IMMERSIBLE SAR PROBE

CALIBRATION REPORT

Part Number: IXP – 050

S/N 0082

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Indexsar Limited
Oakfield House
Cudworth Lane
Newdigate
Surrey RH5 5DR
Tel: +44 (0) 1306 631 233
Fax: +44 (0) 1306 631 834
e-mail: enquiries@indexsar.com

INTRODUCTION

This Report presents measured calibration data for a particular Indexsar SAR probe (S/N 0082) 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. Calibrations are determined by comparing probe readings with theoretical computations in canonical test geometries, 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 belt driven by a stepper motor.

The probe is attached to an amplifier that is connected via 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 coupler and power meter. The signal generator is used to output a signal of 900 (or 1800) MHz at constant power, which is monitored on the power meter. The probe is positioned so that its sensors line up with the rotation center of the dipole. By recording E-field measurements 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 in 1800 MHz simulated brain liquid. 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 centered within the liquid (Figure 1). The box is positioned so that its outer surface is 2mm from the dipole.

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.

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 output voltages are in units of V*200):

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

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. 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. equilibrate the peak magnitudes of the three channels) in the liquid. The following equation is used (where output voltages are in units of V*200):

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

A chart of the spherical isotropy for probe 0082 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 0082 is +/- 0.25 dB (Figure 4).

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 theoretical predictions of the decay profile:

a) 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 [3]; or,

b) SAR decay curve modelled by Flomerics [4] using a sphere and a balanced dipole in a similar test configuration.

To measure SAR decay the probe is inserted through the neck of a spherical phantom filled with 900 MHz simulant liquid, and the tip is positioned at the inside surface of the flask. A 900 MHz 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 [3] or [4]). 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 (e.g. Figure 5).

The final calibration factors for the probe are listed below:

Probe S/N 0082 at 900 MHz	**X**	**Y**	**Z**
Air Factors	300	290	330
DCP (V*200)	20	20	20
Liquid Factors	0.336	0.347	0.347

Note: see equation (3) for guidance on how to apply these factors

5. 1800 MHz Liquid Calibration

The calibration process is then repeated for 1800 MHz. The test set up is modified slightly to use 1800 MHz simulant liquid and a standard 1800 MHz balanced dipole.

As with the 900 MHz calibration SAR decay is measured and the resultant function fitted to modelled results. The final calibration factors for 1800 MHz are as follows:

Probe S/N 0082 at 1800 MHz	**X**	**Y**	**Z**
Air Factors	300	290	330
DCP (V*200)	20	20	20
Liquid Factors	0.510	0.530	0.530

Note: see equation (3) for guidance on how to apply these factors

PROBE SPECIFICATIONS

Indexsar probe 0082, 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 0082	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)	2.5		

Dynamic range	S/N 0082	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 0082	CENELEC [1]	IEEE [2]
Over range 0.01 – 100 W/kg (+/- dB)	0.125	0.50	0.25

Isotropy (measured at 900MHz)	S/N 0082	CENELEC [1]	IEEE [2]
Axial rotation with probe normal to source (+/- dB)	0.25	0.5	0.25
Spherical isotropy covering all orientations to source (+/- dB)	0.50	1.0	0.50

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

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

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

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.

Tests such as in Figure 6 indicate that the probe plus amplifier combination correctly reflect the power level of pulsed GSM signals without the need for any specific scheme of correction. The minor deviations from equivalence shown in Figure 6 can be allowed for if required.

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. TC211.

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

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

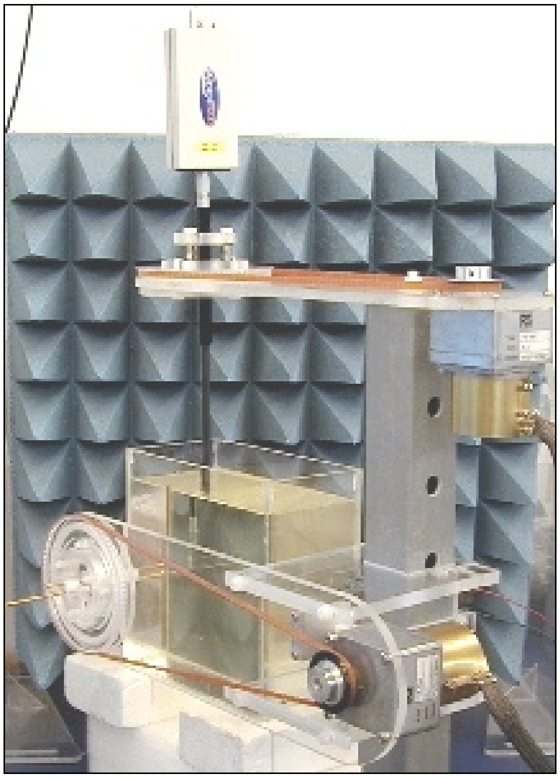

Figure 1. Calibration jig showing probe, dipole and box filled with simulated brain liquid

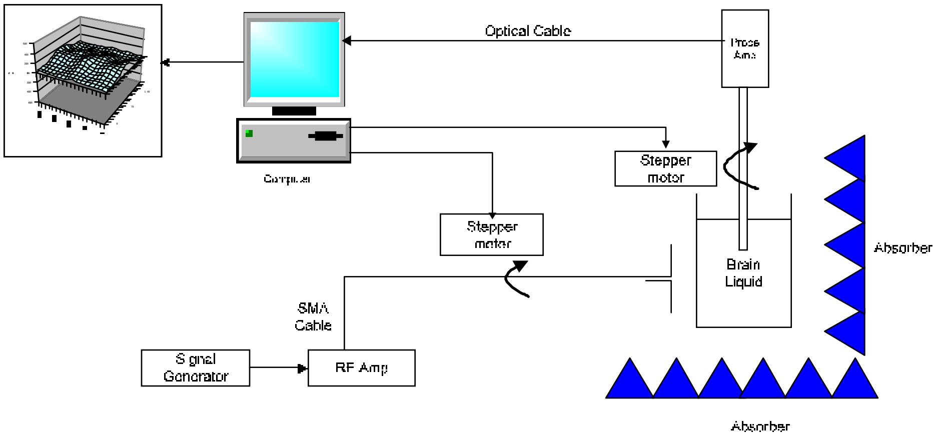

Figure 2. Schematic diagram of the test geometry used for isotropy determination

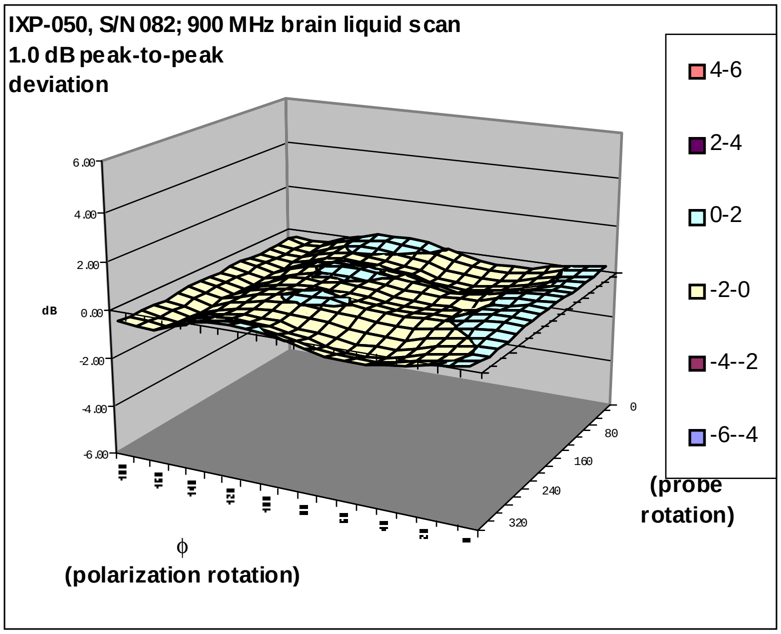

Figure 3. Spherical isotropy for probe S/N 0082. The peak-to-peak deviation of E-field measurements has a range of +/- 0.50 dB

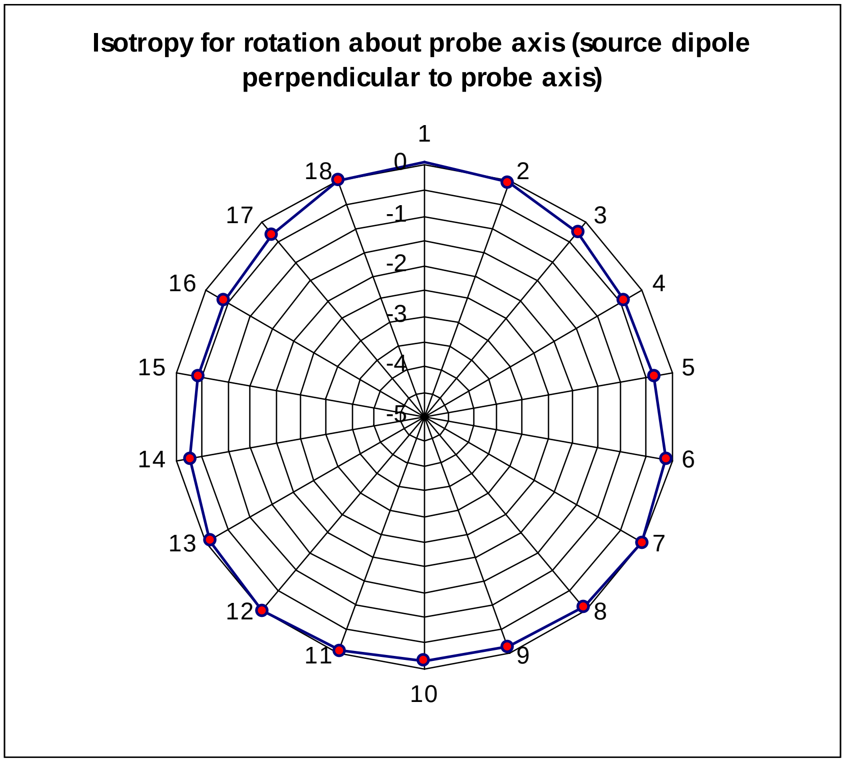

Figure 4. Rotational isotropy of probe 0082 with source dipole perpendicular to probe and to the side (probe in a field gradient).

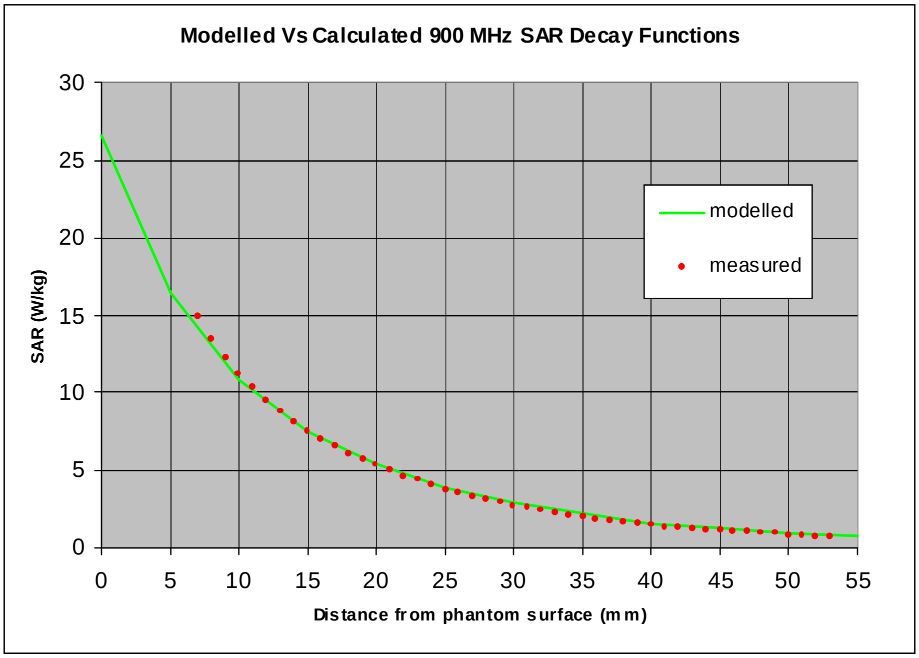

Figure 5. The measured SAR decay function along the axis of a sphere with channel factor magnitudes adjusted to fit to the theoretical function for the canonical test geometry employed.

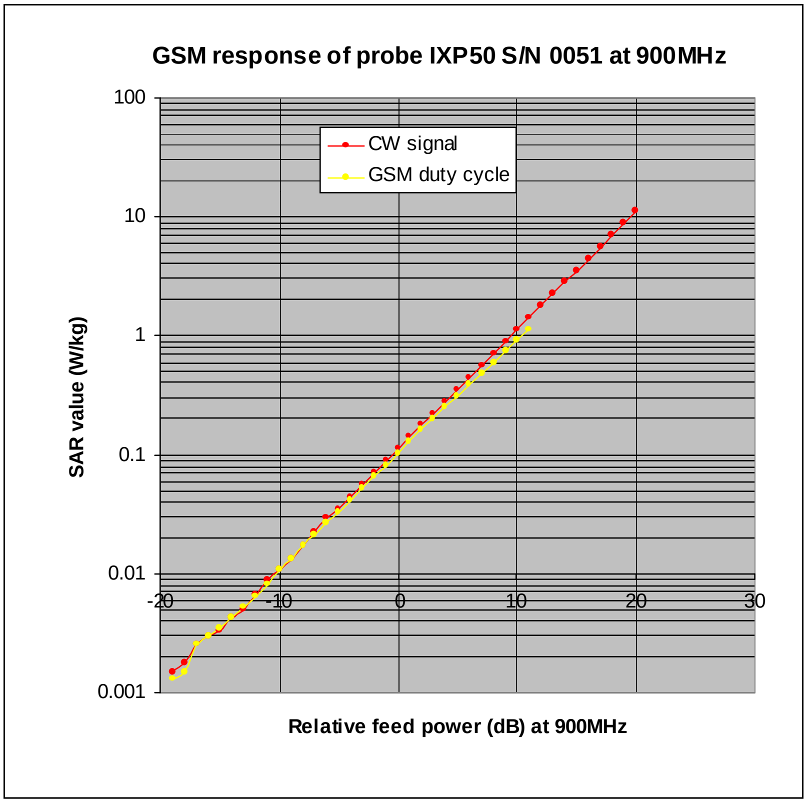

Figure 6. The GSM response of representative IXP-050 probe at 900MHz.