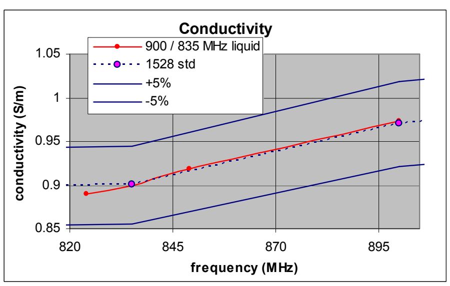
# Tissue Parameters

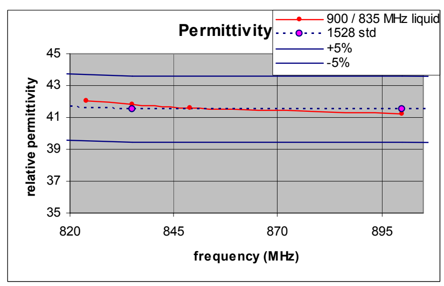
## 850MHz Head liquid:

**Recipe:**
The following recipe is provided in percentage by weight.
49.46% distilled water
49.46% DGBE
1.0% salt
0.1% bactericide

**Di-electric constants measured on 01/07/2003. SAR measurements were made within 24 hours of the measurement of liquid parameters.**

| Freq. (MHz) | Rel. Perm. | Condy (S/m) |
|---|---|---|
| 824.2 | 42.02 | 0.89 |
| 836.6 | 41.84 | 0.899 |
| 848.8 | 41.62 | 0.918 |
| 900 | 41.2 | 0.973 |



## 850MHz Body Liquid:

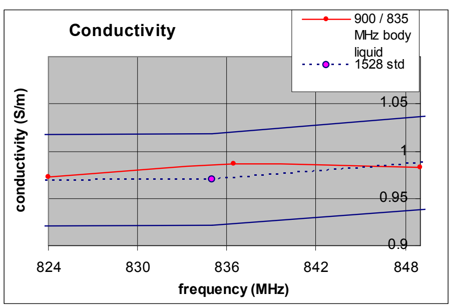
**Recipe:**

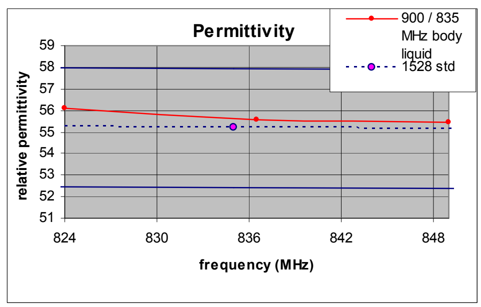
The following recipe is provided in percentage by weight.

| | |
|---|---|
| 49.8% | distilled water |
| 40.6% | DGBE |
| 8.9% | salt |
| 0.6% | HEC |
| 0.1% | bactericide |

**Di-electric constants measured on 01/07/2003. SAR measurements were made within 24 hours of the measurement of liquid parameters.**

| Freq. (MHz) | Rel. Perm. | Condy (S/m) |
|---|---|---|
| 824.2 | 56.07 | 0.973 |
| 836.6 | 55.55 | 0.987 |
| 848.8 | 55.46 | 0.983 |



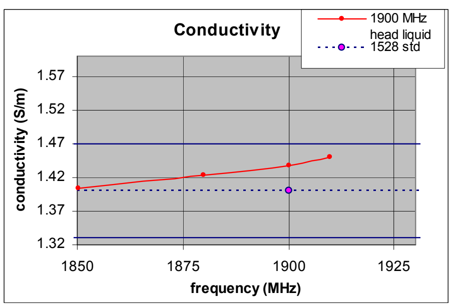
## 1900MHz Head liquid:

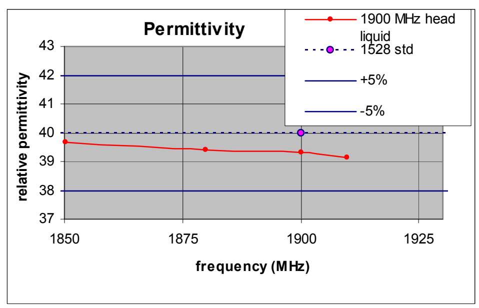
**Recipe:**
The following recipe is provided in percentage by weight.

| | |
|---|---|
| 54.9% | distilled water |
| 44.92% | DGBE |
| 0.18% | salt |
| 0.1% | bactericide |

**Di-electric constants measured on 01/08/2003. SAR measurements were made within 24 hours of the measurement of liquid parameters.**

| Freq. (MHz) | Rel. Perm. | Condy (S/m) |
|---|---|---|
| 1850.2 | 39.66 | 1.403 |
| 1880 | 39.38 | 1.424 |
| 1900 | 39.29 | 1.437 |
| 1909.8 | 39.12 | 1.45 |



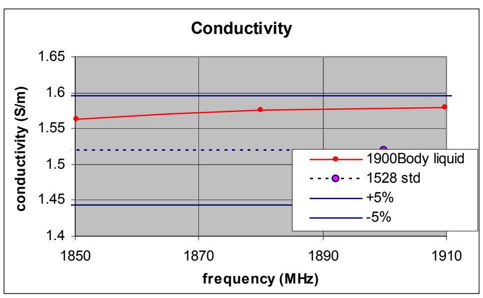
# 1900MHz Body Liquid:

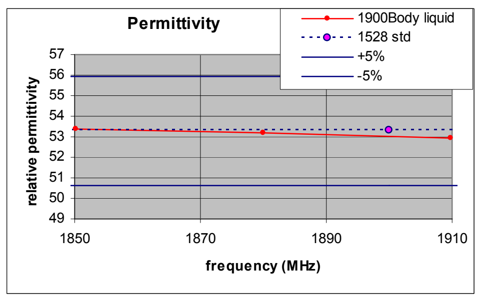
**Recipe:**
The following recipe is provided in percentage by weight.

| | |
|---|---|
| 69.17% | distilled water |
| 30.29% | DGBE |
| 0.44% | salt |
| 0.1% | bactericide |

**Di-electric constants measured on 01/08/2003. SAR measurements were made within 24 hours of the measurement of liquid parameters.**

| Freq. (MHz) | Rel. Perm. | Condy (S/m) |
|---|---|---|
| 1850.2 | 53.35 | 1.563 |
| 1880 | 53.16 | 1.576 |
| 1909.8 | 52.96 | 1.58 |




# Environment 01/07/2003 – 01/09/2003:

| | |
|---|---|
| Temperature**:** | **22.0 °C ± 2°C** |
| Humidity: | **45% _ 55 %** |

**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 |
| 850MHz Head Tissue Simulant | Cetecom Inc. | 850 Head | N/A | 01/07/2003 |
| 850MHz Body Tissue Simulant | Cetecom Inc. | 850 Body | N/A | 01/07/2003 |
| 1900MHz Head Tissue Simulant | Cetecom Inc. | 1900 Head | N/A | 01/08/2003 |
| 1900MHz Body Tissue Simulant | Cetecom Inc. | 1900 Body | N/A | 01/08/2003 |
| 900MHz Dipole | IndexSAR – IEEE 1528 design | IXD-090 | 090-0016 | 07/01/02 |
| 1900MHz Dipole | IndexSAR – IEEE 1528 design | IXD-190 | 190-0016 | 7/30/02 |
| Directional coupler | Werlatone | C6529 | 11249 | N/A |
| 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 | 0123 | 10/25/2002 |
| Probe amplifier | Indexsar | IXA-010 | 043 | N/A- |
| Thermometer | Control Company | 4039 | 20410549 | 11/20/2002 |
| Dielectric Measurement Kit | IndexSar | Di-Line | N/A | N/A |

# Equipment Calibration/Performance Documents:



Please Note:
(The following pages of Appendix C show calibration documents. These calibration documents are inserted into this appendix. The header information with page numbering scheme is a part of this report and is included on all pages of the report and appendixes. This header is used to track all of the contents of this report.)

Report No. SN0016_090-180-245

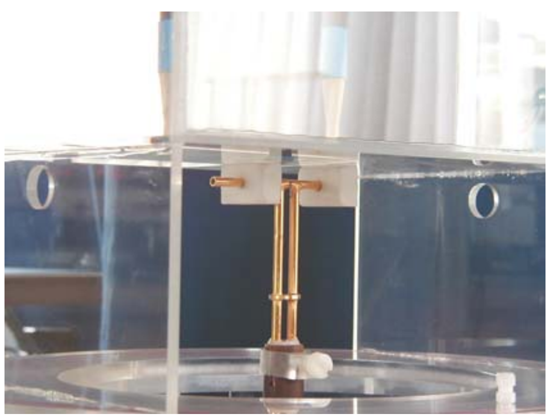
**July 1st 2002**

# INDEXSAR
# Validation Dipoles
# Type IXD-090, IXD-180 & IXD-245

## Performance measurements

**S/N: 090-0016**
**S/N: 180-0016**
**S/N: 245-0016**

MI Manning



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**Newdigate, Surrey RH5 5DR. UK.**
Tel: +44 (0) 1306 631233 Fax: +44 (0) 1306 631834
e-mail: enquiries@indexsar.com

## 1. Measurement Conditions

Measurements were performed using a box-shaped phantom made of PMMA with dimensions designed to meet the accuracy criteria for reasonably-sized phantoms that do not have liquid capacities substantially in excess of the volume of liquid required to fill the Indexsar upright SAM phantoms used for SAR testing of handsets against the ear.

An HP 8753B vector network analyser was used for the return loss measurements. The dipole was placed in a special holder made of low-permittivity, low-loss materials. This holder enables the dipole to be positioned accurately in the centre of the base of the Indexsar box-phantom used for flat-surface testing and validation checks.

The validation dipoles are supplied with special spacers made form a low-permittivity, low-loss foam material. These spacers are fitted to the dipole arms to ensure that, when the dipole is offered up to the phantom surface, the spacing between the dipole and the liquid surface is accurately aligned according to the guidance in the relevant standards documentation. The spacers are rectangular with a central hole equal to the dipole arm diameter and dimensioned so that the longer side can be used to ensure a spacing of 15mm from the liquid in the phantom (for tests at 900MHz and below) and the shorter side can be used for tests at 1800MHz and above to ensure a spacing of 10mm from the liquid in the phantom. The spacers are made on a CNC milling machine with an accuracy of 1/40$^{th}$ mm but they may suffer wear and tear and need to be replaced periodically. The material used is Rohacell, which has a relative permittivity of approx. 1.05 and a negligible loss tangent.

The apparatus supplied by Indexsar for dipole validation tests thus includes:

Balanced dipoles for each frequency required are dimensioned according to the guidelines given in IEEE 1528 [1]. The dipoles are made from semi-rigid 50 ohm co-ax, which is joined by soldering and is gold-plated subsequently. The constructed dipoles are easily deformed, if mis-handled, and periodic checks need to be made of their symmetry.

Rohacell foam spacers designed for presenting the dipoles to 2mm thick PMMA box phantoms. These components also suffer wear and tear and should be replaced when the central hole is a loose-fit on the dipole arms or if the edges are too worn to ensure accurate alignment. The standard spacers are dimensioned for use with 2mm wall thickness (additional spacers are available for 4mm wall thickness).

## 2. SAR Measurement

SAR validation checks using the dipoles can be performed with the box-phantom located on the SARA2 phantom support base on the SARA2 robot system. Tests may be conducted at a feed power level of 0.25W. However, the actual power level should be recorded and used to normalise the results obtained to the standard input power conditions of 1W (forward power). The results can then be compared with Table 8.1 in [1]. Brain liquids should be used so that measurement results can be compared with the (computed) reference values tabulated in IEEE 1528.

## 3. Dipole handling

The dipoles are made from standard, copper-sheathed coaxial cable. In assembly, the sections are joined using ordinary soft-soldering. This is necessary to avoid excessive heat input in manufacture, which would destroy the polythene dielectric used for the cable. The consequence of the construction material and the assembly technique is that the dipoles are fragile and can be deformed by rough handling. Conversely, they can be straightened quite easily as described below:

If a dipole is suspected of being deformed, a normal workshop lathe can be used as an alignment jig to restore the symmetry. To do this, the dipole is first placed in the headstock of the lathe (centred on the plastic or brass spacers) and the headstock is rotated by hand (do NOT use the motor). A marker (lathe tool or similar) is brought up close to the end of one dipole arm and then the headstock is rotated by 0.5 rev. to check the opposing arm. If they are not balanced, judicious deformation of the arms can be used to restore the symmetry.

If a dipole has a failed solder joint, the dipole can be fixed down in such a way that the arms are co-linear and the joint re-soldered with a reasonably-powerful electrical soldering iron. Do not use gas soldering irons. After such a repair, electrical tests must be performed as described below.

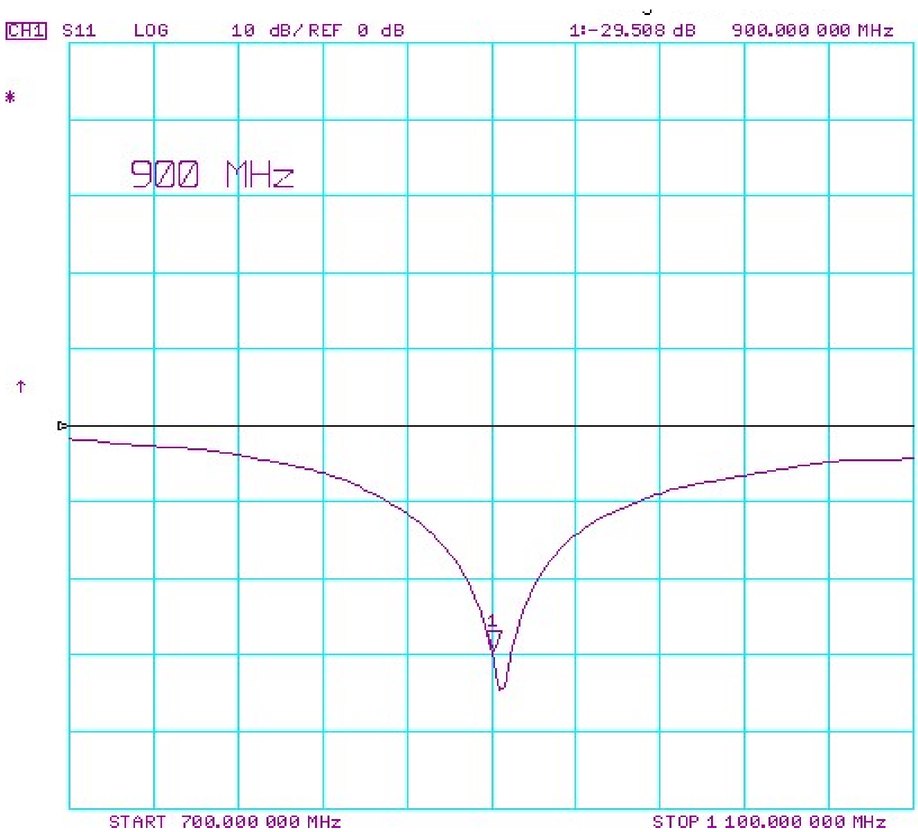
Please note that, because of their construction, the dipoles are short-circuited for DC signals.

## 4. Performance Measurement

The dipoles are individually tested at their nominal frequency to ensure that they exhibit a return loss of less than -20dB when used with brain or body liquids.

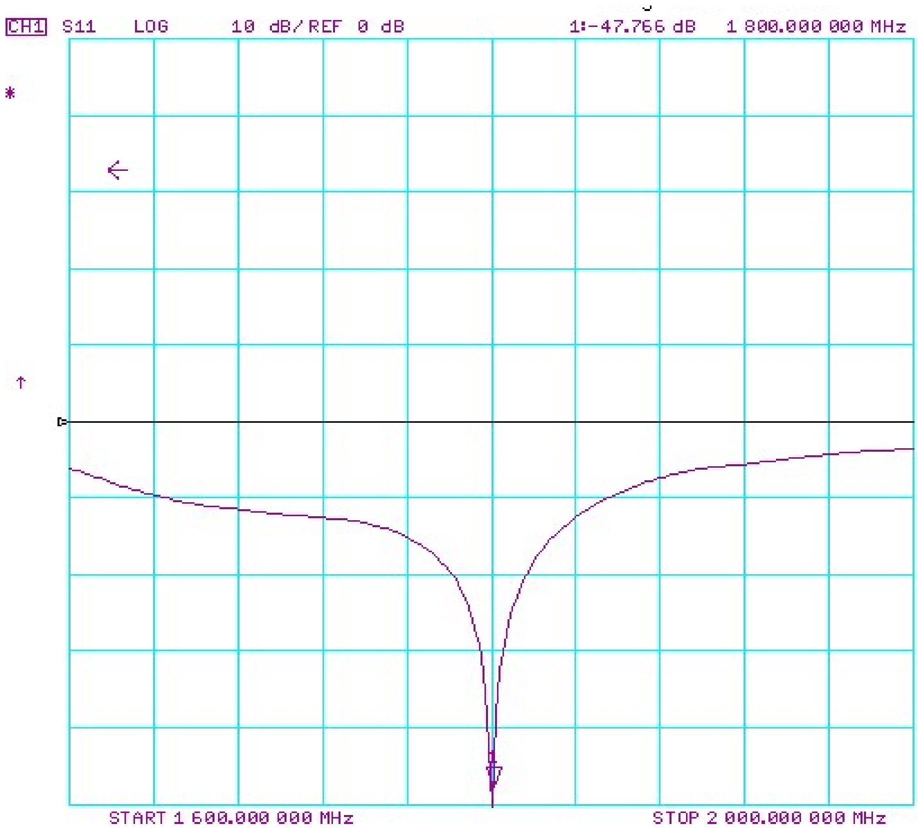
The dipoles are designed to have low return loss ONLY when presented against a lossy-phantom at the specified distance. If the user has a Vector Network Analyser (VNA) it is best to perform a return loss measurement on a specific dipole when it is in a measurement-location against a box phantom. If this is not the case, the return loss should be measured with the dipole positioned at the specified distance from a suitable container of lossy liquid. The distances specified in the standards are 15mm from the lossy liquid (900MHz and below) and 10mm from the liquid (1500MHz and above). The Indexsar foam spacers (described above) should be used to ensure this condition during measurement.

S11 plots for the dipoles with nominal frequencies of 900MHz, 1800MHz and 2450MHz are shown below.

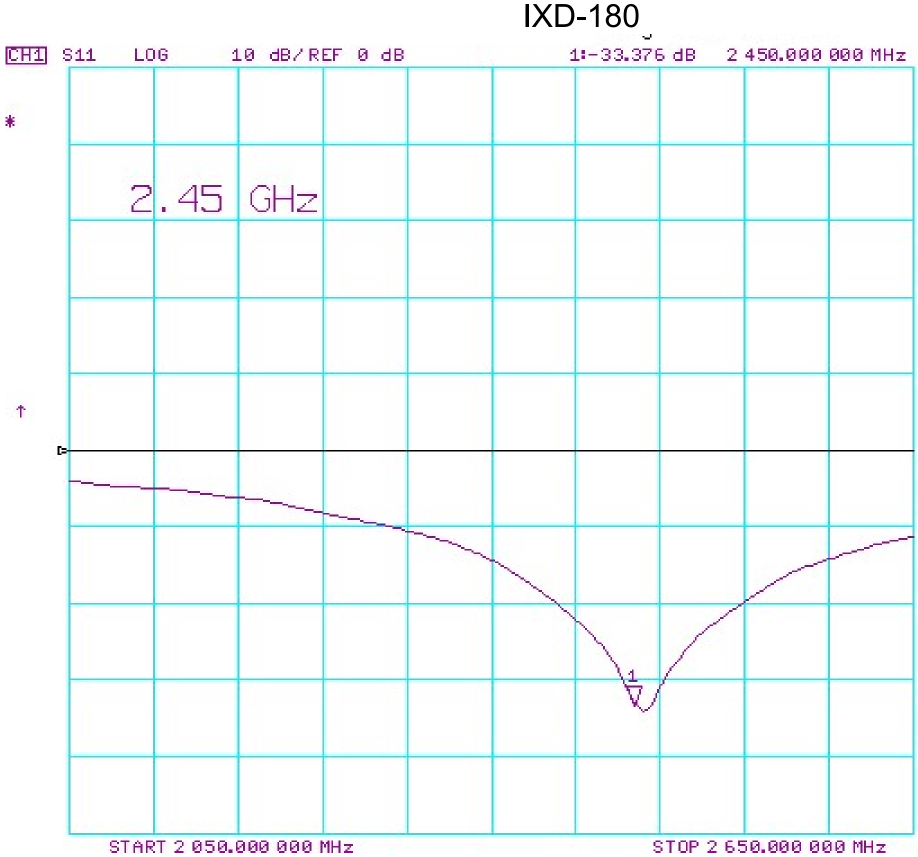



IXD-090

**Appendix C**




IXD-180



IXD-245

## 5. Tuning the dipole

The dipole dimensions are based on calculations that assumed specific liquid dielectric properties. If the liquid dielectric properties are somewhat different, the dipole tuning will also vary. A pragmatic way of accounting for variations in liquid properties is to 'tune' the dipole (by applying minor variations to its effective length). For this purpose, Indexsar can supply short brass tube lengths to extend the length of the dipole and thus 'tune' the dipole. It cannot be made shorter without removing a bit from the arm. An alternative way to tune the dipole is to use copper shielding tape to extend the effective length of the dipole. Do both arms equally.

It should be possible to tune a dipole as described, whilst in place in the measurement position as long as the user has access to a VNA for determining the return loss.

## 6. Reference

[1] Draft recommended practice for determining the peak spatial-average specific absorption rate (SAR) in the human body due to wireless communications devices: Experimental Techniques.

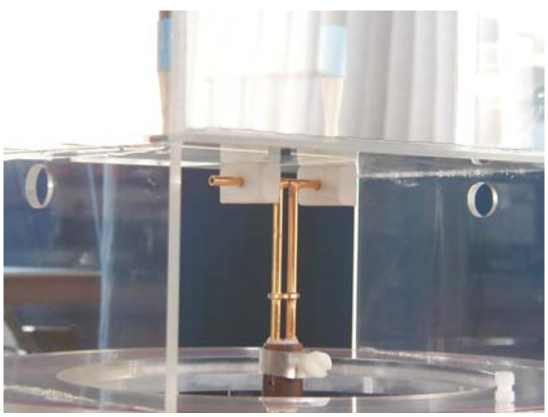
Report No. SN0016_1900

**30th July 2002**

# INDEXSAR
# 1900MHz validation Dipole
# Type IXD-190 **S/N 0016**

## Performance measurements

MI Manning



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**Newdigate, Surrey RH5 5DR. UK.**
Tel: +44 (0) 1306 631233   Fax: +44 (0) 1306 631834
e-mail: enquiries@indexsar.com

## 7. Measurement Conditions

Measurements were performed using a box-shaped phantom made of PMMA with dimensions designed to meet the accuracy criteria for reasonably-sized phantoms that do not have liquid capacities substantially in excess of the volume of liquid required to fill the Indexsar upright SAM phantoms used for SAR testing of handsets against the ear.

An HP 8753B vector network analyser was used for the return loss measurements.
The dipole was placed in a special holder made of low-permittivity, low-loss materials. This holder enables the dipole to be positioned accurately in the centre of the base of the Indexsar box-phantom used for flat-surface testing and validation checks.

The validation dipoles are supplied with special spacers made from a low-permittivity, low-loss foam material. These spacers are fitted to the dipole arms to ensure that, when the dipole is offered up to the phantom surface, the spacing between the dipole and the liquid surface is accurately aligned according to the guidance in the relevant standards documentation. The spacers are rectangular with a central hole equal to the dipole arm diameter and dimensioned so that the longer side can be used to ensure a spacing of 15mm from the liquid in the phantom (for tests at 900MHz and below) and the shorter side can be used for tests at 1800MHz and above to ensure a spacing of 10mm from the liquid in the phantom. The spacers are made on a CNC milling machine with an accuracy of $1/40^{th}$ mm but they may suffer wear and tear and need to be replaced periodically. The material used is Rohacell, which has a relative permittivity of approx. 1.05 and a negligible loss tangent.

The apparatus supplied by Indexsar for dipole validation tests thus includes:

Balanced dipoles for each frequency required are dimensioned according to the guidelines given in IEEE 1528 [1]. The dipoles are made from semi-rigid 50 Ohm co-ax, which is joined by soldering and is gold-plated subsequently. The constructed dipoles are easily deformed, if mis-handled, and periodic checks need to be made of their symmetry.

Rohacell foam spacers designed for presenting the dipoles to 2mm thick PMMA box phantoms. These components also suffer wear and tear and should be replaced when the central hole is a loose-fit on the dipole arms or if the edges are too worn to ensure accurate alignment. The standard spacers are dimensioned for use with 2mm wall thickness (additional spacers are available for 4mm wall thickness).

## 8. SAR Measurement

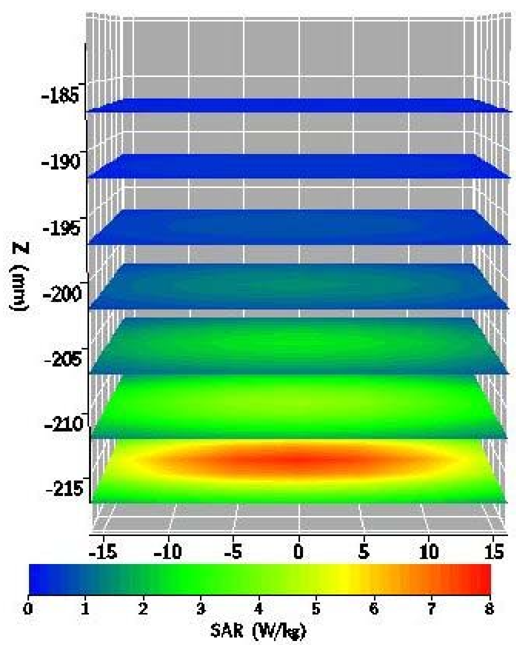
A SAR validation check was performed with the box-phantom located on the SARA2 phantom support base on the SARA2 robot system. Tests were conducted at a feed power level of approx. 0.25W. The actual power level was recorded and used to normalise the results obtained to the standard input power conditions of 1W (forward power). The ambient temperature was 25.4°C and the relative humidity was 67% during the measurements.

The phantom was filled with a 1900MHz brain liquid using a recipe from [1], which had the following electrical parameters (measured using an Indexsar DiLine kit) at 1900MHz:

| | |
|---|---|
| Relative Permittivity | **38.82** |
| Conductivity | **1.46 S/m** |

The SARA2 software version 0.281 was used with an Indexsar probe previously calibrated at NPL (S/N 0071) using the NPL-supplied calibration factors [2].

The 3D measurements made using the dipole at the bottom of the phantom box are shown below:




The results, normalised to an input power of 1W (forward power) were:

| | |
|---|---|
| Averaged over 1 cm3 (1g) of tissue | **40.068 W/kg** |
| Averaged over 10cm3 (10g) of tissue | **21.168 W/kg** |

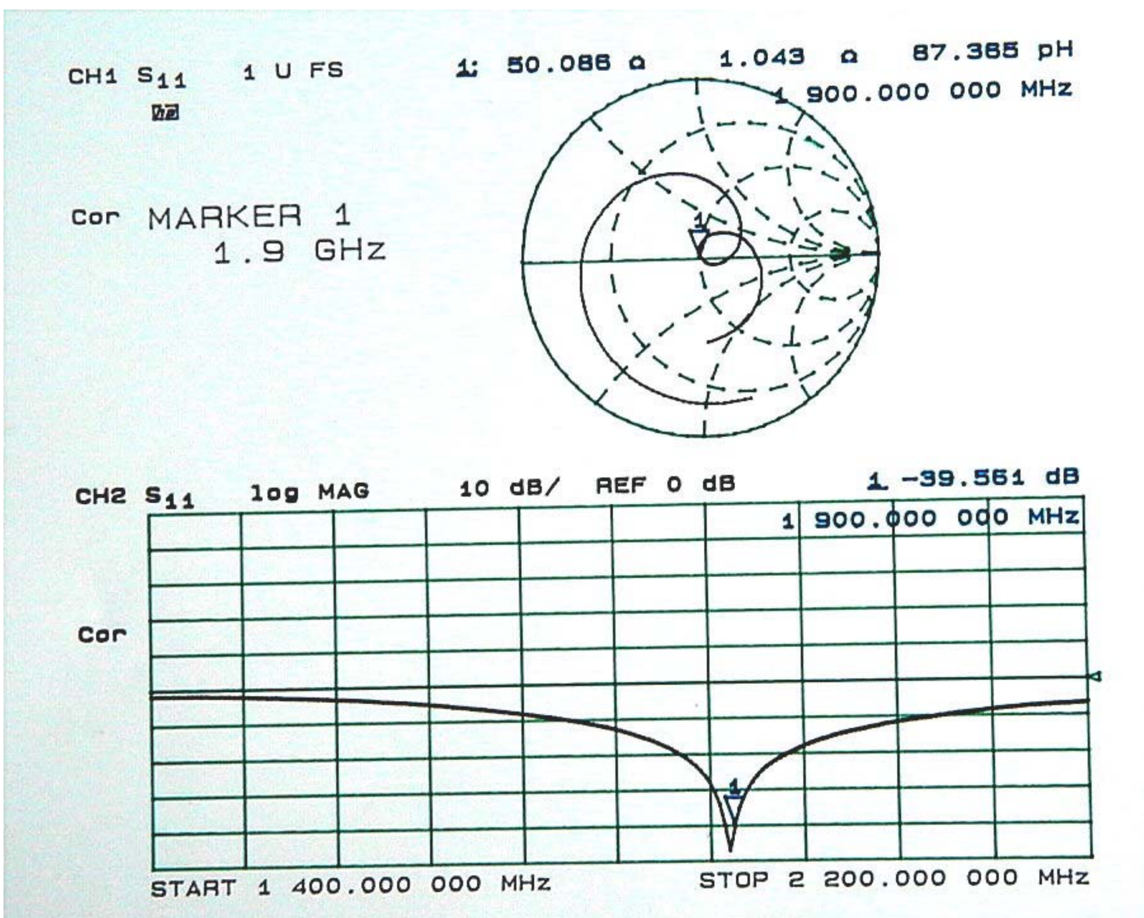
These results can be compared with Table 8.1 in [1]. The agreement is within 3%.

## 9. Dipole impedance and return loss

The dipoles are designed to have low return loss ONLY when presented against a lossy-phantom at the specified distance. A Vector Network Analyser (VNA) was used to perform a return loss measurement on the specific dipole when in the measurement-location against the box phantom. The distance was as specified in the standard i.e. 10mm from the liquid (for 1900MHz). The Indexsar foam spacers (described above) were used to ensure this condition during measurement.

The impedance was measured at the SMA-connector with the network analyser.
The following parameters were measured:

| | |
|---|---|
| Dipole impedance at 1900 MHz | Re{Z} = **50.086 Ω** |
| | Im{Z} = **1.043 Ω** |
| Return loss at 1900MHz | **-39.561 dB** |



## 10. Dipole handling

The dipoles are made from standard, copper-sheathed coaxial cable. In assembly, the sections are joined using ordinary soft-soldering. This is necessary to avoid excessive heat input in manufacture, which would destroy the polythene dielectric used for the cable. The consequence of the construction material and the assembly technique is that the dipoles are fragile and can be deformed by rough handling. Conversely, they can be straightened quite easily as described in this report.

If a dipole is suspected of being deformed, a normal workshop lathe can be used as an alignment jig to restore the symmetry. To do this, the dipole is first placed in the headstock of the lathe (centred on the plastic or brass spacers) and the headstock is rotated by hand (do NOT use the motor). A marker (lathe tool or similar) is brought up close to the end of one dipole arm and then the headstock is rotated by 0.5 rev. to check the opposing arm. If they are not balanced, judicious deformation of the arms can be used to restore the symmetry.

If a dipole has a failed solder joint, the dipole can be fixed down in such a way that the arms are co-linear and the joint re-soldered with a reasonably-powerful electrical soldering iron. Do not use gas soldering irons. After such a repair, electrical tests must be performed as described below.

Please note that, because of their construction, the dipoles are short-circuited for DC signals.

## 11. Tuning the dipole

The dipole dimensions are based on calculations that assumed specific liquid dielectric properties. If the liquid dielectric properties are somewhat different, the dipole tuning will also vary. A pragmatic way of accounting for variations in liquid properties is to 'tune' the dipole (by applying minor variations to its effective length). For this purpose, Indexsar can supply short brass tube lengths to extend the length of the dipole and thus 'tune' the dipole. It cannot be made shorter without removing a bit from the arm. An alternative way to tune the dipole is to use copper shielding tape to extend the effective length of the dipole. Do both arms equally.

It should be possible to tune a dipole as described, whilst in place in the measurement position as long as the user has access to a VNA for determining the return loss.

## 12. References

[1] Draft recommended practice for determining the peak spatial-average specific absorption rate (SAR) in the human body due to wireless communications devices: Experimental Techniques.

[2] Calibration report on SAR probe IXP-050 S/N 0071 from National Physical Laboratory. Test Report EF07/2002/03/IndexSAR. Dated 20 February 2002.

**IMMERSIBLE SAR PROBE**

**CALIBRATION REPORT**

**Part Number: IXP – 050**

# S/N 0123

**25th October 2002**

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## INTRODUCTION

This Report presents measured calibration data for a particular Indexsar SAR probe (S/N 0123) 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) 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 characterisation procedure, the probe is placed in an isotropy measurement 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 MHz) is inserted horizontally into the bracket attached to a second belt (Figure 1). 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.

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

3. Selecting channel sensitivity factors to optimise isotropic response

The basic measurements obtained using the calibration jig (Fig 1) 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 3. 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.

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):

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

It should be noted that the 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.

4. 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 0123.

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):

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

A 3D representation of the spherical isotropy for probe S/N 0123 using these factors is shown in Figure 3.

The rotational isotropy can also 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. 5).

The design of the cells used for determining probe conversion factors are waveguide cells is 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 posititon 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. A fuller description of the waveguide method is given below.

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 IEEE1528 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

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

where the density $\rho$ is conventionally assumed to be 1000 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.

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

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.

**CALIBRATION FACTORS MEASURED FOR PROBE S/N 0123**

The probe was calibrated at 900, 1800, 1900 and 2450MHz MHz 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 m 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$^{o}$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.

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

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

Where σ 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.

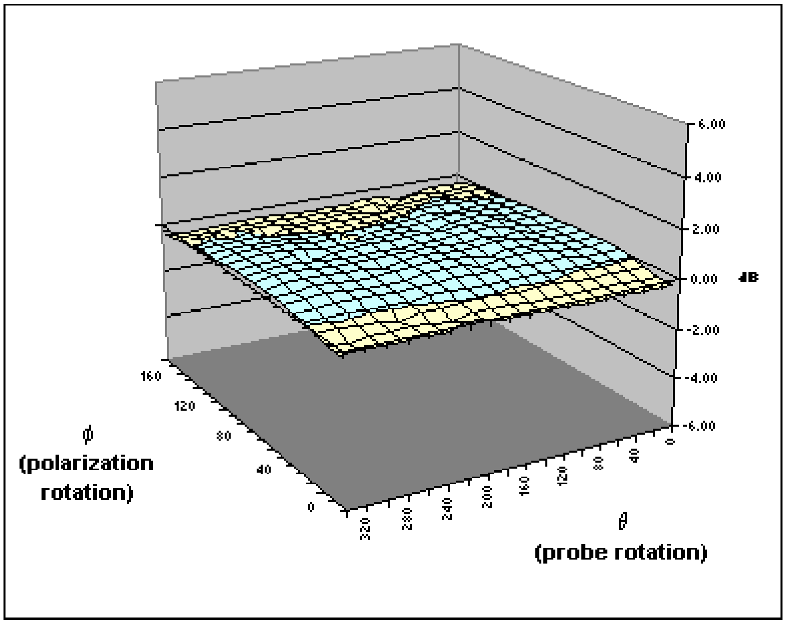
Figure 7 shows the linearised probe response to GSM signals, Figure 8 the response to GPRS signals (GSM with 2 timeslots) and Figure 9 the response to CDMA IS-95A and W-CDMA signals.

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.

## SUMMARY OF CALIBRATION FACTORS FOR PROBE IXP-050 S/N 0123

**IXP-050** **S/N0123** 25/10/2002

Spherical isotropy measured at 900 MHz 0.44 (+/-) dB




| | X | Y | Z | | |
|---|---|---|---|---|---|
| Air factors | 346 | 318 | 386 | (V*200) | |
| DCPs | 20 | 20 | 20 | (V*200) | |
| GSM | 9 | 13.6 | 8.7 | (V*200) | |
| GPRS | 17.9 | 18 | 13.6 | (V*200) | |
| CDMA | 20 | 20 | 20 | (V*200) | |
| f (MHz) | Axial isotropy (+/- dB) | | SAR conversion factors (liq/air) | | Notes |
| | BRAIN | BODY | BRAIN | BODY | |
| 835 | 0.15 | 0.18 | 0.401 | 0.466 | 4 |
| 900 | 0.14 | 0.16 | 0.480 | 0.509 | 4 |
| 1800 | 0.14 | 0.14 | 0.542 | 0.600 | 4 |
| 1900 | 0.14 | 0.14 | 0.562 | 0.610 | 4 |
| 2000 | 0.14 | - | 0.6 | - | 4 |
| 2450 | 0.15 | 0.15 | 0.768 | 0.816 | 4 |

Notes

1) Extrapolated values in italics

2) Calibrations done at 22C +/- 2C

3) Probe calibration by substitution against NPL-calibrated probe (Probe IXP-050 S/N0071; NPL Cal Rept. No: EF07/2002/03/IndexSAR

4) Waveguide calibration

*(the graph shows a simple, spreadsheet representation of surface shown in 3D in Figure 3 below)*

## PROBE SPECIFICATIONS

Indexsar probe 0123, 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 0123 | 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 0123 | 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 0123 | CENELEC [1] | IEEE [2] |
|---|---|---|---|
| Over range 0.01 – 100 W/kg (+/- dB) | 0.125 | 0.50 | 0.25 |

| **Isotropy (measured at 900MHz)** | S/N 0123 | CENELEC [1] | IEEE [2] |
|---|---|---|---|
| Axial rotation with probe normal to source (+/- dB) at 835, 900, 1800, 1900 and 2450 MHz | Max. 0.18 (see summary table) | 0.5 | 0.25 |
| Spherical isotropy covering all orientations to source (+/- dB) | 0.44 | 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.

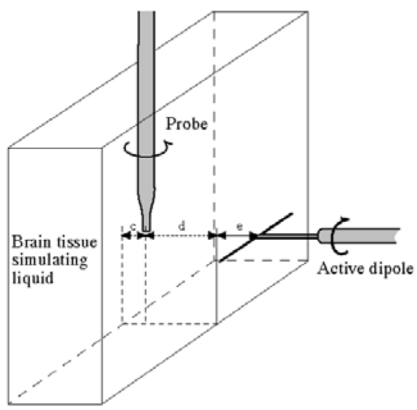



*Figure 1. Spherical isotropy jig showing probe, dipole and box filled with simulated brain liquid (see Ref [2], Section A.5.2.1)*

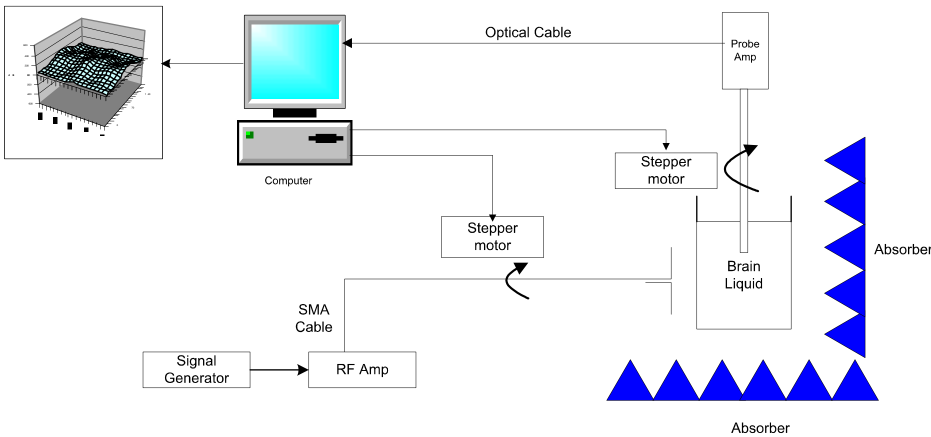



*Figure 2. Schematic diagram of the test geometry used for isotropy determination*

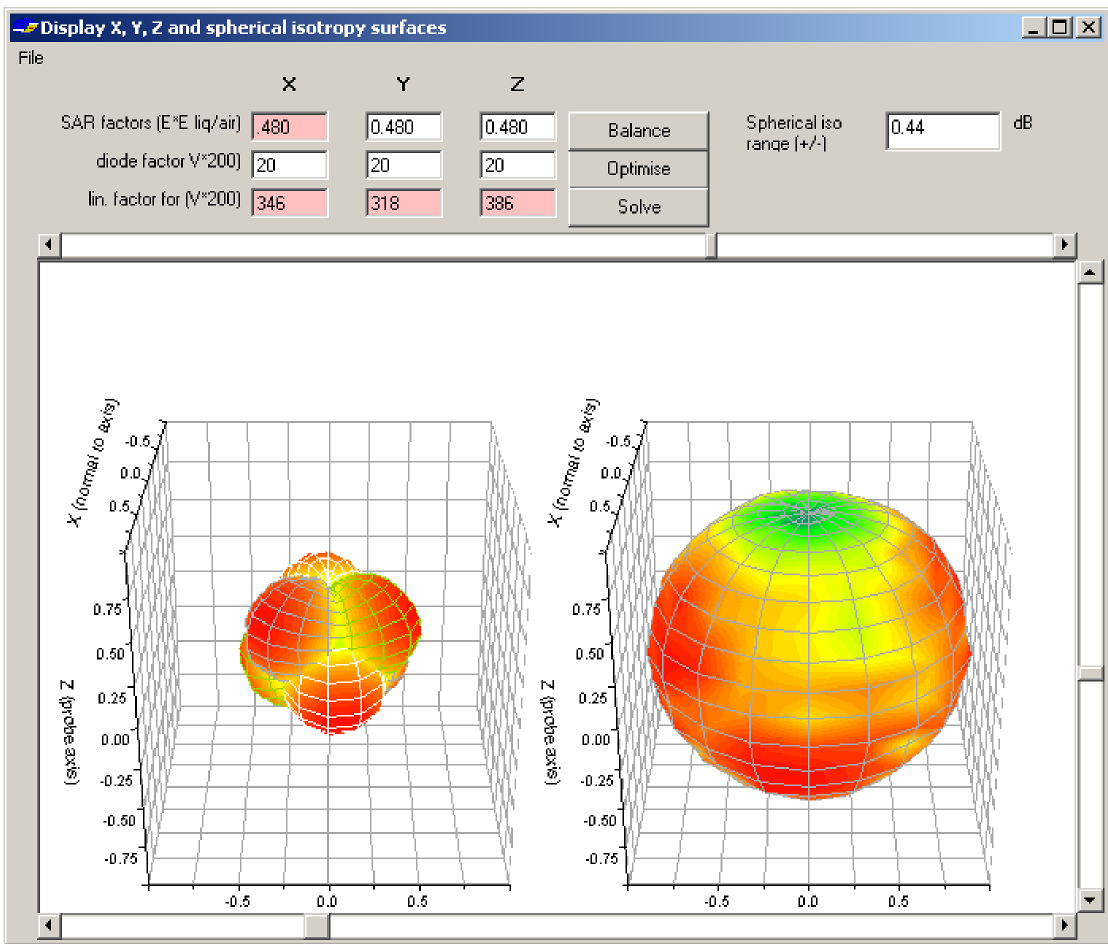



*Figure 3. Graphical representation of the probe response to fields applied from each direction. The diagram on the left shows the individual response characteristics of each of the three channels and the diagram on the right shows the resulting probe sensitivity in each direction. The colour range in the figure images the lowest values as blue and the maximum values as red. For the probe S/N 0123, this range is (+/-) 0.44 dB. The probe is more sensitive to fields parallel to the axis and less sensitive to fields normal to the probe axis.*

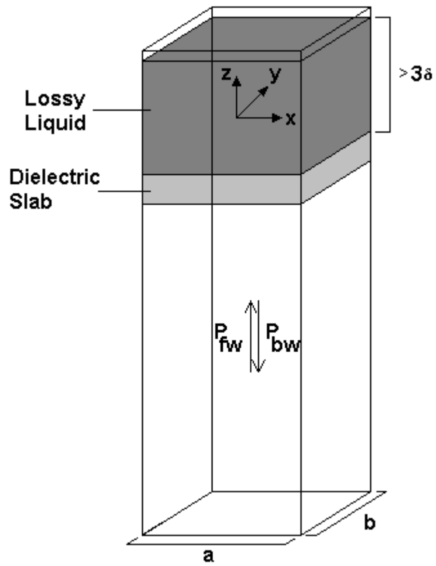
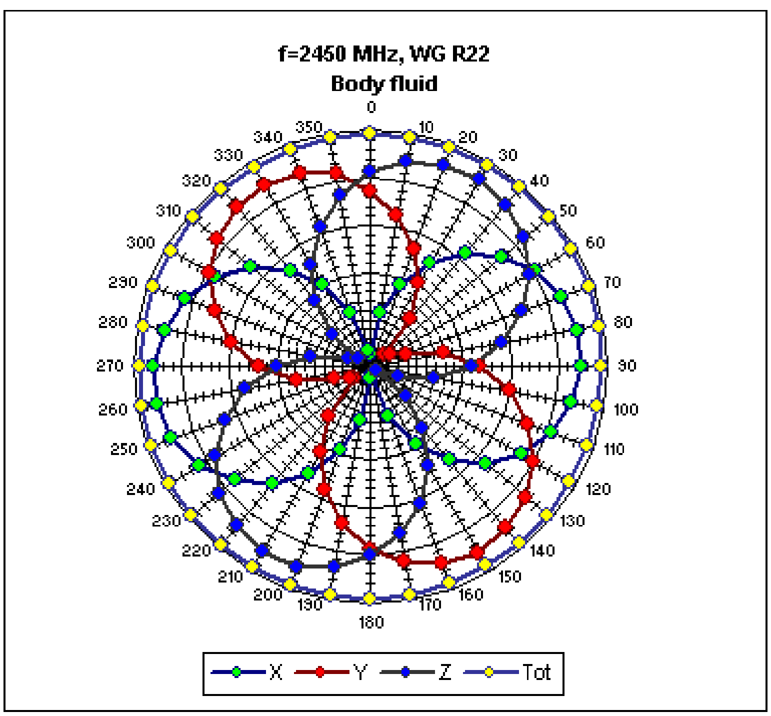



*Figure 4. Geometry used for waveguide calibration (after Ref [2]. Section A.3.2.2)*

**IXP-050 S/N 0123** **25-Oct-02**



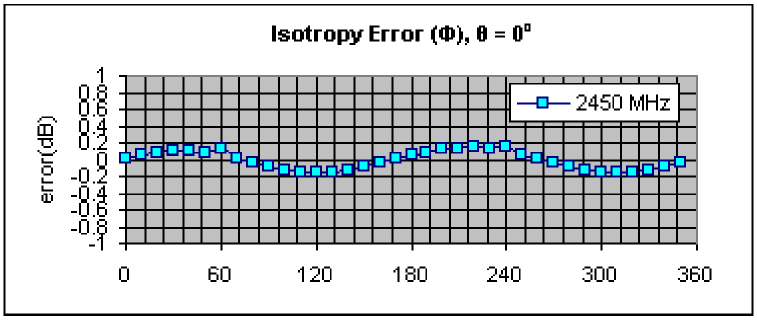



*Figure 5. Example of the rotational isotropy of probe S/N 0123 obtained by rotating the probe in a liquid-filled waveguide at 2450 MHz. Similar distributions are obtained at the other test frequencies (1800 and 1900 MHz) both in brain liquids and body fluids (see summary table)*

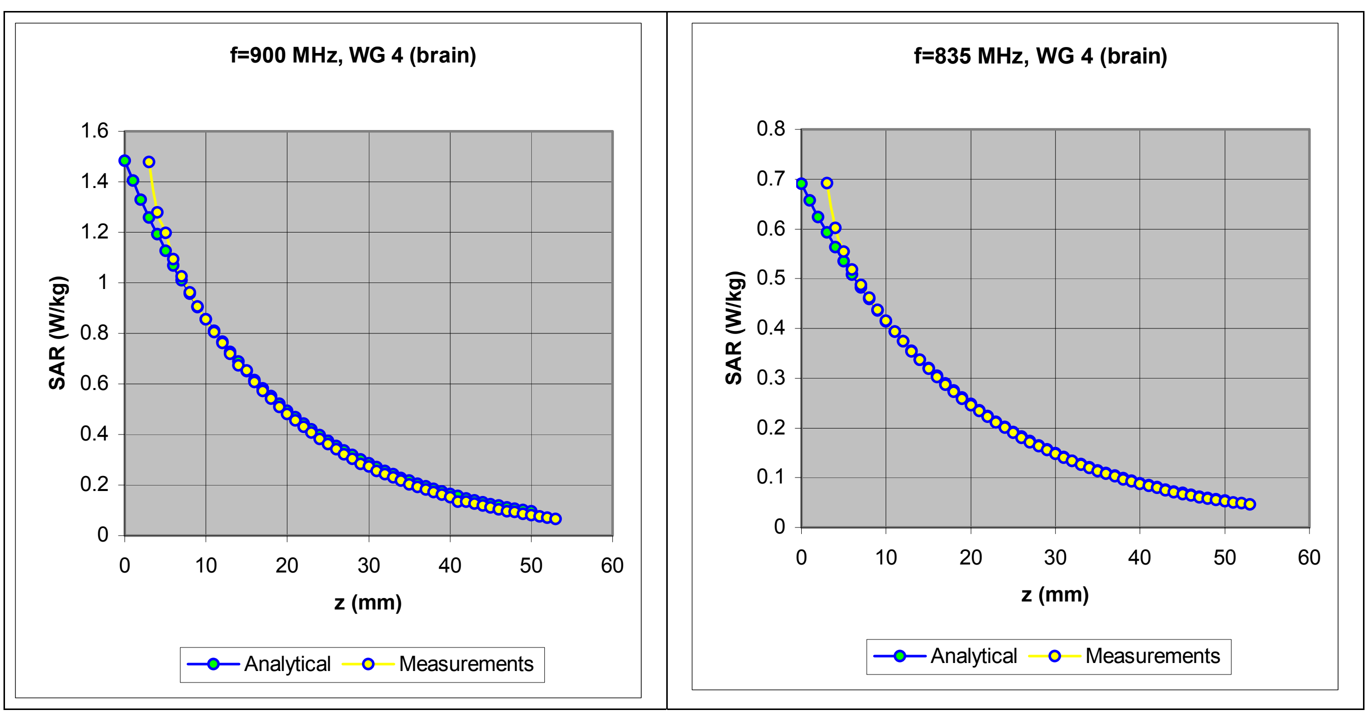


*Figure 6. The measured SAR decay function along the centreline of the WG4 waveguide with conversion factors adjusted to fit to the theoretical function for the particular dimension, frequency, power and liquid properties employed.*

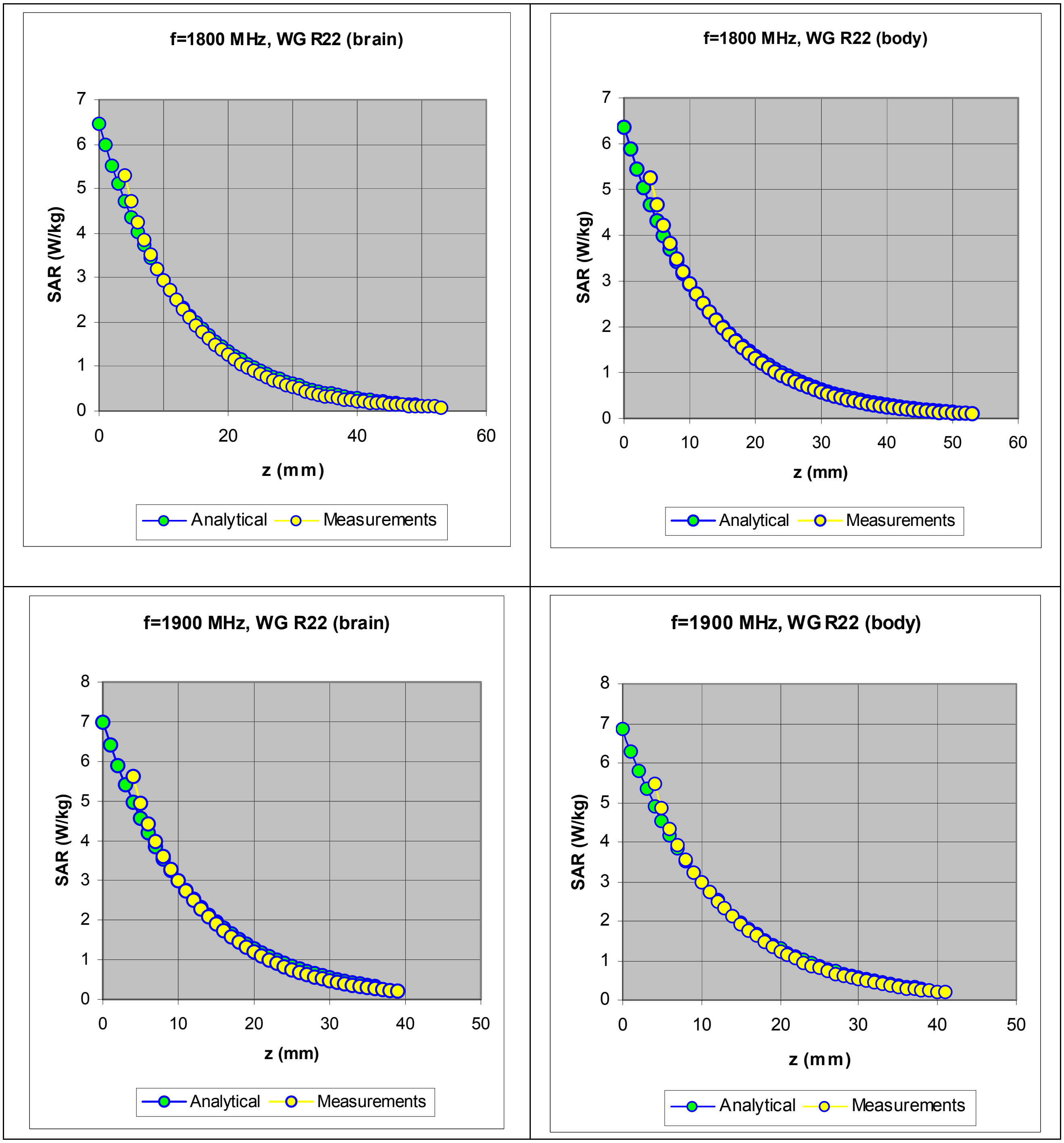



*Figure 7. The measured SAR decay function along the centreline of the R22 waveguide with conversion factors adjusted to fit to the theoretical function for the particular dimension, frequency, power and liquid properties employed.*

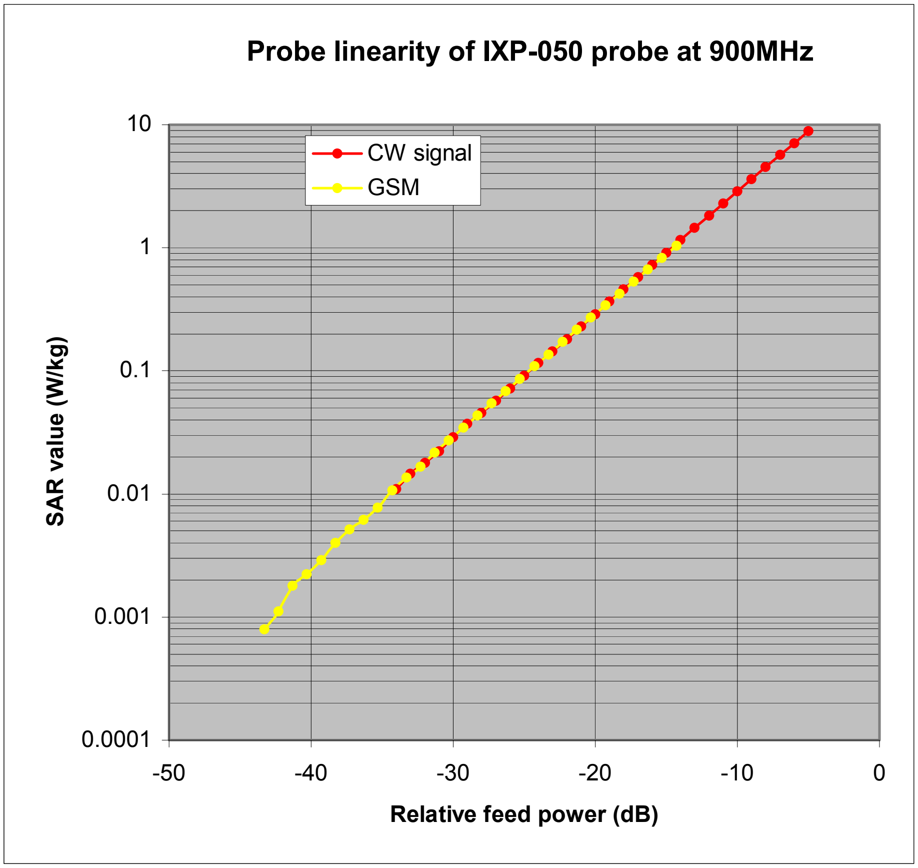



*Figure 8. The GSM response of an IXP-050 probe at 900MHz.*

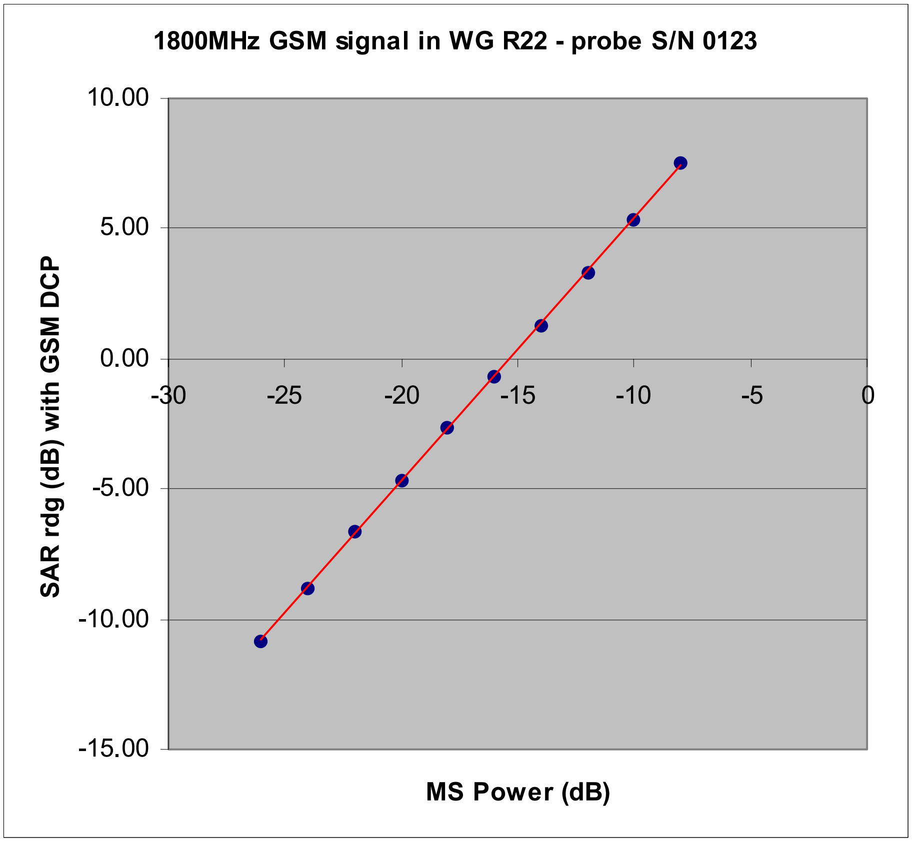



*Figure 8a. The actual GSM response of IXP-050 probe S/N 0123 at 1800MHz*

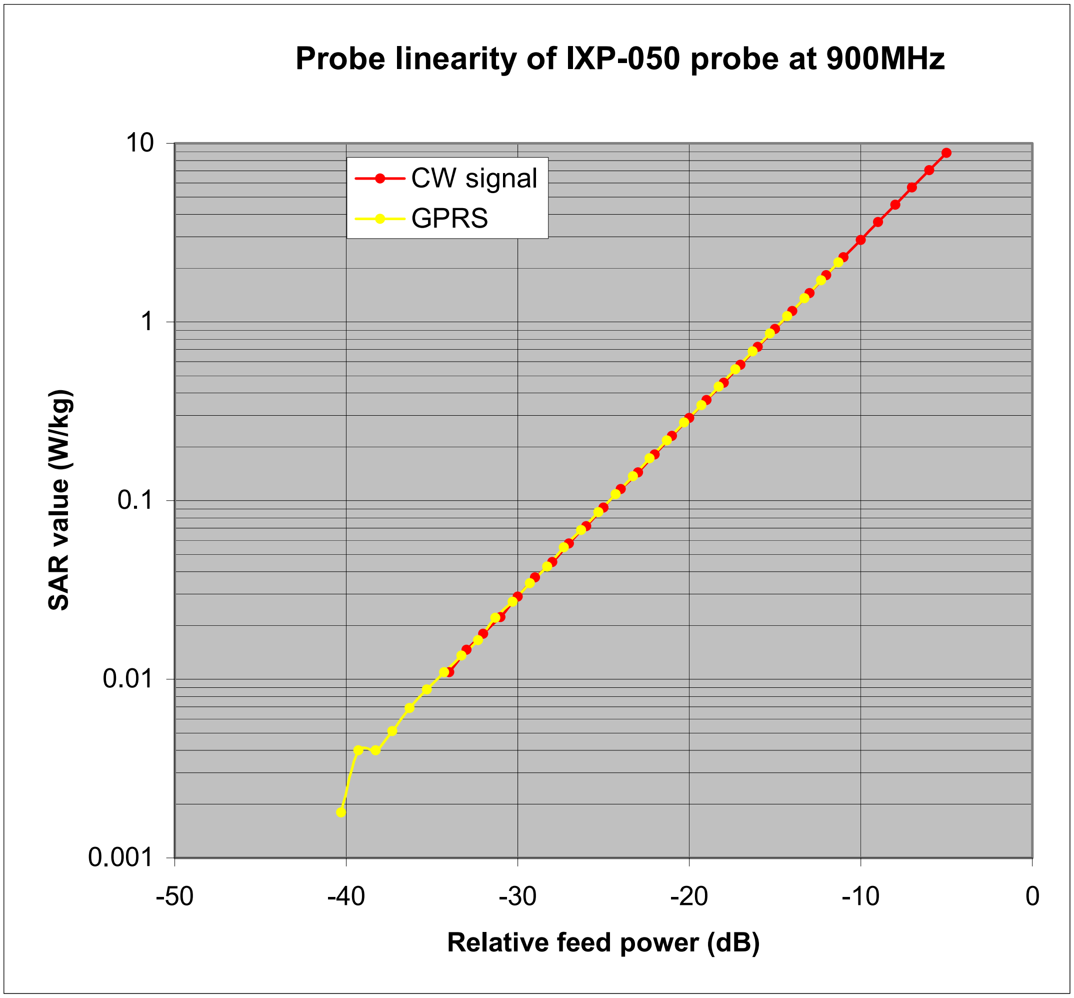
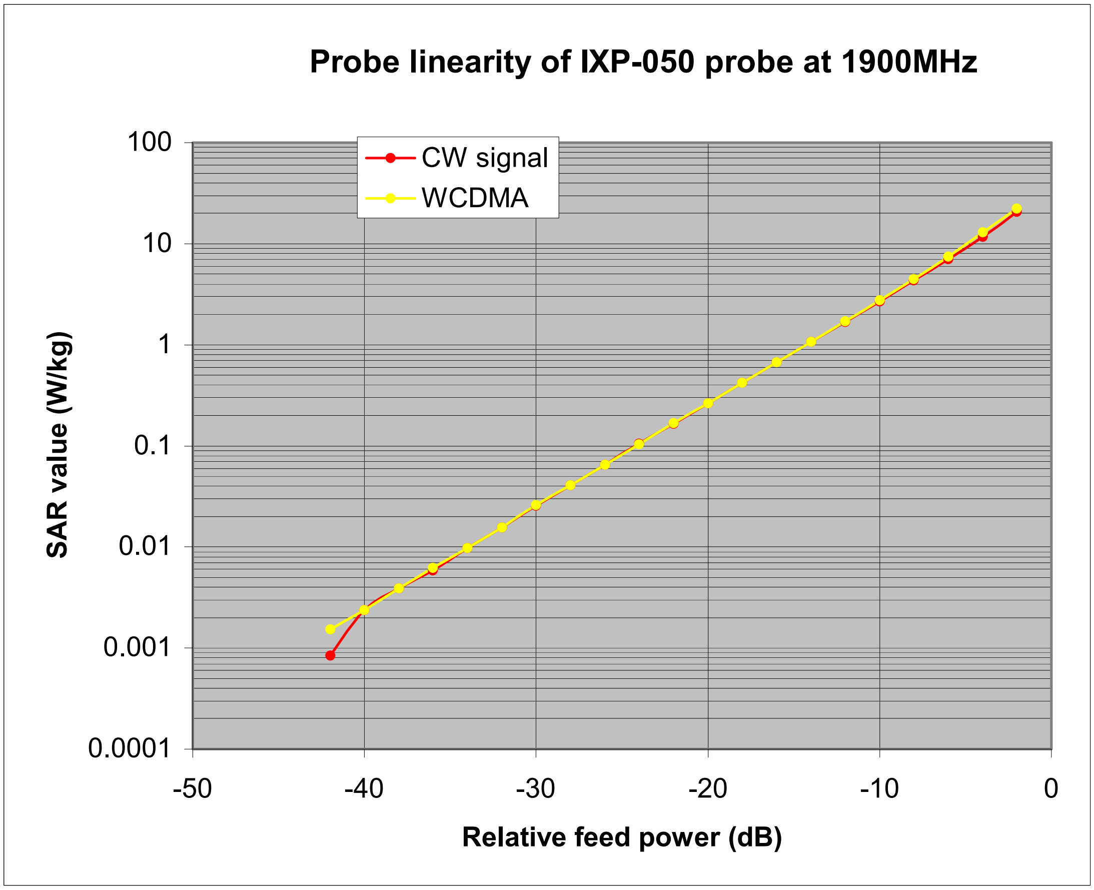



*Figure 9. The GPRS response of an IXP-050 probe at 900MHz.*


Probe linearity of IXP-050 probe at 1900MHz
CW signal
WCDMA
SAR value (W/kg)
Relative feed power (dB)
100
10
1
0.1
0.01
0.001
0.0001
-50
-40
-30
-20
-10
0

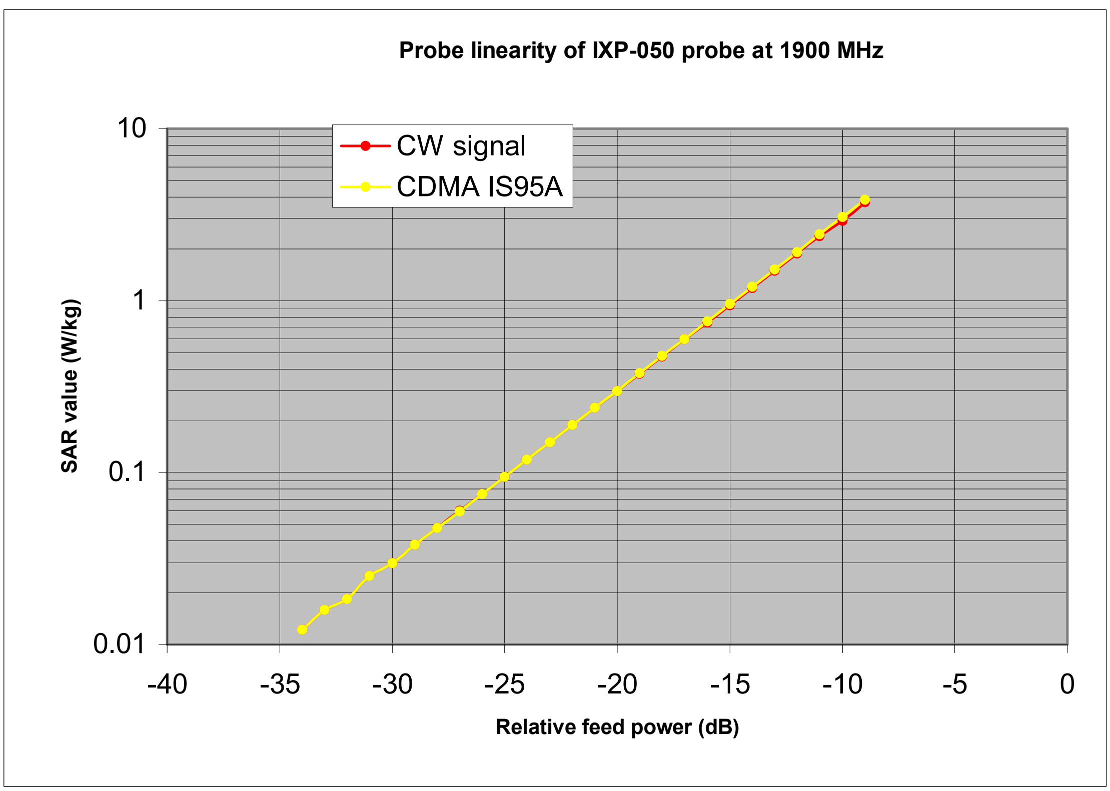

Probe linearity of IXP-050 probe at 1900 MHz
CW signal
CDMA IS95A
SAR value (W/kg)
Relative feed power (dB)
10
1
0.1
0.01
-40
-35
-30
-25
-20
-15
-10
-5
0

*Figure 10. The CDMA 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) |
|---|---|---|
| 835 MHz BRAIN | 43.3 | 0.911 |
| 835 MHz BODY | 58.9 | 0.985 |
| 900 MHz BRAIN | 42.5 | 0.97 |
| 900 MHz BODY | 58.45 | 1.044 |
| 1800 MHz BRAIN | 38.97 | 1.33 |
| 1800 MHz BODY | 52.53 | 1.51 |
| 1900 MHz BRAIN | 38.43 | 1.429 |
| 1900 MHz BODY | 52.02 | 1.62 |
| 2000 MHz BRAIN | 37.42 | 1.36 |
| 2450 MHz BRAIN | 39.29 | 1.737 |
| 2450 MHz BODY | 62.9 | 2.08 |

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*e-mail: enquiries@indexsar.com*

# Calibration Certificate
# Dosimetric E-field Probe

| | |
|---|---|
| Type: | **IXP-050** |
| Manufacturer: | **IndexSAR, UK** |
| Serial Number: | **0123** |
| Place of Calibration: | **IndexSAR, UK** |

**IndexSAR Limited hereby declares that the IXP-050 Probe named above has been calibrated for conformity to the IEEE 1528 and CENELEC En 50361 standards on the date shown below.**

| | |
|---|---|
| Date of Initial Calibration: | **25th October 2002** |

**The probe named above will require a calibration check on the date shown below.**

| | |
|---|---|
| Next Calibration Date: | **October 2003** |

**The calibration was carried out using the methods described in the calibration document. Where applicable, the standards used in the calibration process are traceable to the UK's National Physical Laboratory.**

**Calibrated By:**

**Approved By:**

***Please keep this certificate with the calibration document. When the probe is sent for a calibration check, please include the calibration document.***