Product Service

Annex 3

Calibration certificate of Anritsu MS4623B VNA

Certificate of Calibration

Anritsu
Discover What's Possible™

Customer:
INDEXSAR LTD
INDEXSAR LTD_

OAKFIELD HOUSE
NEWDIGATE
SURREY RH5 5BG
UNITED KINGDOM

ANRITSU EMEA LIMITED
200 CAPABILITY GREEN
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UNITED KINGDOM
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Date of Issue:	17/02/2015	Certificate N°:	RMA20027002
Customer:	INDEXSAR LTD	Order No:	Contract
Manufacturer:	Anritsu Company		

Model	Serial Number	Description
MS4623B	003102	VNA,10 MHZ-6 GHZ,ACTIVE

Anritsu EMEA Limited does hereby certify the above listed equipment complies to published or stated specifications at the measured parameters, and has been calibrated to the general requirements of ISO 17025 against instruments whose accuracies are traceable to National or International Standards, where such standards are applicable.

Repair required before calibration	(yes)
Electrical Safety	(yes)
Laser safety class	( )

Authorised Signature

Murray Coleman
Head of Customer Services (EMEA)

Note: Original calibration results are attached and copies held on file at Anritsu EMEA Limited.
The attached results relate only to the instrument under calibration.
Anritsu EMEA Limited Quality system is certified to ISO9001:2000 (Cert. No. FQA 0353178)
This Certificate comprises of:
Certificate of Calibration
Cal Report
25 Page(s) of test results

Product Service

Annex 4

Calibration certificate of Anritsu 36581KKF/1 auto-cal kit

Certificate of Calibration

Anritsu
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Customer:
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INDEXSAR LTD_

OAKFIELD HOUSE
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Date of Issue:	**22/01/2015**	**Certificate N°:**	**RMA20026648**
Customer:	**INDEXSAR LTD**	**Order No:**	**1045ANR**
Manufacturer:	**Anritsu Company**		

Model	Serial Number	Description
MS4623B	**003102**	VNA.,10 MHZ-6 GHZ,ACTIVE
36581KKF/1	**001902**	TESTED & CHARACTERIZED TO 6 GHZ

Anritsu EMEA Limited does hereby certify the above listed equipment complies to published or stated specifications at the measured parameters, and has been calibrated to the general requirements of ISO 17025 against instruments whose accuracies are traceable to National or International Standards, where such standards are applicable.

Within specification before calibration	(yes)
Repair required before calibration	(no)
Electrical Safety	(yes)
Laser safety class	( )

Authorised Signature

Murray Coleman
Head of Customer Services (EMEA)

Note: Original calibration results are attached and copies held on file at Anritsu EMEA Limited.
The attached results relate only to the instrument under calibration.
Anritsu EMEA Limited Quality system is certified to ISO9001:2000 (Cert. No. FQA 0353176)
This Certificate comprises of:
Certificate of Calibration
Call Report
13 Page(s) of test results

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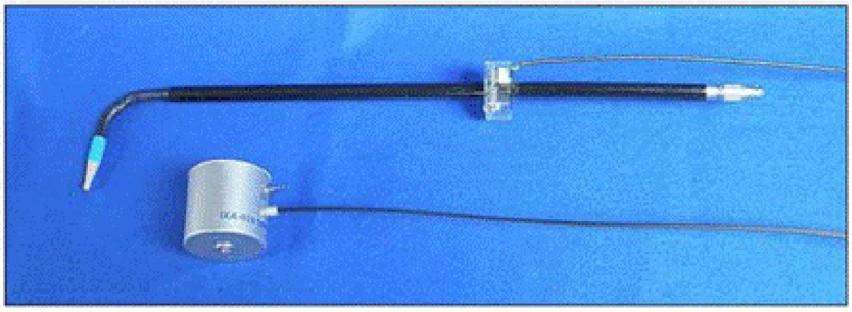
IMMERSIBLE SAR PROBE

CALIBRATION REPORT

Part Number: IXP–020

S/N L0006

March 2015



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Calibration Certificate 1503/L0006
Date of Issue: 31 March 2013
Immersible SAR Probe

Type:	IXP-020
Manufacturer:	IndexSAR, UK
Serial Number:	L0006
Place of Calibration:	IndexSAR, UK
Date of Receipt of Probe:	10 February 2015
Calibration Dates:	13 – 20 March 2015
Customer:	TUV Sud

IndexSAR Ltd hereby declares that the IXP-050 Probe named above has been calibrated for conformity to the current versions of IEEE 1528, IEC 62209-1, IEC 62209-2, and FCC SAR 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:	[signature]	**Technical Manager**
Approved by:	[signature]	**Director**

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

INTRODUCTION

L-shaped probes are designed solely for use on the SARA-C SAR-measuring system. They are not designed to work on SARA2 or any other robot-positioning system, but can be positioned manually if software is available to read out SAR measurement values..

This Report presents measured calibration data for a particular Indexsar SAR probe (S/N L0006) only and describes the procedures used for characterisation and calibration.

Indexsar probes are characterised using procedures that, where applicable, follow the recommendations of IEC 62209-1 [Ref 1], IEEE 1528 [Ref 2], IEC 62209-2 [Ref 3] and FCC SAR [Ref 4] standards, or equivalent. 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 the following stages:-

1) Determination of the relative channel sensitivity factors which optimise the probe's overall axial isotropy in 900MHz brain fluid.

2) Measure the incidental spherical isotropy using these derived channel sensitivity factors.

3) Since isotropy and channel sensitivity factors are frequency independent, these channel sensitivity factors can be applied to model the exponential decay of SAR in a waveguide fluid cell at each frequency of interest, 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] - [4]. 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 mV and DCP is the diode compression potential, also in mV.

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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-020 probes with CW signals the DCP values are typically 100mV.

For this value of DCP, the typical linearity response of IXP-050 probes to CW and to GSM modulation is shown in Figure 7, along with departures of this same dataset from linearity.

In turn, measurements of E-field are determined using the following equation:

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

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

Within SARA-C, an L-probe's predominant mode of operation is with the tip pointing directly towards the source of radiation. Consequently, optimising the probe's response to boresight signals ("axial isotropy") is far more important than optimising its spherical isotropy (where the direction, as well as the polarisation angle, of the incoming radiation must be taken into account).

The setup for measuring the probe's axial isotropy is shown in Figure 1, and this allows spherical isotropy to be measured at the same time. Moreover, since isotropy is frequency-independent, measurements are normally made at a frequency of 900MHz as lower frequencies are more tolerant of positional inaccuracies.

A box phantom containing 900MHz head fluid is irradiated by a tuned dipole, mounted at the side of the phantom on the SARA2 robot's seventh axis. Note: although the probe is used on SARA-C, it is actually calibrated on SARA2. The dipole is connected to a signal generator and amplifier via a directional coupler and power meter. The absolute power level is not important as long as it is stable, with stability being monitored using the coupler and power meter.

During calibration, the spherical isotropy response is measured by changing the orientation of the probe sensors with respect to the dipole, while keeping the long shaft of the probe vertical and the probe sensors at precisely the same position in space. Correctly aligning the probe sensors in this way is essential to an accurate measurement of isotropy.

Initially, the short shaft of the probe is positioned parallel to the phantom wall with its sensors at the same vertical height as the centre of the source dipole and the line joining sensors to dipole perpendicular to the phantom wall (see

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Figure 1). In this position, the probe is said to be at a position angle of -90 degrees. During the scan, the probe is rotated from -90 to +90 degrees in 10 degree steps, and at each position angle, the dipole polarisation changes from 0 to 360 degrees in 20 degree steps. The short shaft of the probe thereby starts moving increasingly end-on to the dipole, and after passing through perpendicularity, it carries on until facing in the opposite direction from its starting position, all the time with the centroid of the sensors occupying the same position in space.

While all relative probe and dipole orientations contribute to the probe's spherical isotropy response, only the subset of measurements made when the probe is exactly end-on to the dipole, contributes to the calculation of axial isotropy. The relative channel sensitivities can be adjusted either to give the most uniform response to all incoming directions and polarisations (spherical isotropy) or just to boresight signals (axial isotropy). Unfortunately, in practice, the two isotropies are not mutually optimisable by the same relative channel gains, so a choice must be made based or the usual mode of operation. That is why Indexsar optimises for Axial Isotropy.

At each probe position/dipole polarisation pair, an Indexsar 'Fast' amplifier samples the probe channels 500 times per second for 0.4 s. The raw $U_{o/p}$ 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 a full set of data has been collected, the Air Factors are adjusted using a special Excel Solver routine to equalise the output from each channel and hence minimise the axial isotropy (see Figure 3). This automated approach to optimisation removes the effect of human bias. These optimised channel sensitivity values can then be applied to the entire dataset as a check on the resulting spherical isotropy, as shown in Figure 4.

4. 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 perpendicular distance from 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 4:

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

Here, the density ρ is conventionally assumed to be 1000 kg/m^3, *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 δ (which is the reciprocal of the waveguide-mode attenuation coefficient) is a property of the lossy liquid and is given by Equation (5).

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

where σ is the conductivity of the tissue-simulant liquid in S/m, ε_r is its relative permittivity, and ω is the radial frequency (rad/s). Values for σ and ε_r are obtained prior to each waveguide test using an Indexsar DiLine measurement kit, which uses the TEM method as recommended in [2]. σ and ε_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°C; if this is not possible, the values of σ and ε_r should reflect the actual temperature. Values employed for calibration are listed in the tables below.

Dedicated waveguides have been designed to accommodate the geometry of an L-shaped probe as it traces out the decay profile. Traditional straight probes measure the decay rate of a vertical-travelling signal above a horizontal dielectric window; for the L-shaped probes, the geometry has had to be changed, and the waveguide now lies horizontally and instead of being open at the end, is capped with a metal plate (see Figure 2). A slot is cut in the top ("b") face through which tissue simulant fluid can be poured, and through which the probe can enter the guide and be offered up to the now vertical waveguide window.

During calibration, the probe tip is moved carefully towards the dielectric window until the flat face of the tip is just touching the exact centre of the face. 200 samples are then taken and written to an Excel template file before moving the probe into the liquid away from the waveguide window. This cycle is repeated 150 times at each separation. The spatial 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.

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

Different waveguides are used for 700MHz, 835/900MHz, 1450MHz, 1800/1900MHz, 2100/2450/2600MHz 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 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.

For calibrations at 450MHz, where waveguide calibrations become unfeasible, a full 3D SAR scan over a tuned dipole is performed, and the conversion factor adjusted to make the measured 1g and 10g volume-averaged SAR values agree with published targets.

CALIBRATION FACTORS MEASURED FOR PROBE S/N L0006

The probe was calibrated at 450, 835, 900, 1800, 1900, 2100, 2450 and 2600 MHz in liquid samples representing brain liquid at these frequencies.

The calibration was for CW signals only, and the horizontal axis of the probe was parallel to the direction of propagation of the incident field i.e. end-on to the incident radiation.

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 **Error! Bookmark not defined.** indicates the calibration status of all test equipment used during probe calibration.

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MEASUREMENT UNCERTAINTIES

A complete measurement uncertainty analysis for the SARA-C measurement system has been published in Reference [3]. Table 17 from that document is re-created below, and lists the uncertainty factors associated just with the calibration of probes.

Source of uncertainty	Uncertainty value ± %	Probability distribution	Divisor	c_i	Standard uncertainty ui ± %	v_i or v_{eff}
Forward power	3.92	N	1.00	1	3.92	∞
Reflected power	4.09	N	1.00	1	4.09	∞
Liquid conductivity	1.308	N	1.00	1	1.31	∞
Liquid permittivity	1.271	N	1.00	1	1.27	∞
Field homgeneity	3.0	R	1.73	1	1.73	∞
Probe positioning	0.22	R	1.73	1	0.13	∞
Field probe linearity	0.2	R	1.73	1	0.12	∞
Combined standard uncertainty		RSS			6.20	

At the 95% confidence level, therefore, the expanded uncertainty is 12.4%

SUMMARY OF CAL FACTORS FOR PROBE IXP-020 S/N L0006

Relative Channel Sensitivities (to optimise Axial Isotropy)				
	X	Y	Z	
Air Factors	72.81	90.02	77.16	$(V/m)^2/mV$
CW DCPs	100	100	100	mV

Measured Isotropy at 900MHz	Probe orientation range relative to dipole	(+/-) dB
Axial Isotropy	0° (end-on to dipole)	0.01
Spherical Isotropy	±20°	0.17
	±30°	0.28
	±60°	0.58
	±90°	0.63

SAR Conversion Factors/ Boundary Corrections (Head Fluid)				
Frequency* (MHz)	SAR Conv Factor	Boundary Correction f(0)	Boundary Correction d(mm)	Notes
450	0.298	0.0	1.0	3
700	0.300	1.2	1.1	4
835	0.304	0.8	1.5	1,2
900	0.305	1.0	1.4	1,2
1800	0.373	0.9	1.5	1,2
1900	0.382	0.5	2.3	1,2
2100	0.396	0.6	2.0	1,2
2450	0.423	0.9	1.5	1,2
2600	0.427	1.1	1.4	1,2
Notes				
1)	Calibrations done at 22°C +/-2°C			
2)	Waveguide calibration			
3)	By validation			
4)	By extrapolation			

*The valid frequency of SARA-C probe calibrations are ±100MHz (F<300MHz) and ±200MHz (F>300MHz).

Physical Information	
Sensor offset (mm)	2.7
Elbow – Tip dimension (mm)	84.55

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PROBE SPECIFICATIONS

Indexsar probe L0006, 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:

Dimensions	S/N L0006	BSEN [1]	IEEE [2]
Vertical shaft (mm)	510		
Horizontal shaft (mm)	90		
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 L0006	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

Isotropy (measured at 900MHz)		S/N L0006	BSEN [1]	IEEE [2]
Axial	Probe at 0°	0.01	0.5	0.25
Spherical	Probe at ±20°	0.17	N/A	N/A
	Probe at ±30°	0.28		
	Probe at ±60°	0.58		
	Probe at ±90°	0.63		

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. Outer case materials are PEEK and heat-shrink sleeving.
Chemical resistance	Tested to be resistant to TWEEN and sugar/salt-based simulant liquids but probes should be removed, cleaned and dried when not in use. NOT recommended for use with glycol or soluble oil-based liquids.

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REFERENCES

References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.

For a specific reference, subsequent revisions do not apply.

For a non-specific reference, the latest version applies.

[1] IEC 62209-1.
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
Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques

[3] IEC 62209-2
Human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices – Human models, Instrumentation, and procedures – Part 2: Procedure to determine the specific absorption rate (SAR) for wireless communication devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz)

[4] FCC KDB 865664

[5] Indexsar Report IXS-0300, October 2007.
Measurement uncertainties for the SARA2 system assessed against the recommendations of BS EN 62209-1:2006

[6] SARA-C SAR Testing System: Measurement Uncertainty, v1.0.3. October 2011.

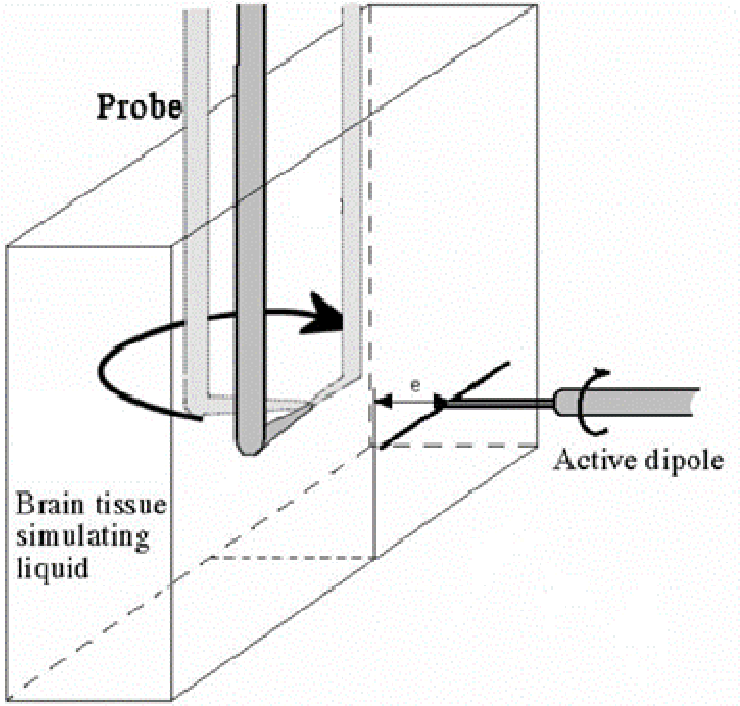

Figure 1 Isotropy jig showing probe, dipole and box filled with simulated brain liquid (see Ref [2], Section A.5.2.1)

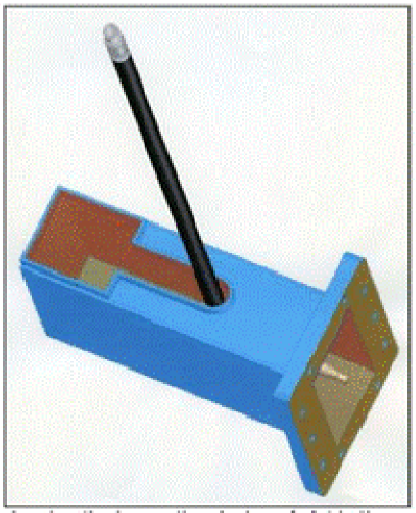

Figure 2 Schematic showing the innovative design of slot in the waveguide termination

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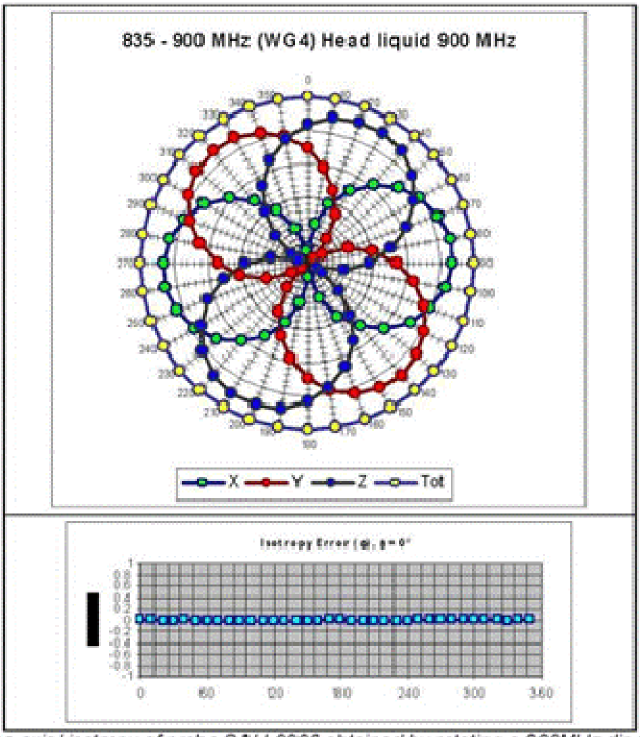

Figure 3 The axial isotropy of probe S/N L0006 obtained by rotating a 900MHz dipole with probe tip aligned with dipole boresight (NB Axial Isotropy is frequency independent)

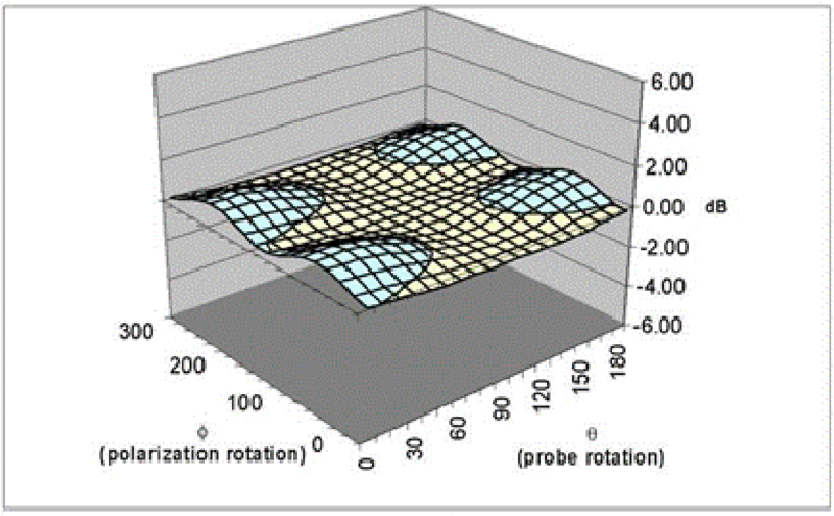

Figure 4 Residual Surface Isotropy at 900 MHz after optimisation for axial isotropy

COMMERCIAL-IN-CONFIDENCE

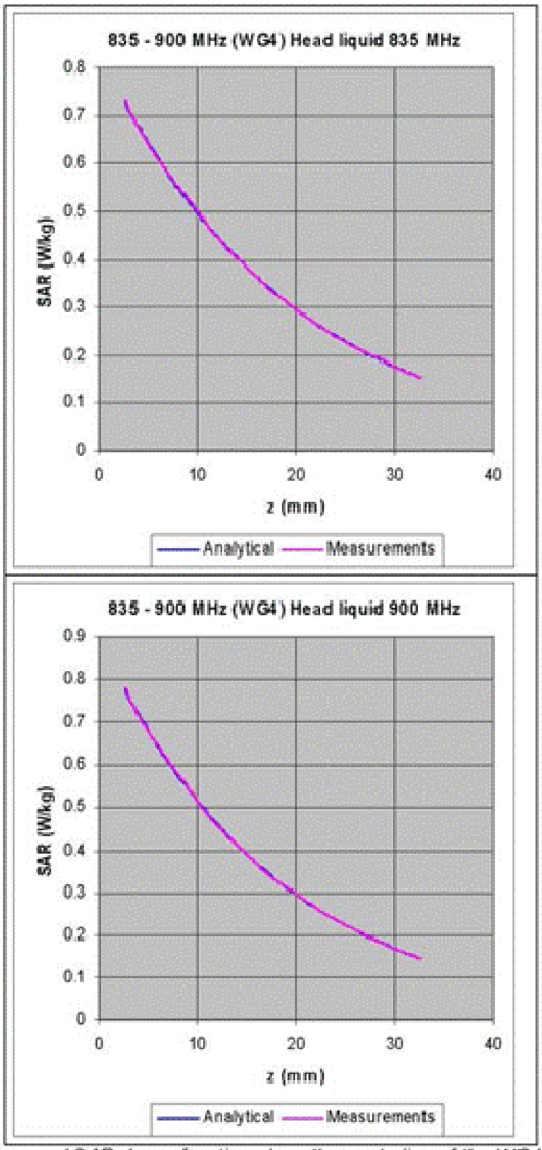

Figure 5 The measured SAR decay function along the centreline of the WG4 waveguide with conversion factors adjusted to fit to the theoretical function for the particular dimension, frequency, power and liquid properties employed.

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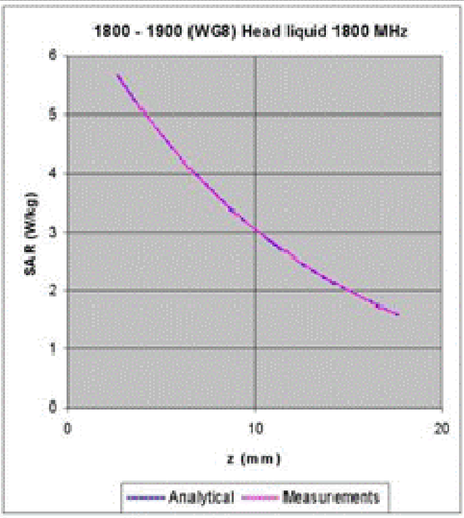

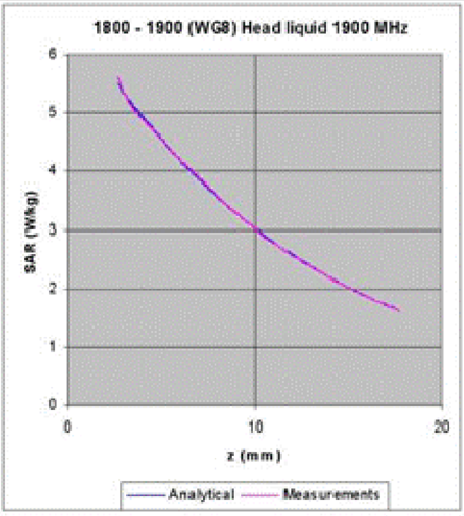

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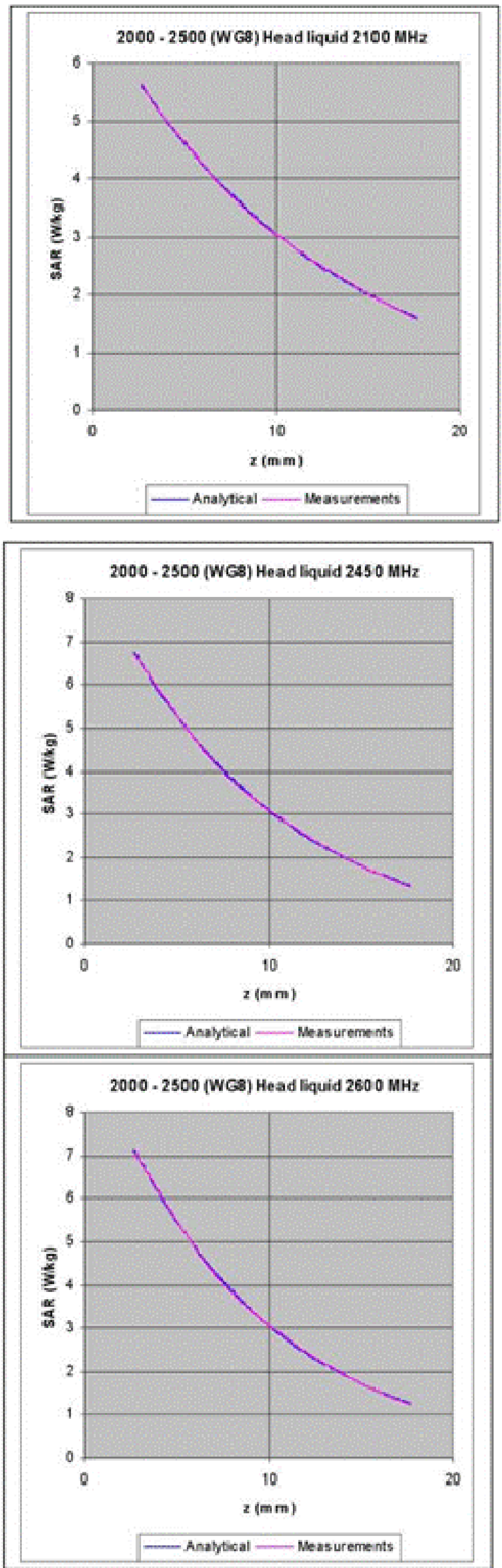

Figure 6. The measured SAR decay function along the centreline of the R22 waveguide with conversion factors adjusted to fit to the theoretical function for the particular dimension, frequency, power and liquid properties employed.

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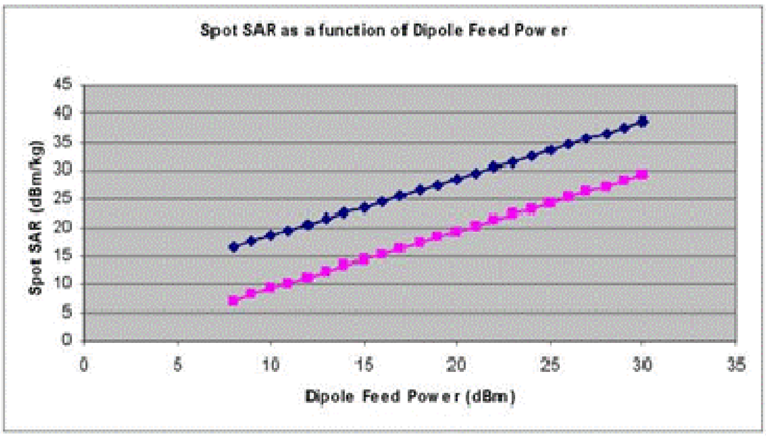

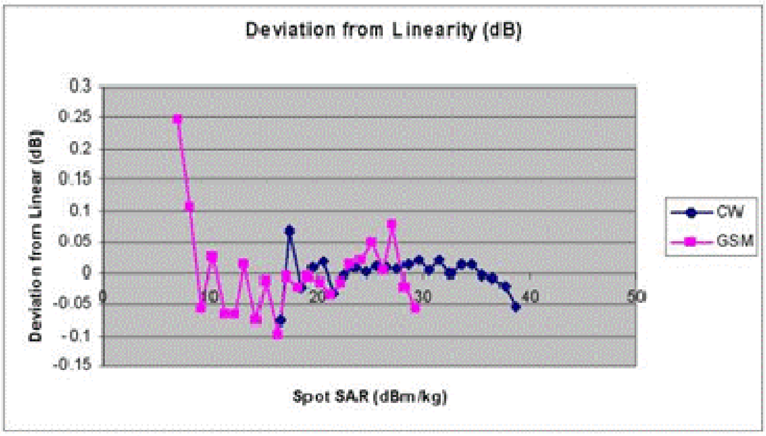

Figure 7: The typical linearity response of 5mm probes to both CW (blue) and GSM (pink) modulation in close proximity to a source dipole. The top diagram shows the SAR reading as a function of dipole feed power, with GSM modulation being approx a factor of of 8 (ie 9dB) lower than CW. The lower diagram shows the departure from linearity of the same two datasets.

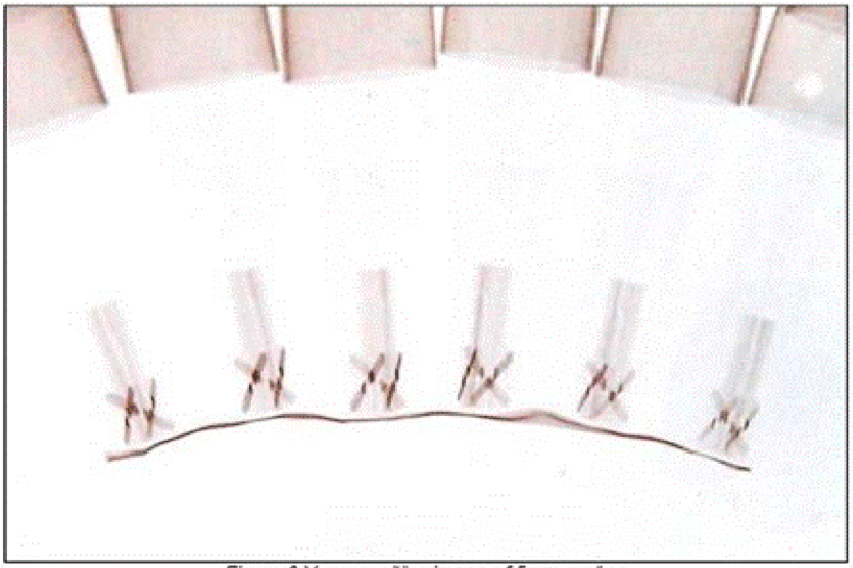

Figure 8 X-ray positive image of 5mm probes

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

Frequency (MHz)	Fluid Type	Measured		Target		% Deviation		Verdict	
		Relative Permittivity	Conductivity (S/m)	Relative Permittivity	Conductivity (S/m)	Relative Permittivity	Conductivity	Relative Permittivity	Conductivity
450	Head	44.142	0.845	43.5	0.87	1.5	-2.9	Pass	Pass
835		42.114	0.901	41.5	0.90	1.5	0.1	Pass	Pass
900		41.13	0.961	41.5	0.97	-0.9	-0.9	Pass	Pass
1800		39.719	1.428	40.0	1.40	-0.7	2.0	Pass	Pass
1900		39.744	1.396	40.0	1.40	-0.6	-0.3	Pass	Pass
2100		40.541	1.463	39.8	1.49	1.9	-1.8	Pass	Pass
2450		39.265	1.815	39.2	1.80	0.2	0.8	Pass	Pass
2600		38.715	1.975	39.0	1.96	-0.7	0.8	Pass	Pass

Table of test equipment calibration status

Instrument description	Supplier / Manufacturer	Model	Serial No.	Last calibration date	Cal certificate number	See Annex	Calibration due date
Power sensor	Rohde & Schwarz	NRP-Z23	100063	14/08/2013	10-300287035	1	14/08/2015
Power sensor	Rohde & Schwarz	NRP-Z23	100169	06/08/2014	1400-48811	2	06/08/2016
Dielectric property measurement	Indexsar	DiLine (sensor lengths: 160mm, 80mm and 60mm)	N/A	(absolute) – checked against NPL values using reference liquids	N/A		N/A
Vector network analyser	Anritsu	MS6423B	003102	17/02/2015	RMA20027002	3	17/02/2016
SMA autocalibration module	Anritsu	36581KKF/1	001902	22/01/2015	RMA20021769	4	22/01/2016

TÜV SÜD Product Service

Annex 1

Calibration Certificate of NRP-Z23 power sensor, S/N 100063

ROHDE&SCHWARZ

Calibration Certificate
Kalibrierschein

Certificate Number 10-300287035
Zertifikatsnummer

Unit Data

Item / Gegenstand	Average power sensor
Manufacturer / Hersteller	ROHDE & SCHWARZ
Type / Typ	NRP-Z23
Material Number / Materialnummer	1137.8002.02
Serial Number / Seriennummer	100063
Asset Number / Inventarnummer	

Order Data

Customer / Auftraggeber	IndexSAR Ltd Oakfield House, RH5 5BG Newdigate GB
Order Number / Bestellnummer	-
Date of Receipt / Eingangsdatum	2013-08-08

Performance

Place and Date of Calibration / Ort und Datum der Kalibrierung	Memmingen, 2013-08-14
Scope of Calibration / Umfang der Kalibrierung	Standard Calibration
Statement of Compliance (Incoming) / Konformitätsaussage (Anlieferung)	Measurement results within specifications
Statement of Compliance (Outgoing) / Konformitätsaussage (Auslieferung)	Measurement results within specifications
Extent of Calibration Documents / Umfang des Kalibrierdokuments	2 Pages Calibration Certificate 17 Pages Outgoing Results 17 Pages Incoming Results

This calibration certificate documents, that the named item is tested and measured against defined specifications.
Measurement results are located usually in the corresponding interval with a probability of approx. 95% (coverage factor k = 2).
Calibration is performed with test equipment and standards directly or indirectly traceable by means of approved calibration techniques to the PTB/DKD or other national / international standards, which realize the physical units of measurement according to the International System of Units (SI).
In all cases where no standards are available, measurements are referenced to standards of the R&S laboratories.
Principles and methods of calibration correspond with EN ISO/IEC 17025. The applied quality system is certified to EN ISO 9001.
This calibration certificate may not be reproduced other than in full.
Calibration certificates without signatures are not valid.
The user is obliged to have the object recalibrated at appropriate intervals.

Dieser Kalibrierschein dokumentiert, dass der genannte Gegenstand nach festgelegten Vorgaben geprüft und gemessen wurde. Die Messwerte lagen im Regelfall mit einer Wahrscheinlichkeit von annähernd 95% im zugeordneten Werteintervall (Erweiterte Messunsicherheit mit k = 2).
Die Kalibrierung erfolgte mit Messmitteln und Normalen, die direkt oder indirekt durch Ableitung mittels anerkannter Kalibriertechniken rückgeführt sind auf Normale der PTB/DKD oder anderer nationaler/internationaler Standards zur Darstellung der physikalischen Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Wenn keine Normale existieren, erfolgt die Rückführung auf Bezugsnormale der R&S-Laboratorien.
Grundsätze und Verfahren der Kalibrierung entsprechen EN ISO/IEC 17025.
Das angewandte Qualitätsmanagement-System ist zertifiziert nach EN ISO 9001.
Dieser Kalibrierschein darf nur vollständig und unverändert weiterverbreitet werden.
Kalibrierscheine ohne Signaturen sind ungültig.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

Rohde & Schwarz GmbH & Co. KG; Service Operations West

Date of Issue / Ausstellungsdatum	Head of Laboratory / Laborleitung	Person Responsible / Bearbeiter
2013-08-14	Courage	Ruprecht Schmid

Page 1/2

ROHDE & SCHWARZ GmbH & Co KG · Mühldorfstraße 15 · D-81671 München, Federal Republic of Germany · Telefon (089) 41 29-0 · Telefax (089) 41 29-132 75
Geschäftsführung: Manfred Fleischmann (Vorsitzender), Christian Leicher, Gerhard Geier
Sitz München · Registereintrag: HRA 16 270 · Persönlich haftender Gesellschafter: RUSEG Verwaltungs-GmbH · Sitz München · Registereintrag: AG München HRB 7 534

TÜV SÜD Product Service

Material Number 1137.8002.02 Serial Number 100063

Certificate Number 10-300287035

Calibration Method / Kalibriermethode: NRVC-1109.0930.32

Relative Humidity / Relative Luftfeuchte: 20%-60%

Ambient Temperature / Umgebungstemperatur: $(23\ ^{+1}_{-1})$ °C

Working standards used (having a significant effect on the accuracy) Verwendete Gebrauchsnormale (mit signifikantem Einfluss auf die Genauigkeit)				
Item Gegenstand	Type Typ	Serial Number Seriennummer	Calibration Certificate Number Kalibrierscheinnummer	Cal. Due Kalibr. bis
Dual Channel Powermeter	NRVD	100862	0114 D-K-15195-01-00 2013-08	2014-11-30
Dual Channel Power Meter	NRVD	828583/0023	0113 D-K-15195-01-00 2013-08	2014-11-30
Vector Network Analyzer	ZVM	835228/0020	0102-DKD-K-16101-2011-08	2013-10-31
Access Set for Lin. Measurement	NRVC-B2	848997/0028	0085 D-K-15195-01-00 2013-01	2014-04-30
Calibration Kit Type-N ;50 Ohm	85054B	2705A00160	217-01723 [METAS]	2015-03-31
Power Standard	NRVC	836497/0005	0082 D-K-15195-01-00 2013-01	2014-04-30

Conformity statements take the measurement uncertainties into account.
Die Konformitätsaussagen berücksichtigen die Messunsicherheiten.

Notes
Anmerkungen

Installed options are included in calibration. Depending on installed options, numbers of pages of the record are not consecutive.

Annex 2

Calibration Certificate of NRP-Z23 power sensor, S/N 100169

ROHDE&SCHWARZ

Calibration Certificate / Kalibrierschein

Certificate Number / Zertifikatsnummer **1400-48811**

Unit data

Item / Gegenstand	AVERAGE POWER SENSOR
Manufacturer / Hersteller	Rohde & Schwarz
Type / Typ	NRP-Z23
Material number / Materialnummer	1137.8002.02
Serial number / Seriennummer	ID: 1137.8002.02-100169-aj Ser.: 100169
Asset number / Anlagennummer	
Recomended Calibration Interval	24 Months

Order data

Customer / Auftraggeber	IndexSAR Ltd Oakfield House, Newdigate RH5 5BG Great Britain
On behalf of (where applicable) / In namen von (Wenn gewunscht)	
Order number / Bestellungnummer	1024R&S
Date of receipt / Eingangsdatum	2014-08-06 (YYYY-MM-DD)

Performance

Place and date of calibration / Ort u. Datum d. Kalibrierung	Fleet; 2014-08-06 (YYYY-MM-DD)
Scope of calibration / Umfang der Kalibrierung	Factory Standard Calibration
Statement of Compliance (Incoming) / Konformitätsaussage (Anlieferung)	All measured values are within the data sheet specifications.
Statement of Compliance (Outgoing) / Konformitätsaussage (Auslieferung)	All measured values are within the data sheet specifications.
Extent of calibration documents / Umfang der Kalibrierdokumentation	2 Pages Calibration Certificate 40 Pages Calibration Results 2 Pages Incoming Report

This calibration certificate documents, that the named item is tested and measured against defined specifications.
Measurement results are located usually in the corresponding interval with a probability of approx. 95% (coverage factor k = 2).
Calibration is performed with test equipment and standards directly or indirectly traceable by means of approved calibration techniques to the PTB/DKD or other national / international standards, which realize the physical units of measurement according to the International System of Units (SI). In all cases where no standards are available, measurements are referenced to standards of the R&S laboratories.
Principles and methods of calibration correspond essentially with the technical requirements of EN ISO/IEC 17025. The applied quality system is certified to EN ISO 9001.
This calibration certificate may not be reproduced other than in full. Calibration certificates without signatures are not valid.
The user is obliged to have the object recalibrated at appropriate intervals.

Dieser Kalibrierschein dokumentiert, dass der genannte Gegenstand nach festgelegten Vorgaben geprüft und gemessen wurde. Die Messwerte lagen im Regelfall mit einer Wahrscheinlichkeit von annähernd 95% im zugeordneten Werteintervall (Erweiterte Messunsicherheit mit k = 2).
Die Kalibrierung erfolgte mit Messmitteln und Normalen, die direkt oder indirekt durch Ableitung mittels anerkannter Kalibriertechniken rückgeführt sind auf Normale der PTB/DKD oder anderer nationaler/internationaler Standards zur Darstellung der physikalischen Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI). Wenn keine Normale existieren, erfolgt die Rückführung auf Bezugsnormale der R&S-Laboratorien.
Grundsätze und Verfahren der Kalibrierung entsprechen im Wesentlichen den technischen Anforderungen der EN ISO/IEC 17025.
Das angewandte Qualitätsmanagement-System ist zertifiziert nach EN ISO 9001.
Dieser Kalibrierschein darf nur vollständig und unverändert weiterverbreitet werden. Kalibrierscheine ohne Unterschriften sind ungültig.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

Rohde & Schwarz UK

Date of issue / Ausstellungsdatum	Head of laboratory / Laborleitung	Person responsible / Bearbeiter
2014-08-06 (YYYY-MM-DD)	Carol Mckenzie	Martin Gill

Page (Seite) 1 of 2

ROHDE & SCHWARZ UK Ltd, Ancells Business Park, Fleet Hampshire GU51 2UZ United Kingdom
Registered in England No. 539607

TÜV SÜD Product Service

Material number Materialnummer	1137.8002.02	**Certificate Number**	**1400-48811**
Serial number Seriennummer	ID: 1137.8002.02-100169-aj Ser.: 100169	**Zertifikatsnummer**	

Calibration instruction Kalibrieranweisung: See first page of calibration results

Ambient temperature Umgebungstemperatur: (23 ± 2) °C

Date of receipt Eingangsdatum: 2014-08-06 (YYYY-MM-DD)

Relative humidity Relative Luftfeuchte: 20 % - 60 %

This calibration fulfils the requirements of the standard / guideline
Diese Kalibrierung entspricht den Forderungen der Norm / Richtlinie

Working standards used (having a significant effect on the accuracy)
Verwendete Gebrauchsnormale (mit signifikantem Einfluss auf die Genauigkeit)

Item Gegenstand	**Type** Typ	**Serial number** Seriennummer	**Calibration certificate number** Kalibrierschein Nummer	**Cal. due** Kalibr. bis
See page 2 of calibration results				

UGB **(Uncertainty guard Band): Measurement uncertainty violates the datasheet limit**

UGB1 **A compliance statement may be possible where a confidence level of less than 95 % is acceptable.**
Die Bestätigung der Konformität ist möglich, sofern ein Grad des Vertrauens von weniger als 95% akzeptabel ist.

UGB2 **A non-compliance statement may be possible where a confidence level of less than 95 % is acceptable.**
Die Bestätigung der Nicht-Konformität ist möglich, sofern ein Grad des Vertrauens von weniger als 95% akzeptabel ist.

Conformity statements take the measurement uncertainties into account.
Die Konformitätsaussagen berücksichtigen die Messunsicherheiten.

Ref.: ILAC-G8:1996 "Guidelines on Assessment and Reporting of Compliance with Specification (based on measurements and tests in a laboratory)"

Notes
Anmerkungen

TÜV SÜD Product Service

Annex 3

Calibration certificate of Anritsu MS4623B VNA

Certificate of Calibration

Anritsu
Discover What's Possible™

Customer:
INDEXSAR LTD
INDEXSAR LTD_

OAKFIELD HOUSE
NEWDIGATE
SURREY RH5 5BG
UNITED KINGDOM

ANRITSU EMEA LIMITED
200 CAPABILITY GREEN
LUTON LU1 3LU
UNITED KINGDOM
Tel: +44 (0) 1582 433285
Fax:+44 (0) 1582 456675
Email: service.eso@eu.anritsu.com

Date of Issue:	17/02/2015	**Certificate N°:**	RMA20027002
Customer:	INDEXSAR LTD	**Order No:**	Contract
Manufacturer:	Anritsu Company		

Model	Serial Number	Description
MS4623B	003102	VNA,10 MHZ-6 GHZ,ACTIVE

Anritsu EMEA Limited does hereby certify the above listed equipment complies to published or stated specifications at the measured parameters, and has been calibrated to the general requirements of ISO 17025 against instruments whose accuracies are traceable to National or International Standards, where such standards are applicable.

Repair required before calibration	(yes)
Electrical Safety	(yes)
Laser safety class	( )

Authorised Signature

Murray Coleman
Head of Customer Services (EMEA)

Note: Original calibration results are attached and copies held on file at Anritsu EMEA Limited.
The attached results relate only to the instrument under calibration.
Anritsu EMEA Limited Quality system is certified to ISO9001:2000 (Cert. No. FQA 0353178)
This Certificate comprises of:
Certificate of Calibration
Cal Report
25 Page(s) of test results

TÜV SÜD Product Service

Annex 4

Calibration certificate of Anritsu 36581KKF/1 auto-cal kit

Certificate of Calibration

Anritsu
Discover What's Possible™

Customer:
INDEXSAR LTD
INDEXSAR LTD_

OAKFIELD HOUSE
NEWDIGATE
SURREY RH5 5BG
UNITED KINGDOM

ANRITSU EMEA LIMITED
200 CAPABILITY GREEN
LUTON LU1 3LU
UNITED KINGDOM
Tel: +44 (0) 1582 433285
Fax:+44 (0) 1582 455575
Email: service.esc@eu.anritsu.com

Date of Issue:	**22/01/2015**	**Certificate N°:**	**RMA20026648**
Customer:	**INDEXSAR LTD**	**Order No:**	**1045ANR**
Manufacturer:	**Anritsu Company**		

Model	Serial Number	Description
MS4623B	**003102**	VNA,10 MHZ-6 GHZ,ACTIVE
36581KKF/1	**001902**	TESTED & CHARACTERIZED TO 6 GHZ

Anritsu EMEA Limited does hereby certify the above listed equipment complies to published or stated specifications at the measured parameters, and has been calibrated to the general requirements of ISO 17025 against instruments whose accuracies are traceable to National or International Standards, where such standards are applicable.

Within specification before calibration	(yes)
Repair required before calibration	(no)
Electrical Safety	(yes)
Laser safety class	( )

Authorised Signature

Murray Coleman
Head of Customer Services (EMEA)

Note: Original calibration results are attached and copies held on file at Anritsu EMEA Limited.
The attached results relate only to the instrument under calibration.
Anritsu EMEA Limited Quality system is certified to ISO9001:2000 (Cert. No. FQA 0353176)
This Certificate comprises of:
Certificate of Calibration
Call Report
13 Page(s) of test results

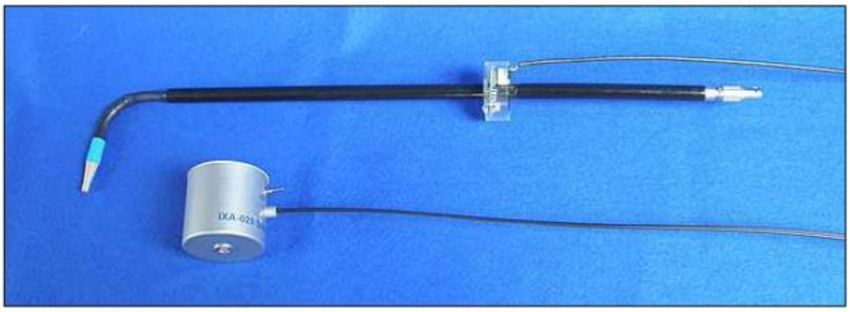
IMMERSIBLE SAR PROBE

CALIBRATION REPORT

Part Number: IXP–021

S/N LG0018

March 2014



Indexsar Limited
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Tel: +44 (0) 1306 632 870
Fax: +44 (0) 1306 631 834
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e-mail: enquiries@indexsar.com

Calibration Certificate 1403/LG0018
Date of Issue: 24th March 2014
Immersible SAR Probe

Type:	IXP-021
Manufacturer:	IndexSAR, UK
Serial Number:	LG0018
Place of Calibration:	IndexSAR, UK
Date of Receipt of Probe:	30 January 2014
Calibration Dates:	11-21 March 2014
Customer:	TUV Sud

IndexSAR Ltd hereby declares that the IXP-025 Probe named above has been calibrated for conformity to the current versions of IEEE 1528, IEC 62209-1, IEC 62209-2, and FCC OET65 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:	A. Brinklow	**Technical Manager**
Approved by:	[signature]	**Director**

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

Product Service

INTRODUCTION

This Report presents measured calibration data for a particular Indexsar SAR probe (S/N LG0018) only and describes the procedures used for characterisation and calibration.

Indexsar probes are characterised using procedures that, where applicable, follow the recommendations of IEC 62209-1 [Ref 1], IEEE 1528 [Ref 2], IEC 62209-2 [Ref 3] and FCC OET65 [Ref 4] 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 the following stages

1) Determination of the channel sensitivity factors which optimise the probe's overall axial isotropy
2) Use of these channel sensitivity factors to compare the SAR decay curve in a waveguide fluid cell with an analytical curve at each frequency of interest, 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:

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

where U_{lin} is the linearised signal, $U_{o/p}$ is the raw output signal in mV and DCP is the diode compression potential, also in mV.

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-021 probes with CW signals the DCP values are typically 100mV.

In turn, measurements of E-field are determined using the following equation:

$$E_{liq}^{2}\ (V/m) = U_{linx} * \text{Air Factor}_{x} * \text{Liq Factor}_{x}$$

$+ U_{liny}$ * Air $Factor_y$* Liq $Factor_y$
$+ U_{linz}$ * Air $Factor_z$* Liq $Factor_z$ (3)

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

Within SARA-C, a probe’s predominant mode of operation is with the tip pointing directly towards the source of radiation. Consequently, optimising the probe’s response to boresight signals (“axial isotropy”) is far more important than optimising its spherical isotropy (where the direction, as well as the polarisation angle, of the incoming radiation must be taken into account).

A 5-6GHz 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 on a turntable and the liquid cell section is filled with 5-6GHz brain fluid to within 1 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_{01} mode is launched into the waveguide by means of an N-type-to-waveguide adapter. The probe is held by the robot in a dedicated jig with the probe’s long shaft horizontal and the short shaft pointing vertically down over the centre of the waveguide opening, Figure 1. In this position, the short shaft lies directly along the waveguide’s main axis in the direction of signal travel. The probe is then lowered along the waveguide axis directly into the liquid until the tip is exactly 5mm 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.

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 during the assessment of axial isotropy. However, the power must be sufficiently above the noise floor and free from drift.

With the probe’s short shaft lying directly along the waveguide axis, the probe’s axial isotropy can be measured by changing their relative position angle. This can be done by either spinning the probe while the waveguide remains stationery (usual procedure for straight probes) or, as is the case for L-probes, the waveguide is turned by hand while the probe does not move. The dedicated Indexsar calibration software requests that the user rotates the waveguide in 10 degree steps about its axis, and at each position, an Indexsar ‘Fast’ amplifier samples the probe channels 500 times per second for

Product Service

0.4 s. The raw $U_{o/p}$ 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 axial isotropy. This automated approach to optimisation removes the effect of human bias.

Figure 3 represents the output from each diode sensor as a function of probe rotation angle.

4. 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 perpendicular distance from 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 4:

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

Here, the density ρ is conventionally assumed to be 1000 kg/m^3, 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 δ (which is the reciprocal of the waveguide-mode attenuation coefficient) is a property of the lossy liquid and is given by Equation (5).

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

where σ is the conductivity of the tissue-simulant liquid in S/m, ε_r is its relative permittivity, and ω is the radial frequency (rad/s). Values for σ and ε_r are obtained prior to each waveguide test using an Indexsar DiLine measurement kit, which uses the TEM method as recommended in [2]. σ and ε_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°C; if this is not possible, the values of σ and ε_r should reflect the actual temperature. Values employed for calibration are listed in the tables below.

There are two ways of accommodating the geometry of an L-shaped probe as it traces out the decay profile. Above 3GHz, as here, the waveguide's fluid cell is short enough that the probe's short shaft can be lowered vertically down into the waveguide without the long shaft fouling on the waveguide edge, Figure 1. By contrast, at lower frequencies, the measurement geometry has to be changed, and the waveguide now lies horizontally and the fluid cell has to be capped with a metal plate at least three penetration depths away from the dielectric window (see Figure 2). A slot is cut in the top ("b") face through which tissue simulant fluid can be poured, and through which the probe can enter the guide and be offered up to the now vertical waveguide window.

During high frequency calibration, the probe is lowered carefully until the flat face of the tip 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 away from the waveguide window. This cycle is repeated 150 times, with a different separation each time, in steps of 0.35mm.

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.

Different waveguides are used for 835/900MHz, 1800/1900MHz, 2100/2450/2600MHz 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 Table A.1.

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.

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.

CALIBRATION FACTORS MEASURED FOR PROBE S/N LG0018

The probe was calibrated at 5200, 5500 and 5800 MHz in liquid samples representing brain tissue at these frequencies.

The calibration was for CW signals only, and the horizontal axis of the probe was parallel to the direction of propagation of the incident field i.e. end-on to the incident radiation.

The reference point for the calibration is in the centre of the probe's cross-section at a distance of 1.39 mm from the probe tip in the direction of the probe amplifier. A value of 1.39 mm should be used for the tip to sensor offset distance in the software. The distance of 1.39 mm 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 18 indicates the calibration status of all test equipment used during probe calibration.

Product Service

MEASUREMENT UNCERTAINTIES

A complete measurement uncertainty analysis for the SARA-C measurement system has been published in Reference [3]. Table 17 from that document is re-created below, and lists the uncertainty factors associated just with the calibration of probes.

Source of uncertainty	Uncertainty value ± %	Probability distribution	Divisor	c_i	Standard uncertainty ui ± %	v_i or v_{eff}
Forward power	3.92	N	1.00	1	3.92	∞
Reflected power	4.09	N	1.00	1	4.09	∞
Liquid conductivity	1.308	N	1.00	1	1.31	∞
Liquid permittivity	1.271	N	1.00	1	1.27	∞
Field homgeneity	3.0	R	1.73	1	1.73	∞
Probe positioning	0.22	R	1.73	1	0.13	∞
Field probe linearity	0.2	R	1.73	1	0.12	∞
Combined standard uncertainty		**RSS**			**6.20**	

At the 95% confidence level, therefore, the expanded uncertainty is ±12.4%

SUMMARY OF CAL FACTORS FOR PROBE IXP-021 S/N LG0018

SAR Calibration Factors / Boundary Corrections*								
Freq (MHz)	Tissue Type	Air Factor X ((V/m)^2/mV)	Air Factor Y ((V/m)^2/mV)	Air Factor Z ((V/m)^2/mV)	Rotational Isotropy (± dB)	SAR Conv Factor	Boundary Correction f(0)	Boundary Correction d(mm)
5200	Head	289.0	322.7	348.3	0.10	0.788	0.55	1.1
5500						0.800	0.50	1.5
5800						0.800	0.66	1.0

Product Service

PROBE SPECIFICATIONS

Indexsar probe LG0018, 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:

Dimensions	S/N LG0018	BSEN [1]	IEEE [2]
Vertical shaft (mm)	510		
Horizontal shaft (mm)	84.15		
Tip length (mm)	10		
Body diameter (mm)	12		
Tip diameter (mm)	2.55	8	8
Distance from probe tip to dipole centers (mm)	1.39		

Dynamic range	S/N LG0018	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

Rotational Isotropy (at 5.2GHz)	S/N LG0018	BSEN [1]	IEEE [2]
Axial rotation with probe normal to source (+/- dB)	0.10	0.5	0.25

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. Outer case materials are PEEK and heat-shrink sleeving.
Chemical resistance	Tested to be resistant to TWEEN and sugar/salt-based simulant liquids but probes should be removed, cleaned and dried when not in use. NOT recommended for use with glycol or soluble oil-based liquids.

Product Service

REFERENCES
References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.

For a specific reference, subsequent revisions do not apply.

For a non-specific reference, the latest version applies.

[1] IEC 62209-1.
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
Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques

[3] IEC 62209-2
Human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices – Human models, Instrumentation, and procedures – Part 2: Procedure to determine the specific absorption rate (SAR) for wireless communication devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz)

[4] FCC OET65
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[5] Indexsar Report IXS-0300, October 2007.
Measurement uncertainties for the SARA2 system assessed against the recommendations of BS EN 62209-1:2006

[6] SARA-C SAR Testing System: Measurement Uncertainty, v1.0.3. October 2011.

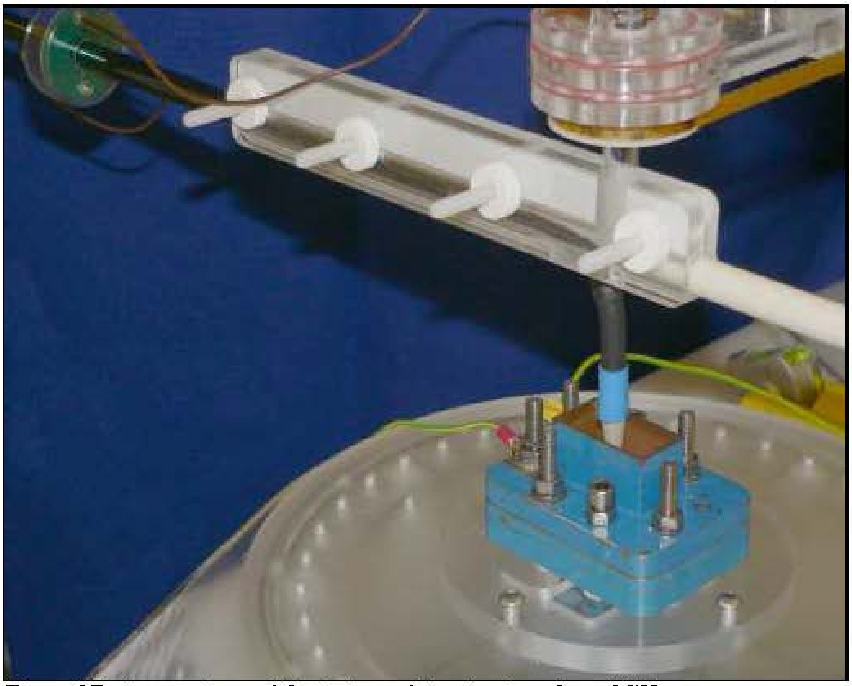

Figure 1 Test geometry used for isotropy determination above 3GHz

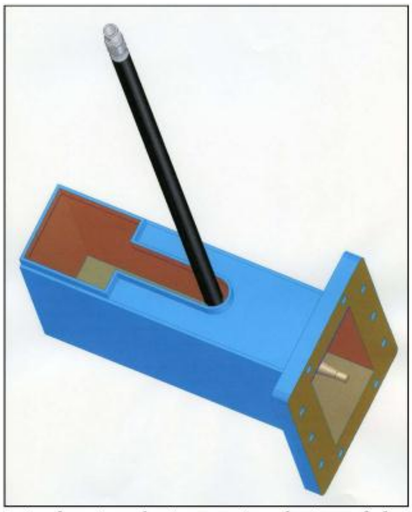

Figure 2. Schematic showing the innovative design of slot in the waveguide termination

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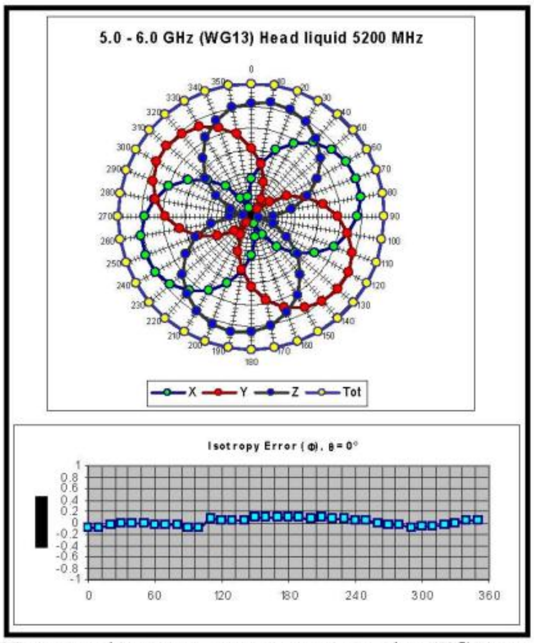

Figure 3Rotational isotropy measurements inside a WG13 waveguide.

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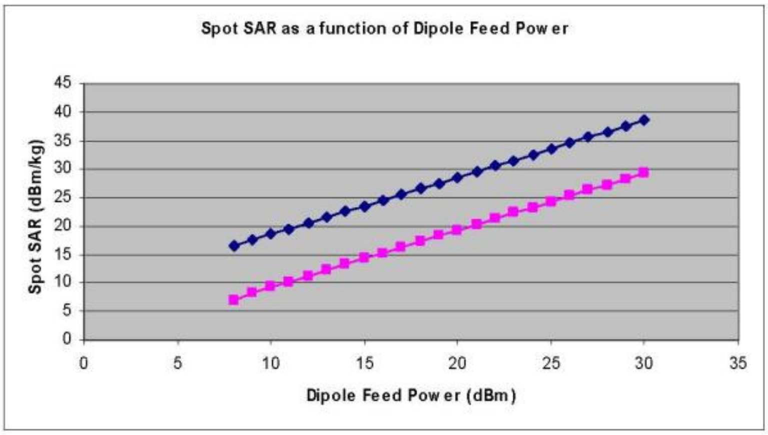

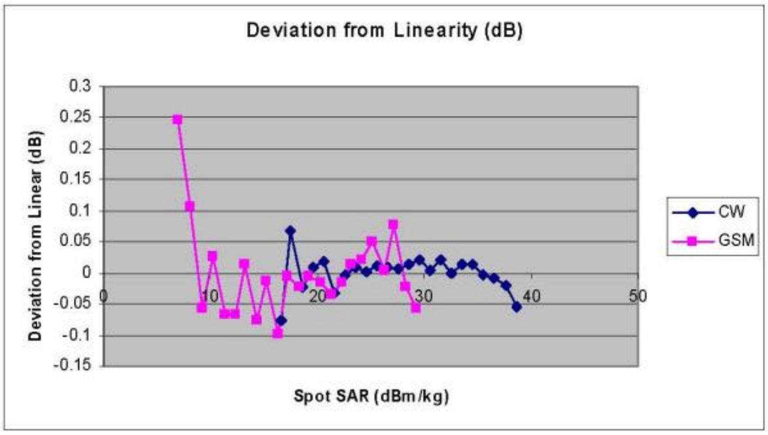

Figure 4 The typical linearity response of IXP-021 probes to both CW (blue) and GSM (pink) modulation in close proximity to a source dipole. The top diagram shows the SAR reading as a function of dipole feed power, with GSM modulation being approx a factor of 8

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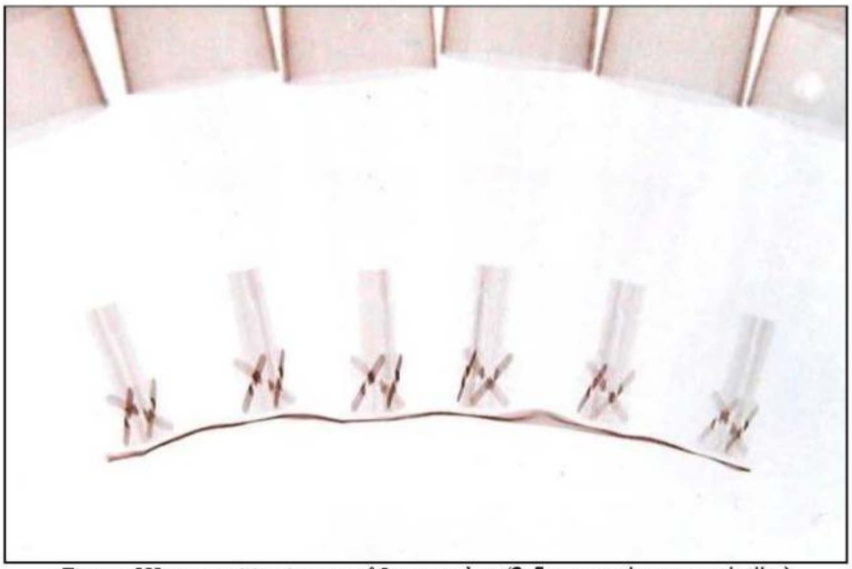

Figure 5X-ray positive image of 5mm probes (2.5mm probes are similar)

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

Frequency (MHz)	Fluid Type	Measured		Target		% Deviation		Verdict	
		Relative Permittivity	Conductivity (S/m)	Relative Permittivity	Conductivity (S/m)	Relative Permittivity	Conductivity	Relative Permittivity	Conductivity
5200	Head	37.39	4.72	36.0	4.66	3.9	1.3	Pass	Pass
5500		36.36	5.12	35.7	4.97	2.0	3.2	Pass	Pass
5800		35.51	5.49	35.3	5.27	0.6	4.2	Pass	Pass

Table of test equipment calibration status as at time of probe calibration

Instrument description	Supplier / Manufacturer	Model	Serial No.	Last calibration date	Calibration due date
Power sensor	Rohde & Schwarz	NRP-Z23	100063	09/08/2012	09/08/2014
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	21/01/2014	21/01/2015
SMA autocalibration module	Anritsu	36581KKF/1	001902	21/01/2014	21/01/2015

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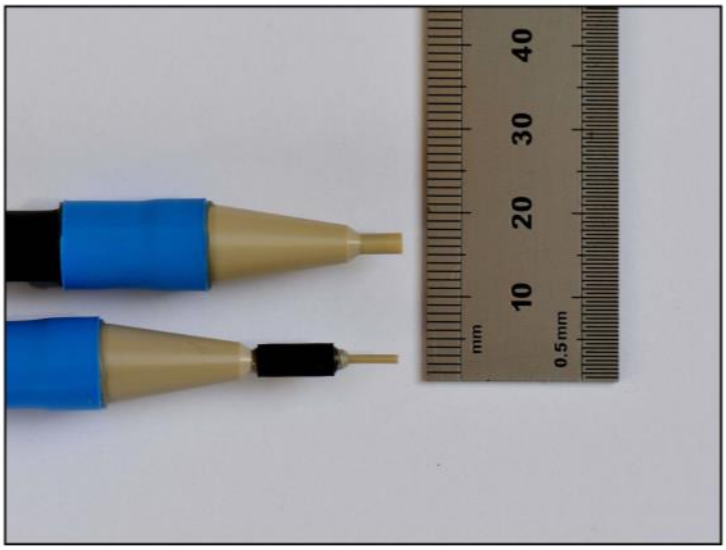
IMMERSIBLE SAR PROBE

CALIBRATION REPORT

Part Number: IXP – 025

S/N G0014

August 2014



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Calibration Certificate 1408/G0014
Date of Issue: 26 August 2014
Immersible SAR Probe

Type:	IXP-025
Manufacturer:	IndexSAR, UK
Serial Number:	G0014
Place of Calibration:	IndexSAR, UK
Date of Receipt of Probe:	N/A
Calibration Dates:	11-21 March 2014
Customer:	TUV Sud

IndexSAR Ltd hereby declares that the IXP-025 Probe named above has been calibrated for conformity to the current versions of IEEE 1528, IEC 62209-1, IEC 62209-2, and FCC OET65 standards, or equivalent, 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:	A. Brinklow	**Technical Manager**
Approved by:	[signature]	**Director**

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

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INTRODUCTION

Straight probes work on either SARA-C (to measure SAR values in flat phantoms containing Body tissue simulant fluid), or on SARA2 (where they, too, can measure in a flat phantom with Body fluid, or in a SAM phantom containing Head fluid).

This Report presents measured calibration data for a particular Indexsar SAR probe (S/N G0014) for use on SARA-C only. **The calibration factors do not apply to, and will not give correct readings on, the IndexSAR SARA2 system.**

Indexsar probes are characterised using procedures that, where applicable, follow the recommendations of IEC 62209-1 [Ref 1], IEEE 1528 [Ref 2], IEC 62209-2 [Ref 3] and FCC OET65 [Ref 4] standards, or equivalent. 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. Where applicable, all test equipment is calibrated by the manufacturers themselves, ensuring traceability to national standards.

CALIBRATION PROCEDURE

1. Objectives

The calibration process comprises the following stages

1) Determination of the channel sensitivity factors which optimise the probe's overall axial isotropy, thereby ensuring independence of probe reading from incident polarisation.

2) Use of these channel sensitivity factors to compare the SAR decay curve in a waveguide fluid cell with an analytical curve at each frequency of interest, 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] - [4]. 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 in mV, $U_{o/p}$ is the raw output signal in mV and DCP is the diode compression potential, also in mV.

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-020 probes with CW signals the DCP values are typically 100mV.

For this value of DCP, the typical linearity response of IXP-025 probes to CW and to GSM modulation is shown in Figure 3, along with departures of this same dataset from linearity.

In turn, measurements of E-field are determined using the following equation:

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

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

Within SARA-C, a probe's predominant mode of operation is with the tip pointing directly towards the source of radiation. Consequently, optimising the probe's response to boresight signals ("axial isotropy") is far more important than optimising its spherical isotropy (where the direction, as well as the polarisation angle, of the incoming radiation must be taken into account).

A 5-6GHz 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 5-6GHz brain fluid to within 1 mm of the open end. The depth of liquid, equivalent to at least 4 penetration depths, ensures both that there is negligible radiation from the waveguide open top, and that the probe calibration is not influenced by reflections either from nearby objects or the liquid/air interface.

During the measurement, a TE_{10} 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 5mm 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.

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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 $U_{o/p}$ 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 axial isotropy. This automated approach to optimisation removes the effect of human bias.

Figure 1 represents the output from each diode sensor as a function of probe rotation angle.

4. 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 4:

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

Here, the density ρ is conventionally assumed to be 1000 kg/m^3, *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 δ (which is the reciprocal of the waveguide-mode attenuation coefficient) is a property of the lossy liquid and is given by Equation (5).

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

where σ is the conductivity of the tissue-simulant liquid in S/m, ε_r is its relative permittivity, and ω is the radial frequency (rad/s). Values for σ and ε_r are obtained prior to each waveguide test using an Indexsar DiLine measurement kit, which uses the TEM method as recommended in [2]. σ and ε_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^{o}C; if this is not possible, the values of σ and ε_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 700MHz, 835/900MHz, 1450MHz, 1800/1900MHz, 2100/2450/2600MHz 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 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.

Prior to the actual calibration run, the probe must be lowered 0.01mm at a time until it is just touching the cross-sectional centre of the dielectric window, at which point live SAR readings will stop increasing. During calibration, 200 samples are taken and written to an Excel template file before moving the probe vertically upwards by one step. 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 calibrations at 450MHz, where waveguide calibrations become unfeasible, a full 3D SAR scan over a tuned dipole is performed, and the conversion factor adjusted to make the measured 1g and 10g volume-averaged SAR values agree with published targets.

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CALIBRATION FACTORS MEASURED FOR PROBE S/N G0014

The probe was calibrated at 5.2, 5.5 and 5.8GHz 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 1.39 mm from the probe tip in the direction of the probe amplifier. A value of 1.39 mm should be used for the tip to sensor offset distance in the software. The distance of 1.39mm for assembled probes has been confirmed by taking X-ray images of the probe tips (see Figure 4).

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 SARA-C measurement system has been published in Reference [6]. Table 17 from that document is re-created below, and lists the uncertainty factors associated just with the calibration of probes.

Source of uncertainty	Uncertainty value ± %	Probability distribution	Divisor	c_i	Standard uncertainty ui ± %	v_i or v_{eff}
Forward power	3.92	N	1.00	1	3.92	∞
Reflected power	4.09	N	1.00	1	4.09	∞
Liquid conductivity	1.308	N	1.00	1	1.31	∞
Liquid permittivity	1.271	N	1.00	1	1.27	∞
Field homogeneity	3.0	R	1.73	1	1.73	∞
Probe positioning	0.22	R	1.73	1	0.13	∞
Field probe linearity	0.2	R	1.73	1	0.12	∞
Combined standard uncertainty		**RSS**			**6.20**	

At the 95% confidence level, therefore, the expanded uncertainty is ±12.4%

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SUMMARY OF CAL FACTORS FOR PROBE IXP-025 S/N G0014

Relative Channel Sensitivities (to optimise Axial Isotropy)				
	X	Y	Z	
Air Factors*	343.22	245.00	371.78	$(V/m)^2/mV$
DCPs	100	100	100	mV

Measured Isotropy	(+/-) dB
Axial Isotropy	0.07

Physical Information	
Sensor offset (mm)	1.39
Elbow – Tip dimension (mm)	0.0

SAR Conversion Factors/ Boundary Corrections							
	Head Fluid			Body Fluid			
Frequency* (MHz)	**SAR Conv Factor**	**Boundary Correction f(0)**	**Boundary Correction d(mm)**	**SAR Conv Factor**	**Boundary Correction f(0)**	**Boundary Correction d(mm)**	**Notes**
5200	0.56	0.65	0.8	0.59	0.67	0.8	1,2
5500	0.54	0.63	0.8	0.63	0.72	0.8	1,2
5800	0.55	1.24	0.6	0.67	0.82	0.7	1,2
Notes							
1)	Calibrations done at 22°C +/-2°C						
2)	Waveguide calibration						
3)	By interpolation						

The valid frequency of SARA-C probe calibrations are ±100MHz (F<300MHz) and ±200MHz (F>300MHz).

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PROBE SPECIFICATIONS

Indexsar probe G0014, 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:

Dimensions	S/N G0014	BSEN [1]	IEEE [2]
Overall length (mm)	350		
Tip length (mm)	10		
Body diameter (mm)	12		
Tip diameter (mm)	2.55	8	8
Distance from probe tip to dipole centers (mm)	1.39		

Typical Dynamic range	S/N G0014	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

Isotropy (measured at 5200MHz)	S/N G0014	BSEN [1]	IEEE [2]
Axial rotation with probe normal to source (+/- dB)	<0.07	0.5	0.25

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 TWEEN20 and sugar/salt-based simulant liquids but probes should be removed, cleaned and dried when not in use. NOT recommended for use with glycol or soluble oil-based liquids.

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For a non-specific reference, the latest version applies.

[1] IEC 62209-1.
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[6] SARA-C SAR Testing System: Measurement Uncertainty, v1.0.3. October 2011.

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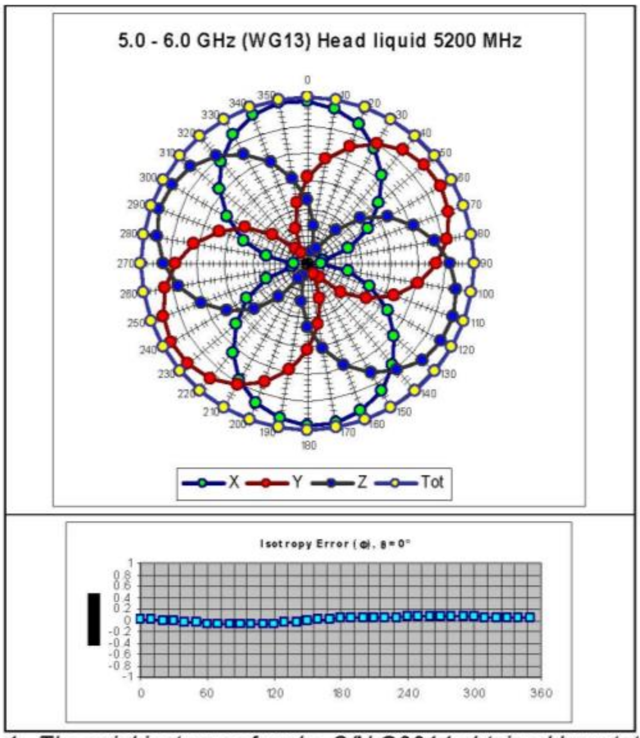

Figure 1. The axial isotropy of probe S/N G0014 obtained by rotating the probe in a liquid-filled waveguide at 5200 MHz. (NB Axial Isotropy is largely independent of frequency)

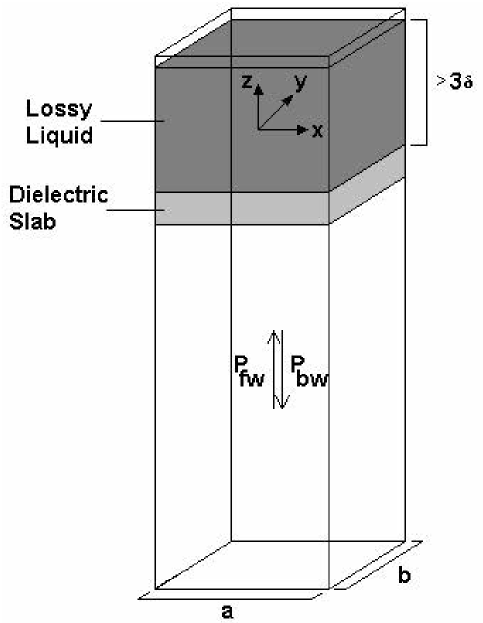

Figure 2. Geometry used for waveguide calibration (after Ref [2]. Section A.3.2.2)

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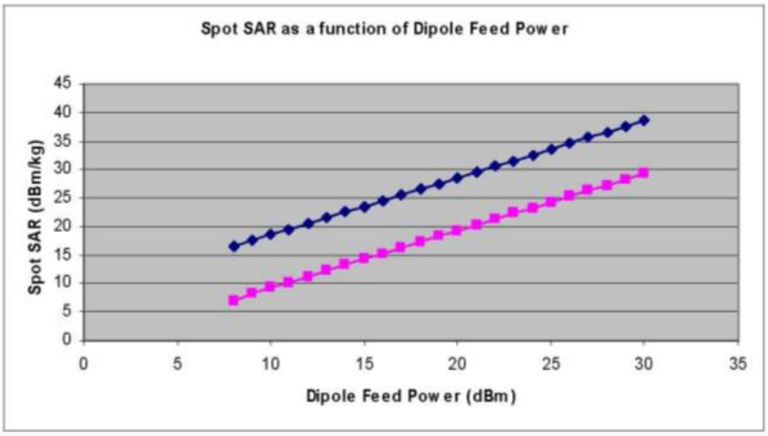

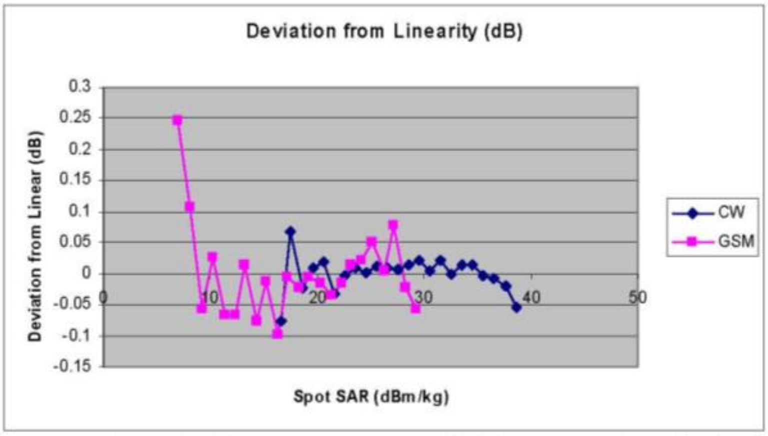

Figure 3 : The typical linearity response of IXP-025 probes to both CW (blue) and GSM (pink) modulation in close proximity to a source dipole. The top diagram shows the SAR reading as a function of dipole feed power, with GSM modulation being approx a factor of 8 (ie 9dB) lower than CW. The lower diagram shows the departure from linearity of the same two datasets.

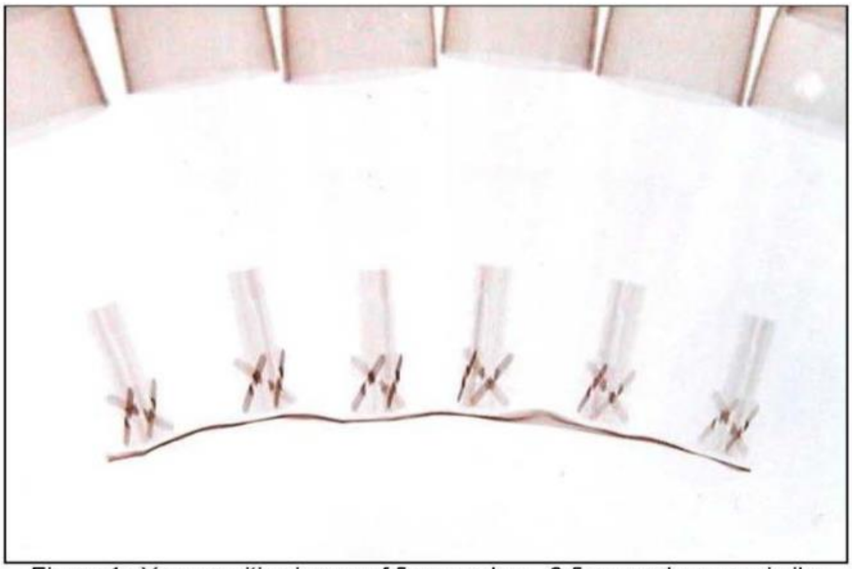

Figure 4 : X-ray positive image of 5mm probes. 2.5mm probes are similar

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

Frequency (MHz)	Fluid Type	Measured		Target		% Deviation		Verdict	
		Relative Permittivity	Conductivity (S/m)	Relative Permittivity	Conductivity (S/m)	Relative Permittivity	Conductivity	Relative Permittivity	Conductivity
5200	Head	37.01	4.82	36.0	4.66	2.8	3.3	Pass	Pass
5500		36.34	5.12	35.7	4.97	1.9	3.0	Pass	Pass
5800		35.61	5.47	35.3	5.27	0.9	3.7	Pass	Pass
5200	Body	49.19	5.30	49.0	5.30	0.4	-0.1	Pass	Pass
5500		48.38	5.62	48.6	5.65	-0.5	-0.5	Pass	Pass
5800		47.41	6.06	48.2	6.00	-1.6	1.1	Pass	Pass

Table of test equipment calibration status at time of calibration

Instrument description	Supplier / Manufacturer	Model	Serial No.	Last calibration date	Cal certificate number	See Annex	Calibration due date
Power sensor	Rohde & Schwarz	NRP-Z23	100063	14/08/2013	10-300287035	1	14/08/2015
Dielectric property measurement	Indexsar	DiLine (sensor lengths: 160mm, 80mm and 60mm)	N/A	(absolute) – checked against NPL values using reference liquids	N/A		N/A
Vector network analyser	Anritsu	MS6423B	003102	21/01/2014	RMA20021769	2	21/01/2015
SMA autocalibration module	Anritsu	36581KKF/1	001902	21/01/2014	RMA20021769	2	21/01/2015