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RF Interference in Hearing Aids from Cellphones Part 1: Near-field cellphone emissions measurements and the effects of hands

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Abstract

Cellular telephones (cellphones) are currently categorized for hearing aid compatibility based on a calculated value (metric) obtained from the measurement of near-field, radio-frequency emissions according to a procedure described in ANSI Standard C63.19 “Measurement of Compatibility between Wireless Communications Devices and Hearing Aids”. There has been a lack of documentation, however, that relates this metric to a cellphone’s potential for interference in actual use, that is, when it is held at the ear in a normal-use position by a hearing aid wearer. In Part 1 of this two-part series, we compare the ANSI C63.19 metric to simpler metrics, still based on the near-field test procedure of the standard, and to near-field measurements made when the cellphones are hand-held. The results justify employing a simpler no-hand metric than the exclusion area procedure presently specified by the standard, but not the addition of a test hand to the procedure. The further effect of the head and interaction with the hearing aid is examined in Part 2 of the series.

Index Terms

cellular phones; electromagnetic interference; hearing aids; mobile antennas; near-field radiation pattern; specific absorption rate

I. Introduction and Background

According to a study conducted in 2008, there were approximately 34.25 million Americans with hearing loss [1]. This number is expected to rise because the percentage of older adults in the U.S. population is rising [2] and because older individuals experience hearing loss at a higher rate than younger individuals [3]. Compact transistorized hearing aids have been in use by individuals with hearing loss since the 1950’s. The introduction of digital cellular telephones (cellphones) in the mid-1990s created a problem for hearing aid users. When cellphones are in close proximity to hearing aids, audible radio frequency interference (RFI)

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may occur. The primary cause of this RFI is the rectification of the audio frequency amplitude modulation (AM) envelope by various semiconductor junctions [4] within the hearing aid. The interference may be heard as a buzzing noise through the wearer's hearing aid [5]. Although any transmission that includes some degree of audio frequency AM can induce audio frequency interference, the modulations most likely to produce audio frequency interference are those that employ some form of time division multiplexing. A prime example is GSM [6] modulation, which pulses with a 1/8 duty cycle at a 216.7 Hz repetition rate.

Interference does not occur with all combinations of cellphones and hearing aids. However, when audio interference does occur, it can cause annoyance, can make understanding speech difficult, and may render normal use of the cellphone impossible for the hearing aid user [7]. Partial solutions, such as inductive neck loops or wired connections from the cellphone to the hearing aid are possible but greatly decrease the ease of use that makes the cellphone so popular [8]. In response to the need for a better solution, work soon commenced both on addressing the technical issues and developing standards to ensure sufficient compatibility so that hearing aid users could successfully use cellphones. References [9], [10], and [11] review early work in these areas. In Europe, hearing aid RF immunity standards were established in International Electrotechnical Commission (IEC) 60118-13 [12]. In the United States, the Institute of Electrical and Electronic Engineers (IEEE) and the American National Standards Institute (ANSI) set up a working group to develop a standard addressing the compatibility problem between cellphones and hearing aids. In contrast to IEC 60118-13, which addresses just hearing aid performance through minimum RF immunity standards, ANSI standard C63.19 [13] categorizes both hearing aids for their immunity to RF interference and wireless devices generally, cellphones in particular, for their propensity to induce audio frequency noise through evaluation of their near-field RF emissions. From these independent emissions and immunity measurements, some prediction of the net interference when a cellphone is used next to a hearing aid can be developed.

In an earlier paper [14] we discussed hearing aid immunity measurements taken in the plane wave approximation of a GTEM (gigahertz transverse electromagnetic) cell as specified in ANSI C63.19 and IEC 60118-13, and an alternative tuned dipole near-field method also specified in ANSI C63.19. The paper proposed an improved variant of the GTEM-based immunity tests that more effectively found a hearing aid's immunity at its worst-case orientation to the applied field. Of practical necessity, neither the hearing aid immunity tests nor the specified cellphone emissions test are performed with the cellphone or hearing aid in their normal use positions, with the head and a hand present, even though these factors can be expected to exert a strong effect.

In Part 1 of this two part series, we take a closer look at the free-space near-field emissions scanning measurement specified in ANSI C63.19 to investigate whether a simpler metric might be as appropriate, and, very significantly, the effect that a hand has on the near-field emissions. A further considered step of measuring the fields with a cellphone in place on a head was not practical to attempt, due to the close spacing of the phone to the head and the intermediate structures of the outer ear and the hearing aid. We expected to find, and did find that simply holding a cellphone, even away from the head, can drastically alter the shape and

magnitude of its near field. The effect of the hand has not heretofore been considered in relation to EMC testing for hearing aid compatibility, in contrast to the somewhat similar case of testing for specific absorption rate (SAR) measurements of cellphones, where numerous investigators have found that the hand can have a substantial influence. In fact, CTIA has proposed a hand phantom for use in cellphone SAR compliance testing [15].

Part 2 of the series will examine the effects of hands and the head on the relation between actual in-use RF coupling and coupling predictions based on the independent emissions and immunity measurements, and whether attempts to quantify near-field changes due to hands contribute to the accuracy of in-use hearing aid interference prediction.

II. Near-field scanning according to C63.19

ANSI C63.19-2011 categorizes wireless devices via the following method. The cellphone (the primary wireless device of interest) is placed in an appropriate operating mode at full power. The root-mean-square (rms) average of the electric near-field, or E-field, is measured, typically by means of a 3-axis probe, in a plane 15 mm above and parallel to the surface of the cellphone at its acoustic output. The E-field is measured every 5 mm or less in a square 50×50 mm, centered over the acoustic output (AO). This scanning is typically accomplished through the use of robotic scanning equipment, as shown in Fig. 1. The measurement process is commonly referred to as scanning the cellphone, and the measured values as scan data. Earlier versions of the standard [16] specified both E- and H-field scanning, but the most recent version specifies only E-field scanning, as the H-field scans were deemed not to add significant value. We characterize both fields in this study.

The 50×50 mm grid of samples is divided into nine (3×3) subgrids that are dimensionally equal but may contain different numbers of samples, as illustrated in Fig. 2. Each subgrid is assigned the value of the highest E-field reading it contains. The three contiguous subgrids on the periphery of the 3×3 matrix with the highest readings are excluded; this is called the exclusion area. The highest value from the six remaining subgrids is then converted to decibels relative to 1 V/m, dB (V/m). To account for the different AM characteristics of the many possible cellphone transmission protocols and their differing audio interference-producing potentials, a protocol-specific Modulation Interference Factor (MIF), in dB, is added to the dB (V/m) to arrive at the final value used to determine the rating category according to Table 8.3 of the standard. The criteria for determining the MIF for any given cellphone transmission protocol were developed based primarily on a study of hearing aid users' subjective speech-to-interference needs and preferences [17] and will be discussed more in Part 2. There are four categories, each separated by 5 dB (V/m). Category 1 is for the highest measured MIF-modified E-fields; phones in this category are considered the most likely to interfere with any given hearing aid. Category 4 is for the lowest measured MIF-modified E-fields; phones in this category are considered the least likely to interfere with any given hearing aid.

The reduction of the entire scanned grid to nine subgrids and the exclusion of three of them may seem an awkward method to arrive at a single metric for the cellphone's potential to interfere with a hearing aid. When the C63.19 working group first developed this method,

cellphones tended to have external antennas with a potential RF hotspot near their base that could be avoided by the user. This method allowed for exclusion of that region, as long as it was not centrally located over the acoustic output. Our measurements will shed light on whether this measurement complication and its rationale still have merit, yielding an increased ability to predict hearing aid interference in comparison to simpler metrics.

III. No-Hand Scans

A. Performing the scans

Scans were performed on eight cellphones – Nokia E71, 6310; Motorola L6, V60, Z6; Blackberry 7230, 8110; and Samsung Slider. These models represent common cellphone configurations such as “candy bar”, clamshell, PDA (personal digital assistant), and slider styles. (Newer “smartphone” styles were not in common use at the beginning of this study, but should not differ substantially from the candy bar and PDA styles.) All phones used the GSM protocol. Employing a Schmid & Partner Engineering AG (SPEAG) DASY5 system, including a model ER3DV6 E-field probe and a model H3DV7 H-field probe, we sampled the 50×50 mm scan grid with 5 mm resolution at a height of 15 mm above the phone surface, producing an 11×11 (121 data points) matrix. We scanned at 10 and 20 mm heights, in addition to the specified 15 mm height, for additional near-field characterization. All scans were performed in an open RF environment with negligible reflections or absorption in relation to the small separation distance between the cellphone and the measurement probe. The cellphones were controlled via a base station simulator, Rhode & Schwartz Digital Radio-communication Tester CMD55, which set the desired frequency and maintained the cellphones at maximum transmit power. To insure the cellphones’ batteries were at full charge, the cellphones were continuously charged when not being scanned. No cellphone was scanned more than 15 minutes before being recharged. Testing was carried out at the facilities of the Center for Devices and Radiological Health of the United States Food and Drug Administration, Silver Spring, Maryland.

Each cellphone was scanned at three frequencies – 890.2, 1784.8, and 1850.2 MHz – and in accordance with the procedures in ANSI C63.19. These frequencies were selected as part of the larger study where cellphone-elicited hearing aid interference would be measured. The cellphone emissions and the hearing aid immunity, therefore, needed to be measured at the same carrier frequencies, preferably including both the low and high cellphone bands. Most modern hearing aids have been engineered to exhibit good overall RF immunity, and the candidate hearing aids generally responded most strongly only at specific frequencies. Through experimentation, the hearing aids and test frequencies to be used were selected together to enable clear interference responses at specific GSM channels. 890.2 MHz is the lowest frequency of the Primary GSM-900 band (uplink channel 1); 1784.8 MHz is the highest frequency of the GSM 1800 band (uplink channel 885); and 1850.2 MHz is the lowest frequency of the GSM 1900 band (uplink channel 512). The resultant 24 E-field and 24 H-field scans (8 phones $\times$ 3 frequencies) produced the “no-hand” scan data for each scan height.

B. Effect of Scan Height

Varying the scan height 5 mm above or below the 15 mm reference height resulted in approximately ± 1 dB field strength variation in either E or H-field, as shown in the histogram of Fig. 3, which plots the differences from the 15 mm measurements at each grid location for all of the phones at the three frequencies. These differences are small and consistent compared to other variations that were encountered, so only the 15 mm height data will be utilized in the following analyses.

C. Comparing no-hand scan metrics

We examined fifteen other potential metrics for categorizing cellphones. These metrics are all averages over square regions of different sizes (from 1 to 5 cm on a side) and different sample spacings (from 0.5 to 5.0 cm). Each metric is the average of a unique subset of the 121 measured values in one scan. All fifteen metrics produced values in a narrow range so only three are shown for comparison in Figs. 4a and 4b. The average of all 121 scanned points was chosen as the reference for all comparisons. Also included, for comparison, are the minimum and maximum points over the scan area referenced to this average. For each comparison in this and subsequent graphs, means (horizontal red bars), standard deviations (vertical green bars), and overall ranges (vertical blue bars) are shown.

The C63.19 exclusion area result, which is defined only for the E-field, gives results about 2 to 3 dB greater than the simple average and just a bit less than the absolute maximum. For both the E and H-fields, taking a 36-point average over the entire scan grid, with the considered scan points spaced at 1 cm instead of 0.5 cm, yielded almost no changes from the full 121-point average. Reducing further to a 9-point average over the entire scan grid, with the considered points spaced at 2.5 cm, yields results within about 1 dB of the 121-point average. Evidently, the scan spacing could be increased with little effect. Even averaging over just the 25 points of the center 2 cm-square around the phone's acoustic output yields little difference compared to the 121-point average. The primary effect of the different calculations is minor offsets in the results. Lacking any justification for a different metric, the 121-point full-scan average will be used as the no-hands reference result in the succeeding analyses, unless otherwise noted.

A change from the present C63.19 exclusion area metric to the simple 121-point average would result in fairly consistent ratings shifts, relative to the C63.19 rating categories. Figs. 5a and 5b illustrate this for the tested low-band and high-band frequencies, respectively. The plotted values for the eight phones are the measured rms E-field metrics in dB (V/m) increased by the +3.3 dB MIF of GSM modulation. The phones are ordered according to their exclusion area-measured values in each frequency band. The consistent 2 to 3 dB difference between the exclusion area metric and the average metric is evident. Offsetting the ratings categories 2 to 3 dB would essentially remove any difference in ratings based on the two metrics.

IV. With-Hand Scans

Several papers [18, 19, 20] have reported that the human hand is the major cause of cellphone antenna loading, which significantly perturbs the near-field distribution around the cellphone.

A. Performing the scans

Each of the 48 scans was repeated, at just the 15 mm height, with the cellphone held in the left and right hands of two different volunteer subjects. Table 1 compares the major hand and wrist dimensions of our subjects to the dimensions of the CTIA hand phantom [15]. Subject K's hands were smaller in each of the six specified linear dimensions by 2% to 14%, while subject J's hands were larger in each dimension by 4% to 23%. Generally, subject K employed a light, fingertip grip, while subject J employed a closer, more encompassing grip, as can be seen in Figs. 6a and 6b. While every effort was made to ensure consistency of grip between scanning and later normal-use positioning on a head (discussed in Part 2 of this series), the individual grips for each phone varied according to the comfortable holding styles for each subject. Actual users change their grip for different phones and even while using one phone [18–23]. The subjects wore no rings or jewelry on their hands or arms. The subjects' hands were supported by low dielectric materials to minimize motion during the scan. Scans were done only at the 15 mm height. Each scan was less than 4 minutes duration. These 96 scans produced the “with-hand” scan data for both subjects.

B. With-Hand Data Pooling

A two-way ANOVA of our 16 E-field metrics (C63 plus the 15 potential metrics initially examined) with subjects (K or J) as one factor and the subjects' hands (left or right) as the other factor showed no significant difference between the left- and right-hand means for each subject ($F[1, 1532] = 0.359$, $p = 0.548$), but significant difference between the two subjects ($F[1, 1532] = 473$, $p < 0.001$). This indicates that the metrics were affected by the hand/grip differences of the subjects, but were not affected consistently by a subject's use of the left- or right-hand. Therefore, the with-hand data analyses pooled the left-and right-hand data for each subject for the same cellphone and frequency, but kept the data for the two subjects separate.

V. Comparing with-hand to no-hand scans

A. Changes in field shape, magnitude

Holding the cellphones resulted in dramatic changes to both the magnitude and the distribution of the near-fields. Figs. 7 and 8 present surface plots showing the changes in the scanned E- and H-fields from the no-hand to the with-left-hand condition for both subjects for one of the tested cellphones at one frequency. Typically, the effect of the hands is to significantly attenuate the measured near-field.

The shifting location of the field maximum is one indication of the strong effect of the hand. Figs. 7D and 8D illustrate how the presence of the hands changes the locations and magnitudes of the maxima of the E- and H-fields for the example cellphone. An overall view

of the shifts of the E-field maximum locations from the no-hand condition to the with-hand condition for all eight phones at the tested low band frequency (890.2 MHz) and one of the two tested high band frequencies (1850.2 MHz) can be seen in Fig. 9a when held by each hand of subject K and Fig. 9b when held by each hand of subject J. Very significant field shape changes can be inferred from these location shifts. A general movement of the maximum locations away from the central region towards the edges is evident. The mean shift for all three tested frequencies for subject K's hands is 1.7 cm, and for subject J's hands, is 2.9 cm. Only four of the 24 no-hand E-field scans have maximum locations on the scan area periphery, while subject K's hands move 20 of the 48 scan maximum locations to an edge. Subject J's hands show an even stronger effect, positioning 31 of the 48 scan maximum locations on the scan area periphery.

B. Relating the with-hand central average

In use, the cellphone is placed near the hearing aid such that the phone's acoustic output is close to the hearing aid's microphone. This is also generally the most potentially RF-sensitive region of the hearing aid, with the most following gain. The primary emissions concern, then, should presumably focus on the cellphone's in-use near-field RF emissions at and around its acoustic output. Fig. 10 relates the with-hand near-fields, both E and H-fields, averaged over a 2 cm square centered on the acoustic output (25-point average) to the corresponding nohand 121-point averages. While the hands can, in a few instances, modestly increase the central field compared to the full-scan average, generally, the effect of a hand is to significantly reduce the field in the region of interest. The larger hand of subject J shows a much stronger effect than the smaller hand of subject K. It is apparent that the no-hand scan can give only the most general, albeit conservative, indication of the field in the region of interest when the cellphone is hand-held.

VI. Conclusions

To evaluate a cellphone's potential for eliciting hearing aid RF interference, ANSI C63.19 presently specifies an exclusion area procedure for determining the relevant E-field magnitude from a no-hand, near-field scan over a 5 cm $\times$ 5 cm area centered 15 mm above the cellphone acoustic output. This procedure, which emphasizes the importance of the central scan region, implicitly assumes that the field shape and strength will not show large changes from the measurement condition in actual use. We have shown that the addition of a hand generally does result in dramatic changes to the near-field shape and strength.

Comparison of the C63.19 exclusion area results to potential simpler no-hand metrics showed closely related results among them, not revealing a preference for any particular one of the metrics examined. However, the metrics based on simple averages of areas centered on the cellphone's acoustic output are easier to understand and implement, and require the same or fewer measurements. A wide measurement area would still seem to be desirable so that all important areas of the field are sampled. The full scan area average chosen as our reference is typically just 2 to 3 dB lower than the corresponding exclusion area calculation.

While acknowledging the potentially large and variable effect of hands, we do not recommend moving to with-hand scans for qualification measurements. This

recommendation is justified for a number of reasons: no-hand scans are easier to conduct and replicate; there is no movement or grip variability, which is an issue with both human and phantom hands; and in the vast majority of cases a no-hand scan will produce a higher (more conservative) measure of the near-field than the corresponding with-hand scan. This is analogous to the situation seen in SAR measurements of cellphones for human exposure compliance, where the dominant factor is the cellphone H-field. The IEEE recommended practice for measuring the peak spatial-average SAR in a human head phantom excludes the hand in order to provide a conservative estimate of the peak spatial SAR associated with the use of a mobile phone for the significant majority of persons [24]. Further, the large number of grips and finger positions makes it difficult to specify a standard hand phantom [23].

There are still more pieces of the puzzle to fill in to determine what any such near-field measurements may mean in relation to the RF interference that couples to a hearing aid in actual use. We have not yet considered the effect of the head and the combined interaction of the cellphone, the hand, the head, and the hearing aid's effective RFI susceptibility in its normal-use environment. Part 2 of this series will conclude with an empirical and statistical view of the relationship between the discussed cellphone near-field scan measurements, hearing aid immunity measurements, and the actual effective RFI coupling in normal use.

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Biographies

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Linda K. Kozma-Spytek received the B.S. and the M.A. degrees from Washington University, St. Louis, MO, in 1981 in speech and hearing sciences and in 1989 in communication arts, respectively. She worked at Central Institute for the Deaf from 1981–1988 in education and research. From 1988–1996, she worked as a research associate in the Center for Auditory and Speech Sciences at Gallaudet University. In 1998, she received her certificate of clinical competence in audiology. Since 1998, she has worked in the Technology Access Program at Gallaudet University as a research audiologist. Currently, she is the co-director of the Rehabilitation Engineering Research Center on Technology for Individuals who are Deaf or Hard of Hearing. Her research interests include issues related to telephone compatibility with hearing devices and voice telecommunications accessibility for individuals with hearing loss. She has contributed to both ANSI and TIA standards and has authored or co-authored papers published in a variety of speech and hearing journals. Ms. Kozma-Spytek is a member of the American Speech Language Hearing Association. In 2005, she received an award from the Hearing Loss Association of America for her work in telecommunications accessibility for hard of hearing people.

Stephen D. Julstrom (M'11) studied electrical engineering at the University of Iowa, 1970–1973. He worked at the Univ. of Iowa School of Music Recording Studio, 1978–1981, supervising students, teaching music recording, and designing a laser projection art control system. From 1981–1992, he was an engineer at Shure, Inc., where he designed wired and wireless microphone circuitry, automatic microphone control and teleconference systems, and surround sound encoders and decoders. Since 1993, he has operated as Julstrom Consulting and Development, Chicago, Illinois, providing research and design services in primarily audio and acoustic-related fields. He has contributed to several ANSI and TIA

standards, has published papers in engineering and audiology journals, and holds 20 patents. In 2011, he received the President's Award from the Hearing Loss Association of America.

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Fig. 1.
A dedicated robotic system is typically used to scan the grid of Fig. 2.

Fig. 2. The 121-sample scan grid 15 mm above a typical cellphone. The red diamonds (◆) and square (◻) are measured points, the square is directly above the Acoustic Output (AO) of the cellphone. The green lines illustrate how the scanned values are partitioned into the 9 subgrids required by the C63.19 standard.

Fig. 3.

Histogram showing the differences in field strength level (dB) of all 121 scan points for all eight phones and three frequencies taken at heights above the phone surface of 10mm and 20mm, compared to the 15mm height (bin size 0.5 dB).

Fig. 4.

Comparing several E-field (Figure 4a) and H-field (Figure 4b) metrics derived from the 5 cm $\times$ 5 cm grid near-field scan to the 121-point full-scan averages for the eight phones at three frequencies ($n = 24$ in each category). Means (horizontal red bars), standard deviations (vertical green bars), and overall ranges (vertical blue bars).

a *b***Fig. 5.**

Comparing the MIF-modified ANSI C63.19 exclusion area and 121-point E-field average metrics, relative to the C63.19 rating categories' (M2-M4) upper limits and ordered according to their exclusion area-measured values at the low-band 890.2 MHz frequency (Figure 5a) and the high-band 1784.8 MHz frequency (Figure 5b).

a *b*

Fig. 6. With-hand near-field scans were performed with the small-hand, fingertip grip of subject K (Figure 6a) and the large-hand, encompassing grip of subject J (Figure 6b).

Fig. 7.

The electric field measured 15 mm above a Motorola Z6 cellphone at 1784.8 MHz. 7A is without a hand, 7B is with Subject K's left hand, and 7C is with Subject J's left hand. 7D illustrates the changes in the location and magnitude of the maximum in the scan for the left and right hands of both subjects. (Circle areas are proportional to field strength.)

Fig. 8.

The magnetic field measured 15 mm above a Motorola Z6 cellphone at 1784.8 MHz. 8A is without a hand, 8B is with Subject K's left hand, and 8C is with Subject J's left hand. 8D illustrates the changes in the location and magnitude of the maximum in the scan for the left and right hands of both subjects. (Circle areas are proportional to field strength.)

Fig. 9.

Each arrow represents the movement of the location of the E-field maximum within the scan area for each of the eight tested phones at 890.2 MHz (black) and 1850.2 MHz (orange) from its nohand position to its position when held by each hand of subject K (Fig. 9a, $n=32$) and subject J (Fig. 9b, $n=32$). (Some arrows are hidden under other arrows.)

Fig. 10.

Comparing the central 25-point 2 cm-square field strength average taken with the subjects' left and right hands to the no-hand 121-point average for the eight phones and three frequencies, and both E and H-fields ($n = 48$ in each category). Means (horizontal red bars), standard deviations (vertical green bars), and overall ranges (vertical blue bars).

Table 1

Major hand and wrist dimensions of our two subjects compared to the CTIA hand phantom dimensions as defined in [15].

Major Hand & Wrist Dimensions (mm)	Subject K	CTIA Phantom	Subject J
Wrist Width	58	61.4	64
Wrist Circumference	160	162.9	181
Hand Length	161	186.5	211
Hand Circumference	193	200.2	235
Palm Length	100	105.7	130
Hand Width	81	85	95