# Tissue Recipes

The following recipes are provided in percentage by weight.

**1900MHz Head:**
54.9% distilled water
44.92% DGBE
0.18% salt
0.1% bactericide

**1900MHz Body:**
69.17% distilled water
30.29% DGBE
0.44% salt
0.1% bactericide

**Tiusue Parameters measured**

8/7/02 22.1°C
1900MHz Head

| Freq. (MHz) | Amplitude (dB) | Phase (deg) | Rel. Perm. | Condy (S/m) |
|---|---|---|---|---|
| 1850.2 | -35 | 124.25 | 40.1 | 1.389 |
| 1880 | -35.65 | 111 | 39.93 | 1.419 |
| 1909.8 | -36.25 | 98.7 | 39.7 | 1.445 |

8/7/02 22.1°C
1900MHz Body

| Freq. (MHz) | Amplitude (dB) | Phase (deg) | Rel. Perm. | Condy (S/m) |
|---|---|---|---|---|
| 1850.2 | -35.25 | -42.4 | 53.01 | 1.556 |
| 1880 | -35.6 | -57.6 | 52.77 | 1.573 |
| 1909.8 | -35.92 | -75.6 | 52.77 | 1.591 |

8/23/02 21.4°C
1900MHz Head

| Freq. (MHz) | Amplitude (dB) | Phase (deg) | Rel. Perm. | Condy (S/m) |
|---|---|---|---|---|
| 1850.2 | -35.98 | 120.9 | 40.28 | 1.44 |
| 1880 | -36.2 | 109.8 | 39.98 | 1.447 |
| 1900 | -36.4 | 99.5 | 39.98 | 1.456 |
| 1909.8 | -36.5 | 93.9 | 40.02 | 1.462 |

8/23/02 21.4°C
1900MHz Body

| Freq. (MHz) | Amplitude (dB) | Phase (deg) | Rel. Perm. | Condy (S/m) |
|---|---|---|---|---|
| 1850.2 | -35.26 | -46.25 | 53.33 | 1.56 |
| 1880 | -35.51 | -62.6 | 53.19 | 1.573 |
| 1909.8 | -35.67 | -78.4 | 53.01 | 1.579 |

8/29/02 & 8/30/02 22.1°C
(note: 8/29/02 measurements done at 2:30PM, 8/30/02 measurements done by 11:00AM)
1900MHz Head

| Freq. (MHz) | Amplitude (dB) | Phase (deg) | Rel. Perm. | Condy (S/m) |
|---|---|---|---|---|
| 1850.2 | -36 | 138.8 | 38.99 | 1.424 |
| 1880 | -36.3 | 126 | 38.83 | 1.436 |
| 1900 | -36.63 | 115.6 | 38.84 | 1.452 |
| 1909.8 | -36.85 | 110.45 | 38.85 | 1.463 |

8/29/02 & 8/30/02 22.1°C
1900MHz Body

| Freq. (MHz) | Amplitude (dB) | Phase (deg) | Rel. Perm. | Condy (S/m) |
|---|---|---|---|---|
| 1850.2 | -35.31 | -46.15 | 53.32 | 1.563 |
| 1880 | -35.57 | -62.5 | 53.18 | 1.576 |
| 1909.8 | -35.7 | -78 | 52.98 | 1.581 |

**Environment**

Temperature: 22.2
Humidity: 45% _ 5 %

## Test Equipment

| Instrument description | Supplier/Manufacturer | Model | Serial No. | Calibration (date) |
|---|---|---|---|---|
| Bench top Robot | Mitsubishi supplied by Indexsar | RV-E2 | Serial No. | N/A |
| SAM Phantom | Upright shell phantom made by Antennessa digitized and mounted by Indexsar | SAM | 04/02 FT08 | N/A |
| 2450MHz Head Tissue Simulant | Cetecom Inc. | 2450 Head | S/N: 6 | 07/24/2002 |
| 2450MHz Body Tissue Simulant | Cetecom Inc. | 2450 Body | S/N: 7 | 07/24/2002 |
| 2450MHz Dipole | IndexSAR – IEEE 1528 design | IXD-245 | 10 | 07/02/2002 |
| Netwok Analyzer | Agilent | 8753ES | US39172511- | 04/04/2002- |
| RF Amplifier | Vectawave | N/A | N/A | N/A |
| Power Meter | Rohde and Schwartz | NRVD | 836875/020 | 5/2002 |
| Power Sensor | Rohde and Schwartz | URV5-Z2 | 836029/034 | 5/2002- |
| Power Sensor | Rohde and Schwartz | URV5-Z2 | 836029/035 | 5/2002- |
| SAR Probe | IndexSAR | IXP-050 | S/N 0106 | 7/10/2002 |
| Probe amplifier | Indexsar | IXA-010 | S/N 043 | N/A- |
| Thermometer | Control Company | 4039 | 20410549 | Due 11/20/2002 |

**IMMERSIBLE SAR PROBE**

**CALIBRATION REPORT**

**Part Number: IXP – 050**

# S/N 0106

**10th July 2002**


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## INTRODUCTION

This Report presents measured calibration data for a particular Indexsar SAR probe (S/N 0106) and describes the procedures used for characterisation and calibration.

Indexsar probes are characterised using procedures that, where applicable, follow the recommendations of CENELEC [1] and IEEE [2] standards. The procedures incorporate techniques for probe linearisation, isotropy assessment and determination of liquid factors (conversion factors). Calibrations are determined by comparing probe readings with analytical computations in canonical test geometries (waveguides, boxes and spheres) using normalised power inputs.

Each step of the calibration procedure and the equipment used is described in the sections below.

## CALIBRATION PROCEDURE

### 1. Equipment Used

For the first part of the calibration procedure, the probe is placed in a calibration jig as pictured in Figure 1. 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 2.

A balanced dipole (900 or 1800 MHz) is inserted horizontally into the bracket attached to a second belt (Figure 1). The dipole also can 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, the spherical isotropy of the probe can be 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. When it is necessary to place the probe in liquid, a rectangular box made from PMMA (200mm internal width, 200mm internal height and 100mm internal depth; wall thickness 4mm) is filled with the appropriate liquid and positioned on the stand so that the probe tip is positioned within the liquid (Figure 1). The box is positioned so that its outer surface is 2mm from the dipole. The procedure follows that described in Ref [2]. Section A.5.2.1.

### 2. 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:

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

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 the DCP values are typically 0.10V (or 20 in the voltage units used by Indexsar software, which are V*200).

3. Optimizing channel sensitivity factors in air

The first step of the calibration process is to calibrate the Indexsar probe to a W&G EMR300 E-field meter in air. The principal reasons for this are to balance the channels in air and to obtain air factors that are used in subsequent steps of the calibration procedure. It should be noted that the air factors are not separately used for normal SAR testing.

The probe and a 900 MHz standard dipole are positioned in the calibration jig as outlined in the section above. With the Indexsar probe located in air, individual channel output voltages are recorded as probe and dipole are rotated. An ‘air factor’ is applied to each of the probe’s three channels in order to equilibrate the peak magnitudes of each channel. 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):

$$E_{air}^{2}\ (V/m) = U_{linx} * \text{Air Factor}_x + U_{liny} * \text{Air Factor}_y + U_{linz} * \text{Air Factor}_z \qquad (2)$$

It should be noted that the IXP-050 probes are optimised for use in tissue simulating liquids and do not behave isotropically in air.

4. 900 MHz Liquid Calibration

The second phase of calibration requires the channel output voltages of the Indexsar probe to be measured in a box filled with 900 MHz simulated brain liquid, balanced to optimise the probe isotropy. Later, the conversion factors are determined either using a waveguide or by comparison to a reference probe that has been calibrated by NPL.

The box of liquid is placed on the stand as described above and as pictured in Figure 1. Channel outputs for the different orientations of probe and dipole are recorded and entered into a spreadsheet. These measurements are multiplied by the previously determined air factors. Another factor, referred to as the 'liquid factor' is also applied to the measurements of each channel. The magnitude of the liquid factor for each channel is selected so as to optimise the isotropy of the probe (i.e. balance the peak magnitudes of the three channels) in the liquid. The following equation is used (where output voltages are in units of V*200):

$$E_{liq}^2\ (V/m) = U_{linx} * \text{Air Factor}_x * \text{Liq Factor}_x + U_{liny} * \text{Air Factor}_y * \text{Liq Factor}_y + U_{linz} * \text{Air Factor}_z * \text{Liq Factor}_z \qquad (3)$$

An automated optimisation program balances the channel factors and then performs an optimisation to minimise the probe isotropy across the whole range of angles of presentation of the source field. A 3D representation of the spherical isotropy for probe S/N 0106 is shown in Figure 3.

The rotational isotropy is also determined. With the dipole at 90° to the probe axis the rotational isotropy for probe 0106 at 900 MHz is +/- 0.09 dB. Note that waveguide measurements were used to determine rotational isotropy at higher frequencies (Fig. 5).

The NPL reference probe is then measured in exactly the same way in the same set-up. The average readings for all angles of rotation are then placed into the spreadsheet of the probe being calibrated. This adjusts the magnitude of the calibration factors until they are similar to the NPL reference probe.

The final step of the 900 MHz calibration requires the measurement of SAR decay in a generic, spherical phantom and fitting the measured data to one of the two following analytical predictions of the decay profile:

1. SAR decay curve modelled using a 200mm diameter sphere energised by a balanced dipole in a 'benchmark configuration' developed as part of an Eureka Project [4] or SAR decay curve modelled by Flomerics [5] using a sphere and a balanced dipole in a similar test configuration.

2. SAR decay curve in a liquid-filled upright waveguide obtained from the procedure described in Ref [2], Section A.3.2.2.

To measure SAR decay via method 1, the probe is inserted through the neck of a spherical phantom filled with simulant liquid, and the tip is positioned at the inside surface of the flask. A suitable balanced dipole is aligned with the probe tip and placed a specific distance from the outer surface of the sphere (depending on whether comparison is made with calculated results from [4] or [5]). As the probe is progressively withdrawn along the centre line of the sphere, E-field measurements are taken. A multiplier is applied to the liquid factors so as to equilibrate the resultant decay function with the modelled results (as shown for waveguides in Figure 6).

For method 2, the probe calibration is carried out using waveguide cells as shown in Figure 4. 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 positition and is filled with liquid within 10 mm of the open end. The seperator 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.

The liquid dielectric parameters used for the probe calibrations are tabulated at the end of this document. The final calibration factors for the probe are listed in the summary chart on the next page:

**GSM RESPONSE**

To measure the GSM response of the probe and amplifier, the probe is held vertically in a cube phantom 30mm from the side of the cube at which the balanced dipole is presented. The dipole is oriented vertically (parallel to the probe axis) for tests at 900MHz.

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 GSM. 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 1 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 GSM setting. The results are entered into a spreadsheet. Using the spreadsheets, the GSM power is calculated by taking 9dB from the measured CW power.

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

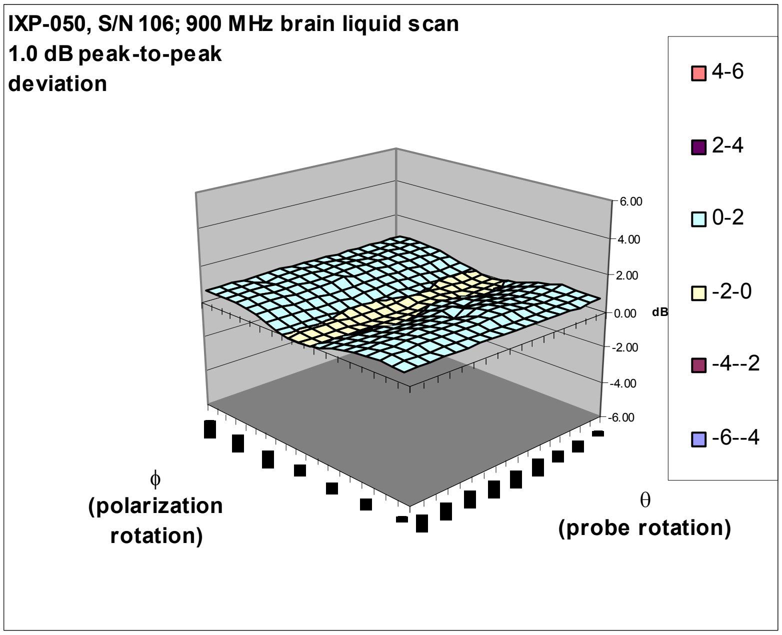
$$SAR\ (W/kg) = E_{liq}^{2}\ (V/m) * \sigma(S/m) / 1000 \qquad (4)$$

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

Using this procedure, the results obtained for the GSM response are shown in Figure 6. Additional tests have shown that the GSM response is similar at 1800MHz and is not affected by the orientation between the source and the probe.

The example shown in Figure 7 indicates that the particular plus amplifier combination probe tested correctly reflect the power level of pulsed GSM signals without the need for any specific scheme of correction. For other probes a correction is needed to the linearisation factor for each channel of the probe. Where appropriate, this is indicated in the summary page of calibration factors for each probe.

## SUMMARY OF CALIBRATION FACTORS FOR PROBE IXP-050 S/N 0106




*(simple, spreadsheet representation of surface shown in 3D in Figure 3 below)*

| Spherical isotropy (+/- dB) | 0.50 |
|---|---|

| X factor | Y factor | Z factor | |
|---|---|---|---|
| 145 | 214 | 131 | Combined |
| 405 | 405 | 405 | Air |
| 0.359 | 0.528 | 0.324 | Air/liq |
| 20 | 20 | 20 | DCP |

| | | | |
|---|---|---|---|
| 8 | 8 | 8 | DCPs for GSM |
| 20 | 20 | 20 | DCPs for CDMA/CW |

| f (MHz) | Axial isotropy (+/- dB) BRAIN | Axial isotropy (+/- dB) BODY | Conversion factors BRAIN factor | X | Y | Z | Conversion factors BODY factor | X | Y | Z | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 835 | 0.16 | *0.16* | 0.95 | 0.341 | 0.502 | 0.308 | *1.14* | *0.409* | *0.602* | *0.369* | 1) |
| 900 | 0.09 | *0.09* | 1.00 | 0.359 | 0.528 | 0.324 | *1.2* | *0.431* | *0.634* | *0.389* | 2), 4) |
| 1800 | 0.20 | 0.25 | 1.50 | 0.538 | 0.792 | 0.486 | 1.80 | 0.646 | 0.950 | 0.583 | 3), 4) |
| 1900 | 0.22 | 0.25 | 1.60 | 0.574 | 0.845 | 0.518 | 1.80 | 0.646 | 0.950 | 0.583 | 3) |
| 2450 | 0.24 | 0.16 | 1.95 | 0.700 | 1.030 | 0.632 | 2.50 | 0.897 | 1.320 | 0.810 | 3), 4) |

*extrapolated values in italic*

Notes

1) From validation measurement with 835MHz dipole and fluid
2) Probe calibration factors from substitution against NPL-calibrated probe
   (Probe IXP-050 S/N 0071 ; NPL Cal Report No: EF07/2002/03/IndexSAR)
3) From waveguide
   determination
4) Checked using validation geometry with dipole and box phantom

**PROBE SPECIFICATIONS**

Indexsar probe 0106, 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:

| **Dimensions** | S/N 0106 | CENELEC [1] | IEEE [2] |
|---|---|---|---|
| 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 | | |

| **Dynamic range** | S/N 0106 | CENELEC [1] | IEEE [2] |
|---|---|---|---|
| Minimum (W/kg) | 0.01 | <0.02 | 0.01 |
| Maximum (W/kg)<br>N.B. only measured to 35 W/kg | >35 | >100 | 100 |

| **Linearity of response** | S/N 0106 | CENELEC [1] | IEEE [2] |
|---|---|---|---|
| Over range 0.01 – 100 W/kg (+/- dB) | 0.125 | 0.50 | 0.25 |

| **Isotropy (measured at 900MHz)** | S/N 016 | CENELEC [1] | IEEE [2] |
|---|---|---|---|
| Axial rotation with probe normal to source (+/- dB) at 835, 900, 1800, 1900 and 2450 MHz | Max. 0.25 (see summary table) | 0.5 | 0.25 |
| Spherical isotropy covering all orientations to source (+/- dB) | 0.50 | 1.0 | 0.50 |

| | |
|---|---|
| **Construction** | 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. |
| **Chemical resistance** | Tested to be resistant to glycol and alcohol containing simulant liquids but probes should be removed, cleaned and dried when not in use. |

**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.

[4] Stevens, N. *et al*., Comparison of the numerical and experimental evaluation of the SAR employing a spherical benchmark configuration. *To be published*.

[5] Maggs, J., Modelling of the E-field distribution within a lossy spherical phantom energised by balanced dipole sources. *Flomerics, unpublished*.

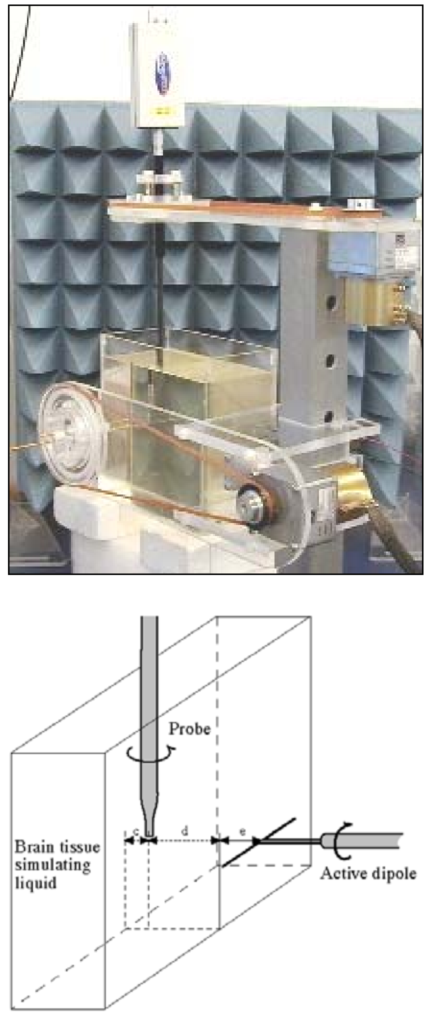



*Figure 1. Calibration jig showing probe, dipole and box filled with simulated brain liquid (see Ref [2], Section A.5.2.1)*

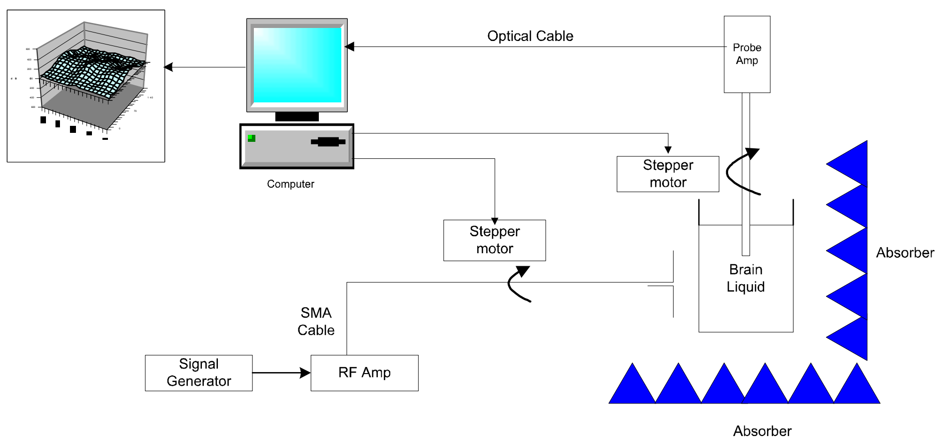



*Figure 2. Schematic diagram of the test geometry used for isotropy determination*

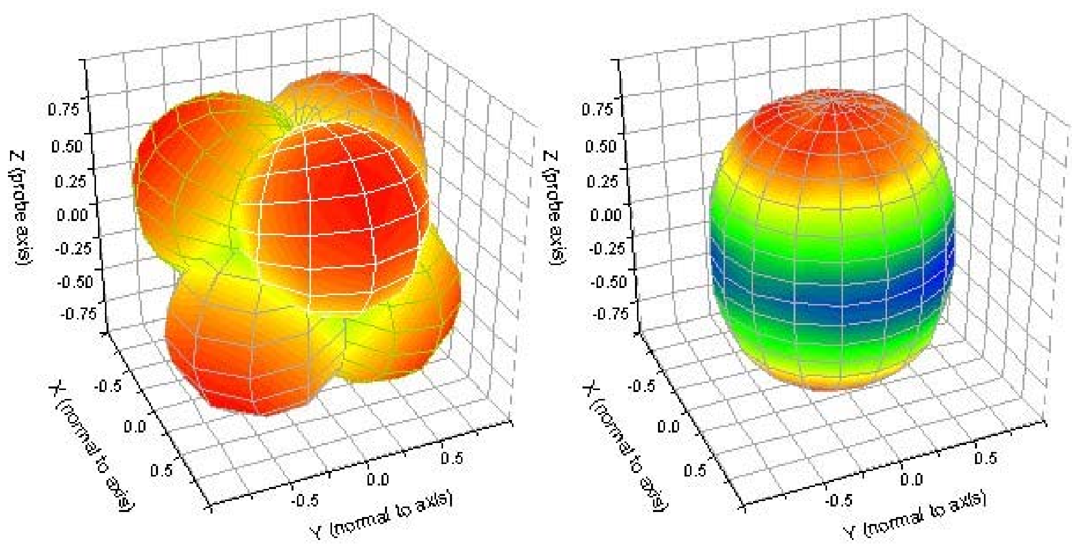



*Figure 3. Graphical representation of the probe response to fields applied from each direction. The diagram on the left shows the individual response characteristics of each of the three channels and the diagram on the right shows the resulting probe sensitivity in each direction. The colour range in the figure images the lowest values as blue and the maximum values as red. For the probe S/N 0106, this range is (+/-) 0.50 dB. The probe is more sensitive to fields parallel to the axis and less sensitive to fields normal to the probe axis.*

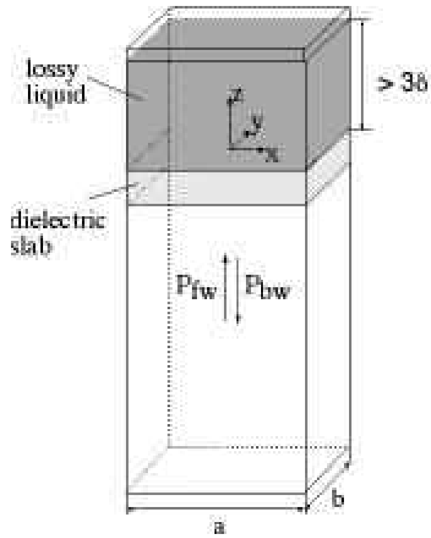
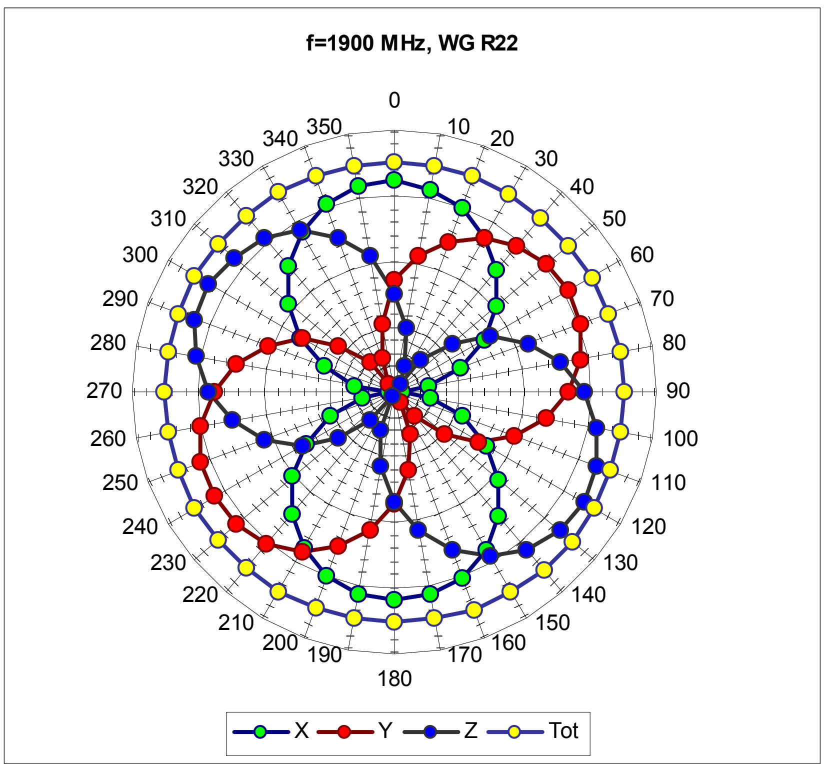



*Figure 4. Geometry used for waveguide calibration (after Ref [2]. Section A.3.2.2)*



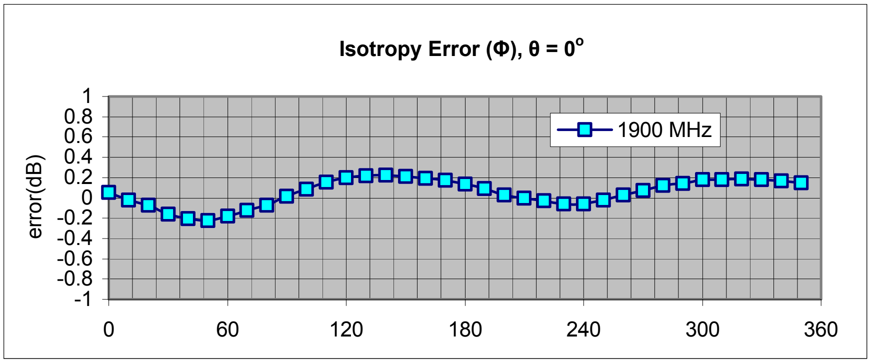
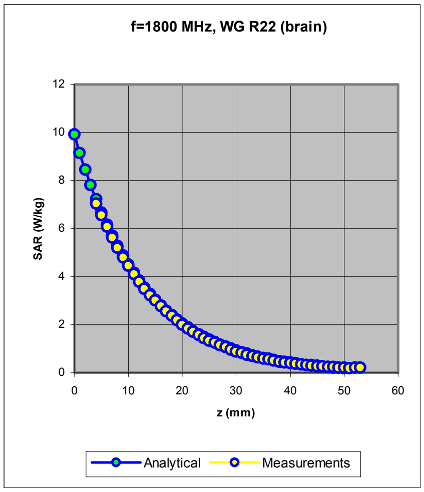
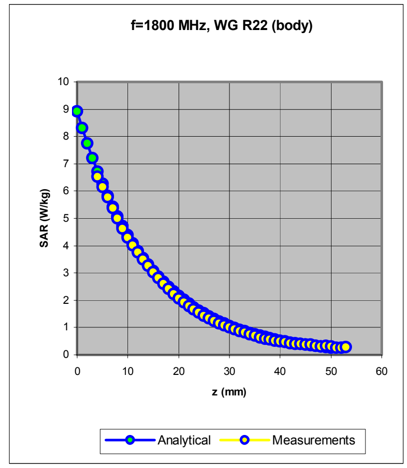
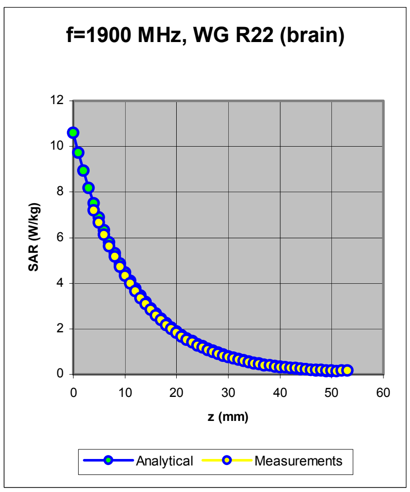
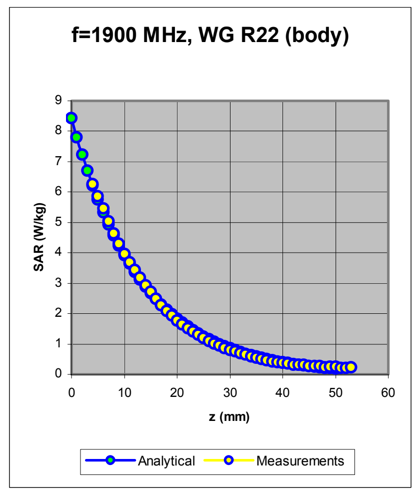


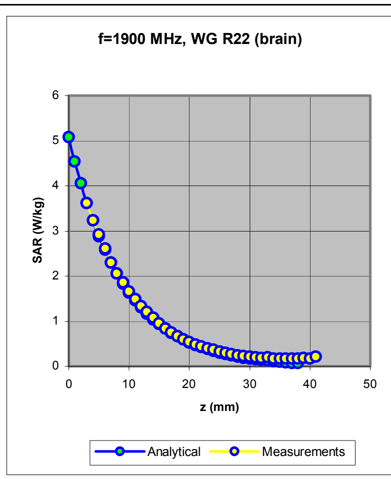

*Figure 5. Example of the rotational isotropy of probe S/N 0106 obtained by rotating the probe in a liquid-filled waveguide at 1800 MHz. Similar distributions are obtained at the other test frequencies (1800 and 2450 MHz) both in brain liquids and body fluids (see summary table)*


f=1800 MHz, WG R22 (brain)
SAR (W/kg)
z (mm)
Analytical
Measurements


f=1800 MHz, WG R22 (body)
SAR (W/kg)
z (mm)
Analytical
Measurements


f=1900 MHz, WG R22 (brain)
SAR (W/kg)
z (mm)
Analytical
Measurements


f=1900 MHz, WG R22 (body)
SAR (W/kg)
z (mm)
Analytical
Measurements


f=1900 MHz, WG R22 (brain)
SAR (W/kg)
z (mm)
Analytical
Measurements

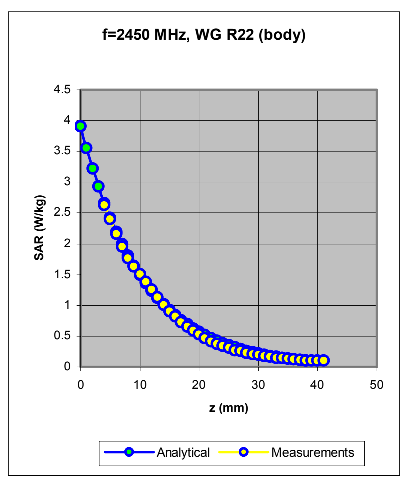

f=2450 MHz, WG R22 (body)
SAR (W/kg)
z (mm)
Analytical
Measurements

*Figure 6. 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.*

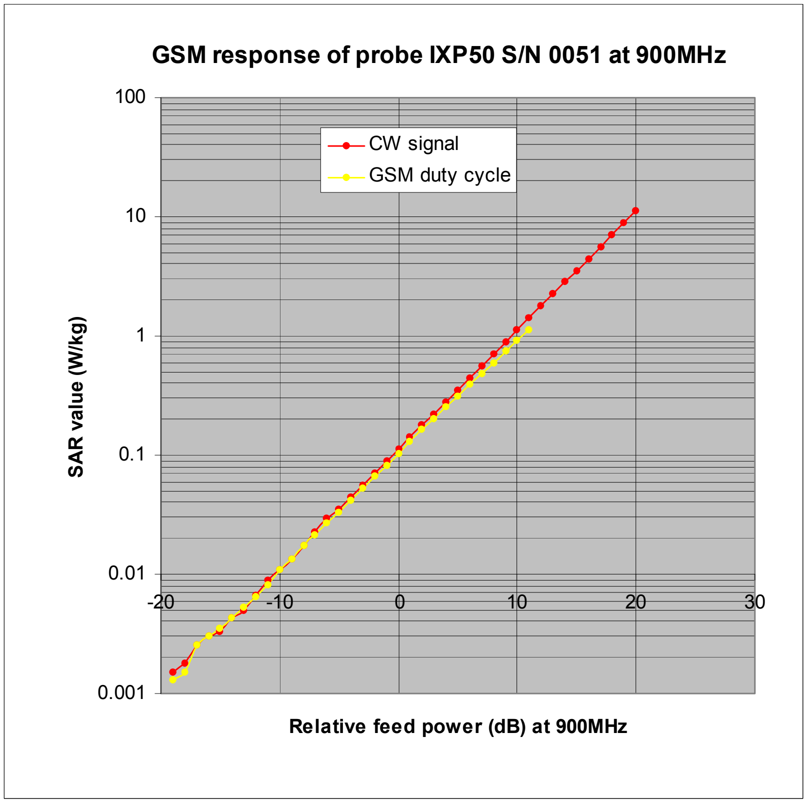



*Figure 7. The GSM response of representative IXP-050 probe at 900MHz.*

**Table indicating the dielectric parameters of the liquids used for calibrations at each frequency**

| Liquid used | Relative permittivity (measured) | Conductivity (S/m) (measured) |
|---|---|---|
| 835 MHz BRAIN | 42.85 | 0.90 |
| 900 MHz BRAIN | 41.95 | 0.96 |
| 1800 MHz BRAIN | 39.19 | 1.34 |
| 1800 MHz BODY | 51.62 | 1.37 |
| 1900 MHz BRAIN | 38.82 | 1.46 |
| 1900 MHz BODY | 51.38 | 1.47 |
| 2450 MHz BRAIN | 37.65 | 1.88 |
| 2450 MHz BODY | 55.28 | 1.92 |