Determining Hearing Aid - Wireless Phone EMC

The work of a recent study represents a major contribution to the efforts of ANSI Accredited Standards Committee C63.19 on performance criteria for phone emissions and hearing aid immunity.

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BACKGROUND

Last year ITEM *Update* reported the results of the University of Oklahoma EMC Center's Clinical Study of electromagnetic interference to hearing aids from wireless phones.[1] That study quantified the existence and severity of the interfering buzz or static from PCS 1900 (J-STD-007), TDMA 800 MHz (IS-54), and CDMA 800 MHz (IS-95) phones. In addition, the results confirmed that bystander interference to a hearing aid wearer was of less concern than user interference and that research efforts should be directed toward the effective use of the wireless digital phone by a hearing aid user.[2]

This article provides an update of the Center's continuing program of research to determine the potential for interaction between wireless phones and hearing aids, to evaluate the effectiveness of proposed solutions to mitigate negative interactions, and to develop test methods and criteria leading to EMC design standards for hearing aids and digital wireless devices.

The second phase of the research program, conducted during the past year, has provided results in three areas:

- Acoustic measurements of hearing aids within a sound-isolation chamber
- Clinical determination of a speech-to-interference ratio that will permit effective use of digital phones by hearing aid wearers
- Measurement of the RF immunity of a variety of hearing aids in a waveguide

All of the Phase II work forms a major contribution to the efforts of the ANSI Accredited Standards Committee C63.19 (chaired by Stephen Berger of Siemens Rolm and Tom Victorian of Starkey Laboratories) to develop standards for methods of measurement and performance criteria for phone emissions and hearing aid immunity.

WIRELESS PHONE TECHNOLOGY

The nature and cause of hearing aid interference have been extensively investigated. The pulsing characteristics of the digital phone RF carrier, when picked up by the wiring in the hearing aid (usually at the microphone) and detected in the first amplifier stage, produce a pulsed waveform with numerous components in the audible frequency range. The following factors have been confirmed to affect the level of electromagnetic interference (EMI):

- Format of the wireless device signal
- Type of hearing aid
- Specific features of the aid
- Effectiveness of EMI shielding and circuit modifications
- Hearing loss characteristics of the user
- Separation between the phone and the hearing aid
- Relative orientation of the phone and aid
- Ipsilateral versus contralateral use

Early reports of interference in Europe, Australia and other countries confirmed the existence of an annoying "buzz" in some hearing aids exposed to digital phones in the Global System for Mobile communications (GSM; TDMA at 217 Hz), but did not examine other phone technologies.[3,4] Wireless phone technologies can be most easily identified by three distinguishing characteristics:

- The carrier frequency at which the phone operates
- Whether the phone uses an analog or digital format for the voice channel
- 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 (NADC) phone transmits in the range of 824 to 849 MHz and the Personal Communication Services (PCS) phone transmits between 1850 and 1910 MHz. Analog (AMPS) systems using Frequency Division Multiple Access (FDMA) 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 the pulsed (digital) signal at one of a number of possible repetition rates, such as TDMA-50 Hz (IS-136) or TDMA-217 Hz (J-STD-007, known as PCS 1900 in the United States, GSM at 900 MHz, and DCS at 1800 MHz in other parts of the world). Code Division Multiple Access (CDMA) systems employ a spread-spectrum type of technology governed by IS-95 and J-STD-008. The repetition rate and structure of each technology determine the nature of the interfering noise.

PHASE II-A: LABORATORY ACOUSTIC MEASUREMENTS IN A SOUND CHAMBER

Phase II-A involved the development and evaluation of a repeatable test method for characterizing the audible interference. It also afforded the opportunity to compare the magnitude and pattern of interference as a function of hearing aid type, phone technology, separation distance, and the relative alignment and orientation of the hearing aid and the phone. Testing was conducted to determine the repeatability of the measurements as a contribution to the ANSI ASC C63.19 standards working group.

The acoustic test equipment used for the measurements included an acoustic sound-isolation chamber, B&K couplers, microphones, pre-amplifiers and a real-time acoustic spectrum analyzer. Actual phones representing the three basic digital signal formats described above were used in all tests. To ensure the RF immunity of the test equipment, including the microphones and the sound analyzer, and to avoid disturbance of the RF field, the acoustic coupler was separated from the hearing aid by Tygon® tubing.

An input referenced interference spectrum (IRIS) approach was developed at the Oklahoma EMC Center to examine differences between phone technologies while eliminating differences due to hearing aid features and settings. This approach examines the entire spectrum of interference and generates an equivalent acoustic input to represent the interference generated by a specific phone technology.

PHASE II-A RESULTS

Three basic IRIS patterns were identified for the three wireless phone technologies. These patterns were determined to be consistent across a variety of hearing aids and gain settings. In other words, the TDMA-50 Hz phone produced the same pattern of interference at the input to the first amplifier stage independent of the hearing aid being used. The level of interference was sensitive to the separation distance between the hearing aid and the phone (4, 16, and 60 cm), and very sensitive to small changes in relative alignment and rotation of the phone about two orthogonal axes.

Repeatability tests indicated that the interference measurement did not change appreciably as a function of measurement settling time, time of day, repeated phone removal and placement in the test fixture, repeated hearing aid removal and placement in the test fixture, and system calibration.

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

Phase II-B, a clinical study of 24 hearing aid wearers, was designed to determine the range of speech-to-interference ratios (signal-to-noise ratios in dB) that allow the effective use of digital phones by hearing aid wearers. Measurements of speech recognition (words identified correctly from a standard audio-taped NU-6 monosyllabic word list) and annoyance (quantified on a 0 - 5 scale; 0 indicating no interference; 5 indicating unbearable interference) were made with five different levels of the IRIS signal for each phone technology, mixed with speech at 65 dB sound pressure level (SPL).

The five interference levels resulted in speech-to-noise ratios of 30, 20, 10, 0 and -10 dB SPL. Annoyance ratings were obtained at the beginning and end of each complete test session as well as following each individual test during the session.

All testing was conducted at the Hough Ear Institute in Oklahoma City using an audiometric booth and Beltone 2000 audiometer. Overall SPL, A-weighted SPL, C-weighted SPL, Speech Interference Level (SIL), and the Articulation Index (AI) associated with each mixed sound source were determined in order to identify the single measure that best represents the impact of the interference on speech recognition, independent of the phone technology source.

PHASE II-B RESULTS

In general, there was only a slight decline in speech recognition (6.5% of the "no interference" baseline) for speech-to-noise ratios of 30 or 20 dB SPL and the pattern was similar for CDMA, TDMA-50 Hz, and TDMA-217 Hz. At lower speech-to-noise ratios, speech recognition dropped substantially (up to an 87% loss with respect to baseline). Due to the higher 217-Hz repetition rate which produces larger harmonics in the audible speech frequencies, the PCS 1900 phone signal produced a greater loss in intelligibility at 0 and -10 dB SPL compared with the CDMA and TDMA-50 Hz signals at those same speech-to-noise ratios.

Annoyance ratings obtained before, during and after the test session appeared to increase linearly with an increase in the interference level from 35 dB SPL (average rating of 0.2) through 75 dB SPL (average rating of 4.0) in 10 dB steps. Ratings collected prior to the speech recognition test session were lower than those collected after the session, which in turn were lower than those collected at the end of each test during the session.

Of the various sound spectrum weighting schemes used to provide a single numerical representation of the different interference signals, the Articulation Index (AI) yielded the highest correspondence to the speech recognition scores across all three phone signals. Based on this result, it is believed that the AI is a good indicator of the effectiveness of speech communication for a hearing aid wearer using a digital wireless phone and that the AI can be applied to the evaluation of future digital signal formats in addition to its use for current schemes. It is likely that some form of the AI will be incorporated into the ANSI ASC C63.19 standard.

PHASE II-C: WAVEGUIDE TESTING

A total of 34 hearing aids from various manufacturers were tested in a 900-MHz waveguide on loan from the National Acoustic Laboratories of Australia (NAL).[5] Tests were conducted with both a 900-MHz RF carrier that was 80% amplitude modulated with a 1-kHz sine wave and a TDMA-50 Hz (IS-136) phone. Using the acoustic measurement equipment described in Phase II-A above, 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° rotation on three orthogonal axes was made possible by a gimbals mechanism designed by NAL.

PHASE II-C RESULTS

The Phase II-C results confirmed those reported by the NAL 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 (ILM40 - Immunity Level Microphone 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 II-C 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
- Developing solid, scientifically-based test procedures using the proper equipment

RESEARCH PROGRAM SUMMARY

Results of the Phase I clinical study suggested that bystander interference is not a serious issue. Although there is the potential for some bystander interference, research should focus on phone user interference.

The Phase II-A acoustic measurements provided valuable information for establishing standardized methods of measurement as set forth in the proposed ANSI ASC C63.19 standard, while the Phase II-B study of speech-to-interference ratios has provided input on the required performance criteria for phone emissions and hearing aid immunity included in the ANSI standard.

Finally, the Phase II-C 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 as well as information on detailed reports for each study can be accessed through the EMC Center's Website at: http://www.ou.edu/engineering/emc

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REFERENCES

1. A. Ravindran, R.E. Schlegel, H. Grant, P. Matthews, and P. Scates, "EMI to Hearing Aids from Wireless Phones," *ITEM Update 1996*, 1996, pp. 44-45.
2. A. Ravindran, R.E. Schlegel, H. Grant, P. Matthews, and P. Scates, "Study Measures Interference to Hearing Aids from Digital Phones," *The Hearing Journal, 50*, 1997, pp. 32-34.
3. European Hearing Instrument Manufacturers Association (EHIMA), "Hearing Aids and GSM Mobile Telephones: Interference Problems, Methods of Measurement, and Levels of Immunity," EHIMA GSM Project Final Report 1995-11-01, Delta Acoustics & Vibration and Telecom Denmark, 1995.
4. European Telecommunications Standards Institute (ETSI), "GSM EMC Considerations," ETSI Technical Report GSM 05.90, Valbonne Cedex, France, 1993.
5. J.R. Le Strange, D. Byrne, K.H. Joyner, and G.L. Symons, "Interference to Hearing Aids by the Digital Mobile Telephone System, Global System for Mobile Communications (GSM)," NAL Report No. 131, Chatswood, New South Wales, Australia, National Acoustic Laboratories, Australian Hearing Services, 1995.

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CONCLUSION

The key to filter selection is to compare apples with apples. If the filter exhibits good response in the 50-ohm environment, the filter will perform in a 50-ohm environment, but the filter response will definitely be changed in a different environment. There are several ways to check if the filter is suitable. One way is to check values via transfer function. Another way is to simulate filter response in a given environment. It is important to understand the environment and filter requirements in order to make an effective filter selection.

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