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American National Standard for Methods of Measurement of Compatibility between Wireless Communication Devices and Hearing Aids

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American National Standards Institute

Secretariat

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Abstract: Uniform methods of measurement for compatibility between hearing aids and wireless communications devices are set forth in this standard.
Keywords: American National Standard, electromagnetic compatibility, hearing aid, hearing aid compatibility (HAC), measurement methods, operational compatibility, personal communications service (PCS), wireless communications device

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Introduction

(This introduction is not part of ANSI C63.19-2001, American National Standard for Methods of Measurement of Compatibility Between Wireless Communications Devices and Hearing Aids.)

In the fall of 1995, the Federal Communications Commission (FCC) initiated a steering committee to initiate a summit on hearing aid compatibility and accessibility to digital wireless telecommunications. The goal of the summit was to formalize and continue discussions among the three key affected interests in this issue; organizations representing people with hearing loss, hearing aid manufacturers, and the digital wireless telephone industry. The ultimate purpose of the summit was to find a resolution of the interference problem that was acceptable to the industries involved.

A summit meeting was held on January 3–4, 1996, in Washington, D.C. At this summit meeting, three working groups were formed to pursue issue resolution. Subsequently, the long-term solutions user and bystander interference group reached a consensus that a standards project was needed to document the consensus definition of and method of measurement for hearing aid compatibility and accessibility to wireless telecommunications. Subsequently, ANSI C63 was petitioned to undertake the joint standards projects documenting the methods of measurement and defining the limits for hearing aid compatibility and accessibility to wireless telecommunications.

At its April 1996 meeting, ANSI C63 established a task group under its subcommittee on medical devices (SC 8). The charge to this task group (TC C63.19) was to develop such standards in cooperation with representatives of organizations representing people with hearing loss, hearing aid manufacturers, the digital wireless telephone industry, and other interested parties. This document is the result of that committee's efforts.

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American National Standard for Methods of Measurement of Compatibility between Wireless Communication Devices and Hearing Aids

1. Overview

1.1 Scope

This standard applies to both wireless communications devices (WD) and hearing aids. It sets forth uniform methods of measurement and parametric requirements for the electromagnetic and operational compatibility and accessibility of hearing aids used with wireless communications devices, including cordless, cellular, and Personal Communications Service (PCS) phones, operating in the range of 800 MHz to 3 GHz. However, this version is focused on existing services, which are in common use. Accordingly, in this version tests are provided for services in the 800–950 MHz and 1.6–2.0 GHz frequency bands. Future versions may add tests for the 2.4 GHz or other frequency bands, as they come into more common use.

This standard is intended to apply to all types of hearing aids with acoustic output, including (as examples): behind-the-ear (BTE), in-the-ear (ITE), in-the-canal (ITC), and completely-in-the-canal (CIC) types. Test methods are provided for hearing aids operating in acoustic (microphone input) mode or in T-coil input mode.

The field levels called for in various places shall be maintained within the limits for RF safety, set forth in IEEE Std C95.1, 1999 Edition.[1]

1.2 Purpose

The purpose of this standard is to establish categories for hearing aids and for WDs that can indicate to health care practitioners and hearing aid users which hearing aids are compatible with which WDs, and to provide tests that can be used to assess the electromagnetic characteristics of hearing aids and WDs and assign them to these categories. The various parameters required, in order to demonstrate compatibility and

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accessibility, are measured. The design of the standard is such that when a hearing aid and WD achieve one of the categories specified, as measured by the methodology of this standard, the indicated performance is realized.

In order to provide for the usability of a hearing aid with a WD, several factors must be coordinated:

a) Radio frequency (RF) measurements of the near-field electric and magnetic fields emitted by a WD to categorize these emissions for correlation with the RF immunity of a hearing aid.
b) Magnetic field measurements of a WD emitted via the audio transducer associated with the T-coil mode of the hearing aid, for assessment of hearing aid performance.
c) Measurements with the hearing aid and a simulation of the categorized WD T-coil emissions to assess the hearing aid RF immunity in the T-coil mode.

The WD's radio frequency (RF) and audio band emissions are measured. Hence, the following are measurements made for the WDs:

a) RF E-Field emissions
b) RF H-Field emissions
c) T-coil mode, magnetic signal strength in the audio band
d) T-coil mode, magnetic signal and noise articulation index
e) T-coil mode, magnetic signal frequency response through the audio band

Corresponding to the WD measurements, the hearing aid is measured for:

a) RF immunity in microphone mode
b) RF immunity in T-coil mode

The hearing aid T-coil reception characteristics are also important when assuring the usability of the T-coil mode. When these characteristics are coordinated, the goals of compatibility and accessibility are accomplished.

Two principal conditions expose hearing aid equipped users to undesired RF electromagnetic disturbances. The far-field condition corresponds to the type of field a hearing aid equipped bystander would experience when adjacent to a WD user. The near-field condition corresponds to the more intense fields that a hearing-aid-equipped user of a WD would experience. This standard assesses the near-field or user condition.

This standard describes preferred test methods and test facilities and, in some cases, alternative test methods and facilities. If alternative test methods or facilities are employed, every effort shall be made to establish correlation with the preferred ones. Any deviation from the preferred test methods, as set forth in this standard, shall be fully described in the test report.

Wherever the term *shall* is used in this document, it indicates something mandatory. The term *should* indicates something that is advisory.

1.3 Organization and use of the document

These technical requirements define the measurement methods and categorical levels to ensure hearing aid operational compatibility with wireless devices (WD).

To ensure hearing aid and WD compatibility, it is essential that uniform measurement methods be defined for hearing aid immunity to electric and magnetic fields and WD emission of electric and magnetic fields. In addition, in order to provide for T-coil mode, the WD T-coil signal must be evaluated for signal strength, intended/unintended signal ratio and the frequency response of the signal in the audio band.

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There are several factors impacting hearing aid performance when used in the presence of a WD. The hearing aid can be exposed to near-field illumination (when the hearing aid user uses a WD) or to far-field illumination (when the radiating element is at a distance from the hearing aid user). Different styles of hearing aids (BTE, ITE, ITC, and CIC) are positioned differently with respect to the WD. WDs can operate at different frequencies and utilize different transmission schemes.

Hearing aids can operate in an acoustic coupling mode or a T-coil coupling mode. In acoustic mode, hearing aids use a microphone to pick up acoustic sound waves generated by the WD. In T-coil mode, the microphone output is disabled (or attenuated) and a magnetic field signal, generated by the WD, becomes the signal source. During T-coil operation the magnetic field generated by the WD is intended to be the primary coupling mechanism to the hearing aid. The WD also can produce unintended magnetic fields (the result of circulating currents). Such magnetic fields produce noise, if detected during T-coil operation, or may introduce interference in hearing aid circuits, even in the acoustic mode.

The WD generates an electromagnetic field as the main communication means with the public telephone network. However, it is possible for this field to interfere with the hearing aid's proper operation. Interference is produced as a result of pickup and demodulation within the hearing aid circuitry. The goal is to control the electric and magnetic field distribution such that levels in direct proximity to the hearing aid (with WD in normal position) are manageable and do not interfere with basic hearing aid functionality.

The technical requirements have been organized into nine general clauses. The following is the summary of each clause:

Clause 1—Overview: describes the scope and purpose of the document.

Clause 2—References: references used in this standard.

Clause 3—Definitions, acronyms, and abbreviations: definitions, acronyms, and abbreviations used in this standard.

Clause 4—Wireless device, RF emissions test: prescribes the measurements of the near electric (E) and magnetic (H) fields generated by pulsed RF wireless communications devices (WD) in the region controlled for use by a hearing aid.

Clause 5—Hearing aid RF near-field immunity test: prescribes the measurement method to be used in determining the immunity level of a hearing aid to radiated electromagnetic fields originating from a WD.

Clause 6—Wireless device audio band, magnetic emission test: describes the WD audio band magnetic emission measurement. Two quantities are measured—the desired and undesired magnetic field levels.

Clause 7—Performance: provides the criterion required for acceptable interoperability of a hearing aid with a WD. When these criteria are met, as defined by the tests described in this standard, a hearing aid operates acceptably with a WD. The performance criterion for the T-coil mode, which is contained in 7.3.1 and 7.3.2, are a recommended, but not mandatory, portion of this standard. Hence, the mandatory portion of this standard is the set of parameters governing the acoustic or microphone mode of operation.

Clause 8—Calibration and measurement uncertainty: provides guidance for estimating the uncertainty and reproducibility of measurements made in accordance with this standard.

Clause 9—Test report: outlines the general requirements of the test report and follows the similar arrangement described in Clause 10 of ANSI C63.4-1992.

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Figure 1 depicts the organization and use of this standard. Both the WD and hearing aid have mandatory tests (Clause 4 and Clause 5) and optional tests (for the T-coil mode, Clause 6). The appropriate test is run for each device and a category is determined, using the parameters found in Clause 7. The category information is then made available to the end user. Using the category information from both a WD and hearing aid, the end user is able to determine the performance to be expected from any particular WD and hearing aid combination. Clause 8 and Clause 9 provide guidance on calculating the measurement uncertainty and preparation of the test report. The test report is delivered to the relevant authority, requiring the testing.

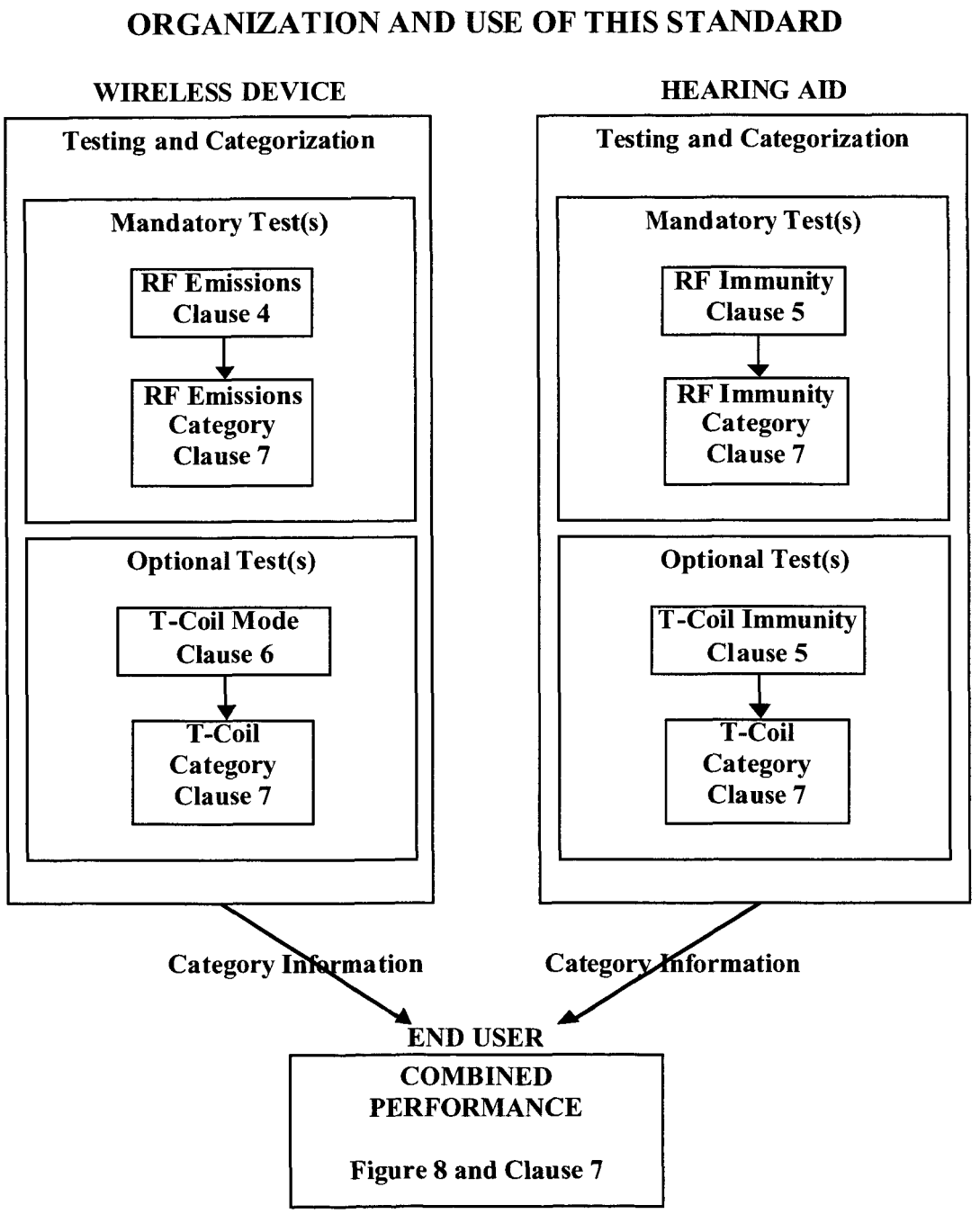


Figure 1—Organization of this standard

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The measurements of WD emissions and hearing aid EMC are performed fairly close to the source of these emissions, where small errors in instrumentation, EM field measurements, and hearing aid position can manifest in large uncertainties in measurement results. Clause 8 describes the uncertainties involved in these measurements and instrument calibration procedures to control these.

This standard also contains several informative annexes with additional information about the measurements, instrumentation, calibration of instruments, and uncertainty of the measurements.

This standard is intended to provide a measure of the compatibility between hearing aid devices and WD products. The device categories are based on testing with hearing aid devices in the laboratory and in actual use. However, there is a wide range of human perception of normal communications with WD or even wired communications. Thus, even when compatibility between a particular hearing aid and WD is indicated by these tests, it cannot be guaranteed that the vocal output of the WD will be intelligible to all users of the two devices.

2. References

The following references shall form a part of this standard to the extent that they are referenced herein. When any of the references are superseded by a revision, the version specified in this document shall apply.

ANSI C63.2-1996, American National Standard for Electromagnetic Noise and Field Strength Instrumentation, 10 Hz to 40 GHz—Specifications.[2]

ANSI C63.4-1992, American National Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz.

ANSI C63.5-1998, American National Standard for Electromagnetic Compatibilty—Radiated Emission Measurements in Electromagnetic Interference (EMI) Control—Calibration of Antennas (9 kHz to 40 GHz).

ANSI C63.14-1998, American National Standard Dictionary for Technologies of Electromagnetic Compatibility (EMC), Electromagnetic Pulse (EMP), and Electrostatic Discharge (ESD) (Dictionary of EMC/EMP/ESD Terms and Definitions).

ANSI S3.5-1969, American National Standard Methods for the Calculation of the Articulation Index.

ANSI S3.7-1995 (R1999), American National Standard Method for Coupler Calibration of Earphones.

ANSI S3.22-1996, American National Standard Specification of Hearing Aid Characteristics.

ANSI S3.25-1979, American National Standard Occluded-Ear Simulator.

Draft ANSI S3.79, American National Standard Methods for the Calculation of the Speech Intelligibility Index.[3]

EIA RS-504-1983, Magnetic Field Intensity Criteria for Telephone Compatibility with Hearing Aids.[4]

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FCC 47 CFR 2, Frequency Allocation and Radio Treaty Matters; General Rules and Regulations (1997).[5]

FCC 47 CFR 15, Radio Frequency Devices (1997).

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IEC 61000-4-3:1998, Electromagnetic Compatibility for Electrical and Electronic Equipment—Part 4: Testing and Measurement Techniques—Section 3: Radiated, Radio Frequency, Electromagnetic Field Immunity Test.

IEC 61094-1 (1992-06), Measurement Microphones—Part 1: Specifications for Laboratory Standard Microphones.

IEC 61094-2 (1992-03), Measurement Microphones—Part 2: Primary Method for Pressure Calibration of Laboratory Standard Microphones by the Reciprocity Technique.

IEC 61094-3 (1995-11), Measurement microphones—Part 3: Primary Method for Free-Field Calibration of Laboratory Standard Microphones by the Reciprocity Technique.

IEC 61094-4 (1995-11), Measurement Microphones—Part 4: Specifications for Working Standard Microphones.

IEC 711:1981, Occluded-Ear Simulator for the Measurement of Earphones Coupled to the Ear by Ear Inserts.

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IEC 60318-2 (1998-08), Ed. 1.0, Electroacoustics—Simulators of human head and ear—Part 2: An interim acoustic coupler for the calibration of audiometric earphones in the extended high-frequency range.

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IEEE Std 269-1992, IEEE Standard Method for Measuring Transmission Performance of Telephone Sets.

IEEE Std 291-1991, IEEE Standards Methods for Measuring Electromagnetic Field Strength of Sinusoidal Continuous Wave, 30 Hz to 30 GHz.

IEEE Std 299-1991, IEEE Standard for Measuring the Effectiveness of Electromagnetic Shielding Enclosures.

IEEE Std 661-1979, IEEE Standard Method for Determining Objective Loudness Ratings of Telephone Connections.

IEEE Std 1027-1996, IEEE Standard Method for Measurement of the Magnetic Field in the Vicinity of a Telephone Receiver.

IEEE Std 1028-1996, IEEE Recommended Practice for RF Absorber Performance Evaluation in the Range 30 MHz to 5 GHz.

IEEE Std 1309-1996, IEEE Standard Method for the Calibration of Electromagnetic Field Sensors and Field Probes, Excluding Antennas, from 9 kHz to 40 GHz.

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IEEE Std C95.3-1991 (R1997), IEEE Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields—RF and Microwave.

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ITU-T, Blue Book, Volume V, Telephone Transmission Quality Series P Recommendations, Recommendation P.37-1993, Magnetic Field Strength around the Earcap of Telephone Handsets which Provide for Coupling to Hearing Aids. [10]

ITU-T, Blue Book, Volume V, Telephone Transmission Quality Series P Recommendations, Recommendation P.50-1993, Artificial Voices.

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TIA/EIA/IS-91, Mobile Station-Base Station Compatibility Standard for 800 MHz Analog Cellular (Oct. 1994).

TIA/EIA/IS-95, Mobile Station-Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System (July 1993).

TIA/EIA/IS-136.1, 800 MHz TDMA Cellular-Radio Interface—Mobile Station-Base Station Compatibility —Digital Control Channel (Dec. 1994).

TIA/EIA/IS-136.2, 800 MHz TDMA Cellular-Radio Interface—Mobile Station-Base Station Compatibility —Traffic Channels and FSK Control Channel (Dec. 1994).

TIA/EIA/IS-137, 800 MHz TDMA Cellular-Radio Interface—Minimum Performance Standards for Mobile Stations (Dec. 1994).

TIA/EIA/IS-138, 800 MHz TDMA Cellular-Radio Interface—Minimum Performance Standards for Base Stations (Dec. 1994).

TIA/EIA TSB31-A, Part 68—Rationale and Measurement Guidelines (March 1992).

3. Definitions, acronyms, and abbreviations

3.1 Definitions

Definitions in ANSI C63.14-1998 and IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition [B13], apply throughout this document, unless otherwise noted in the definitions in 3.1 of this standard. Particular product standards or applicable regulation definitions take precedence. Definition sources (if applicable) are enclosed in brackets following the definition.

3.1.1 accessibility: The capability of a wireless communications device (WD) used together with a hearing aid device to provide the audibility and intelligibility needed for communication.

3.1.2 articulation weighting factor: A weighting factor that is used to normalize readings of interference from differing sources based upon the acoustic spectral content of the interference. As one example, interference created by a 217 Hz TDMA source degrades hearing intelligibility by approximately 5 dB more than

[11]NIS standards are published by NAMUS (UKAS) and may be ordered from UKAS, National Physical Laboratory, Teddington, Middlesex, TW11 OLW, England; Tel. 011-81-943-7140, FAX 011-81-943-7134.

[12]For information on how to purchase NIST publications, contact the Superintendent of Documents, US Government Printing Office, Washington, DC 20402, USA.

[13]TIA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/).

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that from a 50 Hz TDMA signal. This is because of the relative impact of the 217 Hz interference signal on the regions of the audio spectrum that are most important to speech recognition.

3.1.3 audio coupling mode: Transmission of a signal between two pieces of equipment using sound.

3.1.4 audio frequency: Any frequency corresponding to a normally audible sound wave.

NOTES:

1) Audio frequencies range roughly from 15 hertz to 20,000 hertz.

2) This term is frequently shortened to audio and used as a modifier to indicate a device or system intended to operate at audio frequencies, for example, audio amplifier.

3.1.5 audio band: The frequency range from 15 hertz to 20,000 hertz (*see also:* **audio frequency**).

3.1.6 audio band magnetic signal—desired (ABM1): Measured quantity of the desired magnetic signal.

3.1.7 audio band magnetic signal—undesired (ABM2): Measured quantity of the undesired magnetic signal, such as interference from battery current and similar non-signal elements.

3.1.8 audio band magnetic (ABM) articulation weighting factor (AWF): Audio band magnetic AWF from ABM1 and ABM2.

3.1.9 band: Frequency range between two defined limits.

3.1.10 compatibility: The capability of a wireless communications device (WD) and a hearing aid, used together, to provide the user with the audibility and intelligibility needed for communication. The more specific term *T-coil compatibility* means that the coupling of the WD signal to the hearing aid T-coil meets the requirement set forth in this standard.

3.1.11 digital wireless telephone: Radio-frequency-based wireless telephones utilizing digital transmission formats over an air interface.

NOTE—Generally these are devices regulated under Parts 22 and 24 of the Rules of the Federal Communications Commission. Annex G contains a more detailed discussion of these devices.

3.1.12 directional coupler: A transmission coupling device for separately (ideally) sampling (through a known coupling loss for measuring purposes) either the forward (incident) or the backward (reflected) wave in a transmission line.

3.1.13 emission bandwidth (B): The signal width, in Hertz, between two points, one below the carrier center frequency and one above the carrier center frequency, that are 26 dB down relative to the maximum level of the modulated carrier. It is based on the use of measurement instrumentation employing a peak detector function with an instrument resolution bandwidth approximately equal to 1.0 percent of the emission bandwidth of the device under measurement. [Extraction from FCC 15.303(c)]

3.1.14 far-field region: That region of the field of an antenna where the angular field distribution is essentially independent of the distance from a specified point in the antenna region.

NOTES:

1) For a half-wavelength dipole, the reference point is usually taken as the center of the antenna, but may be anywhere on the surface of the antenna.

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2) For a half-wavelength dipole, the far-field region is considered to exist at distances much greater than $\lambda/2\pi$, where λ is the wavelength. For a half-wavelength dipole, this distance is at the geometric center of the transition region between the near-field and far-field regions.

3) The distance 3λ is considered to lie in the far-field region.

3.1.15 forward power: That power supplied by the output of an amplifier (or generator) traveling towards a load. [SAE J551/1]

3.1.16 hearing aid: A professionally dispensed, wearable, air-conduction, sound amplifying device that is intended to compensate impaired hearing.

3.1.17 input referenced interference level (IRIL): The equivalent acoustic input sound pressure level (typically at 1 kHz) that would produce the same acoustic output in a hearing aid as that produced by a RF interference source. IRIL may be obtained by subtracting the acoustic gain in dB from the acoustic interference output.

3.1.18 intentional radiator: A device that intentionally generates and emits radio frequency energy by radiation or induction. [FCC 15.3(o)]

3.1.19 measurement reference point: Generally, the center of the earpiece receiver speaker openings. Physical location may be offset from earpiece center, if a secondary induction source is used.

NOTE—Wireline phones referenced this as ERP (ear reference point); this conflicts with the use of ERP as effective radiated power.

3.1.20 near-field region: That part of space between the antenna and the far-field region.

NOTES:

1) The near-field includes the quasi-static and induction fields varying as r^{-3} and r^{-2}, respectively, but does not include the radiation field varying as r^{-1}.

2) For a half-wavelength dipole, the near-field region is considered to exist at distances much less than $\lambda/2\pi$, where λ is the wavelength.

3) For a very short dipole, or equivalent radiator, the outer boundary is commonly taken to exist at a distance of $\lambda/2\pi$ from the antenna surface.

4) For the purposes of this standard, the near-field is considered to be a distance of no more than 1/5 of a wavelength from the WD at the operating frequency. Therefore, the near-field is calculated to be 7.5 cm for 800 MHz, decreasing to 2 cm for 3 GHz.

3.1.21 net power: Forward power minus reflected power at the same location on a transmission line. [SAE J551/1]

3.1.22 personal communications service device: Intentional radiators operating in the frequency band specified by the applicable regulating agency that provide a wide array of mobile and ancillary fixed communication services to individuals and businesses. [Modification of FCC 15.303(g)]

3.1.23 reflected power: That power traveling towards the amplifier (or generator) reflected by a load caused by impedance mismatch between the transmission line and load. [SAE J551/1]

3.1.24 sound pressure level (SPL): The sound pressure level, in decibels, of a sound is 20 times the logarithm to the base 10 of the ratio of the pressure of this sound to the reference pressure.

NOTE—For this standard the reference level shall be 20 μPascals.

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3.1.25 tele-coil (T-coil): An inductive coil used in some hearing aids to allow reception of a magnetic field signal, instead of an acoustic signal. The magnetic or inductive mode of reception is commonly used in conjunction with telephones, auditorium loop systems and other systems that provide the required magnetic field output.

3.1.26 transverse electromagnetic (TEM) cell: A measuring device that is designed to utilize the transverse electromagnetic (TEM) mode over the frequency range of interest. Common examples are the two port TEM cell (also known as the Crawford Cell) and the wideband TEM cell.

3.1.27 wideband TEM (WB TEM) cell: A TEM cell that has been altered to extend the usable frequency range. Often this is achieved by replacing one port of a two port TEM cell with a wideband load. One example is commonly called a GTEM.

3.1.28 wireless communications device (WD): A communications device using radio frequency energy. These devices are used in a wireless communications networks such as cellular or personal communication service.

3.2 Acronyms and abbreviations

ABM	audio band magnetic
ABM1	audio band magnetic signal—desired
ABM2	audio band magnetic signal—undesired
AGC	automatic gain control
AM	amplitude modulation
ANSI	American National Standards Institute
AWF	articulation weighting factor
BTE	behind the ear (hearing aid)
CDMA	code division multiple access
CFR	Code of Federal Regulations
CIC	completely in the canal (hearing aid)
CW	carrier wave
DAI	digital audio interface
dB	decibel
dB SPL	decibels referenced to a sound pressure level of 20 μPascals
EHIMA	European Hearing Instrument Manufacturers Association
ETSI	European Telecommunications Standards Institute
f	frequency
GSM	global system for mobile
i.d.	inside diameter
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IRAN	input referred ambient noise
IRIL	input referred interference level
ISO	International Organization for Standardization
ITC	in the canal (hearing aid)
ITE	in the ear (hearing aid)
NADC	North American Digital Cellular
o.d.	outside diameter
OSPL	output sound pressure level
P	transmit power or forward power (Watts)
PC	personal computer
PCS	personal communications services
Q	quality factor

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RF	radio frequency
RMS	root mean square
Rx	receiver
SPL	sound pressure level
T-coil	tele-coil
TDMA	time division multiple access
TEM	transverse electromagnetic
Tx	transmitter
VSWR	voltage standing wave ratio
WB TEM	Wideband transverse electromagnetic
WD	wireless communications device

4. Wireless device, RF emissions test

This clause provides guidance on the measurements of the near electric (E) and magnetic (H) fields generated by wireless communications devices (WD) in the region controlled for use by a hearing aid. Clause 5 sets forth the companion measurement—the immunity of the hearing aid. For the purposes of this standard, the term *pulsed* refers to the use of a non-continuous RF envelope or carrier. Examples of wireless telephone systems of this type are described in Annex G. These systems may be deployed at a variety of RF frequency ranges, but this standard is restricted to the range of 800 MHz to 3 GHz. Additionally, it is generally considered sufficient to measure a particular pulsed RF WD at the frequencies at which the WD is capable of transmission as part of its normal operation, as specified by the manufacturer. However, the evaluation need not be limited to those frequencies.

4.1 Test equipment and facilities

Portions of this standard place requirements on the test facilities, in addition to the general requirements of ANSI C63.4-1992, and are discussed below, as well as in C.1. Unless stated otherwise, the requirements of ANSI C63.4-1992 apply to the test facilities, including the site design, dimensions, and validation. Additional site validation requirements above 1 GHz are currently under development.

The stability of the measurement equipment, facilities and setup can significantly affect the accuracy of the measurement. Therefore, it is important that a careful review be made of the factors affecting measurement uncertainty, as described in Clause 8 and Annex E of this standard. Efforts made to reduce the measurement uncertainty improve the stability and reproducibility of the measurement.

4.1.1 Test equipment

Subclause 4.1.1 provides a list of the test equipment required to perform this test. The test equipment used shall meet the applicable specifications of Annex D.

a) E-field, near-field probe
b) H-field, near-field probe
c) Probe positioning system
d) WD support
e) RF enclosure

4.1.2 Near-field measurement system

The near-field measurement system shall consist of a small (with respect to a wavelength) electric field probe and a magnetic field probe, suitable for measuring the field strength of the RF fields without significantly perturbing the fields generated by the WD. Typically, such probes are constructed of low dielectric

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plastics and utilize high-resistance conductors to deliver the measurement information from the active element to the measurement equipment.

IEEE Std C95.3-1991 advises that to avoid certain measurement errors, a probe should not be used closer than a distance equal to 3 times the length of the active elements of the probe. Because of the required 1 cm measurement distance, the active elements of these probes shall be less than the smaller of either 0.33 cm or 0.1 of a wavelength in their largest dimension at the frequency of measurement.

The probes shall be calibrated to a measurement uncertainty of no worse than ±2 dB. Probe calibration in accordance with IEEE Std 1309-1996 is discussed in C.3 of this standard.

A method for holding and moving the probes close to the WD is also required. This mechanism shall be capable of a sufficient accuracy and repeatability in position so as to guarantee a measurement uncertainty within ±2 dB; also, this mechanism shall minimally perturb the RF fields to be measured. Therefore, it is recommended that all parts of the probe holding and movement mechanism be made using RF-transparent materials, or be kept at a distance so as to not degrade the measurement accuracy.

The use of an automated movement system, such as robotic arms or three-axis positioners, is preferred, as it can provide superior probe placement accuracy and placement repeatability. However, each system used shall be verified as having the required placement accuracy and repeatability. Alternatively, manual placement systems may be used. It is recommended that a placement fixture be used with manual systems to assist in accurate probe placement. Such a fixture should be constructed of expanded foam or other RF-transparent materials.

4.2 Test setup and validation

4.2.1 Test setup

The WD shall be supported in such a way that there are no RF reflecting objects within a distance of at least 2 wavelengths at the frequency of measurement, or at a distance such that the total reflections from these objects is kept at least 20 dB below the desired direct signal. The purpose of a 2 wavelength distance to the nearest RF reflection object is to maintain at least a 20 dB reflection loss due to these objects. If it is not practical to measure the reflection loss, then the 2 wavelength spacing rule may be used. The WD and measurement probe shall be contained within a shielded enclosure conforming to C.1.1. Support structures such as expanded foam and low dielectric constant plastics may be used for supporting the WD. The region of the WD that is to be in close proximity to a hearing aid during normal operating conditions shall be available for access by the measurement system.

4.2.2 WD setup and use

In actual use, the wearer of a hearing aid would place the WD in a position that gives the best acoustic coupling from the WD to the hearing aid. In other words, the WD would be located so that the user could best hear the WD desired acoustic output. This would typically be with the speaker of the WD in close proximity to the microphone of the hearing aid. This is likely to be true for all types of hearing aids. For the purposes of this standard, it is assumed that the proximity of the WD and the hearing aid meet this assumption. For this reason a 5 cm by 5 cm region—1 cm from surface of the WD—is controlled, so as to be usable by a hearing aid. This region begins at the top of the WD housing and covers the WD receiver area. It is centered about the center line of the WD. See Figure A.2 for further details.

The WD shall be operated at its maximum RF output power, and at the normal operating temperature and voltage, as specified by the manufacturer. To assure WD operation at maximum RF output power automatic power control shall be disabled. Since the presence of wires or conductors in the close vicinity of the WD will disturb the RF fields, the WD should also be operated solely under its own power source, with no exter-

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nal connections unless specifically required by the manufacturer for normal operation. It is assumed that the user of a WD will operate the device in a manner that is consistent with the recommendations of the manufacturer with regards to maximum efficiency of the WD. Some WDs have more than one antenna position (for example, stowed and deployed). In such cases, it is only necessary to test the WD in the condition of maximum antenna efficiency, as defined by the manufacturer. This is considered to be the normal operation for the WD. If the fields were found to be higher at another antenna position, the results would be of little concern as the user of the WD would simply have to move the antenna to the more efficient position to reduce the field strength at the hearing aid. However, in cases where the advertised category can only be achieved in certain user controllable configurations it is very important that the consumer be properly informed. Therefore, when the category advertised can only be achieved in certain antenna position(s) or other user configuration instructions are required, these conditions shall be reported with the assigned category in the user documentation, label, or other locations where the category information is communicated to the user.

4.3 Near-field test procedure

The electric field probe, and, separately, the magnetic field probe, are to be used to measure the highest field strength in the 5 cm by 5 cm scan surface. The average field strength,[14] measured over many pulse cycles, may be measured, with the peak then being calculated from the measured average value and the known duty cycle of the WD.

The 5 cm by 5 cm area is divided into nine subgrids (see the diagram in Figure A.2). Three contiguous subgrids on the perimeter may be excluded from the measurement. This allows for RF "hot spots" that can easily be avoided in actual use.[15] The highest reading found in the area defined by the middle subgrid and the five remaining subgrids determines the category rating. The field probe is carefully moved through the measurement area and the maximum reading is located. In order to accurately scan the entire 5 cm by 5 cm area, the center of the probe shall be moved through this area. Accordingly the total area covered by the outside edge of the probe shall be the 5 cm by 5 cm area, increased by half (1/2) the probe diameter on all sides. The method of displaying the data is not important as long as good measurement techniques are followed and the resultant highest field strength is obtained.

The distance from the WD reference plane to the nearest point on the probe element shall be 1.0 cm. The WD reference plane is a plane parallel with the front "face" of the WD and containing the highest point on its contour. The probe element is that portion of the probe that is designed to receive and sense the field being measured. The physical body of the probe housing shall not be used when setting this 1.0 cm distance as this would place the sensing elements at an indeterminate distance from the reference plane. Although it is theoretically possible to measure at almost any distance and calculate the equivalent field strengths at 1.0 cm, it is not recommended as these calculations are very difficult and prone to errors.

In the case of a field probe that may have less than three orthogonal elements, it is necessary to rotate the probe to obtain the measurement. Two methods may be used. In the preferred method, the probe shall be rotated in three dimensions for maximum alignment and the reading at maximum field alignment used. An alternative method is to rotate the probe about its geometric center so as to obtain measurements in all three mutually orthogonal orientations. The geometric center is the point that is physically located at the center of the electromagnetic sensing element of the probe. This may be determined from physical measurements, or

[14]Many field probes have relatively slow response times and cannot measure the peak field strength in a time varying RF signal. Therefore, the reading is an average of the peak field, averaged over the response time of the probe.

[15]The presence of RF "hot spots," typically at the base of the WD antenna, presented a particular problem for the committee. At these locations, extreme field amplitudes are found but these extremes fall off very quickly, often being a fraction of the peak value in less than a cm. In addition, it is unclear that these areas transfer proportionate power in reality, due to their responsiveness to loading effects. In practical use, a user can shift the WD slightly and find a location of good acoustic output while avoiding such RF "hot spots." Representatives of consumers, WD, and hearing aid manufacturers discussed this issue at length in the committee and concluded that allowing for a RF "hot spot" exclusion was important in finding a solution which met the requirements of users and was realistically achievable by all parties.

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from field pattern measurements during calibration. The maximum field shall be the vector sum of all three individual mutually orthogonal measurements. Note that even when using three element probes, the probe may be rotated so as to align one element for maximum field coupling. When this is done the reading of the single, maximally aligned element is used as the field reading at that location. Readings taken in this manner are preferred over those taken with the non-aligned method because of the greater accuracy. However, when the alignment method is used, the probe shall be realigned at every measurement point.

4.3.1 Detailed near-field test procedure example

4.3.1.1 Pre-test procedure

The steps listed here shall be performed before the WD near-field emissions test is performed. However, these steps need not be performed before every test. They shall be performed periodically, consistent with good laboratory practice and as required, for example, before testing types of WDs not assessed previously at a laboratory.

1) Calibrate E- and H-field probes for peak reading of the modulation used by the intended WD (see Annex C).
2) Check for probe positioning system repeatability and accuracy.
3) Confirm interference of reflective objects is less than –20 dB of the intended signal. This may be done by performing the same measurements on the same WD using multiple WD positions and orientations. The readings shall not differ, due to reflections, by more than ±0.8 dB.

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Pre-Test Instructions

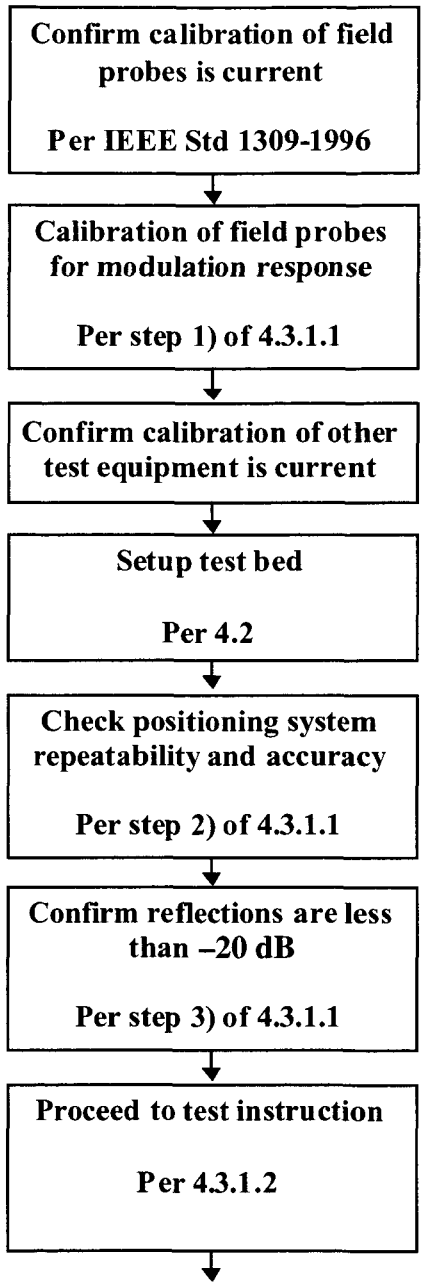


Figure 2—WD near-field emissions pre-test flowchart

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4.3.1.2 Test procedure

The following are sample step-by-step test procedures. Other comparable procedures may be used.

4.3.1.2.1 Manual scanning method

When performing the test manually, a test fixture shall be used to improve positioning accuracy. Such a fixture shall be constructed from low dielectric materials, such as foam plastic, which do not significantly affect the readings being taken. An example of such a test fixture is shown in Figure 4. In this fixture, permissible exclusion blocks are used to isolate the six subgrids used for the evaluation. The permissible exclusion block is shaped in such a way as to close off three of the subgrid areas. Thus, the six areas to be used to determine the WD's peak emissions are identified and outlined for the final manual scan.

1) Confirm the proper operation of the field probe, the probe measurement system, and other instrumentation.

2) Position the WD in its intended test position.

3) Configure the WD operation for maximum rated RF output power, at the desired channel and other operating parameters, as intended for the test.

4) Perform an initial scan of the 5 x 5 cm area.

   The physical opening in the test fixture shall be wider than the 5 x 5 cm area by half the diameter of the probe. Thus the opening is such that the center of the probe scans the full 5 x 5 cm area.

   The probe shall be held in such a way as to not significantly influence the readings. The use of an extension handle, made of low dielectric material, allows the body of the operator to remain sufficiently distant from the test area. In addition, such a probe handle can also serve to assist in maintaining the required 1 cm separation distance from the WD under test.

5) Identify the five contiguous subgrids around the center subgrid with the lowest field readings. Place the exclusion block into the fixture in the three contiguous subgrids containing the highest field readings. The reason for allowing three contiguous subgrids to be excluded is that extreme "hot" spots are often encountered at the base of the antenna. These high field areas are very localized and easily avoided by the user. Therefore, an exclusion is allowed so as not to make the requirements needlessly harsh.

6) Rescan the remaining six subgrid areas. Identify the highest field reading within the six subgrid area, made up of the center subgrid and the five subgrids identified in step 5). Care shall be taken to identify the highest emission within the six subgrid area. Once the highest emission is identified, the probe should be rotated to align it for the maximum reading. The rotation is recommended in order to eliminate errors due to anisotropy in the probe.

7) Convert the highest field reading taken in step 6) to peak V/m or A/m, as appropriate. This conversion shall be done using the appropriate factors derived from the calibration specified in Annex C.3.

8) Compare this reading to the categories in Clause 7 and record the resulting category.

9) Repeat steps 1) through 8) for both the E- and H-field. The lowest category, per Figure 12, obtained in step 8) for either E- or H-field, determines the overall WD category. Record the WD category rating.

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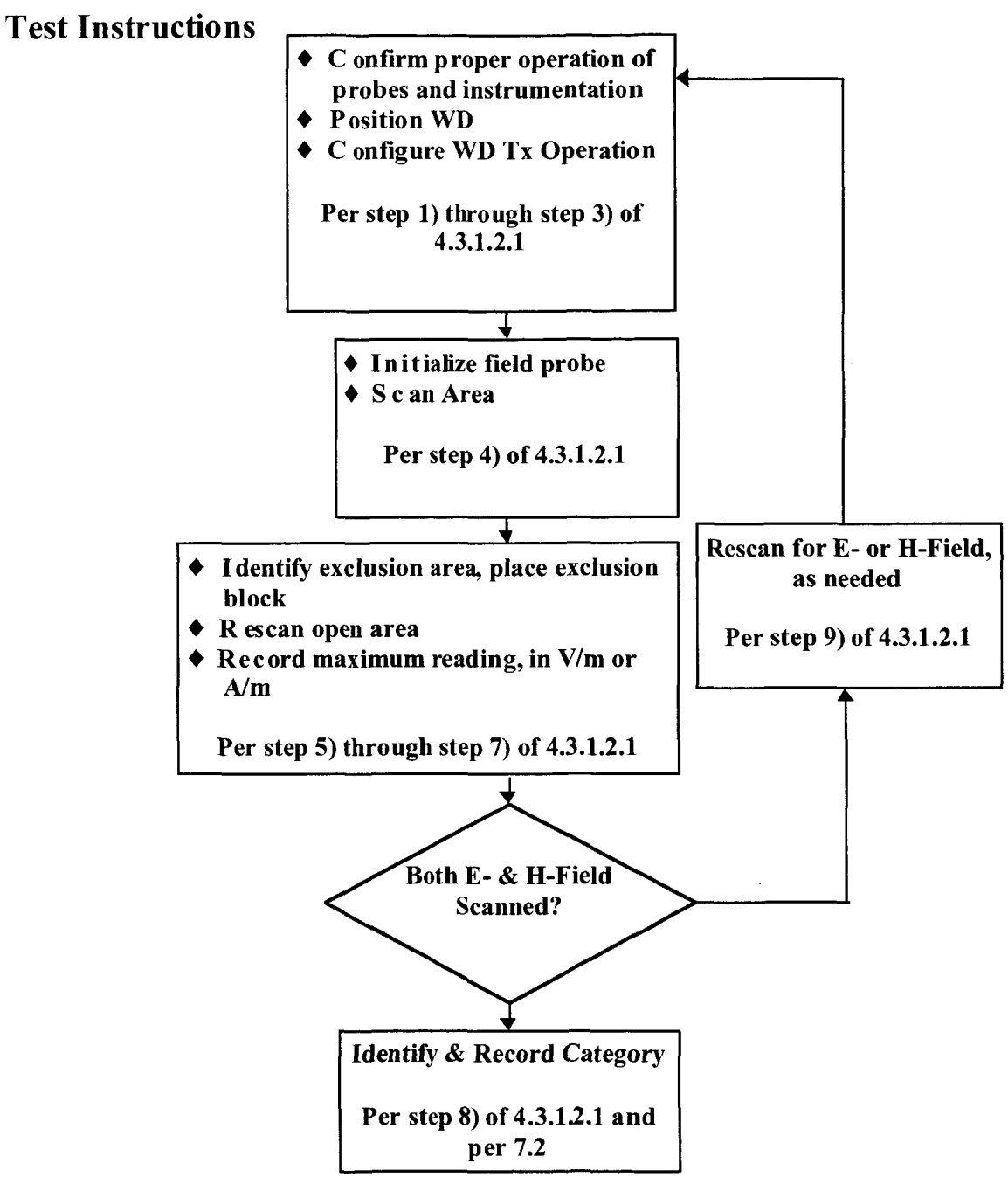


Figure 3—WD near-field emission manual test flowchart

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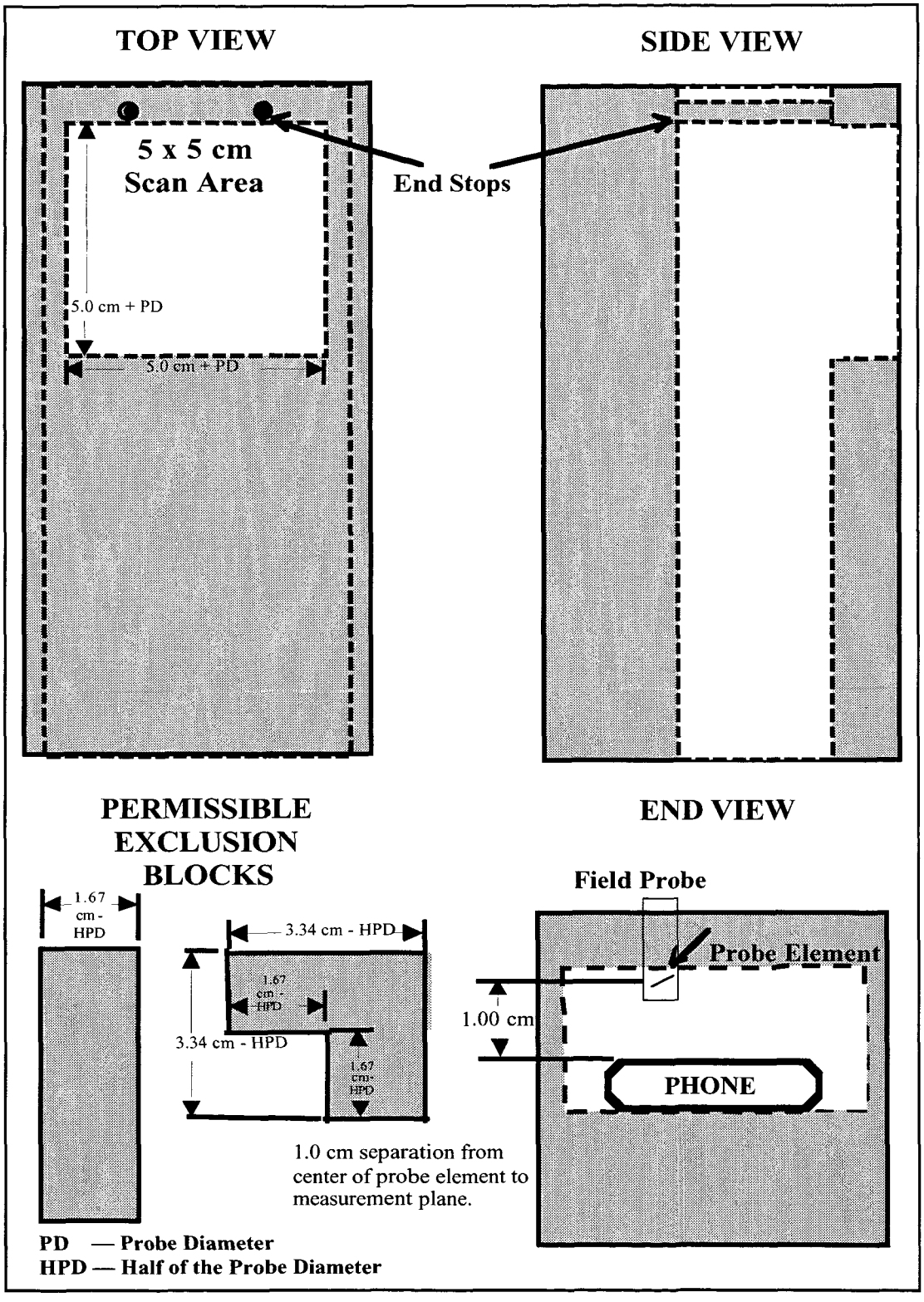


Figure 4—Near-field emissions test fixture, manual scan method

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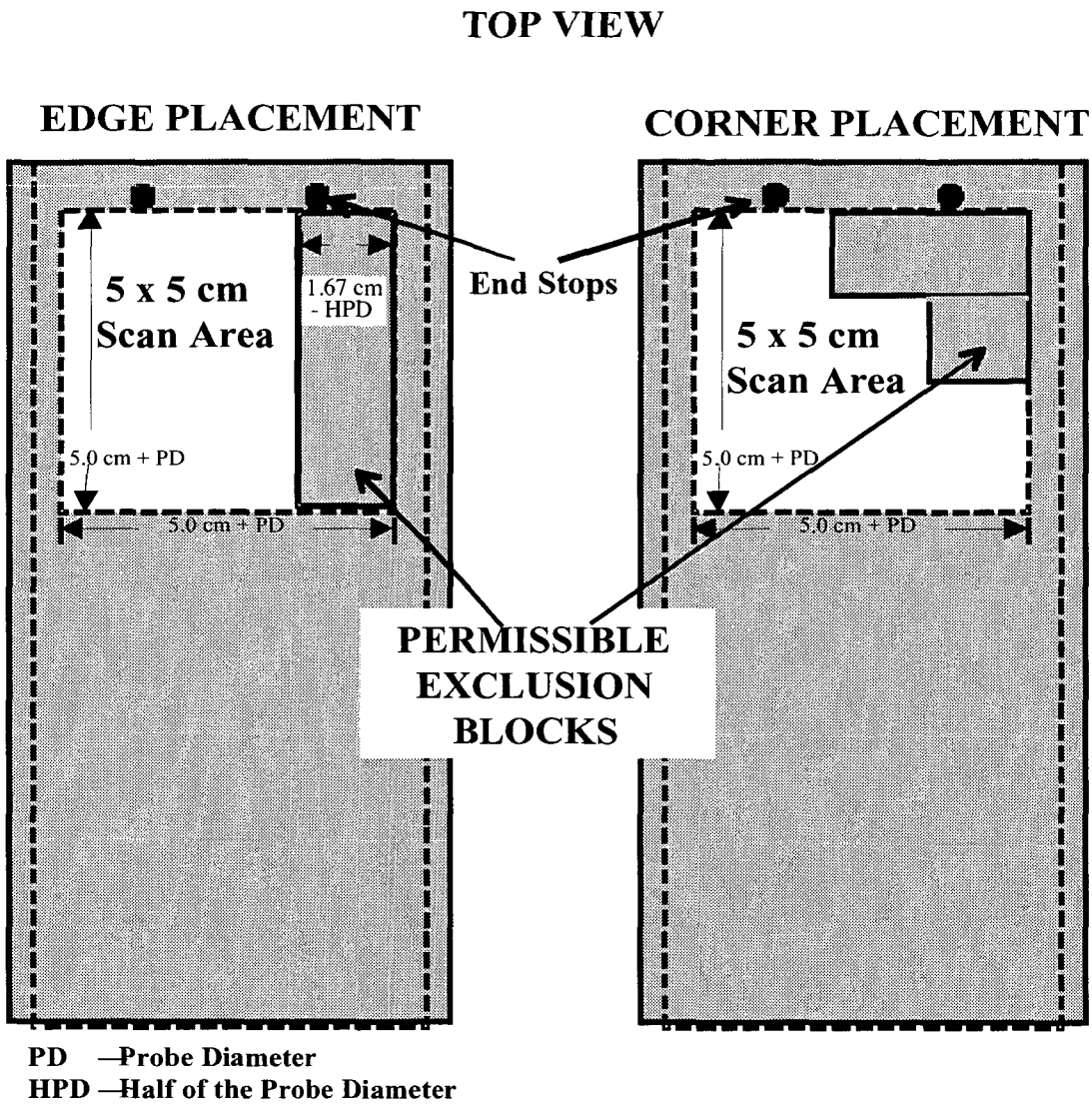


Figure 5—Exclusion block placement

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4.3.1.2.2 Automated scanning method

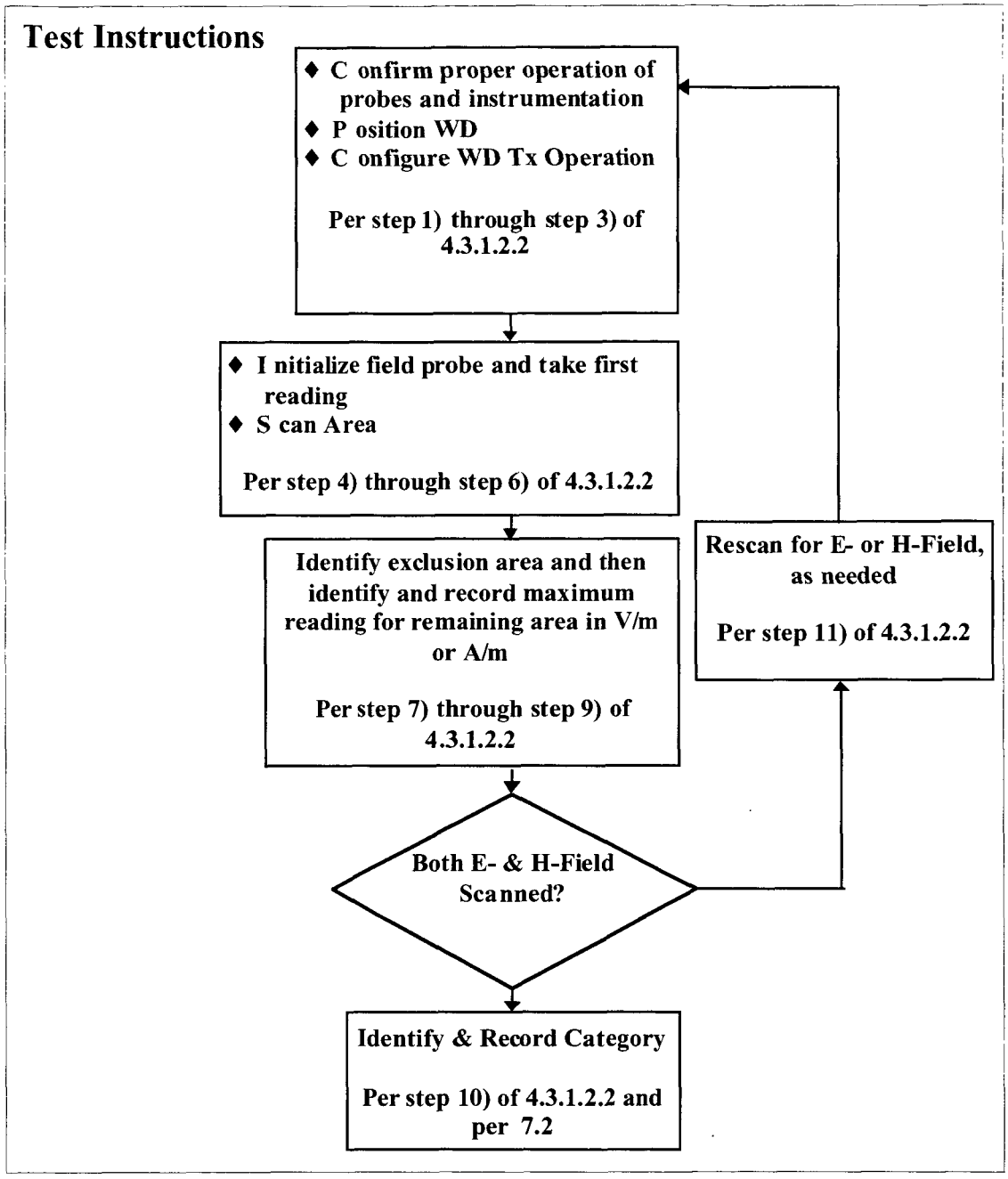


Figure 6—WD near-field emission automatic test flowchart

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1) Confirm the proper operation of the field probe, the probe measurement system, and other instrumentation.

2) Position the WD in its intended test position.

3) Configure the WD operation for maximum rated RF output power, at the desired channel and other operating parameters, as intended for the test.

4) Locate the field probe at the initial test position. If the field alignment method is used, align the probe for maximum field reception.

5) Record the reading.

6) Scan the 5 x 5 cm areas, repeating steps 4) and 5) for each measurement point. The distance between measurement points shall be sufficient to assure the identification of the peak reading.

7) Identify the five contiguous subgrids around the center subgrid with the lowest field readings.

8) Identify the highest field reading within the six subgrids, made up of the center subgrid and the five subgrids identified in step 7).

9) Convert the highest field reading taken in step 8) to peak V/m or A/m, as appropriate. This conversion shall be done using the appropriate factors derived from the calibration specified in C.3 of this standard.

10) Compare this reading to the categories in Clause 7 and record the resulting category.

11) Repeat step 1) through step 10) for both the E- and H-field. The lowest category, per Figure 12, obtained in step 10) for either E- or H-field determines the overall WD category. Record the WD category rating.

5. Hearing aid RF near-field immunity test

This clause prescribes the measurement method to be used in determining the immunity level of a hearing aid to radiated electromagnetic fields originating from a WD. The method is intended to simulate the RF fields experienced by a hearing-aid-equipped user of a WD and so evaluates the hearing aid's immunity.

This test procedure uses near-field illumination in assessing the hearing aid immunity rather than far-field illumination. This is a more realistic simulation of the near-field condition experienced by the hearing aid, the result is a better correlation between the measured immunity level and the immunity level experienced by an actual hearing-aid-equipped user of a WD.

Far-field illumination testing, such as in a WB TEM, offers advantages of being more repeatable and less sensitive to issues of placement and positioning. Far-field illumination testing is commonly required in other standards as well. Some may prefer to test immunity using a WB TEM either to avoid duplicative testing or for other reasons. Annex I provides guidance on WB TEM testing as an alternate method. However, in case of dispute, the results obtained with the near-field illumination test, as described in this clause, shall take precedent.

All acoustic measurements are to be made unweighted (i.e., with the instrumentation set for "linear" or flat frequency response), unless otherwise noted.

The evaluation of the interference effect of the WD's RF emissions on a hearing aid in acoustic coupling mode is procedurally very similar to that used for the T-coil mode. For this reason, the procedures for evaluating a hearing aid's immunity to the RF emission, set forth in this clause, is called for in evaluating the T-coil coupling mode. For simplicity, some helpful notes are contained within the procedures in this clause for evaluation of the T-coil coupling mode. However, for the T-coil mode, an evaluation must be made of the effects of baseband interference sources to fully evaluate the signal quality that a user experiences.

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5.1 Test facilities and equipment

Subclauses 5.1 through 5.1.2 describe the test facility and equipment to be used for these measurements.

5.1.1 General test conditions

5.1.1.1 Ambient conditions

See 8.2 for ambient conditions.

5.1.1.2 Power supply voltage

A fresh battery of the type specified by the hearing aid manufacturer shall be mounted inside of the hearing aid during the immunity test. The battery should be within ±5% of its rated voltage, under no-load conditions.

5.1.1.3 Test sites

Any indoor site meeting the conditions as specified in 8.2 and C.1.1 is acceptable, provided the equipment used for application of radio-frequency fields is electromagnetically shielded to the extent necessary to meet federal government RF safety regulations and electromagnetic emission regulations. A soundproof booth is not a mandatory requirement. However, ambient noise levels in the test area should be as low as possible and consistent for the duration of the test.

5.1.2 Test equipment

Subclause 5.1.2 lists the test equipment needed to perform the near-field immunity tests, using the generic test equipment hookup diagram shown in Figure 7. The test equipment used shall meet the applicable specifications of Annex D.

a) Two resonant dipoles designed to radiate between 800–950 MHz and 1.6–2.48 GHz
b) RF signal generator
c) RF power amplifier
d) RF directional coupler
e) RF power meters (2)
f) Microphones
    1) Pressure field microphone
    2) Free field microphone
g) Microphone preamplifier
h) Frequency analyzer
i) Ear coupler
j) Microphone calibrator
k) Audio signal generator
l) Acoustic transmission line
m) Hearing aid immunity test fixture
n) RF cables

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5.2 Test setup and validation

Subclause 5.2.1 describes how to configure the experimental setup required for hearing aid RF immunity tests. Before hearing aid testing commences, the experimental setup shall be validated. Subclauses 5.2.1 through 5.2.5 include a set of pretest procedures designed to validate the experimental setup in order to ensure the accuracy of the results. In order to verify that the hearing aid performs per the manufacturer's specifications, 5.2.5 advises that the hearing aid be pretested per ANSI S3.22-1996.

5.2.1 Hearing aid near-field immunity test setup

Figure 7 is a schematic of how the equipment listed in 5.1.2 is set up for RF immunity testing. As shown, the hearing aid acoustic output is connected to the microphone via an acoustic transmission line and ear coupler. The microphone is then coupled to the audio frequency analyzer via a preamplifier. This constitutes the audio frequency measurement system. From the RF source, an RF signal is fed to an RF power amplifier, to supply power to the dipole. A two-way directional coupler with RF power meter is placed in line just before the dipole in order to monitor forward and reflected RF power into the dipole. The RF power level to the dipole is set using a CW RF signal. After the proper test level is established, 1 kHz 80% AM modulation is added for the actual test.[16]

The relative spacing between the hearing aid under test and the dipole is critical to the accuracy and repeatability of the test. Figures D.2 through D.8 describe the construction of a recommended fixture. Other fixture implementations are allowed, provided that they can be demonstrated to give equivalent performance.

5.2.2 Check for RF interference to test equipment

Set up the equipment as illustrated in Figure 7 and as described in 5.2.1. With the hearing aid battery removed and RF off, record the ambient spectrum and sound pressure level. Then energize the dipole with the maximum RF power that will be used in the test, plus 3 dB, at 900 MHz. Apply 1 kHz 80% AM modulation. Record the audio band spectrum and overall sound pressure level from the frequency analyzer. Alternative measurements can be made at the 1/3 octave bands from 300 Hz to 3.4 kHz to determine if any change in SPL, due to the RF from the dipole, has occurred.

Repeat the procedure with a 1 W, 1.8 GHz RF signal modulated with a 1 kHz 80% AM modulation. Record the spectrum and overall sound pressure level.

There should be no change in spectrum and overall sound pressure level from ambient during this system check (with the hearing aid battery removed), indicating that the system is immune to interference. If there is an increase in recorded sound pressure level or peaks in the spectrum that appear due to exposure to the energized dipole, it shall be necessary to provide a separation distance between the victim device (which shall be determined) and the radiating dipole. Repeat the above test with increasing separation distance between the victim device and dipole and record the distance at which the interference disappears. Configure the test setup described in 5.2.1 such that this minimum separation distance is achieved between the test equipment and the dipole. If the determined separation distance is impractical, shielding may be employed to eliminate the interference to the test equipment.

[16]The 1 kHz 80% AM modulation is used because of its availability in most signal generators and its common usage in other RF immunity test standards. The 1 kHz 80% AM modulation has a fixed and well understood relationship to the modulations used in WDs. This relationship and the physics which determine the relationship is described in Appendix 4, "Square Law Detection of RF Signals," of Joyner, K.H. et al, Interference to Hearing Aids by the Digital Mobile Telephone System, Global System for Mobile Communications (GSM), NAL Report #131 [B16] and in Annex A, "Rationale for the choice of modulation for tests related to the protection against RF emissions from digital radio telephones," in IEC 61000-4-3-1998.

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5.2.3 Characterization of tubing acoustic attenuation and resonances (informative)

Longer lengths of tubing have the effect of attenuating the higher audio frequencies as well as introducing tubing resonances. Therefore, it is important to characterize the acoustic transmission line used in testing (see C.6).

Depending on the measurement, characterization of tubing over the entire frequency range may not be necessary. Because acoustic output SPL measurements are at 1 kHz and 1.3 kHz, tubing attenuation needs only to be determined at these two frequencies for near-field immunity testing. This can be accomplished easily by connecting the desired length of tubing to the acoustic output of the hearing aid being tested, and with its volume set at the reference test position (RTP), as defined in ANSI S3.22-1996, its acoustic output SPL relative to changing input SPL at a fixed frequency can be measured. From these input/output curves, the input SPL relative to a changing acoustic output level at this fixed frequency can be easily determined. However, if an accurate view of the overall spectrum is desired, then the tubing should be characterized.

5.2.4 Audio input source setup

The experimental setup for 5.2.4 is illustrated in Figure 7. For a description of the audio input source, see C.2.

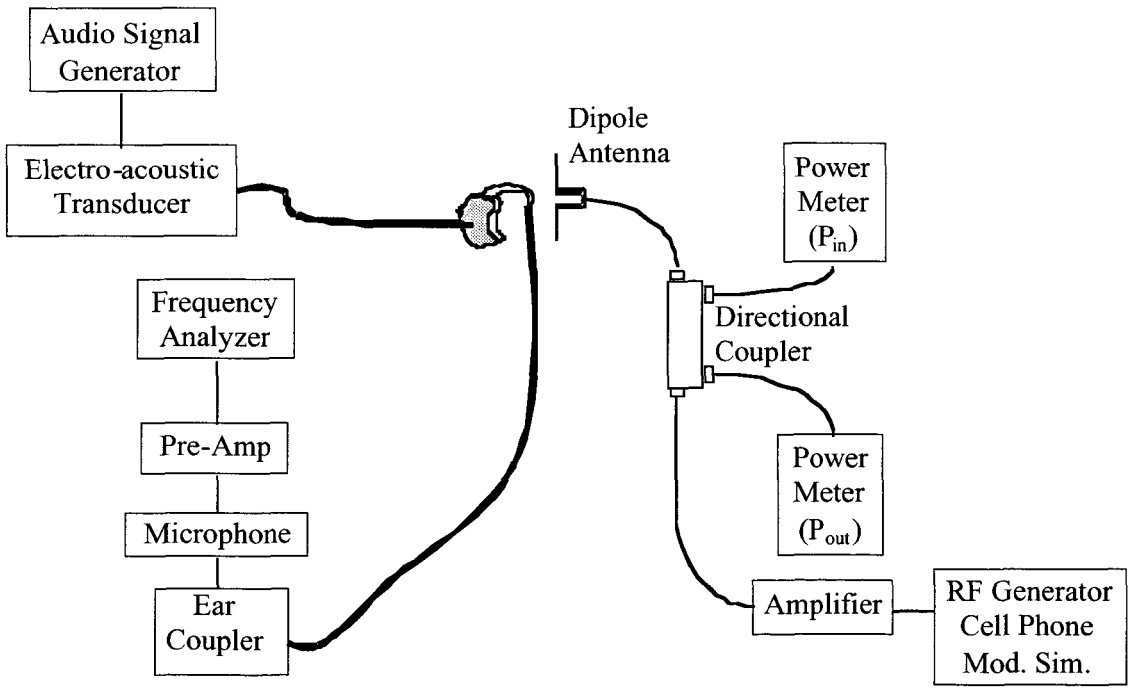


Figure 7—Near-field immunity test setup

5.2.5 Pretests required for the hearing aid under test (informative)

Select the appropriate pretests from ANSI S3.22-1996.

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5.3 RF immunity test procedure

Subclause 5.3 describes the procedures for testing a hearing aid for immunity to near-field electromagnetic interference. The measurements are performed first using the dipole for the 800–950 MHz band and then repeated with the dipole for the 1.6–2.48 GHz band.

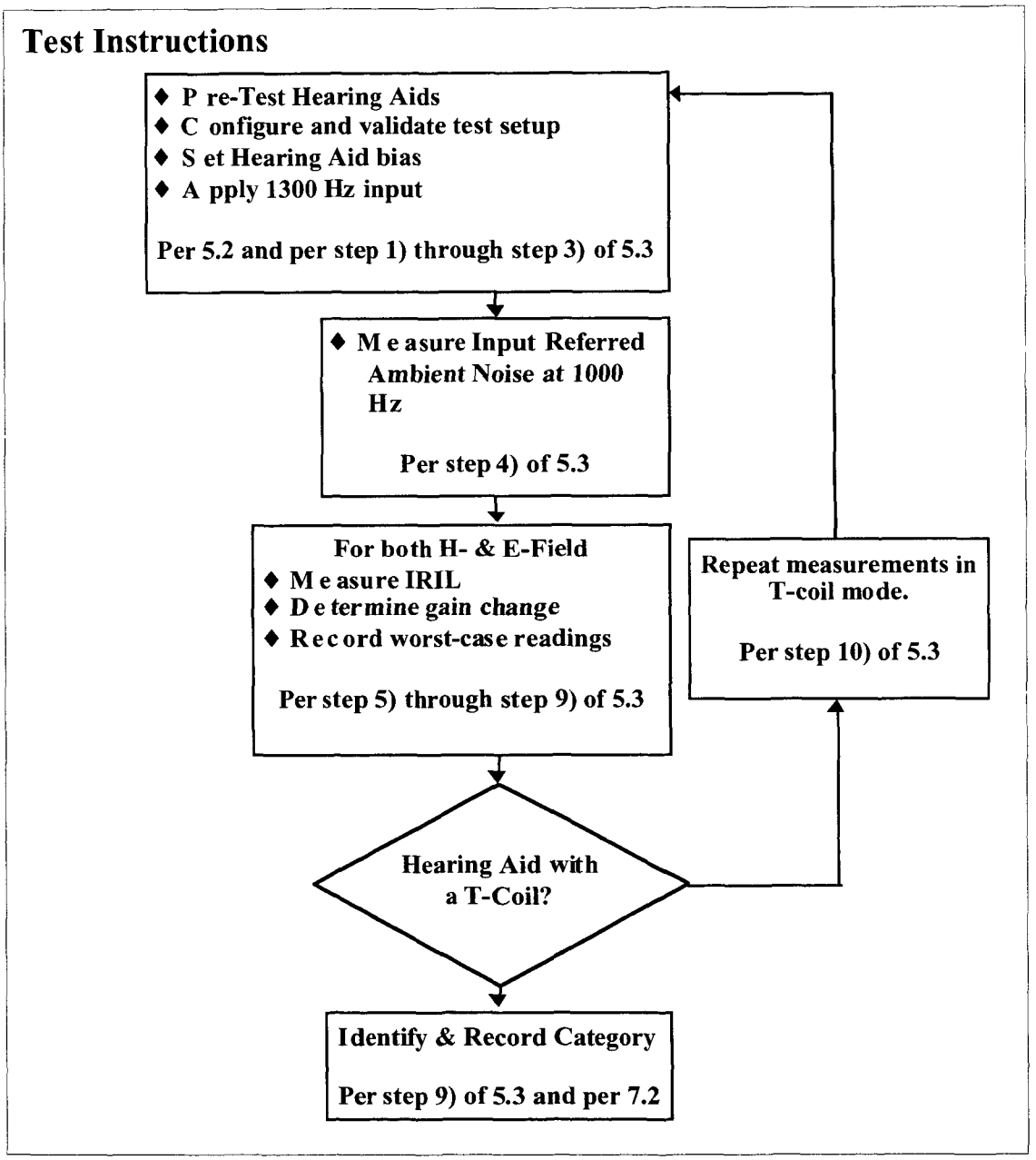


Figure 8—Hearing aid immunity test flowchart

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1) Equipment setup

—Configure the equipment as illustrated in Figure 7 and described in 5.2.

2) Hearing aid setup

—Set the hearing aid to acoustic mode. Couple the hearing aid through an acoustic transmission line, as defined in 5.2.3. The acoustic transmission line, in turn, is connected to an ear coupler in a hearing aid test box or other suitable test arrangement. Adjust the hearing aid to the reference test gain with 60 dB(SPL) input using HFA (high frequency average) measurements as defined in ANSI S3.22-1996. Secure the volume control against movement with non-conductive tape, glue, or other means.

—Connect the audio input source. Perform an input/output measurement curve from minimum 50 dB(SPL) to 90 dB(SPL) in 5 dB steps, at 1000 Hz and 1300 Hz. In the following steps this input/output characteristic information shall be used to determine IRIL levels at 1 kHz and to determine the 65 dB(SPL) input-related biasing level at 1300 Hz.

3) Set 1300 Hz hearing aid bias

—Apply a 1300 Hz acoustic bias signal to the microphone input tube. The bias signal sets the hearing aid to a known acoustic output level, which allows for the detection of any RF carrier effects on compression circuitry. With the frequency analyzer resolution bandwidth set to 30 Hz, measure the hearing aid acoustic output at 1300 Hz. Adjust the amplitude of the 1300 Hz signal to produce 65 dB(SPL) at the hearing aid microphone input port, as determined from the measured hearing aid input/output characteristics from step 2). Document acoustic output level and the gain at 1300 Hz.

—During T-coil mode test, apply a 1300 Hz magnetic bias signal to the hearing aid T-coil that gives an equivalent acoustic output at 1300 Hz to that delivered by an acoustic input of 65 dB(SPL).

NOTES:

1) It is desirable that a 1300 Hz sine wave test signal be used to determine any gain changes that may occur due to RF carrier effects; however, accurate results may not be possible with some hearing aids by using simple sine wave signals. Such devices may require the use of voice-like signals, e.g., real voice and artificial voice (see ITU-T P. 50-1993). Such signals may have frequency weighting and temporal characteristics that require additional processing to correlate with sine-wave-based test methods. It is up to the tester to ensure that non-sine test signals are properly implemented. A suggested method would be to include an artificial speech signal along with the 1300 Hz signal. The reference gain can then be determined by using just the 1300 Hz portion of the combined artificial voice/1300 Hz signal.

2) Apply a 1300 Hz magnetic bias signal to the hearing aid telephone coil that gives an equivalent acoustic output at 1300 Hz equal to the acoustic input of 65 dB(SPL). Then apply a 1 kHz modulated RF signal without changing the source power to the magnetic bias signal. The general assumption used to determine T-coil "gain" for IRIL measurements is that the T-coil magnetic input is set so that the acoustic output for a T-coil signal is equivalent to the acoustic 65 dB input and therefore the gain is assumed equivalent. If the acoustic output now reduces at 1300 Hz during the testing, then there is a gain deviation, which shall be treated as described in step 6).

4) Measure the input referred ambient noise (IRAN) at 1000 Hz

—Record the acoustic output SPL from the hearing aid, in the 1000 Hz filter band, with the RF source and acoustic source turned off. Using the input/output characteristics at 1000 Hz, determine the gain for the measured acoustic output level. Subtract the 1000 Hz gain from the acoustic output SPL. The result is the ambient acoustical noise referred to the input, which shall be called the input referred ambient noise (IRAN). The IRAN should be sufficiently below the target input referred interference level (IRIL) to permit accurate measurement. (Example: IRAN=50 dB, IRIL=60 dB; results in an expected error of 0.4 dB introduced by the IRAN.)

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5) IRIL measurement (H-field)

—Turn off the acoustic bias.

—Energize the dipole at its middle frequency with a RF signal modulated with 1 kHz AM modulated signal.

—Using the hearing aid immunity test fixture (see D.12) and adjusting the RF power level to the dipole so that the hearing aid is not in saturation, determine the worst-case orientation, i.e., the one that produces the highest acoustic output level in the hearing aid. This is done by first adjusting the RF input until a response is elicited from the hearing aid. Then move the dipole relative to the hearing aid until the position in which the acoustic output is worst-case is determined. If during this process the hearing aid begins to saturate, reduce the RF input amplitude until the hearing aid is no longer in saturation. Fix the dipole and hearing aid in the relative position that produces the greatest response from the hearing aid.

NOTE—The hearing aid immunity test fixture, as shown in D.12, allows complete spherical rotation of the dipole around the hearing aid. This greatly facilitates accurately finding the orientation of the dipole that produces the most interference in the hearing aid.

—When determining the worst-case orientation for the H-field test, the closest surface of the hearing aid shall be at a distance of 1 cm from the center of the dipole. When determining the worst-case orientation for the E-Field test, required in step 7), the closest surface of the hearing aid shall be at a distance of 1 cm from the tip of the dipole. See Figure 3 for clarification.

—After determining the worst-case orientation, sweep the RF carrier frequency, starting at its lowest frequency, using frequency steps of no greater than 2 MHz up to the highest frequency in the band. Determine the frequency that produces the worst-case result.

—Adjust the RF power level until 55 dB(IRIL) is achieved at this worst-case frequency and in the worst-case position.

—Determine and record the net CW RF power level (forward power minus reflected power) that produces an IRIL level of 55 dB(SPL). Once the required 55 dB(SPL) response is achieved, turn off the modulation and record the net CW RF power level. Recording the net CW RF level avoids all of the variations in the responses to modulated RF signals that occur among various manufacturers and models of RF instrumentation. All RF instruments indicate the same level, within instrument uncertainty, in response to a CW (unmodulated) RF signal.

—The RF power recorded is the net RF power, as measured with a power meter and directional coupler. If the dipole has a broadband matching section, the VSWR shall be no greater than 1.92 anywhere within the band. The reflected or reverse RF power shall be no more than 10% of the input power. Tune the dipole or adjust the matching section, if necessary, to achieve better matching, which will lower the VSWR.

—From the recorded RF power levels, determine the resulting H-field strength produced by the dipole, derived from the antenna calibration procedure in C.4. The following steps are used to derive the field strength from the calibration chart derived in C.4:

i) At the frequency of interest, determine the net RF power into the dipole.

ii) Locate this frequency in the calibration chart and subtract the chart power at this frequency from the measured net power level. Example:

$(P_{measured}–P_{chart})$

iii) Add this value to the calibrated field strength value used to create the chart. Examples:

for E-field, $(P_{measured}–P_{chart}) + 49.54$

for H-field, $(P_{measured}–P_{chart})$

iv) The result is the E or H-field strength at a 1 cm distance.

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—This shall be the maximum H-Field immunity for the band swept.

6) Determination of gain change

—Remove the RF signal and disable the RF modulation and apply the 1300 Hz acoustic bias to the hearing aid. Adjust the amplitude of the bias so that an equivalent input level of 65 dB(SPL) is achieved.

—Using the same worst-case frequency and orientation from the previous measurement, energize the dipole with a CW RF signal, using the same peak RF level used in step 5). Record any gain changes greater than 2 dB.

NOTE—The unmodulated RF level shall be increased by 5.1 dBm to achieve the same peak RF power levels as those achieved by 1 kHz 80% AM modulation.

—The purpose of this step is to determine if the hearing aid gain is affected by the RF exposure of the test. If the gain does change, then the actual hearing aid gain under the RF exposure test condition shall be used in calculating the acoustic input referenced level rather than the hearing aid gain measured before the test. In order the properly account for gain compression or expansion in the hearing aid the following steps are taken:

i) Record the maximum gain deviation during RF exposure.

ii) Add or subtract the gain deviation from the acoustic output level measured in step 5).

iii) Use the new, adjusted acoustic output level in determining the IRIL value and related test results.

iv) Additionally, there is a specified limit for gain compression located in Clause 7 as part of Figure 5. The hearing aid must meet both the interference output limit and the gain compression limit to achieve a given category.

—For example, if the 1 kHz acoustic output level at 900 MHz is 100 dB(SPL) and there has been less than a 2 dB deviation in the 1300 Hz bias level at 900 MHz, then there has been no significant deviation in the gain and no special treatment is required. Complete the calculations in the normal fashion. From the 1 kHz I/O curve previously generated, determine the acoustic input that corresponds to a 100 dB acoustic output. This shall be the IRIL level measured at 1 kHz for 900 MHz.

—However, if the acoustic output level at 1 kHz is 100 dB SPL and there has been a decrease of 6 dB SPL in the 1300 Hz bias level at 900 MHz, then an adjustment shall be made for the gain compression. 6 dB shall be added to the 1 kHz acoustic output level at 900 MHz. From the 1 kHz I/O curve, determine the acoustic input that corresponds to the new 106 dB acoustic output.

7) IRIL and gain change measurements (E-field)

—Repeat step 5) and step 6) while exposing the hearing aid to within 1 cm of the tip of one radiating dipole element. This should expose the hearing aid under test to the maximum electric field from the dipole.[17]

8) Acoustic IRIL measurements (E-field and H-field) for 1.6–2.48 GHz

—Repeat step 4) through step 7) for the 1.6–2.48 GHz band using the correct dipole for that frequency range.

9) Record data

—Record the minimum E- and H-field levels for each of the frequency bands that produce an IRIL level of 55 dB SPL. This is the desired overall test result, which shall be compared against

[17]A dipole produces its maximum H-field at the center of the dipole and the maximum E-field near the tip of the dipole. A hearing aid is tested both near the center and tip of the dipole so as to evaluate its immunity to both high E-field and high H-field emissions. Thus, the hearing aid immunity test is repeated, once 1 cm from the center of the dipole, and then 1 cm from the tip of the dipole.

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the limit threshold as outlined in Table 1. Determine the category according to the immunity ranges given in Table 1. Record the category achieved by the hearing aid under test.

10) T-coil Measurements (E-Field and H-Field)

—Repeat step 1) through step 9) of 5.3 with the hearing aid in T-coil mode, if applicable.

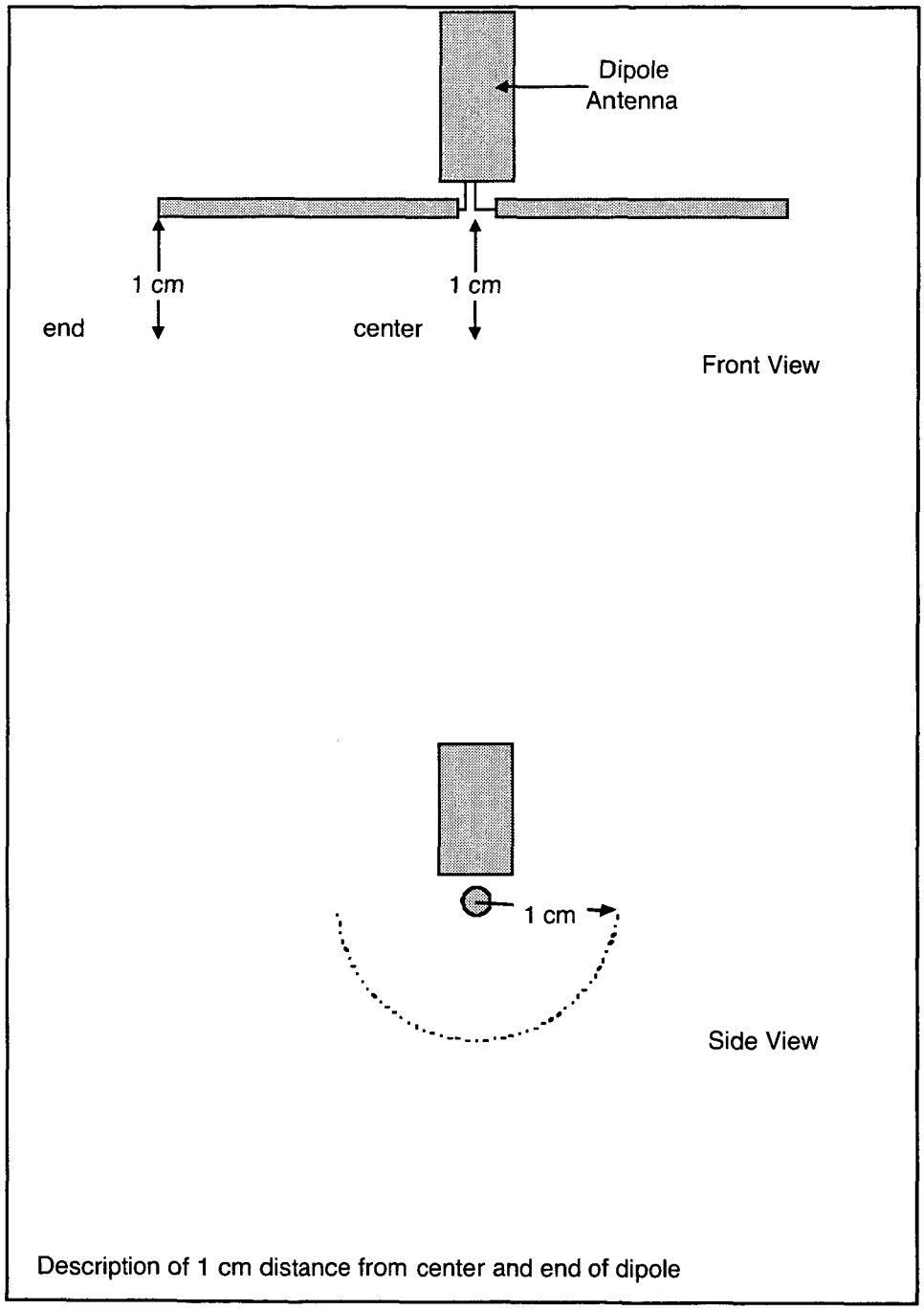


Figure 9—Illustration of test positions—1 cm distance from center and end of dipole

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6. Wireless device audio band, magnetic signal test

Clause 6 describes the measurement of the audio band magnetic signal from the WD. Three quantities are measured and evaluated. The first is the field intensity of the desired signal at the center of the audio band. The second is the frequency response of the desired signal measured across the audio band. The third is the signal quality, which is defined as the difference between the desired and undesired magnetic field levels. The measurement procedure is fully described in 6.3.1. Parameters for each of these quantities are found in Clause 7.

Measure both the desired and undesired magnetic signals with the WD in calling mode.

The measurement shall not include undesired properties from the WD's RF field.

Recommended test facilities and equipment, including probe coils and test equipment, are described in 6.1.

Test configuration and setup are described in 6.2.

Measurement procedure for audio band magnetic fields is described in 6.3.

Annexes include additional information as outlined.

6.1 Test facilities and equipment

See Annex C and Annex D for test facility requirements.

6.1.1 Test equipment

6.1.1.1 Foundational test equipment

The following test equipment, or equivalent instruments, is required to perform this test. Test equipment used shall meet the applicable specifications of Annex D.

a) Ear simulator
b) Audio signal source
c) 1/3 octave bandpass filter
d) A-weighting bandpass filter
e) Frequency generator
f) Probe coil assembly
g) Helmholtz calibration coils
h) Microphone pre-amplifier
i) True RMS voltmeter
j) Base station simulator/RF communications test set with audio input/output
k) Power supply
l) Microphone calibrator
m) Telephone test head

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6.1.1.2 Additional test equipment

The following equipment may be required and is applicable to acoustic output measurements.

a) Anechoic or shielded chamber (magnetic, RF, or acoustic)
b) Graphics recorder
c) Optional controller
d) Microphone, pressure
e) Power supply
f) Test interface adapter (TIA)

6.2 Test configurations and setup

Figure 10 illustrates the basic test configuration for magnetic field measurements.

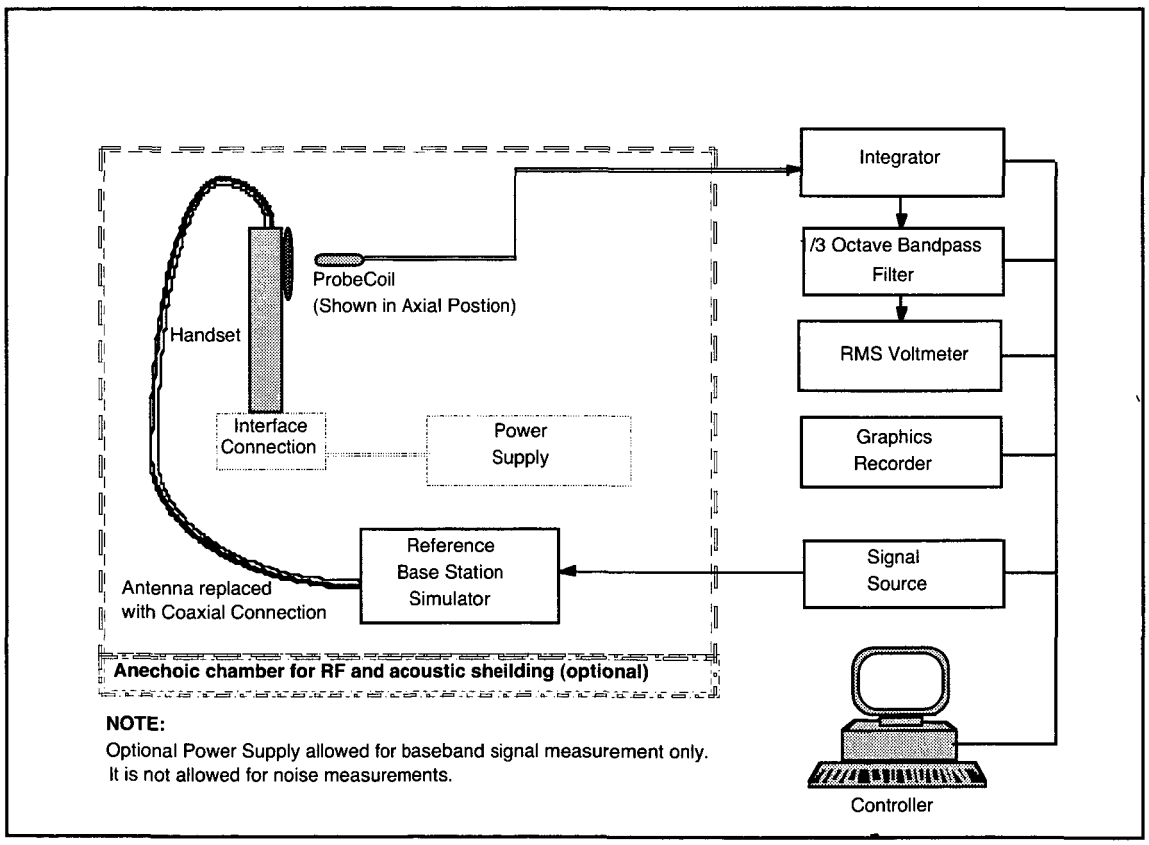


Figure 10—Magnetic field measurement test setup

Note that the setup of Figure 10 assumes that the proper input level to the WD, required to produce a 94 dB SPL acoustic output, has already been determined. Determining the correct input level to the WD requires the use of an ear simulator, which is not shown in Figure 10.

The receive audio signal for the WD may be injected into the base station simulator, which transmits it to the WD while the WD is on a call. An alternate method is to use the WD manufacturer's test mode, if available.

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6.2.1 Ambient and test system noise

It is necessary that the magnetic, RF, and acoustic ambient levels be low enough as to not significantly affect the intended measurement. In order to achieve these levels, magnetic, RF, and acoustic shielding may be required. In some cases, a full RF and/or acoustic anechoic chamber may be required to accurately perform the intended measurements.

Care shall be taken to ensure that measured field strengths due to noise in the test system should be at least 10 dB below the lowest signal to be measured. This may be achieved by placing the probe and receiver in the position to be used for receiver field strength measurements. Remove the WD and measure the remaining noise field strength in the same way and over the same frequency range used for receiver measurements.

6.2.2 Base station simulator method

A base station simulator, as shown in Figure 10, allows the WD to be in its conversation mode. It is required that the base station simulator provide the complimentary audio signal processing to the WD (i.e., compression and pre-emphasis for analog modes and voice coding and interleaving for digital). Through the base station simulator, command the WD to transmit at maximum RF power.

NOTE—The WD is set to transmit at maximum RF power to ensure that associated baseband effects, such as battery surge currents, are accounted for. However, the WD antenna is replaced by a coax so as to mask the affects of the RF transmission signal from the measurement.

Set the base station simulator to provide a low-level RF signal, approximately –50 dBm, using a frequency near the center of the frequency band. Inject a P.50 artificial speech signal for the digital mode and either the P.50 or a 1025 Hz sine wave for analog. The test operator is cautioned about using a sine wave for digital modes and is referred to IEEE Std 269-1992 for additional information.

6.2.3 Manufacturer's test mode method

The WD can be placed in test mode. This is normally done through the interface connection shown with the dotted lines in the test setup in Figure 10. The base station simulator is replaced by a passive RF load to allow the WD to transmit at maximum RF power without disturbing others. In test mode, provide an audio input by injecting the signal into the system connector and redirecting it to the earphone through the electrical sidetone path or other electrical loopback path. An alternate method is to inject a PCM coded signal into the virtual digital interface, also referred to as the Digital Audio Interface (DAI).

It is considered the responsibility of each WD manufacturer to fulfill and verify the specification points. Some advantages to the test mode method are that the base station simulator is not needed and the digital voice coder is bypassed so a sine wave signal can be used. The WD RF is set to a channel near the center of the frequency band and the RF power is set to its maximum.

6.2.4 Calibration of the probe coil

Specifications and the required response curve for the probe coil are contained in C.5.

6.3 Test procedure for audio band magnetic field

Subclause 6.3 describes the procedures used to measure the audio band magnetic performance of the WD derived from the receive audio signal. In addition to measuring the absolute signal levels, the A-weighted magnitude of the unintended signal shall also be determined.

Measurements shall not include undesired properties from the WD's RF field; therefore, use of a coaxial connection to a base station simulator may be necessary. However, even with a coaxial connection to a base

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station simulator, there is still RF leakage from the WD, which may interfere with the desired measurement. Pre-measurement checks should be made to avoid this possibility.

Testing shall be performed in a multistage sequence by first measuring the desired audio band magnetic field (ABM1) that is useful to a hearing aid T-coil. The undesired magnetic components (ABM2) shall be examined in a secondary test stage to determine possible effects from the WD display and battery current paths that may disrupt the desired audio band signal.

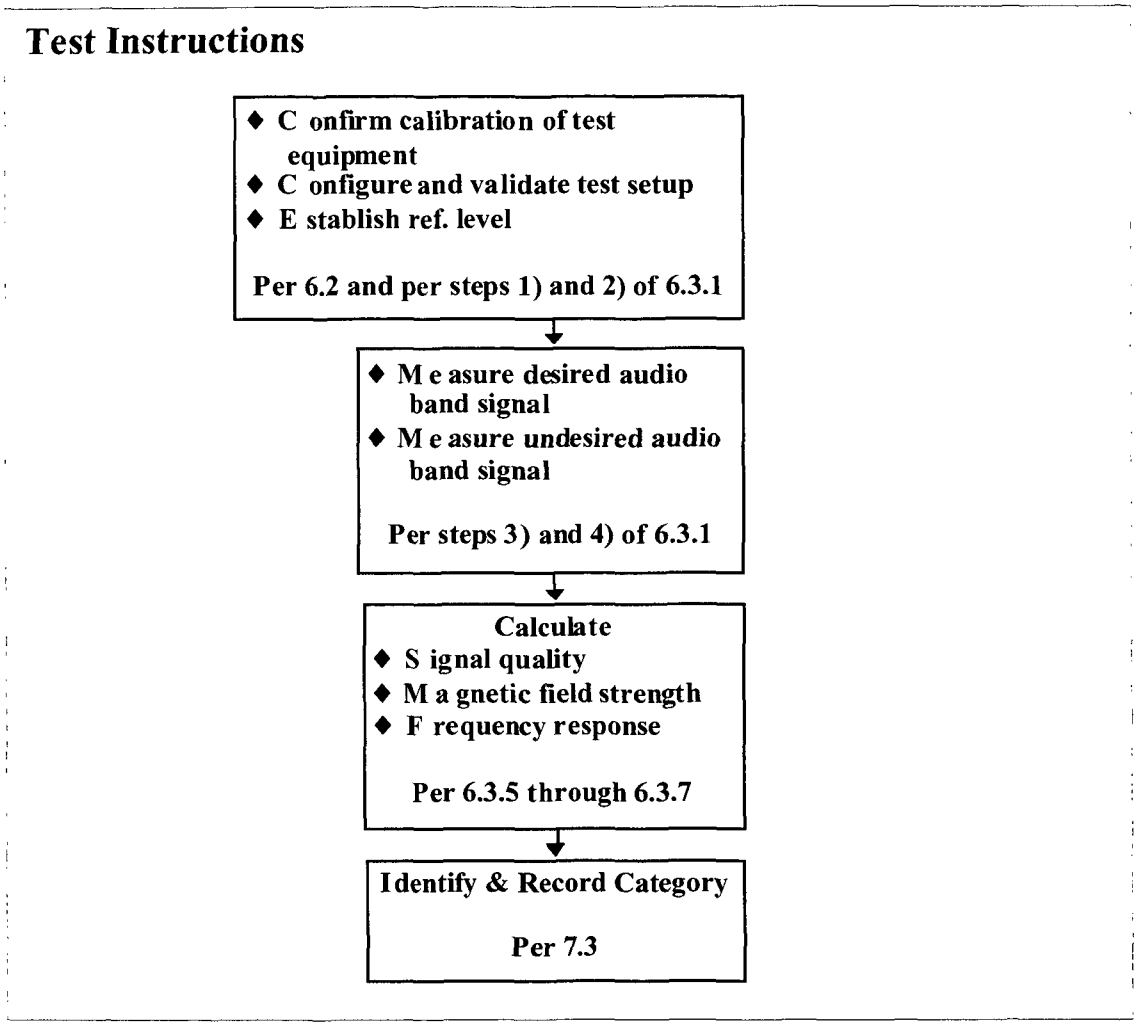


Figure 11—WD audio band, magnetic signal test flowchart

6.3.1 Test flow for audio band magnetic field test

The following summarizes the basic test flow:

1) Calibrate equipment that requires calibration prior to testing.
2) Determine acoustic reference point for WD device. The drive level is set such that the handset produces 94 dB(SPL), 0 dB(Pa) in the ear simulator at 1 kHz, 1/3 octave band. This drive level shall be used for the audio band signal test (ABM1 at f). A frequency of 1025 Hz shall be used

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for the reference frequency. The 1025 frequency was selected rather than 1 kHz because a 1 kHz reference frequency may interfere with emission harmonics or test equipment fundamental frequencies. If interference is found at 1025 Hz, an alternate reference frequency may be used.

3) Measure desired audio band magnetic signals (ABM1 at f) in ISO 266 R10 standard 1/3 octave bands. The desired audio band input signal shall be centered in each 1/3 octave band maintaining the same acoustic output level as determined in step 2) and the reading taken for that band.

4) Measure undesired audio band magnetic signals (ABM2) with no signal applied (or digital zero applied, if appropriate) using an A-weighted bandpass filter. The measurement is only required at the axial measurement point. Measurements at the radial positions may also be made to provide additional information for product design. The physical setup, particularly the placement of the probe coil, shall not be disturbed between steps 3) and 4).

5) Calculate AI per ANSI S3.5-1969.

6.3.2 Test signals

It is generally simpler and therefore preferred to use pure tone or sine wave test signals for audio band tests. However, accurate results may not be possible with some voice coders using simple sine wave signals. Such devices may require the use of voice-like signals such as real voice or artificial voice, as described in ITU-T P.50-1993 (P.50 voice). Such signals may have frequency weighting and temporal characteristics that require additional processing to correlate with sine wave based test methods. It is up to the tester to ensure that non-sine test signals are properly implemented.

6.3.3 Measurement of source magnitude

All measurements in this subclause shall use the probe-coil-voltage to ampere-per-meter conversion process outlined in IEEE Std 1027-1996. Relevant portions are included in Annex C of this standard.

6.3.4 Measurement of source magnitude and direction

6.3.4.1 Setup of receiver assembly

Seal the handset receiver to the ear simulator. Adjust the input signal until 94 dB(SPL), 0 dB(Pascal) is measured in the ear simulator at 1 kHz with a 1/3 octave band filter.

For the actual test a 1025 Hz ± 10 Hz signal is recommended for sine test signals. For voice-like test signals, such as ITU-T P.50 artificial speech, the speech should be band-limited to the 1/3 octave centered at 1025 Hz and the level set to 94 dB(SPL) (note that this is not the same as setting the artificial speech level to 94 dB(SPL) using the entire signal bandwidth). The voltage required to produce this SPL in the 1025 Hz band should be maintained for audio band signal measurements at all frequencies.

6.3.4.1.1 Auxiliary induction sources

To increase durability and battery life and to decrease component weight, a WD manufacturer may elect to incorporate an induction coil in addition to a non-inductive speaker assembly (e.g., piezo-electric). The location of the additional coil should be near but not necessarily centered on the speaker opening. The probe coil, in the axial orientation, may be used to establish the reference axis for such assemblies.

Measurements of the audio band signal as described in 6.3.4.2 are performed using the auxiliary induction source reference axis. The location of which may be obtained from the WD manufacturer or found by the probe coil mapping using a "sniffer" probe, as described in 6.3.7.

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6.3.4.2 Desired audio band magnetic signal measurement

Measure the audio band signal at each of the five positions shown in Figure A.3. Each measurement is made in 1/3 octave bands centered at the ISO 266 R10 series of standard test frequencies between 200 and 5000 Hz. All results should be reported in dB(A/m). Acoustic output data shall be corrected if any frequency weighting of the input test signal is used.

If the audio band undesired noise is less than 10 dB below the audio band desired signal, mu-metal shielding of the WD's display and keypad area and an external DC power source that replaces the WD's normal battery (to minimize paths of battery current) is allowed in order to establish the desired audio band source.

Care shall be taken that the probe is not moved between the desired audio band magnetic signal measurement and the undesired audio band magnetic signal measurement steps for each test position of the probe. In other words the desired signal measurement shall be followed by the undesired signal measurement in order to maintain identical probe position for both tests.

6.3.4.3 Undesired audio band magnetic signal measurement

Turn off the test signal to base station simulator (or send a digital zero code if possible).

Measure the audio band signal at the axial position shown in Figure A.3. Additional measurements at the radial positions may be made to provide further information for product designers. The measurement is made using an A-weighted bandpass filter. All results should be reported in dB(A/m). Acoustic output data shall be corrected if any frequency weighting of the input test signal is used.

As noted in 6.3.4.2, undesired signal measurements shall be made in exactly the same probe positions as the desired signal measurements. Most accurate results are obtained by use of a fixture or by measuring the noise immediately after the signal measurement for each of the probe positions.

Undesired signal measurements shall be made with the batteries in place and without any external shielding of the WD.

6.3.4.4 Probe coil position and orientation

Generally the probe orientation is either axial (probe coil axis is parallel to the receiver earcap axis) or radial (probe coil axis is perpendicular to the receiver earcap axis). The position and orientation of the probe coil used should be stated for all measurements.

Figure A.3 illustrates the five standard probe positions. Position 5) is the axial position of the probe coil; position 1) through position 4) are radial positions. The center of the earpiece holes or slots mark the reference axis unless an auxiliary reference axis is used. The following outlines the measurement orientation details:

1) The reference plane is the planar area containing points of the receiver-end of the WD handset, which in normal handset use rests against the ear.
2) The measurement plane is parallel to and 10 mm in front of the reference plane.
3) The reference axis is normal to the reference plane and passes through the center of the receiver speaker section (or the center of the hole array), or may be centered on a secondary inductive source, if the WD uses a non-inductive speaker assembly as the desired signal source. The actual location of the measurement point shall be noted in the test report as the measurement reference point.

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4) The measurement axis is parallel to the reference axis but may be displaced from that axis by a maximum of 10 mm. Within this constraint the measurement axis may be located where the axial and radial field intensity measurements are optimum with regard to the requirements. In a WD handset with a centered receiver and a circularly symmetrical magnetic field, the measurement axis and the reference axis would coincide.

6.3.5 Calculation of signal quality

Upon completion of measuring the desired audio band magnetic field (primary ABM1) and the undesired magnetic field (secondary ABM2), the signal quality shall be calculated and used to determine the applicable category, per Clause 7. The signal quality is the difference, in dB between ABM1, at 1 kHz in the axial position, and ABM2, measured in the same position.

6.3.6 Magnetic field strength calculation (see IEEE Std 1027-1996)

The magnetic field strength shall be measured over the audio frequency band and, in particular, recorded for acoustic test frequencies from ISO 3-1973 and ISO 266-1975 as in Annex B of this standard. The result is reported in dB relative to one ampere per meter, dB(A/m).

The probe coil produces an electrical signal that is measured in dB relative to one volt, dB(V). This voltage is converted to magnetic field strength units by the use of the following equation:

$$Hr(f) = Vp(f) - P(f)$$

where

$Hr(f)$ is the receiver magnetic field strength at frequency (f) in dB(A/m),
$Vp(f)$ is the output voltage of the probe coil at frequency (f) in dB(V), and
$P(f)$ is the probe sensitivity at frequency (f) in dB(V/A/m).

For example, the typical sensitivity of a probe is –60.5 dB(V/A/m) at 1000 Hz. Therefore, a reading of –80 dB(V) would indicate a magnetic field strength of:

$$\frac{-80 \text{ dB(V)} - (-60.5 \text{ dB(V/A/m)})}{-19.5 \text{ dB(A/m)}}$$

If only $P(1000)$ is known, $P(f)$ can be obtained through the use of the following equation:

$$P(f) = P(1000) - 20 \log (f/1025 \text{ Hz})$$

6.3.7 Audio band signal and noise mapping

This procedure shall be used when it is necessary to locate the reference axis for an auxiliary induction source.

A map shall be made of the magnetic field in the vicinity of the receiver. To map the magnetic field, the three-dimensional magnetic field strength vectors shall be determined at selected points in the vicinity of the receiver unit. This may be accomplished by placing the physical center of the probe coil at the point of interest and measuring the field in three mutually perpendicular directions by turning the probe coil. The field magnitude and direction can then be established through vector addition.

The reference axis shall be a line to the plane established by the face of the receiver area of the phone and shall contain the point of the maximum amplitude in the field map.

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7. Performance

Clause 7 provides the requirements for acceptable interoperability of hearing aids with WDs. When these requirements are met, as defined by the tests described in this standard, a hearing aid operates acceptably with a WD.

The categories begin with a minimal level of performance, which is described as "usable." From this minimum level, steps are provided for both the WD and hearing aid. Improvement in either device moves the performance first to the "regular use" and then to the "excellent performance" categories.

7.1 Articulation weighting factor (AWF)

The following AWF factors shall be used for the standard transmission protocols[18]:

Standard	Technology	AWF
TIA/EIA 553-A	Analog	0
IS-95	CDMA	0
IS-136	TDMA (50 Hz)	0
J-STD-007	GSM (217 Hz)	–5

7.2 Audio coupling mode

Research studies show that an audio signal-to-interference ratio of 20 dB provides a signal quality that is acceptable for normal operation. An improvement of the signal-to-interference ratio of 10 dB to 30 dB improves performance to the level where there is little perception of interference. Alternately, a reduction of the signal-to-interference ratio of 10 dB, to 10 dB, degrades the performance to that which would generally be judged to be usable but not acceptable for regular use.

In addition to immunity and emission requirements, hearing aid response performance, as measured by gain, can be adversely affected by WD RF interference. The criterion established Clause 7 sets the requirement for achieving these levels and gain requirements.

The values in Table 1 are built on a set of premises, which are documented in items a) through d).

a) First, 80 dB(SPL) is assumed as the level of the intended audio input signal.

b) Secondly, the values given are for an equivalent CW signal. Thus, for hearing aid immunity testing, a CW signal is used to establish a field at the specified RF power level. Then the signal is modulated with 1 kHz, 80% AM modulation for the test. Thus, the peak field strength for the test is higher than the CW level by the increase created by the modulation. In a reciprocal fashion, the peak field emissions from the WD are measured. These are then adjusted by the computed AWF, which reflects the interference potential of the modulation method used. The adjusted value is compared to the value given in Figure 5.

[18]The AWF to be used in Figure 5 has been developed from information presented to the committee regarding the interference potential of the various modulation types.

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c) Finally, the hearing aid gain deviation is a measurement of the gain response change of the hearing aid when exposed to the E- and H-fields created by the dipole.

d) The category levels represent available volume control adjustment availability. For instance, if the volume control requires 4 dB to 6 dB of adjustment to use the WD, it is considered within the residual reserve gain of the hearing aid but may become a problem during normal use and therefore is considered usable but not acceptable for regular use.

Where a value is contained in two categories, the stricter limit applies.

Table 1—Hearing aid and telephone near-field parameters

RF Parameters				
Category	**Hearing aid parameters (Hearing aid must maintain <55 dB IRIL interference level and <6 dB gain compression)**		**Telephone parameters**	
Near field	**E-field immunity (CW dB (V/m))**	**H-field immunity (CW dB (A/m))**	**E-field emissions (CW dB (V/m))**	**H-field emissions (CW dB (A/m))**
Category U1	30.0 – 35.0 dB (V/m)	-23.0 – -18.0 dB (A/m)	46 – 51 dB (V/m) + 0.5 × AWF	-4.4 – 0.6 dB (A/m) + 0.5 × AWF
Category U2	35.0 – 40.0 dB (V/m)	-18.0 – -13.0 dB (A/m)	41 – 46 dB (V/m) + 0.5 × AWF	-9.4 – -4.4 dB (A/m) + 0.5 × AWF
Category U3	40.0 – 45.0 dB (V/m)	-13.0 – -8.0 dB (A/m)	36 – 41 dB (V/m) + 0.5 × AWF	-14.4 – -9.4 dB (A/m) + 0.5 × AWF
Category U4	> 45.0 dB (V/m)	> -8.0 dB (A/m)	< 36 dB (V/m) + 0.5 × AWF	< -14.4 dB (A/m) + 0.5 × AWF
Category UX	special	special	special	special

Equipment, which is categorized according to these requirements, shall be coordinated according to Table 2.

It should be noted that because the common interference response of hearing aid circuitry is proportional to the square of the RF field, a 5 dB change in the RF yields a 10 dB change in the interference level.

Table 2—System performance classification table

System classification		
System classification	**Articulation index**	**U category sum**
	AI	Sum of hearing aid (U category) + Telephone (U category)
Usable	0.3	Hearing aid (U category) + Telephone (U category) = 4
Normal use	0.5	Hearing aid (U category) + Telephone (U category) = 5
Excellent performance	0.7	Sum of hearing aid (U category) + Telephone (U category) > = 6

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7.3 Audio band magnetic coupling mode

In order to be rated for T-coil use, a WD shall meet the requirements for signal level and signal quality contained in 7.3. The same signal-to-interference categories are used as defined for audio coupling mode. However, in the coupling mode there are two interference sources—RF interference and audio band magnetic interference. Accordingly, the target signal-to-interference ratio shall be met by the combined total interference from both sources. In order to allow for accurate coordination of these sources, it is assumed that the RF interference is at the required category limit and the audio band interference shall be at least 6 dB below this level. Therefore, for a 20 dB rating the audio band signal-to-interference shall be 26 dB, which assumes the RF interference is already at the 20 dB level. This applies to both the communications device emissions and the hearing aid immunity.

7.3.1 Audio band magnetic coupling field intensity[19]

The audio band magnetic signal from the WD, when measured as specified in this standard, shall meet the parameters set forth below for the axial field intensity and the radial field intensity. These measurements shall be made with the WD operating at an acoustic output of 94 dB(SPL), 0 dB(Pa), as measured into the specified ear simulator.

These levels are designed to be compatible with hearing aids that produce the same acoustic output level for either an acoustic input level of 65 dB(SPL) or a magnetic input level of –30.0 dB(A/m) (31.6 mA/m) at either 1.0 or 1.6 kHz. The hearing aid operational measurements are performed per ANSI S3.22-1996.

7.3.1.1 Axial field intensity

The axial component of the magnetic field, directed along the measurement axis and located at the measurement plane, shall be ≥ –13 dB(A/m) at 1 kHz.

7.3.1.2 Radial field intensity

The radial components of the magnetic field, as measured at four points 90° apart, and at a distance ≥ 16mm from the measurement axis, shall be ≥ –18 dB(A/m) at 1 kHz.

7.3.2 Frequency response[19]

The frequency response of the of the axial component of the magnetic field shall follow the response curve specified in EIA RS-504-1983, over the frequency range 300 Hz–3300 Hz.

[19]The parameters contained in 7.3.1 and 7.3.2 are relatively new and accordingly do not have a long history to use in assessing their universal applicability. However, there is good evidence that these parameters are required to assure the desired level of T-coil performance. Accordingly, 7.3.1 and 7.3.2 shall be considered as a recommended practice and not a mandatory part of this standard.

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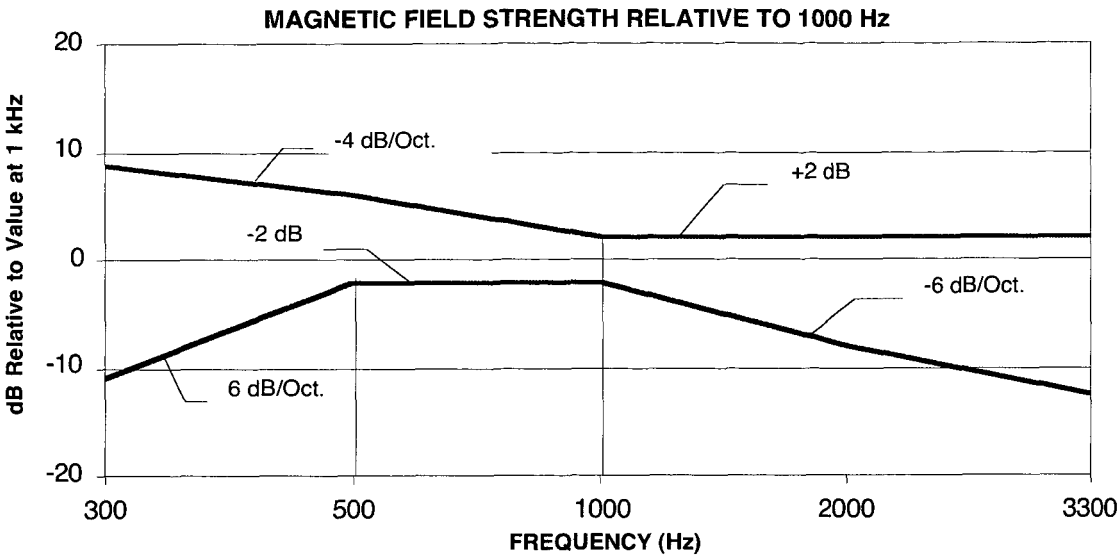


Figure 12—Magnetic field frequency response for WDs with an axial field between –10 dB to –13 dB (A/m) at 1 kHz

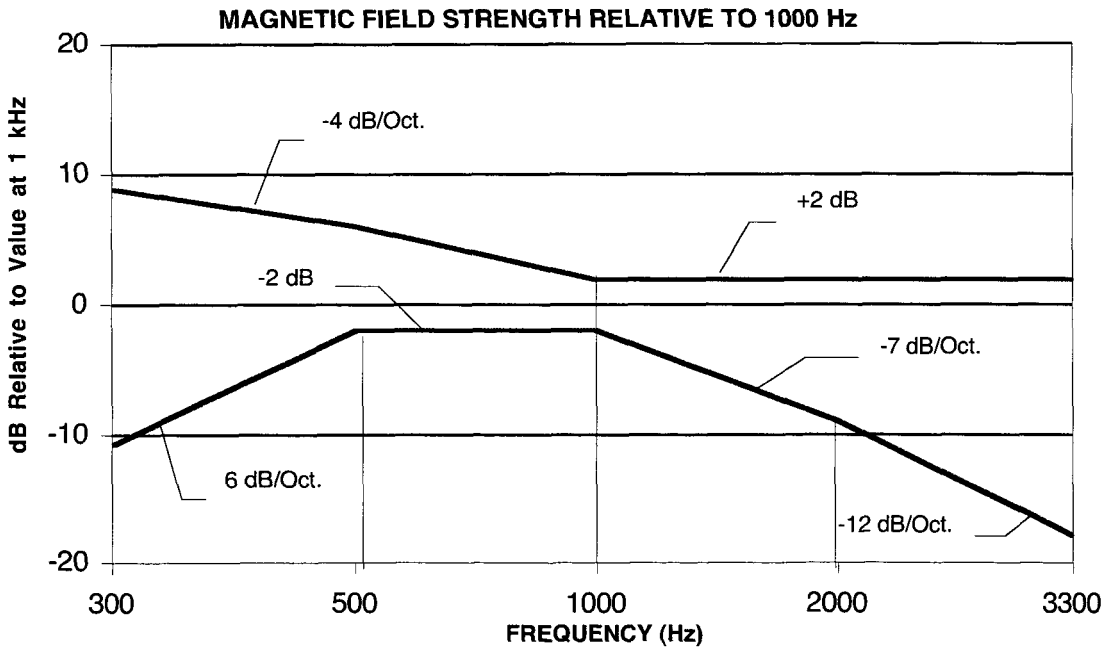


Figure 13—Magnetic field frequency response for WDs with an axial field that exceeds –10 dB(A/m) at 1 kHz

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7.3.3 Signal quality

Subclause 7.3.3 provides the signal quality requirement for the intended T-coil signal from a WD. Only the RF immunity of the hearing aid is measured in T-coil mode. It is assumed that a hearing aid can have no immunity to an interference signal in the audio band, which is the intended reception band for this mode. The only criteria that can be measured is the RF immunity in T-coil mode. This is measured using the same procedure as for the audio coupling mode and at the same levels.

The signal quality of the axial component of the magnetic field, as determined in 6.3.5, shall be used to determine the T-coil mode category per Table 3.

A device is classified beginning with its audio coupling mode category, U1 through U4. If the device meets the additional requirements of 7.3.3 it qualifies for the T-designation (U1T, etc.).

Table 3—Magnetic coupling parameters

Magnetic coupling parameters		
Category	**Hearing aid parameters**	**Telephone parameters**
	Near field immunity (w/27.8 dBm CW into dipole)	**WD signal quality (Signal + noise-to-noise ratio in dB)**
Category U1T	75 – 85 dB (IRIL)	-10 – -20 dB + AWF
Category U2T	65 – 75 dB (IRIL)	0 – -10 dB + AWF
Category U3T	55 – 65 dB (IRIL)	10 – 0 dB + AWF
Category U4T	< 55 dB (IRIL)	> 10 dB + AWF
Category UXT	special	special

NOTE—A comparable hearing aid immunity test can be performed by fixing the acoustic output power requirement at 75 dB (IRIL) for all categories and varying the power into the dipole from 22.8 dBm for category U0, increasing by +5 dB for each higher category.

7.4 Accessories and options

A product may be qualified with an accessory, option, or in an alternative mode of operation. However, in these cases all claims of compliance shall clearly state all components or conditions necessary to realize the stated performance level. Examples might be:

a) Product WD Model #abc, when used with Headset Adapter Model #def, complies with category U4T.

b) Product WD Model #abc, with Optional Firmware Version #ghi, complies with category U3.

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8. Calibration and measurement uncertainty

8.1 General

It is important that measurements made using the procedures in this standard follow acceptable practices, sometimes called "good engineering practices," as they relate to the calibration of the instrumentation used. The basic accuracy and reproducibility of measurements made in accordance with this standard depend primarily upon the accuracy of the test equipment used, the care with which the calibration and the measurements are conducted, and the inherent stability of the WD under test. Where a given set of measurements is repeated in the same laboratory and by the same operator, a relatively high degree of reproducibility should normally be obtained. However, when comparing measurements made by different laboratories, allowances should be made for the influencing factors mentioned.

As a minimum, the following guidance should be used:

For each measurement instrument, the following shall be clearly marked on the instrument

a) Date of last calibration
b) Date of next calibration
c) Validation initials and/or source and location of calibration records

Such calibration records are also used as inputs into the calculation of overall measurement uncertainty, which is discussed in 8.4.

8.2 Ambient conditions

All tests in this standard shall be performed at the manufacturer's recommended normal operating temperature and humidity and, if important, at a nominal barometric pressure. This includes both the hearing aid and the WD as well as the test instrumentation.

For reference, the basic ambient conditions are:

Ambient temperature:	23 °C +/– 5 °C
Relative humidity (RH):	0 %<RH<80 %
Atmospheric pressure:	101.3 kPa + 10 to –5 kPa (760 mm Hg + 35mm to –150 mm)
Acoustic ambient noise:	> 10 dB below the measurement level

8.3 Specific calibration requirements

Specific calibration requirements for the equipment discussed are contained in Annex C. When any of the equipment listed is required for a test, the calibration listed in Annex C shall be conducted before the subject measurement is made.

8.4 Measurement uncertainty

Typically, the overall uncertainty is calculated in part by identifying uncertainties in the instrumentation chain used in performing each of the measurements in Clause 4 through Clause 7 of this standard. The figures associated with each technique show the basic components of the instrumentation chain and hence each component is evaluated as to its individual uncertainty (based on its calibration tolerances). The most common guidance documents for such evaluations are NIS 81, NIS 3003 and NIST Technical Note 1297. Sample measurement uncertainty calculations and typical uncertainty values are given in Annex E.

The overall uncertainty shall be reported along with the test results required in Clause 9.

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9. Test report

Test reports are the means of presenting the test results to the appropriate procuring or regulatory agency or for archiving the data in the permanent files of the testing organization. As such, test reports shall be clearly written, in unambiguous language. Unless otherwise specified, the general requirements of the test report shall follow the details contained in Clause 10 of ANSI C63.4-1992.

The test conditions listed in 9.1 through 9.14 shall be described in the test report in order for the test results to be properly documented.

9.1 Test plan

Using the guidance of this standard, a specific test plan shall be prepared and included in the test report. The test plan shall detail how the more general guidance from this standard was specifically applied to the WD or hearing aid tested. Specifics of the WD's or hearing aid's operating state, test orientation, and other details shall be included. If any adjustments or modifications to the guidelines given in this standard are required, these shall be recorded as well.

9.2 Applicable standards

In addition to this standard, any standards that were used in assessing the WD or hearing aid shall be clearly described in the test report. Where referenced standards have more than one measurement procedure, or where the referenced measurement procedure has options, the test report shall state which procedures or options were used. The test report shall also state the issue or year of the referenced standard(s) used.

9.3 Equipment unit tested

The test report shall list all equipment tested, including product type, model number, and any marketing designations. Serial numbers and any other distinguishing identification features shall also be included in the test report. A detailed description of any modifications made to the WD or hearing aid under test shall be recorded. Where applicable, figures or photographs should be provided to document the physical implementation of modifications. Identification or detailed description shall also be made of any accessories or cables. The rationale for selecting the WD or hearing aid tested (including the equipment units needed to be functionally complete and the necessary cabling) shall be noted in the test report.

9.4 Test configuration

The setups of the equipment and cable or wire placement on the test site that produce the highest emissions shall be clearly shown and described. It is allowable to use drawings or photographs for this purpose. A block diagram showing the interconnection of the major functional units is also useful.

The operating state of the WD or hearing aid under test shall be recorded, such as the means used to assure that the WD was operating in the desired mode (i.e., digital or analog transmission mode for dual mode devices), the transmission channel, RF power level, and loudness control. In addition, when applicable the base station simulator used, the type of computer control (with software revision levels), a description of feeding circuits, and a description of other similar support equipment shall be recorded.

9.5 List of test equipment

A complete list of all test equipment used shall be included with the test report. Manufacturer's model and serial numbers, and date of last calibration and calibration interval, shall be included. Measurement cable

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loss, measuring instrument bandwidth and detector function, video bandwidth (if appropriate), and antenna factors shall also be included, where applicable. When appropriate, site calibration data shall be included or summarized and the location of the complete calibration data shall be referenced.

9.6 Units of measurement

Measurements of operating frequency, including variations of the operating frequency with ambient temperature and input voltage, and occupied bandwidth of intentional radiators, shall be reported in units of Hertz or multiples thereof [e.g., kiloHertz (kHz), megahertz (MHz)]. Measurements of RF input power to intentional radiators shall be reported in units of watts.

All information necessary to reproduce a given measurement shall be recorded. If a reference voltage is used, the location of the reference voltage within the system and how it was measured, for example, open or closed circuit, shall be recorded. For other types of measurements the locations of measurement reference point or plane, alignment, and other relevant factors shall be recorded. All formulas of conversions and conversion factors, if used, shall be included in the measurement report.

9.7 Location of test site

The location of the test site shall be identified in the test report. Sites that have received recognition from various accreditation bodies shall use the same site address information as was included in their original application for recognition.

9.8 Measurement procedures

The sequence of testing followed to determine the data included in the test report should be documented.

9.9 Reporting measurement data

The measurement results along with the appropriate limits for comparison shall be presented in tabular or graphical form. Alternatively, recorded charts or photographs of a spectrum analyzer display or other self-displaying instrumentation may be used if the information is clearly presented showing comparison to the limits, and all data conversions are explained. The method of comparing measured data output to the limits shall be included. The measurement uncertainty of the measurements shall also be recorded. The calculations leading to the overall measurement uncertainty shall also be included as an annex.

9.10 General and special conditions

If an alternate test method was used, the test report shall identify and describe the alternate method used, provide justification for its use, and describe how the results obtained were correlated with the methods specified by this standard. Instrumentation, instrument attenuator and bandwidth settings, detector function, WD or hearing aid arrangement, and all other pertinent details of the test shall be provided so that the alternate test method can be replicated. Where automatic scan techniques were used, the name of the program used with version number and an explanation of how the highest emission relative to the limit from the WD or hearing aid under test was determined, and the scan rate used to obtain recorded emissions is to be included in the test report. The actual operating and environmental conditions (e.g., voltage, power line frequency, temperature, relative humidity, etc.) shall be listed in the report.

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9.11 Summary of results

The test report summary section shall indicate the category of WD or hearing aid under test or if the device failed all the category requirements, and give margins (where applicable) with respect to the limits to which it was tested. Due consideration shall be made with respect to the measurement uncertainty in stating the passing or failing result. See 8.4 for a discussion on uncertainty. If the equipment only passes with specific modifications or special attributes, this information shall be included in the summary results.

9.12 Required signatures

The test report shall contain the signature of the representative of the organization performing the tests. In addition, the test report shall contain the identification of the personnel who were responsible for the proper execution of the test, and the name and address of the party requesting the tests. If changes are made during the period of test to bring the WD or hearing aid into compliance, the test report shall so indicate. In addition, the report submitted to the procuring organization or regulatory agency shall include a signed statement by the manufacturer or developer agreeing to the changes and their incorporation into production.

9.13 Test report annexes

The test report shall contain, if required, photographs or detailed sketches of the configuration of the WD or hearing aid under test. Sufficient information shall be recorded for the setup to be reconfigured with adequate detail so as to allow the original test to be replicated with a high likelihood that the test results would be in agreement with the results of the original test, within acceptable tolerances.

9.14 Test report disposition

The test report shall be maintained by the testing organization for a period of at least three years following the date of the test. The manufacturer may be required by a regulatory agency to maintain a copy of the report for a longer period of time.

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Annex A

(normative)

Definition of reference axes

A.1 Axes definition for hearing aid RF immunity tests

The Z-axis is the vertical axis, the X-axis is approximately parallel to the side surface of the user's head and orthogonal to the Z-axis, and the Y-axis is orthogonal to both the Z- and X-axes. Alternately, the Y-axis may be defined by a line through the center points of the ears on the head. The +Z direction is up, the +Y direction is into the head for a right-hand side hearing-aid position, and the +X direction is from the back of the head to the front of the head.

The hearing aid reference orientation is defined by the manufacturer for each type of hearing aid with respect to this framework to represent the typical orientation on the user, similar to the example shown in Figure A.1 for the BTE hearing aid.

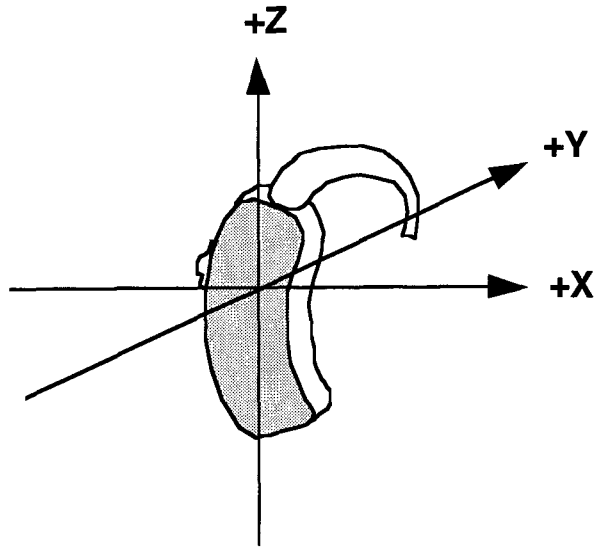


Figure A.1—Behind-the-ear hearing aid

A.2 Reference and plane for WD emission measurements

Figure A.2 describes the references and reference plane that shall be used in the WD emissions measurement.

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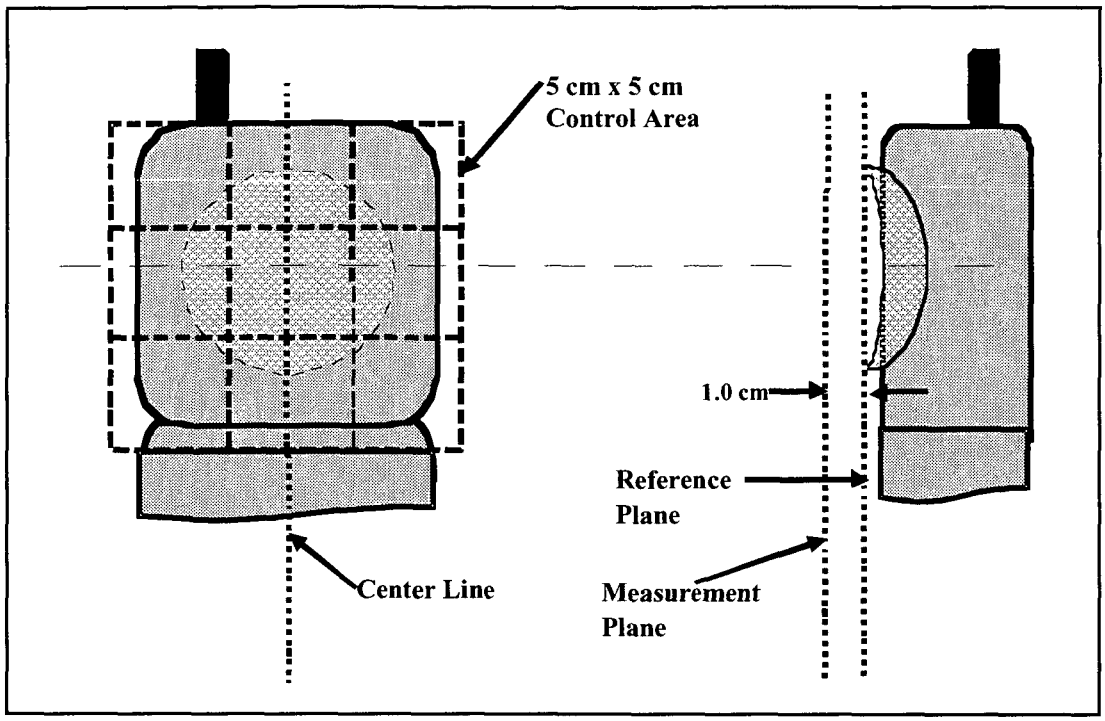


Figure A.2—WD reference and plane for RF emission measurements

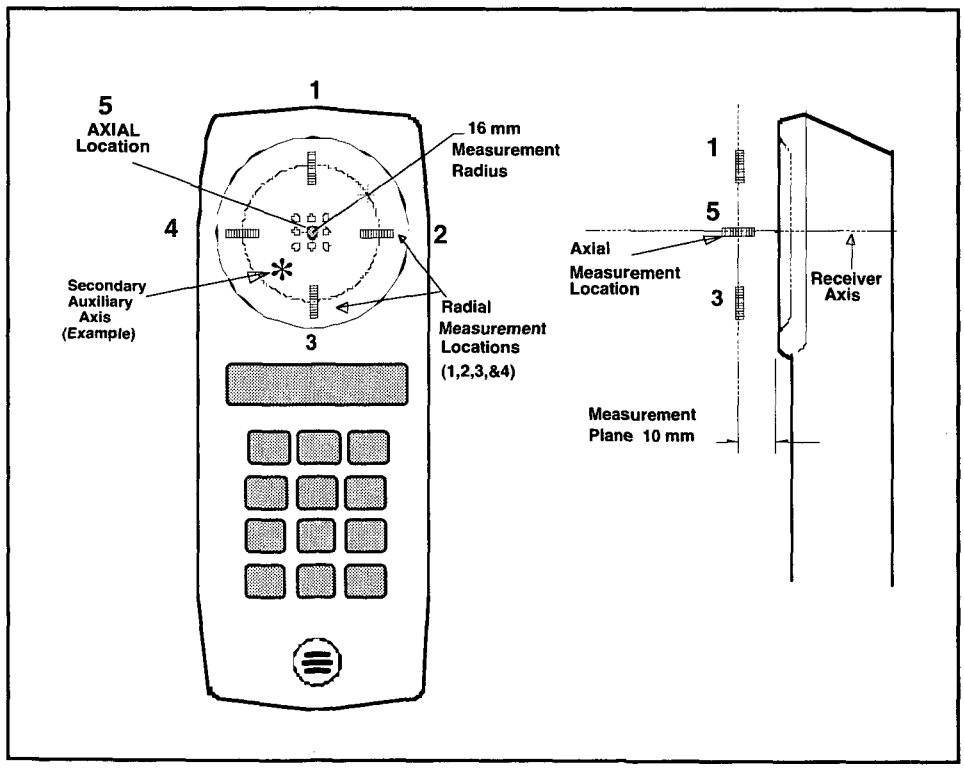


Figure A.3—Axis and planes for WD audio frequency magnetic field measurements

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Figure A.3 illustrates the five standard probe positions. Position 5 is the axial position of the probe coil; position 1 through position 4 are radial positions. The center of the earpiece holes or slots mark the reference axis, unless a secondary or auxiliary axis is used.

a) *Position 1:* The reference plane is the planar area that contains the highest point in the area of the phone that normally rests against the user's ear. It is parallel to the centerline of the receiver area of the phone and is defined by the points of the receiver-end of the WD handset, which, in normal handset use, rest against the ear.

b) *Position 2:* The measurement plane is parallel to, and 1.0 cm in front of, the reference plane.

c) *Position 3:* The reference axis is normal to the reference plane and passes through the center of the receiver speaker section (or the center of the hole array); or may be centered on a secondary inductive source, if the WD uses a non-inductive speaker assembly as the primary audio source.

d) *Position 4:* The measurement axis is parallel to the reference axis but may be displaced from that axis by a maximum of 10 mm. Within this constraint, the measurement axis may be located where the axial and radial field intensity measurements are optimum with regard to the requirements. In a WD handset with a centered receiver and a circularly symmetrical magnetic field, the measurement axis and the reference axis would coincide.

e) *Position 5:* The measurement point for the axial position is located 1.0 cm from the reference plane on the measurement axis. The actual location of the measurement point shall be noted in test reports and designated as the measurement reference point.

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Annex B

(normative)

Acoustic test frequencies

Annex B lists the test frequencies and 1/3 octave test bandwidths to be used for the test contained in this document. These frequencies are from ISO 3-1973 and ISO 266-1975.

1/3-Octave band (Hz)	Included frequencies (Hz)
50	44.7–56.2
63	56.2–70.8
80	70.8–89.1
100	89.1–112.0
125	112–141
160	141–178
200	179–224
250	224–282
315	282–355
400	355–447
500	447–562
630	562–708
800	708–891
1000	891–1120
1250	1120–1410
1600	1410–1780
2000	1780–2240
2500	2240–2820
3150	2820–3550
4000	3550–4470
5000	4470–5620

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Annex C

(normative)

Equipment and setup calibration

C.1 Test enclosures

C.1.1 RF test enclosures

When tests require anechoic enclosures, the quality of the enclosures shall be measured. This can be done using at least two common ways:

a) Measuring and meeting the "volumetric" normalized site attenuation using the procedures described in ANSI C63.4-1992.

b) Calibrating the radiated immunity field using the procedures in IEC 61000-4-3.

The general requirements above also satisfy the requirement that the undesired reflections from those enclosures, which are not perfectly anechoic, are suppressed by at least 20 dB. In addition, such anechoic enclosures shall be tested to ensure that any RF leakage from the RF ambient outside the enclosure is at least 10 dB down from the required measurement level.

The calibration requirements for Wide Band Transverse ElectroMagnetic (WB TEM) devices are based on the direct measurement of the field produced in the test zone. A secondary procedure is performed by calculation, using the power into the device and the physical dimensions of the center conductor (septum) separation from the referenced ground plane. See [B2], [B3], and [B4], and ANSI C63.4-1992 and IEC 118-0:1993.

C.2 Audio input source

An acoustic signal shall be supplied to the hearing aid under test during application of interfering RF test fields, so that hearing aid AGC circuits are in a realistic state of operation, and so that interfering effects on the intended audio signal may be detected. This frequency shall have sufficient separation from 1000 Hz (the RF modulation frequency used in testing) so that as the intended signal it can be independently observed at the hearing aid output by means of tuned filters or an audio signal analyzer or wave analyzer. A frequency of 1300 Hz shall be used provided that the hearing aid frequency response between 1000 Hz and 1300 Hz is smooth (<0.5 dB ripple) and changes less than a total of 2 dB over this range. The pretest data shall be examined to verify this fact. If necessary one or both of the two frequencies involved may be shifted to a region where the response is smoother and the slope is less than 6 dB per octave in the frequency interval. The frequency interval should be at least 1/3 octave and should lie within the bounds of 600 Hz to 3000 Hz.

C.3 Calibration of RF electric and magnetic field probes

Probes used for measuring near-field emissions and calibrating immunity field levels shall be calibrated using the guidelines contained in IEEE Std 1309-1996. The accuracy shall be no worse than +/– 20%. The field pattern shall be isotropic to a tolerance of +/– 20%. The magnetic field probe may have one, two, or three loops. In the case where these probes have less than three mutually orthogonal dipoles or loops, they shall be capable of rotation about their geometric centers to allow calibration and measurement in the three orthogonal axes.

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IEEE Std 1309-1996 provides for three calibration methods and several grades of calibration. The two methods that are most appropriate for this standard's probe calibrations are Method A, using a transfer standard probe, or Method B, using a standard gain horn antenna in an anechoic chamber. The most appropriate grade of calibration is: FD, F2 (f_L, f_M, f_H)[20], A1, I0 for single-axis probes or I1 for "isotropic" probes, R0, T0, and M0. The grade designations are found in Annex A of IEEE Std 1309-1996.

The "maximum interception alignment" as defined and specified in 4.2.2.1 of IEEE Std 1309-1996 shall be used for calibration. The calibration field generation shall be via a pyramidal horn antenna in an anechoic chamber, either as a standard gain antenna, Method B (Table 2 of IEEE Std 1309-1996), or as a reference field generator using a similar probe as a transfer standard, Method A (Table 2 of IEEE Std 1309-1996). Anisotropy of "isotropic" probes shall be measured in accordance with 7.1.3 and Equation (2) of IEEE Std 1309-1996.

The best-case expanded uncertainty, U, for probe calibration is U $\approx \pm 1.1$ dB for Method A and U $\approx \pm 1.0$ dB for Method B. Out of the allowable expanded uncertainty of ±2 dB (see 4.1.2), these calibration uncertainties leave approximately ±0.84 dB to ±0.86 dB in terms of combined standard uncertainty, u_C, for other contributors. That is:

$U = \pm 2$ dB,

therefore

$u_C = \pm 2 \div 2 = \pm 1$ dB;

$u_S^2 = u_C^2 - u_{cal}^2$;

$u_{cal} = U_{cal} \div 2 = \pm 1.1 \div 2 = \pm 0.55$ dB (the value, $U_{cal} = \pm 1.1$ dB, is from Method A); and

$u_S = \sqrt{(1^2 - 0.55^2)} = \pm 0.84$ dB.

See Annex E for further information on estimation of uncertainty.

C.3.1 RF field probe modulation response

In addition, a calibration shall be made of the modulation response of the probe and its instrumentation chain. This calibration shall be performed with the field probe, attached to the instrumentation that is to be used with it during the measurement. The response of the probe system to a CW field at the frequency(s) of interest is compared to its response to a modulated signal with equal peak amplitude. The field level of the test signals shall be more than 10 dB above the ambient level and the noise floor of the instrumentation being used. The ratio of the CW reading to that taken with a modulated field shall be applied to the readings taken of modulated fields of the specified type. This may be done using the following procedure:

a) Fixing the probe in a set location relative to a field generating device, such as a dipole antenna or WB TEM.

b) Illuminate the probe with a CW signal at the intended measurement frequency and with a sufficient amplitude so that the resulting reading is greater than 10 dB above the probe system noise floor but within the systems operating range.

c) Record the reading of the probe measurement system of the CW signal.

[20] f_L, f_M, and f_H refer to the low, middle, and high frequencies, respectively, of the probe-range to be calibrated.

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d) Determine the peak level of the signal being used to drive the field generating device.

e) Substitute a signal using the same modulation as that used by the intended WD for the CW signal.

f) Set the peak amplitude of the modulated signal to equal the amplitude of the CW signal.

g) Record the reading of the probe measurement system of the modulated signal.

h) The ratio of the CW to modulated signal reading is the modulation factor.

The modulation factor obtained by this method shall be applied to readings taken of the actual WD in order to obtain an accurate peak field reading.

C.4 Calibration of dipoles

C.4 describes calibration of dipoles over a range of frequencies, 800–950 MHz and 1.6–2.48 GHz, such that the magnetic field at 1 cm distance from the center of the dipole and the electric field 1 cm out from the end of the dipole is kept constant.

The intent of this procedure is to assure the consistency of the magnetic and electric field levels a hearing aid is exposed to, during immunity testing, over the specified range of test frequencies.

C.4.1 Equipment

a) Broadband dipoles 800–950 MHz or 1.6–2.48 GHz

b) Signal generator

c) HF amplifier

d) Calibrated magnetic field and electric field probe

e) Appropriate test location; i.e., anechoic room, or at least a test area large enough so that reflections off of nearby objects do not disturb the test results.

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C.4.2 Calibration procedure

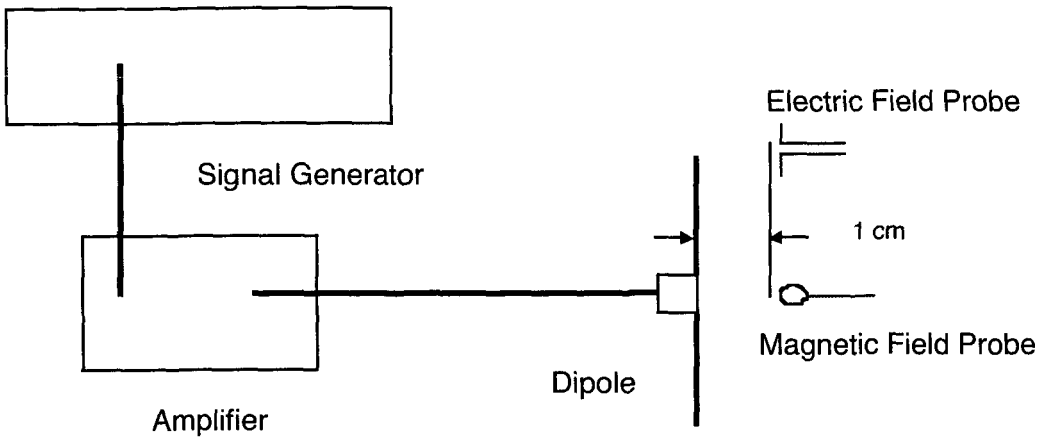


Figure C.1—Dipole calibration procedure

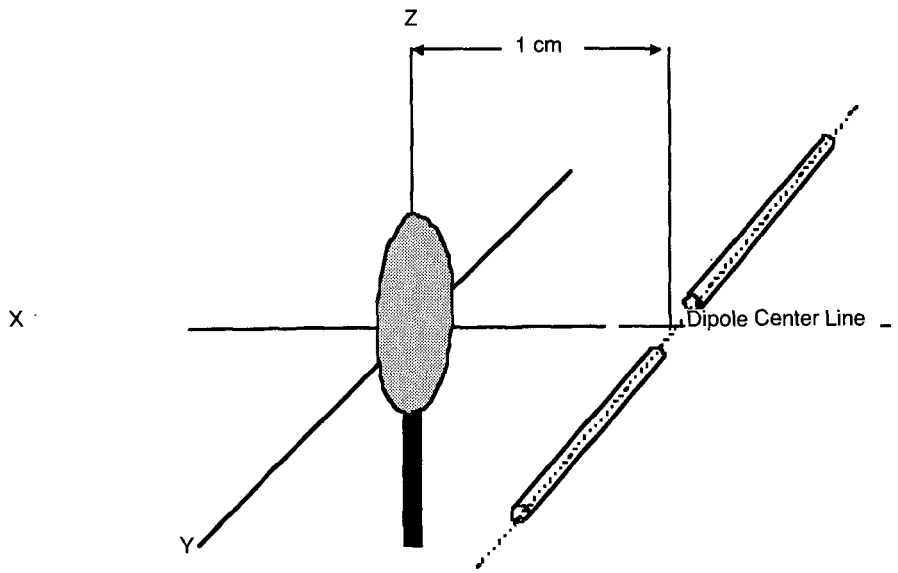


Figure C.2—Probe location for dipole calibration

1) Connect equipment as shown in Figure C.1.
2) Position the magnetic field probe at 1 cm distance from the center line axis of the dipole, which is also fixed in an appropriate fixture (Figure C.2). Make sure that the desired measuring channel of the probe is aligned for maximum reception of the magnetic field generated by the dipole. This may be accomplished by rotating the probe until the maximum value is located. The magnetic field probe shall have been calibrated over the frequency range of 800–950 MHz or 1.6–2.48 GHz using standard calibration techniques.

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3) Adjust the power level of the signal generator at the initial starting frequency such that the desired magnetic field strength at the 1 cm distance from the center of the dipole is achieved.

4) Step the frequency in step increments of ≤1%, adjusting the power fed into the dipole such that the desired magnetic field strength is maintained.

5) Record the frequency and signal generator setting at each frequency for use during the actual immunity test. A sample calibration chart is provided in Table C.1, as an example.

Table C.1—Sample calibration chart

E-field Calibrated value: (49.54 dB V/m)	
Frequency (MHz)	**Net power (dBm)**
800	
801.5	
803	
804.5	
806	
–	
–	
–	
950	

H-field Calibrated value: (0 dB A/m)	
Frequency (MHz)	**Net power (dBm)**
800	
801.5	
803	
804.5	
806	
–	
–	
–	
950	

6) Repeat steps using an electric field probe located off the end of the dipole.

If the dipole has a broadband matching section, check that the VSWR is within the specified VSWR over the test band. Tune the dipole or adjust the matching section, if necessary, to achieve better matching.

C.5 Calibration of hearing aid probe coil

The Helmholtz coil, built in accordance with IEEE Std 1027-1996 (see D.14), is required to calibrate the hearing aid probe coil. The calibration procedure, from Clause 5 of IEEE Std 1027-1996 is contained in D.14.

Metal parts, including fixtures for holding the probe coil, should not be near the Helmholtz coils during calibration. Connection to the probe coil should only be made by twisted leads or a thin shielded wire. The Helmholtz coils should not be located near sources of magnetic fields such as transformers.

To calibrate, establish a known magnetic field at the center of the Helmholtz coils. A constant current should be maintained to the Helmholtz coils at all frequencies of measurement. Insert the probe coil in the field and align its main axis with the field by adjusting its position for maximum output. The coil sensitivity can then be determined at any frequency by using the following equation:

$$P(f) = 20 \log [Vp(f)/Hc]$$

where

$P(f)$ is the probe coil sensitivity vs. frequency in dB V/(A/m)
$Vp(f)$ is the output voltage of the probe coil in volts
Hc is the magnetic field strength generated by the Helmholtz coils in amperes per meter (A/m)

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P(1000), the probe coil sensitivity at 1000 Hz, should be measured first.

The probe coil sensitivity ideally increases at a rate of 6 dB per octave with increasing frequency as expressed in:

$$P(f) = P(1000) - 20 \log (f/1000 \text{ Hz})$$

where

P(1000) is the probe sensitivity at 1000 Hz in dB V/(A/m)
f is the frequency in hertz

The sensitivity shall not deviate from this characteristic by more than 0.5 dB, as illustrated by Figure 5 of IEEE Std 1027-1996 and as shown in Figure C.3:

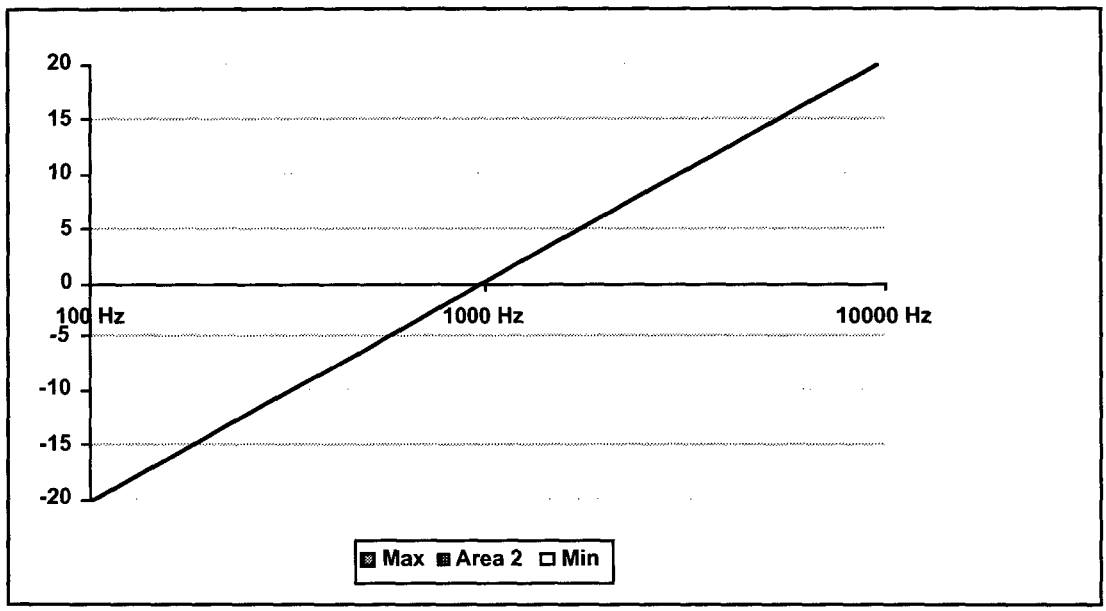


Figure C.3—Probe coil sensitivity

C.5.1 Linearity

Check the system for amplitude linearity, vary the current through the Helmholtz coil to establish fields from –50 dB to 0 dB relative to 1 A/m in 10 dB steps. Check that the output varies in corresponding 10 dB steps (± 0.5 dB).

C.5.2 Signal to noise ratio of the calibration system

Set the current in the Helmholtz coils to create a field of –50 dB relative to 1 A/m. Note the output reading of the probe coil. Turn off the current to the Helmholtz coils and ensure the output drops at least 10 dB.

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C.5.3 Coil sensitivity

C.5.3.1 Coil sensitivity–calculation method

It is possible to calculate the probe coil sensitivity from the following series of equations as described in Annex B of IEEE Std 1027-1996.

For a magnetic field strength of H amperes per meter, the magnetic flux density is:

$$B = \mu H \ [Wb/m^2] \tag{C.1}$$

where

$\mu = 4\pi\ 10^{-7}$ henry per meter = permeability of free space

For a coil of area S, the magnetic flux through the coil is:

$$\phi = B \bullet S \ [Wb] \tag{C.2}$$

Faraday's Law states that the electrical output from a coil placed perpendicularly to a varying field is:

$$v = N\, d\phi/dt \ [\text{volts}] \tag{C.3}$$

where

N = number of turns on the coil

Combining Equation (C.1), Equation (C.2), and Equation (C.3) for a coil placed perpendicular to the field gives:

$$v = N \mu S\ dH/dt [\text{volts}] \tag{C.4}$$

For a sinusoidally varying magnetic field, the magnetic field strength is:

$$H = \hat{H}\sin(\omega t), [\text{A/m}] \tag{C.5}$$

where

$\hat{H}$ = peak amplitude of the field

so

$$dH/dt = \hat{H}\omega\cos(\omega t) \tag{C.6}$$

Therefore, the electrical output from a coil placed perpendicular to a sinusoidal field of H amperes per meter is:

$$v = N \mu S \omega\ \hat{H}\cos(\omega t), [\text{volts}] \tag{C.7}$$

Equation (C.7) shows that the output is proportional to ω, that is, proportional to frequency.

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C.5.3.2 Coil sensitivity–laboratory calibration

For practical multi-layer coils, and certainly for coils with magnetic material cores, better accuracy can be expected by inserting the coil in a known magnetic field and measuring the output.

One method of establishing a known magnetic field is to use a pair of Helmholtz calibration coils as shown in D.14. A set of Helmholtz coils consists of two circular coils of equal diameter and equal number of turns parallel to each other along an axis through the center of the coils, separated by a distance equal to the radius of the coils. Thus the two coils of the Helmholtz coil have equal radii and their centers lie on a common axis. For multiple-turn coils, the diameter of the winding on each coil is much smaller than the diameter of the coil. The two coils are connected in series aiding in order to produce a nearly uniform magnetic field in a region surrounding the center point of the axis between the two coils. (The coils can be connected in parallel aiding, but the current in the coils shall be kept equal.)

The use of Helmholtz coils for probe or sensor calibration is summarized as follows:

a) Helmholtz coils may be used to volumes with dimensions of $0.6r$ (r is the radius of the coil) for highly accurate probe or sensor calibration;

b) Helmholtz coils should be used in series-aiding connection, but may be used in parallel-aiding connection if necessary-with extra current controls and precautions;

c) Balance the products NI in the two coils for maximum accuracy; (N = number of turns on each coil; I = current in the coils, in amperes); and,

d) Consider Helmholtz coils a primary standard: they can be calibrated by a ruler.

C.6 Selection and calibration of acoustic transmission line

C.6.1 Selection of acoustic transmission line

Several methods are available for providing an acoustic transmission line from the hearing aid under test to the measurement instrumentation. Undamped transmission line commonly has unacceptably large variation in its transmission loss over frequency. Adding a 1500 Ω damper is recommended to significantly smooth the loss response as a function of frequency. The 1 m damped acoustic transmission line, commonly called a damped "long horn," is recommended for larger separations. This device is constructed of 600 mm of 2 mm tubing, which connects to the hearing aid. At the end, away from the hearing aid, a 680 Ω damper is inserted to smooth the transition to a 400 mm length of 3 mm tubing. At the end of the 3 mm tubing a 330 Ω is inserted and transitions to an 18 mm length of 4 mm tubing. The 4 mm tubing then connects to the ear coupler and measurement instrumentation (see Figure C.4).

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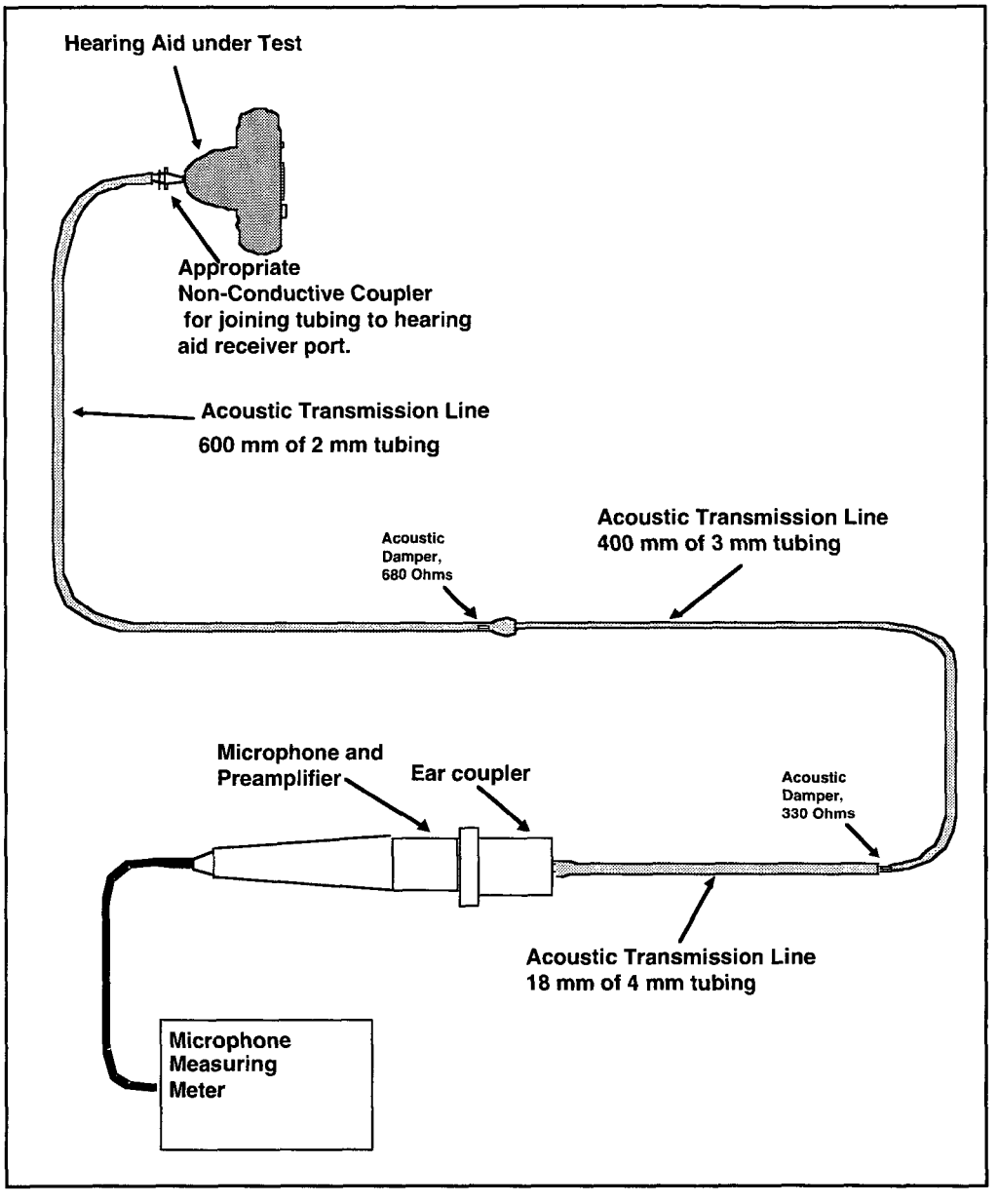


Figure C.4—Construction of 1 m damped "long horn" acoustic transmission line

C.7 Microphone subsystem requirements

The microphone subsystem, which is comprised of the pressure-field microphone, preamplifier, ear coupler, and measuring amplifier, shall meet the requirements of sections 4.7 and 4.7.1 of ANSI S3.22-1996. The pressure frequency response of the microphone used with the earphone coupler, along with its amplifier and readout device, shall be uniform within +/– 1 dB over the frequency range 200–5000 Hz. The calibration of the microphone subsystem shall be accurate at any frequency between 250 and 1000 Hz to within +/– 1 dB.

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Annex D

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Test equipment specifications

D.1 Acoustic damper

Acoustic damper of specified impedance:

a) 330,

b) 680, or

c) 1500 ohms (Knowles part # BF1861 or equivalent)

D.2 Audio frequency analyzer or wave analyzer

a) Frequency range: 20 Hz–20 kHz

b) Resolution bandwidth: 3–300 Hz in 1–3–10 steps

c) Input amplitude range: 1 mV rms to 30 V rms

d) Input impedance: 1 Mohm shunted by up to 30 pF

e) Dynamic range: > 80 dB

f) Spurious responses: at least 80 dB below input reference level

g) Amplitude accuracy: +/– 0.5 dB

D.3 Audio output transducer (receiver)

Knowles part # ED1913 or equivalent.

D.4 Audio signal generator

Frequency range:	20 Hz–20 kHz
Output:	> = 1.0 V rms into 50 ohms
Distortion:	< = 1%
Output impedance:	600 ohms
Frequency range:	up to at least 4 kHz
Maximum output level:	≥ 40 dBm sinusoidal

D.5 Bandpass filter

Input impedance:	≥100 kohm
Bandpass:	200 Hz to 10 kHz
Out-of-band roll-off:	≥ 24 dB per octave

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D.6 Dipole, resonant

The dipoles to be used for these tests are resonant balanced half-wave dipoles tuned for maximum free space radiation in the specified resonant frequency band. Each dipole shall be preliminarily scanned at a 5 mm distance along its axis with an H-field probe to check the balance of the currents on the two arms of the radiator. Current amplitude and distribution along each arm shall be within ±3% between each arm. The gain of the dipole, as measured in an anechoic chamber using the method of identical antennas, is 1.8 dBi, ±0.5 dB.

Resonant frequency:	between 800–950 MHz or 1.6–2.0 GHz
Insertion loss:	< 0.5 dB over 800–950 MHz or 1.8–2.0 GHz, as applicable.
VSWR:	≤1.92:1 over 800–950 MHz or 1.8–2.0 GHz, as applicable (referenced to 50 ohms).
Balance:	≤ ±3%
Gain:	1.8 dBi, ±0.5 dB
Element Diameter:	3.58 mm nominal o.d. (Note—this is the o.d. of RG-402U semi-rigid coax.)

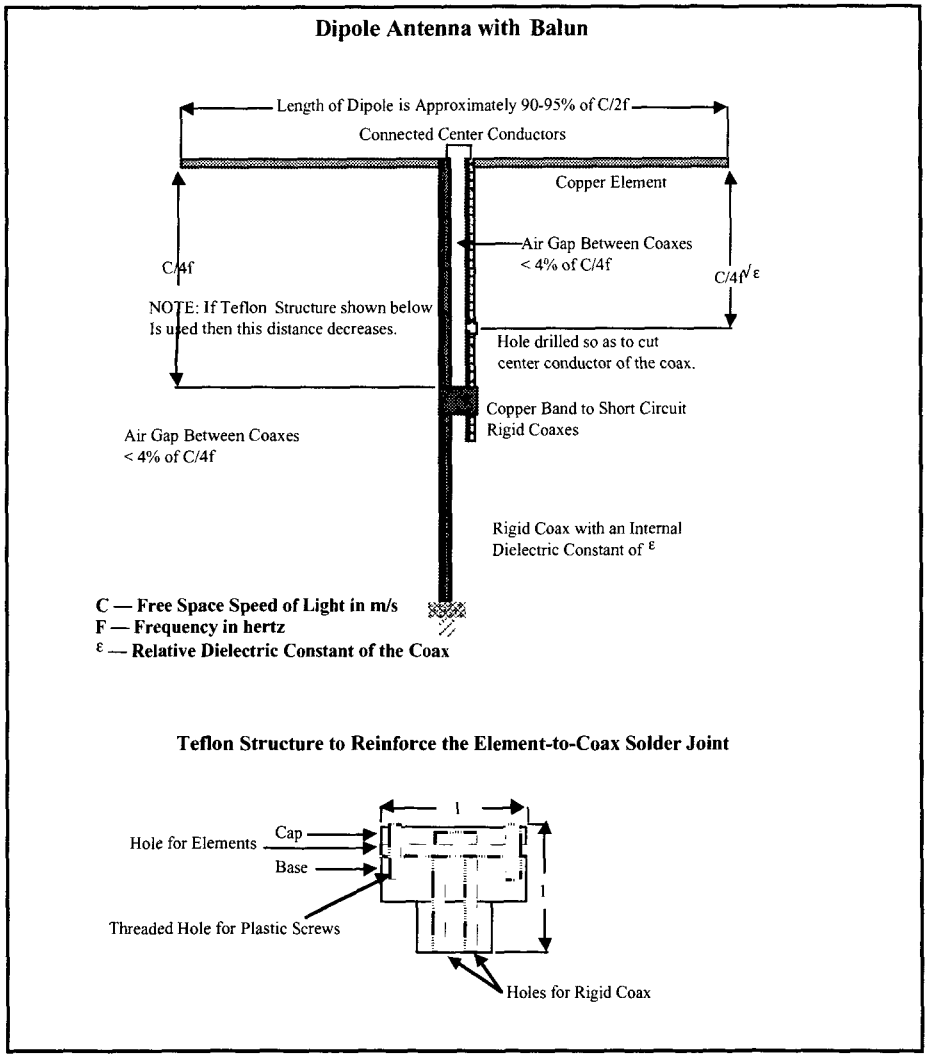


Figure D.1—Balanced dipole antenna

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D.6.1 Broadband dipoles

D.6.1.1 Dipoles for 800–950 MHz

For the band from 800–950 MHz, a thick dipole (RG-402U, 3.58 mm diameter) cut for resonance between approximately 880–900 MHz has a worst-case VSWR ≈ 1.6 in a 50 Ω system ($P_R \leq 5.3$ %) without any matching section, i.e., only a balun. This is because the fractional bandwidth is relatively small. The resonant length for this dipole is 161.2 mm, or approximately 161 mm. This causes the dipole to resonate at ≈890 MHz.

D.6.1.2 Dipoles for 1.6–2.48 GHz

WD bands range from 1.6–2.48 GHz. This expanded frequency range can be covered by a single dipole, as described in this section. While one could build a set of tuned dipoles to cover all of the wireless device frequencies, it is probably more economical to build a single broadband dipole for this range.

NOTE–The dipole specified in D.6.1.1 for the range 800–950 MHz is already a broadband dipole.

Resonant dipoles that are thick, i.e., have length-to-diameter ratios of less than 100, have impedance characteristics that change very slowly with frequency. If these dipoles are mismatched at the resonant frequency, they may be used with acceptable VSWR over wide bands of frequencies, while retaining the characteristics of resonant dipoles. The dipole is tuned to be resonant at the center of the band of wavelengths to be used, and the matching section (often also a balun) is designed to provide transformation from 50 ohms to the geometric mean of the maximum and minimum impedances that is presented by the feed-point of the dipole.

If a dipole made of 3.58 mm diameter stock (RG-402U) is cut to resonate at 1.92 GHz and fed by a 50–83 Ω matching transformer/balun, the worst-case VSWR is less than 1.7. This implies reflected power of approximately 6.7 %. A resonant frequency of 1.92 GHz in such a thick dipole results from a length of 73.8 mm or approximately 74 mm. Some experimentation may be needed, so the dipole should be cut too long to begin with and shortened as necessary.

NOTE—Since "lumped-element" transformers are difficult to realize at these frequencies, other approaches are needed. Some approaches, among others, may be transmission line combinations,[21] microstrip on printed circuit board material, and other similar transformer realizations on PC boards.

If only the bands from 1.6–2.48 GHz are to be covered, a thick dipole cut to resonate at 1.85 GHz has a VSWR < 1.5 when operated in a 50 Ω system, resulting in PR ≈ 4 %. The physical length of the dipole made of RG-402U resonant at 1.85 GHz is 76.5 mm, or approximately 76 mm.

D.7 Directional coupler

Coupling factor:	20 dB
Directivity:	minimum of 30 dB
Maximum incident power:	commensurate with RF power amplifier output (see D.1)
Impedance:	50 ohms
Insertion loss:	0.2 dB maximum
VSWR:	1.15 maximum
Connectors:	Type N female
Frequency range:	0.8 GHz to 3.0 GHz

[21]See, for example, Witt [B26]. While this article is written around antennas for 4 MHz, a similar approach may be taken at 2 GHz.

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D.8 Ear coupler

For the purposes of this document the term *ear coupler* refers to the coupler used in making hearing aid measurements. The term *ear simulator* is used for the coupler used for the WD measurements.

The ear coupler shall have a volume of 2 cc in a closed configuration and suitable for the particular hearing aid under test. The 2 cc coupler may be chosen from those described in section 4.5.2 of ANSI S3.7-1995 (R1986). The ear coupler is the same as and shall meet the requirements for it in ANSI S3.22-1996.

D.9 Ear simulator

For the purposes of this document the term *ear coupler* refers to the coupler used in making hearing aid measurements. The term *ear simulator* is used for the coupler used for the WD measurements.

The ear simulator shall be compliant with IEC 60318-1 (1998-07).

D.10 Frequency generator

Output impedance:	600 ohms
Frequency Range:	≥ 10 kHz
Maximum Output Level:	≥ 40 dBm sinusoidal

D.11 Graphics recorder

Equivalent to:	B&K 2313

D.12 Hearing aid immunity test fixture

The fixture depicted in Figures D.2 through D.8 is the preferred fixture for the hearing aid immunity test. Other implementations are allowing provided that they provide sufficient positioning accuracy and repeatability to support the test.

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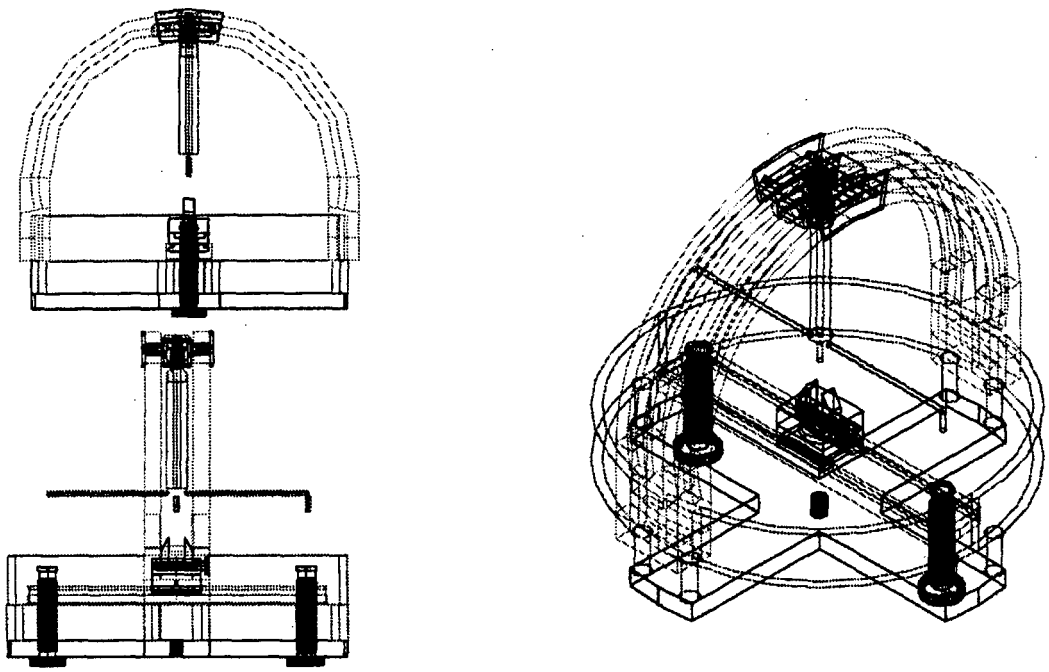


Figure D.2—Hearing aid immunity test fixture

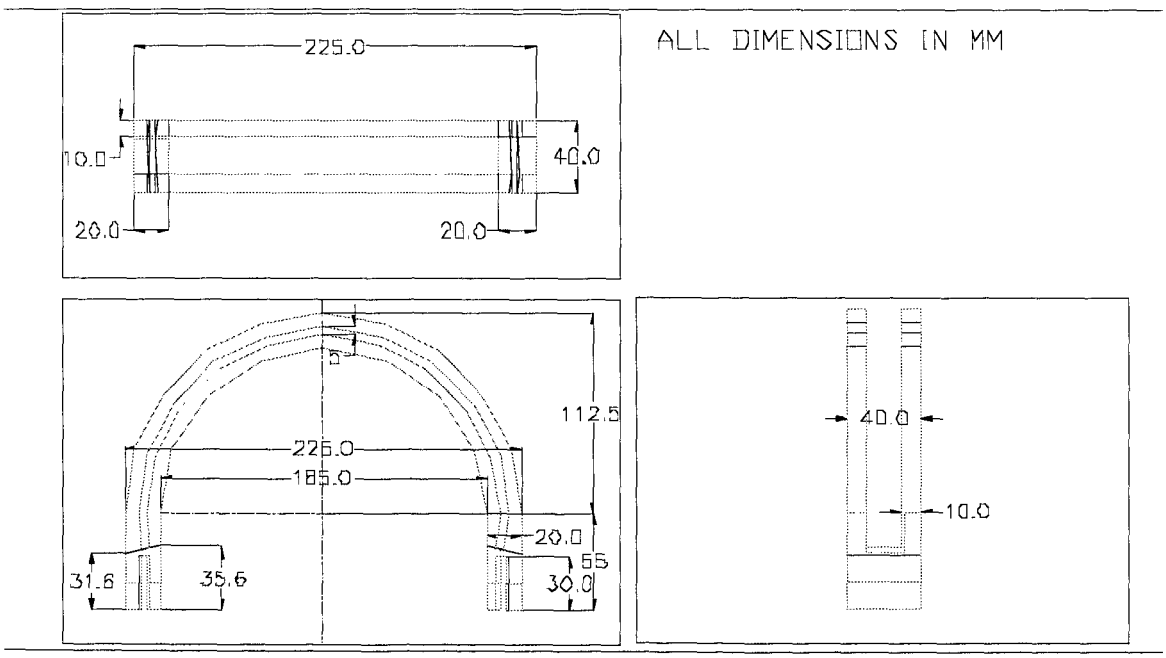


Figure D.3—Yoke for hearing aid immunity test fixture

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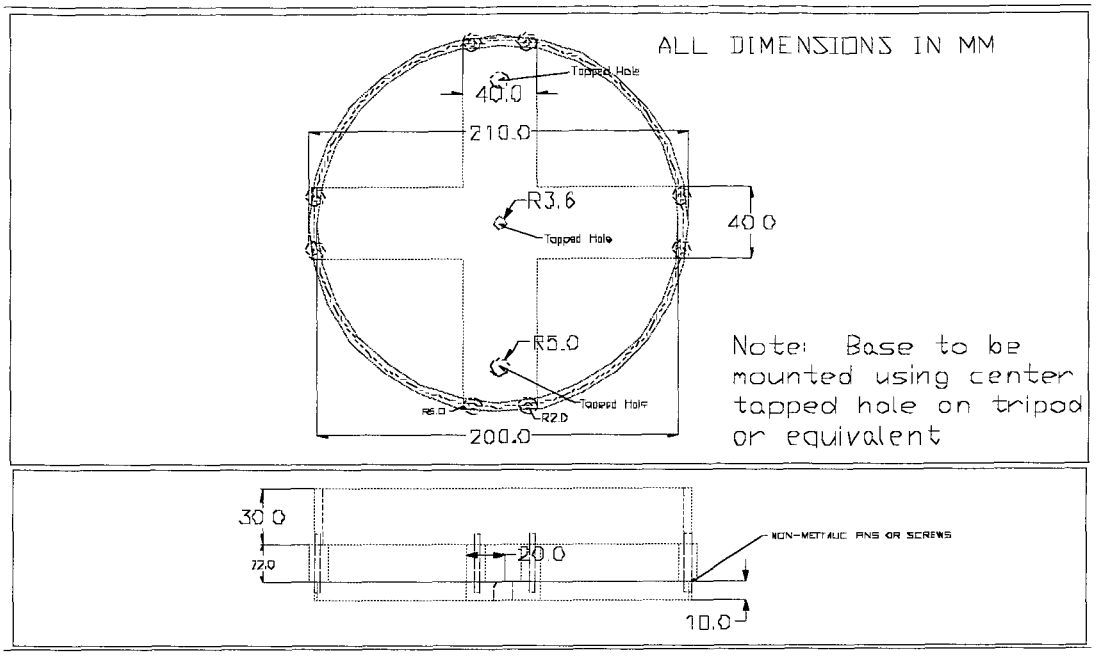


Figure D.4—Base for hearing aid immunity test fixture

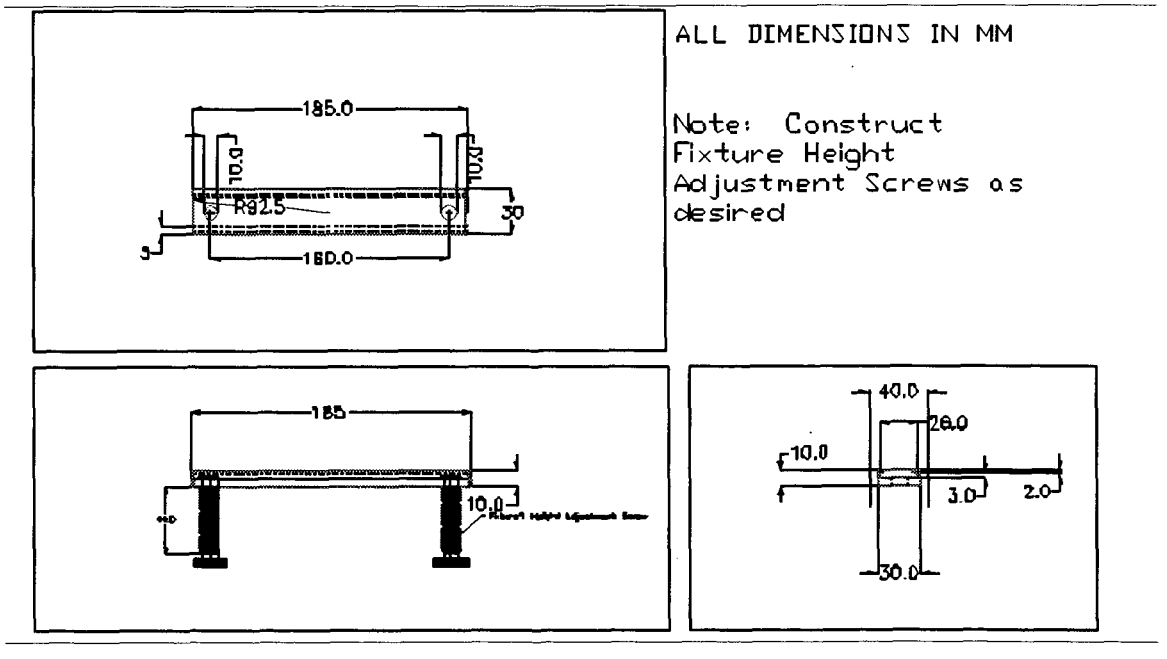


Figure D.5—Stage for hearing aid immunity test fixture

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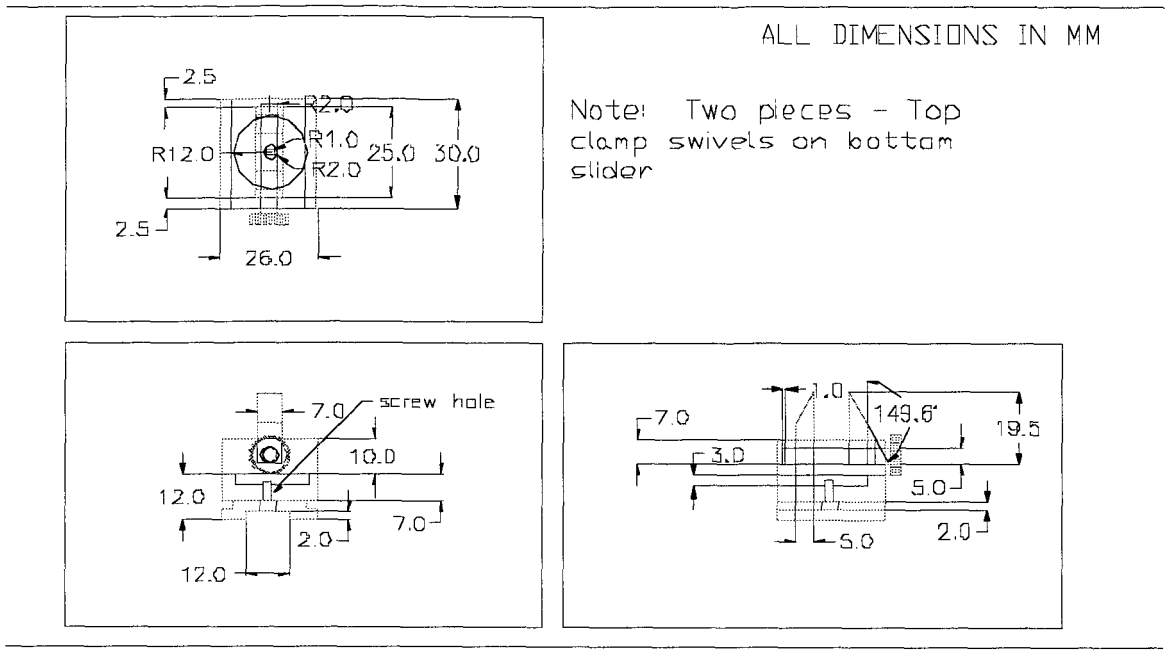


Figure D.6—Hearing aid clamp for hearing aid immunity test fixture

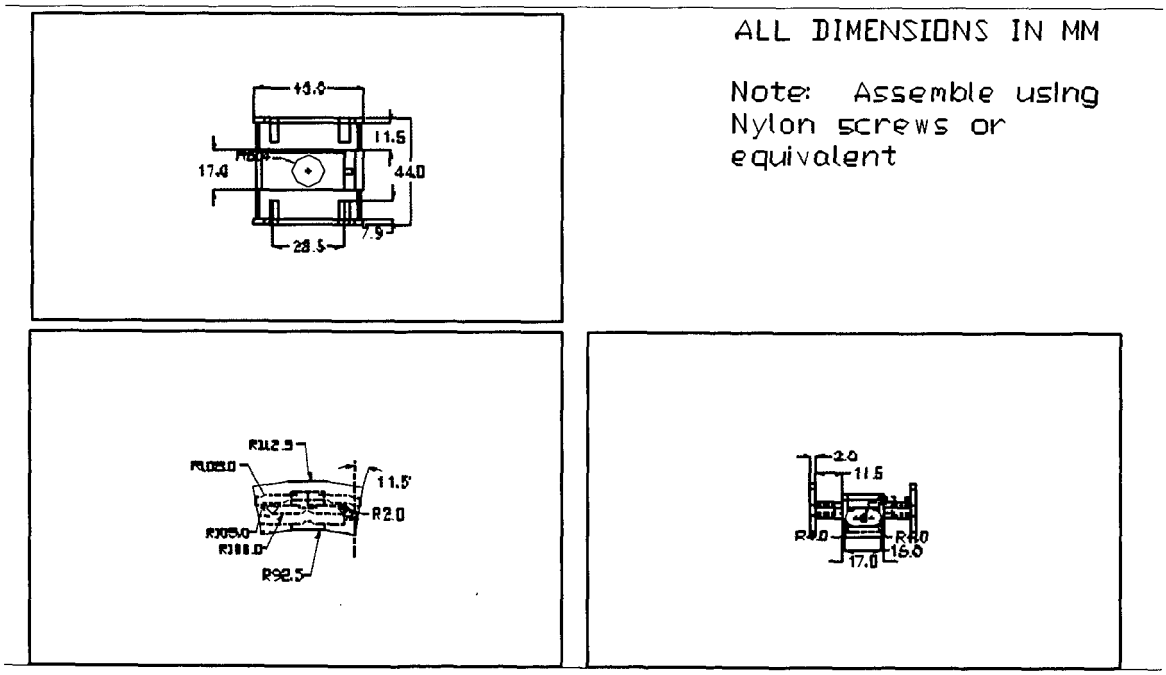


Figure D.7—Antenna slider for hearing aid immunity test fixture

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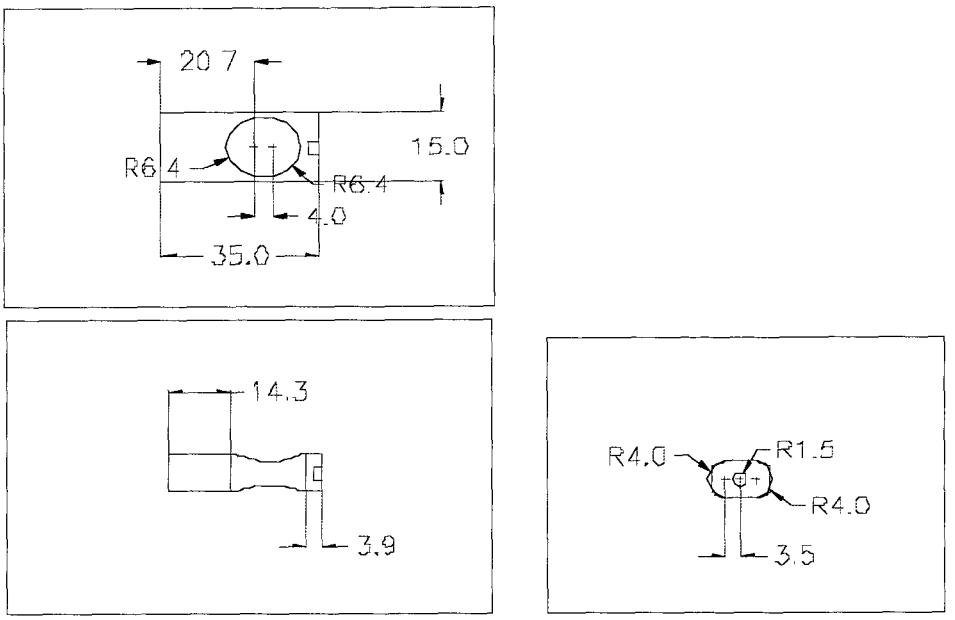


Figure D.8—Antenna lock for hearing aid immunity test fixture

D.13 Hearing aid probe coil

(In accordance with FCC 47 CFR 68 (1997) and IEEE Std 1027-1996)

Maximum:	6.55 mm length X 2.29 mm diameter
DC resistance:	900 Ω
Wire size:	51 AWG
Inductance:	140 mH at 1 kHz
Sensitivity:	–60.5 dB (V/ A/m) at 1 kHz
Sensitivity tolerance:	±0.5 dB from the characteristics illustrated

Frequency	Hi limit	Low limit
100 Hz	-19.5 dB	-20.5 dB
10 kHz	20.5 dB	19.5 dB

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D.13.1 Hearing aid probe coil parameters

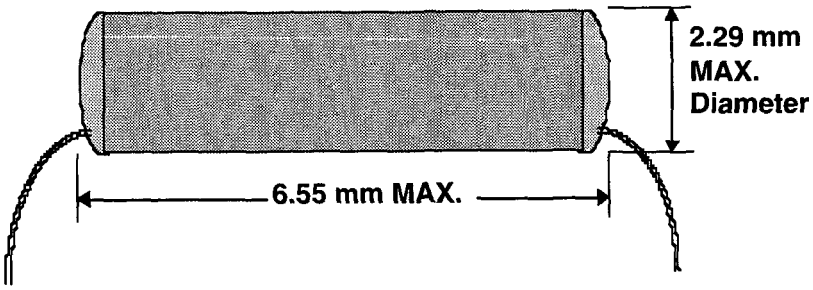


Figure D.9—Typical parameters of the hearing aid probe coil

D.14 Helmholtz calibration coils

Refer to D.14.1 and Figure D.10.

Radius:	143 mm
Windings:	20 turns of no. 24 AWG enameled magnet wire

D.14.1 Helmholtz coil magnetic field generation

Helmholtz coils consist of a pair of identical coils wound in a series-aiding fashion, coaxially aligned and spaced a distance apart that is equal to their radius (see Annex F). The magnetic field at the center of such a pair of coils is axially directed with a strength given by:

$$H_C = \frac{NI}{r\sqrt{1.25^3}}[A/m]$$

where

H_c is the magnetic field strength in amperes per meter
N is the number of turns per coil
I is the current in amperes
r is the coil radius in meters

The above equation assumes that all the turns on each coil can be considered to lie in the same place and have the same radius. In practice this means that the diameter of the wire bundle is much less than the diameter of the coil.

The coil parameters are such that the magnetic field strength is numerically equal to 100 times the current flowing through the coils. Thus, if a 100 W resistor is used to sense the current flow, the magnetic field strength is numerically equal to the voltage across this sensing resistor.

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Nonmetallic materials should be used to construct the coil forms, base, and any supporting structure for locating probe coils that are to be calibrated. The method of interconnecting the coils and bringing out the leads to binding posts on the end of the base, described in D.14 and shown in Figure D.10 and Figure D.11, minimizes any disturbing effects on the desired magnetic field.

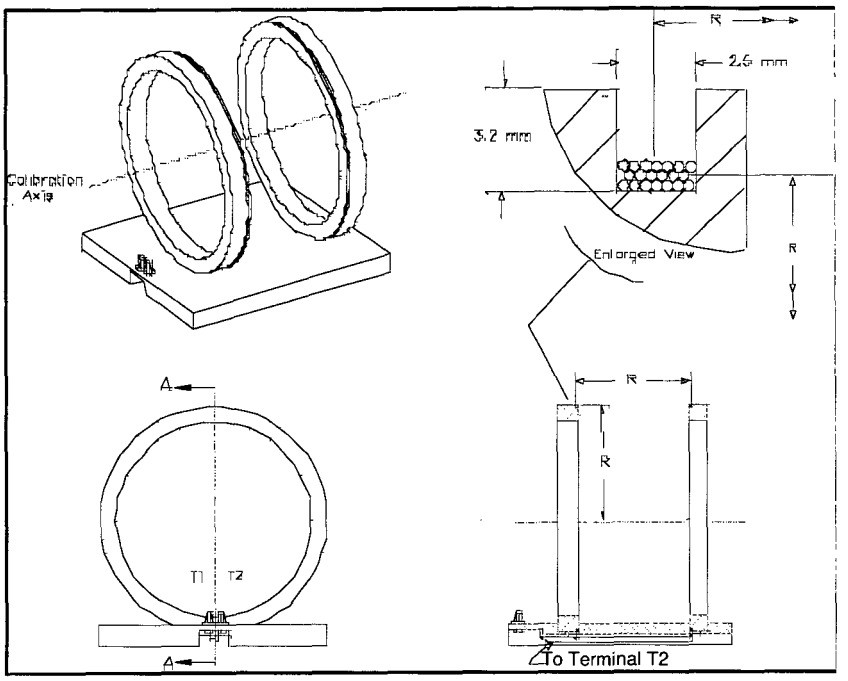


Figure D.10—Helmholtz coil diagram

R = 143 mm
N = 20 turns, AWG No 24 enameled magnet wire, per coil

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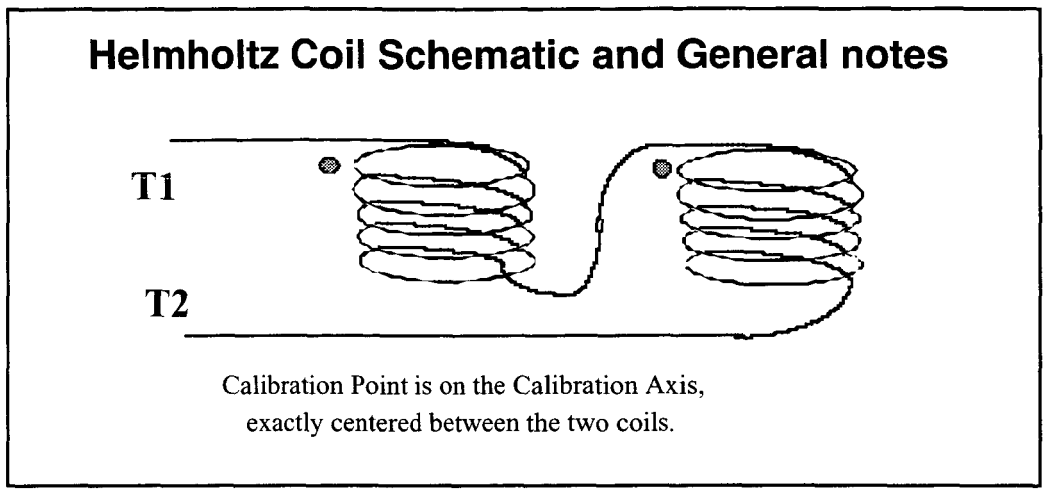


Figure D.11—Helmholtz coil circuit

D.15 Microphone preamplifier

Equivalent to B&K 2639.

D.16 Microphone, free field

Free-field microphone with a free-field frequency response uniform within +/– 1 dB over the frequency range 200–5000 Hz.

D.17 Microphone, pressure

Pressure-field microphone with a pressure frequency response uniform within +/– 1 dB over the frequency range 200–5000 Hz.

D.18 Microphone calibrator

Microphone calibrator compliant with IEC 61094-1 (1992-06) or Wong and Embleton [B27].

D.19 Pressure-field microphone, preamp, 2 cc coupler, and measuring amplifier

These shall meet the requirements of sections 4.7 and 4.7.1 of ANSI S3.22-1996. The pressure frequency response of the microphone used with the earphone coupler, along with its amplifier and readout device, shall be uniform within +/– 1 dB over the frequency range 200–5000 Hz. The calibration of the microphone system shall be accurate at any stated selected frequency between 250–1000 Hz to within +/– 1 dB.

The coupler shall have a volume of 2 cc in a closed configuration and suitable for the particular hearing aid under test. The 2 cc coupler may be chosen from those described in section 4.5.2 of ANSI S3.7-1995.

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D.20 Probe, near-field, E-field

a) *Field perturbation:* The probe and its associated cables shall not perturb the field by more than 1 dB from the measured quantity. Normally this requires probes of diameter less than 1 cm that are connected to the measurement instrumentation through high resistance or non-conductive lines.

D.21 Probe, near-field, H-field

a) *Field perturbation:* The probe and its associated cables shall not perturb the field by more than 1 dB from the measured quantity. Normally this requires probes of diameter less than 1 cm that are connected to the measurement instrumentation through high resistance or non-conductive lines.

D.22 RF cables

a) *Insertion loss:* < 0.5 dB over 800–2480 MHz

b) *VSWR:* < 1.5:1 over 800–2480 MHz (terminated with a 50 ohm load)

D.23 RF communications test set

A base station simulator or other means by which the WD may be configured in the required test conditions.

D.24 RF power amplifier

a) *Frequency range:* 0.8–3.0 GHz

b) *Power output level and gain:* Capable of producing the required field strength within the test volume of the TEM cell using the RF signal generator (described in D.25).

c) *Linearity:* Harmonics of the fundamental carrier frequency shall be at least 30 dB below carrier level (–30 dBc) at the maximum carrier power level used in the test setup. With this carrier level, the AM distortion of the modulated envelope shall be less than 5% at an AM level of 80%.

D.25 RF signal generator

a) *Frequency range:* 0.8–3.0 GHz

b) *Frequency resolution:* 100 Hz

c) *Power output level:* greater or equal to +13 dBm (unmodulated carrier)

d) *Modulation capability:* 0–99% AM at 1000Hz at carrier outputs up to +7 dBm, both internal and external modulation capability

e) *Linearity:* Harmonics of the fundamental carrier frequency shall be at least 40 dB below carrier level (–40 dBc) at the maximum carrier power level used in the test set-up. With this carrier level, the AM distortion of the modulated envelope shall be less than 5% at an AM level of 80%.

f) *Non-harmonic spurious:* less than –40 dBc

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D.26 RF wattmeter

This is for measurement of the directional coupler output. Any RF voltmeter with an input impedance of 50 ohms that can be calibrated in terms of rms Volts may be used as a substitute. Examples are spectrum analyzers, EMI receivers, and RF millivoltmeter instruments.

a) *Frequency range:* 0.8–3.0 GHz

b) *Impedance:* 50 ohms

c) *Amplitude range of input:* +20 to + 40 dBm (2.236 V rms–22.36 V rms across 50 ohms)

D.27 Sine/noise generator

Equivalent to B&K 2636.

D.28 Telephone test head

Equivalent to B&K 4905.

D.29 TEM cell

a) *Frequency range:* 0.8–3.0 GHz

b) *VSWR over frequency range:* < 1.50

c) *Input impedance:* 50 ohms

d) *Septum height in test region:* 2X to 3X maximum dimension of hearing aid

e) *Field uniformity in test region:* 0–6 dB

D.30 Transducer test system

Equivalent to B&K 9596.

D.31 True RMS voltmeter

a) *Input impedance:* ≥100k ohm

b) *Frequency range:* 10 Hz to >10 kHz

c) *Averaging time:* 0.1 sec and 3 seconds

d) *Input sensitivity:* 0.7 mV or better

e) *Accuracy:* ± 3 %

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D.32 Tuned voltage amplifier

Equivalent to:

a) B&K model 2143 frequency analyzer

or

b) HP model HP3581A selective meter

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Annex E

(informative)

Sample measurement uncertainty estimates

Measurement uncertainty reflects the quality and accuracy of a measured result as compared to the true value. Such statements are generally required when stating results of measurements so that it is clear to the user of these measurement results that the results may differ when reproduced by different laboratories. Measurement results vary due to the measurement uncertainty of the instrumentation, and measurement technique, even when using this standard for test setups and compliance measurements.

Most uncertainties are calculated using the tolerances of the instrumentation used in the measurement, the measurement setup variability, and the technique used in performing the test. While not generally included, the variability of the equipment under test also figures into the overall measurement uncertainty.

Another component of the overall uncertainty is based on the variability of repeated measurements (so-called Type A uncertainty). This may mean that the hearing aid immunity tests may have to be repeated by taking down the test setup and resetting it so that there is a statistically significant number of repeat measurements to identify this very important aspect of measurement uncertainty. By combining the repeat measurement results with that of the instrumentation chain using the technique contained in NIS 81 and NIS 3003,[22] the overall measurement uncertainty can be estimated.

Annex E contains sample calculations and typical values for the tests contained in this standard.

E.1 WD near-field emissions measurement uncertainty

E.1 gives a sample uncertainty estimation for the WD near-field emission measurement.

E.1.1 Primary uncertainty factors

The following are judged to be the primary contributors affecting measurement uncertainty for this test:

Contributor	Influence quantity	Type	Source of information
RF reflections	±0.8 dB	Tolerance	4.3.1.1.3 (reflections < –20 dB)
Field probe conversion factor	±1.76 dB	Tolerance	C.3
Field probe anisotropy	±0.5 dB	Tolerance	Typical probe manufacturer data
Positioning accuracy	±1.62 dB	Tolerance	E.2.3.2
Probe cable placement	±1 dB	Tolerance	D.21 and D.22
System repeatability	±2 dB	Tolerance	Estimate
Repeatability of the WD	±0.5 dB	Standard deviation	Estimate

[22]ANSI C63 currently has a project underway that is preparing a document on measurement uncertainty. It is anticipated that, when complete, this document will have the most current and relevant guidance on determining measurement uncertainty for EMC measurements.

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E.1.2 Sample estimation

WD near-field measurement uncertainty estimation						
Contribution	**Data dB**	**Data type**	**Probability distribution**	**Weight**	**Uncertainty dB**	**Notes/comments**
RF reflections	0.8	Tol.	Rectangular	$1/\sqrt{3}$	0.46	Reflections < –20 dB
Field probe conv. factor	1.76	Tol.	Rectangular	$1/\sqrt{3}$	1.02	
Field probe anisotropy	0.5	Tol.	Rectangular	$1/\sqrt{3}$	0.29	
Positioning accuracy	1.62	Accy.	Rectangular	$1/\sqrt{3}$	0.94	
Probe cable placement	1.0	Tol.	Rectangular	$1/\sqrt{3}$	0.58	
System repeatability	2.0	Tol.	Rectangular	$1/\sqrt{3}$	1.15	
EUT repeatability	0.5	Std. dev.	Normal	1	0.5	
Combined standard uncertainty, $u_c(y)$			Normal	1	2.03	
Expanded uncertainty, $U(y)$			Normal	k = 2	4.06	

E.2 Hearing aid near-field immunity measurement uncertainty

E.2 gives a sample uncertainty estimation for the hearing aid near-field immunity measurement.

E.2.1 Primary uncertainty contributors

The following are judged to be the primary contributors affecting measurement uncertainty for this test:

Contributor	**Influence quantity**	**Type**	**Source of information**
RF reflections	±0.8 dB	Tolerance	4.3.1.1.3 (reflections < –20 dB)
Power meter (forward)	±0.06 dB	Tolerance	Typical power meter data
Power meter (reverse)	±0.06 dB	Tolerance	Typical power meter data
Directional coupler	±1.0 dB	Tolerance	Typical directional coupler data
Cable loss	±1.0 dB	Uncertainty	Calibration data
Hearing aid loading of antenna	TBD	Tolerance	Antenna VSWR ≤ 1.9
Mismatch-directional coupler to antenna	±0.19	Tolerance	Calculation for u-shaped distribution
Positioning variation	±1.62 dB	Tolerance	E.2.3.2
Acoustic transmission line loss	TBD		
Microphone	±1.0 dB	Tolerance	Calibration
2 cc coupler	TBD		
Preamplifier	±1.0 dB	Tolerance	Calibration
Frequency analyzer	±0.5 dB	Tolerance	Calibration
System repeatability	±0.5 dB	Std. Dev.	Estimate from experience
Repeatability of the hearing aid	TBD		

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The following factors are assumed to be negligible if the conditions listed are met:

a) Ambient signal: Assumes an RF shielded environment.

b) Ambient environment: Assumes temperature, humidity, and other environmental parameters are within normal laboratory tolerances.

E.2.2 Sample estimation

Hearing aid near-field immunity measurement uncertainty estimation						
Contribution	**Data dB**	**Data type**	**Prob. dist.**	**Weight**	**Uncertainty dB**	**Notes/comments**
RF reflections	±0.8	Tol.	Rect.	1/√3	±0.46	Reflections < –20 dB
Power meter (forward)	±0.06	Tol.	Rect.	1/√3	±0.034	VSWR ≤ 1.08, Γ ≤ 0.04
Power meter (reverse)	±0.06	Tol.	Rect.	1/√3	±0.034	VSWR ≤ 1.08, Γ ≤ 0.04
Directional coupler	±1.0	Tol.	Rect.	1/√3	±0.58	VSWR ≤ 1.15, Γ ≤ 0.07
Cable loss	±1.0	Uncertainty	Norm.	1/2	±0.5	
Hearing aid loading of ant.						VSWR ≤ 1.9, Γ ≤ 0.31
Mismatch	±0.19	Tol.	U-shaped	1/√2	±0.13	$20\text{Log}(1\pm\Gamma_1\Gamma_2)$
Positioning accuracy	±1.62	Tol.	Rect.	1/√3	±0.94	E.2.3.2
Acoustic transmission line						TBD
Microphone	±1.0	Tol.	Rect.	1/√3	±0.58	
2 cc coupler						TBD
Preamplifier	±1.0	Tol.	Rect.	1/√3	±0.58	
Frequency analyzer	±0.5	Tol.	Rect.	1/√3	±0.29	
System repeatability	±0.5	Std. dev.	Norm.	1	±0.5	
EUT repeatability		Std. dev.	Norm.			TBD
Combined standard uncertainty, $u_c(y)$			Norm.	1	1.65	
Expanded uncertainty, U			Norm.	2	3.29	

E.2.3 Positioning variability

E.2.3.1 Resonant dipole field gradients

A resonant dipole shall be used having the following characteristics with a 1 mW net input power. The quantities given are scaleable to adjust for the actual power used in an immunity test.

E.2.3.1.1 At 1900 MHz and 1 cm separation distance

The maximum E-field is 33.3 V/m, which is located 3.3 cm from the center of the dipole. The H-field at this point is 878 μA/m. So the field impedance is 37.93 kΩ. The field varies by 10%, 1 mm from center in the tangential direction and by 20%, 2 mm from center.

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The maximum H-field is 93.7 μA/m, which is located at the center of the dipole. The E-field at this location is 4.19 V/m. The field impedance is 44.74 Ω at this location. The field variation is the same as that given for the E-field.

E.2.3.1.2 At 1900 MHz and 2 cm separation distance

The maximum E-field is 13.9 V/m, which is located 3.0 cm from the center of the dipole. The H-field at this point is 17 μA/m. The field impedance is 817.65 Ω at this point. The field varies by 10%, 3 mm from center in the tangential direction and by 20%, 6 mm from center.

The maximum H-field is 34 μA/m, which is located at the center of the dipole. The E-field at this location is 7.0 V/m. The field impedance is 205.88 Ω at this location. The field variation is the same as that given for the E-field.

E.2.3.2 Uncertainty due to positioning variability

If the immunity test is performed at 1 cm from the dipole and the positioning system has a tolerance of ±2 mm, a variation of ±17% can be expected. Converting ±17% to dB yields a ±1.62 dB uncertainty due to positioning accuracy.

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Annex F

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Use of Helmholtz coils for calibration

The following paper, "Helmholtz Coils for Calibration of Probes and Sensors: Limits of Magnetic Field Accuracy and Uniformity," authored by Edwin L. Bronaugh, NCE, was presented at the 1995 IEEE Symposium on EMC in Atlanta, Ga. Some typographical errors were discovered in the equations in the original published copy. It is therefore reproduced here, with typographical corrections, for the convenience of the reader.

F.1 Abstract

Helmholtz coils have been around us for years, but few people now seem to understand their capabilities. The paper explains the accuracy and field uniformity limits of helmholtz coils for use as a calibration standard for magnetic field probes and sensors. The magnetic field generation accuracy depends on the accuracy with which helmholtz coils are constructed and the accuracy with which the current through them is maintained. The user is shown how to determine the accuracy of the generated magnetic field based on physical measurements of distance or spacing between the coils, their radii, the thicknesses of the windings on each coil and number of turns. Ways to estimate the maximum usable frequency and minimum space needed around them are given. Procedures are given so that the user may determine the field uniformity versus volume around the center point of the set of coils, and thus determine the coil characteristics needed to calibrate a particular probe or sensor. Or, if a given helmholtz coil set can be used for calibration of a given sensor.

F.2 Introduction

Helmholtz coils have been in use for several lifetimes for calibrating magnetic field sensors or probes. More recently, they have been put to work doing low-frequency magnetic field immunity tests. A few years ago, the author presented a paper in England [F1] on the use of Helmholtz coils for immunity testing. The need for that paper became apparent when listening to discussions of Helmholtz coils in test seminars and standards committees. No one seemed to understand the accuracy with which Helmholtz coils could produce magnetic fields and the tradeoffs between the field uniformity and the size of the device under test (DUT). Guesses were made as to how large a device could be tested in a pair of Helmholtz coils, and a cubic volume having dimensions of one-third of the coil radius was often suggested, but wholly incorrect, since this dimension came from TEM (Crawford) cell use.

Now Helmholtz coils are again being considered as one of several methods for calibrating low frequency magnetic field probes and sensors in IEEE Std 1309-1996. It appears that a clear and easy method is needed for a user to assess the expected calibration accuracy of a set of Helmholtz coils and the field uniformity versus size of the DUT, which leads to the size of the Helmholtz coils needed. The size of the coils and field strength required also impact the maximum frequency of calibration and the size of obstruction-free laboratory space needed to assure minimal environmental interaction.

In sensor and magnetometer calibration it is important to obtain the utmost in field uniformity. To make best use of Helmholtz coils for calibration of sensors, the metrologist needs to know the size and shape of the uniform field region of given precision within a set of Helmholtz coils. In this paper, equations are developed for use in determining the size and shape of regions of specified field uniformity in standard Helmholtz coil sets defined below. Regions of commonly used values of uniformity are tabulated, and graphical data and formulas are given that allow the arbitrary selection of uniformity, within reason, and produce dimensions of the uniform region.

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The work reported in this paper is part of a larger project to fully understand and characterize the sources of error in magnetic fields generated by Helmholtz coils. There are other structures for producing very uniform magnetic fields, e.g., the "Rubens' Coil" [F2], but the Helmholtz coils are the simplest to manufacture and characterize.

In a pair of Helmholtz coils, the accuracy of the magnetic fields produced within them is primarily affected by the accuracy with which they are constructed and the accuracy with which the current driving them is known. Secondarily, the accuracy is also affected by the equality and uniformity of the driving currents in the two coils. These secondary effects usually arise because of the frequency of operation and the nearness of large metallic (magnetic) surfaces.

F.3 Definition

A set of Helmholtz coils consists of two circular coils of equal diameter and equal number of turns parallel to each other along an axis through the center of the coils, separated by a distance equal to the common radius of the coils. For multiple turn coils, the diameter of the winding on each coil is much much smaller than the diameter of the coil. The two coils are connected in series aiding in order to produce a nearly uniform magnetic field in a region surrounding the center point of the axis between to two coils. (The coils can be connected in parallel aiding, but the current in the coils shall be kept equal!) This arrangement is shown in Figure F.1.

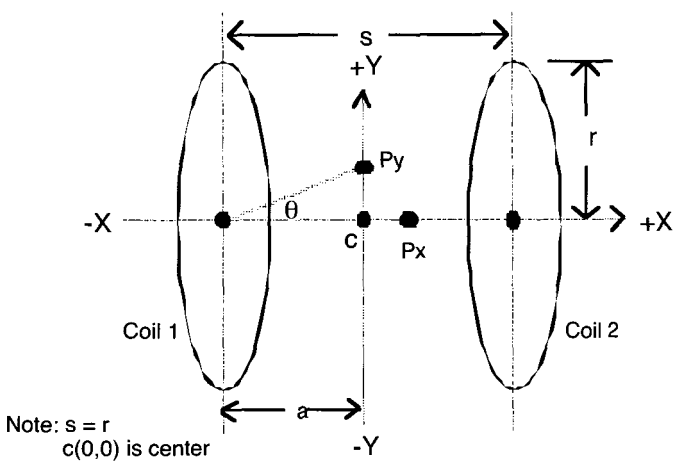


Figure F.1—Helmholtz coil arrangement

F.4 Axial field-strength accuracy

Constructional features such as the radii of the coils and their spacing have a direct effect as can be seen from Equation (F.1) [F3] of the axial magnetic field strength, Hx in A/m, vs. coil size, spacing, number of turns, and current. This equation gives the field strength at a point on the common axis of the two coils, Px on the X-axis in Figure F.1.

$$H_x = H_1 + H_2 = \frac{N_1 I r_1^2}{2(r_1^2 + a_1^2)^{3/2}} + \frac{N_2 I r_2^2}{2(r_2^2 + a_2^2)^{3/2}} \quad \text{(F.1)}$$

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According to the definition of Helmholtz coils, $r_1 = r_2 = r$, $N_1 = N_2 = N$ and $2a_1 = 2a_2 = s = r$, so that after some manipulation, Equation (F.1) becomes:

$$H_x = \frac{NI}{2r}\left\{\left[1+\left(\frac{1}{2}-\frac{x}{r}\right)^2\right]^{-\frac{3}{2}}+\left[1+\left(\frac{1}{2}+\frac{x}{r}\right)^2\right]^{-\frac{3}{2}}\right\} \quad \text{(F.2)}$$

where

N is the number of turns on each coil;
r is the radius of each coil, in meters;
x is the axial position of the magnetic field, in meters from the center of the coil set; and
I is the current in the coils, in amperes.

For the special position at the center of the coil set where $x = 0$, the magnetic field is given by Equation (F.3).

$$H_c = \frac{NI}{r(1.25)^{3/2}} \approx \frac{0.7155NI}{r} \quad \text{(F.3)}$$

The approximation using the four-digit constant (0.7155) is less than 0.006° % low, i.e., the error is less than 60 parts per million. Neglecting this small error, the error in H_c caused by dimensional, constructional, and current variability errors may be found from Equation (F.4), which is also found in Rubens, S. M. [F5].

$$\varepsilon = \frac{\Delta H_c}{H_c} = 0.2\left(\frac{\Delta r_1}{r}+\frac{\Delta r_2}{r}\right)-0.6\frac{\Delta s}{s}+\frac{\Delta I}{I}+\frac{\Delta N}{N} \quad \text{(F.4)}$$

From this relationship, you can see that errors in the coil current and the number of turns are most serious, an error in the coil spacing is less serious, and an error in the coil radius is least serious.

F.5 Coil radius and spacing error effects

Table F.1 shows some errors in dimensions that cause errors of 1%, 2%, and 5% in Hc. It is apparent in Equation (F.4) that equal and opposite errors in the radius of the coils offset each other and not affect the magnetic field. This is correct for points on the center line of the coils; but for fields radially off of the center line, the field uniformity is no longer symmetrical either side of the center of the coil set (discussed later in the paper). The important issue is that the coils can be measured with a "ruler" and an error as large as 2% in coil radius or 1.6% in coil spacing are very obvious for coils of practical dimensions. This is one of the reasons that Helmholtz coils have for years had almost the status of primary standards. When measuring the radius of the coils, measure the diameter from the center of the winding through the center of the coil to the center of the winding at the other end of the diameter and divide by two.

Table F.1—Errors in H_c versus errors in r_1, r_2 and s.

Dimension	ε = 1%	ε = 2%	ε = 5%
r_1	5%	10%	25%
r_2	5%	10%	25%
$r_1 + r_2$	2.5%	5%	12.5%
s	1.66%	3.33%	8.33%

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F.6 Coil current and turns errors

Errors in coil turns and coil current are more serious, not only because they directly affect the magnetic field on a one-to-one basis, but because they are harder to measure accurately. There can also be errors brought about by unequal coil currents and an unequal number of coil turns, which require special methods to avoid.

Coil current errors are dependent on the accuracy and resolution (precision) of the current measuring device or current meter. Nowadays AC and DC current meters can be much more accurate than they once were. There are current meters available that have accuracies better than 0.4 % and resolutions better than 0.00005%, but there are also many available that are much worse. Do not "cut corners" when acquiring the current meter.

Coil turns errors may be determined directly or indirectly. If there are more than two or three turns on each coil, it is difficult to count them and indirect measurements may have be made to determine how much wire is on the coil. The measurement errors can add up to large amounts in these indirect measurements. It is therefore best to assure that the coil manufacturer has counted the turns correctly during construction of the coils. Short of that, it is important to know that there are an integral number of turns on each coil.

An integral number of turns allows a choice of two methods to determine the number of turns. One, a coil resistance measurement easily determines how many coil turns there are since the coil resistance is proportional to the number of turns. While a resistance measurement might not be sufficiently accurate to determine if there are a certain number of whole turns on the coil, such a measurement tells how many turns are there if one has a priori knowledge that there are an integral or whole number of turns on the coil; i.e., the leads come out of the coil at the same point on the circumference. Two, a current probe measurement of the product NI easily gives the number of turns by comparison with the input current to the coil, if it is known that there are an integral number of turns on the coil.

The last term in Equation (F.4), the turns error, may be modified to account for errors in the number of turns on each of the individual coils. Replace $1/2\ N/N$ with $0.5(1/2\ N_1/N + 1/2\ N_2/N)$, where N is the design number of turns. This shows that the error in the axial magnetic field is half that of the turns error in each of the coils. Again, if one coil is too small and the other too large by the same error, the center point magnetic field is not affected, but the symmetry of the uniform field volume is distorted.

F.6.1 Current and turns errors in parallel-fed coils

There are situations in which it is necessary to feed the coils in parallel. This occurs at higher frequencies where the impedance of the coil is large enough to make it difficult to drive the necessary current through the coils when they are connected in series aiding. Use this parallel-aiding connection only when absolutely necessary.

When the coils are connected in parallel-aiding, the two coil currents shall be kept equal and in phase. To do this, they shall come from the same generator through phase-matched paths and be independently adjustable. To evaluate the errors caused by this connection, replace the last two terms in Equation (F.4) with a new last term, as shown in Equation (F.5), in which N is the design value and I is the intended current.

$$\varepsilon = -0.2\left(\frac{\Delta r_1}{r} + \frac{\Delta r_2}{r}\right) - 0.6\frac{\Delta s}{s} + 0.5\left(\frac{\Delta N_1 I_1}{NI} + \frac{\Delta N_2 I_2}{NI}\right) \qquad \text{(F.5)}$$

This shows that the products NI are what shall be controlled and kept as accurate and as equal as possible. If a current probe is connected around each coil, the value of NI in both coils can be set equally and accurately within the resolution and accuracy of the current probe and voltmeter combination used. The last term of Equation (F.5) now becomes $(1/2\ I_{cpa}/I + 1/2\ I_{cpr}/I)$, where $1/2\ I_{cpa}/I$ is the accuracy of the probe and voltmeter, $1/2\ I_{cpr}/I$ is their resolution, and the coefficient 0.5 becomes unity. If a precision current meter is used

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to set the current in one coil and the current probe-voltmeter technique is used to bring *NI* to equality in both coils, the last term of Equation (F.5) becomes (1/2 *I*/*I* + 0.5 1/2 I_{cpr}/I), where 1/2 *I*/*I* is the error in the current meter. For example, if the current accuracy is 0.4°% and the resolution of the current probe-voltmeter is 0.01°%, then the total error in H_x is 0.405°%. The inequality of *NI* in both coils is the resolution of the current probe-voltmeter. This technique can produce a more symmetrical uniform field volume than individually adjusting the coil currents when the coils shall be fed in parallel, and is my recommended approach.

F.7 Radial field-strength

F.7.1 Calculating radial field strength

Equation (F.6) gives the radial magnetic field strength, $H_{1/2}$, at a point off of the coil-axis, e.g., P_y in Figure F.1. When *y*/*r* is zero, this equation gives results identical to Equation (F.2), and when *x*/*r* is also zero, it gives results identical to Equation (F.3). This equation may be used to compute the magnetic field strength anywhere in the space between the coils and its results are plotted in Figure F.2. Figure F.2 is a normalized plot of field strength relative to center, 1/2 H/H_c, versus the axial distance from center, *x*/*r*, for several values of radial distance from center, *y*/*r*.

$$H_\rho = H_{\rho 1} + H_{\rho 2} \tag{F.6}$$

$H_{1/2\,1}$ is the field contribution from coil 1 and $H_{1/2\,2}$ is the field contribution from coil 2.

$$H_{\rho 1} = \frac{NI}{2\pi r}\frac{1}{\sqrt{(1+y/r)^2+K_1^2}}\left[f_1(\theta)+g_1(\theta)\frac{1-(y/r)^2-(x/r+1/2)^2}{(1-y/r)^2+K_1^2}\right] \tag{F.6a}$$

$$H_{\rho 2} = \frac{NI}{2\pi r}\frac{1}{\sqrt{(1+y/r)^2+K_2^2}}\left[f_2(\theta)+g_2(\theta)\frac{1-(y/r)^2-(x/r+1/2)^2}{(1-y/r)^2+K_2^2}\right] \tag{F.6b}$$

where

$$f_c(\theta) = \int_0^{\pi/2} \frac{d\theta}{\sqrt{1-\rho_c^2 \sin^2\theta}} \tag{F.7}$$

$$g_c(\theta) = \int_0^{\pi/2} \frac{d\theta}{\sqrt{1-\rho_c^2 \sin^2\theta}} \tag{F.8}$$

$$\rho_c = \sqrt{\frac{4(y/r)}{(1+y/r)^2+K_c^2}} \tag{F.9}$$

The subscript *c* is 1 for coil #1 and 2 for coil #2

$$K_1 = (x/r + 1/2) \tag{F.10a}$$

$$K_2 = (1/2 - x/r) \tag{F.10b}$$

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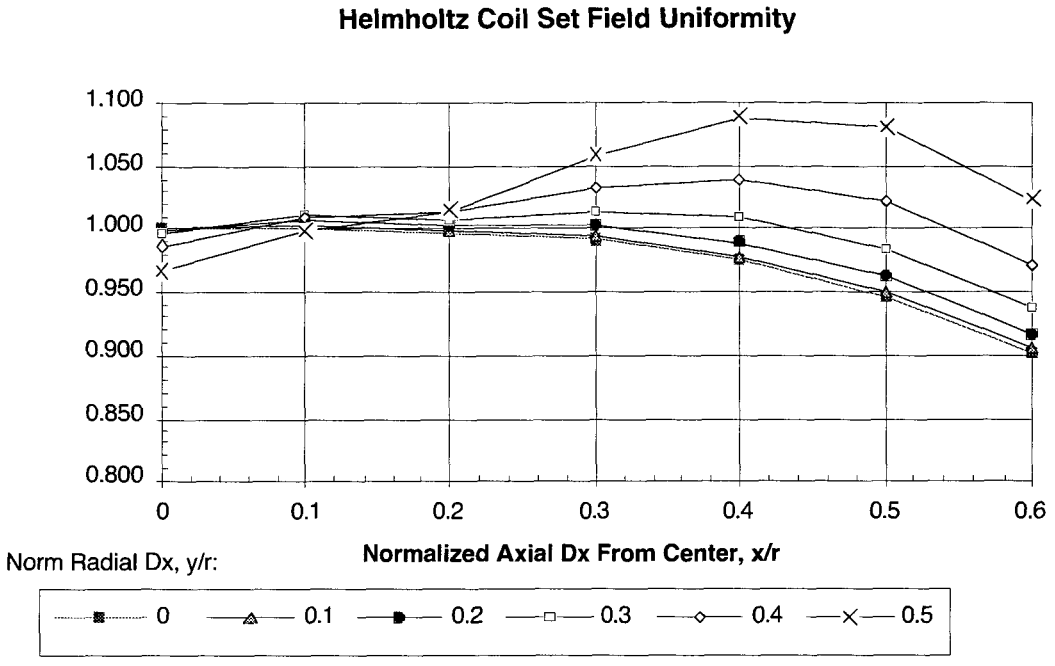


Figure F.2—Normalized magnetic field strength computed from Equation (F.6)

F.7.2 Determining coil size

Table F.2 shows the normalized x and y values for field uniformity of 1%, 2%, 5% and 10%.

Table F.2—Normalized radii for several values of field uniformity (1/2 H/H_c)

Unif.	1%	2%	5%	10%
$\pm x/r$	0.3	0.4	0.5	0.6
$\pm y/r$	0.3	0.4	0.4	0.5

From Table F.2 one can determine the size of coils needed for a particular maximum field-strength uncertainty based on the size of the DUT. Each volume is ellipsoidal or cylindrical, approximately, centered on the center point of the helmholtz coil set, and x/r and y/r are the normalized radii of the ellipsoid. These radii represent half of the maximum dimensions of the DUT relative to the radius of the coils. To find the radii of Helmholtz coils needed for a DUT of a given size, divide the dimensions of the DUT by twice the values in Table F.2. For example, if a magnetic field probe is made up of three orthogonal loops each 20 cm in diameter, and it is desired to keep each loop in the 1% uncertainty or field uniformity volume, the minimum radius of the Helmholtz coils shall be $r = 20/(2\times0.3) = 33.33$ cm. The diameter of both coils should be 0.67 m or greater.

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F.8 Secondary effects

F.8.1 Maximum frequency of operation

To assure that the magnetic fields within the Helmholtz coil set remain as uniform as possible, the upper frequency of use should be limited such that the current around the circumference of both coils stays constant, and the electric and magnetic fields induced by the intended alternating magnetic field are small enough to be neglected [F5]. A further limit is that the frequency of operation should be well below the self-resonance frequency of the coils. A practical limiting frequency is the frequency at which the impedance of the coils is so high that they are difficult to drive. This last limit is the lowest in frequency and is the one that usually prevails. The hierarchy of these limits are shown in Table F.3 and discussed below.

Table F.3—Upper frequency limit

1	Length of wire in coils	Highest frequency
2	Secondary field effects	Lower than 1
3	Self resonance	Lower than 2
4	Fall-off of drive current	Lowest frequency

The frequency at which the currents around the circumference of the coils stays constant is the highest of the possible limiting frequencies. At this frequency the length of the wire in each of the coils is no longer than 0.15 1/2 or 0.10 1/2. Since it is the highest of the limiting frequencies, it is of little practical importance.

From Maxwell's equations, we know that an alternating magnetic field generates an alternating electric field, which in turn, generates another alternating magnetic field, etc. Thus when an AC magnetic field is intentionally created by a pair of Helmholtz coils, it generates a series of electric and magnetic fields in the same test volume where the uniform magnetic fields are desired. Also, since the Helmholtz coils do not usually have an electric shield, they directly generate an electric field that also generates a secondary magnetic field, etc. The magnitude of these effects increases with increasing frequency. The frequency at which these effects cannot be neglected is lower than the highest limiting frequency discussed above, but much higher than the self-resonance frequency of the coils [F5].

The self-resonance frequency of the coils is given by the familiar equation

$$f_0 = 1/(2\pi\sqrt{LC})$$

The inductance L of the coils is easily calculated, but C is the stray capacitance of the coils and is not easily calculated. It could be modeled by the method of moments. This frequency is much lower than the other two limiting frequencies, and it is a limit primarily because the coils are extremely difficult to drive at this frequency since it is a parallel resonance.

A practical maximum frequency is reached before the coils begin to approach resonance. About two orders of magnitude below the self-resonance frequency of the coils is the frequency where for a given generator power, the drive current begins to fall off. The impedance (mostly reactance) of the coils increases with increasing frequency so that more and more generator power is required to maintain the nominal magnetic field. The frequency at which the generator power shall be doubled (3 dB) to maintain the desired coil current is often referred to as the bandwidth or corner frequency of the Helmholtz coil set. It is probably

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reasonable to set the practical upper frequency no higher than the frequency where the generator power would have to be 10 times its level at low frequencies. The term *generator* used here includes any power amplifier needed to produce the required coil current, so that a factor of 10 increase in generator power may be too extravagant, i.e., the cost of the higher-powered amplifier may be prohibitive. The effect is given in Equation (F.11).

$$f_U = \frac{(R_g + R_c)}{2\pi L_T}\sqrt{\left(\frac{P_U}{P_O}\right) - 1}\ , \text{Hz} \tag{F.11}$$

$$L_T = 2N^2 r\{\alpha + \mu[\ln(8r/b) - 2]\}\ , \text{H (series-connected)} \tag{F.12}$$

where

1/2 is the mutual inductance factor, 0.494×10^{-6} for Helmholtz coils [F5];
b is the effective radius of the coil winding, m (see Figure F.3);
R_g is the generator source impedance, 1/2;
R_c is the total resistance of both coils, 1/2; and,
P_u/P_o is the ratio of the generator power at the upper frequency to the generator power at low frequencies.

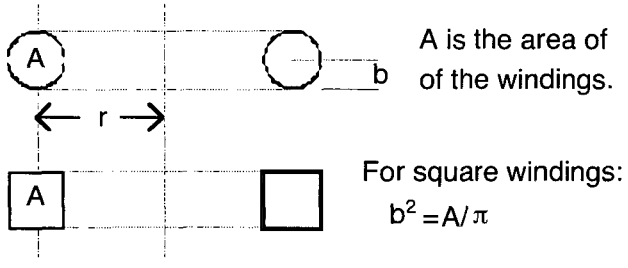


Figure F.3—Alternative coil winding configurations

F.8.2 Effect of loading

A large DUT made of magnetic material may load the coils and concentrate the fields in its vicinity. If inserting the DUT into the test space within the Helmholtz coil set causes the coil current to change by more than a few percent, it should be suspected that the field is distorted and may not be accurate even after returning the coil current to the correct value. The coil current should always be set with the system empty and then reset to the original value after the DUT is inserted. If field distortion is suspected, a larger set of Helmholtz coils should be used.

Using the Helmholtz coil set inside of a shielded enclosure that is too small affects the accuracy of the fields. If a shielded enclosure is used, its smallest dimension shall be more than $6.7r$ to prevent loading of the system and distortion of the fields. This dimension may also be used to determine how far away from the Helmholtz coils large metallic objects should be.

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F.9 Summary

The use of Helmholtz coils for probe or sensor calibration is summarized as follows:

1) Helmholtz coils may be used to volumes with dimensions of 0.6 *r* for highly accurate probe or sensor calibration;
2) Helmholtz coils should be used in the series-aiding connection, but may be used in the parallel-aiding connection if necessary—with extra current controls and precautions;
3) Balance the products *NI* in the two coils for maximum accuracy; and,
4) Consider Helmholtz coils a primary standard: they can be calibrated by ruler.

F.10 Acknowledgment

I wish to acknowledge the assistance of Mr. John D. M. Osburn, The Electro-Mechanics Company, for reading and commenting on this paper before its submission.

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Annex G

(informative)

RF envelope comparison for US WD systems

Comparison of the RF Envelope of US Cellular Systems
by Paul Moller
Motorola General Systems Sector
Jan. 8, 1997

G.1 Introduction

The purpose of this document is to outline the similarities and differences between the current cellular systems being used in the US. The discussion is tailored towards the information that is pertinent to the Hearing Aid Compatibility group, which is addressing the issue of interference to hearing aids from digital cellular phones. There is one major analog and basically three digital cellular systems on the air currently in the US. They are AMPS (IS-91A), NADC (IS-136), PCS1900 (JTC007), and CDMA (IS-95). The following discussion will go through each of these four systems one at a time and identify the highlights of their operation as it relates to the time domain transmitter signatures. Table G.1 shows a summary of the relevant parameters of each of these systems.

Table G.1

	IS-91A	IS-136		JTC007	IS-95
Characteristic	Analog	800 Mhz TDMA (NADC)	800 Mhz GSM	1900 Mhz PCS	800 Mhz CDMA
Transmit Frequency (MHz)	824-849	824-849	890-915	1850-1990	824-849
Peak Transmitter Power (mw)	600	600	2000	1000	250
Lowest Transmitter Power (mw)	7	0.4	20	20	<0.001
Average Transmitter Power (mw)	600	200	235	118	varies
Pulse Repitition (pulses/sec.)	N/A	50	217	217	varies
Pulse Width (ms.)	N/A	6.7	0.6	0.6	varies
Time between pulses (ms.)	N/A	13.4	4	4	varies
Modulation in pulse	FM	pi/4 QPSK (1)	GMSK (2)	GMSK (2)	OQPSK (3)
Power control	Base Station only	Base Station only	Base Station only	Base Station only	Base and Mobile
Notes:					
1) pi/4 QPSK modulation has 8 modulation phase states, which travel in an irregular path between states, resulting in a small amount of AM content.					
2) GMSK modulatin has 4 modulation phase states which travel in a circular path between states, resulting in no AM content.					
3) OQPSK modulation has 4 modulation phase states which travel in an irregular path between states thus resulting in a large AM content.					

G.2 Amps

The Advanced Mobile Phone system that is used in the US is classified as an analog system because the transmitter is on for the full duration of the phone call and the transmitter is Frequency Modulated using an analog representation of the voice signal. Although the base station has control over the subscriber units transmitter power, the power level can change only every few seconds. The transmitter is turned off for

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approximately 75 ms during a "handoff" from one channel to another, i.e., when switching from a signaling channel to a voice channel, or from one voice channel to another.

G.3 NADC

The North American Digital Cellular system is a Time Division Multiple Access (TDMA) system in that each user has one of 3 time slots to transmit in. There are 3 time slots allocated for each channel. The frame repetition rate is 50 hz, thus making any given subscriber unit transmit 50 pulses every second, each pulse being 6.7 ms. long. The modulation during the pulse is (1/4 Quadrature Phase Shift Keying (QPSK). This means that the modulation is essentially phase modulation, but as the modulation phase state moves from one state to another, it does change in amplitude. This results in some amount of AM present on the PM signal in the pulse. Thus one needs to talk about peak power in the pulse and separately average power in the pulse, as well as overall average power. The ramp up and ramp down times of the transmitter are fairly rapidly, thus the average power is very close to 1/3 rd of the peak power. The transmitter power is controlled by the base station, and can change only every several pulses in 4dB steps.

Measuring overall average transmitter power is difficult with many power meters because their sampling time is not correlated to the pulse rate, and they may sample a slightly different number of "on" pulses during successive measurements. The best meters to use are the older bolometer type analog meters, which will perform a long time average, or diode detector type meters that can discern between on and off time of the pulse.

G.4 GSM and PCS

The European 900 MHz GSM system is essentially identical to the US 1900 MHz PCS system. The major differences are the frequencies of operation, and that the PCS system has a transmitter power of 1.0 watts in the burst vs. 2.0 watts for GSM. The PCS system is a Time Division Multiple Access (TDMA) system in that each user has one of 8 time slots to transmit in. There are 8 time slots allocated for each channel. The repetition rate is 217 hz, thus making any given subscriber unit transmit 217 pulses every second, each pulse being 0.6 ms. long. The modulation during the pulse is Gausian Minimum Shift Keying (GMSK). This means that the modulation is phase modulation where the modulation phase state travels in a circle around the origin. This results in a flat power curve in the burst. Also there is some ramp-up and ramp-down time allowed for the transmitter, thus making the overall average power slightly less than 1/8 th of the average power in the pulse. I use a factor of 8.5 when estimating overall average power compared to peak power. The transmitter power is controlled by the base station, and can change by one 2 dB power step every 60 ms. Graph 1 shows the waveform of a single 0.6 ms pulse.

G.5 CDMA

The Code Division Multiple Access (CDMA) system is the most complicated of all of these digital systems. CDMA has time slots, power control groups, modulation symbols, code symbols and chips all as part of the time varying envelope description. Graph 2 shows the transmitter on/off pulsing timings, and graph 3 shows the time varying envelope in the pulse. There are 16 power control groups occurring in every 20 ms. time slot, thus making for 800 1.25 ms. long power control groups every second. A power control group is the basic unit of transmission time. Phones may transmit for 1, 2 or 16 successive power control groups. The phone may transmit during 2, 4, 8 or 16 power control groups of each time slot, thus making for the 8th rate, 4th rate, half rate, and full rate VOCODER rates respectively. The VOice COder DEcodeR (VOCODER) rate chosen for any given time slot depends on the amount of data to be sent, which is directly related to the amount of voice activity. Data in the power control group is always sent at a rate of 9.6K bits per second. Each bit is subdivided into 128 "chips," thus making for 1.228 M chips per second.

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The modulation is Offset QPSK, where the modulation phase state travels an irregular path from one state to another, thus the modulation envelope has a large amount of AM component in the power control group (transmit burst). However this AM component is occurring at the 1.2228 MHz chip rate, and is thus much above the audio band. Since all subscriber units on a given channel are transmitting during the same power control group(s), the transmitter power is controlled to an accuracy of 1 dB. Even the power control group that the subscriber unit will transmit in during the next frame is randomized so that there is a uniform distribution of portables transmitting in all power control groups.

Additionally all subscriber units have 2 sources of power control. One is the base station that will make fine adjustments (closed loop power control), the other is the subscriber unit itself that will make coarse adjustments (open loop power control) based on the incoming receive signal strength. The base station may command a change of 1 dB in power at every power control group (1.25 ms.), and over a power range of 24 dB. Open loop power control occurs much slower. Open loop power control may have to be disabled by means of a hardware change in some if not all manufacturers phones for the purposes of testing hearing aids. The problem with not disabling open loop power control is that since the subscriber unit operates in the same frequency band as the AMPS system, the subscriber unit will receive the AMPS signals and thus adjust its transmitter power in response to the level of those incoming signals, even in test mode.

G.6 Other references

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Annex H

(informative)

Explanation of rationale used in this standard

The testing prescribed in this document has been designed without a simulated or actual human to facilitate test repeatability of measurement as well as ease of use. The performance criterion, as outlined in Clause 8, have been determined to reflect a good correlation of measured emissions with actual use.

Validation of this specification accounted for actual insitu testing. The validation process verified test procedures and limits in a non-human test regime. These verification steps included specified testing and clinical trials as well as phone near-field and insitu comparisons.

If a hearing aid and wireless device pass the respective categories in Clause 7, insitu "real life" usage of said hearing aid and wireless device is guaranteed.

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Annex I

(informative)

Alternate test method for Rf immunity

Concurrent with the development of this standard, the IEC committee for IEC 60118-13, Hearing Aids – Part 13 Electromagnetic Compatibility (EMC) – Product Standard, developed a draft for a proposed revision to IEC 60118-13. This draft was provided to the committee in order to provide for coordination between the two standards.

Each standard (ANSI C63.19-2001 and IEC 60118-13) has different but overlapping scopes. This standard is tasked with providing for the compatibility between WDs and hearing aids. The IEC effort is tasked with providing a test and limits for the RF immunity of hearing aids. Thus, each document contains a test of the RF immunity of hearing aids. Additionally, this standard provides the companion tests of the WD and also requirements to insure the adequacy of the T-coil signal.

In addition, this standard must deal with the utilization of multiple technologies for WDs in the US market.

Two areas of difference are to be found between this document and the current IEC draft. The first is the use of a single limit in the IEC draft versus the category system found here. The second is the use of a WB TEM for testing the RF immunity of hearing aids as contrasted with the use of a dipole and near-field illumination in this document.

The IEC draft proposes the use of a 37.5 dB(V/m) or 75 V/m for the 900 MHz band, and 33.4 dB(V/m) or 50 V/m for the 1800 MHz band. These values fall roughly in the middle of the U1, 30–35 dB(V/m), and U2, 35–40 dB(V/m) categories of this standard.

The IEC draft also proposes the use of the WB TEM for assessing the RF immunity of hearing aids. The committee authoring this document had earlier considered the WB TEM test but rejected it in favor of the near-field illumination dipole test because the dipole test provides a better correlation to the actual user environment and is more predictive of the ultimate user experience.

The WB TEM test is generally regarded as being more stable, and therefore repeatable. Thus, the choice of tests generally offers correlation in favor of the dipole test and stability and repeatability in favor of the WB TEM Test. Far-field illumination testing, such as in a WB TEM, in addition to being more repeatable, is less sensitive to issues of placement and positioning. Also, far-field illumination testing is commonly required in other standards. For these reasons, some may prefer to test immunity using a WB TEM to avoid duplicative testing (or for other reasons). This annex provides guidance on WB TEM testing as an alternate method. However, in case of dispute, the results obtained with the near-field illumination test, as described in Clause 5, shall take precedence.[23]

Joint investigations between the IEC and ANSI committee were pursued in the interest of reaching consensus on a single test. The conclusion reached was that either the dipole test or the WB TEM test yields a satisfactory evaluation of the RF immunity of the hearing aid. However, the tests are not equivalent in that a fixed relationship in the test results could not be established. For reasons of harmonization, the IEC test, as currently drafted, is provided here as an acceptable alternative for the hearing aid RF immunity test.

[23]For further information, see the HAMPIS Report, Comparison of Mobile phone electromagnetic near field with a up scaled electromagnetic fare field, using hearing aid as reference, 21 October 1999, available from DELTA, Venlighedsvej 4, DK-2970 Hørsholm, Denmark, Tel.: +45 45 86 77 22, Fax: +45 45 86 58 98 or from the DELTA Web site at http://www.delta.dk/hampiis/report.htm.

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I.1 WB TEM RF immunity test procedures

1) The RF-test equipment, test configuration, and test procedures as specified in IEC 61000-4-3 shall apply. This requires that a 1 kHz 80% sine modulation of the carrier wave is used.

NOTES:

1) For small systems (such as hearing aids), suitable WB TEM cells and striplines may be used as indicated in Annex D of IEC 61000-4-3.

2) IEC TC77B has announced its intention to republish an update to the material referenced here as IEC 61000-4-20.

2) No objects, other than the hearing aid, which could distort the RF field, shall be present in the test volume.

3) In order to remove the metallic ear simulator or coupler as specified in IEC 60711 and IEC 60126 from the test volume, the normal tubing between the hearing aid and the ear simulator or coupler shall be replaced by tubing of 2 mm bore and with a length typically between 50 mm and 500 mm. For in-the-ear instruments the outlet from the receiver shall be coupled to the tubing by a suitable adapter. This adapter and the length of the tubing are not critical, as the hearing aid gain is determined in each individual test configuration. The complete acoustical coupling arrangement used shall be described when presenting the results. An example of a suitable test arrangement is given in Figure I.1.

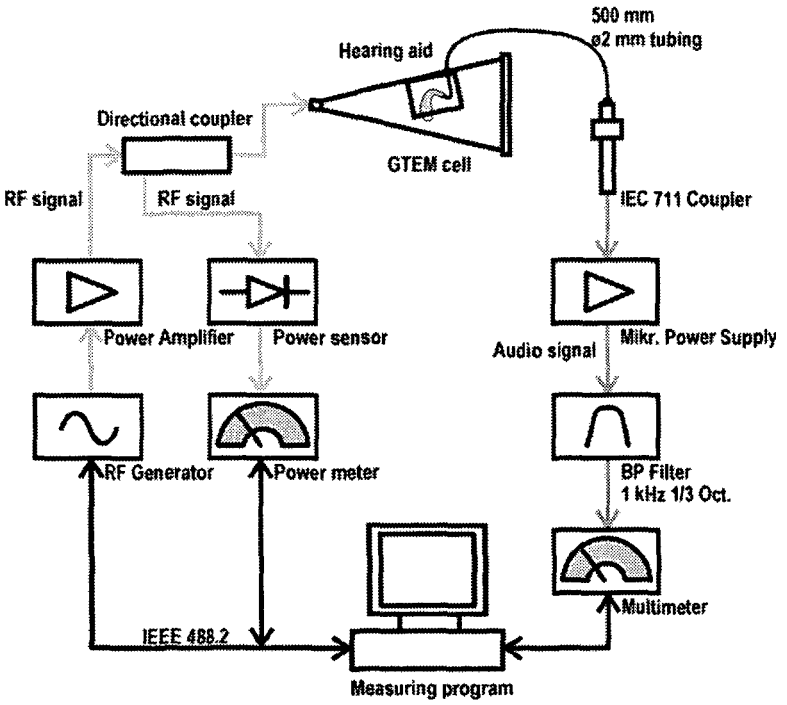


Figure I.1—Example of test arrangement for hearing aid immunity measurements

NOTE—Measurements should be made to ensure that the background noise level of the test configuration is at least 10 dB lower than the lowest interference level to be measured.

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4) The hearing aid volume control shall be adjusted to the reference test gain control position as described in amendment 1 to IEC 60118-0 or amendment 1 to IEC 60118-7. The other controls shall be set to positions giving the widest frequency response and the maximum acoustic output.

5) With the acoustical coupling described in step 3) of I.1 and the test conditions described in step 4) of I.1, the input-output response of the hearing aid shall be measured at 1000 Hz as described in IEC 60118-0 or IEC 60118-7. From the input-output response curve determine the output obtained at 55 dB(SPL) input level. If the hearing aid provide a telecoil, determine the output sound pressure level for an input of 20 mA/m. Examples of input-output response curves are given in Figure I.2.

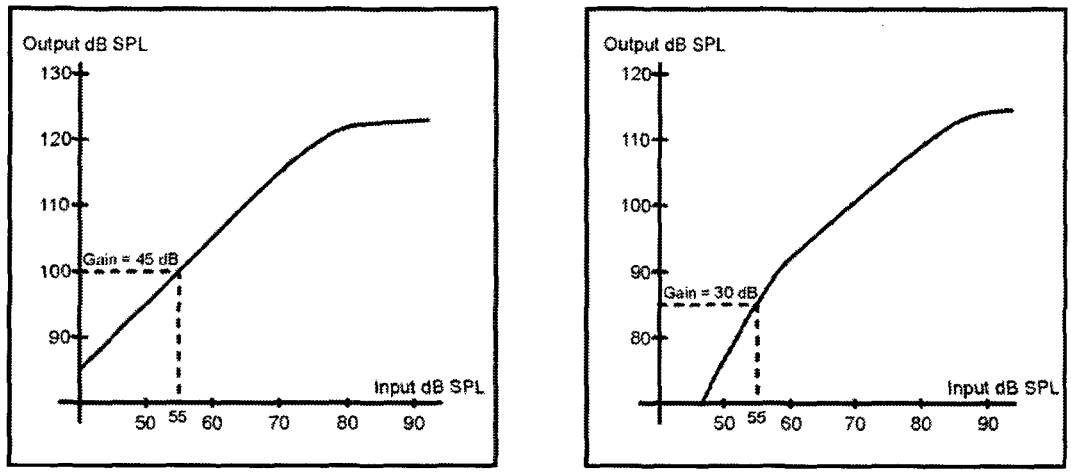


Figure I.2—Examples of input-output response curves at 1000 Hz and the determination of output SPL at an input level of 55 dB SPL

6) The hearing aid, with the controls set as in step 5) of I.1, shall be placed in the RF field, and the sound pressure level of the interference signal at 1000 Hz shall be determined with the use of a band-pass filter with a maximum bandwidth of one-third octave.

The hearing aid shall be placed in the reference orientation and then rotated in steps of 90° in the horizontal plane. For each orientation the carrier frequency shall be stepped or swept as specified in IEC 1000-4-3 using a step size of 1% of the carrier frequency.

The measurement of the interference sound pressure level shall be carried out at the orientation where the interference signal reaches its maximum value. The maximum value within each frequency range is used to characterize the interference.

NOTE—Measurement results from hearing aids with automatic signal processing (ASP) characteristics or other non-linear processing should be interpreted with care, as the interference signal may activate these systems in an unpredictable way. If a "test mode" is provided for programmable hearing aids, it should be used during the test.

Follow the procedure described in step 6) of I.1. If gain change does occur it shall be accounted for in the final result, as described in step 6) of I.1.

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7) In the worst-case orientation, and at the frequency where the interference reaches its maximum value, increase the field strength until the hearing aid output level, as determined in step 5), is reached. The field strength required to produce an IRIL = 55 dB SPL in the hearing aid is then recorded. This field strength, which produces a hearing aid IRIL of 55 dB SPL, is used to determine the hearing aid category using the table in Figure 5 of 7.2.

The measurement shall be carried out with the microphone, directional microphone (if provided), and telecoil (if provided).

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Annex J

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