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 09/04/2003. SAR measurements were made within 24 hours of the measurement of liquid parameters.

Freq. (MHz)	Rel. Perm.	Condy (S/m)
900	41.47	0.979

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 09/04/2003. SAR measurements were made within 24 hours of the measurement of liquid parameters.

Freq. (MHz)	Rel. Perm.	Condy (S/m)
825.25	55.8	0.977
836.5	55.4	0.986
847.75	55.3	0.992

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 09/03/2003. SAR measurements were made within 24 hours of the measurement of liquid parameters.

Freq. (MHz)	Rel. Perm.	Condy (S/m)
1900	40.32	1.392

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 09/03/2003. SAR measurements were made within 24 hours of the measurement of liquid parameters.

Freq. (MHz)	Rel. Perm.	Condy (S/m)
1850.2	53.46	1.531
1880	53.27	1.540
1909.8	53.06	1.551

Environment: 09/03/2003, 09/04/2003 & 06/21/2004:

Temperature**:** **20.1 °C – 23.9°C**
Humidity: **45% _ 55 %**

Test Equipment

Instrument description	Supplier / Manufacturer	Model	Serial No.	Calibration (date)	Calibration Due (date)
Bench top Robot	Mitsubishi supplied by IndexSAR	RV-E2	EA1030108	N/A	N/A
SAM Phantom	Upright shell phantom made by Antennessa digitized and mounted by IndexSAR	SAM	03FT26	04/03	N/A
Flat Phantom	IndexSAR	HeadBox_Spout	N/A	N/A	N/A
Software	IndexSAR	SARA2 v0.420	N/A	N/A	N/A
900 MHz Head Tissue Simulant	Cetecom Inc.	900 Head	N/A	09/04/2003	N/A
850 MHz Body Tissue Simulant	Cetecom Inc.	850 Body	N/A	09/04/2003	N/A
1900 MHz Head Tissue Simulant	Cetecom Inc.	1900 Head	N/A	09/03/2003	N/A
1900 MHz Body Tissue Simulant	Cetecom Inc.	1900 Body	N/A	09/03/2003	N/A
900 MHz Dipole	IndexSAR – IEEE 1528 design	IXD-090	0016	07/20/2003	07/20/2004
1900 MHz Dipole	IndexSAR – IEEE 1528 design	IXD-190	0016	07/20/2003	07/20/2004
Netwok Analyzer	Agilent	8753ES	US39172511	05/03/2004	05/03/2005
Directional coupler	Werlatone	C6529	11249	N/A	N/A
RF Amplifier	Vectawave	VTL5400	N/A	N/A	N/A
Power Meter	HP	EPM-442A	GB37170232	8/19/2003	8/19/2004
Power Sensor	HP	8481A	1926A20587	8/19/2003	8/19/2004
Power Sensor	HP	8481H	3318A15893	02/10/2004	02/10/2005
SAR Probe	IndexSAR	IXP-050	S/N 0106	7/15/2003	7/15/2004
Probe amplifier	IndexSAR	IXA-010	S/N 043	N/A	N/A
Thermometer	Control Company	4039	20410549	11/20/2001	11/20/2004
Dielectric Measurement Kit	IndexSAR	Di-Line	N/A	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

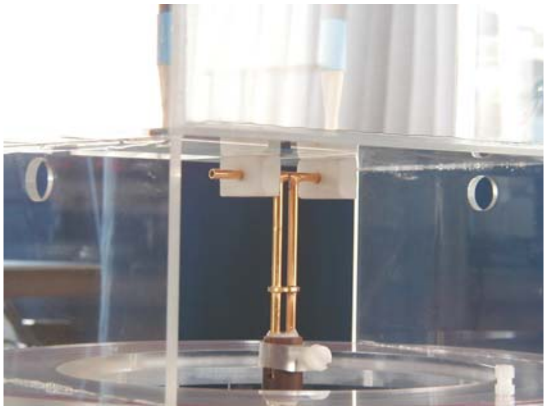
July 1st 2002

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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Tel: +44 (0) 1306 631233 Fax: +44 (0) 1306 631834
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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.

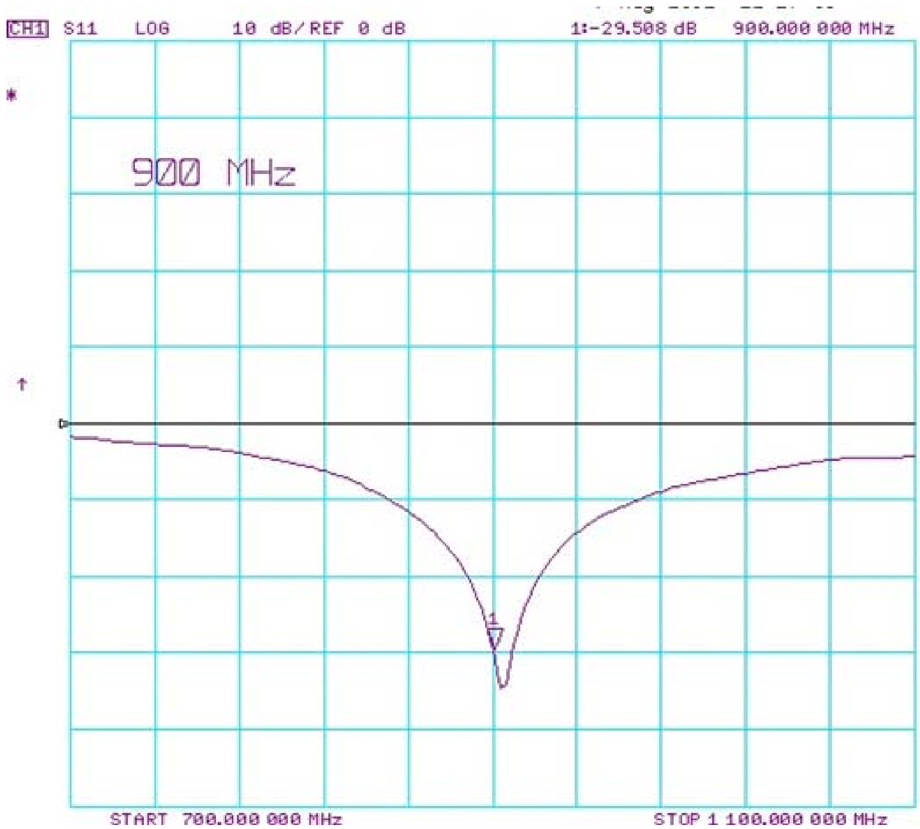
Please note that, because of their construction, the dipoles are short-circuited for DC signals.

4. Performance Measurement

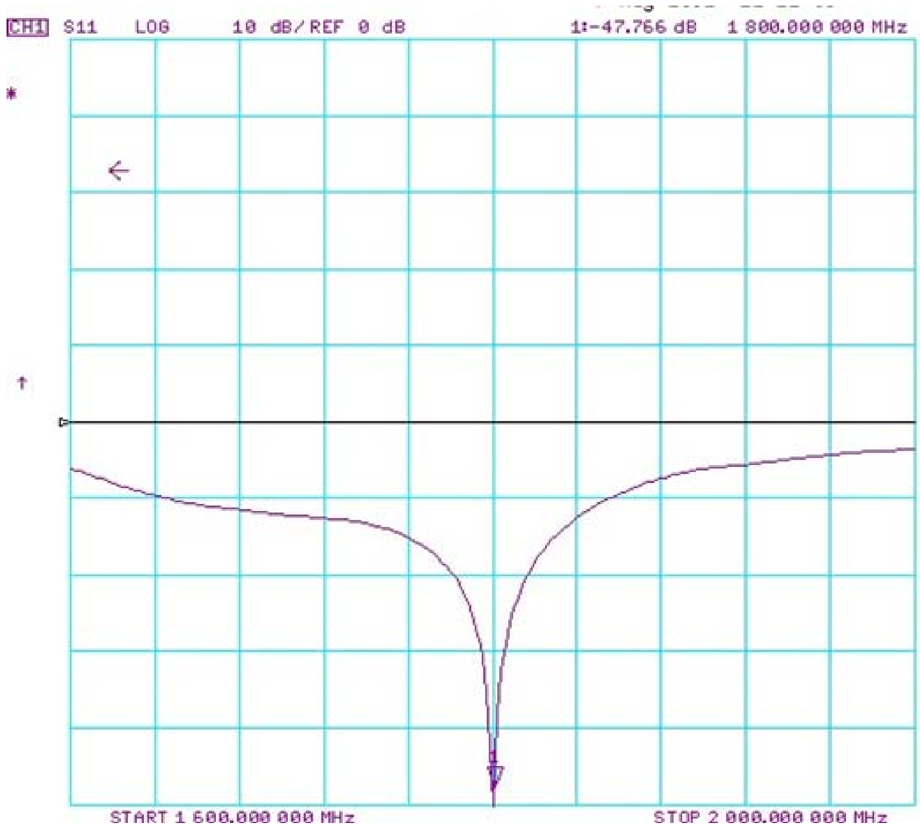
The dipoles are individually tested at their nominal frequency to ensure that they exhibit a return loss of less than -20dB when used with brain or body liquids.

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.

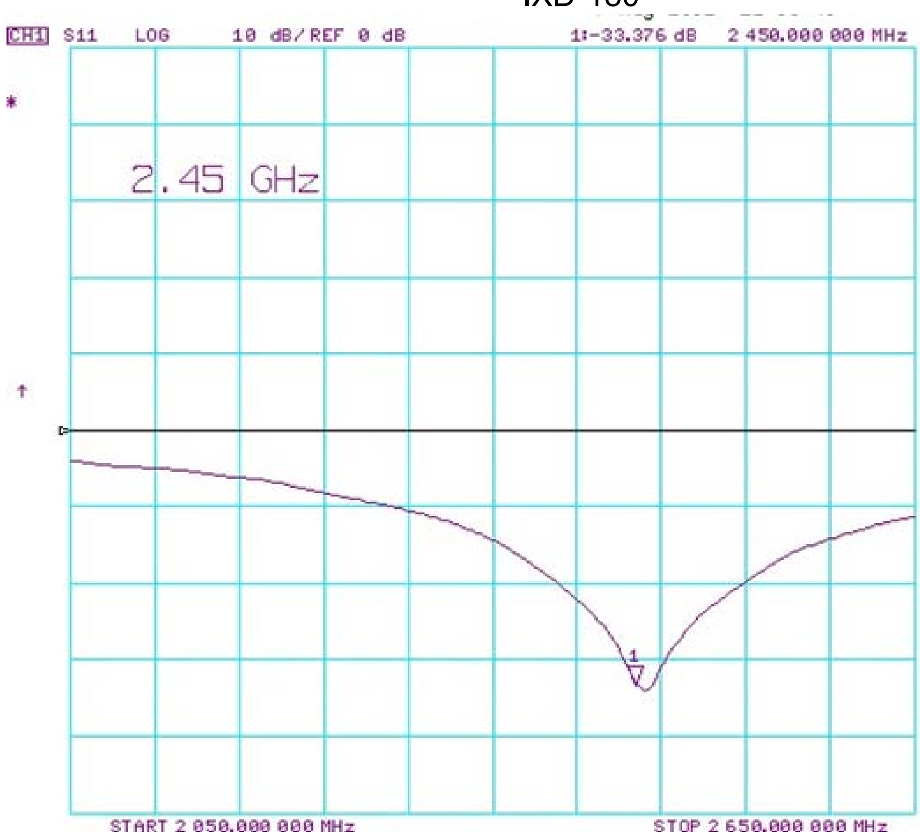
S11 plots for the dipoles with nominal frequencies of 900MHz, 1800MHz and 2450MHz are shown below.



IXD-090



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.

IMMERSIBLE SAR PROBE

CALIBRATION REPORT

Part Number: IXP – 050

S/N 0106

15th July 2003

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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):

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

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

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

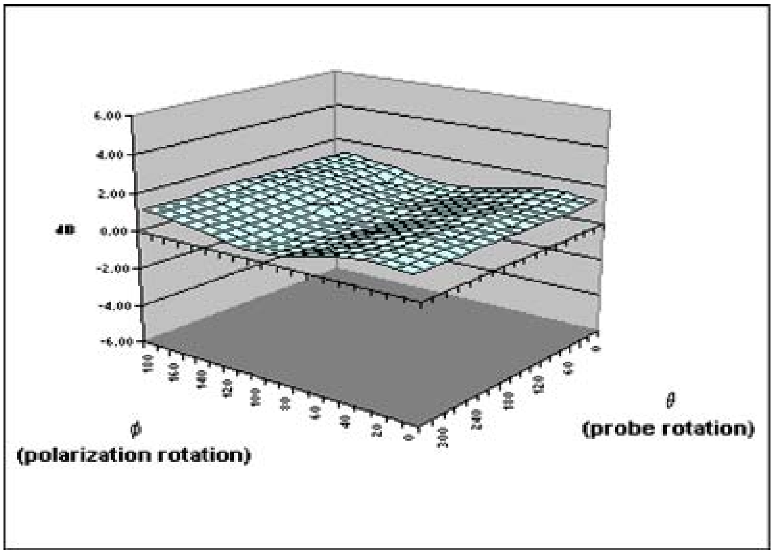
Where σ is the conductivity of the simulant liquid employed.

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 8 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

Spherical isotropy measured at 900 MHz 0.46 (+/-) dB
VPM factors:
X channel angle w.r.t. red dot **0** degrees
Sensor radius **1.25** mm



	X	Y	Z	
Air factors	415	805	371	(V*200)
DCPs	20	20	20	(V*200)
GSM	9.4	2.7	7.8	(V*200)
CDMA	20	20	20	(V*200)

f (MHz)	Axial isotropy (+/- dB)		SAR conversion factors (liq/air) / f(0)		
	BRAIN	BODY	BRAIN	BODY	d (mm)
835	0.05	0.05	0.348 / **0.65**	0.357 / **0.58**	**2**
900	0.05	0.04	0.351 / **0.65**	0.360 / **0.61**	**2**
1800	0.05	0.08	0.408 / **0.15**	0.453 / **0.15**	**2**
1900	0.05	0.08	0.423 / **0.15**	0.477 / **0.15**	**2**
2450	0.10	0.08	0.480 / **0.15**	0.585 / **0.79**	**2**
5200	0.30	-	0.660 / **0.80**	-	**2**
5800	0.30	-	0.660 / **0.80**	-	**2**

Notes
1) Calibrations done at 22C +/- 2C
2) Waveguide calibration
3) Checked using box-phantom validation test

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

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) 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 0106	CENELEC [1]	IEEE [2]
Axial rotation with probe normal to source (+/- dB) at 835, 900, 1800, 1900 and 2450 MHz	Max. 0.30 (see summary table)	0.5	0.25
Spherical isotropy covering all orientations to source (+/- dB)	0.46	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*.

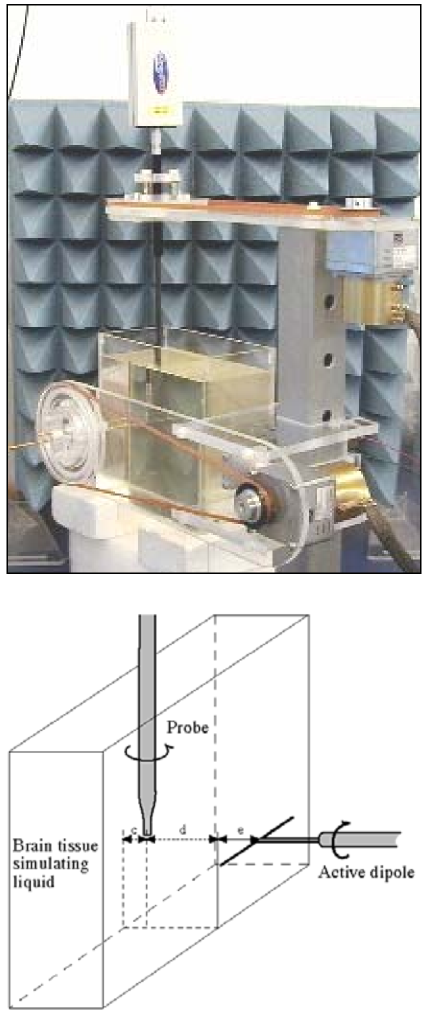


Figure 1. Calibration jig showing probe, dipole and box filled with simulated brain liquid (see Ref [2], Section A.5.2.1)

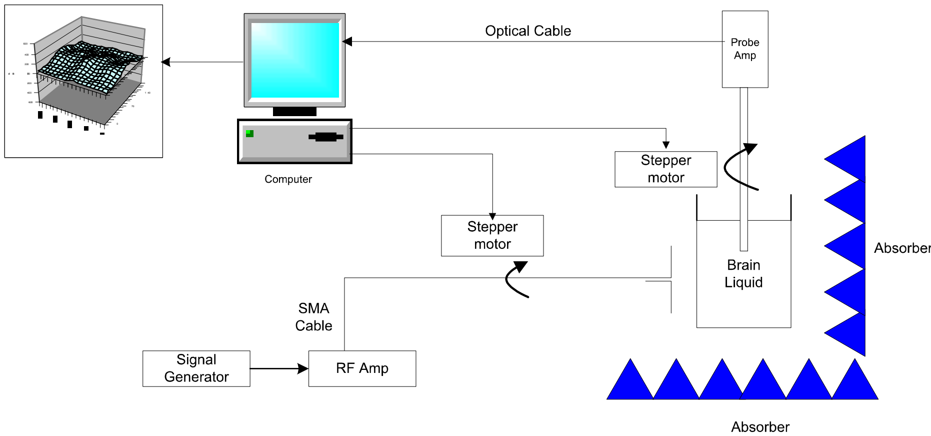


Figure 2. Schematic diagram of the test geometry used for isotropy determination

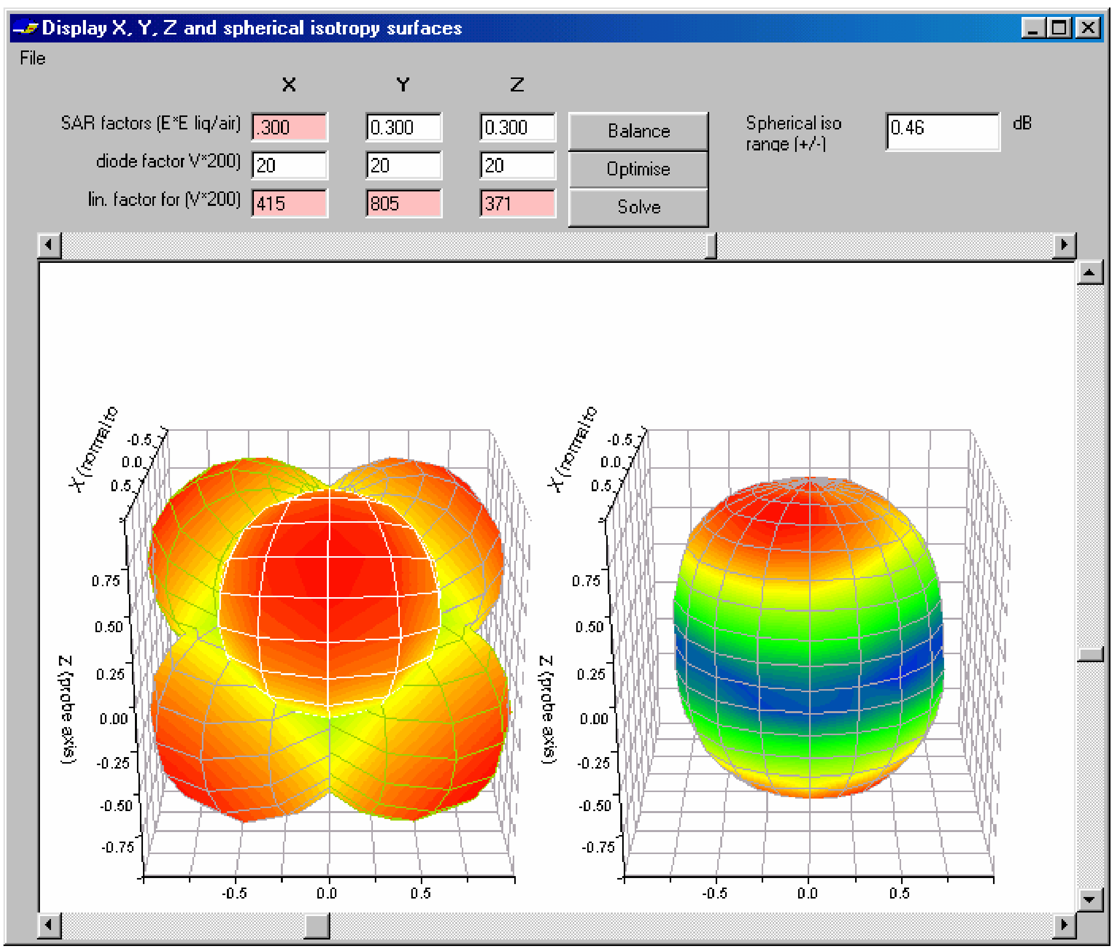


Figure 3. Graphical representation of the probe response to fields applied from each direction. The diagram on the left shows the individual response characteristics of each of the three channels and the diagram on the right shows the resulting probe sensitivity in each direction. The colour range in the figure images the lowest values as blue and the maximum values as red. For the probe S/N 0106, this range is (+/-) 0.46 dB. The probe is more sensitive to fields parallel to the axis and less sensitive to

fields normal to the probe axis.

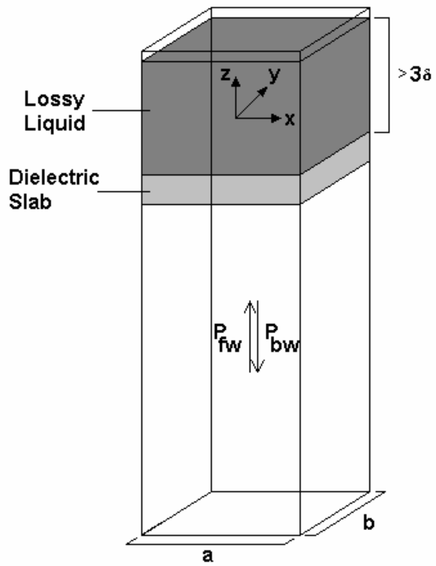
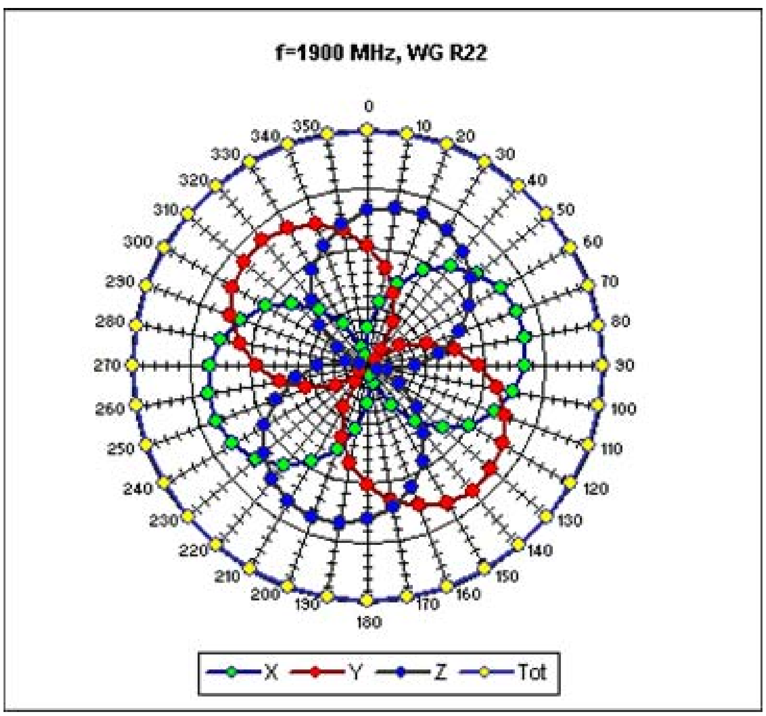


Figure 4. Geometry used for waveguide calibration (after Ref [2]. Section A.3.2.2)



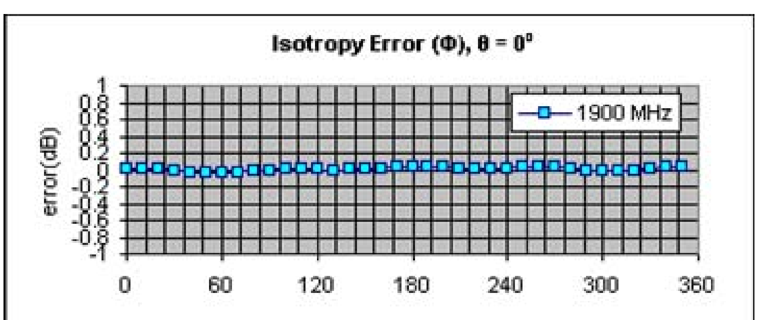


Figure 5. Example of the rotational isotropy of probe S/N 0106 obtained by rotating the probe in a liquid-filled waveguide at 1900 MHz. Similar distributions are obtained at the other test frequencies (1800 and 2450 MHz) both in brain liquids and body fluids (see summary table)

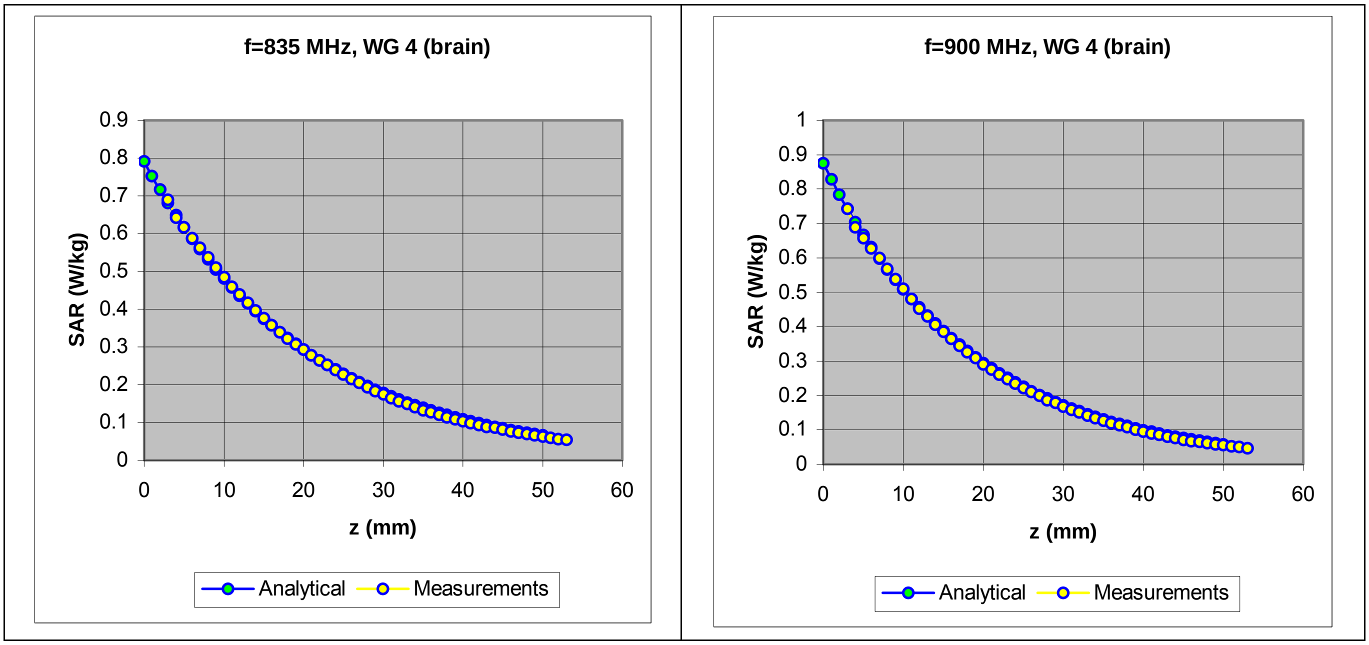
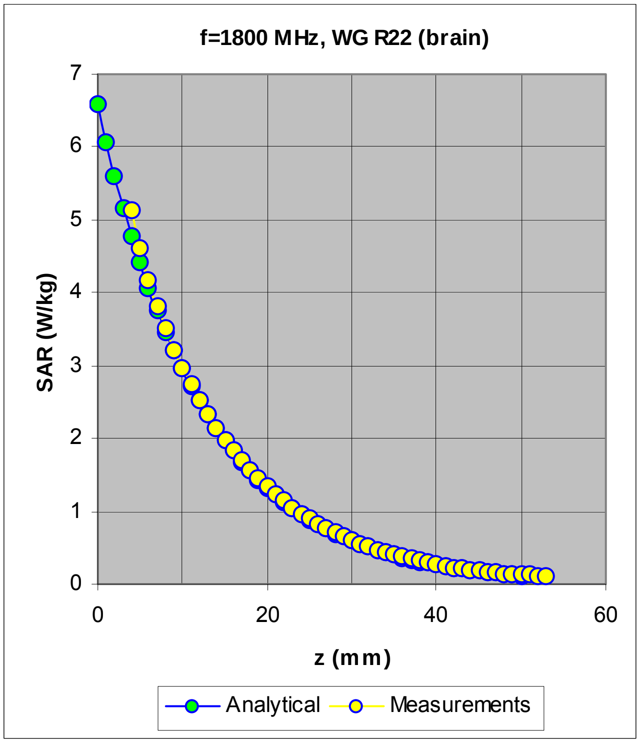
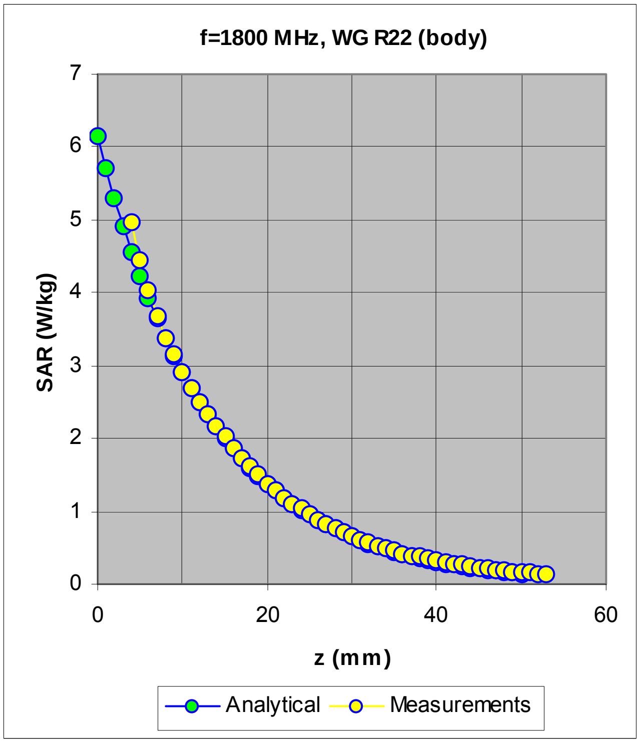
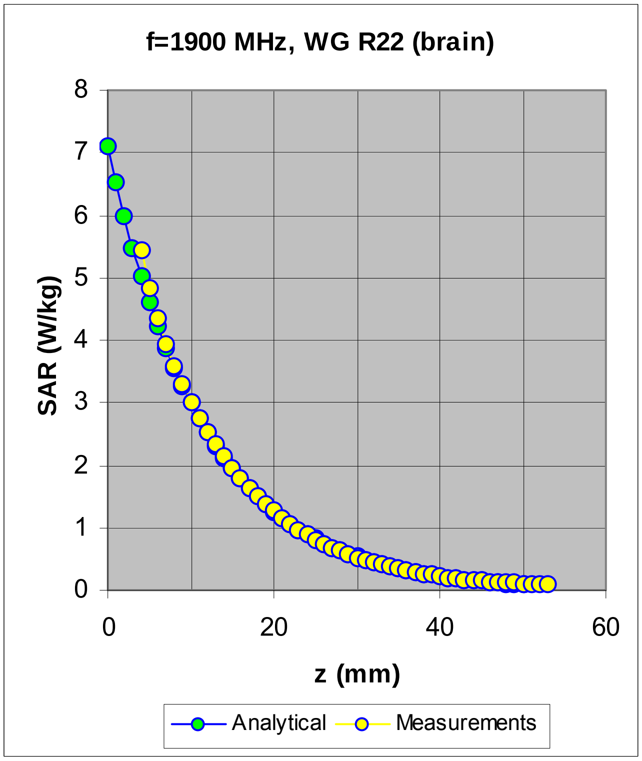
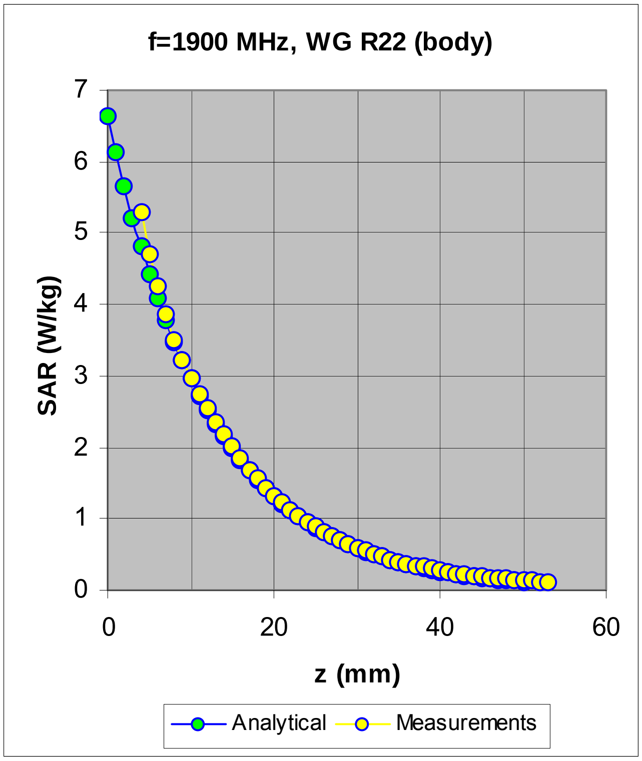


Figure 6. The measured SAR decay function along the centreline of the WG4 waveguide with conversion factors adjusted to fit to the theoretical function for the particular dimension, frequency, power and liquid properties employed.


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

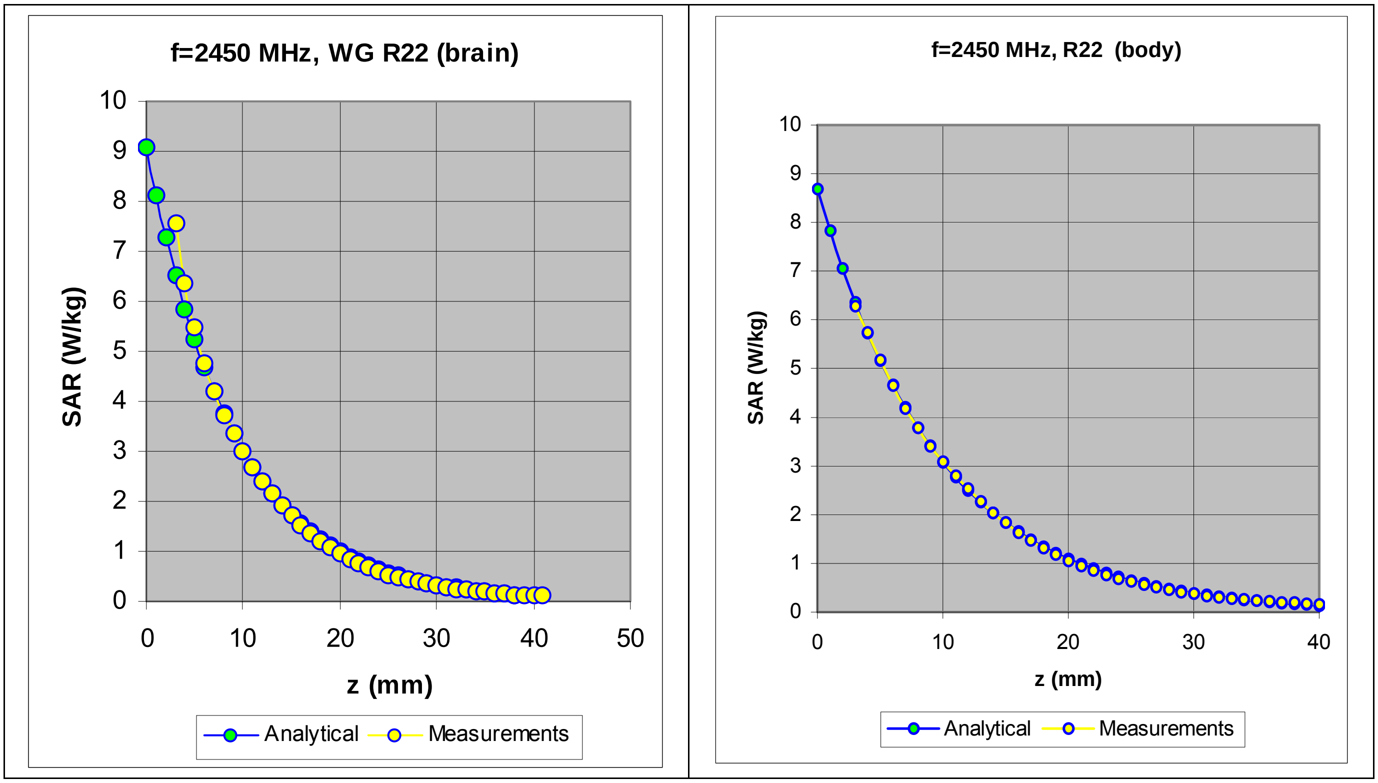


Figure 7. The measured SAR decay function along the centreline of the R22 waveguide with conversion factors adjusted to fit to the theoretical function for the particular dimension, frequency, power and liquid properties employed.

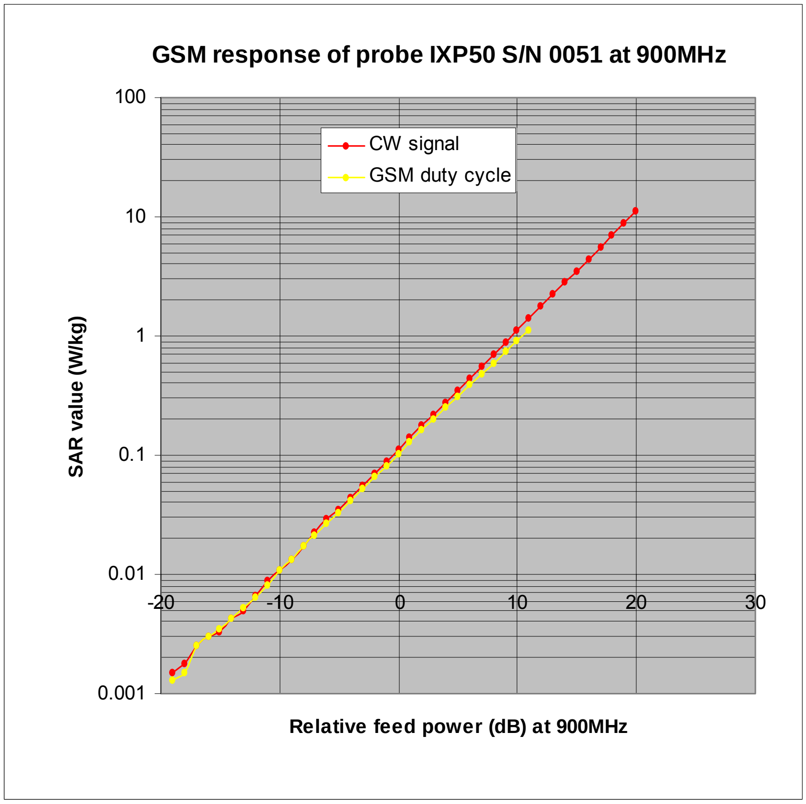
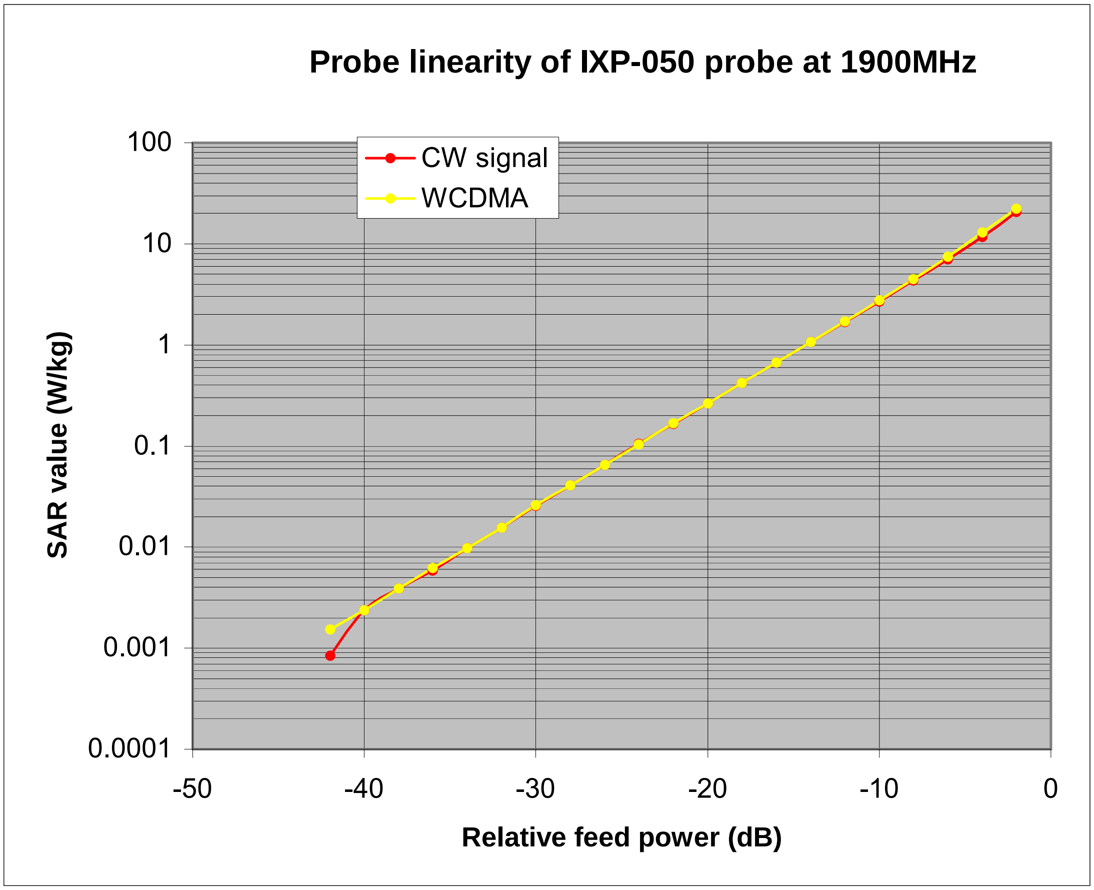


Figure 8. The GSM response of representative IXP-050 probe at 900MHz.



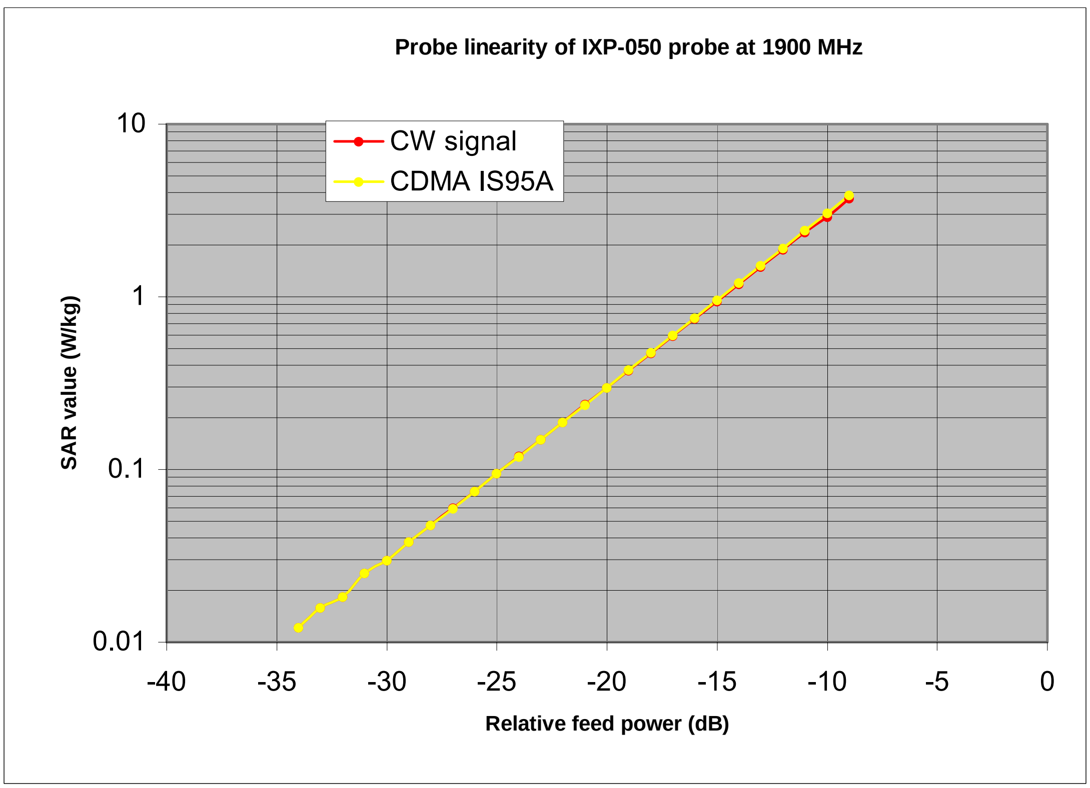


Figure 9. The CDMA response of an IXP-050 probe at 1900MHz

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	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
5200 MHZ BRAIN	35.824	4.715
5800 MHZ BRAIN	36.32	5.452

APPENDIX

Important Notes for the 5.2 - 5.8 GHz waveguide calibrations for Indexsar IXP-050 SAR probes

Introduction
There are several factors to be addressed in using diode-sensor SAR probes at frequencies above 3GHz. Many of the uncertainties in SAR testing rise steeply with increasing frequency.

For SAR measurements above 5 GHz the following significant limitations exist:

1. Even for 5mm diameter probes, rotational isotropy of only +/- 3dB is expected based on theoretical grounds [1] – this is not in line with lower frequency standards requirements of +/- 0.5dB.

2. SAR testing procedures defined in the P1528 draft standard are not applicable and the procedures for validating SAR measurement systems are not in place. It is not possible to check the calibrations against standards-based reference measurements in phantoms.

3. Satisfactory recipes for phantom head and body liquids are not published and uncertainties with liquids measurements require further investigation.

4. The probe dimensions are significant compared to those of the waveguides required for calibration and measurement disturbances may influence the results.

Indexsar have addressed many of these issues as described in this note, and necessary test precautions are recommended, but it should be appreciated that the measurements have higher uncertainty than when using P1528 procedures below 3GHz.

1) Effects of finite size of probe
The limitations of using finite-sized 3-channel probes at 5GHz have been analysed in [1]. At 5GHz in phantom liquids, the E-field decays to 1/e of its value in about 5mm. Because this is comparable with the probe diameter (5mm), the probe spherical isotropy cannot be better than +/- 3dB. There are two ways to limit this. The first is to correct for the anisotropy, which can be done with the latest Indexsar software. The second is to minimise the errors at point of maximum field by testing at the bottom of a phantom box (keeping the probe upright). It is important to use a probe that is as small as possible.

Since the E-field decays so rapidly away from the phantom surface, there is a conflict between the need to avoid boundary effects when the probe is near the surface and the need to measure the decay profile with a reasonable number of steps for reliable extrapolation. Boundary effects need to be allowed for using measurements made during the waveguide calibration.

2) Checking the probe calibration against standard reference values
An important check on SAR measurements is to confirm that a validation check gives answers close to those predicted by computation or analysis. This requires detailed descriptions of the source to be used and the spacing from the phantom and agreement on the 1g and 10g SAR values that are used as the reference values. The full details are not available or tested and agreed yet, so this remains a significant restriction inhibiting ‘validated’ testing.

3) Phantom liquid recipes

Indexsar have started to supply non-hazardous liquids designed and formulated by Bristol University here in the UK. A liquid simulating head-tissue was used for the waveguide calibrations of the IXP-050 SAR probes at 5.2 and 5.8 GHz.

Head liquid measurements supplied by Bristol University

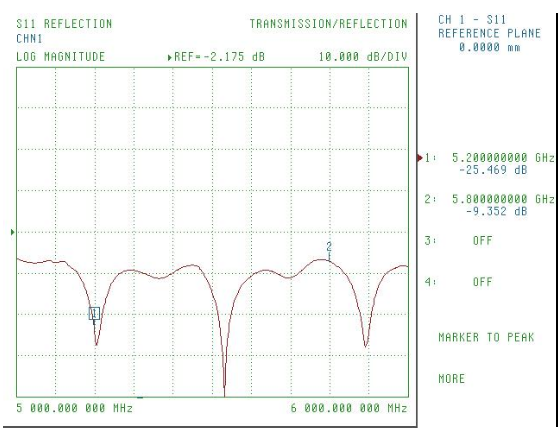
Frequency (GHz)	Conductivity Draft target value (S/m)	Conductivity Measured @ 22^{0}C	Permittivity Draft target value (S/m)	Permittivity Measured @ 22^{0}C
5.2GHz	4.7	4.715 (0.3%)	36	35.824 (-0.5%)
5.8GHz	5.3	5.452 (2.9%)	35.3	36.32 (2.8%)

4) Waveguide calibrations

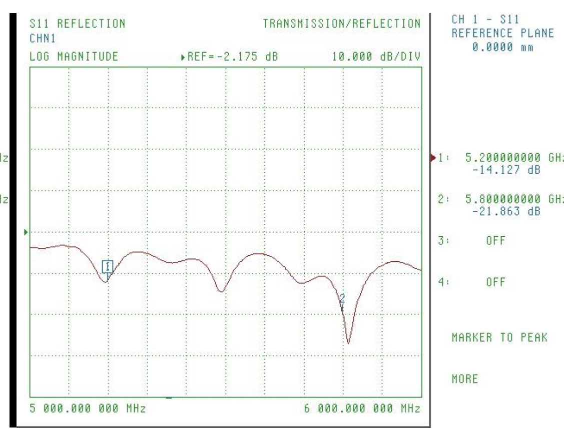
Waveguides have been prepared from WG13 sections (40mm by 20mm internal dimensions). Detachable matching windows are used to connect the upper, liquid-filled section. 300mm launcher sections were manufactured with a return loss specification into a broadband load of greater than 26dB. The matching windows are of different thickness for each frequency as below:

Frequency (GHz)	Penetration depth (mm)	Relative permittivity of separator	Thickness of separator	Depth of liquid-containing section (mm)
5.2 GHz	6.6	6	5.3	30
5.8GHz	6	6	4.4	30

Return loss measurements were made with the waveguides vertical and with a 30mm depth of the head liquid. The following results were obtained:



Return loss with 5.3mm separator

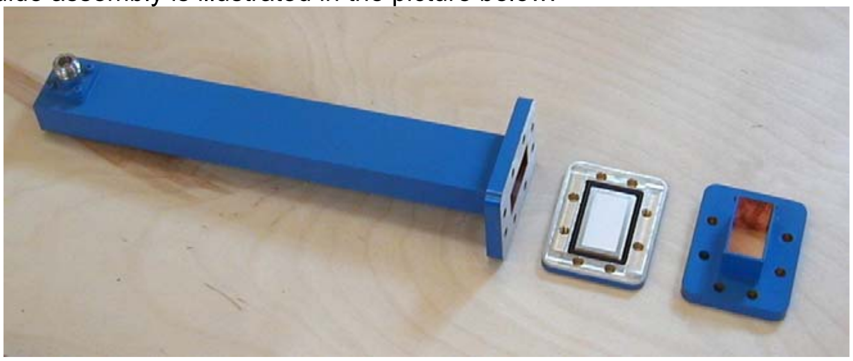


Return loss with 4.4mm separator

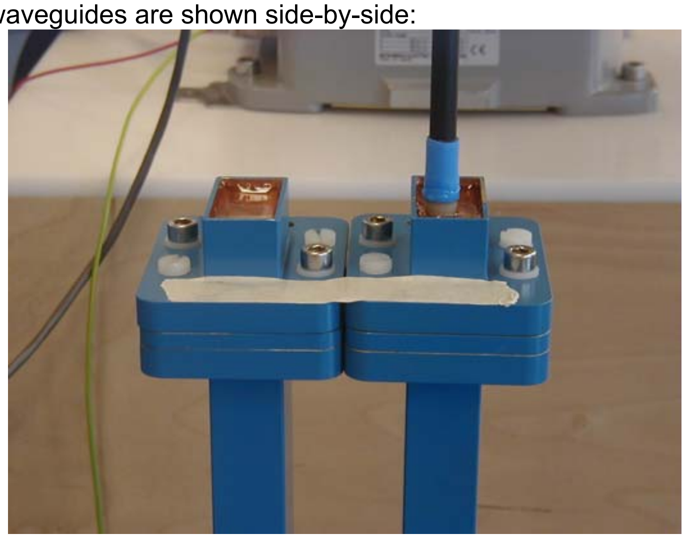
The measurements are summarised below:

Frequency (GHz)	Separator thickness (mm)	Return loss (dB)
5.2	5.3	-25.4
5.8	4.4	-21.8

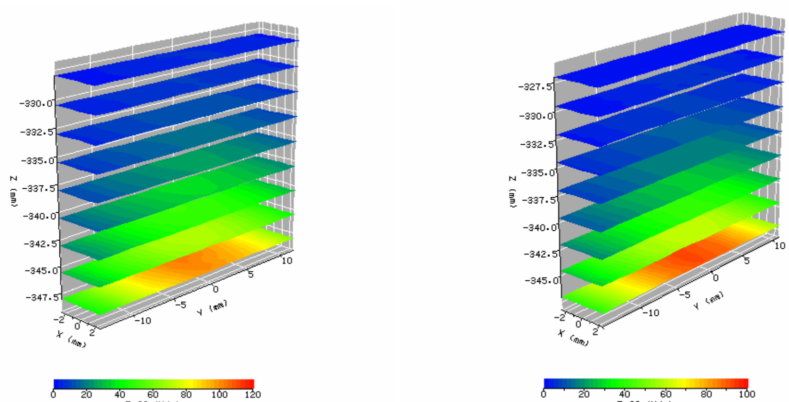
The waveguide assembly is illustrated in the picture below:



The relatively large size of the probe compared to the waveguide dimensions is illustrated below where two waveguides are shown side-by-side:

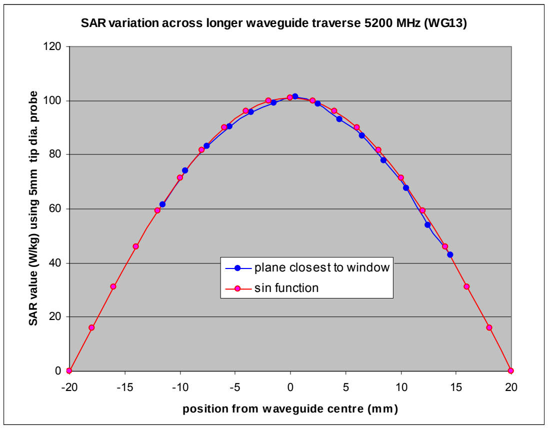


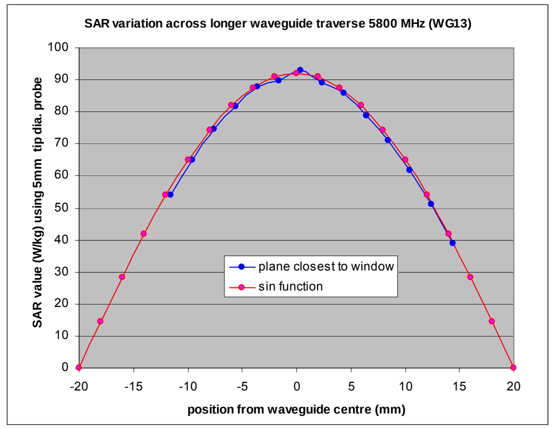
To determine whether the waveguides were producing the field distribution upon which the analytical comparisons depend, 3D SAR measurements were made in each waveguide using the SARA2 system and an Indexsar IXP-050 probe. The results are illustrated in different formats below:



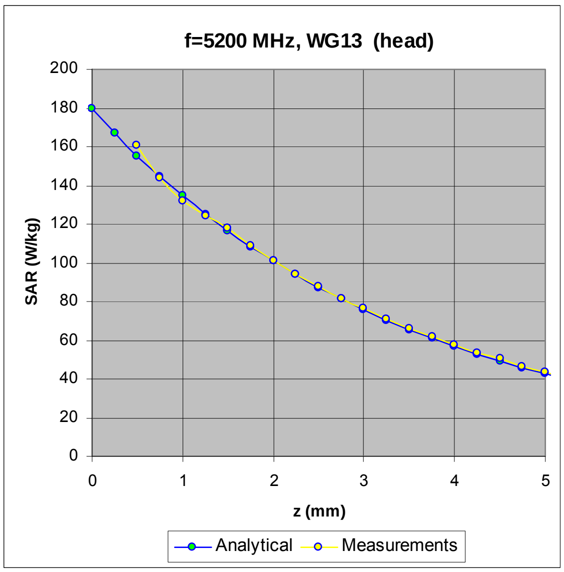
SAR measurements in waveguide at 5.2GHz (left) and at 5.8GHz (right)

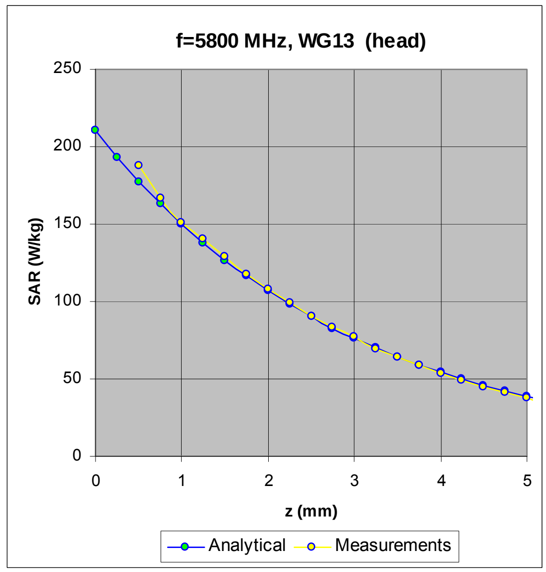
Using the data shown above, the lowest plane of data collected in each case was averaged across the short side and compared with a sine function across the longer dimension of the waveguide. The comparisons are shown below. The data have a small offset applied as the probe scan was not exactly in the centred within the waveguide.:





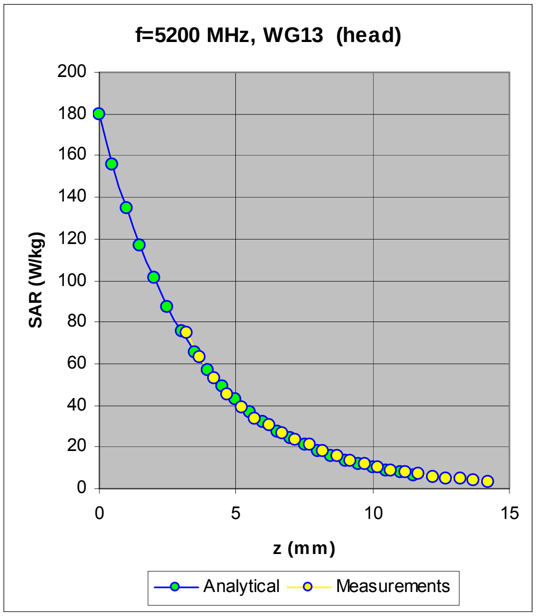
The next check of the waveguides was done using a 1.3mm diameter single-channel probe to measure the decay rate of the centerline profile in the waveguide as precisely as possible for comparison with the expected analytical decay function:

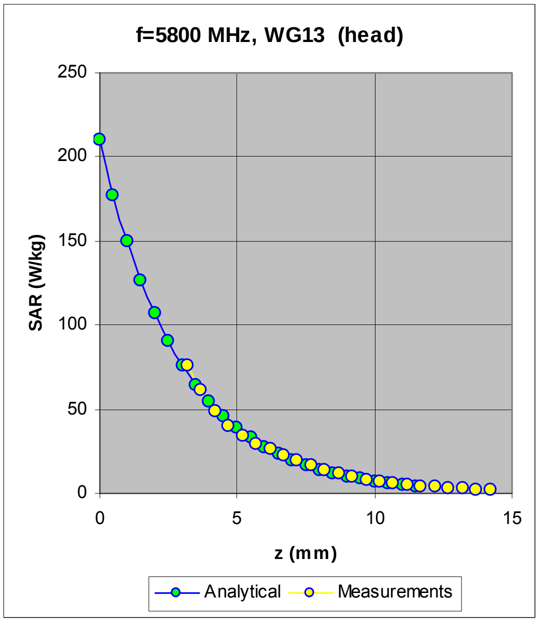




The graphs above show measurements with 1.2mm diameter probe at each frequency. The probe sensor started in contact with the separator window. The sensor is 0.5mm back from the tip. No boundary effect corrections have been applied in the comparison above.

Having completed the waveguide performance checks as described above, IXP-050 SAR waveguide calibrations have been performed on IXP-050 SAR probes. Typical results are shown below, where boundary effect factors have been applied to the measured data:





Calibration factors and boundary effect correction factors applicable to specific probes are given in the specific calibration documents for each probe.

5) Recommendations for measurement procedures

Indexsar Report IXS0223 [1] provides a background to the factors affecting measurements at high frequencies when using SAR probes of size 8 – 5mm tip diameter. Although the Indexsar probes are at the smaller end of this range, SAR probes are not isotropic in 5GHz phantom field gradients and additional precautions have to be taken in measurements. The following measures are recommended:

1) At >5GHz, the SAR field decays to 1/e of its value within 3-4mm of the surface of a phantom with a source adjacent. So, measurements are significantly affected by small errors in the separation distances employed between the probe and the phantom surface. The distance between the probe tip and the plane of the sensors should be allowed for using the same value as that declared in the probe calibration document. Distances between the probe tip and phantom surface should be measured accurately to 0.1mm. The best way to assure this is to use the robot to position the probe in light contact with the phantom wall and then to withdraw the probe by the selected amount under robot control.

2) The preferred test geometry at 5GHz is for testing at the bottom of an open phantom. If tests at the side of a phantom are performed, it will be necessary to apply VPM corrections as described below. In either case, careful monitoring of probe spacing from the phantom is required. Probe isotropy is improved for measuring fields polarised either normal to or parallel to the probe axis. If the source polarization is known, this arrangement should be established, if possible.

3) The probe calibration factors including boundary correction terms should be carefully entered from the calibration document. The probe calibration factors require that the probe be oriented in a known rotational position. The red spot on the Indexsar probe should be aligned facing away from the robot arm.

4) The latest SARA2 software (VPM editions) contain support for correcting for probe anisotropy in strong field gradients and include a procedure for correcting for boundary proximity influences. As noted above, the probe has to be oriented in a given rotational position and some familiarity with the new measurement procedures is necessary. The calculations can be performed either

with or without the extended correction schemes applied and it will be good practice to do both and report on the differences between them.

5) If boundary corrections are used, it may be preferable to go rather closer to the phantom surface than is usually recommended and to perform scans using small steps between the measurement planes so that good data on the SAR profiles are collected within the first 10mm of the phantom depth.

6) It would be prudent to make a larger allowance for measurement uncertainties until tried and tested procedures become recommended in future standards covering the range from 3 to 6GHz. Perhaps a uplift factor of 2 on the measurements could be applied as an additional precautionary measure until such time as target liquid properties, reference values and validation procedures are published in detail and agreed.

6) References

[1] Manning, MI, "Compensating for the finite size of SAR probes used in electric-field gradients", Indexsar Report No. IXS0223, May 2003.