Testing and certification of electric, electronic and radio equipment/installations including telecommunication systems

TEST REPORT OF A 2.4GHZ IEE802.11G WLAN CARDBUS CARD, BRAND SKYWORKS MODEL 32001A , IN CONFORMITY WITH FEDERAL REGULATED SAR (SPECIFIC ABSORPTION RATE) REQUIREMENTS IN AUSTRALIA, CANADA, EU AND THE USA.

REPORT NUMBER: 03081106.R02

FCC listed	:	90828
Industry Canada	:	IC3501
VCCI registered	:	R-1518, C-1598

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Identification of Equipment under Test (EUT)

Test item	:	2.4 GHz IEEE 802.11g WLAN Cardbus card
Manufacturer	:	Skyworks Solutions Inc.
Brand	:	SKYWORKS
Model	:	32001A
Serial numbers	:	1, 2 ,4
Revision	:	n.a.
Receipt number	:	1
Receipt date	:	August 7th 2003
FCC ID	:	RFX32001A

Applicant information

Applicant's representative	:	B. Cormier
Company	:	Skyworks Solutions Inc.
Address	:	20 Sylvan Road
Postal code	:	MA 01827
City	:	Woburn
PO-box	:	n.a
Postal code	:	n.a
City	:	n.a
Country	:	USA
Telephone number	:	+1 78 13 76 30 45
Telefax number	:	+1 61 78 34 81 36

Test(s) performed

Location	:	Niekerk, The Netherlands.
Test(s) started	:	August 25, 2003.
Test(s) completed	:	August 26, 2003
Purpose of test(s)	:	To verify compliance with Federal regulated SAR requirements in th US and Canada.
Test specification(s)	:	IEEE C95.1-1991, FCC OET Bulletin 65 (Supplement C), Industry Canada RSS-102 (Issue 1).
Test engineer	:	P. de Beer.
Project leader	:	P. de Beer.
Report written by	:	P. de Beer.
Report approved by	:	P.A.J.M. Robben, B.Sc.E.E..
Report Number	:	03081106.r02
Report date	:	August 29, 2003.

This report is in conformity with NEN-EN-ISO/IEC 17025: 2000.

The test results relate only to the item(s) tested.

Table of contents

1 General.

1.1 Purpose of tests

Tests were conducted to determine the Safety Levels with respect to human exposure to Radio Frequency Electromagnetic Fields for Evaluating the Environmental Effects of Radio Frequency Radiation to verify compliance with Federal regulated SAR requirements in the US and Canada.

1.2 Applied standards/publications.

The Equipment Under Test (EUT) was tested in conformity with the described test method(s) in the following Standards and/or publications:

- IEEE Std C95.1-1999 edition: IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3kHz to 300GHz

- FCC OET Bulletin 65 (Supplement C) edition 01-01: Evaluating Compliance with FCC Guidelines for Human Exposure to radio Frequency Fields. Additional information for evaluating Compliance of Mobile and Portable Devices with FCC limits for Human Exposure to Radiofrequency Emissions.

- Industry Canada RSS-102 (Issue 1).

1.3 References

The methods and procedures applicable to measurements as performed and indicated in this test report are also described in detail in the following reference documents:

Publications	Year	Title
IEEE Std. 1528-200X Draft	2002	*Draft* Recommended Practice for Determining the Peak Spatial-Average Specific Absorption rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques.
FCC OET Bulletin 65, Edition 97-01	1997	Evaluating Compliance with FCC Guidelines for Human Exposure to radio Frequency Fields
ANSI/IEEE C95.3	2002	IEEE Recommended Practice for the Measurement and Computations of Radio Frequency Electromagnetic Fields With Respect to Human Exposure to Such Fields, 100kHz-300GHz

2 Summary and conclusion.

2.1 Exposure category

The EUT supplied for Specific Absorption Rate (SAR) testing according the standards/publications as indicated in clause 1.2 is a considered to be a

Body worn Device.

According to the characteristics of the EUT and typical application and usage in accordance with the relevant product specifications of the manufacturer the EUT is identified to the exposure category:

General population/Uncontrolled exposure

2.2 Summary of results

The maximum peak spatial-average SAR measured was found to be **0.534** W/Kg at 17.6 dBm EUT power level.
EUT positioned in the "Key board up position", and the EUT is in contact with the phantom (see 6.1.2).

2.3 Compliance

The equipment was found to be compliant with requirements of standards as indicated in the table below:

Exposure Category and SAR Limits	Test Requirements	Compliance (Yes/No)
General population/Uncontrolled exposure 0.08W/kg whole body average and spatial peak SAR of 1.6W/kg, averaged over 1gram of tissue hands, wrist, feet and ankles have a peak SAR not to exceed 4 W/kg, averaged over 10 grams of tissue.	Requirements using guidelines established in IEEE C95.1-1991 FCC OET Bulletin 65 (Supplement C) Industry Canada RSS-102 (Issue 1).	Yes/~~no~~ Yes/~~no~~ Yes/~~no~~
Occupational/Controlled Exposure 0.4W/kg whole body average and spatial peak SAR of 8W/kg, averaged over 1gram of tissue hands, wrist, feet and ankles have a peak SAR not to exceed 20 W/kg, averaged over 10 grams of tissue.	Requirements using guidelines established in IEEE C95.1-1991 FCC OET Bulletin 65 (Supplement C) Industry Canada RSS-102 (Issue 1). ACA Radiocommunications (Electromagnetic Radiation – Human Exposure) Amendment Standard 2000 (No. 1)	N.a N.a N.a N.a

3 Identification of Equipment Under Test (EUT)

The following is the information provided by the applicant.

3.1 Equipment under Test (EUT) details

Description	Model number	Serial number	FCC ID	Cable descriptions
2.4 GHz IEEE 802.11g WLAN Cardbus card	32001A	1,2,4	RFX32001A	None.
Compaq Armada notebook computer	PP2060	AE5 P35000T3x6DM6458	n.a. (DoC)	-Unshielded DC power cord to AC/DC adapter -Shielded parallel cable to printer -Shielded mouse cable to mouse
Compaq AC/DC Power Supply 100-240VAC/1.5A to 18.5 VDC/ 2.7 Amps	PPP003SD	Z1T0017089948	n.a. (DoC)	-Unshielded DC power cord to notebook computer -Unshielded power cord to AC mains
Microsoft Wheel Mouse	USB Optical	53121-076-0591481-0000	n.a. (DoC)	-Shielded mouse cable to notebook computer
HP AC/DC power adapter 100-240 VAC/1 Amps to +18 VDC/1.1 Amps	C6409-60014	n.a.	n.a. (DoC)	-Unshielded DC power cord to printer -Unshielded power cord to AC mains

3.2 Manufacturer:

Name : Skyworks Solutions Inc.
Street : 20 Sylvan Road
Town : Woburn , MA 01827
Country : USA

3.3 EUT test operating configurations

Modulation type/ operating modes	:	DSSS (1, 2, 5.5, 11 MBit/s), OFDM (6, 9, 11, 54 MBit/s), BPSK, QPSK, 16QAM, 64 QAM
Operating frequency range	:	2400-2483.5 MHz (13 channels)
Maximum indicated power	:	+18.6 dBm conducted
Duty cycle during testing		100%
Antenna type(s) and gain/ operating positions	:	2 “rams horn” antennas with gain 1.0 dBi, integrated on the PCB of the product
Power supply/ power source		Power supplied trough the Lap-Top computer
Primary User Functions of EUT		Data Radio Communication Through Air
EUT Accessories		None
Hardware/software changes applied for testing		EUT was made to transmit with 100% duty cycle, instead of with its actual duty cycle of 78%, using the exclusive controlling software for SAR test provided by the manufacturer. Test software cTxRx version 2.0.0

3.4 Additional operating configurations

Power and signal distribution, grounding, interconnecting cabling and physical placement of the EUT under circumstances of testing at the test system are in accordance with the typical application and usage in so far as is practicable, and is in accordance with the relevant product specifications of the manufacturer.
The configuration of the EUT and it’s position are fully detailed and documented in the test report.
It is in avoidable that positions shown in this test report are not in accordance with the normal operation positions of the EUT.
It has to be noted that this may be needed to comply with the measurement requirements dictated by the appropriate standards.

4 Test conditions

4.1 Environmental conditions:

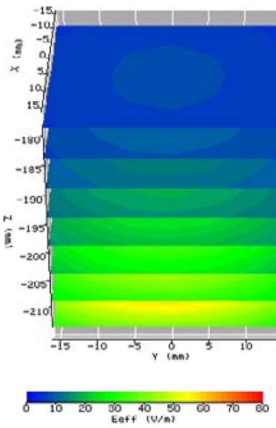
Requirement for	Specification	Determined value
Ambient temperature	+18°C to +25°C Temperature shall not exceed ±2 °C during the test	23.0°C at start to 24.2°C at end of test
Ambient humidity	20% to 75%	64 % at start to 63 % at end of test
Electro Magnetic environment	the ambient interference power shall be less than 0.012 W/kg	below the required lower detection limit of 0.010 W/kg, checked before and after test

4.2 System performance check

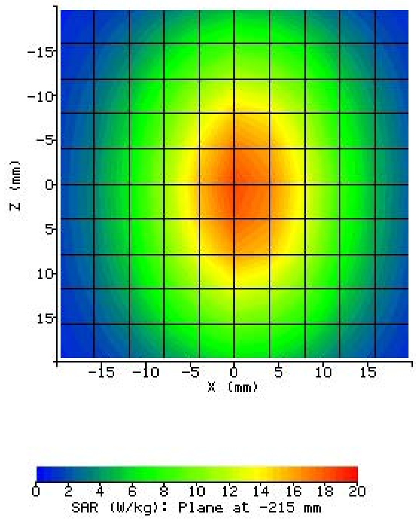
The purpose of the system performance check (*system check*) is to verify that the system operates within its specifications at the device test frequency. The system check is done to make sure that the system works correctly at the time of the compliance test. The system check has been performed using the specified tissue-equivalent liquid and at a chosen fixed frequency that is within ± 10% of the compliance test mid-band frequency. The system check is performed prior to compliance tests and the result must always be within ±10% of the target value corresponding to the test frequency, liquid and the source used. The target values are 1 g or 10 g averaged SAR values measured on systems for which s*ystem validation* has been performed.
The following system performance check results were obtained in accordance with Clause 8 of IEEE 1528 December 29, 2002:

4.2.1 2450 MHz validation Parameters:

Reference dipole	Frequency [MHz]	Max 1g SAR [W/Kg]	Max 10g SAR [W/Kg]	Measured 1g SAR [W/Kg]	Measured 10g SAR [W/Kg]	Deviation [%]
2450	2450		24		23.97	-0.13
2450	2450	52		50.28		-3.30



3d plot of system validation, measured with 0.5 W on dipole.



2d plot of system validation, 0.5 W on dipole.

4.3 Measured maximum output power of EUT

The EUT has been set to the maximum output power level.
The results of tests on the EUT, carried out in accordance with 47 CFR Part 15.247 (b)(1), are depicted in table below. The maximum peak output power (conducted) was measured directly at the antenna connector.

Transmission bitrate DSSS mode (Mbit/s)	Maximum peak output power (conducted, dBm)		
	Channel 1 (2412 MHz)	Channel 6 (2437 MHz)	Channel 11 (2462 MHz)
1	16.2	**17.6**	15.7
2	16.2	**17.6**	15.7
5.5	15.9	**17.4**	15.4
11	16.0	**17.6**	15.7

Transmission bitrate OFDM mode (Mbit/s)	Maximum peak output power (conducted, dBm)		
	Channel 1 (2412 MHz)	Channel 6 (2437 MHz)	Channel 11 (2462 MHz)
9	17.1	**18.4**	15.6
18	17.3	**18.6**	14.7
36	17.2	**17.0**	14.4
54	14.1	13.6	13.7

Note: During the measurements, the AC mains supply voltage of the notebook PC to which the EUT is connected in was varied between 85% and 115% of the nominal value. The maximum measured values are depicted in table above. No differences in measurement results, due to the AC mains voltage variations between 85% and 115% from the nominal value, have been observed.

It has been verified that any variation in output power during the SAR test is consistent with the design and specification of the device. There was no need to perform the tests at lower power. Therefore the test has not been performed at lower power and then scaled to the maximum output power provided that the SAR response of the EUT is linear with the output power.

The spot SAR levels were monitored before and after each full 3D scan. The levels before and after test are indicated in the plots of measurement data, section 8 of this report..

4.4 Tissue Dielectric Parameters

For the purpose of the tests as described in this report the following tissue dielectric parameters have been determined
The in the tables indicated tissue simulating liquids have been used for the in this test report indicated tests and have been checked prior to any tests. The indicated “required values” are derived from IEEE Std. 1528-200X (Draft) and OET Bulletin 65 supplement C. At frequencies other than reference frequencies, for which tissue parameters are given in the standards, the parameters have been determined by the linear interpolation. Depending the intended use of the EUT the interpolated values will refer to the mid-band frequency of each operating mode.

4.4.1 Dielectric parameters for 2.4GHz

Frequency	Tissue type:	Parameter	Determined value	Required Value	Δ(%)
2450 MHz	Body Tissue	**Relative Permittivity, ε_r [ε’]**	55.00	52.7	-4.4
		Conductivity, σ [S/m]	1.93	1.95	-1.0
		Temperature, t [°C]	23.30	-	-
2450 MHz	Head Tissue	**Relative Permittivity, ε_r [ε’]**	37.90	39.2	-3.3
		Conductivity, σ [S/m]	1.82	1.8	+1.0
		Temperature, t [°C]	23.70	-	-

4.4.1.1 Interpolation results

The interpolation results for 2450 MHz Body tissue:

MHz	ε_r [ε’]	σ [S/m]	ε_r [ε’]		σ [S/m]		Measured			
			Min	Max	Min	Max	ε_r [ε’]	Δ(%)	σ [S/m]	Δ(%)
2412.00	**52.75**	**1.91**	**47.78**	**58.03**	**1.72**	**2.11**	54.90	**4.08%**	**1.89**	**-1.05%**
2417.00	52.74	1.92	47.00	58.02	1.73	2.11	54.89	**4.08%**	1.89	**-1.56%**
2422.00	52.74	1.92	47.00	58.01	1.73	2.12	54.92	**4.13%**	1.89	**-1.56%**
2427.00	52.73	1.93	47.46	58.00	1.74	2.12	54.95	**4.21%**	1.90	**-1.55%**
2432.00	52.72	1.93	47.45	58.00	1.74	2.13	54.97	**4.27%**	1.90	**-1.55%**
2437.00	**52.72**	**1.94**	**47.45**	**57.99**	**1.74**	**2.13**	55.00	**4.32%**	**1.91**	**-1.55%**
2442.00	52.71	1.94	47.44	57.98	1.75	2.14	55.01	**4.36%**	1.92	**-1.03%**
2447.00	52.70	1.95	47.43	57.97	1.75	2.14	55.03	**4.42%**	1.93	**-1.03%**
2452.00	52.70	1.95	47.43	57.97	1.75	2.15	55.05	**4.46%**	1.93	**-1.03%**
2457.00	52.69	1.96	47.42	57.96	1.76	2.16	55.05	**4.48%**	1.94	**-1.02%**
2462.00	**52.68**	**1.97**	**47.42**	**57.95**	**1.77**	**2.16**	55.05	**4.50%**	**1.95**	**-1.02%**
2467.00	52.68	1.97	47.41	57.95	1.78	2.17	55.06	**4.52%**	1.96	**-0.51%**
2472.00	52.68	1.98	47.40	57.94	1.78	2.18	55.07	**4.54%**	1.97	**-0.51%**
2477.00	52.67	1.99	47.40	57.93	1.79	2,19	55.07	**4.56%**	1.97	**-1.01%**

4.4.2 Tissue simulating liquid recipes.

The following ingredients were used and suggested in various publications and according IEEE Std. 1528-200X (Draft) and OET Bulletin 65 supplement C.

2450 MHz Head Tissue	2450 MHz Body Tissue
46.7 % Water	Liquid supplied by Bristol University
0 % Salt	
53.3 % DGBE	

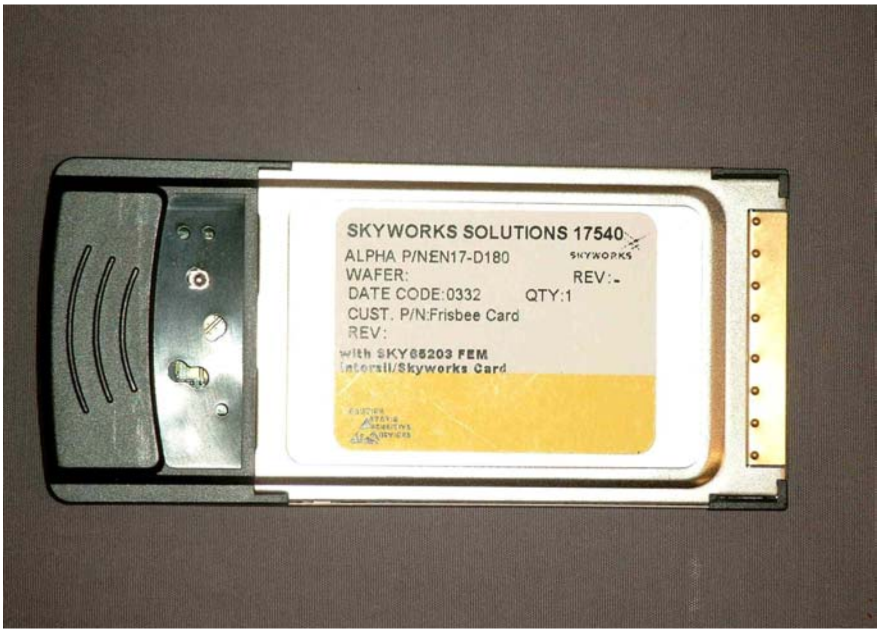
Ingredients of the tissue simulating liquid may have been adjusted to obtain the wanted Relative Permittivity and/or Conductivity.

4.4.3 Tissue simulating liquid temperature requirements:

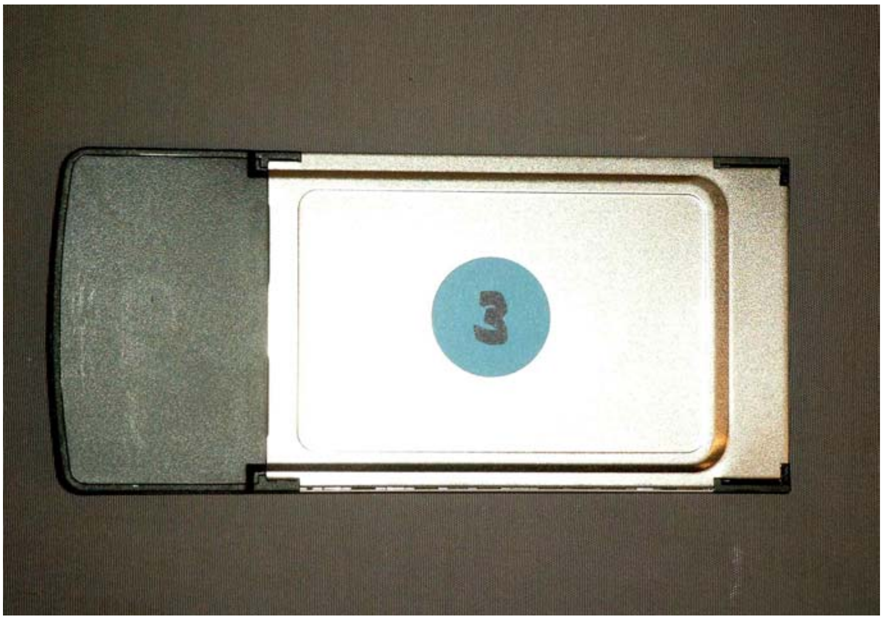
Tissue simulating liquid temperature should be between +20°C to +25°C.
The variation of the liquid temperature shall not exceed ±2°C during the test;
The actual tissue simulating liquid temperature was recorded to be between **22.8°C to 23.4°**C

5 Photographs of EUT and accessories

5.1 Front view



5.2 Rear view



5.3 Accessories

Compaq Armada notebook computer with a Compaq AC/DC Power Supply 100-240VAC/1.5A to 18.5 VDC/ 2.7Amps.
The EUT is located at the left hand side of the lap top.

EUT

6 Identification of EUT-Phantom positions

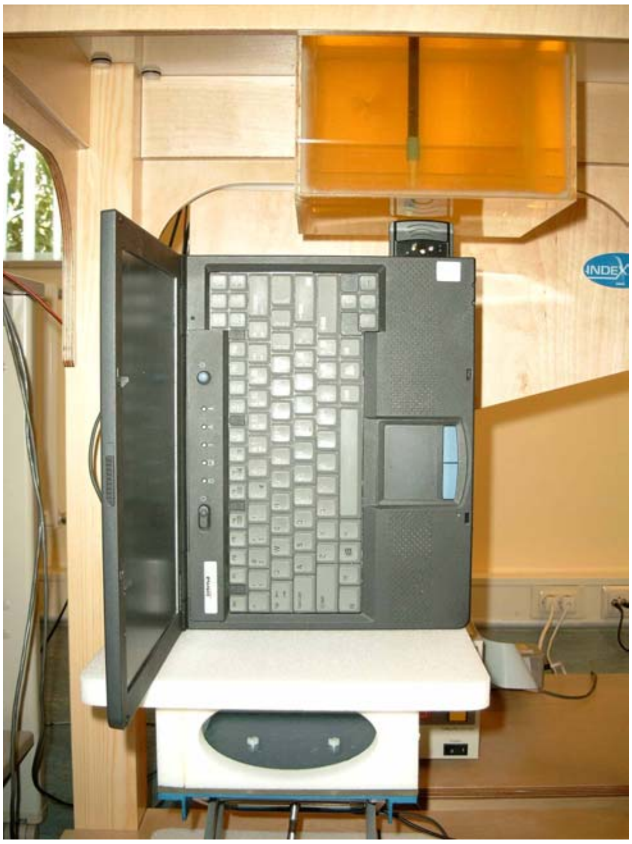
6.1 Body worn configuration

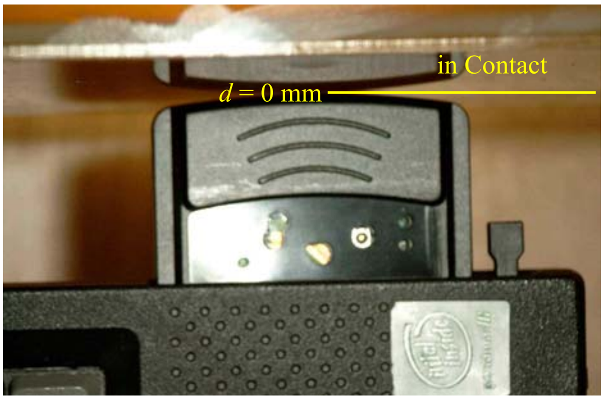
The positions for SAR evaluations were determined by performing a 2D scan to find the hot-spots. A scan in two positions was made, to locate approximately the X, Y and Z coordinates. If these coordinates have been established, the EUT was positioned in such a way that the largest area around the hot-spot would come in contact with the user if the equipment was used as intended. This position is also the position of the EUT against the phantom.
The minimum separation distance was determined, taking into consideration the variety in construction of the host. Lap top computers may have PCMCIA slots at different places and Safety Compliance will depend of the actual location of the EUT. Based on practical applications, the positions have been identified to be worst case, i.e. possible direct contact with the EUT by the user.

Based on the determined results as in section 7 and the Safety Compliance evaluations as described , the following positions have been identified:

6.1.1 Position Up-right

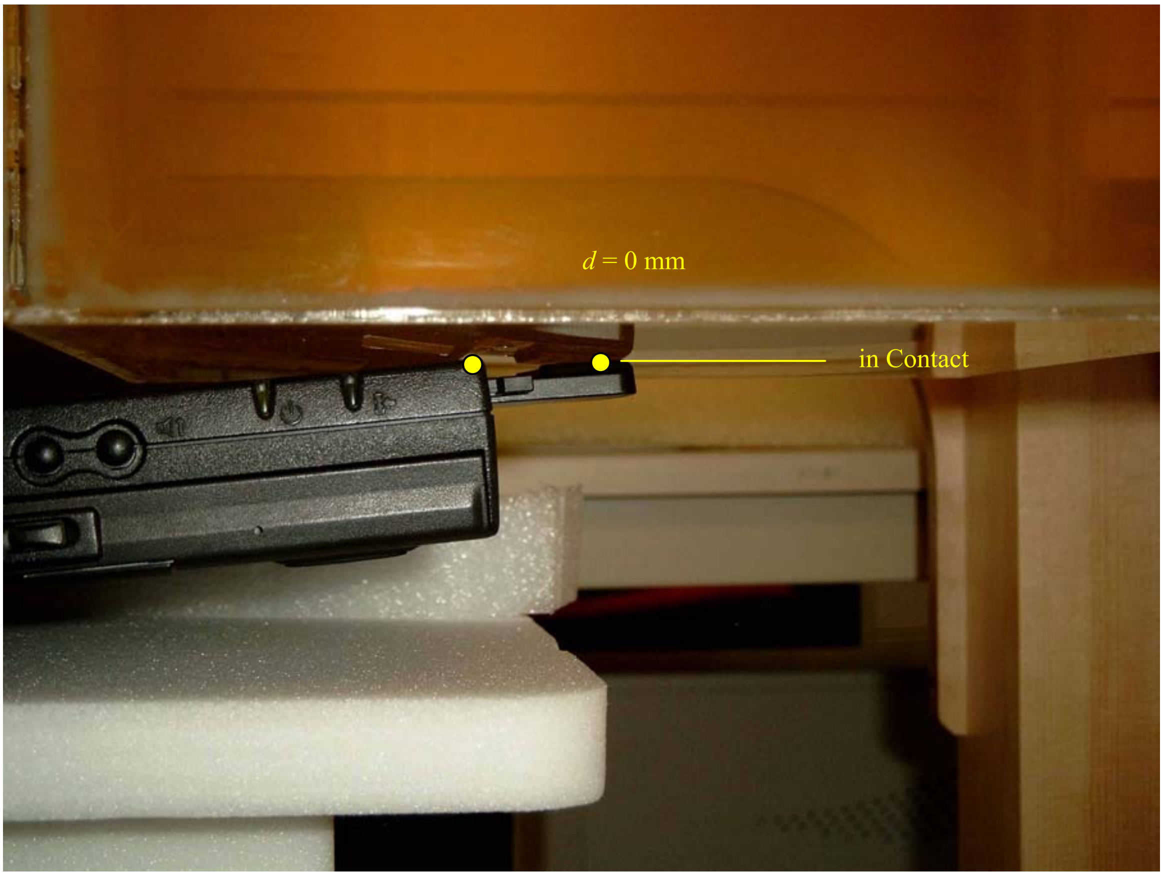
The separation distance, *d* of 0 $_{[mm]}$ (in contact) while EUT was in contact with phantom shell.





6.1.2 Position Key-board up

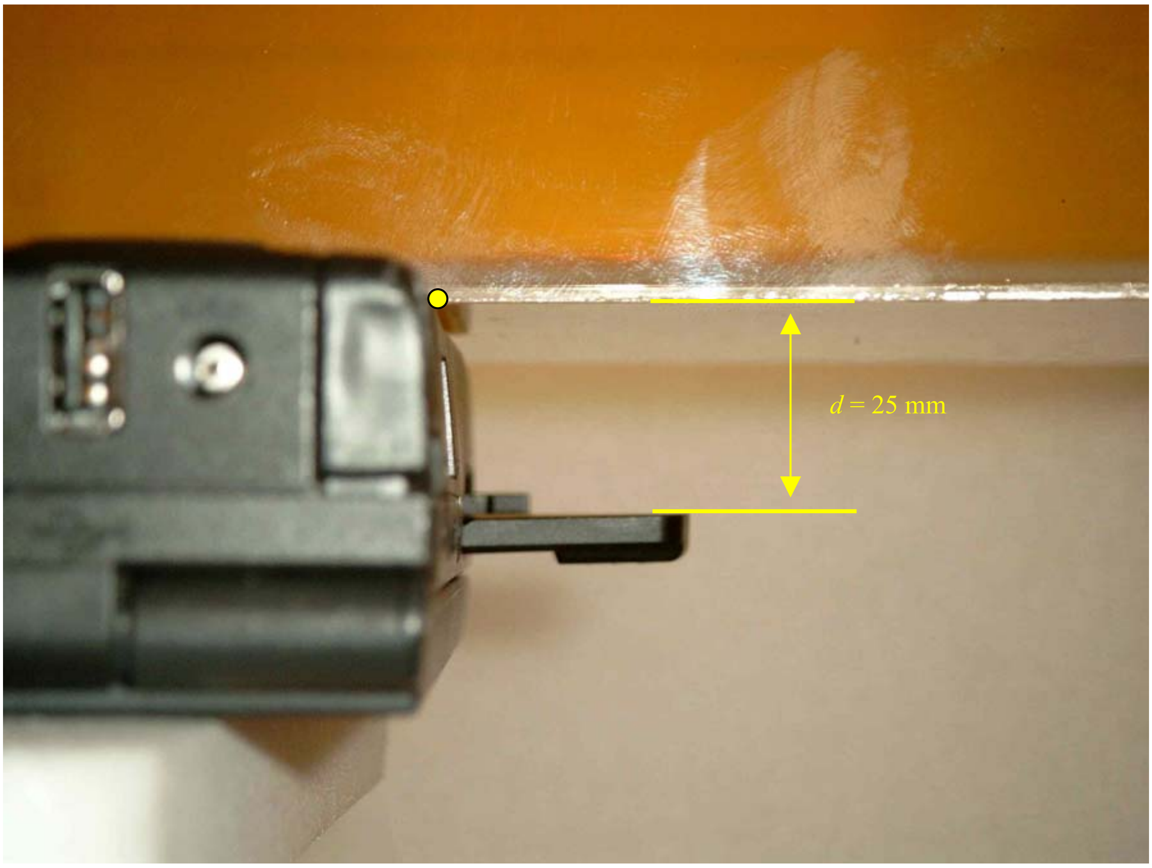
The separation distance, *d* of 0 $_{[mm]}$ (in contact) to while EUT was in contact with phantom shell



The position of the dots show the area where the body of the host lap top PC and the EUT do touch the phantom shell. The EUT has been positioned in the upper slot position, to reflect the worst case.

6.1.3 Position Bottom up

The separation distance, *d* was determined to be 25 mm, and reflects the position where the host would be positioned on the lap.



The position of the dot shows the area where the body of the host lap top PC touches the phantom shell.

7 Test Results

7.1 Determination of worst case configuration/modulation EUT

During the 2D scan , one of the scans was used to determine the worst case configuration/modulation of the EUT.
For the purpose of this test, the hot-spot coordinates were used to move the probe into a fixed position above this hot spot with sufficient readings for reliable detection of the worst case configuration.
The results as listed below were determined without changing the probe position but by changing the data rate, and thus modulation type.

Bit Rate [Mbps]	Local SAR value at channel 6 [W/kg]
1	0.360
2	0.359
5.5	0.359
11	0.359
9	0.226
12	0.209
18	0.201
24	0.135
36	0.135
48	0.054
54	0.058

For the purpose of the SAR evaluations, the measurements were performed with 1Mbps, which was identified as worst case.

7.2 Body worn Configuration results

Test #	EUT position	Worst case test condition	*d*= distance of EUT to Phantom	Antenna position	Freq. [MHz]	Ch	Max SAR 1gSAR [W/Kg]
--	Up right position, the EUT in contact with the (see 6.1.1).	1 MBps	0 mm	Fixed	2412	01	**n.t.**
01			0 mm	Fixed	2437	06	**0.215**
--			0 mm	Fixed	2462	11	**n.t.**
--	Key board up position, the EUT in contact with the phantom (see 6.1.2).	1 MBps	0 mm	Fixed	2412	01	**n.t.**
02			0 mm	Fixed	2437	06	**0.534**
--			0 mm	Fixed	2462	11	**n.t.**
--	User Lap position, the EUT not in contact with the phantom (see 6.1.3).	1 MBps	25 mm	Fixed	2412	01	**n.t.**
03			25 mm	Fixed	2437	06	**0.056**
--			25 mm	Fixed	2462	11	**n.t.**

Note: n.t. = not tested

Note: If SAR values measured at the middle band channel for each position are at least 3.0 dB lower than the SAR limits, then the tests at the lowest and highest channel are not necessary to be reviewed. The measured values of the worst case will be at the middle band channel if also the highest power has been monitored at that channel.

8 Plots of measurement Data

Test #	Ch	EUT position
01	**6**	Up right position, the EUT in contact with the phantom (see 6.1.1)
02	**6**	Key board up position, the EUT in contact with the phantom (see 6.1.2)
03	**6**	User Lap position, the EUT not in contact with the phantom (see 6.1.3)

Date / Time:	25/08/2003	**Position:**	Strait-up (see 6.1.1)
Filename:	6-straitup-3d, 6-straitup-2d	**Phantom:**	HeadBox1.csv
Device Tested:	Skyworks, Smartbus 32	**Head Rotation:**	0
Antenna:	integral	**Test Frequency:**	channel 6 (2460 MHz)
Shape File:	NONE.csv	**Power Level:**	17.6 dBm (PLI -36, 1MBps)

Probe: S/N0132

Cal File: DEFAULT

Cal Factors:

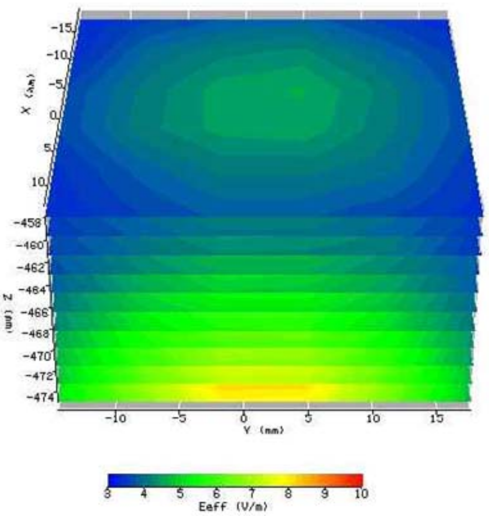
	X	Y	Z
Air	393	408	337
DCP	20	20	20
Lin	.354	.354	.354

Amp Gain: 2

Averaging: 3

Batteries Replaced: 22-08-2003

Liquid:	body tissue
Type:	2.45-Bristol-B-1
Conductivity:	1.91
Relative Permittivity:	55.00
Liquid Temp (deg C):	22.8
Ambient Temp (deg C):	23.0
Ambient RH (%):	64
Density (kg/m3):	1000
Software Version:	1.5 VPM



ZOOM SCAN RESULTS:

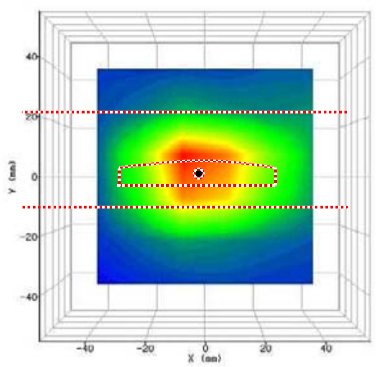
Spot SAR (W/kg):	**Start Scan**	**End Scan**
	0.081	0.082

Change during Scan (%) 1.21

Max E-field (V/m): 9.64

Max SAR (W/kg)	**1g**	**10g**
	0.215	0.123

Location of Max (mm):	**X**	**Y**	**Z**
	-4.0	2.7	-482.9



AREA SCAN:

Scan Extent:

	Min	Max	Steps
Y	-40.0	40.0	6.0
Z	-474.7	-474.7	6.0

Date / Time:	25/08/2003	**Position:**	Flat, keyboar-up (see 6.1.2)
Filename:	6-sait-3d, 6-sait-2d	**Phantom:**	HeadBox1.csv
Device Tested:	Skyworks, Smartbus 32	**Head Rotation:**	0
Antenna:	integral	**Test Frequency:**	channel 6 (2460 MHz)
Shape File:	NONE.csv	**Power Level:**	17.6 dBm (PLI -36, 1MBps)

Probe: S/N0132

Cal File: DEFAULT

Cal Factors:

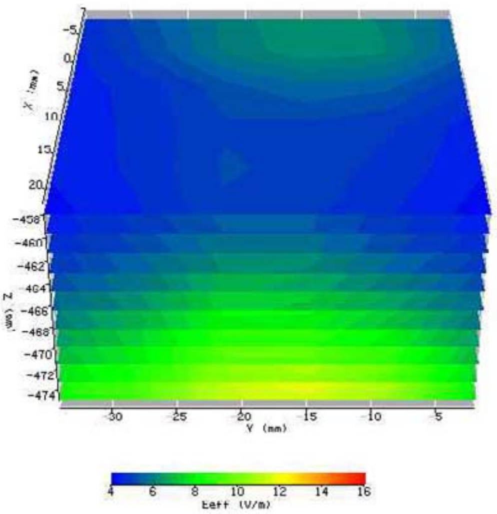
	X	Y	Z
Air	393	408	337
DCP	20	20	20
Lin	.354	.354	.354

Amp Gain: 2

Averaging: 3

Batteries Replaced: 22-08-2003

Liquid:	body tissue
Type:	245 Bristol 1
Conductivity:	5.3
Relative Permittivity:	55
Liquid Temp (deg C):	23.0
Ambient Temp (deg C):	23.5
Ambient RH (%):	64
Density (kg/m3):	1000
Software Version:	1.5 VPM



ZOOM SCAN RESULTS:

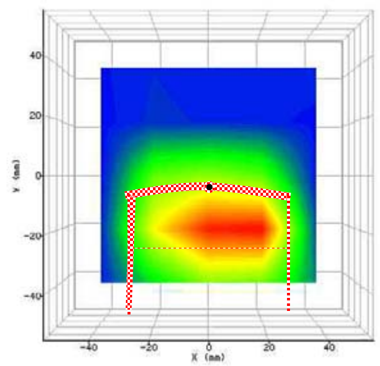
	Start Scan	End Scan
Spot SAR (W/kg):	0.113	0.117

Change during Scan (%): 2.76

Max E-field (V/m): 15.20

	1g	10g
Max SAR (W/kg)	0.534	0.281

	X	Y	Z
Location of Max (mm):	-10.0	-13.2	-482.9



AREA SCAN:

Scan Extent:

	Min	Max	Steps
Y	-40.0	40.0	5.0
Z	-474.7	-474.7	5.0

Date / Time:	25/08/2003	**Position:**	Lap position (see 6.1.3)
Filename:	6-bottom-3d, 6-bottom-2d	**Phantom:**	HeadBox1.csv
Device Tested:	Skyworks, Smartbus 32	**Head Rotation:**	0
Antenna:	integral	**Test Frequency:**	channel 6 (2460 MHz)
Shape File:	NONE.csv	**Power Level:**	17.6 dBm (PLI -36, 1MBps)

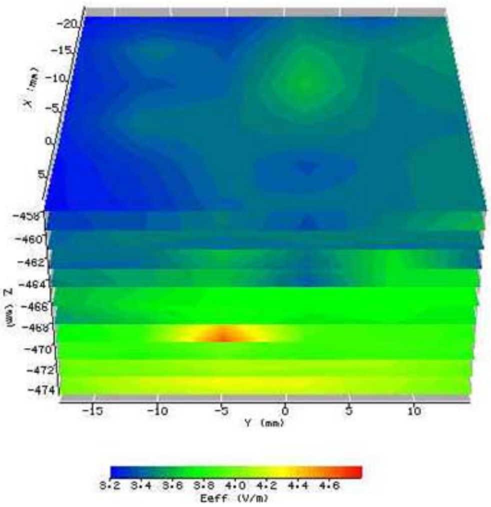
Probe:	S/N0132
Cal File:	DEFAULT

Cal Factors:

	X	Y	Z
Air	393	408	337
DCP	20	20	20
Lin	.354	.354	.354

Amp Gain:	2
Averaging:	3
Batteries Replaced:	22-08-2003

Liquid:	body tissue
Type:	245 Bristol 1
Conductivity:	5.3
Relative Permittivity:	55
Liquid Temp (deg C):	23.4
Ambient Temp (deg C):	24.2
Ambient RH (%):	63
Density (kg/m3):	1000
Software Version:	1.5 VPM



ZOOM SCAN RESULTS:

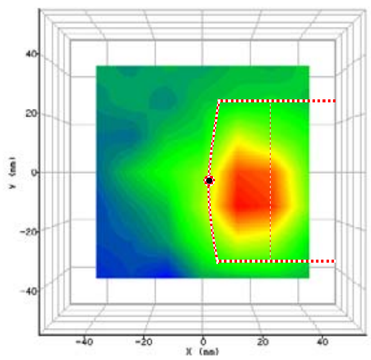
Spot SAR (W/kg):	Start Scan	End Scan
	0.031	0.030

Change during Scan (%): -3.22

Max E-field (V/m): 4.75

Max SAR (W/kg):	1g	10g
	0.056	0.039

Location of Max (mm):	X	Y	Z
	-9.6	-14.4	-482.9



AREA SCAN:

Scan Extent:

	Min	Max	Steps
Y	-40.0	40.0	6.0
Z	-474.7	-474.7	6.0

9 Description of test configuration

9.1 SAR Measurement System

9.1.1 Robot System description

The SAR measurement system used by TNO EPS is the IndexSAR SARA2 system, which consists of a Mitsubishi RV-2A six-axis robot-arm and controller, IndexSAR probe and amplifier and an appropriate phantom as required and considered appropriate for the applied test. The robot is used to move and manipulate the probe to programmed positions inside the phantom to obtain the SAR readings from the EUT.
The system is remote controlled by a PC, which contains the software to control the robot and data acquisition equipment. The software also displays the data obtained from test scans by calculating the measured values into corresponding SAR values based on the currently acceptable calculation methods.

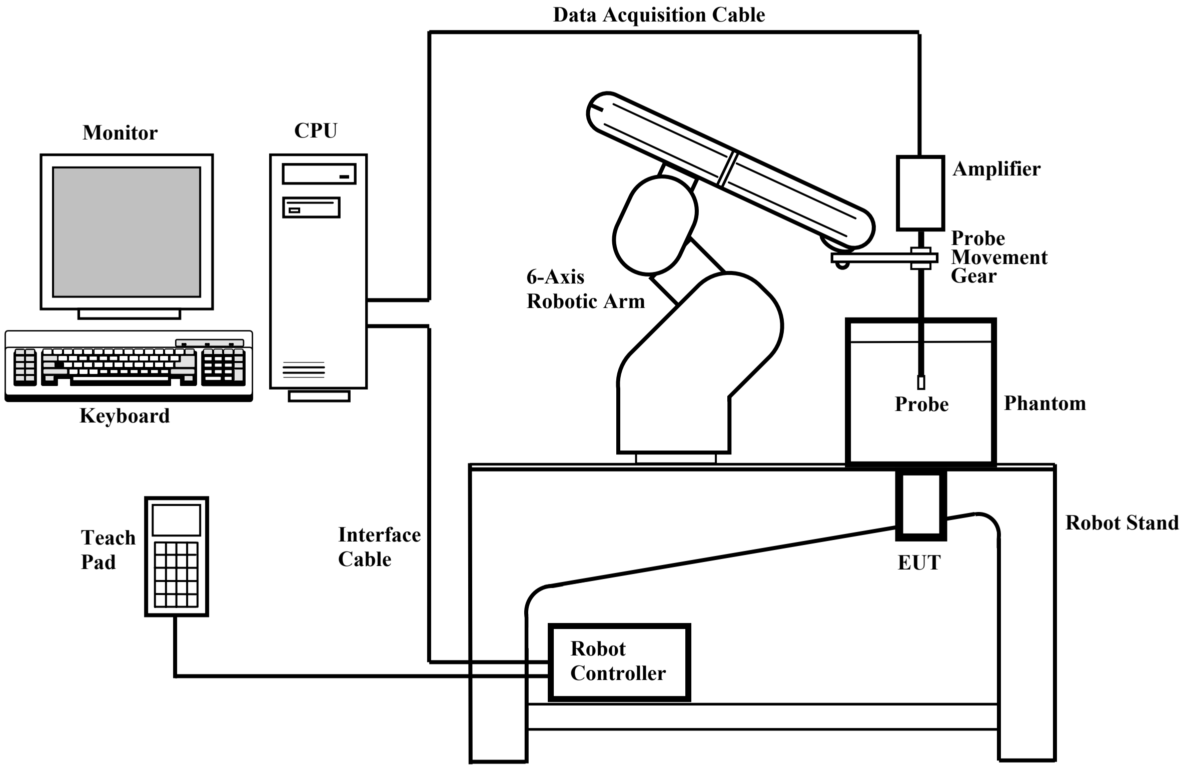


Figure 1: Overview of the SARA2 measurement system

The position and digitized shape of the phantom are made available to the software for accurate positioning of the probe and reduction of set-up time.
E.g. the SAM phantom heads are individually digitized using a Mitutoyo CMM machine to a precision of 0.001mm. The data is then converted into a shape format for the software, providing an accurate description of the phantom shell.

In operation, the system first does an area (2D) scan at a fixed depth within the liquid from the inside wall of the phantom. When the maximum SAR point has been found, the system will then carry out a 3D scan centered at that point to determine volume averaged SAR level.

9.1.2 Probe description

The probes are constructed using three orthogonal dipole sensors arranged on an interlocking, triangular prism core. The probes have built-in shielding against static charges and are contained within a PEEK cylindrical enclosure material at the tip. Probe calibration is described in section 10.1.

9.1.3 Amplifier description

The amplifier unit has a multi-pole connector to connect to the probe and a multiplexer selects between the 3-channel single-ended inputs. A 16-bit AD converter with programmable gain is used along with an on-board micro-controller with non-volatile firmware. Battery life is around 150 hours and data are transferred to the PC via 3m of duplex optical fibre and a self-powered RS232 to optical converter.

9.1.4 Phantom description

Body-worn operating configurations are tested using a flat phantom. The body phantom shell is made of a low-loss dielectric material with dielectric constant and loss tangent less than 5.0 and 0.05 respectively. The shell thickness for all regions coupled to the test device and its antenna are within 2.0 ± 0.2 mm. The phantom was filled with the required head or body equivalent tissue medium to a depth of 15.0 ± 0.5 cm
For body mounted and frontal held push-to-talk devices, a flat phantom of dimensions 20x20x20cm with a base plate thickness of 2mm is used.

For Head mounted devices placed next to the ear, the phantom used in the evaluation of the RF exposure of the user of the wireless device is a IEEE P1528/CENELEC EN50361 compliant phantom, shaped like a human head and filled with a mixture simulating the dielectric characteristics of the brain.
The for SARA2 measurement system used Specific Anthropomorphic Mannequin (SAM) Upright Phantom is fabricated using moulds generated from the CAD files as specified by CENELEC EN50361. It is mounted via a rotation base to a supporting table, which also holds the robotic positioner. The phantom and robot alignment is assured by both mechanical and laser registration systems

9.2 Measurement Procedure

During the SAR measurement, the positioning of the probe is performed with sufficient accuracy to obtain repeatable measurements in the presence of rapid spatial attenuation phenomena. The accurate positioning of the E-field probe is accomplished by using the high precision robot. The robot can be taught to position the probe sensor following a specific pattern of points.
After an area scan has been done at a fixed distance of 8mm from the side of the phantom on the source side, a 3D scan is set up around the location of the maximum spot SAR. First, a point within the scan area is visited by the probe and a SAR reading taken at the start of testing. At the end of testing, the probe is returned to the same point and a second reading is taken. Comparison between these start and end readings enables the power (SAR) drift during measurement to be assessed.

9.2.1 SARA2 Interpolation and Extrapolation schemes

SARA2 software contains support for both 2D cubic B-spline interpolation as well as 3D cubic B-spline interpolation. In addition, for extrapolation purposes, a general n^{-th} order polynomial fitting routine is implemented following a singular value decomposition algorithm presented in [4]. A 4^{th} order polynomial fit is used by default for data extrapolation, but a linear-logarithmic fitting function can be selected as an option. The polynomial fitting procedures have been tested by comparing the fitting coefficients generated by the SARA2 procedures with those obtained using the polynomial fit functions of Microsoft Excel when applied to the same test input data.

9.2.2 Interpolation of 2D area scan

The 2D cubic B-spline interpolation is used after the initial area scan at fixed distance from the phantom shell wall. The initial scan data are collected with approx. 10mm spatial resolution and spline interpolation is used to find the location of the local maximum to within a 1mm resolution for positioning the subsequent 3D scanning.

9.2.3 Extrapolation of 3D scan

For the 3D scan, data are collected on a spatially regular 3D grid having (by default) 6.4 mm steps in the lateral dimensions and 3.5 mm steps in the depth direction (away from the source). SARA2 enables full control over the selection of alternative step sizes in all directions. The digitized shape of the Flat Phantom is available to the SARA2 software, which decides which points in the 3D array are sufficiently well within the shell wall to be 'visited' by the SAR probe. After the data collection, the data are extrapolated in the depth direction to assign values to points in the 3D array closer to the shell wall. A notional extrapolation value is also assigned to the first point outside the shell wall so that subsequent interpolation schemes will be applicable right up to the shell wall boundary.

9.2.4 Interpolation of 3D scan and volume averaging

The procedure used for defining the shape of the volumes used for SAR averaging in the SARA2 software follow the method of adapting the surface of the 'cube' to conform with the surface of the phantom (see Appendix C.2.2.1 in EN 50361). This is called, here, the conformal scheme.
For each row of data in the depth direction, the data are extrapolated and interpolated to less than 1mm spacing and average values are calculated from the phantom surface for the row of data over distances corresponding to the requisite depth for 10g and 1g cubes. This results in two 2D arrays of data, which are then cubic B-spline interpolated to sub mm lateral resolution. A search routine then moves an averaging square around through the 2D array and records the maximum value of the corresponding 1g and 10g volume averages. For the definition of the surface in this procedure, the digitized position of the headshell surface is used for measurement in head-shaped phantoms. For measurements in rectangular, box phantoms, the distance between the phantom wall and the closest set of gridded data points is entered into the software.

For measurements in box-shaped phantoms, this distance is under the control of the user. The effective distance must be greater than 2.5mm as this is the tip-sensor distance and to avoid interface proximity effects, it should be at least 5mm. A value of 6 or 8mm is recommended. This distance is called **dbe** in EN 50361.

For automated measurements inside the head, the distance cannot be less than 2.5mm, which is the radius of the probe tip and to avoid interface proximity effects, a minimum clearance distance of x mm is retained. The actual value of dbe will vary from point to point depending upon how the spatially-regular 3D grid points fit within the shell. The greatest separation is when a grid point is just not visited due to the probe tip dimensions. In this case the distance could be as large as the step-size plus the minimum clearance distance (i.e. with x=5 and a step size of 3.5, **dbe** will be between 3.5 and 8.5mm).

The default step size (**dstep** in EN 50361) used is 3.5mm, but this is under user-control. The compromise is with time of scan, so it is not practical to make it much smaller or scan times become long and power-drop influences become larger.

The robot positioning system specification for the repeatability of the positioning (**dss** in EN50361) is +/- 0.04mm.

The Specific Anthropomorphic Mannequin (SAM) Upright Phantom shell is made by an industrial moulding process from the CAD files of the SAM shape, with both internal and external moulds. For the upright phantoms, the external shape is subsequently digitized on a Mitutoyo CMM machine (Euro C574) to a precision of 0.001mm. Wall thickness measurements made non-destructively with an ultrasonic sensor indicate that the shell thickness (**dph**) away from the ear is 2.0 +/- 0.1mm. The ultrasonic measurements were calibrated using additional mechanical measurements on available cut surfaces of the phantom shells.

The flat phantom is made from Polymethylmethacrylate (PMMA), a low-loss dielectric material with dielectric constant and loss tangent less than 5.0 and 0.05 respectively. The shell thickness for all regions coupled to the test device and its antenna are within 2.0 ± 0.2 mm.

For the upright phantom, the alignment is based upon registration of the rotation axis of the phantom on its 253mm-diameter baseplate bearing and the position of the probe axis when commanded to go to the axial position. A laser alignment tool is provided (procedure detailed elsewhere). This enables the registration of the phantom tip (**dmis**) to be assured to within approx. 0.2mm. This alignment is done with reference to the actual probe tip after installation and probe alignment. The rotational positioning of the phantom is variable – offering advantages for special studies, but locating pins ensure accurate repositioning at the principal positions (LH and RH ears).

10 Additional information supplementary to the Test report

10.1 Electric field probe calibration

10.1.1 Measurement set-up

For the first part of the characterization procedure, the probe is placed in an isotropy measurement jig as pictured in Figure 10.1.1. In this position the probe can be rotated about its axis by a non-metallic belt driven by a stepper motor.

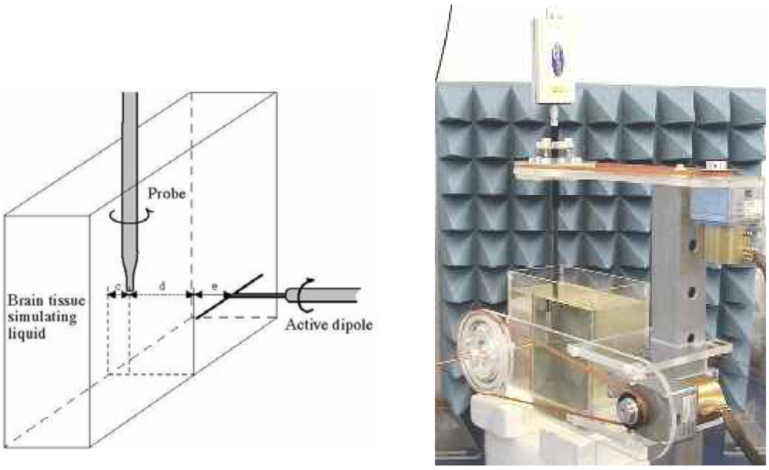


Figure 10.1.1. Spherical isotropy jig (see Ref [2], Section A.5.2.1).

The probe is attached via its amplifier and an optical cable to a PC. A schematic representation of the test geometry is illustrated in Figure 10.1.2.

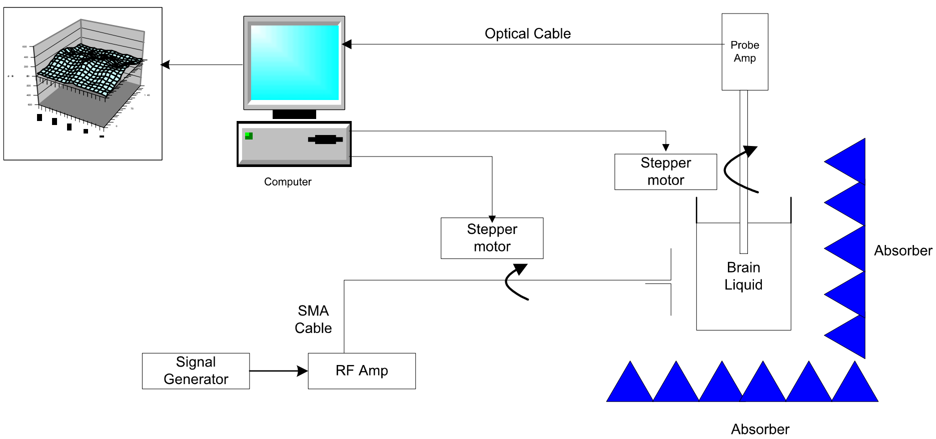


Figure 10.1.2. Schematic diagram of the test geometry used for isotropy determination

A balanced dipole (900 MHz) is inserted horizontally into the bracket attached to a second belt (Fig 10.1.1). The dipole can also be rotated about its axis. A cable connects the dipole to a signal generator, via a directional coupler and power meter. The signal generator feeds an RF amplifier at constant power, the output of which is monitored using the power meter. The probe is positioned so that its sensors line up with the rotation center of the source dipole. By recording output voltage measurements of each channel as both the probe and the dipole are rotated, data are obtained from which the spherical isotropy of the probe can be optimized and its magnitude determined.

The calibration process requires E-field measurements to be taken in air, in 900 MHz simulated brain liquid and at other frequencies/liquids as appropriate.

10.1.2 Linearisation of probe output.

The probe channel output signals are linearised in the manner set out in EN 50361 and IEEE1528. 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 linearized signal, $U_{o/p}$ is the raw output signal in voltage units and DCP is the Diode Compression Potential in similar voltage units.
DCP is determined from fitting equation (1) to measurements of U_{lin} versus source feed power over the full dynamic range of the probe. The DCP is a characteristic of the schottky diodes used as the sensors. For the IXP-050 probes with CW signals the DCP values are typically 0.10V (or 20 in the voltage units used by IndexSAR software, which are V*200).

10.1.3 Selecting channel sensitivity factors to optimize isotropic response

The basic measurements obtained using the calibration jig (Fig 10.1.1) represent the output from each diode sensor as a function of the presentation angle of the source (probe and dipole rotation angles). The directionality of the orthogonally-arranged sensors can be checked by analyzing the data using dedicated IndexSAR software, which displays the data in 3D format as in Figure 10.1.3. The left-hand side of this diagram shows the individual channel outputs after linearization (see above). The program uses these data to balance the channel outputs and then applies an optimization process, which makes fine adjustments to the channel factors for optimum isotropic response.

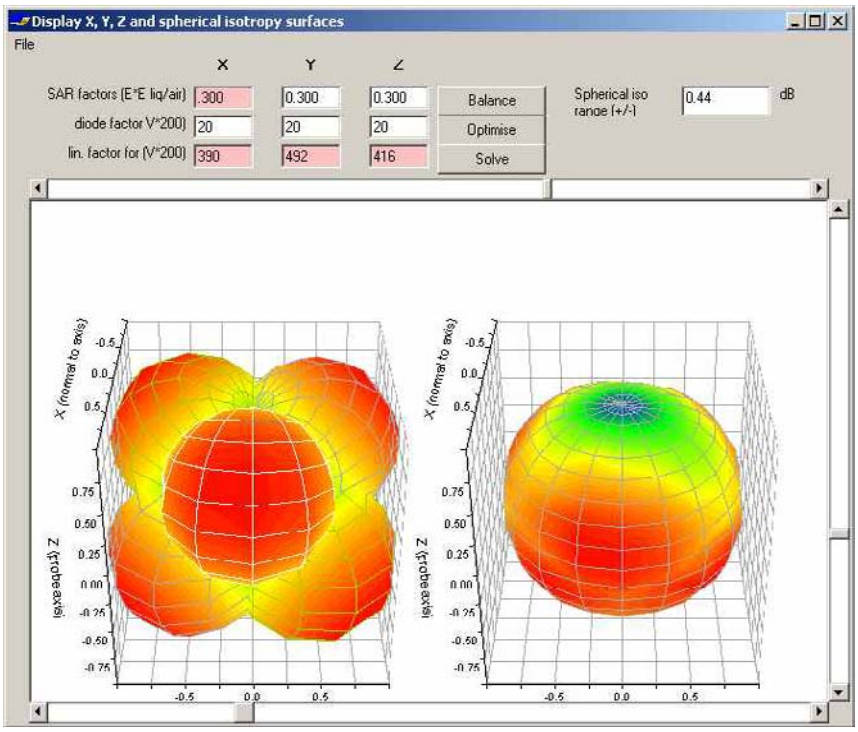


Figure 10.1.3. Graphical representation of the probe response to fields applied from each direction.

The diagram on the left shows the individual response characteristics of each of the three channels and the diagram on the right shows the resulting probe sensitivity in each direction. The colors range in the figure images the lowest values as blue and the maximum values as red. For the probe S/N 0132, this range is (+/-) 0.44 dB. The probe is more sensitive to fields parallel to the axis and less sensitive to fields normal to the probe axis.

The next stage of the process is to calibrate the IndexSAR probe to a W&G EMR300 E-field meter in air. The principal reasons for this are to obtain conversion factors applicable should the probe be used in air and to provide an overall measure of the probe sensitivity.
A multiplier is applied to factors to bring the magnitudes of the average E-field measurements as close as possible to those of the W&G probe. The following equation is used (where linearised output voltages are in units of V*200):

$$E_{air}^2\ (V/m) = U_{linx} * Air\ Factor_x + U_{liny} * Air\ Factor_y + U_{linz} * Air\ Factor_z \qquad (2)$$

It should be noted that the air factors are not separately used for normal SAR testing. The IXP-050 probes are optimized for use in tissue-simulating liquids and do not behave isotropically in air.

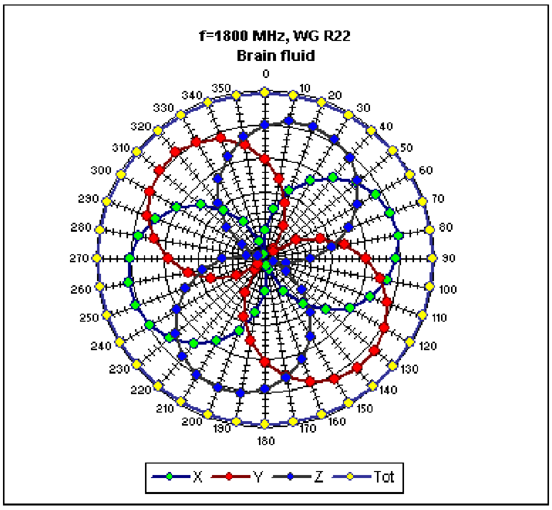
10.1.4 900 MHz Liquid Calibration

Conversion factors for use when the probes are immersed in tissue-simulant liquids at 900 MHz are determined either using a waveguide or by comparison to a reference probe that has been calibrated by NPL. Waveguide procedures are described later.

The conversion factor, referred to as the 'liquid factor' is also applied to the measurements of each channel. The following equation is used (where output voltages are in units of V*200):

$$E_{liq}^2\ (V/m) = U_{linx} * Air\ Factor_x * Liq\ Factor_x + U_{liny} * Air\ Factor_y * Liq\ Factor_y + U_{linz} * Air\ Factor_z * Liq\ Factor_z \qquad (3)$$

The rotational isotropy can also determined from the calibration jig measurements and is reported as the 900MHz isotropy in the summary table. Note that waveguide measurements can also be used to determine rotational isotropy (Fig. 10.1.4).



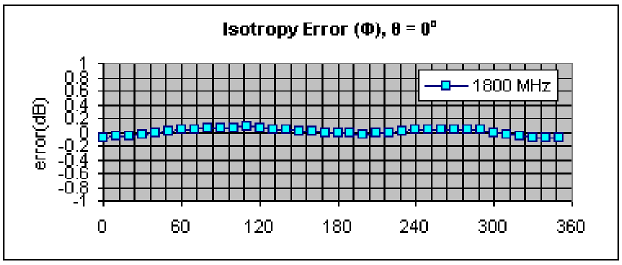


Figure 10.1.4. Example of the rotational isotropy of probe S/N 0132 obtained by rotating the probe in a liquid-filled waveguide at 1800 MHz. Similar distributions are obtained at the other test frequencies both in brain liquids and body fluids

The design of the cells used for determining probe conversion factors are waveguide cells is shown in Figure 10.1.5. The cells consist of a coax to waveguide transition and an open-ended section of waveguide containing a dielectric separator. Each waveguide cell stands in the upright position and is filled with liquid within 10 mm of the open end. The separator provides a liquid seal and is designed for a good electrical transition from air filled guide to liquid filled guide. The choice of cell depends on the portion of the frequency band to be examined and the choice of liquid used. The depth of liquid ensures there is negligible radiation from the waveguide open top and that the probe calibration is not influenced by reflections from nearby objects. The return loss at the coaxial connector of the filled waveguide cell is measured initially using a network analyzer and this information is used subsequently in the calibration procedure. The probe is positioned in the centre of the waveguide and is adjusted vertically or rotated using stepper motor arrangements. The signal generator is connected to the waveguide cell and the power is monitored with a coupler and a power meter. A fuller description of the waveguide method is given below.

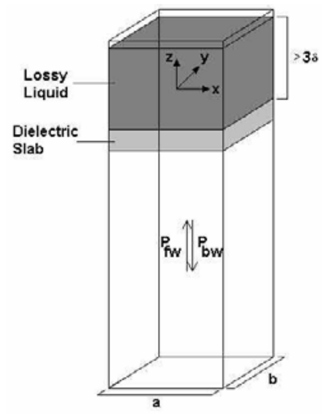


Figure 10.1.5. Geometry used for waveguide calibration (afterIEEE1528. Section A.3.2.2)

10.1.5 Waveguide measurement procedure

The calibration method is based on setting up a calculable specific absorption rate (SAR) in a vertically-mounted WG8 (R22) (IEEE1528) waveguide section. The waveguide has an air-filled, launcher section and a liquid-filled section separated by a matching window that is designed to minimize reflections at the liquid interface. A TE_{01} mode is launched into the waveguide by means of a N-type-to-waveguide adapter. The power delivered to the liquid section is calculated from the forward power and reflection coefficient measured at the input to the waveguide. At the centre of the cross-section of the waveguide, the local spot SAR in the liquid as a function of distance from the window is given by functions set out in IEEE1528 as below.

Because of the low cutoff frequency, the field inside the liquid nearly propagates as a TEM wave. The depth of the medium (greater than three penetration depths) ensures that reflections at the upper surface of the liquid are negligible. The power absorbed in the liquid is determined by measuring the waveguide forward and reflected power. Equation (4) shows the relationship between the SAR at the cross-sectional center of the lossy waveguide and the longitudinal distance (z) from the dielectric separator

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

where the density □ is conventionally assumed to be 1000 kg/m^3, *ab* is the cross-sectional area of the waveguide, 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 determined from a scan along the *z*-axis and compared with the theoretical value determined from Equation (5) using the measured dielectric properties of the lossy liquid.

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

Table A.1 of IEEE1528 can be used for designing calibration waveguides with a return loss greater than 30 dB at the most important frequencies used for personal wireless communications. Values for the penetration depth for these specific fixtures and tissue-simulating mixtures are also listed in Table A.1.

According to IEEE1528, 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 2500 MHz because of the waveguide size is not severe in the context of compliance testing.

10.1.5.1 Calibration factors measured for probe S/N 0132

The probe was calibrated at 900, 1800, 1900 , 2450, 5200 and 5800 MHz in liquid samples representing brain liquid and body fluid (as far as specified) 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 2.7 m 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.

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.

10.1.6 Response to modulated signals

To measure the response of the probe and amplifier to modulated signals, the probe is held vertically in a liquid-filled waveguide.

An RF amplifier is allowed to warm up and stabilise before use. A spectrum analyzer is used to demonstrate that the peak power of the RF amplifier for the CW signals and the pulsed signals are within 0.1dB of each other when the signal generator is switched from CW to modulated output. Subsequently, the power levels recorded are read from a power meter when a CW signal is being transmitted.

The test sequence involves manually stepping the power up in regular (e.g. 2 dB) steps from the lowest power that gives a measurable reading on the SAR probe up to the maximum that the amplifiers can deliver.

At each power level, the individual channel outputs from the SAR probe are recorded at CW and then recorded again with the modulation setting. The results are entered into a spreadsheet. Using the spreadsheets, the modulated power is calculated by applying a factor to the measured CW power (e.g. for GSM, this factor is 9.03dB). This process is repeated 3 times with the response maximized for each channel sensor in turn.

The probe channel output signals are linearised in the manner set out in Section 10.12.2 above using equation (1) with the DCPs determined from the linearisation procedure. Calibration factors for the probe are used to determine the E-field values corresponding to the probe readings using equation (3). SAR is determined from the equation

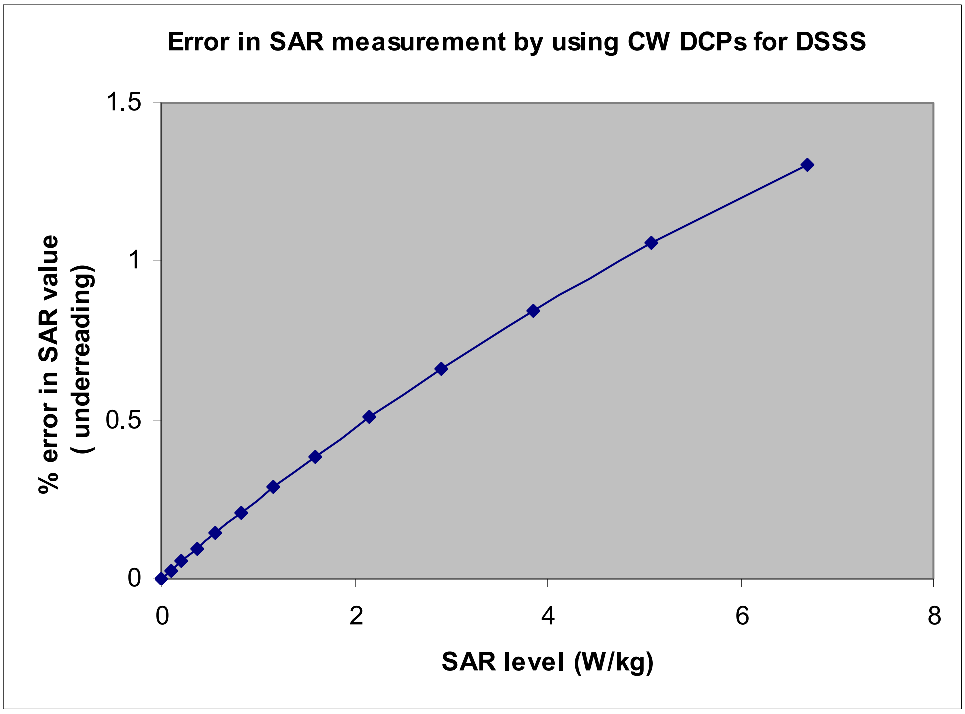
$$\text{SAR (W/kg)} = E_{liq}^2 \text{ (V/m)} * \sigma\text{(S/m)} / 1000 \qquad (6)$$

Where σ is the conductivity of the simulant liquid employed.

Using the spreadsheet data, the DCP value for linearising each of the individual channels (X, Y and Z) is assessed separately. The corresponding DCP values are listed in the summary page of the calibration factors for each probe.

10.1.6.1 Response of the probe to DSSS modulated signals.

The manufacturer of the probe has investigated the response of the probe to modulated signals, specifically in DSSS mode.The results show that with DSSS signals, and under the condition of SAR values below 1W/kg, the underreading of the probe output is less than 0.5%. Considering this, CW probe calibration factors (DCPs) have been used. The table below depicts the underreading in SAR values as a function of SAR level. These tests have been reported in Indexsar report nr. IXS 00224, '*SAR probe response to direct sequence spread spectrum (DSSS) modulated signals",* dated August 2003



10.1.7 VPM (Virtual Probe Miniaturization)

SAR probes with 3 diode-sensors in an orthogonal arrangement are designed to display an isotropic response when exposed to a uniform field. However, the probes are ordinarily used for measurements in non-uniform fields and isotropy is not assured when the field gradients are significant compared to the dimensions of the tip containing the three orthogonally-arranged dipole sensors.

It becomes increasingly important to assess the effects of field gradients on SAR probe readings when higher frequencies are being used. For IndexSAR IXP-050 probes, which are of 5mm tip diameter, field gradient effects are minor at GSM frequencies, but are major above 5GHz. Smaller probes are less affected by field gradients and so probes, which are significantly less than 5mm diameter, would be better for applications above 5GHz.

The IndexSAR report IXS0223 describes theoretical and experimental studies to evaluate the issues associated with the use of probes at arbitrary angles to surfaces and field directions. Based upon these studies, the procedures and uncertainty analyses referred to in IEEE std. 1528 are addressed for the full range of probe presentation angles.
In addition, generalized procedures for correcting for the finite size of immersible SAR probes are developed. Use of these procedures enables application of schemes for virtual probe miniaturization (VPM) – allowing probes of a specific size to be used where physically-smaller probes would otherwise be required.
Given the typical dimensions of 3-channel SAR probes presently available, use of the VPM technique extends the satisfactory measurement range to higher frequencies.

10.1.8 Probe specifications:

IndexSAR probe 0132, along with its calibration, is compared with CENELEC and IEEE standards recommendations in the Tables below. A listing of relevant specifications is contained in the tables below:

Dimensions	S/N 0132	EN 50361	IEEE 1528
Overall length (mm)	350		
Tip length (mm)	10		
Body diameter (mm)	12		
Tip diameter (mm)	5.2	8	8
Distance from probe tip to dipole centers (mm)	2.7		
Dynamic range	S/N 0132	EN 50361	IEEE 1528
Minimum (W/kg)	0.01	<0.02	0.01
Maximum (W/kg) N.B. only measured to 35 W/kg	>35	>100	100
Linearity of response	S/N 0132	EN 50361	IEEE 1528
Over range 0.01 – 100 W/kg (+/- dB)	0.125	0.50	0.25
Isotropy (measured at 900MHz)	S/N 0132	EN 50361	IEEE 1528
Axial rotation with probe normal to source (+/- dB) at 835, 900, 1800, 1900 and 2450MHz	Max. 0.28	0.5	0.25
Spherical isotropy covering all orientations to source (+/- dB)	0.44	1.0	0.50
Construction	Each probe contains three orthogonal dipole sensors arranged on a triangular prism core, protected against static charges by built-in shielding, and covered at the tip by PEEK cylindrical enclosure material. No adhesives are used in the immersed section. Outer case materials are PEEK and heat-shrink sleeving.		
Chemical resistance	Tested to be resistant to glycol and alcohol containing simulant liquids but probes should be removed, cleaned and dried when not in use.		

A copy of the probe calibration certificate has been added as last page to this report.

10.2 SAR System Check

The purpose of the SAR System check is to verify that the system operates within its specifications at the device test frequency. The SAR system check is a simple check of repeatability to make sure that the system works correctly at the time of the compliance test. It is not a verification of the system with respect to external standards. The SAR system check should detect possible short term drift and errors in the system.

The SAR system check is a complete 1 g or 10 g averaged SAR measurement in a simplified test system with a standard source. The instrumentation and procedures are the same as those used for the compliance tests. The SAR system check has been performed using the specified tissue-equivalent liquid and at a chosen fixed frequency that is within ± 10% of the compliance test mid-band frequency. The system check is performed prior to compliance tests and the result have been checked against the requirements (IEEE1528 and CENELEC Standards) and must always be within ±10% of the target value corresponding to the test frequency, liquid and the source used mentioned in these standards.

The following measurement setup has been used for performing SAR system checks using a box phantoms is based on the procedures fully described in IEEE1528. This SAR System Check is performed at the start of each measurement at a specific frequency range , with appropriate simulant liquids.

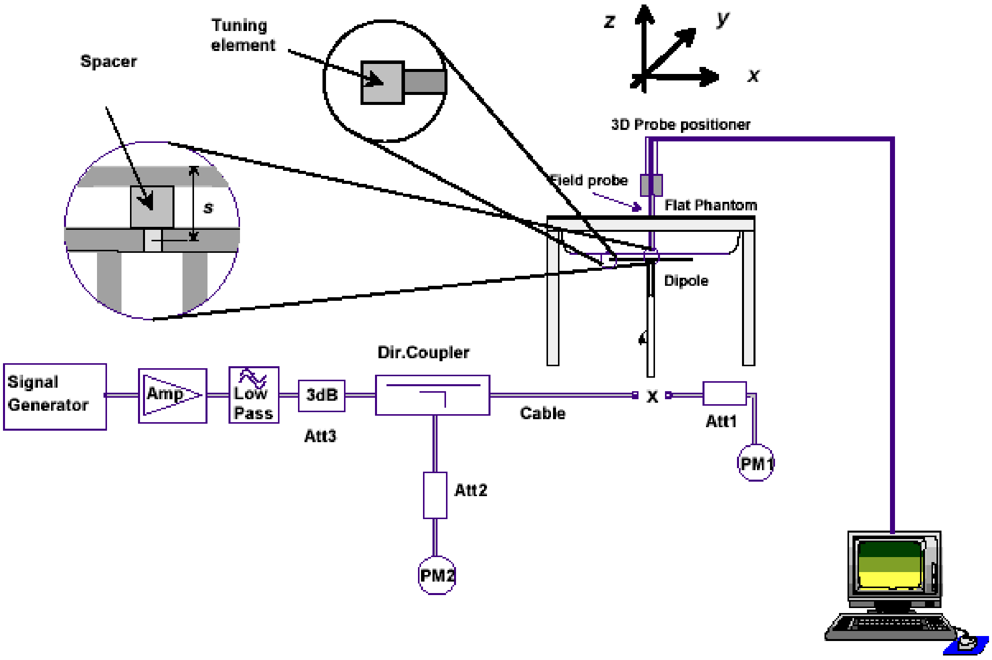


Fig. 10.2.1

With the Signal Generator, Amplifier and directional coupler in place, the source signal has been set up at the relevant frequency and a power meter has been used to measure the power at the end of the SMA cable which is going to be connected to the balanced dipole. The low noise and distortion Signal Generator is adjusted so, that including all cable losses and other losses, the power at the connector X (to be connected to the balanced dipole) is 0.25W (24 dBm) (Reading on PM1 in figure 10.2.1).A calibrated attenuator (Att 1. 20 dB) is used to protect overloading of the Power meter.

No tuning of the balanced dipole was required because fixed tuned and calibrated balanced dipoles for the appropriate test frequencies were used.

10.3 Dielectric property measurement of tissue-simulant liquids for SAR testing

10.3.1 Introduction

This section describes the measurement of the dielectric properties of tissue-equivalent material as part of the SAR characterization procedure and the method used.
The measurement method is based on a published technique *(Toropainen et al , 'Method for accurate measurement of complex permittivity of tissue equivalent liquids', Electronics Letters 36 (1) 2000 pp32-34)* and uses a fixture with 2 parallel planes with a conductor in between. Liquid filling the space between the planes immerses the inner conductor wholly. Measurements of S_{21} with an empty fixture and that of a filled fixture are conducted so that the complex dielectric properties of the fluid can be deduced. The fixture is also referred to as *TEM line.*

10.3.2 TEM line construction

The TEM line construction is shown in Figure 10.3.1 and consists of a central cylindrical transmission line sandwiched between two ground planes

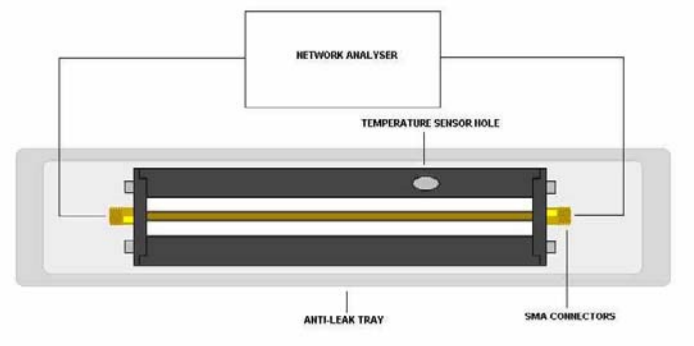


Figure 10.3.1. TEM Line Construction.

Four different sensors can be used with transmission line lengths of 30mm, 60mm, 80mm and 160mm. The transmission line is terminated with SMA connectors at either end using short 50 ohm launcher sections. The assembly is held firmly against a plastic base with a clamping arrangement providing a seal to retain the liquid. The liquid under test is introduced with a pipette to fill the space between the ground planes. Care has been taken to prevent air bubbles and this is particularly important with viscous liquids. A hole is provided in one of the ground planes so that a thermometer probe has been be inserted to monitor the temperature. The TEM line is washed out and thoroughly dried before further use.

A vector network analyser (VNA) is used to measure the performance of the TEM line. A good impedance match will be found when air filled indicating that the transmission line impedance is close to 50 ohm. The transmission loss and phase are measured with and without the liquid to enable the electrical properties to be deduced.

10.3.3 Calculation of dielectric properties from VNA measurements

The complex permittivity of the simulant liquids were measured using a TEM line sensor as recommended in the EN50361 and draft IEEE1528 standards. The method [1] is based on the measurement of complex transmission coefficient of a TEM-line filled with the liquid. Transmission measurement is done using a VNA, recording the magnitude and phase of scattering coefficient S_{21}. The complex permittivity of the liquid is calculated from the magnitude and phase of S_{21} by numerical solution of the equation of transmission coefficient derived by signal flow graph technique

$$S_{21} = \frac{\left(1-\Gamma^2\right)\exp\left(-\mathrm{j}(k-k_0)d\right)}{1-\Gamma^2\exp\left(-\mathrm{j}2kd\right)},$$

$$\Gamma = \frac{1-\sqrt{\varepsilon_r}}{1+\sqrt{\varepsilon_r}},$$

$$k = \frac{2\pi f}{c_0}\sqrt{\varepsilon_r},$$

where Γ is the reflection coefficient at liquid surfaces, k the propagation factor in the liquid, k_0 the air propagation factor, d the length of the sample, f the frequency and $\varepsilon_r = \varepsilon_r' - \mathrm{j}\varepsilon_r''$ the relative complex permittivity of the sample.

10.4 Measurement uncertainty

10.4.1 Introduction

A measurement uncertainty assessment has been undertaken following guidance given in EN50361 and IEEE1528. IndexSAR Ltd has supplied a generic uncertainty analysis for the SARA2 system in the form of a spreadsheet and the supporting assessments are documented in an IndexSAR document IXS-2028. Additionally, uncertainties resulting from the probe positioning system and the upright phantom geometry are discussed in additional documents.

Some of the uncertainty contributions are site-specific and, for these, TNO Electronic Products & Services (EPS) has assessed the uncertainty contributions arising from local environmental and procedural factors.

The resultant uncertainty budget is shown on the next pages:

10.4.2 Uncertainty calculated for IEEE1528 : standard measurements (2450 MHz)

a	*b*	*c*	*d*	*e= f(d,k)*	*f*	*g*	*h= cxg/e*	*i= cxg/e*	*k*
Uncertainty Component	**Section**	**Tol. (± %)**	**Prob. Dist.**	**Div.**	**ci (1-g)**	**ci (10-g)**	**1-g ui (±%)**	**10-g ui (±%)**	**vt**
Measurement System									
Probe Calibration	E2.1	10.0	N	1or k	1	1	5.0	5.0	∞
Axial Isotropy	E2.2	5.93	R	√3	0.7	0.7	2.4	2.4	∞
Hemispherical Isotropy	E2.2	10.92	R	√3	1	1	6.3	6.3	∞
Boundary Effect	E2.3	4.0	R	√3	1	1	2.3	2.3	∞
Linearity	E2.4	0.93	R	√3	1	1	0.5	0.5	∞
System Detection Limits	E2.5	1.0	R	√3	1	1	0.6	0.6	∞
Readout Electronics	E2.6	1.0	N	1or k	1	1	1.0	1.0	∞
Response Time	E2.7	0.0	R	√3	1	1	0.0	0.0	∞
Integration Time	E2.8	1.8	R	√3	1	1	1.0	1.0	∞
RF Ambient Conditions	E6.1	3.0	R	√3	1	1	1.7	1.7	∞
Probe Positioner Mechanical Tolerance	E6.2	0.6	R	√3	1	1	0.3	0.3	∞
Probe Positioning wrt Phantom Shell	E6.3	5.0	R	√3	1	1	2.9	2.9	∞
SAR Evaluation Algorithms	E5.2	8.0	R	√3	1	1	4.6	4.6	∞
Test sample Related									∞
Test Sample Positioning	E4.2	5.0	R	√3	1	1	2.9	2.9	*13*
Device Holder Uncertainty	E4.1	3	R	√3	1	1	1.7	1.7	∞
Output Power Variation	6.6.2	5.0	R	√3	1	1	2.9	2.9	∞
Phantom and Tissue Parameters									∞
Phantom Uncertainty (shape and thickness)	E3.1	4.0	R	√3	1	1	2.3	2.3	∞
Liquid Conductivity Target - tolerance	E3.2	1.0	R	√3	0.7	0.5	0.4	0.3	∞
Liquid Conductivity - measurement uncert.	E3.3	4.7	R	√3	0.7	0.5	1.9	1.4	∞
Liquid Permittivity Target tolerance	E3.2	4.4	R	√3	0.6	0.5	1.5	1.3	∞
Liquid Permittivity - measurement uncert.	E3.3	3.3	R	√3	0.6	0.5	1.1	1.0	∞
Combined Standard Uncertainty		$u_c = \sqrt{\sum_{i=1}^{m} c_i^2 \cdot u_i^2}$					11.7	11.6	
Expanded Uncertainty (95% confidence interval)	Normal k=1.96 **ue=k* u_c**						**22.9%**	**22.7%**	

10.4.3 Uncertainty calculated for IEEE1528 : System performance check (2450 MHz)

a	*b*	*c*	*d*	*e= f(d,k)*	*f*	*g*	*h= cxg/e*	*i= cxg/e*	*k*
Uncertainty Component	**Section**	**Tol. (± %)**	**Prob. Dist.**	**Div.**	**ci (1-g)**	**ci (10-g)**	**1-g ui (±%)**	**10-g ui (±%)**	**vt**
Measurement System									
Probe Calibration	E2.1	10.0	N	1or k	1	1	5.0	5.0	∞
Axial Isotropy	E2.2	5.93	R	√3	0.7	0.7	2.4	2.4	∞
Hemispherical Isotropy	E2.2	10.92	R	√3	1	1	6.3	6.3	∞
Boundary Effect	E2.3	4.0	R	√3	1	1	2.3	2.3	∞
Linearity	E2.4	0.93	R	√3	1	1	0.5	0.5	∞
System Detection Limits	E2.5	1.0	R	√3	1	1	0.6	0.6	∞
Readout Electronics	E2.6	1.0	N	1or k	1	1	1.0	1.0	∞
Response Time	E2.7	0.0	R	√3	1	1	0.0	0.0	∞
Integration Time	E2.8	1.8	R	√3	1	1	1.0	1.0	∞
RF Ambient Conditions	E6.1	3.0	R	√3	1	1	1.7	1.7	∞
Probe Positioner Mechanical Tolerance	E6.2	0.6	R	√3	1	1	0.3	0.3	∞
Probe Positioning wrt Phantom Shell	E6.3	5.0	R	√3	1	1	2.9	2.9	∞
SAR Evaluation Algorithms	E5.2	8.0	R	√3	1	1	4.6	4.6	∞
Dipole Related									∞
Dipole axis to liquid distance	8, E4.2	1.0	R	√3	1	1	0.6	0.6	∞
Input Power & SAR Drift measurements	8, 6.6.2	1.5	R	√3	1	1	0.9	0.9	∞
Phantom and Tissue Parameters									∞
Phantom Uncertainty (shape and thickness)	E3.1	4.0	R	√3	1	1	2.7	2. 7	∞
Liquid Conductivity Target - tolerance	E3.2	1.0	R	√3	0.7	0.5	0.4	0.3	∞
Liquid Conductivity - measurement uncert.	E3.3	4.7	R	√3	0.7	0.5	1.9	1.4	∞
Liquid Permittivity Target tolerance	E3.2	4.4	R	√3	0.6	0.5	1.5	1.3	∞
Liquid Permittivity - measurement uncert.	E3.3	3.3	R	√3	0.6	0.5	1.1	1.0	∞
Combined Standard Uncertainty		$u_c = \sqrt{\sum_{i=1}^{m} c_i^2 \cdot u_i^2}$					10.9	10.8	
Expanded Uncertainty (95% confidence interval)		Normal k=1.96 **ue=k* u_c**					**21.3%**	**21.1%**	

11 List of utilized test equipment.

Inventory number	Description	Brand	Type
03012	Network Analyzer (VNA)	Rohde & Schwarz	ZVC
03013	VNA Calibration Kit	Rohde & Schwarz	
12483	Guide horn	EMCO	3115
12484	Guide horn	EMCO	3115
12488	Guide horn 18 - 26.5 GHz	EMCO	RA42-K-F-4B-C
12533	Signal generator	MARCONI	2032
12559	Digital storage oscilloscope	Le Croy	9310M
12561	DC Power Supply 20A/70V	DELTA	SM7020D
12605	calibrated dipole 28MHz-1GHz	Emco	3121c
12608	HF mill wattmeter	Hewlett Packard	HP435a
12609	Power sensor 10MHz-18GHz	Hewlett Packard	HP8481A
3664	Spectrum analyzer	HP	HP8593E
13078	Preamplifier 0.1 GHz - 12 GHz	Miteq	AMF-3D-001120-35-4p
13526	Signal generator 20 GHz	Hewlett & Packard	83620A
13594	Preamplifier 10 GHz - 25 GHz	Miteq	AMF-6D-100250-10p
14450	2.4 GHz bandrejectfilter	BSC	XN-1783
99068	Detector N-F/BNC-F	Radiall	R451576000
99076	Bandpass filter 4 - 10 GHz	Reactel	7AS-7G-6G-511
99112	Tripod	Chase	--
99136	Bandpass filter 10 - 26.5 GHz	Reactel	9HS-10G/26.5G-S11
03011	RF Amplifier (1 Watt)	IndexSAR	
03010	Bench-top Robot	Mitsubishi	RV-E2
03009	Calibration dipole 2450	IndexSAR	IXD 0022
03008	Calibration dipole 5800	IndexSAR	
03007	Directional Coupler	Hewlett & Packard	779D
03006	Attenuator (3 dB)	Hewlett & Packard	
03005	Hygrometer/room temperature meter		
03004	SAR Probe	IndexSAR	S/N 0134
03003	Phantom box	IndexSAR	N.A.

11.1 Test software

During the tests as indicated in this test report the TNO EPS SARA2 system was operated with:

SARA2 system v.0.281
Mitsubishi robot controller firmware revision RV-E2 Version C9a
IXA-10 Probe amplifier Version 2.4