Additional uncertainty issues arising from the use of upright head phantoms

Background
Uncertainty assessments presented in the standards recommending SAR testing procedures are generally illustrated with respect to the open bath phantom and recommend that additional considerations are given to measurement uncertainties when the angle between the probe shaft and the phantom surface is greater than 30 degrees. The following text illustrates the proposed requirements:

> *Probe Angle -- In view of the following disclaimer, which has been included (proposed) in P1528 for its up-coming re-circulation ballot, to identify that when the probe angle is greater than 30 degrees, additional uncertainty procedures not included in the standard are needed to account for such uncertainty. This means the end user has the responsibility to address the additional uncertainty issues when choosing to do measurements in those conditions.*
>
> *"The angle between the probe axis and the surface normal line is recommended but not required to be less than 30 degree. If this angle is larger than 30 degrees and the closest point on the probe tip housing to the phantom surface is closer than a probe diameter, the boundary effect may become larger and polarization dependent. (This additional uncertainty needs to be analyzed and taken into account, for which modified test procedures and additional uncertainty analysis not described in this recommended practice may be required.)"*

Whilst use of the SARA2 upright head phantom geometry helps to reduce certain key uncertainties of the testing procedures, it necessarily angles the probe at more than 30 degrees to the local phantom surface.

This document explains how additional uncertainties arising from this configuration have been assessed and have been allowed for in the measurement uncertainty assessment. Recommendations are given on how to configure the system for use at different frequencies.

Additional uncertainties with upright head testing – probe angle
It is easier to achieve good axial (rotational) isotropy with a 3-channel immersible SAR probe than it is to achieve full spherical isotropy over all field gradient presentation angles. So the aim of restricting the probe presentation angle to within 30 degrees of the surface normal is to exploit the lower uncertainty associated with rotational isotropy and reduce the larger effects from the spherical isotropy uncertainty. However, spherical anisotropy still affects SAR measurements because field gradient directions can vary markedly over the extent of a volume scan. The standard uncertainty assessment template allows for a reduced contribution of spherical isotropy to the uncertainty if the probe angle is less than 30 degrees.

For the SARA2 assessments, a full contribution to uncertainty from the spherical isotropy has to be allowed for in the uncertainty assessment as in the example assessment of Figure 1. This is the principal way in which the required additional uncertainty allowance is made for the upright phantom geometry in SARA2.

As indicated in Figure 1, the allowance made for spherical isotropy is frequency dependent and can be partially-reduced by a scheme of sensor position correction. Lastly, an optional validation check for tests at the side of a flat phantom can be performed and a procedure for doing this is set out in the Appendix.

Table of Uncertainty Values using template in IEEE1528 CD 1.1 (December 29, 2002)
Example of measurement uncertainty evaluation for handset SAR test
(blue entries are site-specific)

a	b			c	d	e		f	g	h	l	k
Uncertainty Component	Sec.	Tol. (+/-)			Prob. Dist.	Divisor (descrip)	Divisor (value)	c1 (1g)	c1 (10g)	Standard Uncertainty (%) 1g	Standard Uncertainty (%) 10g	
		(dB)		(%)								
Measurement System												
Probe Calibration	E2.1			2.5	N	1 or k	1	1	1	2.50	2.50	
Axial Isotropy	E2.2	0.25	5.93	5.93	R	√3	1.73	0	0	0.00	0.00	
Hemispherical Isotropy in gradient		0.5	12.20	12.20	R	√3	1.73	1	1	7.04	7.04	
Boundary effect	E2.3		4	4.00	R	√3	1.73	1	1	2.31	2.31	
Linearity	E2.4	0.04	0.93	0.93	R	√3	1.73	1	1	0.53	0.53	
System Detection Limits	E2.5		1	1.00	R	√3	1.73	1	1	0.58	0.58	
Readout Electronics	E2.6		1	1.00	N	1 or k	1.00	1	1	1.00	1.00	
Response time	E2.7		0	0.00	R	√3	1.73	1	1	0.00	0.00	
Integration time	E2.8		1.4	1.40	R	√3	1.73	1	1	0.81	0.81	
RF Ambient Conditions	E6.1		3	3.00	R	√3	1.73	1	1	1.73	1.73	
Probe Positioner Mechanical Tolerance	E6.2		0.6	0.60	R	√3	1.73	1	1	0.35	0.35	
Probe Position wrt. Phantom Shell	E6.3		3	3.00	R	√3	1.73	1	1	1.73	1.73	
SAR Evaluation Algorithms	E5		8	8.00	R	√3	1.73	1	1	4.62	4.62	
Test Sample Related												
Test Sample Positioning	E4.2		2	2.00	N	1	1.00	1	1	2.00	2.00	
Device Holder Uncertainty	E4.1		2	2.00	N	1	1.00	1	1	2.00	2.00	
Output Power Variation	6.6.2		5	5.00	R	√3	1.73	1	1	2.89	2.89	
Phantom and Tissue Parameters												
Phantom Uncertainty (shape and thickness)	E3.1		4	4.00	R	√3	1.73	1	1	2.31	2.31	
Liquid conductivity (Deviation from target)	E3.2		5	5.00	R	√3	1.73	0.64	0.43	1.85	1.24	
Liquid conductivity (measurement uncert.)	E3.3		1.1	1.10	N	1	1.00	0.64	0.43	0.70	0.47	
Liquid permittivity (Deviation from target)	E3.2		5	5.00	R	√3	1.73	0.6	0.49	1.73	1.41	
Liquid permittivity (measurement uncert.)	E3.3		1.1	1.10	N	1	1.00	0.6	0.49	0.66	0.54	
Combined standard uncertainty					**RSS**					11.0	10.8	
Expanded uncertainty	(95% Confidence Level)				k=2					**21.5**	**21.2**	

Test Frequency (MHz)	Spherical isotropy to enter into C10 above (dB)		
	5mm	5VPM	3MM
450	0.4	0.4	0.4
835	0.4	0.4	0.4
900	0.5	0.4	0.4
1800	0.6	0.4	0.4
1900	0.6	0.4	0.5
2450	0.9	0.5	0.5

SARA2_Upright.xls

Figure 1: Upright uncertainty assessment making full allowance for spherical isotropy

Additional uncertainties with upright head testing – orientation dependence of boundary effect
To meet the requirement for this additional uncertainty contribution, extensive tests have been performed of how probe response varies with distance from the surface for the full range of possible probe presentation angles. The results of these studies, presented in Rome in 2003, indicate that boundary effects for angled probes are no more than or less than the effects with probes presented normal to the surface. Instead, it was determined that the probe orientation with respect to the field gradient direction was the dominant influence and is not dependent on distance from the surface.

Additional uncertainties with upright head testing – effects of RF frequency
To understand the range of applicability of upright head testing, the effects of frequency have to be given further consideration. Upright testing provides some uncertainty reductions that apply across the frequency band as listed below:

1. Greatly-reduced degradation rate of simulant liquids
2. Avoidance of stratification of liquid at phantom surface
3. Easier inspection of handset positioning
4. Improved simulation of phantom shaping in chin region
5. Avoidance of reflections from the flat, open liquid surface

However, spherical isotropy degrades steadily with increasing frequency placing an upper limit on the frequency for which head testing using an upright geometry is within required uncertainty limits (see Figure 1, the use of which spreadsheet suggests 2450MHz is the highest recommended frequency for testing with 5mm probes).

The spherical isotropy of a SAR probe depends only indirectly upon frequency. It is directly-dependent on the ratio of the probe size (e.g. diameter) to the distances over which the field gradient applies (e.g. skin depth).

At 835MHz, the ratio of probe diameter to skin depth is small for a 5mm probe (say, 0.15). The standards procedures only require probe spherical isotropy to be demonstrated for a ‘uniform field’ which can be approximately attained at 900MHz but cannot easily be established at much higher frequencies.

However, at 5 GHz, the probe diameter to skin depth ratio is around unity and spherical anisotropy in the field gradients is several dB.

Recommendations for upright phantom usage
At low frequencies where “uniform-field” probe isotropy can be assumed, upright phantoms can offer lower uncertainties as well as convenience for head testing. The user can follow the procedure set out in the Appendix to check on the ‘upright’ test configuration using the side of a box phantom. 5mm probes are to be preferred based on their lower spherical isotropy when immersed in a uniform field.

At intermediate frequencies up to 2450MHz, the appropriate value for the spherical isotropy in a field gradient should be applied in the uncertainty assessment (see Figure 1). Upright phantoms are not recommended for head testing at frequencies much above 2450MHz unless smaller probes, which exhibit improved spherical isotropy at the high frequencies are used.

For body testing, where a flat phantom surface is specified, it is always recommended that testing with the SARA2 system be performed using the lower surface of a bath phantom and with the probe scanned normal to the surface. Side bench usage enables flexible DUT positioning in this way below a range of bath phantoms.

Reference[1] MI Manning, ‘SAR probe directivity as influenced by boundary proximity, probe tilt angle and probe size’, IndexSAR report IXS 0228, February 2005 (also available as Powerpoint Rome1.pdf)

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