Interference to Hearing Aids by Digital Mobile Telephones Operating in the 1800 MHz Band.

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Executive Summary

The Australian Mobile Telecommunications Association contracted the National Acoustic Laboratories to characterise the interactions between digital mobile telephones and hearing aids for the Global System for Mobile Communications (GSM) network operating in the 1800 megahertz (MHz) band.

The waveguide test system designed to operate between 800 and 1000 MHz was successfully converted using a transition horn to operate in the 1700 to 2000 MHz radio band and was used to test the immunity of hearing aids to radio frequencies in the 1800 MHz radio band. The project was delayed because the waveguide system did not initially perform adequately at these high frequencies. The problem was resolved, the system was calibrated and controlling software completed. Measurements were carried out at 1750 MHz unless otherwise stated.

Subjective levels of interference produced in hearing aids placed near a GSM digital mobile telephone was tested under various conditions. The GSM digital mobile telephone was programmed to transmit close to 1750 MHz (1749.8 MHz). Also the transmit power level was adjusted and distance between the mobile and hearing aid varied according the test requirements.

A two part program was used in this research. The initial preliminary research program was used to scope out the project and the final study involving hearing aid users provided information about the variable effects of interference on different people.

With the 1750 MHz GSM digital mobile telephone operating at full transmit power the initial preliminary study indicated that a hearing aid in microphone setting would require a high level of immunity to the transmitted radio signals for satisfactory communication by a hearing aid user.

Also the preliminary study indicated that the hearing aid with a medium level of immunity to radiofrequency interference provided protection against bystander interference at a distance of one metre from a 1750 MHz GSM digital mobile telephone operating at maximum transmit power. In addition a hearing aid with low immunity to radio signals could be affected by interference at distances over two metres from the GSM mobile telephone.

In the initial study the spectral analysis of the audible interference produced in hearing aids in microphone setting by a GSM 1750 MHz digital mobile telephone showed that both odd and even harmonics of the 217 Hz repetition rate of the transmitted GSM signal were present and spread across the audio band of the hearing aid.

The outcomes of the final study were based on the observations of nineteen people using hearing aids and allowed the observations of the preliminary study to be confirmed and quantised as well as extending the findings for telecoil operation.

With the 1750 MHz GSM digital mobile telephone operating at full transmit power the final study confirmed that a hearing aid in microphone setting would require a

high level of immunity to the transmitted radio signals for satisfactory communication by a hearing aid user and recommends that the radiofrequency ILM55 immunity level should be greater than 40.4 dB re 1 V/m. It is also recommended that a test field strength of 105 V/m (i.e. 40.4 dB re 1 V/m) be used in the C2 Classification of Australian Standard AS1088.9 [2] for frequency range 1700 to 2000 MHz.

When the hearing aid was in telecoil setting, the base band interference caused by the telecoil picking up the unwanted audio frequency magnetic field about the test mobile caused high levels of interference in the hearing aid when it was in close proximity to the GSM test mobile telephone. This resulted in hearing aids with high levels of immunity to radiofrequency signals in telecoil setting not being able to be used for communication purposes by hearing aid users.

The final study confirmed that the hearing aid with a medium level of immunity to radiofrequency interference provided protection against bystander interference at a distance of one metre from a 1750 MHz GSM digital mobile telephone operating at maximum transmit power. This applied when the hearing aid was in either the microphone or telecoil setting. The corresponding radiofrequency immunity levels for both microphone (ILM55) and telecoil (ILT25) operation should be between 14 and 17 dB re 1 V/m. This result confirms the test field strength level of 7 V/m (i.e. 16.9 dB re 1 V/m) that is used in the C1 Classification of Australian Standard AS 1088.9 [2] for frequency range 1700 to 2000 MHz.

In microphone setting the hearing aids used in the final study produced a variation in the limit of interference from a point where they were touching the GSM test mobile to a distance of 4530 mm as reported by the hearing aid users. All of the hearing aids with a medium or better immunity to radiofrequency signals had a limit of interference between 0 and 35 mm as reported by the hearing aid users.

In telecoil setting the limit of interference ranged between 75 and 5000 mm. For those hearing aids with a medium or better level of immunity to radiofrequency signals the limit of interference was reported by the hearing aid users to be between 75 and 370 mm. At closer distances to the test mobile telephone the interference was at a louder level due to the base band interference resulting from the unwanted audio magnetic fields about the mobile telephone.

As a general comment the hearing aids currently available that were used in this study generally had a greater immunity to radiofrequency interference than those models generally available a decade or more ago. However, base band interference excluded use of telecoil mode for hearing aid users of GSM 1750 MHz digital mobile telephones.

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1 Introduction

The Australian Mobile Telecommunications Association contracted the National Acoustic Laboratories to characterise the interactions between digital mobile telephones and hearing aids for the Global System for Mobile Communications (GSM) network operating in the 1800 megahertz (MHz) band.

A waveguide test apparatus was used to test the immunity of hearing aids to radio frequencies in the 1800 MHz radio band. The project was delayed because the waveguide system did not initially perform adequately at these high frequencies. The problem was resolved, the system was calibrated and controlling software completed. Measurements were carried out at 1750 MHz unless otherwise stated.

Subjective levels of interference produced in hearing aids placed near a GSM digital mobile telephone was tested under various conditions. The GSM digital mobile telephone was programmed to transmit close to 1750 MHz (1749.8 MHz). Also the transmit power level was adjusted and distance between the mobile and hearing aid varied according the test requirements.

A two part program was used in this research. The initial research program was used to scope out the project and the final study involving hearing aid users provided information about the variable effects of interference on different people.

2 Acknowledgements

The Australian Mobile Telecommunications Association (AMTA) has provided part funding for this project.

Telstra Research Laboratories provided technical support in the design of the transition horn that enabled the waveguide test apparatus to operate at 1750 MHz. and also loaned a Nokia type 5130 GSM test mobile telephone that can be programmed to transmit at 1750 MHz (1749.8 MHz) and various transmit power levels. Note that nominal maximum transmit power level is 1 Watt.

3 Definitions and Criteria

3.1 Immunity Level

The immunity level [1] for a hearing aid has been determined by noting the electric field strength of a radiofrequency test signal that produces a *standard response*.

In microphone setting the *standard response* has been chosen to be an *input referred sound pressure level* of 55 dB SPL. In telecoil setting the *standard response* has been chosen to be an *input referred magnetic field level* of 25 decibel relative to one milliampere per metre (dB re 1mA/m). Both *standard responses* correspond to the immunity limits used in Australian Standard AS/NZS 1088.9:1995 and amendment 1/1996-07-05 [2].

Definition of Immunity Levels

Microphone Input: The *immunity level* (ILM55), is the radiofrequency carrier field strength in decibels relative to one volt per metre (dB re 1 V/m) that produces a response in the hearing aid equivalent to a 1000 Hz *input referred sound pressure* equal to 55 dB SPL, when the radiofrequency carrier is 80% amplitude modulated at 1000 Hz.

Telecoil Input: The *immunity level* (ILT25), is the radiofrequency carrier field strength in decibels relative to one volt per metre (dB re 1 V/m) that produces a response in the hearing aid equivalent to a 1000 Hz *input referred magnetic field strength* equal to 25 dB relative to one milliampere per metre (25 dB re 1 mA/m), when the radiofrequency carrier is 80% amplitude modulated at 1000 Hz.

3.2 Subjective Criteria

Test subjects in this study were asked to rate the perceptibility of any interfering sounds produced in their hearing aids under different test situations setup using a programmable GSM mobile telephone operating at 1750 MHz. Also the test subjects were asked to assess whether they would be able to use the mobile telephone with the level of any audible interference produced during the testing phase. The following "perceptibility" and "useability" scales were used.

Perceptibility of Interference

The "perceptibility" rating system uses five steps:

- *Not Perceptible;*
- *Just Perceptible;*
- *Moderately Perceptible;*
- *Annoying;*
- *Very Annoying.*

Useability Rating

The “useability” rating system uses three steps:

- *Always Useable;*
- *Sometimes Useable;*
- *Not useable.*

4 Program of Work

The program of work has been set up as an initial study and a final study.

Initial Study

The initial study has been broken into five divisions of work:

- Waveguide test apparatus;
- Test subject related information;
- Hearing aid testing;
- Subject testing program; and
- Spectral analysis.

Final Study

The final study has been broken into three divisions of work:

- Test subject related information;
- Hearing aid testing; and
- Subject testing program.

4.1 Initial Study

4.1.1 Waveguide Test Apparatus

Modify existing waveguide test apparatus to operate in the 1800 MHz radiofrequency band.

4.1.2 Test Subject Related Information

For the initial study a volunteer from the National Acoustic Laboratories was used to gauge the level of any interference perceived in hearing aids when exposed to a GSM mobile telephone operating at 1750 MHz.

4.1.3 Hearing Aid Testing

Acoustically test the hearing aids used in this study to confirm that they are operating normally. Also test the hearing aids using a 500 mm length of 2 mm internal diameter plastic tubing to determine the acoustic gain with the same length tubing as the hearing aids will be monitored with in the waveguide test apparatus when exposed to the 1750 MHz transmissions. The hearing aid 1 KHz gain is required to determine the radiofrequency immunity level for the hearing aid in microphone setting.

In microphone setting select three hearing aids typical of a low, medium and high level of radiofrequency immunity.

4.1.4 Subject Testing Program

Using “Stetoclips” (a stethoscope like listening tube), the test subject is to listen to any interference produced in a hearing aid by the test GSM mobile telephone operating at 1750 MHz for each test situation.

Interference at 1 metre

With the mobile telephone operating at maximum power level assess the perceptibility of any interference produced in each of the three hearing aids when placed 1 metre from the mobile telephone.

Limit of interference

With the mobile telephone operating at maximum power level assess the distance between the test mobile and each hearing aid when any unwanted interference is *just perceptible.*

Interference with the hearing aid placed near the base of the antenna

With the mobile telephone operating at maximum power level (setting 0) and mid-power level (setting 7) assess the perceptibility of any interference for each hearing aid place near the base of the mobile telephone antenna. Also assess the expected useability of the mobile with the hearing aid based on the level of any perceived interference.

4.1.5 Spectral Analysis

Place each of the three hearing aids used in the initial study near the base of the digital mobile telephone antenna. Measure the spectral response of the acoustic output for any interference generated in the three hearing aids when exposed to a GSM mobile telephone operating at 1750 MHz. If interference is high then lower the power level and retest. For a low immunity hearing aid measure the spectral response at 1 metre.

4.2 Final Study

4.2.1 Test Subject Related Information

Test subjects for the final study were recruited from a data base of hearing aid users who have consented to participate in research projects conducted by the National Acoustic Laboratories (NAL). An *Information and Consent Form* was posted to prospective test subjects. This form briefly explains the purpose of the study and the right of the test subject to withdraw at any time during the study. Also the form explains that the project has been approved by the Australian Hearing Human Ethics Committee and that privacy of information will be observed. Those that returned the *Consent Form* were contacted by telephone to arrange a mutually convenient time to carry out the research.

If a recent audiogram of the test subject is not available on the National Acoustic Laboratories data base then an audiogram is measured by a NAL research audiologist on the day of the subject testing program. From the audiogram the hearing level at

500, 1000 and 2000 Hertz was averaged to determine the three frequency average hearing level (3FA) for the ear being tested. Also the four frequency average hearing level (4FA) was determined by including 4000 Hertz hearing level.

4.2.2 Hearing Aid Testing

The hearing aid of each client participating in the study is tested as in the initial study in microphone setting and the radiofrequency immunity level (ILM55) in microphone setting is measured. Also the radiofrequency immunity level (ILT25) in telecoil setting is measured.

4.2.3 Subject Testing Program

The test subject is to listen using their own hearing aid to any interference produced by the GSM test mobile telephone operating at 1750 MHz for each test situation. During these tests the hearing aid user will use only one of their hearing aids. Both microphone and telecoil settings for each hearing aid will be tested.

Interference at 1 metre

With the 1750 MHz GSM test mobile telephone operating at maximum power level assess the perceptibility of any interference produced in the hearing aid when the test mobile is placed at a distance of 1 metre. The mobile is positioned on the same side of the head as the test subject's own hearing aid. During this test the front of the mobile faces the hearing aid and the mobile is rotated through 90^0 between a vertical orientation and a horizontal orientation with the mobile antenna pointing in the same direction as the back of the head. This rotational procedure was carries out to allow the worst case detection for interference.

Limit of interference

With the mobile telephone operating at maximum power level assess the distance between the test mobile and hearing aid when any unwanted interference is *just perceptible.* The mobile is positioned on the same side of the head as the test subject's own hearing aid. During this test the front of the mobile faces the hearing aid and the mobile is rotated through 90^0 between a vertical orientation and a horizontal orientation with the mobile antenna pointing in the same direction as the back of the head. This rotational procedure was carries out to allow the worst case detection for interference.

Perceptibility rating and useability rating of interference produced in hearing aids by a 1750 MHz GSM mobile telephone operating at maximum power level and held in normal listening position.

The test mobile telephone will be held in the normal listening position on the same side of the head as the hearing aid. The power level of the 1750 MHz GSM test mobile telephone will be set to maximum (setting 0). The test subject will assess the perceptibility of any interference in the hearing aid. Based on the level of any perceived interference, the test subject will assess the expected useability of the mobile with the hearing aid.

Both microphone and telecoil settings for each hearing aid will be tested.

5 Results

5.1 Initial Study

The results for the initial study follow.

5.1.1 Waveguide Test Apparatus

The result of the modification made to the waveguide test apparatus to allow its operation at frequencies between 1700 and 2000 MHz are shown in Figures 1 and 2. A transition horn at the right hand side of the pictures allows the test signal to be fed into the waveguide apparatus that was originally designed to operate at lower frequencies.

Figure 1: Waveguide test apparatus set up for operation between 1700 and 2000 MHz.

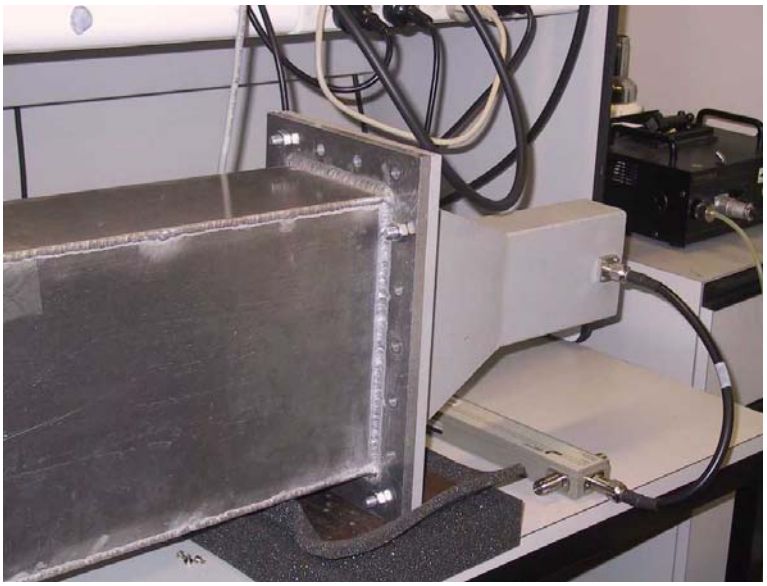

Figure 2: Transition horn at RHS of apparatus.

A manipulator shown in Figure 3 was used to position the hearing aid in the centre of the waveguide. This allowed the hearing aid to be rotated about three mutually orthogonal axes and positioned for maximum level of interference by the radiofrequency test signal.

Figure 3: Typical mounting of a BTE hearing aid in manipulator.

5.1.2 Test Subject Related Information

One test subject was used in the initial study and used a “Stetoclip” to monitor the acoustic output of the hearing aid. Based on 500, 1000 and 2000 Hz, the average three frequency hearing level for the left and right ear was 5.8 dB. Also using 500, 1000, 2000 and 4000 Hz the average four frequency hearing loss for the left and right ear was 17.5 dB.

5.1.3 Hearing Aid Testing

The microphone ILM55 radiofrequency immunity levels for the three hearing aids used in the initial study were 5.4 dB re 1V/m, 22.9 dB re 1V/m and 36.3 dB re 1V/m when measured at 1750 MHz.

5.1.4 Subject Testing Program

The following data are the test results from the one test subject used in this initial study.

Interference at 1 metre

At one metre (=1000mm) from the test mobile telephone transmitting at maximum power the hearing aid with the low radio immunity produced unwanted interference at a *moderately perceptible* level as assessed by the test subject. In the hearing aids classified as having a medium and high level of immunity to radio signals the interference was rated as *not perceptible*.

Limit of interference

In the initial study the limit of interference distance for the three hearing aids in microphone setting was:

- 2500 mm for the low immunity hearing aid;
- 200 mm for the medium immunity hearing aid; and
- 25 mm for the high immunity hearing aid.

Interference with the hearing aid placed near the base of the antenna

With the mobile telephone transmitting at full power and each hearing aid placed near the base of the antenna, the perceived level of interference and expected useability of the mobile with this level of interference was as follows:

- For the low immunity hearing aid the perceived interference was judged to be *very annoying* and the expected useability as *not useable*;
- For the medium immunity hearing aid the perceived interference was judged to be *moderately perceptible* and the expected useability as *sometimes useable*.
- For the high immunity hearing aid the perceived interference was judged to be *just perceptible* and expected useability as *always useable*.

With the mobile telephone transmitting at reduced power, nominally 14 dB below maximum power, measurements indicated this to be 13.4 dB, the perceived level of interference and expected useability of the mobile with this reduced level of interference was as follows:

- For low immunity hearing aid the perceived interference was judged to be *moderately perceptible* and the expected useability as *sometimes useable*;
- For the medium immunity hearing aid the perceived interference was judged to be *just perceptible* and expected useability as *always useable*;
- For the high immunity hearing aid the perceived interference was not tested.

5.1.5 Spectral Analysis

The following graphs show the measured spectral response of interference produced in hearing aids under different test conditions. The vertical scale is a relative measurement in decibels and the horizontal axis is a linear frequency scale.

Spectral results for low radiofrequency immunity hearing aid in microphone setting

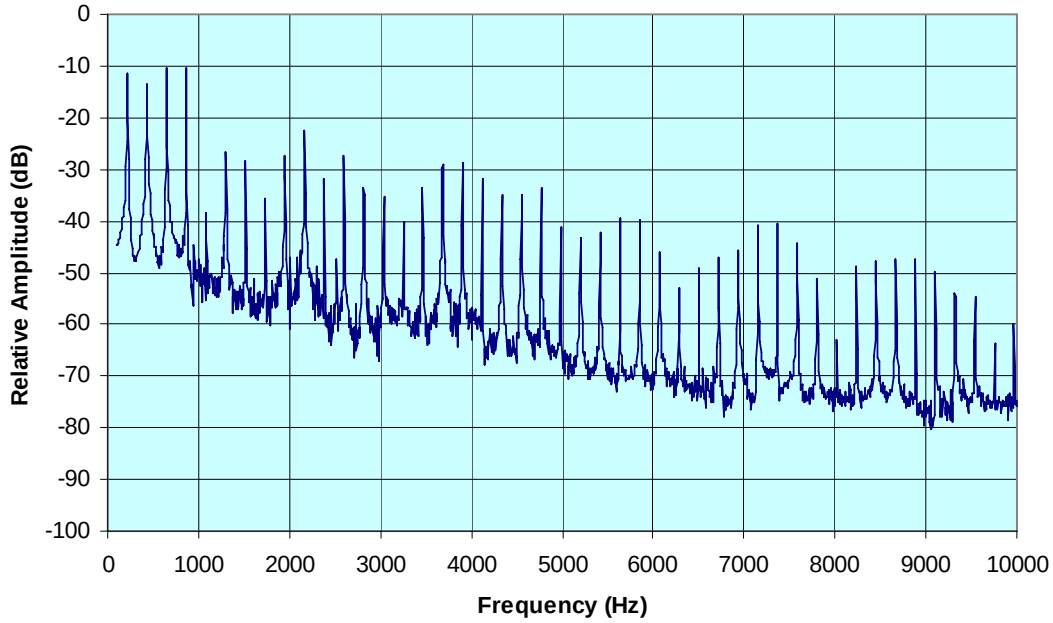

Figure 4: Spectral response of interference produced in a radiofrequency low immunity hearing aid at maximum volume control and placed next to a 1750MHz GSM Mobile transmitting on full power.

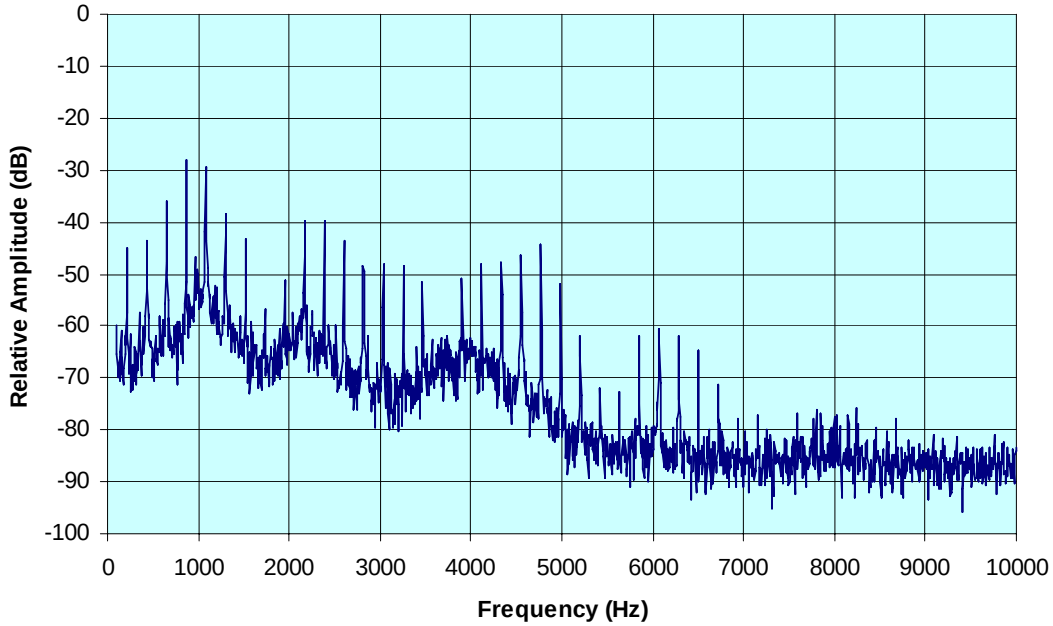

Figure 5: Spectral response of interference produced in a radiofrequency low immunity hearing aid at maximum volume control and placed 1 metre from a 1750MHz GSM Mobile transmitting on full power.

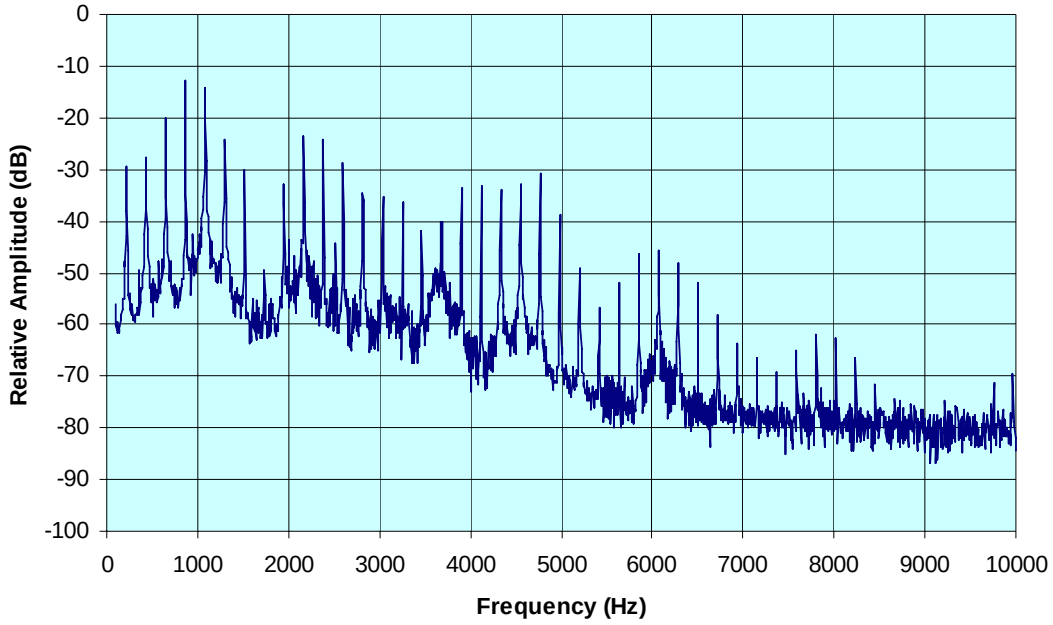

Figure 6: Spectral response of interference produced in a radiofrequency low immunity hearing aid at maximum volume control and placed next to a 1750MHz GSM Mobile transmitting on reduced power, -13.4 dB re maximum output (nominally -14 dB re maximum output).

Spectral results for medium radiofrequency immunity hearing aid in microphone setting

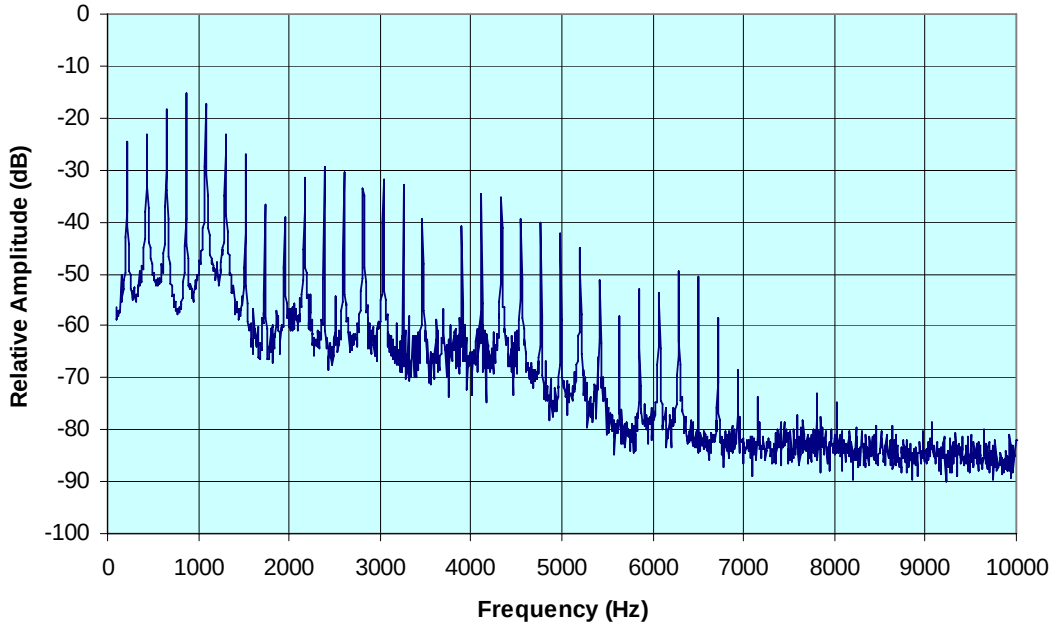

Figure 7: Spectral response of interference produced in a radiofrequency medium immunity hearing aid at reset volume control and placed next to a 1750MHz GSM Mobile transmitting on full power.

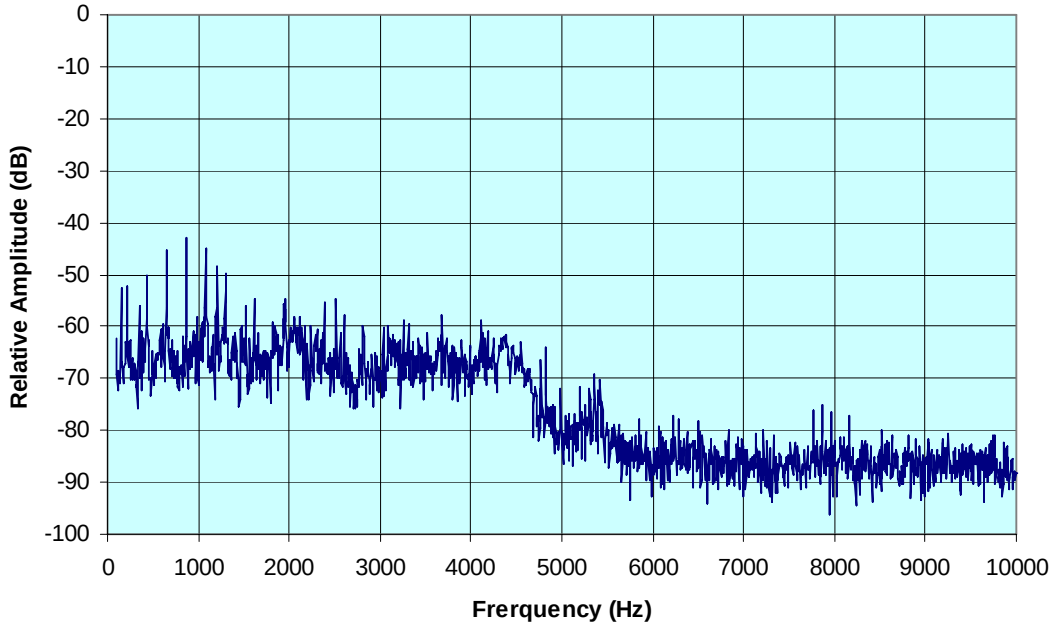

Figure 8: Spectral response of interference produced in a radiofrequency medium immunity hearing aid at reset volume control and placed next to a 1750MHz GSM Mobile transmitting on reduced power, -13.4 dB re maximum output (nominally -14 dB re maximum output).

Spectral results for high radiofrequency immunity hearing aid in microphone setting

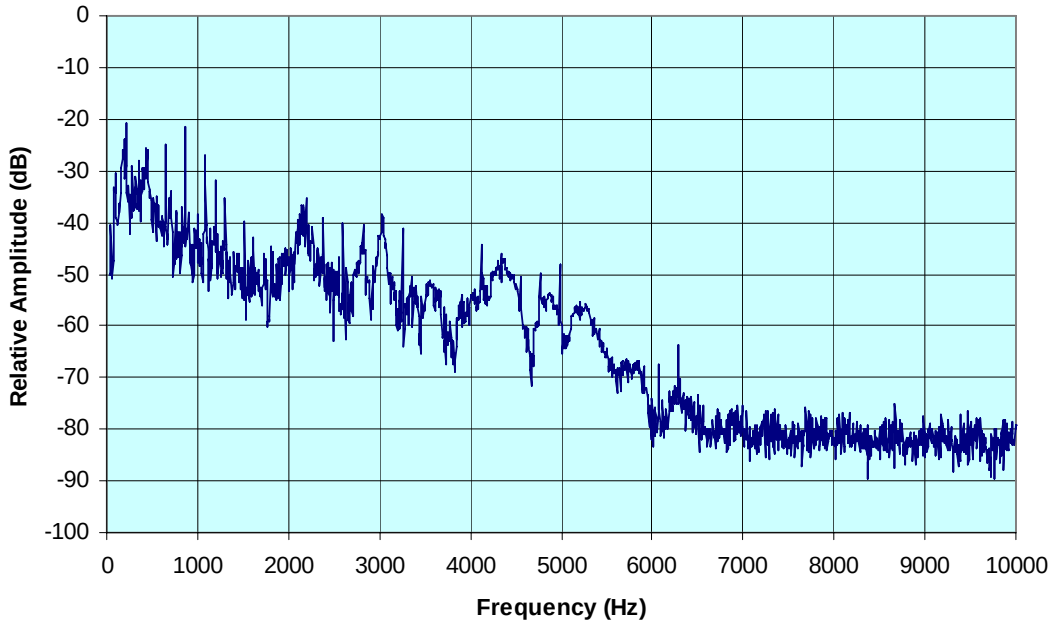

Figure 9: Spectral response of interference produced in a radiofrequency high immunity hearing aid at reset volume control and placed next to a 1750MHz GSM Mobile transmitting on full power.

5.2 Final Study

The results for final study follow.

5.2.1 Test Subject Related Information

The three frequency and four frequency hearing level for the ear used by each observer is shown in Figure 10 for observers 1 to 18. The 19th observer is the result of averaging both ears as Stetoclips were used by this observer.

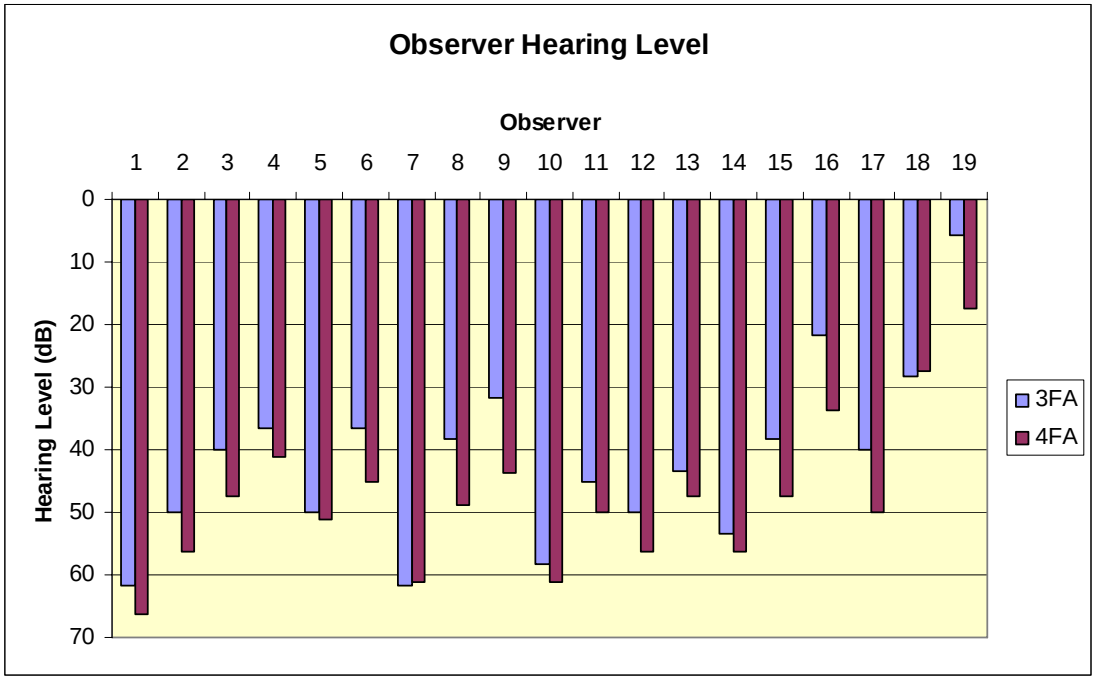

Figure 10: The three frequency and four frequency hearing level for each observer.

5.2.2 Hearing Aid Testing

The radiofrequency (RF) immunity level for each hearing aid (HA) used in the final study was measured in both the microphone setting and telecoil setting and the results are presented in the following diagrams, Figures 11 and 12.

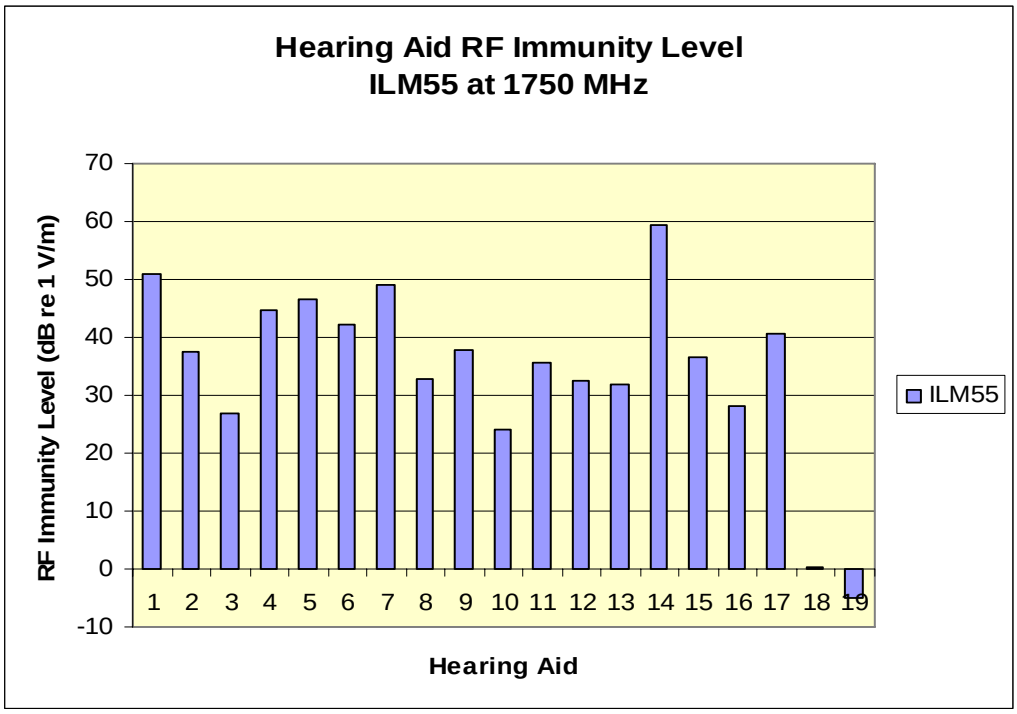

Figure 11: The radiofrequency immunity level for each hearing aid in microphone setting measured at 1750 MHz.

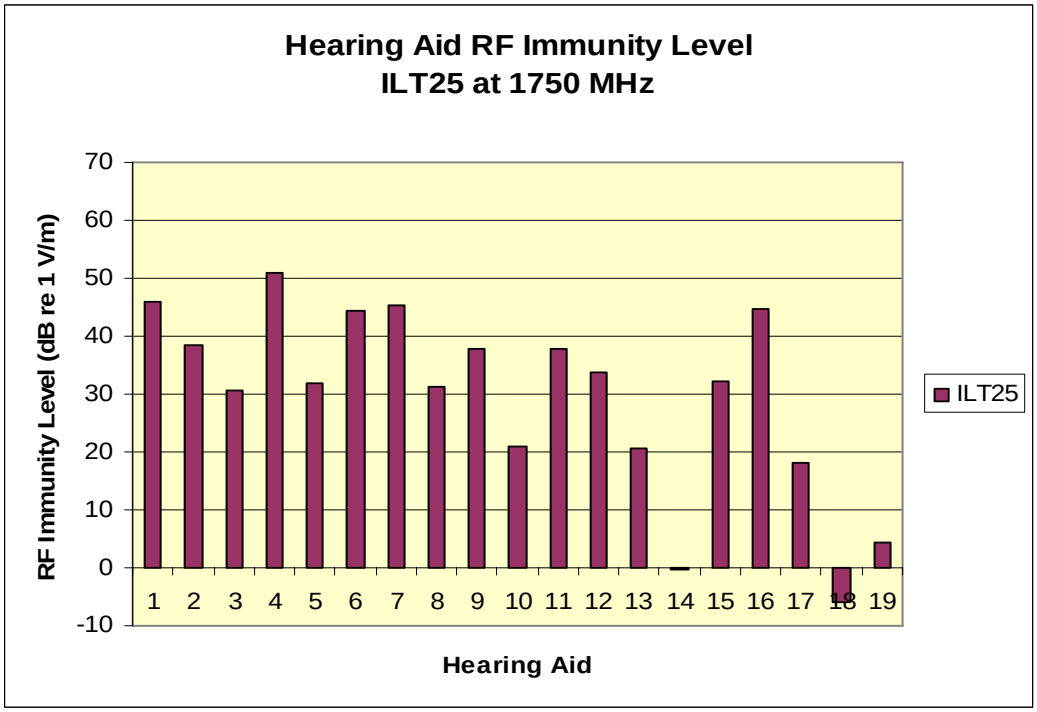

Figure 12: The radiofrequency immunity level for each hearing aid in telecoil setting measured at 1750 MHz.

5.2.3 Subject Testing Program

The results for the subject testing program of the final study follow.

Interference at 1 metre

The perceived level of interference for hearing aids positioned at 1 metre from the test mobile transmitting at maximum power setting at 1750 MHz in microphone and telecoil settings versus radiofrequency immunity level for each hearing aid.

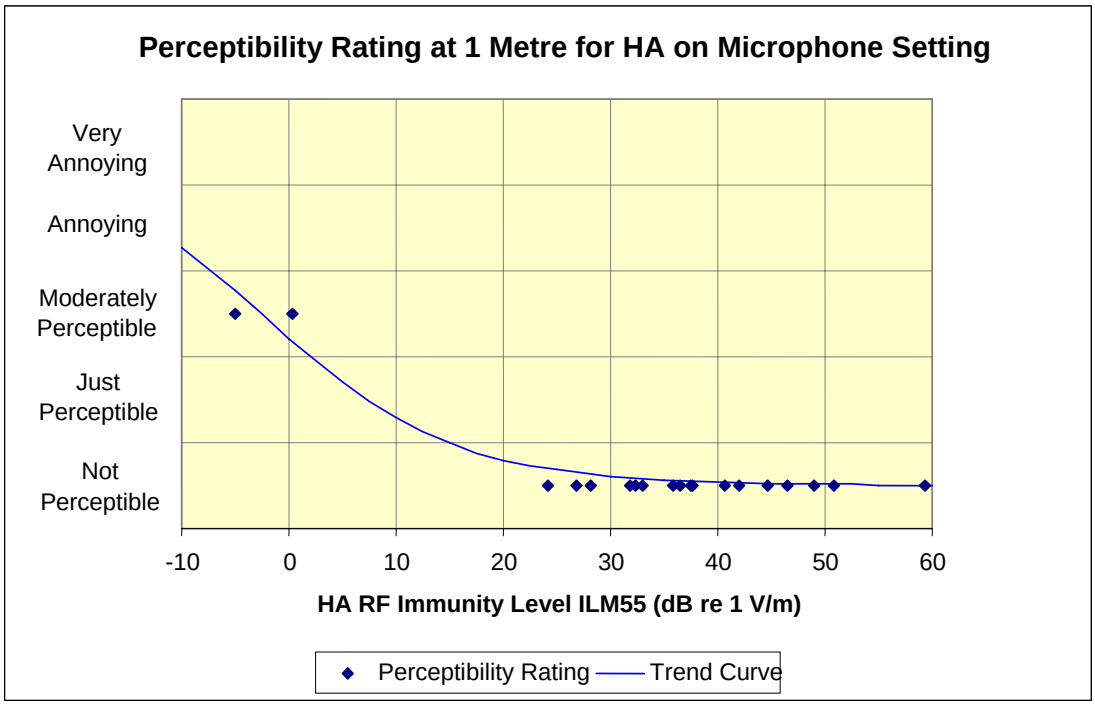

Figure 13: The perceived interference with the hearing aids in microphone setting and positioned 1 metre from the mobile transmitting at maximum power level.

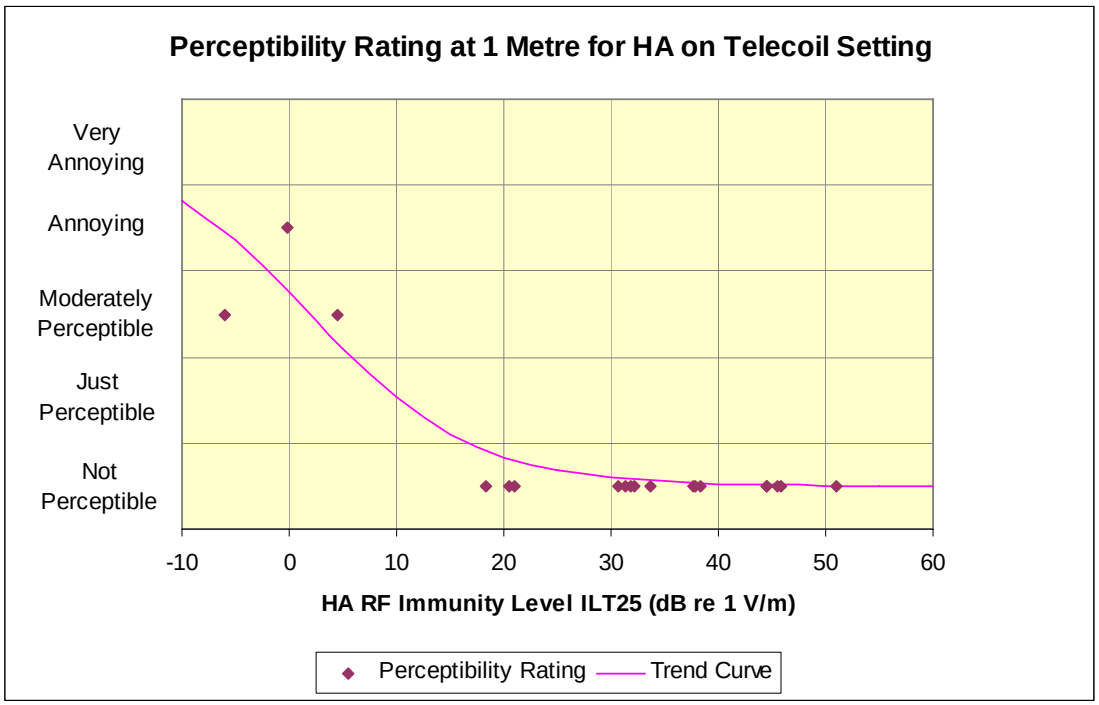

Figure 14: The perceived interference with the hearing aids in telecoil setting and positioned 1 metre from the mobile transmitting at maximum power level.

Limit of interference

The limit of interference is presented in the following graphs where the mobile telephone is operating at maximum transmit power level at 1750 MHz and the hearing aid is in microphone setting and telecoil setting. They show the distance where any perceived interference is at the *just perceptible* level. Also included in microphone setting are those results where the mobile was touching the hearing aid and the interference was *not perceptible*.

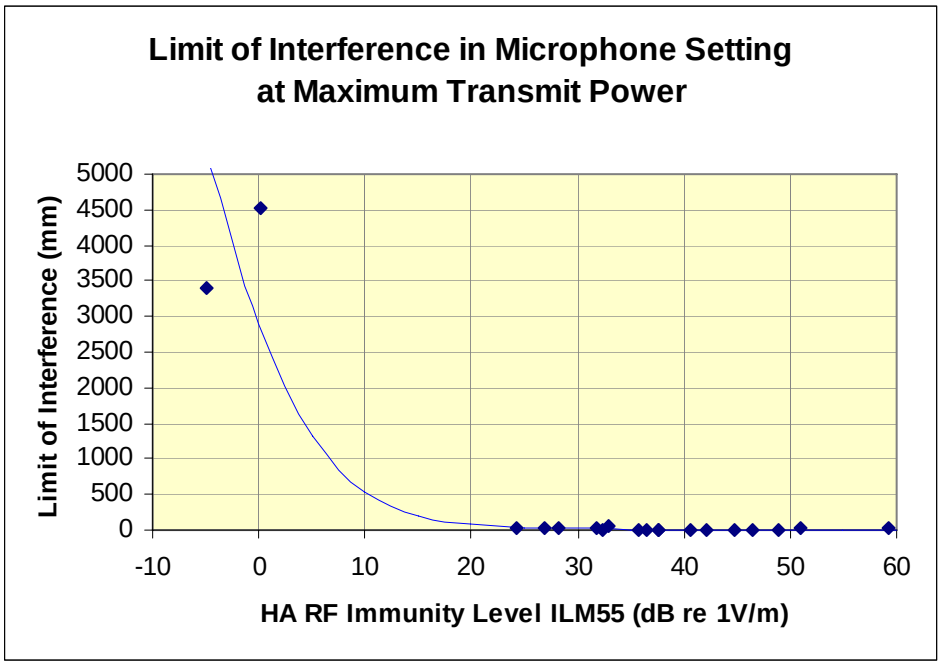

Figure 15: The limit of interference for the hearing aids used in the final study when in microphone setting.

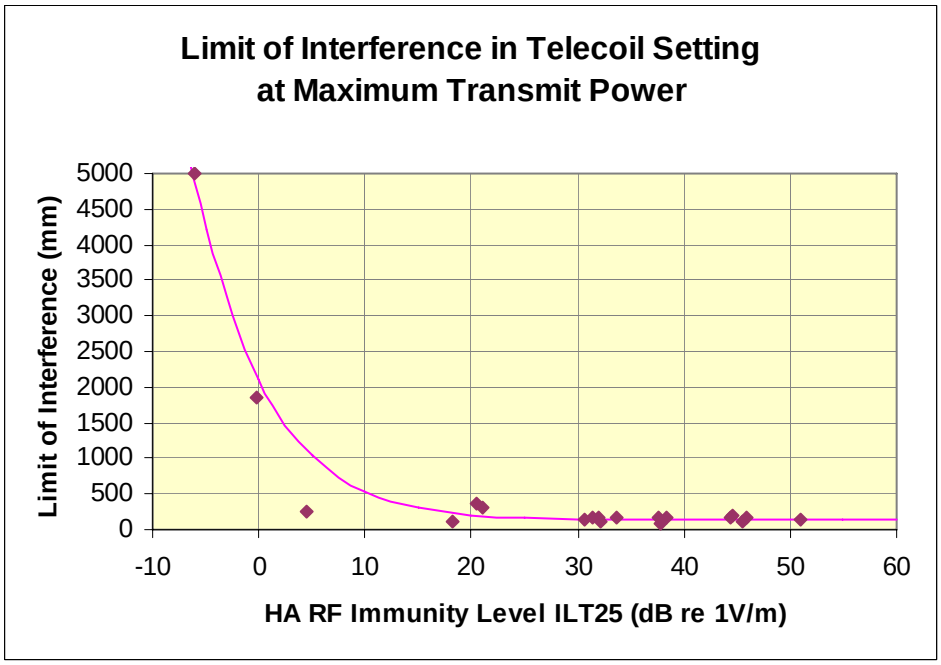

Figure 16: The limit of interference for the hearing aids used in the final study when in telecoil setting.

Perceptibility rating and useability rating of interference produced in hearing aids by a 1750 MHz GSM mobile telephone operating at maximum transmit power level and held in normal listening position.

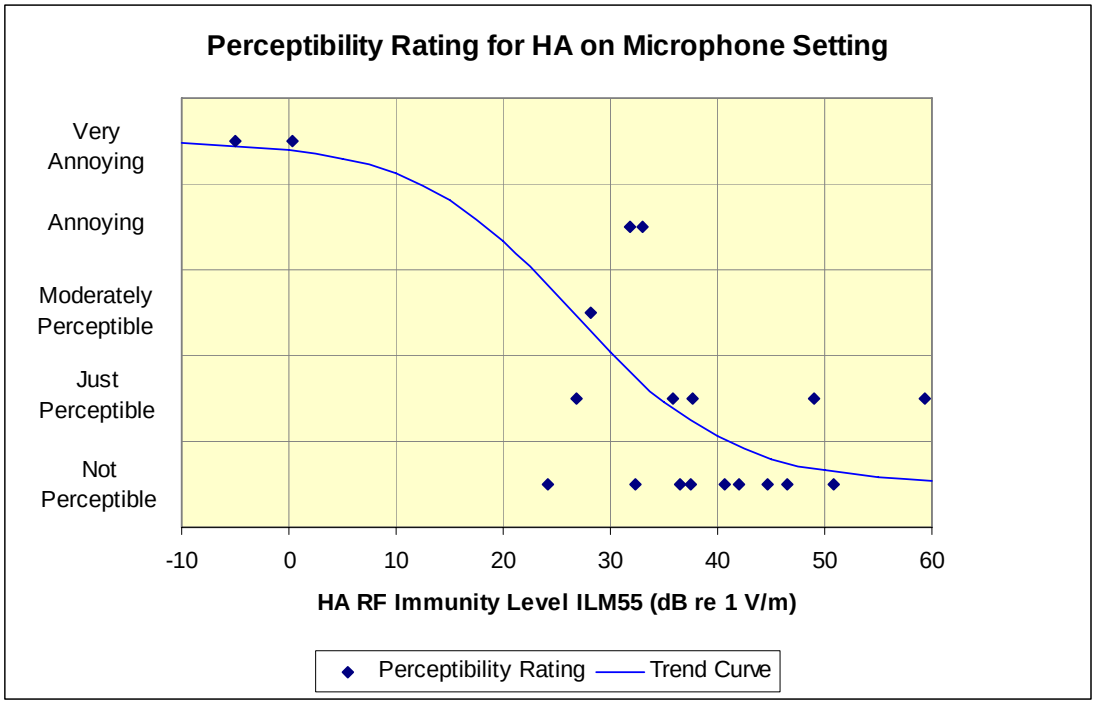

Figure 17: Perceptibility rating of interference produced in hearing aids in microphone setting by a 1750 MHz GSM mobile telephone operating at maximum transmit power level and held in normal listening position.

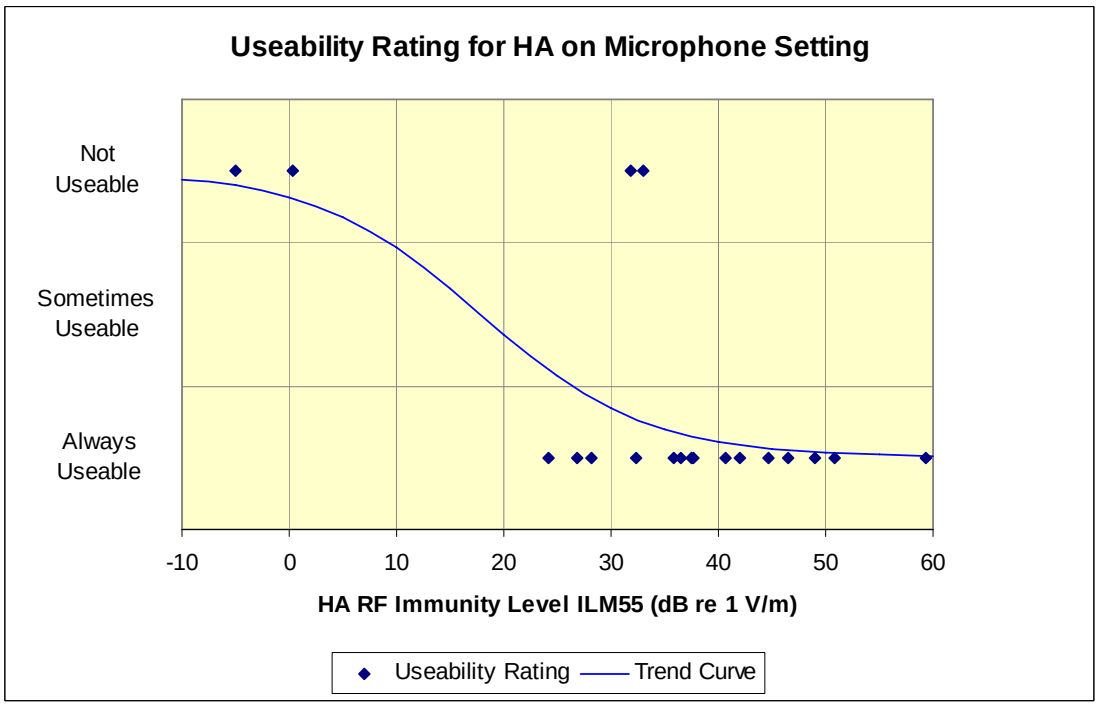

Figure 18: Useability rating of interference produced in hearing aids in microphone setting by a 1750 MHz GSM mobile telephone operating at maximum transmit power level and held in normal listening position.

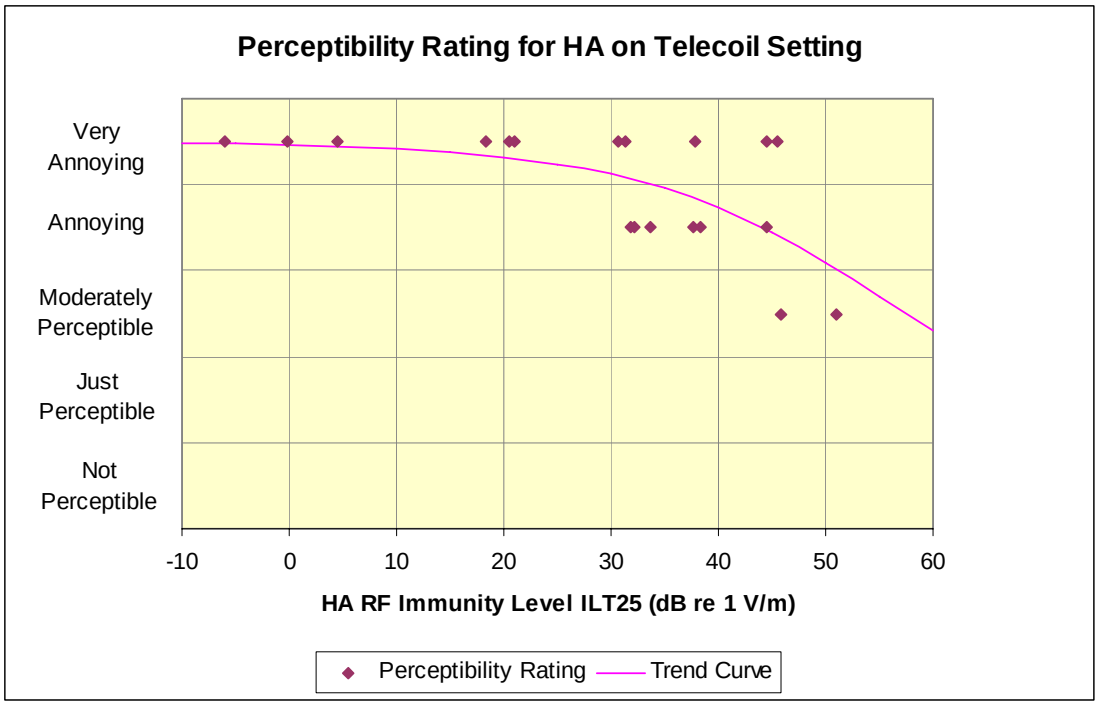

Figure 19: Perceptibility rating of interference produced in hearing aids in telecoil setting by a 1750 MHz GSM mobile telephone operating at maximum transmit power level and held in normal listening position.

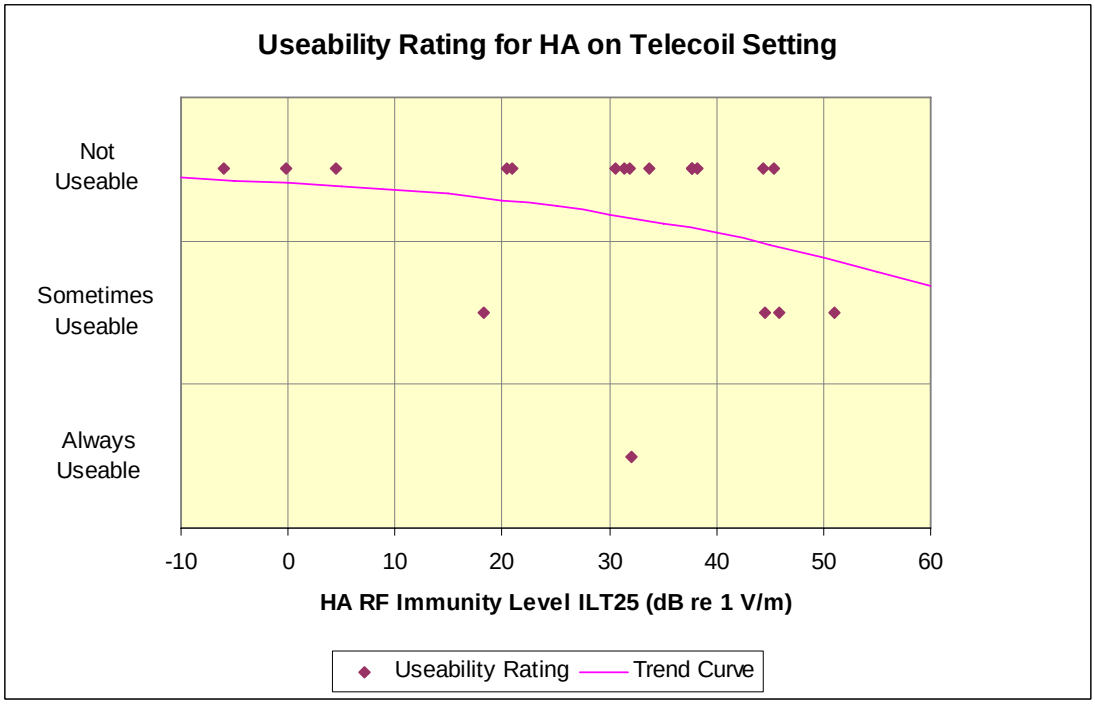

Figure 20: Useability rating of interference produced in hearing aids in telecoil setting by a 1750 MHz GSM mobile telephone operating at maximum transmit power level and held in normal listening position.

6 Analysis of Results

6.1 Initial Study

The aim of the initial study was to investigate the type of interference produced by a GSM 1800 MHz digital mobile telephone and note the general effect on hearing aids that have a low, medium and high level of immunity to radio signals. When subject testing was required in the initial study only one person was used.

6.1.1 Waveguide Test Apparatus

The waveguide test apparatus is depicted in Figures 1, 2 and 3. It was initially designed for use in the 800 to 1000 MHz radiofrequency band. Figure 3 shows a manipulator where the hearing aid under test is positioned in a cradle that can be rotated about three axes that allows the hearing aid to be positioned at any angle within the waveguide test area. The mechanical parts of the manipulator within the waveguide were manufactured from Teflon and external parts were manufactured from brass that had a plated finish.

The long plastic tube that pipes the acoustic output of the hearing out of the waveguide can be seen in Figure 3.

A transition horn was used to allow the smaller waveguide, where the 1700 to 2000 MHz radio signal is launched, to be matched to the larger waveguide. Initially some instability in the system was encountered, but after a great deal of effort the waveguide operation could be made stable by the addition of a small amount of material that absorbs radio signals at the relevant frequencies. The transition horn can be seen at the right hand side of Figures 1 and 2. The absorption was carefully selected and positioned so that it stabilised operation at 1700 to 2000 MHz but did not significantly effect the operation at 800 to 1000 MHz when the original lower radiofrequency launcher replaced the transition horn.

6.1.2 Test Subject Related Information

Considering the three frequency hearing level of 5.8dB and a four frequency hearing level of 17.5 dB for the test subject used in the initial study, it was concluded that the hearing was in the normal range up to 2000 Hz, with a moderate loss at 4000 Hz.

6.1.3 Hearing Aid Testing

For the purposes of the initial study the microphone ILM55 radiofrequency immunity levels for the three hearing aids measured at 1750 MHz were classified as follows:

- The hearing aid with the microphone ILM55 radiofrequency immunity level of 5.4 dB re 1 V/m was classified as having a low level of immunity to radio signals at 1750 MHz;
- The hearing aid with the microphone ILM55 radiofrequency immunity level of 22.9 dB re 1 V/m was classified as having a medium level of immunity to radio signals at 1750 MHz;

- The hearing aid with the microphone ILM55 radiofrequency immunity level of 36.3 dB re 1 V/m was classified as having a high level of immunity to radio signals at 1750 MHz.

These classifications are rather general and not meant to be taken as a general purpose definition for low, medium and high levels of radiofrequency immunity. They are provided to make the following discussions more simple to understand.

6.1.4 Subject Testing Program

The following comments relate to the test results from the one test subject used in the initial study.

Interference at 1 metre

The test results at one metre (=1000mm) from the test mobile telephone transmitting at maximum power provide information about what is called *bystander* interference. In Australia this is unwanted interference produced in a hearing aid positioned at a distance of one metre, or more, from a digital mobile telephone. The test results from the initial study indicate that a hearing aid in microphone setting must have a medium level of immunity to radio signals at 1750 MHz to avoid bystander interference. In some countries a distance of 2 metres is used for bystander interference whereas in Australia a more conservative distance of 1 metre is thought to be more appropriate.

Limit of interference

The limit of interference results from the initial study confirmed that in a hearing aid in microphone setting a medium level of immunity to radio signals at 1750 MHz was required to avoid bystander interference. Also the results indicate that a high level of immunity to radio signals would be required for a hearing aid in microphone setting to be used by a hearing aid user when communicating with a GSM digital mobile telephone operating at 1750 MHz.

Interference with the hearing aid placed near the base of the antenna

Under worst case conditions, where the GSM mobile telephone operating at 1750 MHz is transmitting at full power and a hearing aid is placed near the base of the antenna, the test results confirm that a hearing aid in microphone setting would require a high level of immunity to radio signals for communication to be possible at all times with minimal levels of perceived interference. Also under these worst case conditions a low immunity hearing aid would not be useable as the interference would be *very annoying* and a medium immunity hearing aid could be used by some hearing aid users for some of the time.

In the initial investigation using one observer the GSM digital mobile was also tested with reduced transmitting power set nominally 14 dB below maximum power level. When placed near the base of the mobile antenna the hearing aid would require a medium, or better level of immunity to radio signals for communication using a hearing aid in microphone setting with a 1750 MHz GSM digital mobile telephone. Note that the transmit power of a digital mobile telephone is not always set to maximum, but is controlled by the mobile network based on the received strength of

the mobile signal at the base station. This process is used to optimise total network performance. The high immunity hearing aid was not tested with the reduced transmit power as the medium immunity hearing aid results indicated that communication should be satisfactory for communication. For the low immunity hearing aid the results indicate that this would not be satisfactory for hearing aid users as satisfactory communication would only be possible some of the time.

6.1.5 Spectral Analysis

To see more easily the harmonic relationship in the graphical presentations for spectral analysis of interference produced within the hearing aids a linear scale was used for the horizontal frequency axis in Figures 4 to 9. In all cases both odd and even harmonics of the 217 Hz frame rate of the transmitted GSM time division multiplexed signal are evident.

Spectral results for low radiofrequency immunity hearing aid in microphone setting

Figures 4 to 6 record the spectral interference generated in a low radiofrequency immune hearing aid in microphone setting. At maximum volume control when the hearing aid was held against the mobile telephone, Figure 4, the spectral interference was severe across the audio band and well above the background noise of the hearing aid. When the power level was reduced by 14 dB the spectral interference was still well above the background noise, Figure 6. When the hearing aid was positioned 1 metre from the GSM 1750 MHz digital mobile telephone with the hearing aid volume control set to maximum the spectral interference was still well above the background noise, see Figure 5. The test subject described the level of interference in earlier tests as *very annoying* as recorded in Figure 4 and *moderately perceptible* for results recorded in Figures 5 and 6.

Spectral results for medium radiofrequency immunity hearing aid in microphone setting

Figures 7 and 8 record the spectral interference generated in a medium radiofrequency immune hearing aid in microphone setting at a reset volume control setting. This volume control setting for this hearing aid is approximately 14 dB below maximum level. The spectral interference when the hearing aid was held against the GSM 1750 MHz digital mobile telephone was well above background levels, Figure 7. The test subject in an earlier test described this level of interference as *moderately perceptible*. When the transmitting power of the mobile was reduced to a level nominally 14 dB below maximum the spectral interference can be noted in Figure 8 as 10 to 15 dB above the background noise level up to approximately 1500 Hz and in an earlier test the test subject described this level of interference as being *just perceptible*.

Spectral results for high radiofrequency immunity hearing aid in microphone setting

Figure 9 records the spectral interference generated in a high radiofrequency immune hearing aid in microphone setting at reset volume control. When held against the GSM 1750 MHz digital mobile telephone the spectral interference was 5 to 15 dB above the background noise level between 600 and 1500 Hz. This level of interference in an earlier test was described by the test subject as *just perceptible*.

6.2 Final Study

The aim of the final study was to investigate how interference is perceived and assessed by hearing aid users wearing their own hearing aids and relate these subjective assessments to technical measurements of radiofrequency immunity of their hearing aids. The results for the final study are recorded in Section 5.2 and the analysis of these results follow in Sections 6.2.1 to 6.2.3.

6.2.1 Test Subject Related Information

The hearing levels for the 19 test subjects, or observers, used in the final study are recorded in Figure 10. For observers 1 to 18 the hearing levels are between 22 and 66 dB for the ear used by each observer. Observers 1 to 17 used hearing aids that were prescribed and fitted by their audiologist. Observer 18 had a mild hearing loss and was fitted with an early model hearing aid with low immunity to radio signals at 1750 MHz. Observer 19 did not wear hearing aids, but had a moderate loss at 4 KHz as is evident when comparing the three and four frequency average hearing levels. This observer used a Stetoclip listening tube connected to an older model low power hearing aid through a long length of 2mm diameter plastic tubing and was used in the study to include another hearing aid with low immunity to radio signals at 1750 MHz. Both three and four frequency average hearing levels for each test subject are provided to give some indication of the hearing loss and allows comparison of the average hearing level between 500 and 2000 Hz and also 500 and 4000 Hz. Based on the three frequency hearing level for observers 1 to 18, nine observers would be considered to have a mild hearing loss, seven would be classified as having a moderate hearing loss and two would be classed as having a severe hearing loss.

6.2.2 Hearing Aid Testing

The radiofrequency immunity level for each hearing aid in microphone setting at 1750 MHz is presented in Figure 11 and varies between -5 dB re 1 V/m and +59 dB re 1 V/m. Also in telecoil setting the radiofrequency immunity level for each hearing aid at 1750 MHz is presented in Figure 12 and varies between -6 dB re 1 V/m and +51 dB re 1 V/m. The definitions used for radiofrequency immunity level in both microphone and telecoil settings have been provided in Section 3.1 and have been designated ILM55 and ILT25 respectively. The range of variation in the radiofrequency immunity levels for the hearing aids used in this study in both microphone and telecoil settings varies from a very low to very high level.

In this study those hearing aids with a low level of radiofrequency immunity would be subject to high levels of interference when subjected to high levels of amplitude modulated radio signals at 1750 MHz for both the microphone and telecoil settings. Also those hearing aids with a high level of radiofrequency immunity would be subject to low levels of interference when subjected to high levels of amplitude modulated radio signals at 1750 MHz for both the microphone and telecoil setting. However when a hearing aid is placed near a GSM digital mobile telephone the situation becomes more complicated when the hearing aid is in telecoil setting. It is not sufficient that the hearing aid in telecoil setting have a high level of immunity to radiofrequency signals to ensure low levels of interference. The reason for this that when the hearing aid is near a mobile telephone another factor becomes involved and this is associated with the audio frequency magnetic field surrounding the mobile telephone. The 217 Hz repetition rate of the GSM transmission can cause a 217 Hz

pulsating magnetic field about the mobile telephone. This fundamental frequency and its harmonics can be picked up by the telecoil in the hearing aid as this is in the wanted audio frequency band for the hearing aid. This type of interference has been called base band interference and it can produce very high levels of unwanted interference in a hearing aid set to telecoil even though the hearing aid may have a very high level of radiofrequency immunity to radio signals at 1750 MHz.

Many of the hearing aids used in this study had similar levels of radiofrequency immunity in both microphone and telecoil setting as seen when comparing the results in Figures 11 and 12. This may lead one to the implication that hearing aids with high radiofrequency immunity in microphone setting would also have high radiofrequency immunity in telecoil setting. This is not always the case as seen when comparing the results for hearing aids 5, 13, 14 and 17. In each of these cases the immunity to radiofrequency signals in microphone setting is higher than in telecoil setting. The differences are: 11 dB for hearing aid 13; 14.6 dB for hearing aid 5; 22 dB for hearing aid 17 and 59 dB for hearing aid 14.

6.2.3 Subject Testing Program

This section of the report analyses the results of 19 test subjects. Details of these test subjects are provided in Section 6.2.1.

Interference at 1 metre

The results for the perceived level of interference by hearing aid users when a GSM 1750 MHz digital mobile telephone operating at maximum power is positioned 1 metre (1000 mm) from the hearing aid are presented in Figures 13 and 14. In Australia this distance is used to determine radiofrequency immunity from bystander interference.

In microphone setting as shown in Figure 13, all hearing aid users of hearing aids with an ILM55 radiofrequency immunity level greater than 24dB re 1 V/m indicated that interference was *not perceptible*. Those hearing aid users of hearing aids with an ILM55 less than 0.25 dB re 1 V/m indicated that interference was *moderately perceptible*.

In telecoil setting as shown in Figure 14, all hearing aid users of hearing aids with an ILT25 radiofrequency immunity level greater than 18dB re 1 V/m indicated that interference was *not perceptible*. Those hearing aid users of hearing aids with an ILT25 less than 5 dB re 1 V/m indicated that interference was *moderately perceptible* or *annoying*.

In this study there were not many hearing aids with either an ILM55 or ILT25 between 5 and 18 dB re 1 V/m. However the trend curves for both microphone and telecoil results indicate that the hearing aid radiofrequency immunity levels for bystander interference for both microphone (ILM55) and telecoil (ILT25) operation should be between 14 and 17 dB re 1 V/m to ensure that the perceptible interference would be at the transition between *not perceptible* and *just perceptible* level. This result confirms the estimate used in Australian Standard AS 1088.9 [2] that states 7 V/m, i.e. 16.9 dB re 1 V/m.

Limit of interference

The limit of interference is the distance where any perceived interference is at the *just perceptible* level. Also included in microphone setting are those results where the mobile was touching the hearing aid and the interference was *not perceptible*. With the GSM digital mobile telephone operating at maximum transmit power level at 1750 MHz the results for the limit of interference with the hearing aids in microphone and telecoil settings are presented in Figures 15 and 16 respectively.

For users of hearing aids in microphone setting the limit of interference in Figure 15 ranged between 0 and 35 mm when the ILM55 microphone immunity level was greater than 24 dB. For one hearing aid user of a hearing aid with an ILM55 radiofrequency immunity level of 0.25 dB re 1 V/m the limit of interference was 4530 mm and for another observer using a hearing aid with an ILM55 radiofrequency immunity level of -5 dB re 1 V/m the limit of interference was 3400 mm.

For users of hearing aids in telecoil setting the limit of interference in Figure 16 ranged between 75 and 370 mm when the ILT25 telecoil immunity level was greater than 4.5 dB re 1 V/m. For one hearing aid user of a hearing aid with an ILT25 radiofrequency immunity level of 0 dB re 1 V/m the limit of interference was 1850 mm and for another observer using a hearing aid with an ILT25 radiofrequency immunity level of -6 dB re 1 V/m the limit of interference was 5000 mm. Note that it did not matter how immune a hearing aid was to radiofrequency interference in the telecoil setting, the hearing aid was always at a distance greater than 75 mm from the 1750 MHz GSM digital mobile telephone where the interference was first described as *just perceptible*. At closer distances the interference would be at a louder level. This interference in telecoil setting is what has been called base band interference and is the result of unwanted audio frequency magnetic fields about the mobile telephone and this unwanted disturbance is picked up by the normal telecoil mode of operation.

For the microphone and telecoil *limit of interference* tests, Figures 15 and 16, at a distance of one metre the radiofrequency immunity levels were 5 to 7 db re 1 V/m. This corresponds to the radiofrequency immunity levels of 7 to 10 dB re 1 V/m in the centre of the just perceptible region for the *interference at 1 metre* tests, Figures 13 and 14. The other factor is that there were not many of the hearing aids with an immunity rating in the region of 5 to 18 dB re 1 V/m. Most of the current models of hearing aids used in these tests had radiofrequency immunity levels greater than 24 dB re 1 V/m for microphone setting and greater than 18 dB re 1 V/m for telecoil setting apart from one hearing aid with a telecoil radiofrequency level of 0 dB re 1 V/m. The two older model hearing aids used in these tests were at the low end of the radiofrequency immunity levels.

Perceptibility rating and useability rating of interference produced in hearing aids by a 1750 MHz GSM mobile telephone operating at maximum transmit power level and held in normal listening position.

The results for this test are presented in Figures 17 to 20 where Figures 17 and 18 provide the results when the hearing aid is in microphone setting and Figures 19 and 20 provided the results when the hearing aid is in telecoil setting.

In microphone setting when the hearing aid users held the 1750 MHz GSM digital mobile telephone in the normal listening position that was transmitting at maximum power level, the perception of the interference by the hearing aid users varied from being *very annoying* to *not perceptible*. Also with the perceived level of interference the hearing aid users rated the useability of the 1750 MHz GSM digital mobile telephone as being either *not useable* or *always useable* but there was some overlap of immunity levels for these results. The perceptibility rating results were quite scattered and did not cluster close together. The immunity level for microphone setting was a little over 40 dB re 1 V/m where the trend curve crossed from the *not perceptible* to *just perceptible* rating. The trend curve for the useability rating of a hearing aid with the mobile telephone indicates a lower level for radiofrequency immunity level for the estimated *always useable* rating, however when the raw data is considered there were some *not useable* ratings for levels greater than that indicated by this trend curve. It is recommended that the most appropriate radiofrequency immunity level (ILM55) for microphone setting would be 105 V/m, corresponding to 40.4 dB re 1 V/m. This level would allow the majority of hearing aid users to receive an interference free reception in microphone setting. The appropriate test field strength to use when testing hearing aids for use with 1750 MHz GSM digital mobile telephones would also be 105 V/m, corresponding to 40.4 dB re 1 V/m. It is recommended that this test field strength be used in Australian Standard AS1088.9 [2] for the frequency range 1700 to 2000 MHz.

In telecoil setting the results were scattered as can be seen from Figure 19 and all hearing aid users perceived the interfering sound as being *moderately perceptible*, *annoying* or *very annoying*. There was no hearing aid user that perceived the interfering sound as *just perceptible* or *not perceptible* in telecoil setting when the 1750 MHz GSM digital mobile telephone was held in the normal listening position when transmitting at maximum power level. In the hearing aids tested there were five that had a very high level of radiofrequency immunity that were greater than 40 dB re 1 V/m, the highest being 51 dB re 1 V/m and with this level of radiofrequency immunity any perceived interfering sound would be expected to be extremely soft if that interference was due only to the radiofrequency interference. The reason for the higher than expected level of interference is due to base band interference where the hearing aid in telecoil setting detects the audio frequency magnetic field surrounding the mobile telephone that is pulsating 217 times a second for the GSM transmission system. The assessed useability rating was generally at the *not useable* rating, with four *sometimes useable*. There was one *always useable* rating for an ILT25 radiofrequency immunity level of 32 dB re 1 V/m, however this seems to be an anomalous result as the perceptibility rating was judged to be *annoying* by this hearing aid user. It maybe concluded that for the hearing aids tested in this study that base band interference would preclude hearing aid users from using the test 1750 MHz GSM digital mobile telephone for communication purposes when transmitting at maximum transmit power level. Also that most hearing aid users in telecoil setting found that it would not be possible to use the test mobile telephone when transmitting at power levels that were considerably below the maximum level. If a mobile telephone was designed with a very low level of external audio frequency magnetic field, then many current model hearing aids that have a high immunity to radiofrequency interference would be able to provide hearing aid users with a useful means of mobile telephone communication. One advantage of using telecoil mode is that surrounding acoustic noises are not picked up by the microphone and therefore do not cause unwanted background noises to the wanted telephone speech signal. This

advantage would result in an improved ratio of the wanted speech signal from the mobile telephone to the unwanted acoustic background noises and would improve communication for the hearing aid user.

7 Summary

The program of work in this research study was carried out as an initial preliminary study followed by a more comprehensive final study.

Initial Study Summary

The initial study concentrated on the technical aspects of the testing apparatus as well as an investigation by one observer into the extent of the interference generated in a limited number of hearing aids operating in microphone setting that was caused by a 1750 MHz GSM digital mobile telephone. Also the characteristics of the GSM interference were investigated. The effect of interference in telecoil setting was not studied in the initial investigation. This initial study provided the background and set the scope of the work carried out in the more extensive final study involving a number of hearing aid users.

In the initial study the waveguide test system designed to operate between 800 and 1000 MHz was successfully converted using a transition horn to operate in the 1700 to 2000 MHz radio band. Initially there were some stability problems with the modified equipment that caused considerable delays to the project, however after lengthy investigations a relatively simple solution using some radiofrequency damping material was used to stabilise the operation of the test system.

The test subject used in the initial study had a hearing level in the normal range up to 2000 Hz with a moderate loss at 4 KHz.

Three hearing aids were used in the initial study and were chosen to represent hearing aids with a low, medium and high level of immunity to radio signals at 1750 MHz.

The initial testing carried out at 1 metre provided a preliminary indication of what immunity levels to radiofrequency interference was required of a hearing aid to prevent bystander interference from nearby GSM digital mobile telephones operating at 1750 MHz. The initial results indicated that the hearing aid with a medium level of immunity to radiofrequency interference provided protection against bystander interference.

The limit of interference testing in the preliminary initial study showed that a hearing aid with low immunity to radio signals could receive interference at distances over 2 metres from a 1 Watt 1750 MHz GSM digital mobile telephone.

With the 1750 MHz GSM digital mobile telephone operating at full transmit power of 1 Watt the initial study indicated that a hearing aid in microphone setting would require a high level of immunity to the transmitted radio signals for satisfactory communication by a hearing aid user. In the initial study with the high immunity hearing aid in microphone setting, the observer judged the interference to be *just perceptible* and expected that the GSM mobile telephone would be *always useable* with this level of interference. The medium immunity hearing aid was judged to be *sometimes useable* with a *moderately perceptible* level of interference. The low immunity hearing aid was judged to be *not useable* in microphone setting with a *very annoying* level of interference.

In normal operation the transmit power of a 1750 MHz GSM digital mobile telephone is not always set to maximum as it can be controlled by the mobile network. In the initial study the mobile transmit power level was reduced by 14 dB below the maximum level. When placed near the base of the mobile antenna a hearing aid would require a medium, or better level of immunity to radio signals for communication using a hearing aid in microphone setting with a 1750 MHz GSM digital mobile telephone. For the low immunity hearing aid the results indicate that this level of immunity would not be satisfactory for hearing aid users as useful communication would only be possible some of the time.

In the initial study the spectral analysis of the interference produced in hearing aids in microphone setting by a GSM 1750 MHz digital mobile telephone showed that both odd and even harmonics of the 217 Hz repetition rate of the transmitted GSM signal were present. In cases where interference was severe the harmonics spread across the full audio spectrum of the hearing aid and were 30 to 40 dB above the background noise level. In cases where the interference was at a lower moderate level the harmonics were still present to above 6 kHz and at levels 20 to 30 dB above the background noise. In cases where the interference was at the *just perceptible* level the easily observable harmonics that were between 5 and 15 dB above the background noise level were noted mainly below 1500 Hz, however there were still some harmonics between 5 and 10 dB above the background noise level at higher frequencies. Whether the interference was caused by a GSM 1750 MHz digital mobile telephone at a distance from a low immunity hearing aid, or in a higher immunity hearing aid that was place closer to the mobile telephone, the spectral response of the interference was similar in all cases until the harmonics became buried in the background noise of the hearing aid.

Final Study Summary

The final research study investigated how interference in hearing aids caused by a GSM 1750 MHz digital mobile telephone is perceived and assessed by nineteen hearing aid users. Seventeen were wearing their own hearing aids. Also these subjective assessments were related to the technical measurements of the radiofrequency immunity of the hearing aids. Eighteen of the observers used in this study had hearing losses classified as mild, moderate or severe. The nineteenth observer had a moderate loss at 4 KHz.

The range of variation in the radiofrequency immunity levels for the hearing aids used in this study in both microphone and telecoil settings varied from a very low to very high level. Normally it would be expected that those hearing aids at the low end of the radiofrequency immunity scale would pick up a high level of interference from the GSM 1750 MHz digital mobile telephone and those hearing aids with a high immunity would have minimal interference from the test mobile. This proved to be the case when the hearing aid was in microphone setting. However when the hearing aid was in telecoil setting, the base band interference caused by the telecoil picking up the unwanted audio frequency magnetic field about the test mobile caused high levels of interference in the hearing aid when it was in close proximity to the GSM test mobile telephone. This resulted in hearing aids with high levels of immunity to

radiofrequency signals in telecoil setting not being able to be used for communication purposes by hearing aid users.

At a distance of 1 metre from the GSM 1750 MHz digital mobile telephone operating at maximum transmit power level only a few of the hearing aids tested were reported as having audible interference by the hearing aid test subjects. This applied when the hearing aid was in either the microphone or telecoil setting. Under these test conditions it was determined that the radiofrequency immunity levels for both microphone (ILM55) and telecoil (ILT25) should be between 14 and 17 dB re 1 V/m to ensure that the perceptible interference would be at the transition between *not perceptible* and *just perceptible*. This result confirms the level of 7 V/m, i.e. 16.9 dB re 1 V/m, which is used in the Australian Standard AS 1088.9 [2].

The distance from the GSM 1750 MHz digital mobile telephone operating at maximum transmit power level where the audible interference is at the *just perceptible* level has been called the limit of interference in this study. In microphone setting the hearing aids used in this study produced a limit of interference variation from a point where they were touching the GSM test mobile to a distance of 4530 mm as reported by the hearing aid users. In some hearing aids that were touching the test mobile telephone the interference was reported as being *not perceptible*. All of the hearing aids with a medium or better immunity to radiofrequency signals had a limit of interference between 0 and 35 mm as reported by the hearing aid users.

In telecoil setting the limit of interference ranged between 75 and 5000 mm. For those hearing aids with a medium or greater level of immunity to radiofrequency signals the limit of interference was reported by the hearing aid users to be between 75 and 370 mm. At closer distances to the test mobile telephone the interference was at a louder level due to the base band interference resulting from the unwanted audio magnetic fields about the mobile telephone.

In the final series of tests the hearing aid users held the GSM 1750 MHz digital mobile telephone operating at maximum transmit power level in the normal listening position in relation to their hearing aids. With hearing aids in microphone setting the hearing aid users reported the perceived interference to be between *very annoying* and *not perceptible* and rated the useability of the mobile telephone as either *not useable* or *always useable*. The results indicated that a hearing aid must have a high level of immunity to radio signals when a GSM 1750 MHz digital mobile telephone is used by a hearing aid user for communication purposes. The required ILM55 immunity level would be 40.4 dB re 1 V/m. The appropriate test field strength to use when testing hearing aids for use with 1750 MHz GSM digital mobile telephones would be 105 V/m, corresponding to 40.4 dB re 1 V/m. It is recommended that this test field strength be used in the C2 Classification of Australian Standard AS1088.9 [2] for the frequency range 1700 to 2000 MHz.

When the hearing aid was in telecoil mode and the mobile telephone operating at maximum transmit power level and held in the normal listening position the hearing aid users perceived the interfering sound as being *moderately perceptible*, *annoying* or *very annoying* and the useability rated generally rated as *not useable*, with a few *sometimes useable* and one anomalous *always useable* rating. The poor results in

telecoil setting were the result of base band interference as discussed in other sections of the report.

8 Conclusion

The waveguide test system designed to operate between 800 and 1000 MHz was successfully converted using a transition horn to operate in the 1700 to 2000 MHz radio band.

With the 1750 MHz GSM digital mobile telephone operating at full transmit power the initial preliminary study indicated that a hearing aid in microphone setting would require a high level of immunity to the transmitted radio signals for satisfactory communication by a hearing aid user.

Also the preliminary study indicated that the hearing aid with a medium level of immunity to radiofrequency interference provided protection against bystander interference at a distance of one metre from a 1750 MHz GSM digital mobile telephone operating at maximum transmit power. In addition a hearing aid with low immunity to radio signals could be affected by interference at distances over two metres from the GSM mobile telephone.

In the initial study the spectral analysis of the audible interference produced in hearing aids in microphone setting by a GSM 1750 MHz digital mobile telephone showed that both odd and even harmonics of the 217 Hz repetition rate of the transmitted GSM signal were present and spread across the audio band of the hearing aid.

The outcomes of the final study were based on the observations of nineteen people using hearing aids and allowed the observations of the preliminary study to be confirmed and quantised as well as extending the findings for telecoil operation.

With the 1750 MHz GSM digital mobile telephone operating at full transmit power the final study confirmed that a hearing aid in microphone setting would require a high level of immunity to the transmitted radio signals for satisfactory communication by a hearing aid user and recommends that the radiofrequency ILM55 immunity level should be greater than 40.4 dB re 1 V/m. It is also recommended that a test field strength of 105 V/m (i.e. 40.4 dB re 1 V/m) be used in the C2 Classification of Australian Standard AS1088.9 [2] for frequency range 1700 to 2000 MHz.

When the hearing aid was in telecoil setting, the base band interference caused by the telecoil picking up the unwanted audio frequency magnetic field about the test mobile caused high levels of interference in the hearing aid when it was in close proximity to the GSM test mobile telephone. This resulted in hearing aids with high levels of immunity to radiofrequency signals in telecoil setting not being able to be used for communication purposes by hearing aid users.

The final study confirmed that the hearing aid with a medium level of immunity to radiofrequency interference provided protection against bystander interference at a distance of one metre from a 1750 MHz GSM digital mobile telephone operating at maximum transmit power. This applied when the hearing aid was in either the microphone or telecoil setting. The corresponding radiofrequency immunity levels for both microphone (ILM55) and telecoil (ILT25) operation should be between 14 and 17 dB re 1 V/m. This result confirms the test field strength level of 7 V/m (i.e.

16.9 dB re 1 V/m) that is used in the C1 Classification of Australian Standards AS 1088.9 [2] for frequency range 1700 to 2000 MHz.

In microphone setting the hearing aids used in the final study produced a variation in the limit of interference from a point where they were touching the GSM test mobile to a distance of 4530 mm as reported by the hearing aid users. All of the hearing aids with a medium or better immunity to radiofrequency signals had a limit of interference between 0 and 35 mm as reported by the hearing aid users.

In telecoil setting the limit of interference ranged between 75 and 5000 mm. For those hearing aids with a medium or better level of immunity to radiofrequency signals the limit of interference was reported by the hearing aid users to be between 75 and 370 mm. At closer distances to the test mobile telephone the interference was at a louder level due to the base band interference resulting from the unwanted audio magnetic fields about the mobile telephone.

As a general comment the hearing aids currently available that were used in this study generally had a greater immunity to radiofrequency interference than those models generally available a decade or more ago. However, base band interference excluded use of telecoil mode for hearing aid users of GSM 1750 MHz digital mobile telephones.

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9 References

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