Specific Absorption Rate (SAR) Estimation for Cellular Phone

ARIB STANDARD

VERSION 1.0

ARIB STD－T56

January 27, 1998

Association of Radio Industries and Businesses (ARIB)

General notes for the English version of the ARIB Standard T56

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The original "Specific Absorption Rate(SAR) Estimation for Cellular Phones (ARIB STD-T56)" is written in Japanese and has been approved (January 27,1998). This document is the translation of the Standard into English. In case of dispute, the Japanese text shall prevail.

Introduction

The basic technological conditions of standard specifications concerning radio equipment and systems operating on radiowaves are defined by the ARIB in the "Standard Regulations" that are discussed and finalized through the participation of radio equipment manufacturers, telecommunications operators and users.

The Standard Regulations is a private standard that includes national technical standards defined with the purpose of promoting the effective utilization of frequencies and to prevent interference with other users; maintain the appropriate quality and compatibility of radio equipment; and to promote the convenience of radio equipment manufacturers, telecommunications operators and users.

The Research and Development Center for Radio Systems (the present Association of Radio Industries and Businesses) stipulates RCR STD-38 “Standard for Protection Against Radiowave" as a voluntary standard to protect the human body during radiowave use. The evaluation of cellular phones is defined in section "2.2.2.4 Standards for Low-Power Radio Transmitter " of the Standard Regulations. Inclusive in that section is the note that proper precautions must be taken since extremely high SAR values may be locally generated when using transmitters near the body. It is, therefore, assumed that recent portable cellular phones, etc. may fall under this standard.

The basis of STD-38 is the "Indices to Protect the Body Upon Use of Radiowaves" discussed in 1990 by the Telecommunications Technology Council (TTC of MPT). In April 1997, TTC proposed the "Ideal Conditions for Protecting the Body Upon Radiowave Use" (Recommendation No. 89, Nov. 1996), which is related to STD-38, with the intention to introduce specific guidelines to be applied for equipment used extremely near the body, such as portable cellular phones, etc. This recommendation newly defines specific guidelines of local absorption and revised the “Guidelines to Protect the Body Upon Use of Radiowaves”. To verify the applicability of the local absorption guidelines to portable cellular phones, etc., there is a need to make local SAR evaluations focusing on the human head. This evaluation is made through experimental and theoretical approaches, with review of standardization activities underway in Western countries, etc. In terms of the experimental method, several practical methods have been suggested recently, and these methods are actually starting to be used in

North America,. Under these circumstances, Recommendation No. 89 points out the necessity for establishing a concrete measurement method in Japan.

As a result of this situation, ARIB has surveyed all relevant technologies and developed this document for the purpose of experimentally evaluating local SAR. Based on the decision that the local absorption guidelines should be standardized through extensive discussion while taking future international trends into account, this standard indicates guidelines only for reference.

Radio equipment manufacturers, telecommunications operators, and users are expected to appropriately evaluate the technical information included in this standard to ensure compliance with the SAR guidelines for portable cellular phones and terminals with the goal to promote the smooth use of the radio spectrum.

Contents

Bibliography:

Ideal Conditions for Protecting the Body During Radiowave Use
Recommendation No.89 made by the Telecommunications Technology Council (TTC)

Chapter 1. General Provisions

1.1 Outline

The Specific absorption rate (SAR) standard measurement method (hereafter referred to as「Measurement Method」) has been employed to summarize the standard Measurement Method in order to experimentally evaluate the compliance of portable devices and mobile devices (hereafter referred to as「Cellular Phone」) with local absorption guidelines.

The Measurement Method subsumes several measurement methods that are known to be practical, and then provides technical standards required to use these methods.

This Measurement Method may need to be revised due to progress in research and technology. Revisions will be made if and when the validity of the changes is verified.

1.2 Scope

This Measurement Method applies to cellular phones on the frequency band from 800MHz to 3GHz. However, the guidelines target radiowave emission to the human head. This guideline does not apply to other body parts or body implants.

Chapter 2. Basic Items of Measurement Method (Requirements)

2.1 Principle of Measurement Method

For evaluating compliance with the local absorption guidelines for portable devices such as cellular phones, there is a need to get a dosimetry (dosimetry: induced current density and SAR level) of the head and local parts of the body. However, it would be quite difficult to get measurements using actual human subjects. For this reason, a simulated human model called a "Phantom" has been employed to experimentally locate the local peak SAR (W/kg) within the phantom when the portable cellular phone is actually used. Such measurements are generally employed to evaluate SAR inside the body [1]- [3]. To estimate SAR with high precision, there is a need to increase the precision with which we simulate the phantom shape, electrical properties of materials used, shape of cellular phone, shape of antenna, emission properties, phantom and antenna location.

For measurements, the cellular phone and phantom is placed in a condition that simulates the actual situation in use. The SAR is computed by measuring the electric field, temperature, and other physical readings of the phantom using a sensor. At this time, there is a need to get measurements in an unechoic chamber or shielded room to prevent the radiowave emitted from the cellular phone from interfering with other radio stations, or to prevent radiowaves from other radio stations from affecting the measurement. Because the SAR measurement is for the adjacent field, a radiowave darkroom for securing measurement precision is not necessary.

The typical methods of SAR estimation using a phantom are as follows:

1) electric field distribution measurement method;
2) temperature distribution measurement method; and
3) magnetic field distribution method.

The basic structure and operational principles for each method will be outlined below.

2.1.1 Electric Field Distribution Measurement Method

The correlation between the electric intensity of the body E (root-mean-square value; r.m.s. value) and SAR is represented with the following formula:

$$SAR = \sigma |E|^2/\rho \ [W/kg]$$

Where, σ represents the conductivity [S/m] of various human tissues and ρ is the density [kg/m^3] of human tissue. SAR is assessed by measuring the intensity of the electric field E [V/m] in the human body, with the above formula. The electric field strength is measured using an electric field probe inserted in the phantom. However, the compaction rate of the wavelength increases, thus requiring high precision resolution measurements. Therefore, it is necessary to use an extremely small size electric field probe (several millimeters in length in case of a dipolar element). Since the electric vector is not constant, there is a need for isotropic directivity as with a triaxial structure.

The applicable limit of the electric field distribution measurement method is that evaluations are greatly dependent on the performance of the electric sensor. Compact electric sensors currently available on the market have an element length of several millimeters, and is said to be capable of measuring frequencies of up to 10GHz in free-space. However, as mentioned earlier, since the wavelength compaction rate inside the phantom tends to be greater (approx. 1/7 from several hundred MHz to 10GHz), it is thus, only possible to get accurate SAR estimations of between 2-3GHz, at the best. In terms of the SAR tissue volume resolution, it is compatible with up to at least 1g, on the assumption that a cubical composition is being used.

The following details an example of the estimation method.

1. Measurement Using 1D Direction Scanning Electric Sensor

As illustrated in Fig. 2.1-1 , measurements are taken by altering the location of the electric sensor embedded inside a jelly or solid phantom in a one-dimensional direction[10]. Generally there is only one electric sensor that is inserted in a hole that is born in a specific place in the phantom. It is possible to move in the one-dimensional direction. For this reason, SAR estimation of the eyeball, for example, and other specific portions are quite easy. However, it is difficult to measure the SAR distribution over a wide range of area such as the entire inner parts of the head.　Moreover, there is a need to move the actual portable radio equipment if in case it is required to specify a location to attain the peak SAR such as in the cases to make evaluations on associated radio equipment of varying shapes.　The characteristic of this method is that it is fairly easy to configure the measurement system, and that the measurement procedures are also quite easy.

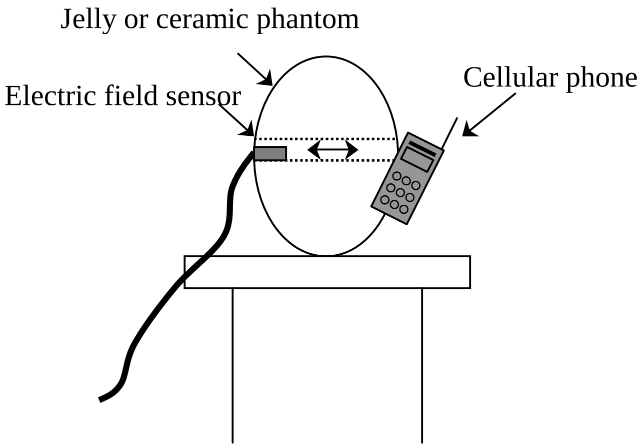

Fig. 2.1-1　An example of measurement method using 1D direction scanning electric field sensor

2.　Measurement with aerial scanning electric field sensor [4], [5]

As shown in Fig. 2.1-2., a container resembling the shape of a human body is filled with aqueous solution phantom, and the inner phantom is three-dimensionally scanned with an implanted electric field sensor.　It is possible to yield highly precise measurement results among SAR estimations actually using portable radio equipment.　To accurately adjust the location of the sensor there is a need program control the industrial robot over a personal computer.　However, the disadvantage of this system is that the unit tends to be fairly large. To obtain accurate measurements, there is a need to accurately set the phantom electric constant and calibrate the sensor measurements within the phantom.

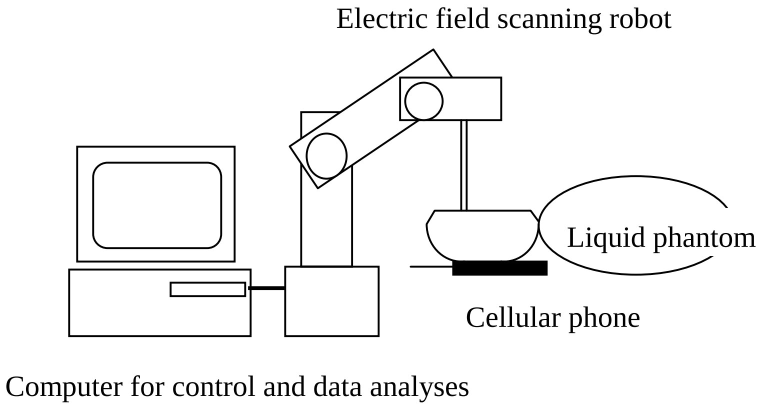

Fig. 2.1-2. Example of measurement with aerial scanning electric field sensor

2.1.2 Temperature Distribution Measurement Method

Since SAR and the temperature rise due to the electric absorption are proportional, SAR is measured by the distribution of the temperature rise.

The following formula represents the correlation between the rise in the phantom temperature and SAR.

$$SAR = c\,(\Delta T / \Delta t)$$

Where, ΔT (K) is temperature rise, c (J/kg･K) is the specific heat of various body tissue, and Δt (sec) is the exposure duration. Temperature can be measured using a thermal sensor or infrared camera (referred to as thermographic camera, infrared ray thermal picture device or temperature distribution analyze).

When using a thermal sensor, the sensor is inserted into the phantom to measure the temperature rise of that portion. On the other hand, as indicated in Fig. 2.1-3, when using a thermograph, there is a need to configure the phantom so that it can be divided, after electromagnetic irradiation without any division, the divided temperature distribution is measured with the thermograph [6]. This method allows the SAR distribution to be measured by surface, and since there is no need to insert a thermal sensor in the phantom, the SAR distribution can be measured with high precision. However, there is a need to specially configure a high output amplifier of more than 100W and an antenna that can handle such a high output power for the phantom to be applied with high temperature rise.

Further, upon taking actual measurements there is a need to appropriate set the parameters such as radiowave irradiation time, time from onset of irradiation to temperature measurement, etc. According to reports on studies conducted in the U.S. there are SAR evaluations of car phone antenna using jelly phantom [7]. When using a thermograph it is possible to measure the SAR distribution with high resolution of 0.01g unit.

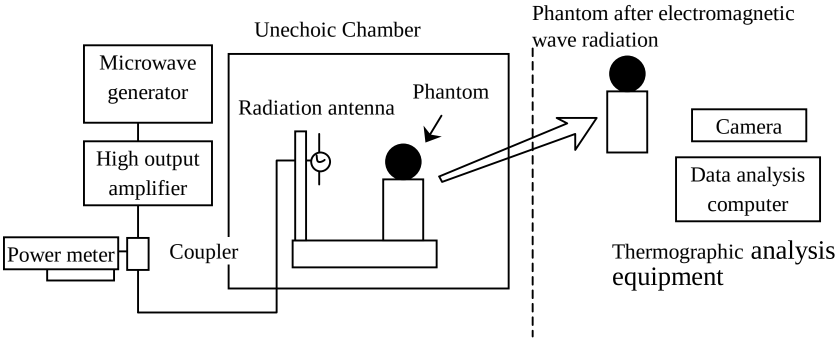

Fig. 2.1-3 Example of measuring temperature distribution (Thermography)

2.1.3 Magnetic Field Measurement Method

It has been reported that SAR of the phantom surface and inside can be sought by measuring the injection magnetic field on the phantom surface under similar installation conditions as when measuring electric field distributions. Since there are only limited number of reports that prove precision, future studies are expected substantiate the results [8] [9].

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2.2 Basic Phantom Conditions

2.2.1 Validity of Homogeneous Phantom

The head consists of the brain, skull, scalp (skin), eyeballs and various other tissues, all of which have different electrical constants. Therefore, the electric characteristics of the head are extremely uneven, thus, making the internal SAR distribution created by using cellular phones extremely complex.

It is possible to use a numerical model that precisely simulates the head structure. However, for experimentation it is better to use a homogeneous phantom to ensure simple and repeatable measurement procedures and results, since it is extremely difficult to create a heterogeneous structure. To prove the appropriateness of the SAR estimations created with a homogeneous phantom, several studies have compared SAR distributions between homogeneous and heterogeneous head models [1], [2]. Based on the results of these studies, we can state the following.

- Internal SAR distribution depends on the heterogeneous structure of the head tissue. Thus, the SAR distributions of homogeneous head models differ from those of heterogeneous head models.

- SAR distribution on the surface of the head depends on the shape of the head. Thus, the superficial SAR distributions are almost identical regardless of which model was used.

- The local peak SAR is generated on the surface of the head in both heterogeneous and homogeneous head models. The SAR of homogeneous models either equal or exceed those of heterogeneous models.

It has recently been reported that the difference between the homogeneous and heterogeneous models are insignificant in terms of maximum SAR values (compatible with local exposure index) averaged in local tissue masses of around 10g [3].

It is realistic to make maximum local SAR evaluations on the head using homogeneous phantoms, based on the above supporting evidence.

2.2.2 Electrical Characteristics of Phantom

2.2.2.1 Electrical Characteristics of Biological Tissue

The electric characteristics of biological tissue vary drastically according to its kind, and further, tend to have a strong frequency response. The readings are also greatly affected by age and measurement conditions, as well, thus, it was quite difficult to pinpoint an accurate electrical constant and specify universal numerical values. For this reason, the measurement values of electrical constants of biological tissue reported up to now are greatly different even for the same frequency and same tissue. Table 2.2-1 illustrates the electrical constant of the head tissue used in several head SAR simulations of 800MHz and 900MHz cellular phones, in which considerable fluctuations can be observed.

Table 2.2-1: Electrical constant of head tissue in 800/900MHz band used in several simulations (relative permittivity ε_r /conductivity σ , S/m)

Head Tissue	Hombach, et al. [2]	Watanabe, et al. [1]	Gandhi, et al. [4]
Brain	53.8/1.17 (gray)	52.7/1.05	45.26/0.92
Bone	20.9/0.33	9.67/0.0508	17.4/0.25
Skin	40.7/0.65	59.1/1.26	35.4/0.63
Eyeball	67.9/1.68	80.0/1.90	67.9/1.68
Muscle	57.4/0.82	59.1/1.26	51.76/1.11

2.2.2.2 Homogeneous Medium

Most homogeneous full-body models assume the electrical constant of 2/3 muscle[1] as the electrical characteristics. On the other hand, the electrical constant of homogeneous head phantoms used for SAR evaluations are taken from either the brain, the muscles, or other high water content tissues.
Table 2.2-2 illustrates the reported electrical constants for homogeneous head phantoms.

The peak value of the local SAR generated on the surface of the homogeneous phantom upon exposure to cellular phones are greatly dependent on the electrical constant of the phantom medium (the local SAR peak tends to increase with higher conductivity). Therefore, safety evaluation can be achieved by assuming an electrical constant of higher water content tissue (brain and muscle) with higher conductivity.

For an homogeneous phantom model composed of liquid or gel phantom material, a container is necessary. The glass fiber reinforcement epoxy has a low dielectric loss characteristic at high frequency and is one candidate. The dielectric constant of this material is less than 10. If the thinness of the container is smaller than that shown in 2.3.1.2, its influence on the SAR distribution can be ignored. This is described in bibliography [3].

Table 2.2-2: Electrical constant of homogeneous head phantom used in 800/900MHz band (relative permittivity ε_r /conductivity σ , S/m)

Research Group	Nojima, et al. [5]	Balzano, et al. [6]	Hombach, et al. [2]
Phantom Medium	Ceramic	Liquid	Liquid
Assumed Tissue	High water content tissue	Brain tissue	Brain tissue (mean of grey & white matter)
Electrical Constant	52.0/1.45	41/1.1 1.2	41/0.88

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[1] 2/3 muscle is a tissue whose electric constant is 2/3 times that of muscles that are high water content tissues. This is based on the fact that the ratio of high water content tissues to low water content tissues is 2/3.

2.2.2.3 Effects of Hand Operation

The hand holding the cellular phone directly touches the case of the cellular phone and is extremely close to the antenna. Therefore, it is thought to be strongly and electromagnetically coupled to the antenna. It is also forecast that the SAR distribution generated on the head is strongly affected by the shape and position (location) of the hand holding the cellular phone.

However, according to numerical simulation reports, it is known that the local SAR peak generated on the head with a cellular phone that isn't held by hand (floating in air) is about the same as that when it is held by hand under normal conditions (the hand holding cellular phone doesn't cover the antenna) [1],[7]. Recent experimentation has also supported similar tendencies, and reports have indicated that the underestimation of the local SAR peak on the head, without a hand, is less than 5% [3].

Therefore, it appears that it is not necessary to take the hand model into account in evaluation of the local SAR peak on head. However, it should be noted that the hand may strongly affect the local SAR depending on the type of cellular phones, such as built-in antenna type cellular phones.

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2.2.3 Measurement of Liquid, Gel Materials, and Dielectric Constant (ε_r) and tan δ of Solid.

2.2.3.1 Measurement of Liquid and Gel Materials

The procedures to measure the dielectric constant (ε_r) and dielectric loss (tan δ) of the liquid and gel phantom materials are indicated below.

• Analysis Method	: S_{11} reflection analysis
• Analysis Equipment	: Vector network analyzer Personal computer Hot dielectric probe kit inlc. program (HP85070B)
• Material Conditions	: Unlimited size, nonmagnetic, isotropic and homogeneous in quality.
• Sample Shape	: Diameter >20 mm Thickness $<20/\sqrt{\varepsilon_r}$ mm Grain size: <0.3 mm
• Major Specifications of Analysis Equipment	
Frequency Range	200MHz to 20GHz
Accuracy	ε_r ：$\pm$5%, tan δ：$\pm$10%
Parameter	ε_r, tan δ
Sample	Liquid, flat, solid, semi-solid
Temperature Range	-40 to +200°C

<Measurement model>

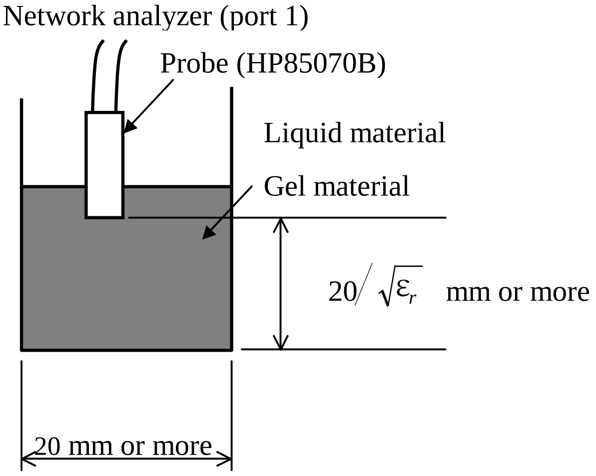

Fig. 2.2-1 Liquid and gel phantom: dielectric constant and loss measurement system

Note: As a measurement method of dielectric constant (ε_r) and dielectric loss (tan δ), there are the S-parameter method (air-line method), the slotted line method, and other measurement methods which are currently under study, and it is necessary to continue further examination. (The measurement precision for the air-line method and slotted line method is ±5% for both ε_r and tan δ.)

2.2.3.2 Measurement of Solid Materials

The procedures to measure the dielectric constant(ε_r) and tan δ of the solid phantom materials are summarized as below.

- Analysis Method : S parameter (NIST precision)
- Analysis Equipment : Vector network analyzer
  Personal computer
  Coaxial sample holder (APC-7mm Airline)
  Material analysis program (HP85071B)

- Material Conditions : Nonmagnetic, isotropic and homogeneous in quality.
- Sample Shape : Outer diameter 7mm
  Inner diameter 3.04 mm
  Optimal length: n λ g/2; integer, λ g; wave length in phantom

- Major Specifications of Analysis Equipment
  Frequency Range 100MHz to 110GHz
  Parameter $\varepsilon_{r,}$tan δ

<Analysis model >

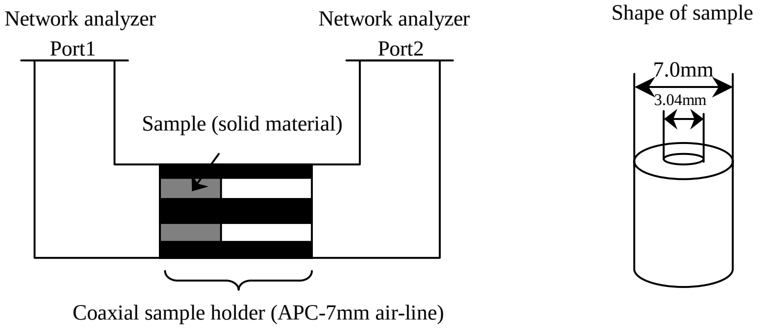

Fig. 2.2-2　Solid material dielectric constant(ε_r) and tan δ　measurement system

Precautions on analysis : There must be no gap between the outer/inner surface of the sample and the surface of the coaxial sample holder.

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2.2.4　Recipe for Phantoms

2.2.4.1　Recipe for Liquid Phantom

The following describes the procedure to create the liquid for the phantom having electric characteristics that simulate the electric characteristics of the brain tissue.　In this report, five liquid examples for phantoms are highlighted according to cellular phone frequencies from among the solution preparation specifications of Schmid & Partner Engineering and Motorola. (The solution of the Schmid & Partner Engineering is combined based on the data of Camelia Gabriel, UK.)

2.2.4.1.1 Composition of sample (for DASY)

	Purpose	Dielectric Constant ε_r (error)	Conductivity σ [S/m] 1/Ωm (error)	Frequency Factor *1 (error)
Recipe 1 (450M/900MHz same)	for 900MHz for 450MHz	42.5 (±5%) 47.2 (±5%)	0.85 (±10%) 0.45 (±10%)	6.0 (±10%) 6.7 (±10%)
Recipe 2	for 900MHz	41.2 (±5%)	1.20 (±10%)	6.0 (±10%)
Recipe 3	for 1,800MHz	41.0 (±5%)	1.65 (±10%)	4.8 (±10%)

*1. The frequency factor is the constant used for the DASY system.

2.2.4.1.2 Preparation of Materials (weight ratio: %)

	Water	Sugar	Salt	Cellulose	Preservative
Recipe 1	40.1	58.0	0.8	1.0	0.1
Recipe 2	40.4	56.0	2.5	1.0	0.1
Recipe 3	45.0	53.9	-	1.0	0.1

2.2.4.1.3 Specific Proportions

	Water (kg)	Sugar (kg)	Salt (g)	Cellulose (g)	Preservative (g)
Recipe 1	1.383	2.00	27.6	34.5	3.4
	2.074	3.00	41.4	51.7	5.2
	2.766	4.00	55.1	69.0	6.9
Recipe 2	1.443	2.00	89.3	35.7	3.6
	2.164	3.00	133.9	53.6	5.4
	2.886	4.00	178.6	71.4	7.1
Recipe 3	1.670	2.00	—	37.1	3.7
	2.505	3.00	—	55.7	5.6
	3.340	4.00	—	74.2	7.4

2.2.4.1.4 Equipment to Prepare Solution

- 5 liter beaker
- Measuring cup: large and small
- Spatula

- Agitator
- Electronic balance (turn on power 30 minutes before weighing samples)
- Heater
- Polyethylene tank (20 liters) for stock
- Pump
- Water boiler
- Deep pot (10 liters)

2.2.4.1.5　Preparation Procedures

(1)　Weigh materials.

- Weigh the materials necessary with reference to the proportion table of the ingredients indicated in section 2.2.4.1.3.

(2)　Mix and agitate solution.

- Heat water in a beaker or deep pot (large volume) to around 40°C, then add and dissolve the salt and cellulose by agitation.
- Continue agitation.　Separate sugar in easily dissolvable contents.　Then add to agitated solution.
- When the sugar dissolves, add preservative and agitate.
  There is a need to carefully adjust the mixture of cellulose to create an homogeneous phantom solution since cellulose is difficult to dissolve, and even if it does dissolve the viscosity after dissolution remains extremely high.
- Be especially carefully in properly managing the heating temperature of the solution so that the solution doesn't evaporate during the above processes.
- When the solution is completed, pour it into an airtight polyethylene tank for storage.

(3)　Evaluation and correction of electric characteristics.

- Refer to Section 2.2.3.1 "Measuring Liquid and Gel Materials" for details on evaluating electric characteristics.
- Corrections are made by adding water.　(changes in characteristics are dependent on the evaporation degree of the water in the solution).

- Repeat measurement and corrections until a proper electric characteristic is attained.

(4) Be careful when refilling phantom with solution.

- Pour the solution in currently in the tank into the phantom mold. Leave it as is for 2 to 3 hours, then debubble the solution.
- Manage the temperature of the solution. (20°C±5°C)
- Manage the stock solution when not in use.
  Drain the solution from the phantom and pour into an airtight polyethylene tank.
  When leaving the solution in the phantom, take measures to prevent evaporation.

(5) Quality Control Procedures

- Evaluation of characteristics and corrective measures for Section 3.
- The solution should be replaced in 3-4 months. (to prevent degradation of the solution characteristics due to deterioration)
- It is extremely important to separate and control the solution by frequency, date of manufacture since similar solutions are prepared.

2.2.4.1.6 Example of Motorola

(1) Electric constant of Gel Phantom

	Purpose	Dielectric Constant ε_r	Conductivity σ 1/Ωm
Brain solution	for 400MHz for 900MHz	50.3% (±5%) 41.2% (±5%)	0.75% (±5%) 1.22% (±5%)
Muscle solution	for 400MHz for 900MHz	62.5% (±5%) 54.7% (±5%)	0.90% (±5%) 1.38% (±5%)

(2) Composition of Solution (weight ratio: %)

	Water	Sugar	Salt	Cellulose (HEC)	Preservative
Brain	40.4	56.0	2.5	1.0	0.1
Muscle	52.4	45.0	1.5	1.0	0.1

(By George Hartsgrove of Ottawa, Canada, et. al [1])

Bibliograpy:

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2.2.4.2 Recipe for Jelly Phantoms

2.2.4.2.1 Characteristics

Two types of jelly phantoms are suggested.

(1) By Guy, et al [1]. By changing the proportion of the ingredients for each frequency it becomes possible to create a preparation equivalent to the complex dielectric constant of the muscle tissue in the range between 13.56MHz to 2450MHz. The validity period of use is one month. Hereafter, this model shall be called Gel Phantom I.

(2) By Furuya, et al [2, 3]. It is a semi-solid that can maintain an independent shape. This phantom is a mixture of one type and allows for a complex dielectric constant that closely resembles that of muscle tissue containing high levels of fluid, between the range of 400MHz to 1.5GHz. Preservatives are also used, and the surface is covered with a plastic film to keep the complex dielectric constant of the phantom intact for more than several months. Hereafter, this model shall be called Jelly Phantom II.

2.2.4.2.2 Preparing Jelly Phantom I [1]

(1) Ingredients

It is possible to create a jelly phantom with electric characteristics defined in Item 2.2.4.2.4, by mixing the ingredients according to the designated weight (gram unit) as indicated in Table 2.2-3.

Table 2.2-3 Material and Composition (weight ratio: %)

Frequency [MHz]	Distilled Water	NaCl	TX-150	Polyethylene Powder
200	74.92	0.894	8.39	15.79
300-915	75.15	0.996	8.42	15.44
2450	75.48	1.051	8.46	15.01

Note 1: TX-150 is a thickener (viscosity improver).

Note 2: No ingredients are toxic and all can be easily procured.

(2) Production Procedures

The details are described in reference [1], however an outline follows below.

1) Add NaCl and polyethylene powder to distilled water at room temperature, and then agitate.

2) Add TX-150 and further agitate.

3) Slowly pour mixture into container.

2.2.4.2.3 Preparing Jelly Phantom II [2, 3]

(1) Ingredients

Mix the ingredients according to the designated weight (gram unit) as indicated in Table 2.2-4. Additives to the phantom include agar and NaN3 preservatives.

Table 2.2-4 Material and Composition (weight ratio: %)

Distilled Water	NaCl	NaN3	Agar	TX-151	Polyethylene Powder
85.712	0.866	0.051	2.656	2.143	8.571

Note 1: Thickener TX-151 equals TX-150 in its thickening performance.

Note 2: NaN3 is toxic. Be sure to wear rubber gloves and dust-proof masks while handling it. NaCL, which is 1.1 times heavier, can also be used as substitute, however, the length of use is shortened to several weeks.

Note 3: No ingredients except NaN3 are toxic and all are easily procured in Japan.

(2) Production Procedures

The only point varying from the procedures used to prepare Jelly Phantom I, is that the distilled water for Jelly Phantom II is prepared by warming the distilled water on a gas stove.

1) Dissolve NaCl and NaN3 in distilled water.
2) Add TX-151 and agitate.
3) Add polyethylene powder and agitate.
4) When all the ingredients are evenly mixed, stop the heating process. Then slowly pour mixture into the container.

2.2.4.2.4 Electric Characteristics

(1) Frequency Response

Table 2.2-5 illustrates high fluid content tissue such as muscle, skin, etc. [4] and the dielectric constant and conductivity of the jelly phantom prepared according to the above procedures.

Table 2.2-5: Dielectric constant and conductivity of high water content tissue and each jelly phantom.

	High fluid content tissue		Jelly Phantom I [1]		Jelly Phantom II	
Frequency [MHz]	Dielectric constant ε_r	Conductivity σ [S/m]	Dielectric constant ε_r	Conductivity σ [S/m]	Dielectric constant ε_r	Conductivity σ [S/m]
200	56.5	1.28	56.7±0.7	1.06±0.02	51.0	1.38
300	54.0	1.37	54.8±0.7	1.17±0.01	51.4	1.40
433	53.0	1.43	53.5±0.5	1.21±0.01	51.4	1.43
750	52.0	1.54	52.5±0.6	1.26±0.04	50.9	1.51
915	51.0	1.60	51.1±0.6	1.27±0.02	50.8	1.55
1500	49.0	1.77			50.2	1.75
2450	47.0	2.21	47.4±0.9	2.17±0.08	48.9	2.29
3000	46.0	2.26			49.2	2.74

Note 1: The electrical constants for Jelly Phantom I were measured with the slot line method at 22°C.

Note 2: The electrical constants of Jelly Phantom II were measured using a HP85070M dielectric coaxial probe at 28°C. The measurement accuracy is within 5%, and that of the dielectric loss tangent is ±10%.

Bibliography:

[1] C. Chou, G. Chen, A.W. Guy and K.H. Luk, "Formulas for preparing phantom muscle tissue at various radiofrequencies", Bioelectromagnetics 5, pp. 435-441, 1984.

[2] K. Furuya, L. Hamada, K. Ito, H. Kasai, "A new muscle-equivalent phantom for SAR estimation", IEICE Trans. Commun., Vol. E78-B, No. 6, pp. 871-873, 1995.

[3] K. Furuya, R. Hamada, K. Ito, K. Kasai, "Development of a new muscle-equivalent phantom for SAR estimation", Shingaku Engineering Journal, AP94-109, pp. 35-42, 1995.

[4] C.C. Johnson and A.W. Guy, "Nonionizing electromagnetic wave effects in biological materials and systems", Proc. IEEE, Vol. 60, No. 6, pp. 692-718, 1972.

2.2.4.3 Recipe for Solid Phantoms

2.2.4.3.1 Target characteristics

(1) Tables 2.2-6 and 2.2-7 are two representative examples of dielectrics of human biological tissue (muscle and brain) containing high levels of fluids which have been reported by thesis, etc. and are widely known. These include "W.Guy, C.C. Johnson Values" [1], [2], [3], [4] and "C. Gabriel Values" [5], [6], [7].

Table 2.2-6: "W.Guy, C.C. Johnson Values" (Muscle Tissue)

Frequency / Item	915MHz	1500MHz
Dielectric constant ε_r	51	49
Dielectric loss tan δ	0.61	0.43
Conductivity rate σ(S/Ωm)	1.60	1.77

Typical Value

Table 2.2-7: "C. Gabriel Value" (Brain Tissue)

Frequency Item	915MHz	1500MHz
Dielectric constant εr	51.9	48.2
Dielectric loss tan δ	0.39	0.35
Conductivity rate σ(S/Ωm)	1.01	1.36

Typical Value

(2) The tolerance of dielectric constant for the solid phantom shall be Typical Value±20% for dielectric constant (εr) and Typical Value±30% for dielectric loss (tan δ) and Conductivity rate(σ).

2.2.4.3.2 Production Method

The following illustrates one way in which the solid phantoms are made with the dielectric characteristics indicated in Table 2.2-6.

(1) Material Composition

The following three materials are the ingredients. The physical properties of each material are indicated in Table 2.2-8 , et al [8], [9].

a) High polymer (molecular) resin:	PVDF (fluorine resin)
b) Ceramic power :	(Ba, Ca)(Ti, Sn)O^3
c) Conductive powder:	Carbon powder

Table 2.2-8: Physical properties of compositional materials.

Material Physical Property	PVDF	(Ba, Ca)(Ti, Sn)O^3	Carbon
Dielectric constant εr	3.1	16,000	-
Dielectric loss tan δ	0.071	0.05	-
Conductivity rate σ[S/Ωm]	1×10^{-14}	1×10^{-12}	1000
Density [g/cm^3]	1.8	5.7	1.9
Specific heat [J/kg.k]	3000	420	-
Grain size [μm)	-	30	20

The measurement frequency for ε_r and tan δ values is 900MHz.(Typical Value)

(2) Setting the compositional contents of complex dielectric materials.

Table 2.2-9 illustrates the composition of the solid phantom materials to represent high fluid content biological dielectric characteristics (shown in Table 2.2-6) at 900MHz and 1.5GHz.

However, the composite ratio is subject to change since the physical properties of each materials are not constant in actuality.

Table 2.2-9: Composite ratio of solid phantom materials for 900MHz and 1500MHz (vol. %)

Material / Physical Property	PVDF	(Ba, Ca)(Ti, Sn)O^3	Carbon
for 900MHz	57	10	33
for 1500MHz	53	18	29

Typical Value

(3) Processing Method

for creating this solid phantom, high-temperature and high-pressure processing is required and special production equipment is used. Details are described in Bibliography [9] below. Fig. 2.2-3 outlines the production process.

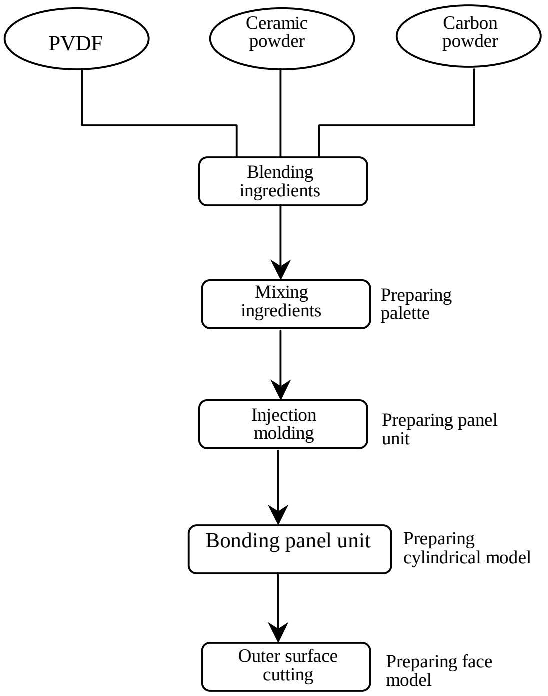

Fig. 2.2-3 Outline of solid phantom manufacturing process

Bibliography:

[1] C.C. Johnson, A.W. Guy, "Nonionizing electromagnetic wave effects in biological materials and systems", Proceedings of the IEEE, Vol. 60, No. 6, June 1972.

[2] T. Kobayashi and T. Nojima, "Solid and liquid materials that simulate biological electric properties, and their application," Shingaku Engineering Journal, MW92-35, RCS92-13, pp. 31-38.

[3] T. Omori, "Electromagnetics and biological materials," Daily Industrial Newspaper Company, pp. 159-164.

[4] S. Watanabe, M. Taki, T. Nojima, O. Fujiwara, "Characteristics of the SAR distributions in a head exposed to electromagnetic fields radiated by a hand-held portable radio", IEEE Transactions on Microwave Theory Techniques, Vol. No. 10, Oct. 1996.

[5] S. Gabriel, R. W. Lau, C. Gabriel, "The dielectric properties of biological tissues: II. Measurements in the frequency range 100Hz to 20GHz", Phys. Med. Biol., 41, pp. 2251-2269, 1996.

[6] S. Gabriel, R. W. Lau, C. Gabriel, "The dielectric properties of biological tissues: III. Parametric models for the dielectric spectrum of tissues", Phys. Med. Biol., 41, pp. 2271-2293, 1996.

[7] AI/OE-TR-1996-0037, "Compilation of the dielectric properties of body tissues at RF and microwave frequencies", Armstrong Laboratory (AFMC), Occupational and Environmental Health Directory Radiofrequency Radiation Division.

[8] T. Kobayashi, T. Nojima, K. Yamada, S. Uebayashi, "Dry phantom composed of ceramics and its application to SAR estimation", IEEE Transactions on Microwave Theory Techniques, Vol. 41, No. 1, June 1993.

[9] H. Tamura, Y. Ishikawa, T. Kobayashi, T. Nojima, "A dry phantom material composed of ceramic and graphite powder", IEEE Transactions on electromagnetic compatibility, Vol. 39, No. 2, May 1997.

2.2.5 Standard phantom model

2.2.5.1 Standard head size

The phantom model that is currently commonly used to evaluate SAR are available in form of a Solid Model (Murata Manufacturing Co., LTD), DASY Model (S&P Eng. make), Kato/Fujiwara proposed Model [1], Jensen et al proposed Model [2], and Body Size Data [3], as illustrated in Table 2.2.5-1. Refer to Fig. 2.2-4 for dimensional parameters (A~D).

Table 2.2.5-1 Dimensions of each phantom model

(Unit: mm)

Model Dimensions	Solid Phantom	DASY Phantom	Kato/Fujiwara Model	Jensen Model	Body Size Data	IDX phantom
A	167	150 (190)*1	145	157.4	158.0	140
B	218	240	255	216.4	234.0	235
C	220	230	192.5	216.4	199.5	220
D	197	210	-	-	182.0	202

*1. 150 mm with one side of face cut.　190 mm when left/right symmetrical

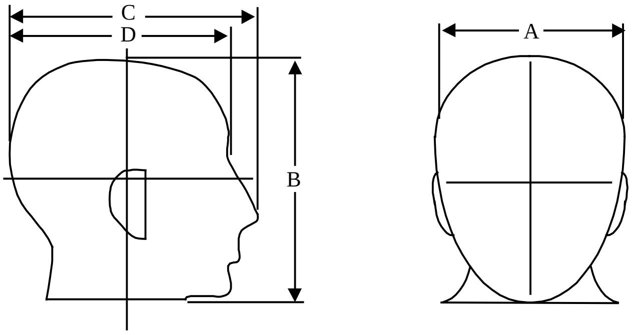

Fig. 2.2-4 Head model dimension parameters

Bibliography:

[1] A. Kato and S. Fujiwara, "Determining localized SAR of microwave frequency using a real head model", Shingaku Engineering Journal, EMCJ92-67 (1992-12).

[2] M.A. Jensen and Y. Rahmat-Samii, "EM interaction of handset antennas and a human in person communication", Proceedings of the IEEE, Vol. 83, No. 1, June 1995.

[3] Data collected on human measurements for design purposes" (published June 20, 1996"

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2.3 Measurement Position and Operating Conditions

This section describes the standard measurement positions. Because the designs of cellular phones and antennas are becoming increasingly varied, there should be one method applicable to all phone types. Also the phone is used by different persons in many positions (angles). To overcome the difficulty of defining and measuring all angles (positions) possible and to make the procedure simple and repeatable, a standard operating position is adopted.

There will be many different phantoms available (homogenous, heterogeneous) and phantom sizes and form vary. The wall and ear thickness of the phantom is difficult to control during manufacturing. Furthermore, the SAR and power density values are highly distance dependent. Therefore the maximum distance from the surface of the Cellular Phone or other mobile device in standard operating position to the phantom liquid or other measuring device must be defined in order to achieve uniform, accurate and repeatable test results.

2.3.1 Standard Position

2.3.1.1 Standard Position of cellular phones

The compliance test is made in the standard position (normal use), which must be defined by the manufacturer. The standard position must offer convenient use and good acoustic coupling. It is illustrated in Fig. 2.3-1 and defined below.

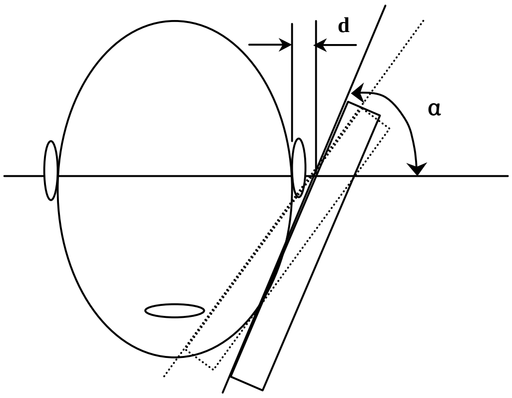

Fig. 2.3-1: Estimated standard location.

1) The center of the earpiece is aligned to the center of the auditory canal.

2) The surface of the handset at the earpiece touches the head model or parallels the phantom if an artificial ear is used.

3) The center of the microphone or the centerline of the device should be aligned to the plane containing the three lines joining the center of the ears (auditory canals) and the center of the closed mouth.

4) The body of the handset should be parallel to the cheek (or the angle between the handset and the line connecting the both centers of the ears (auditory canals) of the head model

(angle “α”) should be defined by the manufacturer. Please refer to suggestions in CENELEC, SECRETARIATS, SC211/B WGMTE, Feb. 1997, as it must follow the typical operating position of the device.

5) The distance between the Phantom ingredients (liquid) and the surface of the handset at place of the earpiece center “d” must be no more than 6mm.

6) The handsets must be tested on the side of the head producing maximum RF energy coupling from the antennas and other radiating structures. If the test position (angles) for maximum RF energy coupling is unclear, the device should be tested on both sides of the head (using left and right hand phantoms).

7) Cellular Phones with retractable antennas should be tested with antennas in their fully extended and retracted positions. (If a partially extended antenna may result in higher RF energy coupling, as determined by other means, such test conditions should be considered.)

8) If the cellular phone is supplied with different antennas for different systems, it must be tested with all antenna types.

9) If the normal operating condition of a device is proposed by the manufacturer, the maximum SAR should be evaluated with respect to that condition.

2.3.1.2　Position correlation of the Subject analyzer and Sensor

Table 2.3-2 indicates the position correlation of the Subject analyzer and the Sensor using DASY as an example.

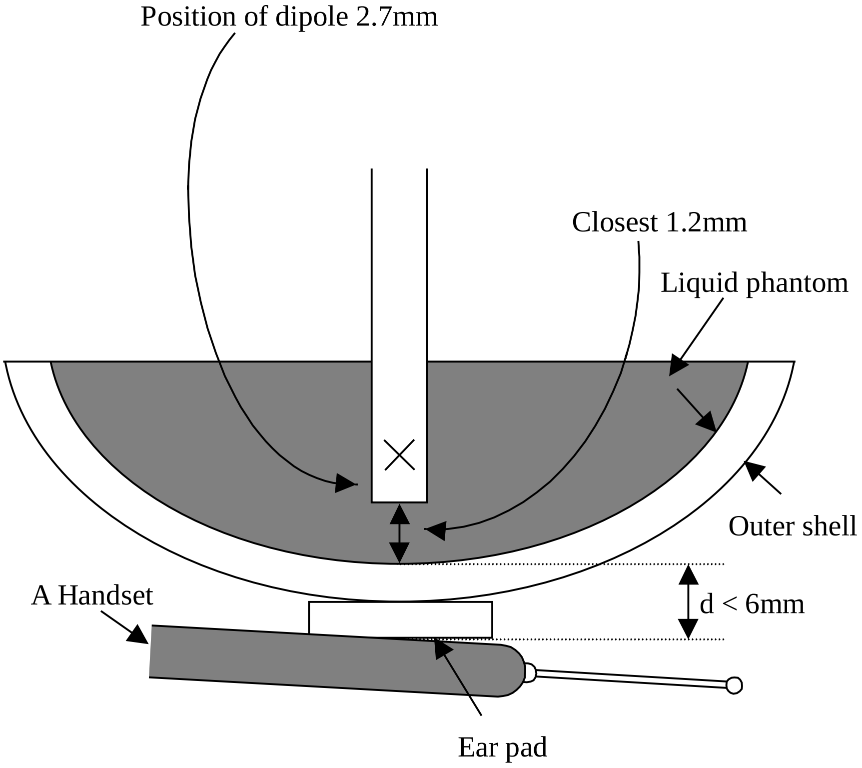

Fig.2.3-2 An example of the spatial relationship of a liquid phantom and a handset

2.3.1.3　Standard Position of Other Cellular Portables and Mobile Devices

Other portable devices and transmitters that are carried or used next to the body should be tested at typical operating distances from the body and positions (defined by the manufacturer) producing maximum RF energy coupling to the body.　In this case, it should be necessary to use a whole body phantom and evaluation methods should be developed in the future.

2.3.2 Transmission Conditions

The transmission conditions during testing are outlined below.

1) Transmitter output must be held at its maximum value.
2) For continuous transmission, follow the designed transmission format using the simulated base band signals. In case of burst transmission, transmission time ratio should be adjusted to the operational limit.
3) A signal mode that can be generated at the standard operation position. Since, for example, PDC packet transmission takes place with the cellular phone on the table, the evaluation of operation locations 2.1(1)-(6) is not subject for review.

Bibliography:

[1] CENELEC, SECRETARIAT, SC211/B, WGMTE, Feb. 1997.

2.4 Sensor

2.4.1 Electric Sensor

An electric sensor consists of a basic antenna, DET (detection circuit) and transmission line. The incident wave is converted into DC (direct current) voltage over the antenna and DET (diode, etc.), and then provided to the signal processor (analyzer) over the transmission line. The composition should have an applicable frequency range that is higher than 800MHz and lower than 3GHz, that only responds to electric fields, without pseudo-responses to magnetic fields. What's more, there should be minimal interference with the electromagnetic fields analyzed (shielding, etc.), with a structure that is not dependent on the direction of the incident wave or polarization of electric fields (3-axial structure, etc.)[1].

Table 2.4-1 illustrates the notable response characteristics of electric sensors that are currently available on the market.

It is vital that the instruments are calibrated to heighten the precision in analyzing electric intensity. Calibration of commercial probes can yield analysis precision better than ±1.0dB. The probes are calibrated using known intensities specified in standards for analyzing electric fields. Standard calibration methods include the following, [2]:

1) Free-space standard-field method
2) Waveguide calibration
3) Standard probe

Next, there is a need for a dynamic range with a lower limit that is less than -10dB and an upper limit that is higher than -5dB of the standard value. To endow a probe with directional symmetry, it would, for example, be possible to place the 3 sensors so that they are orthogonal. (it is possible to keep the difference between the maximum and minimum value within 4dB, in terms of the probe properties on the market.)[2]. The response time is determined based on the mobile time of the measurement point, however, it is advised that high speed response (less than 1 sec.) is maintained to shorten the measurement time[2].
High precision spatial resolution is required to analyze SAR for 1g or 10g. As the specific gravity of the phantom is approx. 1.2g/cm^3, 1g and 10 correspond to 9mm and 20multimedia cubes. Thus, if the length of the antenna is smaller than these dimensions, the required resolution can be obtained. Commercial probes with minute dipoles of 2~4mm and can be used for both 1g and 10g measurements.

Table 2.4-1 Notable Electric Sensor Responses

(Astec Co., Ltd.: 7100 isotropic broadband probe system)

	7121 Probe	7122 Probe	7123 Probe
Frequency Range	0.1-18GHz	10kHz-1GHz	10kHz-1GHz
Dynamic Range	2-500V/M, 48dB	1-250V/M, 48dB	4-300V/M, 38dB
Calibration Accuracy	±0.5dB (0.1-1GHz) ±1.0dB (1-18GHz)	±0.5dB	±0.5dB
Directional Symmetry	+6, -5dB (0.1-1GHz) ±1.5dB (1-18GHz)	-0.05, +1.5dB	-0.05, +1.5dB
Sensor	8mm dipole	150mm dipole	50mm dipole

(Matsushita Inter-Techno Co., Ltd.: DASY2 System)

	ET3DV5/ET3DV5R	ET3DV4/ET3DV4R
Frequency Range	10MHZ-6GHz	100MHZ-6GHz
Dynamic Range	5μW/g-100mW/g	2V/m-900V/m
Calibration Accuracy	±5% (aerial) ±10% (liquid) (100MHz-2.5GHz)	±5% (aerial) (100MHz-2.5GHz)
Directional Symmetry	±0.6dB	±0.6dB
Sensor	approx. 3mm	3mm

(Meiko Trading : IDX System)

Probe model name	E-Field Probe (BPE-5001)
Frequency range	150MHz ~ 2.2GHz
Dynamic range	2μW/g ~ 10mW/g
Calibration precision	±4%
Directional Symmetry	±0.5dB
Sensor	2.5mm dipole

Bibliography:

[1] CENELEC, SECRETARIAT SC211B, WGMTE, Feb. 1997.

[2] IEEE Std C95.3-1991

2.4.2 Thermographic Camera (Infrared thermographic camera, Temperature Distribution Analyzer)

This unit generally consists of a infrared (IR) sensor (camera) and image data processing/ display section.

The camera is cooled in liquid argon or a compact freezer since it must operate under cryogenic (low temperature) conditions. By using this unit it becomes possible to analyze and record superficial temperature distribution of an object, as high-resolution temperature distribution images. The analysis procedures resemble the step of general visible light cameras, and the image analysis is displayed as 2-dimensional (2D) images at almost real-time. This instrument becomes an ideal unit to analyze peak SAR since it can display peak hold through signal processing or improve the resolution by compressing noise.

Table 2.4-2 illustrates the representative characteristics. With this system it is possible to conduct SAR analysis with minimal error for both 1g and 10g units, since based on the picture element of the display, the aerial resolution is around 1mm^2 (0.01g equivalent) if, for example, the phantom dimension is 200mm x 200mm, and it is displayed in full-scale across the screen. And since the results are based on indirect analyses the risk of error in the reading is also extremely low.

Table 2.4-2 Example of Thermographic Camera Response

Temperature analysis range	40-300°C
Temperature analysis resolution	0.025°C
Temperature analysis precision	±0.4% (full-scale)
Pixel (picture element) of display	320 x 240

2.4.3. Temperature Probe

By using the following characteristics, a fluorescent thermometer is used as the temperature probe for SAR measurement.

(1) Characteristics of Fluorescent Thermometer

1) It has electrical insulation properties. The sensor that is a fluorescent substance, optical fiber in which optical transfer takes place over, and other materials are electrically insulated.

2) Measurement without thermal affect to the object to be measured. As the sensor has a extremely low thermal capacity, measurement can be performed without thermal affect to the object to be measured.

3) Fast response speed. Since the thermal capacity around the sensor is extremely small, it becomes possible to yield fast response speed and accurate analyses.

4) Temperature measurement is possible in an electromagnetic environment. As the sensor itself serves as insulation and fiber optics are used for transmission, Temperature analysis is possible in strong electric and magnetic fields without thermally affecting the object to be measured.

(2) Principle

The proportional correlation between free time and temperature attenuation in fluorescent intensity of the fluorescent substance used in the thermal sensor. Fig. 2.4-1 shows the configuration of a fluorescent thermometer.
The fluorescent thermometer consists of flash lamp, pump fiber, sensor (fluorescent substance), optical fiber and detector.

The operation is as follows:

1) When the flash lamp is flashed it is radiated through the pump fiber on the fluorescent substance that is the thermal sensor built-in at the tip of the optical fiber.

2) The fluorescent substance flashes a spectrum that is materialistically unique. The spectrum radiated from the fluorescent substance passes through the optical fiber and is detected by the detector.

3) Fig. 2.4-2 shows the correlation between sensitivity and time. Representing the oscillation time for the flash lamp light source by t_0, the spectrum light sensitivity with free conductive attenuation for the fluorescent substance as S_1, measure time τ required to attenuate from S_1 to S_1/e is measured.

4) Fig. 2.4-3 shows the correlation between attenuation time τ and temperature. This makes it possible to analyze the temperature.

(3) Sensor structure

Fig. 2.4-4 shows the structure of the sensor.

(4) Application

Used for medical equipment utilizing microwaves in the biochemical field.

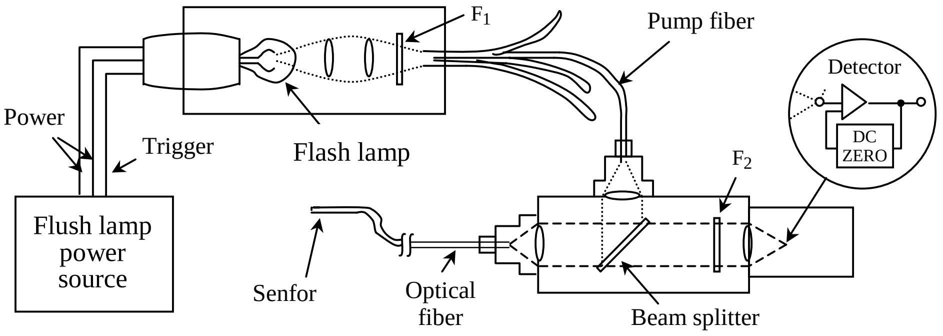

Figure 2.4.1 The fluorescent thermometer structure

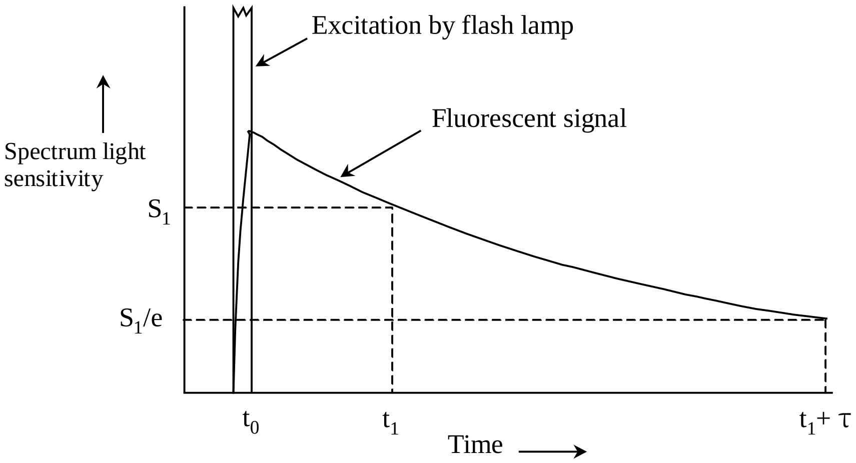

Fig. 2.4-2　Attenuation time analysis

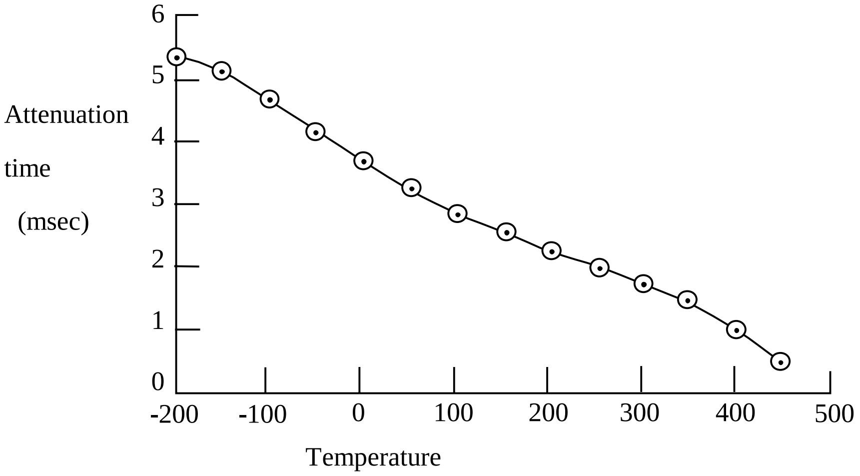

Fig. 2.4-3　Attenuation time measurement

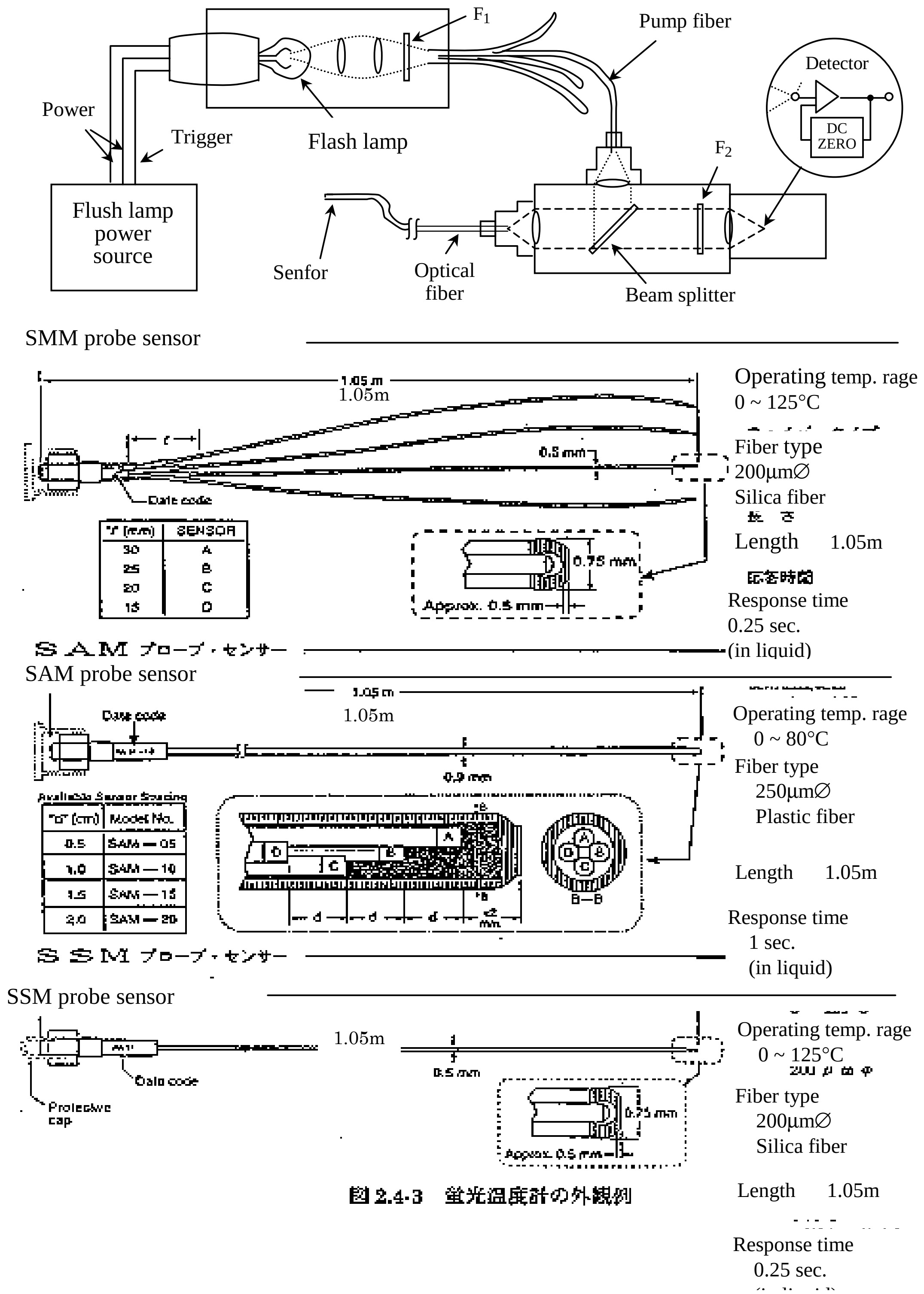

Fig. 2.4-4 Example of external view of fluorescent thermometer

2.5 Evaluation of indices for adaptability based on the measured values

(1) Analyze error factors for the measurement system and compensate the errors before obtaining the SAR values. Valid measured values must be 2-digit numbers.

(2) Assess inaccuracy and evaluate the indices for adaptability based on the maximum measured values. Refer to Appendix 6.1 for assessment of error analysis and inaccuracy.

Chapter 3. Specific Analysis Procedures

3.1 SAR Measurement Method [1] using liquid phantom and spatial scanned electric sensor

3.1.1 Principle of Measurement

This analyzing method to measure the electric field strength at each point in the liquid phantom (consisting of the outer shell and liquid conductive substance) by using the electric field probe and calculate the SAR based on the actually measured electric field strength.

3.1.2 Configuration of Measurement System

Fig. 3.1-1 illustrates the configuration of the measurement system. The conditions required for each consisting element are as follows.

(1) Phantom

The “average” shape of the human head should be simulated. In other words, major curvatures, lengths and other specifications of the human head should be mean values. The phantom is filled with the liquid which simulates the medium constant of the human head (commercially available liquid can also be used). For this reason, the phantom must function as the container which holds the liquid. The thickness of the outer shell of the phantom and the medium constant must be values which do not affect the measurements (refer to sub-section. 2.2.2.2). The scanning pattern must be set so as to allow the SAR peak to be estimated.

(2) Electric Field Sensor

The electric field sensor should be isotropic with three mutually orthogonal dipoles; length of each dipole element is less than 4mm. If it is shorter than 4mm, it will have a spatial resolution of better than 0.01cm^3, thus, allowing for SAR estimations for 1g and 10g tissue volumes.

(3) Robot for Measurement

Moving the probe with a precision of around 0.02mm is sufficient to evaluate averaged SAR values for 1g and 10g tissue volumes.

(4) Cellular phone table

This is used to support and lock the cellular phone at the specified position while analyzing. The table must be able to fix the cellular phone at the correct position without affecting the analysis.

3.1.3 Measurement Procedure

With this measurement equipment, move the electric field probe position three-dimensionally by the robot and measure the electric field at each analysis point in the head model and calculate the SAR value. The measurement procedure is shown in Fig. 3.1-2. Details are as below:

(i) Fix the cellular phone at the standard position.

(ii) In order to estimate the SAR peak position inside the head model, measure the electric field distribution inside the model along the curvatures of the phantom surface. If a frequency above 900MHz is used, space must be divided into 1cm units. The approximate position of the SAR distribution peak can be obtained.

(iii) In order to estimate the SAR peak for average 1g and 10g tissue volumes, space must be further divided into smaller units. In this instance, the position of the probe should be moved three-dimensionally. With this method, the SAR peak can be obtained with extremely high precision.

3.1.4 Calibration Method and Measurement Errors

(1) Calibration of medium constant of solution

Dielectric constant and conductivity for the solution filled into the head phantom can be analyzed based on amplitude and phase analyses by utilizing the network analyzer (may also be combined with the slot coaxial line with the probe), (refer to sub-section. 2.2.3).

Ingredients of the solution should be adjusted to resemble the mean medium constant of the human head.

(2) Calibration of SAR value

Calibrate the SAR values measured with the electric field probe based on the SAR values measured by the temperature probe. As the electric field probe has finite size, it is impossible to measure the SAR value at the boundary between the solution and the outer shell. For this reason, this value is estimated by the external insertion method. If there is SAR analysis data using the standard dipole, the results of analysis can be verified by using this data.

(3) Measurement error

As error factors, the properties of the solution (dielectric constant, conductivity, temperature, etc.) and errors caused by the measuring equipment can be considered. The SAR analysis errors based on the measuring equipment is ±20% in the DAYS system. Errors based on the properties of the solution can be comparatively reduced by accurate analysis on dielectric constant and conductivity. Errors in the SAR measurement attributed to the property of the solution can be suppressed to several percent. The SAR analysis value for the overall system will be approximately 20%, [1].

3.1.5 Precautions Upon Measurements

(1) Property of solution

A solution must be made for each frequency according to the medium constant. The medium constant of the solution changes due to evaporation as time elapses. Thus, there is a need for periodically checking the property of the solution by analyzing the medium constant or by other methods.

(2) Cellular phone setting

Settings should satisfy the conditions outlined in sub-section 2.3.

(3) Reproducibility of measurement results

In order to ensure reproducible the measurement results, the equipment fixing the cellular phone in position must be very accurate. Also, record the position of the cellular phone in a computer, or photograph the cellular phone as tested.

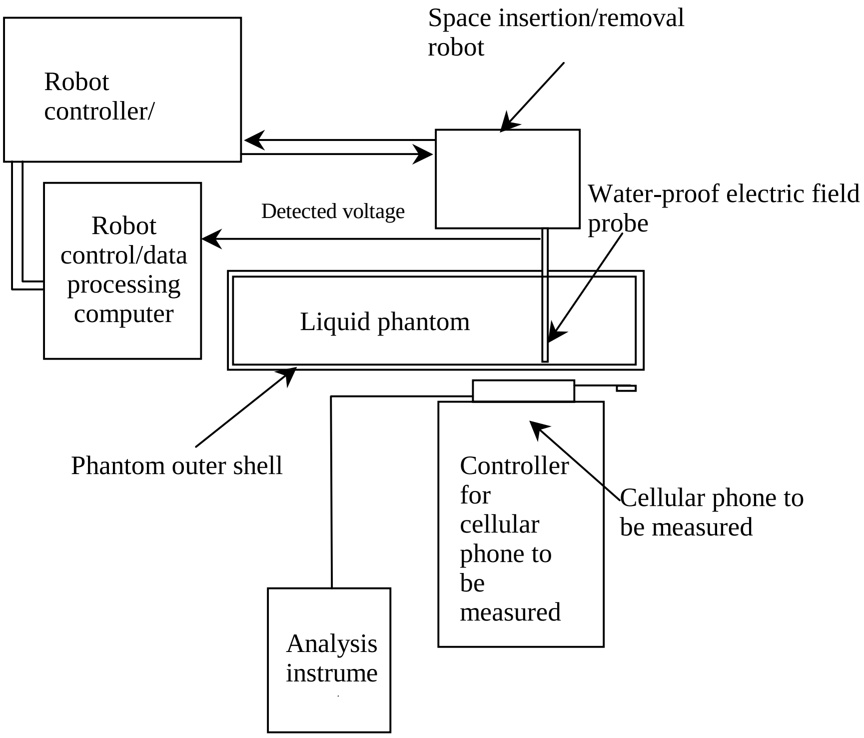

Fig. 3.1-1 Configuration of SAR Measurement system with the spatial scanned electric sensor

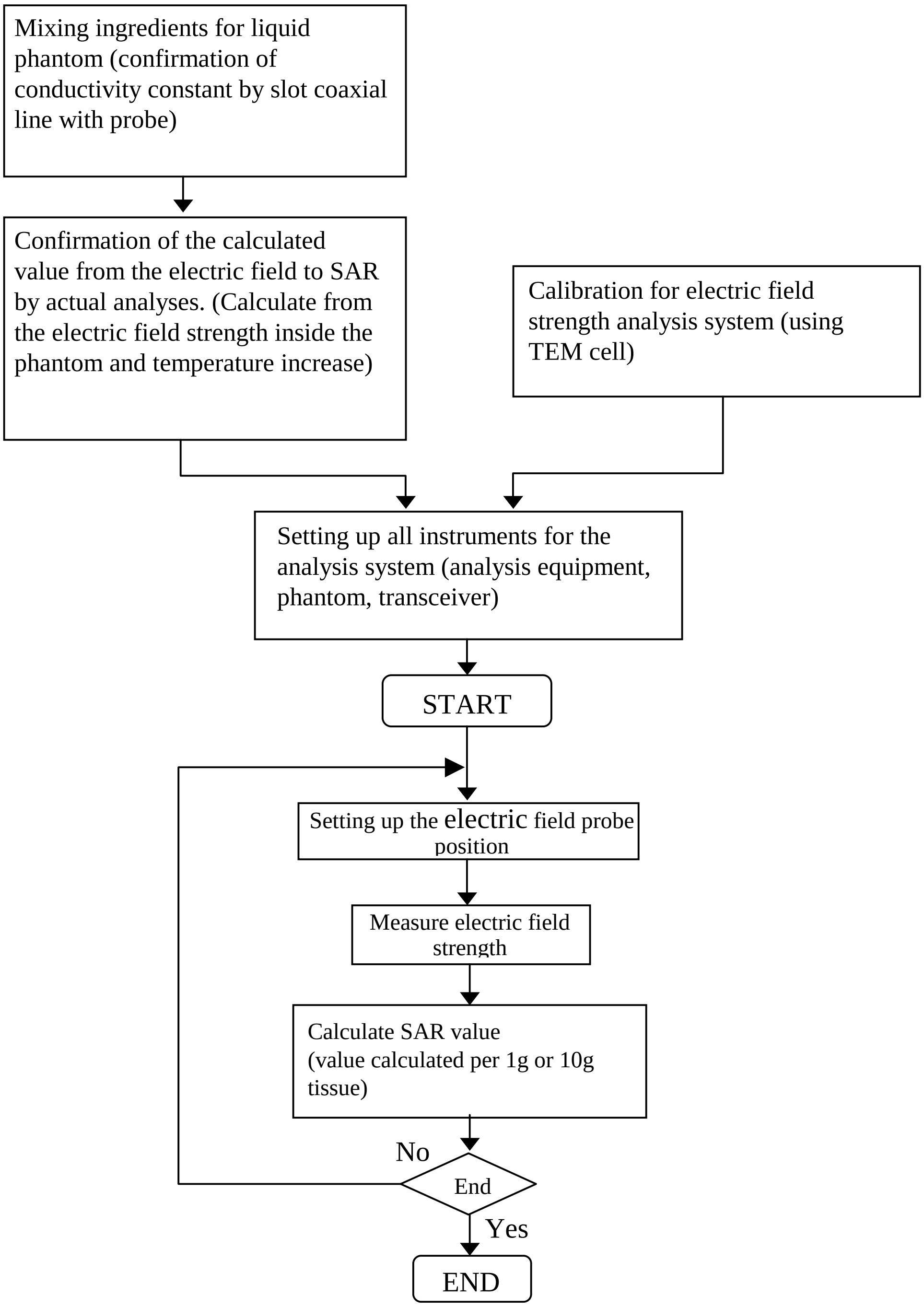

Fig. 3.1-2　SAR Measurement procedure by electric field distribution method

3.2 Thermographic Method for SAR Evaluation

3.2.1 SAR Expressed in terms of Incremental Values of Temperature

In the thermographic method, as is explained in 3.1 (2), an SAR distribution is evaluated in terms of the distribution of incremental values of temperature induced on the cross section of a head model. Namely, the SAR value for a point can be obtained using the following equation:

$$SAR = c\,(\Delta T / \Delta t)\ [\mathrm{w/kg}] \qquad (1)$$

where $c[J \cdot kg^{-1} \cdot K^{-1}]$, is the specific heat of the head model, $\Delta T[K]$ is the incremental value of temperature, $\Delta t[s]$ is the exposure duration. Note that equation (1) is an approximation because we neglect the effect of thermal conduction and diffusion. Equation (1) produces accurate SAR evaluation if the incremental value of temperature and the exposure duration are limited to a few degrees and less one minute, respectively [1], [2]. To realize these conditions, the emission power (averaged over the exposure duration) must be more than 100 W. Emission powers, on the other hand, of portable handsets are much lower and depend on the modulation type and / or multiple access system (FDMA, TDMA, etc.). For PDC handsets, for example, averaged value of the transmission power varies from 3 mW to 300 mW. For SAR measurements, handsets should be evaluated with the emission power set to the maximum, that is, 300 mW for PDC handsets. 300 mW, however, is too weak to apply the thermographic method. For this reason, simulated models of handsets emitting more than 100 W, are used.

3.2.2 Descriptions of Measurement System

The basic setup of the measurement system is shown in Fig. 3.2-1. The following are requirements for the elements of the system:

(1) Simulated Handsets

Shapes and electric properties of chassis and structure of antennas should be the same as the original ones. Maximum permissible input power of the antennas should be greater than 100 W

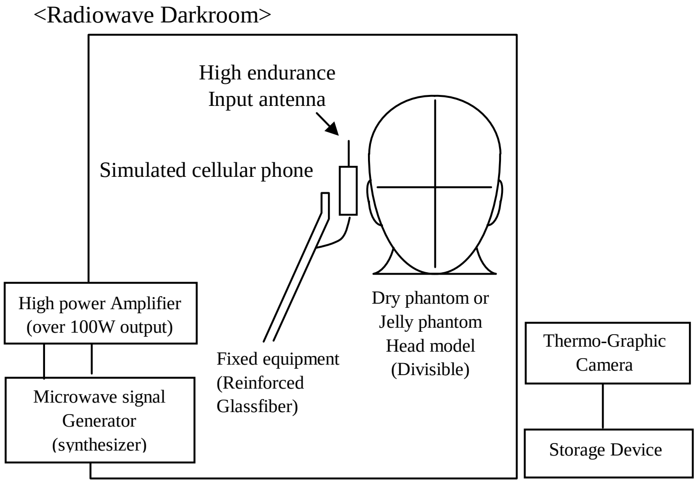

Fig. 3.2-1　Configuration of SAR distribution using thermography

for CW, and the rise in the temperature of the antennas and chassis should be less than 1 [K], even if the duration of the emission is about one minute.

(2) Phantoms

The phantom should be formed to simulate the human head in the approximate sense.　It should be possible to divide the head model into pieces to observe the incremental values of temperature on various cross sections of the head.　Both semisolid and solid phantoms can be used.　For the case of semisolid phantoms, shells to form the head model and partitions to maintain the cross section forms are necessary.　As the partition material, silk cloth is used [1], [2].　Solid phantoms are preferable for this measurement method, since partitions are not necessary and the properties of the phantoms are stable with respect to time[3].

(3) Thermographic Cameras

Cameras described in 3.4.2 can be used.

3.2.3 Measurement Procedures

First step is to observe the initial temperature distribution on the surface and the cross sections of the head model, and confirm that the distribution is uniform and stable.　Next, the head model and the handset are aligned to reproduce the normal operating condition.　The normal operating condition has the ear-piece and the mouth-piece adjacent to the ear and the mouth of the head model, respectively. It is necessary to adjust the position of the handset so that the point of peak SAR appears on a cross section of the head model. The head model is irradiated by RF radiation (CW signal) by the handset with emission power P [W]. A temperature distribution is induced on the head model as a result of the thermal effect of the RF radiation. The temperature rise ΔT at a point on the phantom is proportional to the energy absorbed at that point, so that a point with higher SAR value has greater ΔT value. The head model is irradiated until its temperature distribution is measurable (note that ΔT should be less than one minute). After the head model is irradiated, confirm that the handset is switched off, and divide the head model into pieces and place the cross section of the head model in front of the thermographic camera to observe its temperature distribution. Temperature increases, ΔT, are obtained by comparing the temperature distribution to the initial temperature distribution. SAR values are estimated using equation (1) once ΔT is obtained. The maximum value of the observed temperature increase is the average value within the area corresponding to the monitor cell of the thermographic camera. Hence, if the cell's dimension, projected on the head model, is less than $(10)^{1/3}$=2.15cm, SAR averaged over 10 g of head tissue can be obtained arithmetically. If the SAR found by using the standard emission power P [W] is X, the SAR value corresponding to p [W] for the actual handset can be obtained, simply, from X multiplied by p/P.

3.2.4 Measurement Uncertainties

The uncertainties inherent in this method are described below.

(1) Uncertainties from the use of Simulated Handsets

The differences between the near-field of the simulated handset and that of the actual handset are negligible, provided that shapes and materials of the antennas and chassis are the same. With respect to the impedance matching of the antennas, it is necessary to apply narrow band tuning to the simulated handset to realize high emission power. The difference between losses of the power at the antennas is 1% at most, even if the VSWR of the actual handset and the simulated handset are 1.2 and 1.05, respectively, so the uncertainty due to narrow band tuning is negligible.

(2) Temperature Measurement Uncertainty

The origin of this uncertainty is the thermal diffusion within the head model. Experiments show that, except for surface of the head model, the effect of thermal diffusion is negligible provided that both the exposure duration and the time necessary for measurement are less than one minute. If the RF frequencies range from 1GHz to 2 GHz, maximum value of the SAR distribution appears on the side of the head closest to the handset. The value of that peak SAR at the differential volume element is approximately 20 % lower than the true value. As is shown in Fig. 3.2-2, the area where the SAR value can be decreased is restricted to the area close to the surface, within a few mm. Therefore, for SAR averaged over 10g of tissue, the side dimension of which is about 2.15cm, the effect of the temperature decrease is within a few %, i.e., negligible. Strictly speaking, besides the uncertainties described above, uncertainties due to the measurement equipment should also be examined, but these can be corrected after the measurements are made.

Fig. 3.2-2 An example of the temperature distribution on a cross section and surface of a head model

Precautions during Measurements

(1) Since RF radiation levels of 100-200 W exceed the RF radiation safety guidelines, the head model and all radiation equipment must be set up in a sealed room and no one must enter the room while the equipment is active.

(2) In the case of solid phantoms, the peak value can be obtained easily from the temperature distribution on the surface. For the case of gel phantoms, the presence of the shell prevents us from measuring the temperature distribution on the surface. For this reason,

the point at which the peak SAR appears should be predicted in advance by field measurements, etc., and it is necessary to adjust the exposure condition so that the peak SAR appears right on the cross section.

(3) The temperature distribution is measured using a thermographic camera, after the head model is irradiated with RF radiation. Usually it takes some seconds to evaluate the temperature distribution, and the peak value of the temperature distribution decreases within this period due to thermal diffusion. It is necessary, therefore, to measure the temperature as soon as possible.

3.3 SAR Evaluation with a Dry Phantom and an Electric Field Probe

3.3.1 Basics of the Measurement (Field and SAR)

In the SAE evaluation with a dry phantom and an electric field probe, the electric field probe is placed within the head model, close to the auricle. The position of the handset is moved and peak SAR is evaluated through electric field measurements. In general, SAR on the point (x, y, z) in the tissue exposed to RF radiation is given by

$$SAR(x,y,z)\frac{\sigma(x,y,z)\left|E(x,y,z)\right|}{\rho(x,y,z)}(w/kg)$$

where „ E(x, y, z)„ (V/m) is the rms. value of the electric field strength, σ(x, y, z) (S/m) is the conductivity, and ρ(x, y, z) (kg/m^3) is the density at that point. When the cellular handset is used close to the body of the user, the field induced inside the body is determined by the boundary condition of the configuration of the head, and the distribution of electromagnetic properties, namely, relative permittivity, conductivity, and permeability. Therefore, it suffices to measure the electric field in a homogeneous head model that simulates the “average” human head. Since dry phantoms are solid, the position of the electric field is fixed, close to the auricle, and peak SAR value is obtained by moving the position of the handset.

3.3.2 System Configurations

(1) Phantoms

Phantoms should be shaped to simulate the average human head. Namely, the main curves and dimensions of the phantom should be those of the average human head. Dielectric properties of the phantom should be close to the average values of the dielectric properties of human heads. For example, a dry phantom consisting of high-dielectric ceramics, carbon, and bonding resin can be used.

(2) Probes

The elemental dipoles of the electric field probes should be about 4 mm long, and they must be isotropic. It is assumed that if elemental dipole length is less than 4 mm, then the resolution is higher than 0.01 cm^3 . This allows the evaluation of SAR averaged over 1g of tissue.

3.3.3 Measurement Procedures

In this method, peak SAR is obtained by moving the cellular handsets. Strictly speaking, peak SAR should be evaluated from the SAR distribution corresponding to the normal operating position of the handset (Fig. 3.3-2). Since the position of the electric field probe is fixed, the point of peak SAR and the location of the probe usually do not match if the handset is in the normal operating condition. It is expected, however, that by moving the position of the handset, the point of peak SAR can be moved closer to the location of the electric field probe (Fig. 3.3-3).

3.3.4 Calibration and Uncertainties

(1) Calibration

Calibration of this measurement system is based on the SAR evaluation with thermography. Standard dipole antennas or simulated handsets can be used for calibration. The SAR distribution obtained by the thermographic method is the distribution corresponding to the antenna input power of 100 W. This SAR distribution is normalized to obtain the SAR distribution corresponding to the antenna-input power of 1 W, that is, divided by 100. Next, with the same standard dipole antenna or simulated handset, set the antenna-input power to 1 W and measure the electric field strength with the probe. Let the observed rms. value of the electric field strength be |E|. If the normalized SAR value obtained by the thermographic method is X, then the calibration factor c is defined by

$$C = \frac{X}{|E|^2}$$

With this calibration factor, SAR values are evaluated from the measured electric field strength |E| by the following equation:

$$\mathrm{SAR} = C \times |\mathbf{E}|^2$$

(2) Uncertainties

since the thermographic method is used for calibration of this system, uncertainties mainly arise from the uncertainties of the thermographic method. That is, the uncertainties are the summation of the uncertainties in the thermographic method and those in the calibration process.

3.3.5 Precautions during Measurements

(1) In general, peak SAR appears on the surface of the head model. However, placing the electric field probe on the surface yields near-field measurements, not the SAR measurement (electric field inside of the head model). Typical example is shown in Fig. 3.2-4. To overcome this problem, the electric field probe is placed 1-2cm inside the surface and the SAR value on the surface is obtained by extrapolation.

(2) SAR evaluation results strongly depend on the position of the handset. To produce reproducible results, it is recommended that the position of the handset be recorded by cameras, etc.

(3) Dielectric properties of the dry phantom depend on the frequency of the RF radiation. The dielectric property can be approximated within a limited range of frequency for a particular dry phantom. It is necessary, therefore, to prepare dry phantoms for each frequency range.

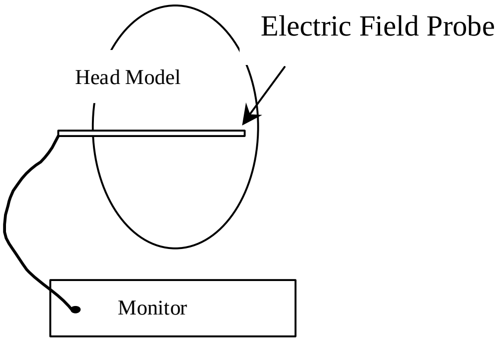

Fig. 3.3-1 Basic setup of the system

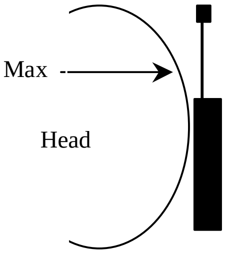

Fig. 3.3-2 Normal operating condition of the handset

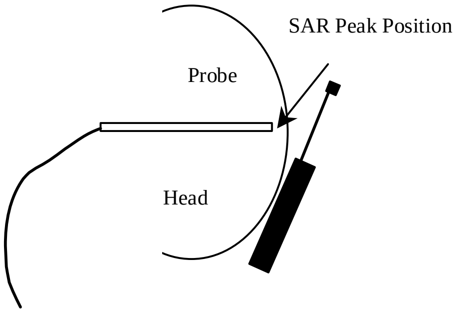

Fig. 3.3-3 Shifting the position of the handset

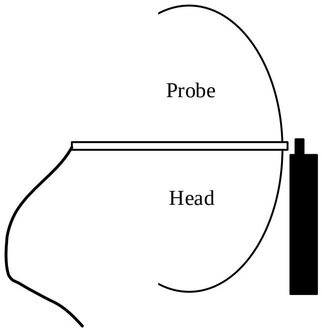

Fig. 3.3-4 Typical example in measuring near field

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Chapter 4. Conditions for Radio Equipment for which SAR Measurement is not Required

4.1 Transmission Conditions and Bases

Radio equipment with average transmission powers of 20mW or less “stipulated as the average power among antenna powers” by the Radio Law satisfies the Telecommunications Technology Council Agenda No. 89 “Guideline in Protecting the Body Upon Radiowave Use”, do not require SAR evaluation.

When 20mW is absorbed into 10g or more of tissue, the SAR value of the average 10g tissue volume will always be 2W/kg or less. Therefore, if the transmission power of the radio equipment is below 20mW and the smallest analysis unit is 10g (of tissue), the SAR is maintained below 2W/kg under any condition. Such radio equipment should satisfy the requirements of the whole-body averaged SAR.

4.2 Testing Method and Requirement

4.2.1 Testing Method

The following method is employed.

1) If the radio equipment has a measurement terminal, use a calibrated power meter to measure the transmission power of the radio equipment.

2) If the radio equipment has no measurement terminal, the analysis method specified in the following agenda of the Telecommunications Technical Council must be used.

   * Agenda No. 88 “Technical Requirements regarding the Measurement Method for Antenna Power for Built-in Antenna Type Radio Equipment” which is a Partial Report of the “Technical Requirements regarding the Measurement Method for Antenna power for Radio Equipment”

4.2.2 Requirement

Measure the mean transmission power of the radio equipment in accordance with the testing method described in 4.2.1, and verify that it is 20mW or under.
(Radiocommunications Act, Section 2, Item 70 “Mean Power”)

Chapter 5. Definition of Terms

- Radiowave

Radiowave refers to a type of electromagnetic wave whose frequencies range from the radio frequency, which is the voice band frequency, to the 3000GHz infrared ray band and propagates in air (in the atmosphere or in a vacuum) at optical speeds.

- Radiowave Protection Guideline

Regarding Agenda No. 38 “Radiowave Protection Guideline against Human Body in Use of Radiowaves” issued in June 1988, The Telecommunications Technology Council submitted a report titled “Radiowave Protection Guideline” in June 1990. That report states “this guideline is recommended for maintaining a safe environment by preventing the electromagnetic field from imposing unnecessary biological effects on the human body when the human tissue is exposed to the electromagnetic field during use of radiowaves (frequencies between 10kHz and 300GHz). It also states “the guideline consists of numerical values for electromagnetic field strength, etc., the evaluation method for the electromagnetic field, and the protection for reducing the impact of electromagnetic radiation on human bodies”.

- Basic Guideline

This is one of the guidelines specified by the Radio Protection Guideline and used for evaluating the safety factors based on various biological effects (body temperature increase, electric shock, burning from high-frequency, etc.) This is positioned as the basis for the concept of the Radiowave Protection Guideline and described by SAR, conductive current, contact current, etc.

- Control Guideline

This is one of the guidelines specified by the Radio Protection Guideline. It is actually used for evaluations, indicated as the physical phenomena (electric intensity, magnetic intensity, electric density, current and specific absorption rate) that can be measured to satisfy the basic guidelines. The Control Guideline further address the Electromagnetic Intensity Guideline, Local Absorption Guideline, and Supplementary Guideline.

- Electromagnetic Intensity Guideline

This is one of the guidelines specified by the Radio Protection Guideline. It evaluates the safety of the subject space in terms of the electric intensity, magnetic intensity, and electric density of the target space.

- Supplementary Guideline

The guideline is used to finely evaluate the details according to the Basic Guideline, when the Electromagnetic Intensity Guidelines are not satisfied.

- Specific Absorption Rate (SAR)

SAR refers to the power absorption per mass unit, when the body is radiated with an electromagnetic field. The time differential of energy dW absorbed by minute mass element dm, included in minute volumetric element dV of density ρ[kg/m^3] is calculated using the following formula:

$$\mathrm{SAR}\ [\mathrm{W/kg}] = d(dW/dm)/dt = d(dW/\rho dV)/dt$$

The following two formulae are more practical:

$$\mathrm{SAR}[\mathrm{W/kg}] = \sigma\ |\mathbf{E}|^2 / \rho$$

Where, σ[S/m] is the conductivity of physical matter (in other words, biological tissue) , E[V/m] is the r.m.s. (effective) value of electric intensity inside the subject physical matter.

$$\mathrm{SAR}[\mathrm{W/kg}] = c(dT/dt)$$

c [J _ kg-1 _ K-1] is the heat capacity of the physical matter, and dT/dt is the temperature rise rate within the physical matter.

- Averaging Time

For time function P(t) of power, the time mean energy is defined by the following formula. In this instance, time $_{t2-t1}$ is called “averaging time.”

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

The averaging time for obtaining the whole body averaged SAR is 6 minutes.

The averaging time for local SAR is also specified as 6 minutes by the Telecommunications Technology Council Agenda No. 89. This analyzing method is based on assumption of the worst condition wherein the cellular phone terminal to be evaluated is connected with transmission only for 6 minutes Thus, for terminals using the TDMA, the frame cycle can be substituted for the averaging time.

- Whole body averaged SAR

The value [W/kg] is obtained by dividing the total power absorbed by the human body [J] within 6 minutes (360 sec) by the full body weight [kg] then again by 360. The value calculated by this method is equivalent to that gained by dividing volume integration (integral value for the SAR distribution over the entire body) by the full volume.

- Local SAR

SAR is given as a numerical value per minute volume element and becomes a space distribution function which depends on the electromagnetic wave radiation condition. For this distribution function, the mean value in arbitrary 10g tissue volume is called local SAR. The maximum value is also called the local peak SAR. However, the 10g tissue volume is specified by the Telecommunications Technology Council Agenda No. 89 and CENELEC 1995 while the value of 1g is adopted by ANSI/IEEE C95.1-1992 of the United States.

- Electric Field Strength

The vector is the quotient that divides the force of the minute electric load with the level of electric load, when a point is applied with static minute electric loads. Here, the electric intensity E is applied with E=F/q[V/m] when F is force and q is the electric load.

- Magnetic Field Strength

The vector is the rotation that becomes the current density and displacement current density. It is equal to the value of the flux density divided by the permeability of the medium. The unit is A/m.

- Electric Power Density

The discharge power per unit area that is vertical to the direction of electromagnetic propagation. For example, in the case of a planar wave, if electric density is S[W/m2], electric intensity is E[V/m] and magnetic intensity is H[A/m], by applying a free space impedance of 120π[Ω] would satisfy the following relationship: S=E2/120π=120πxH2

- Uniform Exposure

When the electromagnetic field of the spatial area in which the human body exists is almost even, and the entire body is exposed to that electromagnetic field. This also includes the cases when the free segment impedance isn't 120π[Ω]. When the distance from the radiation source is larger than the free space wavelength it is considered uniform (this, for example, would mean that for frequencies under 0.3MHz the distance should be more than 15m, frequencies of 0.3MHz to 300MHz more than 10m, and frequencies over 300MHz more than 5m).

- Nonuniform Exposure

Any situation that cannot be considered as uniform exposure.

- Local Exposure

When one part of the human body is intensively exposed to electromagnetic fields. This includes near adjacent irradiation from an antenna that is much smaller than the human body, and short wavelength radiowaves causing spot radiation.

- Full-Body Exposure

When the entire body, not just local, is exposed to electromagnetic fields. Though the level of exposure is not necessarily even, this indicates cases that are not covered by local exposure.

- Low-Power Radiation Source

Low power electromagnetic radioactive sources operating at frequencies from 100kHz to 3GHz.

- Hot Spot

The phenomena in which incident electromagnetic energy into the human body is concentrated on one part of the human body. This term is commonly used, especially when the electric concentration inside the body is larger than the electric absorption on the surface. Under the conditions of local exposure to the area adjacent to the head during the use of a cellular phone, the hot spot generally concentrates on the head surface, but not within the brain. Spheres under 8cm in diameter may show a different response. Refer to the Telecommunications Technology Council Agenda No. 89.

- Far Field

The electromagnetic fields where the distance from the electromagnetic radiation source is further than either 2D2/l or l/2, without scattered reflection. In this formula, D is the maximum dimension of the antenna and l is the wavelength in free space.

- Near Field

Electromagnetic fields that cannot be considered as far fields.

- Phantom

This is a simulated human model used to experimentally estimate specific absorption rate (SAR). The phantom must have electric characteristics, shape, size, etc., similar to those of the human body. A phantom using the same material for the entire model is called an “even phantom” and a phantom which simulates the electric characteristics of each tissue is called an “uneven phantom”. For a mean phantom model composed of liquid or gel phantom material, a container is necessary. Glass fiber reinforcement epoxy has a low dielectric loss characteristic at high frequency and can be a candidate for the container. The dielectric constant of this material is less than 10. If the thinness of the container is less than that shown in 2.3.1.2, the influence on SAR distribution can be ignored.

- Uncertainty

This is an estimated value which indicates the difference between the actually measured value and the true value of a certain quantity and is expressed by mean error, determined error, standard deviation, etc.

Chapter 6. Appendix

6.1 Error/Uncertainty Processing Procedures

6.1.1 Errors and Uncertainty

Fig. 6.1-1 is a block diagram that outlines the system in which SAR is analyzed and indicates the factors for errors/uncertainty expected in each block given the SAR analysis method using the electric sensor.

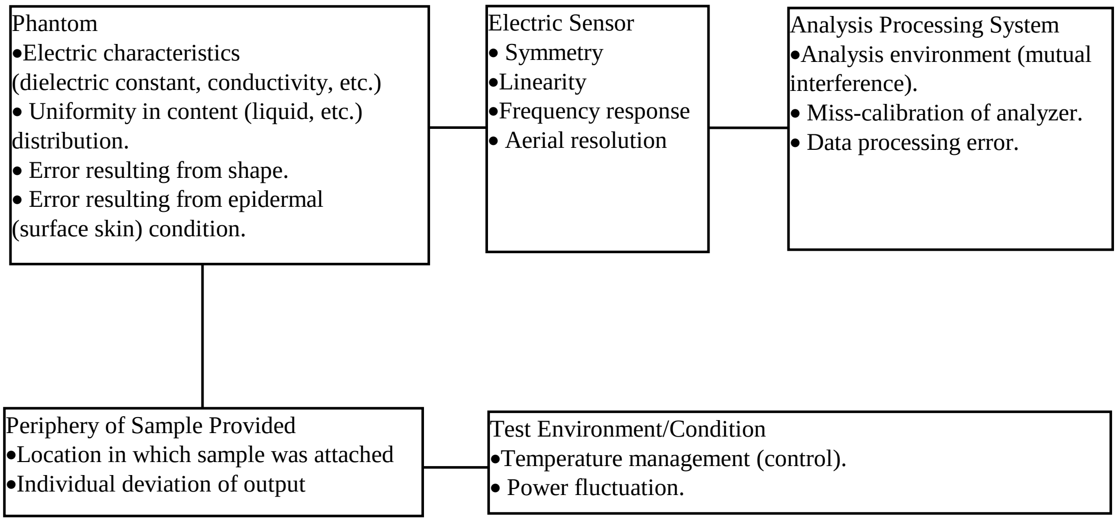

Fig. 6.1-1: Diagram of major causes of error in the SAR analysis system.

The following can be used as reference for error analyses.

(1) Use of the homogeneous phantom gives more conservative SAR values than the heterogeneous phantom

(2) The electric sensor can be calibrated with higher precision than the temperature probe or (thermography).

(3) Uncertainty about the location of the measurement can be eliminated by detecting and evaluating the condition wherein the SAR is highest.

6.1.2 Assessment of uncertainty

The following can be used as a reference for error analyses.

(1) As described in IEEE materials for analysis methods(1), uncertainty which occurs with the method of analyzing the SAR by detecting the temperature or the electric field is assumed to reach ±1dB to ±3dB for an actual overall analysis system. It is reported that with the electric probe scanning type-analyzing system, uncertainty of the analyzed local peak SAR value can be suppressed below 20% [2].

(2) The local SAR which is specified by the Local Absorption Guidelines has been set in consideration of the sufficient safety constant based on the threshold which is expected to cause confirmed biological effects(3). More precisely, the general environment guidelines have a safety constant which is 50 times higher and controlled environment guidelines have a safety constant 10 times higher than the threshold. The local SAR in the guidelines(4) in the United States is defined as the standard value by taking the safety constant as the margin of safety into account.

(3) As described in NIS 81 “EMC Test Results and Application of Uncertainty” [5], if the analyzed value which includes uncertainty in normal distribution satisfies the guideline, this indicates that the result of analyses satisfies the guideline with high probability.

(4) When the analyzed value satisfies the guideline and the uncertainty in normal distribution is included in the margin of safety with sufficient leeway, whether or not the fact that the analyzed value satisfies the guideline and the result of analyses satisfies the guideline makes any difference to the risk of biological effects occurring has not been confirmed.

(5) Table 6.1-1 summarizes problems regarding uncertainty in the EMC analyses.
Fig. 6.1-2 illustrates a determination or decision based of the items described above.

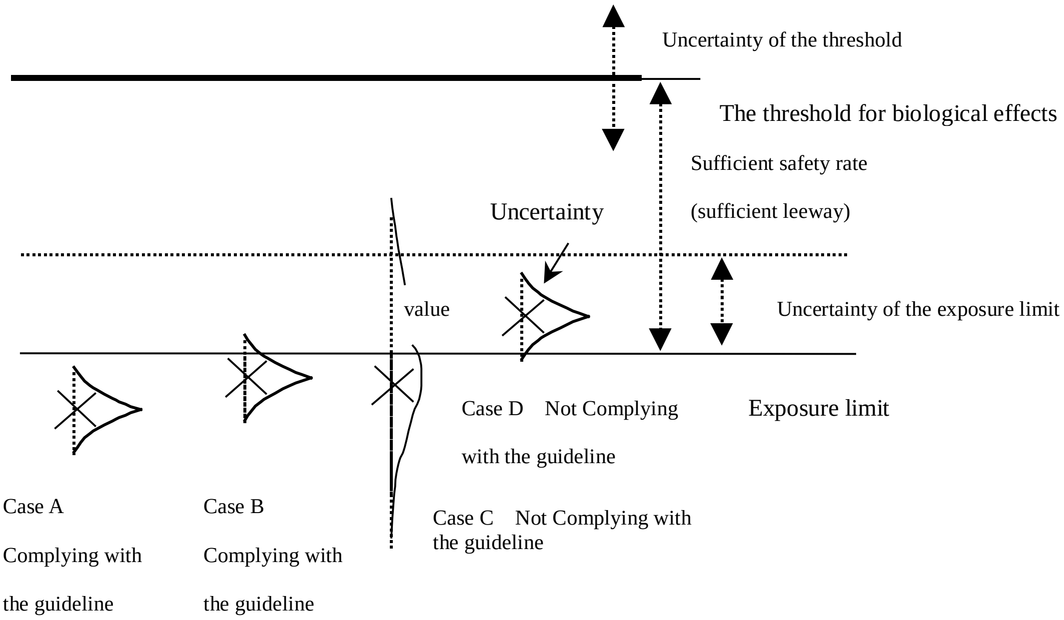

Fig. 6.1-2 An example of criteria for assessing compliance with the guideline

Table 6.1-1: Comparison of EMI and SAR

Comparative Item	EMI (EMC)	SAR
Target affected	Electronic equipment => other electronic equipment	Cellular phone, etc. => human body
Characteristics of standard value.	• When the standards are exceeded the electromagnetic waves tend to interfere with operations of other equipment; resulting in malfunctions.	• This doesn't mean that values exceeding the standards will directly and immediately affect the human body. • The standard value refers to the standards of the Radiowave Protection Guideline. ...(1) (There is no evidence in affecting the human body when readings were below standards: ICNIRP).
	• The validity of the standards are being improved by introducing regulations for those affected by electromagnetic noise to improve resistance.	• Though the effects on the human body are thought to be at a higher level, the threshold has not been proven at this point. ...(2)
Probe quality issues.	•The analysis method is established.	• The analysis method is not established yet. ...(3) (standardization of the phantom, simulated human body, and analysis procedures using the phantom remains to be established.)
Error processing procedures.	•There is debate surrounding the uncertainty of the standards.	• First of all there is a need to: 1. Clarify the correlation of 1 and 2, indicated above; and 2. standardize and establish the analysis procedures. ...(3) • This will establish the groundwork to debate error processing procedures.

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Specific Absorption Rate (SAR) Estimation

for Cellular Phone

ARIB STANDARD

Version 1.0

ARIB STD－T56

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