Technology gp.	1	1	4	1	**7**	2	0	1	**3**	**10**
Participated in Infrared & Inductive Loop Techno. Gp.	4	8	2	1	**15**	2	0	0	**2**	**17**
Participated in FM and related Technology gp.	6	7	2	1	**16**	0	1	1	**2**	**18**
Participated in Microphone Techno. gp.	6	4	3	0	**13**	2	1	1	**4**	**17**
Is a clinician/therapist	1	3	0	2	**6**	2	0	0	**2**	**8**
B. Ratings	*Mean*	*Mean*	*Mean*	*Mean*	*Gp. Mean*	*Mean*	*Mean*	*Mean*	*Gp. Mean*	**Gnd. Mean**
The facilities were adequate for the purpose of the Forum	4.9	4.7	4.8	5.0	**4.8**	4.5	4.5	5.0	4.7	**4.7**
The facilities were accessible	4.8	4.6	4.9	5.0	**4.8**	4.7	4.5	5.0	4.7	**4.8**
The "White Papers" provided an appropriate background for the Forum	4.5	4.7	4.3	5.0	**4.6**	4.0	5.0	4.0	4.3	**4.5**
C. Benefits	**# of people**	**# of people**	**# of people**	**# of people**	**# of people**	**# of people**	**# of people**	**# of people**	**# of people**	**# of people**
Helped you identify new business opportunities	5	4	6	0	**15**	0	0	0	0	**15**
Exposed you to new or innovative technology	10	10	6	1	**27**	2	0	1	3	**30**
Helped you identify direction for new product development	5	8	9	1	**23**	3	0	0	3	**26**
Helped you identify a need(s) for new technology	6	7	5	1	**19**	3	0	0	3	**22**
Gave you an opportunity to network with manufacturers, researchers, clinicians and others	11	11	9	1	**32**	4	2	1	7	**39**

**NOTE: refers to persons who answered the survey before the end of the forum.

Table 4 - Stakeholder Comments on Overall Forum Performance

Evaluator's note:

1. No resource providers returned the survey.
2. On the whole, there were fewer surveys [n=45] "returned" from the group; and of the ones received, there were fewer comments by all the stakeholder groups, compared to year 1.
3. Confusion about survey responding – 9 of the participants *prematurely* filled in the overall survey and several people left without responding to the survey at the end. One participant however, faxed it to us after returning to his place!
4. Comments in *italics* in the following tables represent *premature evaluations* [see observation above].

Participant group	Which aspects of the forum need to be improved?	Which aspects of the Forum were most useful or well done?
Consumers [green surveys]	• Time. We tried to accomplish too much in too short a time. 2 full days of sessions would have been more conclusive [manu?] • Just a little more advance explanation of the session process. Otherwise, fine! • Devise a way to continue the forum on internet: e-group, e-list, etc. • Again, the end-users were not experienced enough. • ***More attention to involving all technologies in discussions*** • ***The groups were probably too large, the continuity of knowledge across participants was so broad that communication was limited. The moderator's poor knowledge of the subject made it impossible to avoid entirely new subjects and/or orthogonal domains. The areas were too broad*** • ***Beginning information*** • ***I think the forum did very well. Not much needed to be improved.*** • No comments [blank] from: 6	• Networking [manu?] • The interactions in the sessions themselves! • Variance of participants; knowledgeability of participants. • Networking. • *The learning and sharing experience* • *Interactions with professionals and consumers* • *Contacts with professionals with related interests.* • *Talking with participants* • *Information exchange* • *We were able to agree and disagree about the microphone technology. Everybody was able to share their opinion at the meeting.* • No comments [blank] from: 7

Participant group	Which aspects of the forum need to be improved?	Which aspects of the Forum were most useful or well done?
Technology producers [pink surveys]	• White papers, pre-forum material explains meeting papers, structure better. • More participation by large companies who could be potential partners. • Wider range of end-users ---it would have been helpful to have individuals with mild-to-moderate losses as well. • Time between Saturday am session and lunch – need more time for presenters to put together summary presentation. • Forum moderators should deeply know terminology and concepts in hearing and devices. More manufacturers for "reality checks" and to be put in hot seat. • Would be nice to be able to attend all the sessions, but this might mean a longer forum, or duplication of sessions. • No comments [blank] from: 6	• Hearing from consumers of [their] needs. • Networking opportunities • Meeting people from a variety of backgrounds. Thank you for an interesting two days!! • Networking. • Excellent facilitators! Wonderful diversity among participants. • Broad representation. • The sessions: lots of great inputs from participants. Very thought provoking and educational! Thanks ! • No comments [blank] from: 5
Manufac-turers [blue surveys]	• Summary speeches representative of discussions/presentations could be more representative of discussions. • Discussions tended to get bogged down in one/two issues - better moderation needed. • Higher level of technical discussion • Some gaps, not discussed due to shortage of time. Need to look at "systems" aspect, not just technologies used in implementation. • Development/presentation of Summary notes - I suggest session consolidation in all cases. • None. • Very 1st Focus groups used to identify needs should narrow focus OR, rather discuss general problems (e.g., "I can't hear in noise;" "I can't roam while using line-of-sight IR systems." Some of the inquiries seemed a bit naive.	• Diversity • It was very useful, good networking • Input from end-users • All aspects • Interaction and brainstorming • Profound discussions • Participation by all • *Collect information form all levels of the topics - "user," researchers, manufacturers, and associated parties related to similar use.* • Blank (no comments) - 2

Participant group	**Which aspects of the forum need to be improved?**	**Which aspects of the Forum were most useful or well done?**
	• We would like to have Biographies [background info about participants? White papers?] early to research, etc. • More help for end-users to participate • Looks great as it is, for the time being at least. • *The session (on FM-tech.; Friday morning) ended up being a focus group for the design of a specific product. I thought we were to identify directions for longer term technology research.* • *Appears to be very well done* • Blank [no comments] - 1	
Resource Providers [yellow surveys]	• *All ok* • I would like to attend all 4 [topic areas] • Perhaps just better identifying expertise of participants with session requirements.	• *All ok.* • The group sessions. • Being able to offer my knowledge to assist in crystallizing some ideas/concepts.

Project Web-Sites

Project Websites

RERC on Technology Transfer (T^2RERC)
& Related Partner Agencies

Hearing Enhancement Project Website

http://cosmos.ot.buffalo.edu/hearing/

Partner and Related Sites in alphabetical Order:

AZtech Incorporated
http://cosmos.ot.buffalo.edu

Center for Assistive Technology – University at Buffalo (CAT/UB)
http://cat.buffalo.edu

Federal Laboratory Consortium (FLC)
http://www.federallabs.org

Federal Laboratory Consortium - Mid-Atlantic Region
http://www.federallabs.org/Northeast/start.html

Independent Living Center of Western New York (ILC)
http://www.buffnet.net/%7Eamhilc/

National Institute of Disability and Rehabilitation Research (NIDRR)
http://www.ed.gov/offices/OSERS/NIDRR/index.html

RERC on Technology Transfer (T^2-RERC) – University at Buffalo
http://cosmos.buffalo.edu/t2rerc/

RERC on Hearing Enhancement – Lexington Center for the Deaf
http://www.hearingresearch.org

Research Triangle Institute (RTI)
http://www.rti.org

U.S. Department of Education (USDE)
http://www.ed.gov