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**REPORT ON**

The Specific Absorption Rate Assessment of the  
Symbol LS3478 Scanner

Report Number: WS612336 – 001 Issue 1.00

October 2004

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LS3478 Scanner

Report No: WS612336 – 001 Issue 1.00

**FCC ID:** H9P2164381  
**IC:** 1549D-2164381

**PREPARED FOR:** Symbol Technologies  
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Holtsville  
NY 11742-1300  
New York  
United States of America

**ATTESTATION:** The wireless portable device described within this report has been shown to be capable of compliance for localised specific absorption rate (SAR) for General Population/Uncontrolled Exposure Limits as defined in the European standard EN50361: 2002 and Australian Communications Authority Radio communications (Electromagnetic Radiation – Human Exposure) Standard 2003 of 2.0W/kg, FCC standard Supplement C (Edition 01-01) to OET Bulletin 65 (Edition 97-01) and RSS-102 Issue 1 (Provisional) September 25, 1999 of 1.6 W/kg.

The measurements shown in this report were made in accordance with the procedures specified in European standard EN50361: 2002, Supplement C (Edition 01-01) to OET Bulletin 65 (Edition 97-01), RSS-102 Issue 1 (Provisional) September 25 and IEEE 1528-2003.

All reported testing was carried out on a sample of equipment to demonstrate compliance with the above standards. The sample tested was found to comply with the requirements in the applied rules.



A. Miller  
**Senior SAR Test Engineer**

**APPROVED BY:**



M Jenkins  
**UKAS Signatory**

**DATED:** 8<sup>th</sup> October 2004

**DISTRIBUTION:** Symbol Technologies Corporation (CD ROM). Copy No: 1  
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Copy No.: 1

*Note: The test results reported herein relate only to the item tested as identified above and on the Status Page.*

*Report reissued due to minor typographical errors*



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## **EXECUTIVE SUMMARY**

The Specific Absorption Rate Assessment of the  
Symbol LS3478 Scanner

**PROJECT MANAGER: M. Glasspool**



## 1.1 STATUS

|                                  |  |
|----------------------------------|--|
| <b>MANUFACTURING DESCRIPTION</b> | Wireless Laser Scanner                       |
| <b>STATUS OF TEST</b>            | Specific Absorption Rate Testing             |
| <b>APPLICANT</b>                 | Symbol Technologies Inc                      |
| <b>MANUFACTURER</b>              | Symbol Technologies Inc                      |
| <b>TYPE NUMBER</b>               | LS3478                                       |
| <b>PART NUMBER</b>               | LS3478-ER20005WW                             |
| <b>SERIAL NUMBER</b>             | ALP80432                                     |
| <b>HARDWARE VERSION</b>          | Build Status Rev 9 (To be released as Rev A) |
| <b>BLUETOOTH MODULE</b>          | Symbol Bluetooth Module                      |
| <b>TYPE</b>                      | 21-64381                                     |
| <b>PART NUMBER</b>               | 21-64381-02                                  |
| <b>CLASS</b>                     | Class 1                                      |
| <b>POWER</b>                     | +20dBm                                       |

### TEST SPECIFICATIONS:

US Federal Government, Code of Federal Regulations, Title 47 Telecommunication, Chapter I Federal Communications Commission, part 2, section 1093.

Federal Communications Commission (FCC) OET Bulletin 65c, Edition 01-01, Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields – Additional Information for Evaluating Compliance of Mobile and Portable Devices with FCC Limits for Human Exposure to Radiofrequency Emissions

CENELEC EN 50360: July 2001, Product Standard to demonstrate the compliance of mobile phones with the basic restrictions related to human exposure electromagnetic (300 MHz - 3 GHz).

CENELEC EN 50361: July 2001, Basic standard for the measurement of Specific Absorption Rate related to human exposure to electromagnetic fields from mobile phones (300 MHz - 3 GHz).

RSS-102 Issue 1 (Provisional) September 25, 1999: Evaluation Procedure for Mobile and Portable Radio Transmitters with respect to Health Canada's Safety Code 6 for Exposure of Humans to radio Frequency Fields.

Australian Communications Authority – Radio communications (Electromagnetic Radiation – Human Exposure) Standard 2003.

### REFERENCES:

IEEE 1528 –2003: Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Body Due to Wireless Communications Devices: Experimental Techniques

Council Recommendations 1999/519/EC on the limitations of exposure of the general public to electromagnetic fields (0 Hz - 3 GHz) annex II.

**BABT REGISTRATION NUMBER:** WS612336

**RECEIPT OF TEST SAMPLES:** 9<sup>th</sup> September 2004  
**START OF TEST:** 10<sup>th</sup> September 2004  
**FINISH OF TEST:** 10<sup>th</sup> September 2004



**1.2 DECLARATION OF BUILD STATUS**

| <b>MAIN EUT</b>             |  |
|-----------------------------|--|
| MANUFACTURING DESCRIPTION   | Wireless Laser Scanner   |
| MANUFACTURER                | Symbol Technologies Inc  |
| TYPE                        | LS3478   |
| PART NUMBER                 | LS3478-ER20005WW   |
| SERIAL NUMBER               | ALP80420 & ALP80432  |
| HARDWARE VERSION            | Rev 9 (To be released as Rev A)  |
| COUNTRY OF ORIGIN           | USA  |
| UK AGENT                    | Symbol Technologies Inc  |
| FCC ID                      | H9P2164381   |
| INDUSTRY CANADA ID          | 1549D-2164381  |
| TECHNICAL DESCRIPTION       | The LS3478 is part of the Symbol NGIS series of Laser Scanners supporting a Bluetooth Connectivity. The Handheld imager used for reading all major bar code symbologies. |
| <b>BATTERY/POWER SUPPLY</b> |  |
| MANUFACTURING DESCRIPTION   | Battery  |
| MANUFACTURER                | Motorola   |
| PART NUMBER                 | 21-62606-01  |
| HARDWARE VERSION            | Rev A  |
| VOLTAGE                     | 3.7 V dc   |
| COUNTRY OF ORIGIN           | China  |
| <b>RADIO MODULES</b>        |  |
| MANUFACTURING DESCRIPTION   | Symbol Bluetooth Module  |
| MANUFACTURER                | Symbol Technologies Inc  |
| TYPE                        | 21-64381   |
| PART NUMBER                 | 21-64381-02  |
| POWER                       | 100mW (+20dBm - Class 1)   |
| TRANSMITTER OPERATING RANGE | 2400 – 2483.5MHz   |
| RECEIVER OPERATING RANGE    | 2400 – 2483.5MHz   |
| INTERMEDIATE FREQUENCIES    | Not Applicable (Direct conversion)   |
| ITU DESIGNATION OF EMISSION | 1M00F1D  |
| FCC ID                      | H9P2164381   |
| INDUSTRY CANADA ID          | 1549D-2164381  |
| DHSS/FHSS/COMBINED OR OTHER | FHSS   |

Signature

Date  
 D of B S Serial No

6<sup>th</sup> September 2004  
 OR612336



### 1.3 **SUMMARY**

The LS3478 is part of the Symbol NGIS series of Laser Scanners supporting a Bluetooth Connectivity. The Handheld scanner used for reading all major bar code symbologies.

Prior to full SAR assessment, the device was placed into the appropriate test mode and an area scan was performed on each face of the device to ascertain the location of the transmitter to enable the SAR testing to be performed on the appropriate face. The device was connected to a STB3478 cradle which in turn was connected to a PC running test software to enable the Scanner to configure into a CW test mode.

SAR testing was carried out at the top, middle and bottom frequency of the operating bands.

For Body SAR assessment, testing was performed with the device placed as close as possible to the Flat phantom. Four sides of the Scanner (left, right sides, top and base) were placed in turn against the 2mm side of the phantom. Flat Phantom dimensions 220mmx200mmx150mm and with a sidewall thickness of 2.0mm. The phantom was filled to a depth of 150mm with 2450MHz body simulant liquid. The dielectric properties were in accordance with the requirements for the dielectric properties specified in Supplement C (Edition 01-01) to OET Bulletin 65 (Edition 97-01) the frequency under test.

An area scan was carried out in each position to ascertain the maximum energy area location. The position chosen for full SAR assessment was the Top of the Scanner, as it represented the worst-case position for SAR measurement. It is acknowledged that this is not representative of the normal worn position of use, but considered to give the manufacturer the worst-case SAR level.

For Bluetooth SAR assessment the device was placed into a test mode using onboard software supplied by the client, which enabled the device to be placed into a CW test mode. The channels 0, 39 & 78 were selected in turn and the maximum SAR levels recorded.

No accessories were supplied for assessment with the device

The maximum 10g volume averaged SAR level measured for all the tests performed did not exceed the 2 W/kg level defined for limiting the exposure of the general population to time-varying electric and magnetic fields by ICNIRP (1998), which is the relevant Standard for testing according to the CENELEC EN50361 test method.

The maximum 1g volume averaged SAR level measured for all the tests performed did not exceed the limits for General Population/Uncontrolled Exposure (W/kg) Partial Body of 1.6 W/kg. Level defined in Supplement C (Edition 01-01) to OET Bulletin 65 (97-01).

#### **WORST CASE SAR VALUE / POSITION / MODE**

**POSITION:** The LS3478 Top facing to phantom  
**DISTANCE:** 0.0cm from terminal case to phantom  
**MODE:** CW  
**SAR VALUE:** 0.253 W/kg (1g Limit 1.6 W/kg)  
0.107 W/kg (10g limit 2.0 W/kg)



**1.4 TEST RESULT SUMMARY**

**SYSTEM PERFORMANCE / VALIDATION CHECK RESULTS**

Prior to formal testing being performed a System Check was performed in accordance with OET(65)c and the results were compared against published data in standard IEEE 1528-2003. The following results were obtained: -

| Dipole Used | Frequency (MHz) | Max 1g SAR (W/kg)* | Percentage Drift on 1g Reference | Max 10g SAR (W/kg)* | Percentage Drift on 10g Reference |
|-------------|-----------------|--------------------|----------------------------------|---------------------|-----------------------------------|
| 2450        | 2450            | 49.9*              | -4.78%                           | 23.42*              | -2.43%                            |

\*Normalised to 1W

**MAXIMUM SAR VALUES**

The following is a summary of the maximum SAR values found during the assessment.

**BODY ASSESSMENT SPECIFIC ABSORPTION RATE (MAXIMUM SAR) 1G AND 10G RESULTS FOR THE SYMBOL TECHNOLOGIES LS3478 INDUSTRIAL GRADE CHARGER**

| Position  | Channel Number | Frequency (MHz) | Max Spot SAR (W/kg) | Max 1g SAR (W/kg) | Max 10g SAR (W/kg) | SAR Drift dB | Area scan (Figure number) |
|---|----------------|-----------------|---------------------|-------------------|--------------------|--------------|---------------------------|
| Unit front Facing   | 78             | 2480            | NA                  | NA                | NA                 | NA           | Figure 18                 |
| Unit Right-hand side facing   | 78             | 2480            | NA                  | NA                | NA                 | NA           | Figure 19                 |
| Unit Left-hand side facing  | 78             | 2480            | NA                  | NA                | NA                 | NA           | Figure 20                 |
| Unit Top Facing   | 78             | 2480            | 0.28                | 0.195             | 0.081              | -0.04        | Figure 21                 |
| Unit Top Facing   | 40             | 2442            | 0.36                | 0.253             | 0.107              | -0.05        | Figure 22                 |
| Unit Top Facing   | 0              | 2402            | 0.26                | 0.179             | 0.073              | -0.24        | Figure 23                 |
| Limit for General Population (Uncontrolled Exposure) 1.6 W/kg (1g) & 2.0 W/kg (10g) |                |                 |                     |                   |                    |              |                           |





## 1.4 TEST RESULT SUMMARY

### OUTPUT POWER OF TEST DEVICE MEASUREMENT METHOD

For the Symbol Technologies LS3478 Scanner.

The Spectrum Analyser was tuned to the test frequency. The device output power setting was controlled via the 'Test Mode' on each handset being set to the conditions specified in the Summary on page 5 of this document. The device was then rotated through 360 degrees until the highest power level was observed in both planes of polarisation. The device was then replaced with a substitution antenna, the signal to the antenna was adjusted to equal the related level detected from the device.

### MAXIMUM POWER

Recorded from the Symbol Technologies LS3478 Scanner

| Radio Device    | Frequency (MHz) | Raw Result (dBm) | Substitution Level (dBm) | Substitution Antenna Gain (dB) | Result EIRP (dBm) | Result EIRP (mW) |
|-----------------|-----------------|------------------|--------------------------|--------------------------------|-------------------|------------------|
| Bluetooth Radio | 2402            | -42.17           | 4.02                     | 9.08                           | 13.1              | 20.41            |
| Bluetooth Radio | 2442            | -43.19           | 1.26                     | 9.13                           | 10.39             | 10.94            |
| Bluetooth Radio | 2480            | -43.59           | 0.27                     | 9.15                           | 9.42              | 8.75             |



## **TEST DETAILS**

The Specific Absorption Rate Assessment of the  
Symbol LS3478 Scanner.

**TEST ENGINEER: A. MILLER**



## 2.1 TEST EQUIPMENT

The following test equipment was used at BABT:

| INSTRUMENT DESCRIPTION                | MANUFACTURER  | MODEL TYPE | INVENTORY NO. | SERIAL NUMBER | CALIBRATION DATES |          |
|---------------------------------------|---------------|------------|---------------|---------------|-------------------|----------|
|                                       |               |            |               |               | From              | To       |
| Bench-top Robot                       | Mitsubishi    | RV-E2      | 4691          | EA009006      | N/A               | N/A      |
| 2450 MHz – Head Tissue Simulant       | BABT          | Head       | N/A           | Batch 1       | 31/08/04          | 14/09/04 |
| 2450 MHz – Body Tissue Simulant       | BABT          | Body       | N/A           | 1             | 31/08/04          | 14/09/04 |
| 2450 MHz Calibration Dipole           | BABT          | IEEE1528   | A             | N/A           | 09/09/04          | 10/09/04 |
| RF Amplifier                          | Vectawave     | 10M-2.5G   | 4697          | N/A           | N/A               | N/A      |
| Directional Coupler                   | Krytar        | 1850       | 4651          | N/A           | N/A               | N/A      |
| 20dB Attenuator                       | Narda         | 766F-10    | EMC 1791      | 1791          | 28/05/04          | 28/05/05 |
| Power Meter                           | Rohde Schwarz | NRV        | 2472          | 860327/025    | 27/05/04          | 27/05/05 |
| Hygrometer                            | Rotronic      | I-1000     | 3230          | N/A           | 04/10/03          | 04/10/04 |
| Digital Thermometer                   | Digitron      | T208       | 3178          | N/A           | 16/09/03          | 16/09/04 |
| Thermocouple                          | RS            | 219-4539   | 4859          | N/A           | 16/06/03          | 16/09/04 |
| SAR Probe                             | IndexSAR      | IXP-050    | N/A           | 84            | 17/04/03          | 17/04/05 |
| Flat Phantom box 2mm side(200mm cube) | IndexSAR.     | N/A        | N/A           | N/A           | N/A               | N/A      |

## 2.2 TEST SOFTWARE

The following software was used to control the BABT SARA2 System:

| INSTRUMENT                                    | VERSION NO.       | DATE       |
|---|-------------------|------------|
| SARA2 system                                  | v2.3 VPM          | 29/02/2004 |
| Mitsubishi robot controller firmware revision | RV-E2 Version C9a | -          |
| IXA-10 Probe amplifier                        | Version 2.5       | -          |



### 2.3 DIELECTRIC PROPERTIES OF SIMULANT LIQUIDS

The fluids were calibrated in our laboratory and re-checked prior to any measurements being made against reference fluids stated in IEEE 1528-2003 of 0.9% NaCl (Salt Solution) at 23°C and also for Dimethylsulphoxide (DMS) at 21°C.

The fluids were made at BABT under controlled conditions from the following OET(65)c formulae and reference made to Draft Standard IEEE1528-2003. The composition of ingredients may have been modified accordingly to achieve the desired target tissue parameters required for routine SAR evaluation:

#### OET 65(c)Recipes

| Ingredients<br>(% by weight) | Frequency (MHz) |       |       |      |       |       |       |      |      |      |
|------------------------------|-----------------|-------|-------|------|-------|-------|-------|------|------|------|
|                              | 450             |       | 835   |      | 915   |       | 1900  |      | 2450 |      |
| Tissue Type                  | Head            | Body  | Head  | Body | Head  | Body  | Head  | Body | Head | Body |
| Water                        | 38.56           | 51.16 | 41.45 | 52.4 | 41.05 | 56.0  | 54.9  | 40.4 | 62.7 | 73.2 |
| Salt (NaCl)                  | 3.95            | 1.49  | 1.45  | 1.4  | 1.35  | 0.76  | 0.18  | 0.5  | 0.5  | 0.04 |
| Sugar                        | 56.32           | 46.78 | 56.0  | 45.0 | 56.5  | 41.76 | 0.0   | 58.0 | 0.0  | 0.0  |
| HEC                          | 0.98            | 0.52  | 1.0   | 1.0  | 1.0   | 1.21  | 0.0   | 1.0  | 0.0  | 0.0  |
| Bactericide                  | 0.19            | 0.05  | 0.1   | 0.1  | 0.1   | 0.27  | 0.0   | 0.1  | 0.0  | 0.0  |
| Triton X-100                 | 0.0             | 0.0   | 0.0   | 0.0  | 0.0   | 0.0   | 0.0   | 0.0  | 36.8 | 0.0  |
| DGBE                         | 0.0             | 0.0   | 0.0   | 0.0  | 0.0   | 0.0   | 44.92 | 0.0  | 0.0  | 26.7 |
| Dielectric Constant          | 43.42           | 58.0  | 42.54 | 56.1 | 42.0  | 56.8  | 39.9  | 54.0 | 39.8 | 52.5 |
| Conductivity (S/m)           | 0.85            | 0.83  | 0.91  | 0.95 | 1.0   | 1.07  | 1.42  | 1.45 | 1.88 | 1.78 |

#### IEEE 1528 Recipes

| Frequency (MHz)                                 | 300   | 450   | 835  | 900   |       |       | 1450 | 1800  |       |       |       | 1900  | 1950  | 2000  | 2100 |     | 2450 |       |       | 3000  |       |
|---|-------|-------|------|-------|-------|-------|------|-------|-------|-------|-------|-------|-------|-------|------|-----|------|-------|-------|-------|-------|
| Recipe #  | 1     | 1     | 3    | 1     | 1     | 2     | 3    | 1     | 1     | 2     | 2     | 3     | 1     | 2     | 4    | 1   | 1    | 2     | 2     | 3     | 1     |
| <b>Ingredients (% by weight)</b>                |       |       |      |       |       |       |      |       |       |       |       |       |       |       |      |     |      |       |       |       |       |
| I,2-Propanediol                                 |       |       |      |       |       | 64.81 |      |       |       |       |       |       |       |       |      |     |      |       |       |       |       |
| Bactericide                                     | 0.19  | 0.19  | 0.5  | 0.1   | 0.1   |       | 0.5  |       |       |       |       | 0.5   |       |       |      |     |      |       |       |       | 0.5   |
| Diacetin  |       |       | 48.9 |       |       |       | 49.2 |       |       |       |       | 49.43 |       |       |      |     |      |       |       |       | 49.75 |
| DGBE  |       |       |      |       |       |       |      | 45.41 | 47    | 13.84 | 44.92 |       | 44.92 | 13.84 | 45   | 50  | 50   | 7.99  | 7.99  |       | 7.99  |
| HEC   | 0.98  | 0.98  |      | 1     | 1     |       |      |       |       |       |       |       |       |       |      |     |      |       |       |       |       |
| NaCl  | 5.95  | 3.95  | 1.7  | 1.45  | 1.48  | 0.79  | 1.1  | 0.67  | 0.36  | 0.35  | 0.18  | 0.64  | 0.18  | 0.35  |      |     |      |       | 0.16  | 0.16  | 0.16  |
| Sucrose   | 55.32 | 56.32 |      | 57    | 56.5  |       |      |       |       |       |       |       |       |       |      |     |      |       |       |       |       |
| Triton X-100                                    |       |       |      |       |       |       |      |       |       |       | 30.45 |       |       |       |      |     |      |       |       | 19.97 | 19.97 |
| Water   | 37.56 | 38.56 | 48.9 | 40.45 | 40.92 | 34.4  | 49.2 | 53.82 | 52.64 | 55.36 | 54.9  | 49.43 | 54.9  | 55.36 | 55   | 50  | 50   | 71.88 | 71.88 | 49.75 | 71.88 |
| <b>Measured dielectric parameters</b>           |       |       |      |       |       |       |      |       |       |       |       |       |       |       |      |     |      |       |       |       |       |
| $\epsilon'_r$                                   | 46    | 43.4  | 44.3 | 41.6  | 41.2  | 41.8  | 42.7 | 40.9  | 39.3  | 41    | 40.4  | 39.2  | 39.9  | 41    | 40.1 | 37  | 36.8 | 41.1  | 40.3  | 39.2  | 37.9  |
| $\sigma$ (S/m)                                  | 0.86  | 0.85  | 0.9  | 0.9   | 0.98  | 0.97  | 0.99 | 1.21  | 1.39  | 1.38  | 1.4   | 1.4   | 1.42  | 1.38  | 1.41 | 1.4 | 1.51 | 1.55  | 1.88  | 1.82  | 2.46  |
| Temp. (°C)                                      | 22    | 22    | 20   | 22    | 22    | 22    | 20   | 22    | 22    | 21    | 22    | 20    | 21    | 21    | 20   | 22  | 22   | 20    | 20    | 20    | 20    |
| <b>Target dielectric parameters (Table 5-1)</b> |       |       |      |       |       |       |      |       |       |       |       |       |       |       |      |     |      |       |       |       |       |
| $\epsilon'_r$                                   | 45.3  | 43.5  | 41.5 | 41.5  |       |       | 40.5 | 40    |       |       |       |       |       |       | 39.8 |     | 39.2 | 38.5  |       |       |       |
| $\sigma$ (S/m)                                  | 0.87  | 0.87  | 0.9  | 0.97  |       |       | 1.2  | 1.4   |       |       |       |       |       |       | 1.49 |     | 1.8  | 2.4   |       |       |       |



## 2.3 DIELECTRIC PROPERTIES OF SIMULANT LIQUIDS -CONTINUED

The dielectric properties of the tissue simulant liquids used for the SAR testing at BABT are as follows:-

| FLUID TYPE AND FREQUENCY | RELATIVE PERMITTIVITY $\epsilon_r$ ( $\epsilon'$ ) TARGET | RELATIVE PERMITTIVITY $\epsilon_r$ ( $\epsilon'$ ) MEASURED | CONDUCTIVITY $\sigma$ TARGET | CONDUCTIVITY $\sigma$ MEASURED |
|--------------------------|---|---|------------------------------|--------------------------------|
| Head 2450MHz             | 39.2  | <b>36.66</b>  | 1.80 S/m                     | <b>1.856</b>                   |
| Body 2450MHz             | 52.7  | <b>50.33</b>  | 1.95 S/m                     | <b>2.036</b>                   |

Fluid Mass Density,  $\rho = 1000 \text{ kg/m}^3$

## 2.4 TEST CONDITIONS

### TEST LABORATORY CONDITIONS

Ambient Temperature: Within +15°C to +35°C at 20% RH to 75% RH.  
 The actual Temperature during the testing ranged from 23.9°C to 24.6°C.  
 The actual Humidity during the testing ranged from 39.4% to 57.0% RH.

### TEST FLUID TEMPERATURE RANGE

| TISSUE SIMULATING LIQUID TEMPERATURE: +20°C TO +25°C. |             |             |
|---|-------------|-------------|
| FREQUENCY (MHz)                                       | <b>2450</b> | <b>2450</b> |
| BODY / HEAD FLUID                                     | <b>HEAD</b> | <b>BODY</b> |
| MIN TEMPERATURE                                       | 21.9°C      | 21.9°C      |
| MAX TEMPERATURE                                       | 21.9°C      | 22.3°C      |

### SAR DRIFT

SAR Drift during scans. The maximum SAR Drift, drift due to the mobile phone electronics, was recorded as -5.38% (-0.240dB) for all of the testing. The value of 5.38% has been included in the measurement uncertainty for this assessment.



## 2.5 MEASUREMENT UNCERTAINTY

| ERROR SOURCES  | EN 50361 Description (Subclause) | Uncertainty (%) | Probability Distribution | Divisor | ci  | ci <sup>2</sup> | Standard Uncertainty (%) | Stand Uncert <sup>2</sup> | (Stand Uncert <sup>2</sup> ) X (ci <sup>2</sup> ) |  |
|--|----------------------------------|-----------------|--------------------------|---------|-----|-----------------|--------------------------|---------------------------|---|--|
| <b>Measurement Equipment</b>   |                                  |                 |                          |         |     |                 |                          |                           |   |  |
| Calibration  | 7.2.1.1                          | 10              | Normal                   | 2.00    | 1   | 1               | 5.00                     | 25.00                     | 25.00   |  |
| Isotropy   | 7.2.1.2                          | 10.6            | Rectangular              | 1.73    | 1   | 1               | 6.12                     | 37.45                     | 37.45   |  |
| Linearity  | 7.2.1.3                          | 2.92            | Rectangular              | 1.73    | 1   | 1               | 1.69                     | 2.84                      | 2.84  |  |
| Probe Stability  | -                                | 2.46            | Rectangular              | 1.73    | 1   | 1               | 1.42                     | 2.02                      | 2.02  |  |
| Detection limits   | 7.2.1.4                          | 0               | Rectangular              | 1.73    | 1   | 1               | 0.00                     | 0.00                      | 0.00  |  |
| Boundary effect  | 7.2.1.5                          | 1.7             | Rectangular              | 1.73    | 1   | 1               | 0.98                     | 0.96                      | 0.96  |  |
| Measurement device   | 7.2.1.6                          | 0               | Normal                   | 1.00    | 1   | 1               | 0.00                     | 0.00                      | 0.00  |  |
| Response time  | 7.2.1.7                          | 0               | Normal                   | 1.00    | 1   | 1               | 0.00                     | 0.00                      | 0.00  |  |
| Noise  | 7.2.1.8                          | 0               | Normal                   | 1.00    | 1   | 1               | 0.00                     | 0.00                      | 0.00  |  |
| Integration time   | 7.2.1.9                          | 2.3             | Normal                   | 1.00    | 1   | 1               | 2.30                     | 5.29                      | 5.29  |  |
| <b>Mechanical constraints</b>  |                                  |                 |                          |         |     |                 |                          |                           |   |  |
| Scanning system  | 7.2.2.1                          | 0.57            | Rectangular              | 1.73    | 1   | 1               | 0.33                     | 0.11                      | 0.11  |  |
| Phantom shell  | 7.2.2.2                          | 1.43            | Rectangular              | 1.73    | 1   | 1               | 0.83                     | 0.68                      | 0.68  |  |
| Matching between probe and phantom   | 7.2.2.3                          | 2.86            | Rectangular              | 1.73    | 1   | 1               | 1.65                     | 2.73                      | 2.73  |  |
| Positioning of the phone 'Y' Coordinate  | 7.2.2.4                          | 1.5             | Normal                   | 1.00    | 1   | 1               | 1.50                     | 2.25                      | 2.25  |  |
| Positioning of the phone 'Z' Coordinate  | 7.2.2.4                          | 1.73            | Normal                   | 1.00    | 1   | 1               | 1.73                     | 2.99                      | 2.99  |  |
| <b>Physical Parameters</b>   |                                  |                 |                          |         |     |                 |                          |                           |   |  |
| Liquid conductivity (deviation from target)  | 7.2.3.2                          | 5               | Rectangular              | 1.73    | 0.5 | 0.25            | 2.89                     | 8.33                      | 2.08  |  |
| Liquid conductivity (measurement error)  | 7.2.3.2                          | 5               | Rectangular              | 1.73    | 0.5 | 0.25            | 2.89                     | 8.33                      | 2.08  |  |
| Liquid permittivity (deviation from target)  | 7.2.3.3                          | 5               | Rectangular              | 1.73    | 0.5 | 0.25            | 2.89                     | 8.33                      | 2.08  |  |
| Liquid permittivity (measurement error)  | 7.2.3.3                          | 5               | Rectangular              | 1.73    | 0.5 | 0.25            | 2.89                     | 8.33                      | 2.08  |  |
| Drifts in output power of the phone, probe, temperature and humidity                                 | 7.2.3.4                          | 5.38            | Rectangular              | 1.73    | 0.5 | 0.25            | 3.11                     | 9.65                      | 9.65  |  |
| Perturbation by the environment  | 7.2.3.5                          | 3               | Rectangular              | 1.73    | 1   | 1               | 1.73                     | 3.00                      | 3.00  |  |
| <b>Post-Processing</b>   |                                  |                 |                          |         |     |                 |                          |                           |   |  |
| SAR interpolation and extrapolation  | 7.2.4.1                          | 2.4             | Rectangular              | 1.73    | 1   | 1               | 1.39                     | 1.92                      | 1.92  |  |
| Maximum SAR evaluation   | 7.2.4.2                          | 2.4             | Rectangular              | 1.73    | 1   | 1               | 1.39                     | 1.92                      | 1.92  |  |
| <b>Combined standard uncertainty</b>   | 11.16                            |                 |                          |         |     |                 | <b>Total</b>             | 124.57                    |   |  |
| <b>Expanded uncertainty = 22.32 % (Using a Coverage Factor of K=2) (confidence interval of 95 %)</b> |                                  |                 |                          |         |     |                 |                          |                           |   |  |



## 2.6 SAR MEASUREMENT SYSTEM

### ROBOT SYSTEM SPECIFICATION

The SAR measurement system being used is the IndexSAR SARA2 system, which consists of a Mitsubishi RV-E2 6-axis robot arm and controller, IndexSAR probe and amplifier and SAM phantom Head Shape. The robot is used to articulate the probe to programmed positions inside the phantom head to obtain the SAR readings from the DUT.

The system is controlled remotely from a PC, which contains the software to control the robot and data acquisition equipment. The software also displays the data obtained from test scans.

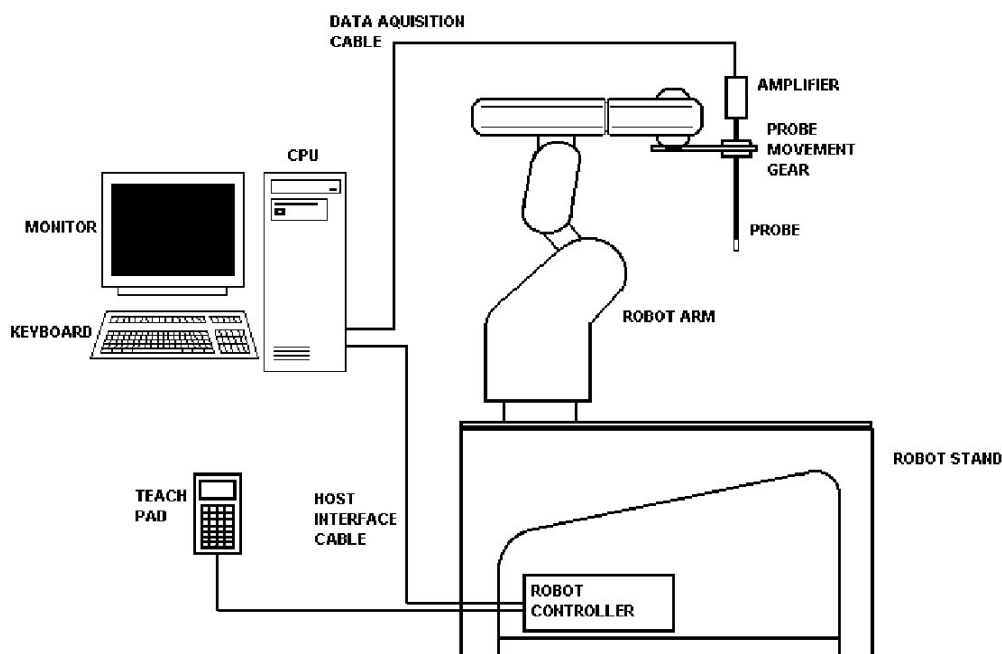


Figure 1: Schematic diagram of the SAR measurement system

The position and digitised shape of the phantom heads are made available to the software for accurate positioning of the probe and reduction of set-up time.

The SAM phantom heads are individually digitised using a Mitutoyo CMM machine to a precision of 0.001mm. The data is then converted into a shape format for the software, providing an accurate description of the phantom shell.

In operation, the system first does an area (2D) scan at a fixed depth within the liquid from the inside wall of the phantom. When the maximum SAR point has been found, the system will then carry out a 3D scan centred at that point to determine volume averaged SAR level.



## 2.6 SAR MEASUREMENT SYSTEM

### PROBE AND AMPLIFIER SPECIFICATION

#### **IXP-050 IndexSAR isotropic immersible SAR probe**

The probes are constructed using three orthogonal dipole sensors arranged on an interlocking, triangular prism core. The probes have built-in shielding against static charges and are contained within a PEEK cylindrical enclosure material at the tip. Probe calibration is described in the following section.

#### **IXP-039 Amplifier**

The amplifier unit has a multi-pole connector to connect to the probe and a multiplexer selects between the 3-channel single-ended inputs. A 16-bit AtoD converter with programmable gain is used along with an on-board micro-controller with non-volatile firmware. Battery life is around 150 hours and data are transferred to the PC via 3m of duplex optical fibre and a self-powered RS232 to optical converter.

#### **Phantoms**

The Specific Anthropomorphic Mannequin (SAM) Upright Phantom is fabricated using moulds generated from the CAD files as specified by CENELEC EN50361. It is mounted via a rotation base to a supporting table, which also holds the robotic positioner. The phantom and robot alignment is assured by both mechanical and laser registration systems.





## 2.6 SAR MEASUREMENT SYSTEM

### PROBE CALIBRATION PROCEDURE

#### EQUIPMENT USED

For the first part of the characterisation procedure, the probe is placed in an isotropy measurement jig as pictured in Figure 2. In this position the probe can be rotated about its axis by a non-metallic belt driven by a stepper motor.

The probe is attached via its amplifier and an optical cable to a PC. A schematic representation of the test geometry is illustrated in Figure 3.

A balanced dipole (900 MHz) is inserted horizontally into the bracket attached to a second belt (Figure 2). The dipole can also be rotated about its axis. A cable connects the dipole to a signal generator, via a directional coupler and power meter. The signal generator feeds an RF amplifier at constant power, the output of which is monitored using the power meter. The probe is positioned so that its sensors line up with the rotation center of the source dipole. By recording output voltage measurements of each channel as both the probe and the dipole are rotated, data are obtained from which the spherical isotropy of the probe can be optimised and its magnitude determined.

The calibration process requires E-field measurements to be taken in air, in 900 MHz simulated brain liquid and at other frequencies/liquids as appropriate.

#### LINEARISING PROBE OUTPUT

The probe channel output signals are linearised in the manner set out in Refs [1] and [2]. The following equation is utilized for each channel:

$$U_{lin} = U_{o/p} + U_{o/p}^2 / DCP \quad (1)$$

where  $U_{lin}$  is the linearised signal,  $U_{o/p}$  is the raw output signal in voltage units and DCP is the diode compression potential in similar voltage units.

DCP is determined from fitting equation (1) to measurements of  $U_{lin}$  versus source feed power over the full dynamic range of the probe. The DCP is a characteristic of the schottky diodes used as the sensors. For the IXP-050 probes with CW signals the DCP values are typically 0.10V (or 20 in the voltage units used by IndexSAR software, which are  $V*200$ ).

#### SELECTING CHANNEL SENSITIVITY FACTORS TO OPTIMISE ISOTROPIC RESPONSE

The basic measurements obtained using the calibration jig (Fig 2) represent the output from each diode sensor as a function of the presentation angle of the source (probe and dipole rotation angles). The directionality of the orthogonally-arranged sensors can be checked by analysing the data using dedicated IndexSAR software, which displays the data in 3D format as in Figure 4. The left-hand side of this diagram shows the individual channel outputs after linearisation (see above). The program uses these data to balance the channel outputs and then applies an optimisation process, which makes fine adjustments to the channel factors for optimum isotropic response.



## 2.6 SAR MEASUREMENT SYSTEM

### PROBE CALIBRATION PROCEDURE - Continued

The next stage of the process is to calibrate the IndexSAR probe to a W&G EMR300 E-field meter in air. The principal reasons for this are to obtain conversion factors applicable should the probe be used in air and to provide an overall measure of the probe sensitivity.

A multiplier is applied to factors to bring the magnitudes of the average E-field measurements as close as possible to those of the W&G probe.

The following equation is used (where linearised output voltages are in units of V\*200):

$$E_{air}^2 (V/m) = \begin{aligned} &U_{linx} * Air Factor_x \\ &+ U_{liny} * Air Factor_y \\ &+ U_{linz} * Air Factor_z \end{aligned} \quad (2)$$

It should be noted that the air factors are not separately used for normal SAR testing. The IXP-050 probes are optimised for use in tissue-simulating liquids and do not behave isotropically in air.

### 900 MHz LIQUID CALIBRATION

Conversion factors for use when the probes are immersed in tissue-simulant liquids at 900 MHz are determined either using a waveguide or by comparison to a reference probe that has been calibrated by NPL. Waveguide procedures are described later. The summary sheet indicates the method used for the probe S/N 0084.

The conversion factor, referred to as the 'liquid factor' is also applied to the measurements of each channel. The following equation is used (where output voltages are in units of V\*200):

$$E_{liq}^2 (V/m) = \begin{aligned} &U_{linx} * Air Factor_x * Liq Factor_x \\ &+ U_{liny} * Air Factor_y * Liq Factor_y \\ &+ U_{linz} * Air Factor_z * Liq Factor_z \end{aligned} \quad (3)$$

A 3D representation of the spherical isotropy for probe S/N 0084 using these factors is shown in Figure 4

The rotational isotropy can also be determined from the calibration jig measurements and is reported as the 900MHz isotropy in the summary table. Note that waveguide measurements can also be used to determine rotational isotropy (Fig. 6).

The design of the cells used for determining probe conversion factors are waveguide cells is shown in Figure 5. The cells consist of a coax to waveguide transition and an open-ended section of waveguide containing a dielectric separator. Each waveguide cell stands in the upright position and is filled with liquid within 10 mm of the open end. The separator provides a liquid seal and is designed for a good electrical transition from air filled guide to liquid filled guide. The choice of cell depends on the portion of the frequency band to be examined and the choice of liquid used. The depth of liquid ensures there is negligible radiation from the waveguide open top and that the probe calibration is not influenced by reflections from nearby objects. The return loss at the coaxial connector of the filled waveguide cell is measured initially using a network analyser and this information is used subsequently in the calibration procedure. The probe is positioned in the centre of the waveguide and is adjusted vertically or rotated using stepper motor arrangements. The signal generator is connected to the waveguide cell and the power is monitored with a coupler and a power meter. A fuller description of the waveguide method is given below.



## 2.6 SAR MEASUREMENT SYSTEM

### PROBE CALIBRATION PROCEDURE - Continued

The liquid dielectric parameters used for the probe calibrations are listed in the Tables below. The final calibration factors for the probe are listed in the summary chart.

### WAVEGUIDE MEASUREMENT PROCEDURE

The calibration method is based on setting up a calculable specific absorption rate (SAR) in a vertically-mounted WG8 (R22) waveguide section [1]. The waveguide has an air-filled, launcher section and a liquid-filled section separated by a matching window that is designed to minimise reflections at the liquid interface. A  $TE_{01}$  mode is launched into the waveguide by means of a N-type-to-waveguide adapter. The power delivered to the liquid section is calculated from the forward power and reflection coefficient measured at the input to the waveguide. At the centre of the cross-section of the waveguide, the local spot SAR in the liquid as a function of distance from the window is given by functions set out in IEEE 1528 as below:

Because of the low cutoff frequency, the field inside the liquid nearly propagates as a TEM wave. The depth of the medium (greater than three penetration depths) ensures that reflections at the upper surface of the liquid are negligible. The power absorbed in the liquid is determined by measuring the waveguide forward and reflected power. Equation (4) shows the relationship between the SAR at the cross-sectional center of the lossy waveguide and the longitudinal distance ( $z$ ) from the dielectric separator

$$SAR(z) = \frac{4(P_f - P_b)}{\rho ab\delta} e^{-2z/\delta} \quad (4)$$

where the density  $\rho$  is conventionally assumed to be  $1000 \text{ kg/m}^3$ ,  $ab$  is the cross-sectional area of the waveguide,  $P_f$  and  $P_b$  are the forward and reflected power inside the lossless section of the waveguide, respectively. The penetration depth  $\delta$ , which is the reciprocal of the waveguide-mode attenuation coefficient, is determined from a scan along the  $z$ -axis and compared with the theoretical value determined from Equation (5) using the measured dielectric properties of the lossy liquid.

$$\delta = \left[ \text{Re} \left\{ \sqrt{(\pi/a)^2 + j\omega\mu_o(\sigma + j\omega\epsilon_o\epsilon_r)} \right\} \right]^{-1} \quad (5)$$

Table A.1 of [1] can be used for designing calibration waveguides with a return loss greater than 30 dB at the most important frequencies used for personal wireless communications. Values for the penetration depth for these specific fixtures and tissue-simulating mixtures are also listed in Table A.1.

According to [1], this calibration technique provides excellent accuracy, with standard uncertainty of less than 3.6% depending on the frequency and medium. The calibration itself is reduced to power measurements traceable to a standard calibration procedure. The practical limitation to the frequency band of 800 to 2500 MHz because of the waveguide size is not severe in the context of compliance testing.



## **2.6 SAR MEASUREMENT SYSTEM**

### **PROBE CALIBRATION PROCEDURE - Continued**

#### **CALIBRATION FACTORS MEASURED FOR PROBE S/N 0084**

The probe was calibrated at 900, 1800, 1900 and 2450MHz in liquid samples representing both brain liquid and body fluid at these frequencies. The calibration was for CW signals only, and the axis of the probe was parallel to the direction of propagation of the incident field i.e. end-on to the incident radiation. The axial isotropy of the probe was measured by rotating the probe about its axis in 10 degree steps through 360 degrees in this orientation.

The reference point for the calibration is in the centre of the probe's cross-section at a distance of 2.7 mm from the probe tip in the direction of the probe amplifier. A value of 2.7 mm should be used for the tip to sensor offset distance in the software.

It is important that the diode compression point and air factors used in the software are the same as those quoted in the results tables, as these are used to convert the diode output voltages to a SAR value.

#### **DIELECTRIC PROPERTIES OF LIQUIDS**

The dielectric properties of the brain and body tissue-simulant liquids employed for calibration are listed in the tables below. The measurements were performed prior to each waveguide test using an IndexSAR DiLine measurement kit, which uses the TEM method as recommended in [2].

#### **AMBIENT CONDITIONS**

Measurements were made in the open laboratory at  $22 \pm 2.0^\circ\text{C}$ . The temperature of the liquids in the waveguide used was measured using a mercury thermometer.

#### **RESPONSE TO MODULATED SIGNALS**

To measure the response of the probe and amplifier to modulated signals, the probe is held vertically in a liquid-filled waveguide.

An RF amplifier is allowed to warm up and stabilise before use. A spectrum analyser is used to demonstrate that the peak power of the RF amplifier for the CW signals and the pulsed signals are within 0.1dB of each other when the signal generator is switched from CW to modulated output. Subsequently, the power levels recorded are read from a power meter when a CW signal is being transmitted.

The test sequence involves manually stepping the power up in regular (e.g. 2 dB) steps from the lowest power that gives a measurable reading on the SAR probe up to the maximum that the amplifiers can deliver.

At each power level, the individual channel outputs from the SAR probe are recorded at CW and then recorded again with the modulation setting. The results are entered into a spreadsheet. Using the spreadsheets, the modulated power is calculated by applying a factor to the measured CW power (e.g. for GSM, this factor is 9.03dB). This process is repeated 3 times with the response maximised for each channel sensor in turn.



## 2.6 SAR MEASUREMENT SYSTEM

### PROBE CALIBRATION PROCEDURE - Continued

The probe channel output signals are linearised in the manner set out in Section 1 above using equation (1) with the DCPs determined from the linearisation procedure. Calibration factors for the probe are used to determine the E-field values corresponding to the probe readings using equation (3). SAR is determined from the equation

$$\text{SAR (W/kg)} = E_{\text{liq}}^2 \text{ (V/m)} * \sigma \text{ (S/m)} / 1000 \quad (6)$$

Where  $\sigma$  is the conductivity of the simulant liquid employed.

Using the spreadsheet data, the DCP value for linearising each of the individual channels (X, Y and Z) is assessed separately. The corresponding DCP values are listed in the summary page of the calibration factors for each probe.

Figure 9 shows the linearised probe response to 900MHz GSM signals, Figure 9a the response to 1800MHz GSM signals, Figure 10 the response to GPRS signals (GSM with 2 timeslots) and Figure 11 & 12 the response to CDMA IS-95A and W-CDMA signals.

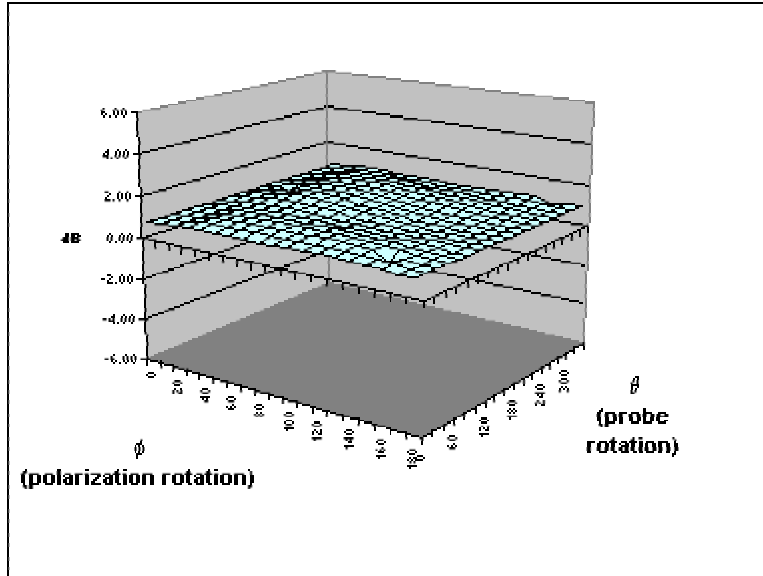
Additional tests have shown that the modulation response is similar at 1800MHz and is not affected by the orientation between the source and the probe.



**2.6 SAR MEASUREMENT SYSTEM**

**PROBE CALIBRATION PROCEDURE - Continued**

**SUMMARY OF CALIBRATION FACTORS FOR PROBE IXP-050 S/N 0084**



|                    | X    | Y    | Z    |         |
|--------------------|------|------|------|---------|
| <b>Air factors</b> | 500  | 410  | 385  | (V*200) |
| <b>DCPs</b>        | 20   | 20   | 20   | (V*200) |
| <b>GSM</b>         | 10.9 | 13   | 11.4 | (V*200) |
| <b>GPRS</b>        | 16.1 | 16.1 | 14.7 | (V*200) |
| <b>CDMA</b>        | 20   | 20   | 20   | (V*200) |

| f (MHz) | Axial isotropy (+/- dB) |      | SAR conversion factors(liq/air) |       | Notes |
|---------|-------------------------|------|---------------------------------|-------|-------|
|         | BRAIN                   | BODY | BRAIN                           | BODY  |       |
| 900     | 0.09                    | 0.09 | 0.279                           | 0.300 | 3,4   |
| 1800    | 0.12                    | 0.10 | 0.342                           | 0.375 | 3,4   |
| 1900    | 0.13                    | 0.10 | 0.354                           | 0.405 | 3,4   |
| 2450    | 0.12                    | 0.09 | 0.396                           | 0.468 | 3,4   |

| Notes |   |
|-------|---|
| 1)    | Calibrations done at 22C +/- 2C   |
| 2)    | Probe calibration by substitution against NPL-calibrated probe (Probe IXP-050 S/N0071; NPL Cal Rept. No: EF07/2002/03/IndexSAR) |
| 3)    | Waveguide calibration   |
| 4)    | Checked using box-phantom validation test   |

(The graph shows a simple, spreadsheet representation of surface shown in 3D in Figure 4)



## 2.6 SAR MEASUREMENT SYSTEM

### PROBE CALIBRATION PROCEDURE - Continued

#### PROBE SPECIFICATIONS

IndexSAR probe 0084, along with its calibration, is compared with CENELEC and IEEE standards recommendations (Refs [1] and [2]) in the Tables below. A listing of relevant specifications is contained in the tables below:

| <b>DIMENSIONS</b>                              | <b>S/N 0084</b> | <b>CENELEC [1]</b> | <b>IEEE [2]</b> |
|--|-----------------|--------------------|-----------------|
| Overall length (mm)                            | 350             | -                  | -               |
| Tip length (mm)                                | 10              | -                  | -               |
| Body diameter (mm)                             | 12              | -                  | -               |
| Tip diameter (mm)                              | 5.2             | 8                  | 8               |
| Distance from probe tip to dipole centers (mm) | 2.7             | -                  | -               |

| <b>DYNAMIC RANGE</b> | <b>S/N 0084</b> | <b>CENELEC [1]</b> | <b>IEEE [2]</b> |
|----------------------|-----------------|--------------------|-----------------|
| Minimum (W/kg)       | 0.01            | <0.02              | 0.01            |
| Maximum (W/kg)       | >100            | >100               | 100             |

| <b>LINEARITY OF RESPONSE</b>        | <b>S/N 0084</b> | <b>CENELEC [1]</b> | <b>IEEE [2]</b> |
|-------------------------------------|-----------------|--------------------|-----------------|
| Over range 0.01 – 100 W/kg (+/- dB) | 0.125           | 0.50               | 0.25            |

| <b>Isotropy (measured at 900MHz)</b>  | <b>S/N 0084</b> | <b>CENELEC [1]</b> | <b>IEEE [2]</b> |
|---|-----------------|--------------------|-----------------|
| Axial rotation with probe normal to source (+/- dB) at 900, 1800, 1900 and 2450 MHz<br><small>(see summary table)</small> | Max. 0.13       | 0.5                | 0.25            |
| Spherical isotropy covering all orientations to source (+/- dB)   | 0.34            | 1.0                | 0.50            |

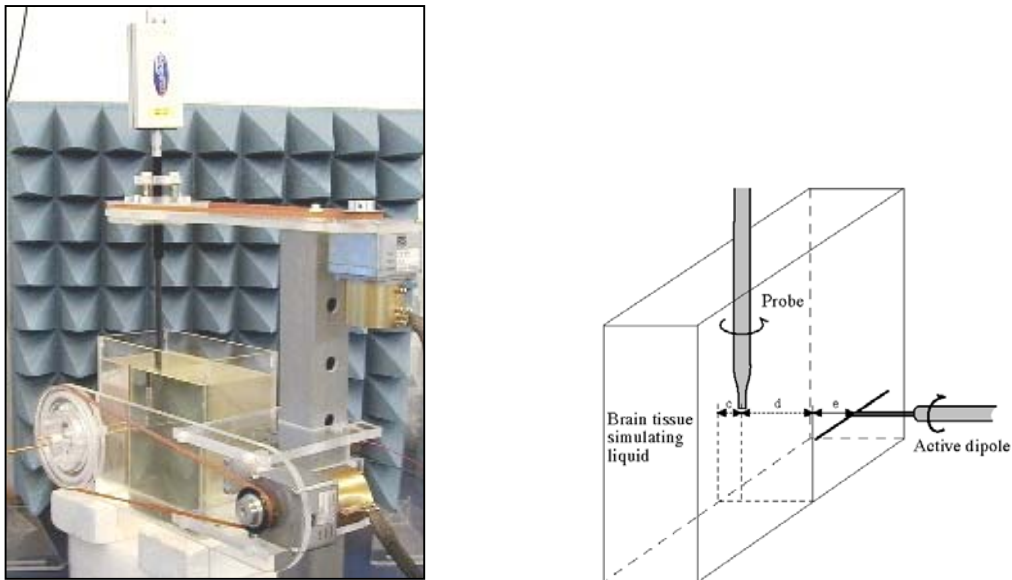
|                            |  |
|----------------------------|--|
| <b>CONSTRUCTION</b>        | Each probe contains three orthogonal dipole sensors arranged on a triangular prism core, protected against static charges by built-in shielding, and covered at the tip by PEEK cylindrical enclosure material. No adhesives are used in the immersed section. Outer case materials are PEEK and heat-shrink sleeving. |
| <b>CHEMICAL RESISTANCE</b> | Tested to be resistant to glycol and alcohol containing simulant liquids but probes should be removed, cleaned and dried when not in use.  |

## 2.6 SAR MEASUREMENT SYSTEM

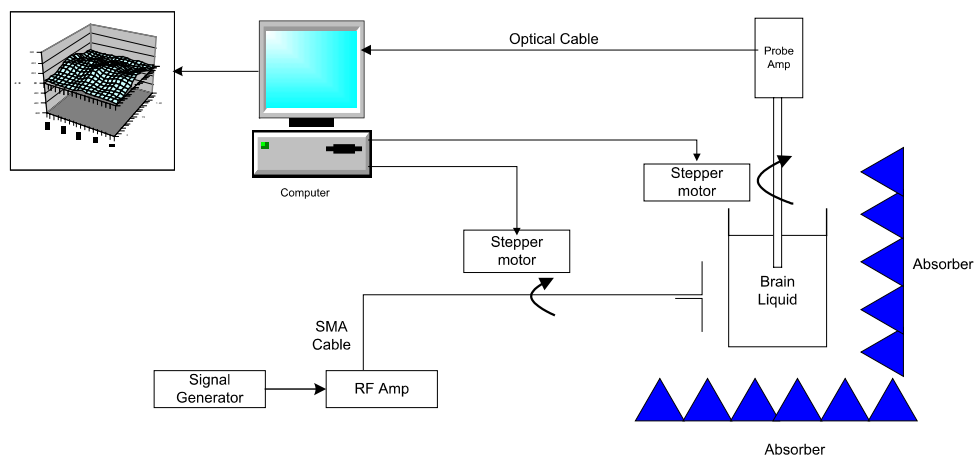
### PROBE CALIBRATION PROCEDURE - Continued

#### REFERENCES

- [1] CENELEC, EN 50361, July 2001. Basic Standard for the measurement of specific absorption rate related to human exposure to electromagnetic fields from mobile phones.
- [2] IEEE 1528, Recommended practice for determining the spatial-peak specific absorption rate (SAR) in the human body due to wireless communications devices: Experimental techniques.
- [3] Calibration report on SAR probe IXP-050 S/N 0071 from National Physical Laboratory. Test Report EF07/2002/03/IndexSAR. Dated 20 February 2002.



**Figure 2.** Spherical isotropy jig showing probe, dipole and box filled with simulated brain liquid (see Ref [2], Section A.5.2.1)



**Figure 3.** Schematic diagram of the test geometry used for isotropy determination

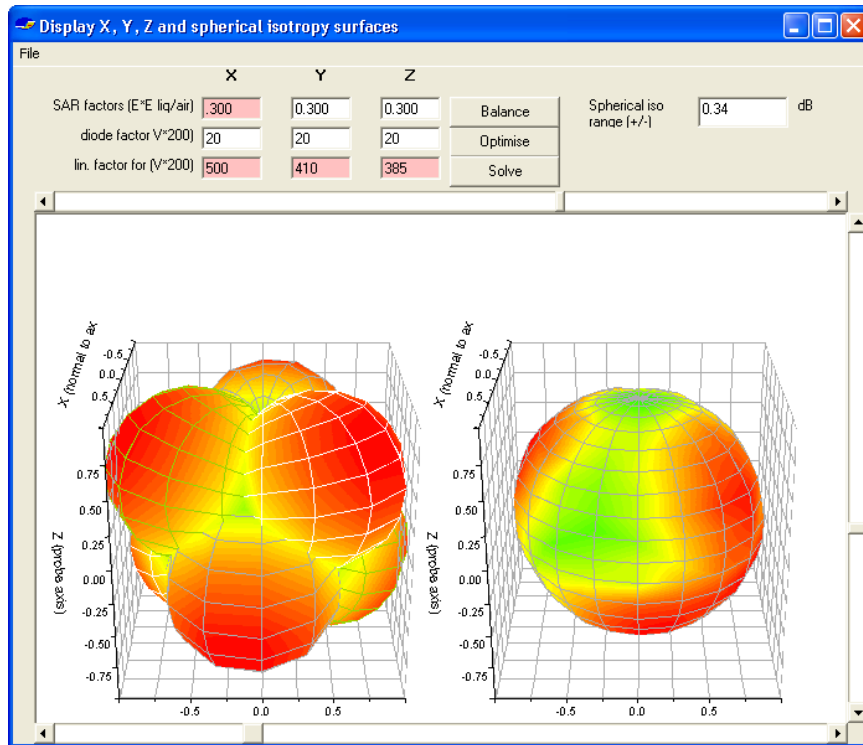




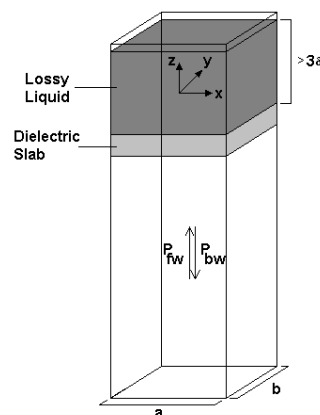
## 2.6 SAR MEASUREMENT SYSTEM

### PROBE CALIBRATION PROCEDURE - Continued

#### REFERENCES



**Figure 4.** Graphical representation of the probe response to fields applied from each direction. The diagram on the left shows the individual response characteristics of each of the three channels and the diagram on the right shows the resulting probe sensitivity in each direction. The colour range in the figure images the lowest values as blue and the maximum values as red. For the probe S/N 0084, this range is (+/-) 0.34 dB. The probe is more sensitive to fields parallel to the axis and less sensitive to fields normal to the probe axis.



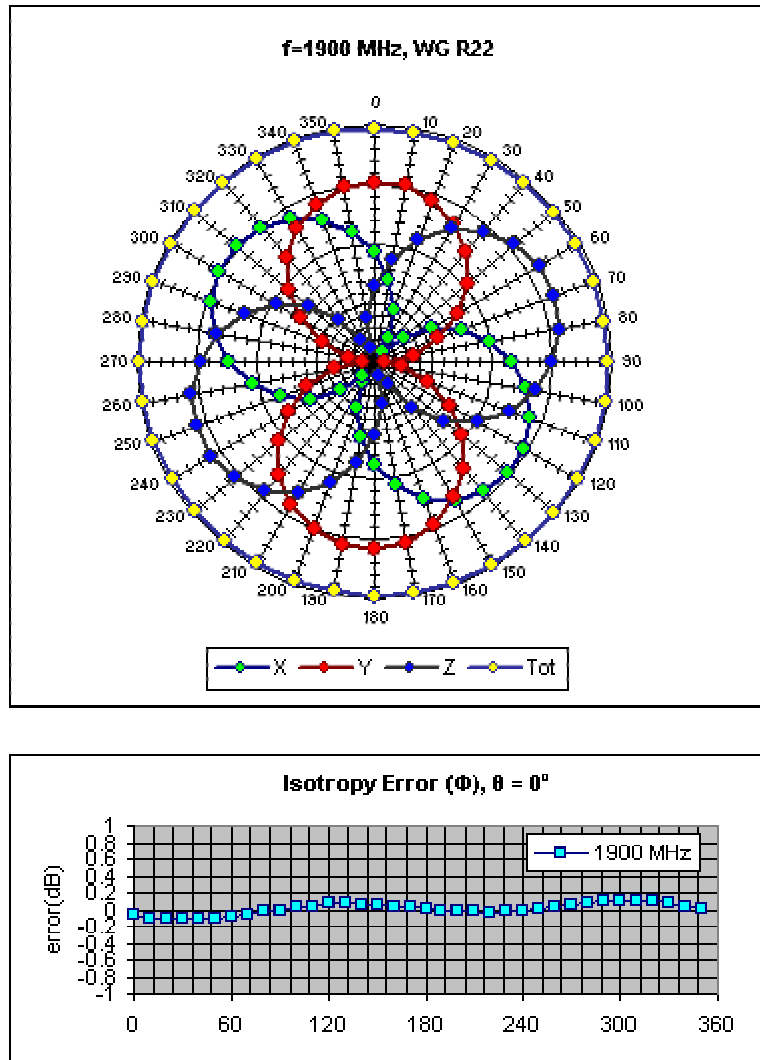
**Figure 5.** Geometry used for waveguide calibration (after Ref [2]. Section A.3.2.2)



## 2.6 SAR MEASUREMENT SYSTEM

### PROBE CALIBRATION PROCEDURE - Continued

#### REFERENCES



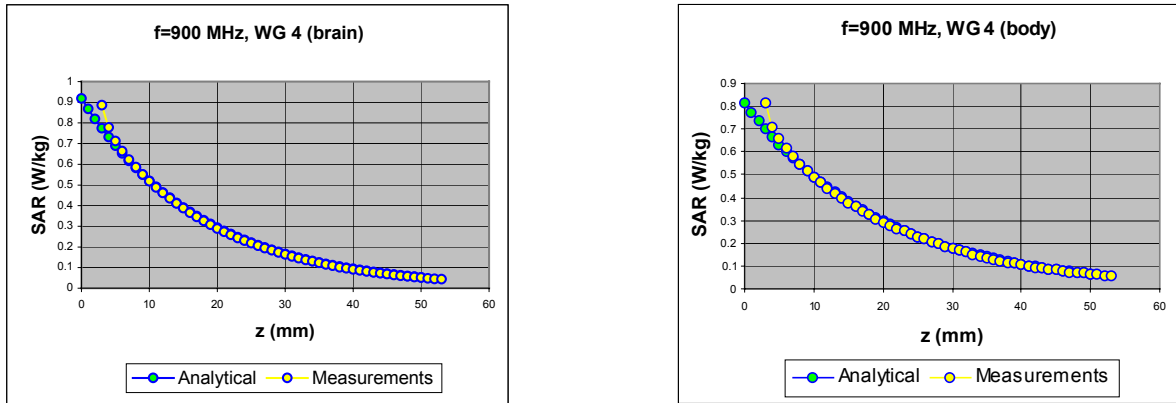
**Figure 6.** Example of the rotational isotropy of probe S/N 0084 obtained by rotating the probe in a liquid-filled waveguide at 1800 MHz. Similar distributions are obtained at the other test frequencies (900, 1900 and 2450 MHz) both in brain liquids and body fluids (see summary table)



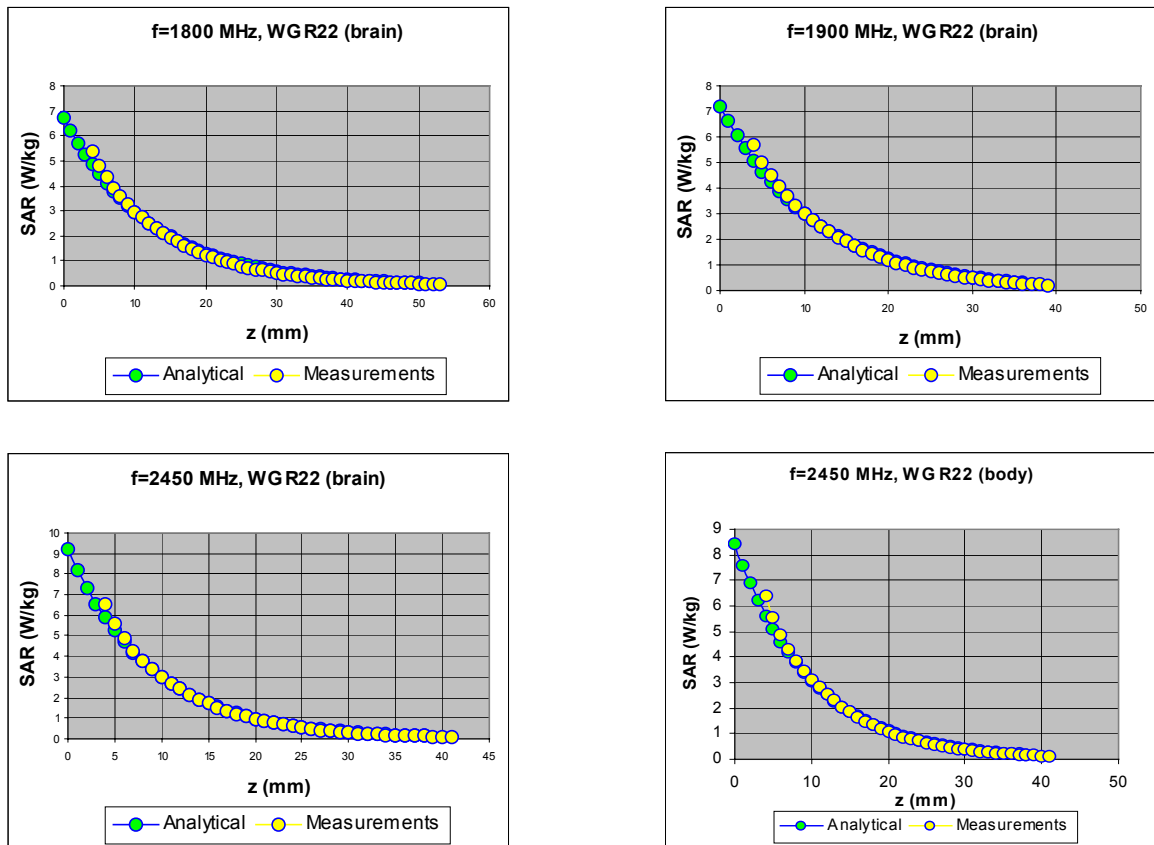
## 2.6 SAR MEASUREMENT SYSTEM

### PROBE CALIBRATION PROCEDURE - Continued

#### REFERENCES



**Figure 7.** The measured SAR decay function along the centreline of the WG4 waveguide with conversion factors adjusted to fit to the theoretical function for the particular dimension, frequency, power and liquid properties employed.

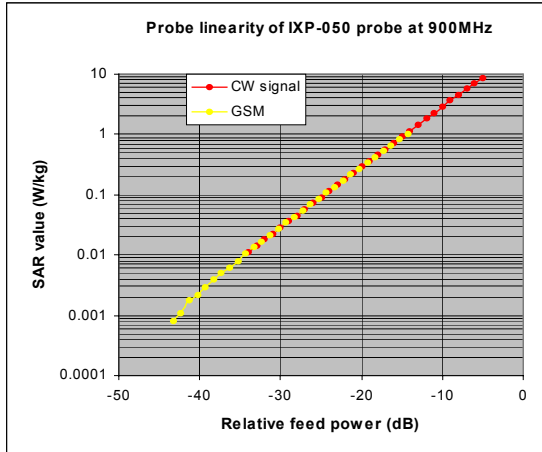


**Figure 8.** The measured SAR decay function along the centreline of the R22 waveguide with conversion factors adjusted to fit to the theoretical function for the particular dimension, frequency, power and liquid properties employed.

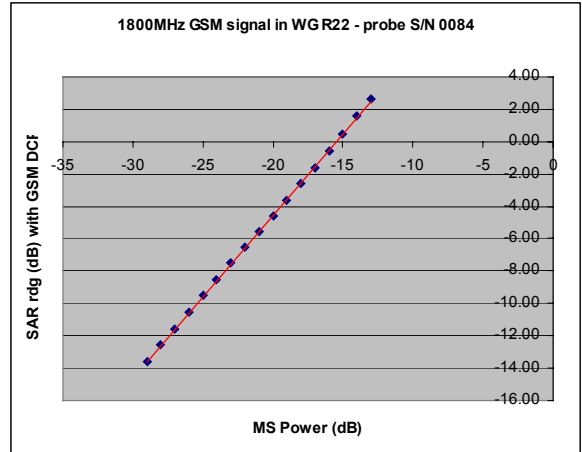


2.6 SAR MEASUREMENT SYSTEM

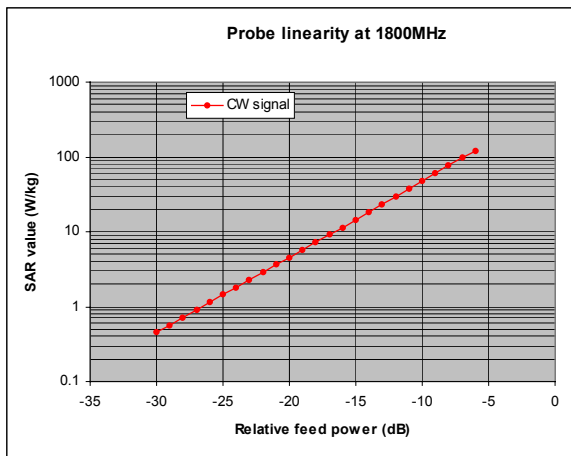
PROBE CALIBRATION PROCEDURE - Continued



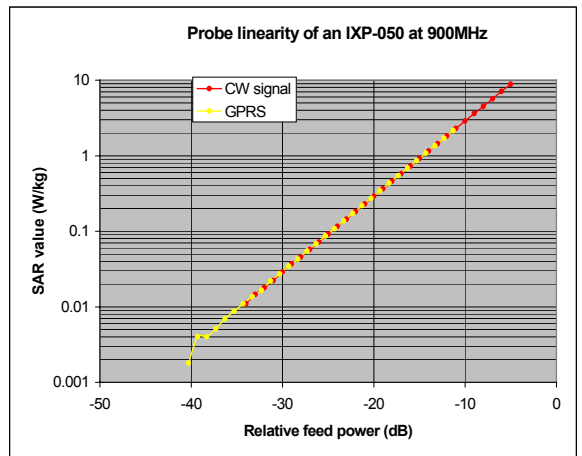
**Figure 9.** The GSM response of an IXP-050 probe at 900MHz



**Figure 9a.** The actual GSM response of IXP-050 probe S/N 0084 at 1800MHz.



**Figure 9b.** The actual CW response of IXP-050 probe SN0084 up to 100W/kg

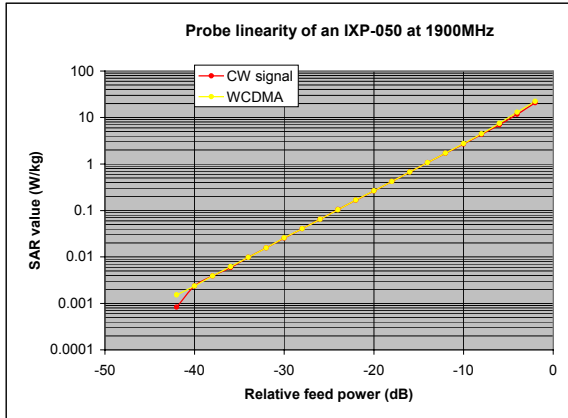


**Figure 10.** The GPRS response of an IXP-050 probe at 900MHz.

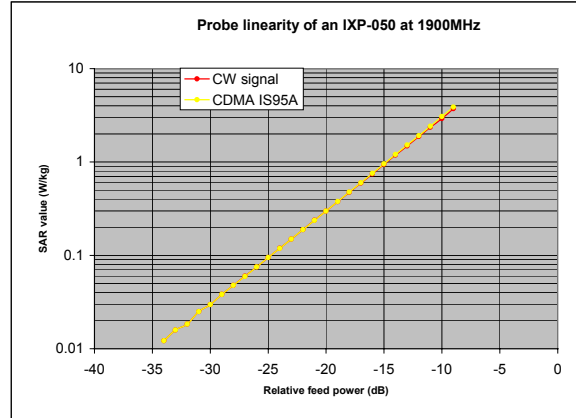


## 2.6 SAR MEASUREMENT SYSTEM

### PROBE CALIBRATION PROCEDURE - Continued



**Figure 11.** The WCDMA response of an IXP-050 probe at 1900MHz.



**Figure 12.** The CDMA IS95A response of an IXP-050 probe at 1900MHz.

### TABLE INDICATING THE DIELECTRIC PARAMETERS OF THE LIQUIDS USED FOR CALIBRATIONS AT EACH FREQUENCY

| Liquid used    | Relative permittivity (measured) | Conductivity (S/m) (measured) |
|----------------|----------------------------------|-------------------------------|
| 900 MHz BRAIN  | 41.8                             | 1.00                          |
| 900 MHz BODY   | 57.5                             | 1.031                         |
| 1800 MHz BRAIN | 38.64                            | 1.38                          |
| 1800 MHz BODY  | 54.3                             | 1.587                         |
| 1900 MHz BRAIN | 38.12                            | 1.47                          |
| 1900 MHz BODY  | 52.97                            | 1.46                          |
| 2450 MHz BRAIN | 38.67                            | 1.881                         |
| 2450 MHz BODY  | 52.19                            | 1.949                         |



## 2.6 SAR MEASUREMENT SYSTEM

### SAR MEASUREMENT PROCEDURE



*Figure 13: Principal components of the SAR measurement test bench*

The major components of the test bench are shown in the picture above. A test set and dipole antenna control the handset via an air link and a low-mass phone holder can position the phone at either ear. Graduated scales are provided to set the phone in the 15 degree position. The upright phantom head holds approx. 7 litres of simulant liquid. The phantom is filled and emptied through a 45mm diameter penetration hole in the top of the head.

After an area scan has been done at a fixed distance of 8mm from the surface of the phantom on the source side, a 3D scan is set up around the location of the maximum spot SAR. First, a point within the scan area is visited by the probe and a SAR reading taken at the start of testing. At the end of testing, the probe is returned to the same point and a second reading is taken. Comparison between these start and end readings enables the power drift during measurement to be assessed.

#### **SARA2 Interpolation and Extrapolation schemes**

SARA2 software contains support for both 2D cubic B-spline interpolation as well as 3D cubic B-spline interpolation. In addition, for extrapolation purposes, a general  $n^{\text{th}}$  order polynomial fitting routine is implemented following a singular value decomposition algorithm presented in [4]. A 4<sup>th</sup> order polynomial fit is used by default for data extrapolation, but a linear-logarithmic fitting function can be selected as an option. The polynomial fitting procedures have been tested by comparing the fitting coefficients generated by the SARA2 procedures with those obtained using the polynomial fit functions of Microsoft Excel when applied to the same test input data.

#### **Interpolation of 2D area scan**

The 2D cubic B-spline interpolation is used after the initial area scan at fixed distance from the phantom shell wall. The initial scan data are collected with approx. 10mm spatial resolution and spline interpolation is used to find the location of the local maximum to within a 1mm resolution for positioning the subsequent 3D scanning.



## 2.6 SAR MEASUREMENT SYSTEM

### SAR MEASUREMENT PROCEDURE - Continued

#### Extrapolation of 3D scan

For the 3D scan, data are collected on a spatially regular 3D grid having (by default) 6.4 mm steps in the lateral dimensions and 3.5 mm steps in the depth direction (away from the source). SARA2 enables full control over the selection of alternative step sizes in all directions.

The digitised shape of the head is available to the SARA2 software, which decides which points in the 3D array are sufficiently well within the shell wall to be 'visited' by the SAR probe. After the data collection, the data are extrapolated in the depth direction to assign values to points in the 3D array closer to the shell wall. A notional extrapolation value is also assigned to the first point outside the shell wall so that subsequent interpolation schemes will be applicable right up to the shell wall boundary.

#### Interpolation of 3D scan and volume averaging

The procedure used for defining the shape of the volumes used for SAR averaging in the SARA2 software follow the method of adapting the surface of the 'cube' to conform with the curved inner surface of the phantom (see Appendix C.2.2.1 in EN 50361). This is called, here, the conformal scheme.

For each row of data in the depth direction, the data are extrapolated and interpolated to less than 1mm spacing and average values are calculated from the phantom surface for the row of data over distances corresponding to the requisite depth for 10g and 1g cubes. This results in two 2D arrays of data, which are then cubic B-spline interpolated to sub mm lateral resolution. A search routine then moves an averaging square around through the 2D array and records the maximum value of the corresponding 1g and 10g volume averages. For the definition of the surface in this procedure, the digitised position of the headshell surface is used for measurement in head-shaped phantoms. For measurements in rectangular, box phantoms, the distance between the phantom wall and the closest set of gridded data points is entered into the software.

For measurements in box-shaped phantoms, this distance is under the control of the user. The effective distance must be greater than 2.5mm as this is the tip-sensor distance and to avoid interface proximity effects, it should be at least 5mm. A value of 6 or 8mm is recommended. This distance is called **dbe** in EN 50361.

For automated measurements inside the head, the distance cannot be less than 2.5mm, which is the radius of the probe tip and to avoid interface proximity effects, a minimum clearance distance of  $x$  mm is retained. The actual value of **dbe** will vary from point to point depending upon how the spatially-regular 3D grid points fit within the shell. The greatest separation is when a grid point is just not visited due to the probe tip dimensions. In this case the distance could be as large as the step-size plus the minimum clearance distance (i.e with  $x=5$  and a step size of 3.5, **dbe** will be between 3.5 and 8.5mm).

The default step size (**dstep** in EN 50361) used is 3.5mm, but this is under user-control. The compromise is with time of scan, so it is not practical to make it much smaller or scan times become long and power-drop influences become larger.

The robot positioning system specification for the repeatability of the positioning (**dss** in EN50361) is +/- 0.04mm.



## 2.6 SAR MEASUREMENT SYSTEM

### SAR MEASUREMENT PROCEDURE - Continued

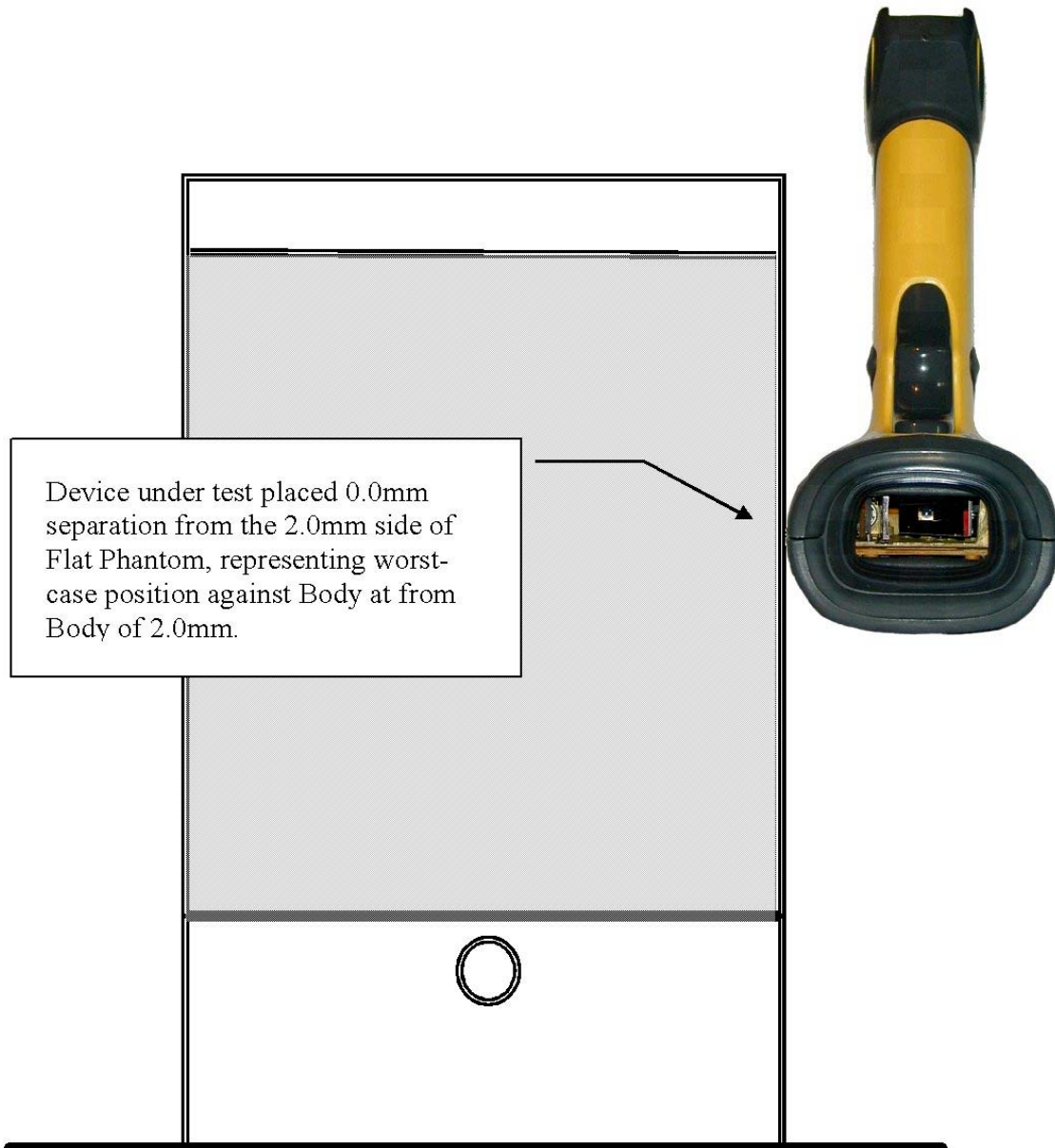
The phantom shell is made by an industrial moulding process from the CAD files of the SAM shape, with both internal and external moulds. For the upright phantoms, the external shape is subsequently digitised on a Mitutoyo CMM machine (Euro C574) to a precision of 0.001mm. Wall thickness measurements made non-destructively with an ultrasonic sensor indicate that the shell thickness (**dph**) away from the ear is 2.0 +/- 0.1mm. The ultrasonic measurements were calibrated using additional mechanical measurements on available cut surfaces of the phantom shells.

For the upright phantom, the alignment is based upon registration of the rotation axis of the phantom on its 253mm-diameter baseplate bearing and the position of the probe axis when commanded to go to the axial position. A laser alignment tool is provided (procedure detailed elsewhere). This enables the registration of the phantom tip (**dmis**) to be assured to within approx. 0.2mm. This alignment is done with reference to the actual probe tip after installation and probe alignment. The rotational positioning of the phantom is variable – offering advantages for special studies, but locating pins ensure accurate repositioning at the principal positions (LH and RH ears).



## 2.7 TEST POSITIONS

### OET65(c) FLAT PHANTOM TEST POSITIONS – GRAPHICAL REPRESENTATION

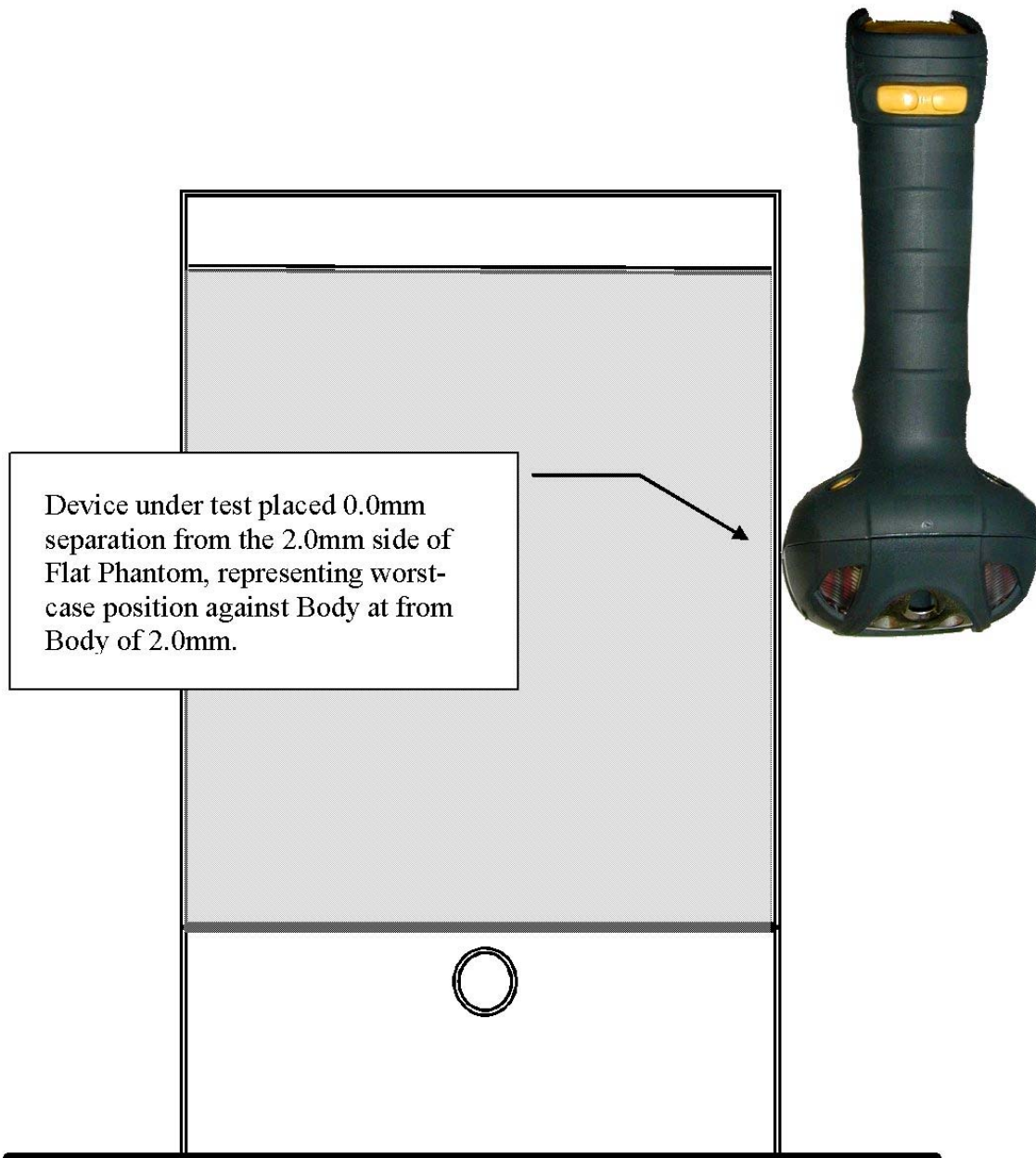


**Figure 14.** – LS3478 Test position for body assessment with the LHS of the device positioned 0.0 cm from phantom side.



## 2.7 TEST POSITIONS

### OET65(c) FLAT PHANTOM TEST POSITIONS – GRAPHICAL REPRESENTATION



**Figure 15.** – LS3478 Test position for body assessment with the RHS of the device parallel 0.0 cm from phantom side.



## 2.7 TEST POSITIONS

### OET65(c) FLAT PHANTOM TEST POSITIONS – GRAPHICAL REPRESENTATION

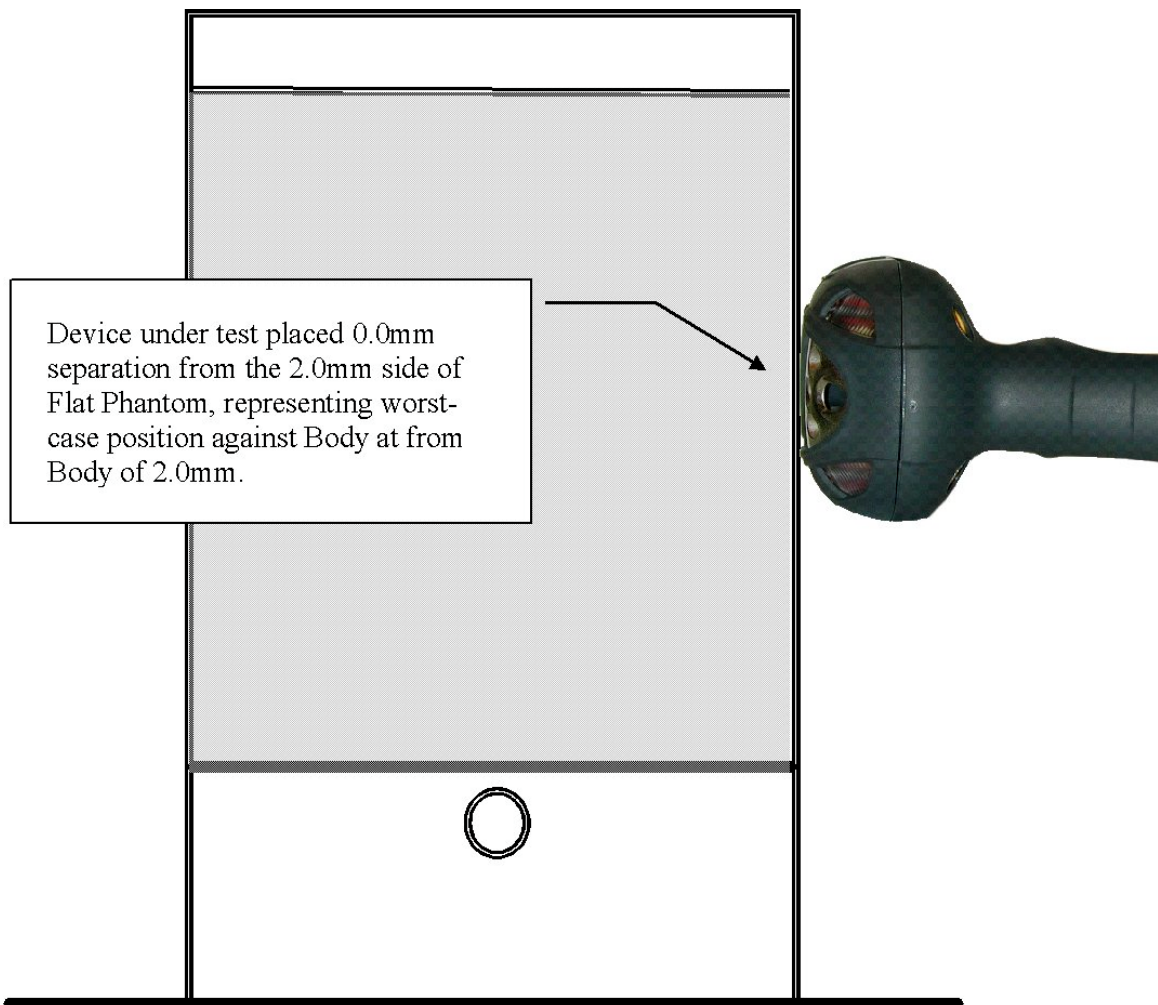


**Figure 16.** – LS3478 Test position for body assessment with the front of the device 0.0 cm from phantom side



## 2.7 TEST POSITIONS

### OET65(c) FLAT PHANTOM TEST POSITIONS – GRAPHICAL REPRESENTATION



**Figure 17.** – LS3478 Test position for body assessment with the Top of the device 0.0 cm from phantom side.



**2.8 TEST RESULTS INCLUDING SAR DISTRIBUTIONS (AREA SCANS – 2D)**

|                                    |                       |                             |             |
|------------------------------------|-----------------------|-----------------------------|-------------|
| SYSTEM / SOFTWARE:                 | SARA2 / 2.3 VPM       | INPUT POWER DRIFT:          | 0.0dB       |
| DATE / TIME:                       | 10/09/2004 10:46:55   | DUT BATTERY MODEL/NO:       | 21-62606-01 |
| FILENAME:                          | 612336_001a.txt       | PROBE SERIAL NUMBER:        | 0084        |
| AMBIENT TEMPERATURE:               | 23.9°C                | LIQUID SIMULANT:            | 2450 Body   |
| DEVICE UNDER TEST:                 | Symbol LS3478         | RELATIVE PERMITTIVITY:      | 50.33       |
| RELATIVE HUMIDITY:                 | 49.6%                 | CONDUCTIVITY:               | 2.036       |
| PHANTOM S/NO:                      | HeadBox01.csv         | LIQUID TEMPERATURE:         | 22.2°C      |
| PHANTOM ROTATION:                  | 0°                    | MAX SAR Y-AXIS LOCATION:    | 0.00 mm     |
| DUT POSITION:                      | RHS facing            | MAX SAR Z-AXIS LOCATION:    | -147.50 mm  |
| ANTENNA CONFIGURATION:             | Fixed internal        | MAX E FIELD:                | 3.50 V/m    |
| TEST FREQUENCY:                    | 2442MHz               | SAR 1g:                     | N/A         |
| AIR FACTORS:                       | 500 / 410 / 385       | SAR 10g:                    | N/A         |
| CONVERSION FACTORS:                | 0.354 / 0.354 / 0.354 | SAR START:                  | N/A         |
| TYPE OF MODULATION:                | CW                    | SAR END:                    | N/A         |
| MODN. DUTY CYCLE:                  | 100%                  | SAR DRIFT DURING SCAN:      | N/A         |
| DIODE COMPRESSION FACTORS (V*200): | 20 / 20 / 20          | PROBE BATTERY LAST CHANGED: | 06/09/04    |
| INPUT POWER LEVEL:                 | 100mw (Nominal)       | EXTRAPOLATION:              | poly4       |

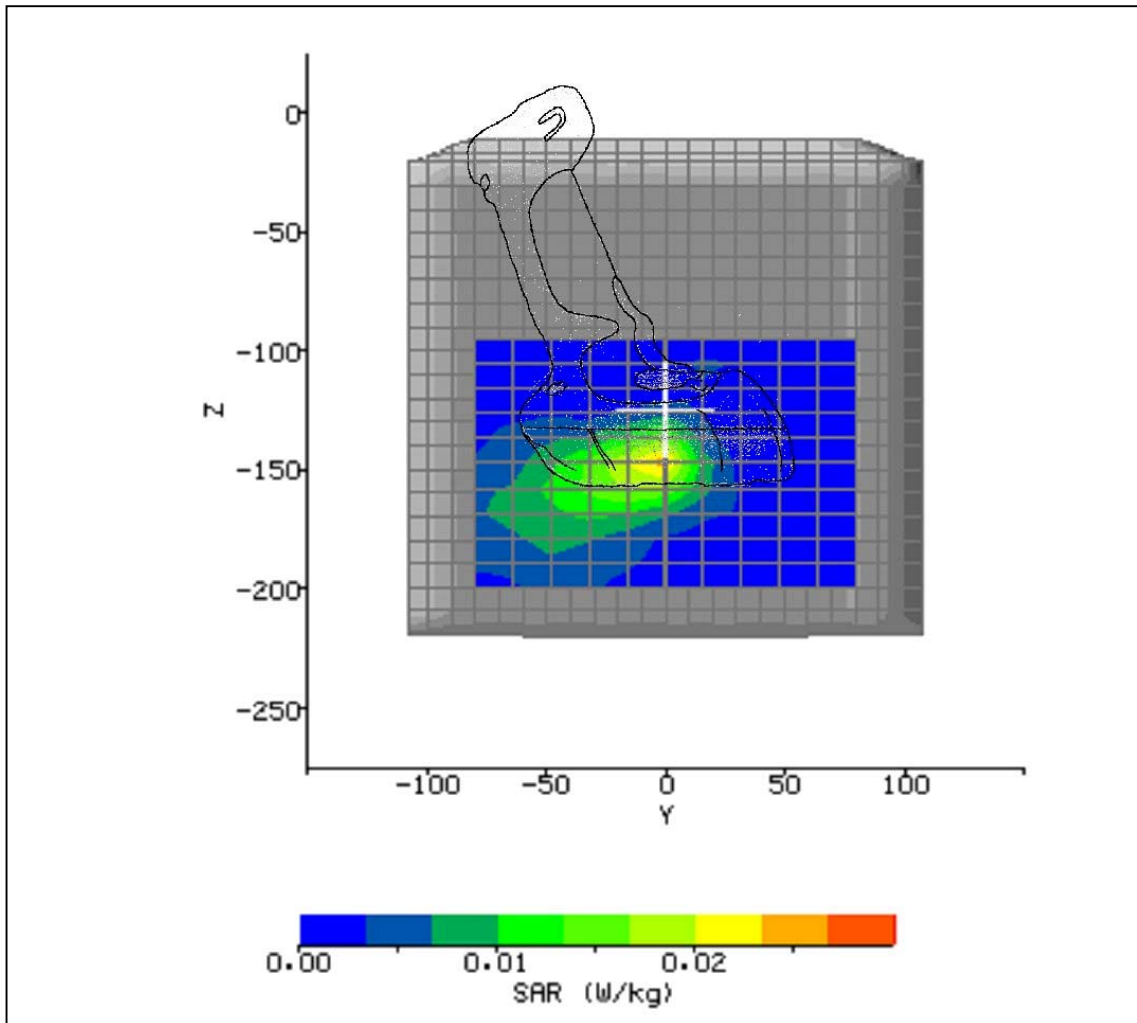


Figure 18



**2.8 TEST RESULTS INCLUDING SAR DISTRIBUTIONS (AREA SCANS – 2D)**

|                                    |                       |                             |             |
|------------------------------------|-----------------------|-----------------------------|-------------|
| SYSTEM / SOFTWARE:                 | SARA2 / 2.3 VPM       | INPUT POWER DRIFT:          | 0.0dB       |
| DATE / TIME:                       | 10/09/2004 11:08:19   | DUT BATTERY MODEL/NO:       | 21-62606-01 |
| FILENAME:                          | 612336_002a.txt       | PROBE SERIAL NUMBER:        | 0084        |
| AMBIENT TEMPERATURE:               | 24.6°C                | LIQUID SIMULANT:            | 2450 Body   |
| DEVICE UNDER TEST:                 | Symbol LS3478         | RELATIVE PERMITTIVITY:      | 50.33       |
| RELATIVE HUMIDITY:                 | 53.9%                 | CONDUCTIVITY:               | 2.036       |
| PHANTOM S/NO:                      | HeadBox01.csv         | LIQUID TEMPERATURE:         | 22.3°C      |
| PHANTOM ROTATION:                  | 0°                    | MAX SAR Y-AXIS LOCATION:    | 16.00 mm    |
| DUT POSITION:                      | LHS facing            | MAX SAR Z-AXIS LOCATION:    | -158.00 mm  |
| ANTENNA CONFIGURATION:             | Fixed internal        | MAX E FIELD:                | 3.23 V/m    |
| TEST FREQUENCY:                    | 2442MHz               | SAR 1g:                     | N/A         |
| AIR FACTORS:                       | 500 / 410 / 385       | SAR 10g:                    | N/A         |
| CONVERSION FACTORS:                | 0.354 / 0.354 / 0.354 | SAR START:                  | N/A         |
| TYPE OF MODULATION:                | CW                    | SAR END:                    | N/A         |
| MODN. DUTY CYCLE:                  | 100%                  | SAR DRIFT DURING SCAN:      | N/A         |
| DIODE COMPRESSION FACTORS (V*200): | 20 / 20 / 20          | PROBE BATTERY LAST CHANGED: | 06/09/04    |
| INPUT POWER LEVEL:                 | 100mw (Nominal)       | EXTRAPOLATION:              | poly4       |

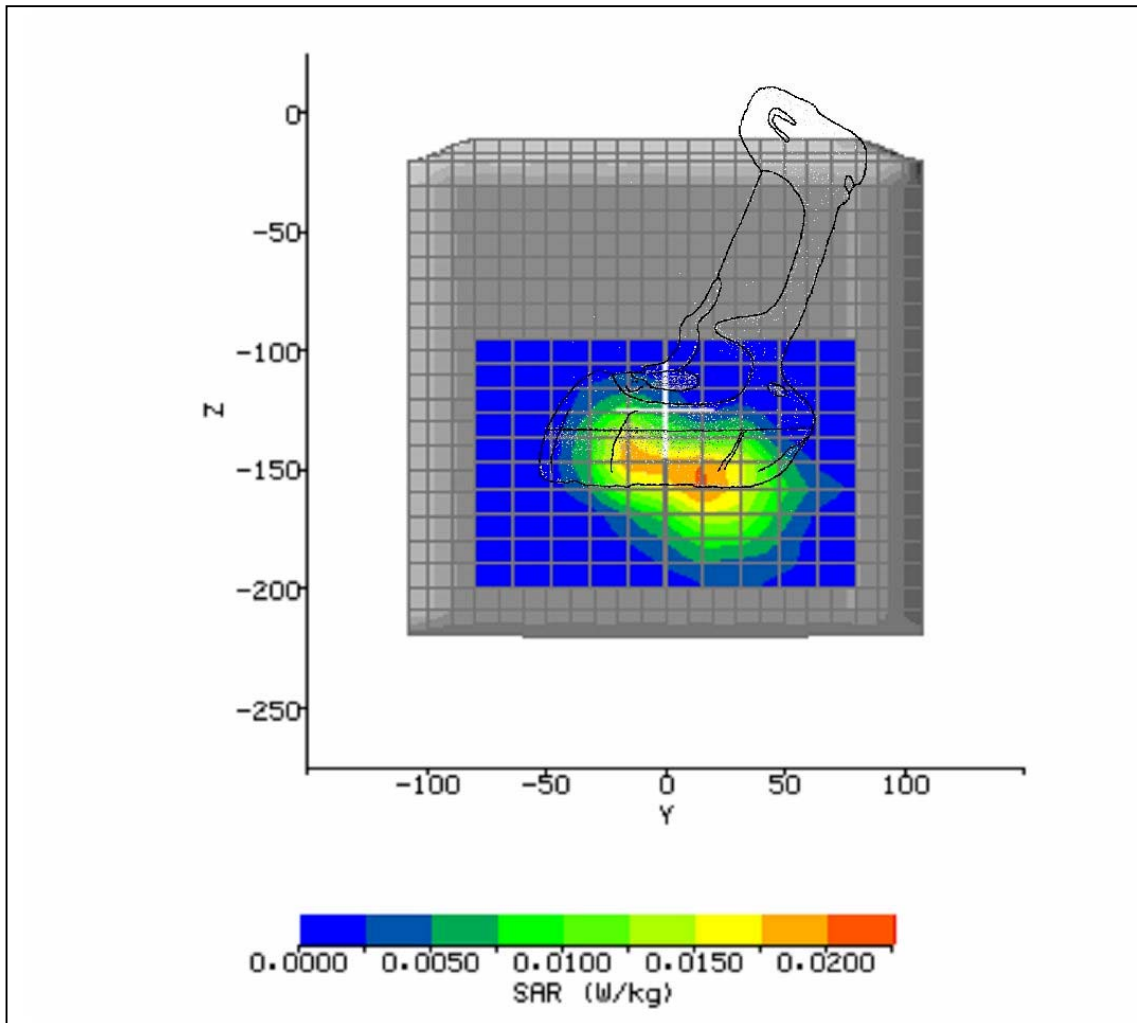


Figure 19



**2.8 TEST RESULTS INCLUDING SAR DISTRIBUTIONS (AREA SCANS – 2D)**

|                                    |                       |                             |             |
|------------------------------------|-----------------------|-----------------------------|-------------|
| SYSTEM / SOFTWARE:                 | SARA2 / 2.3 VPM       | INPUT POWER DRIFT:          | 0.0dB       |
| DATE / TIME:                       | 10/09/2004 11:24:21   | DUT BATTERY MODEL/NO:       | 21-62606-01 |
| FILENAME:                          | 612336_003a.txt       | PROBE SERIAL NUMBER:        | 0084        |
| AMBIENT TEMPERATURE:               | 24.6°C                | LIQUID SIMULANT:            | 2450 Body   |
| DEVICE UNDER TEST:                 | Symbol LS3478         | RELATIVE PERMITTIVITY:      | 50.33       |
| RELATIVE HUMIDITY:                 | 42.2%                 | CONDUCTIVITY:               | 2.036       |
| PHANTOM S/NO:                      | HeadBox01.csv         | LIQUID TEMPERATURE:         | 22.2°C      |
| PHANTOM ROTATION:                  | 0°                    | MAX SAR Y-AXIS LOCATION:    | -16.00 mm   |
| DUT POSITION:                      | Front facing          | MAX SAR Z-AXIS LOCATION:    | -158.00 mm  |
| ANTENNA CONFIGURATION:             | Fixed internal        | MAX E FIELD:                | 3.06 V/m    |
| TEST FREQUENCY:                    | 2442MHz               | SAR 1g:                     | N/A W/kg    |
| AIR FACTORS:                       | 500 / 410 / 385       | SAR 10g:                    | N/A W/kg    |
| CONVERSION FACTORS:                | 0.354 / 0.354 / 0.354 | SAR START:                  | W/kg        |
| TYPE OF MODULATION:                | CW                    | SAR END:                    | W/kg        |
| MODN. DUTY CYCLE:                  | 100%                  | SAR DRIFT DURING SCAN:      | dB          |
| DIODE COMPRESSION FACTORS (V*200): | 20 / 20 / 20          | PROBE BATTERY LAST CHANGED: | 06/09/04    |
| INPUT POWER LEVEL:                 | 100mw (Nominal)       | EXTRAPOLATION:              | poly4       |

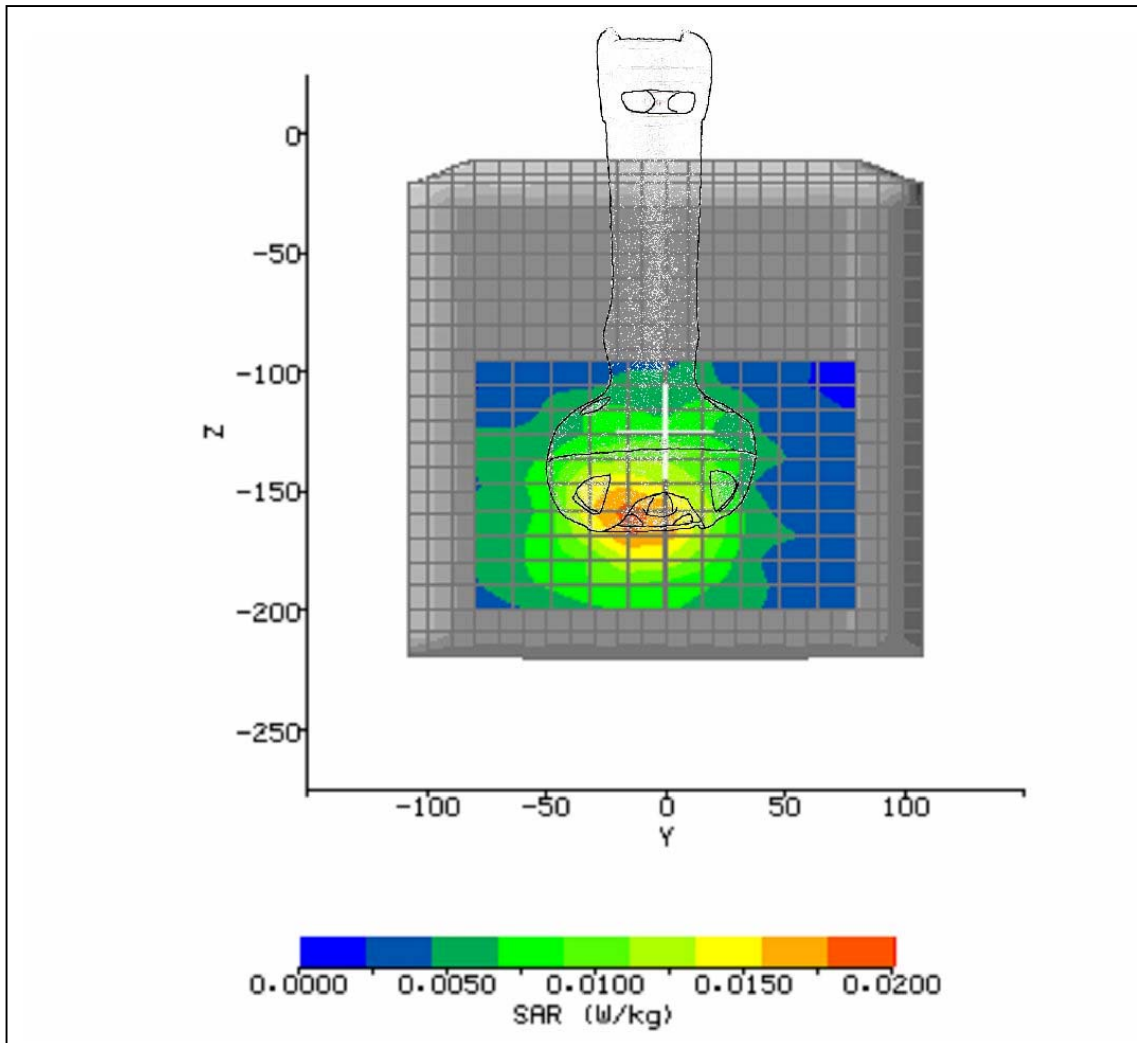


Figure 20



2.8 TEST RESULTS INCLUDING SAR DISTRIBUTIONS (AREA SCANS – 2D)

|                                    |                       |                             |             |
|------------------------------------|-----------------------|-----------------------------|-------------|
| SYSTEM / SOFTWARE:                 | SARA2 / 2.3 VPM       | INPUT POWER DRIFT:          | 0.0dB       |
| DATE / TIME:                       | 10/09/2004 12:49:19   | DUT BATTERY MODEL/NO:       | 21-62606-01 |
| FILENAME:                          | 612336_004.txt        | PROBE SERIAL NUMBER:        | 0084        |
| AMBIENT TEMPERATURE:               | 24.6°C                | LIQUID SIMULANT:            | 2450 Body   |
| DEVICE UNDER TEST:                 | Symbol LS3478         | RELATIVE PERMITTIVITY:      | 50.33       |
| RELATIVE HUMIDITY:                 | 54.2%                 | CONDUCTIVITY:               | 2.036       |
| PHANTOM S/NO:                      | HeadBox01.csv         | LIQUID TEMPERATURE:         | 22.2°C      |
| PHANTOM ROTATION:                  | 0°                    | MAX SAR Y-AXIS LOCATION:    | 12.80 mm    |
| DUT POSITION:                      | Top facing            | MAX SAR Z-AXIS LOCATION:    | -137.00 mm  |
| ANTENNA CONFIGURATION:             | Fixed internal        | MAX E FIELD:                | 11.67 V/m   |
| TEST FREQUENCY:                    | 2442MHz               | SAR 1g:                     | 0.195 W/kg  |
| AIR FACTORS:                       | 500 / 410 / 385       | SAR 10g:                    | 0.081 W/kg  |
| CONVERSION FACTORS:                | 0.468 / 0.468 / 0.468 | SAR START:                  | 0.040 W/kg  |
| TYPE OF MODULATION:                | CW                    | SAR END:                    | 0.040 W/kg  |
| MODN. DUTY CYCLE:                  | 100%                  | SAR DRIFT DURING SCAN:      | -0.04 dB    |
| DIODE COMPRESSION FACTORS (V*200): | 20 / 20 / 20          | PROBE BATTERY LAST CHANGED: | 06/09/04    |
| INPUT POWER LEVEL:                 | 100mw (Nominal)       | EXTRAPOLATION:              | poly4       |

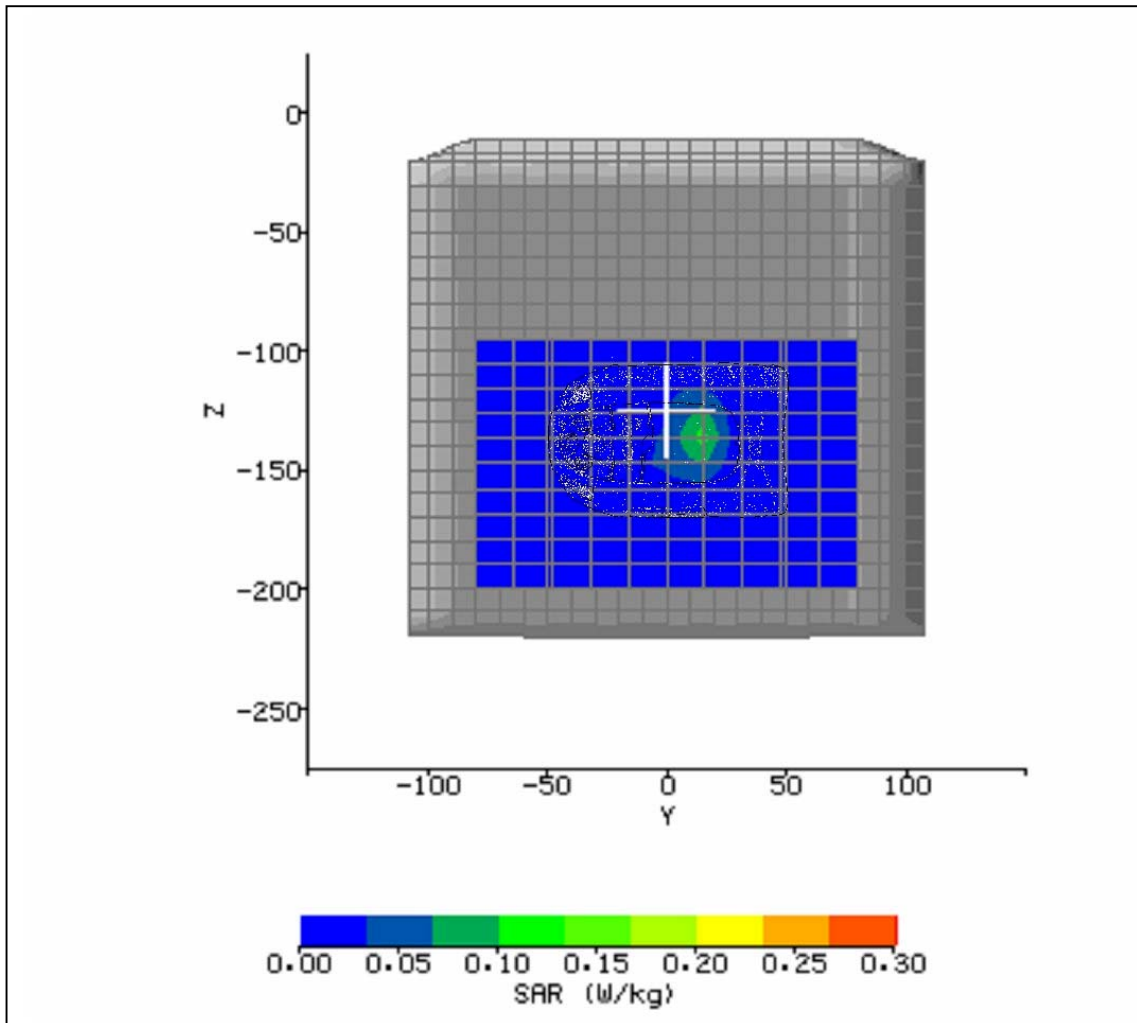


Figure 21





**2.8 TEST RESULTS INCLUDING SAR DISTRIBUTIONS (AREA SCANS – 2D)**

|                                    |                       |                             |             |
|------------------------------------|-----------------------|-----------------------------|-------------|
| SYSTEM / SOFTWARE:                 | SARA2 / 2.3 VPM       | INPUT POWER DRIFT:          | 0.0 dB      |
| DATE / TIME:                       | 10/09/2004 13:41:54   | DUT BATTERY MODEL/NO:       | 21-62606-01 |
| FILENAME:                          | 612336_005.txt        | PROBE SERIAL NUMBER:        | 0084        |
| AMBIENT TEMPERATURE:               | 24.2°C                | LIQUID SIMULANT:            | 2450 Body   |
| DEVICE UNDER TEST:                 | Symbol LS3478         | RELATIVE PERMITTIVITY:      | 50.33       |
| RELATIVE HUMIDITY:                 | 39.4%                 | CONDUCTIVITY:               | 2.036       |
| PHANTOM S/NO:                      | HeadBox01.csv         | LIQUID TEMPERATURE:         | 22.1°C      |
| PHANTOM ROTATION:                  | 0°                    | MAX SAR Y-AXIS LOCATION:    | 11.20 mm    |
| DUT POSITION:                      | Top facing            | MAX SAR Z-AXIS LOCATION:    | -137.00 mm  |
| ANTENNA CONFIGURATION:             | Fixed internal        | MAX E FIELD:                | 13.25 V/m   |
| TEST FREQUENCY:                    | 2402MHz               | SAR 1g:                     | 0.253 W/kg  |
| AIR FACTORS:                       | 500 / 410 / 385       | SAR 10g:                    | 0.107 W/kg  |
| CONVERSION FACTORS:                | 0.468 / 0.468 / 0.468 | SAR START:                  | 0.054 W/kg  |
| TYPE OF MODULATION:                | CW                    | SAR END:                    | 0.053 W/kg  |
| MODN. DUTY CYCLE:                  | 100%                  | SAR DRIFT DURING SCAN:      | -0.05 dB    |
| DIODE COMPRESSION FACTORS (V*200): | 20 / 20 / 20          | PROBE BATTERY LAST CHANGED: | 06/09/04    |
| INPUT POWER LEVEL:                 | 100mw (Nominal)       | EXTRAPOLATION:              | poly4       |

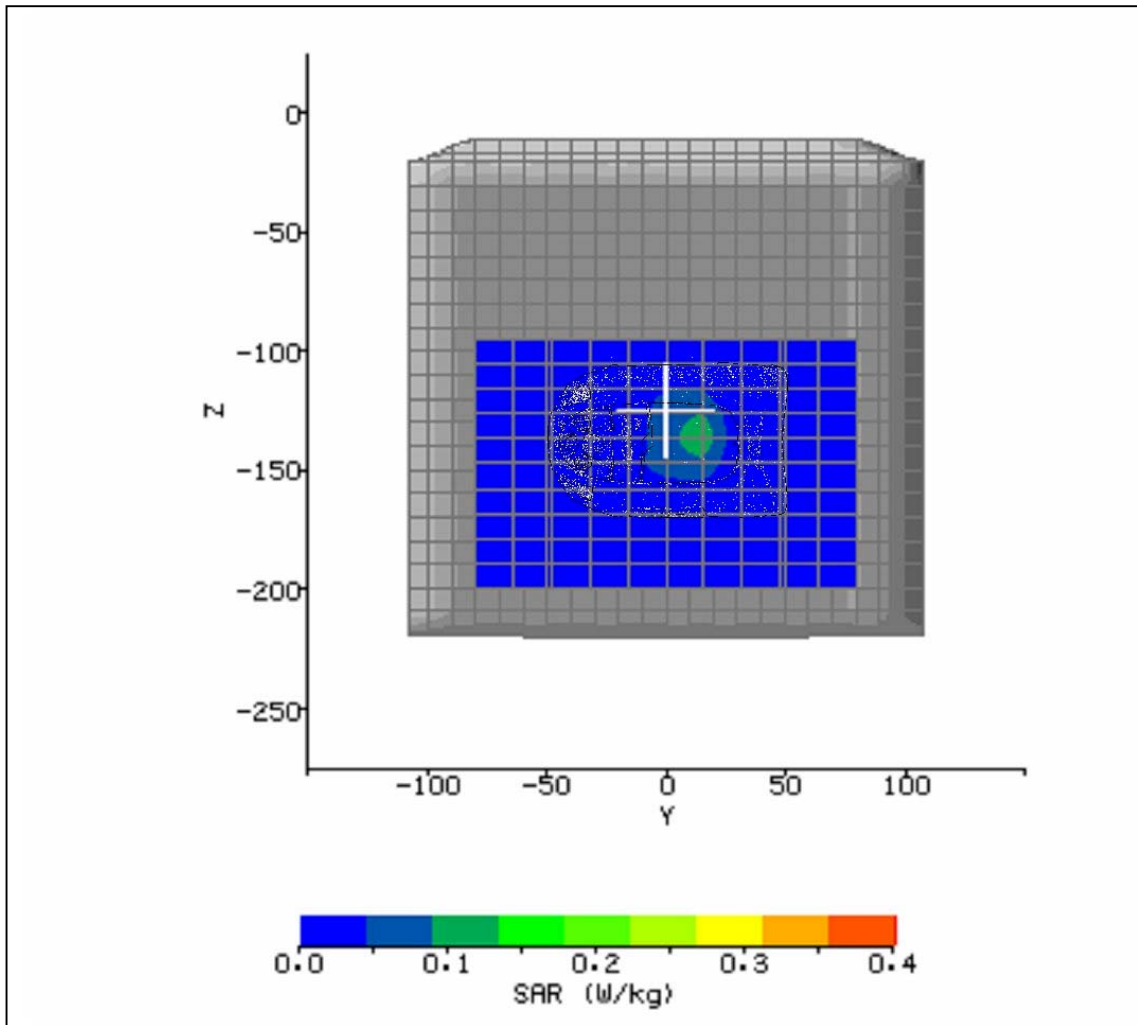


Figure 22



**2.8 TEST RESULTS INCLUDING SAR DISTRIBUTIONS (AREA SCANS – 2D)**

|                                    |                       |                             |             |
|------------------------------------|-----------------------|-----------------------------|-------------|
| SYSTEM / SOFTWARE:                 | SARA2 / 2.3 VPM       | INPUT POWER DRIFT:          | 0.0 dB      |
| DATE / TIME:                       | 10/09/2004 14:54:36   | DUT BATTERY MODEL/NO:       | 21-62606-01 |
| FILENAME:                          | 612336_006.txt        | PROBE SERIAL NUMBER:        | 0084        |
| AMBIENT TEMPERATURE:               | 24.2°C                | LIQUID SIMULANT:            | 2450 Body   |
| DEVICE UNDER TEST:                 | Symbol LS3478         | RELATIVE PERMITTIVITY:      | 50.33       |
| RELATIVE HUMIDITY:                 | 57.0%                 | CONDUCTIVITY:               | 2.036       |
| PHANTOM S/NO:                      | HeadBox01.csv         | LIQUID TEMPERATURE:         | 22.1°C      |
| PHANTOM ROTATION:                  | 0°                    | MAX SAR Y-AXIS LOCATION:    | 14.40 mm    |
| DUT POSITION:                      | Top facing            | MAX SAR Z-AXIS LOCATION:    | -135.95 mm  |
| ANTENNA CONFIGURATION:             | Fixed internal        | MAX E FIELD:                | 11.34 V/m   |
| TEST FREQUENCY:                    | 2480MHz               | SAR 1g:                     | 0.179 W/kg  |
| AIR FACTORS:                       | 500 / 410 / 385       | SAR 10g:                    | 0.073 W/kg  |
| CONVERSION FACTORS:                | 0.468 / 0.468 / 0.468 | SAR START:                  | 0.035 W/kg  |
| TYPE OF MODULATION:                | CW                    | SAR END:                    | 0.033 W/kg  |
| MODN. DUTY CYCLE:                  | 100%                  | SAR DRIFT DURING SCAN:      | -0.24 dB    |
| DIODE COMPRESSION FACTORS (V*200): | 20 / 20 / 20          | PROBE BATTERY LAST CHANGED: | 06/09/04    |
| INPUT POWER LEVEL:                 | 100mw (Nominal)       | EXTRAPOLATION:              | poly4       |

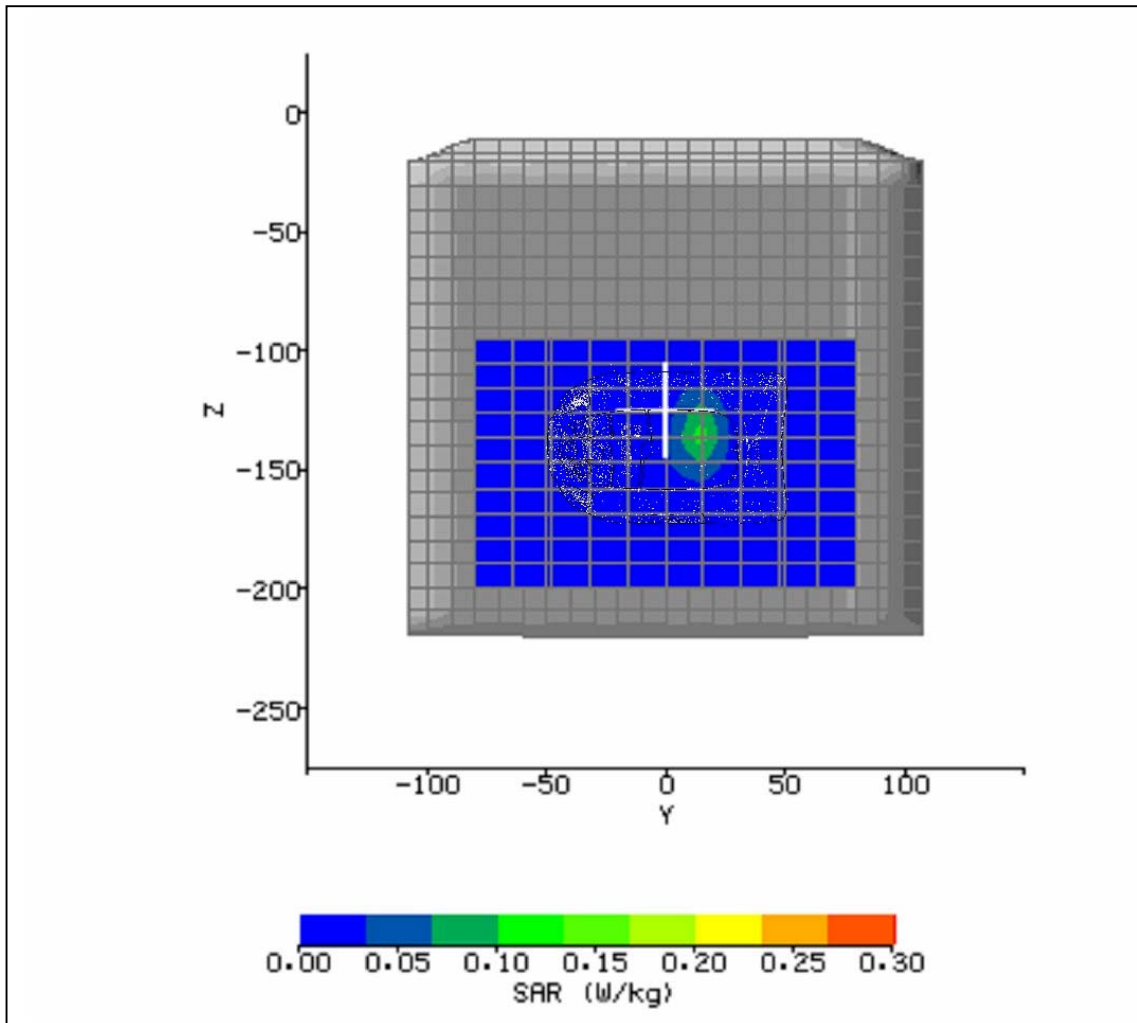


Figure 23

2.9 TEST POSITIONAL PHOTOGRAPHS

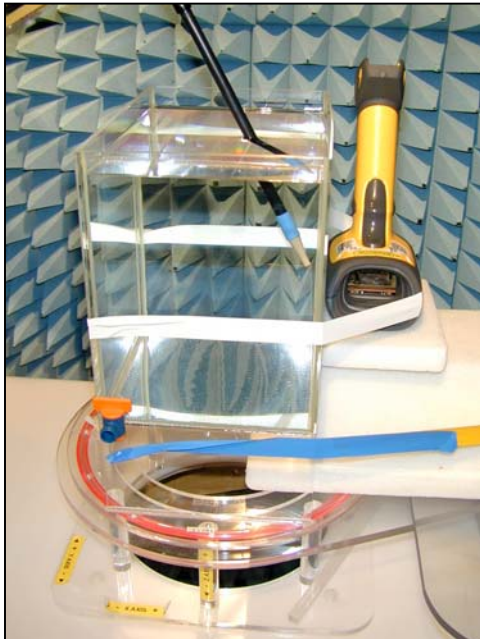


Figure 24. Positional photograph of the LS3478  
LHS facing to Phantom side



Figure 25. Positional photograph of the LS3478  
RHS facing to Phantom side



Figure 26. Positional photograph of the LS3478  
Front facing to Phantom side



Figure 27. Positional photograph of the LS3478  
Top facing to Phantom side



2.10 RECORD PHOTOGRAPHS



Figure 28. Side view



2.10 RECORD PHOTOGRAPHS



Figure 29. Front view

2.10 RECORD PHOTOGRAPHS



Figure 30. Battery removed.

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IC: 1549D-2164381



2.11 COPYRIGHT STATEMENT

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