Hearing Aid Electromagnetic Interference from Digital Wireless Telephones

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***Abstract*—Several in-the-ear (ITE) and behind-the-ear (BTE) hearing aids were tested for audible interference at various distances from five types of digital wireless telephones. The interference which takes the form of a buzzing and a static sound was quantified using a calibrated system including a frequency analyzer and a pressure field microphone. The output of the each hearing aid was coupled to the microphone via Tygon tubing and a standard 2 cc coupler. The highest interference-induced sound pressure level (SPL), 122.5 dB, was measured from a BTE hearing aid placed within 2 cm of a transmitting Global System for Mobile Communications (GSM) phone. In this case, interference was detected up to a separation distance of almost 3 m. While all phones tested produced a similar interference level within 2 cm of this hearing aid, interference SPL from the code division multiple access (CDMA)-based system decreased more rapidly with distance than the time division multiple access (TDMA)-based phones tested.**

***Index Terms*—Electromagnetic interference, hearing aid, wireless telephones.**

I. Introduction

A NUMBER of studies have reported that electromagnetic interference (EMI) from Global System for Mobile Communications (GSM) digital cellular telephones disrupt the proper operation of hearing aids [1]–[4]. In the United States, EMI from the various digital wireless telephones as well as the new GSM-based Personal Communication Services (PCS) is a concern. The main source of the interference in time division multiple access (TDMA) technologies, of which GSM and PCS-1900 are a subset, is considered to be the pulsed nature of the signal (the pulse repetition rate). The frequency with which each pulse occurs is in the audible range. This fundamental frequency along with its harmonics is perceived as interference. In code division multiple access (CDMA), which is a spread-spectrum system, interference may result due to the voice encoder/decoder (vocoder) as well as automatic adjustments in output power levels made to accommodate varying distance to the nearest base station (such as when traveling in an automobile). The interference may preclude the hearing aid wearer from using new digital communications technologies and may produce annoying and potentially harmful induced sound pressure levels. The purpose of this study was to evaluate the interaction of various digital wireless telephone technologies with several types of hearing aids and to develop a standard test method.

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TABLE I
TYPES OF HEARING AIDS TESTED

Hearing Aid	Type
A	BTE, Output Compression
B	BTE, Peak Clipper
C	BTE, Input Compression
D	ITE, Linear Peak Clipper, Class D
E	ITE, Linear Peak Clipper, High Frequency
F	ITE, Peak Clipper, Push-Pull
G	BTE, Output Compression
H	ITE, Linear Peak Clipper, Class D

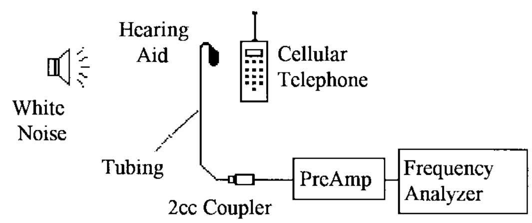

Fig. 1. Test configuration.

II. Methods

Eight hearing aids [four behind-the-ear (BTE) and four in-the-ear (ITE)] were evaluated for electromagnetic interference from five different types of digital wireless telephones. The hearing aids tested are listed in Table I in terms of style and amplifier type and are a reasonable representation of the BTE and ITE hearing aids currently on the market. Sound pressure level (SPL) and frequency spectrum measurements were made using a Bruel and Kjaer (B&K) Type 2144 Frequency Analyzer coupled to the hearing aid via a 0.75-m piece of Tygon tubing (3 mm O.D.), B&K DB 0138 2 cc Coupler, B&K 1-in Pressure Field Microphone Type 4144, and B&K Preamplifier Type 2639T (Fig. 1). The system was calibrated using a B&K Type 4220 Pistonphone. Prior to testing, the immunity of the test equipment to each of the transmitting wireless telephones was verified.

The volume control on each hearing aid was set for maximum gain to demonstrate a worst-case interference scenario and each aid was tested in both microphone (M) and telephone (T) coil mode where applicable. The T-coil allows the hearing aid user to amplify only signals transmitted via the telephone

[5]. Magnetic fields produced by the telephone are received by the T-coil, amplified and converted to a corresponding acoustic signal. This mode of operation bypasses the microphone and results in amplification of the intended signal, thus eliminating background noise and acoustic feedback. Interference-induced SPL's in decibels (dB) (referenced to 20 μPa) were recorded at various separation distances between the hearing aid and wireless phone with and without a background white noise source. White noise was not used when testing in T-coil mode. An approximately 70 dB white noise acoustic signal was applied in order to bias the hearing aid as well as to approximate speech. A simple white noise generator was used to produce the signal. Its speaker was placed at fixed location in order to maintain 70 dB at the hearing aid. Application of a biasing signal is also important in order to assess the effect of the interference on the performance (i.e., gain) of the hearing aid. Separation between the phone and hearing aid was defined as the distance between the outermost surface of the hearing aid and the ear piece of the wireless phone. The smallest separation distance tested was approximately 2 cm, the next was 20 cm, and then every 20 cm, thereafter. No part of the phone was allowed to come into physical contact with the hearing aid during testing. The phones were oriented in a position of function (45° off the vertical axis) relative to the hearing aids which approximates typical use of the phone. Ambient SPL's without a transmitting wireless phone were also recorded.

The five digital wireless telephones employed in testing were Global System for Mobile Communications (GSM) at 0.6 W, 902 MHz, 217 Hz frame rate, Personal Communication Services (PCS-1900) at 0.6 W, 1.88 GHz, 217 Hz frame rate (J-STD-007), North American Digital Cellular (NADC) at 0.6 W, 835 MHz, 50 Hz pulse repetition rate (IS-136), time division multiple access at 1.3 W, 814 MHz, 11 Hz frame rate (ITU-R M.[8A/XB]) and code division multiple access (CDMA) at 0.2 W, 847 MHz (IS-95). The CDMA phone was operated in both full and variable vocoder rates during testing. Each phone was operated in test mode and transmitted full power without the need for a base station. All testing was conducted in a radio frequency (RF) anechoic chamber. The acoustic attenuation of the tubing versus frequency was determined using a Phonic Ear HC2000 Hearing Aid Analyzer. Using this system, two frequency response curves were obtain: one curve with the standard 2 cm tubing length in place and one with the tubing length used in testing. The relative attenuation was determined by direct comparison of these two curves.

III. Results

In general, the hearing aids tested produced similar levels of interference in both microphone and telephone coil modes. This section will report on results from the microphone mode testing since hearing aids are typically set to microphone mode when used with wireless telephones. The initial interference level as well as the rate of decrease in measured interference as a function of separation distance varied greatly, depending on the type of phone and hearing aid tested. The variable interaction among the hearing aids tested (A–H) from the same PCS-1900 digital wireless telephone is illustrated in Fig. 2 (without white noise). In general, BTE hearing aids are capable of experiencing higher levels of interference. This corroborates the fact that many BTE hearing aids are capable of higher gain than the ITE aids. The highest interference induced SPL's were measured from hearing aid A, an output compression BTE aid, when placed within 2 cm of the wireless phone. Plots of sound pressure levels versus separation distance for hearing aid A without white noise and each wireless phone tested are given in Fig. 3. As shown, at separation distances of approximately 2 cm, GSM, PCS-1900, NADC, TDMA (11 Hz), and CDMA (variable vocoder rate) telephones produced similar levels of interference (122.5 dB, 121.0 dB, 118.0 dB, 119.3 dB, 122.1 dB respectively). While the CDMA phone in the variable rate vocoder (listed as "vary" in the figure) produced a similar SPL at a separation of 2 cm, the SPL versus distance drop-off rate was two to three times more rapid (Fig. 3). The CDMA phone in full rate vocoder produced an SPL of 94.3 dB. At acoustic frequencies above approximately 500 Hz, attenuation of the tubing was found to be significant (~10 dB).

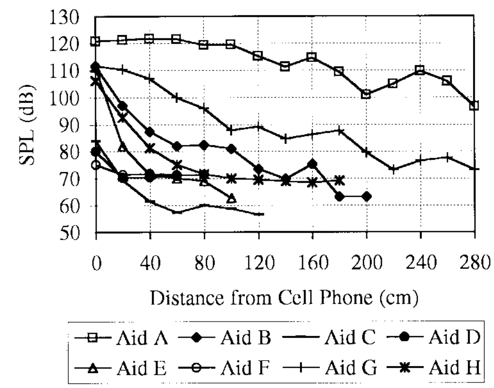

Fig. 2. Hearing aid EMI from a PCS-1900 digital wireless telephone.

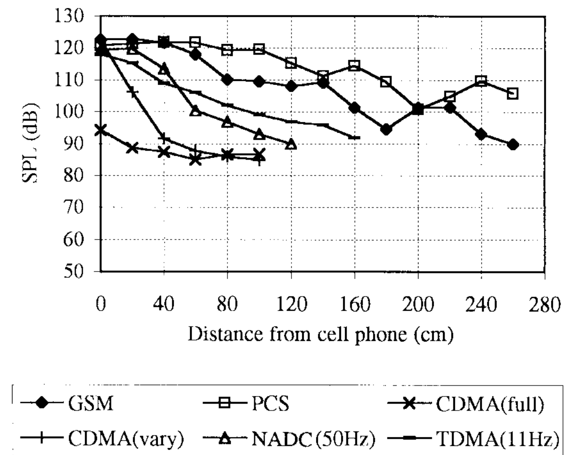

Fig. 3. Hearing aid A EMI.

The output spectra of hearing aid A when exposed to the various digital wireless phones are given in Figs. 5–10. In each case, 70 dB white noise was provided as a biasing signal to the hearing aid. The response of the hearing aid to the white noise is shown in Fig. 4. The hearing aid output spectra

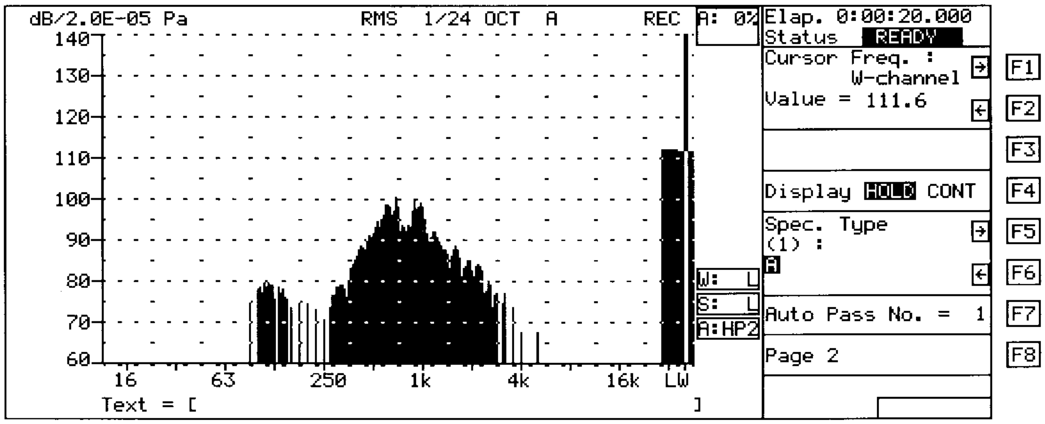

Fig. 4. White noise through hearing aid A.

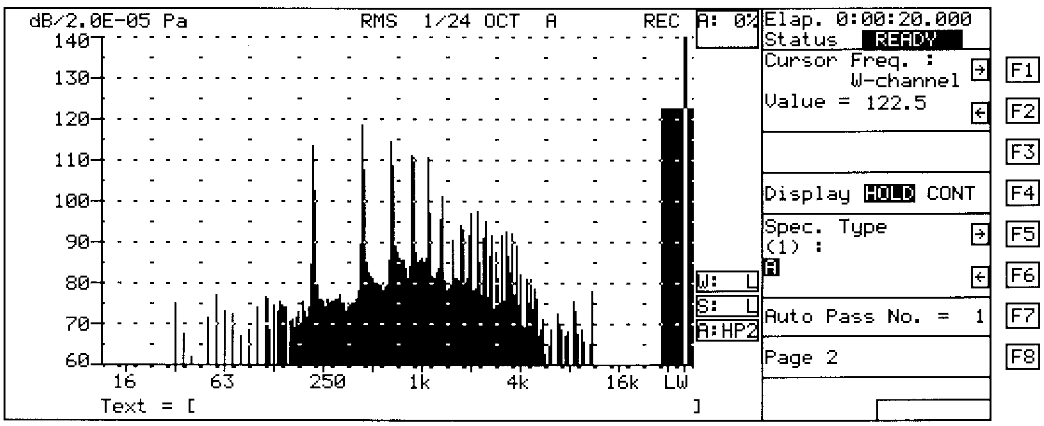

Fig. 5. Hearing aid A and GSM digital cellular telephone.

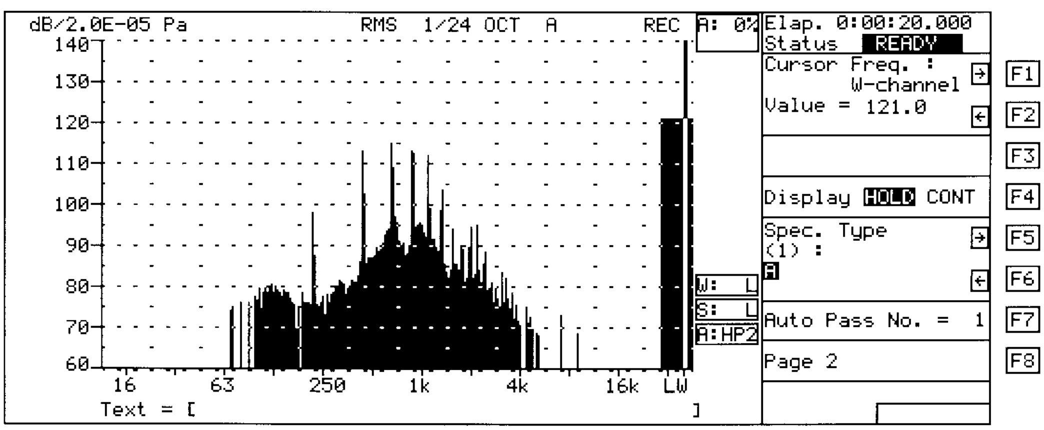

Fig. 6. Hearing aid A and PCS-1900 digital wireless telephone.

(Figs. 5 and 6) from the GSM and the PCS-1900 phones each show a peak at the 217 Hz modulation frequency as well as peaks at the subsequent harmonic frequencies. Similarly, the spectrum from exposure to the NADC cell phone show peaks at the modulation frequency and at its harmonics (Fig. 7). The hearing aid response to the 11 Hz TDMA cellular phone shows a few discrete peaks at the lower frequency range (Fig. 8), but these are not significantly higher than the overall envelope. The spectral response of the hearing aid exposed to the CDMA phone in variable rate vocoder is broad band with no discrete peaks and approximately 10 dB above the input white noise (Fig. 9). In full rate vocoder, the response to the CDMA phone is practically indistinguishable from the input white noise response (Fig. 10).

In addition to the peaks associated with the digital wireless modulation, an apparent decrease in hearing aid gain was also observed in response to wireless phone exposure. In some cases, the digital wireless phone emissions had an adverse

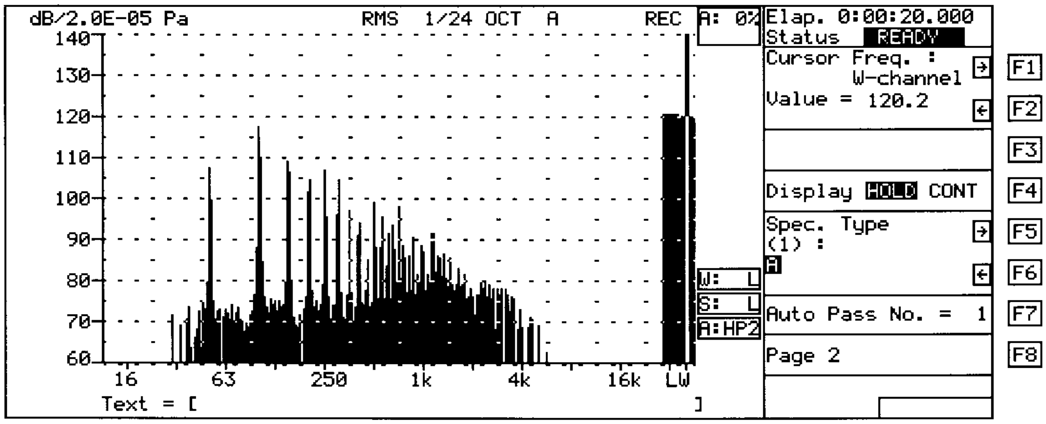

Fig. 7. Hearing aid A and NADC digital cellular telephone.

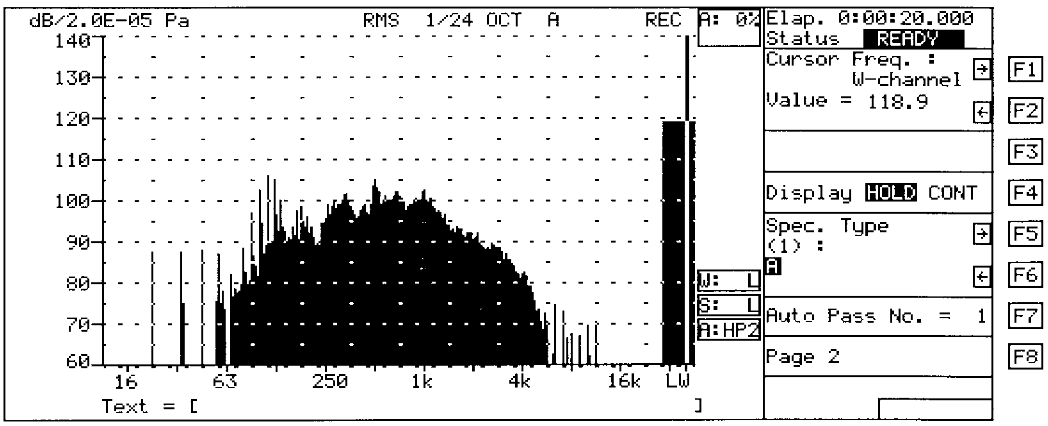

Fig. 8. Hearing aid A and 11 Hz TDMA digital cellular telephone.

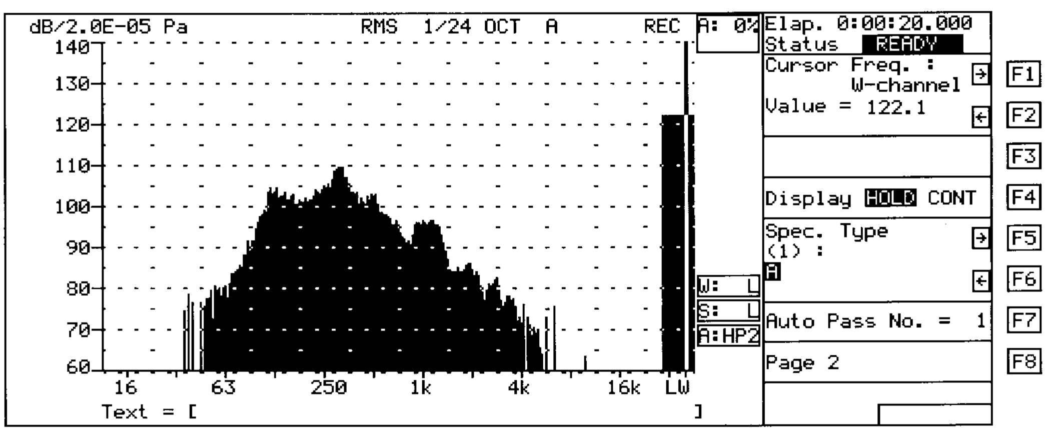

Fig. 9. Hearing aid A and variable rate CDMA digital cellular telephone.

affect on the hearing aid's ability to amplify the intended input signal in addition to superimposing an audible buzz. For example, the output spectrum of GSM exposure shows approximately a 12 dB overall decrease in the white noise signal. A similar effect is observed in NADC exposure. In the case of PCS-1900 exposure, no significant effect on the white noise was found. Since the effect of 11 Hz TDMA and CDMA exposure is similar to the white noise itself, the effect on hearing aid gain, if any, is difficult to determine.

IV. Discussion

Spectral analysis of the interference from the TDMA-based technologies revealed discrete peaks in the frequency domain. These peaks correspond to the TDMA pulse repetition rate and its harmonics. The type of interference produced by these technologies may be described as a buzzing sound. In the case of CDMA, analysis in the frequency domain revealed a broad band response resembling white noise. This was also corrobo-

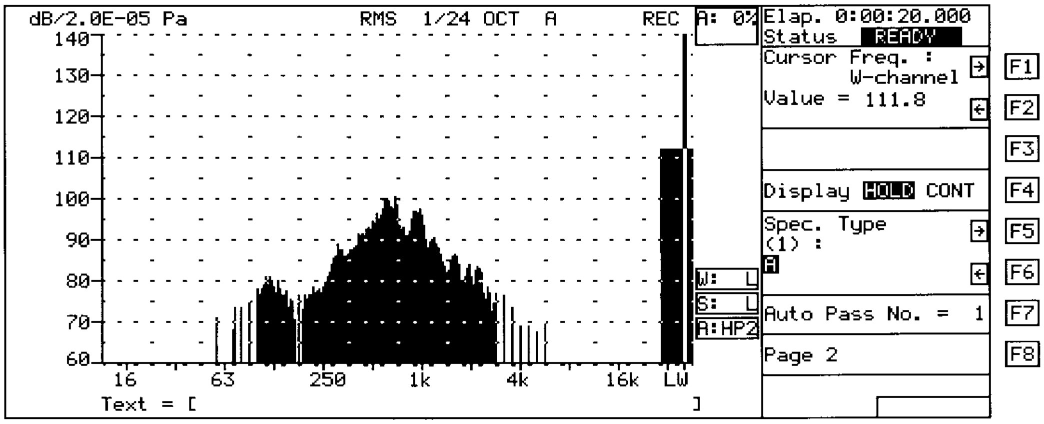

Fig. 10. Hearing aid A and full rate CDMA digital cellular telephone.

rated in subjective testing where the interference was noted to sound more like static than a distinct buzz. In no case, did the measured interference level exceed the maximum SPL output rating of the hearing aid. Further work will include testing with the hearing aids set to a gain level representative of typical use. In order to determine absolute interference levels, a tubing attenuation factor must be included. However, for the purpose of comparing the effects of various types of digital wireless telephones on one hearing aid or worst case relative effects on several hearing aids, this factor may be ignored. The presence of the user's head when the hearing aid is in actual use may result in attenuation of the induced interference. It is important to note that the interference induced sound pressure level is strongly dependent on the relative orientation of the hearing aid with respect to the wireless phone. In this study, the plane of the hearing aid was maintained parallel with that of the wireless phone. Studies using other orientations may yield different results. In addition to the audible buzz or static, an apparent reduction in hearing aid gain was observed. This effect is an interference phenomenon and one that is often overlooked. The results from this study illustrate the need for an acoustic biasing input signal so that a reduction in gain may be evaluated.

The data presented thus far as well as testing methods prescribed by and currently under development by standards organizations all involve in-air type testing. In actual use, the hearing aid user's head is also in the presence of the wireless phone and thereby perturb the fields. The presence of the head may attenuate the fields resulting in a reduction in interference experienced by the hearing aid. *In-situ* testing with human subjects is necessary to determine the potential effect of the head on measured interference induced sound pressure levels in the vicinity of wireless wireless telephones.

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