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Ericsson SAR Measurement Specification

Part	**Document name**	**Document number**	**Rev**
1	Introduction and purpose	ERA/T/U-98:446	C
2	Tissue liquid preparation	ERA/T/U-98:404	D
3	Measurements of dielectric parameters	ERA/T/U-98:405	F
4	System accuracy verification	EUS/TR/X-98:1585	F
5	Calibration of equipment	EUS/TR/X-98:1586	D
6	DUT preparation and characterization	ERA/T/U-98:439	H
7	SAR measurement procedure	ERA/T/U-98:441	H
8	Documentation of results	ERA/T/U-98:447	C
9	Bibliography	ERA/T/U-99:047	D
10	Glossary of symbols	EUS/TR/X-99:1336	A

Ericsson SAR measurement specification, part 1:

Introduction and purpose

1. Introduction

It is an Ericsson policy that all RF transmitting products shall comply with existing recommendations, standards and regulations on human exposure to electromagnetic fields. In the reference section below, the most important RF safety guidelines are listed [1-8]. If no national standard or regulation is available in a country, the international recommendation from ICNIRP [1] shall be applied for Ericsson products.

The RF safety guidelines specify *basic restrictions* and *reference levels*. In the frequency range of interest for mobile communications, the basic restrictions are expressed as Specific Absorption Rate (SAR) limits and the reference levels as field strength or power density limits. The reference levels are provided for the purpose of simple measurements of compliance with the basic restrictions, and they are primarily applicable in the farfield region of a RF source. Measured values greater than the reference levels do not necessarily mean that the basic restrictions are exceeded.

In the nearfield region of mobile communication devices (handsets or base station antennas), field strength values exceeding the reference levels may be observed. Compliance with the basic SAR restrictions has therefor to be verified. SAR (W/kg) is a measure of the rate of RF energy absorption in tissue. The table below shows the *localized* SAR limits for the general public (uncontrolled environment) and workers (controlled environment) in the ICNIRP and ANSI/IEEE guidelines. Mobile communication equipment are usually used by the general public and should consequently be in compliance with the general public limits, which are 2.0 W/kg averaged in 10 gram of tissue in the ICNIRP guidelines and 1.6 W/kg averaged in 1 gram in the ANSI/IEEE standard. Because of the lower limit and the smaller averaging mass, the ANSI/IEEE limit is slightly more conservative than the ICNIRP limit. The averaging times are also different, 6 minutes in the ICNIRP recommendations and 30 minutes in the IEEE guidelines.

The 2.0 W/kg (10 g) SAR limit has also been adopted in a European Prestandard from CENELEC [3] and in guidelines from the Ministry of Post and Telecommunications in Japan [4]. The 1.6 W/kg (1g) SAR limit has been adopted by the FCC as a regulation in the U.S. [6], and also as the basic restriction in preliminary Australian and Canadian standards [5,6]. The FCC requires SAR testing of mobile phones since 1997 [6,10]. Similar requirements were introduced in Australia February 1, 1999 [7] and will be introduced in Canada during 1999. In Europe and Japan regulations are expected within the next few years.

SAR test standards for mobile communication equipment are under development by IEC, CENELEC, IEEE and ARIB. In the year 2000, it is expected that the first international standard will be published. Technical documents describing SAR test methods and procedures are already available from CENELEC, ARIB, ACA and the FCC [7-10].

Standard/Guideline	**Localized SAR limit (W/kg) General public (uncontrolled)**	**Localized SAR limit (W/kg) Workers (controlled)**
ICNIRP (1998)	2.0 (10 g)	10 (10 g)
ANSI/IEEE (1992)	1.6 (1 g)	8.0 (1g)

2. Purpose of the Ericsson SAR measurement specification

The purpose of the Ericsson SAR measurement specification is to describe how SAR tests shall be conducted in the three SAR test laboratories in Ericsson, which are:

- The Ericsson EMF Research Laboratory at Ericsson Research in Kista (Contacts: ERA/T/UF Christer Törnevik or ERA/T/UD Martin Siegbahn)
- The ECS SAR laboratory at Ericsson Mobile Communications in Lund (Contacts: ECS/TN/FAC Thomas Bolin or ECS/TA/FA Ramadan Plicanic)
- The EUS SAR laboratory at Ericsson Inc. in RTP (Contacts: EUS Russ Holshouser or EUS Mark Douglas)

All these laboratories are equipped with the DASY3 SAR test system from Schmid & Partner Engineering AG (SPEAG). Since there is not yet an official standard that defines and describes SAR test procedures, it is necessary to specify internal Ericsson procedures for testing of mobile communication equipment. When an international SAR test standard is available, the Ericsson SAR measurement specification will be partly or completely replaced by this standard.

The Ericsson SAR measurement specification may be submitted to agencies like the FCC (USA), ACA (Australia) and Industry Canada if requested.

3. Applicability of the Ericsson SAR measurement specification

The Ericsson SAR test measurement specification shall always be followed when testing for compliance with SAR limits for handheld radio products or base station antennas in any of the Ericsson SAR laboratories.

Based on results from maximum exposure calculations and experience gained from earlier SAR measurements in Ericsson, it is known that certain low-power products can not exceed the SAR limits in any operational condition. These products do not have to be SAR tested, unless required by national or international standards and regulations.

The table below gives output power levels below which SAR testing is generally not necessary.

Type of equipment	Output power level in mW, below which SAR testing is generally not required	Example of Ericsson products
Mobile terminal	20	DECT Portable Part
Base station antenna	100	DECT Radio Fixed Part DECT RLL Fixed Access Unit

3. Content of the Ericsson SAR measurement specification

The Ericsson SAR test measurement specification contains the following documents:

Part 1: Introduction and purpose
The current document. It gives a short introduction to exposure limits and SAR, summarizes SAR standards and regulations and explains the purpose of the Ericsson SAR measurement specification.

Part 2: Tissue liquid preparation
This documents describes how the liquid materials used to simulate body tissue in the SAR test phantom should be prepared in order to obtain the correct dielectric properties.

Part 3: Measurements of dielectric parameters
This part describes the procedure used to experimentally verify that the dielecric properties of the tissue liquid is within the specifications given in part 2.

Part 4: System accuracy verification
This document describes the procedures used to verify that the SAR test system is working properly.

Part 5: Calibration of equipment
This document provides calibration information for the equipment used in Ericsson's SAR measurement laboratories.

Part 6: DUT preparation and characterization
This document gives information about how the device under test should be characterized and setup prior to a SAR test.

Part 7: SAR measurement procedure
This part of the specification describes the practical process of measuring SAR for various product types using the test equipment in the Ericsson SAR laboratories.

Part 8: Documentation of results
This document describes how SAR test results should be documented and stored.

Part 9: Bibliography
This part contains copies of SAR regulation documents, references to important basic and SAR related research papers, and lists documentation that should be provided with the SAR test equipment and available in the Ericsson SAR test facilities.

Part 10: Glossary of symbols and acronyms
This document explains the meaning of symbols and acronyms used in the other parts of the Ericsson SAR measurement specifications.

References

[1] ICNIRP, "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)", International Commission on Non-Ionizing Radiation Protection (ICNIRP), Health Physics, vol. 74, pp 494-522, April 1998.

[2] ANSI/IEEE C95.1-1992, "Safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz", The Institute of Electrical and Electronics Engineers Inc., New York, 1991.

[3] CENELEC ENV 50166-2, "Human exposure to electromagnetic fields: High-frequency (10 kHz – 300 GHz)", European Prestandard, European Committee for Electrotechnical Standardization (CENELEC), January 1995.

[4] MPT, "Radio-radiation protection guidelines for human exposure to electromagnetic fields", Telecommunications Technology Council, Ministry of Posts and Telecommunications, Japan, April 1997.

[5] AS/NZS 2772.1(Int):1998, Interim Australian/New Zealand Standard, "Radiofrequency fields, Part 1: Maximum exposure levels – 3 kHz to 300 GHz", Standards Australia/Standards New Zealand, 1998.

[6] FCC Report and Order, ET Docket 93-62, FCC 96-326, Federal Communications Commission (FCC), August 1996.

[7] Radiocommunications (Electromagnetic Radiation Human Exposure) Standard 1999, Australian Communications Authority (ACA), May 1999.

[8] Safety code 6, Canadian Standard, Health Canada, 1999.

[9] ARIB STD-T56, "Specific Absorption Rate (SAR) estimation for cellular phone", ARIB Standard Version 1.0, Association of Radio Industries and Businesses (ARIB), January 27, 1998.

[10] FCC OET Bulletin 65, Supplement C, "Evaluating compliance with FCC guidelines for human exposure to radiofrequency electromagnetic fields", Edition 97-01, Federal Communications Commission (FCC), 1997.

[11] CENELEC ES 59005, "Considerations for evaluation of human exposure to Electromagnetic Fields (EMFs) from Mobile Telecommunication Equipment (MTE) in the frequency range 30 MHz – 6 GHz", European Specification, European Committee for Electrotechnical Standardization (CENELEC), September 1998.

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Ericsson SAR measurement specification, part 2:

Tissue liquid preparation.

1 Introduction

For the preparation of tissue simulating liquid to be used in the generic twin phantom with DASY3 the following preparation procedure is used. The liquid should have properties similar to the human tissue [1],[2],[3]. A batch of tissue simulating liquid may last several months or more. It is recommended that a batch be disposed of and replaced with a new batch when it becomes difficult to keep its dielectric parameters within the ranges specified.

2 Preparation of liquid

2.1 Ingredients

Water	distilled water
Sugar	as available in food shops
Salt	as available in food shops
Cellulose	HEC Hydroxyethyl-cellulose (Optional ingredient)
Preservative	Preventol D7 Bayer AG or Sodium Nitrate

2.2 Preparation materials

Scale

Stirrer with hotplate

Jars and beakers

Mixing spoon

3. Recipe for tissue simulating liquid

The tables in sections 3.1 and 3.2 give common recipes for tissue simulating liquids that may be used to achieve the dielectric parameters shown in section 4. Other recipes may also be used to achieve the dielectric parameters shown in section 4. Other recipes may also be used , based on the needs of regulatory agencies or other groups inside or outside of Ericsson.

3.1 Recipe at 835 MHz and 900 MHz

Ingredient	835 MHz and 900 MHz (head)		835 MHz and 900 MHz (muscle)	
Distilled water	39.72 %	3350 g	56.00 %	3953 g
HEC	0.92 %	78.0 g	1.21 %	85.8 g
NaCl	1.18 %	99.4 g	0.76 %	53.6 g
Preservative	0.19 %	16.1 g	0.27 %	18.8 g
Sugar	57.99 %	4891 g	41.76 %	2948 g
Total amount		6.7 l		6.7 l

3.2 Recipe at 1640 MHz and 1800 MHz

Ingredient	1640 MHz (head)		1800 MHz (head)	
Distilled water	44.18 %	3765 g	44.97 %	3827 g
HEC	1.00 %	85.5 g	1.0 %	85.4 g
NaCl	-	-	-	-
Preservative	0.10 %	8.4 g	0.10 %	8.3 g
Sugar	54.72 %	4663 g	53.93 %	4589 g
Total amount		6.7 l		6.7 l

4. Dielectric parameters for the recipes.

Parameter	835 MHz (head)	900 MHz (head)	1640 MHz (head)	1800 MHz (head)
Dielectric constant ε'	42.8	42.0	41.3	41.0
Conductivity σ (S/m)	0.91	0.97	1.51	1.65

Parameter	835 MHz (muscle)	900 MHz (muscle)
Dielectric constant ε'	57.5	57.0
Conductivity σ (S/m)	1.00	1.05

The parameters are measured according to [5].

5. Preparation procedure

1. Add the water to a large container. Begin heating and stirring.

2. Add the cellulose , preservative and salt (if required). While keeping the container covered, leave the solution on the heating plate until the mixture becomes sufficiently transparent and homogeneous. The temperature of the mixture should be hot enough to aid in mixing the ingredients but cool enough to prevent a significant amount of water evaporation.

3. Add the sugar. Hand stirring may be necessary at the beginning until the sugar is sufficiently dissolved.

4. Keep the liquid hot and the container covered until the solids are dissolved and the liquid is homogenous.

5. Turn the hotplate off and allow the liquid to cool off to room temperature prior to performing dielectric measurements.

6. References

[1] Gabriel C., Gabriel S., Corthout, *The dielectric properties of biological tissue: I literature survey*, Phys. Med. Biol., vol 41, pp 2231-2249, 1996.

[2] Gabriel S., Lau R.W., Gabriel C, *The dielectric properties of biological tissues: II measurements in the frequency range 10 Hz to 20 GHz,* Phys. Med. Biol., vol 41, pp 2251-2269, 1996

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

[4] Federal Communications Commission, Office of Engineering & Technology, *Evaluating Compliance with FCC Guidelines for Human exposure to Radiofrequency Electromagnetic Fields*. OET bulletin 65, 1997.

[5] *Ericsson SAR measurement specification, part 3: Measurements of dielectric parameters,* ERA/T/U-98:405

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Ericsson SAR measurement specification, part 3:

Measurements of dielectric parameters.

1. Introduction

This document describes measurement procedure using network analyzer for testing tissue simulating liquid to be used with the DASY3 system. The measurement uses coaxial probe technique for evaluating permittivity and conductivity. The tissue liquid parameters shall be measured before testing a device. If the complete test takes more than a week, the liquid parameters shall be re measured at least once per week. Measurements are recorded in a log book.

2. Equipment

HP network analyzer HP8752C or similar

HP dielectric probe kit HP85070B or HP85070A

HP 85070 software (any software version)

PC using GPIB card [3] for communication with network analyzer.

Syringe

small glass jars for liquid samples

Thermometer

3. Procedure for testing brain simulating liquid

1. Turn the NWA (Network analyzer) on and allow at least 30 min warm up.
2. Start the PC and run the HP 85070 software.
3. Mount dielectric probe kit so that interconnecting cable to NWA will not be moved during measurement or calibration.
4. Perform calibration according to the HP85070 B manual. In short the following steps are covered
   - Inspect the probe and ensure that it is properly cleaned.
   - Pour distilled water in a sample container and measure the water temperature ($\pm$ 1^{o}C).
   - Set start and stop frequency, frequency step and water temperature.
   - Perform measurement with probe in air.
   - Perform measurement using the short circuiting block. Assure proper contact which requires attaching the block firmly. Monitor the polar chart on the network analyzer to assure good contact as explained in the manual.
   - Perform measurement with probe in distilled water.

5. Remeasure distilled water to check calibration. Assure that the probe is thoroughly cleaned before performing the measurement.
6. Inspect the liquid for inhomogeneities. Surface bubbles can be moved to one side, but if there are numerous bubbles throughout the liquid (e.g. as happens after a new liquid has been poured into a phantom), wait until the bubbles have floated to the surface before proceeding. Also remove any debris or lumps in the liquid.
7. Stir the liquid to be measured. Take a sample (approximately 50 ml or more) with a syringe from the liquid container
8. Measure liquid shortly after calibration of the network analyzer and at most within an hour of this calibration.
9. Put the sample liquid into a small container.
10. Put the dielectric probe into the small container. Check that there are no air bubbles in front of the opening in the dielectric probe kit.
11. Perform measurements. Repeat measurement three times to increase reliability and use average value for comparison with target value. If a single measurement deviates substantially from the rest then redo that measurement to reject possible artifact.
12. Conductivity σ can be calculated from ε'' according to
    $\sigma = \omega\varepsilon_o\varepsilon'' \cong \varepsilon''$ f (GHz)/18.
13. Clean the probe thoroughly after use.

4. Dielectric parameters.

If the measured dielectric parameters are not within their target ranges, ingredients may be added to adjust the parameters. One can add water to increase the permittivity, sugar to reduce the permittivity or salt to increase the conductivity. Parameters should each be within a $\pm$5% range of target values. The target values are values specified either by the system manufacturer or by a regulatory agency. In some cases (e.g. at frequencies of 1800 MHz and higher) it may not be possible to achieve an accuracy of $\pm$5%, due to limitations on achievable parameters using common ingredients (e.g. water, sugar and salt). In any case, the dielectric parameters must be acceptable by the applicable regulatory agency. The accuracy specified by the dielectric probe kit manufacturer [2] is $\pm$5% for the dielectric constant ε' and $\pm$0.05 for the loss tangent $\varepsilon''/\varepsilon'$.

5. References

[1] HP 8572C Network analyzer User's guide. Hewlet Packard part number 08752-90157.
[2] HP 85070B Dielectric probe kit manual, Hewlet Packard part number 85070-90009.
[3] Ericsson SAR measurement specification , part 2:Tissue liquid preparation ERA/T/U-98:404

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Ericsson SAR Measurement Specification, part 4:

System Accuracy Verification

1. Introduction

This document is a guide for the accuracy verification of the Dosimetric Assessment System 3 (DASY3). It is a standard guide for use at all Ericsson SAR measurement laboratories. System accuracy verification must be performed at regular and frequent intervals to ensure the accuracy of the system.

The system accuracy verification test consists of measuring the SAR in a flat phantom using a standard dipole antenna and comparing the results to a reference value. Standard dipoles and reference values are provided by the manufacturer of the DASY system, Schmid & Partner Engineering AG (SPEAG). A separate accuracy verification test is necessary for each tissue simulant and frequency range.

In the remainder of this document, a list of necessary equipment is provided, and a detailed procedure for the dipole test is given.

2. Equipment

- DASY3 system from SPEAG:
  - robot and robot controller
  - data acquisition electronics (DAE)
  - dosimetric E-field probe (see part 7 “SAR Measurement Procedure” for probe specifications)
  - PC card
- Personal computer
- Flat phantom
- SPEAG Dipole antenna kit:
  - Dipole antenna (one for each tested frequency range)
  - Manual for that antenna
  - Antenna stand
  - Plastic dipole spacers
- 50 ohm coax line
- Coaxial connectors
- Signal generator
- Power amplifier (optional)
- Power meter

3. Test Site Environment

3.1 Temperature

The ambient temperature in the laboratory and the temperature in the tissue simulating liquid should be in the range 18 C to 25 C inclusive. These temperatures should be recorded with the measurement data in the data log.

3.2 Electromagnetic interference

Any reflectors/scatterers other than the setup itself (i.e. conductive objects, cables, etc.) and any other radio frequency sources should not be closer than 50 cm from the transmitter under test in order to exclude any significant influence of the environment on the results. If this cannot be achieved, the effect of the reflectors, cables or transmitter should be investigated by SAR evaluations by performing an assessment with the reflector and without it.

3.3 Supply voltage

In general, the supply voltage can alter the performance of measurement equipment. However, at Ericsson, the power supplies of SAR measurement equipment are filtered, so it is not necessary to check the supply voltage.

4. Dipole Verification Procedure

4.1 Setup of the Tissue Simulant

1. Ensure that the proper tissue simulant is present in the flat phantom.
2. Stir the liquid to ensure that it is homogeneous.
3. Measure the dielectric constant and conductivity of the simulant, as described in part 3, “Measurements of dielectric parameters.” The measurement results must be within the required target range. Also, the frequency at which the simulant parameters are satisfied must be the same as the resonant frequency of the dipole antenna used.

4.2 Setup of the Dipole Antenna

1. Turn on the signal generator, power meter and power amplifier (if used). Allow them sufficient time to warm up, to reduce drift.
2. Connect the dipole antenna to the antenna stand.
3. Place the proper dipole spacer over the center of the dipole antenna, as indicated in the manual for that antenna.
4. Place the dipole antenna under the flat phantom and adjust the height of the stand until the spacer is touching the shell of the flat phantom. The center of the dipole antenna should be positioned under the middle of the flat phantom, as indicated by a mark on the flat phantom.
5. Connect one end of the coax line to the power meter sensor and the other end to the output of the signal generator. If the power amplifier is used, connect it between the signal generator and the power meter sensor.
6. Set the signal generator to transmit in CW mode and ensure that any signal modulation is turned off. This ensures that the power amplifier will transmit a pure sinusoid.
7. Set the frequency of the signal generator to the resonant frequency of the dipole antenna.
8. Set the output power of the signal generator (and optionally adjust the gain of the power amplifier) so that one watt of power is delivered to the power meter.
9. Disconnect the coax line from the power meter and connect it to the dipole antenna.

4.3 Setup of the DASY

1. Mount the 3D electric field probe, as shown in the SPEAG manual.
2. Remove the plastic cover on the phantom.
3. Power up the DAE. The LED indicates that the power is on.
4. Power up the computer.
5. Turn on the robot controller
6. Start the DASY3 software on the computer.
7. Choose the appropriate measurement configuration in the “Setup” menu of the software for the dipole measurement. Record the dielectric constant and conductivity of the simulant in the program.
8. Press the robot button on the toolbar to set up the communications between the software and the robot. Go through the self-check procedure in the software to ensure that the system is properly running and set up for measurement.
9. Verify that the robot knows the reference points on the phantom. Check the distance between the reference points and the probe tip with the plastic spacer. If it does not accurately locate one or more of the reference points to within ±5 mm, install the reference points. Should the installation fail to give results within the tolerances set out in the factory settings for the phantom, the procedure will give an

error and the user will have to reinstall the reference points. Afterward, move the probe to the resting point above the flat section.

4.4 Measurement Procedure

1. Open a measurement file. Select the predefined dipole test provided by SPEAG. This file includes all of the necessary measurements for the dipole test. Rename the file with an appropriate name and save it in the appropriate directory.
2. Tell the robot to move the probe tip below the surface of the liquid. Stir the liquid again to remove any bubbles trapped under the probe tip.
3. Select and start the measurement jobs in the file. These include the reference check, coarse scan, fine scan, and drift measurements (see part 7, "SAR Measurement Procedure" for information on the peak SAR determination procedure).

4.5 Analysis of Measured Data

1. Compare the one-gram and ten-gram averaged peak SAR values to the standard values provided in reference documents. If they do not agree within ±5%, check the system parameters (e.g. antenna output power, dielectric parameters of the simulant, homogeneity of the liquid) and repeat the measurement.
2. Also check that the distribution of measured SAR agrees with that provided in the reference data. The peak SAR should be located over the center of the dipole, and the SAR should monotonically decrease away from this point. If the SAR distribution does not compare well with the reference data, repeat the measurement.
3. Make sure that the drift measurement is within ±5% (±0.21 dB). If not, check the system parameters and repeat the measurement.
4. Save the measurement data and enter it into the logbook.
5. Move the probe out of the liquid and clean it with warm water.

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Ericsson SAR Measurement Specification, part 5:

Calibration of Equipment

1. Introduction

This document provides calibration information for the equipment used in Ericsson's SAR measurement facilities. This document is a standard guide for use at all Ericsson SAR measurement laboratories. In this document, a list of equipment that is critical for SAR compliance measurement is provided (including manufacturer and frequency of calibration), and the addresses of the manufacturers are given. It is the responsibility of Ericsson staff to keep track of calibration dates and ensure that the equipment has been sent for calibration. In some cases, the equipment may need to be sent off-site for calibration. Equipment calibration is mandatory according to the rules of ISO 9000 and any other applicable standards to which Ericsson laboratories are accredited or are seeking accreditation (e.g. ISO 25, ISO/IEC 17025, EN 45001).

2. Equipment and Calibration Information

Equipment	Manufacturer	Calibrate every…
Network Analyzer	Hewlett-Packard	1 year
Dielectric probe kit	Hewlett-Packard	1 year
Probes (E and H field)	SPEAG	1 year
Data Acquisition Electronics	SPEAG	1 year
Dipole antennas	SPEAG	2 years
Signal generator	Hewlett-Packard	1 year
Power meters	Hewlett-Packard	1 year
Power sensors	Hewlett-Packard	1 year

3. Addresses of Manufacturers

Hewlett Packard Test & Measurement
Mail Stop 51LSJ
P.O. Box 58199
Santa Clara, CA
95052-9952

SPEAG (Schmid & Partner Engineering AG)
Staffelstrasse 8
8045 Zürich
Switzerland
Tel: +41 1 280 0860

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Ericsson SAR Measurement Specification, part 6:

DUT Preparation and Characterization

1 Introduction

This part describes how the properties of the DUT should be characterized and how the DUT is prepared prior to a SAR measurement.

2 DUT characterization

2.1 The peak output power level

For SAR compliance measurements, the peak output power level of the DUT is set to the maximum power level of that device. The DUT is also programmed to deliver the highest output power that the production units are expected to deliver, taking into account factory tolerances. If this is not possible for some reason, a lower peak power level can be set but the resulting SAR values must then be normalized to the maximum level after the measurement according to equation 1. The peak power level is either measured with a power meter, with a sensor suitable for the carrier frequency and the duty cycle, or a digital radio tester.

$$SAR_{norm} = SAR_{meas} \cdot \frac{P_{max}}{P_{meas}} \tag{1}$$

2.2 The carrier frequency

SAR measurements shall be performed for three carrier frequencies, the lowest possible, the middle and the highest possible for each transmitter band of the DUT. The carrier frequency is measured with a spectrum analyzer. For base stations containing several transmitters for the same band, SAR testing is conducted at the three frequencies with each TRX transmitting at separate channels with a two channel frequency distance between the TRXs.

2.3 The duty-cycle

If the duty-cycle of the signal transmitted by the DUT is not known it can be measured with a spectrum analyzer with the center frequency set equal to the carrier frequency of the transmission and the span set to zero. For TDMA systems, the RF exposure assessment shall always be performed with the maximum possible duty-cycle (denoted d). In a CDMA system, on the other hand, bursting is often introduced gradually when the voice activity of the user changes but during the SAR measurement it has to be fixed and at the maximum value. If the maximum duty-cycle is not possible to obtain, the assessed SAR results have to be normalized to the used duty-cycle according to:

$$SAR_{norm} = SAR_{meas} \cdot \frac{d_{max}}{d_{meas}} \tag{2}$$

Analog mobile communications systems use continuous transmission and thus the duty-cycle is always equal to one.

2.4 Antenna configuration

- For handset devices with extendable antennas, SAR measurements have to be performed both with the antenna retracted and pulled out.
- Handsets must be tested with all available antenna types specified for that device by Ericsson. Antennas that can assume different positions, for instance swivel antennas, are tested in intended use positions that are specified by Ericsson.
- Base stations with several integrated antennas, for instance micro and pico base stations, are measured for all possible antenna configurations that will be used at the base station site.
- Base station antennas are measured with the radiating elements configured so that the maximum possible exposure situation is obtained.

3 Preparing and setting up the DUT for a SAR measurement

3.1 Handset setup

The mobile phone shall be tested in a cheek position on both the left and right sides of the phantom.

Definition of the cheek position (see Fig. 1, below):

a) Position the device with the centre of the ear-piece against the ear reference point, and with the vertical centre line of the body of the device in a plane parallel to the sagittal plane of the phantom.

b) While maintaining the device in this plane, align the centre line with the reference plane containing the ear and mouth reference points.

c) While maintaining the device in the reference plane, move it until any point on the front side is in contact with the cheek of the phantom.

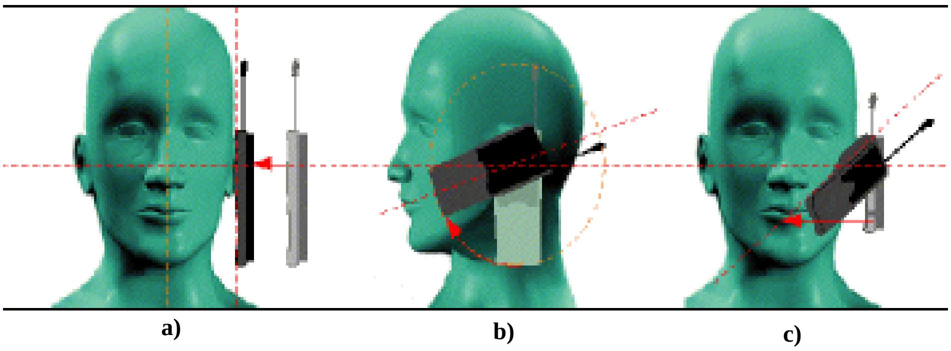

Figure 1. A handheld DUT positioned at the left cheek of the head phantom.

For push-to-talk handsets, the normal use position is in front of the face and the exposure from such a device is assessed by placing it 5 cm below the flat section of the phantom

3.2 Setup of base station antennas and other fixed equipment

Figure 2 shows the setup for SAR testing of base station antennas or other fixed equipment with integrated antennas. The unit is positioned below the flat section of the DASY phantom on a stand or table which is adjustable so that several different distances between the phantom shell and the unit can be tested. The test distance is dependent on the application and should correspond to a typical minimum exposure separation between the user and the product.

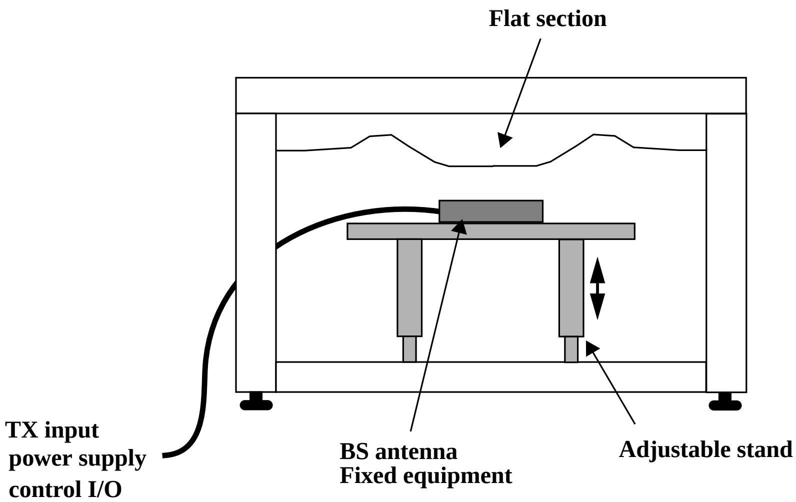

Figure 2. The setup for measurements of SAR in the flat section from base station antennas or other fixed equipment with integrated antennas.

Products for consumer use, for instance GSM or WLAN PC-cards etc., are tested at a distance of typically 5 cm.

For base station antennas and other fixed equipment, SAR testing can normally be conducted according to the following procedure. 1) Measure the DUT for 0 cm to the phantom shell at the three frequencies stated in section 2.2. 2) For the frequency giving the highest SAR, measure at increasing fixed distances (e.g. 2.5, 5, 7.5, ... cm) until the obtained SAR is below the limit. 3) Perform measurements for the two other frequencies at that distance. The obtained distance is then the so called compliance distance for the DUT. However, for equipment with very low output power level, below 50 mW, testing at 0 cm is sometimes sufficient.

If the a base station antenna contains multiple radiating elements and is too large to be measured in a single scan, SAR testing should focus on the element which was found to give the maximum values in a free space H-field scan covering the complete structure.

3.3 RF, power supply and control cables

- Handsets operate on battery power and before the SAR measurements the battery must contain enough charge for the measurement time, a fully charged battery is recommended. For compliance testing, no power supply or control cable should be connected to the handset since they will interfere with the fields radiated from the antenna. RF cables connected to prototype handset with no integrated transmitter circuitry must be placed in such a way that the interference with the radiated fields is limited, ferrites on the cable close to the connectors are recommended. Section 5 describes the cable setup when testing devices supplied with external RF power.
- Base stations with integrated antennas are supplied with power from an external power line and this cable shall be connected to the DUT in such a way that interference to the radiated fields is limited. This also applies to control and transmission cables.
- Base station antennas are supplied with RF power from a signal generator and the cables should be connected via a directional coupler giving a possibility of monitoring the reflected power. This setup is explained in section 4.

4 Monitoring the DUT during the SAR measurement

Since handsets operate on batteries it is important to monitor the output signal from the DUT during the exposure assessment and a spectrum analyzer with a sensor antenna placed close to the device is recommended. If a digital radio tester is used for controlling the DUT the reported power level is easily monitored but for DUTs supplied with the RF signal from a generator the cable configurations shown in Fig. 3 should be used.

For the case of a DUT supplied with RF power through a cable, when the antenna is placed close to the phantom a load mismatch is introduced and RF power will be reflected back to the generator. A power meter monitoring this amount of power is connected through a directional coupler to the feeding cable according to Fig 3 (a) or (b). The power meter 1 in figure (a) measures the forward power from the generator, normally this power doesn't change much during a SAR measurement and a setup according to (b) is in most cases sufficient.

Note, before the SAR measurement is started the power delivered from the signal generator to the DUT should be measured at the end connector of the supplying cable.

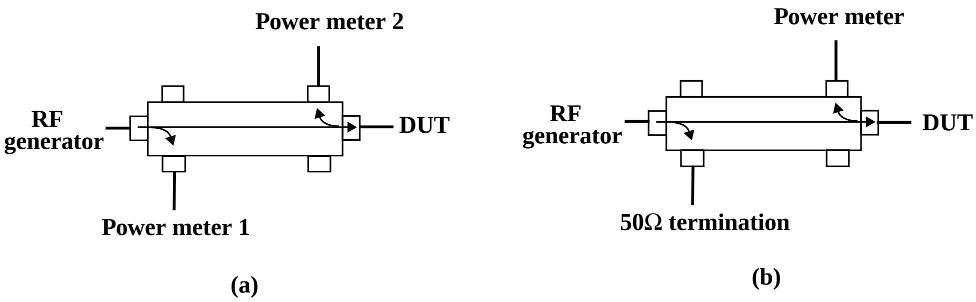

Figure 3. Cable configurations for monitoring forward and reflected power with a directional coupler. (a) shows the setup for monitoring both properties and (b) the reflected power measurement setup.

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Ericsson SAR Measurement Specification, part 7:

SAR Measurement Procedure

1 Introduction

This part of the Ericsson SAR Measurement Specification describes the practical process of assessing the specific absorption rate (SAR) in a phantom with the SPEAG dosimetric assessment system (DASY) [1]. The requirement for use of this instruction is a basic knowledge of the DASY hardware and software, including probe mounting and powering up the system[2].

2 Measurement system

2.1 Equipment

The main parts of the SPEAG dosimetric assessment system (DASY) are a six axis robot with controller, an E-field probe, a stand incorporating a user phantom and a stand for positioning the mobile phone (DUT) close to the phantom. A computer with a PC card controls the robot and collects the data from the probe. Fig. 1 below shows an overview of the DASY.

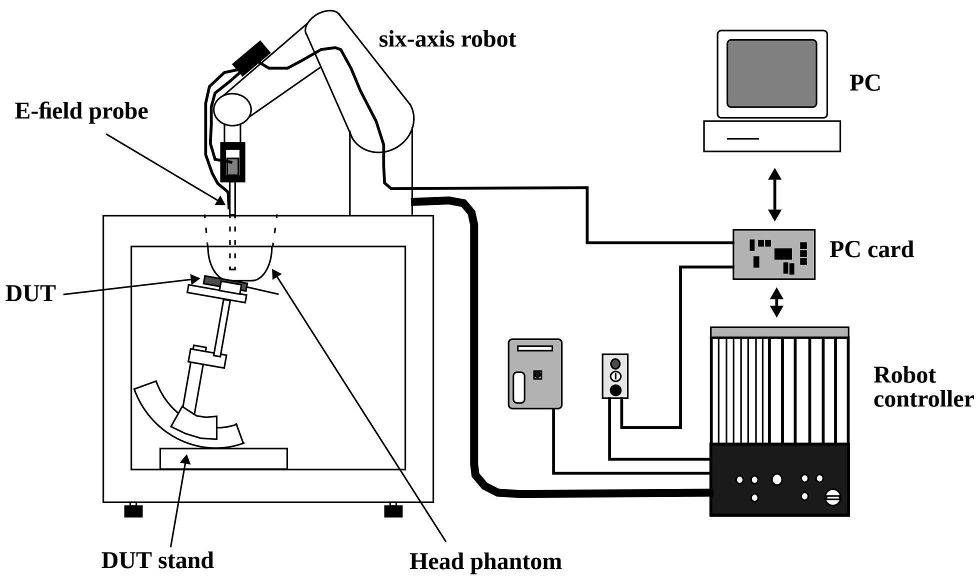

Figure 1. The dosimetric assessment system used for measuring SAR in a head phantom structure.

2.1.1 Probe specification

The ET3DV5/6 probe by Schmid & Partner Engineering AG for measurements of SAR is sensitive to E-fields and thus incorporates three small dipoles arranged so that the overall response is close to isotropic [3][4]. The table below summarizes the technical data for the probe which is used at all Ericsson SAR measurement laboratories.

Property	Data
Frequency range	30 MHz - 3 GHz
Linearity	±0.2 dB
Dynamic Range	5 mW/kg - 100 W/kg
Directivity (around probe axis)	≤±0.2 dB
Directivity (normal to probe axis)	±0.4 dB
Spatial resolution	< 0.125 mm^3
Probe positioning repeatability	±0.2 mm

Table 1 The technical data for the SAR probe ET3DV5.

2.1.2 Phantom and tissue simulating liquid

The DASY phantom shape is based on anatomical data representing a cross-section of all mobile phone users. The phantom is a fiberglass shell with a thickness equal to 2 mm and it consists of three measurement areas or sections, one section corresponding to right hand side use and an identical but mirrored section for the left hand side. The phantom shell is filled with a tissue simulating liquid at the frequency of interest. In the middle of the phantom there is a flat section for other exposure measurements including tests of devices held close to the waist. The flat section of the phantom is also used for system verification.

2.2 Peak SAR determination procedure

The DUT is positioned below the phantom according to the binder part on DUT preparation and characterization and the transmitter is powered on before the SAR measurement starts. The SAR is measured using the following steps:

1. Reference check: the robot moves the probe to a fixed reference position in the tissue liquid and the E-field is recorded.

2. Coarse scan: the probe is moved in a coarse grid following the inner surface of the phantom. In this measurement the robot is guided by the optical sensor in the tip of the probe and the size of the scanned region is selected large enough to guarantee that all possible peak SAR areas are included. The specific absorption rate (SAR) is calculated from the recorded E-fields by the following expression:

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

where σ is the conductivity in Siemens/meter and ρ is the density in kg/m^3 (the usually used value is ρ = 1000 kg/m^3 = 1 g/m^3) of the liquid. Spline interpolation is used to determine the point of maximum SAR.

3. Fine scan: Measurements are taken on a fine grid around the position of the maximum SAR. The grid typically consists of 5x5x7 points with 8x8x5 mm between the individual points and thus contains about 31 grams of tissue. Numerical extrapolation is then used to determine the SAR values between measurement points in the cube and in the small region between the cube and the inner surface of the phantom where the E-field sensors cannot be positioned. The extrapolation distance is thus the sum of the probe tip - sensor offset, the surface detection distance and the grid offset. The extrapolation is based on fourth-order polynomial functions. Next, a 3D spline interpolation algorithm is used to get all points within the measured volume in a 1mm grid (approximately 31 000 points). Finally, the SAR is averaged over a 1g cube (1000 points). The cube is shifted throughout the fine scan area until the highest averaged SAR is found. The same procedure is repeated for a 10 gram cube (10 000 points).

4. Finally, a second reference point measurement is performed for comparison with the measurement performed in 1. From this data the system drift during the SAR measurements is evaluated.

2.3 SAR assessment uncertainty

The uncertainty of the DASY has been determined according to the NIS81 [5] and NIST1297 documents [6]. The total uncertainty of the SAR assessment is composed of three main factors: measurement uncertainty, source uncertainty and phantom uncertainty. Each of these uncertainties consists of a number of individual factors. A detailed breakdown of uncertainties, according to T.Schmid et.al. [7], is provided in the following tables. The combined uncertainty (K=1) of the SAR assessment is ±16% and includes a +15% offset (overestimation). The extended uncertainty (K=2) is ±32% with a +15% offset [8].

A) Measurement uncertainty

Uncertainty description	**Error**	**Distrib.**	**Weight**	**Std. Dev.**	**Offset**
Probe uncertainty					
-axial isotropy	± 0.2dB	U-shape	0.5	± 2.4%	
-spherical isotropy	± 0.4dB	U-shape	0.5	± 4.8%	
-isotropy from gradient	± 0.5dB	U-shape	0		
-spatial resolution	± 0.5%	normal	1	± 0.5%	
-linearity error	± 0.2dB	rectang.	1	± 2.7%	
-calibration error	± 3.3%	normal	1	± 3.3%	

Uncertainty description	Error	Distrib.	Weight	Std. Dev.	Offset
SAR Evaluation Unc.					
-data acquisition error	± 1%	rectang.	1	± 0.6%	
-ELF and RF disturbances	± 0.25%	normal	1	± 0.25%	
-conductivity assessment	± 10%	rectang.	1	± 5.8%	
Spatial Peak SAR Evaluation Uncertainty					
-extrapol + boundary effect	± 3%	normal	1	± 3%	
-probe positioning error	±0.1 mm	normal	1	± 1%	
-integrat. and cube orient	± 3%	normal	1	± 3%	
-cube shape inaccuracies	± 2%	rectang.	1	± 1.2%	
Total Measurement Uncertainty				± **10.2%**	

B) Source uncertainty

Uncertainty description	Error	Distrib.	Weight	Std. Dev.	Offset
-device positioning	± 6%	normal	1	± 6%	
-laboratory setup	± 3%	normal	1	± 3%	
Total Source Uncertainty				± **6.7%**	

C) Uncertainties of covering the exposure of 80% of the entire user group

Uncertainty description	Error	Distrib.	Weight	Std. Dev.	Offset
-Internal anatomy (tissue distribution)				(± 7%)	(+ 10%)
-shape				(± 7%)	(+ 5%)
-other influences					(≥ 0%)
Total Phantom Uncertainty				(± **10%**)	(+ **15%**)

D) Combined uncertainties

Uncertainty description	Uncertainty	Offset	min.	max.
-total measurement uncertainty	± 10.2%	+ 5%		
-total source uncertainty	± 6.7%			
-total phantom uncertainty	(± 10%)	(+ 15%)		
Combined uncertainty (K=1)	(± 16%)	(+ 15%)	(– 1%)	(+ 31%)
Extended uncertainty (K=2)	**(± 32%)**	**(+ 15%)**	**(– 17%)**	**(+ 47%)**

2.4 Test Site Environment

Temperature: The ambient temperature in the laboratory and the temperature in the tissue simulating liquid should be in the range 18 C to 25 °C inclusive. These temperatures should be recorded with the measurement data in the data log.

Electromagnetic interference: Any reflectors/scatterers other than the setup itself (i.e. conductive objects, cables, etc.) and any other radio frequency sources should not be closer than 50 cm from the transmitter under test in order to exclude any significant influence of the environment on the results. If this cannot be achieved, the effect of the reflectors, cables or transmitter should be investigated by SAR evaluations by performing an assessment with the reflector and without it.

Supply voltage: In general, the supply voltage can alter the performance of measurement equipment. However, at Ericsson, the power supplies of SAR measurement equipment are filtered, so it is not necessary to check the supply voltage.

3 Measurement setup

Before the measurement is conducted the device under test and the DASY equipment have to be properly setup in order to limit the sources of error.

3.1 DUT setup

Depending on the DUT use the appropriate instructions, i.e either section 3.1.1 or section 3.1.2. For additional instructions see binder part on DUT preparation and characterization.

3.1.1 Handset setup

1. Power up the handset and set the carrier frequency, the power level and if possible the duty-cycle of the transmitter to the appropriate values.

2. Position the device under the proper section of the phantom.

3.1.2 Base station antenna setup

1. Position the base station antenna below the flat section of the phantom.

2. Connect the cable from the directional coupler and the signal generator.

3. Power up the signal generator and set the carrier frequency and the power level.

4. Let the generator warm up.

3.2 Additional setup

1. Power up the spectrum analyzer and set the center frequency, span and sweep time to appropriate values considering the DUT transmitter. Let the analyzer warm up before proceeding.

2. Take still pictures of the measurement setup and the DUT to be used in the documentation.

3.3 DASY setup

The instructions of this section are only valid under the assumption that the equipment is calibrated and verified.

1. Mount the probe for SAR measurements on the DAE.

4. Power up the DAE. The LED indicates power on.

5. Power up the computer.

6. Power up the robot controller.

7. Start the DASY-software on the computer.

7. Choose the appropriate configuration in the "Setup" menu. NOTE, check that the medium parameters in the "options" window are equal to those measured previously with the dielectric probe kit for the liquid in the phantom.

8. Press the robot button on the toolbar to set up the communications between the software and the robot. Go through the self-check procedure in the software to ensure that the system is properly running and set up for measurement.

9. Remove the plastic cover on the phantom.

10. Verify that the system knows the reference points on the phantom. Check the distance between the reference points and the probe tip with the plastic spacer. If it does not accurately locate one or more of the points to within ±5 mm, install the reference points. Should the installation fail to give results within the tolerances set out in the factory settings for the phantom, the procedure will give an error and the user will have to reinstall the reference points. Afterwards, move the probe to the resting point above the flat section.

11. Stir the liquid in the phantom to ensure that it is homogeneous. Surface bubbles can be moved to one side, but if there are numerous bubbles throughout the liquid (e.g. as happens after a new liquid has been poured into a phantom), wait until the bubbles have floated to the surface before proceeding. Also remove any debris or lumps in the liquid.

4 Measurement procedure

1. Open the appropriate predefined measurement file and rename it. Or, prepare a new measurement file by selecting jobs from the menu.

2. Move the probe so that the tip is below the surface of the liquid in the selected measurement section. Stir the liquid again to remove any bubbles trapped under the probe tip.

3. Check the setup of the DUT.

4. Start the transmitter in the DUT. Check the signal with the spectrum analyzer.

5. Select the desired measurement jobs and start the SAR measurement.

6. Check the system drift. If the measurement data is not within ±5% (±0.2 dB), check the DUT and the DASY and repeat the measurement.

7. Save the measurement data.

5 Post measurement procedure

1. When the SAR measurements are finished, power off the DUT.

2. Move the probe to the resting point and clean it with warm water.

3. Enter information on the performed measurements in the laboratory logbook.

6 References

[1] Thomas Schmid, Oliver Egger, Niels Kuster, "Automated E-field scanning system for dosimetric assessments", *IEEE Transactions on Microwave Theory and Techniques*, vol. 44, pp. 105-113, January 1996.

[2] Schmid&Partner Engineering AG, "DASY3 User Manual", April 1999 Edition, Zurich, Switzerland.

[3] Klaus Meier, Michael Burkhardt, Thomas Schmid and Niels Kuster, "Broadband calibration of E-field probes in lossy media", *IEEE transactions on Microwave Theory and Techniques*, vol. 44, no. 10, pp. 1954-1962, October 1996.

[4] K. Pokovic, T Schmid and N. Kuster, "E-field Probe with Improved Isotropy in Brain Simulating Liquids", *Proceedings ELMAR*, Zadar, Croatia, June 23-25, 1996.

[5] NIS 81, "The treatment of uncertainty in EMC measurements", Technical Report, NAMAS Executive, National Physical Laboratory, Teddington, Middlesex, England, Edition 1, May 1994.

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[7] T. Schmid and N. Kuster, "Preliminary uncertainty budget for SAR evaluations with DASY3," contribution to IEEE Standards Coordinating Committee 34, Subcommittee 2, July, 1998.

[8] ISO/IEC Guide Expres (1995-01),"Guide to the expression of uncertainty in measurement (1995)", Ed. 1.0 English, 1995.

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Ericsson SAR measurement specification, part 8:

Documentation of results

1. Introduction

It is very important that a SAR test and the obtained results are well documented and that the data is stored in a safe way. A SAR test should be able to repeat in any of the Ericsson SAR laboratories based on the information in the documentation. Depending on the type of test, different types of reports may be issued. These are described below.

2. SAR test report

A SAR test report shall always be issued when a new product is tested for compliance with RF safety recommendations, standards and regulations. The SAR test report should be an internal and confidential document. If the SAR test is required for type approval, as for handheld mobile telephones in the U.S. and Australia, the SAR test may be sent to the regulator (for example the FCC or ACA) if demanded.

3. Declaration of conformity

A Declaration of Conformity (DOC) should be written when a SAR test report has been issued. This is normally the only document that is sent to the regulators that require SAR tests (FCC, ACA). The DOC is an open document that can be sent to, for example, customers and authorities that have requested information on SAR compliance test results for a product.

4. Technical report

Results from R&D related SAR measurements, for example of prototypes, modified products and non-Ericsson products, should normally not be documented in a SAR test report, but in a technical report. The format of this report may vary, depending of the type of test. The report should however include all information necessary to repeat the test later. In order to document detailed information from a SAR compliance measurement of a new product, a technical report may be issued in addition to the normal SAR test report. The technical report should be an internal and confidential document.

5. Storage of test data and reports

The test results (raw data) shall be stored in the SAR test laboratory. A backup of the data files shall be stored in a safe place. The SAR test reports, DOC documents and technical reports shall be stored locally where the tests have been conducted. Copies of SAR test reports and DOCs should normally also be stored in the appropriate product compliance folders and also be distributed to the other Ericsson SAR test laboratories.

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[2] Radiocommunications (Electromagnetic Radiation Human Exposure) Standard 1999, Australian Communications Authority (ACA), May 1999.

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[3] Thomas Schmid, Oliver Egger, Niels Kuster, "Automated E-field scanning system for dosimetric assessments", *IEEE Transactions on Microwave Theory and Techniques*, vol. 44, pp. 105-113, January 1996.

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[7] S.Gabriel, R.W. Lau and C. Gabriel, "The dielectric properties of biological tissues: II. Measurements in the frequency range 10 Hz to 20 GHz", Phys. Med. Biol. 41 (1996), pp. 2251-2269.

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[11] T. Schmid and N. Kuster, "Preliminary uncertainty budget for SAR evaluations with DASY3," contribution to IEEE Standards Coordinating Committee 34, Subcommittee 2, July, 1998.

User’s manuals and system data provided with the equipment:

[12] Schmid&Partner Engineering AG, "DASY3 User Manual", April 1999 Edition, Zurich, Switzerland.

[13] Hewlett-Packard Company, "HP85070B Dielectric Probe Kit User’s manual", HP part number 85070-90009, 1993.

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Ericsson SAR Measurement Specification, part 10:

Glossary of Symbols and Acronyms

σ	Conductivity (S/m)
ε_0	Permittivity of free space = 8.854 x 10^{-12} F/m
ε'	Relative real part of complex permittivity (unitless)
ε''	Relative imaginary part of complex permittivity (unitless)
f	Frequency (Hz)
ω	Radial frequency (rad/s)
ACA	Australian Communications Authority
ANSI	American National Standards Institute (USA)
ARIB	Association of Radio Industries and Businesses (Japan)
AS/NZS	Australian Standard / New Zealand Standard
BW	Bandwidth
CDMA	Code-Division Multiple Access
CENELEC	European Committee for Electrotechnical Standardization
CW	Continuous wave
DAE	Data Acquisition Electronics
DASY	Dosimetric Assessment System
DECT	Digital Enhanced Cordless Telephone
DOC	Declaration of Conformity
DUT	Device under test
E-field	Electric field
EMF	Electromagnetic field
ES	European Standard
FCC	Federal Communications Commission (USA)
GPIB	General Purpose Interface Bus
GSM	Global System for Mobile communications
HEC	Hydroxyethyl-cellulose
HP	Hewlett-Packard
ICNIRP	International Commission on Non-Ionizing Radiation Protection (Europe)
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers (USA)
LED	Light-emitting diode
MPT	Ministry of Posts and Telecommunications (Japan)
MTE	Mobile Telecommunication Equipment
NWA	Network Analyzer
OET	Office of Engineering and Technology of the FCC
PC	Personal Computer
RLL	Radio Local Loop
RF	Radio Frequency
SAR	Specific Absorption Rate (W/kg)
SPEAG	Schmid and Partner Engineering AG
TDMA	Time-Division Multiple Access