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Hearing Aid and Cellular Telephone Compatibility: Working Toward Solutions

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Abstract

The ability of hearing aid wearers to use cellular telephones using digital transmission formats has become a prominent issue. This article presents the requirements, technical challenges, and emerging standards for the combined use of hearing aids with cellular telephones.

Key Words: Hearing aids, radio frequency interference, telephones

Abbreviations: ANSI = American National Standards Institute, FCC = Federal Communications Commission, RF = radio frequency

Cellular telephones increasingly use digital transmission formats to gain a variety of advantages made available by these advanced signal encoding schemes. However, as with so many technical advances, there are also undesired side effects. A prominent example, which is currently getting a great deal of attention, is the interference potential that digital transmission formats have for many hearing aids. This article examines the causes of this interference and presents the solutions that are emerging to address it.

For a hearing aid to operate effectively with any telephone, including a cellular telephone, it must have two things: an input signal at the required level and a signal quality that is acceptably free of noise or interference. Some hearing aids offer a telecoil, also called a t-coil, mode, in which the hearing aid receives and amplifies the magnetic field produced by a telephone rather than the acoustic signal. So, for each reception mode of the hearing aid, the requirements of signal strength and signal quality must be met to ensure proper operation of the hearing aid. In the case of cellular telephones, a very important aspect of signal quality is the potential of the radio frequency (RF) transmission to interfere with the hearing aid circuitry. Logically, this is a subtopic of signal quality. However, because of its importance, in this article, the coordination of telephone RF emissions with hearing aid RF immunity will be treated as a third requirement. In summary, then, to ensure proper operation for a given reception mode, the requirements of signal strength, signal quality, and RF emission/immunity coordination must be met. Table 1 summarizes these issues.

This article will examine the issues presented by each of these requirements, the challenges and measurement techniques required to address them, and, finally, solutions that are emerging.

ACOUSTIC MODE CHALLENGES

In the acoustic mode, we begin with the requirement of adequate loudness. Because the delivery of speech is a basic requirement of cellular telephones, it can generally be assumed that there will be adequate loudness. In addition, cellular telephones almost universally provide user control of the loudness through the volume control feature.

The second requirement is signal quality. In general, cellular telephones provide superior signal quality. Background noise elimination circuits are commonly used and provide performance that is superior to landline telephones. However, because of the mobile nature of these products, noise in the user's environment presents a real challenge in some situations. Cellular telephones will be used in a much wider variety of environments than their landline cousins.

Finally, to have acceptable performance, the immunity of the hearing aid must match the

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Table 1 Operational Requirements

Acoustic Mode (Microphone Mode)	*Magnetic Mode (T-Coil Mode)*
Adequate acoustic volume	Adequate magnetic field intensity
Low background noise	Acceptable magnetic signal-to-noise ratio
Coordinated RF emissions and immunity	Coordinated RF emissions and immunity

RF emissions present in the area of the telephone in which the hearing aid is being used. This is the most significant challenge for the acoustic mode of operation. Hearing aids do not have any legal requirement for RF immunity. In Europe, the European Telecommunications Standards Institute is working with the European Hearing Instrument Manufacturers Association to establish a 3 V/m requirement and test standard, IEC 60118-13 (International Electrotechnical Commission, 1997). Because there has been no mandatory requirement, hearing aids with a very broad range of immunity to RF can be found on the market.

The emissions of the telephone are largely determined by the licensed operating power. Typically, cellular telephones are licensed to transmit with 1 or 2 watts of RF power. As the antenna and receiver are typically located near the top of the telephone, a hearing aid will most often be used very close to the base of the antenna. In this area, intense RF fields can be expected. It is not uncommon to find telephones and hearing aids that have a 30- to 40-dB gap between their emissions and immunity (European Hearing Instruments Manufacturers Association, 1995; Joyner, 1993). It is this difference that allows for the audio rectification and the resulting "buzz" commonly experienced by hearing aids used with cellular telephones.

T-COIL MODE CHALLENGES

In the case of the t-coil mode, the challenges are similar but have their own uniqueness. The t-coil was originally developed for use with analog telephones. When this mechanism was developed, the receiver elements in almost all telephones produced large magnetic leakage fields. These fields could be received and translated into the intended speech signal. However, newer technologies are much more energy efficient and produce correspondingly lower magnetic field levels. Some technologies produce almost no magnetic field. To ensure an adequate magnetic field signal level, additional circuitry is required. This raises issues of additional cost, complexity, and reduced battery life.

Magnetic field signal quality is a much more formidable issue than acoustic signal quality. In the traditional landline telephone, the receiver element is the only electronic component in the handset capable of producing a magnetic field. However, in a cellular telephone, there are a lot of electronics in the handset, all in very close proximity to the receiver element. Battery surge currents, power supply components, keyboard scanning, and display refresh cycles all can create magnetic fields that add noise to the desired signal. With the increasingly small size of cellular telephones, all of these functions operate in very close proximity to each other.

Several research studies have been conducted to quantify the signal-to-noise requirement. Data indicate that a 20- to 26-dB signal-to-interference ratio is a good range for normal use. This conclusion is supported by the primary research studies in this area. The three primary North American studies have been performed by the University of Oklahoma, Dr. Levitt of City University of New York with Dr. Harkins of Gallaudet University, and Dr. Killion of Etymotic Research with Harry Teder. The research focus and protocol of each study were different. However, the conclusions of these studies have shown remarkable consistency on the fundamental issues involved. Further work is under way to refine this range to a single number, defining the level for normal use. A 10-dB degradation, to a range of 10 to 16 dB, yields a system that could be characterized as usable, but inadequate for regular use. Alternatively, an improvement of 10 dB, to a range of 30 to 36 dB, yields an excellent performance level, where there is little discernible noise or interference.

The third element is the coordination of the RF emissions and immunity. This issue is identical for the two modes except that different circuit elements are involved in the t-coil and acoustic modes.

MOVING TOWARD SOLUTIONS

To deal with this problem, two kinds of equipment, cellular telephones and hearing aids, developed by two entirely different industries, must be designed as a single system. To accomplish this, the critical parameters must be identified and specifications developed that each equipment manufacturer will follow. In this way, the immunity of the hearing aids can be matched to the emissions of the telephone so as to deliver to the user the intended performance.

Early in 1996, the Federal Communications Commission (FCC) called together a summit among the hearing industry, the wireless industry, and consumers to resolve the compatibility issue between hearing aids and cellular telephones. As a result of those efforts, in the spring of 1996, the American National Standards Institute (ANSI) ASC 63 formed task group C63.19 to develop a measurement standard for hearing aid compatibility with wireless communication devices. The goal of this task group was to develop a set of tests that would evaluate the compatibility of hearing aids with cellular telephones. This technical undertaking came to include three research projects and over 90 engineers from more than 50 different companies working together on the standard.

SYSTEM COORDINATION

As ANSI C63.19 is drafted (ANSI 2001), the standard uses a categorization system that is based on coordinating the characteristics of a hearing aid and cellular telephone. The users will decide the level of performance that they require and then obtain the equipment that delivers that performance. By using a categorization system, improvement can come from either the telephone side or the hearing aid side of the equation.

To be intelligible, the signal delivered to the user must have an acceptable signal-to-noise or signal-to-interference ratio. Three performance categories are used, which may be characterized as usable, acceptable for normal use, and excellent performance.

The target performance is then parameterized and allocated between the system components, the telephone, and hearing aid. A general division must be made between the E and H field performance of the equipment so a target immunity for both the E and H fields must be set for the hearing aid. These immunity targets must be coordinated for both near-field E and H field of the radiating device in the area controlled for the use of the hearing aid.

In ANSI C63.19, an area 5 cm square, which is subdivided into nine subareas, is evaluated for use by a hearing aid (Fig. 1). This area is defined as being 1 cm from the surface of the telephone over the area of the receiver. The field strength in this area is to be scanned using near-field probes for both the E and H fields. Because the area is deep within the near-field of the antenna, sharp field gradients and RF "hot spots" are common. Up to fourfold field variations can be found within this 5-cm-square area. The standard requires that the center square and five other connecting squares meet the performance requirements. This allows for isolated "hot spots" near the antenna, while requiring that 75 percent of the area be at or below the prescribed level.

Hence, when telephones provide fields at or below the emission limits and hearing aids exhibit immunities at or above the immunity targets, the required audio performance will be delivered.

Table 2 summarizes these results and guides the user in equipment selection. The user begins by deciding on the level of performance required. Each category, usable, normal use, and excellent performance, is determined by the delivered signal-to-interference ratio. So if the need is only to use a telephone infrequently, such as for emergency situations, a telephone and hearing aid of the lowest category, U1, will be adequate. By increasing either the telephone or hearing aid by one performance category, to U2,

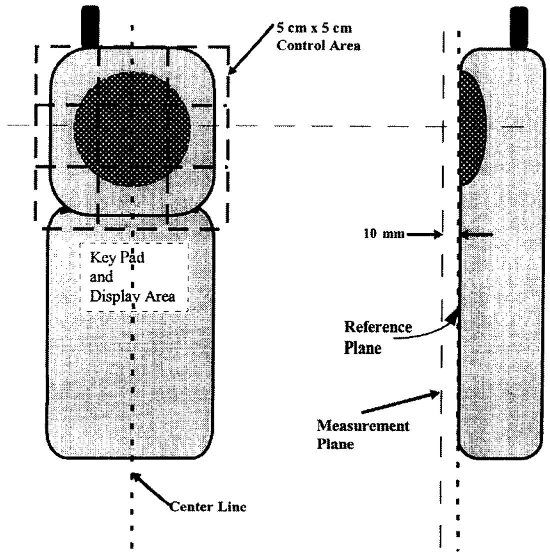

Figure 1 Control area for hearing aid use.

Table 2 System Performance Classification

System Description	*Signal-to-Interference (dB)*	*Hearing Aid U Category*	*Telephone U Category*
Usable	10–16	U2 or higher	U2 or higher
Normal use	20–26	U1 or higher	U4 or higher
Normal use	20–26	U3 or higher	U2 or higher
Excellent performance	30–36	U2 or higher	U4
Excellent performance	30–36	U3 or higher	U3 or higher
Excellent performance	30–36	U4	U2 or higher

a system for normal use results. Increasing either piece of equipment by two categories, to U3, or by increasing both by one category, to U2, results in an excellent performance level. In this way, maximum flexibility is provided to users in their equipment choices.

A similar table is used for the t-coil mode. The U designation has a T added to it if the piece of equipment is also rated for the t-coil mode. So, for normal use, a telephone or hearing aid of category U3T should be used, with the other piece of equipment being U2T or higher.

It should be noted that the lowest category limit imposes stringent requirements on the equipment it governs. A U1 or U1T rating is a rigorous requirement. No level of system performance can be ensured when unrated equipment is used. This is true even when that equipment is used with a corresponding piece of equipment of the highest rating.

The advantages of this system are numerous. First, it deals realistically with a user's current situation. A user who owns either a telephone or hearing aid and is buying the other can get the performance he or she desires by obtaining a higher category in the new piece of equipment. Although it remains true that performance with unrated equipment cannot be ensured in the general case, it can be tested in particular cases. A user can simply test the new product with their current telephone or hearing aid. Care should be taken that the telephone is in its maximum power transmission mode when making such a comparison. So, for example, a person who owns a telephone and is buying a new hearing aid can try a category U1, U2, or U3 hearing aid to get the performance he or she desires.

A second advantage is that this system allows for various hearing aids and cellular telephone technologies to implement solutions on different schedules. There are many different types of hearing aids and cellular telephones. Different technologies are involved in each industry. In addition, various companies have different schedules for the development and introduction of new products. If a single-limit approach had been adopted, in a one-size-fits-all approach, it would inevitably have been poorly adapted to all but a select group of products in each industry. On one extreme, any given limit would have been too demanding for some technologies. A single limit would have severely disadvantaged some technologies and product types, which might be very useful for other advantages that those products offered. On the other extreme, different technologies would not have been challenged enough. Some product types can be brought to much higher performance levels and should be challenged to do so. The categorization system allows this diversity to take place.

EARLY SOLUTION

To provide a complete solution, a system must meet the requirements listed in Table 1 of coordinated emission and immunity and an appropriate signal strength, with good signal quality. The earliest solutions offered have been in the form of accessories to standard products and specialized products. Several headset or neckloop devices are on the market that offer acoustic output and an enhanced magnetic field output. These products, by their nature, place a distance between the telephone and the hearing aid. This simple mechanism effectively deals with the RF interference problem. The RF gradient is extremely large in the area close to the antenna. As has been said, a change of only 5 cm has been measured in some models to reduce the field strength by a factor of four. So the normal separation distance provided by such accessories is more than sufficient to deal with the interference problems.

Other types of solutions are being vigorously pursued. High-immunity hearing aids are already on the market. One of the most promising developments in this area is the introduction of hearing aid components with immunity features built in. Early in the FCC summit process, a technology exchange began between the cellular telephone industry and the hearing aid industry. Part of this exchange was the offering of assistance by RF specialists from the telephone industry. RF protection is most effective if built directly into sensitive circuit components such as amplifiers and microphones. Today, there are commercially available components with decoupling capacitors built into them. Some product demonstrations have shown hearing aids with only two additional capacitors built into the appropriate components that are usable with major classes of cellular telephones.

USER CONTROLLABLE OPTIONS

The research performed to date demonstrates that educated users can materially improve their situation. At least four important parameters are under the user's control: equipment selection, maximization for acoustic reception, minimization of the RF field, and cross-orientation of the emitter and reception circuit. ANSI C63.19 was written to allow categories of equipment. When properly matched, the user will receive the desired performance. However, the user needs to know that properly matched equipment is required and that improperly matched equipment will often fail to meet expectations. The effective dissemination of user education material will be an important part of the final solution for this effort.

The maximum acoustic field is typically at the center of the handset receiver. For best reception, this is where the hearing aid microphone should be located. For many hearing aids, especially the behind-the-ear types, the user may not hold the equipment for best reception. In the behind-the-ear hearing aid, the microphone is either above or behind the ear. If the user holds the handset in the normal position, with the receiver centered on the user's ear, the microphone is not receiving the best acoustic signal. Simply holding the handset so that the receiver and microphone are centered, rather than the receiver and the ear being centered, can do a lot to improve reception.

The third thing that the user can do is to avoid RF "hot spots." Many handsets have hot spots, especially around the antenna and the feed to the base of the antenna. The RF fields change very rapidly around these areas. Holding the telephone so that a hearing aid is just a little further from a high field area can make a lot of difference. In many cases, this means having the hearing aid on the far side of the receiver from the antenna.

Orientation is a third factor. When the antenna or other RF emitter is lined up with the sensitive circuit in a hearing aid, maximum interference will occur. On the other hand, when these two elements are cross-polarized, then a lot of reduction in the interference can be realized. A rotation of a few degrees can yield a significant reduction.

SUMMARY

The development of wireless telephones and hearing aids that can be effectively used together is being vigorously pursued by both the hearing instrument and wireless telephone industries. The requirements of such a system are set forth in the measurement requirements of ANSI C63.19. One of the new factors in the wireless telephone environment, which is different from the traditional landline telephone, is that these telephones must emit RF to operate. Hence, the requirement is to coordinate the immunity of the hearing aid with the electromagnetic environment in which it must operate.

In t-coil mode, the need to coordinate the RF environment with the hearing aid's immunity also exists. In addition, the telephone must deliver an audio frequency magnetic signal of an amplitude and signal quality so as to be usable by the hearing aid.

Significant advances have been made on each of these fronts. The most sensitive circuits within hearing aids have been analyzed, and various techniques have proven effective in improving the immunity. In some cases, component suppliers to the hearing aid industry are incorporating solutions at the component level. In a similar vein, much research has been focused on the nature of the electromagnetic field created around the receiver section of the telephone. Various remedies have been explored. Headset and neckloop devices, special antennas, and other products are already on the market. Research has been announced investigating remedies such as special battery designs that reduce power supply noise currents, special antennas, and RF shielding to create a protected area for the use of the hearing aid. However, this issue is more complicated because the transmission of RF energy is a necessary function of wireless telephones. This is unlike the case for hearing aids, where the reception of RF energy into the audio circuits is an unintended effect, so anything that reduces the RF reception in hearing aids in a cost-effective and producible manner can be used. However, changes to the RF environment of the receiver area of the telephone must be carefully coordinated with the specifications for signal transmission to the base station.

For the t-coil mode, the primary focus has been on reducing the unwanted emission in the audio frequency band and increasing the desired signal in an attempt to improve the signal-to-interference ratio. Emission sources such as battery surge currents, keyboard scan, and display currents are all being addressed. Various techniques are applied such as improved layout to reduce circuit loop size and increased decoupling on primary current paths. Considerable improvements are being reported in this area.

The ever-increasing use of electronics creates de facto systems that must operate acceptably. However, these systems may not be under the control of a single company or even a single industry. The case discussed here of wireless telephones and hearing aids is a case in point. There is a societal desire that these devices operate well together. However, to accomplish this goal, significant technical barriers must be overcome. This article has discussed the challenges that must be met to achieve the desired system performance.

Significant efforts are under way to develop compatible products both in improved hearing aid immunity and wireless telephone signal quality. Solutions are already beginning to appear on the market on both the hearing aid and the telephone side of the equation.

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