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Wireless Telephone-Hearing Aid Electromagnetic Compatibility Research at the University of Oklahoma

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Abstract

A multiphase study examining electromagnetic compatibility (EMC) between wireless digital telephones and hearing aids has been under way at the University of Oklahoma EMC Center since May 1995. In a phase 1 clinical study involving 68 hearing aid wearers, interference varied significantly by telephone technology, hearing aid type, and hearing loss characteristics. More than 80 percent of the tests resulted in either no interference or a detection threshold distance less than 1 meter. Metallic shielding of the units yielded positive results. Various elements of phase 2 involved instrument-based tests of hearing aid interference using telephones in a sound-isolation chamber and radio frequency signals in a waveguide, along with clinical studies of speech-to-interference ratios, all leading to the development of standards of measurement and performance criteria for telephone emissions and hearing aid immunity. Results to date confirm that bystander interference is of less concern than user interference, which is the focus of continuing research.

Key Words: Bystander interference, electromagnetic compatibility, electromagnetic interference, hearing aid, input referenced interference spectrum, radio frequency waveguide, speech-to-interference ratio, user interference, wireless digital communications

Abbreviations: ASC = Accredited Standards Committee, AMPS = advanced mobile telephone system, ANSI = American National Standards Institute, BTE = behind the ear, CDMA = code division multiple access, CIC = completely in the canal, EMC = electromagnetic compatibility, GSM = Global System for Mobile Communications, IRIL = input referenced interference level, IRIS = input referenced interference spectrum, IS = international standard, ITC = in the canal, ITE = in the ear, J-STD = "J" standard, NAL = National Acoustic Laboratories, PCS = personal communication services, RF = radio frequency, TDMA = time division multiple access

Based on reports of interference in hearing aids from digital wireless telephones in Europe, Australia, and other countries, the introduction of digital wireless technology in the United States raised concerns about the potential for interference with hearing aids in the United States. The most notable of previous studies are (1) the Australian studies by Joyner et al (1993) and Le Strange et al (1995), (2) the European Hearing Instrument Manufacturers Association Global System for Mobile Communications (GSM) Project by DELTA Acoustics and Vibration and Telecom Denmark (1995), and (3) research by the European Telecommunication Standards Institute (1993). All three studies confirmed the existence of an annoying "buzz" in some hearing aids exposed to digital GSM phones. The University of Oklahoma Center for the Study of Wireless Electromagnetic Compatibility (EMC) initiated a program of research to determine the potential for interaction between wireless phones and hearing aids, evaluate the effectiveness of proposed solutions to mitigate negative interactions, and develop test methods and criteria

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leading to EMC design standards for hearing aids and digital wireless devices.

The Center for the Study of Wireless Electromagnetic Compatibility was established at the University of Oklahoma in the fall of 1994 to advance the collaborative efforts of industries, government, and business in identifying and resolving interindustry EMC issues. The EMC Center links various societies, trade organizations, and other wireless device stakeholders concerned with EMC issues and serves as an interface to a variety of standards organizations including the American National Standards Institute (ANSI), Association for the Advancement of Medical Instrumentation, and the International Electrotechnical Commission. The Center also provides educational services to wireless device users who might be concerned with interaction with other electronic devices and organizes an annual forum on EMC challenges and progress. To date, the Center's primary focus has been on industry-driven research along with in-house and on-site testing of devices and environments with respect to EMC.

Wireless Phone-Hearing Aid EMC Research Objectives

On May 8, 1995, an initial planning meeting was hosted by the Oklahoma EMC Center in Dallas, Texas, to formulate an overall research program for investigating wireless phone-hearing aid interaction. This meeting was attended by representatives from the wireless phone and hearing aid industries. Topics included research study objectives, phone and hearing aid technology reviews, testing studies completed to date, and formation of a study design group for peer review. The study design group consisted of approximately 50 representatives from hearing aid manufacturers, wireless phone manufacturers and service providers, hearing aid user groups, audiologists, government agencies, and other researchers. A follow-up forum was held in Norman, Oklahoma, on June 6, 1995, to evaluate the existing research, define research program goals, identify relevant variables for investigation, and develop the outline of a test protocol that would lead to resolution of the interference issue. During the past 5 years, many others have added their contributions of time and effort to meet the EMC challenge. In January 1996, a summit meeting was convened in Washington, DC, to focus attention on the interaction issue with the goal of providing "universal access to wireless digital technology." This meeting resulted in the formation of separate working groups to address a short-term solution, a long-term solution, and hearing aid compatibility. The groups' efforts have evolved into the development of standards for methods of measurement and performance criteria for phone emissions and hearing aid immunity. The progress of the ANSI Accredited Standards Committees (ASCs) C63.19 and C63.20 is reported elsewhere in this issue (Berger, 2001). ANSI standard C63.19 received final approval in May 2001.

Aided by the reports of previous studies, significant factors to be addressed in the research program were identified, beginning with a simple documentation of the existence and severity of the interfering buzz or static. This could be accomplished through laboratory acoustic measurements or clinical studies of speech intelligibility and annoyance. Under the advice of the study design group and with the confirmation of the Federal Communications Commission, it was determined that a clinical study involving actual hearing aid wearers should receive the highest priority. In addition, the study should test the effectiveness of proposed solutions. It was readily apparent that the potential for interference could be addressed from two viewpoints: that of a hearing aid wearer experiencing interference from an unknowing bystander using a wireless phone versus that of a hearing aid wearer desiring access to digital wireless technology. These perspectives have since been commonly labeled as bystander interference versus user interference.

The following factors were identified as potentially affecting the level of electromagnetic interference: format of the wireless device signal (telephone technology or standard), type of hearing aid, specific manufacturers and models, hearing loss characteristics, separation between the telephone and the hearing aid, relative orientation of the telephone and aid, and ipsilateral versus contralateral use. It is important to note that the completeness of this initial list allowed substantial progress to be made in the early stages of the research program.

Wireless Telephone Technology

Wireless telephone technology can be most easily identified by three distinguishing characteristics: (1) the carrier frequency at which the telephone operates, (2) whether the telephone uses an analog or digital format for the voice channel, and (3) the specific signal format or protocol used. Within the United States, wireless systems operate in one of two basic carrier frequency bands. The North American Digital Cellular telephone transmits in the range of 824 to 849 MHz, and the personal communication services (PCS) telephone transmits between 1850 and 1910 MHz. Analog (advanced mobile telephone system [AMPS]) systems using frequency division multiple access allow multiple users to access the system by assigning a separate channel to each user in the cell. Time division multiple access (TDMA) systems assign users both a specific channel and a time slot so that multiple users can share time on a single channel. This results in a pulsed (digital) signal at one of a number of possible repetition rates, such as TDMA-50 Hz (international standard IS-136) or TDMA-217 Hz ("J" standard J-STD-007, known as PCS 1900 in the United States). A TDMA-217 Hz GSM system is in use in many other countries at 900 and 1800 MHz. Code division multiple access (CDMA) systems employ a spread-spectrum type of technology governed by IS-95 and J-STD-008. It is heretofore recommended that a particular telephone technology always be referenced by its industry standard identification number (IS and J-STD numbers above) rather than the colloquial name, which often leads to confusion.

Oklahoma EMC Center Research Program

Figure 1 depicts the overall multiphase hearing aid EMC research program under way at the University of Oklahoma. The phase 1 clinical study, conducted in collaboration with the Oklahoma City–based Hough Ear Institute, was initiated in December 1995, with preliminary results presented in January 1996 and complete results available in April 1996. An extensive EMC Center report provides the details of the study (Ravindran et al, 1996), which are summarized below and in Ravindran et al (1997). Phase 2 consisted of three parallel elements. Phase 2A involved acoustic measurements of hearing aids within a sound-isolation chamber. Phase 2B examined speech-to-interference ratios in an attempt to determine a range of values allowing effective use of digital phones by hearing aid wearers. Phase 2C focused on the use of the Australian Hearing Services National Acoustic Laboratories (NAL) waveguide to measure the radio frequency (RF) immunity of a number of hearing aids.

PHASE 1: CLINICAL STUDY

Phase 1 of the research program focused on testing 78 people (68 hearing aid wearers and 10 people with unimpaired hearing) to (1) evaluate the degree of interaction between wireless phones and hearing aids; (2) document the existence and relative severity of the interaction as a function of hearing aid type, hearing loss characteristics, and wireless phone technology; and (3) determine the effectiveness of proposed solutions such as shielding the hearing aid and shielding the telephone antenna. Hearing aid types consisted of behind the ear (BTE), in the ear (ITE) full-shell, ITE half-shell, in the canal (ITC), and completely in the canal (CIC). Three telephone technologies were studied: (1) 1900 MHz PCS (TDMA-217 Hz; J-STD-007), (2) 800 MHz D-AMPS (TDMA-50 Hz; IS-136), and (3) 800 MHz CDMA (IS-95). Hearing loss characteristics included hearing loss configuration (flat, sloping, ski slope, and rising), hearing loss severity (no loss, mild, moderate, moderately severe, severe, and profound), and hearing loss etiology.

Two interference measures, detection threshold (the distance at which a hearing aid user detects interference, not necessarily annoying) and annoyance ratings (0–5 scale; 0 = no interference to 5 = unbearable), at fixed distances between 25 and 300 cm (10 in to 10 ft), were used to determine the interference to a hearing aid wearer owing to bystander use of a wireless telephone. Two additional measures, speech recognition (words identified correctly from a Northwestern University Auditory Test No. 6 standard audiotaped word list) and annoyance rating, were used to determine the degree of interference when hearing aid wearers were exposed to a digital telephone at a 2-cm distance (less than 1 in).

Phase 1 Results

All telephones were tested in their worst-case interference mode (highest operating power and CDMA with a variable vocoder rate) to determine the maximum potential interference, realizing that telephones operate at varying power levels, all of which are less severe as an interference source compared with full-power operations. Caution must be exercised in using

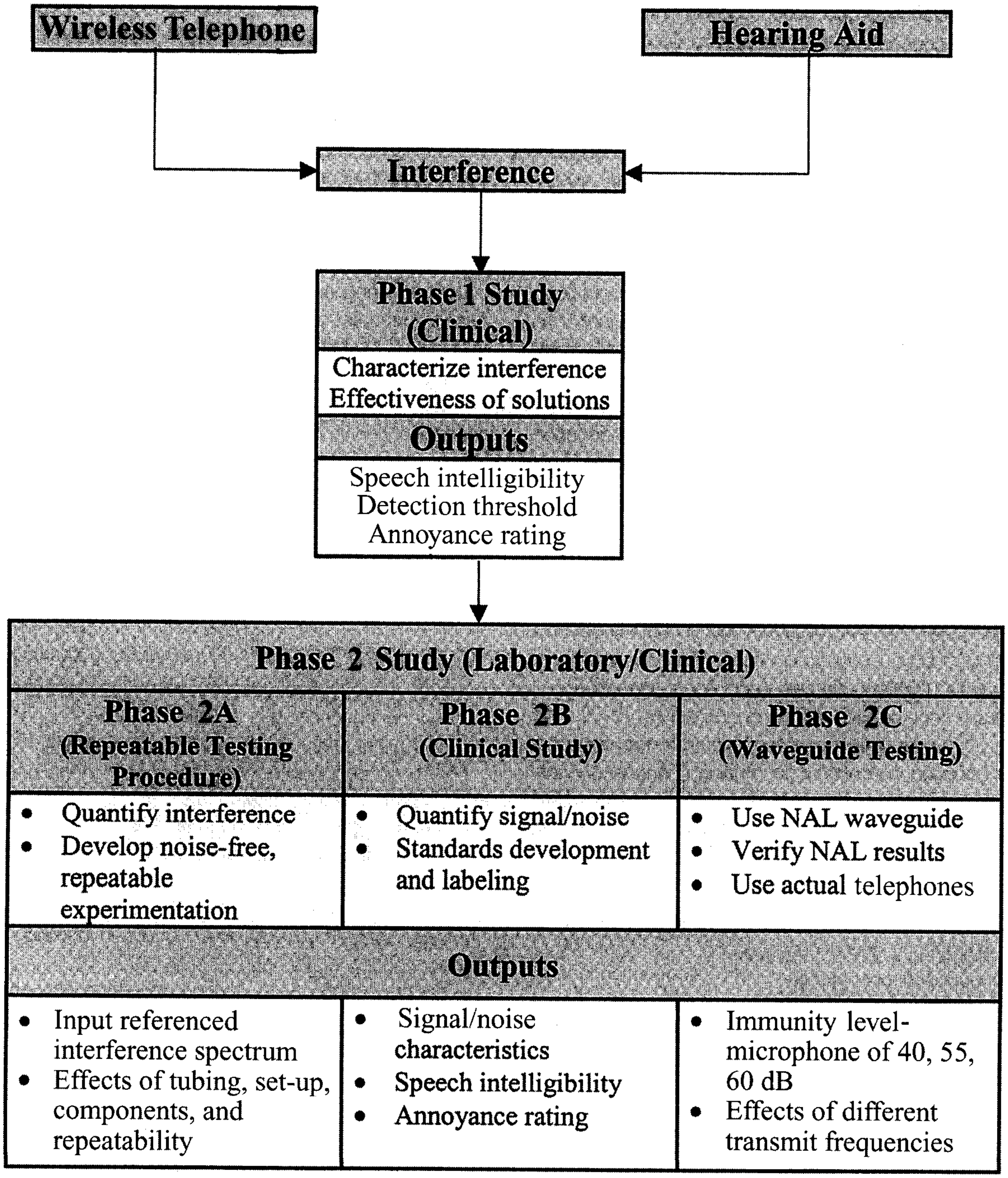

Figure 1 Overview of the Oklahoma Hearing Aid EMC Research Program.

these results to directly contrast one telephone technology with another, owing to differences in the frequency bands used and differences in the implementation of these technologies. Hence, the results should be interpreted carefully.

A statistical analysis of the clinical data was performed, and the following general conclusions can be drawn:

1. All three tested telephone technologies interfered in many, but not all, instances with hearing aids with respect to all four interference measures: bystander detection threshold, bystander annoyance ratings (25–300 cm), speech recognition, and annoyance rating at 2 cm.
2. Hearing aid wearers did not report any interference while using analog cellular telephones.
3. Unimpaired hearing participants responded in a very different fashion from hearing aid

users in the speech recognition and annoyance tests. Hence, their use as test subjects may be inappropriate in examining hearing aid interference, developing standards, and evaluating solutions.

4. All test factors generated statistically reliable differences in interference.
5. Bystander interference was less noticeable than expected. More than 80 percent of the tests involving hearing aid users resulted in either no interference or a detection threshold less than 1 meter (3.3 ft). In fact, in 16 percent of the tests, participants reported no interference even when the telephone was at a distance of less than 4 inches (10 cm).
6. Bystander interference was less severe than expected. The average distance at which any annoyance was reported was less than 2 feet. Only 2 percent of the tests at 1 meter (3.3 ft) and 12 percent of the tests at half a meter (1.6 ft) resulted in annoyance levels classified as 3 or greater. However, the results varied by hearing aid type, hearing loss configuration, and telephone technology.
7. User interference was evidenced by lower speech recognition scores for all three tested telephone technologies in their maximum interference configuration. Speech recognition changes varied by hearing aid type, hearing loss configuration, and telephone technology.
8. Among hearing aid types, BTE users experienced the most interference, whereas ITC users experienced the least interference. It is possible that the higher gain settings of the BTE units made the interference louder and, hence, more annoying. Surprisingly, the CIC aid produced a higher degree of interference than expected. This phenomenon has also been noted in other studies and requires further examination. Among hearing loss configurations, ski slope hearing loss participants experienced the least interference from RF signals. The perception of interference increased with an increase in hearing loss severity.
9. Shielding the BTE hearing aids with a metallic coating effectively reduced bystander interference at all distances. Placing a copper shield between the telephone antenna and the hearing aid reduced interference, but the technical feasibility and manufacturability of any shielding and its impact on telephone and system performance have not been evaluated.
10. In addition to the individual factors, the following interaction (combination) effects were also statistically significant: (a) telephone technology and hearing aid type and (b) hearing loss configuration and hearing aid type. For example, participants with BTE hearing aids noticed comparatively greater interference from J-STD-007 telephone signals. Similarly, CIC users reported greater than expected interference from IS-136 telephone signals.

PHASE 2A: LABORATORY ACOUSTIC MEASUREMENTS IN SOUND CHAMBER

Phase 2A was formulated to compare the magnitude and pattern of interference as a function of hearing aid type including gain type, phone technology including repetition rate, separation distance, and the relative alignment and orientation of the hearing aid and the telephone. The equipment used in the phase 2 testing is illustrated in Figure 2. To ensure the RF immunity of the test equipment, including the microphones and the sound analyzers, and to avoid disturbance of the RF field, the acoustic coupler is separated from the hearing aid by Tygon® tubing (Norton Performance Plastics, Akron, Ohio). An input referenced interference spectrum (IRIS) approach was developed at the Oklahoma EMC Center to examine differences between the telephone technologies while eliminating differences owing to differing hearing aid features and settings (Fig. 3). This approach examines the entire spectrum of interference and generates an equivalent acoustic input to represent the interference generated by a specific telephone technology. Additional details are given in Schlegel and Grant (2000).

Phase 2A Results

Three basic IRIS patterns were identified for the three wireless telephone technologies. These patterns were determined to be consistent across a variety of hearing aids and gain settings. In other words, the TDMA-50 Hz telephone produced the same pattern of interference independent of the hearing aid being used. The level of interference was sensitive to separation distance and very sensitive to small changes in relative alignment and orientation of the hearing aid and telephone.

Much of the Phase 2A work is driven by involvement in the ANSI ASC C63.19 standards

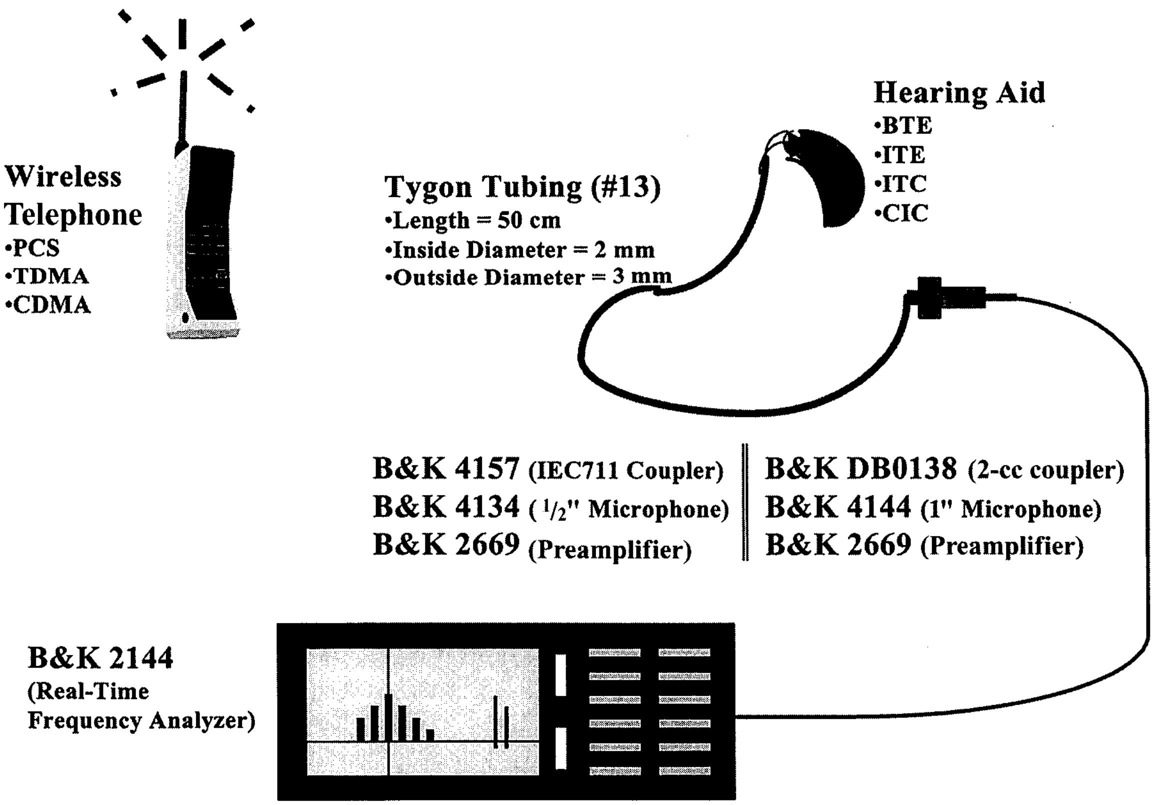

Figure 2 Equipment for acoustic measurements of hearing aid interference.

working group. As testing progressed, valuable information was being learned with respect to test equipment selection and configuration, test procedures, and measurement repeatability (reliability).

PHASE 2B: CLINICAL DETERMINATION OF THE SPEECH-TO-INTERFERENCE RATIO

Phase 2B was a clinical study involving 24 hearing aid wearers to determine the range of speech-to-interference ratios (signal-to-noise ratios in dB) that allow effective use of digital telephones by hearing aid wearers. Measurements of speech recognition and annoyance were made with five different levels of the IRIS signal for each telephone technology mixed with speech at 65 dB. Overall sound pressure level, A-weighted sound pressure level, and the articulation index associated with each mixed sound source have been determined to identify the single measure that best represents the impact of the interference, independent of the telephone technology source.

Phase 2B Results

Speech recognition was reduced only slightly for speech-to-interference ratios of 20 to 30 dB SPL but was substantially affected for lower ratios (losses up to 87%). PCS 1900 (J-STD-007) produced greater losses at 0 and –10 dB than did the other technologies. Annoyance ratings appeared to increase linearly with increases in the interference level from 35 dB SPL (rating 0.2) to 75 dB SPL (rating 4.0). The articulation index corresponded best with the obtained scores across the telephone signals and was a good indicator of the effectiveness of speech communication for hearing aid wearers using digital wireless telephones. Additional details are provided in Srinivasan et al (1998) and Schlegel et al (1998).

PHASE 2C: WAVEGUIDE TESTING

A total of 34 hearing aids from various manufacturers were tested in the NAL waveguide (Le Strange et al, 1995) with both a 900-MHz RF carrier that was 80 percent amplitude modulated and a TDMA-50 Hz (IS-136) telephone. Using the

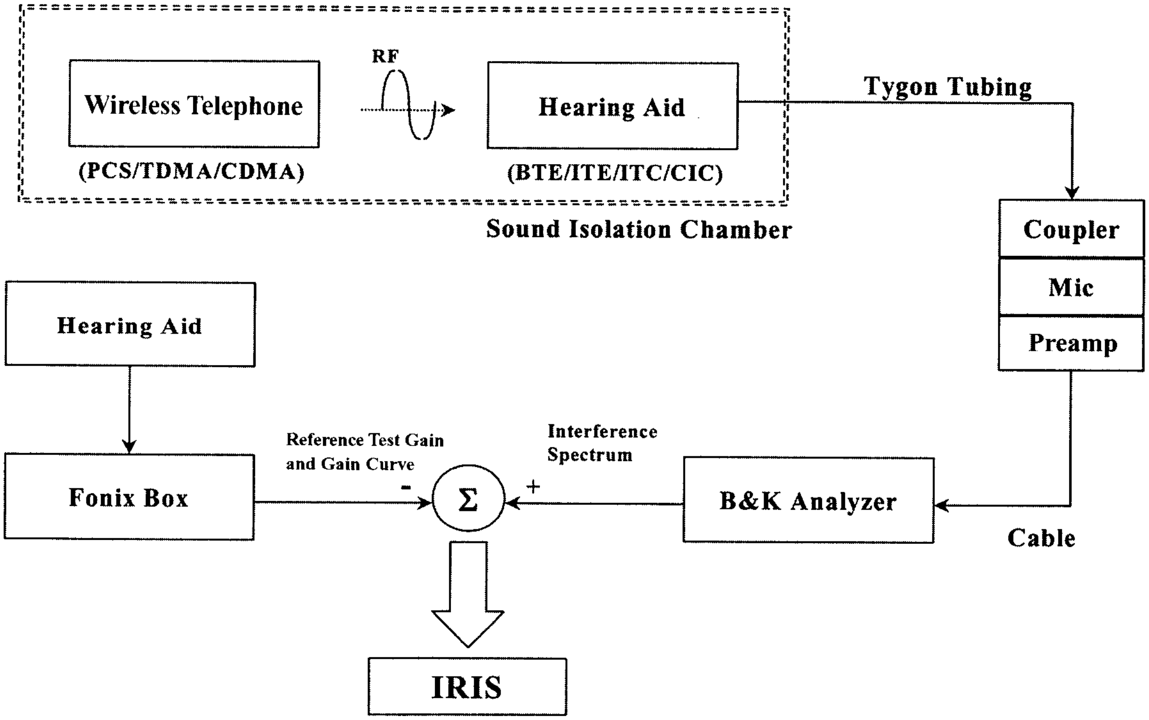

Figure 3 Determination of the input referenced interference spectrum.

acoustic measurement equipment illustrated in Figure 2, the input referenced interference level (IRIL) was plotted as a function of RF field strength and alignment of the hearing aid in the RF field. Full 360-degree rotation on three orthogonal axes was made possible by a gimbals mechanism designed by NAL.

Phase 2C Results

The phase 2C results confirmed those reported by the NAL (Le Strange et al, 1995) with respect to the shape of the curve depicting interference magnitude as a function of the RF field strength and with respect to the square-law detection property, which states that a 1-dB increase in field strength results in a 2-dB increase in the IRIL. Hearing aid immunity was scored by determining the field strength required to produce an acoustic (microphone) IRIL of 40 dB SPL (immunity-level microphone of 40 dB). A broad range of immunity to the RF signals was found across the different aids, with some aids yielding good immunity and others exhibiting very poor immunity. One hearing aid that demonstrated good immunity to the RF signal had a microphone with built-in RF filtering.

Phase 2C also verified the importance of identifying the factors that affect measurement variability (repeatability), determining the criticality of orientation, confirming the use of the proper test measures and their value in achieving successful compatibility, and developing solid, scientifically based test procedures using the proper equipment.

RESEARCH PROGRAM SUMMARY

Results of the phase 1 clinical study suggested that bystander interference is not a serious issue. Although there is the potential for some bystander interference, research should focus on telephone user interference. The phase 2A acoustic measurements provided valuable information for establishing standardized methods of measurement as set forth in the ANSI ASC C63.19 standard, whereas the phase 2B study of speech-to-interference ratios provided input on the required performance criteria for telephone emissions and hearing aid immunity included in the standard. Finally, the phase 2C waveguide testing confirmed the NAL results with respect to the square-law detection property and the shape of the response curve of interference magnitude as a function of RF field strength. Updates on the progress of the current research can be accessed through the EMC Center's Web site at http://www.ou.edu/engineering/emc.

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