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Calibration Certificate
Dosimetric E-field Probe

Type:	**IXP-050**

Manufacturer:	**IndexSAR, UK**

Serial Number:	**0177**

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:	**18th April 2007**

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

Next Calibration Date:	**April 2008**

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:	A. Brinklow

Approved By:	M J Manning

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 0177) 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. Objectives

The calibration process comprises three stages

1) Determination of the channel sensitivity factors which optimise the probe's overall rotational isotropy in 1800MHz brain fluid
2) 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
3) Determination of the effective tip radius and angular offset of the X channel which together optimise the probe's spherical isotropy in 900MHz brain fluid

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:

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

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).

In turn, measurements of E-field are determined using the following equation (where output voltages are also in units of V*200):

an upright position and the
o within 10 mm of the open
ligible radiation from the wa
s not influenced by reflectio

a TE_{01} mode is launched in
veguide adapter. The prob
il the tip is exactly 10mm a
rticular separation ensures
vaveguide where boundary

hat the probe tip is centred

cale and range of boundary

between the SAR at the c
unction of the longitudinal c
by Equation 4:

$$\frac{(\ldots - P_b)}{ab\delta} e^{-2z/\delta}$$

entionally assumed to be 1
waveguide, and P_f and P_b
lossless section of the wav
hich is the reciprocal of th

e is lowered carefully until i
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plate file before moving the
ated 50 times. The vertica
practical considerations o
1mm steps at low frequenc
at 5GHz.

complete, a Solver routine
by varying the conversion
d range.

out using a probe substitut

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.

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 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 P1528 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.

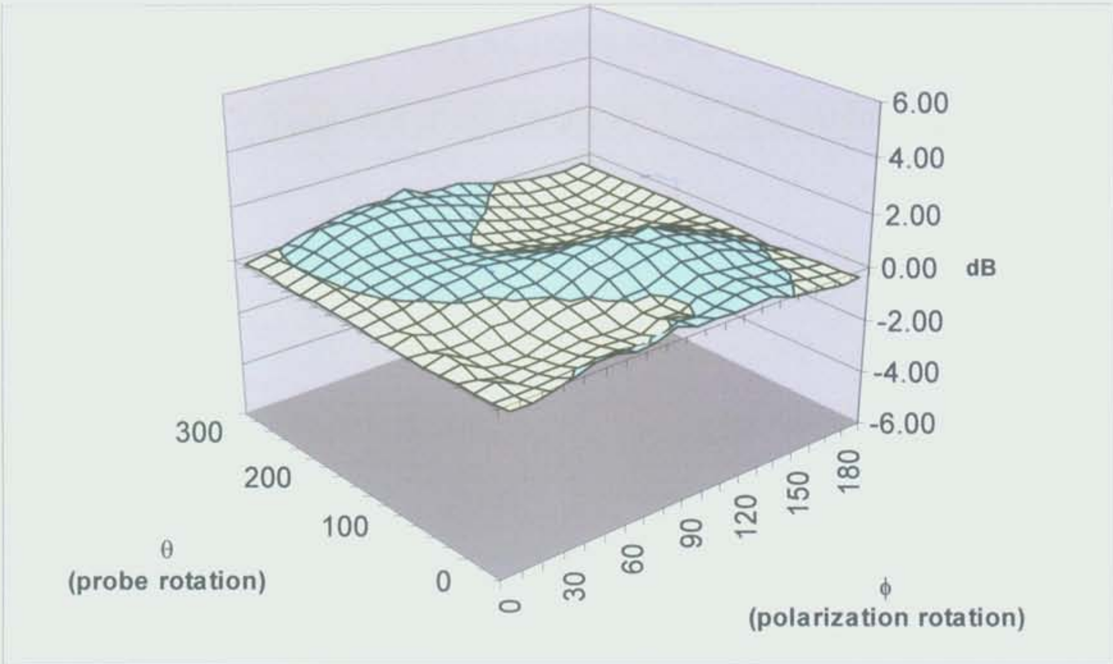
Given the typical dimensions of 3-channel SAR probes presently available, use of the VPM technique extends the satisfactory measurement range to higher frequencies.

CALIBRATION FACTORS MEASURED FOR PROBE S/N 0177

The probe was calibrated at 835, 900, 1800, 1900, 2450, 5200 and 5800 MHz in liquid samples representing both brain liquid and body fluid at these frequencies. For the 450MHz calibration, only brain fluid was involved. 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 8).

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.



Surface Isotropy diagram of IXP-050 Probe S/N 0177 at 900MHz after VPM (rotational isotropy at side +/-0.07dB, spherical isotropy +/-0.88dB)

Probe tip radius	1.36
X Ch. Angle to red dot	11

	Head		Body	
Frequency	**Bdy. Corrn. – f(0)**	**Bdy. Corrn. – d(mm)**	**Bdy. Corrn. – f(0)**	**Bdy. Corrn. – d(mm)**
835	0.53	3.0	1.00	1.2
900	0.50	3.0	1.00	1.2
1800	0.71	1.5	0.70	1.6
1900	0.63	1.6	0.72	1.6
2450	1.00	1.2	0.52	1.8
5200	1.00	1.3	1.00	1.7
5800	1.00	1.5	1.00	1.8

SUMMARY OF CALIBRATION FACTORS FOR PROBE IXP-050 S/N 0177

Spherical isotropy measured at 900MHz	0.88	(+/-) dB

	X	Y	Z	
Air Factors	398	370	433	(V*200)
CW DCPs	20	20	20	(V*200)

Freq (MHz)	Axial Isotropy (+/- dB)		SAR ConvF (liq/air)		Notes
	Head	Body	Head	Body	
450	-	-	0.284	-	
835	-	-	0.301	0.285	1,2
900	-	-	0.312	0.293	1,2
1800	0.07	-	0.356	0.380	1,2
1900	-	-	0.369	0.393	1,2
2450	-	-	0.397	0.446	1,2
5200	-	-	0.491	1.017	1,2
5800	-	-	0.388	0.642	1,2

Notes	
1)	Calibrations done at 22°C +/-2°C
2)	Waveguide calibration

PROBE SPECIFICATIONS

Indexsar probe 0177, 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 0177	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 0177	CENELEC [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

Isotropy (measured at 900MHz)	S/N 0177	CENELEC [1]	IEEE [2]
Axial rotation with probe normal to source (+/- dB)	0.07 Max (See table above)	0.5	0.25
Spherical isotropy covering all orientations to source (+/- dB)	0.88	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.

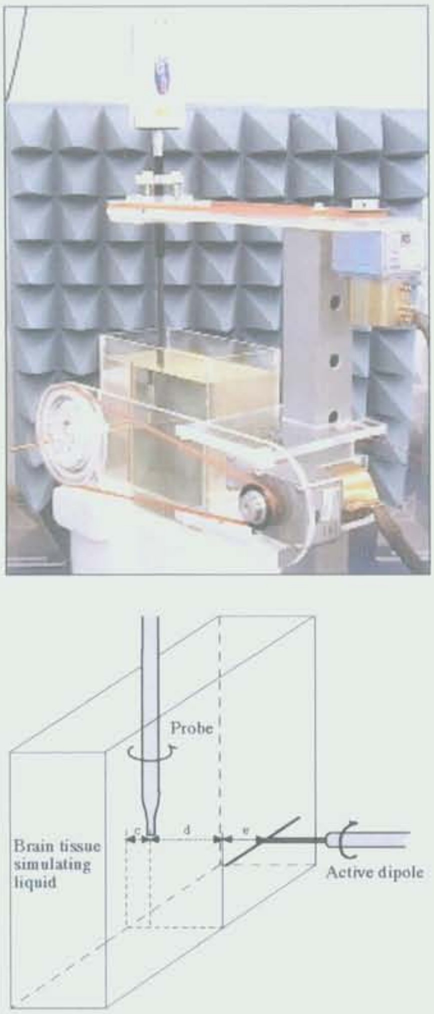


Figure 1. Spherical isotropy jig showing probe, dipole and box filled with simulated brain liquid (see Ref [2], Section A.5.2.1)

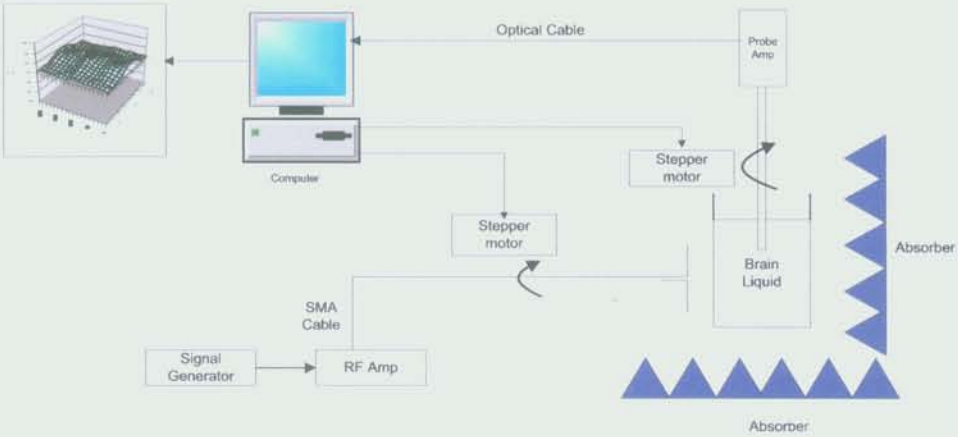


Figure 2. Schematic diagram of the test geometry used for isotropy determination

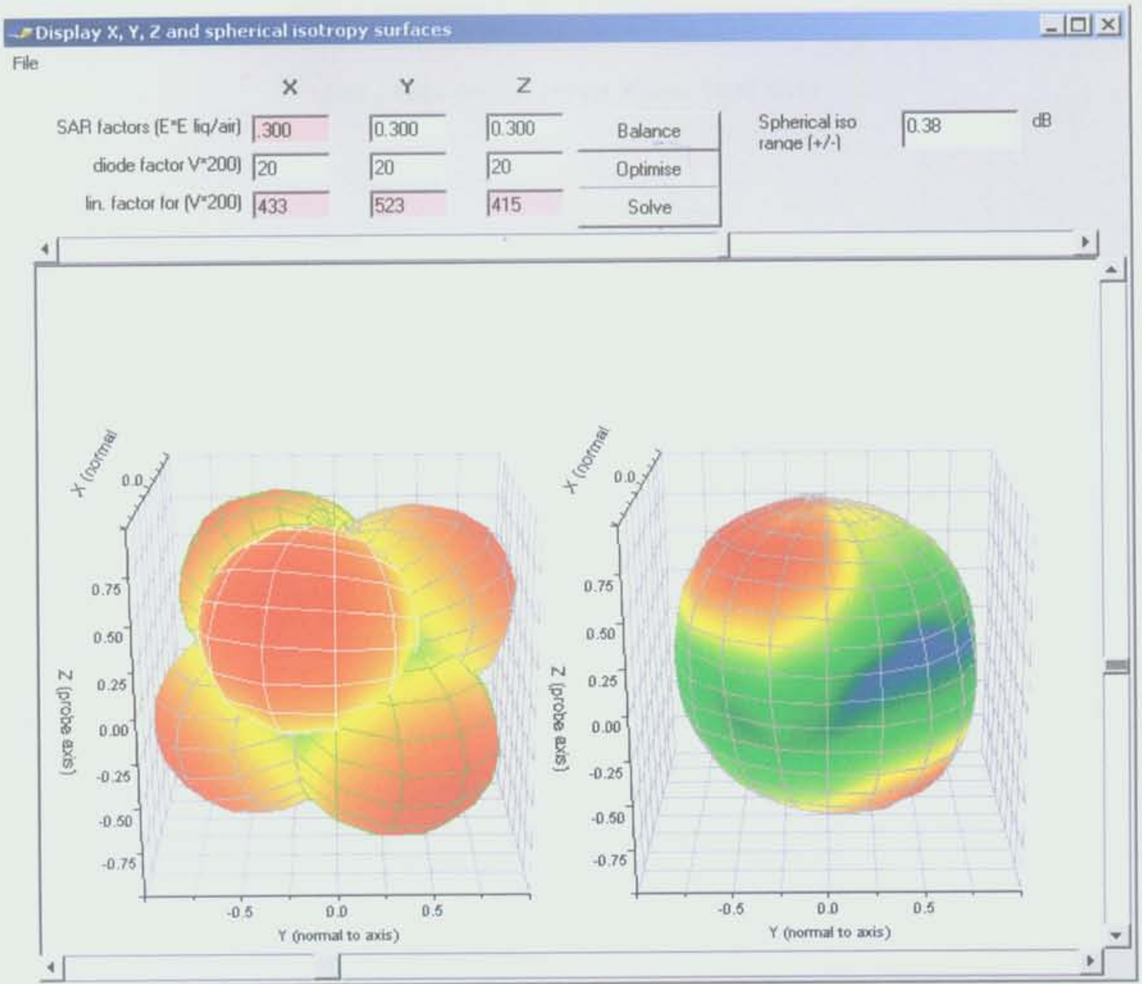


Figure 3. Graphical representation of a probe's response to fields applied from each direction. The diagram on the left shows the individual response characteristics of each of the three channels and the diagram on the right shows the resulting probe sensitivity in each direction. The colour range in the figure images the lowest values as blue and the maximum values as red. For the probe S/N 0177, this range is (+/-) 0.88 dB.

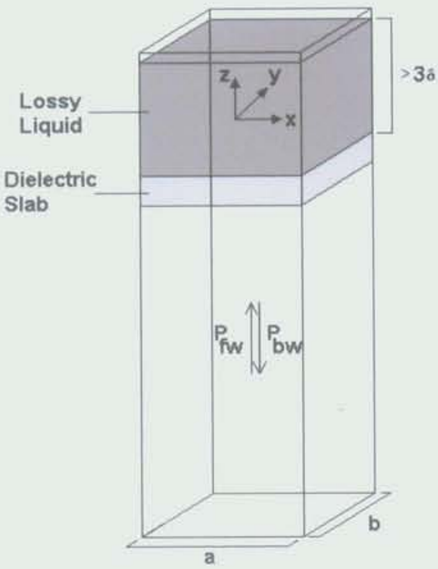


Figure 4. Geometry used for waveguide calibration (after Ref [2]. Section A.3.2.2)

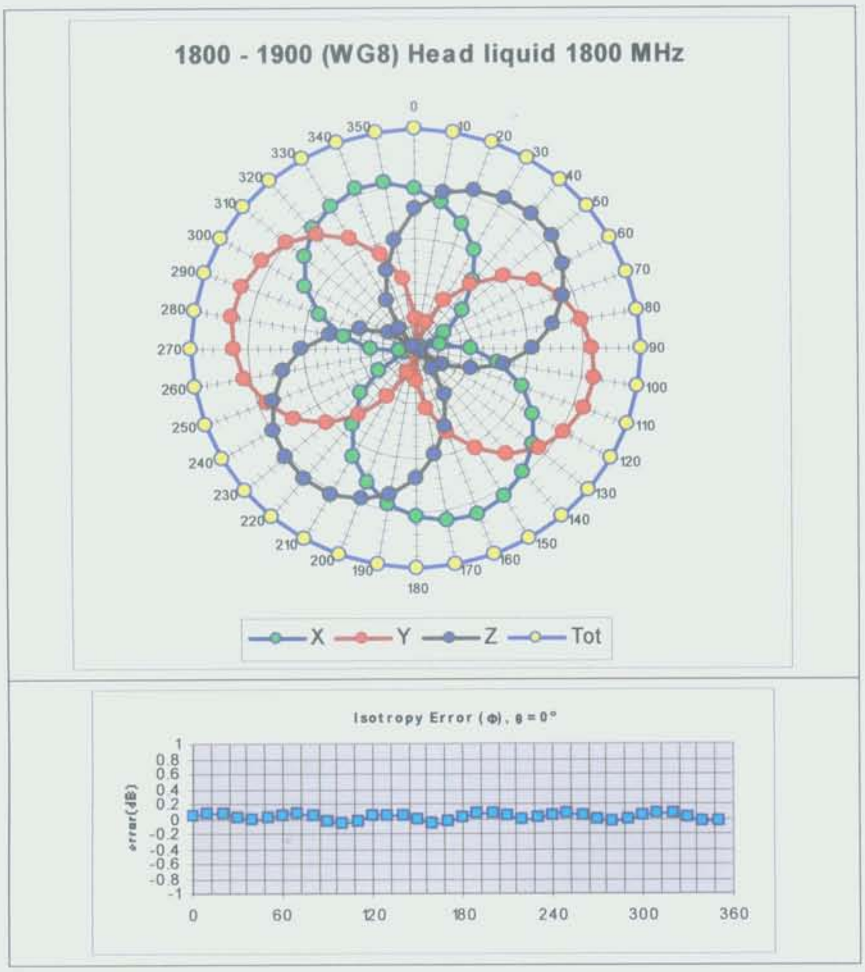


Figure 5. The rotational isotropy of probe S/N 0177 obtained by rotating the probe in a liquid-filled waveguide at 1800 MHz.

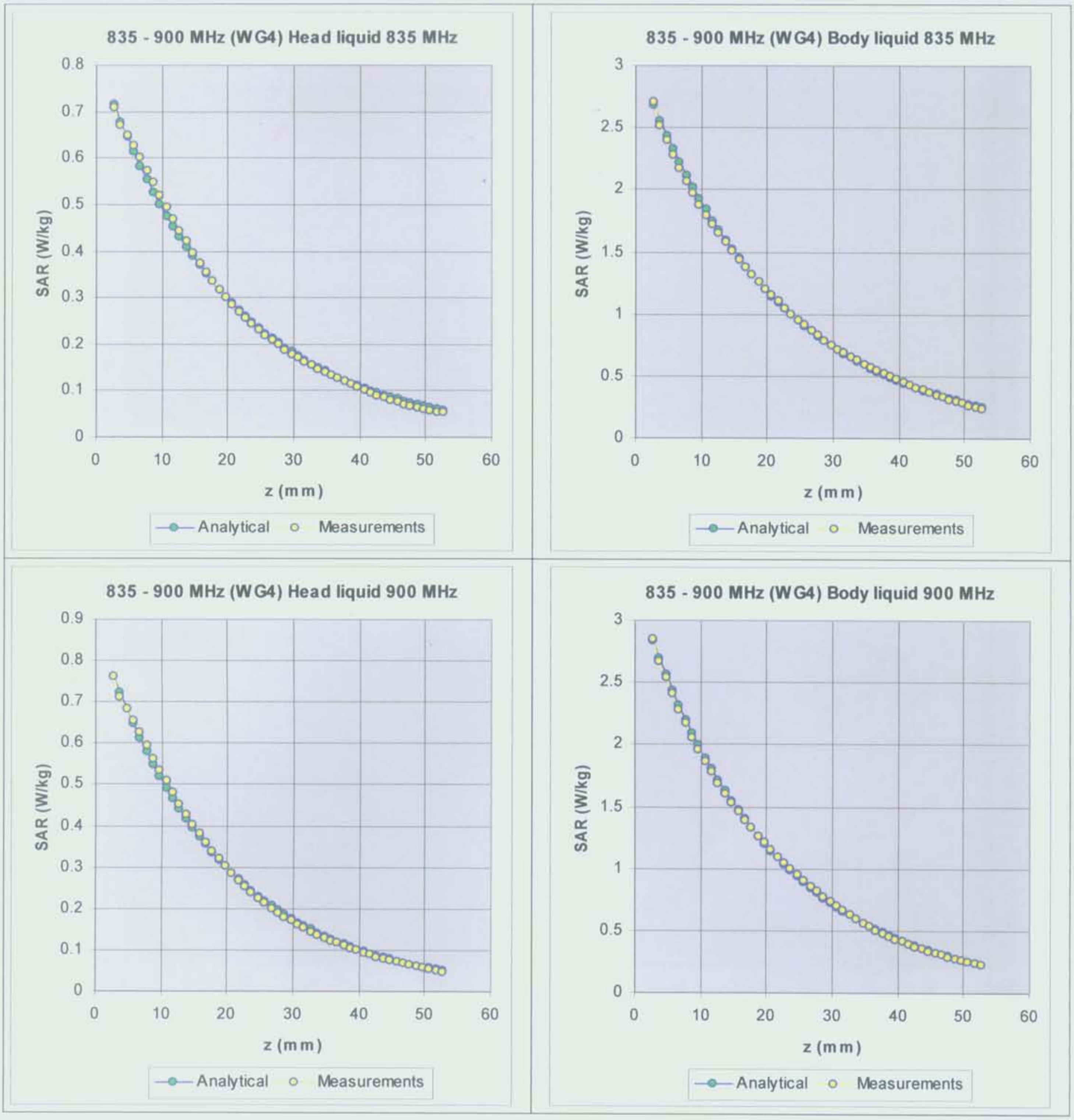
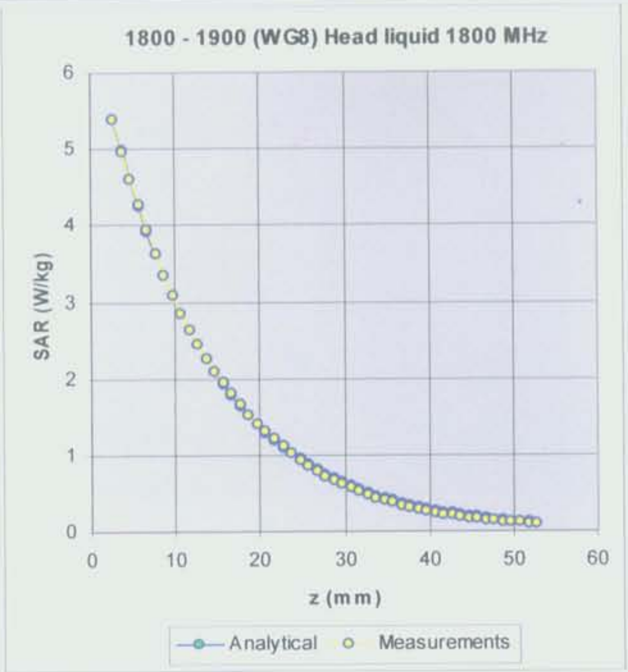
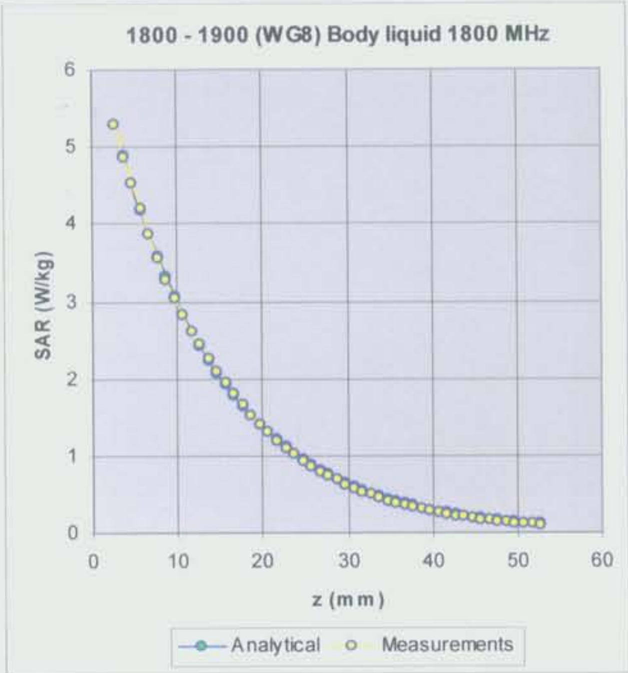
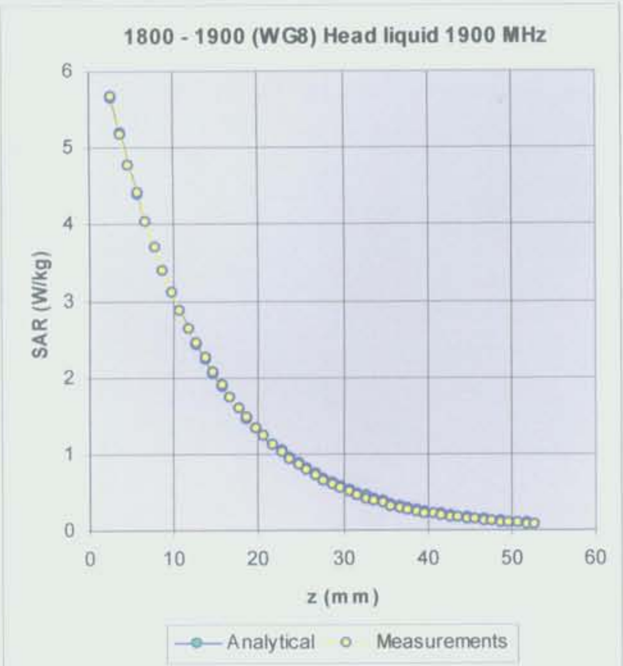
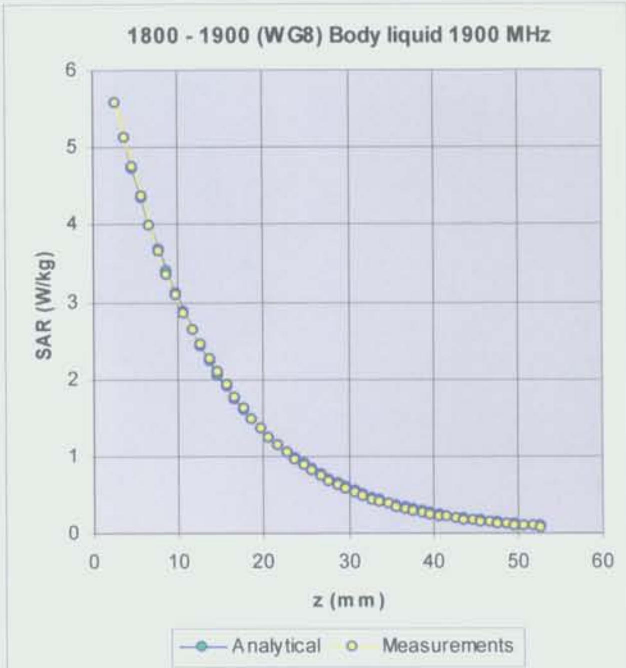


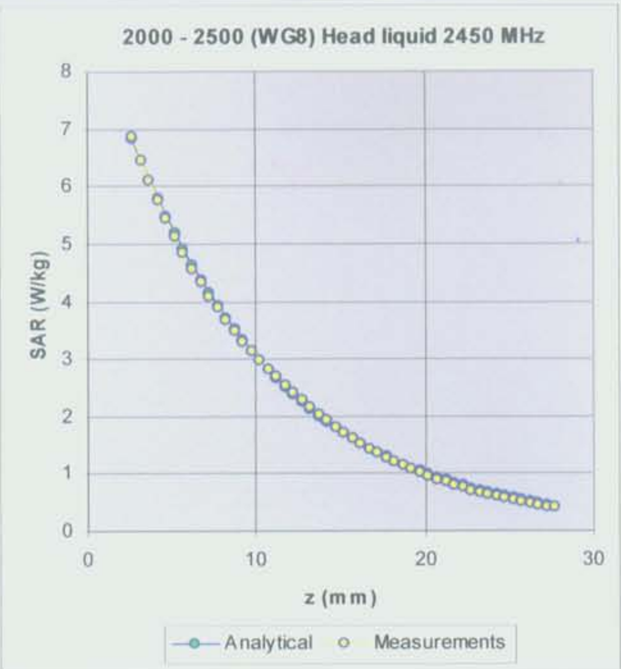
Figure 6. The measured SAR decay function along the centreline of the WG4 waveguide with conversion factors adjusted to fit to the theoretical function for the particular dimension, frequency, power and liquid properties employed.

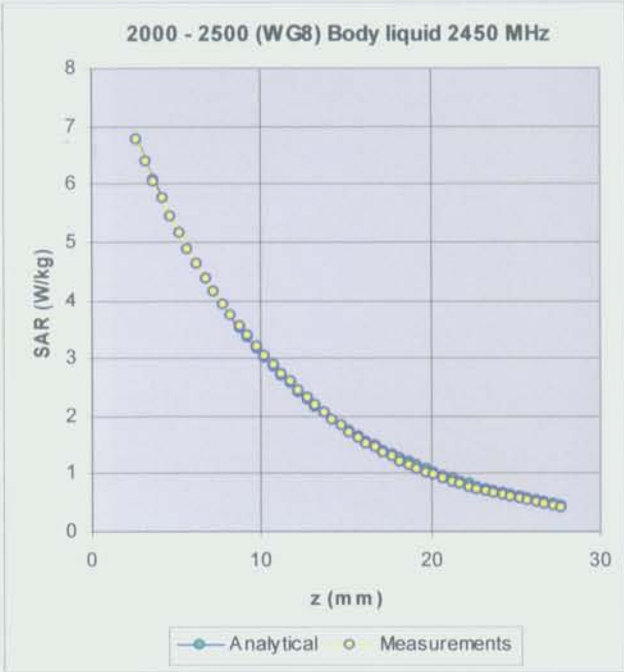

1800 - 1900 (WG8) Head liquid 1800 MHz
SAR (W/kg)
z (mm)
Analytical
Measurements

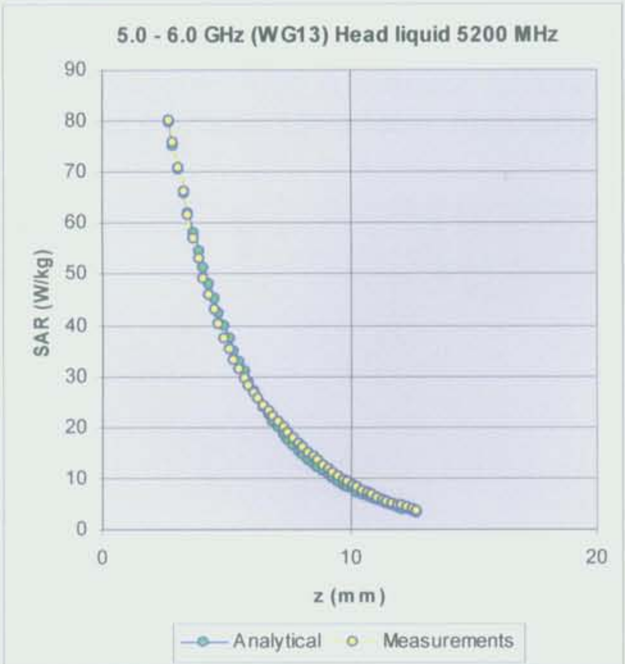

1800 - 1900 (WG8) Body liquid 1800 MHz
SAR (W/kg)
z (mm)
Analytical
Measurements

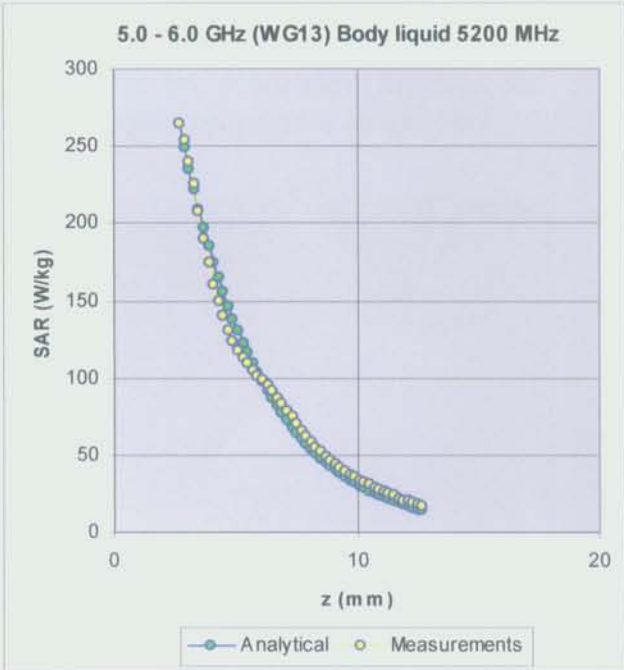

1800 - 1900 (WG8) Head liquid 1900 MHz
SAR (W/kg)
z (mm)
Analytical
Measurements


1800 - 1900 (WG8) Body liquid 1900 MHz
SAR (W/kg)
z (mm)
Analytical
Measurements


2000 - 2500 (WG8) Head liquid 2450 MHz
SAR (W/kg)
z (mm)
Analytical
Measurements


2000 - 2500 (WG8) Body liquid 2450 MHz
SAR (W/kg)
z (mm)
Analytical
Measurements


5.0 - 6.0 GHz (WG13) Head liquid 5200 MHz
SAR (W/kg)
z (mm)
Analytical
Measurements


5.0 - 6.0 GHz (WG13) Body liquid 5200 MHz
SAR (W/kg)
z (mm)
Analytical
Measurements

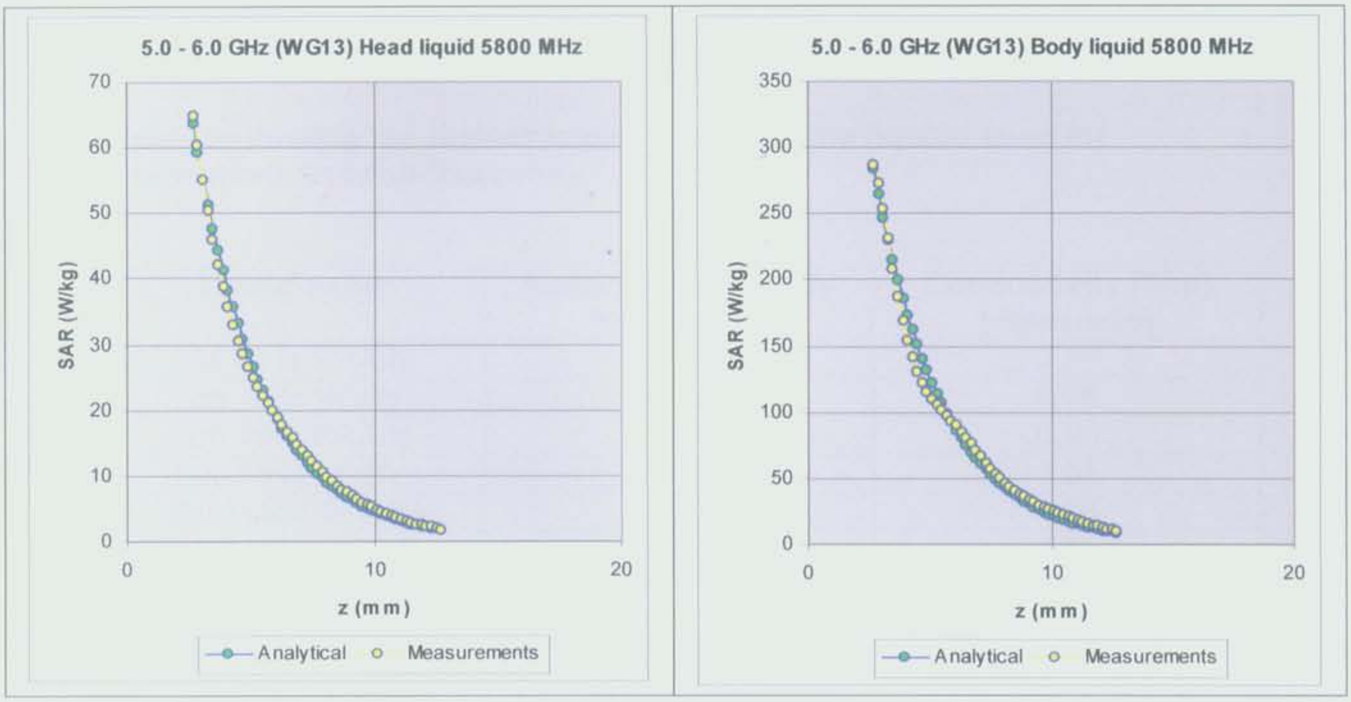


Figure 7. The measured SAR decay function along the centreline of the R22 waveguide with conversion factors adjusted to fit to the theoretical function for the particular dimension, frequency, power and liquid properties employed.

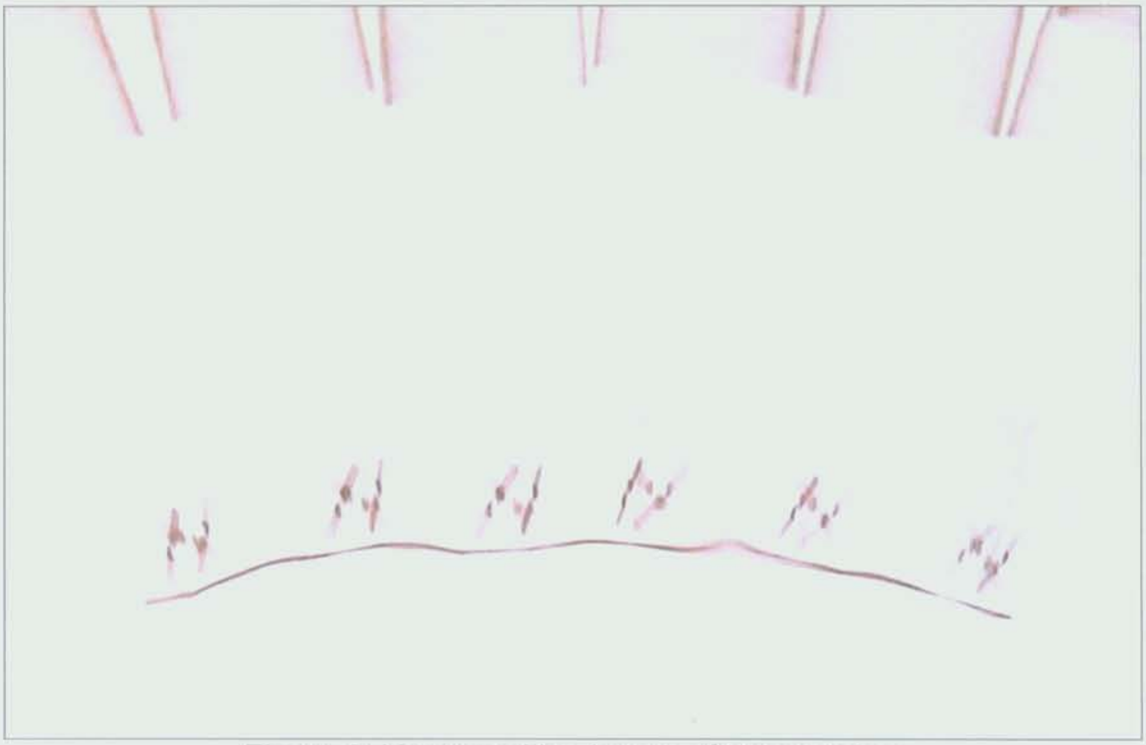


Figure 8: X-ray positive image of 5mm probes

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	39.34	0.87
835 MHz BODY	56.86	0.95
900 MHz BRAIN	38.56	0.93
900 MHz BODY	56.33	1.01
1800 MHz BRAIN	40.10	1.36
1800 MHz BODY	54.39	1.55
1900 MHz BRAIN	39.71	1.45
1900 MHz BODY	54.07	1.65
2450 MHz BRAIN	39.38	1.89
2450 MHz BODY	54.00	2.14
5200 MHz BRAIN	36.90	5.28
5200 MHz BODY	53.70	5.85
5800 MHz BRAIN	34.35	5.86
5800 MHz BODY	51.87	6.89