Appendix – MISCELLANEOUS

1 Test Equipment

Instrument description	Supplier / Manufacturer	Model	Serial No.	Calibration (date)	Calibration Due (date)
Bench top Robot	Mitsubishi supplied by IndexSAR	RV-E2	EA1030108	N/A	N/A
Phone holder	IndexSAR	NA	N/A	N/A	N/A
Software	IndexSAR	SARA2-HAC v0.420	N/A	N/A	N/A
850 MHz Dipole	IndexSAR – IEEE 1528 design	IXD-085	0091	08/15/2007	08/15/2008
1900 MHz Dipole	IndexSAR – IEEE 1528 design	IXD-190	0016	08/15/2007	08/15/2008
Directional coupler	Werlatone	C6529	11249	N/A	N/A
RF Amplifier	Vectawave	VTL5400	N/A	N/A	N/A
HAC Probe	IndexSAR	IXP-090	A0002	01/17/2008	01/17/2009
HAC Probe	IndexSAR	IXP-070	H0010	01/17/2008	01/17/2009
Digital Radio Comm. Tester	Rohde & Schwarz	CMU 200	109879	05/01/2008	05/01/2009
Thermometer / Humidity	Dickson	TM320	05280062	10/23/2007	10/23/2008
Network Analyzer	HP	8753ES	US39172511	11/30/2007	11/30/2008
Power Meter	HP	EPM-442A	GB37170232	10/18/2007	10/18/2008

Appendix – MISCELLANEOUS

2 Equipment Calibration/Performance Documents:

Validation Dipoles Performance Measurements

Please Note:
(The following pages of Appendix C show calibration documents. These calibration documents are inserted into this appendix. The header information with page numbering scheme is a part of this report and is included on all pages of the report and appendixes. This header is used to track all of the contents of this report.)

Appendix – MISCELLANEOUS

2.1 Dipole handling

The dipoles are made from standard, copper-sheathed coaxial cable. In assembly, the sections are joined using ordinary soft-soldering. This is necessary to avoid excessive heat input in manufacture, which would destroy the polythene dielectric used for the cable. The consequence of the construction material and the assembly technique is that the dipoles are fragile and can be deformed by rough handling. Conversely, they can be straightened quite easily as described below:

If a dipole is suspected of being deformed, a normal workshop lathe can be used as an alignment jig to restore the symmetry. To do this, the dipole is first placed in the headstock of the lathe (centred on the plastic or brass spacers) and the headstock is rotated by hand (do NOT use the motor). A marker (lathe tool or similar) is brought up close to the end of one dipole arm and then the headstock is rotated by 0.5 rev. to check the opposing arm. If they are not balanced, judicious deformation of the arms can be used to restore the symmetry.

If a dipole has a failed solder joint, the dipole can be fixed down in such a way that the arms are co-linear and the joint re-soldered with a reasonably-powerful electrical soldering iron. Do not use gas soldering irons. After such a repair, electrical tests must be performed as described below.

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

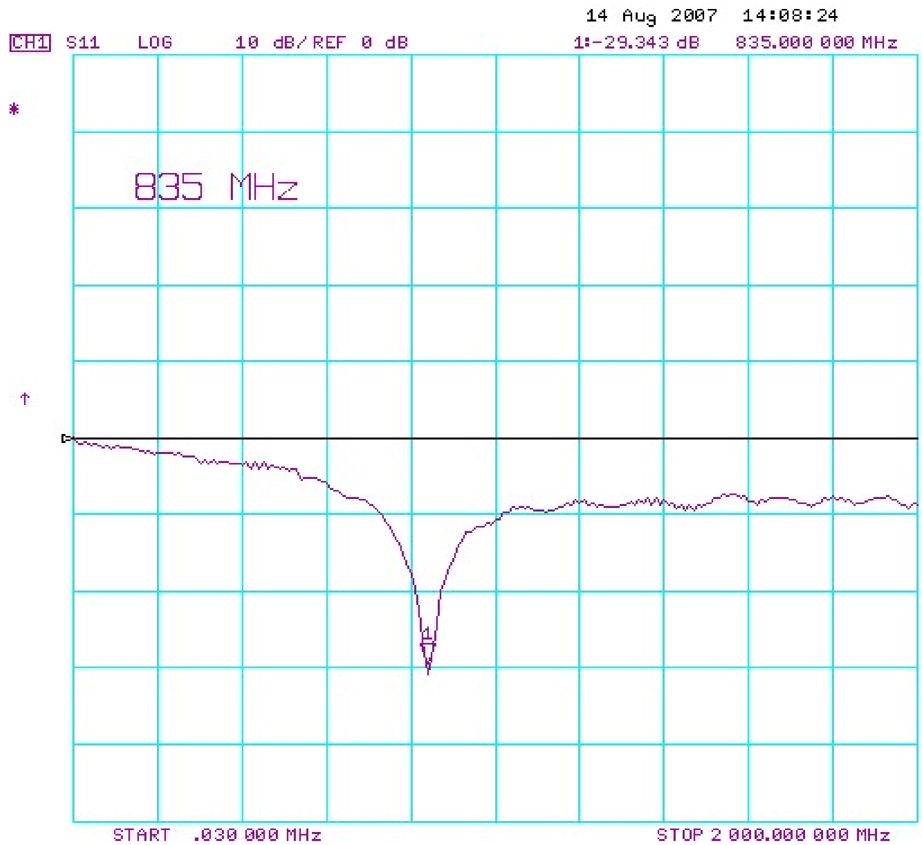
2.2 Performance Measurement

The dipoles are individually tested at their nominal frequency to ensure that they exhibit a return loss of less than -10.00dB when used.

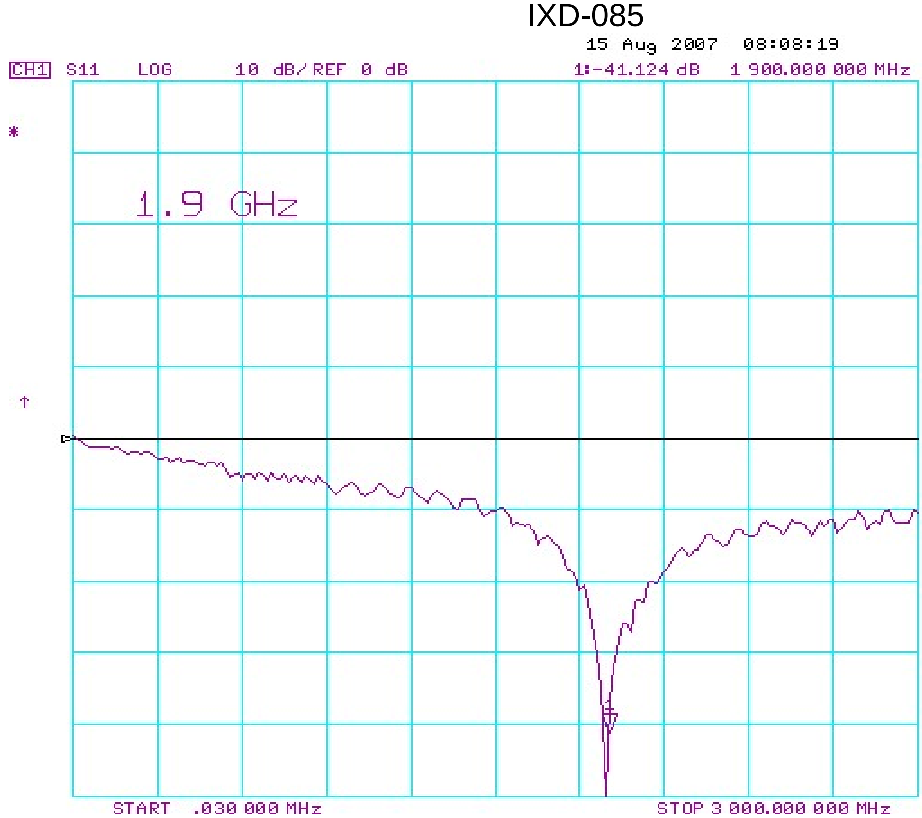
The dipoles are designed to have low return loss. If the user has a Vector Network Analyser (VNA) it is best to perform a return loss measurement on a specific dipole when it is in a measurement – free air.

S11 plots for the dipoles with nominal frequencies of 850MHz, 900MHz, 1800MHz, 1900MHz and 2450MHz are shown below.
Please note: The date of verification is show on each plot.

Appendix – MISCELLANEOUS



IXD-085



IXD-190

Appendix – MISCELLANEOUS

2.3 Tuning the dipole

The dipole dimensions are based on ANSI C63.19-2007 Annex D tables.
It cannot be made shorter without removing a bit from the arm. An alternative way to tune the dipole is to use copper shielding tape to extend the effective length of the dipole. Do both arms equally.

It should be possible to tune a dipole as described, whilst in place in the measurement position as long as the user has access to a VNA for determining the return loss.

2.4 Reference

[1] ANSI C63.19-2007, American National Standard for Methods of Measurement of Compatibility between Wireless Communication Devices and Hearing Aids.

Report No: A0002/0801

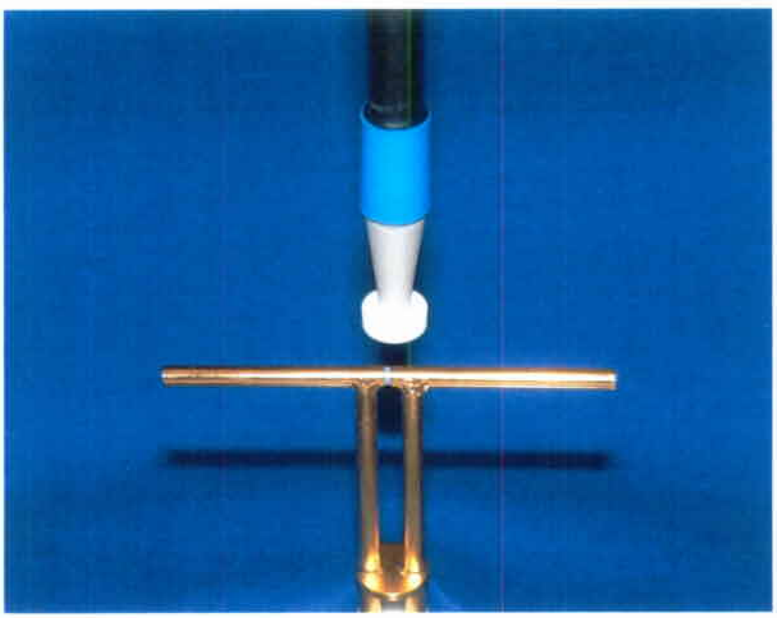
NEAR-FIELD E-FIELD PROBE
FOR USE IN AIR

CALIBRATION REPORT

Part Number: IXP-090

S/N A0002

January 2008



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Calibration Certificate A0002 / 0801
Near-field E-field Probe

Type:	**IXP-050 with ceramic sleeve**

Manufacturer:	**IndexSAR, UK**

Serial Number:	**A0002**

Place of Calibration:	**IndexSAR, UK**

IndexSAR Limited hereby declares that the IXP-050 Probe named above has been calibrated for use in air at the frequencies of 835 and 1880MHz.

Date of Initial Calibration:	**17th January 2008**

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

Next Calibration Date:	**January 2009 (1 year)** **January 2010 (2 Years)**

Calibration factors on page 3 to be applied as described in the SARA2_HAC Users' Manual.

Calibrated By:	A. Brinklow

Approved By:	M J Manning

SUMMARY RESULTS FOR A0002

835 MHz			
	X	Y	Z
Air Factors [(V/m)^2/mV]	198.9	199.9	201.3
Conversion Factor	0.87		
DCP [mV]	100		
Axial Isotropy [±dB]	0.08		
Spherical Isotropy [±dB]	0.39		

1880 MHz			
	X	Y	Z
Air Factors [(V/m)^2/mV]	199.4	196.0	204.6
Conversion Factor	1.00		
DCP [mV]	100		
Axial Isotropy [±dB]	0.09		
Spherical Isotropy [±dB]	0.55		

Probe Modulation Factor: 1.04

INTRODUCTION

This Report presents measured calibration data for a particular Indexsar E-field probe (S/N A0002) and describes the generic procedures used for characterisation and calibration.

The IXP-090 probes have the same construction used for IXP-050 SAR probes but are modified by application of a dielectric sleeve at the tip to optimise the isotropy in air.

Each step of the calibration procedure and the equipment used is described in the sections below.

CALIBRATION PROCEDURE

The calibration process comprises three stages

1) Determination of the channel sensitivity factors which optimise the probe's overall axial isotropy in air
2) Applying conversion factors for selected frequencies by transfer calibration against a known, reference probe.
3) Validating the probe calibration by performing dipole scan measurements according to ANSI C63.19-2006 (Ref [1]).

1) Determining channel sensitivity factors at 835MHz and 1880MHz

A test jig was used to hold the probe in the near-field of a balanced centre-fed dipole with the sensors aligned with the dipole feed point (also the rotation centre). Using a dipole appropriate for the calibration frequency, the probe and source dipole were rotated in 10 degree steps (dipole) and 20 degree steps (probe) to characterise the spherical isotropy. Following the measurements, the data for each channel were balanced by assigning a channel sensitivity factor to each. The factors are adjusted to optimise the axial isotropy range, the response where the dipole is horizontal.

The measurements are performed at 835MHz and 1880MHz.

The results yield the overall spherical isotropy range for all angles of probe orientation and dipole polarisation presentation as well as calibration values for the channel sensitivity factors. The results for a typical probe are shown in Figure 1 & Figure 2, and tabulated below.

Isotropy data for probe A0002

Frequency (MHz)	Spherical Isotropy (dB)	Rotational Isotropy (dB)
835	±0.39	±0.08
1880	±0.55	±0.09

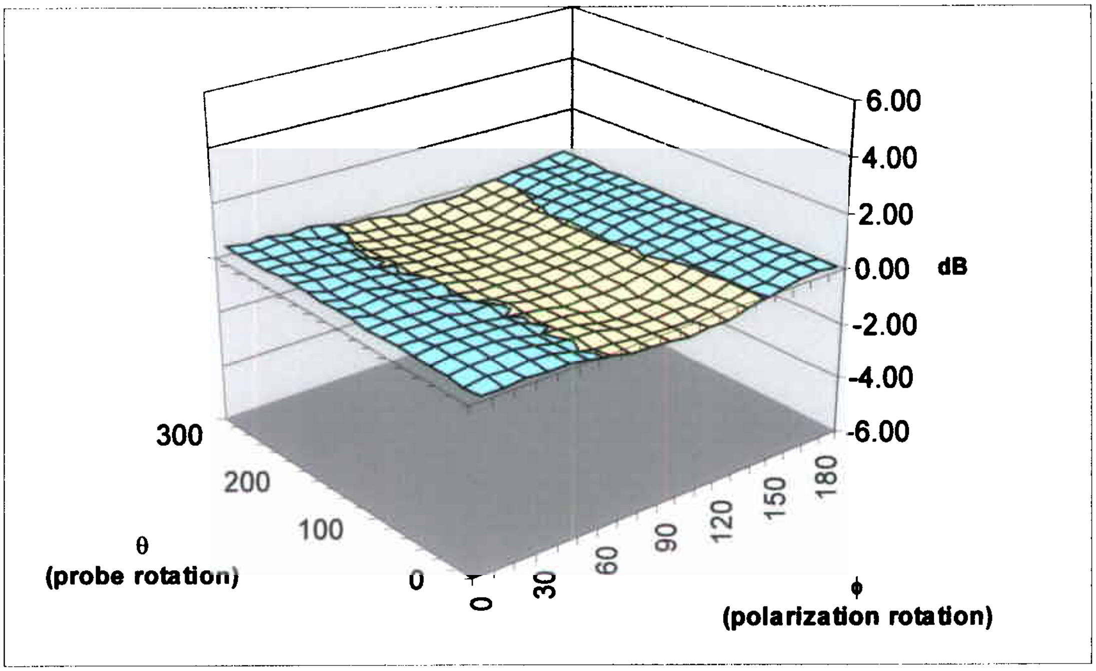


Figure 1: : Directivity map for probe A0002 at 835MHz indicating the range of sensitivity with probe and dipole rotation angles. The overall variability shown is +/- 0.39 dB.

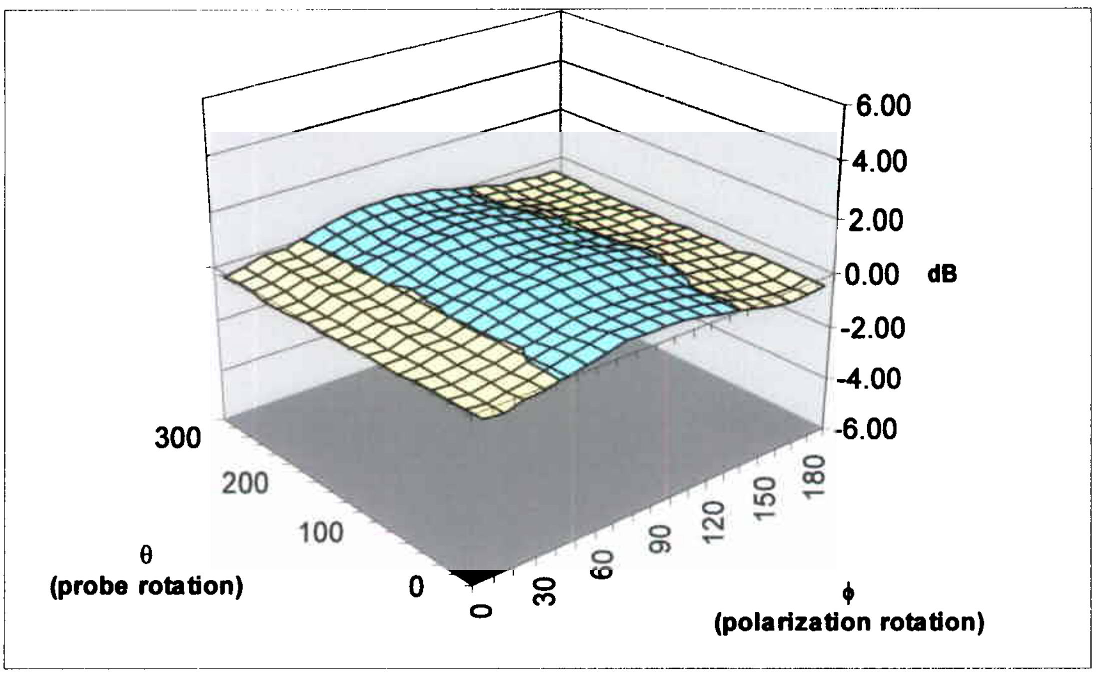


Figure 2: : Directivity map for probe A0002 at 1880MHz indicating the range of sensitivity with probe and dipole rotation angles. The overall variability is +/- 0.55dB

2 & 3) Finding Conversion Factors for each Frequency

The isotropy measurement was repeated at each frequency with a reference probe which had been calibrated at the UK's National Physical Laboratory (NPL). A representative NPL probe calibration report for a transfer standard is attached as Appendix 1. The relative levels between the probe-under-test and the reference probe allow a transfer calibration to be assigned.

The calibration performed at NPL, however, is only strictly valid under uniform field conditions and, as such, can necessarily only provide approximate transfer values when applied in the non-uniform fields seen around a dipole. To ensure the calibration values reported here are reliable for near fields around wireless devices, therefore, the derived transfer conversion factors are used as starting points in a probe validation scan along a dipole and adjusted to meet numerical FDTD simulations presented in ANSI C63.19-2006 (Ref [1]) and converted from peak to rms.

The current C63.19 standard requires that HAC measurements are performed at a distance that places the closest part of the probe sensors at 10 mm spacing from the closest point of the device under test. This, however, is a configuration having no traceable connection with independent probe calibrations performed in quasi-uniform fields (as in anechoic chambers or waveguides). For calibrated probes, the calibration point is the centre of the sensor arrays, which gives a different spacing of the probe from the closest point of the reference dipoles used for this test and is the only configuration for which the calculated FDTD reference values apply.

For a dipole validation of the E-field probe performance, the gauge-block separation of the probe tip to dipole separation is 7.3 mm. This is achieved on the HACtest system by issuing the command **mv 2 730** to raise the probe from the point of contact with the dipole.

By performing repeat scan with modulated and unmodulated signals, the probe modulation factor (PMF) can also be determined. The modulation factor for GSM has been determined as 1.04 for A0002, independent of frequency.

The following results were obtained

a) At 835MHz

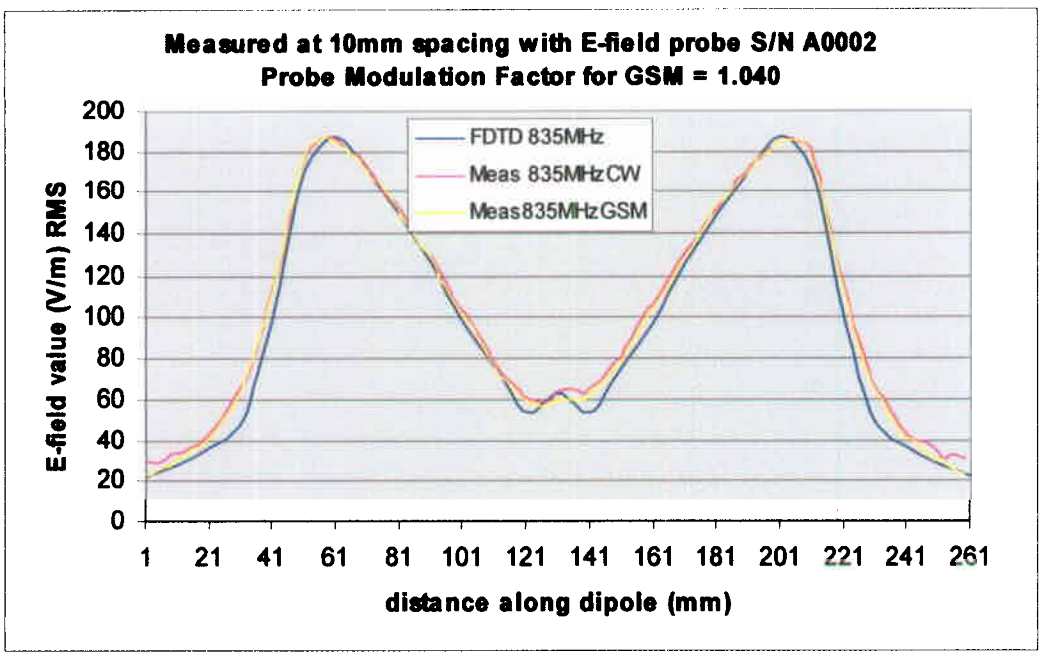


Figure 3: 835MHz dipole validation scans from which the probe modulation factor for GSM has been determined

b) At 1880MHz

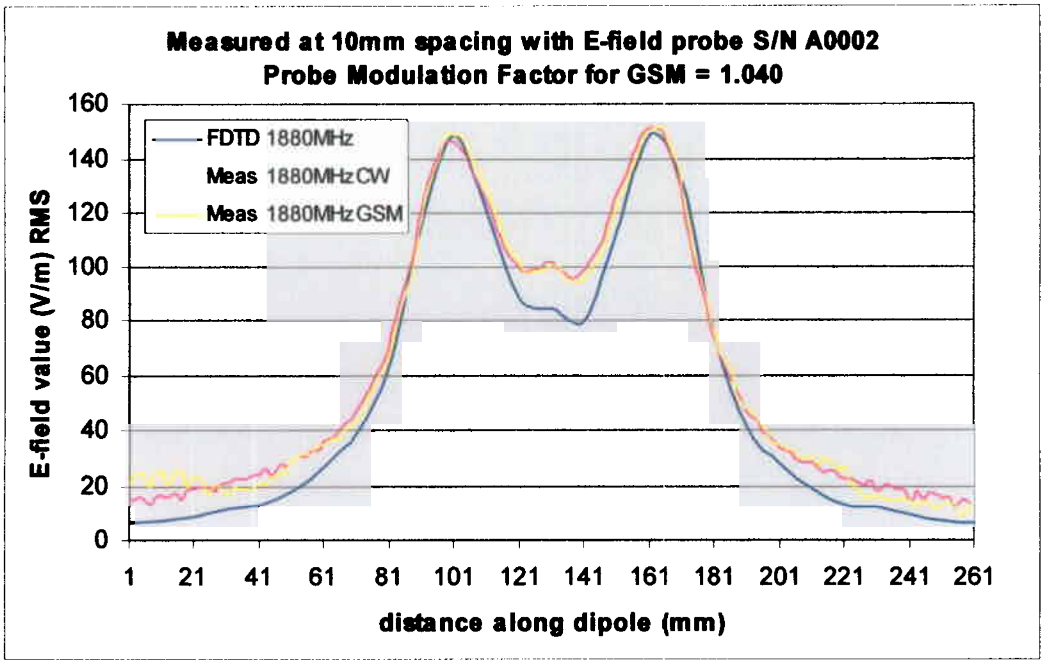


Figure 4: 1880MHz dipole validation scans from which the probe modulation factor for GSM has been determined

ROTATIONAL ISOTROPY CHECK

The FCC has removed their requirement for static rotational isotropy measurements for HAC probes over test sources. A justification for this is that it may be inappropriate to measure probe isotropy in the steep field gradients of the near field. The physical separation of the dipole sensors means that the position of the measured maximum shifts laterally with probe rotation angle.

A more relevant test is to perform complete scans (either 1D or 2D) at varying probe rotation angles. To perform this test, dipole validation scans were conducted on A0002 rotated in steps of 90 degrees with the results shown in Figure 5 & Figure 6.

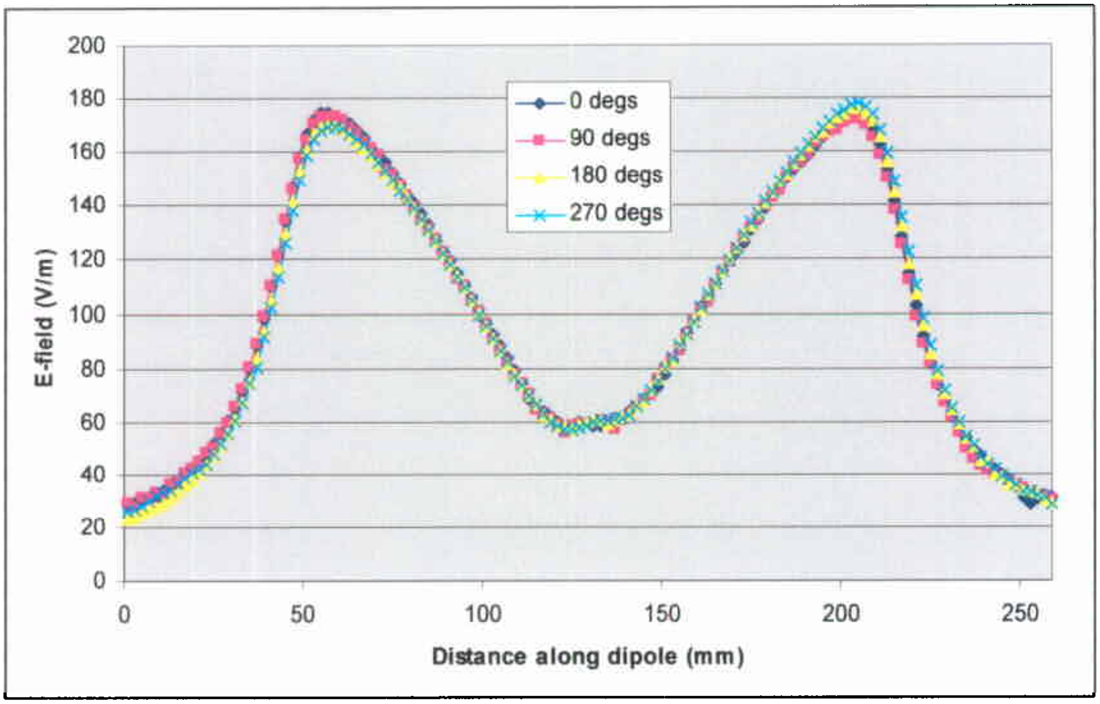


Figure 5: 835MHz dipole validation scans performed at 90 degree rotation increments of the probe with respect to the dipole.

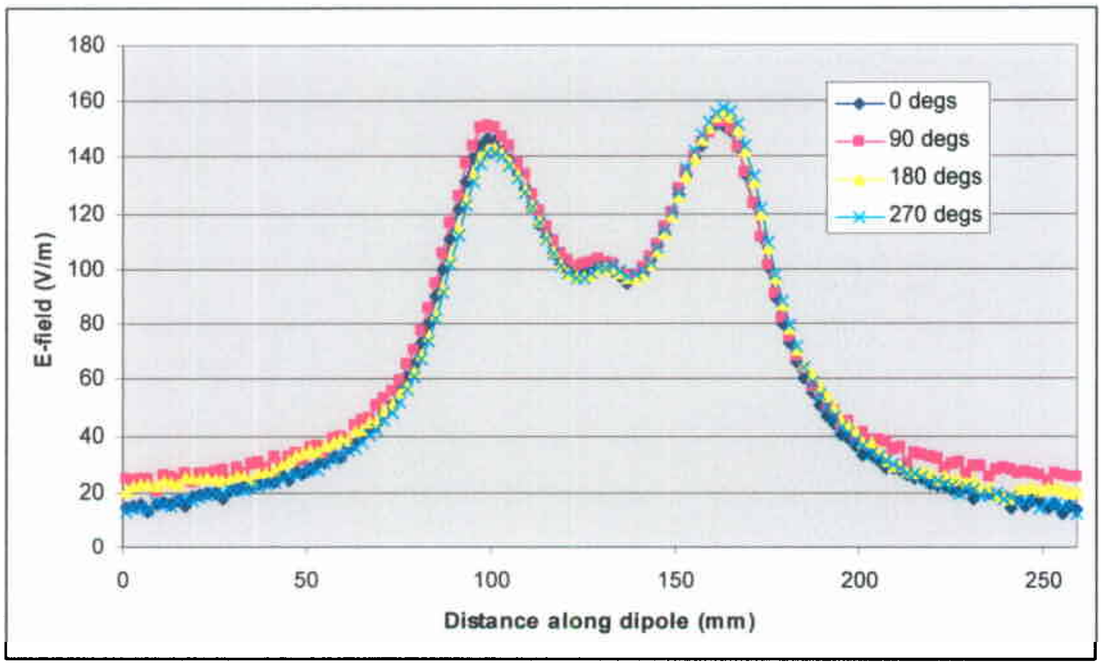


Figure 6: 1880MHz dipole validation scans performed at 90 degree rotation increments of the probe with respect to the dipole.

Across a batch of probes, differences in the probe axial orientation within the support cradle typically leads to a worst-case uncertainty (at 1880MHz) in the measured E-field of ±7%. This number feeds through to Table 1 listing sources of measurement uncertainty.

Note: All the measurements performed in this report are obtained with the probe positioned with the red dot on the connector barrel facing in the –Y direction (ie outwards)

UNCERTAINTY CONSIDERATIONS

Annex E (informative) in the current version of the hearing aid compatibility standard for methods of measurement [1] provides a sample uncertainty estimation table (Table E.1). This template has been used for an uncertainty assessment of the near-field measurement uncertainties. The previous discussion (Sections 2 & 3: Finding Conversion Factors for Each Frequency) is relevant in this regard. The following commentary is provided in support of each of the data entries in the following spreadsheet Table.

RF Reflections

This has been investigated by adding additional material of the type used in system construction in the vicinity of the near-field measurements. In one test, the source and probe were independently supported and then the effect of removing the whole robot structure was determined. These tests show insignificant efects of surrounding material. It is noted, however, that during a dipole scan, at the very low field levels past each extreme of the dipole arm that an effect on the <10V/m field is detected when the probe is also close to the acrylic table top. These effects are not detected at higher field levels relevant to DUT measurements. A value for this effect of **0.05dB** is entered into uncertainty assessment Table.

Field Probe conv. Factor

The measurement of a probe's conversion factor is a 2-stage process. Firstly, a transfer calibration is performed against an NPL-calibrated probe, over the full range of probe and source dipole polarisation angles, with the probes separated from the source by approximately 10cm. This separation ensures the probes are in a relatively uniform field, similar to the conditions during the NPL calibration process. Uncertainties arise from the quoted uncertainty in the NPL calibration, RF mismatches from signal generator to source dipole, and source drift, and amount to **0.32dB**.

The second stage of the calibration process involves locating the probe-under-test in the non-uniform field close to a dipole. A scan along the length of the dipole, at the separation specified in C63.19, can then allow a comparison to be made against the field distribution derived by mathematical modelling. It is observed that across a batch of probes, the uncertainty in the correction factor is **0.31dB**.

When these two contributions are taken together, a total probe calibration uncertainty of **0.45dB** is obtained.

Field probe anisotropy

The spherical isotropy is measured in a robot jig, which rotates the probe and a balanced dipole source through all rotation angles in 20 degree steps. Across a complete batch of probes, the worst-case spherical isotropy is identified. A typical value for this effect is 0.88dB. However, with the probe positioned closer to the source in regions where there are steep field gradients, variations of **+/-0.30dB** (+/-7%) have been measured (see for example Figure 6) and entered into the uncertainty assessment Table

Positioning accuracy
The key factor here is the consistency with which a touch position can be established as software is used to subsequently raise the probe height with a precision of 0.01mm. Users are recommended to use a piece of paper as a shim between the probe tip and the source device and to determine the touch position to be when light friction is felt between the two. This procedure should allow 0.1mm positioning accuracy. As fields are decaying by 0.9dB/mm (see below) at the measurement position, an uncertainty of **0.1dB** is entered into uncertainty assessment Table.

As a caution, users of the Cartesian HACtest framework are recommended not to place or remove items from the bench top after the probe position has been set to avoid changes in supported weight contributing to displacement between the probe and source.

Probe cable placement
The probe cable is an optical fibre, so electrical effects are unlikely. It is possible that altering the tension on the fibre could contribute to probe displacement but as long as the cable routing is unconstrained, no significant effects are expected from this cause. A value for this effect of **0.1dB** is entered into uncertainty assessment Table.

System repeatability
System repeatability has been studied in an extended series of investigations described in [2]. The system repeatability itself was found to be mainly influenced by variations in the source power feed, for which the RF amplifier in the power feed-train had a dependence on diurnal variations in ambient laboratory conditions. A combined value of **0.5dB** to account for the many factors studied in IXS0300 is entered into uncertainty assessment Table.

Table 1

Uncertainty template for WD Near-Field Measurement Uncertainty

Table of Uncertainty Values using template in ANSI-PC63.19-2001 Revision Draft 3.4 Section E.1

Spreadsheet available on HACSAR CD as RFuncertainty.xls

Contribution	Data (dB)	Data (+/-%)	Data Type	Probability distribution	Divisor (descrip)	Divisor (value)	Standard Uncertainty (+/- %)	Standard Uncertainty (dB)
Near-Field Measurement								
RF Reflections	0.05	1.2	Specification	R	√3	1.73	0.67	
Field Probe Calibration	0.45	10.9	Specification	N	1	1.00	10.92	
Field Probe Anisotropy	0.3	7.2	Specification	N	1	1.00	7.15	
Positioning Accuracy (lateral)	0.1	2.3	Specification	R	√3	1.73	1.34	
Positioning Accuracy (10mm measurement height)	0.1	2.3	Specification	R	√3	1.73	1.34	
Probe Cable Placement	0.1	2.3	Specification	R	√3	1.73	1.34	
System Repeatability	0.5	12.2	Standard Deviation	R	√3	1.73	7.04	
Repeatability of the WD	0.5	12.2	Standard Deviation	R	√3	1.73	7.04	
		0.0		R	√3	1.73	0.00	
		0.0		R	√3	1.73	0.00	
Combined standard uncertainty				**RSS**			**16.6**	**0.7**
Expanded uncertainty (coverage factor=2)				k=2			32.5	**1.2**

DISCUSSION

Agreement between measured scan data obtained with an independently-calibrated E-field probe and FDTD computations at a distance of 10mm from balanced dipoles (feed power 100mW) is good when the sensors of the probes are centred on the 10mm distance.

However, the E-field is decaying by around 0.9dB/mm (at 835MHz), and measurements taken with the nearest part of the sensor at 10mm from the dipole surface (as proposed in the draft standard [1]) will be correspondingly smaller.

REFERENCES

[1] American National Standard for Methods of Measurement of Compatibility between Wireless Communications Devices and Hearing Aids ANSI C63.19.-2006 (Revision of ANSI C63.19.-2001).

[2] Characterising the measurement of GSM signals with the IXP-050 SAR probe and IXP-020 probe amplifier A Brinklow & MI Manning 2nd April 2007. Indexsar Report IXS0301.

APPENDIX 1

NATIONAL PHYSICAL LABORATORY

Teddington Middlesex UK TW11 0LW Switchboard 020 8977 3222

Certificate of Calibration

INDEXSAR ELECTRIC FIELD STRENGTH PROBE
Probe Type: IXP-090 S/N: A0012

0478

FOR:	IndexSAR Limited Oakfield House Cudworth Lane Newdigate Dorking Surrey RH5 5BG
ORDER NUMBER:	0497
DESCRIPTION:	A broadband, isotropic electric field probe type: IXP-090, manufactured by IndexSAR, s/n: A0012. The probe system has been calibrated over the frequency range 835 to 1900 MHz. The probe was connected to an amplifier Type IXA-020, belonging to NPL, which was optically coupled to a computer running CheckSAR software.
DATE(S) OF CALIBRATION:	22 January 2007
PREVIOUS NPL CERTIFICATE:	None

Reference: E06120274/2 **Page 1 of 5**

Date of issue: 22 January 2007 **Signed:** (Authorised Signatory)

Checked by: **Name:** K P Holland **for Managing Director**

MEASUREMENT

The calibration of field strength monitors involves the generation of a calculable linearly polarised electromagnetic field, approximating to a plane wave, into which the probes or sensors are placed.

This type of probe has three independent antennas constructed at right angles to each other. All three antennas are switched on during the calibration as in the normal isotropic mode of operation.

Over the frequency range of 835 to 1900 MHz, the probe is positioned in a low reflectivity mount inside a microwave anechoic chamber on the bore sight of a linearly polarised horn antenna. The antenna under test is always perpendicular to the direction of propagation and parallel to the electric field.

For each frequency and field strength setting, the sensor is rotated to enable the sensitivity of each antenna to be measured separately.

For each measurement, the input power to the test facility was adjusted so that the field strength at the plane of reference of the probe was set to a specified value. The 'unlinearised' output from the antenna under test, as displayed on the computer, was then recorded along with the applied field strength.

The term "field strength" refers to the r.m.s. value of the electric or magnetic wave amplitude.

The probe was zeroed via the computer before each measurement.

UNCERTAINTIES

The measurement uncertainties apply only when the probe is supported in a low reflectivity mount and used with all three antennas switched on as in the normal isotropic mode of operation.

If the sensor is positioned with one antenna aligned for maximum coupling with the electric field in a linearly polarised EM field, then the uncertainty in the corresponding antenna 'unlinearised' output are given in the results and summarised below.

± 0.62 dB for frequencies from 835 to 900 MHz
± 0.47 dB for frequencies from 1880 to 1900 MHz

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements. The results and uncertainties relate to the on-the-day values and make no allowance for drift or operation under other environmental conditions.

RESULTS

These results have been obtained without any adjustment to the probe sensitivity.

The tables below show the individual readings of each antenna, with the identified axis aligned with the electric field.

Measurement Temperature 23 ± 2°C

Table 1
Probe Type: IXP-090 S/N: A0012

Frequency MHz	Unlinearised Output mV Indicated	Range	Field Strength V/m Actual	Uncertainty dB	Antenna
835.0	0.5198	Auto	10.0	±0.62	X
835.0	0.5229	Auto	10.0	±0.62	Y
835.0	0.4628	Auto	10.0	±0.62	Z
835.0	4.5217	Auto	30.0	±0.62	X
835.0	4.7067	Auto	30.0	±0.62	Y
835.0	3.9808	Auto	30.0	±0.62	Z
835.0	37.8101	Auto	100.0	±0.62	X
835.0	38.7158	Auto	100.0	±0.62	Y
835.0	34.1824	Auto	100.0	±0.62	Z
835.0	103.3504	Auto	200.0	±0.62	X
835.0	105.1501	Auto	200.0	±0.62	Y
835.0	94.6838	Auto	200.0	±0.62	Z
900.0	0.5140	Auto	10.0	±0.62	X
900.0	0.5161	Auto	10.0	±0.62	Y
900.0	0.4526	Auto	10.0	±0.62	Z
900.0	4.4269	Auto	30.0	±0.62	X
900.0	4.6480	Auto	30.0	±0.62	Y
900.0	4.0082	Auto	30.0	±0.62	Z
900.0	37.3219	Auto	100.0	±0.62	X
900.0	37.6830	Auto	100.0	±0.62	Y
900.0	34.6019	Auto	100.0	±0.62	Z
900.0	100.7327	Auto	200.0	±0.62	X
900.0	103.7757	Auto	200.0	±0.62	Y
900.0	95.2217	Auto	200.0	±0.62	Z

Checked by:

Table 1
Probe Type: IXP-090 S/N: A0012

Frequency MHz	Unlinearised Output mV Indicated	Range	Field Strength V/m Actual	Uncertainty dB	Antenna
1880.0	0.4068	Auto	10.0	±0.47	X
1880.0	0.4021	Auto	10.0	±0.47	Y
1880.0	0.3726	Auto	10.0	±0.47	Z
1880.0	3.6441	Auto	30.0	±0.47	X
1880.0	3.9279	Auto	30.0	±0.47	Y
1880.0	3.5305	Auto	30.0	±0.47	Z
1880.0	31.9370	Auto	100.0	±0.47	X
1880.0	33.6146	Auto	100.0	±0.47	Y
1880.0	30.6003	Auto	100.0	±0.47	Z
1880.0	151.2707	Auto	300.0	±0.47	X
1880.0	156.0021	Auto	300.0	±0.47	Y
1880.0	146.2984	Auto	300.0	±0.47	Z
1900.0	0.4169	Auto	10.0	±0.47	X
1900.0	0.4546	Auto	10.0	±0.47	Y
1900.0	0.4164	Auto	10.0	±0.47	Z
1900.0	3.8024	Auto	30.0	±0.47	X
1900.0	4.0944	Auto	30.0	±0.47	Y
1900.0	3.6605	Auto	30.0	±0.47	Z
1900.0	33.4649	Auto	100.0	±0.47	X
1900.0	34.3962	Auto	100.0	±0.47	Y
1900.0	31.3803	Auto	100.0	±0.47	Z
1900.0	155.4086	Auto	300.0	±0.47	X
1900.0	160.5556	Auto	300.0	±0.47	Y
1900.0	148.8553	Auto	300.0	±0.47	Z

Report No: H0010/0801

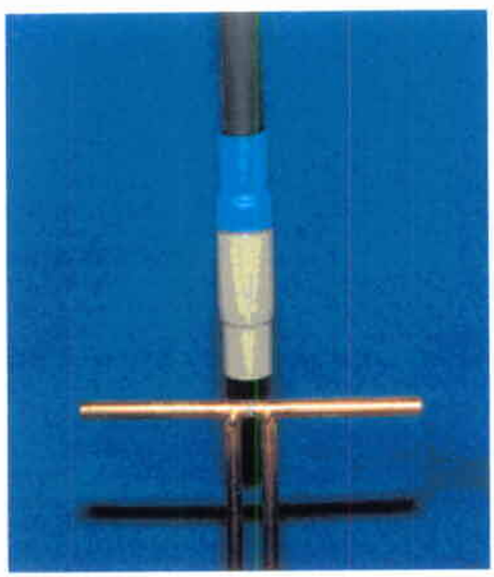
NEAR-FIELD H PROBE

CALIBRATION REPORT

Part Number: IXP – 070

S/N H0010

January 2008



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e-mail: enquiries@indexsar.com

Calibration Certificate H0010 / 0801
Near-field H-field Probe

Type:	**IXP-070**

Manufacturer:	**IndexSAR, UK**

Serial Number:	**H0010**

Place of Calibration:	**IndexSAR, UK**

IndexSAR Limited hereby declares that the IXP-070 Probe named above has been calibrated for use in air at the frequencies of 835 and 1880MHz.

Date of Initial Calibration:	**17th January 2008**

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

Next Calibration Date:	**January 2009 (1 year)** **January 2010 (2 year)**

Calibration factors on page 3 to be applied as described in the SARA2_HAC Users' Manual.

Calibrated By:	A. Brinklow

Approved By:	M.J.Manning

SUMMARY RESULTS FOR H0010

835 MHz			
	X	Y	Z
Air Factors [(A/m)^2/mV]	0.000427	0.000303	0.000279
Conversion Factor	3.01		
DCP [mV]	100		
Axial Isotropy [±dB]	0.02		
Spherical Isotropy [±dB]	0.74		

1880 MHz			
	X	Y	Z
Air Factors [(A/m)^2/mV]	0.000361	0.000240	0.000299
Conversion Factor	1.41		
DCP [mV]	100		
Axial Isotropy [±dB]	0.09		
Spherical Isotropy [±dB]	1.61		

Probe Modulation Factor: 1.04

INTRODUCTION

This Report presents measured calibration data for a particular Indexsar H-field probe (S/N H0010) and describes the generic procedures used for characterisation and calibration.

The Indexsar H-field probe (Model No. IXP-070) is a three channel, orthogonally-arranged probe with 3 single-loop H-field sensors. These are arranged (as far as possible) concentrically. The construction is shown in Figure 1. The sensors are cased in a 10mm diameter PEEK tip.

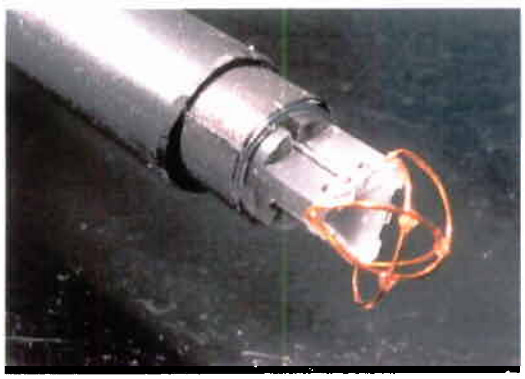

Figure 1 Construction of 3-channel H-field sensor

The sensor loops are arranged at a specific angle with respect to the probe shaft as shown in Figure 2.

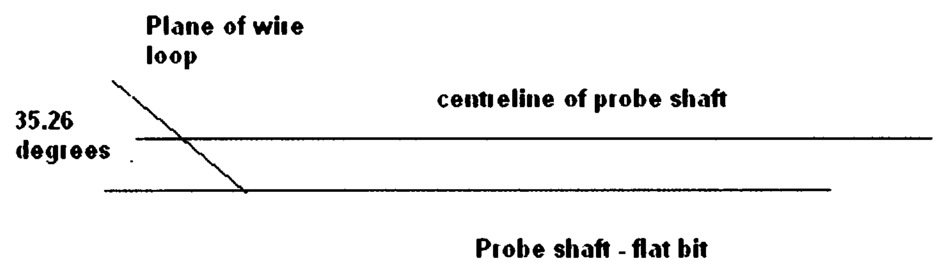

Figure 2 Angular definitions

Each step of the calibration procedure and the equipment used is described in the sections below.

CALIBRATION PROCEDURE

The calibration process comprises three stages

1) Determination of the channel sensitivity factors which optimise the probe's overall spherical isotropy in air
2) Applying conversion factors for selected frequencies by transfer calibration against a known, reference probe.
3) Validating the probe calibration by performing dipole scan measurements according to ANSI C63.19-2006 (Ref [1]).

1) Determining channel sensitivity factors at 835MHz and 1880MHz

Balancing channel sensitivity and determining spherical isotropy
The probes is mounted in a rotation fixture and exposed to the near-field radiation of an 835MHz balanced dipole, which can itself be rotated through programmed angular intervals. The fixture is shown in Figure 3.

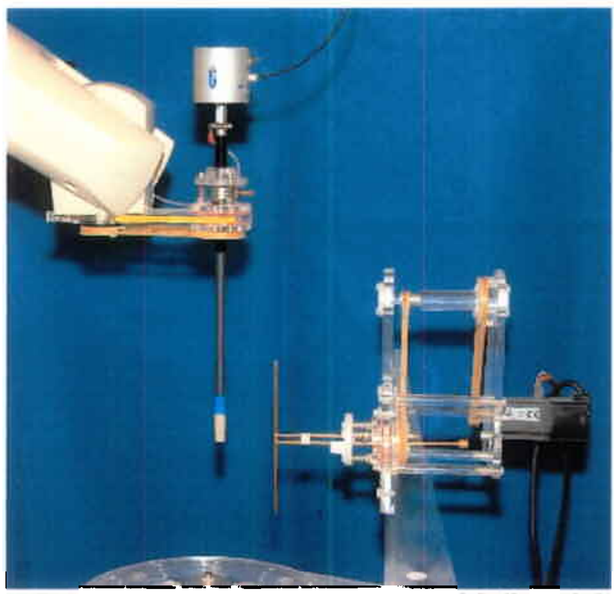

Figure 3 Test setup for measuring the near-field directivity of the H-field probes

The dipole is fed with a CW signal of 835MHz frequency and the probe is rotated in steps of 20 degrees for a full rotation. This process is repeated for 10 degree angular translations of the source dipole, for which measurements start with the dipole arms parallel to the probe shaft.

Following the measurements, the data for each channel are balanced by assigning a channel sensitivity factor to each. The factors are adjusted to optimise the spherical isotropy range.

The measurements are also performed at 1880MHz.

The results yield the overall spherical isotropy range for all angles of probe orientation and dipole polarisation preesentation as well as calibration values for the channel sensitivity factors. The results for a probe H0010 are shown in Figures 4 and 5.

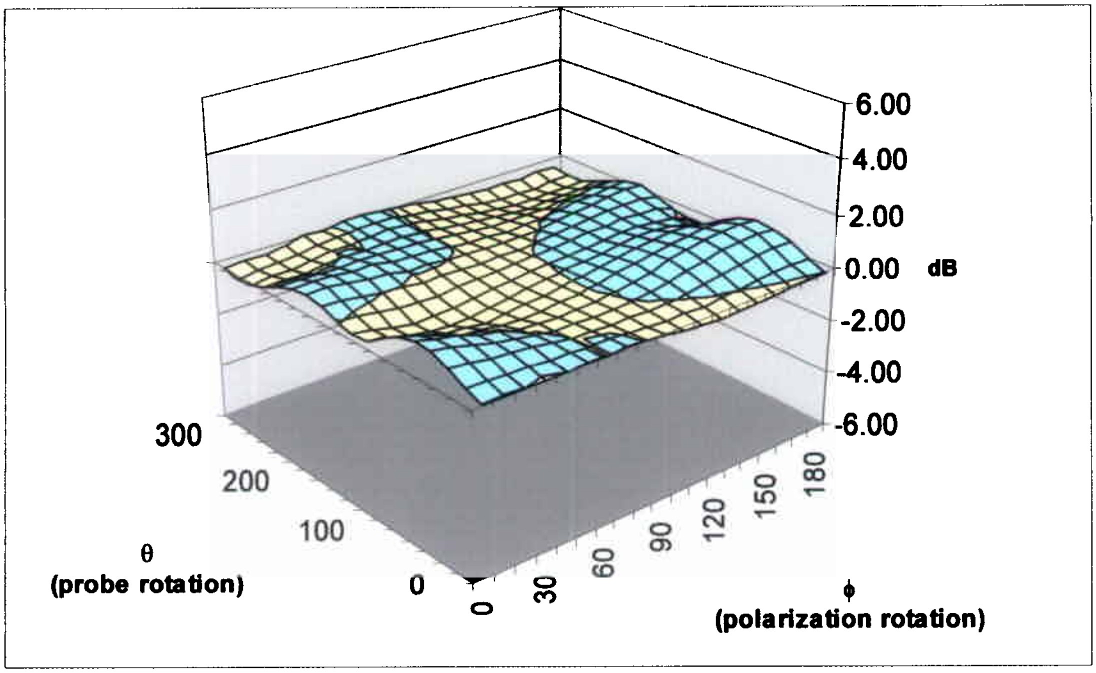

Figure 4 Directivity map for probe H0010 at 835MHz indicating the range of sensitivity with probe and dipole rotation angles. The overall variability is +/- 0.74dB.

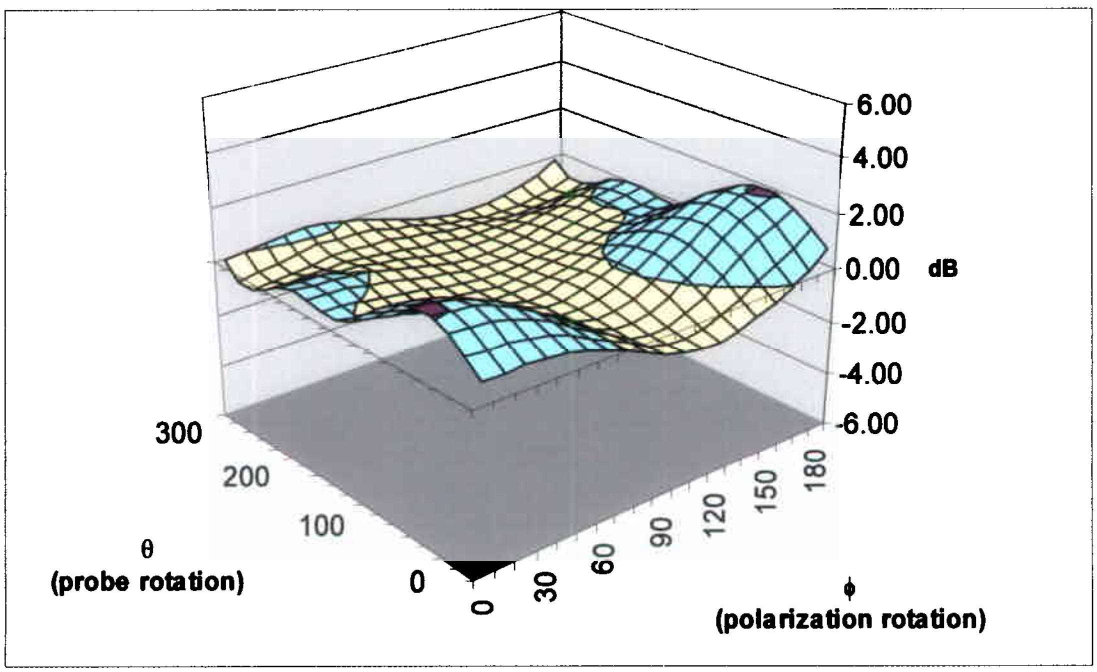

Figure 5 Directivity map for probe H0010 at 1880MHz indicating the range of sensitivity with probe and dipole rotation angles. The overall variability is +/- 1.61 dB.

Typical measured spherical & rotational isotropy range in air

Frequency (MHz)	Spherical Isotropy (dB)	Rotational Isotropy (dB)
835	±0.74	±0.02
1880	±1.61	±0.09

2 & 3) Finding Conversion Factors for each Frequency
Representative Indexsar IXP-070 probes are sent for calibration at the UK's National Physical Laboratory. The NPL calibrated probes are used as transfer standards for checking the calibration of other IXP-070 probes from the same batch.

ETS-Lindgren may offer 1309 standard calibrations for these probes in due course. When the probes need re-calibrating, it is recommended that these are performed by ETS-Lindgren.

Using reference dipole field values to check the probe calibration factors
The current C63.19 standard in its issued version [1] requires that HAC measurements are performed at a distance that places the closest part of the probe sensors at 10 mm spacing from the closest point of the device under test. This, however, is a configuration having no traceable connection with independent probe calibrations performed in quasi-uniform fields (as in anechoic chambers or waveguides). For calibrated probes, the calibration point is the centre of the sensor arrays, which gives a different spacing of the probe from the closest point of the reference dipoles used for this test and is the only configuration for which the calculated FDTD reference values apply.

For a dipole validation of the H-field probe performance, the gauge-block separation of the probe tip to dipole separation is 5.5 mm. This is achieved on the HACtest system by issuing the command **mv 2 550** to raise the probe from the point of contact with the dipole.

To check the system performance using the listed calibration factors, dipole validation tests have been performed and compared to the standards reference values using the supplied spreadsheet vref835_IX_1880_H13.xls, which provides an easy framework for comparing saved dipole scans against the reference values fof the E- and H- values at 10mm spacing. By performing repeat scan with modulated and unmodulated signals, the probe modulation factor (PMF) can be determined. The modulation factor for GSM has been determined as 1.04+/-0.01 for representative probe S/N H0010, independent of frequency.

Figure 6 and Figure 7 show the results obtained during dipole validation tests at 835 MHz and 1880 MHz respectively.

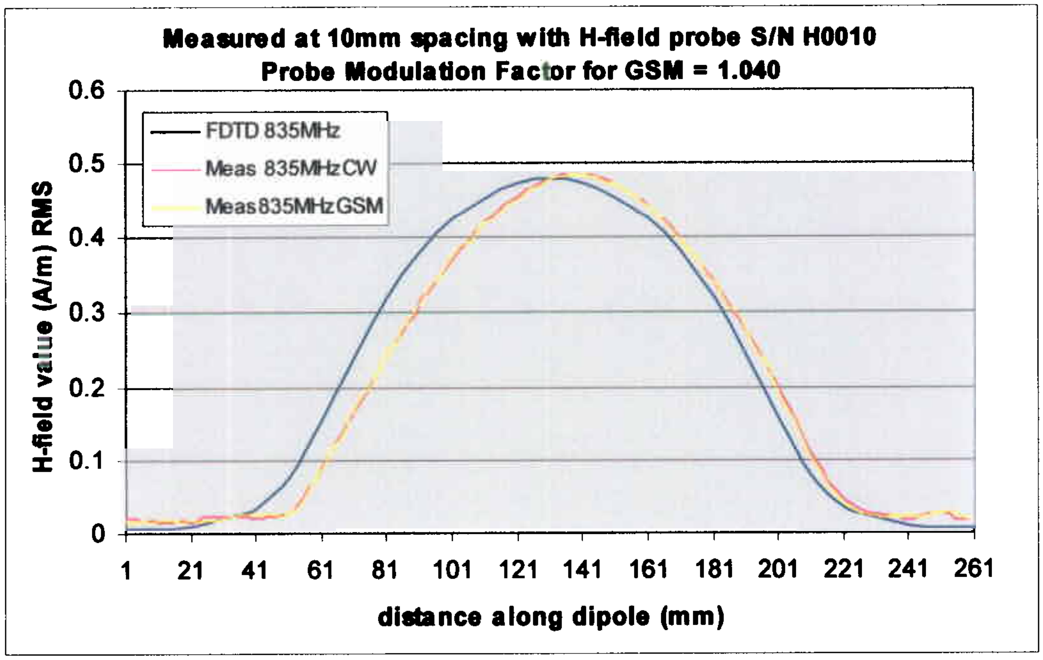

Figure 6: 835MHz dipole validation scans from which the probe modulation factor for GSM has been determined

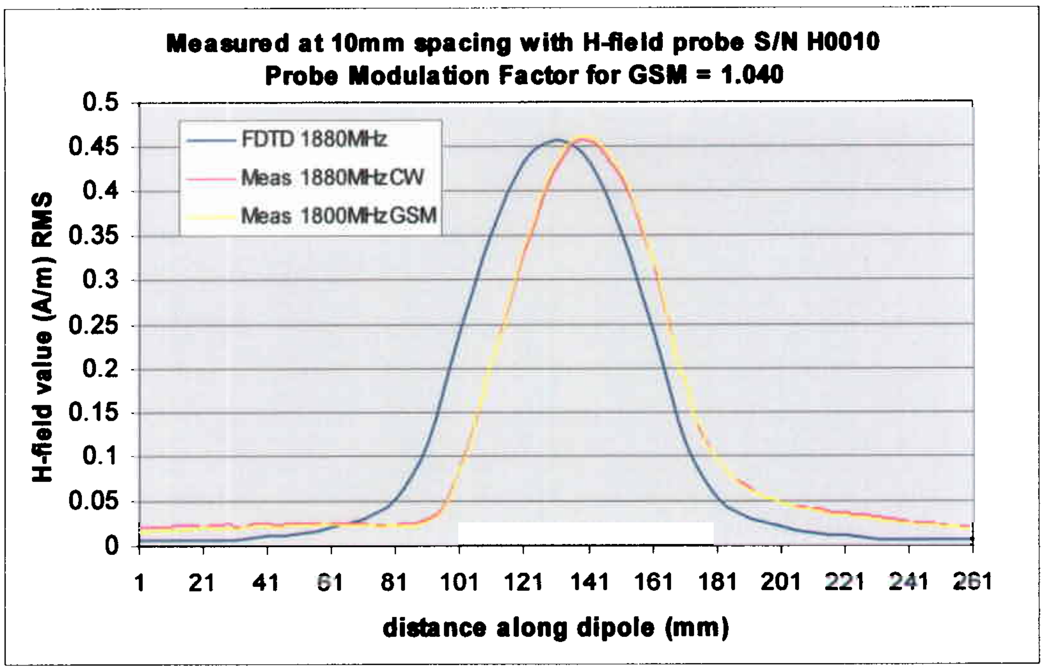

Figure 7: 1880MHz dipole validation scans from which the probe modulation factor for GSM has been determined

Practical check of probe rotational isotropy

The FCC has removed their requirement for static rotational isotropy measurements for HAC probes over test sources. A justification for this is that it may be inappropriate to measure probe isotropy in the steep field gradients of the near field. The physical separation of the dipole sensors means that the position of the measured maximum shifts laterally with probe rotation angle.

A more relevant test is to perform complete scans (either 1D or 2D) at varying probe rotation angles. To perform this test, dipole validation scans were conducted on H0010 rotated in steps of 90 degrees with the results shown in Figures 8 & 9.

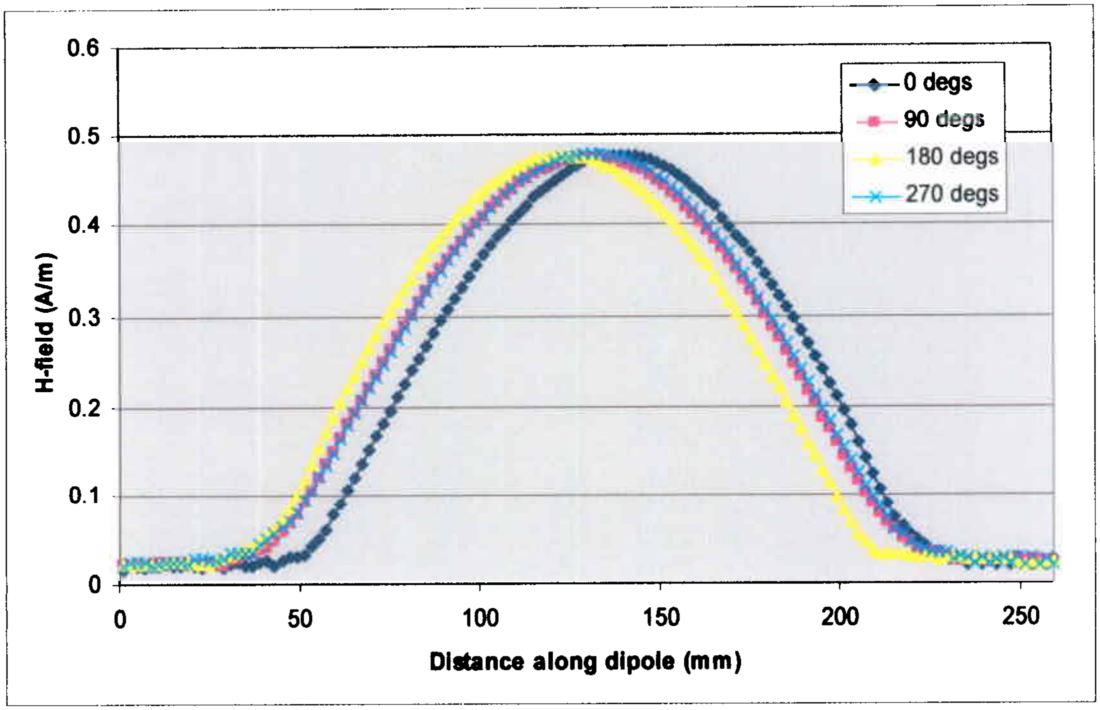

Figure 8 835MHz dipole validation scans performed at 90 degree rotation increments of the probe with respect to the dipole.

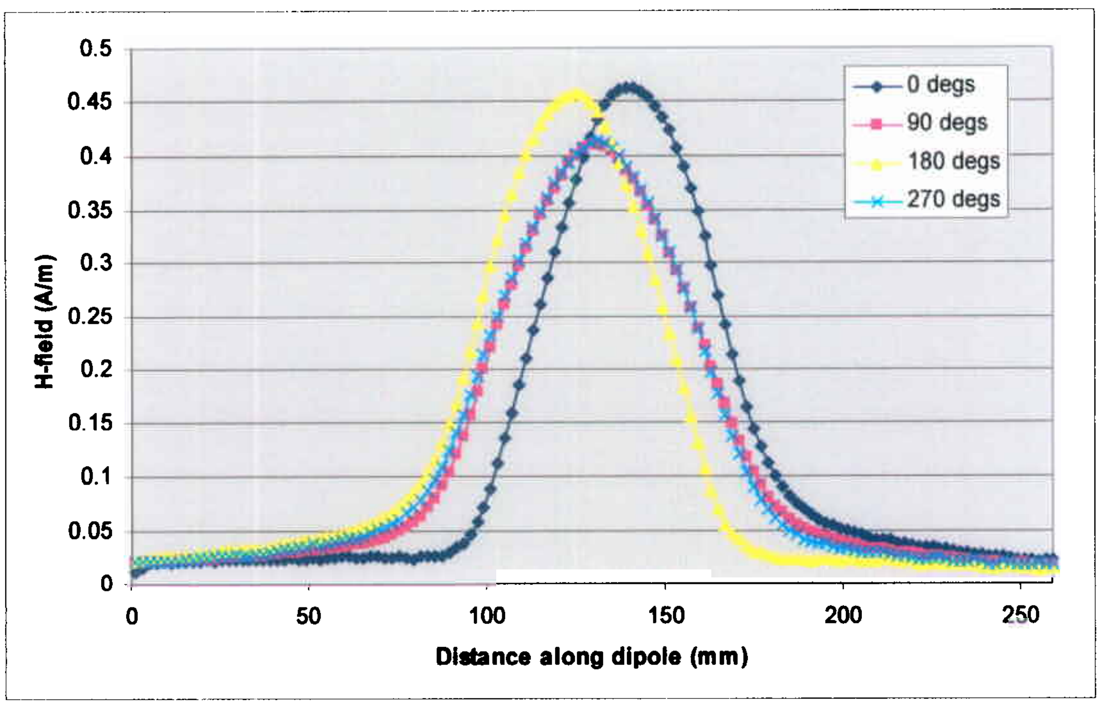

Figure 9 1880MHz dipole validation scans performed at 90 degree rotation increments of the probe with respect to the dipole.

Across a batch of probes, differences in the probe axial orientation within the support cradle typically leads to a worst-case uncertainty (at 1880MHz) in the measured H-field of ±8%. This number feeds through to Table 1 listing sources of measurement uncertainty.

Note: All the measurements performed in this report are obtained with the probe positioned with the red dot on the connector barrel facing in the –Y direction (ie outwards)

Probe linearity and sensitivity

The linearity of response of a representative IXP-070 probe to varying input powers to an 1880MHz validation dipole is shown in Figure 9. Over this range, the response is linear within +/- 0.08dB. The lowest point in this range corresponds to a field strength of 0.02 A/m.

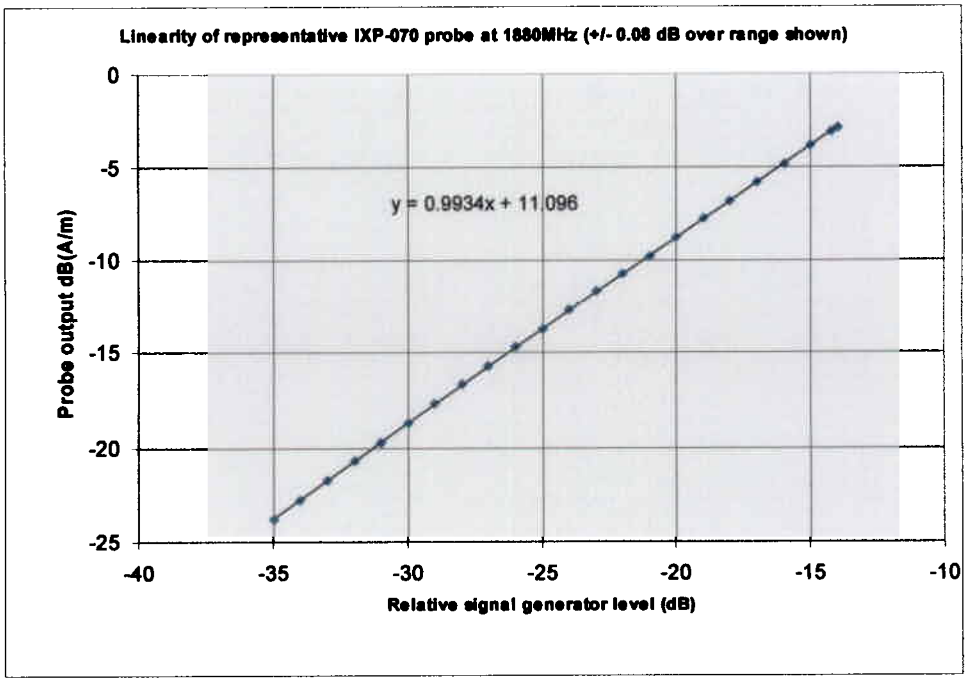

Figure 9: 1880MHz field measurements at varying input powers at 10mm spacing above centre point of 1880MHz dipole

UNCERTAINTY CONSIDERATIONS

Annex E (informative) in the current version of the hearing aid compatibility standard for methods of measurement [1] provides a sample uncertainty estimation table (Table E.1). This template has been used for an uncertainty assessment of the near-field measurement uncertainties. The previous discussion (Sections 2 & 3: Finding Conversion Factors for Each Frequency) is relevant in this regard. The following commentary is provided in support of each of the data entries in the following spreadsheet Table.

RF Reflections

This has been investigated by adding additional material of the type used in system construction in the vicinity of the near-field measurements. In one test, the source and probe were independently supported and then the effect of removing the whole robot structure was determined. These tests show insignificant efects of surrounding material. It is noted, however, that during a dipole scan, at the very low field levels past each extreme of the dipole arm that an effect on the <10V/m field is detected when the probe is also close to the acrylic table top. These effects are not detected at higher field levels relevant to DUT measurements. A value for this effect of **0.05dB** is entered into uncertainty assessment Table.

Field Probe conv. Factor

The measurement of a probe's conversion factor is a 2-stage process. Firstly, a transfer calibration is performed against an NPL-calibrated probe, over the full range of probe and source dipole polarisation angles, with the probes separated from the source by approximately 10cm. This separation ensures the probes are in a relatively uniform field, similar to the conditions during the NPL calibration process. Uncertainties arise from the quoted uncertainty in the NPL calibration, RF mismatches from signal generator to source dipole, and source drift, and amount to **0.32dB**.

The second stage of the calibration process involves locating the probe-under-test in the non-uniform field close to a dipole. A scan along the length of the dipole, at the separation specified in C63.19, can then allow a comparison to be made against the field distribution derived by mathematical modelling. It is observed that across a batch of probes, the uncertainty in the correction factor is **0.17dB.**

When these two contributions are taken together, a total probe calibration uncertainty of **0.36dB** is obtained.

Field probe anisotropy

The spherical isotropy is measured in a robot jig, which rotates the probe and a balanced dipole source through all rotation angles in 20 degree steps. Across a complete batch of probes, the worst-case spherical isotropy is identified. A typical value for this effect is 1.6dB. However, with the probe positioned closer to the source in regions where there are steep field gradients, variations of +/-**0.33dB** (+/-8%) have been measured (see Figure 9) and entered into the uncertainty assessment Table.

Positioning accuracy

The key factor here is the consistency with which a touch position can be established as software is used to subsequently raise the probe height with a precision of 0.01mm. Users are recommended to use a piece of paper as a shim between the probe tip and the source device and to determine the touch position to be when light friction is felt between the two. This procedure should allow 0.1mm positioning accuracy. As fields are decaying by 0.9dB/mm (see below) at the measurement position, an uncertainty of **0.1dB** is entered into uncertainty assessment Table.

As a caution, users of the Cartesian HACtest framework are recommended not to place or remove items from the bench top after the probe position has been set to avoid changes in supported weight contributing to displacement between the probe and source.

Probe cable placement

The probe cable is an optical fibre, so electrical effects are unlikely. It is possible that altering the tension on the fibre could contribute to probe displacement but as long as the cable routing is unconstrained, no significant effects are expected from this cause. A value for this effect of **0.1dB** is entered into uncertainty assessment Table.

System repeatability

System repeatability has been studied in an extended series of investigations described in [2]. The system repeatability itself was found to be mainly influenced by variations in the source power feed, for which the RF amplifier in the power feed-train had a dependence on diurnal variations in ambient laboratory conditions. A combined value of **0.5dB** to account for the many factors studied in IXS0301 is entered into uncertainty assessment Table.

Table 1

Uncertainty template for WD Near-Field Measurement Uncertainty: H-field probes

Table of Uncertainty Values using template in ANSI-PC63.19-2001 Revision Draft 3.4 Section E.1

Spreadsheet available on HACSAR CD as RFuncertainty.xls

Contribution	Data (dB)	Data (+/- %)	Data Type	Probability distribution	Divisor (descrip)	Divisor (value)	Standard Uncertainty (+/- %)	Standard Uncertainty (dB)
Near-Field Measurement								
RF Reflections	0.05	1.2	Specification	R	√3	1.73	0.67	
Field Probe Calibration	0.363	8.7	Specification	N	1	1.00	8.72	
Field Probe Spherical Anisotropy (typical)	0.33	7.9	Specification	N	1	1.00	7.89	
Positioning Accuracy (lateral)	0.1	2.3	Specification	R	√3	1.73	1.34	
Positioning Accuracy (10mm measurement hei	0.1	2.3	Specification	R	√3	1.73	1.34	
Probe Cable Placement	0.1	2.3	Specification	R	√3	1.73	1.34	
System Repeatability	0.5	12.2	Standard Deviation	R	√3	1.73	7.04	
Repeatability of the WD	0.5	12.2	Standard Deviation	R	√3	1.73	7.04	
		0.0		R	√3	1.73	0.00	
		0.0		R	√3	1.73	0.00	
Combined standard uncertainty				**RSS**			**15.6**	**0.6**
Expanded uncertainty (coverage factor=2)				k=2			30.6	**1.2**

REFERENCES

[1] American National Standard for Methods of Measurement of Compatibility between Wireless Communications Devices and Hearing Aids ANSI C63.19.-2006 (Revision of ANSI C63.19.-2001).

[2] Characterising the measurement of GSM signals with the IXP-050 SAR probe and IXP-020 probe amplifier A Brinklow & MI Manning 2nd April 2007. Indexsar Report IXS0301.

APPENDIX 1

NATIONAL PHYSICAL LABORATORY

Teddington Middlesex UK TW11 0LW Switchboard 020 8977 3222

Certificate of Calibration

INDEXSAR MAGNETIC FIELD STRENGTH PROBE
Probe Type: IXP-070 S/N: H0016

0478

FOR:	IndexSAR Limited Oakfield House Cudworth Lane Newdigate Dorking Surrey RH5 5BG
ORDER NUMBER:	0497
DESCRIPTION:	A broadband, isotropic magnetic field probe type: IXP-070, manufactured by IndexSAR, s/n: H0016. The probe system has been calibrated over the frequency range 835 to 1900 MHz. The probe was connected to an amplifier Type IXA-020, belonging to NPL, which was optically coupled to a computer running CheckSAR software.
DATE(S) OF CALIBRATION:	18 January 2007
PREVIOUS NPL CERTIFICATE:	None

Reference: E06120274/1 **Page 1 of 6**

Date of issue: 22 January 2007 **Signed:** (Authorised Signatory)

Checked by: **Name:** K P Holland **for Managing Director**

MEASUREMENT

The calibration of field strength monitors involves the generation of a calculable linearly polarised electromagnetic field, approximating to a plane wave, into which the probes or sensors are placed.

This type of probe has three independent antennas constructed at right angles to each other.

Over the frequency range of 835 to 1900 MHz, the NPL Tapered TEM transmission cell is used to generate the known field for the calibration.

For each frequency and field strength setting, the sensor is rotated to enable the sensitivity of each antenna to be measured separately.

For each measurement, the input power to the test facility was adjusted so that the field strength at the plane of reference of the probe was set to a specified value. The 'unlinearised' output from the antenna under test, as displayed on the computer, was then recorded along with the applied electric field strength.

The term "field strength" refers to the r.m.s. value of the electric or magnetic wave amplitude.

The probe was zeroed via the computer before each measurement.

UNCERTAINTIES

The measurement uncertainties apply only when the probe is supported in a low reflectivity mount and used with all three antennas switched on as in the normal isotropic mode of operation.

If the sensor is positioned with one antenna aligned for maximum coupling with the electric field in a linearly polarised EM field, then the uncertainty in the corresponding antenna 'unlinearised' output are given in the results and summarised below.

± 0.80 dB for frequencies from 835 to 1900 MHz

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements. The results and uncertainties relate to the on-the-day values and make no allowance for drift or operation under other environmental conditions.

RESULTS

These results have been obtained without any adjustment to the probe sensitivity.

The tables below show the individual readings of each antenna, with the identified axis aligned with the magnetic field.

Measurement Temperature 23 ± 2°C

Table 1

Probe Type: IXP-070 S/N: H0016

Frequency MHz	Unlinearised Output mV Indicated	Range	Field Strength A/m Actual	Uncertainty dB	Antenna
835.0	1.169	Auto	0.030	±0.80	X
835.0	0.563	Auto	0.030	±0.80	Y
835.0	0.850	Auto	0.030	±0.80	Z
835.0	11.788	Auto	0.100	±0.80	X
835.0	6.322	Auto	0.100	±0.80	Y
835.0	9.355	Auto	0.100	±0.80	Z
835.0	135.714	Auto	0.500	±0.80	X
835.0	89.389	Auto	0.500	±0.80	Y
835.0	113.783	Auto	0.500	±0.80	Z
835.0	169.931	Auto	0.600	±0.80	X
835.0	114.875	Auto	0.600	±0.80	Y
835.0	143.254	Auto	0.600	±0.80	Z
835.0	239.048	Auto	0.800	±0.80	X
835.0	164.775	Auto	0.800	±0.80	Y
835.0	203.417	Auto	0.800	±0.80	Z
900.0	1.295	Auto	0.030	±0.80	X
900.0	0.639	Auto	0.030	±0.80	Y
900.0	0.949	Auto	0.030	±0.80	Z
900.0	12.955	Auto	0.100	±0.80	X
900.0	6.944	Auto	0.100	±0.80	Y
900.0	10.086	Auto	0.100	±0.80	Z
900.0	145.470	Auto	0.500	±0.80	X
900.0	93.939	Auto	0.500	±0.80	Y
900.0	119.581	Auto	0.500	±0.80	Z

Checked by:

NATIONAL PHYSICAL LABORATORY
Continuation Sheet

Table 1 Probe Type: IXP-070 S/N: H0016					
Frequency MHz	Unlinearised Output mV		Field Strength A/m	Uncertainty	Antenna
	Indicated	Range	Actual	dB	
900.0	181.813	Auto	0.600	±0.80	X
900.0	118.917	Auto	0.600	±0.80	Y
900.0	150.374	Auto	0.600	±0.80	Z
900.0	256.014	Auto	0.800	±0.80	X
900.0	171.746	Auto	0.800	±0.80	Y
900.0	212.572	Auto	0.800	±0.80	Z
1880.0	2.022	Auto	0.030	±0.80	X
1880.0	0.798	Auto	0.030	±0.80	Y
1880.0	1.823	Auto	0.030	±0.80	Z
1880.0	19.238	Auto	0.100	±0.80	X
1880.0	8.552	Auto	0.100	±0.80	Y
1880.0	17.907	Auto	0.100	±0.80	Z
1880.0	190.930	Auto	0.500	±0.80	X
1880.0	110.521	Auto	0.500	±0.80	Y
1880.0	182.862	Auto	0.500	±0.80	Z
1880.0	238.161	Auto	0.600	±0.80	X
1880.0	139.919	Auto	0.600	±0.80	Y
1880.0	227.444	Auto	0.600	±0.80	Z
1900.0	2.100	Auto	0.030	±0.80	X
1900.0	0.817	Auto	0.030	±0.80	Y
1900.0	1.888	Auto	0.030	±0.80	Z
1900.0	19.937	Auto	0.100	±0.80	X
1900.0	8.902	Auto	0.100	±0.80	Y
1900.0	18.825	Auto	0.100	±0.80	Z
1900.0	196.420	Auto	0.500	±0.80	X
1900.0	113.661	Auto	0.500	±0.80	Y
1900.0	188.880	Auto	0.500	±0.80	Z

Reference: E06120274/1
Checked by:

Table 1
Probe Type: IXP-070 S/N: H0016

Frequency MHz	Unlinearised Output mV Indicated	Unlinearised Output mV Range	Field Strength A/m Actual	Uncertainty dB	Antenna
1900.0	234.480	Auto	0.600	±0.80	X
1900.0	143.541	Auto	0.600	±0.80	Y
1900.0	234.718	Auto	0.600	±0.80	Z

Reference: E06120274/1
Checked by: