Uncertainty budget for HAC according to ANSI C 63.19
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Source of Uncertainty	Description	Tolerance ±%	Probability Distribution	Div.	c_i E	c_i H	Standard Uncertainty ±%, E	Standard Uncertainty ±%, H	Remark
Measurement System									
Probe Calibration	1	5,1	N	1	1	1	5,1	5,1	
Axial Isotropy	2	4,7	R	√3	1	1	2,7	2,7	
Sensor Displacement	3	16,5	R	√3	1	0,145	9,5	1,4	
Boundary Effect	4	2,4	R	√3	1	1	1,4	1,4	
Linearity		4,7	R	√3	1	1	2,7	2,7	SAR
Scaling to Peak Envelope Power	5	2,0	R	√3	1	1	1,2	1,2	
System Detection Limit	6	1,0	R	√3	1	1	0,6	0,6	
Readout Electronics		0,3	N	1	1	1	0,3	0,3	SAR
Response Time	7	0,8	R	√3	1	1	0,5	0,5	
Integration Time		2,6	R	√3	1	1	1,5	1,5	SAR
RF Ambient Conditions		3,0	R	√3	1	1	1,7	1,7	SAR
RF Reflections	8	12,0	R	√3	1	1	6,9	6,9	
Probe Positioner	9	1,2	R	√3	1	0,67	0,7	0,5	
Probe Positioning	10	4,7	R	√3	1	0,67	2,7	1,8	
Extrapolation and Interpolation		1,0	R	√3	1	1	0,6	0,6	SAR
Test Sample Related									
Decice Positioning Vertical	11	4,7	R	√3	1	0,67	2,7	1,8	
Device Positioning Lateral	12	1,0	R	√3	1	1	0,6	0,6	
Device Holder and Phantom	13	2,4	R	√3	1	1	1,4	1,4	
Power Drift		5,0	R	√3	1	1	2,9	2,9	SAR
Phantom and Setup Related									
Phantom Thickness	14	2,4	R	√3	1	0,67	1,4	0,9	

Combined Standard Uncertainty			14,7	10,9	
Expanded Uncertainty on Power			**29,4**	**21,8**	
Expanded Uncertainty on Field			**14,7**	**10,9**	

1. Probe Calibration Uncertainty
The uncertainties are stated on the calibration certificate. Uncertainty for a Calibration Factors does not exceed 5.1% (k=1) for free-space probes.
For the evaluation of specific frequencies, the compensation of the frequency behaviour according to the certificate mustbe considered.

2. Axial Isotropy Uncertainty
The axial isotropy tolerance accounts for probe rotation around its axis and represents the dependencyof the field polarizations.
This parameter is assessed by SPEAG during initial calibration.
The maximal deviationfrom axial isotropy of SPEAG free-space probes is ±0.20 dB, corresponding to ±4.7% .

3. Sensor Displacement
Sensor displacement is specific for different types of probes due to their internal construction.
The H3D type probes have 3 loops sensors with a common center.
ER3D type electrical field probes cannot have a coincident center of their 3 dipole sensors, requiring a physical displacement of the single sensors.
The influence on the measurement of a gradient field reveals this displacement compared to the probe calibration in a rather homogeneous field.
The error is calculated as follows basing on the field 10 mm above the dipole surface: E- and H-field maximum location is determined.
Axial probe rotation at this location reveals the effect of sensor displacement of ±0.66 dB (worst-case) for E-field and ±0.1 dB (worst-case) for H-field, or 16.5% (on power) for E-field and 2.4% (on power) for H-field.
The corresponding sensitivity for the H-field is therefore 0.145.

4. Boundary Effect Uncertainty
Metallic parts have a minimum distance of 7mm from the probe sensors resulting in a minimalinfluence on the field measurement.
During the scanning of the probe, variations of less than 0.1 dB have been observed when scanning the field of a dipole.
This inverse effect is therefore considered under this item.

5. Scaling to Peak Envelope Power
For the evaluation of the HAC field measurement results, the peak envelope power is evaluated,applying the inverse of the duty cycle on the result representing the time averaged field (representing the average power).
This scaling does not affect the relative accuracy if the factor represents the actual signal properly.

6. Uncertainty Due to System Detection Limit
System detection limit uncertainties may arise when the measured field strength is too close to the detection limit of the probe (i.e., probe sensitivity) and the associated system instrumentation.
The values assessed for 1W/kg SAR correspond to signals from typically 30V/m for E-field and 0.1A/m for H-field at 900 MHz.
Such values lead to results in the lowest field classes and are therefore comparable to the SAR situation.

7. Response Time Uncertainty
The time response of the field probes has been assessed by exposing the probe to a well-controlled field producing signals larger than HAC E- and H-fields of class M4.
The signal response time is evaluated as the time required by the system to reach 90% of the expected final value after an on/off switch of the power source with an integration time of 500 ms and a probe response time of <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.
If the device under test does not emit a CW signal, the integration time applied to measure the electric field at a specific point may introduce additional uncertainties due to the discretization.
The tolerances for the different systems had the worst-case of 2.6%.

8. RF Reflections
Reflections of the RF signal, especially due to metallic objects near the setup, will have an impact on the free field measurements.
Also persons moving in the vicinity of the setup have an influence on the measured fields should therefore keep the distance from the operating measurement setup.
Absorbers can be used to substantially reduce these reflections, e.g. on the floor, at the basis and before the DASY4 robot system arm, at the ceiling and around the setup.
The influence of the reflections has been evaluated monitoring the multimeter job function while changing absorber configuration and moving reflecting surfaces.
The worst-case influence observed in field was approximately 6% in field (corresponding to 12% in power).
The situation of the actual laboratory shall be evaluated in a similar way and by following the considerations described in the standard (multiple measurements with various phantom positions).

9. Probe Positioner Mechanical Tolerance
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.
The absolute accuracy for short distance movements is better than ±0.1mm, i.e., the equivalent measurement tolerance on power under consideration is 1.2% for E-field and 0.8% for H-field and double for the values in terms of power.
The averaging has a reduction e
ect, estimated to be 50%.

10. Probe Positioning
The probe positioning procedures affect the tolerance of the separation distance between the probe tip and the field source.
After any movement or touching of the HAC phantom, the DASY4 Surface Check Job - HAC shall be run.
The vertical probe positioning error will be reduced to 0.2mm (worst case), considering the check of the distance by the operator.
This results in 2.4% error for the E-field and 1.6% for the H-field.
On power the values are 4.7% (E-field) and a sensitivity factor for the H-field of 0.67.
The field gradient considered for E- and H-field was determined by a Z-scan above the field maximum in the measurement plane 10mm above

a dipole surface.

11. Device Positioning vertical
The device is positioned below the Test Arch phantom, touching the frame from below.
A positioning uncertainty of 0.2mm is estimated.
The actual values may be smaller for devices with a smooth, plain surface.
For specially shaped devices with an irregular surface not matching the frame, the values might need enlargement.
The 0.2mm leads to 4.7% (power) influence for the E-field, and due to the smaller field gradient slightly less for the H-field.

12. Device Positioning lateral
Lateral shift of the device due to inaccurate positioning may shift the field sideways.
Due to the well defined raster, the maxima within the subgrids are a effcted.
If the maximum remains in the center subgrid, there is no influence on the result.
If however the field maximum is in a peripheral subgrid which will be excluded, the value at the boundary to the remaining evaluated subgrid is affected.
The gradient has been determined from sample files to be less than 1% per mm for the field.
If a side shift will not exceed 0.5mm, the power influence remains within 1%.

13. Device Holder Disturbance
The effect of the device holder and the Test Arch spacer material on the wireless device field distribution and maximum amplitude strongly depends on the antenna design.
A general prediction is not possible. In the given table, a value of 0.1 dB has been used as a typical example.
A user is responsible to verify the value for the actual device under test and correct the input if needed.

14. Phantom Uncertainty
During the production, the Test Arch phantom frame thickness has been determined to be within 0.1mm.
The influence is equivalent to the vertical positioning error, but smaller: 2.4% for E-field power, and 30% less for H-field.

IEEE 1528:

Probe linearity uncertainty (E.2.4)
E-field probe linearity uncertainty is assessed using the procedures described in 4.3.1 and Clause A.2 according to the square of the measured E-field strength magnitude.
Since diode sensors can become peak detectors in pulsed fields, pulsed signals at 10% duty factor with a repetition rate of 500 Hz (more conservative uncertainty than 11 Hz or 217 Hz, for example) should be used to assess probe linearity.
The assessment should be in the range of 0.4–100 W/kg in steps of 3 dB or less.
The SAR tolerance is determined as the maximum deviation in the square of the measured and actual field strength for the entire assessment.
A rectangular probability distribution has been assumed for probe linearity uncertainty in Table 5.

Field-probe readout electronics uncertainty (E.2.6)
Field-probe readout electronics uncertainties should be assessed for all the uncertainty sources described in 4.3.2 and Clause A.9.
All uncertainties related to the probe readout electronics, including the gain and linearity of the instrumentation amplifier, its loading effect on the probe, and accuracy of the signal conversion algorithm, should be evaluated to estimate the maximum SAR uncertainty.
The expected ranges of these uncertainty components can be generally assessed by using simulated terminations in place of the field probes and the use of manufacturer specifications for the electronic components.
The different uncertainties should be combined with the RSS method and entered in the corresponding row of Table 5, which assumes a normal probability distribution.

Probe integration-time uncertainty (E.2.8)
Probe integration-time uncertainties may arise when test devices do not emit a continuous signal, such as the digital modulations used in some handsets.
When the integration time and discrete sampling intervals used in the probe electronics are not synchronized with the modulation characteristics of the measured signal, the RF energy at each measurement location may not be fully or correctly captured.
This uncertainty must be evaluated according to the signal characteristics of the test device prior to the SAR measurement.

For signals with amplitude or pulse modulation components and a periodicity greater than 1% of the probe integration time, additional SAR tolerances must be considered when the probe integration time is not an exact multiple of the longest periodicity.
The uncertainty should be assessed according to the maximum uncertainty expected for unsynchronized probe integration time with an assumed rectangular probability distribution.

RF ambient conditions (E.6.1)
Measurement uncertainties may occur when unwanted RF ambient signals are present during a SAR test.
The ambient RF level is evaluated by performing SAR measurements using the same equipment setup as used for testing the handset, but with the RF power switched off.

Interpolation, extrapolation, and integration algorithm uncertainty (E.5)
The use of interpolation, extrapolation, and integration algorithms is discussed in Clause 6 and Annex F.
These algorithms are used to determine the highest peak spatial-average SAR values from the discrete measured data points.
These algorithms may add uncertainty due to general assumptions of field behavior, and therefore these may not perfectly predict the E-field distribution in the tissue-equivalent liquid for a specific handset.
The algorithm uncertainty is a function of the resolution chosen for the measurement and the post-processing methods used in the area scans and zoom scans.