Spectrum Sciences Institute
RF Dosimetry Research Board

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# Probe Design and Calibration Requirements

# SSI/DRB-TP-D01-032

## PART of SAR Measurements Requirements

## SSI/DRB-TP-D01-030

***DRAFT***

***Prepared jointly with:***

APREL Laboratories

**Near Field Measurements Laboratory**

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# 1.0 INTRODUCTION

## 1.1 Purpose and Scope

The purpose of this document is to standardize the test procedures to be followed in calibrating miniature isotropic electric-field (E-Field) probes. This Standard includes the methodology and procedures to be followed in calibrating E-field probes to be used for Specific Absorption Rate (SAR) measurements, in accordance with industry standards and practices.

This Standard defines:

- the methodology and procedures to be followed in the laboratory calibration of the miniature isotropic E-field probes.
- the hardware and software required, the test procedures, and, where applicable, the required limits for calibration of the miniature isotropic E-field probes.

This Standard includes tests to determine the following parameters:

1. Sensor Sensitivity
2. Simulated Tissue Enhancement Factor

This Standard is part of a Certification Program Methodology as described in a separate document entitled "SSI/DBR TP-D01-030, Specific Absorption Rate (SAR) Standard For Portable Telecommunications Devices, March 1998". SSI/DBR TP-D01-032 contains specific criteria that must be met for SAR certification.

## 1.2 Test Facilities

All calibration work as described in this Standard shall be performed at an ISO/IEC Guide 25 accredited laboratory.

## 1.3 Test Personnel

Personnel performing the calibration will be experienced in relevant measurements (eg physical properties or RF characteristics) and supervised by a person proficient in SAR measurements.


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## 1.4 Test Equipment

The required test equipment, hardware and software, is identified is each individual procedure. Equipment may be substituted or updated from time to time. Should this occur, such change shall be noted in the test report. Equipment shall be calibrated to standards traceable to International Standards.

## 1.5 Standard Environmental Conditions

All measurements and calibration should be performed under normal laboratory conditions for physical properties and electrical characteristics as stipulated by ISO/IEC Guide 25. The nominal temperature for physical property measurements and for electrical characterization are 20°C and 23°C, respectively.

# 2.0 BACKGROUND

The miniature isotropic electric-field (E-field) probe (Fig. 2.1) is a three-channel device used to measure RF electric fields. The sensors are three mutually-orthogonal dipoles, each 2.5 mm, or less, in length. For each channel of the probe, the dipole and two high-impedance lines are deposited on a planar substrate. Located at the center of the dipole is a Schottky diode (shown in Fig. 2.1). The three substrates are assembled to form a beam. Along the substrate are three pairs of high impedance conductors that connect the dipoles to a single output connector. The probe is enclosed in a protective sleeve to avoid contact with the corrosive elements of the simulated tissue. The total length of the probe is approximately 25 cm. The probe does not perturb significantly the field being measured. It is isotropic so that no matter how the probe is positioned relative to the electric field, the sum of the outputs of the three channels always gives the same value. The probe is very fragile, can be damaged by mechanical shock, and should be safely stored when not in use.

In the case of the triangular probe, because of the geometry of the probe elements, if the probe axis is aligned perpendicular to the E-field, and the probe is rotated so that the output of Channel x is maximized, then Channel x's dipole will form a 35.3° angle with the E-field. The relationship between the sensitivity of each channel with the probe axis perpendicular to the electric field (e) to the sensitivity for the E-field tangential to the dipole ($\eta$) is then:


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$\eta = e/\cos^2(35.3°) = 1.50e$

Free space calibration of E-field probes can be performed using a TEM cell with operating frequency at or below 1 GHz. Free space calibration of E-field probes can be performed in an open area test site (OATS) or in a RF shielded enclosure for operating frequency at or above 1 GHz.

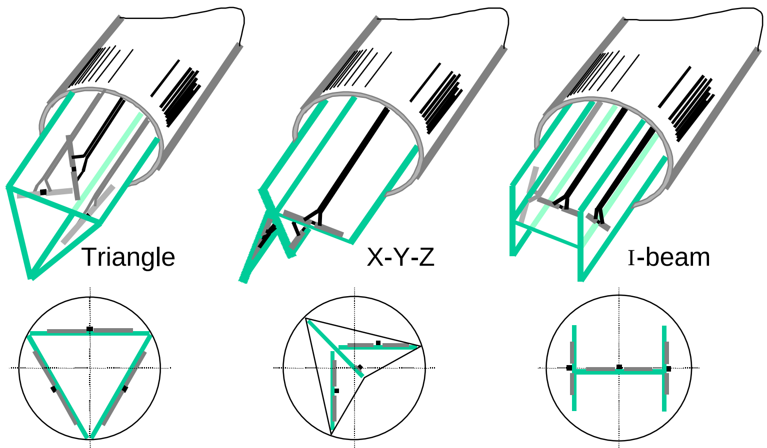


Figure 2.1

The following plots show the output of an E-field probe versus angular position for rotation in a vertical plane in a TEM cell.

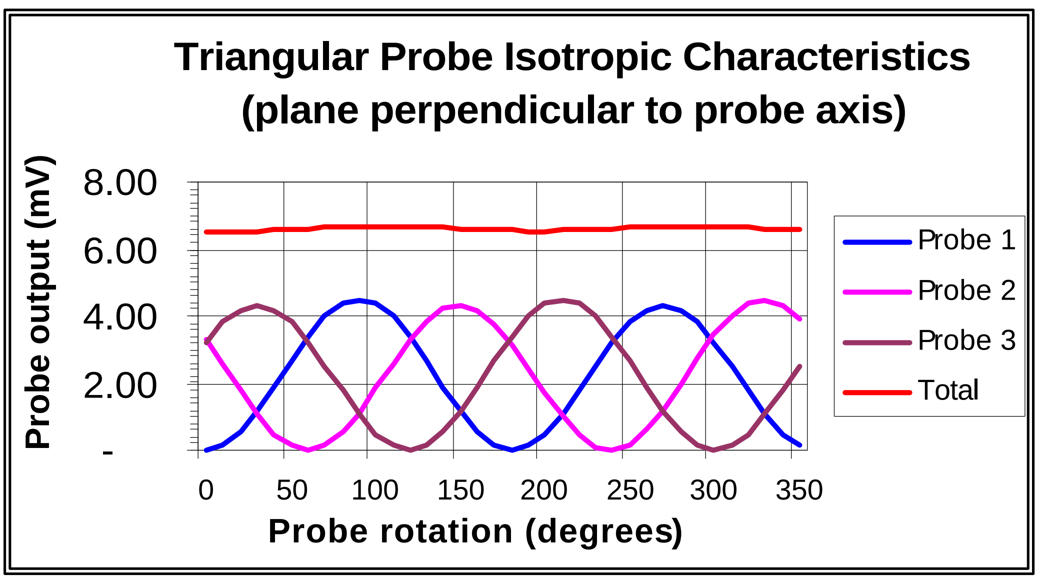


Figure 2.2


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# 3.0 ELECTRIC-FIELD PROBE MEASUREMENT SYSTEM CALIBRATION

This section describes the tasks necessary to characterize the electrical performance of the E-field probe. Note that two types of calibration are specified. Section 3.1 describes calibration below or at 1 GHz. Section 3.2 describes calibration at frequencies above 1 GHz.

The E-field probe measurement system has two main components: a) the probe, which is connected to the inputs of b) the data acquisition card that is installed in a computer. The probe is connected to the data acquisition card by means of shielded cables. The system is calibrated as one unit, not as individual components. If any component is modified or replaced, the system must be re-calibrated.

The system calibration is performed by determination of the free space E-field from the probe outputs in a test RF field.

## 3.1 Determining E-Field Probe Sensitivities at Frequencies up to 1 GHz

### 3.1.1 References

- SAR Measurement Operational Guide, O.M. Garay and Q. Balzano, 1995, Motorola, Florida Corporate Electromagnetics Research Laboratory, Fort Lauderdale, Florida.
- "Calibration of Low Frequency Electric and Magnetic Field Probes", W. Köhler, EMC '96, International Symposium on Electromagnetic Compatibility, Rome, Italy, September 1996
- "Calibration of Electromagnetic Field Probes in Different Measurement Sites: Comparison of Results", G. Agnello, P. Bertotto, M. Borsero, G. Pierucci, V. Squizzato, EMC '96, International Symposium on Electromagnetic Compatibility, Rome, Italy, September 1996
- "Electric Field Probes for Cellular Phone Dosimetry", H.I. Bassen, Center for Devices and Radiological Health, FDA, Attachment 6a, Minutes IEEE Standards Coordinating Committee - 34, Subcommittee – 2 (Certification of Wireless Handsets), Qualcomm, La Jolla, California, 3&4 December, 1997.
- "New Perspective in Broad Band Sensors Calibration", Licitra, Francia, Giusti, Pocai, EMC '96, International Symposium on Electromagnetic Compatibility, Rome, Italy, September 1996


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### 3.1.2 Definition

The sensitivity of each of the three probe channels is a DC voltage produced at the outputs with the probes exposed to a specified free space electrical field.

### 3.1.3 Minimum Standard

The sensitivity of the probes depends on the manufacturer of the probes and individual components used to manufacture the probes. As such, there is no minimum requirement for sensitivity of the probes.

### 3.1.4 Test Equipment

| Description | Manufacturer | Model |
|---|---|---|
| RF Signal Generator | Hewlett Packard | 8662A |
| RF Amplifier 0.5 – 1 GHz | APREL | RFPA-1000 |
| TEM Test Cell | Fischer Custom Communications | FCC-TEM-JM1 |
| RF Power Meter | Rohde & Schwarz | NRVS |
| Miniature E-field probe | Narda | 8021B |
| Probe support fixture | APREL | N/A |
| Computer | Northern Micro | Pentium 75 |
| Software | Microsoft | Office 97 Pro |
| Software | APREL | SAR Measurement |
| Data acquisition card | ComputerBoards | CIO-DAS08-PGH |
| Miscellaneous Cables | N/A | N/A |


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### 3.1.5 Test Configuration

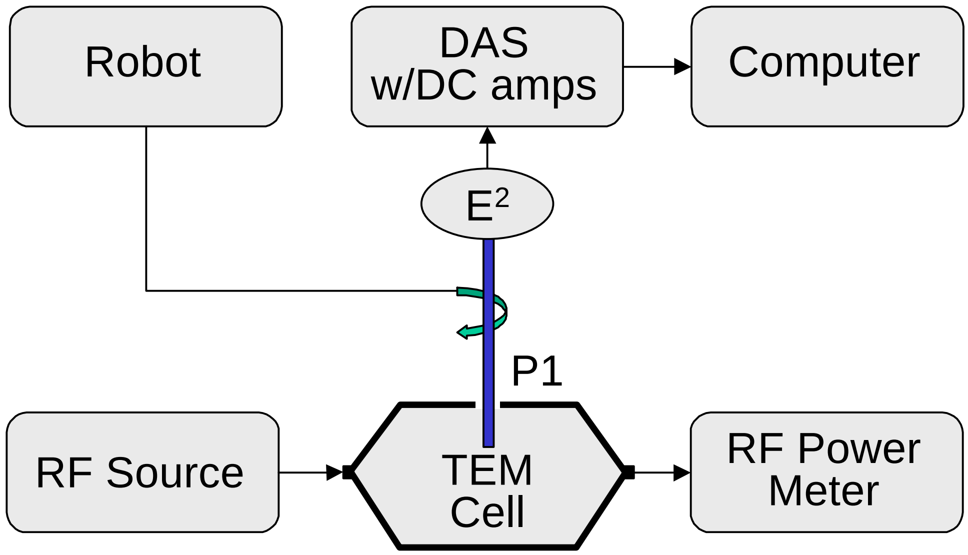


Figure 3.1

### 3.1.6 Test Procedure

1. Connect the equipment as shown in the test configuration.
2. Set the RF generator frequency to 1GHz.
3. Adjust the RF generator output so that the power density inside the TEM Cell is 1mW/cm2. (For the FCC Model FCC-TEM-JM1 Cell, the correct power level is 153 mW.)
4. Mount the probe of the system to be calibrated in the support fixture.
5. Insert the probe through the side aperture of the TEM Cell. The probe handle should be at the geometric center of the aperture, i.e. midway between the septum and the upper surface, and orthogonal to the side of the Cell. The sensing portion of the probe should be located at a point halfway across the depth of the cell (volumetric center).
6. Once the prescribed position is obtained, it must be maintained during the rest of the measurement. The only movement of the probe allowed is rotation on its axis to position the dipoles in the plane of E-field.
7. Verify that the RF power level remains constant throughout the measurement. While the probe is being rotated through 360 degrees, record the maximum measured on each channel.


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8. Set the RF generator to a desired calibration frequency and repeat steps 4 through 7.

### 3.1.7 Test Data Table

The sensitivities in mV/ (mW/cm$^2$) for each channel can be recorded in the following table:

| **Frequency** | **Channel 0 (Pins 6 & 1)** | | **Channel 1 (Pins 2 & 3)** | | **Channel 2 (Pins 4 & 5)** | |
|---|---|---|---|---|---|---|
| **(MHz)** | | | | | | |
| | **e** | **η** | **e** | **η** | **e** | **η** |
| | | | | | | |
| 835 | | | | | | |
| | | | | | | |
| 1000 | | | | | | |
| | | | | | | |

## 3.2 Determining E-Field Probe Sensitivities at Frequencies above 1 GHz

### 3.2.1 References

- "Calibration of Low Frequency Electric and Magnetic Field Probes", W. Köhler, EMC '96, International Symposium on Electromagnetic Compatibility, Rome, Italy, September 1996
- "Calibration of Electromagnetic Field Probes in Different Measurement Sites: Comparison of Results", G. Agnello, P. Bertotto, M. Borsero, G. Pierucci, V. Squizzato, EMC '96, International Symposium on Electromagnetic Compatibility, Rome, Italy, September 1996
- "Electric Field Probes for Cellular Phone Dosimetry", H.I. Bassen, Center for Devices and Radiological Health, FDA
- "New Perspective in Broad Band Sensors Calibration", Licitra, Francia, Giusti, Pocai, EMC '96, International Symposium on Electromagnetic Compatibility, Rome, Italy, September 1996


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### 3.2.2 Definition

The sensitivity of each of the three probe channels is a DC voltage produced at the outputs with the probes exposed to a free space electrical field at frequencies greater than or equal to 1 GHz.

### 3.2.3 Minimum Standard

The sensitivity of the probes depends on the manufacturer of the probes and individual components used to manufacture the probes. As such, there is no minimum requirement for sensitivity of the probes.

### 3.2.4 Test Equipment

| **Description** | **Manufacturer** | **Model** |
|---|---|---|
| RF Signal Generator | Hewlett Packard | 8340B |
| TWT Amplifier<br>(1.4 – 2.4 GHz) | Hughes | 1177H-10F000 |
| Anechoic Shielded Room | APREL | N/A |
| Horn Antenna (1 – 18 GHz) | APREL | AA-118 |
| RF Power Meter | Rohde & Schwarz | NRVS |
| Miniature E-field probe | Narda | 8021B |
| Probe support fixture | APREL | N/A |
| Computer | Northern Micro | Pentium 75 |
| Software | Microsoft | Office 97 Pro |
| Software | APREL | SAR Measurement |
| Data acquisition card | ComputerBoards | CIO-DAS08-PGH |
| Miscellaneous Cables | N/A | N/A |


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### 3.2.5 Test Configuration

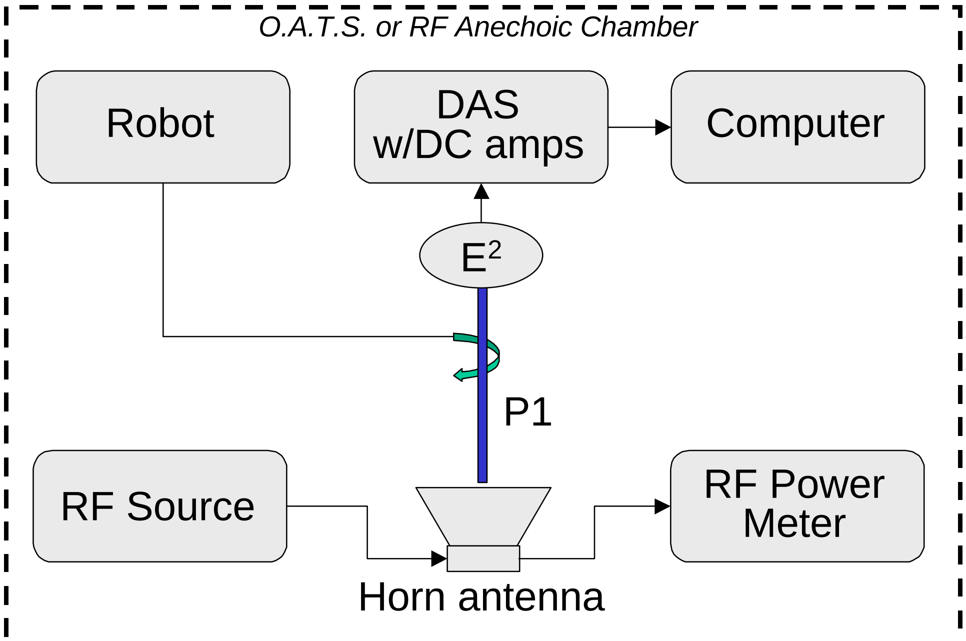


Figure 3.2

### 3.2.6 Test Procedure

1. Mount the miniature RF probe of the system to be calibrated in a support fixture.
2. Setup the equipment so that the horn antenna is coaxial with, and separated from the probe by 1 m.
3. Set the RF generator output at 1GHz.
4. Adjust the RF generator output so that the power density at the miniature RF probe is $1mW/cm^2$
5. Once the prescribed position is obtained, it must be maintained during the rest of the measurement. The only movement of the probe allowed is rotation on its axis to position the dipoles in the plane of E-field.
6. While the probe is being rotated through 360 degrees, record the maximum measured on each channel.
7. Verify the 1 GHz results against those obtained with the TEM cell at the same frequency before proceeding
8. Set the RF generator to a desired calibration frequency and repeat steps 4 through 6.


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### 3.2.7 Test Data Table

The sensitivities in mV/ (mW/cm$^2$) for each channel can be recorded in the following table:

| **Frequency** | **Channel 1 (Pins 6 & 1)** | | **Channel 2 (Pins 2 & 3)** | | **Channel 3 (Pins 4 & 5)** | |
|---|---|---|---|---|---|---|
| **(GHz)** | | | | | | |
| | **e** | η | **e** | η | **e** | η |
| | | | | | | |
| 1.0 | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

## 4.0 DETERMINING THE ENHANCEMENT FACTOR OF SIMULATED TISSUE

### 4.1 Background

The enhancement factor describes the ratio of the sensitivity of the probe sensors in different media to their sensitivity in air. The calibration factor needs only be calculated once for each probe type

### 4.2 References

- SAR Measurement Operational Guide, O.M. Garay and Q. Balzano, 1995, Motorola, Florida Corporate Electromagnetics Research Laboratory, Fort Lauderdale, Florida.
- “Broadband Calibration of E-Field Probes in Lossy Media”, K. Meier, M. Burkhardt, T. Schmid, and N. Kuster, 1996, IEEE Transactions on Microwave Theory and Techniques. 44:1954-1962.

### 4.3 Definition

**enhancement factor**: the ratio of the sensitivity of the probe sensors in different media to their sensitivity in air.

## 4.4 Minimum Standard

The enhancement factor of the probes depends on the simulated tissue formulation. As such, there is no minimum requirement for the enhancement factor of the probes.

## 4.5 Test Equipment

| Description | Manufacturer | Model |
|---|---|---|
| Precision Thermistor | Omega | ON-901-44004 |
| Precision Dual-Channel Thermometer | Guildline | 5150 |
| Insulated Flat Phantom | APREL | |
| Synthetic Tissue Mixture | APREL | SSI/DRB-TP-D01-033 |
| Reference Half-Wave Dipole | APREL | various |
| RF Signal Generator | Hewlett Packard | 8340B |
| Amplifier | various | various |
| RF Power Meter | Rohde & Schwarz | NRVS |
| Miniature E-field probe | Narda | 8021B |
| Probe support fixture | APREL | N/A |
| Computer | Northern Micro | Pentium 75 |
| Software | Microsoft | Office 97 Pro |
| Software | APREL | SAR Measurement |
| Data acquisition card | ComputerBoards | CIO-DAS08-PGH |
| Miscellaneous Cables | N/A | N/A |


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## 4.6 Test Configuration

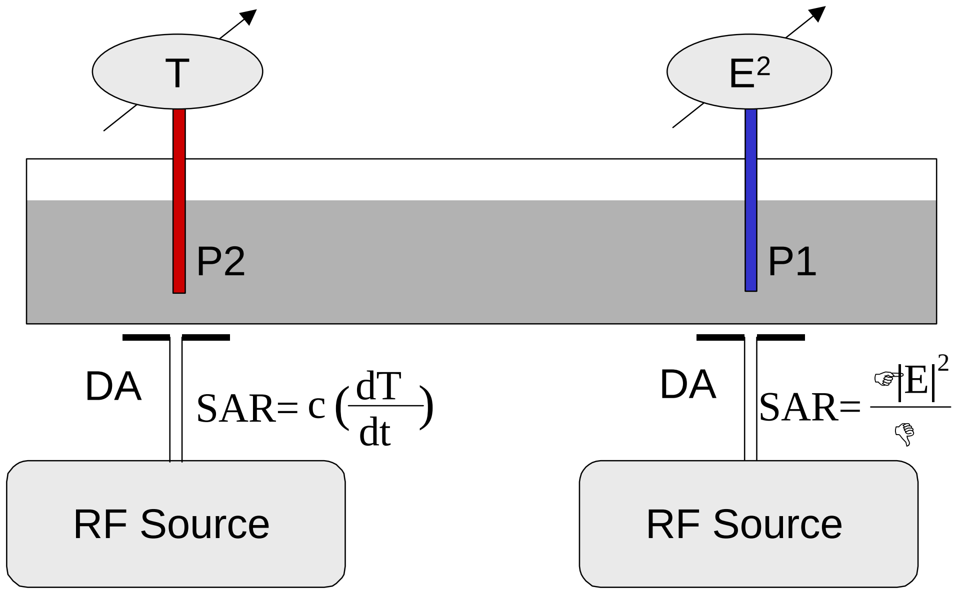


Figure 4.1

## 4.7 Test Procedure

1. A RF-transparent thermistor-based temperature probe (used with the Guildline 5150 Precision Dual-Channel Thermometer) and an isotropic E-field probe are placed side-by-side in a planar phantom while both are exposed to RF energy from a half wave dipole antenna located below the phantom (See Fig. 4.1). The E-field probe and data acquisition system was previously calibrated (see Section 3.0).
2. First, the location of the maximum E-field close to the phantom's bottom is determined as a function of power into the dipole.
3. Then, the E-field probe is moved sideways so that the temperature probe, while affixed to the E-field probe, is placed at the previous location of the E-field probe.
4. Finally, temperature changes for 30-second exposures at the same RF power levels used for the E-field measurement are recorded.
5. Care is taken to allow cooling to the original temperature and temperature stabilization between tests. (The heated region of the mixture is briefly stirred to accelerate the process).


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## 4.8 Test Data Table

| Frequency: (MHz) | | | | Date: |
|---|---|---|---|---|
| RF Power | E-Field Measurement µV Sensor | | | Temperature change Measurement (°C) |
| Watts | 1 | 2 | 3 | 30 Seconds |
| | | | | |
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## 4.9 Test Data Analysis

The data from the insulated flat phantom measurements are used to determine the enhancement factor (γ) of the simulated tissue from the following relationships:

$$SAR = C\frac{\Delta T}{\Delta t} \qquad (1)$$

$$SAR = \frac{s\ |E|^2}{r} \qquad (2)$$

or

$$SAR = 3.77x10^{-4}\frac{s}{rg}\sum_{1}^{3}\frac{V_i}{h_i} \qquad (3)$$

where C is the heat capacity of the simulated tissue (see SSI/DRB-TP-D01-033)
ΔT is the temperature rise in °C measured for an elapsed time of Δt seconds (30s)


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$|E|^2$ is the total RMS E-field level (V/m) induced within the exposed tissue

σ is the conductivity of the simulated tissue (see SSI/DRB-TP-D01-033)

ρ is the density of the simulated tissue (see SSI/DRB-TP-D01-033)

$V_i$ are the rectified signal voltages measured on each of the three sensors in the probe

$\eta_i$ are the sensor sensitivities relating the signal from a single sensor and the field component in the direction of the sensor

γ is the tissue enhancement factor which related the sensitivity of the probe in different media to their sensitivity in air.

Taking the derivative of equations (1) and (3) with respect to the RF power (P) delivered to the dipole:

$$\frac{d(SAR)}{dP} = \frac{C}{\Delta t}\frac{d\Delta T}{dP} \qquad (4)$$

$$\frac{d(SAR)}{dP} = 3.77x10^{-4}\frac{s}{rg}\frac{d}{dP}\left(\sum_1^3 \frac{V_i}{h_i}\right) \qquad (5)$$

Let $m_T = \frac{d\Delta T}{dP}$ which is the slope of a temperature change (ΔT) versus power (P) graph;

and $m_V = \frac{d}{dP}\left(\sum_1^3 \frac{V_i}{h_i}\right)$ which is the slope of the total compensated measured voltage $\left(\sum_1^3 \frac{V_i}{h_i}\right)$ versus power (P) graph.

Setting equations 4 and 5 equal to each other and solving for γ we get:

$$g = 3.77x10^{-4}\frac{s}{r}\frac{\Delta t}{C}\frac{m_V}{m_T}$$


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