
Spectrum Sciences Institute RF Dosimetry Research Board



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SAR Measurements Requirements

SSI/DRB-TP-D01-030



DRAFT

Prepared jointly with:

APREL
Laboratories
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- NOTICE -

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1.0 INTRODUCTION

In July 1997, Health Canada distributed a “Proposed Revision of Safety Code 6” amending its guidelines for evaluating the environmental effects of radio frequency (RF) electromagnetic fields. One of the areas discussed in Safety Code 6, and which Industry Canada is implementing, is compliance with the limits for safe exposure to RF emissions due to mobile and portable devices such as non-fixed wireless transmitters and hand-held cellular telephones.

The new Health Canada guidelines differentiate between portable and mobile devices according to their proximity to exposed persons. For portable devices, RF evaluation must be based on specific absorption rate (SAR) limits. Human exposure to RF emissions from mobile devices 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. The purpose of this document is to provide parties filing applications for equipment authorization with guidance on complying with the new SAR requirements. Currently, industry groups and other organizations are working to develop standardized product test procedures to evaluate RF exposure compliance with MPE and SAR limits.¹ Future revisions of this document may be issued, as appropriate.

The Industry Canada 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 Health Canada 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 will be developed to provide applicants with guidance on the type of information that is generally applicable for substantiating compliance.

Further information concerning this document can be obtained by contacting the Spectrum Sciences Institute, (613) 820-6471 or e-mail to inform@spectrum-sciences.org

¹ 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/>.



The following documents for part of this requirement for SAR measurements:

Phantom Design Requirements	SSI/DRB-TP-D01-031
Probe Design and Calibration Requirements	SSI/DRB-TP-D01-032
Tissue Recipe and Calibration Requirements	SSI/DRB-TP-D01-033
Positioning and Scanning Requirements	SSI/DRB-TP-D01-034
Uncertainty assessment requirements	SSI/DRB-TP-D01-035

2.0 RULES FOR COMPLIANCE OF MOBILE AND PORTABLE DEVICES

Mobile and portable transmitting devices that operate in the Cellular Radiotelephone Services, 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 Services are subject to routine environmental evaluation for RF exposure prior to equipment authorization or use. Unlicensed PCS, U-NII and millimeter wave devices authorized by Industry Canada rules are also subject to routine environmental evaluation for RF exposure prior to equipment authorization or use. All of the above devices are covered by their respective Radio Specification Standards (RSS series).

2.1 Mobile Devices

For the 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 MPE. Mobile devices may also be evaluated with



respect to the SAR limits given 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.

Detailed SAR limits are given in the Safety Code 6 (draft). The most stringent are limits for general population and they include in section 2.3 below. SAR limits for general population are the base for certification for the SAR.

All RF handheld communication devices operating at the distance of less than 200 mm from human body have to be certified to these requirements for non-ionizing radiation safety. Certification should be based on measurements of SAR, unless a device is specifically exempt and shown to be safe by computations according to allowance for computational certification (see Section 2.5 of this report).

- General - spatial peak SAR not exceeding 1.6 W/kg averaged over 1 gram of tissue defined as a tissue volume in shape of a cube
- Hands, wrist, feet, ankles - spatial peak SAR not exceeding 4 W/kg averaged over 10 grams of tissue defined as a tissue volume in shape of a cube
- Eye - peak SAR not exceeding 0.2 W/kg averaged over eye volume

2.2 Portable Devices

For the 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 handset and wireless transmitters that are carried next to the body. Portable devices are evaluated with respect to SAR limits for RF exposure.² 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.

² Both the Health Canada exposure criteria are based on a determination that potentially harmful biological effects can occur at a 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.



2.3 Exposure Categories

With respect to SAR evaluation, the 1997 Health Canada exposure criteria, upon which the Industry Canada 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 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.



3.0 PROCEDURES FOR EVALUATING MOBILE AND PORTABLE DEVICES

The Industry Canada standard requires routine environmental evaluation of RF exposure for certain mobile and portable devices. Unless the device is categorically excluded from routine environmental evaluation, applications to Industry Canada for equipment authorization must include an affirmative statement indicating that, to the best knowledge of the applicant, the device is in compliance with the Industry Canada-adopted limits for RF exposure. The standard may require applicants to provide technical data to substantiate compliance.

Portable devices may be evaluated with respect to SAR limits using measurement. Some devices operating at a low power may be exempt or under restricted conditions, certified on bases of computational methods. Certification may be granted only when required technical information to support the evaluation procedures used to determine compliance is submitted and accepted.

3.1 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.

3.2 SAR Evaluation of Portable or Mobile Devices

Human exposure to RF emissions from portable devices, as defined by Health Canada, must be evaluated with respect to the Industry Canada-adopted limits for SAR. Evaluation of mobile devices 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

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respect to field strength or power density. For certain devices which are designed to be used in both mobile and portable configurations, 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.

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. SAR evaluations are not applicable for devices operating above 6 GHz.

3.3 Techniques for Evaluating Handsets

Portable communication devices used by consumers typically operate over the range of several watts to a milliwatt, or less, using either analog or digital modulation techniques. Most portable telephones have antennas that radiate within a few centimeters of the user's head. The field strength and field distribution near the antenna are highly dependent on the location, orientation and electromagnetic characteristics of adjacent objects. The head and hand are normally in the reactive near-field region of the antenna where the electromagnetic field is mostly non-propagating. The energy absorbed in the head and hand is mainly due to electric fields induced by the magnetic fields generated by currents flowing through the feedpoint, along the antenna and body of the portable 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 or hand. To account for near-field effects portable devices are evaluated with realistic head models called a phantom (see Procedure SSI/DRB-TP-D01-031).

SAR evaluation of low power handsets can be achieved with either electric field measurements inside tissue media. SAR is determined according to this equation:

$$SAR = \frac{\sigma |E|^2}{\rho} \quad (1)$$

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 watt/kilogram or milliwatt/gram. Under certain circumstances SAR can also be determined from temperature elevation in tissue according to the equation:

$$SAR = C \frac{\Delta T}{\Delta t} \quad (2)$$



where C is the specific heat of tissue, ΔT is the temperature rise and Δt is the exposure duration. 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, but are useful in the calibration of the E-field probe (see Procedure SSI/DRB-TP-D01-032).

3.4 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 SSI/DRB-TP-D01-034 standard describes handset-positioning procedures for evaluating portable communication devices using the Universal Head-arm (SSI/DRB-TP-D01-031) with its integral alignment aids.

A device normally used next to the ear is positioned in a normal operating position with the vertical center-line of the body of the handset aligned with the central line on the hand simulator as well as the central line of the head simulator (Universal Head). This will result in the earpiece being lined up with the head simulator's virtual ear canal. The central line on the head simulator represents the imaginary line created by the intersection of the plane consisting of the three lines joining both ears and the tip of the mouth with the side of a human head. The symmetrical design of the Universal head accommodates both left and right side of the head testing in the one setup. With the earpiece pressed against the head, the next step is to back off the device by the thickness of the compresses human ear (~4mm). It is recommended that a picture of the setup position be used to document the test positions used to demonstrate compliance.

For handsets that are designed to operate like a push-to-talk transmitter, the typically used test position is to align the device as above but back it off by the distance from the face to the tip of the nose (~25mm). In this case the central line on the head simulator represents the imaginary line created by the intersection of the plane containing the tip of the nose and the mouth that would bisect the front of a human head. The mouthpiece of the portable communication device will thus be aligned with the virtual 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. 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



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 possible to predict which antenna configuration will result in maximum energy absorption in tissues. This is due to the design and performance of an antenna and its interaction with the chassis while it is extended or retracted.

3.5 Tissue Simulations 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. 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. The other type is a liquid consisting of water, sugar, salt and a compound called HEC which adjusts the viscosity of the liquid (see Procedure SSI/DRB-TP-D01-033). The gel is typically used for SAR evaluations with high power applications using thermographs 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 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 (see Procedure SSI/DRB-TP-D01-031). The average tissue properties for brain and muscle given in Procedure SSI/DRP-TP-D01-033 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 Procedure SSI/DRB-TP-D01-033). 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 characterized with the slotted line technique. With the slotted line technique, a coaxial line is filled with the tissue material and voltage standing wave measurements are made inside the slotted line with a network analyzer, through a tiny slot along the line, and such data is used to compute the tissue properties. Slotted line measurements are more accurate than the more convenient coaxial probe technique.

3.6 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. 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. Probes may be 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 (see Procedure SSI/DRB-TP-D01-032). Alternatively, 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. 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. The probes for commercial SAR systems are usually sent to the manufacturers for periodic calibration at fixed frequencies using standard exposure setups. All technically supportable calibration methods are considered acceptable.

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

3.7 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 a 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 may be 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 should be used in most situations. 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. Since there is no straightforward way to determine the actual peak performance frequency, test handsets at the high, middle and low frequencies of the transmission band.

When SAR evaluation is performed with a built-in CW test signal that does not vary 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, if 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.

3.8 SAR Measurement Procedures - Field Scanning

A head model is usually placed on its side that 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. 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 a 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 centered around the peak SAR location, is then scanned with a 1-5 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 cm³ volume in the shape of a cube to determine the one-gram average SAR (a 10 cm³ volume for a ten-gram average SAR for the extremities). The average density of most high water-content tissues is about 1020-1040 kg/m³, which requires the tissue volume to be about 1 cm long on each side (2 cm for 10 gram average SAR). 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, a curve-fitting process may be applied to the measured data to allow more points to be used in the average. 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 2.5-7.0 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.

3.9 Measurement Uncertainties

The margin of error for typical measurement 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 Industry Canada 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 (see Procedure SSI/DRB-TP-D01-035). Information on such uncertainties is relevant to SAR evaluation and should be included in order to support compliance with SAR exposure limits.