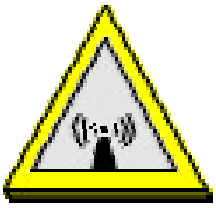
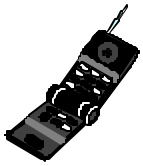
Federal Communications Commission
Office of Engineering & Technology

Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields



Additional Information for Evaluating Compliance of Mobile and Portable Devices with FCC Limits for Human Exposure to Radiofrequency Emissions



Supplement C
(Edition 01-01)
to
OET Bulletin 65
(Edition 97-01)

Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields

Additional Information for Evaluating Compliance of Mobile and Portable Devices with FCC Limits for Human Exposure to Radiofrequency Emissions

SUPPLEMENT C
Edition 01-01
to
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Edition 97-01

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IMPORTANT NOTE

This version of Supplement C supercedes the 97-01 edition and is issued in connection with the FCC's OET Bulletin 65, Version 97-01. The information in this supplement provides additional guidance for use by applicants for FCC equipment authorization in evaluating mobile and portable devices for compliance with the FCC's guidelines for human exposure to radiofrequency (RF) electromagnetic fields. Users of this supplement should also consult Bulletin 65 for complete information on FCC policies, guidelines and compliance-related issues concerning human exposure to RF fields. OET Bulletin 65 can be viewed and downloaded from the FCC's Office of Engineering and Technology's World Wide Web Internet Site: http://www.fcc.gov/oet/.

ACKNOWLEDGEMENTS

The SAR measurement procedures described in "***DRAFT*** **Recommended Practice for Determining the Spatial-Peak Specific Absorption Rate (SAR) in the Human Body due to Wireless Communications Devices: Experimental Techniques**," under Project Number P1528 of the Standards Coordinating Committee 34, Subcommittee 2, of the Institute of Electrical and Electronics Engineers (IEEE SCC-34 / SC-2) have been considered in this edition of Supplement C.

Contributions from the following FCC staff members are also acknowledged: **Bruce Franca, Robert Cleveland and Kenneth Nichols**

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INTRODUCTION

In August, 1996, the Commission adopted a *Report and Order* in ET Docket 93-62 amending its rules for evaluating the environmental effects of radiofrequency (RF) electromagnetic fields. Specifically, the Commission adopted new guidelines and procedures for evaluating human exposure to RF emissions from FCC-regulated transmitters and facilities.[1] As a part of this proceeding, new limits were adopted for human exposure to RF emissions from certain mobile and portable devices. Two subsequent FCC Orders were issued to refine and clarify the decisions adopted in the original *Report and Order*.[2] A revised version of OET Bulletin 65, "Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields" was also issued.[3] One of the areas discussed in Bulletin 65 is compliance with the limits adopted by the Commission for safe exposure to RF emissions due to mobile and portable devices such as non-fixed wireless transmitters and hand-held cellular telephones. The first edition of Supplement C (97-01) was released in 1997. The purpose of this revised supplement is to provide parties filing applications for equipment authorization with guidance on complying with the latest requirements using up-to-date test procedures. ***This supplement is not intended, however, to establish mandatory procedures, and other methods and procedures may be acceptable if based on sound engineering practice.***

The FCC guidelines differentiate between portable and mobile devices according to their proximity to exposed persons. For portable devices (47 CFR §2.1093), RF evaluation must be based on specific absorption rate (SAR) limits. Human exposure to RF emissions from mobile devices (47 CFR §2.1091) can be evaluated with respect to Maximum Permissible Exposure (MPE) limits for field strength or power density or with respect to SAR limits, whichever is most appropriate. Industry groups and other organizations have been working to develop standardized product test procedures to evaluate RF exposure compliance with SAR limits.[4] The appropriate procedures may be considered in future revisions of this supplement.

FCC rules require applicants for equipment authorization of certain portable and mobile devices to include an affirmative statement of compliance attesting that the devices comply with FCC limits for RF exposure. The rules also require that technical information be provided upon request for supporting

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[1] See *Report and Order*, in ET Docket 93-62, FCC 96-326, 11 FCC Rcd. 15123 (1996). The Commission's environmental rules for RF exposure are described in 47 CFR §1.1307(b).

[2] See *First Memorandum Opinion and Order*, ET Docket 93-62, FCC 96-489, 11 FCC Rcd. 17512 (1997). See also *Second Memorandum Opinion and Order and Notice of Proposed Rule Making*, ET Docket 93-62, FCC 97-303, 12 FCC Rcd. 13494 (1997).

[3] OET Bulletin 65, Edition 97-01, released August 25, 1997. This document can be downloaded from the FCC's World Wide Web Internet site: http://www.fcc.gov/oet/.

[4] Standards Coordinating Committee 34, Subcommittee 2, of the Institute of Electrical and Electronics Engineers, Inc. (IEEE SCC-34/SC-2) has been developing recommended procedures for evaluating portable devices for compliance with SAR limits using experimental or numerical methods. Additional information is available at the IEEE Standards Association Internet Web Site: http://standards.ieee.org/ and the SCC-34/SC-2 Web Site: http://grouper.ieee.org/groups/scc34/sc2/.

compliance. The information described in Appendix B may provide applicants with additional guidance on the type of documentation that would normally be included in test reports for demonstrating compliance.

Further information concerning this supplement may be obtained by contacting the Laboratory Division of FCC's Office of Engineering and Technology at (301) 362-3000 or Kwok Chan at (301) 362-3055. Information on topics discussed in the OET Bulletin 65 or other supplements can be obtained from the FCC's RF safety group at (202) 418-2464 or e-mail to: rfsafety@fcc.gov.

SECTION 1: FCC RULES FOR RF COMPLIANCE OF MOBILE AND PORTABLE DEVICES

As stated in the FCC rules, mobile and portable transmitting devices that operate in the Cellular Radiotelephone Service, the Personal Communications Services (PCS), the Satellite Communications Services, the General Wireless Communications Service, the Wireless Communications Service, the Maritime Services (ship earth stations only) and Specialized Mobile Radio Service authorized, respectively, under Part 22 (Subpart H), Part 24, Part 25, Part 26, Part 27, Part 80, and Part 90 of the FCC rules are subject to routine environmental evaluation for RF exposure prior to equipment authorization or use. Portable devices operating in the Wireless Medical Telemetry Service (WMTS) and the Medical Implant Communications Service (MICS), authorized under Subparts H and I of Part 95 are subject to routine environmental evaluation for RF exposure prior to equipment authorization or use. Unlicensed PCS, U-NII and millimeter wave devices authorized under Part 15 of FCC rules are also subject to routine environmental evaluation for RF exposure prior to equipment authorization or use. All other mobile and portable devices are categorically excluded from routine environmental evaluation for RF exposure.[5]

MOBILE DEVICES

The FCC rules for evaluating mobile devices for RF compliance are found in 47 CFR §2.1091. For purposes of RF exposure evaluation, a mobile device is defined as a transmitting device designed to be used in other than fixed locations and to be generally used in such a way that a separation distance of at least 20 centimeters is normally maintained between the transmitter's radiating structures and the body of the user or nearby persons. In this context, the term "fixed location" means that the device, including its antenna, is physically secured at a permanent location and is not able to be easily moved to another location. Examples of mobile devices, as defined above, would include cellular and PCS mobile telephones, other radio devices that use vehicle-mounted antennas and certain other transportable transmitting devices. Transmitters designed to be used by consumers or workers that can be easily re-located, such as a wireless modem operating in a laptop computer, are considered mobile devices if they meet the 20 centimeter separation requirement. These devices are normally evaluated for exposure potential with the MPE limits given in Appendix A. Mobile devices may also be evaluated with respect to the SAR limits given in Appendix A for RF exposure compliance, but in such cases it is usually simpler and more cost-effective to evaluate compliance with respect to MPE limits based on field strength or power density.

PORTABLE DEVICES

The FCC rules for evaluating portable devices for RF exposure compliance are contained in 47 CFR §2.1093. For purposes of RF exposure evaluation, a portable device is defined as a transmitting device designed to be used with any part of its radiating structure in direct contact with the user's body

[5] See 47 CFR §§ 1.1307(b)(1), 2.1091 and 2.1093 for details.

or within 20 centimeters of the body of a user or bystanders under normal operating conditions. This category of devices would include hand-held cellular and PCS telephones that incorporate the radiating antenna into the hand-piece and wireless transmitters that are carried next to the body. Portable devices are evaluated with respect to SAR limits for RF exposure.[6] The applicable SAR limit for portable transmitters used by consumers is 1.6 watts/kg, which is averaged over any one gram of tissue defined as a tissue volume in the shape of a cube.

EXPOSURE CATEGORIES

With respect to field strength, power density and SAR requirements, both the 1992 ANSI/IEEE standard and the NCRP exposure criteria (See References [1] and [30]), upon which the FCC guidelines are based, recommend limits with respect to both occupational/controlled and general population/uncontrolled exposures. The compliance requirements for each category are based on a person's awareness and ability to exercise control over his or her exposure.

OCCUPATIONAL / CONTROLLED EXPOSURE

In general, occupational/controlled exposure limits are applicable to situations in which persons are exposed as a consequence of their employment, who have been made fully aware of the potential for exposure and can exercise control over their exposure. This exposure category is also applicable when the exposure is of a transient nature due to incidental passage through a location where the exposure levels may be higher than the general population/uncontrolled limits, but the exposed person is fully aware of the potential for exposure and can exercise control over his or her exposure by leaving the area or by some other appropriate means. Awareness of the potential for RF exposure in a workplace or similar environment can be provided through specific training as part of a RF safety program. If appropriate, warning signs and labels can also be used to establish such awareness by providing prominent information on the risk of potential exposure and instructions on methods to minimize such exposure risks.

GENERAL POPULATION / UNCONTROLLED EXPOSURE

The general population/uncontrolled exposure limits are applicable to situations in which the general public may be exposed or in which persons who are exposed as a consequence of their employment may not be made fully aware of the potential for exposure or cannot exercise control over their exposure. Members of the general public would come under this category when exposure is not employment-related; for example, in the case of a wireless transmitter that exposes persons in its vicinity. Warning labels placed on low-power consumer devices such as cellular telephones are not considered sufficient to allow the device to be considered under the occupational/controlled category, and the general population/uncontrolled exposure limits apply to these devices.

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[6] Both the ANSI/IEEE and NCRP exposure criteria are based on a determination that potentially harmful biological effects can occur at a SAR level of 4.0 W/kg as averaged over the whole-body. Appropriate safety factors were then added to arrive at limits for both whole-body exposure (0.4 W/kg for "controlled" or "occupational" exposure and 0.08 W/kg for "uncontrolled" or "general population" exposure, respectively) and for partial-body exposure (localized SAR), such as might occur in the head of the user of a hand-held cellular telephone.

SECTION 2: GUIDELINES FOR EVALUATING MOBILE AND PORTABLE DEVICES

FCC rules require routine environmental evaluation of RF exposure for certain mobile and portable devices described in 47 CFR §§2.1091 and 2.1093. Applications to the FCC for equipment authorization of these transmitters must include an affirmative statement indicating that, to the best knowledge of the applicant, the device complies with the FCC-adopted limits for RF exposure. In most cases, it will also be necessary for the applicant to provide certain information to document the test procedures used to evaluate compliance. The rules also require applicants to provide technical data to substantiate compliance when it is requested.[7]

Mobile devices identified in 47 CFR §2.1091 that operate at 1.5 GHz or below with an effective radiated power (ERP) of 1.5 watts or more, or those that operate at frequencies above 1.5 GHz with an ERP of 3.0 watts or more are required to perform routine environmental evaluation for RF exposure prior to equipment authorization or use; otherwise, they are categorically excluded. Mobile devices may be evaluated with respect to field strength, power density or SAR limits, as appropriate. Occasionally, if it is determined that the operation of a categorically excluded mobile device has the potential of exceeding MPE limit because of its design or operating conditions, it may be necessary for the applicant to provide additional information to substantiate compliance and to determine if an RF evaluation is needed. When RF compliance of a categorically excluded device cannot be determined with the additional information, an RF evaluation may be requested as provided for in 47 CFR §1.1307 (c) and (d).

Certain portable devices identified in 47 CFR §2.1093 are required to perform routine environmental evaluation for RF exposure prior to equipment authorization or use. Such portable devices may be evaluated with respect to SAR limits using either measurement or computer modeling methods. Because of the lack of standardized test protocols, the FCC has been requesting technical information to support the evaluation procedures used to determine compliance while standardized SAR test procedures are being developed by industry groups and other organizations. The information in Appendix B identifies the type of technical descriptions that would normally be appropriate for demonstrating compliance. Appendix D describes SAR measurement procedures for handsets and similar transmitters.

DETERMINATION OF DEVICE AND EXPOSURE CATEGORIES

Before routine RF evaluation can proceed, it must be determined whether a device should be considered under the "mobile" or "portable" category, and whether exposure would occur under the occupational/controlled or general population/uncontrolled conditions. These decisions will generally determine whether a device should be evaluated with respect to field strength, power density or SAR limits, and which set of exposure conditions and limits should be used to demonstrate compliance.

[7] See 47 CFR §2.1091 and §2.1093.

For certain devices, such as wireless modem modules and other transmitters that are designed to be integrated into other products or designed to operate in multiple configurations, RF exposure evaluation for both mobile and portable conditions may be necessary. When portable configurations are applicable, RF compliance must be determined with respect to SAR limits. In situations where a transmitter is in close proximity to the operator but nearby persons are normally further away from the device, occupational/controlled exposure limits may be applied if the exposure is work-related.[8] Under such conditions, the operator must be aware of the exposure conditions and can exercise control to limit the exposure duration and/or conditions to satisfy compliance. Nearby persons are usually exposed to a weaker field. Since they have no knowledge of their exposure conditions, the more restrictive general population/uncontrolled exposure limits must be applied.

MPE EVALUATION OF MOBILE DEVICES

Human exposure to RF emissions from mobile devices (47 CFR §2.1091) may be evaluated based on the MPE limits adopted by the FCC for electric and magnetic field strength and/or power density, as appropriate, since exposures are assumed to occur at distances of 20 cm or more from persons.[9] The 1992 ANSI/IEEE standard (See Reference [1]) specifies a minimum separation distance of 20 cm for performing reliable field measurements to determine adherence to MPE limits.[10] If the minimum separation distance between a transmitter and nearby persons is more than 20 cm under normal operating conditions, compliance with MPE limits may be determined at such distance from the transmitter. When applicable, operation instructions and prominent warning labels may be used to alert the exposed persons to maintain a specified distance from the transmitter or to limit their exposure durations and usage conditions to ensure compliance. If the use of warning labels on a transmitter is not effective or desirable, the alternative of performing SAR evaluation with the device at its closest range to persons under normal operating conditions may be used.

The field strength and power density limits adopted by the FCC are based on whole-body averaged exposure and the assumption of spatially averaged RF field levels relate most accurately to estimating whole-body averaged SAR. This means some local values of exposures exceeding the stated field strength and power density limits may not necessarily imply non-compliance if the spatial average of RF fields over the exposed portions of a person's body does not exceed the limits. Field strength and power density measurements are typically made in all directions surrounding the radiating structures of a mobile device in normal operating configurations, without the influence of nearby persons and objects. The measurements are spatially averaged over the exposed portions of an average person's body to

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[8] An example would be certain transmitters used at checkout stands.

[9] The FCC adopted limits for field strength and power density that are generally based on Sections 17.4.1 and 17.4.2, and the time-averaging provisions recommended in Sections 17.4.1.1 and 17.4.3, of "Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields," NCRP Report No. 86 (1986), National Council on Radiation Protection and Measurements (NCRP). With the exception of the limits on exposure to power density above 1500 MHz and the limits for exposure to lower frequency magnetic fields, these MPE limits are also generally based on the guidelines contained in the RF safety standard developed by the Institute of Electrical and Electronic Engineers, Inc. (IEEE) and adopted by the American National Standards Institute (ANSI). See Section 4.1 of ANSI/IEEE C95.1-1992, "Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz".

[10] Although ANSI/IEEE does not explicitly state when SAR measurements are preferable to MPE measurements, we believe that the 20 cm distance is appropriate based on Sec. 4.3(3) of ANSI/IEEE C95.1-1992.

determine compliance. In certain situations such as vehicle-mounted antennas or other antennas located on metallic surfaces, the exposure should be evaluated with the antenna mounted on a metallic surface to account for the localized peaks produced by standing waves due to ground reflections near the antenna.

SAR EVALUATION OF PORTABLE OR MOBILE DEVICES

Human exposure to RF emissions from portable devices (47 CFR §2.1093), as defined by the FCC, must be evaluated with respect to the FCC-adopted limits for SAR. Evaluation of mobile devices, as defined by the FCC, may also be performed with respect to SAR limits, but in such cases it is usually simpler and more cost-effective to evaluate compliance with respect to field strength or power density limits. For certain devices that are designed to be used in both mobile and portable configurations similar to those described in 47 CFR §2.1091(d)(4), such as certain desktop phones and wireless modem modules, compliance for mobile configurations is also satisfied when the same device is evaluated for SAR compliance in portable configurations.

Since SAR limits do not apply to devices operating above 6.0 GHz (See References [1] and [30]), millimeter wave devices operating under §15.253 and §15.255 of the FCC rules in portable configurations must be evaluated with respect to power density limit. At shorter wavelengths above 6.0 GHz, instead of the usually recommended 20 cm measurement distance for lower frequencies, reliable power density measurements can normally be made at 5 cm or more from the transmitter. If a device normally operates at closer than 5 cm from persons, power densities may be computed using numerical modeling techniques (e.g., FDTD or finite element methods) to determine compliance. In certain occupational/controlled exposure conditions, operating instructions and warnings labels may be required to limit the exposure duration and conditions to satisfy compliance.

SAR EVALUATION TECHNIQUES

Portable transmitters used by consumers typically operate over the output power range of less than 100 mW to several watts, using either analog or digital modulation techniques. For most handsets, the antenna radiates within 1-2 cm of the user's head or body. Even at low power levels, relatively high field strengths would be expected near the antenna. The field strength and field distributions are highly dependent on the location, orientation and electromagnetic characteristics of adjacent objects, such as the user's body. The user of a handset is normally in the reactive near-field region of the antenna where the electromagnetic field is mostly non-propagating. The energy absorbed by the user is mainly due to the electric fields induced by magnetic fields generated from current flowing along the antenna and other radiating structures of the device. The RF energy is scattered and attenuated as it propagates through the body tissues. Maximum energy absorption is usually expected in the more absorptive high water-content tissues near the surface of the head or body. To account for near-field energy coupling effects, portable transmitters are evaluated with realistic head and body models using SAR measurement or computer modeling techniques (See References [3], [9-10], [13-14], [18] and [28]).

SAR compliance for low power transmitters are evaluated with electric field measurements inside homogeneous tissue models or computer modeling techniques using anatomically equivalent tissue models (See References [3], [10], [13] and [35]). In either case, SAR is determined according to this equation:

$$SAR = \frac{|E|^2 \sigma}{\rho},$$

where $|E|$ is the magnitude of the measured or computed RMS electric field, σ is the conductivity and ρ is the mass density of the tissue-equivalent media. SAR is a measure of the rate of energy absorption per unit mass at a specific location in the tissue media. SAR may be expressed in units such as watts/kg or milliwatts/gm. Under certain circumstances, SAR can also be determined from temperature rises due to RF energy absorption in tissue media according to the equation:

$$SAR = C\frac{dT}{dt},$$

where C is the specific heat of tissue, δT is the temperature rise and δt is the exposure duration (See References [2-3], [19] and [31]). However, in order to use temperature techniques, relatively high power is required to expose the tissue over a very short duration to avoid thermal diffusion errors. Therefore, temperature methods are typically not applicable for evaluating low power transmitters for SAR.

HANDSET AND OTHER TRANSMITTER TEST POSITIONS

Because of near-field coupling effects, small changes in the positioning of a test device may sometimes lead to unexpected changes in energy absorption in the tissue medium. To address this matter, the SCC-34/SC-2 has developed specific test positions for testing handsets. These test positions are described in Appendix D. As explained in the SCC-34/SC-2 SAR measurement document (See Reference [19]), handsets should be tested on the left and right side of a head phantom in a range of test configurations to obtain a conservative estimate of the exposures expected by the user population. For handsets with retractable antennas, SAR should be evaluated with the handset antenna in its fully extended and fully retracted positions for each test configuration. Most handsets generally do not perform well with their antennas partially extended. If such antenna positions can lead to excessive RF current flow on the chassis, maximum energy absorption in the cheek region may be expected. Since such conditions do not represent normal usage, operating instructions and caution statements should be used to inform users to avoid operating with these antenna positions.

SCC-34/SC-2 has also recommended use of a specific head model for SAR evaluation (See Reference [19]). Although the head model has been specified by SCC-34/SC-2, it is not yet commercially available. In the interim until the SCC-34/SC-2 head model becomes available, other head phantoms may continue to be used to evaluate handsets for SAR compliance with the device test positions recommended by the SCC-34/SC-2, unless the handset cannot be positioned properly or the test positions do not correspond to the normal use positions of the device. In those instances, applicants for equipment authorization should contact the Commission's laboratory for alternative test procedures. These test device positions should also be used with computational modeling methods to evaluate SAR compliance.

The effect of a hand holding a handset has also been an issue with respect to obtaining accurate SAR measurements. Test facilities have been evaluating handsets by placing the device in a non-metallic holder to position it precisely against the head or body phantom. When handsets are evaluated without a hand model, more energy is absorbed in the head phantom that allows a more conservative exposure condition to be evaluated. Since a standardized hand model is not available, handsets should be tested in a low-loss dielectric holder to minimize device test position uncertainty.

For devices that are designed to operate in body-worn operating configurations, such as shoulder, waist or chest-worn transmitters, SAR compliance should be evaluated using a flat phantom with the procedures described in Appendix D.

TISSUE MODELS

The dielectric properties of the tissue media used for testing the SAR of a handset are specified in Appendix C. The RF energy absorption characteristics of body tissues is related to the tissue water content. High water-content tissues such as muscle and skin can absorb more RF energy than low water-content tissues such as fat and bone or skull. At RF and microwave frequencies, tissue properties are characterized by their permittivity and conductivity at normal body temperatures, about 37°C. The tissue dielectric parameters are temperature sensitive. For high water content tissues, permittivity may decrease at a rate of about 0.5 %/°C and conductivity may increase at a rate of about 2 %/°C (See Reference [8]). The simulated tissues used in SAR measurements usually follow similar temperature variations. The dielectric properties of simulated tissue materials are formulated with the equivalent tissue properties at 37°C, for room temperature use, to facilitate SAR evaluation under ambient conditions.

There are several formulations for making high water-content simulated tissues. An opaque gel consisting of water, salt, polyethylene powder and a gelling agent called TX-151 has been used for high power applications using thermographic or temperature methods to measure SAR (See Reference [8]). A liquid mixed from water, sugar, salt and a compound called HEC for adjusting the liquid viscosity is commonly used for measuring the SAR of low power transmitters (See Reference [15]). At above 1.2-1.5 GHz, the sugar is usually replaced with glycol or other chemical agents to achieve the required dielectric parameters specified in Appendix C. Note: Glycol may react with certain plastic material, including the phantom shell and E-field probe housing; therefore, it should be used with caution.

The liquid tissue medium is transparent, which offers advantages in setting up and performing measurements. It also simplifies the SAR measurements by using only one type of homogeneous tissue medium. The liquid is contained in a shell representing the head or body, typically molded from fiberglass or other plastic materials with very low RF absorption. The measured dielectric constant and conductivity of the tissue medium should be within the tolerance requirements specified for the target tissue parameters listed in Appendix C (See References [11-12], [15] and [19]). The tissue dielectric parameters should usually be measured daily when SAR measurements are performed or more often if the parameters are expected to deviate due to temperature changes or conditions of higher evaporation rates. The tissue dielectric parameters can be usually characterized with several techniques. A coaxial probe, slotted line or TEM line may be used with a network analyzer to measure the reflection parameters of the tissue material for computing the dielectric parameters (See References [6], [16] and [19]).

SAR MEASUREMENT SYSTEM DESCRIPTIONS AND REQUIREMENTS

An SAR measurement system usually consists of a small diameter isotropic electric field probe, a multiple axis probe positioning system, a test device holder, one or more phantom models, the field probe instrumentation, a computer and other electronic equipment for controlling the probe and making the measurements (See References [26-27] and [35]). Other supporting equipment, such as a network analyzer, power meters and RF signal generators, are also required to measure the dielectric parameters of the simulated tissue media and to verify the measurement accuracy of the SAR system.

Several types of electric field probes have been used for making SAR measurements. The probes are on the order 25-30 cm long. It is recommended that the probe tip diameter should be less than 8.0 mm to achieve an acceptable spatial resolution in the measurement and to minimize probe boundary-effects errors (See Reference [19]). These probes are constructed with three miniature

dipoles, typically about 1.5-2.5 mm long, loaded with a diode sensor at the gap of each dipole for measuring electric field strength in three orthogonal directions. The sensors, each consisting of a dipole and a diode detector, are deposited and bonded on a substrate that offers minimal perturbation to the incident field. The substrates are usually arranged in an I-beam (H-beam) or triangular (delta) configurations to allow each detector to measure the field component parallel to its axis with minimal effects from the other two sensors. The detected RF signal is carried on high resistance leads along the length of the probe to minimize RF pickup. The signal is filtered by the high resistance lines to produce a very low frequency signal at the probe output. The probe is fastened to the probe positioner where it is connected to the probe electronics. The signals are compensated and converted by instrumentation amplifiers and precision A/D converters and processed by computer software to SAR values.

The electric field probe and associated instrumentation are usually calibrated together on most SAR measurement systems (See Reference [19]). At low field strength levels, the sensors in the probe are designed to operate as true square-law detectors and the output voltage is proportional to the square of the measured electric field. At higher field strength levels, the output of the diode detector becomes directly proportional to electric field and the probe must be properly compensated. A probe must be calibrated in the type of tissue media formulated for the test frequencies. Some probes are calibrated in two stages, in air and then in tissue media, to obtain calibration factors that can be used to convert the detected signal to SAR. Below 800 MHz, probes are typically calibrated using thermal (temperature rise) techniques. At higher frequencies, standard waveguides may be filled with the required tissue medium to calibrate the probe output voltages against analytically calculated field values (See References [17], [19] and [31]). The applicable field probe calibration requirements are described in the SCC-34/SC-2 SAR measurement procedures (See Reference [19]).

Besides probe calibration, the accuracy of the SAR measurement system should also be verified using calibrated RF signal source(s) within the transmitting frequency band(s) of the test device. The SAR measurement system should usually be verified daily when SAR measurements are performed. If the measured 1-g SAR values deviate by more than 10% from the target reference value(s) specified for the RF signal source(s), the discrepancies must be resolved before continuing with the SAR measurement. It is recommended that a flat phantom and a half-wave dipole matched to the tissue medium be used to verify the accuracy of SAR measurement systems (See Appendix D).

Several head and body models have been used by different test facilities to evaluate SAR. The measured SAR is dependent on the RF current distribution and RF energy coupling characteristics established by the test device and the tissue model. As indicated above, until the SCC-34/SC-2 head model is commercially available, the FCC will continue to accept other head models provided the test procedures described in this document are followed.

DEVICE TEST CONDITIONS

Most handsets and portable transmitters are battery operated. Devices must be tested at full power to demonstrate SAR compliance, which may sometimes drain a fully charged battery in less than half an hour. Depending on the measurement resolution and the field scanning procedures used, it may take 10-20 minutes to complete each measurement; therefore, it is important to start each test with a fully charged battery. In order to verify whether a device has been tested at full power, conducted output power measurements should be performed before and after each SAR measurement to confirm the output power. The use of external DC power adapters or other signal leads that are not normally

required during normal use should be avoided because they may perturb the field and change the exposure conditions.

Most handsets have built-in test modes that may be used for basic performance evaluations. Such test signals offer a consistent means for testing SAR and are recommended for evaluating SAR. When test modes are not available or inappropriate for testing a handset, the actual transmission should be activated through a base station simulator or similar equipment.

Handsets should be tested at the high, middle and low frequency channels in each transmission mode. The performance of a handset may vary within a transmission band due to its design. In some cases where helical or patch antennas are used, device performance may shift because of dielectric loading from the user's body. If a device operates with a duty factor, the maximum duty factor should be used for evaluating SAR. Handsets operating in CDMA mode should be tested with full vocoder rate at 100% duty factor because the output power for these devices usually varies randomly according to RF propagation conditions between the devices and the base station.

SAR MEASUREMENT PROCEDURES

The detailed procedures for testing handsets are described in Appendix D.

SAR COMPUTATION GUIDELINES AND DESCRIPTIONS

The SAR measurement configurations for testing portable transmitters, such as device positioning, test conditions and tissue model requirements for the head and body should be used to evaluate SAR with computational methods. While the SCC-34/SC-2 is developing recommended computational procedures for SAR evaluation (See Reference [20]), the following describes the procedures that have been typically used by others to simulate SAR test conditions. Additional guidance on the type of information that should be included in test reports to demonstrate SAR compliance using computational modeling techniques is included in Appendix B of this supplement.

Currently, the finite-difference time-domain (FDTD) algorithm is the most widely accepted computational method for SAR modeling (See References [13], [24], [32-33] and [38-41]). This method adapts very well to the tissue models that are usually derived from MRI or CT scans (See References [10], [13] and [37]), such as those currently used by many research institutions. The FDTD method offers great flexibility in modeling the inhomogeneous structures of anatomical tissues and organs. It has been used in many far-field electromagnetic applications during the last three decades. With recent advances in computing technology, it has become possible to apply this method to near-field applications for evaluating handsets.

In the early development of SAR modeling using FDTD techniques, computations were performed with rectangular and spherical dielectric models exposed in the near field of a dipole or a monopole positioned on a metal box to verify the technique's applicability for evaluating handsets (See References [7], [21-22], [25] and [36]). Currently, different techniques have been developed to model the exact shape and dimensions of a handset (See References [40]), including its display and keypad, through computer aid design (CAD) data provided by the handset manufacturer. While this effort is continuing, concern has been expressed over the validity of most handset models that do not consider the effects of the inner electronics and complex chassis or shielding structures of a handset as part of the device model.

Computing resources and memory requirements are often of concern for most numerical simulations. The memory required for FDTD computations is directly related to the resolution of the tissue and handset models. The numerical algorithms used to implement the FDTD method may vary with the optimization techniques used to improve the modeling accuracy and computational efficiency. To satisfy the wave propagation requirements in infinite free space, numerical absorbing boundaries are applied to truncate the computation domain to simulate reflectionless propagation through the absorbing boundaries. Several types of absorbing boundary conditions (ABC) have been developed for FDTD computations, including Mur, Liao, retarded-time and the perfectly-matched-layers (See References [4-5] and [29]). The performance of these ABCs may vary but their effects on SAR in highly absorptive dielectric media, such as body tissues, are normally insignificant.

A sinusoidal waveform is typically used as the excitation source at the antenna feed-point of a handset to perform the computations. The signal is allowed to propagate and interact with the objects modeled in the computational domain by means of numerical iterations. The FDTD algorithm iterates the field propagation in both space and time until the field conditions in the computational domain reach sinusoidal steady state. The total field at selected tissue locations can be computed to determine the SAR. In order to maintain numerical stability for the computational algorithms, the Courant condition that provides the minimum relationship for selecting the time and spatial resolutions used in the computation must be satisfied (See References [24] and [38-39]). The iteration speed and expected computational errors are related to the parameters used for meeting the Courant condition.

One of the advantages of using computational modeling is its ability to model the complex heterogeneous structures of anatomical tissues and to simulate the field scattering that occurs within the tissues. The handset and the head or other tissue structures are digitized according to the permittivity and conductivity of the respective material and dielectric media. In order to compute SAR accurately, the appropriate tissue dielectric properties must be used in the computation. The list of tissue dielectric parameters compiled by Dr. Camelia Gabriel constitutes the most widely accepted database for this information (See Reference [12]). The dielectric parameters of selected tissues have been derived from this database and made available for viewing and downloading at the FCC's Office of Engineering and Technology's World Wide Web Internet Site: http://www.fcc.gov/oet/.

Generally, the basic FDTD algorithms and associated special techniques are validated with benchmark models when the computational techniques are developed. Once the computational accuracy is established, validations are only required when changes are made to certain algorithms. The similar benchmark validation procedures are also used to verify the validity of head and body models constructed for the computations. The use of benchmark validations to confirm computational and modeling accuracy can be viewed as the equivalent of equipment calibration in SAR measurements. Since validation techniques generally vary among different test sites, it may be necessary to include the technical information on benchmark validation procedures to substantiate compliance.

Special FDTD techniques have been concurrently developed by various researchers to provide more accurate and efficient methods for modeling handsets and antennas (See References [23], [32] and [34]). It has been recently shown that the exact dimensions of an antenna and its location on the handset must be precisely modeled in order to obtain accurate results (See Reference [40]). Since the inner electronics of a handset are typically not modeled, appropriate means should be used to verify the validity of a handset model for compliance testing.

Currently there are no standard procedures for selecting the electric field components surrounding an FDTD cell or at a grid point to determine the total electric field at a tissue location. The total field is typically computed from the averages of 3-12 field components that are located at a grid

point or surrounding a cell in the tissue model and have introduced SAR variations in the computations. These variations are usually dependent on the local field gradients. There is also no standard method for computing the one-gram averaged SAR and various methods have been used. At a tissue interface or along an irregular surface of the phantom, the local field values are computed from field components in different tissue types. To accurately compute the one-gram SAR in the shape of a one-gram cube involving different tissues can be difficult. Until computational procedures are available from SCC-34/SC-2 (See Reference [20]), the procedures used to compute the one-gram SAR should be described in the test report to support compliance.

The sinusoidal or pulsed signal used to excite the antenna of a handset is typically of arbitrary amplitude. The computed SAR values must be normalized to the measured output power of the actual device. It is recommended that the final SAR be normalized to the maximum conducted output power measured by the manufacturer. When technical data is requested, the information described in Appendix B may be used to determine the type of supporting information for demonstrating compliance.

MEASUREMENT AND COMPUTATIONAL UNCERTAINTIES

Although measurement and computational techniques are being improved, standardized procedures have not yet been established. Therefore, the margin of error for typical measurement and computational systems is directly related to the latest technical developments for SAR evaluation. Systems that use unreliable techniques or those that do not produce repeatable results should not be used to test devices for FCC compliance.

Measurement uncertainties are the results of errors related to system instrumentation, field probe response and calibration, tissue dielectric properties and tissue parameter characterization. Uncertainties due to measurement procedures include test device placement, probe positioning, the algorithms used to interpolate, extrapolate and analyze the measurement data to determine the one-gram averaged SAR. A list of the SAR measurement uncertainty components described in the SCC-34/SC-2 SAR document is included Appendix D.

For numerical methods, computational uncertainties are usually the results of errors due to numerical algorithm implementation, benchmark validation, methods used to compute SAR from the field components and procedures used to determine the one-gram averaged SAR. Uncertainties in the test device and tissue models are due to modeling techniques, tissue model implementation, assignment of tissue dielectric parameters and the modeling resolution. Information on such uncertainties is relevant to SAR evaluation and may be requested in order to support compliance with SAR exposure limits (See Reference [20]).

SECTION 3: RF EXPOSURE COMPLIANCE FOR SPREAD SPECTRUM TRANSMITTERS

For spread spectrum transmitters operating under 47 CFR §15.247, it is specified in 47 CFR §15.247(b)(4) that these devices must operate in a manner that ensures the public is not exposed to RF energy levels in excess of the Commission's guidelines.[11] These devices are categorically excluded from routine environmental evaluation because they generally operate at relatively low power levels where there is a high likelihood of compliance with the RF exposure standards. For some low power devices, it may be necessary to ensure compliance with the RF exposure limits by using a combination of simple procedures such as installation and operating instructions, warning instructions and/or warning labels on the device to ensure that the device will not expose nearby persons above the applicable MPE limits[12]. In most cases, the "worst case" distance at which an MPE limit is met for mobile devices can be estimated according to the power density produced by an isotropic source with radiated output power equivalent to that transmitted by the device as discussed in OET Bulletin 65.[13]

If a transmitter is designed to operate next to the body of its user or at close proximity to persons, a RF evaluation may be requested according to 47 CFR §1.1307(c) and (d). These types of evaluations are typically limited to transmitters that are intended to operate in very close proximity to the body, using 0.5 watt of output power or more with a high signal transmitting duty factor, and which do not incorporate obvious effective means for users to meet RF exposure compliance.[14] When RF evaluation is requested, the procedures described in this supplement for evaluating mobile and portable devices with respect to MPE or SAR limits may be used.

For purposes of determining RF exposure, the transmission protocols used by certain spread spectrum transmitters may qualify the device for source-based time averaging. The applicable duty factor may be determined according to the RF output power "on" and "off" time durations, either as a signal with a repeatable duty cycle or by establishing a worst case duty factor using power off durations

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[11] See *Report and Order*, in ET Docket 96-8, FCC 97-114, Amendment of Parts 2 and 15 of Commission's Rules Regarding Spread Spectrum Transmitter.

[12] Warning instructions and labels also include certain caution statements that are needed to ensure compliance. Warnings are typically used in situations where there could be imminent danger, such as exposing to the main beam of a high gain antenna operating at substantially high output power. Caution statements and labels are more appropriate for informing the users of most Spread Spectrum devices to follow specific installation and operating requirements to ensure compliance for all exposed persons.

[13] Power density estimates based on simplified sources are different than the computational methods used in routine SAR evaluation where the test device and/or tissue models are constructed numerically to simulate the exposure conditions and to calculate power density or SAR.

[14] Both conducted and radiated output power should be considered in near-field exposure conditions. The output indicated in the above (500 mW) is appropriate when the device and its antenna are both operating at more than 2.5 – 3.0 cm from a person's body, such as certain hand-held terminals. If a device, its antenna or other radiating structures are operating at closer than 2.5 cm from a person's body or in contact with the body, SAR evaluation may be necessary when the output is more than 50 – 100 mW, depending on the device operating configurations and exposure conditions.

identified by the transmission protocol. Duty factors related to device usage, frequency hopping or other similar transmission conditions are normally not acceptable as source-based, time averaging factors for RF evaluations.

For transmitters that use external or remote antennas for indoor or outdoor operations, appropriate installation procedures should be provided to the installer to ensure the antenna is installed to provide the specified distance from nearby persons to satisfy compliance. For other transmitters which do not normally operate next to persons, such as a wireless LAN transmitter located on a desktop, certain operating and usage instructions may be included in the operator's manual to caution users to maintain a specified distance from the transmitter to ensure compliance. In some of the above situations where a low power device is designed to operate near the body of the user, the use of a warning label on the transmitter to caution users to limit their exposure duration and/or maintain certain specific usage conditions can also be acceptable for demonstrating compliance.[15]

As is explained in the FCC's *Report and Order* in ET Docket 96-8 (FCC 97-114, Section 9), these are steps that can be taken by the responsible parties to ensure that these devices are operated in accordance with the RF guidelines for human exposure adopted by the Commission. The methods used to ensure compliance must be effective, and the installation, operation and warning instructions or warning labels should explain their purpose and provide appropriate means for satisfying compliance.[16] The appropriate equations for estimating power densities produced by typical antennas, including high gain aperture antennas, are described in OET Bulletin 65. It should be emphasized that categorical exclusion from routine environmental evaluation must not be interpreted as an exemption from compliance with the RF exposure requirements in §15.247(b)(4).

METHODS TO ENSURE COMPLIANCE FOR SPREAD SPECTRUM TRANSMITTERS

The examples shown in the Table 1 are not intended to establish mandatory procedures for RF exposure compliance for spread spectrum transmitters. Other methods and procedures may be acceptable based on device output power, operating configurations and exposure conditions. The range of power levels and distances used are approximate values representative of typical operating conditions for most spread spectrum transmitters operating at 915 or 2450 MHz. For certain fixed and mobile transmitters that are not designed to be carried next to the body of a user during normal operation, the use of appropriate operating and warning instructions in the operator's manual or warning labels on the device may offer effective means to prevent users and nearby persons from exposure at a specified distance from the device where RF exposure limits could be exceeded.[17]

Table 1. Applicable Methods to Ensure Compliance for Spread Spectrum Transmitters.

[15] This does not include devices that are designed to operate in contact with a person's body, such as cordless phones and certain body-worn transmitters.

[16] See footnote 12.

[17] See footnote 12.

Transmitter or Device Type[18]	**Output**[19]	**Applicable Methods to Ensure Compliance**[20]
Cordless phone handsets and most other transmitters using monopole or dipole type antennas as an integral part of the device.	≤ 0.3 W at 915 MHz or ≤ 0.2 W at 2450 MHz	If the device or its antenna operates at less than 2.5 cm from a person's body (excluding hands, wrists, feet and ankles), the potential for exceeding SAR limit is dependent on the operating configurations and exposure conditions of the device. Operating and warning instructions in the operator's manual may be used to ensure compliance. If such instructions are ineffective for ensuring compliance, especially when the output is greater than 50-100 mW, it may be necessary to demonstrate compliance with respect to SAR limit.
Cordless phone handsets and other transmitters that are carried next to the body of the user or operate at distances closer than approximately 5 cm to the body of users or nearby persons.	> 0.3 W at 915 MHz or > 0.2 W at 2450 MHz	Generally at above 300 mW (200 mW at 2450 MHz), the potential for exceeding SAR limit is dependent on the antenna design and device operating conditions. Warning instructions and warning labels may be used to limit the exposure durations and/or conditions to ensure compliance. However, if manufacturers believe that such warning instructions and labels will not be effective in keeping persons at the specified distances necessary to ensure compliance, especially when the output is greater than 400-500 mW, it may be necessary to demonstrate compliance with respect to SAR limit.[21]
Transmitters using monopole or dipole type antennas as an	> 0.3 W at 915 MHz	Operating and warning instructions in the operator's manual indicating the minimum

[18] The applicable methods for ensuring compliance are divided into transmitter groups according to their output power levels. The operating configurations and exposure conditions of a transmitter and its antenna(s) must be clearly defined in order for the above procedures to be applicable.

[19] The output power levels indicated in the above table are EIRP for fixed and mobile operations defined in 47 CFR §§1.1307 and 2.1091. For portable operating configurations, as defined in 47 CFR §2.1093, both conducted and radiated (EIRP) output power should be considered for near-field exposure conditions. EIRP is the product of the maximum output power available at the antenna terminal of the transmitter and the antenna gain. When applicable, a source-based time-averaging duty factor may be considered for determining compliance.

[20] When a transmitter transmits simultaneously at multiple frequencies or operates in conjunction with other transmitters or antennas, all transmitters, antennas and operating frequencies must be considered to determine RF exposure compliance. When a fixed-mounted antenna is co-located with other antennas, the requirements of 47 CFR §1.1307(b)(3) are applicable.

[21] This output level is applicable when the device and its antenna are both operating more than 2.5 – 3.0 cm from a person's body; excluding hands, wrists, feet and ankles.

integral part of the device, normally operating at closer than 20 cm to users or nearby persons but more than approximately 5 cm away from such persons.	or > 0.2 W at 2450 MHz	separation distance between the antenna and nearby persons in order to avoid extended periods of exposure at closer than this distance to ensure SAR compliance. When operating and warning instructions are ineffective, the use of warning labels on the transmitting element may also be necessary to caution nearby persons to limit their exposure duration and/or conditions to ensure compliance. If warning labels are not desirable, SAR evaluations, even though they may not be required, may be used to demonstrate compliance to obviate the need for any warning label that might otherwise be necessary.
Transmitters using external antennas, including Omni, patch, logarithmic, parabolic reflector and dish type antennas. For outdoor operations, antennas generally mounted at remote locations such as the top or side of most buildings where the antennas are at least 20 cm away from nearby persons.	> 2.5 W at 915 MHz	Professional installation: provide installers with instructions indicating the separation distance between the transmitter/antenna and nearby persons to ensure RF exposure compliance, and to inform installers to ensure compliance through proper installation. Professional installation is preferred for these types of operations. However, end-user installation may require certain additional information to allow persons who do not have professional skills to properly install the antennas to ensure compliance.
	≤ 2.5 W at 915 MHz or ≤ 4 W at 2450 MHz	Transmitters operating at 2.5 W EIRP (1.5 W ERP) or less at 915 MHz, or at 4 W EIRP (2.4 W ERP) or less at 2450 MHz, generally are not expected to exceed MPE limits when nearby persons are 20 cm or more from most antennas; special instructions and warnings are normally not necessary to ensure compliance.
Transmitters using indoor antennas that operate at 20 cm or more from nearby persons.	> 2.5 W at 915 MHz	If the MPE distance is greater than that required for normal operation of the device, operating instructions, warning instructions and/or warning labels may be used to ensure compliance by indicating the minimal separation distance to comply with MPE limits. If the antennas are professionally installed to ensure compliance, warning instructions and warning labels are not necessary.
	≤ 2.5 W at 915 MHz or ≤ 4 W at	Transmitters operating at 2.5 W EIRP (1.5 W ERP) or less at 915 MHz, or at 4 W EIRP (2.4 W ERP) or less at 2450 MHz, generally are not expected to exceed MPE limits when nearby

	2450 MHz	persons are 20 cm or more from most antennas. Therefore, special instructions and warnings are normally not necessary to ensure compliance.
Transmitters using high gain antennas for indoor or outdoor operations.	> 4.0 W at 2450 MHz	If MPE limit may be exceeded in the main beam of the antenna, installation procedures, warning instructions and/or warning labels as described above may be used to ensure compliance by providing professional installers and end-users with instructions to point the main beam of the antenna at locations not occupied by persons and to warn others to maintain a specified distance from the antenna.

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APPENDIX A: FCC EXPOSURE CRITERIA

Note: For further information and details on these limits see OET Bulletin 65, §§1.1307, 1.1310, 2.1091 and 2.1093 of FCC rules.

FCC LIMITS FOR MAXIMUM PERMISSIBLE EXPOSURE (MPE)

(A) Limits for Occupational/Controlled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-3.0	614	1.63	(100)*	6
3.0-30	1842/f	4.89/f	($900/f^2$)*	6
30-300	61.4	0.163	1.0	6
300-1500	--	--	f/300	6
1500-100,000	--	--	5	6

(B) Limits for General Population/Uncontrolled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	($180/f^2$)*	30
30-300	27.5	0.073	0.2	30
300-1500	--	--	f/1500	30
1500-100,000	--	--	1.0	30

f = frequency in MHz *Plane-wave equivalent power density

NOTE 1: See Section 1 for discussion of exposure categories.

NOTE 2: The averaging time for General Population/Uncontrolled exposure to fixed transmitters is not applicable for mobile and portable transmitters. See 47 CFR §§2.1091 and 2.1093 on source-based time-averaging requirements for mobile and portable transmitters.

FCC LIMITS FOR SPECIFIC ABSORPTION RATE (SAR)

(A) Limits for Occupational/Controlled Exposure (W/kg)

Whole-Body	Partial-Body	Hands, Wrists, Feet and Ankles
0.4	8.0	20.0

(B) Limits for General Population/Uncontrolled Exposure (W/kg)

Whole-Body	Partial-Body	Hands, Wrists, Feet and Ankles
0.08	1.6	4.0

NOTE 1: See Section 1 for discussion of exposure categories.

NOTE 2: ***Whole-Body SAR*** is averaged over the entire body, ***partial-body SAR*** is averaged over any 1 gram of tissue defined as a tissue volume in the shape of a cube. ***SAR for hands, wrists, feet and ankles*** is averaged over any 10 grams of tissue defined as a tissue volume in the shape of a cube.

NOTE 3: At frequencies above 6.0 GHz, SAR limits are not applicable and MPE limits for power density should be applied at 5 cm or more from the transmitting device.

Note 4: The time averaging criteria for field strength and power density do not apply to general population SAR limit of 47 CFR §2.1093.

APPENDIX B: INFORMATION FOR DOCUMENTING SAR COMPLIANCE

The information described in this Appendix should be included in test reports submitted for equipment authorization that requires SAR evaluation. The information is generally necessary to evaluate test results and to determine RF exposure compliance.

I: Information on Test Device and Exposure Categories

II: Specific Information for SAR Measurements

III: Specific Information for SAR Computations

I: INFORMATION ON TEST DEVICE AND EXPOSURE CATEGORIES

1) General information

a) FCC ID – each RF exposure test report must include the FCC ID of the device evaluated.
b) an affirmative statement of compliance with FCC RF exposure (see 47 CFR §2.909)
c) device category– identify if the SAR evaluation is for a mobile or portable transmitter
d) RF exposure environment – state the applicable exposure condition for the transmitter operating environment, Occupational/Controlled or General Population/Uncontrolled

2) Device operating configurations and test conditions

a) whether the test device is a production unit or an *identical* prototype (see 47 CFR §2.908)
b) a brief description of the test device operating configurations, including
    i) operating modes and operating frequency range(s)
    ii) maximum device rating for each operating mode and frequency range
    iii) operating tolerances
    iv) antenna type and operating positions
    v) applicable body-worn configurations
    vi) battery options that could affect the SAR results
c) procedures used to establish the test signals
d) applicable source-based time-averaging duty factor and the duty factor used in the tests
e) maximum output power measured before and after each SAR test

II: Specific Information for SAR Measurements

1) Measurement system and site description

a) a brief description of the SAR measurement system
b) a brief description of the test setup

2) Electric field probe calibration

a) a description of the probe, its dimensions and sensor offset etc.
b) a description of the probe measurement errors
c) most recent calibration date

3) SAR measurement system verification

a) A brief description of the RF radiating source used to verify the SAR system performance within the operating frequency range of the test device (see Appendix D)
b) a list of the tissue dielectric parameters, ambient and tissue temperatures, output power, peak and one-gram averaged SAR for the measured and expected target test configurations
c) a list of the error components contributing to the total measurement uncertainty

4) Phantom description

a) a description of the head and body phantoms used in the tests, including shell thickness and other tolerances

5) Tissue dielectric property

a) the composition of ingredients for the tissue material used in the SAR tests
b) the tissue dielectric parameters measured at the middle of each operating frequency range of the test device
c) the temperature range and operating conditions of the tissue material during each SAR measurement

6) Device positioning

a) a description of the dielectric holder or similar mechanisms used to position the test device in the specific test configurations
b) a description of the positioning procedures used to evaluate the highest exposure expected under normal operating configurations
c) sketches and illustrations showing the device positions, with respect to the phantom; including separation distances and angles, as appropriate
d) a description of the antenna operating positions, extended, retracted or stowed etc. and the configurations tested in the SAR evaluation

7) Peak SAR locations

a) a description of the coarse resolution, surface or area scan procedures used to search for all possible peak SAR locations within the phantom
b) a description of the interpolation procedures applied to the measured points to identify the peak SAR locations at a finer spatial resolution
c) description, illustration and SAR distribution plots showing the peak SAR locations with respect to the phantom and the test device
d) identifying the peak SAR locations used to evaluate the highest one-gram averaged SAR

8) **One-gram averaged SAR**
   a) a description of the fine resolution, volume or zoom scan procedures used to determine the highest one-gram averaged SAR in the shape of a cube
   b) a description of the extrapolation procedures used to estimate the SAR value of points close to the phantom surface that are not measurable
   c) a description of the interpolation procedures applied to the measured and extrapolated points to obtain SAR values at a finer spatial resolution within the zoom scan volume
   d) a description of the integration procedures applied to the interpolated SAR values within the zoom scan volume to determine the highest 1 or 10-gram SAR in the shape of a cube

9) **Total measurement uncertainty**
   a) a tabulated list of the error components and uncertainty values contributing to the total measurement uncertainty (see Appendix D)
   b) reporting the combined standard uncertainty and expanded uncertainty (for $k \geq 2$) of each measurement
   c) if compliance cannot be ensured after taking measurement uncertainty into account, an explanation of the procedures that have been used to reduce the measurement uncertainty and applicable means that can be used to ensure compliance

10) **Test results for determining SAR compliance**
   a) if the channels tested for each configuration (left, right, cheek, tilt/ear, extended, retracted etc.) have similar SAR distributions, a plot of the highest SAR for each test configuration should be sufficient; otherwise additional plots should be included to document the differences
   b) all of the measured SAR values should be documented in a tabulated format with respect to the test configurations

III: SPECIFIC INFORMATION FOR SAR COMPUTATIONS

1) Computational resources

a) a summary of the computational resource required to perform the SAR computations for the test transmitter and phantom configurations

b) a summary of the computational requirements with respect to modeling and computing parameters for determining the highest exposure expected for normal device operation, such as minimal computational requirements and those used in the computation

2) FDTD algorithm implementation and validation

a) a summary of the basic algorithm implementation applicable to the particular SAR evaluation, including absorbing boundary conditions, source excitation methods, certain standard algorithms for handling thin metallic wires, sheets or dielectric materials etc.

b) descriptions of the procedures used to validate the basic computing algorithms described in a) and analysis of the computing accuracy based on these algorithms for the particular SAR evaluation

3) Computational parameters

a) a tabulated list of computational parameters such as cell size, domain size, time step size, tissue and device model separation from the absorbing boundaries and other essential parameters relating to the computational setup requirements for the SAR evaluation

b) a description of the procedures used to handle computation efficiency and modeling accuracy for the phantom and the test device

4) Phantom model implementation and validation

a) identify the source of the phantom model, its original resolution and the procedures used to code and assign tissue dielectric parameters for the SAR evaluation

b) verify the phantom model is appropriate for determining the highest exposure expected for normal device operation

c) describe procedures used to verify that the particular phantom model has been correctly constructed for making SAR computations, such as comparing computed and measured SAR results of a dipole source

5) Tissue dielectric parameters

a) a description of the types of tissues used in the phantom models and the sources of tissue dielectric parameters used in the computations

b) verify that the tissue types and dielectric parameters used in the SAR computation are appropriate for determining the highest exposure expected for normal device operation

c) a tabulated list of the dielectric parameters used in the device and phantom models

6) Transmitter model implementation and validation

a) a description of the essential features that must be modeled correctly for the particular test device model to be valid

b) descriptions and illustrations showing the correspondence between the modeled test device and the actual device, with respect to shape, size, dimensions and near-field radiating characteristics

c) verify that the test device model is equivalent to the actual device for predicting the SAR distributions for satisfying 47 CFR §§2.907 and 2.908 of Commission Rules
d) verify the SAR distribution at the high, middle and low channels, similar to those considered in SAR measurements for determining the highest SAR

7) Test device positioning

a) a description of the device test positions (left, right, cheek, tilt/ear, extended and retracted etc.) used in the SAR computations
b) illustrations showing the separation distances between the test device and the phantom for the tested configurations, similar to the reporting procedures used in SAR measurements

8) Steady state termination procedures

a) a description of the criteria and procedures used to determine that sinusoidal steady state conditions have been reached throughout the computational domain for terminating the computations
b) reporting the number of time steps or sinusoidal cycles executed to reach steady state
c) a description of the expected error margin provided by the termination procedures

9) Computing peak SAR from field components

a) a description of the procedures used to compute the sinusoidal steady total electric field with selected field components at each tissue location
b) a description of the expected error margin provided by the algorithms used to compute the SAR at each tissue location according to the selected field components and tissue dielectric parameters

10) One-gram averaged SAR procedures

a) a description of the procedures used to search for the highest one-gram averaged SAR, including the procedures for handling inhomogeneous tissues within the one-gram cube
b) specify the weight and dimensions of the one-gram cube of tissue
c) a description of the expected error margin provided by the algorithms used in computing the one-gram SAR

11) Total computational uncertainty – a description of the expected error and computational uncertainty for the test device and tissue models, test configurations and numerical algorithms etc.

12) Test results for determining SAR compliance

a) illustrations showing the SAR distribution of dominant peak locations produced by the test transmitter, with respect to the phantom and the test device, similar to those reported in SAR measurements
b) a description of how the maximum device output rating is determined and used to normalized the SAR values for each test configuration
c) a description of the procedures used to compute source-based time-averaged SAR

APPENDIX C: TISSUE DIELECTRIC PARAMETERS

The head and body tissue parameters given in this Appendix should be used to test transmitters operating in the cellular, PCS, U-NII, spread spectrum (47 CFR §15.247) and other frequencies bands (See References [8], [12] and [15]). When a transmission band overlaps with one of the target frequencies specified in this Appendix, the tissue dielectric parameters of the tissue medium at the middle of a device transmission band should be within 5% of the parameters specified at that target frequency. At other frequencies, the dielectric parameters should be linearly interpolated between the closest pair of target frequencies specified in this Appendix to determine the applicable dielectric parameters corresponding to the middle of a device transmission band. It has been reported that a 5% tolerance in tissue parameters may not be easily achieved at certain frequencies. Under such circumstances, 10% tolerance may be used until more precise tissue recipes are available.

To maintain consistency in using SAR measurement and computational methods to determine compliance, the homogeneous phantom models used in SAR measurements are also recommended for use in SAR computations. When inhomogeneous models are used to compute SAR, the tissue dielectric parameters based on the 4-Cole-Cole equation, as described by Dr. Camelia Gabriel [12], may be used. Selected tissue parameters are available for viewing and downloading at the FCC's Office of Engineering and Technology's World Wide Web Internet Site: http://www.fcc.gov/oet/.[22]

[22] The tissue dielectric properties provided in this Appendix and at the FCC Web Site are based on the 4-Cole-Cole model described by C. Gabriel, "Compilation of the Dielectric Properties of Body Tissues at RF and Microwave Frequencies," Brooks Air Force Technical Report AL/OE-TR-1996-0037.

TISSUE DIELECTRIC PARAMETERS FOR HEAD AND BODY PHANTOMS

The head tissue dielectric parameters recommended by the IEEE SCC-34/SC-2 in P1528 have been incorporated in the following table. These head parameters are derived from planar layer models simulating the highest expected SAR for the dielectric properties and tissue thickness variations in a human head (See Reference [11]). Other head and body tissue parameters that have not been specified in P1528 are derived from the tissue dielectric parameters computed from the 4-Cole-Cole equations described in Reference [12] and extrapolated according to the head parameters specified in P1528.

Target Frequency	Head		Body	
(MHz)	ε_r	σ (S/m)	ε_r	σ (S/m)
150	52.3	0.76	61.9	0.80
300	45.3	0.87	58.2	0.92
450	43.5	0.87	56.7	0.94
835	41.5	0.90	55.2	0.97
900	41.5	0.97	55.0	1.05
915	41.5	0.98	55.0	1.06
1450	40.5	1.20	54.0	1.30
1610	40.3	1.29	53.8	1.40
1800 – 2000	40.0	1.40	53.3	1.52
2450	39.2	1.80	52.7	1.95
3000	38.5	2.40	52.0	2.73
5800	35.3	5.27	48.2	6.00

(ε_r = relative permittivity, σ = conductivity and ρ = 1000 kg/m^3)

The following tissue formulations are provided for reference only as some of the parameters have not been thoroughly verified. The composition of ingredients may be modified accordingly to achieve the desired target tissue parameters required for routine SAR evaluation.

TYPICAL COMPOSITION OF INGREDIENTS FOR LIQUID TISSUE PHANTOMS

Ingredients (% by weight)	**Frequency (MHz)**									
	450		835		915		1900		2450	
Tissue Type	Head	Body	Head	Body	Head	Body	Head	Body	Head	Body
Water	38.56	51.16	41.45	52.4	41.05	56.0	54.9	40.4	62.7	73.2
Salt (NaCl)	3.95	1.49	1.45	1.4	1.35	0.76	0.18	0.5	0.5	0.04
Sugar	56.32	46.78	56.0	45.0	56.5	41.76	0.0	58.0	0.0	0.0
HEC	0.98	0.52	1.0	1.0	1.0	1.21	0.0	1.0	0.0	0.0
Bactericide	0.19	0.05	0.1	0.1	0.1	0.27	0.0	0.1	0.0	0.0
Triton X-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.8	0.0
DGBE	0.0	0.0	0.0	0.0	0.0	0.0	44.92	0.0	0.0	26.7
Dielectric Constant	43.42	58.0	42.54	56.1	42.0	56.8	39.9	54.0	39.8	52.5
Conductivity (S/m)	0.85	0.83	0.91	0.95	1.0	1.07	1.42	1.45	1.88	1.78

Salt: 99^{+}% Pure Sodium Chloride Sugar: 98^{+}% Pure Sucrose
Water: De-ionized, 16 MΩ^{+} resistivity HEC: Hydroxyethyl Cellulose
DGBE: 99^{+}% Di(ethylene glycol) butyl ether, [2-(2-butoxyethoxy)ethanol]
Triton X-100 (ultra pure): Polyethylene glycol mono [4-(1,1, 3, 3-tetramethylbutyl)phenyl]ether

Tissue Recipe as reported by Hartsgrove et. al. in "Simulated Biological Materials for Electromagnetic Radiation absorption Studies," Bioelectromagnetics 8:29-36 (1987)

Ingredients (% by weight)	**Head/Brain**	**Body/Muscle**
Water	40.4	52.5
Salt (NaCl)	2.5	1.4
Sugar	56.0	45.0
HEC	1.0	1.0
Bactericide	0.1	0.1
Dielectric constant @ 900 MHz	41.2	54.7
Conductivity @ 900 MHz (S/m)	1.22	1.38

APPENDIX D: SAR MEASUREMENT PROCEDURES

The SAR measurement procedures described in this Appendix are primarily intended for testing wireless handsets and similar transmitters that operate next to a person's head. The test configurations for evaluating body-worn SAR compliance are also described. The procedures in this Appendix should be used in conjunction with the general information provided in Section 2.

SAR is evaluated using simulated tissue medium contained in a realistic human shaped phantom shell that allows a small diameter, miniature electric field probe to measure the electric field within the tissue regions exposed to the transmitter configured in normal operating positions. Since the RF energy absorption characteristics of human tissues are frequency dependent, the dielectric properties of simulated tissue media used for SAR evaluations must match the target tissue properties specified at the operating frequency range of the device (See Appendix C).

PHANTOM CONSIDERATIONS

Handsets that are held on the side of a person's head next to the ear have been tested using two general types of realistic-shaped head phantoms: with and without a simulated external ear attached to the head model. A simulated ear with a thickness of approximately 2-3 mm, consisting of low-loss dielectric material has been used to model a person's ear compressed by the earpiece of a wireless handset on some head models. Others have used a 2-4 mm thick, circular shaped, low-loss dielectric spacer to simulate the ear separation distance.

The IEEE SCC-34/SC-2 has established criteria for developing a standardized head model to test handsets for SAR compliance. This head model has been derived from selected head dimensions of male, U.S. Army personnel (See Reference [42]). The committee has specified the phantom shell to be constructed of low-loss dielectric material with dielectric constant less than 5.0 and loss tangent not exceeding 0.05. The thickness of the phantom shell should be 2.0 mm with less than $\pm$ 0.2 mm variations in shape and thickness for regions where SAR is to be measured and $\pm$ 0.5 mm for other regions. A 4.0 mm thick low-loss dielectric spacer is used to simulate the ear separation distance on this head model.

A reference plane has been defined by three points consisting of a point on each ear spacer and the tip of the mouth to minimize test device positioning errors. The points on each ear spacer are known as the ear reference points; each is located at 1.5 cm above the ear canal location in the reference plane. During SAR measurements, the centerline on the front of a handset is aligned to this predefined reference plane and the earpiece is positioned at the level of the ear reference point. The ear spacer is tapered abruptly to zero thickness below the ear reference point, along a line perpendicular to the reference plane. By using a standardized head model with specific ear simulation requirements, device positioning errors are reduced and lower SAR measurement uncertainty is expected (See Reference [19]).

The construction of a liquid phantom must allow unrestricted electric field probe access to search for all possible peak SAR locations produced by a portable transmitter under test. The tissue material within the phantom shell measured from the ear reference point should be at least 15 cm deep. In most situations, split head models are used to test transmitters on the left and right side of the head. A separate flat phantom should be used to test exposures in body-worn configurations and other body

regions that are relatively flat, such as the chest and abdomen.

Note: . When the SCC-34/SC-2 head phantom becomes commercially available, the Commission will issue a Public Notice establishing a transition period of 3-6 months to allow interested parties to acquire this head phantom. After the transition period, the SCC-34/SC-2 head phantom should be used for SAR testing. Until that time, other head phantoms may be used with the procedures in this Appendix. These procedures must be used for applications evaluated by Telecommunications Certification Bodies (TCBs).

RECOMMENDED CHARACTERISTICS OF HEAD AND BODY PHANTOMS

The following information provides additional guidance on head and body models that are considered acceptable for routine evaluation of most wireless handsets and similar portable transmitters. The SCC-34/SC-2 head conforms to the relevant portions of these criteria:

- The shape, dimensions and complexity of a human shaped head phantom should be appropriate for evaluating the near-field exposure conditions expected by the users of a transmitter device under normal operating conditions.

- The head phantom should include a portion of the neck, preferably extending to the base of the neck. Shoulders are not necessary.

-

- For existing head phantoms, before the SCC-34/SC-2 phantom is available, a lossless spacer that provides 6.0 mm or less separation from any point on the outer surface of the ear spacer to the tissue medium should be used. A 4.0 ± 0.2 mm thick low-loss dielectric spacer similar to that recommended for the SCC-34/SC-2 head phantom is recommended.

- Body-worn operating configurations should be tested using a flat phantom. The length and width of the phantom should be at least twice the corresponding dimensions of the test device, including its antenna. The body dielectric parameters specified in Appendix C should be used to demonstrate body-worn SAR compliance.

- The head and body phantom shell should be made of low-loss dielectric material with dielectric constant and loss tangent less than 5.0 and 0.05 respectively. The shell thickness for all regions coupled to the test device and its antenna should be within 2.0 ± 0.2 mm. The phantom should be filled with the required head or body equivalent tissue medium to a depth of 15.0 ± 0.5 cm.

RECOMMENDED DEVICE TEST POSITIONS FOR TYPICAL WIRELESS HANDSET

Specific test positions have been prescribed by the SCC-34/SC-2 for testing handsets using the standardized head model recommended by this committee. For routine SAR evaluation, these test positions, as descibed below, should be used for testing handsets and similar portable transmitters that operate on the side of a person's head, next to the ear. Flat phantom models should be used to test handsets and push-to-talk (PTT) devices that can be held in front of the user's face or transmit in body-worn operating configurations using belt-clips, holsters or similar accessories. The test device should be

placed in a holder or positioner made of low-loss dielectric material with dielectric constant and loss tangent less than 5.0 and 0.05 respectively. If the device holder is suspected to perturb the fields from the test device, which may affect device performance or introduce unacceptable SAR measurement errors, such as handsets with internal antennas, the error must be assessed and accounted for in the total measurement uncertainty. Device holder perturbation may be verified by testing the device on a flat phantom in each frequency band and antenna position with and without using the holder.

DEVICES OPERATING NEXT TO A PERSON'S EAR

This category includes most wireless handsets with fixed, retractable or internal antennas located toward the top half of the device, with or without a foldout, sliding or similar keypad cover. The handset should have its earpiece located within the upper ¼ of the device, either along the centerline or off-centered, as perceived by its users. This type of handset should be positioned in a normal operating position with the "test device reference point" located along the "vertical centerline" on the front of the device aligned to the "ear reference point" (See Reference [19]). The "test device reference point" should be located at the same level as the center of the earpiece region. The "vertical centerline" should bisect the front surface of the handset at its top and bottom edges. A "ear reference point" is located on the outer surface of the head phantom on each ear spacer. It is located 1.5 cm above the center of the ear canal entrance in the "phantom reference plane" defined by the three lines joining the center of each "ear reference point" (left and right) and the tip of the mouth (See Reference [19]).[23]

A handset should be initially positioned with the earpiece region pressed against the ear spacer of a head phantom. For the SCC-34/SC-2 head phantom, the device should be positioned parallel to the "N-F" line defined along the base of the ear spacer that contains the "ear reference point". For interim head phantoms, the device should be positioned parallel to the cheek for maximum RF energy coupling. The "test device reference point" is aligned to the "ear reference point" on the head phantom and the "vertical centerline" is aligned to the "phantom reference plane". This is called the "initial ear position". While maintaining these three alignments, the body of the handset is gradually adjusted to each of the following positions for evaluating SAR:

1) "Cheek/Touch Position" – the device is brought toward the mouth of the head phantom by pivoting against the "ear reference point" or along the "N-F" line for the SCC-34/SC-2 head phantom. This test position is established:

   i) When any point on the display, keypad or mouthpiece portions of the handset is in contact with the phantom.

   ii) (or) When any portion of a foldout, sliding or similar keypad cover opened to its intended self-adjusting normal use position is in contact with the cheek or mouth of the phantom.

   For existing head phantoms – when the handset loses contact with the phantom at the pivotingpoint, rotation should continue until the device touches the cheek of the phantom or breaks its last contact from the ear spacer.

2) "Ear/Tilt Position" – With the handset aligned in the "Cheek/Touch Position":

[23] The terms "test device reference point", "vertical centerline", "ear reference point", "phantom reference plane" and "initial ear position" in this section are specific references used to align a test device to the head phantom.

i) If the earpiece of the handset is not in full contact with the phantom's ear spacer (in the "Cheek/Touch position") and the peak SAR location for the "Cheek/Touch" position is located at the ear spacer region or corresponds to the earpiece region of the handset, the device should be returned to the "initial ear position" by rotating it away from the mouth until the earpiece is in full contact with the ear spacer.

ii) (otherwise) The handset should be moved (translated) away from the cheek perpendicular to the line passes through both "ear reference points" (note: one of these ear reference points may not physically exist on a split head model) for approximate 2-3 cm. While it is in this position, the handset is tilted away from the mouth with respect to the "test device reference point" by 15°. After the tilt, it is then moved (translated) back toward the head perpendicular to the line passes through both "ear reference points" until the device touches the phantom or the ear spacer. If the antenna touches the head first, the positioning process should be repeated with a tilt angle less than 15° so that the device and its antenna would touch the phantom simultaneously. This test position may require a device holder or positioner to achieve the translation and tilting with acceptable positioning repeatability.

If a device is also designed to transmit with its keypad cover closed for operating in the head position, such positions should also be considered in the SAR evaluation. The device should be tested on the left and right side of the head phantom in the "Cheek/Touch" and "Ear/Tilt" positions. When applicable, each configuration should be tested with the antenna in its fully extended and fully retracted positions. These test configurations should be tested at the high, middle and low frequency channels of each operating mode; for example, AMPS, CDMA, and TDMA. If the SAR measured at the middle channel for each test configuration (left, right, Cheek/Touch, Tile/Ear, extended and retracted) is at least 2.0 dB lower than the SAR limit, testing at the high and low channels is optional for such test configuration(s). If the transmission band of the test device is less than 10 MHz, testing at the high and low frequency channels is optional. A complete set of tests for a handset operating with a retractable antenna has 24 configurations for each operating mode, as shown in the following table.

Recommended handset and head phantom test positions for FCC compliance evaluation

Phantom Configurations	**Device Test Positions**	**Antenna Position**	**SAR (W/kg) Device Test channel, Frequency & Output**		
			Channel: ___ ___ MHz ___ mW	**Channel: ___ ___ MHz ___ mW**	**Channel: ___ ___ MHz ___ mW**
Left Side of Head	**Cheek / Touch**	extended			
		retracted			
	Ear / Tilt	extended			
		retracted			
Right Side of Head	**Cheek / Touch**	extended			
		retracted			
	Ear / Tilt	extended			
		retracted			

RECOMMENDED TEST POSITIONS FOR BODY-WORN AND OTHER CONFIGURATIONS

Body-worn operating configurations should be tested with the belt-clips and holsters attached to the device and positioned against a flat phantom in normal use configurations. Devices with a headset output should be tested with a headset connected to the device. The body dielectric parameters specified in Appendix C should be used. Both the physical spacing to the body of the user as dictated by the accessory and the materials used in an accessory affect the SAR produced by the transmitting device. For purpose of determining test requirements, accessories may be divided into two categories: those that do not contain metallic components and those that do.

When multiple accessories that do not contain metallic components are supplied with the device, the device may be tested with only the accessory that dictates the closest spacing to the body. When multiple accessories that contain metallic components are supplied with the device, the device must be tested with each accessory that contains a unique metallic component. If multiple accessories share an identical metallic component (e.g., the same metallic belt-clip used with different holsters with no other metallic components), only the accessory that dictates the closest spacing to the body must be tested.

Body-worn accessories may not always be supplied or available as options for some devices that are intended to be authorized for body-worn use. A separation distance of 1.5 cm between the back of the device and a flat phantom is recommended for testing body-worn SAR compliance under such circumstances. Other separation distances may be used, but they should not exceed 2.5 cm. In these cases, the device may use body-worn accessories that provide a separation distance greater than that tested for the device provided however that the accessory contains no metallic components..

In order for users to be aware of the body-worn operating requirements for meeting RF exposure compliance, operating instructions and caution statements should be included in the manual. The information should allow users to make informed decisions on the type of body-worn accessories and operating configurations that are appropriate for the device. The following are *examples* of typical statements that provide end-users with the necessary information about body-worn accessories:

1. For a product that has the potential to be used in a body worn configuration and has been tested and certified with a specific accessory device(s):

"For body worn operation, this phone has been tested and meets the FCC RF exposure guidelines when used with the (*manufacturer name*) accessories supplied or designated for this product. Use of other accessories may not ensure compliance with FCC RF exposure guidelines. "

2. For a product that has the potential to be used in a body worn configuration and has not been certified with a specific accessory device(s):

"For body worn operation, this phone has been tested and meets FCC RF exposure guidelines when used with an accessory that contains no metal and that positions the handset a minimum of (specified distance) from the body. Use of other accessories may not ensure compliance with FCC RF exposure guidelines."

3. For a product that has the potential to be used in a body worn configuration with future manufacturer designed accessories:

"For body worn operation, this phone has been tested and meets the FCC RF exposure guidelines when used with a (*manufacturer name*) accessory designated for this product or when used with an accessory that contains no metal and that positions the handset a minimum of (specified distance) from the body."

Transmitters that are designed to operate in front of a person's face, in push-to-talk configurations, should be tested for SAR compliance with the front of the device positioned at 2.5 cm from a flat phantom. Frontal face-phantoms are typically not recommended because of the potential of higher E-field probe boundary-effects errors in the non-smooth regions of these face phantoms, such as the nose, lips and eyes etc. For devices that are carried next to the body, such as shoulder, waist or chest-worn transmitters, SAR compliance should be tested with the accessories, including headsets and microphones, attached to the device and positioned against a flat phantom in normal use configurations.

DOCUMENTATION

Device test positions should be documented graphically and identify the separation distances and tilt angles used during the SAR evaluation. This will allow, if necessary, the test to be repeated accurately with the device positioned as specified in the test report. A close-up photo(s) of the actual test device positioned against the phantom during the SAR measurement should also be included in the test report to document the test setup.

TISSUE DIELECTRIC PROPERTY REQUIREMENTS

The tissue media should be checked at the beginning of a series of SAR measurements to determine if the dielectric parameters are within the tolerances of the specified target values. The dielectric parameters should be verified daily and more often as required by the ambient conditions. For example, when the liquid temperature deviates by more than 2°C from that recorded for the measured dielectric parameters and under conditions of extremely low humidity or high evaporation rates. The tissue parameters should be measured with the coaxial probe, slotted line or TEM line techniques described in the SCC-34/SC-2 SAR measurement document (See Reference [19]).

The tissue dielectric parameters specified in Appendix C should be used as the target values for testing (See References [11-12] and [19]). These parameters are generally accepted as equivalent to the corresponding tissue properties at 37°C, for use in single-tissue homogeneous phantom models. Examples of the typical composition of ingredients used to achieve these parameters under normal ambient conditions are also included in Appendix C. The use of other compositions and formulations to arrive at the same tissue parameters may also be acceptable. SAR measurements should be performed under normal ambient conditions, suitable for the test equipment, typically within 20-26° C and 30-70% humidity. The temperature of the tissue medium during the SAR measurement should be within ± 2.0°C of the temperature at which the dielectric parameters are measured. The relative permittivity and conductivity of the tissue material should be within 5% of the values given in Appendix C, 10% when precise tissue recipes are not available at certain frequencies. Transmitters operating at other frequencies should be tested using tissue parameters based on the linearly interpolated values shown in Appendix C, corresponding to the mid-band frequency of each operating mode. The instrumentation error associated with the measured tissue parameters should be accounted for in the overall SAR measurement uncertainty.

ELECTRIC FIELD PROBE CHARACTERISTICS AND CALIBRATION

The E-field probes used for SAR measurements should have a dynamic range of 0.01-100 W/kg to cover the range of signal levels and modulation characteristics used by most mobile and portable wireless devices. The field probes used in SAR measurements are typically calibrated to measure single frequency fields. The probe output follows the square-law response of its detectors at low field strength levels. As the field strength level increases, special circuitry or compensation software are used to achieve a linear response. When measuring pulsed signals with low duty factors or high peak-to-average ratios, the probe must be calibrated with correction factors to accurately measure SAR with respect to the average power. If the signal level exceeds the square-law response of the diode detectors in an E-field probe, the output can become sensitive to the signal modulation and the error is usually dependent on the form of modulation. A probe must be properly calibrated to measure the SAR corresponding to the average energy absorption produced by a modulated signal. A probe linearity of $\pm$ 0.25 dB should be ensured at the device test frequencies during routine SAR evaluation.

The variation in sensitivity among the sensors in a field probe must be correctly compensated for during probe calibration. It is highly desirable for a probe to have a uniform response to all incident fields, independent of field polarization and direction of propagation. However, the isotropic response of a probe is often non-ideal due to construction tolerances, asymmetry in sensor location, differences in detector sensitivity among the channels, differences in line impedance and feedback from the feed lines. It is extremely important that these undesirable characteristics are carefully evaluated during probe calibrations by rotating the probe along its axis and orienting the probe and its sensors to different field polarizations and directions of propagation. The axial and hemispherical isotropy errors of a probe should be within $\pm$ 0.25 and $\pm$ 0.5 dB, respectively, at the device test frequencies during routine SAR measurement.

A field probe must be calibrated in tissue media with the target dielectric parameters specified in Appendix C, corresponding to the operating frequency ranges of the test device. The responses of a field probe are dependent on signal frequency, modulation characteristics, power level, field polarization, field gradients and the direction of field propagation. Other factors such as RF noise, static and ELF fields, temperature, humidity and the proximity of media boundaries from the probe tip can also affect the calibration of a field probe. At less than 800 MHz, probes are calibrated using thermal techniques. At above 800 MHz, an appropriate waveguide filled with the required tissue medium may be used to calibrate the output voltages of a probe against analytically calculated field values (See References [17], [19] and [27]).

SYSTEM VERIFICATION

Routine record keeping procedures should be established for tracking the calibration and performance of SAR measurement systems. When SAR measurements are performed, the entire measurement system should be checked daily within the device transmitting frequency ranges to verify system accuracy. A flat phantom irradiated by a half-wavelength dipole is typically used to verify the measurement accuracy of a system. The measurement system should also be evaluated periodically with and without the built-in compensation and correction factors to verify the measurement sensitivity and to identify system components that could be out of tolerance. When a radiating source is not available at the operating frequency range of the test device to verify system accuracy, a source operating within 100 MHz of the mid-band channel of each operating mode may be used. The measured one-gram SAR should be within 10% of the expected target values specified for the specific

phantom and RF source used in the system verification measurement.

The following describes the recommended test configuration for verifying SAR measurement systems using a flat phantom and a dipole radiating source to determine if the system meets its performance (Note: systems may be verified at 300 MHz until standard dipoles at below 300 MHz are available):

1. A balanced half-wave ($\lambda/2$) dipole should be used as the radiating source. The dipole should be matched to the source impedance of the signal generator. The specific flat phantom should be filled with the required tissue medium at its intended operating frequency. The current distribution along the two arms of the half-wave dipole should be matched to within 5% of each other. The thickness of the dipole must not exceed the separation distance between the outer surfaces of the dipole and the phantom shell by 20%. The construction of the dipole should provide extremely stable operating characteristics at its intended operating frequency to produce repeatable SAR distributions in the specific flat phantom. The recommended dipole specifications described in the latest SCC-34/SC-2 draft on SAR measurement procedures should be used (See Reference [19]).
2. Before the dipole can be used to verify the performance of SAR measurement systems, its radiating characteristics must be fully characterized at the intended operating frequency.
3. The phantom shell (or box) should be constructed of low-loss dielectric material with dielectric constant less than 5 and loss tangent less than 0.05. The material thickness on the side that couples to the dipole (the bottom) must not be thicker than 6.5 mm for use at below 1.0 GHz and 5.0 mm at other frequencies. The variations in shell thickness along regions coupled to the dipole must be less than $\pm$ 0.2 mm. The material for the other sides must not be thicker than 10 mm.
4. The phantom should be at least ¾wavelength long, in the direction parallel to the dipole and ½ wavelength wide, in the direction perpendicular to the dipole. Smaller phantom dimensions may be acceptable if it can be demonstrated that the measured one-gram SAR is within $\pm$ 1% of that produced by a phantom with the required phantom dimensions. The phantom should hold of 15 $\pm$ 0.5 cm of the required tissue medium.
5. The SAR system should be verified using this flat phantom setup, preferably, at the mid-band frequency of a test device, but not more than 100 MHz from this frequency.
6. The dielectric parameters of the tissue medium used to verify the SAR system should be within 5% of those used to obtain the reference data (target SAR values) and should also satisfy the requirements specified in Appendix C.
7. A uniform separation distance of 15.0 mm $\pm$ 0.2 mm should be maintained between the dipole axis and the inside surface of the phantom shell (tissue medium surface) at the dipole feed-point location. At above 1.0 GHz, a separation distance of 10.0 mm $\pm$ 0.2 mm should be used. A precision low-loss dielectric spacer and holding apparatus should be used to maintain dipole positioning repeatability.
8. Each end of the dipole should not deviate by more than 2° from the dipole axis with respect to the dipole feed-point. The sagging of the phantom, due to the weight of the tissue medium, at its closest location to the dipole feed-point should be within 1° from the straight line joining the two points on the phantom that are closest to the ends of the dipole, with respect to each of these points on the phantom.

9. The measured one-gram SAR at the surface of the phantom above the dipole feed-point should be within 10% of the target reference value. The SAR distribution must be identical to the reference data.

10. Since the dielectric properties of the phantom shell and its thickness along regions coupled to the dipole may affect the dipole impedance and the measured SAR values, the target SAR values may only be applicable for the specific combination of dipole and flat phantom configuration. The following table contains a summary of the acceptable range of dipole and phantom separation distances for the dipole dimensions described in P1528.

Dipole Thickness, Flat Phantom Sagging and Separation Distance Requirements

Frequency (MHz)	Dipole Length	Half of Dipole Length	2 ° Dipole Deviation	1 ° Phantom Sagging	Maximum Shell Thickness	Dipole to Tissue Separation	Max. Dipole Dia.	Min. Air Gap	0.5% of 0.6 λ (Sagging)
300	420.0	210.0	7.3	3.67	6.5	15.0	6.4	5.3	3.00
450	288.0	144.0	5.0	2.51	6.5	15.0	6.4	5.3	2.00
835	161.0	80.5	2.8	1.41	6.5	15.0	6.4	5.3	1.08
900	149.0	74.5	2.6	1.30	6.5	15.0	6.4	5.3	1.00
1450	89.1	44.6	1.6	0.78	5.0	10.0	3.8	3.1	0.62
1800	72.0	36.0	1.3	0.63	5.0	10.0	3.8	3.1	0.50
1900	68.0	34.0	1.2	0.59	5.0	10.0	3.8	3.1	0.47
2000	64.5	32.3	1.1	0.56	5.0	10.0	3.8	3.1	0.45
2450	51.8	25.9	0.9	0.45	5.0	10.0	3.8	3.1	0.37
3000	41.5	20.8	0.7	0.36	5.0	10.0	3.8	3.1	0.30

(all dimensions in mm)

TEST SITE AMBIENT CONDITIONS

The RF interference characteristics and ambient conditions at a test facility should be fully characterized to determine their influences on the SAR measurement. RF noise may enter the measurement equipment either by conduction through cables or through radiated fields. These unwanted signals may be rectified by metal-to-metal junctions and semiconductor devices resulting in DC offsets or low frequency signals that cannot be separated from the desired signal detected by the electric field probe. Other conditions such as ground loops and cable conditions that can change the loading conditions of the instrumentation, resulting in noise or oscillation, should also be evaluated regularly. These conditions should be checked daily before SAR measurements are performed. The impact of RF interference on SAR measurements may be verified by performing a SAR measurement with the test device powered off. During compliance measurements, the RF environment should be closely monitored to ensure measurement accuracy. The ambient conditions at a test site, such as the temperature and humidity, may affect the operating stability of the measurement equipment and tissue dielectric parameters. These conditions should also be closely monitored during each SAR measurement to ensure measurement accuracy.

TEST DEVICE OPERATING CONDITIONS

Most handsets and portable transmitters are battery operated. The devices should operate with a fully charged battery for each SAR test. The performance and operating tolerances of a test device should be fully characterized to ensure that it is identical to the production units for meeting compliance.

The output power of the test sample should not be set using test software or test mode sequences to artificially higher or lower output levels than those pre-programmed for production units. Transmitters should be tested at the maximum output level for normal operation within the intended wireless networks, to avoid undesirable performance issues that could lead to SAR changes. The measured SAR values may be scaled to cover certain output tolerances expected among production units during normal use provided the scaled values are within 5% of the measured values. Unless an external DC power adapter or other signal leads are required for the normal operation of a device, such as connecting a headset to the device for body-worn use, they should not be used in the SAR tests.

OUTPUT POWER

In order to determine if device output has been stable during a SAR measurement, conducted power should be measured before and after each SAR test to verify if the output changes are within the tolerance specified for the device. Conducted output power can be measured at a service output port available on most handsets or with an antenna adapter. It is also recommended that the SAR should be checked at a reference location, such as above the ear reference point of the head phantom, immediately before and after each SAR measurement to verify device output and SAR drifts.

BATTERY OPTIONS

Most wireless handsets and portable transmitters may operate with several battery options, such as internally built-in batteries, standard battery packs, a slim pack to save space or a long lasting pack for extended use without frequent recharging. These batteries often have different cell configurations and physical dimensions. In some situations, the battery design may cause some device performance and SAR variations. If the radiated output power of a handset varies with its battery options, the corresponding SAR may also change. An increase in radiated output power could mean higher energy absorption in tissues. However, a reduction in radiated power due to mismatch or increased RF current on the device housing could also lead to higher SAR. For devices that operate linearly, the measured SAR is expected to be proportional to output power. When changes in radiated output are used to estimate whether there is sufficient SAR margin to ensure compliance for all the battery options, the output changes should be linearly proportional to the measured SAR.

DEVICE OPERATING CAPABILITIES

For certain devices that are designed to operate with a substantially low operating duty factor where constant peak output power is neither supported by the hardware nor its battery, SAR compliance should be evaluated at the highest operating duty factor expected during normal use. If a device or its battery is not designed to maintain a constant average output power, SAR should be evaluated with respect to the highest exposure expected based on battery capacity. The measured SAR should typically correspond to the average output power measured before and after the SAR measurement. Testing a device beyond its intended maximum capability and/or capacity may sometimes lead to unpredictable performance conditions that could produce unacceptable test results. These types of test configurations should not be used.

DEVICE OPERATING MODES

If a portable transmitter has built-in test modes that can be used to evaluate the highest exposure

during normal use, SAR should be tested with these test modes. An unmodulated carrier is usually used in AMPS mode test sequences. For TDMA mode, the test mode signal is usually modulated by the time-division duty factor. Testing TDMA devices with an unmodulated CW signal and adjusting the SAR with a duty factor is not recommended. The test mode signal for CDMA, direct-sequence transmitters should correspond to the full vocoder rate and maximum occupied bandwidth of the device. Frequency hopping spread spectrum devices should be tested at fixed frequencies corresponding to the high, middle and low frequency channels to avoid field probe sampling time incompatibility issues. For devices that operate with a transmission band less than 10 MHz, testing at the middle channel is generally sufficient; otherwise, SAR should be tested at the high, middle and low channels.

For devices that operate in multiple modes within the same frequency band, all modes with a maximum source-based time-averaged output within 1.0 dB of the mode with the highest output should be tested to demonstrate compliance. For example, testing SAR in AMPS mode is sufficient for both AMPS and TDMA modes if the time-averaged peak output power for TDMA mode is at least 1.0 dB lower than the AMPS mode. For devices that operate with complex modulations, SAR should be tested with the transmission characteristics corresponding to the highest exposure during normal use. When test mode signals are not available or inappropriate for testing such device, the test signal should be activated through a base-station simulator or equivalent test equipment. The signal power from a base-station simulator must not produce any measurable SAR within the measurement regions of the phantom. The downlink signals at the location of the test device should be about 20-30 dB lower than the uplink signal produced by the test device to avoid measurement errors.

SOURCE-BASED TIME AVERAGING

Duty factors related to device usage, software programming or asynchronous operations that are not inherent to or defined by the transmission protocols of the wireless network providing services to the transmitter generally do not satisfy source-based time averaging requirements. However, for certain devices that are hardware limited by design and are restricted to operate with a maximum RF duty factor, source-based time averaging (See 47 CFR §2.1093) may be considered. When source-based time averaging is required to demonstrate compliance, the device must be tested for SAR compliance with the source-based time-averaging factor included in the test signal. Devices operating with built-in duty factors should not be tested with CW equivalent signals to avoid over-stressed operating conditions, which could lead to unpredictable device performance and produce unacceptable test results. The time averaging criteria used for the Occupational/Controlled exposure environment are not source-based and must not be applied to devices operating in the General Population/Uncontrolled exposure environment (See 47 CFR §§2.1091(d)(1)-(2) and §2.1093(d)(4)-(5)).

RECOMMENDED SAR MEASUREMENT PROCEDURES

The SAR measurement protocol and test procedures should be documented. The calibration traceability of field probes and other supporting equipment should be attached to the SAR reports when such information is requested. In each SAR report, the rationale for evaluating a device with the specific test configurations to demonstrate compliance should be clearly documented. The device operating conditions, such as output power stability (drifts), performance variations (tolerances) or other physical, mechanical and electrical variations, which could introduce unacceptable changes in SAR results must be carefully characterized and considered in the SAR evaluation to determine compliance. The test sample used in a SAR evaluation must be substantially identical (see 47 CFR §2.908) to production units to ensure the test results are acceptable for demonstrating compliance.

For measurements using homogeneous phantoms, the peak SAR locations are usually located at or near the surface of the phantom. The measurement system must search for these peaks and determine the highest SAR averaged over any one gram of tissue medium in the shape of a cube through additional measurements at one or more of these peak locations. Since the field probe is calibrated at the geometric center of its sensor elements, where the measurement point is defined. The highest SAR typically occurring near the surface of a homogeneous phantom cannot be measured by an electric field probe with its sensors located 2-4 mm behind the probe tip. These SAR values must be computed by extrapolating the closest measured points to the surface of the phantom for determining the highest one-gram averaged SAR.

The spatial resolution of a field probe is related to a small volume surrounding the sensors within the probe. The size of this measurement volume is probe dependent. The measured field values are reduced at maximum field location and enhanced at minimum field locations according to this averaging volume. To minimize this type of measurement error, probes with a tip diameter larger than 8.0 mm should not be used (See Reference [19]). In steep gradient or non-uniform fields, higher isotropy error may be expected because the sensors are displaced at the probe tip and from the probe axis. At boundaries of dielectric interfaces, the tip of a probe must be immersed at least 2-3 probe diameters beyond the sensors to measure SAR correctly within the tissue medium. This boundary effect happens at both the air-to-tissue and tissue-to-phantom-surface interface. To minimize such measurement errors, it is also necessary to avoid making measurements with the probe tip in direct contact with the phantom surface. For most probes, a separation of at least half a probe diameter should be maintained between the probe tip and the phantom surface to avoid requiring complex compensation procedures to further reduce probe boundary-effects errors.

PROCEDURES TO SEARCH FOR PEAK SAR LOCATIONS

There are no established procedures on how to search for the peak SAR locations and measure the one-gram averaged SAR in the shape of a cube. Different extrapolation, interpolation and integration algorithms have been used in existing measurement systems to determine the highest one-gram SAR to show compliance. The following procedures should be used to ensure the test results are acceptable.

To search for the peak SAR locations produced by a test device in a head or body phantom, the electric field probe should be scanned along the inside surface of the phantom filled with the required tissue medium. A coarse resolution scan, also know as area scan, is used to determine the approximate peak locations near the surface of the phantom, typically in an area larger than that projected by the transmitter and its antenna. The measurement should be performed at a fixed distance of 8.0 mm or less

from the inside surface of the phantom, with less than ± 1.0 mm variation. Laterally, the measurement points should provide a spatial resolution that is sufficient for the interpolation algorithms used by the SAR measurement system to identify the peak SAR locations to within ± 5.0 mm. This typically requires an area scan resolution of 1-2 cm. The SAR distribution may be plotted to verify the peak SAR locations with respect to the near-field exposure characteristics of the transmitter. All peaks within 2.0 dB (58.5%) of the highest peak identified by the interpolated data should be evaluated with a fine resolution volume scan to determine the highest one-gram averaged SAR (See Reference [19]). A SAR plot of the surface scan region with a sketch or picture of the test device superimposed on the contours should be used to identify the peak SAR locations.

If a peak SAR location is near the edge of a scan region, within 5.0 mm for one-gram SAR and 10.8 mm for 10-gram SAR (half the linear dimensions of the cube), the area scan should be repeated with an expanded scanning region. When SAR is measured along the side wall of a phantom or on curved surfaces where the probe axis is not perpendicular to the phantom surface, probe isotropy and probe boundary-effects errors must be carefully considered for making accurate measurements. For some measurement systems, the E-field probe may have been calibrated or compensated to measure SAR with the probe axis oriented within ± 30° from that normal to the phantom surface. If this is not the case, either the phantom or the field probe should be re-oriented to reduce the measurement error.

PROCEDURES FOR DETERMINING ONE-GRAM AVERAGED SAR

The fine resolution volume scan region, also known as the zoom scan region, should be centered at the peak SAR locations determined by the extrapolated data from the area scan measurements. The number of measurement points required in a zoom scan to provide an accurate one-gram averaged SAR is dependent on the field gradients at the peak SAR location. In smooth gradients, the one-gram averaged SAR can be correctly predicted with only a few measurement points. When steep field gradients exist, many measurement points evenly distributed within the one-gram volume of the tissue medium may be required to correctly predict the volume averaged SAR. The zoom scan region should extend in each direction for at least 1.5 times the linear dimensions of a 1- or 10-gram cube of tissue from each peak. The zoom scan spatial resolution should allow the interpolation algorithms used by the SAR measurement system to compute SAR values on a 2 mm grid with less than 5% error, which typically requires a zoom scan resolution of 5-8 mm (See Reference [19]).

The peak field values near the surface of a homogeneous phantom are usually not measurable because the sensors in a field probe are located at 2-4 mm behind the tip of the probe and the measurement point is defined at the geometric center of the sensors where the calibration is defined. These SAR values must be computed by extrapolating the closest measured points to the surface of the phantom to determine the highest one-gram averaged SAR. The extrapolation algorithm must compensate for the field attenuation based on a series of measurement points along a straight line, extending from the phantom surface through the peak SAR location, in the zoom scan region. The first two measurement points should be inside the one-gram averaging volume. Both points should be less than 1.0 cm from the phantom and liquid surface. The last measurement point should be outside the one-gram averaging volume, typically within the zoom scan region. The SAR value for the last measurement point should be less than 25% of the value measured for first point closest to the phantom surface. The separation distance between adjacent measurement points should be less than 5.0 mm. The extrapolation coefficients should be determined with an appropriate curve-fitting algorithm, such as a 4^{th} order polynomial least-square fit. The same set of coefficients should be used to extrapolate the SAR values that cannot be measured within the zoom scan region (See Reference [19]). The extrapolated SAR values should have the same spatial resolution as the zoom scan measurements.

The interpolated and extrapolated SAR values from the zoom scan measurement are integrated in the shape of a 1- or 10-gram cube, for example, with a trapezoidal algorithm, to determine the highest volume averaged SAR in the zoom scan region. SAR compliance is determined according to the highest 1- or 10-gram SAR measured for all the zoom scans performed for each area scan. The error associated with the extrapolation, interpolation and integration algorithms used in the area and zoom scans should be analyzed and included in the total measurement uncertainty.

MEASUREMENT UNCERTAINTIES

Measurement uncertainties are calculated using the tolerances of the instrumentation used in the measurement, the measurement setup variability, and the technique used to perform the SAR evaluation. The overall uncertainty is calculated in part by identifying uncertainties in the instrumentation chain used in performing each of the procedures in the evaluation. Methods for evaluating and expressing measurement uncertainties can be found in the NIST Technical Note 1297 (TN1297)[24], entitled "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results". Another source of reference is the NIS 81 document, entitled "The Treatment of Uncertainty in EMC [25] published by the National Physical Laboratory of the United Kingdom.

TYPES OF MEASUREMENT UNCERTAINTIES

In general, the components of uncertainty may be categorized according to the method used to evaluate them. The evaluation of uncertainty by the statistical analysis of series of observations is termed a "Type A" evaluation of uncertainty. The evaluation of uncertainty by means other than the statistical analysis of series of observations is termed a "Type B" evaluation of uncertainty. Each component of uncertainty, however evaluated, is represented by an estimated standard deviation termed "standard uncertainty", which equals the positive square root of the estimated variance. Details of Type A and Type B uncertainties are explained in NIST - TN1297[24].

The "combined standard uncertainty" of the measurement result represents the estimated standard deviation of the result. It is obtained by combining the individual standard uncertainties of both "Type A" and "Type B" evaluations using the usual root-sum-squares method of combining standard deviations by taking the positive square root of the estimated variances.

"Expanded uncertainty" is a measure of uncertainty that defines an interval about the measurement result within which the measured value is confidently believed to lie. It is obtained by multiplying the combined standard uncertainty by a "coverage factor". Typically, the coverage factor ranges from two to three. For a normal distribution, if the combined standard uncertainty is a reliable estimate of the standard deviation, a coverage factor of two defines an interval having a level of confidence of approximately 95%. A coverage factor of three defines an interval having a level of confidence greater than 99%.

A detail report of uncertainty should consist of a complete list of the components specifying for

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[24] NIST Technical Note 1297 can be downloaded from the Internet site http://physics.nist.gov/Pubs/guidelines/TN1297/tn1297s.pdf. It can also be order by contacting NIST Calibration Program, Building 820, Room 232, Gaithersburg, MD 20899-0001 or by telephone at (301)-975-2002.

[25] NIS 81 can be ordered by contacting United Kingdom Accreditation Services (UKAS), 21-47 High Street. Feltham, Middlesex TW13 4UN; Tel: +44(0)20 8917 8556, Fax: +44(0)20 8917 8500/8499.

each the method used to obtain its numerical value. The uncertainty in the result of a measurement generally consists of multiple components which may be grouped into either "Type A" or "Type B" uncertainties. There is not always a simple correspondence between the classification of categories "Type A" or "Type B" evaluation of uncertainty and the previously used classification of random and systematic uncertainties in earlier standards. The term "systematic uncertainty" can be misleading and should be avoided.

DETERMINING TOTAL SYSTEM MEASUREMENT UNCERTAINTY

SAR measurement uncertainties are the results of errors due to system instrumentation, field probe response and calibration, and the dielectric parameters of the tissue medium. Uncertainties due to measurement procedures include test device placement, probe positioning procedures, the extrapolation, interpolation and integration algorithms used to determine the one-gram averaged SAR. The error components associated with the total SAR measurement uncertainty for evaluating portable transmitters can be grouped into four main categories - assessment, source, device positioning and phantom uncertainties. Assessment uncertainty is related to the instrumentation and procedures used to assess the spatial peak SAR value in a given SAR distribution for a given setup. Source uncertainty is related to the test and operating parameters of the test device used in an evaluation that produced the SAR distribution. Device positioning uncertainty is related to the changes in SAR due to variations in device test position. Phantom uncertainty describes the variation of a phantom model with respect to the desired model and tissue dielectric parameters defined in the measurement protocol, such as those recommended by SCC-34/SC-2.

The total SAR measurement uncertainty stated in a SAR report quantifies the quality and accuracy of the measurements with respect to the uncertainty of the instrumentation and measurement techniques used for the evaluation. A summary of the uncertainty analysis, including the uncertainty components considered for the SAR measurement should be described in the test report to support compliance. A statement of compliance indicating the maximum measured one-gram averaged SAR with the corresponding expanded measurement uncertainty for each operating mode and operating configuration tested for the device should be included in the SAR report. Expanded uncertainty should be determined for a confidence interval of 95% or higher, which corresponds to a "coverage factor" of two or more.

The measurement uncertainty components that should be considered in a typical SAR evaluation, similar to those recommended by the SCC-34/SC-2, are described below. The SAR equipment manufacturer may have evaluated some of these uncertainty components according to specific measurement conditions, however, additional analyses may be required for the uncertainty components that are dependent on the operating conditions and test configurations of an individual test device. When pre-grant and post-grant samples are tested by the FCC, the Commission will give the applicant or grantee the benefit of the uncertainty for its measurements to establish compliance. A device will not be failed when it is measured above the limit by less than the uncertainty of the Commission's measurement. For this reason, applicants are encouraged to avoid using any equipment or test procedures with large measurement uncertainties to evaluate SAR compliance. In general, the following uncertainty components should be addressed to estimate the total SAR measurement uncertainty (See Reference [19]):

DOCUMENTING THE MEASUREMENT UNCERTAINTY OF SAR EVALUATIONS

A. Assessment Error (measurement system)
   I. Probe Calibration Error
      1. Axial Isotropy Error
      2. Hemispherical Isotropy Error
      3. Spatial Resolution Tolerance
      4. Boundary-effects Error
      5. Linearity Error
      6. Sensitivity Error
      7. Response Time Error
      8. Integration Time Error
   II. Readout Electronics Error
   III. Errors from RF Ambient Conditions
   IV. Probe Positioner Calibration Error (absolute)
   V. Probe Positioning Error with respect to the Phantom Shell
   VI. Errors from the Extrapolation, Interpolation and Integration Algorithms
B. RF Source Error (test device)
   I. Test Sample Output Power Drift Error
   II. SAR Variation due to Performance Tolerance of the Test Sample
   III. SAR Variation due to Tolerance of Production Units
C. Test Device Positioning Error
   I. Test Sample Positioning Error
   II. Device Holder or Positioner Tolerance
D. Phantom and Setup Errors (See Reference [19])
   I. Phantom Production Tolerance (shape and thickness)
   II. Target Liquid Conductivity Tolerance
   III. Measured Liquid Conductivity Error
   IV. Target Liquid Permittivity Tolerance
   V. Measured Liquid Permittivity Error

DOCUMENTING THE MEASUREMENT UNCERTAINTY FOR SAR SYSTEM VERIFICATION

A. Assessment Error (measurement system)

I. Probe Calibration Error
    1. Axial Isotropy Error
    2. Hemispherical Isotropy Error (when applicable)
    3. Spatial Resolution Tolerance
    4. Boundary-effects Error
    5. Linearity Error
    6. Sensitivity Error
    7. Response Time Error
    8. Integration Time Error
II. Readout Electronics Error
III. Errors from RF Ambient Conditions
IV. Probe Positioner Calibration Error (absolute)
V. Probe Positioning Error with respect to the Phantom Shell
VI. Errors from the Extrapolation, Interpolation and Integration Algorithms

B. RF Source Error (typically a half-wave dipole)
    I. Input Power Measurement Error
    II. Output Power Drift Error

C. RF Source Positioning Error
    I. Separation Distance Error from the Source to the Tissue Medium
    II. RF Source (dipole) Holder or Positioner Tolerance

D. Phantom and Setup Error (See Reference [19])
    I. Phantom Construction Tolerance (shape, dimensions and thickness)
    II. Target Liquid Conductivity Tolerance
    III. Measured Liquid Conductivity Error
    IV. Target Liquid Permittivity Tolerance
    V. Measured Liquid Permittivity Error