

2000 Telecommunications Technology Council Report

Deliberation No.118

“Measurement of SAR from Mobile Phone Terminals and Other Terminals that are Intended for Use in Close Proximity to the Side of the Head”

**“Specific Absorption Rate Measurement Method for mobile Phone Terminals
with Emphasis on Those Terminals That Are Intended for Use in Close
Proximity to the Side of the Head” Report Contents**

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1 Foreword

In order to prevent adverse health effects of electromagnetic fields(EM) radiated from radio equipment, the Telecommunications Technology Council submitted a study report in June 1990 entitled "Radio-Radiation Protection Guidelines for Human Exposure to Electromagnetic Fields" (commonly referred to as the radio-radiation protection guidelines) in terms of the strengths of incident EM fields and other factors^[1]. The values dictated by the radio-radiation protection guidelines are set to ensure human bodies exposed to EM fields with sufficient safety factors taking into consideration changes in the status of the users and environmental conditions(e.g., location of installation) of radio equipments. The guidelines have already been in effect as defined in Article 21, 3 of the Radio Law.

Furthermore, with the rapid spread of mobile phone terminals in recent years, there is growing concern about possible adverse effects of radio radiation from such devices on the human health. To address this concern, the Telecommunications Technology Council published a report entitled "Radio-Radiation Protection Guidelines for Human Exposure to Electromagnetic Fields" in April 1997, in which it established the radio-radiation protection guidelines [partial-body absorption guidelines defined in terms of specific absorption rate (SAR)]^[2]. These guidelines apply to radio equipment used in the proximity of the human body, such as mobile phone terminals. Currently, this report is used as voluntary standards in production of radio equipment and other activities^{[3][4]}.

Several methods have been developed and proposed for measuring SAR caused by mobile phone terminals. Standards organizations in the U.S. and Europe are now standardizing the SAR measurement method for the purpose of using it for the legislation of the partial-body absorption guidelines. The standardization process is near completion^{[5][6]}.

This report describes a standardized method for measuring partial-body SAR associated with mobile phone terminals that are intended for use in close proximity to the side of the head, which is used to show compliance with the partial-body absorption guidelines after their legislation. In the standardization process, various factors, including the above-mentioned recent research results and the trends in the standardization activities overseas, were taken into account.

The SAR value specified in the partial-body absorption guidelines is defined as the amount of EM energy absorbed by the unit mass of the human body within the unit time. The SAR should inherently be evaluated inside the actual human body. Since it is impossible to insert test equipment in the human body for SAR measurement, however, the report discusses a method whereby an anthropomorphic human model (phantom) is used to indirectly evaluate SAR. Due consideration is given to realize operability and integrity at standard measurement institutions, regarding that the safety factors of the applicable guideline values cover the diversity of the body tissues of individual humans as well as differences in SAR measurements resulting from the use of the phantom.

The measurement method described herein makes it possible to obtain the maximum SAR value that can be produced by the radio device under test. The device can be considered to be in compliance with the radio-radiation protection guidelines as long as the measured value does not exceed the threshold specified in the partial-body absorption guidelines. The SAR that is generated inside the actual human body by the mobile phone terminal under normal usage conditions is usually smaller than the measured values by using this

measurement method and can often become even smaller depending on the antenna's radiation properties or the system conditions.

The measurement method based on this report should be fully utilized in order to promote the safe use of radio waves. It is also necessary to revise this measurement method in response to revisions of the radio-radiation protection guidelines, advances in measurement technology, changes in the way mobile phone terminals are used, emergence and proliferation of new radio systems, international trends in related areas, etc.

2 Purpose and scope

2.1 Purpose

The purpose of this specific absorption rate measurement method (hereinafter referred to as this measurement method) is to ensure the smooth operation of the radio-radiation protection guidelines by providing a standardized measurement method to be used for determining whether a particular mobile phone terminal complies with the partial-body absorption guidelines of the radio-radiation protection guidelines.

With this measurement method, an electric field probe is used as a standard measurement means. Technical requirements associated with measuring the partial-body SAR caused by mobile phones using the probe are defined.

2.2 Scope

2.2.1 Applicable devices

This measurement method is applicable only to mobile phone terminals and similar devices that are pressed against the temporal side of the human head when in use and whose radio radiation source exists in close proximity to the side of the head.

It does not apply to exposures in other parts of the human body or in cases where a metallic object or other foreign matter is contained in the human body.

2.2.2 Frequency range

This measurement method applies to the frequency range between 300 MHz and 3 GHz. The frequency bands currently used for the domestic mobile phone service are 800 MHz, 1500 MHz, and 1900 MHz. The frequency range between 300 MHz and 3 GHz has been chosen, however, taking into account possible changes in the operation trends in the near future.

3 Definitions

- Electromagnetic waves

Waves of electric and magnetic fields propagating through the vacuum and matters. These include extremely low-frequency fields from power lines, radio waves for communications, light from the sun (infrared, visible, and ultraviolet rays), and radiations used for medical treatment (X-rays and γ -rays). They are divided into ionizing radiations (whose wavelengths are shorter than that of the ultraviolet ray) and non-ionizing radiations (whose wavelengths are longer than that of the ultraviolet ray).

- Radio wave

Electromagnetic waves whose frequencies are below 3000 GHz as defined in Article 2 of the Radio Law. In the radio-radiation protection guidelines, it refers to those electromagnetic waves in the frequency range between 10 kHz and 300 GHz.

- Radio-radiation protection guidelines

Guidelines that recommend the requirements to meet for ensuring the safety of radio use so that any individual exposed to radio radiation (limited to the frequency range between 10 kHz and 300 GHz) is protected from any undesirable biological effect of the radiation^{[1][2]}.

- Partial-body absorption guidelines

Guidelines intended for use in cases where part of the human body is subject to concentrated exposure to an electromagnetic field associated with electromagnetic radiation from a wireless device being used in the extreme proximity of the human body^[2].

- Specific absorption rate (SAR)

The electric power absorbed by the unit mass of the human tissue exposed to an electromagnetic field. It is the time derivative of the energy (dW) absorbed by an infinitesimal mass (dm) contained in an infinitesimal volume element (dV) of a given density (ρ) [kg/m^3]. The SAR is calculated as follows:

$$\text{SAR} [\text{W}/\text{kg}] = d (dW / dm) / dt = d (dW / \rho dV) / dt = \sigma E^2 / \rho$$

The SAR is expressed in units of watts per kilogram (W/kg).

σ [S/m] is the conductivity of the matter (i.e. tissue), and E [V/m] is the rms electric field strength in the matter.

- Average power

The average \bar{P} of the power $P(t)$ that changes from time t_1 to time t_2 is calculated using the following equation. The time derivative $t_2 - t_1$ used in this calculation is called the average time.

$$\bar{P} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} P(t) dt$$

- Average time

The average time is 6 minutes when calculating the whole-body SAR.

The average time for calculating the partial-body SAR is also defined as 6 minutes in the radio-radiation protection guidelines. This measurement method assumes a condition in which the mobile phone terminal under test continues to be engaged in transmission-only operation for 6 consecutive minutes.

- **Average whole-body SAR**

The energy [J] absorbed by the whole human body for any given 6 minutes (360 seconds) divided by the whole body weight [kg] and then divided by 360, represented in W/kg.

- **Partial-body SAR**

The SAR is expressed in units of infinitesimal volume elements and represents a space distribution function that depends on the radiation conditions of electromagnetic waves and the exposed part of the human body tissue. The SAR value averaged over any 1g or 10g of tissue with relation to this distribution function is called the partial-body SAR. Of such averages, the largest value is referred to as the maximum partial-body SAR. Note that, in this measurement method, 1g or 10g of tissue is in the shape of a cube.

- **Electric field strength**

The magnitude of the electric field vector, expressed in units of volts per meter (V/m).

- **Magnetic field strength**

The magnitude of the magnetic field, expressed in units of amperes per meter (A/m).

- **Power density (power flux density)**

Radiated power per unit area normal to the direction of propagation. For instance, given the rms electric field strength of E [V/m] and the rms magnetic field strength of H [A/m] and that the wave impedance in free space equals 120π [Ω], the power density S [W/m^2] of a plane wave is expressed as $S = E^2/120\pi = 120\pi \cdot H^2$.

- **Phantom**

An anthropomorphic model of the human body used to estimate SAR on an experimental basis. Two types of phantom may be used: one is called a homogeneous phantom that uses the same material in all parts of the model and the other is called a heterogeneous phantom that is comprised of material with electrical properties similar to the corresponding tissues. This measurement method employs a homogeneous phantom consisting of a shell (container) that represents the shape of the human body and a liquid material that fills the shell.

- **Uncertainty**

The estimated amount by which the measured value of a quantity may depart from the true value. Uncertainty can be expressed in terms of average error, probability error, standard deviation, etc.

- **Boundary effect**

An effect of the boundary between two media of the phantom on the probe sensitivity or an effect on the electric field distribution and current density produced when the probe is located close to the media boundary.

- **Detection limit**

The lower (or upper) detection limit is defined by the minimum (or maximum) SAR of the measurement equipment.

- **Permittivity (ϵ)**

Permittivity is defined by dividing the electric flux density D by the electric field strength E . The permittivity is a variable that represents the dielectric properties of biological tissues and phantoms.

$$\epsilon = \epsilon_r \epsilon_0 = \frac{D}{E}$$

$$\epsilon_r = \epsilon_r' - j\epsilon_r'' = |\epsilon_r| e^{-j\delta} = \epsilon_r' + \frac{\sigma}{j\omega\epsilon_0}$$

where

- ϵ_0 : Permittivity in the vacuum
- ϵ_r : Complex relative permittivity
- ϵ_r' : Real part of the relative permittivity
- ϵ_r'' : Imaginary part of the relative permittivity
- δ : Eulerian angle of the complex relative permittivity
- σ : Conductivity

Permittivity is expressed in units of farad per meter (F/m).

- **Dielectric loss tangent**

The ratio of the real part of the complex specific permittivity to the imaginary part of it.

- **Conductivity (σ)**

The ratio of the conduction-current density in a medium to the electric field strength. Conductivity is expressed in units of siemens per meter (S/m).

- **Intrinsic impedance (of free space)**

The ratio of the electric field strength to the magnetic field strength of a propagating electromagnetic wave. The intrinsic impedance of a plane wave in free space is 120π [Ω] – approximately 377Ω .

- **Isotropy**

Characteristic of a probe (or antenna) that allows it to respond equally to incident electromagnetic fields independently of their direction of incidence as long as those fields are of the same strength.

- **Linearity**

The maximum deviation from the defined reference line with relation to a given interval of the measurement range.

- **Response time**

The time required for an electromagnetic field measurement equipment to reach 90% of the final value after being placed in the field to be measured.

- **Probe scanning equipment**

An automated positioning device that holds and moves the electric field probe (sensor) in three dimensions to a specified position inside the phantom.

- **Electric field probe**

In connection with this measurement method, an instrument that measures the electric field strength in the phantom fluid in an isotropic manner with a high level of spatial resolution.

- **SAR measurement equipment**

A piece of equipment that measures the electric field strength in the phantom fluid by means of an electric field probe. The SAR is calculated on the basis of the value measured by this equipment. It consists of an electric field probe, an amplifier, a microcomputer, etc.

- **Base station simulator**

A device that controls the operation of the device under test by radio.

- **Sensitivity**

The sensitivity of the measurement system is the ratio of its output signal (e.g., voltage) to the measured quantity (e.g., electric field).

- **Penetration depth**

The penetration depth generally refers to the distance from the boundary of a medium to the point at which the electric field strength of a plane electromagnetic wave incident on a lossy, semi-infinite region is reduced to $1/e$ of its initial value on the incident surface.

4 Rationale of the measurement

The SAR measurement method simulates radio exposures by means of an anthropomorphic model (phantom) of the human body in order to estimate on an experimental basis the SAR that can be induced in the human body. The measurement system should preferably be capable of representing the actual exposure conditions sufficiently well and allow more accurate estimations to be made. Several methods have been proposed in the past whereby the SAR is evaluated based on the measurement of the electric field distribution inside the phantom, temperature rise distribution induced by the internal electric field, etc. These methods have been used as voluntary standards in Japan as well for the purpose of mobile phone SAR measurements^[4].

The rationale of the SAR measurement method adopted in this report that uses a probe scanning equipment is to measure the electric field distribution inside a phantom, filled with a fluid having dielectric properties similar to those of the human body, with high accuracy by means of an isotropic electric field probe and to calculate the 1-g or 10-g averaged partial-body SAR based on the measured values. The relationship between the SAR and the electric field strength is as follows:

$$\text{SAR}(x,y,z) = \sigma E^2(x,y,z) / \rho \text{ [W/kg]}$$

where SAR (x,y,z) and E (x,y,z) are the SAR and electric field strength values (rms values) measured at the location (x,y,z), respectively. σ and ρ are the conductivity of the phantom and the density of the body tissues, respectively. This measurement method excels other conventional methods in respects of the accuracy and repeatability of SAR distribution measurement. To ensure the reliability of measured values, however, details need to be predetermined including the conditions of the measurement system and the partial-body SAR calculation method.

5 Conditions of the measurement system

5.1 General

As shown in Figure 5.1, the measurement system is composed of the phantom, SAR measurement equipment, probe scanning equipment, holder for mobile phone terminal to be tested (hereinafter referred to as the test device), and a base station simulator.

In conducting the measurement, the following environmental conditions must be met:

- The ambient temperature must be between 15°C and 30°C.
- The measurement must not affect any other radio facilities.
- Care must be taken to prevent surrounding electromagnetic sources from affecting the measurement.
- Care must be taken to prevent reflections from surrounding objects (floor, positioning device, etc.) from affecting the measurement.

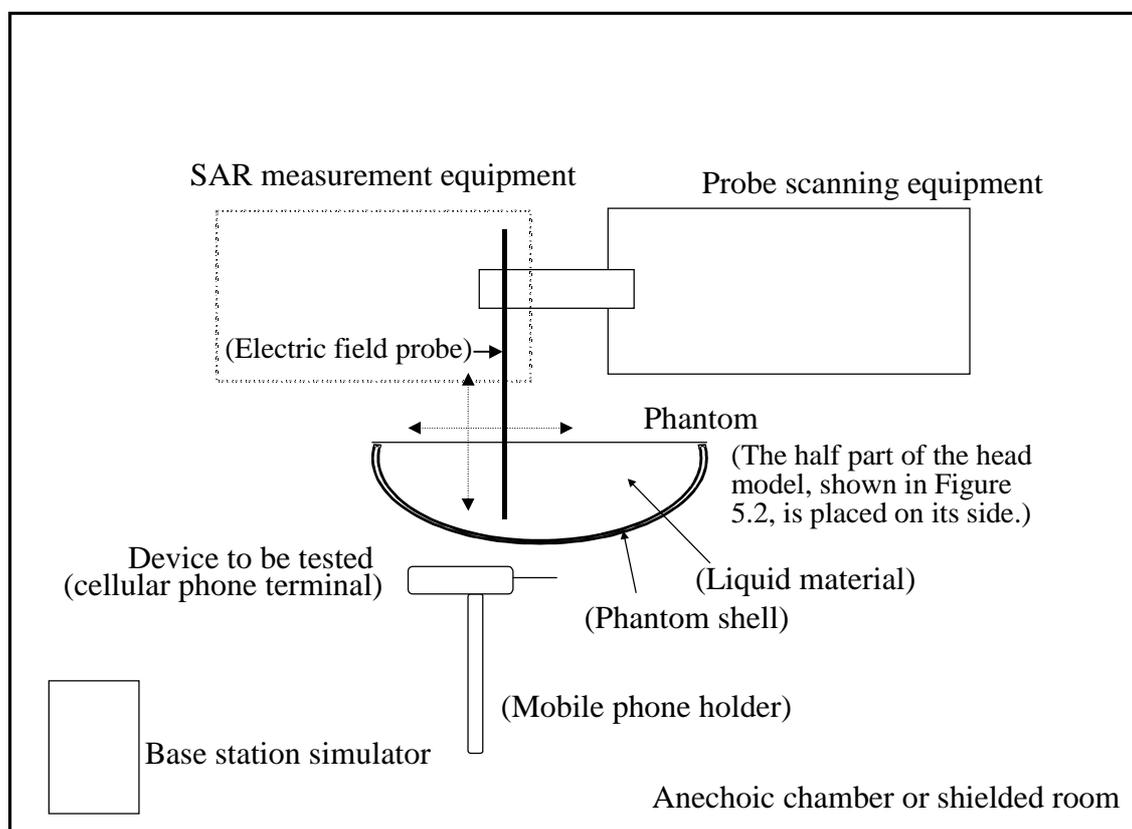


Figure 5.1 Basic Configuration of the Measurement System

5.2 Phantom

5.2.1 General

Since the size and shape of the phantom are essential parameters for evaluating the SAR value, it is desirable that they closely approximate to those of the human head and neck. Also, it should have dielectric properties similar to those of the human head tissues. To enable scans to be performed inside the phantom using an electric field probe, the head and neck part of this phantom shell is divided into two halves (right and left), filled with a liquid material. The shell is used as a molded container and should have as little effect on the measurement as possible. No hand model is used (Section 3.3 of Annex 1).

5.2.2 Shape and dimensions

The shape and dimensions of the phantom must be as specified in 1 of Annex 1. This requirement is based on the consideration for international standardization trends. This will result in overestimated measurement results, compared with those cases where a phantom having the shape and dimensions of a typical Japanese user's head is used (Section 3.1 of Annex 1). Figure 5.2 shows the phantom model.

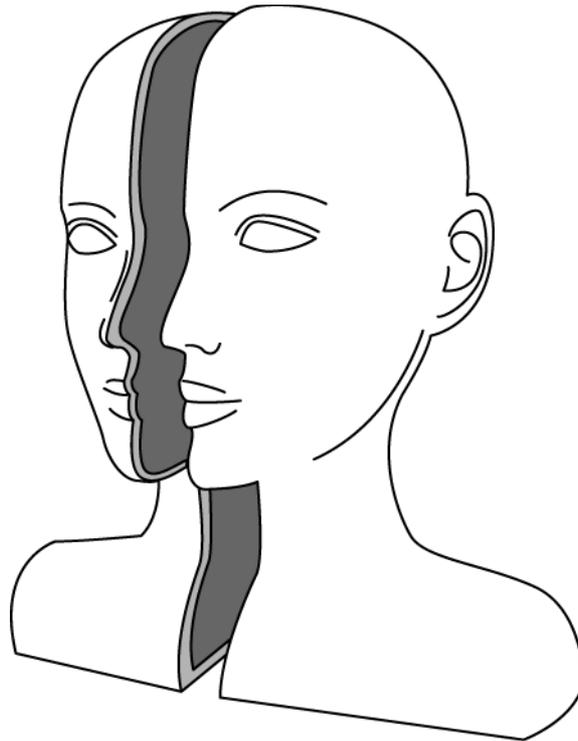


Figure 5.2 Phantom Model

5.2.3 Phantom Shell

- The the dielectric loss tangent and relative dielectric constant of the shell material must be 0.05 or less and 5 or less, respectively.
- The thickness of the part of the shell that comes into contact with the mobile phone must be 2 ± 0.2 mm, except for the ear. For the other parts, the thickness of the shell must not exceed 5 mm.

- The ear must be a 6-mm-thick lossless spacer pinna model, including the 2-mm-thick shell, which represents the condition of the mobile phone being held against the ear.
- Marks shall be put on the surface of the shell so that the locations of the reference points for positioning the device to be tested, described in Chapter 1 of Annex 1, can be identified - right ear (RE), left ear (LE), and mouth (M) reference points.

5.2.4 Liquid material

The dielectric properties of the liquid material used to fill the phantom must be as shown in Table 5.1. These values assume that the same liquid material is used for the 1-g and 10-g SAR averaging. If conductivity σ differs for 1-g and 10-g averages, the conductivity value σ that yields a larger SAR value is listed in Table 1. Intermediate values between the values listed in the table must be calculated through linear interpolation. Samples recipes for the liquid material are presented in Chapter 2 of Annex 1.

Table 5.1 Dielectric Properties of the Liquid

Frequency (MHz)	Real part of the relative dielectric constant ϵ_r'	Conductivity σ (S/m)
300	45.3	0.87
450	43.5	0.87
835	41.5	0.90
900	41.5	0.97
1450	40.5	1.20
1800	40.0	1.40
1900	40.0	1.40
2000	40.0	1.40
2450	39.2	1.80
3000	38.5	2.40

5.3 SAR measurement equipment

- The lower SAR detection limit must be 0.02 W/kg or less. The upper detection limit must be 100 W/kg or more (peak value at the input of a pulse-modulated signal).
- The linearity must be within the range of ± 0.5 dB for the SAR range between 0.02 W/kg and 100 W/kg. Note that 100 W/kg is the peak value at the input of a pulse-modulated signal.
- The isotropy must be within the range of ± 1 dB.
- The sensitivity, linearity, and isotropy must be evaluated inside the liquid in which the dielectric properties of human tissues are to be simulated at measurement frequencies.
- Each small dipole element of the electric field probe sensor must be 5 mm or less in length. The external dimension of the protection cover of the sensor must be 8 mm or less. Also, the electric field probe must be calibrated at regular intervals.
- When measuring the SAR associated with TDMA or other pulse signals, the measured values must be repeatable within an error margin of $\pm 5\%$.

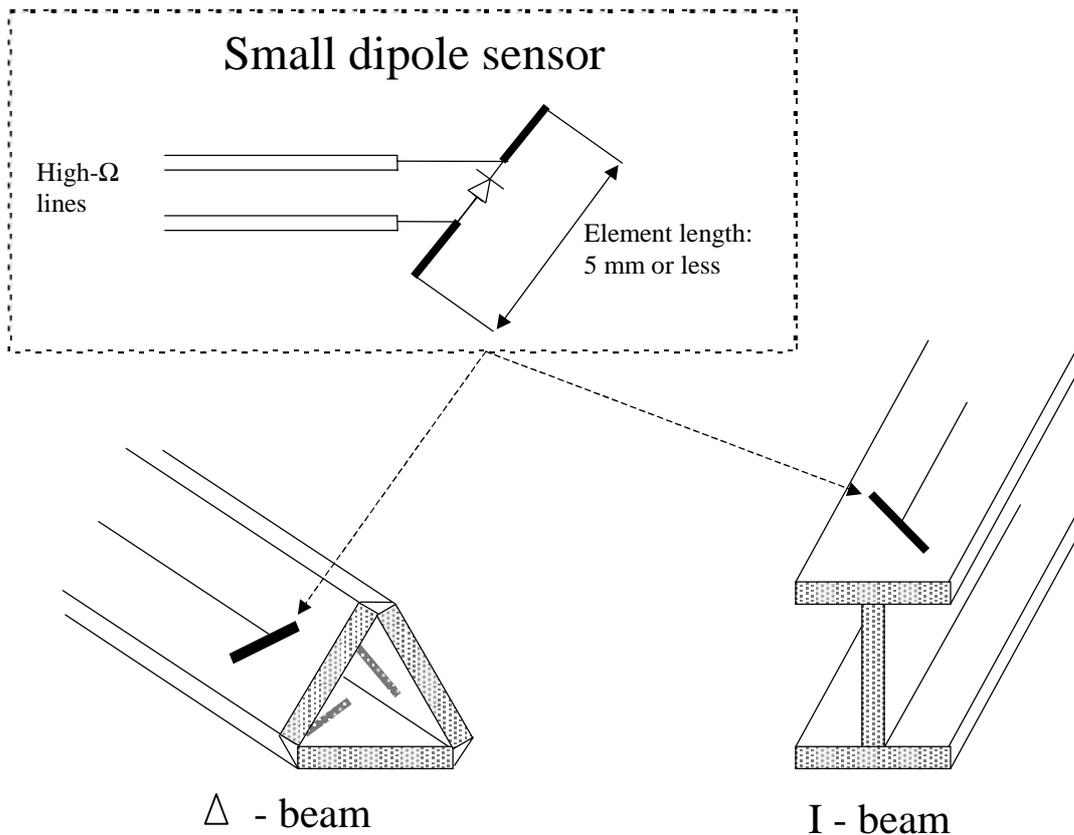


Figure 5.3 Example of the Electric Field Probe

5.4 Probe scanning equipment

5.4.1 General

The scanning equipment must be capable of scanning inside the liquid to evaluate the three-dimensional SAR distribution. Its mechanical structure must not impede the SAR measurement.

5.4.2 Technical requirements

- (1) Accuracy
The accuracy of positioning the probe tip over the measurement range must be within ± 0.2 mm.
- (2) Positioning resolution
The positioning resolution must be 1 mm or less.

5.5 Mobile phone holder

- The mobile phone holder must be capable of holding the mobile phone at the position to the phantom specified in Section 6.1.3.
- The error of the inclination angle must be within $\pm 1^\circ$.
- The holder must be made of a material for which the the dielectric loss tangent and relative dielectric constant must be 0.05 or less and 5 or less, respectively.

6 Procedures for measurement

6.1 Setup of the measurement system

6.1.1 General

- The dielectric properties of the phantom liquid must be measured prior to the SAR measurement. The measurement of the dielectric properties must be conducted under the same temperature condition as the SAR measurement. The temperature error margin must be within the range of $\pm 2^{\circ}\text{C}$.
- The measured values of the real part of the relative dielectric constant and conductivity of the phantom liquid must be within an error margin of $\pm 5\%$ with respect to the values shown in Table 5.1. The measurement method is described in Section 2.2 of Annex 1.
- The depth of the phantom liquid must be 15 cm or more at the location where the peak SAR is induced.
- Prior to the measurement, stir the liquid carefully so that no air bubbles will be trapped in the liquid.
- The reference point of the probe scanning equipment must be aligned with that of the phantom with an accuracy of ± 0.2 mm.
- Check that the measurement system and each of its components are operating normally as specified.

6.1.2 Test device

- The test device must use its own internal transmitter for the measurement.
- The antenna, battery, and accessories must be those specified by the manufacturer of the test device.
- The battery must be fully charged prior to each measurement and have no external connections.
- The antenna power and frequency must be controlled using the internal test program or adequate test equipment (base station simulator).
- The antenna must be set to its maximum output power level in the communication mode (such as voice communication) corresponding to the use of the test device at the temporal side of the head. For multi-mode terminals, the requirements specified in Annex 2 must apply. The transmission operation must be a continuous operation using dummy baseband or other signals which matches the signaling system of the pertinent communication mode.
- When a base station simulator is used, the simulator's antenna must be located at a distance of 50 cm or more from the test device. The input power level at the simulator's antenna feed point must be no greater than -30 dB when compared with the antenna power level of the test device.

6.1.3 Typical measurement positions

The test device must be measured on both the right and left sides of the phantom with respect to the two positions defined below.

- (1) Cheek position

- a) Align the vertical center line and horizontal line of the test device, shown in Figure 6.1, in parallel with the median plane of the phantom while positioning the device so that the central point of the ear piece crosses the straight line between RE and LE [Figure 6.2 (a)]. While maintaining the test device in this place parallel to the median plane, rotate the device around the central point of the ear piece so that the reference plane consisting of the three ear and mouth reference points (M, RE, and LE) is aligned with the vertical center line [Figure 6.2 (a)].
 - b) With the central point of the ear piece aligned with the RE-LE line, translate the test device toward the phantom until it touches the ear [Figure 6.2 (b)]. While maintaining the vertical center line of the test device in the reference plane and keeping the device in contact with the ear, move the bottom of the device until any point on its front side comes into contact with the cheek of the phantom [Figure 6.2 (c)]. However, if the contact with the ear is lost before the device touches the cheek, conduct the measurement at that position [Figure 6.2 (c)].
- (2) Tilted position
- a) Position the test device in the cheek position described in (1) [Figure 6.2 (c)].
 - b) While maintaining the vertical center line of the test device in the reference plane described in (1), move the device outward from the cheek position by an angle of 15 degrees (Figure 6.3). However, if the contact with the ear is lost before the angle of 15 degrees is reached, conduct the measurement at that position.

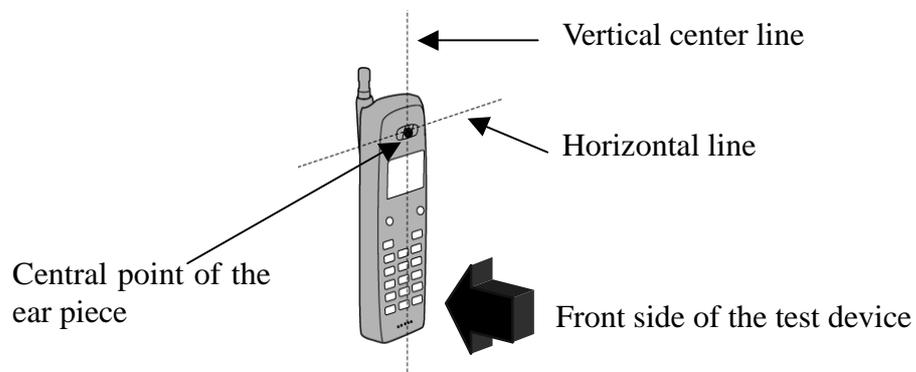


Figure 6.1 Example of the Test Device

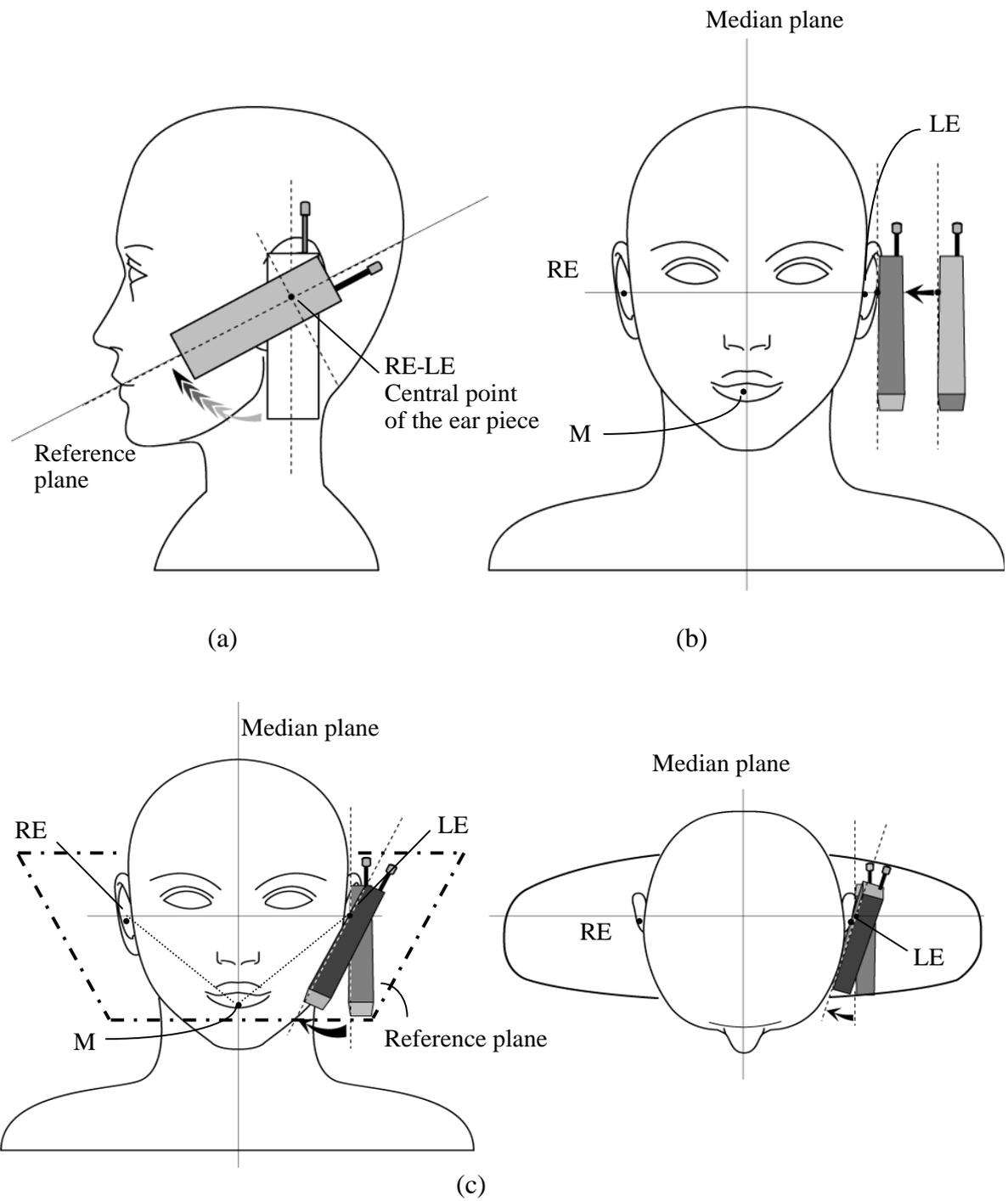


Figure 6.2 Cheek Position

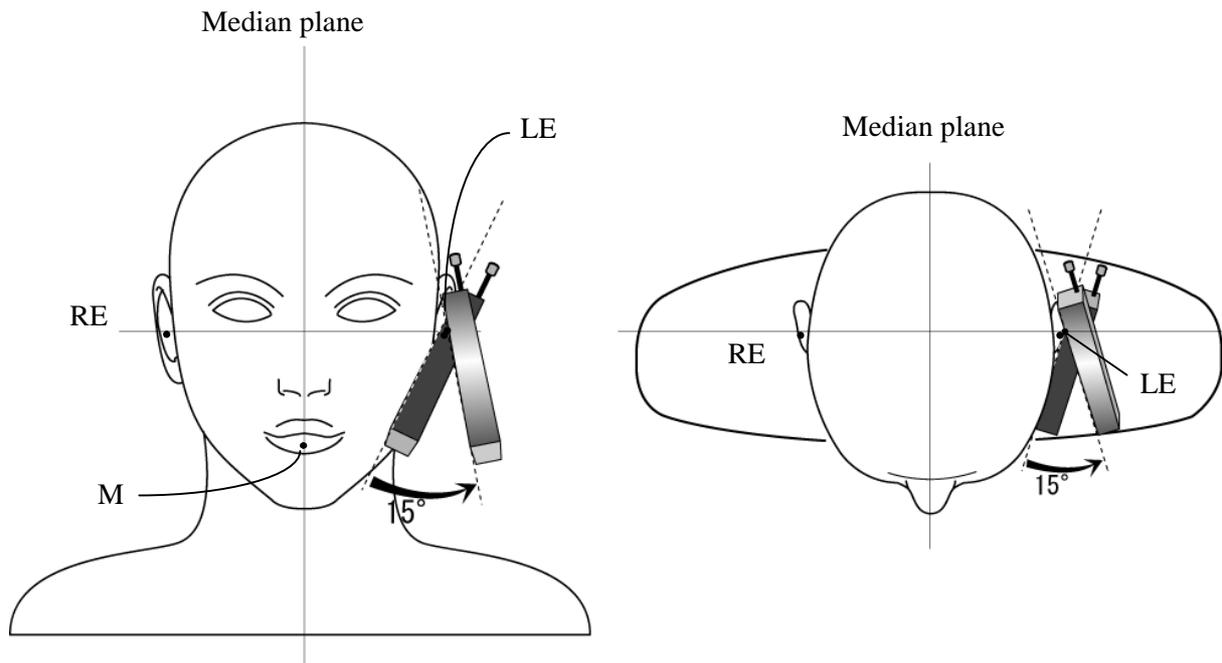


Figure 6.3 Tilted Position

6.2 Measurement

6.2.1 General conditions

- (1) Perform measurements on the right and left sides of the phantom with respect to both positions described in (1) and (2) of Section 6.1.3, by using the frequencies near the center of each operating band.
- (2) At the position of the test device where the maximum SAR value is detected, conduct tests with relation to the maximum and minimum frequencies of the transmitting band.
- (3) When the test device has a retractable antenna, carry out the tests described in (1) and (2) with the antenna extended and retracted.
- (4) When measuring a test device that supports a multi-mode function or multiple operational frequency bands, perform the tests described in (1) to (3) for the corresponding maximum transmission output level (Annex 2) with relation to each transmission mode or band.

Figure 6.4 shows the basic measurement procedure that meets the above conditions.

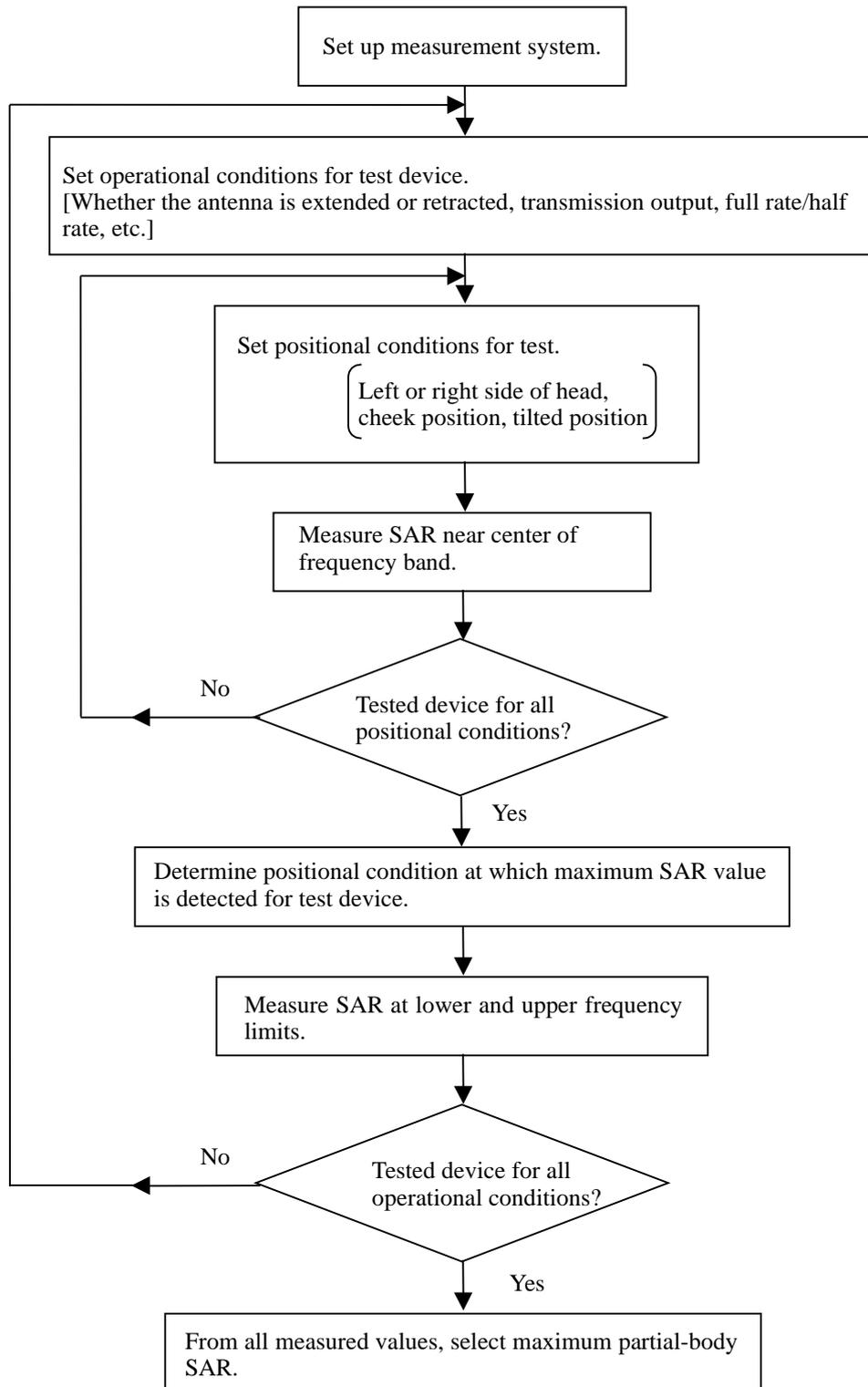


Figure 6.4 Basic Measurement Procedure

6.2.2 Details of the measurement procedure

Furthermore, with relation to the general conditions described in Section 6.2.1, perform the following operations and measurements.

- (1) Measure the SAR at one selected measurement point within 10 mm from the inner surface of the phantom shell. The measurement point must be in the proximity of the antenna of the test device.
- (2) At the measurement point selected in (1), measure the SAR again three minutes after the initial measurement. Check that the difference between this measured value and the one measured in (1) is within $\pm 5\%$, in order to verify the stability of the operation of the entire measurement system.
- (3) Measure the SAR distribution inside the phantom. The measurement must be conducted in steps of less than 20 mm. When a scan is performed near the inner surface, the distance between the center of the electric field probe tip and the inner surface of the phantom must be less than 8 mm with a deviation of ± 0.5 mm. The scan must be performed in the closest possible proximity of the inner surface of the phantom shell (less than 8 mm). The scan must be conducted in steps of 5 mm or less to a depth of at least 25 mm. Then, proceed to (6).
- (4) From the obtained SAR distribution, identify the location of the maximum SAR as well as all the locations where the measured SAR values have been 50% or more of the maximum SAR. This step is necessary to search for the maximum SAR value.
- (5) In a volume whose minimum dimensions are 30 mm \times 30 mm \times 25 mm, measure the SAR in steps of less than 5 mm. Place the center of the area on the location where the maximum SAR value has been detected.
- (6) By using the interpolation and extrapolation procedures described in Section 6.2.3, determine the partial-body SAR at the spatial resolution necessary for mass averaging.
- (7) Measure the SAR again at the measurement point used in (1). If the difference between this measured value and the one measured in (2) is $\pm 5\%$ or greater, repeat the measurement with some appropriate treatment, e.g., charging the battery fully.

6.2.3 Calculation of the SAR value

(1) Interpolation

If measurement intervals are coarse for the given mass, perform interpolation between measurement points when calculating the partial-body SAR.

Annex 3 shows an example of the interpolation method.

(2) Extrapolation

The electric field probe to be used usually contains three closely-spaced orthogonal dipoles. These dipoles are embedded in a protective tube. The measurement point is several millimeters from the probe tip. This offset must be taken into consideration when determining the position of the SAR measurement.

Annex 3 shows an example of the extrapolation method.

(3) Average volume

The tissue used to calculate the partial-body SAR must be in the form of a cube. Its density shall be 1 g/cm³.

If the cube crosses the inner surface of the phantom shell, orient the cube so that three of its vertexes come into contact with the inner surface of the phantom shell or that the center of one of its sides touches the surface tangentially.

Modify the side of the cube that is the closest to the inner surface of the phantom shell so that it conforms to the surface. The added volume must be subtracted from the opposite side of the cube.

Annex 3 shows how to obtain the average volume of a cube.

(4) Search for the maximum value

In accordance with Annex 3, move the location of the cube over the phantom inner surface near the partial-body peak SAR.

The cube having the partial-body peak SAR must not be on any boundary of the scan area. If so, move the scan area and perform the measurement again.

The partial-body peak SAR value obtained as described above is regarded as the measurement result.

7 Evaluation

7.1 Guideline values used to verify compliance

The partial-body SAR values (for any 10g tissue excluding the extremities) specified in the partial-body absorption guidelines of the radio-radiation protection guidelines ^[2], published in April 1997 by the Telecommunications Technology Council, are to be applied.

Those devices whose average antenna power is 20 mW or less, as defined in Article 2, Item 1, No. 70 of the Radio Law, meet the partial-body SAR requirements in the general environment^[2].

7.2 Uncertainty

Generally, the uncertainties associated with SAR measurements should be estimated by following the general rules defined in the IEC reference document^[7]. Based on reported research samples^[8] and values indicated in the documentation accompanying similar commercially available measuring equipment, it is estimated that this measurement method enables SAR measurements to be conducted with an uncertainty of 30% or less.

7.3 Evaluation method

The measurement results must be directly compared with the guideline values. If the measured value is not more than the corresponding guideline value, the test device is regarded as being compliant with the partial-body absorption guidelines.

Since additional safety factors are included in the partial-body absorption guideline values for the general environment^[2], the uncertainty associated with this measurement method is not needed to be evaluated.

8 Validation test and calibration of the measurement system

8.1 Validation test of the measurement system

Since this measurement system consists of various components, simplified performance tests must be performed to check the basic operation of each component before conducting an validation test for the entire system. These simplified performance tests must be carried out using a flat phantom and a standard dipole antenna.

The validation test for the entire measurement system must be conducted with the radio equipment developed for the validation test. If such radio equipment is not available, a standard dipole antenna must be used instead. The measurement system must be subject to the validation test for the entire measurement system at least once a year.

8.2 Calibration of the SAR measurement equipment

Those components of the SAR measurement equipment that are related to the electric field probe need to be calibrated.

The amplifier and other components are calibrated in the specified manner as required.

9 Issues to be tackled

9.1 Broadening the applicable scope of the measurement method

This measurement method assumes the currently most typical usage of a mobile phone terminal (i.e., use on the temporal side of the head) because of the necessity of demonstrating the measurement procedure concretely. The basic part of this measurement method can be extended and applied to those devices that are used differently from typical mobile phone terminals. If devices used differently from the currently used mobile phones come into wide use in the future, it will be necessary to establish additional measurement procedures based on their unique usage.

Since it is expected that there will be rapid advances in the wireless technology and that more diverse types of device will come into use that operate in the proximity of the human body, efforts should be made to develop measurement methods that are applicable to a wider variety of uses of radio equipment, in addition to existing procedures, such as this measurement method, whereby a phantom that faithfully simulates the human head is used.

9.2 Harmonization with international standards

This measurement method is based on the same concept as those that are being studied and standardized by the standards bodies in the U.S. and Europe^{[5][6]}. An internationally concerted effort toward standardization has just begun^[9].

Given the increasing significance of the globalization of data communications equipment, it will be necessary to contribute to the development of internationally standardized measurement methods as well as to modify this measurement method as required in order to ensure its harmonization with the international standards.

9.3 SAR values

This report presents a standard SAR measurement method applicable to mobile phone terminals that are used on the temporal side of the human head. It is intended to establish a procedure for measuring the SAR and evaluating compliance with the radio-radiation protection guidelines in a standardized manner. The method is expected to make it possible provide adequate information with relation to concern about possible adverse effects of radio radiation from mobile phone terminals on the human health.

This measurement method measures the maximum SAR value that can be induced under normal usage conditions. Therefore, the device is regarded as being compliant with the radio-radiation protection guidelines as long as the measured value does not exceed the partial-body absorption guideline value. The SAR that is induced in the human body under actual usage conditions is often smaller than the measured value because of the system's transmission output control (the terminal's output level is automatically reduced depending on the condition of the communication).

It is necessary to promote a correct understanding of the SAR values obtained using this measurement method.

Annex 1 Phantom specifications

1 Specifications (data sheets)

The external and internal dimensions of the phantom shell are defined by the three-dimensional CAD data (Figure 1 shows part of the data). For details, refer to <http://www.itis.ethz.ch/>.

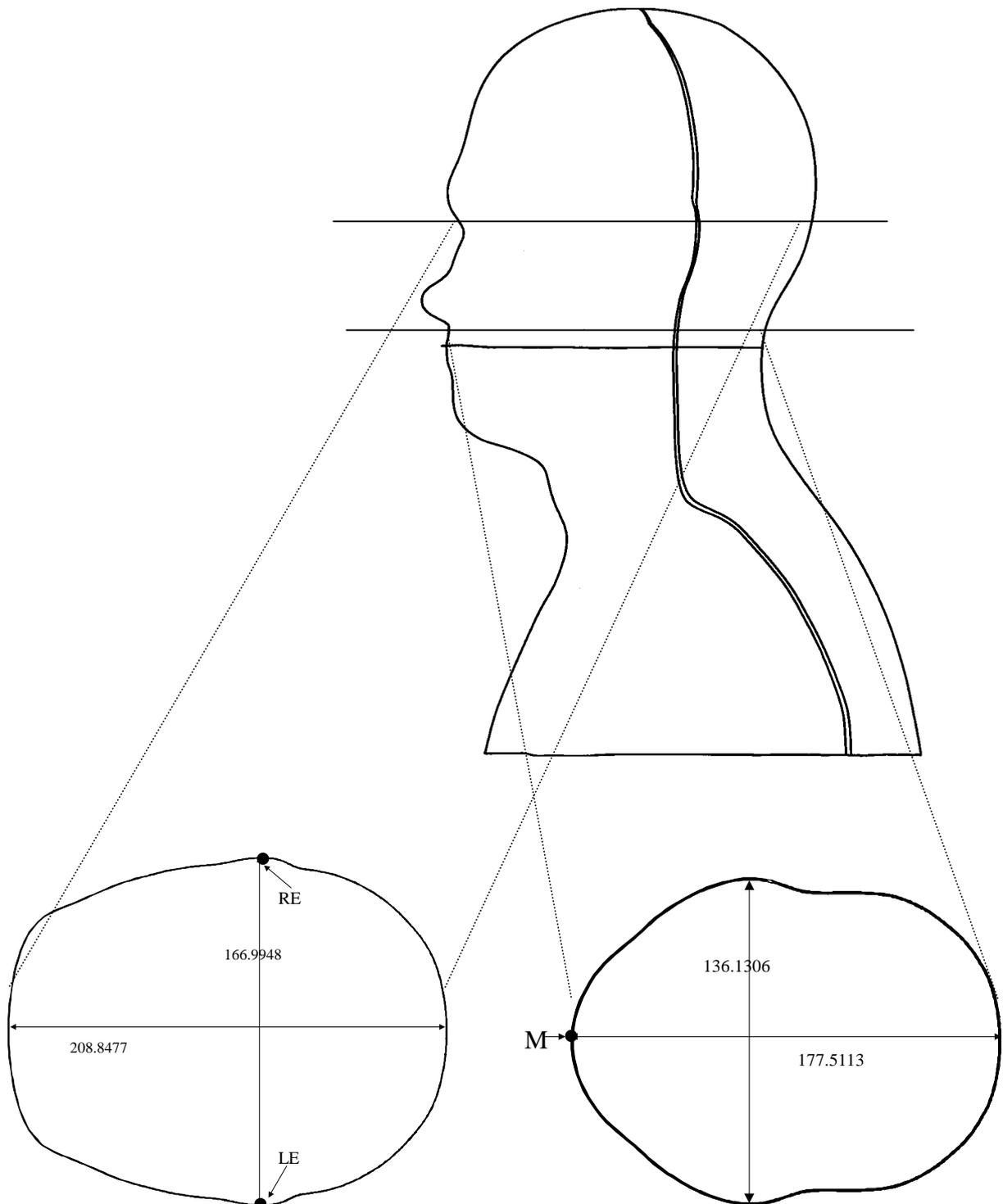


Figure 1 Part of the Phantom Data Sheets (External Dimensions Only)

2 Preparation and measurement of the phantom liquid

In preparing the phantom liquid, consideration is given so that the same phantom can be used for both the 1-g and 10-g averaging processes.

2.1 Preparation of the phantom liquid

The following materials are used to prepare the phantom liquid:

- Sucrose (98 %)
- Sodium Chloride (Salt)(99 + %)
- De-ionized water (16 MΩ resistivity)
- Hydroxyethyl Cellulose (HEC)
- Bactericide
- Diethylene Glycol Butyl Ether (DGBE)
- 1,2-propanediol
- 2-(2butoxyethoxy) ethanol

Sample recipes of the phantom liquid are shown below.

- (1) 300 MHz solution
 - 55.32% Sucrose
 - 37.56% De-ionized water
 - 5.95% Sodium Chloride
 - 0.98% HEC
 - 0.19% Bactericide

- (2) 450 MHz solution
 - 56.32 % Sucrose
 - 38.56 % De-ionized water
 - 3.95 % Sodium Chloride
 - 0.98 % HEC
 - 0.19 % Bactericide

- (3) 835 MHz solution
 - 56.0% Sucrose
 - 41.45% De-ionized water
 - 1.45% Sodium Chloride
 - 1.0% HEC
 - 0.1% Bactericide

- (4) 900 MHz solution
 - 56.63% Sucrose

- | | | |
|--|--------|------------------|
| | 40.71% | De-ionized water |
| | 1.48% | Sodium Chloride |
| | 0.99% | HEC |
| | 0.19% | Bactericide |
- (5) 900 MHz alternative solution
- | | | |
|--|--------|------------------|
| | 64.81% | 1,2-propanediol |
| | 34.40% | De-ionized water |
| | 0.79% | Sodium Chloride |
- (6) 1450 MHz solution
- | | | |
|--|--------|------------------|
| | 45.51% | DGBE |
| | 53.82% | De-ionized water |
| | 0.67% | Sodium Chloride |
- (7) 1800 MHz solution
- | | | |
|--|--------|---------------------------|
| | 44.92% | 2-(2butoxyethoxy) ethanol |
| | 54.90% | De-ionized water |
| | 0.18% | Sodium Chloride |

2.2 Measurement of the phantom liquid

The dielectric properties of the phantom liquid can be measured using the slotted line method^[10], contact probe method^{[11][12]}, or TEM line method^{[13][14]}. For the actual procedures and other details, refer to the pertinent reference documents.

3 Rationale

3.1 Shape of the phantom

Results of the researches conducted so far indicate that a larger head may be subject to greater exposure than a smaller one because of stronger coupling with radiated energy^[15].

The anthropometric survey of U.S. Army personnel in 1988 provides data based on various samples of different age, racial, and ethnic groups^[16]. The use of a model with 90th percentile adult male head dimensions based on these data leads to overestimated measurement results.

The 90th percentile value is determined so as to include 90% of the samples, excluding the remaining 10% that have larger dimensions than the rest.

The protrusion of the back of the ear is an essential parameter for the SAR measurement that directly influences the distances between the mobile phone terminal and antenna and the head. Since the shape of the ear provides the basis for the positioning of the mobile phone terminal, it must be designed so as to enable correct, repeatable positioning.

3.2 Medium of the phantom

The head consists of multiple tissues, including brain, skull, skin, and eyes, and the electrical constants differ for each tissue. The dielectric properties of the head is therefore non-uniform. This causes the SAR distribution in the head to become very complex when

the mobile phone terminal is used.

Although numerical simulations enable the use of a theoretical model that provides a detailed representation of the human head structure, it is difficult in reality to construct a phantom with a heterogeneous structure. Considering the simplicity and repeatability of measurements, it is desirable to employ a homogeneous phantom. In order to verify the validity of SAR values estimated through measurements using the homogeneous phantom, studies have been reported in which the partial-body SAR distribution in a homogeneous head model is compared with that in a heterogeneous head model^{[17][18]}. The results of these studies reveal the following:

- The SAR distribution in the head depends on the non-uniform structure of the head tissues, and the SAR distribution in a homogeneous head model is different from that in a heterogeneous head model.
- The SAR distribution on the surface of the head depends on the shape of the head, and the SAR distribution of the surface of a homogeneous head model is almost the same as that of a heterogeneous head model having the same shape.
- The maximum partial-body SAR occurs on the surface of the head for both homogeneous and heterogeneous head models. The value measured for the homogeneous head model is equal to or larger than that of the heterogeneous head model.

Also, regarding the maximum SAR averaged over 10 g of partial-body tissue (which corresponds to the partial-body absorption guideline value), it has been reported that the difference between the homogeneous and heterogeneous head models is negligible^[8].

As explained above, it is possible to evaluate the maximum partial-body SAR in the head through measurements using a homogeneous phantom model.

3.3 Influence of the hand

Since the hand holding the mobile phone terminal touches the phone case and is in the extreme proximity of its antenna, strong electromagnetic coupling occurs between the hand and the antenna. Therefore, the SAR distribution induced in the head is expected to be strongly influenced by the shape and position of the hand holding the mobile phone terminal. The numerical simulations conducted so far, however, show that the maximum partial-body SAR to be induced in the head by the mobile phone terminal that is not held by the hand (suspended in the air) is comparable to that to be induced when the phone is held by the hand in a typical holding position (the hand holding the terminal does not cover its antenna)^{[17][19]}. A recent experimental measurement has also indicated a similar tendency. Its report states that the fact that the mobile phone terminal is not held by the hand causes the maximum partial-body SAR in the head to be underestimated by no more than 5%^[20].

Therefore, the hand model does not need to be taken into consideration when evaluating the maximum partial-body SAR in the head.

Annex 2 Handling of multi-mode terminals

1 PDC full packet mode

In the PDC full packet and other communication modes that use all TDMA slots, the terminal is connected to a PDA or other device and is usually not used on the temporal side of the human head. This measurement method is therefore not applicable to these modes.

2 IMT-2000 mode

In data transmission and other communication modes that do not involve transmission or reception of voice traffic, the terminal is usually not used on the temporal side of the human head and, therefore, this measurement method is not applicable to these modes.

3 Communication mode supporting both voice and data

For a communication mode supporting both voice and data, conduct a measurement at the maximum antenna power level that can occur when the terminal is used on the temporal side of the human head.

Annex 3 Examples of the evaluation of measurement data processing

1 General

This annex shows examples of the scan and data processing that can be applied to Section 6.2.3.

2 Coarse scan to search for the maximum value

The SAR distribution is measured on a two- (x,y) or three-dimensional (x,y,z) grid, preferably covering as much of the exposed half of the head as possible. The exact location of the surface must be detected beforehand or determined during the scan by using an appropriate surface detection system mechanically or optically. For devices held in the close proximity of the human body and operating above 300 MHz, only a two-dimensional scan over the surface is sufficient to detect the peak SAR. The maximum spacing between the grid points should be determined for each evaluation technique. It has been shown that a 20 mm x 20 mm (x,y) grid is sufficient to reach the required precision if two staggered cubes are used to evaluate the location of the maximum value. The maximum partial-body SAR is evaluated on an interpolated 1-2 mm grid.

3 Cube scan

A cube scan can be performed in the following procedure: The SAR is evaluated in relation to a volume of 32 mm × 32 mm × 30 mm by measuring 5 × 5 × 7 points (x,y,z) around the partial-body SAR maximum SAR volume detected by the coarse scan. If the maximum value is detected on the surface, the surface of the cube is deformed at each measurement point so that it conforms to the phantom surface.

4 Extrapolation

The data for the surface must be obtained by extrapolation because the center of the small dipole antenna is in the inner side of the probe tip and there is a distance between the inner surface of the phantom and the measurement point closest to it. The extrapolation is based on a polynomial fit of the measured data, e.g., fourth order, by the least squares method (exponential fits are not suited for those cases where many distributions can occur). This polynomial is then used to extrapolate the SAR values between the surface and the probe tip in 1-mm steps (triangular values in Figure 1).

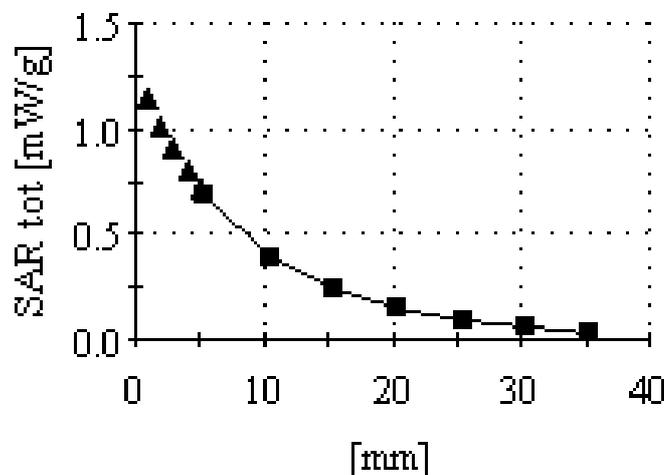


Figure 1 Example of Extrapolation of SAR Data to the Inner Surface of the Phantom

Note: ■ represents measured data; ▲ represents a value extrapolated in 1-mm steps by the

polynomial fit.

5 Interpolation

The values on a 1-mm grid within a measured and extrapolated cube can be interpolated easily, e.g., by using three staggered cubes.

6 Integration

An easy and accurate way to integrate over a 1-g or 10-g cube is by the common trapezoidal algorithm. If the cube touches the phantom surface, the evaluation procedure is as follows: The side of the maximum partial-body SAR cube touching the inner surface of the phantom is parallel to that surface, i.e., one side of the cube conforms to the phantom surface and the opposite side of the cube is also parallel to this surface, as shown in Figure 2.

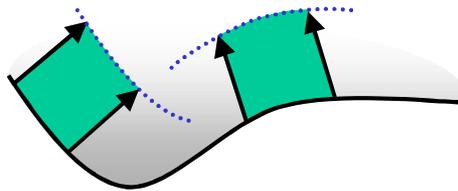


Figure 2 Orientation and Surface of the Cube Relative to the Phantom Surface

The maximum partial-body SAR must be determined by evaluating and comparing all possible states with relation to the 1-g or 10-g cube within the measured region. The process must be repeated until the maximum SAR value averaged over the cube volume is reached.

References

- (1) Telecommunications Technology Council Report, "Radio-Radiation Protection Guideline for Human Exposure to Electromagnetic Field", Jun., 25, 1990
- (2) Telecommunications Technology Council Report, "Radio-Radiation Protection Guideline for Human Exposure to Electromagnetic Field", Apr., 24, 1997
- (3) Association of Radio Industries and Businesses STANDARD RCR STD-38 Ver.2.0, "Standard for Protection Against Radiowave", Oct., 26, 1999
- (4) Association of Radio Industries and Businesses STANDARD ARIB STD-T56 Ver.1.0, "Specific Absorption Rate(SAR) Estimation for Cellular Phone", Jan., 27, 1998
- (5) EUROPEAN STANDARD prEN50361 "Basic standard for the measurement of Specific Absorption Rate related to human exposure to electromagnetic fields from mobile phones(300MHz - 4GHz)".
- (6) IEEE SCC34, "Recommended Practice for Determining the Spatial-Peak Specific Absorption Rate(SAR) in the Human Body Due to Wireless Communications Devices: Experimental Techniques"
- (7) IEC "Guide to the expression of uncertainty in measurement", Ed. 1, 1995
- (8) N.Kuster, R., Kästle, and T.Schmid, "Dosimetric evaluation of handheld mobile communications equipment, with known precision", IEICE Trans. Commun., vol.E80-B, pp.645-652, May 1997
- (9) IEC/PT62209, "Procedure to Determine the Specific Absorption Rate (SAR) for Hand-Held Mobile Telephones"
- (10) S.Omori, I Yokoshima, H.Nakane, "High Frequency and Microwave Measurement", CORONA PUBLISHING CO.,LTD., pp.134-136, Feb.1992
- (11) "HP8570A Dielectric Probe kit Data Sheet", HP Literature Number 5952-2381, Feb. 1991
- (12) E.C.Burdette, F.L.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, vol. MTT-28, no.4, pp414-427, Apr. 1980
- (13) "HP85071A Transmission Line Software Data Sheet", HP Literature Number 5952-2382, Feb. 1991
- (14) H.R. Garner, A.C.Lewis, and T.Ohkawa, "Measurement of the Microwave Absorption for Small Samples in a Coaxial Line", IEEE Transactions on Microwave Theory and Techniques, vol.39, no.5, May, 1991
- (15) Schönborn, F., M. Burkhardt and N. Kuster, "Differences in Energy Absorption Between Heads of Adults and Children in the Near Field of Sources.", Health Physics, vol. 74, pp. 160-168, 1998.
- (16) Gordon et al., 1988 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics, Technical Report NATICK/TR-89/044 ,(1989)
- (17) S.Watanabe, M.Taki, T.Nojima, and O.Fujiwara, "Characteristics of the SAR distributions in a head exposed to electromagnetic fields radiated by a hand-held portable radio", IEEE Trans. Microwave Theory Tech., vol.44, Oct., 1996
- (18) V.Hombach, K.Meier, M.Burkhardt, E.Kühn, and N.Kuster, "The dependence of EM energy absorption upon human head modeling at 900MHz", IEEE Trans. Microwave Theory Tech., vol.44, pp.1865-1873, Oct., 1996
- (19) M.A.Jensen and Y.Rahmat-Samii, "Performance analysis of antennas for hand-held transceivers using FDTD", IEEE Trans. Antennas Propag., vol.42, pp.1106-1113, Aug., 1994
- (20) N. Kuster, Q. Balzano, and J.C. Lin, Eds., "Mobile Communications Safety", Chapman & Hall, London, 1997.

Reference Materials

- Reference Material 1: 1990 Telecommunications Technology Council Report
"Radio-Radiation Protection Guidelines for Human Exposure to
Electromagnetic Fields" (Excerpts)
- Reference Material 2: 1997 Telecommunications Technology Council Report
"Radio-Radiation Protection Guidelines for Human Exposure to
Electromagnetic Fields" (Excerpts)
- Reference Material 3: Validation Tests for the Measurement Method
- Reference Material 4: Calibration of the SAR Measurement Equipment

Reference Material 1

Telecommunications Technology Council Report Report No. 38 "Radio-Radiation Protection Guidelines for Human Exposure to Electromagnetic Fields" (Excerpts) (June 25, 1990)

Chapter 1 Purpose and Scope

The radio-radiation protection guidelines are established for the purpose of assisting in the proper development of the radio system that is in social and economic demand, by securing the safety of human bodies from the operation of radio facilities. The guidelines provide basic conceptions and permissive values to evaluate the safety of an electromagnetic field to which human bodies are exposed, i.e. whether or not the electromagnetic field possibly induces undesirable phenomena in human bodies (such as a temperature rise in the inner body, an electric shock, or a high-frequency burn). They also provide several methods of measuring and estimating an electromagnetic field strength around a radio facility and some measures to protect human bodies from exposure. The guidelines thus give the basis for establishing safety standards, recommendations, or implementation manuals for radio use. The permissive values shown here are presumed sufficient safety factors for human bodies, and it is not implied that the excess of any of these values directly causes an adverse effect on the human body.

The scope of the guidelines is the frequencies from 10 kHz to 300 GHz, considering the present spectrum allocation and the technological trends in radio use, while it is desirable that the entire frequency range (below 3,000 GHz) defined in Article 2 of the Radio Law is covered.

The guidelines should generally be applied to all aspects of radio-radiation exposure, i.e. not only exposure at the workplace but also exposure in other daily activities. The application of these guidelines should be based on due consideration for various factors, such as characteristics of radio radiation sources and actual condition of exposure, as well as on the basic conceptions of the guidelines.

The guidelines are established based on the common understanding of experts. However, there still remain some tentative aspects. Therefore, as studies on this field progress and new scientifically proved facts and conceptions are developed, the guidelines should be revised accordingly.

Chapter 3 Protection Guidelines

3.1 Characteristics and structure

3.1.1 Physiological effects of electromagnetic fields

The tissues of a human body are considered as a conductive object with certain electric constants in terms of electromagnetism. With regard to the interactions between electromagnetic fields and human bodies, theoretical analysis has been conducted from the viewpoint of the electrical characteristics of the human body, and experimental analytical methods have been established by using electromagnetic phantoms whose conductivity and

permittivity are the same as those of the human body. According to the results of these studies, physiological effects of electromagnetic fields can be classified into thermal effects, stimulation effects, and other effects, as shown in Table 1.

Table 1 Relationship between electromagnetic waves and physiological effects

Effect type		Factors of physiological changes	Quantities to be evaluated	Relationship with electromagnetic waves
Thermal effects	Whole body heating	Heat adjustment response Rise in inner body temperature Thermal stress	Whole body average SAR Temperature increase (inner body)	Macro-level interaction (Dosimetric approaches can be applied.)
	Partial body heating	Heating of organism	Partial body average SAR Temperature increase (particular part of organism)	
Stimulation effects		Excitation of nerves and muscles due to electrical stimulus	Induced current (density)	
Other effects		Unknown	Electromagnetic field strength, etc. (modulated frequency)	Micro-level interaction

Of these physiological effects, many studies have been conducted on thermal and stimulation effects, and their casual relationship with the electromagnetic field strength has been quantitatively identified. The results of these studies indicate that stimulation effects are dominant in the frequency range below 100 kHz, whereas thermal effects are dominant in the range above 100 kHz. Other effects, however, have not been identified in relation to phenomena in the organism and have therefore not been determined to be harmful to human health.

For these reasons, the physiological effects of an electromagnetic field are limited to thermal and stimulation effects in the radio-radiation protection guidelines. Effects caused by pulse waves and modulated waves are included so long as they are regarded as thermal or stimulation effects. Contact current induced by an electromagnetic field is also taken into account, though it is not an effect that an electromagnetic field directly causes on the human organism.

It should be noted that while foreign countries have also established radio-radiation protection guidelines based on similar conceptions, any undesirable effects, including thermal effects, stimulation effects, and other effects, have not been observed within the scope of those guidelines.

3.1.2 Problems of evaluating physiological effects

Thermal effects of an electromagnetic field on the human organism induce a rise in the body temperature due to the Joule heat generated in the tissue. This temperature increase is closely related to the amount of energy absorbed by the tissue and is evaluated in terms of specific absorption rate (SAR), or the amount of energy absorbed by the unit mass of tissue during the unit time. On the other hand, stimulation effects are related to the current density induced in the tissue of the human body. Both SAR and induced current are considered to be dependent on the electric field strength in the human body tissue and the conductivity of the tissue.

Thus, physiological effects of an electromagnetic field have a close relationship with the electric field strength in the tissue. Since the electric field strength in the tissue is not directly measurable, however, the electromagnetic phenomena in the inner body must be estimated by alternative means. However, there are no formally established estimation procedures yet, and a few research institutions are making estimations by their own particular methods. At present, therefore, it is not typical to measure the electromagnetic phenomena in the inner body.

The radio-radiation protection guidelines must be designed to help us quickly evaluate the safety of radio equipment in various situations where we have to use such equipment. The guidelines would be of little use if they were described in terms of quantities that cannot directly be measured with relation to the electromagnetic phenomena in the body. Therefore, it is necessary to evaluate the safety by converting the electromagnetic phenomena in the body into measurable quantities (electromagnetic field strength or electrical current).

3.1.3 Structure of the radio-radiation protection guidelines

In general, the radio-radiation protection guidelines will be applied to the following three cases:

- 1) Evaluation of an electromagnetic environment in a given space,
- 2) Evaluation of radiation from radio equipment and use of such equipment, and
- 3) Evaluation of protection measures against electromagnetic fields.

Case 1 involves evaluation of an electromagnetic field where the existence of human beings are electrically negligible. If the source of radio radiation is far enough and if a metallic or other object that might scatter radio waves is not in the close proximity of the body, the electromagnetic phenomena in the human body can be considered to have a more or less fixed relationship to the electric field strength and magnetic field strength measured when no human being is in the space. Under these conditions, the radio-radiation protection guidelines can be set based on the electromagnetic field strength in a space where no human being exists. These guidelines are referred to as the electromagnetic strength guidelines. However, they cannot be applied to all cases because electromagnetic fields are sometimes non-uniform in the near-field region of the source. For these inapplicable electromagnetic environments, evaluation of the electromagnetic environment in a given space may not be appropriate. This situation is discussed in case 2.

Case 2 involves evaluation of the interrelationship between the source of electromagnetic radiation and the human body. If there is a constant relationship between the source and the body, evaluation of this relationship can be regarded as evaluation of the source itself. In other words, although the case 1 approach can be used if the source is sufficiently remote, evaluation must generally be conducted based on the electromagnetic phenomena in the body. The guidelines for evaluation based on the electromagnetic phenomena in the body

are referred to as the basic guidelines.

However, the basic guidelines include descriptions using quantities whose measurement is difficult, it will be difficult to apply the guidelines as the actual radio-radiation protection guidelines for the evaluation of all case 2 problems. To address the case 2 problems more practically, it is necessary to set guidelines based on evaluation of measurable quantities. Such guidelines are referred to as the supplementary guidelines. These guidelines supplement the electromagnetic field strength guidelines in accordance with the basic guidelines and consist of the following four sections:

- (1) Non-uniform or partial-body electromagnetic field exposure,
- (2) Contact current,
- (3) Induced current, and
- (4) Low-power radiation sources.

It should be noted that case 2 should ideally be considered in terms of the basic guidelines since the supplementary guidelines can only provide a simplified evaluation method for the electromagnetic phenomenon in the body.

Case 3 includes problems that can be addressed only through direct evaluation of the electromagnetic phenomenon in the body. Such problems requires evaluation in accordance with the basic guidelines and, therefore, careful estimation and evaluation at research institutes are required.

The radio-radiation protection guidelines are thus composed of the electromagnetic field strength guidelines, the supplementary guidelines, and the basic guidelines. The first two guidelines are intended for the application to practical uses and will be referred to as the administrative guidelines. The basic guidelines provide the basis for the administrative guidelines as well as the basis for safety evaluation of special cases that cannot be covered by the administrative guidelines.

The radio-radiation protection guidelines have been established on the basis of the current research results and the actual conditions of radio spectrum use. For this reason, the guidelines should be supplemented or revised in response to changes in the situations. Advances in the studies on physiological effects of electromagnetic fields should be reflected mainly in the basic guidelines, while advances in the studies on methods of measurement and evaluation of electromagnetic phenomena in the tissue, as well as development of radio spectrum use, should be reflected in the administrative guidelines. Given the nature of these guidelines, the basic guidelines should not be readily revised, while the administrative guidelines may be modified as required.

3.1.4 Two-stage structure of the administrative guidelines

To ensure that evaluations based on the protection guidelines are reliable, it is necessary to verify, as required, that the protection guidelines are being used adequately and that the electromagnetic environment remains unchanged. If these situations can be verified and controlled, the administrative guidelines (electromagnetic field strength guidelines or supplementary guidelines), which are based on the permissive values obtained through conversion from the basic guidelines, should be applied. However, in case the conditions of radio use are not well recognized, there is a risk of unintentional failure to satisfy the basic guidelines. Sufficient attention to the electromagnetic fields cannot be expected in such a case. Therefore, in order to secure a sufficient degree of safety under such circumstances, it is necessary to establish guidelines that consider additional safety factors, as other foreign countries have done.

From this perspective, the administrative guidelines are divided into condition P, under which the objectives of the radio-radiation protection guidelines are well recognized and the

electromagnetic environment is under control, and condition G, under which neither the radio-radiation protection guidelines nor the conditions of radio use are well understood. The safety factor for condition G is set to about five times as high as that for condition P in terms of power density, considering the uncertainty resulting from insufficient control of the electromagnetic fields under condition G.

3.1.5 Application procedures for the radio-radiation protection guidelines

The following procedures should be taken to apply the radio-radiation protection guidelines, which consist of the administrative guidelines (electromagnetic field strength guidelines or supplementary guidelines) and the basic guidelines.

In actual evaluation, the electromagnetic field strength guidelines are first applied regardless of the conditions of the source of emission. Condition P should be applied if the circumstances of radio use are well recognized and controlled based on the radio-radiation protection guidelines; otherwise, condition G should be applied. A particular space (place) is considered safe if the electromagnetic field strength guidelines are satisfied.

The electromagnetic field is often non-uniform or in the near-field region. Under these conditions, the evaluation based on the electromagnetic field strength guidelines tends to exceed the actual electromagnetic field strength. Therefore, if the electromagnetic field strength guidelines are not satisfied, the supplementary guidelines should be applied for detailed safety evaluation.

If these evaluation procedures show that the administrative guidelines for condition G are not satisfied, either such conditions must be controlled as condition P or measures must be taken to satisfy the guidelines. If the administrative guidelines for condition P fail to be met, the basic guidelines may not be satisfied. In this case, corrective measures should be taken, or the basic guidelines should be applied to evaluate the possibility of hazards to human bodies more directly.

Evaluation based on the basic guidelines includes certain quantities for which concrete methods of measurement or evaluation have not been fully established. For this reason, the radio-radiation protection guidelines illustrate only several evaluation methods. These evaluations should be made based on the methods that are recognized as appropriate methods by research institutes.

3.2 Administrative guidelines

The administrative guidelines have been established based on the basic guidelines and are used for the actual evaluations of an electromagnetic environment. These guidelines are composed of the electromagnetic field strength guidelines and the supplementary guidelines and are applied based on the measurement and estimation methods for the electromagnetic field strength shown in Chapters 4 and 5.

3.2.1 Electromagnetic field strength guideline values

(1) Condition P

The electromagnetic field strength guideline values for condition P are shown in Tables 2(a) and 2(b).

If an electromagnetic field strength in any part of the space to be measured fails to satisfy the permissive values, the supplementary guidelines given in Section 3.2.2 (1) should be applied.

Figures 1 and 2 show graphs of the permissive values in Tables 2(a) and 2(b).

**Table 2(a) Electromagnetic Field Strength Guidelines for Condition P
(Average Time: 6 Minutes)**

Frequency f	rms electric field strength E [V/m]	rms magnetic field strength H [A/m]	Power density S [mW/cm ²]
10 kHz - 30 kHz	614	163	
30 kHz - 3 MHz	614	$4.9f^{-1}$ (MHz) (163 - 1.63)	
3 MHz - 30 MHz	$1,842f^{-1}$ (MHz) (614 - 61.4)	$4.9f^{-1}$ (MHz) (1.63 - 0.163)	
30 MHz - 300 MHz	61.4	0.163	1
300 MHz - 1.5GHz	$3.54f^{1/2}$ (MHz) (61.4 - 137)	$f(\text{MHz})^{1/2}/106$ (0.163 - 0.365)	$f(\text{MHz})/300$ (1 - 5)
1.5 GHz - 300 GHz	137	0.365	5

**Table 2(b) Electromagnetic Field Strength Guidelines for Condition P at Low
Frequencies
(Average Time < 1 Second)**

Frequency f	rms electric field strength E (V/m)	rms magnetic field strength H (A/m)
10 kHz - 100 kHz	2,000	163

Note 1: When contact hazard is not prevented, the rms electric field strength must not exceed 137 V/m (average time < 1 second) at frequencies below 15 MHz. Even if this requirement fails to be met, however, Section 3.2.2 (2) can be applied when the practical value is less than the values shown in Tables 2(a) and 2(b).

Note 2: When the isolated condition for the human body is not met, the rms electric field strength (average time: 6 minutes) must not exceed $3,200f^{-3/2}$ V/m (i.e., 614 V/m to 20 V/m) for frequencies from 3 MHz to 30 MHz, 20 V/m for frequencies from 30 MHz to 100 MHz, and $0.2f$ V/m (i.e., 20 V/m to 61.4 V/m) for frequencies from 100 MHz to 300 MHz, where f denotes the frequency in MHz. Even if this requirement fails to be met, however, Section 3.2.2 (3) can be applied when the practical value is less than the values shown in Table 2(a).

Note 3: When either the electric field strength or the magnetic field strength varies within the average time shown in Table 2(a), the square root of the squares of the rms value averaged over the average time should be used. When the power density varies within the average time, the average of rms values over the average time should be used.

Note 4: When the electromagnetic field comprises multiple frequency components of significant levels with respect to the guideline values, determine the ratio of the squared electric and magnetic field strengths of each frequency component to the square of its corresponding guideline value. Likewise, determine the ratio of the power density of each frequency component to its guideline value. The sum of these fractions must not exceed 1.

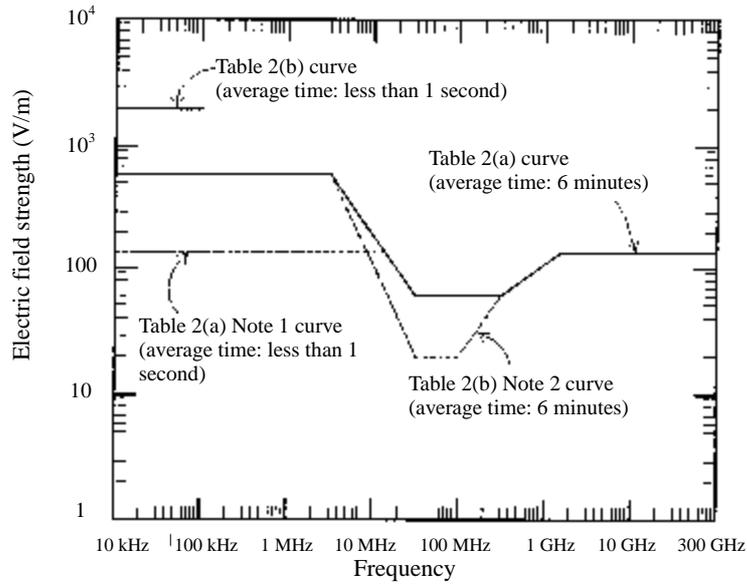


Figure 1 Electric Field Strength Guidelines (Condition P)

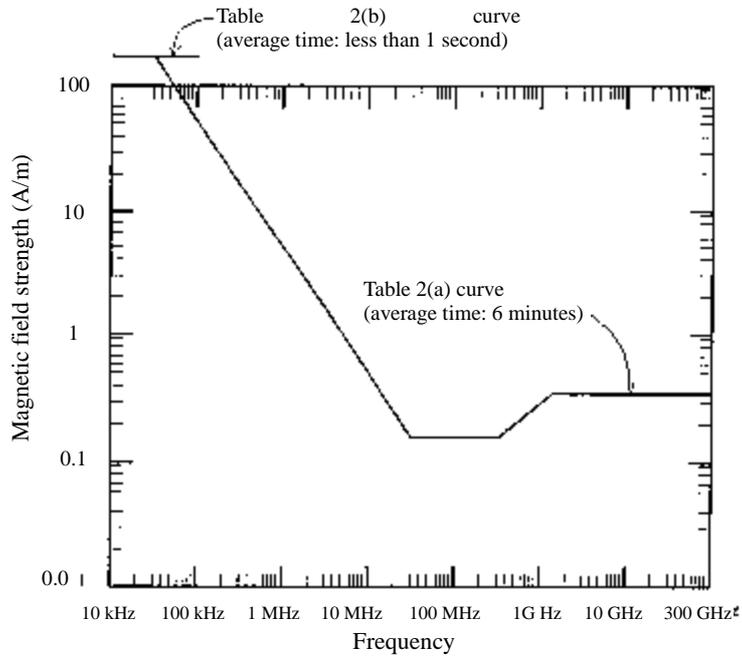


Figure 2 Magnetic Field Strength Guidelines (Condition P)

(2) Condition G

The electromagnetic field strength guideline values for condition G are shown in Tables 3(a) and 3(b).

If an electromagnetic field strength in any part of the space to be measured fails to satisfy the permissive values, the supplementary guidelines given in Section 3.2.2 (1) should be applied.

Figures 3 and 4 show graphs of the permissive values in Tables 3(a) and 3(b).

**Table 3(a) Electromagnetic Field Strength Guidelines for Condition G
(Average Time: 6 Minutes)**

Frequency f	rms electric field strength E [V/m]	rms magnetic field strength H [A/m]	Power density S [mW/cm ²]
10 kHz - 30 kHz	275	72.8	
30 kHz - 3 MHz	275	2.18f ⁻¹ (MHz) (72.8 - 0.728)	
3 MHz - 30 MHz	824f ⁻¹ (MHz) (275 - 27.5)	2.18f ⁻¹ (MHz) (0.728 - 0.0728)	
30 MHz - 300 MHz	27.5	0.0728	0.2
300 MHz - 1.5 GHz	1.585f ^{1/2} (MHz) (27.5 - 61.4)	f ^{1/2} (MHz)/237.8 (0.0728 - 0.163)	f(MHz)/1500 (0.2 - 1)
1.5 GHz - 300 GHz	61.4	0.163	1

**Table 3(b) Electromagnetic Field Strength Guidelines for Condition G at Low
Frequencies (Average Time < 1 Second)**

Frequency f	rms electric field strength E (V/m)	rms magnetic field strength H (A/m)
10 kHz - 100 kHz	894	72.8

Note 1: When contact hazard is not prevented, the rms electric field strength must not exceed 61.4 V/m (average time < 1 second) at frequencies below 15 MHz. Even if this requirement is fails to be met, however, Section 3.2.2 (2) can be applied when the practical value is less than the values shown in Tables 3(a) and 3(b).

Note 2: When the isolated condition for the human body is not met, the rms electric field strength (average time: 6 minutes) must not exceed 1,430f^{-3/2}V/m (i.e., 275 V/m to 9 V/m) for frequencies from 3 MHz to 30 MHz, 9 V/m for frequencies from 30 MHz to 100 MHz, and 0.09f V/m (i.e., 9 V/m to 27 V/m) for frequencies from 100 MHz to 300 MHz, where f denotes the frequency in MHz. Even if this requirement fails to be met, however, Section 3.2.2 (3) can be applied when the practical value is less than the values shown in Table 3(a).

Note 3: When either the electric field strength or the magnetic field strength varies within the average time shown in Table 3(a), the square root of the squares of the rms value averaged over the average time should be used. When the power density varies within the average time, the average of rms values over the average time should be used.

Note 4: When the electromagnetic field comprises multiple frequency components of significant levels with respect to the guideline values, determine the ratio of the squared electric and magnetic field strengths of each frequency component to the square of its corresponding guideline value. Likewise, determine the ratio of the power density of each frequency component to its guideline value. The sum of these fractions must not exceed 1.

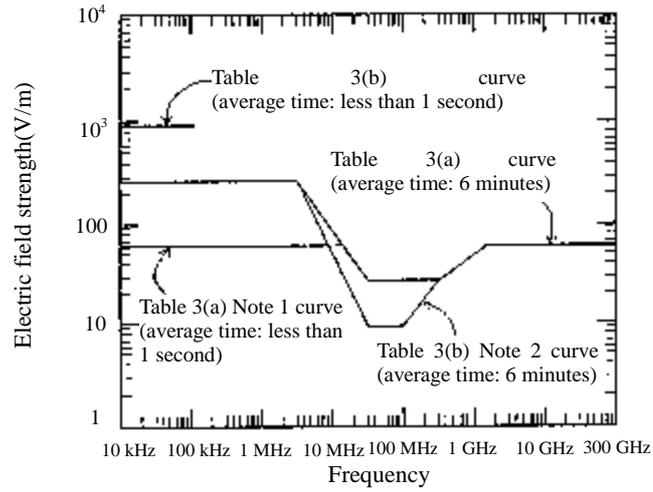


Figure 3 Electric Field Strength Guidelines (Condition G)

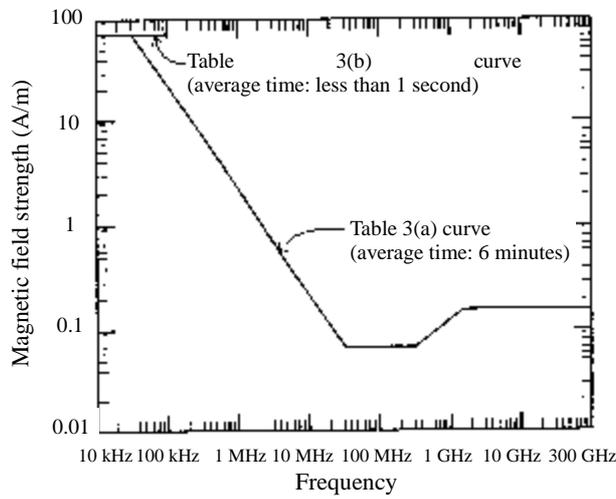


Figure 4 Magnetic Field Strength Guidelines (Condition G)

3.2.2 Supplementary guidelines

These guidelines are used to enable more detailed evaluation with respect to such factors as the conditions of exposure to the human body and physiological effects to be considered, if the electromagnetic field strength guidelines alone are not sufficient for demonstrating that the radio-radiation protection guidelines are met.

(1) Guidelines for use in cases of non-uniform or partial-body exposure to electromagnetic fields

The administrative guidelines can be considered to be satisfied if all the conditions for the frequency ranges concerned have been fulfilled.

If any of the frequency ranges concerned overlaps two of the subdivisions listed below, calculate the ratio of the squared value for each frequency component to the square of its corresponding guideline value for i), ii) (a) and (b), and iii) (a) and (b). The sum of these fractions must not exceed 1.

For radio devices to be used in spaces within 20 cm from the human body (within 10 cm at frequencies over 300 MHz), judgment must be made for each particular situation. If there is a risk of exceeding the values indicated in the basic guidelines, evaluation should preferably be done in accordance with the basic guidelines.

i) Frequencies below 300 MHz

In spaces separated by 20 cm or more from electromagnetic radiation sources and metallic objects, the spatial average of the power density distribution over the entire region to be occupied by the human body (the root-mean-square of the electric field strength or magnetic field strength) should not exceed the value of the electromagnetic field strength guidelines (Section 3.2.1) for the corresponding condition (Condition P or G).

Notes 1 through 4 for Table 2 or 3 also apply to this section.

ii) Frequencies from 300 MHz to 1 GHz

(a) In spaces separated by 10 cm or more from electromagnetic radiation sources and metallic objects, the spatial average of the power density distribution over the entire region to be occupied by the human body (the root-mean-square of the electric field strength or magnetic field strength) should not exceed the value of the electromagnetic field strength guidelines (Section 3.2.1) for the corresponding condition (Condition P or G).

Notes 1 through 4 for Table 2 or 3 also apply to this section.

(b) The special maximum of the power density in the region occupied by the human body, excluding the extremities, should not exceed 20 mW/cm² (6-minute average value). However, this refers only to spaces separated by 10 cm or more from electromagnetic radiation sources and metallic objects.

Notes 3 and 4 for Table 2 or 3 also apply to this section.

iii) Frequencies from 1 GHz to 3 GHz

(a) In spaces separated by 10 cm or more from electromagnetic radiation sources and metallic objects, the spatial average of the power density distribution over the entire region to be occupied by the human body (the root-mean-square of the electric field strength or magnetic field strength) should not exceed the value of the electromagnetic field strength guidelines (Section 3.2.1) for the corresponding condition (Condition P or G).

Notes 1 through 4 for Table 2 or 3 also apply to this section.

(b) The special maximum of the power density in the region occupied by the human

body, excluding the extremities, should not exceed 20 mW/cm² (6-minute average value). However, this refers only to spaces separated by 10 cm or more from electromagnetic radiation sources and metallic objects.

Notes 3 and 4 for Table 2 or 3 also apply to this section.

- (c) The special maximum of the power density incident to the human head should not exceed 10 mW/cm² (6-minute average value). However, this refers only to spaces separated by 10 cm or more from electromagnetic radiation sources and metallic objects.

Notes 3 and 4 for Table 2 or 3 also apply to this section.

iv) Frequencies above 3 GHz

- (a) In spaces separated by 10 cm or more from electromagnetic radiation sources and metallic objects, the spatial average of the power density distribution over the entire region to be occupied by the human body (the root-mean-square of the electric field strength or magnetic field strength) should not exceed the value of the electromagnetic field strength guidelines (Section 3.2.1) for the corresponding condition (Condition P or G).

Notes 1 through 4 for Table 2 or 3 also apply to this section.

- (b) In spaces separated by 10 cm or more from electromagnetic radiation sources and metallic objects, the special maximum of the power density incident to the skin surface should not exceed 50 mW/cm² for Condition P or 10 mW/cm² for Condition G (6-minute average value).

Notes 3 and 4 for Table 2 or 3 also apply to this section.

- (c) In spaces separated by 10 cm or more from electromagnetic radiation sources and metallic objects, the power density incident to the eye should not exceed 10 mW/cm² (6-minute average value).

Notes 3 and 4 for Table 2 or 3 also apply to this section.

All of the above conditions are summarized in Table 4.

Table 4 Supplementary Guidelines for Cases of Non-uniform or Partial-body Exposure

	10 kHz - 300 MHz	300 MHz - 1 GHz	1 GHz - 3 GHz	3 GHz - 300 GHz
Spatial average of electromagnetic field strength	Condition P: Must not exceed the values of the electromagnetic field strength guidelines shown in Table 2 (Notes 1 through 4 also apply). Condition G: Must not exceed the values of the electromagnetic field strength guidelines shown in Table 3 (Notes 1 through 4 also apply).			
Spatial maximum of electromagnetic field strength	Other than extremities: 20 mW/cm ²		Skin surface: Condition P: 50 mW/cm ² Condition G: 10 mW/cm ²	
			Head: 10 mW/cm ²	Eyes: 10 mW/cm ²
Relevant space	Space occupied by the human body and separated by 20 cm or more from electromagnetic radiation sources and metallic objects	Space occupied by the human body and separated by 10 cm or more from electromagnetic radiation sources and metallic objects		

Note: The "guidelines for use in cases of non-uniform or partial-body exposure to electromagnetic fields" are clarified in the Radio-Radiation Protection Guidelines for Human Exposure to Electromagnetic Fields published in 1997 by the Telecommunications Technology Council.

(2) Guidelines for contact current

(a) When contact hazard is not prevented under Condition P

The requirement given in Note 1 for Table 2 does not need to be met if the contact current measured at frequencies from 10 kHz to 100 kHz (average time < 1 second) does not exceed 10-3f(Hz) mA, or the contact current measured at frequencies from 100 kHz to 15 MHz does not exceed 100 mA.

However, if the contact current comprises multiple frequency components of significant levels with respect to the guideline values, calculate the ratio of the squared contact current of each frequency component to the square of its corresponding guideline value. The sum of these fractions must not exceed 1.

(b) When contact hazard is not prevented under Condition G

The requirement given in Note 1 for Table 3 does not need to be met if the contact current measured at frequencies from 10 kHz to 100 kHz (average time < 1 second) does not exceed $4.5 \times 10^{-4}f(\text{Hz})$ mA, or the contact current measured at frequencies from 100 kHz to 15 MHz does not exceed 45 mA.

However, if the contact current comprises multiple frequency components of significant levels with respect to the guideline values, calculate the ratio of the squared contact current of each frequency component to the square of its corresponding guideline value. The sum of these fractions must not exceed 1.

(3) Guidelines for induced current

(a) When the isolated condition is not met under Condition P

The requirement given in Note 2 for Table 2 does not need to be met if the induced current measured at the ankles at frequencies from 3 MHz to 300 MHz (average time: 6 minutes) does not exceed 100 mA per ankle.

However, if the induced current comprises multiple frequency components of significant levels with respect to the guideline values, calculate the ratio of the square induced current of each frequency component to the square of its

corresponding guideline value. The sum of these fractions must not exceed 1.

(b) When the isolated condition is not met under Condition G

The requirement given in Note 2 for Table 3 does not need to be met if the induced current measured at the ankles at frequencies from 3 MHz to 300 MHz (average time: 6 minutes) does not exceed 45 mA per ankle.

However, if the induced current comprises multiple frequency components of significant levels with respect to the guideline values, calculate the ratio of the square induced current of each frequency component to the square of its corresponding guideline value. The sum of these fractions must not exceed 1.

(4) Guidelines for low-power radiation sources

Electromagnetic radiation sources with a rated output of 7 watts or less at frequencies from 100 kHz to 3 GHz do not require evaluation under the administrative guidelines or other supplementary guidelines since they are considered to satisfy the basic guidelines under normal usage conditions. Caution should be taken, however, when the radiation source is extremely close to the human body or when the radiated energy concentrates in a particular direction because a large SAR may be induced partially in such cases.

Note: The "guidelines for low-power radiation sources" have been deleted because they are included in the partial-body absorption guidelines in the report submitted in 1997 by the Telecommunications Technology Council (Radio-Radiation Protection Guidelines for Human Exposure to Electromagnetic Fields).

3.3 Basic guidelines

The basic guidelines, presented in Table 5, provide both the conceptual basis for the administrative guidelines and the grounds for judging the possibility of physiological effects occurring.

Table 5 Basic Guidelines

<ol style="list-style-type: none">1 The whole-body averaged SAR over any given 6-minute period must not exceed 0.4 W/kg.2 At frequencies between 10 kHz and 100 kHz, the induced current density in the tissue must not exceed $0.35 \times 10^{-4} f[\text{Hz}] \text{ mA/cm}^2$.3 The current flowing in from the outside the body, such as contact current, must not exceed $10^{-3} f[\text{Hz}] \text{ mA}$ (average time < 1 second) at frequencies between 10 kHz and 100 kHz, or 100 mA (average time: 6 minutes) at frequencies between 100 kHz and 100 MHz.4 In addition to 1, 2, and 3 above, the following conditions should also be taken into account:<ol style="list-style-type: none">(a) Even though the whole-body averaged SAR over any given 6-minute period is below 0.4 W/kg, the SAR for any 1 gram of tissue (average time: 6 minutes) should not exceed 8 W/kg (25 W/kg for the skin surface and extremities).(b) At frequencies below 3 GHz, the power density incident to the eye must not exceed 10 mW/cm^2 (average time: 6 minutes).
--

3.4 Remarks

(1) Radio use for medical purposes

For medical uses of electromagnetic waves, the radio-radiation protection guidelines apply to electromagnetic field exposure by medical professionals. However, the guidelines do not apply to exposure to patients, which must be considered with regard to its medical benefits, and such exposure is therefore not covered as long as the medical practitioner's use of electromagnetic waves is based on a full understanding of the safety limitations shown in the guidelines. Although radio radiation may be effective, for instance, for knee joint treatment, such radio use can be dangerous to other parts of the body. For this reason, it should be avoided to irradiate electromagnetic waves over an unnecessarily wide range of the body, and caution needs to be taken to prevent electromagnetic field leakage.

(2) Pacemaker users

The radio-radiation protection guidelines do not apply to pacemaker users, who should follow their doctor's instructions when using radio devices.

(3) People with metallic objects embedded in their bodies

Caution must be taken when the person has a metallic object embedded in his or her body, since even an electromagnetic field strength that is below the limits set by the guidelines can cause unexpected phenomena such as heat in a particular part of the body.

(4) People wearing metallic objects

Caution must be taken when the person is wearing a metallic object, especially near an induction heater, since the metal can generate heat even at an electromagnetic field strength that is below the limits set by the guidelines.

Reference Material 2

Telecommunications Technology Council
Report No. 89 "Radio-Radiation Protection Guidelines for Human
Exposure to Electromagnetic Fields" (Excerpts)
(April 24, 1997)

4 Partial-body absorption guidelines

4.1 Necessity of clarifying guidelines for low power radiation sources such as mobile phone terminals

After the first radio-radiation protection guidelines were published by the Telecommunications Technology Council in 1990, handy small-sized radio equipment such as mobile phone terminals have been developed one after another and become popular. We now have a situation where it is increasingly frequent for us to be exposed to low power radiation sources in the close proximity of the human body such as the head. However, there is no clear description in the previous guidelines about the limits for exposures from such low power radiation sources.

Fortunately, inner-body SAR measurement systems using phantoms have recently developed to keep pace with the development of small-sized equipment, whereas such systems were formerly available only to special institutes and were not accurate enough. Therefore, it is necessary to rapidly establish concrete, easy-to-understand guidelines concerning low power radiation sources in order to avoid misunderstanding among general users and prevent them from becoming unduly anxious about radio equipment.

4.2 Amendment to the administrative guidelines

Considering the results of recent research reports, international trends of human exposure guidelines, and rapidly growing use of mobile phone terminals, it is recommended to amend the administrative guidelines in the radio-radiation protection guidelines of 1990.

With this amendment, the guidelines for low power radiation sources in the current supplementary guidelines will be deleted and partial-body absorption guidelines will be newly established for low power radiation sources. This amendment considers the compatibility with international recommendations from International Commission on Non-Ionizing Radiation Protection (ICNIRP) and other organizations and aims to provide easy-to-understand guidelines concerning low power radiation sources such as mobile phone terminals. The new administrative guidelines consist of electromagnetic field strength guidelines, supplementary guidelines, and partial-body absorption guidelines.

(1) Electromagnetic field strength guidelines

Same as the electromagnetic field strength guidelines in the previous radio-radiation protection guidelines published in 1990.

(2) Supplementary guidelines

The supplementary guidelines in the previous radio-radiation protection guidelines will be replaced by new supplementary guidelines, as shown in Annex 1, as a result of the establishment of the partial-body absorption guidelines.

(3) Partial-body absorption guidelines

(3-1) Application of the partial-body absorption guidelines

The partial-body absorption guidelines apply to frequencies from 100 kHz to 3 GHz.

The guidelines are basically intended for small-sized radio equipment, such as mobile phone terminals, whose antenna and case contributing to an electromagnetic field source are used in the extreme proximity of the human body. These guidelines are generally applied to those cases where the distance between the human body and the electromagnetic field source (typically the antenna) and metallic parts (case, etc.) is no more than 20 cm at frequencies from 100 kHz to 300 MHz, or no more than 10 cm at frequencies from 300 MHz to 3 GHz. At longer distances, if either the former administrative guidelines (electromagnetic field strength guidelines and supplementary guidelines) or the partial-body absorption guidelines are met, then the basic guidelines may be considered to be satisfied.

(3-2) Controlled environment

All the following conditions must be satisfied.

<1> The whole-body averaged SAR over any given 6-minute period must not exceed 0.4 W/kg.

<2> The partial-body SAR for any 10-gram tissue must not exceed 10 W/kg (6-minute average time) (20 W/kg for extremities).

<3> When contact hazard is not prevented, the contact current must not exceed 100 mA (6-minute average time) at frequencies from 100 kHz to 100 MHz.

However, if the contact current comprises multiple frequency components of significant levels with respect to the guideline values, calculate the ratio of the squared contact current of each frequency component to the square of its corresponding guideline value. The sum of these fractions must not exceed 1.

Note: Radio stations operating at frequencies above 100 MHz do not require evaluation based on the guideline condition described in <3> with relation to the contact current.

(3-3) General environment

All the following conditions must be satisfied.

<1> The whole-body averaged SAR over any given 6-minute period must not exceed 0.08 W/kg.

<2> The partial-body SAR for any 10-gram tissue must not exceed 2 W/kg (6-minute average time) (4 W/kg for extremities).

<3> When contact hazard is not prevented, the contact current must not exceed 45 mA (6-minute average time) at frequencies from 100 kHz to 100 MHz.

However, if the contact current comprises multiple frequency components of significant levels with respect to the guideline values, calculate the ratio of

the squared contact current of each frequency component to the square of its corresponding guideline value. The sum of these fractions must not exceed 1.

Note: Radio stations operating at frequencies above 100 MHz do not require evaluation based on the guideline condition described in <3> with relation to the contact current.

4.3 Remark

Cautions to radio users for medical purposes, pacemaker users, and people with metallic objects embedded in their body are the same as those given in the former radio-radiation protection guidelines published in 1990.

Recently, there have been some reports in the mass media citing concern about possible effects of radio waves on the human body on the grounds that they have adverse effects on electronic medical devices such as pacemakers. Such reports are not scientifically correct, however. Radio waves affect pacemakers and other electronic medical devices because electromagnetically induced signals in the circuitry of such devices cause them to malfunction. These effects should not be treated in the same manner as the influence of radio waves on the human body. For the guidelines to safeguard electronic medical devices from being affected by radio equipment such as mobile phone terminals, refer to "Guidelines on the Use of Radiocommunication Equipment Such As Cellular Telephones - Safeguards for Electronic Medical Equipment," which was published by the Electromagnetic Compatibility Council in March 1997.

I Electromagnetic field strength guidelines (abstract) [Same as the existing guidelines (no changes)]

**Table 1 Electromagnetic Field Strength Guidelines for Controlled Environment
(Condition P) (Average Time: 6 Minutes)**

Frequency f	rms electric field strength E [V/m]	rms magnetic field strength H [A/m]	Power density S [mW/cm ²]
10 kHz - 30 kHz	614	163	
30 kHz - 3 MHz	614	$4.9f^{-1}$ [MHz] (163-1.63)	
3 MHz - 30 MHz	$1842f^{-1}$ [MHz] (614-61.4)	$4.9f^{-1}$ [MHz] (1.63-0.163)	
30 MHz - 300 MHz	61.4	0.163	1
300 MHz - 1.5 GHz	$3.54f^{1/2}$ [MHz] (61.4-137)	$f^{1/2}$ [MHz] /106 (0.163-0.365)	f [MHz]/300 (1-5)
1.5 GHz - 300 GHz	137	0.365	5

**Table 2: Electromagnetic Field Strength Guidelines for General Environment
(Condition G) (Average Time: 6 Minutes)**

Frequency f	rms electric field strength E [V/m]	rms magnetic field strength H [A/m]	Power density S [mW/cm ²]
10 kHz - 30 kHz	275	72.8	
30 kHz - 3 MHz	275	$2.18f^{-1}$ [MHz] (72.8-0.728)	
3 MHz - 30 MHz	$824f^{-1}$ [MHz] (275-27.5)	$2.18f^{-1}$ [MHz] (0.728-0.0728)	
30 MHz - 300 MHz	27.5	0.0728	0.2
300 MHz - 1.5 GHz	$1.585f^{1/2}$ [MHz] (27.5-61.4)	$f^{1/2}$ [MHz] /237.8 (0.0728-0.163)	f [MHz]/1500 (0.2-1)
1.5 GHz - 300 GHz	61.4	0.163	1

II Supplementary guidelines (abstract)

(1) Supplementary guidelines for cases of non-uniform or partial-body exposure

	10 kHz - 300 MHz	300 MHz - 1 GHz	1 GHz - 3 GHz	3 GHz - 300 GHz
Spatial average of electromagnetic field strength	Controlled environment: Table 1 is applied. General environment: Table 2 is applied.			
Spatial maximum of electromagnetic field strength		Other than extremities: Controlled env.: 20 mW/cm ² General env.: 4 mW/cm ²		Skin surface: Controlled env.: 50 mW/cm ² General env.: 10 mW/cm ²
			Head: Controlled env.: 10 mW/cm ² General env.: 2 mW/cm ²	Eyes: Controlled env.: 10 mW/cm ² General env.: 2 mW/cm ²
Relevant space	Space occupied by the human body and separated by 20 cm or more from electromagnetic radiation sources and metallic objects	Space occupied by the human body and separated by 10 cm or more from electromagnetic radiation sources and metallic objects		
Average time	6 minutes			

(2) Guidelines for contact current

Frequency	Contact current
10 kHz - 100 kHz	10 ⁻³ f[Hz] mA (average time < 1 second)
	4.5 × 10 ⁻⁴ f[Hz] mA (average time < 1 second)
100 kHz - 15 MHz	100 mA or less (average time: 6 minutes)
	45 mA or less (average time: 6 minutes)

Upper column: Controlled environment
Lower column: General environment

(3) Guidelines for induced current at the ankle

Frequency	Induced current
3 MHz - 30 MHz	100 mA or less (average time: 6 minutes)
	45 mA or less (average time: 6 minutes)

Upper column: Controlled environment
Lower column: General environment

III Partial-body absorption guidelines (abstract)

These guidelines are applied to small radio equipment used in close proximity to the human body(*) at frequencies from 100 kHz to 3 GHz.

* The distance from the electromagnetic field radiation source is within 20 cm at frequencies between 100 kHz and 300 MHz and within 10 cm for frequencies between 300 MHz and 3 GHz.

	Controlled environment	General environment
Whole-body SAR	0.4 W/kg	0.08 W/kg
Partial-body SAR	For any 10-g tissue 10 W/kg 20 W/kg (extremities)	For any 10-g tissue 2 W/kg 4 W/kg (extremities)
Contact current	When the contact hazard is not prevented and the frequency ranges from 100 kHz to 100 MHz 100 mA	When the contact hazard is not prevented and the frequency ranges from 100 kHz to 100 MHz 45 mA

(Average time: 6 minutes)

Note: When the contact current comprises multiple frequency components of significant levels with respect to the guideline values, calculate the squared contact current of each frequency component to the square of its corresponding guideline value. The sum of these fractions must not exceed 1.

Reference Material 3 Validation Tests for the Measurement Method

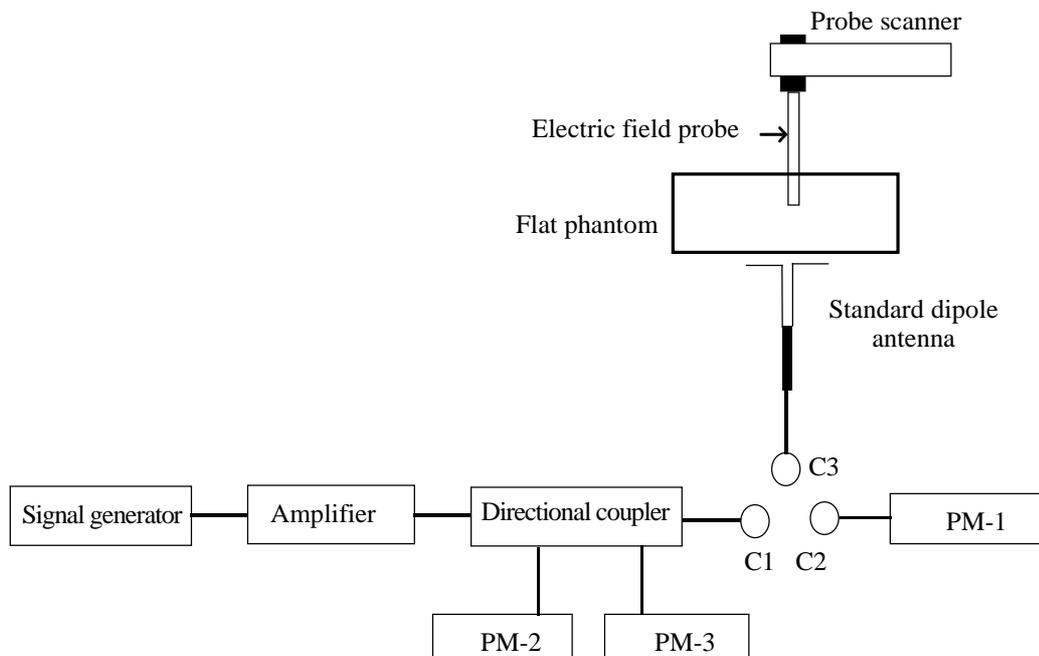
The evaluation testing for the measurement system consists of (1) a simplified performance test and (2) an evaluation test for the entire system.

1 Simplified performance test

The simplified performance test is aimed at verifying that the measurement system operates normally. The test is conducted at regular intervals. However, whenever the liquid material has been replaced due to a change in the frequency band in use or for any other reason, this simplified performance test must be carried out to check the measurement system.

1.1 Basic setup

Figure 1 shows the basic setup for the simplified performance test. Each component of the setup must meet their respective requirements listed below.



PM: Power meter (including an attenuator as required)

Figure 1 Basic Setup for the Simplified Performance Test

1.1.1 Phantom

- The bottom of the phantom must be large enough (at least larger than the dipole) to approximate an SAR distribution with respect to an infinitely large flat phantom (the maximum difference in the partial-body peak SAR is below 1%).
- The depth of the liquid in the phantom must be such that the effect of waves reflected from the upper surface can be ignored (at least more than three times the penetration depth and 15 cm or more).
- The phantom shell should be made of a material with permittivity of 5 or less and loss

- tangent of 0.05 or less.
- The thickness of the bottom of the phantom must be 6.5 mm or less with respect to the antenna direction.
 - The thickness of the bottom of the phantom must be uniform with respect to the antenna direction with a precision of ± 0.2 mm.
 - When filled with a liquid of the appropriate depth, the sagging of the bottom surface of the phantom must be less than 0.5% of the dimensions of the bottom surface with respect to the antenna direction.
 - The same liquids required for SAR evaluation testing must be used.
 - The flat phantom must be mounted on a structure made of a rugged material of low dielectric constant and low conductivity so that the influence on the electromagnetic field distribution can be ignored.

1.1.2 Dipole antenna

- The dipole antenna must have a loopback balun of one-fourth wavelength. The gap of the feedpoint must be 1 mm or less. Resonant conditions must be met at the test frequencies.
- The dipole antenna must be placed in parallel to the bottom of the phantom. The antenna element and the bottom of the phantom must be parallel within $\pm 2^\circ$.
- The dipole antenna must be positioned far above the floor so that the influence of the partial-body SAR maximum SAR due to the effects of floor reflections can be ignored.
- The distance between the feedpoint on the dipole center axis and the phantom liquid must be 15 mm below 1 GHz and 10 mm above 1 GHz. This distance must be uniform with a precision of ± 0.2 mm.
- When placed in the vicinity of the phantom, the dipole antenna must have a return loss better than 20 dB at its power feed connector (C3 in Figure 1).

1.1.3 Power feeder system

To accurately control the power feed to the dipole antenna, a power feeder system must be set up as shown in Figure 1. The procedure for the power feed to the dipole antenna is as follows:

- (1) Connect C1 and C2, and adjust the output level of the signal generator for the desired forward power as read by power meter PM-1.
- (2) After adjusting the signal generator in the previous step, record the reading of power meter PM-2.
- (3) Connect C1 and C3, and adjust the output level of the signal generator so that the reading by power meter PM-2 is the same as that recorded in the previous step.
- (4) If the signal generator does not allow adjustment in 0.01-dB steps, determine the antenna input level taking into account the difference between the readings by power meter PM-2 recorded in steps (2) and (3).
- (5) Verify that the reading by power meter PM-3 is not changed from the value obtained from the previous check conducted under the same conditions.

The component requirements are as follows:

- The signal generator and amplifier must be capable of supplying the desired antenna input stably. If the signal generator can deliver a sufficiently high output level, an amplifier is generally not necessary.
- When supplying low level signals using a high power amplifier, be careful about the noise level. If necessary, connect a low pass filter and an attenuator to the output side of the amplifier in order to reduce the effect of harmonics and noise.
- Connect an attenuator to power meters PM-1, PM-2, and PM-3 as required, based on their input level.
- Power meter PM-1 and the attenuator connected to PM-1 must be calibrated adequately.
- The directional coupler and power meter PM-2 and PM-3 may be substituted for by transit power meters.
- Power meters PM-2 and PM-3 or transit power meters must have a low drift and a resolution of 0.01 dBm. These power meters, however, do not require absolute calibration.
- If conversion connectors are necessary to connect C1, C2, and C3, use high quality connectors.

1.2 Test procedure

- (1) Measure the partial-body SAR maximum SAR as described in Section 6.2.2.
- (2) Normalize the obtained SAR value to the antenna input power, and compare it with the reference value provided by an adequate organization (or the recommended value specified by the SAR measurement equipment manufacturer).
- (3) Verify that the comparison result is within the $\pm 10\%$ range (or the tolerance range specified by the manufacturer).

1.3 Tests related to the electric field probe and SAR calculation method

The performance of each SAR measurement system component can be evaluated using the measurement system for the simplified performance test. The method is described below.

1.3.1 Basic setup

The same setup that is used for the simplified performance test must be used.

1.3.2 Test procedure

- (1) SAR evaluation: Perform the standard partial-body SAR maximum SAR measurement. The results are normalized to the antenna input power and compared with the reference value provided by an adequate organization (or the recommended value specified by the SAR measurement equipment manufacturer).
- (2) Linearity evaluation: Repeat the measurement in (1) for different antenna input powers. The power levels are adjusted to produce partial-body SAR maximum SAR values of approximately 10.2 W/kg and 0.5 W/kg.
- (3) Modulated wave measurement evaluation: Repeat the measurement in (1) with

pulse-modulated signals adjusted to produce a partial-body SAR maximum SAR value of 10 W/kg (with a repetition rate of 10 Hz and a duty factor of 0.1).

- (4) Isotropy evaluation: Place the electric field probe directly above the dipole center (feedpoint) at a distance of 5 mm from the phantom surface (or the recommended distance specified by the SAR measurement equipment manufacturer that takes boundary effects into account). The probe is rotated around its axis at least 180° in steps no larger than 15°. Verify that variations in the measured values are within the tolerance range with respect to the reference value indicated by the specified calibration organization (or the recommended tolerance range specified by the SAR measurement equipment manufacturer).
- (5) System offset evaluation: Repeat the measurement in (1) with the antenna input power adjusted to produce a partial-body SAR maximum SAR of approximately 0.05 W/kg.
- (6) Extrapolation routine evaluation: Measure the SAR over the phantom surface directly above the dipole antenna center (feedpoint) by using the extrapolation method that is employed for the standard SAR evaluation test. The measured value is compared with the reference value indicated by the specified calibration organization (or the recommended value specified by the SAR measurement equipment manufacturer).

2 Evaluation test for the entire measurement system

This test is performed to evaluate the entire measurement system, including errors resulting from the phantom container (shape) and the position of the test device.

Different measurement systems, calibration methods, phantom recipes, etc. are used at each test site. In order to ensure that measurement results are independent of the test environment, the entire measurement system needs to be checked to verify that SAR measurements are appropriately conducted. The evaluation test for the entire measurement system must be performed once a year (or whenever a major change is made to the system). For this test, the measurement equipment calibrated by an adequate organization must be used.

2.1 Basic setup

The same setup that is used for the standard partial-body SAR maximum SAR evaluation test must be used.

2.2 Wireless handset for the evaluation test

- The handset must operate at the desired frequency range.
- The handset must be positioned as described in Section 6.1.3.
- Its output must be within ± 0.3 dB of the target value.
- It must be possible to control both frequency and output.
- The battery must be fully charged, and it must be verified that the output level does not change before and after the measurement.
- The SAR values must be predetermined, which are to be measured using the procedure described in Chapter 6.

The standard dipole may be used until an internationally standardized wireless handset is developed for the evaluation test.

2.3 Test procedure

- (1) Measure the partial-body SAR maximum SAR as described in Section 6.2.2.
- (2) Compare the obtained SAR value with the reference value indicated by an adequate organization.
- (3) Verify that the comparison result is within the tolerance range with respect to the reference value indicated by the adequate organization.

Reference Material 4 Calibration of the SAR Measurement Equipment

1 Electric field probe

1.1 Rationale

An electric field probe consists of three small orthogonal dipole sensors with Schottky diodes between their elements. The output voltage of each sensor is proportional to the rms electric field strength in the space in which the sensor exists. In the strong electric field beyond the square-law detection region of the diode, the output voltage is compressed and, therefore, compensation is required. Since each sensor has orthogonal directivity, the square root of the sum of squares (or the correction value) is proportional to the absolute value of the electric field strength measured by the probe. This is expressed as follows:

$$|E|^2 = \sum_{i=1}^3 |E_i|^2 = \sum_{i=1}^3 f(V_i) / K_i$$

Where $f(V_i)$ is the compensation function of the received voltage V_i of each sensor, and K_i is the absolute sensitivity of each sensor in the phantom.

1.2 Absolute sensitivity

Since absolute sensitivity K_i is expressed as the product of the absolute sensitivity in free space and the relative sensitivity in tissue simulating media, the calibration of absolute sensitivity K_i is first done in free space (in the air) and then in the media.

1.2.1 Calibration in free space

The absolute sensitivity of each sensor of the electric field probe in free space can be calibrated by positioning the probe in a standard electric field. The standard electric field can be produced using a standard antenna, waveguide, TEM cell, etc. Since it is necessary to produce a relatively strong electric field, a high power amplifier is required when using a standard antenna. Make sure that the device is appropriate for the frequency range to be tested^[1].

1.2.2 Calibration in tissue simulating media

The calibration of the relative sensitivity of the electric field probe in tissue simulating media requires that an electric field be excited that produces a known strength distribution in the media. To achieve this, there are two methods: (1) by using a temperature probe and (2) by using a waveguide^{[2][3][4][5]}.

1.3 Isotropy check

Isotropy must be checked in two cases: when the probe is rotated around its axis and when the probe axis is inclined. In the former case, the probe is rotated along its axis from 0° to 360° in steps of 15° or less. In the latter case, the probe axis is rotated from 90° (axial) to

0° (normal) in steps of 30° or less with the probe tip (center of the three sensors) in the same position. In addition, the probe is rotated along its axis 360° in steps of 15° or less.

Two methods have been proposed for these isotropy checks: (1) by using a flat phantom and dipole antenna^{[4][5]} and (2) by using a spherical phantom and dipole^[6].

1.4 Probe linearity check

The probe linearity is not dependent on the surrounding media but depends only on the diode characteristics. Therefore, linearity checks can be made either in free space or in tissue simulating media. These checks must be done with the sensor output voltage range corresponding to 0.02 W/kg to 100 W/kg.

When the check is performed in free space, the relative sensitivity needs to be taken into consideration. Generally, since the sensitivity (sensor output voltage as opposed to the measured electric field strength) of the electric field probe in free space is smaller than in phantom liquid, an electric field strength greater than that in the media needs to be produced when performing a linearity check in free space.

The linearity is defined as the maximum deviation from the linear reference curve determined by the measured value.

1.5 Detection limit check

Detection limits can be evaluated by varying (decreasing) the electric field strength applied to the sensor in the linearity check described in Section 1.4. When the check is done under conditions similar to the actual measurement conditions, the use of the measurement system setup used for the simplified performance test is recommended.

1.6 Boundary effect check

In the closest vicinity of the boundaries of the media, the response of the electric field probe can deviate from the normal value. This phenomenon is called a boundary effect^[7]. The boundary effect can be evaluated using a test setup such as the one used for the simplified performance test^{[4][5]}.

1.7 Response time check

The response time is defined as the time required before 90% of the final value is reached after a step variation or switch on/off of the power source when the electric field probe is exposed to an adequate electromagnetic field. The step must be equivalent to an SAR value of at least 0.4 W/kg.

1.8 Spatial resolution check

The center of each of the three small orthogonal dipole sensors is displaced from each other. This results in an error in the measurement of SAR values if the electric field strength or

polarization in the space suddenly changes. It is therefore necessary to clarify the spatial resolution of the electric field probe.

To check the spatial resolution, two methods have been proposed: (1) by using a miniaturized antenna ^[6] and (2) by using two dipole antennas ^{[4][5]}.

[References]

- (1) K. Jokela, P. Hyysalo, and L. Puranen, "Calibration of specific absorption rate (SAR) probes in waveguide at 900 MHz", IEEE Transactions on Instrumentation and Measurements, vol. 47, no. 2, pp. 432-438, Apr. 1998.
- (2) K. Meier, M. Burkhardt, T. Schmid, and N. Kuster, "Broadband calibration of E-field probes in lossy media", IEEE Transactions on Microwave Theory and Techniques, vol. 44, no. 10, pp. 1954-1962, Oct. 1996.
- (3) K. Pokovic, T. Schmid and N. Kuster, "Robust setup for precise calibration of E-field probes in tissue simulating liquids at mobile communication frequencies", Proceedings ICECOM'97, pp. 120-124, Dubrovnik, Croatia, Oct. 12-17, 1997.
- (4) K. Pokovic, "Advanced electromagnetic probes for near-field evaluation", Diss. ETH Nr. 13334, Zurich, 1999.
- (5) K. Pokovic, T. Schmid, A. Christ and N. Kuster, "Design and characterization of E-field probes for lossy media", IEEE Transactions Microwave Theory and Techniques, Nov.2000, accept.
- (6) Faraone, A., O. McCoy, C. K. Chou and Q. Balzano. "Characterization of Miniaturized E-Field Probes for SAR Measurements", Proc. IEEE Intl. Symposium on Electromagnetic Compatibility, Washington, DC, August 21-26, 2000.
- (7) Smith, "The Electric-Field Probe Near a Material Interface with Application to the Probing of Fields in Biological Bodies", IEEE Trans. MTT-27, pp270-278, March, 1979