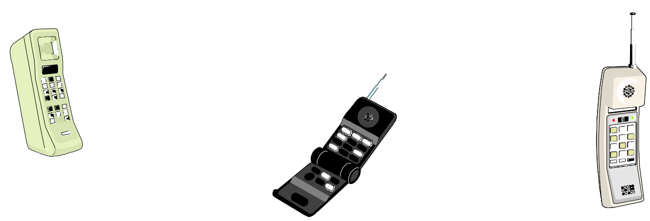
Federal Communications Commission
Office of Engineering & Technology

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
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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

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IMPORTANT NOTE

This supplement 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 following individuals and organizations from outside the FCC reviewed an early discussion paper regarding recommendations for RF exposure evaluation procedures for this supplement to OET Bulletin 65. Their valuable comments and suggestions greatly enhanced the accuracy and usefulness of this document, and their assistance is gratefully acknowledged.

Individual members of Standards Coordinating Committee 34, Subcommittee 2, of the Institute of Electrical and Electronics Engineers (IEEE SCC-34, SC-2).

Contributions from the following present and former FCC staff members are also acknowledged:

Michael Buas, Bruce Franca, Steven Kaminer, Julius Knapp and Lawrence Petak

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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 refined and clarified 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 recently.[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 purpose of this supplement is to provide parties filing applications for equipment authorization with guidance on complying with these new requirements. ***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 new 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. Currently, industry groups and other organizations are working to develop standardized product test procedures to evaluate RF exposure compliance

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[1] See *Report and Order,* in ET Docket 93-62, FCC 96-326, 11 FCC Rcd 15123 (1997). 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, 11 FCC Rcd 15123 (1997). See also *Second Memorandum Opinion and Order and Notice of Proposed Rule Making,* ET Docket 93-62, released on August 25, 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/. Paper copies can be obtained from the Commission’s duplicating contractor, International Transcription Service, Inc., (202) 857-3800.

with MPE and SAR limits.[4] Future revisions of this supplement may be issued, as appropriate.

The 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 compliance. Sometimes it may be necessary to request certain technical data to support test procedures. A list of technical items that are normally used to evaluate SAR compliance is given in Appendix B to provide applicants with guidance on the type of information that is generally applicable for substantiating compliance.[5]

Further information concerning this supplement can be obtained by contacting Kwok Chan of the FCC's Office of Engineering and Technology, (301) 725-1585, ext 217. 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.

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[4] Subcommittee 2 of Standards Coordinating Committee 34 (SCC-34) sponsored by the Institute of Electrical and Electronics Engineers, Inc. (IEEE) was recently formed to develop recommendations with respect to evaluation of 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://stdsbbs.ieee.org/groups/scc34/sc2/.

[5] We have reviewed the techniques currently in use for evaluating SAR and developed a checklist to provide applicants with recommendations on procedures that are generally accepted for evaluating RF exposure due to mobile and portable devices.

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

As noted in OET Bulletin 65, 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. 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.[6]

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 one 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. Transmitting devices designed to be used by consumers or workers that can be easily re-located, such as wireless devices associated with a personal computer and transportable cellular telephones ("bag" phones), are considered to be 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.

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[6] See 47 CFR § 2.1091 and 47 CFR § 2.1093 for details.

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 body of the user or within 20 centimeters of the body of the user under normal operating conditions. This category of devices would include hand-held cellular and PCS telephones that incorporate the radiating antenna into the handpiece and wireless transmitters that are carried next to the body. Portable devices are evaluated with respect to SAR limits for RF exposure.[7] For most portable transmitters used by consumers, the applicable SAR limit is 1.6 watts/kg as averaged over any one gram of tissue, defined as a tissue volume in the shape of a cube.

Exposure Categories

With respect to MPE field strength, power density and SAR evaluation, both the 1992 ANSI/IEEE standard and the NCRP exposure criteria (See References [1] and [19]), 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.

In general, the occupational/controlled exposure limits are applicable to situations in which persons are exposed as a consequence of their employment, 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 an 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.

The general population/uncontrolled exposure limits are applicable to situations in which the general public may be exposed or in which the persons who are exposed as a

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7 Both the ANSI/IEEE and NCRP exposure criteria are based on a determination that potentially harmful biological effects can occur at an SAR level of 4 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 (localized SAR), such as might occur in the head of the user of a hand-held cellular telephone.

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.

SECTION 2
GUIDELINES FOR EVALUATING MOBILE AND PORTABLE DEVICES

The new FCC rules require routine environmental evaluation of RF exposure for certain mobile and portable devices. Unless the device is categorically excluded from routine environmental evaluation, applications to the FCC for equipment authorization must include an affirmative statement indicating that, to the best knowledge of the applicant, the device is in compliance with the FCC-adopted limits for RF exposure. In some cases it may 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.[8]

Unless otherwise categorically excluded, mobile devices 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 watts or more are required to perform routine environmental evaluation for RF exposure prior to equipment authorization or use. 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 the 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).

Portable devices may be evaluated with respect to SAR limits using either measurement or computational methods. Standardized SAR test procedures are being developed by industry groups and other organizations. However, in view of the present lack of standardized procedures and protocols, the FCC may request technical information to support the evaluation procedures used to determine compliance. The technical items listed in Appendix B may provide guidance on the type of information that would normally be appropriate for demonstrating compliance.

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8 See 47 CFR §2.1091 and §2.1093.

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 limits would be applicable for determining compliance.

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. In such cases, RF compliance must be determined with respect to SAR limits when portable configurations are applicable. There are other situations where the operator of a device is in close proximity to the transmitter but nearby persons are normally further away from the device.[9] Under such conditions, the occupational/controlled exposure limits may be applied to the operator provided he or she is aware of the exposure conditions and can exercise control to limit the exposure durations and/or conditions to satisfy compliance. The more restrictive, general population/uncontrolled exposure limits must be applied to nearby persons who have no knowledge of their exposure conditions but are normally further away from the transmitter where the exposure is generally weaker.

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.[10] The 1992 ANSI/IEEE standard (Reference [1]) specifies a minimum separation distance of 20 cm for performing reliable field measurements

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

[10] 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".

to determine adherence to MPE limits.[11] 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 it is determined that the device cannot meet the applicable field strength or power density limits under normal operating conditions, operation and warning instructions and/or prominent warning labels may be used to caution users and nearby persons to maintain a specified distance from the transmitter and to limit their exposure durations and/or usage conditions to ensure compliance. In some cases if the use of warning labels on a transmitter is not desirable, the alternative of performing SAR evaluation with the device at its closest range to persons under normal operating conditions may be used. If the device complies with SAR limits warnings labels are not required.

The field strength and power density limits adopted by the FCC are based on whole-body averaged exposure. They are also based on the assumption that spatially averaged RF field levels relate most accurately to estimating whole-body averaged SAR. This means 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 body does not exceed the limits. In general, evaluations using field strength or power density measurements should be made in all directions surrounding the test device, without the influence of nearby persons and objects, and spatially averaged over the body dimensions of an average person. In certain situations such as vehicle-mounted antennas or other antennas located on metallic surfaces, exposure should be evaluated with the antenna positioned on a metal surface to account for ground reflections which may result in higher localized peak power densities near the antenna. The applicable procedures for RF evaluation with respect to MPE limits are available in OET Bulletin 65 and in ANSI/IEEE C95.3, "IEEE Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields - RF and Microwave" (Reference [2]).

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 compliance with 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. For certain devices which 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, MPE compliance for the mobile configuration is also satisfied when the device is evaluated with SAR limits for the portable configuration.

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[11] 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.

If a handset operates in dual modes, compliance within the same frequency band may be satisfied by testing the worst case operating mode for RF exposure. For example, testing SAR in the AMPS mode is sufficient for both AMPS and TDMA modes provided the peak output power of the TDMA mode does not exceed that transmitted in the AMPS mode. Since SAR evaluations are not applicable for devices operating above 6 GHz (See References [1] and [19]), RF exposure from millimeter wave portable devices operating under Part 15 of the FCC rules must be evaluated with respect to power density limits. At shorter wavelengths above 6 GHz, reliable power density measurements can normally be made at 5 cm or more from the transmitter, instead of the usually recommended 20 cm at lower frequencies. If the normal operating condition of a device is closer than 5 cm from persons, power densities may be computed with numerical techniques to determine compliance, or warning instructions and labels on the device may be used to limit the exposure durations and/or conditions to satisfy compliance.

Techniques for Evaluating Handsets

Handsets used by consumers typically operate over the range of less than 100 mW to several watts, using either analog or digital modulation techniques. For most handsets the antenna radiates within 2-3 cm of the user's head. Even at low power levels, relatively high field strengths would be expected. Near the antenna, the field strength and field distribution are highly dependent on the location, orientation and electromagnetic characteristics of adjacent objects. The head is normally in the reactive near-field region of the antenna where the electromagnetic field is mostly non-propagating. The energy absorbed in the head is mainly due to electric fields induced by the magnetic fields generated by currents flowing along the antenna and chassis of the device. The RF energy is scattered and attenuated as it propagates through the tissues of the head, and maximum energy absorption is expected in the more absorptive high water-content tissues near the surface of the head. To account for near-field effects handsets are evaluated with realistic head models (See References [3] and [13]).

SAR evaluation of low power handsets can be achieved with either electric field measurements inside tissue media or computational methods using tissue models (See References [3], [8], [13] and [23]). 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 tissue conductivity and ρ is the tissue mass density. SAR is a measure of the rate of energy absorption per unit mass at a specific location in the tissue. SAR may be expressed in units such as watts/kg or milliwatts/gm. Under certain circumstances SAR can also be determined from temperature elevation in tissue according to the equation:

$$SAR = C\frac{\delta T}{\delta t} ,$$

where C is the specific heat of tissue, δT is the temperature rise and δt is the exposure duration (See References [2], [3] and [20]). 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.

Test Position of Handsets and Transmitters

Because of near-field effects, small changes in the position of a handset may sometimes result in unexpected changes in energy absorption in the head. The lack of standardized test positions for evaluating handsets can result in difficulties in determining RF compliance with SAR limits. Currently, a number of test facilities are using various handset positioning procedures. The following is a description of one commonly used position for testing portable handsets. First, the device is positioned in a normal operating position with the center of its ear-piece aligned with the location of the ear canal on a simulated head model. With the ear-piece pressed against the head, the next step is to align the vertical center-line of the body of the handset with an imaginary plane consisting of the three lines joining both ears and the tip of the mouth. While maintaining these alignments, the body of the handset is gradually moved towards the cheek until any point on the mouth-piece or keypad is in contact with the cheek. Other test positions representing normal operating positions are also acceptable for evaluating handsets. It is recommended that a picture of the setup position be used to document the test positions, which may be used to demonstrate compliance when technical information is requested. When SAR is evaluated with numerical computation, an illustration of the test models may be used to confirm the test position of a handset.

Whether a handset should be tested on the left or right side of a head phantom is typically determined by the location of the antenna on the handset. In most cases, with the recommended test position of a handset described above, the handset should be placed on the side of the head with the antenna located towards the front of the head. This generally allows a longer portion of the antenna to be in close proximity to the head and minimizes the portion of the antenna which extends beyond or behind the head. If other test positions are used, similar procedures may be applied to determine which side of the head should be used for SAR evaluation. In situations where the antenna is not a traditional monopole or whip configuration and it is obvious that both sides of the head will produce similar results, it is acceptable to evaluate SAR with the handset on either side of the head.

For certain handsets that are designed to operate like a push-to-talk transmitter, but in full duplex mode, the typically used test position is to align the mouth-piece with the mouth of the head phantom with the device in contact with the tip of the nose in an upright position. For devices that are carried next to the body, such as shoulder, waist or chest-worn transmitters, SAR compliance can be evaluated in the appropriate operating position defined by the manufacturer which offers maximum RF energy absorption in the respective regions of the body.[12]

With respect to all possible test positions of typical handsets, if the antenna is retractable, it is necessary to perform SAR evaluations with the antenna in its fully extended and retracted positions to determine compliance. It is not always easy to predict which antenna configuration will result in maximum energy absorption in tissues. This is mostly due to the design and performance of an antenna and its interaction with the chassis while it is extended or retracted. Most handsets generally do not perform well with their antennas partially extended and if such 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, they should be discouraged by providing users with appropriate operating instructions.

Tissue Models for SAR Measurements

The tissue models used for testing handsets must be appropriate for the operating frequency of the device. Body tissues are typically classified according to their 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. The electrical properties of tissues at RF and microwave frequencies are characterized by their permittivity and conductivity at normal body temperatures, about 37°C. These tissue parameters are also temperature sensitive. For high water content tissues, permittivity decreases at a rate of about 0.5%/°C and conductivity increases at about 2%/°C (See Reference [7]). The simulated tissues used in SAR evaluations usually follow similar variations. They are typically formulated with the equivalent tissue properties at 37°C, for room temperatures use, to facilitate SAR evaluation under ambient conditions.

There are two types of formulations for making simulated high water-content tissues such as brain and muscle. One type is an opaque gel consisting of water, salt, polyethylene powder and a gelling agent called TX-151 (See Reference [7]). The other type is a liquid consisting of water, sugar, salt and a compound called HEC which adjusts the viscosity of the liquid (See Reference [11]). The gel is typically used for SAR evaluations with high power applications using thermographic or temperature measurement methods. The liquid material is transparent, it offers additional advantages in setting up and performing measurements by allowing only one type of tissue, that with the highest energy absorption characteristics, to represent worst case conditions. In this case, the liquid tissue material is contained in a shell

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[12] Appropriate operating positions include manufacturer's suggested operating positions and other typical usage positions where maximum RF energy coupling to users or nearby persons are possible.

of the head or other body sections, about 1-3 mm thick, typically molded from fiberglass or other plastic materials with very low RF absorption. Most of these homogenous head models are designed to satisfy compliance by overestimating SAR by about 5-10 % (See Reference [23]). The average tissue properties for brain, skull and muscle given in Appendix C may be used as a guide for developing appropriate phantoms for SAR evaluation. Generally it is difficult to prepare tissue materials with the exact properties. Therefore, it is often desirable to prepare tissue material with somewhat higher conductivity and lower permittivity to avoid underestimating SAR.

The permittivity and conductivity of simulated liquid tissues prepared for SAR evaluation must be measured to ensure that they are appropriate for the operating frequencies of the device (See Reference [10]). These parameters are usually measured periodically or before each SAR evaluation to determine if it is necessary to add appropriate amounts of water to restore the original dielectric properties, as a result of evaporation. Currently, tissue properties are usually characterized either with the coaxial probe or slotted line technique. The coaxial probe technique measures the reflection coefficient of the tissue material with a network analyzer and uses such data to compute the tissue properties (See References [6] and [12]). With slotted line measurements, a coaxial line is filled with the tissue material and voltage standing wave measurements are made inside the slotted line through a tiny slot along the line. Slotted line measurements are more accurate, but coaxial probe techniques are preferred because it is more convenient.

Most test facilities use separate head models for testing handsets on the left and right side of the head. While some models include ears and others do not, a few have also used a spacer to represent the ear. For head models that do not include ears, it is argued that the handset is placed closer to the head, and therefore, higher energy absorption is expected in the head. However, this may be dependent on the antenna design of the phone and the current distribution in the antenna and chassis of the handset. Since there is no available published data on the effects of the ear on SAR evaluation, the FCC will accept both types of head models at the present time. However, the preferred head model for testing normal handset operations is one that includes collapsed ears as they are typically compressed by the ear-piece of a handset.

The effect of a hand holding a handset has also been an issue with respect to obtaining accurate SAR evaluation. In typical operating positions, most handsets are held by the users with their fingers on the side of the device which typically provides minimal or no contact between the back of the handset and the user’s palm. Therefore, most test facilities evaluate handsets by placing the device in a non-metallic holder, allowing the handset to be positioned precisely against the head. Since hands normally absorb energy radiated from the handset, energy absorption in the head may be reduced. If a handset inecevaluated without a hand, more energy is absorbed in the head which may represent a worst case. Recent reports indicate that hands may introduce up to 10% changes in SAR. However, there have been no detailed investigations on the effects of the hand on SAR levels in the head. It in probably more important to maintain precise control of the test position of a handset. Also, a generic hand model may not always hold every handset in a consistent manner. Although we recommend that handsets be tested without a hand, at the present time we will accept SAR evaluations with a handset placed in an appropriately simulated hand to represent normal operating conditions.

SAR Measurement System Requirements and Descriptions

The measurement system used for evaluating SAR usually consists of a small diameter isotropic electric field probe, a multiple axis probe positioning system, the instrumentation and computer equipment for controlling the probe and making the measurements (See References [3], [16], [17] and [23]). Certain supporting equipment may be required for calibrating the electric field probe, validating the measurement system and characterizing the tissue material.

Several types of electric field probes are currently used for SAR measurements. Typically probes are on the order of 3-5 mm in diameter and about 25-30 cm long. They use 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 detectors, consisting of the dipole and diode, are deposited and bonded on a substrate that offers minimal perturbation to the incident field. The substrates may be arranged in several configurations, such as I-beam, triangular or other designs to allow each detector to measure the field component parallel to its axis and with minimal effects from the other two. High resistance lines are used along the length of the probe to prevent RF pickup which may lead to inaccurate readings at the sensor. The other end of the probe is usually fastened to a custom holder on the robot arm of a positioning system where the leads are connected through EMI-shielded leads to the instrumentation amplifiers. The amplified signals are processed with precision A/D converters or voltmeters connected to the computer.

The electric field probes are usually calibrated together with the system instrumentation. The sensors of the probes are designed to operate as true square-law detectors where the output voltage is proportional to the square of the electric field. The probes must be calibrated in the type of tissue media formulated for the test frequency and at that frequency. 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 output voltages of the detectors to SAR. In other cases, a one step approach is used where a waveguide is filled with the appropriate tissue material and the output voltages of the probe are compared against analytically calculated field values. For other systems, probes have also been calibrated using computational methods to simulate an experimental exposure condition where the output voltages of a probe are compared against the computed field strengths.

For two-step calibrations, the probe is normally calibrated in the uniform fields of a TEM cell followed by in-tissue calibration with temperature methods using rectangular tissue models irradiated with a dipole. Calibration factors for different tissue types are different, therefore, the appropriate tissue material must be used. Before each SAR measurement, the probes are re-calibrated in air (using a TEM cell) to determine if their previous calibrations have changed. Any change in this calibration factor will require the probe to be re-calibrated in the tissue media, which is normally a more time-consuming process. The probes for commercial SAR systems are usually sent to the manufacturers for periodic calibration at fixed frequencies using standard exposure setups. Until there is more data on whether a given calibration technique is the more desirable or most accurate, all technically supportable calibration methods are considered acceptable. However, if technical data is requested to support the test methods the calibration procedures should be explained.

Besides probe calibration, the entire measurement system is normally validated before each SAR measurement, using established procedures, by comparing against some known results. Some facilities use a cellular handset as a reference and perform an SAR test to determine if previous measurements can be achieved within a certain margin of error. Others have used spherical or rectangular phantoms irradiated by a dipole to perform similar measurements. These procedures are highly recommended for confirming system accuracy before making compliance measurements and to determine if a system is performing as expected.

Device Test Conditions for SAR Measurements

Most handsets and portable transmitters are battery operated. During SAR evaluation, the devices are operated at full power which may drain a fully charged battery in less than half an hour. Depending on the measurement resolution and the electric field scanning procedures, it may take anywhere from 20 minutes to an hour or more to complete an SAR test. Therefore, it is important to start each test with a new and fully charged battery. In order to confirm if a device is operating at full power, either conducted or radiated power measurements are normally used to verify such conditions both before and after the SAR test. The use of external DC power adapters or signal leads should be avoided because they may perturb the field and change the exposure conditions. Furthermore, such conditions do not generally reflect actual usage conditions.

Most handsets have built-in test modes for basic performance evaluations. These test modes typically provide either a CW signal or a test signal representative of the transmission technology. Such test signals offer a consistent means for testing SAR and have been used in most situations. Therefore, test modes are preferred. If a test mode signal is not available or inappropriate for testing a handset, the actual transmission may be activated through a base station simulator.

The performance of a handset may vary when operated on various frequencies within its transmission band. In some cases where helical antennas are used, the intended peak performance at mid-band frequencies may shift because of tissue loading from the head. Since this is dependent on the design of the individual device, it is recommended that a handset be configured in a normal usage position, either with an actual user or a head phantom, to determine the actual peak performance frequency of the device. This can usually be verified with voltage standing wave ratio (VSWR) measurements, and SAR evaluation may be performed at the frequency with the lowest VSWR. There are also some test facilities that prefer to test handsets at the high, middle and low frequencies of the transmission band. When VSWR measurements are not available or are inappropriate for the test conditions, it may be necessary to evaluate certain handsets at the high, middle and low frequencies.

When SAR evaluation is performed with a built-in test signal that varies with a clearly defined peak duty factor, source-based time averaging may be applied. For example, duty factors of 1/3 and 1/8 can be applied to handsets based on the cellular TDMA (IS-136) or GSM standards, respectively, tested with a CW signal. Time averaging is not applicable if the actual signal with the appropriate duty factor is used in the SAR evaluation. Source-based time averaging generally does not apply to CDMA signals 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 - Field Scanning

A head model is usually placed on its side which allows a handset to be placed underneath the head to facilitate field measurements. The field probe is inserted into the liquid from above and measurements can then be made on the inside surface of the head next to the phone (See References [3] and [23]). The procedures established at most test facilities for evaluating handsets with SAR measurements usually start with a coarse measurement at 1-2 cm resolution where the electric field probe is scanned throughout the entire region of tissues next to the handset and its antenna. This provides an SAR distribution near the surface of the phantom, closest to the phone, where the approximate location of the peak SAR can be identified. A smaller region about 1-3 cm long in each direction, centered around the peak SAR location, is then scanned with a 1-3 mm finer resolution to determine the one-gram average SAR.

The fine resolution scan may take 20 minutes to more than an hour to complete. In some cases, a pause in the testing may be necessary in order to replace batteries in the device to maintain the test signal level. The measurements obtained from this fine resolution scan are averaged over a 1 cm^3 volume in the shape of a cube to determine the one-gram average SAR. The average density of most high water-content tissues is about 1020-1040 kg/m^3 (See Reference [14]) which requires the tissue volume to be about 1 cm long on each side. The number of measurement points required in the fine scan to provide accurate one-gram average SAR is dependent on the field gradients at the peak SAR location. In smooth gradients, the one-gram average SAR can be correctly predicted with only a few measurement points. When steep field gradients exist, many measurement points evenly distributed within a cubic centimeter of the tissue material may be required to correctly predict the one-gram average SAR. To overcome this problem, some test sites have applied a curve-fitting process to the measured data to allow more points to be used in the average. There is no published data on appropriate techniques for determining the one-gram average SAR and different methods have been accepted for computing this value. When technical data is requested, a description of the procedures used to compute the one-gram average should be included.

The measurements provided by electric field probe normally do not correspond to the location at the tip of a probe because the detectors are located behind the tip. For homogeneous phantoms, the peak field values are at the surface of the phantom, but the detectors of the probe are generally 2.5-5.0 mm behind the tip of the probe. Therefore the field measurements must be extrapolated to the surface of the phantom to compensate for field attenuation introduced by this offset distance. This can be done by taking a number of measurement points in a straight line perpendicular to the phantom surface at the peak SAR location and applying a curve-fitting process for the extrapolation.

SAR Computation Guidelines and Descriptions

The discussions in previous sections on portable handsets are mostly related to SAR evaluation with measurement methods. The general procedures described in the SAR measurement sections for handset positioning, device test conditions and tissue model requirements for the head, hands and ears are also applicable for evaluating SAR with computational methods. The computational procedures that are typically used to evaluate portable handsets are described in the following.

Currently, the finite-difference time-domain (FDTD) algorithm is the most widely accepted computational method for SAR modeling (See References [8], [13], [15], [21], [24], [25] and [26]). This method adapts very well to the tissue models which are usually derived from MRI or CT scans (See Reference [8]), such as those available from the visible man project.[13] FDTD offers great flexibility in modeling the inhomogeneous structures of anatomical tissues and organs. The FDTD method 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 early applications of SAR modeling with FDTD computations, results were verified with rectangular and spherical dielectric models exposed in the near-field with dipoles or monopoles positioned over a metal box to verify the technique's applicability for evaluating handsets. Currently, different techniques have been developed to model the exact shape and size of typical handsets (See References [15], [22] and [24]), including a handset's display and keypad, through computer aid design (CAD) data provided by certain manufacturers. While this effort is continuing, concern has been expressed over the validity of handset

[13] Contact National Library of Medicine for more information on how to obtain images in the database.

models when the effects of inner electronics and complex chassis or shielding structures are not considered as part of the modeling.

Computing resources, mainly memory requirements, are of concern for most numerical simulations. The memory requirement for FDTD is directly related to the resolution of the tissue and handset models. The computational algorithms used to implement the FDTD method may vary, mostly due to certain optimization techniques used to improve modeling accuracy and efficiency. In order to satisfy the requirements of wave propagation in infinite free space, numerical absorbing boundaries are applied to truncate the computation domain to simulate reflectionless propagation through such boundaries. There are several types of absorbing boundary conditions (ABC) that are applicable for the FDTD technique, including the Mur, Liao, retarded-time and perfectly-matched-layers (See References [4], [5] and [18]). The performance of these ABCs may vary, but their effects on SAR in highly absorptive dielectric media, such as body tissues, are normally insignificant.

An excitation source, typically a sinusoidal waveform, is introduced at the antenna feed-point of the handset which is allowed to propagate and interact with objects in the computational domain. The FDTD algorithm allows the fields to propagate in both space and time until a sinusoidal steady state is reached where the total field at selected tissue locations can be computed to determine SAR. In order to maintain numerical stability in the computational algorithms, there is a basic requirement called the Courant condition which provides the minimum relationship for selecting the time and spatial resolutions used in the computation (See Reference [25]). These parameters generally determine how fast the algorithm can progress and the amount of errors resulting from the numerical simulation.

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 tissues are digitized and represented by their respective dielectric properties, permittivity and conductivity. In order to accurately compute SAR, the dielectric properties of tissues must be available for performing the computation. The list of tissue dielectric properties compiled by Dr. Camelia Gabriel constitutes the most widely accepted database for this information and is recommended (Reference [10]). Similar tissue dielectric properties derived from this database 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/.

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. Similar benchmark validation procedures are also used to confirm the validity of head and tissue models. 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 request technical information on benchmark validation procedures to substantiate compliance.

Special FDTD techniques have been concurrently developed to provide more accurate and efficient methods for modeling handsets and antennas. It has been recently shown by researchers that the exact dimensions of an antenna and its location on the handset must be precisely modeled in order to obtain accurate results. Since the inner electronics of a handset are typically not modeled, it may be necessary to verify such handset models with antenna gain or field-pattern data that are generally available during product development.

Currently there are no standard procedures on how many or which electric field components should be used to determine the total electric field at a point inside the tissue. Typically, the total field is computed from the averages of 3-12 field components located either at or around a grid point in the tissue model, which may introduce local variations in SAR. Such variations are usually dependent on local field gradients. There are also no standard methods for computing the one-gram average SAR and various methods have been used. At tissue interfaces or on an irregular surface of the phantom, the local field values are computed from field components in different tissue types. Computing the one-gram SAR in the shape of a one-gram cube can be difficult. Until standardized procedures are available, it may be necessary to describe such procedures to support compliance when technical data is requested.

The sinusoidal or pulsed signal used to excite the antenna of a handset typically consists of an arbitrary amplitude. The final results should be normalized to the appropriate output power of the actual device. It is recommended that the results should be normalized to the maximum output power measured by the manufacturer using methods similar to those described in the measurement sections of this supplement. When technical data is requested, the list of items given in Appendix B may be used for guidance as to the type of information that is appropriate for demonstrating compliance.

Measurement and Computational Uncertainties

Although many 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 that do not produce repeatable results should not be used to test devices for FCC compliance.

Measurement uncertainties are the results of errors due to system instrumentation, field probe response and calibration, tissue dielectric property usage and characterization. Uncertainties due to measurement procedures include test device placement, probe positioning, procedures used to extrapolate measurements to the surface of a phantom and methods used to determine one-gram SAR averages. For numerical methods, computational uncertainties may be the result of errors due to implementation of numerical algorithms, benchmark validation procedures, procedures for computing SAR from field components and methods used to determine one-gram SAR averages. Uncertainties due to test device and tissue modeling may be due to test-device modeling techniques, tissue model implementation, assignment of tissue dielectric properties and modeling resolution. Information on such uncertainties is relevant to SAR evaluation and may be requested in order to support compliance with SAR exposure limits.

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.[14] 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 (See Reference [9]). In most cases, the "worst case" distance at which an MPE limit is met for mobile devices can be estimated according to the field strength or power density produced by an isotropic source with radiated power equivalent to that transmitted by the device as discussed in OET Bulletin 65.

If a transmitter is designed to operate next to the body of its user or at close proximity to persons, an 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 of alerting users to the potential for RF exposure. 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 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.

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[14] 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.

For transmitters that use external or remote antennas for indoor or outdoor operations, appropriate installation procedures should be provided to the installer so that a specified distance will be maintained between the transmitter and 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 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 with MPE limits.

As is explained in the FCC's *Report and Order* in ET Docket 96-8 (FCC 97-114), 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.[15] 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. 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.

Methods to Ensure Compliance for Spread Spectrum Transmitters

The examples shown in the following table (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 conditions and exposure environments. 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 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.

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15 See *Report and Order*, ET Docket 96-8, FCC 97-114, Section 9, "RF Exposure Hazards".

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

Transmitter or Device Type[16]	EIRP[17]	Applicable Methods to Ensure Compliance
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	These transmitters generally are not expected to exceed MPE limits (0.61 mW/cm^2 at 915 MHz and 1.0 mW/cm^2 at 2450 MHz); special instructions or warnings are normally not necessary to ensure compliance.
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 EIRP (200 mW at 2450 MHz), the potential for exceeding MPE and/or SAR limits is dependent on the design of the antenna 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, it may be necessary to demonstrate compliance with respect to SAR limits; especially when the output is greater than 400-500 mW EIRP.

[16] The applicable methods for ensuring compliance are divided into transmitter groups according to their output power levels.

[17] The EIRP indicated in the above table is the product of the maximum output power available at the antenna terminal of the transmitter, the gain of the antenna and the applicable duty factor described in this section. It is important that the normal usage conditions for the particular transmitter/antenna must be defined in order for the above procedures to be applicable.

Transmitters using monopole or dipole type antennas as an 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.	> 0.3 W at 915 MHz or > 0.2 W at 2450 MHz	Operating and warning instructions in the operator's manual indicating the minimal separation distance between the antenna and nearby persons in order to avoid extended periods of exposure at closer than this distance that might exceed MPE limits. 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, MPE or 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 (1.5 W ERP) ≤ 2.5 W at 915 MHz or ≤ 4 W at 2450 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. 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 (1.5 W ERP)	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 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. 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.

REFERENCES

[1] American National Standards Institute (ANSI), "Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz," ANSI/IEEE C95.1-1992 (previously issued as IEEE C95.1-1991). Copyright 1992 by the Institute of Electrical and Electronics Engineers, Inc. (IEEE), New York, N.Y. 10017. For copies contact the IEEE: 1-800-678-4333 or 1-908-981-1393.

[2] American National Standards Institute (ANSI), "Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields - RF and Microwave." ANSI/IEEE C95.3-1992. Copyright 1992, The Institute of Electrical and Electronics Engineers, Inc. (IEEE), New York, NY 10017. For copies contact the IEEE: 1-800-678-4333 or 1-908-981-1393.

[3] Balzano, Q., O. Garay, and T. Manning, "Electromagnetic energy exposure of simulated users of portable cellular telephones," IEEE Transactions on Vehicular Technology, Vol. 44 (3), pp. 390-403, 1995.

[4] Berenger, J., "A Perfectly Matched Layer for the Absorption of Electromagnetic Waves," Journal of Computational Physics, 114, pp. 185-200, 1994.

[5] Berntsen, S. and S. Hornsleth, "Retarded Time Absorbing Boundary Conditions," IEEE Transactions on Antenna and Propagation, 42(8), pp. 1059-1064, August 1994.

[6] Burdette, E., F. Cain and J. Seals, "In vivo Probe Measurement Technique for Determining Dielectric Properties at VHF Through Microwave Frequencies," IEEE Transactions on Microwave Theory and Techniques, 8(4), pp. 414-427, April 1980.

[7] Chou, C., G. Chen, A. Guy and K. Luk, "Formulas for Preparing Phantom Muscle Tissue at Various Radiofrequencies," Bioelectromagnetics, 5, pp. 435-441, 1984.

[8] Dimbylow, P., and S. Mann, "SAR Calculations in an Anatomically Realistic Model of the Head for Mobile Communication Transceivers at 900 MHz and 1.8 GHz," Phys. Med. Biol., 39(12), pp. 1537-1553, 1994.

[9] Federal Communications Commission (FCC), "Amendment of Part 2 and Part 15 of the Commission's Rules Regarding Spread Spectrum Transmitters", *Report and Order*, ET Docket 96-8, FCC 97-114, adopted April 10, 1997.

[10] Gabriel, C., "Compilation of the Dielectric Properties of Body Tissues at RF and Microwave Frequencies," Brooks Air Force Technical Report AL/OE-TR-1996-0037, 1996.

[11] Hartsgrove, G., A. Kraszewski and a. Surowiec, "Simulated Biological Materials for electromagnetic Radiation Absorption Studies," Bioelectromagnetics, 8, pp. 29-36, 1987.

[12] Hewlett-Packard Company, "Basics of Measuring the Dielectric Properties of materials," Application Note 1217-1. For copies contact Hewlett-Packard at 1-800-452-4844.

[13] Gandhi, O., G. Lazzi and C. Furse, "EM Absorption in the Human Head Neck for Mobile Telephones at 835 and 1900 MHz," IEEE Trans. on Microwave Theory and Techniques, 44 (10), pp. 1884-1897, October 1996.

[14] International Commission on Radiological Protection No. 23, "Report of the Task Group on Reference Man," Pergamon Press, October 1974.

[15] Kunz, K. and R. Luebbers, "The finite Difference time Domain Method for Electromagnetics," CRC Press, 1993

[16] Kuster, N., R. Kastle, and T. Schmid, "Dosimetric Evaluation of Handheld Mobile Communications Equipment with Known Precision," IEICE Transactions, E80-A(5), pp. 1-8, May 1997.

[17] Meier, K., M. Burkhardt, T. Schmid and N. Kuster, "Broadband Calibration of E-field Probes in Lossy Media," IEEE Transactions on Microwave Theory and Techniques, 44(10), pp. 1954-1962, October 1996.

[18] Mur, G., "Absorbing Boundary Conditions for the Finite-Difference Approximation of the time-Domain electromagnetic Field Equations," IEEE Transactions on Electromagnetic Compatibility, 23(4), pp. 377-382, November 1981.

[19] National Council on Radiation Protection and Measurements (NCRP), "Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields," NCRP Report No. 86, 1986. Copyright NCRP, Bethesda, MD, 20814, USA. For copies contact NCRP Publications: 1-800-229-2652.

[20] National Council on Radiation Protection and Measurements (NCRP), "A Practical Guide to the Determination of Human Exposure to Radiofrequency Fields," NCRP Report No. 119, 1993. Copyright NCRP, Bethesda, MD 20814. For copies contact: NCRP Publications at: 1-800-229-2652.

[21] Okoniewski, M. and M. Stuchly, "A Study of the Handset Antenna and Human Body Interaction," IEEE Transactions on Microwave Theory and Techniques, 4(10), pp. 1855-1864, October 1996.

[22] Okoniewski, M., E. Okoniewski and M. Stuchly, "Three-Dimensional Subgridding Algorithm for FDTD," IEEE Transactions on Antenna and Propagation, 45(3), pp. 422-429, March 1997.

[23] Schmid, T., O. Egger and N. Kuster, "Automated E-Field Scanning System for Dosimetric Assessments," IEEE Trans. Microwave Theory and Techniques, 44(1): 105-113, January 1996.

[24] Taflove, A., "Computational Electrodymanics - The Finite-Difference Time-Domain Method," Artech House, 1995.

[25] Taflove, A. "Review of the Formulation and Applications of the Finite-Difference Time-Domain Method for Numerical Modeling of Electromagnetic Wave Interactions with Arbitrary Structures," Wave Motion, 10, pp. 547-582, 1988.

[26] Yee, K., "Numerical Solution of Initial Boundary Value Problems Involving Maxwell's Equations in Isotropic Media," IEEE Transactions on Antenna and propagation, 14(3), pp. 302-307, May 1966.

APPENDIX A
FCC EXPOSURE CRITERIA
(Field Strength, Power Density and SAR)

Note: For further information and details on these limits see OET Bulletin 65

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.

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 g 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 g of tissue defined as a tissue volume in the shape of a cube.

NOTE 3: At frequencies above 6 GHz, SAR limits are not applicable and MPE limits for field strength and power density should be applied.

APPENDIX B
LIST OF TECHNICAL ITEMS FOR SAR EVALUATIONS

This list may be helpful for applicants in evaluating compliance with SAR limits for exposure to RF emissions. The information on this list is generally necessary in order to evaluate SAR test results and to determine RF exposure compliance.

Information for Test Device Setup and System Uncertainties

General Information:

- FCC ID __________________________
- device category: mobile or portable
- RF exposure environment: controlled or uncontrolled
- test method: measurement or computation
- affirmative statement indicating compliance with FCC-adopted limits

Antenna Description:

- antenna type: monopole, dipole, helix, patch or others
- antenna location on device: left, right, top, bottom, front, back etc.
- antenna dimensions: length, diameter, or width (patch antennas)
- antenna configuration: fixed, retractable, external or others
- antenna gain (dBi)

Test Signal and Output Power:

- test signal source: test mode, base station simulator or others
- signal modulation: CW, AMPS, TDMA, GSM, CDMA, Spread Spectrum or others
- output power measurement conditions: free space (radiated), SAR test configuration or conducted
- output power measured with: power meter, base station simulator, spectrum analyzer or others
- output power measured at ________ MHz, ___ % duty factor
- max. power measured before SAR with fully charged battery: ________ mW (EIRP, ERP or net output)
- max. power measured after SAR: ________ mW, after ______ minutes of SAR test, ___ battery changes (max. power after SAR is only applicable to RF exposure evaluation with SAR measurements)

Test Position and Condition:

- handset position: setup description, picture, illustration etc.
  center of ear piece aligned with ear canal of phantom,
  ear piece against phantom,
  in alignment with 3-point (ears & mouth) plane of reference
  normal usage position, antenna orientation and distance from phantom
  antenna extended or retracted
  left or right side of head, max. RF coupling condition
  tested with or without hand
- CENELEC positions: 80° or other positions
- other positions: setup description, picture, illustration etc.

Measurement or Computation Uncertainty:

- description of measurement or computational uncertainties
- individual sub-system uncertainties
- estimated total system uncertainties (%)

Information for SAR Measurement

System and Phantom Descriptions:

. description of measurement system & performance
. description of positioning system & performance
. overall system performance verification procedures
. RF susceptibility verification
. system verification results
. description of phantom - shape, size and complexity
. phantom with ear, without ear or using spacer
. phantom shell thickness at ear, cheek or other locations

Tissue Properties:

. types of tissues used
. composition of ingredients
. description of methods used to characterize tissue materials and ambient conditions
. dielectric constants
. conductivities (S/m)
. tissue densities (kg/m^3)

Electric Field Probe Descriptions and Calibration:

. E-field probe description & performance, probe type and serial no.
. E-field probe calibration procedures
. media and frequency for E-field probe calibration
. probe offset (mm), isotropic response
. E-field probe calibration factor
. calibration or expiration date

SAR Measurement Parameters, Procedures and Results:

. SAR test frequencies
. description of coarse scan region, size _____ x _____ x _____cm^3, scanning resolution ______ mm
. description of fine scan region, size _____ x _____ x _____cm^3, scanning resolution ______ mm
. source-based time averaging applied to SAR (if tested with CW)
. SAR distribution of worst case test results (frequency, antenna position - fixed, extended or retracted)
. identification of peak SAR location
. highest peak SAR (W/kg) and its test configuration
. 1-gram averaged peak SAR (W/kg)
. other SAR test positions
. 1-gram SAR for other positions
. description of 1-gram average procedures, highest SAR gradient at peak location (W/kg/mm)
. description of procedures used to extrapolate SAR to phantom surface

Information for SAR Computation

Basic FDTD Parameter Descriptions:

- domain size ____ x ____ x ____, cell size ____ x ____ x ____ mm^3, time step _____ x 10^{-12} sec
- ABC type, layers or other parameters
- source excitation: CW, pulse or others
- total time steps or cycles
- description of methods used to determine sinusoidal steady state conditions
- description of special FDTD techniques used
- benchmark descriptions of FDTD techniques & results

Tissue Model Descriptions:

- source of head or tissue model
- model resolution _____ x _____ x ____ mm^3
- description of model shape, size & complexity
- description of tissue types
- tissue dielectric properties
- benchmark descriptions & results

Test Device Model Descriptions:

- overall description of device or handset modeling
- descriptions of antenna modeling
- descriptions of modeling for case, display, keypad, shields, battery & packaging etc.
- verification of test device modeling and methods used

SAR Computation Parameters, Procedures and Results:

- power level for normalizing SAR, (determined by test lab or manufacturer and frequency)
- description and illustration of test configuration
- source-based time averaging applied to SAR if applicable
- SAR distribution of worst case results (frequency, antenna position: fixed or retracted)
- identification of peak SAR location
- highest peak SAR (W/kg) and test configuration
- 1-gram averaged peak SAR (W/kg)
- other SAR test positions
- 1-gram SAR for other positions
- description of 1-gram average procedures, highest SAR gradient at peak location (W/kg/mm)

APPENDIX C
TISSUE DIELECTRIC PROPERTY DATA

The average tissue properties provided in this Appendix are commonly used to prepare measurement phantoms for testing handsets at cellular, PCS, U-NII and spread spectrum frequencies (See References [7], [10] and [11]). However, other parameters are possible and may be substituted if appropriate. Dielectric properties of these tissues at other frequencies or for other tissue types generally used in numerical computation methods 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/[18].

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[18] 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.

Average Tissue Properties for Brain, Skull and Muscle

Tissue	ε_r	σ (S/m)	ρ (kg/m^3)
835 MHz			
Brain	46.1	0.74	1030.0
Skull	16.7	0.23	1850.0
Muscle	56.1	0.95	1040.0
915 MHz			
Brain	45.7	0.77	1030.0
Skull	16.6	0.24	1850.0
Muscle	55.9	0.98	1040.0
1900 MHz			
Brain	43.4	1.20	1030.0
Skull	15.5	0.46	1850.0
Muscle	54.3	1.45	1040.0
2450 MHz			
Brain	42.5	1.51	1030.0
Skull	15.0	0.60	1850.0
Muscle	53.6	1.81	1040.0
5725 MHz			
Brain	38.4	4.17	1030.0
Skull	12.6	1.63	1850.0
Muscle	49.1	5.11	1040.0

(ε_r = relative permittivity, σ = conductivity and ρ = mass density)