



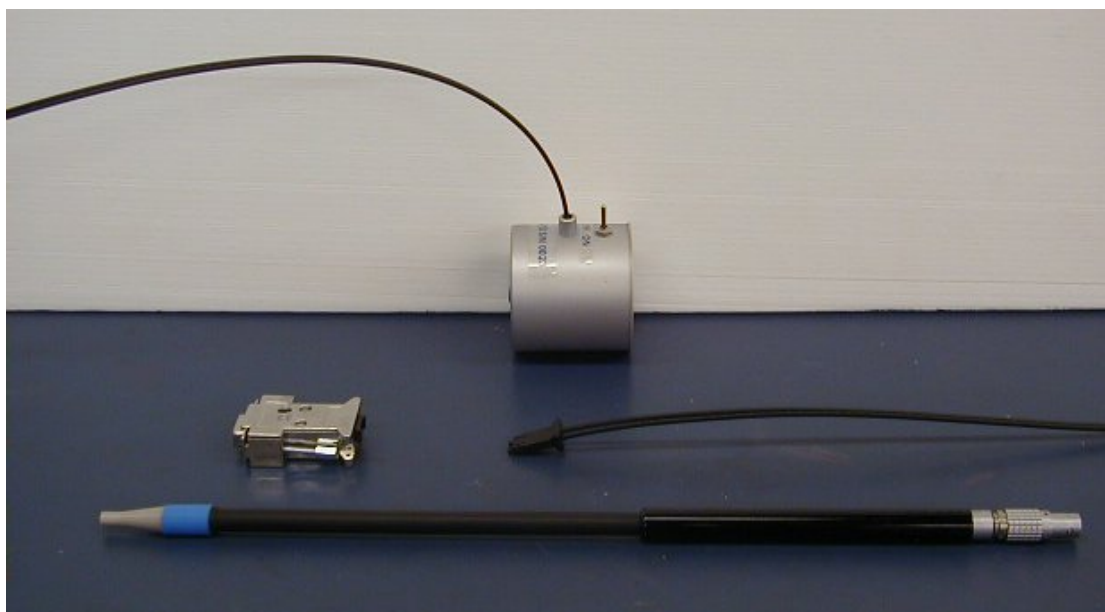
## **IMMERSIBLE SAR PROBE**

### **CALIBRATION REPORT**

**Part Number: IXP – 050**

**S/N 0201**

**June 2009**



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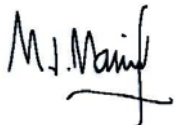
**e-mail: [enquiries@indexsar.com](mailto:enquiries@indexsar.com)**

**Calibration Certificate 0811/0201**  
**Date of Issue: 7<sup>th</sup> June 2009**  
**Immersible SAR Probe**

Type:	IXP-050
Manufacturer:	IndexSAR, UK
Serial Number:	0201
Place of Calibration:	IndexSAR, UK
Date of Receipt of Probe:	7 <sup>th</sup> June 2010
Calibration Dates:	7 <sup>th</sup> — 14 <sup>th</sup> June 2009
Customer:	S.E.T.

IndexSAR Ltd hereby declares that the IXP-050 Probe named above has been calibrated for conformity to the IEEE 1528 and BSEN 62209-1 standards using the methods described in this calibration document. Where applicable, the standards used in the calibration process are traceable to the UK's National Physical Laboratory.

Calibrated by:		Technical Manager
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Approved by:		Director
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Please keep this certificate with the calibration document. When the probe is sent for a calibration check, please include the calibration document.

## INTRODUCTION

This Report presents measured calibration data for a particular Indexsar SAR probe (S/N 0201) only and describes the procedures used for characterisation and calibration.

Indexsar probes are characterised using procedures that, where applicable, follow the recommendations of BSEN 622009-1 [Ref 1] & IEEE [Ref 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. Objectives

The calibration process comprises four stages

- 1) Determination of the channel sensitivity factors which optimise the probe's overall rotational isotropy in 900MHz brain fluid
- 2) Determination of the channel sensitivity factors and angular offset of the X channel which together optimise the probe's spherical isotropy in 900MHz brain fluid
- 3) Numerical combination of the two sets of channel sensitivity factors to give both acceptable rotational isotropy and acceptable spherical isotropy values
- 4) At each frequency of interest, application of these channel sensitivity factors to model the exponential decay of SAR in a waveguide fluid cell, and hence derive the liquid conversion factors at that frequency

### 2. 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 mV 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 100mV.

Conventionally, when used in conjunction with the SARA2 test jig, all measured voltages and voltage-derived values are quoted in units of V\*200

eg a DCP value of 100mV corresponds to 20 in V\*200 units. Conversely, in the SARA C and HACSAR measurement systems, unmodified mV values are used throughout. As a consequence, the cal factors for this probe are listed in two tables, one for SARA2 and one for SARA C / HACSAR.

In turn, measurements of E-field are determined using the following equation (where output voltages are also in units of mV):

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

Here, “Air Factor” represents each channel’s sensitivity, while “Liq Factor” represents the enhancement in signal level when the probe is immersed in tissue-simulant liquids at each frequency of interest.

### 3. Selecting channel sensitivity factors to optimise isotropic response

After manufacture, the first stage of the calibration process is to balance the three channels’ Air Factor values, thereby optimising the probe’s overall axial response (“rotational isotropy”).

To do this, a 900MHz waveguide containing head-fluid simulant is selected. Like all waveguides used during probe calibration, this particular waveguide contains two distinct sections: an air-filled launcher section, and a liquid cell section, separated by a dielectric matching window designed to minimise reflections at the air-liquid interface.

The waveguide stands in an upright position and the liquid cell section is filled with 900MHz brain fluid to within 10 mm of the open end. 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.

During the measurement, a TE<sub>01</sub> mode is launched into the waveguide by means of an N-type-to-waveguide adapter. The probe is then lowered vertically into the liquid until the tip is exactly 10mm above the centre of the dielectric window. This particular separation ensures that the probe is operating in a part of the waveguide where boundary corrections are not necessary.

Care must also be taken that the probe tip is centred while rotating.

The exact power applied to the input of the waveguide during this stage of the probe calibration is immaterial since only relative values are of interest while the probe rotates. However, the power must be sufficiently above the noise floor and free from drift.

The dedicated Indexsar calibration software rotates the probe in 10 degree steps about its axis, and at each position, an Indexsar ‘Fast’ amplifier samples the probe channels 500 times per second for 0.4 s. The raw U<sub>o/p</sub> data from each sample are packed into 10 bytes and transmitted back to the PC

controller via an optical cable.  $U_{linx}$ ,  $U_{liny}$  and  $U_{linz}$  are derived from the raw  $U_{o/p}$  values and written to an Excel template.

Once data have been collected from a full probe rotation, the Air Factors are adjusted using a special Excel Solver routine to equalise the output from each channel and hence minimise the rotational isotropy. This automated approach to optimisation removes the effect of human bias.

Figure 6 represents the output from each diode sensor as a function of probe rotation angle.

#### 4. Measurement of Spherical Isotropy

The setup for measuring the probe's spherical isotropy is shown in Figure 2.

A box phantom containing 900MHz head fluid is irradiated by a vertically-polarised, tuned dipole, mounted to the side of the phantom on the robot's seventh axis. During calibration, the spherical response is generated by rotating the probe about its axis in 20 degree steps and changing the dipole polarisation in 10 degree steps.

By using the VPM technique discussed below, an allowance can also be made for the effect of E-field gradient across the probe's spatial extent. This permits values for the probe's effective tip radius and X-channel angular offset to be modelled until the overall spherical isotropy figure is optimised.

The dipole is connected to a signal generator and amplifier via a directional coupler and power meter. As with the determination of rotational isotropy, the absolute power level is not important as long as it is stable.

The probe is positioned within the fluid so that its sensors are at the same vertical height as the centre of the source dipole. The line joining probe to dipole should be perpendicular to the phantom wall, while the horizontal separation between the two should be small enough for VPM corrections to be applicable, without encroaching near the boundary layer of the phantom wall. VPM corrections require a knowledge of the fluid skin depth. This is measured during the calibration by recording the E-field strength while systematically moving the probe away from the dipole in 2mm steps over a 20mm range.

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, a representative image of which is shown 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.

## 5. Determination of Conversion (“Liquid”) Factors at each frequency of interest

A lookup table of conversion factors for a probe allows a SAR value to be derived at the measured frequencies, and for either brain or body fluid-simulant.

The method by which the conversion factors are assessed is based on the comparison between measured and analytical rates of decay of SAR with height above a dielectric window. This way, not only can the conversion factors for that frequency/fluid combination be determined, but an allowance can also be made for the scale and range of boundary layer effects.

The theoretical relationship between the SAR at the cross-sectional centre of the lossy waveguide as a function of the longitudinal distance ( $z$ ) from the dielectric separator is given by Equation 3:

$$SAR(z) = \frac{4(P_f - P_b)}{\rho ab \delta} e^{-2z/\delta} \quad (3)$$

Here, the density  $\rho$  is conventionally assumed to be 1000 kg/m<sup>3</sup>,  $ab$  is the cross-sectional area of the waveguide, and  $P_f$  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 a property of the lossy liquid and is given by Equation (4).

$$\delta = \left[ \text{Re} \left\{ \sqrt{(\pi/a)^2 + j\omega\mu_o(\sigma + j\omega\epsilon_o\epsilon_r)} \right\} \right]^{-1} \quad (4)$$

where  $\sigma$  is the conductivity of the tissue-simulant liquid in S/m,  $\epsilon_r$  is its relative permittivity, and  $\omega$  is the radial frequency (rad/s). Values for  $\sigma$  and  $\epsilon_r$  are obtained prior to each waveguide test using an Indexsar DiLine measurement kit, which uses the TEM method as recommended in [2].  $\sigma$  and  $\epsilon_r$  are both temperature- and fluid-dependent, so are best measured using a sample of the tissue-simulant fluid immediately prior to the actual calibration.

Wherever possible, all DiLine and calibration measurements should be made in the open laboratory at  $22 \pm 2.0^\circ\text{C}$ ; if this is not possible, the values of  $\sigma$  and  $\epsilon_r$  should reflect the actual temperature. Values employed for calibration are listed in the tables below.

By ensuring the liquid height in the waveguide is at least three penetration depths, reflections at the upper surface of the liquid are negligible. The power absorbed in the liquid is therefore determined solely from the waveguide forward and reflected power.

Different waveguides are used for 835/900MHz, 1800/1900MHz, 2450/2600MHz and 5200/5800MHz measurements. Table A.1 of [1] can be used for designing calibration waveguides with a return loss greater than 20

dB at the most important frequencies used for personal wireless communications, and better than 15dB for frequencies greater than 5GHz. Values for the penetration depth for these specific fixtures and tissue-simulating mixtures are also listed in the aforementioned 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 5800 MHz because of the waveguide size is not severe in the context of compliance testing.

During calibration, the probe is lowered carefully until it is just touching the cross-sectional centre of the dielectric window. 200 samples are then taken and written to an Excel template file before moving the probe vertically upwards. This cycle is repeated 150 times. The vertical separation between readings is determined from practical considerations of the expected SAR decay rate, and range from 0.2mm steps at low frequency, through 0.1mm at 2450MHz, down to 0.05mm at 5GHz.

Once the data collection is complete, a Solver routine is run which optimises the measured-theoretical fit by varying the conversion factor, and the boundary correction size and range.

For 450 MHz calibrations, a slightly different technique must be used — the equatorial response of the probe-under-test is compared with the equivalent response of a probe whose 450MHz characteristics have already been determined by NPL. The conversion factor of the probe-under-test can then be deduced.

### **VPM (Virtual Probe Miniaturisation)**

SAR probes with 3 diode-sensors in an orthogonal arrangement are designed to display an isotropic response when exposed to a uniform field. However, the probes are ordinarily used for measurements in non-uniform fields and isotropy is not assured when the field gradients are significant compared to the dimensions of the tip containing the three orthogonally-arranged dipole sensors.

It becomes increasingly important to assess the effects of field gradients on SAR probe readings when higher frequencies are being used. For Indexsar IXP-050 probes, which are of 5mm tip diameter, field gradient effects are minor at GSM frequencies, but are major above 5GHz. Smaller probes are less affected by field gradients and so probes, which are significantly less than 5mm diameter, would be better for applications above 5GHz.

The IndexSAR report IXS0223 [4] describes theoretical and experimental studies to evaluate the issues associated with the use of probes at arbitrary angles to surfaces and field directions. Based upon these studies, the procedures and uncertainty analyses referred to in [2] are addressed for the full range of probe presentation angles.

In addition, generalized procedures for correcting for the finite size of immersible SAR probes are developed. Use of these procedures enables application of schemes for virtual probe miniaturization (VPM) – allowing probes of a specific size to be used where physically-smaller probes would otherwise be required.

Given the typical dimensions of 3-channel SAR probes presently available, use of the VPM technique extends the satisfactory measurement range to higher frequencies.

### **CALIBRATION FACTORS MEASURED FOR PROBE S/N 0201**

The probe was calibrated at 835, 900, 1800, 1900, 2100 and 2450 MHz in liquid samples representing brain and body liquid 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. The distance of 2.7mm for assembled probes has been confirmed by taking X-ray images of the probe tips (see Figure 9).

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.

### **CALIBRATION EQUIPMENT**

The table on page 20 indicates the calibration status of all test equipment used during probe calibration.



## MEASUREMENT UNCERTAINTIES

A complete measurement uncertainty analysis for the SARA2 measurement system has been published in Reference [3]. Table 10 from that document is re-created below, and lists the uncertainty factors associated just with the calibration of probes.

Source of uncertainty	Uncertainty value $\pm$ %	Probability distribution	Divisor	$c_i$	Standard uncertainty $u_i \pm$ %	$v_i$ or $v_{eff}$
Incident or forward power	5.743	N	1.00	1	5.743	$\infty$
Reflected power	5.773	N	1.00	1	5.773	$\infty$
Liquid conductivity	1.120	N	1.00	1	1.120	$\infty$
Liquid permittivity	1.085	N	1.00	1	1.085	$\infty$
Field homogeneity	0.002	R	1.73	1	0.001	$\infty$
Probe positioning: $\pm 0.05$ mm	0.55	R	1.73	1	0.318	
Influence on Probe pos: 11%/mm						
Field probe linearity	4.7	R	1.73	1	2.714	$\infty$
<b>Combined standard uncertainty</b>		<b>RSS</b>			<b>8.729</b>	

At the 95% confidence level, therefore, the expanded uncertainty is 17.1%

**SUMMARY OF CALIBRATION FACTORS**  
(for use with SARA C & HACSAR)

	<b>X</b>	<b>Y</b>	<b>Z</b>	<b>Units</b>
<b>Air Factors</b>	76.02	92.08	71.90	$(V/m)^2/mV$
<b>CW DCPs</b>	100	100	100	mV

<b>Freq (MHz)</b>	<b>Head</b>			<b>Body</b>		
	<b>SAR Conv Factor</b>	<b>Bound Corrn. – f(0)</b>	<b>Bound Corrn. – d(mm)</b>	<b>SAR Conv Factor</b>	<b>Bound Corrn. – f(0)</b>	<b>Bound Corrn. – d(mm)</b>
<b>450</b>	0.321	-	-	0.326	-	-
<b>900</b>	0.282	1.05	1.4	0.298	1.01	1.5
<b>1800</b>	0.338	1.28	1.2	0.398	0.95	1.6
<b>2450</b>	0.376	0.87	1.6	0.431	0.80	1.8

<b>Miscellaneous</b>	
Sensor offset	2.7 mm
X Ch. Angle to red dot	1.4°

<b>Measured Isotropy at 900MHz</b>	<b>(+/-) dB</b>
Spherical Isotropy	0.36
Axial Isotropy	0.06

**SUMMARY OF CALIBRATION FACTORS**  
(for use with SARA 2)

	<b>X</b>	<b>Y</b>	<b>Z</b>	<b>Units</b>
<b>Air Factors</b>	354	376	470	$(V/m)^2/(V*200)$
<b>CW DCPs</b>	20	20	20	V*200

<b>Freq (MHz)</b>	<b>Head</b>			<b>Body</b>		
	<b>SAR Conv Factor</b>	<b>Bound Corrn. – f(0)</b>	<b>Bound Corrn. – d(mm)</b>	<b>SAR Conv Factor</b>	<b>Bound Corrn. – f(0)</b>	<b>Bound Corrn. – d(mm)</b>
<b>450</b>	0.321	-	-	0.326	-	-
<b>900</b>	0.282	1.05	1.4	0.298	1.01	1.5
<b>1800</b>	0.338	1.28	1.2	0.398	0.95	1.6
<b>2450</b>	0.376	0.87	1.6	0.431	0.80	1.8

<b>Miscellaneous</b>	
Tip radius	1.25 mm
X Ch. Angle to red dot	1.4°

<b>Measured Isotropy at 900MHz</b>	<b>(+/-) dB</b>
Spherical Isotropy	0.36
Axial Isotropy	0.06

## PROBE SPECIFICATIONS

Indexsar probe 0201, along with its calibration, is compared with BSEN 62209-1 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>	S/N 0201	BSEN [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		

<b>Dynamic range</b>	S/N 0201	BSEN [1]	IEEE [2]
Minimum (W/kg)	0.01	<0.02	0.01
Maximum (W/kg) N.B. only measured to > 100 W/kg on representative probes	>100	>100	100

<b>Isotropy (measured at 900MHz)</b>	S/N 0201	BSEN [1]	IEEE [2]
Axial rotation with probe normal to source (+/- dB)	0.06 (See table above)	0.5	0.25
Spherical isotropy covering all orientations to source (+/- dB)	0.36	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.. Outer case materials are PEEK and adhesive-lined heat-shrink sleeving.
<b>Chemical resistance</b>	Tested to be resistant to glycol, Indexsar-supplied liquids based on sugar/salt/Tween in the long term, and alcohol containing simulant liquids in the short term, but probes should be removed, cleaned and dried when not in use.

## REFERENCES

- [1] BSEN 62209-1:2006. Human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices — Human models, instrumentation, and procedures — Part 1: Procedure to determine the specific absorption rate (SAR) for hand-held devices used in close proximity to the ear (frequency range of 300 MHz to 3 GHz)
- [2] IEEE 1528, 2003 Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques
- [3] Indexsar Report IXS-0300, October 2007. Measurement uncertainties for the SARA2 system assessed against the recommendations of BS EN 62209-1:2006
- [4] Indexsar Report IXS-0223, May 2003. Compensating for the finite size of SAR probes used in electric field gradients

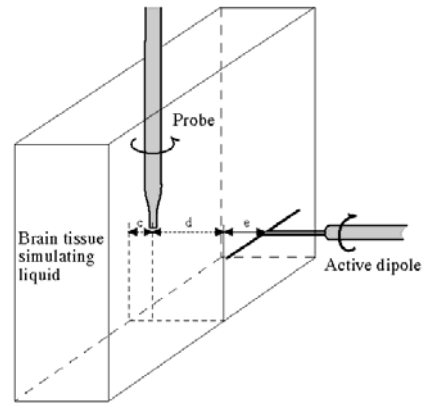
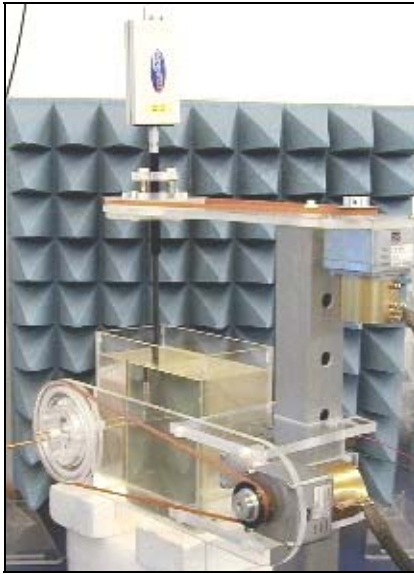


Figure 1. Spherical isotropy jig showing probe, dipole and box filled with simulated brain liquid (see Ref [2], Section A.5.2.1)

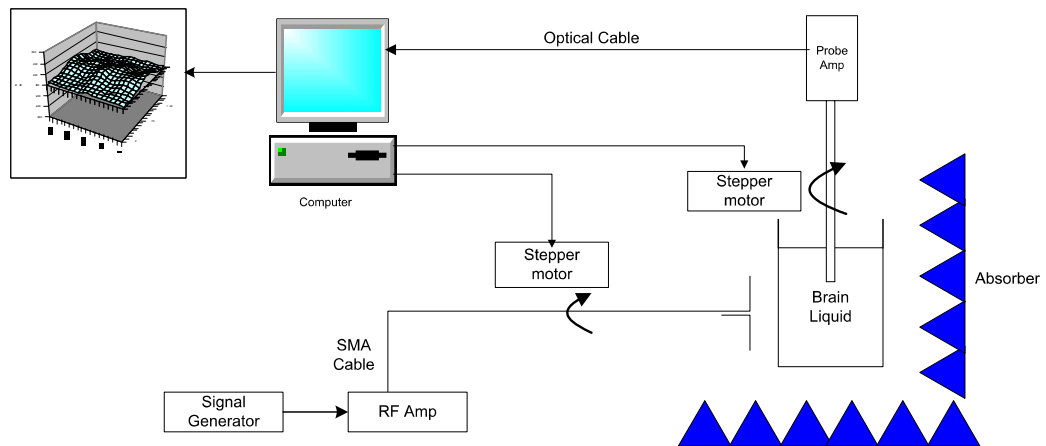


Figure 2 Schematic diagram of the test geometry used for isotropy determination

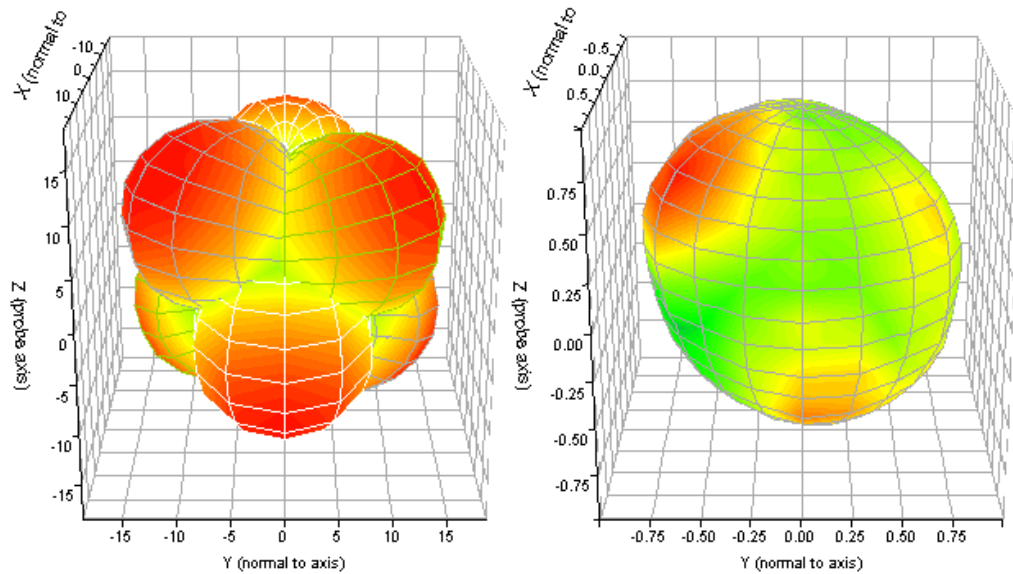


Figure 3 Graphical representation of a probe's response to fields applied from each direction. The diagram on the left shows the individual response characteristics of each of the three channels and the diagram on the right shows the resulting probe sensitivity sensitivity in each direction. The colour range in the figure images the lowest values as blue and the maximum values as red. For probe S/N 0201, this range is (+/-) 0.36dB.

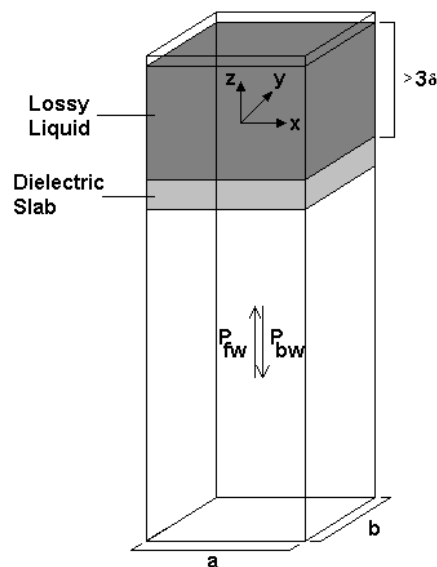


Figure 4 Geometry used for waveguide calibration (after Ref [2]. Section A.3.2.2)

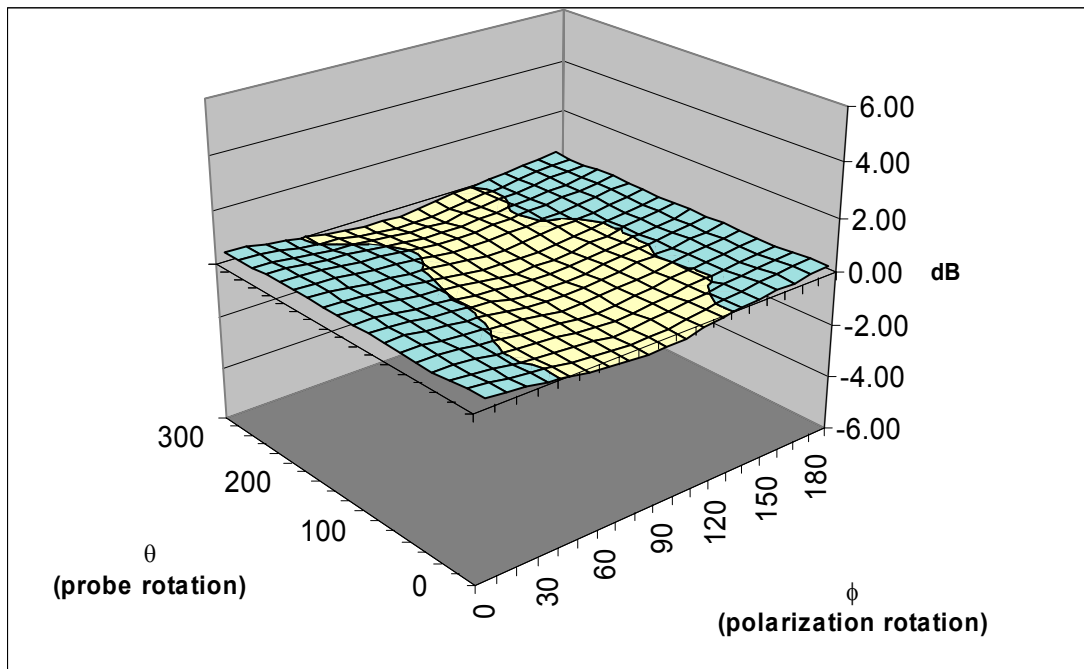


Figure 5 Surface Isotropy diagram of IXP-050 Probe S/N 0201 at 900MHz after VPM (rotational isotropy axial  $\pm 0.06\text{dB}$ , spherical isotropy  $\pm 0.36\text{dB}$ )

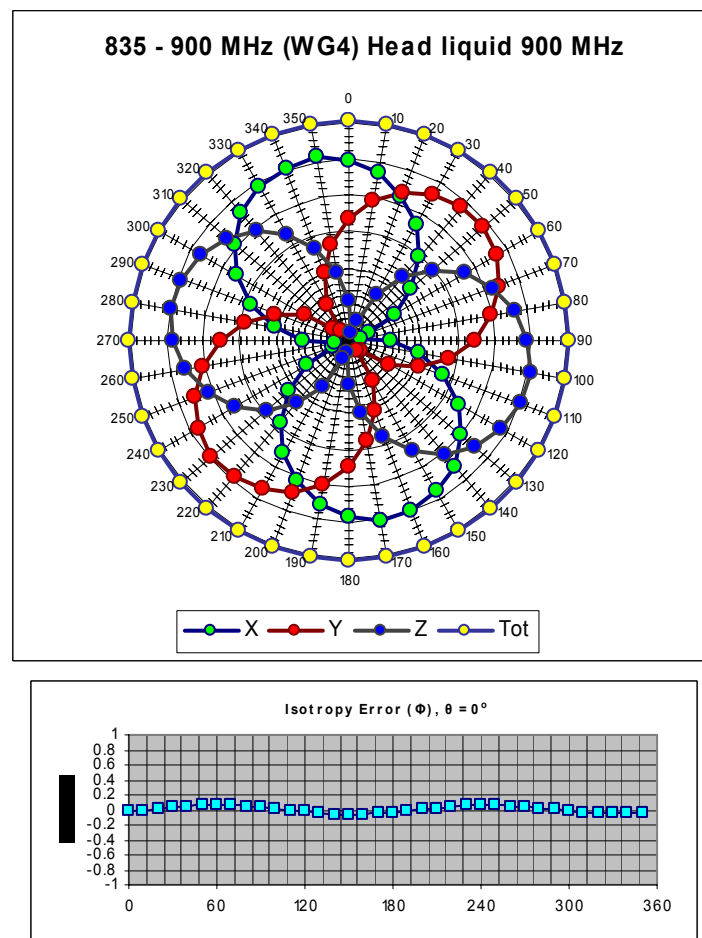
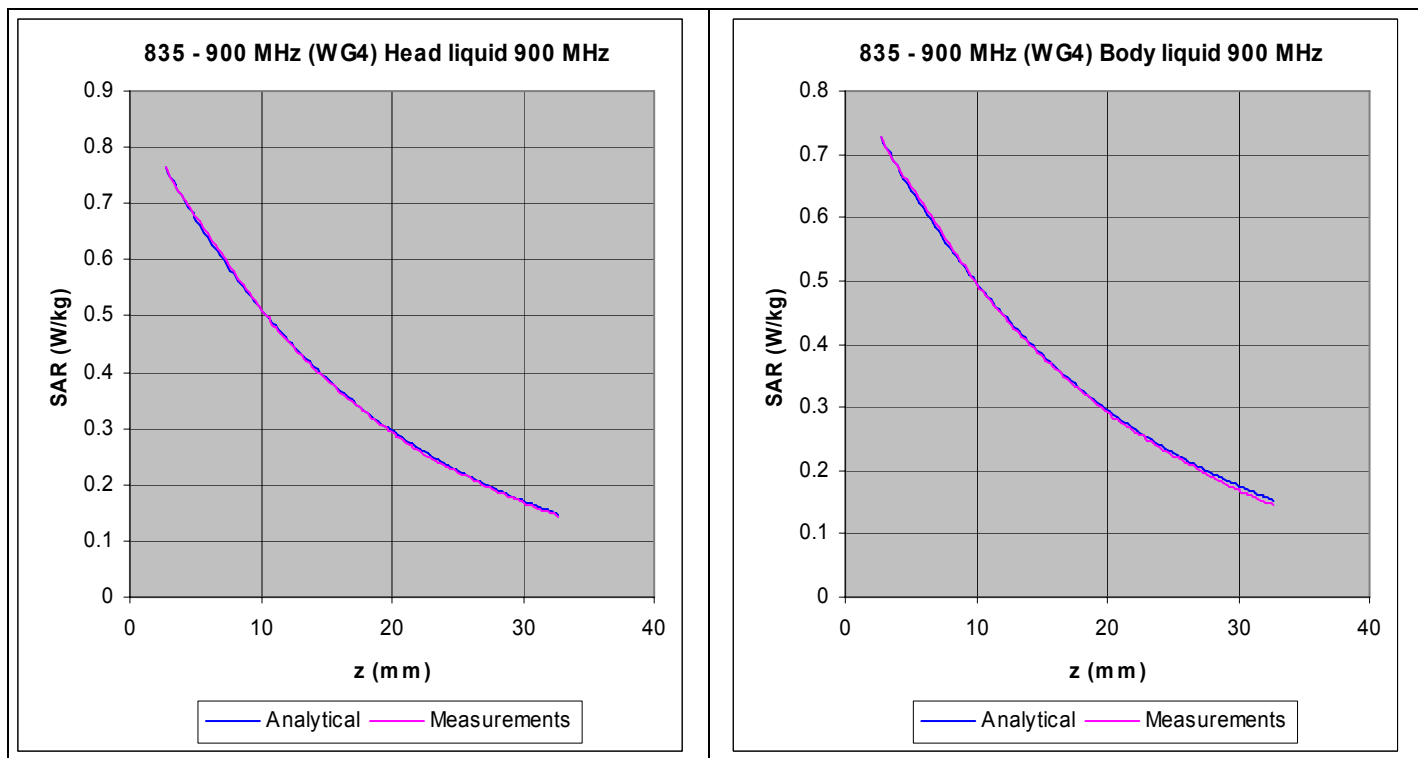
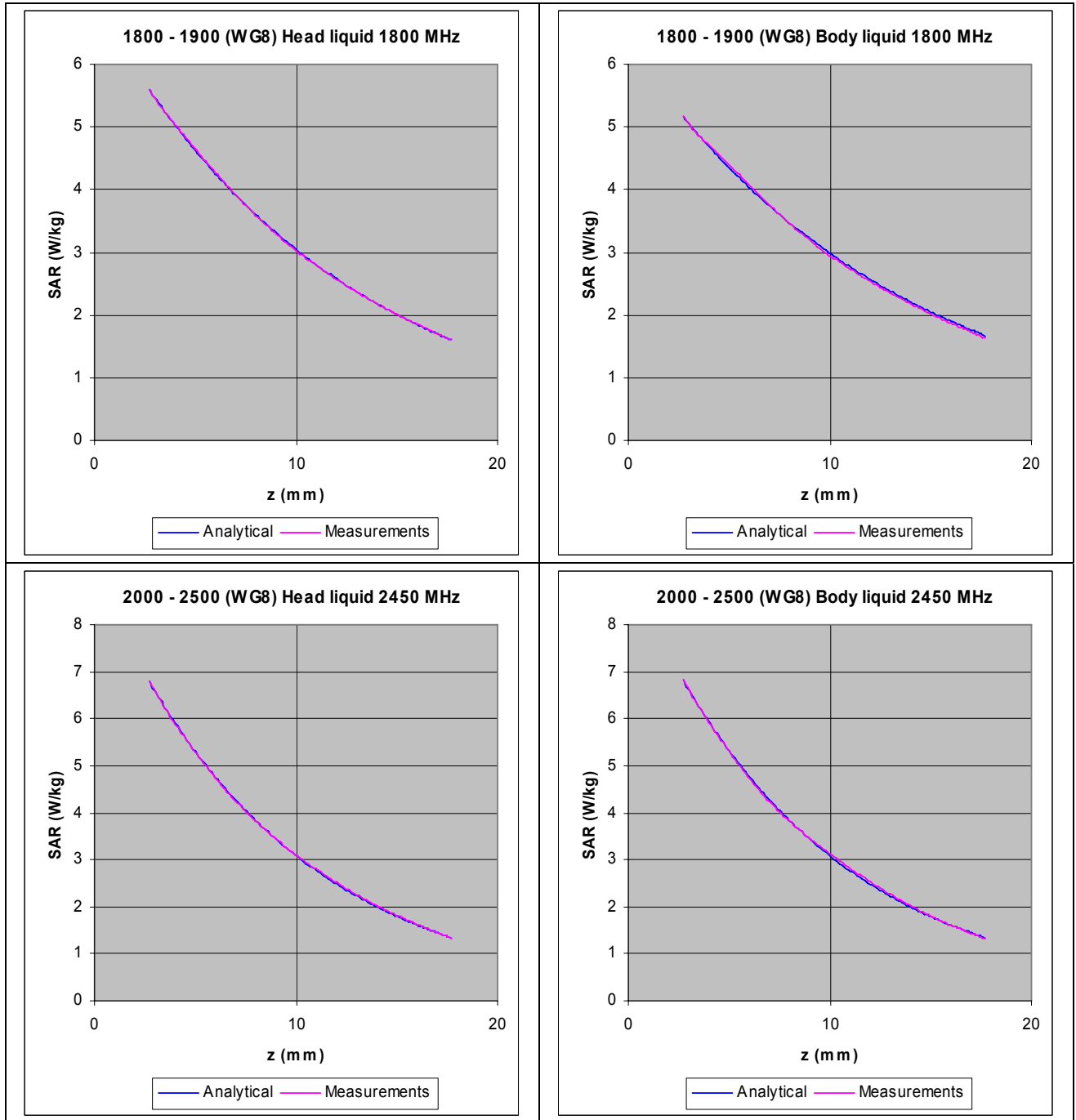


Figure 6. The rotational isotropy of probe S/N 0201 obtained by rotating the probe in a liquid-filled waveguide at 900 MHz.





*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 WG8 waveguide with conversion factors adjusted to fit to the theoretical function for the particular dimension, frequency, power and liquid properties employed.*

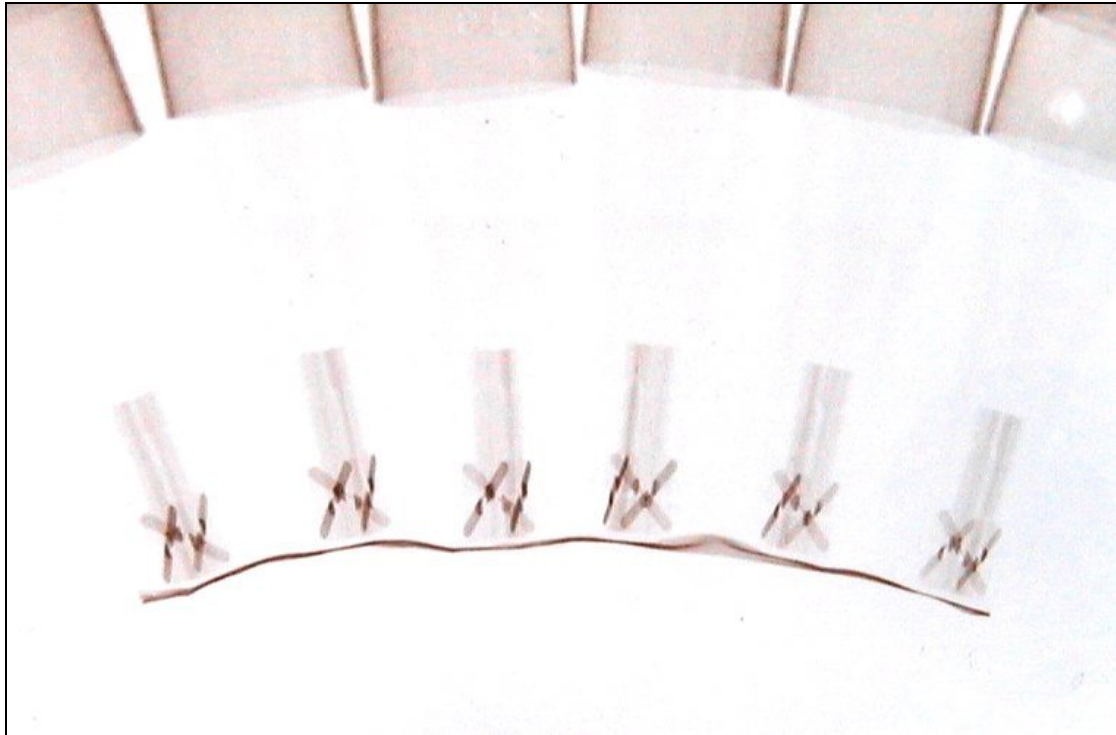


Figure 9: X-ray positive image of 5mm probes

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

Frequency (MHz)	BRAIN		BODY	
	Relative permittivity (measured)	Conductivity (S/m) (measured)	Relative permittivity (measured)	Conductivity (S/m) (measured)
450	44.73	0.84	56.65	0.73
900	40.92	0.96	54.59	1.04
1800	39.92	1.43	53.35	1.48
2450	38.29	1.81	52.38	2.12

**Table of test equipment calibration status**

<b>Instrument description</b>	<b>Supplier / Manufacturer</b>	<b>Model</b>	<b>Serial No.</b>	<b>Last calibration date</b>	<b>Calibration due date</b>
Power sensor	Rohde & Schwarz	NRP-Z23	100063	16/06/2009	16/6/2011
Dielectric property measurement	Indexsar	DiLine (sensor lengths: 160mm, 80mm and 60mm)	N/A	(absolute) – checked against NPL values using reference liquids	N/A
Vector network analyser	Anritsu	MS6423B	003102	09/10/2009	09/10/2011
SMA autocalibration module	Anritsu	36581KKF/1	001902	09/10/2009	09/10/2011