No: WTL-SAR-01

Measurement Uncertainty Evaluation Report

（DASY4 SAR Testing System）

V 3.1

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Approved by ________________

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History

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1. Overview

1.1 Uncertainty Background

1) Uncertainty Concept
The components of uncertainty may generally be categorized according to the method used to evaluate them.

Type A Evaluation	based on any valid statistical method for treating data
Type B Evaluation	typically based on scientific judgment using all of the relevant information available
Combined Standard Uncertainty	represents the estimated standard deviation of the results
Expanded Uncertainty	measure of uncertainty that defines an interval about the measurement results within which the measured value is confidently believed to lie
Coverage Factor	A factor k that is used to obtain the expanded uncertainty from the combined uncertainty with a known probability (P) of containing the true value of the measured.

2) Steps in establishing an uncertainty budget

- Assign a probability distribution and determine the standard uncertainty of each distribution

Normal Distribution	$u(x_j) = \frac{uncertainty}{k}$
Rectangular Distribution	$u(x_j) = \frac{a_i}{\sqrt{3}}$
U-shape Distribution	$u(x_j) = \frac{M}{\sqrt{2}}$

- Assign the sensitivity of coefficient (ci) in order to convert the variability of the uncertainty component into the variability of the final unit (e.g. SAR)

- Determine the combined standard uncertainty $u_c(y) = \sqrt{\Sigma\, u^2(x_i)}$

- Determine the expanded uncertainty $U = k\, u_c(y)$

1.2 SAR system overview

The general components contributing to the measurement uncertainty of a typical SAR test system are identified as follows:

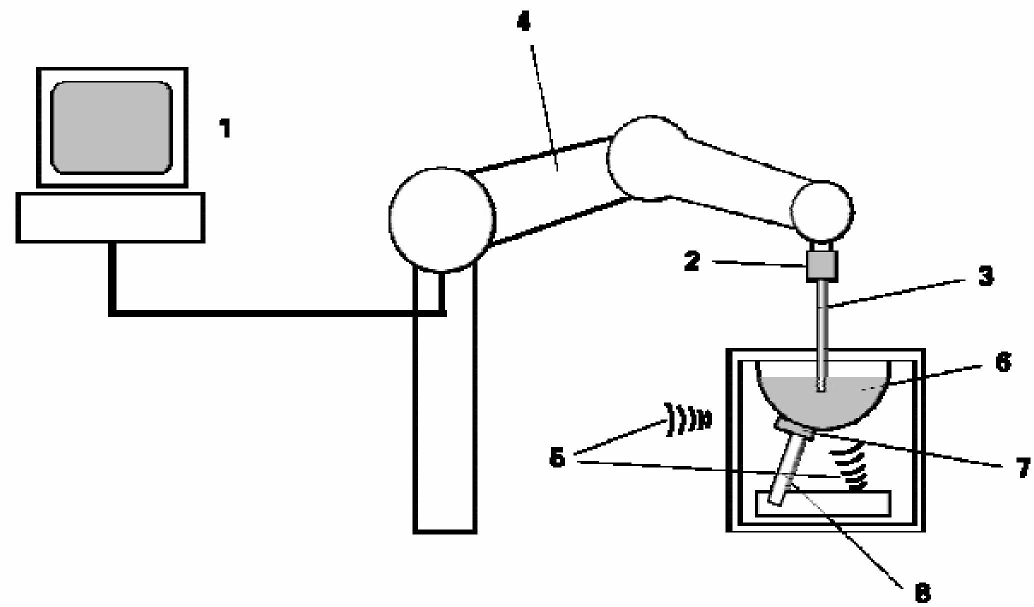
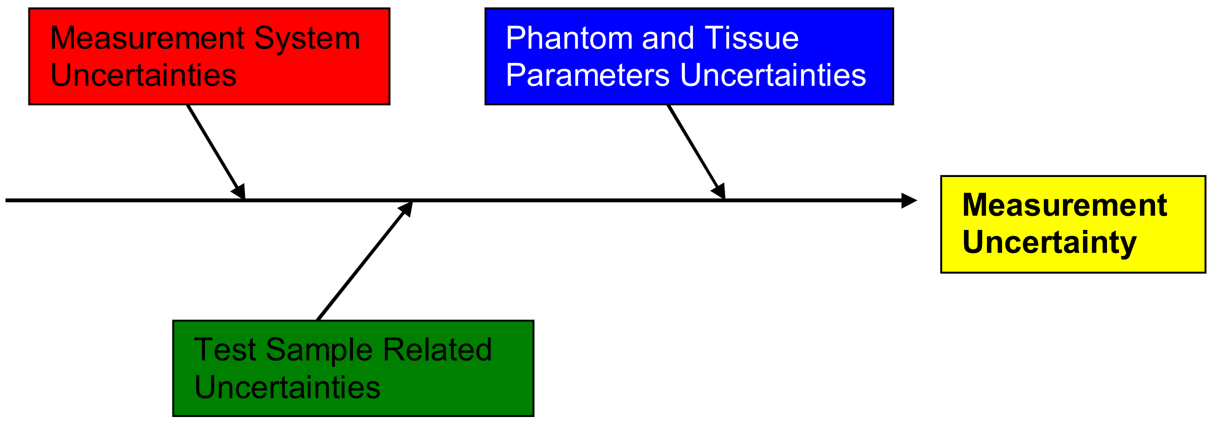


Figure E.1— The general components contributing to the measurement uncertainty of a typical SAR test system: (1) data recording and control unit, (2) field-probe readout electronics, (3) dosimetric E-field probe, (4) field-probe positioner, (5) ambient fields, (6) phantom shell filled with tissue-equivalent liquid, (7) test device, (8) device holder/positioner.

To be specific for DASY4 SAR system, these components can be further divided into three categories to evaluating the measurement uncertainty of Handset SAR Testing:

－Measurement System Uncertainties;
－Test Sample Related Uncertainties;
－Phantom and Tissue Parameters Uncertainties.



2. Reference

1) Guide to the expression of uncertainty in measurement (GUM). BIPM, IEC, IFCC, ISO,IUPAC, IUPAP, OIML, Ist edition, 1995.
2) International Vocabulary of Basic and General Terms in Metrology(VIM).
3) CNAS—CL07 General Requirements for Evaluating and Reporting Measurement Uncertainty
4) CNAS—GL05 Guidance on the Application of the Requirements for Measurement Uncertainty
5) DASY4 Handbook
6) IEEE Std 1528 2003
7) EN 62209-1 2006
8) IEC 62209-1 2005

3. Uncertainty Assessment under IEEE1528

3.1 Measurement System Uncertainty

The following uncertainty components are identified in accordance with IEEE 1528-2003 Annex E. These are the Type B uncertainty components and the relevant evaluations are based on Probe calibration certificate or the manufacturer's specifications.

1) Probe calibration uncertainty

Description:	SPEAG conducts the probe calibration in compliance with international and national standards under ISO/IEC 17025. The uncertainties are stated on the calibration certificate.
Distributions:	Normal
Evaluation Type:	Type B
Tolerance (%)	6.3
Section in P1528.	E.2.1

2) Probe isotropy uncertainty—axial and hemispherical

Description:	The axial isotropy tolerance accounts for probe rotation around its axis, while the hemispherical isotropy error includes all probe orientations and field polarizations. The uncertainties are stated on the calibration certificate.
Distributions:	Rectangular
Evaluation Type:	Type B
Tolerance (%)	0.5 (Axial) 2.6 (Hemispherical)
Section in P1528.	E.2.2

3) Uncertainty from probe boundary effects

Description:	The probe boundary effect is an enhanced sensitivity in the immediate vicinity of medium boundaries, due to a capacitive coupling effect between the probe and the medium boundary at the liquid and phantom shell surfaces. The uncertainties are stated on the calibration certificate.
Distributions:	Rectangular

Evaluation Type: Type B

Tolerance (%) 0.8

Section in P1528. E.2.3

4) Probe linearity uncertainty

Description: Field probe linearity uncertainty includes errors from the assessment and compensation of the diode compression effects for CW and pulsed signals with known duty cycles. The uncertainties are stated on the calibration certificate.

Distributions: Rectangular

Evaluation Type: Type B

Tolerance (%) 0.6

Section in P1528. E.2.4

5) Field-probe sensitivity and SAR system detection limit uncertainty

Description: System detection limit uncertainties may arise when the measured field strength is too close to the detection limit of the probe. SPEAG warrants that he uncertainty of detection limits assessed for the range 0.4 W/kg to 10 W/kg is within 0.25% (DASY4 handbook)

Distributions: Rectangular

Evaluation Type: Type B

Tolerance (%) 0.25

Section in P1528. E.2.5

6) Field-probe readout electronics uncertainty

Description: SPEAG conducts the DAE calibration in compliance with international and national standards under ISO/IEC 17025. The combination of all uncertainties related to the probe readout electronics is within 0.3% (DASY4 handbook).

Distributions: Normal

Evaluation Type: Type B

Tolerance (%) 0.3

Section in P1528. E.2.6

7) Signal step-response-time uncertainty

Description: The response time of SPEAG's probes is <5 ms. In the current implementation, DASY4 waits longer than 100 ms after having reached the grid point before starting a measurement, i.e., the response time uncertainty is negligible. (DASY4 handbook)

Distributions: Rectangular

Evaluation Type: Type B

Tolerance (%) 0.0

Section in P1528. E.2.7

8) Probe integration-time uncertainty

Description: The conservative evaluation is used as the in the analysis and the worst-case value is <2.6% (DASY4 handbook)

Distributions: Rectangular

Evaluation Type: Type B

Tolerance (%) 2.6

Section in P1528. E.2.8

9) RF ambient conditions

Description: RF reflections and ambient fields to be less than 3% of the minimum system sensitivity. The worst-case value is used. (DASY4 handbook)

Distributions: Rectangular

Evaluation Type: Type B

Tolerance (%) 3 (Reflection)
3 (Noise)

Section in P1528. E.6.1

10) Probe positioner mechanical tolerances (directions parallel to phantom surface)

Description: The mechanical tolerance of the field probe positioner can introduce probe positioning uncertainties. The specified repeatability of the RX robot family used in DASY4 systems is ±25 μm, SARtolerance is better than 1.5% (DASY4 handbook)

Distributions: Rectangular

Evaluation Type: Type B

Tolerance (%) 1.5

Section in P1528. E.6.2

11) Probe positioning tolerance with respect to the phantom shell surface(directions normal to phantom surface)

Description: The optical surface detection has a precision of better than 0.2 mm, resulting in an SAR tolerance <2.9% (DASY4 handbook)

Distributions: Rectangular

Evaluation Type: Type B

Tolerance (%) 2.9

Section in P1528. E.6.3

12) Interpolation, extrapolation, and integration algorithm uncertainty

Description: The extrapolation, interpolation and averaging uncertainty is less than 1.0% provided the sensor distance is between 4 and 5mm. (DASY4 handbook)

Distributions: Rectangular

Evaluation Type: Type B

Tolerance (%) 1.0

Section in P1528. E.5.2

3.2 Test Sample Related Uncertainty

The following uncertainty components are identified in accordance with IEEE 1528-2003 Annex E. Some of them are Type A uncertainty components and the relevant evaluations are based on experimental evaluations.

1) Device holder perturbation uncertainty

Description:	The conservative evaluation is used as the in the analysis and the worst-case RMS value is <3.6% (DASY4 handbook)
Distributions:	Normal
Evaluation Type:	Type B
Tolerance (%)	3.6
Section in P1528.	E.4.1

2) Handset positioning uncertainty with a specific test device holder

Description:	It is evaluated experimentally in Annex A of this document
Distributions:	Normal
Evaluation Type:	Type A
Tolerance (%)	3.7
Section in P1528.	E.4.2

3) DUT Output power variation- SAR drift measurement

Description:	The measurements are considered valid as long as the drift is less than ±5.0% (IEEE1528-2003).
Distributions:	Rectangular
Evaluation Type:	Type B
Tolerance (%)	5.0
Section in P1528.	6.6.2

3.3 Phantom and Tissue Parameters Uncertainty

The following uncertainty components are identified in accordance with IEEE 1528-2003 Annex E. Some of them are Type A Type A uncertainty components and the relevant evaluations are based on experimental evaluations.

1) Phantom uncertainty

Description:	The SAR measurement uncertainty due to SPEAG phantom shell production tolerances is better than 4.0%.(DASY4 handbook)
Distributions:	Rectangular
Evaluation Type:	Type B
Tolerance (%)	4.0
Section in P1528.	E.3.1

2) Tissue-equivalent liquid dielectric parameter uncertainty

Description:	The tissue dielectric parameters used in SAR tests should not exceed ±5.0% of those specified inthe standard. (IEEE1528-2003).
Distributions:	Rectangular
Evaluation Type:	Type B
Tolerance (%)	5.0
Section in P1528.	E.3.2 E.3.3

3) Assessment of liquid dielectric parameter measurement uncertainties

Description:	The components related are evaluated experimentally in section 5 of this document
Distributions:	Normal
Evaluation Type:	Type A
Tolerance (%)	4
Section in P1528.	E.3.2 E.3.3

3.4 Total Assessment

a Uncertainty Component	b1 Section in P1528	c Tol (%)	d Prob . Dist.	e = f(d,k) Div.	g Ci (1g)	i = cxg/e 1g ui (%)	k Vi (Veff)
Probe calibration	E.2.1	6.3	N	1	1	6.3	∞
Axial isotropy	E.2.2	0.5	R	$\sqrt{3}$	$(1-C_p)^{1/2}$	0.20	∞
hemispherical isotropy	E.2.2	2.6	R	$\sqrt{3}$	$\sqrt{C_p}$	1.06	∞
Boundary effect	E.2.3	0.8	R	$\sqrt{3}$	1	0.46	∞
Linearity	E.2.4	0.6	R	$\sqrt{3}$	1	0.35	∞
System detection limit	E.2.5	0.25	R	$\sqrt{3}$	1	0.15	∞
Readout electronics	E.2.6	0.3	N	1	1	0.3	∞
Response time	E.2.7	0	R	$\sqrt{3}$	1	0	∞
Integration time	E.2.8	2.6	R	$\sqrt{3}$	1	1.5	∞
RF ambient Condition -Noise	E.6.1	3	R	$\sqrt{3}$	1	1.73	∞
RF ambient Condition - reflections	E.6.1	3	R	$\sqrt{3}$	1	1.73	∞
Probe positioning- mechanical tolerance	E.6.2	1.5	R	$\sqrt{3}$	1	0.87	∞
Probe positioning- with respect to phantom	E.6.3	2.9	R	$\sqrt{3}$	1	1.67	∞
Max. SAR evaluation	E.5.2	1	R	$\sqrt{3}$	1	0.58	∞
Test sample positioning	E.4.2	3.7	N	1	1	3.7	9
Device holder uncertainty	E.4.1	3.6	N	1	1	3.6	∞
Output power variation -SAR drift measurement	6.62	5	R	$\sqrt{3}$	1	2.89	∞
Phantom uncertainty (shape and thickness tolerances)	E.3.1	4	R	$\sqrt{3}$	1	2.31	∞
Liquid conductivity - deviation from target values	E.3.2	5	R	$\sqrt{3}$	0.64	1.85	∞
Liquid conductivity - measurement uncertainty	E.3.2	4	N	1	0.64	2.56	5
Liquid permittivity - deviation from target values	E.3.3	5	R	$\sqrt{3}$	0.6	1.73	∞
Liquid permittivity - measurement uncertainty	E.3.3	4	N	1	0.6	2.40	5
Combined standard uncertainty				RSS		10.71	430
Expanded uncertainty (95% CONFIDENCE INTERVAL)				K=2		21.43	

4. Uncertainty Assessment under IEC/EN 62209-1

4.1 Measurement System Uncertainty

The following uncertainty components are identified in accordance with IEC/EN 62209-1 chapter 7. These are the Type B uncertainty components and the relevant evaluations are based on Probe calibration certificate or the manufacturer's specifications.

1) Probe calibration uncertainty

Description:	SPEAG conducts the probe calibration in compliance with international and national standards under ISO/IEC 17025. The uncertainties are stated on the calibration certificate.
Distributions:	Normal
Evaluation Type:	Type B
Tolerance (%)	6.3
Section in 62209-1.	7.2.1

2) Probe isotropy uncertainty—axial and hemispherical

Description:	The axial isotropy tolerance accounts for probe rotation around its axis, while the hemispherical isotropy error includes all probe orientations and field polarizations. The uncertainties are stated on the calibration certificate.
Distributions:	Rectangular
Evaluation Type:	Type B
Tolerance (%)	0.5 (Axial) 2.6 (Hemispherical)
Section in 62209-1.	7.2.1.2

3) Uncertainty from probe boundary effects

Description:	The probe boundary effect is an enhanced sensitivity in the immediate vicinity of medium boundaries, due to a capacitive coupling effect between the probe and the medium boundary at the liquid and phantom shell surfaces. The uncertainties are stated on the calibration certificate.
Distributions:	Rectangular

Evaluation Type:	Type B
Tolerance (%)	0.8
Section in 62209-1.	7.2.1.5

4) Probe linearity uncertainty

Description:	Field probe linearity uncertainty includes errors from the assessment and compensation of the diode compression effects for CW and pulsed signals with known duty cycles. The uncertainties are stated on the calibration certificate.
Distributions:	Rectangular
Evaluation Type:	Type B
Tolerance (%)	0.6
Section in 62209-1.	7.2.1.3

5) Field-probe sensitivity and SAR system detection limit uncertainty

Description:	System detection limit uncertainties may arise when the measured field strength is too close to the detection limit of the probe. SPEAG warrants that he uncertainty of detection limits assessed for the range 0.4 W/kg to 10 W/kg is within 0.25% (DASY4 handbook)
Distributions:	Rectangular
Evaluation Type:	Type B
Tolerance (%)	0.25
Section in 62209-1.	7.2.1.4

6) Field-probe readout electronics uncertainty

Description:	SPEAG conducts the DAE calibration in compliance with international and national standards under ISO/IEC 17025. The combination of all uncertainties related to the probe readout electronics is within 0.3% (DASY4 handbook).
Distributions:	Normal
Evaluation Type:	Type B
Tolerance (%)	0.3

Section in 62209-1. 7.2.1.6

7) Signal step-response-time uncertainty

Description: The response time of SPEAG's probes is <5 ms. In the current implementation, DASY4 waits longer than 100 ms after having reached the grid point before starting a measurement, i.e., the response time uncertainty is negligible. (DASY4 handbook)

Distributions: Rectangular

Evaluation Type: Type B

Tolerance (%) 0.0

Section in 62209-1. 7.2.1.7

8) Probe integration-time uncertainty

Description: The conservative evaluation is used as the in the analysis and the worst-case value is <2.6% (DASY4 handbook)

Distributions: Rectangular

Evaluation Type: Type B

Tolerance (%) 2.6

Section in 62209-1. 7.2.1.8

9) RF ambient conditions

Description: RF reflections and ambient fields to be less than 3% of the minimum system sensitivity. The worst-case value is used. (DASY4 handbook)

Distributions: Rectangular

Evaluation Type: Type B

Tolerance (%) 3 (Reflection)
3 (Noise)

Section in 62209-1. 7.2.3.6

10) Probe positioner mechanical tolerances (directions parallel to phantom surface)

Description: The mechanical tolerance of the field probe positioner can introduce probe positioning uncertainties. The specified repeatability of the RX robot family used in DASY4 systems is ±25 μm, SARtolerance is better than 1.5% (DASY4 handbook)

Distributions: Rectangular

Evaluation Type: Type B

Tolerance (%) 1.5

Section in 62209-1. 7.2.2.1

11) Probe positioning tolerance with respect to the phantom shell surface(directions normal to phantom surface)

Description: The optical surface detection has a precision of better than 0.2 mm, resulting in an SAR tolerance <2.9% (DASY4 handbook)

Distributions: Rectangular

Evaluation Type: Type B

Tolerance (%) 2.9

Section in 62209-1. 7.2.2.3

12) Interpolation, extrapolation, and integration algorithm uncertainty

Description: The extrapolation, interpolation and averaging uncertainty is less than 1.0% provided the sensor distance is between 4 and 5mm. (DASY4 handbook)

Distributions: Rectangular

Evaluation Type: Type B

Tolerance (%) 1.0

Section in 62209-1. 7.2.4

4.2 Test Sample Related Uncertainty

The following uncertainty components are identified in accordance with IEC/EN 62209-1 chapter 7. Some of them are Type A uncertainty components and the relevant evaluations are based on experimental evaluations.

4) Device holder perturbation uncertainty

Description:	The conservative evaluation is used as the in the analysis and the worst-case RMS value is <3.6% (DASY4 handbook)
Distributions:	Normal
Evaluation Type:	Type B
Tolerance (%)	3.6
Section in 62209-1.	7.2.2.4.2

5) Handset positioning uncertainty with a specific test device holder

Description:	It is evaluated experimentally in Annex A of this document
Distributions:	Normal
Evaluation Type:	Type A
Tolerance (%)	4.0
Section in 62209-1.	7.2.2.4

6) DUT Output power variation- SAR drift measurement

Description:	The measurements are considered valid as long as the drift is less than ±5.0% (IEC/EN 62209-1).
Distributions:	Rectangular
Evaluation Type:	Type B
Tolerance (%)	5.0
Section in 62209-1.	7.2.3.5

4.3 Phantom and Tissue Parameters Uncertainty

The following uncertainty components are identified in accordance with IEC/EN 62209-1 chapter 7. Some of them are Type A Type A uncertainty components and the relevant evaluations are based on experimental evaluations.

1) Phantom uncertainty

Description:	The SAR measurement uncertainty due to SPEAG phantom shell production tolerances is better than 4.0%.(DASY4 handbook)
Distributions:	Rectangular
Evaluation Type:	Type B
Tolerance (%)	4.0
Section in 62209-1.	7.2.2.2

2) Tissue-equivalent liquid dielectric parameter uncertainty

Description:	The tissue dielectric parameters used in SAR tests should not exceed ±5.0% of those specified inthe standard. (IEC/EN 62209-1).
Distributions:	Rectangular
Evaluation Type:	Type B
Tolerance (%)	5.0
Section in 62209-1.	7.2.3.3 7.2.3.4

3) Assessment of liquid dielectric parameter measurement uncertainties

Description:	The components related are evaluated experimentally in section 5 of this document
Distributions:	Normal
Evaluation Type:	Type A
Tolerance (%)	4
Section in 62209-1.	7.2.3.3 7.2.3.4

4.4 Total Assessment

a	b	c	d	e = f(d,k)	g	i = cxg/e	k
Uncertainty Component	Section in 62209-1	Tol (%)	Prob . Dist.	Div.	Ci (10g)	10g ui (%)	Vi (Veff)
Probe calibration	7.2.1	6.3	N	1	1	6.3	∞
Axial isotropy	7.2.1.2	0.5	R	$\sqrt{3}$	$(1-C_p)^{1/2}$	0.20	∞
hemispherical isotropy	7.2.1.2	2.6	R	$\sqrt{3}$	$\sqrt{C_p}$	1.06	∞
Boundary effect	7.2.1.5	0.8	R	$\sqrt{3}$	1	0.46	∞
Linearity	7.2.1.3	0.6	R	$\sqrt{3}$	1	0.35	∞
System detection limit	7.2.1.4	0.25	R	$\sqrt{3}$	1	0.15	∞
Readout electronics	7.2.1.6	0.3	N	1	1	0.3	∞
Response time	7.2.1.7	0	R	$\sqrt{3}$	1	0	∞
Integration time	7.2.1.8	2.6	R	$\sqrt{3}$	1	1.5	∞
RF ambient Condition -Noise	7.2.3.6	3	R	$\sqrt{3}$	1	1.73	∞
RF ambient Condition - reflections	7.2.3.6	3	R	$\sqrt{3}$	1	1.73	∞
Probe positioning- mechanical tolerance	7.2.2.1	1.5	R	$\sqrt{3}$	1	0.87	∞
Probe positioning- with respect to phantom	7.2.2.3	2.9	R	$\sqrt{3}$	1	1.67	∞
Max. SAR evaluation	7.2.4	1	R	$\sqrt{3}$	1	0.58	∞
Test sample positioning	7.2.2.4	4	N	1	1	4	9
Device holder uncertainty	7.2.2.4.2	3.6	N	1	1	3.6	∞
Output power variation -SAR drift measurement	7.2.3.5	5	R	$\sqrt{3}$	1	2.89	∞
Phantom uncertainty (shape and thickness tolerances)	7.2.2.2	4	R	$\sqrt{3}$	1	2.31	∞
Liquid conductivity - deviation from target values	7.2.3.3	5	R	$\sqrt{3}$	0.43	1.24	∞
Liquid conductivity - measurement uncertainty	7.2.3.3	4	N	1	0.43	1.72	5
Liquid permittivity - deviation from target values	7.2.3.4	5	R	$\sqrt{3}$	0.49	1.41	∞
Liquid permittivity - measurement uncertainty	7.2.3.4	4	N	1	0.49	1.96	5
Combined standard uncertainty				RSS		10.32	334
Expanded uncertainty (95% CONFIDENCE INTERVAL)				K=2		20.63	

5. Conclusion

With proper preparation and execution of SAR measurement according to the standard protocols, the measurement uncertainty is within the 30 %(K=2) as defined in IEEE1528 and IEC/EN 62209-1

6. Annex A

According to section E.4.2.1 of IEEE1528-2003 and 7.2.2.4.2.1 of IEC/EN 62209-1
Positioning tolerance of a specific handset in a specific device holder is evaluated as follows:
The positioning uncertainty of a specific handset tested in a specific device holder is assessed by repeat measurements of the 1 g or 10 g SAR. This minimum of **five tests** should be sufficient to establish a reasonable value for the degrees of freedom. The average SAR for the total number of measurements (*N*) is used to determine the SAR uncertainty according to the standard deviation and degrees of freedom (*vi* = *N* – 1) of the number of tests performed.

Average Value $$\overline{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

Standard Deviation(SD) $$\sqrt{\frac{\sum (x-\overline{x})^2}{(n-1)}}$$

	1	2	3	4	5	6	7	8	9	10	SD	Average	Tolerance
1g	0.645	0.629	0.644	0.602	0.648	0.658	0.67	0.679	0.665	0.681	0.024168	0.6521	3.7%
10g	0.457	0.45	0.462	0.429	0.465	0.474	0.48	0.488	0.48	0.489	0.018775	0.4674	4.0%

7. Annex B

According to section E.3.3 of IEEE1528-2003 and sub clause J7of IEC/EN 62209-1

Assessment of liquid dielectric parameter measurement uncertainties is evaluated as follows:

The uncertainty budget for dielectric measurement derives from inaccuracies in the calibration data, analyzer drift, and random errors. Other possible sources of errors are the tolerances on the sample holder hardware and deviations from the optimal dimensions for the specified frequencies.

$$\varepsilon'_{rtolerance}[\%] = 100 \times \left| \frac{\varepsilon'_{rmeasured} - \varepsilon'_{rref}}{\varepsilon'_{rref}} \right| \qquad \sigma_{tolerance}[\%] = 100 \times \left| \frac{\sigma_{measured} - \sigma_{ref}}{\sigma_{ref}} \right|$$

	1	2	3	4	5	SD
Permittivity	80.35	80.24	80.4	80.63	80.86	0.24825
Ref(80.03)	0.004	0.00262	0.00462	0.0075	0.01037	0.3%

	1	2	3	4	5	SD
Conductivity	0.1941	0.1908	0.1891	0.188	0.1887	0.00244
Ref(0.18)	0.07833	0.06	0.05056	0.04444	0.04833	1.4%

	a		b	c	ui = (a/b) × (c)	
Uncertainty component	Tol (± %)	Prob dist	Div	ci	Standard uncertainty (± %)	vi or veff
Repeatability (n repeats, mid band)	1.4	N	1	1	1.4	4
Reference liquid target ε'_r or σ	3	R	$\sqrt{3}$	1	1.73	∞
Network analyzer-drift,linearity, etc.	5	R	$\sqrt{3}$	1	2.89	∞
Combined standard uncertainty		U			3.65	5