IEC 62209-3 Validation Results
GPI Model Confirmation

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1 Executive Summary

The SAR measurement system validation procedure described in IEC 62209-3 [1] is a three step procedure the consists of a) GPI model creation, b) model confirmation, and c) the critical data space search. This automatically generated document reports on the outcome of the *model confirmation*.

The SAR measurement system described in Table 1 successfully completed the GPI model confirmation step.

The results of the GPI model confirmation are shown in Table 2.

Measurement system name	A SAR System
Manufacturer	A Manufacturer
Phantom type	Flat
Hardware version	AD 385 12B
Software version	V2.0

Table 1: Measurement system analyzed in this report.

Test	**Success Criterion**	**Outcome**	**Pass / Fail**
Acceptance of data	$\Delta SAR \in [-U, +O]$	See Table 7	**Pass**
Normality	$p \geq 0.05$	0.343	**Pass**
Similarity	location $\in$ [-1, 1]	-0.092	**Pass**
	scale $\in$ [0.5, 1.5]	0.916	**Pass**

Table 2: Summary of the GPI Model confirmation outcomes for the measurement system described in Table 1.

2 Introduction

2.1 Purpose of Report

This report provides the results of the *model confirmation* step for the SAR measurement system validation procedure described in IEC 62209-3 [1]. The GPI model is a model that describes the expected measurement error and uncertainty for the given SAR measurement system of interest as a function of exposure parameters.

The goal of the model confirmation step is to independently confirm, using statistical methodology, the validity of the GPI model, establishing its trustworthiness or rejecting its applicability. It assesses the ability of the GPI model to generalize beyond the exposure configurations employed in its construction.

This report has been automatically generated by an online-accessible, GUI-based validation application (`http://sarvalidation.site/` version 1.0.5) using measured data obtained with the SAR measurement system described in Table 1.

Background and additional information on the methodology can be found in the open-access paper [2]. The open-source software leveraged by the online application is provided with IEC 62209-3 and can be found at `https://github.com/ITISFoundation/publication-IEC62209`.

2.2 GPI Model Confirmation

SAR measurement system validation in IEC 62209-3 [1] consists of these three steps:

a) Gaussian process interpolation (GPI) model creation

b) GPI model confirmation

c) Critical data space search

The results of *GPI model confirmation* (b) are reported in this document. The process involves the following steps (see Annex D, Clause D.4.4):

1) The GPI software generates a set of test configurations that is independent from the configurations used to construct the GPI model, based on the GPI model of the system under validation created in step a). That confirmation test set encompasses 50 configurations, which is sufficient to confirm the GPI model and has an associated measurement effort in the order of one day.

2) These model confirmation measurements are performed by an independent test lab. The lab is free to decide on the order in which the test configurations are measured, e.g., to optimize testing time and reduce manual interventions.

3) The test lab enters the data into the analysis software, which determines whether the model is successfully confirmed. If the confirmation fails, the lab may go back to step 1) to refine the model with the newly obtained data. If the test lab is not satisfied with the GPI model confirmation, they may contact the system manufacturer for assistance.

Successful GPI model confirmation is the precondition for moving ahead with step c).

2.3 Success Criteria

All of the following criteria must be met for the model confirmation step to be successfully concluded:

- **acceptance**
  for the system to be considered acceptable for use in accordance with IEC 62209-3, all test configuration SAR deviations ($\Delta SAR_j, j = 1$ to N) between the measured SAR values and the numerical SAR target values (specified by IEC) must be within the acceptance criteria given in Clause D.4.7 of [1]:

$$-U < r_{s,j} < +O, \qquad j = 1 \,..\, N$$

  where $r_{s,j}$ is the linear deviation between the measured SAR ($SAR_{m,j}$) and the numerical target ($SAR_{num,j}$) given by:

$$r_{s,j} = 100\ \% \times \left(\frac{SAR_{m,j} - SAR_{num,j}}{SAR_{num,j}}\right)$$

and the deviation in dB is $\Delta SAR_j = 10 \times log_{10}(r_{s,j})$. The error bounds [-$U$, +$O$] are given by:

$$+O = 2 \times u_s + 15\ \%$$

$$-U = -100 \times \frac{2 \times u_s + 15\ \%}{100 + 2 \times u_s + 15\ \%}$$

where 2 x u_s is the reported measurement uncertainty of the SAR measurement with a 95 % confidence level.

When expressed in dB, the error bounds are equal, meaning that $10 \times log_{10}(O) = 10 \times log_{10}(U)$, so the requirement simplifies to:

$$\left|\Delta SAR_j\right| = 10 \times log_{10}(+O)$$

- **normality: p $\geq$ 5 %**
  the result of the Shapiro-Wilk test for normality must reject the hypothesis that the SAR deviations of the measured test configurations are not normal distributed (p-value greater than 5 %).
- **location** $\in$ **[-1, 1]**
  measured deviations of the test data collected as part of the model confirmation should be substantially similar to those of the configurations used for model construction. A Q-Q plot is used to compare the shapes of the two distributions. The location of the Q-Q plot must be within the [-1, 1] range.
- **scale** $\in$ **[0.5, 1.5]**
  measured deviations of the test data collected as part of the model confirmation should be substantially similar to those of the configurations used for model construction. A Q-Q plot is used to compare the shapes of the two distributions. The scale of the Q-Q plot must be within the [0.5, 1.5] range.

3 Model Confirmation

3.1 Limits of Relevant Exposure Parameter Space

The test configurations for model confirmation were generated for measurement on the system detailed in Table 1 according to the parameters in Table 3, which therefore define the extent of the exposure parameter space for which the GPI model can be considered to be confirmed.

Parameter	**Value**
Measurement area: x,y (mm)	80,160
Frequency range (MHz)	300 – 6000
Size of training data	50

Table 3: Range of the exposure parameter space covered by the test configurations. The GPI model can therefore be considered to be confirmed within this range.

3.2 Performance on Acceptance Criteria

The test data for the GPI model confirmation are shown in Figure 1. The complete details on the exposure conditions and measurement results are tabulated in Table 7 in Appendix A. The obtained deviations (ΔSAR_{10g}) of the test configuration measurements from the target values are shown in Figure 1, along with the acceptance thresholds. The pass/fail result is shown in Table 4.

Test	**Success Criterion**	**Outcome**	**Pass / Fail**
Acceptance of data	$\Delta SAR \in [-U, +O]$	See Table 7	Pass

Table 4: Result for the acceptance criterion.

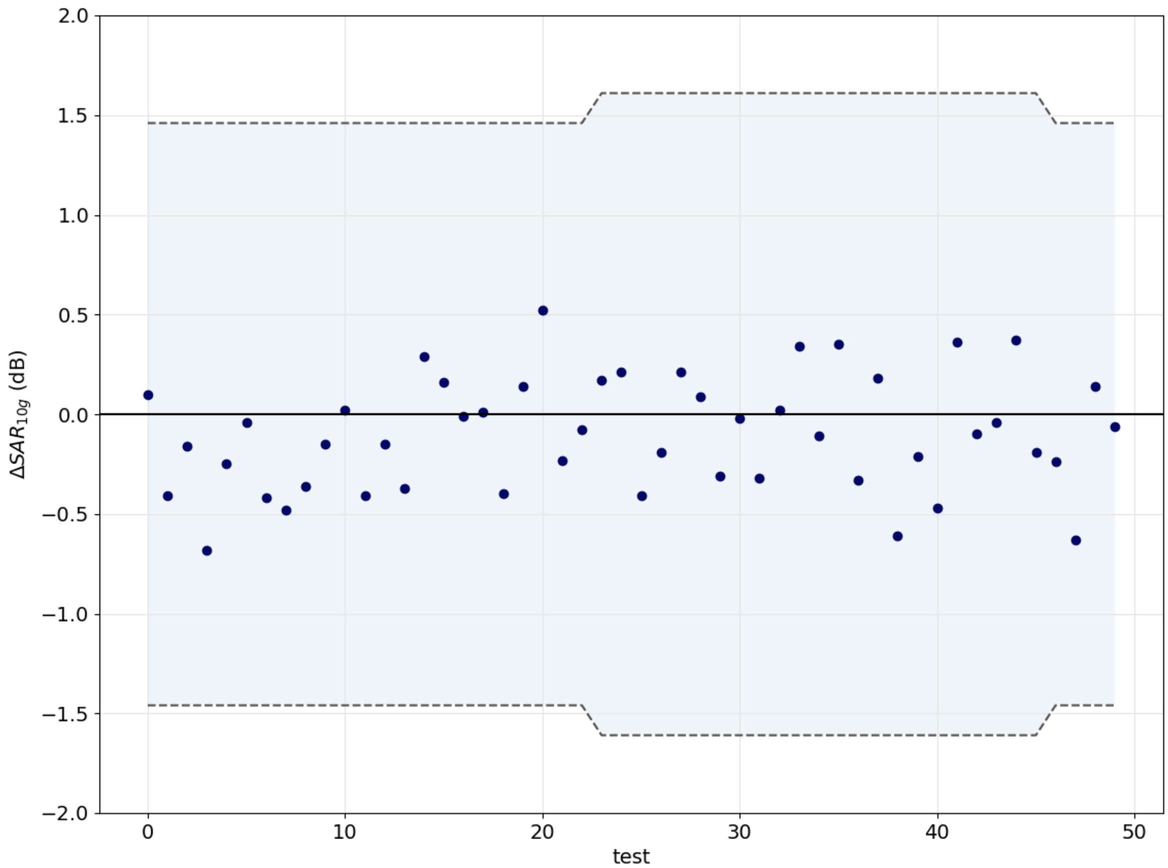

Figure 1: Deviations of the measured SAR_{10g} from the target values for the confirmation test configurations. The deviations are compared to the maximum permissible errors (mpe; dashed lines). Blue dots are inside the mpe. Any red dots are outside the mpe.

3.3 Normality

This part of the analysis evaluates how well the GPI model established in the first step generalizes to new exposure conditions. If the GPI model is generally valid, the deviations between measured and target SAR values are expected to be non-systematic and normally distributed. Deviations from a random normal distribution would therefore be indicative of an unreliable GPI model that insufficiently reproduces reality.

The Shapiro-Wilk test is applied to test for normality. Table 5 shows the p-value from the Shapiro-Wilk test and the pass/fail result.

Test	**Specification**	**Value**	**Pass / Fail**
Normality	$p \geq 5\,\%$	$34.3\,\%$	**Pass**

Table 5: Summary results of the *GPI Model Confirmation* step for the measurement system described in Table 1.

3.4 Similarity

The QQ-plot in Figure **??** compares the experimentally found probability distribution of the deviations between the GPI model prediction and the measurement results (percentiles) against the expected standard normal distribution. The location and scale of the fitted linear relationship should be within acceptance ranges if the GPI model provides a valid representation of the performance of the measurement system under test. The success criteria, outcomes, and pass/fail classification are shown in Table 6.

Test	**Success Criterion**	**Outcome**	**Pass / Fail**
Similarity	location $\in$ [-1, 1]	-0.092	**Pass**
	scale $\in$ [0.5, 1.5]	0.916	**Pass**

Table 6: Summary of the GPI model confirmation results for the measurement system described in Table 1.

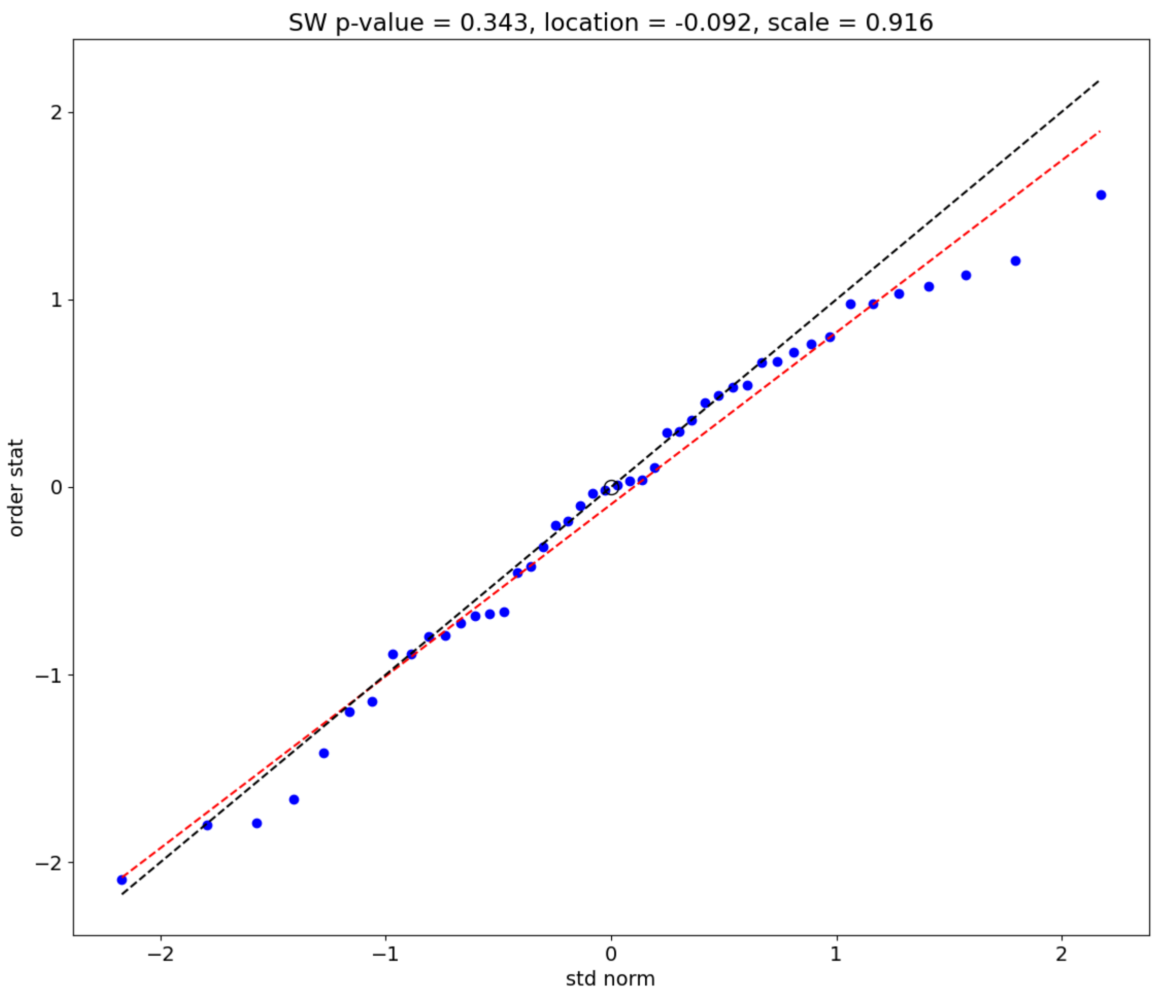

Figure 2: QQ-plot of the SAR deviations, comparing the probability distributions of the created validation model and the test set. These SAR deviations are expected to be normally distributed. The linear regression line (red) through the resulting points (blue) should be close to the reference line (black).

References

[1] IEC 62209-3, “Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices - Part 3: Vector measurement-based systems (Frequency range of 600 MHz to 6 GHz)”, Committee Draft, February 2023.

[2] C. Bujard, E. Neufeld, M. Douglas, J. Wiart, N. Kuster, “A Gaussian-process-model-based approach for robust, independent, and implementation-agnostic validation of complex multi-variable measurement systems: application to SAR measurement systems,” online `https://arxiv.org/abs/2211.12907`, uploaded April 12, 2023.

A Test Data Set Configurations and Measurement Outcomes

Table 7: Test configurations and measurement outcomes for 10-gram average SAR.

ant.	P_f (dB)	Mod	PAPR (dB)	BW (MHz)	s (mm)	θ (°)	x (mm)	y (mm)	SAR (W/kg)	u_s (%)	ΔSAR (dB)	mpe (dB)	Pass ?
D300	21	M2	10.00	0.0	25	30	-7	76	0.179	25	0.1	1.5	Y
D300	34	M1	0.00	0.0	15	195	13	54	4.430	25	-0.4	1.5	Y
D450	14	M11	5.73	3.0	15	180	8	-7	0.074	25	-0.2	1.5	Y
D450	27	M9	6.41	1.4	15	225	-18	-70	1.310	25	-0.7	1.5	Y
D750	11	M12	6.65	3.0	15	330	31	34	0.066	25	-0.2	1.5	Y
D750	21	M12	6.65	3.0	25	345	25	63	0.448	25	-0.0	1.5	Y
D835	19	M18	5.67	20.0	25	75	-34	-52	0.276	25	-0.4	1.5	Y
D835	24	M13	2.91	5.0	5	300	18	7	1.300	25	-0.5	1.5	Y
D900	20	M8	5.76	1.4	15	60	22	29	0.643	25	-0.4	1.5	Y
D900	22	M16	6.44	5.0	15	315	-23	-49	1.070	25	-0.1	1.5	Y
D900	26	M11	5.73	3.0	5	240	5	70	2.730	25	0.0	1.5	Y
D1450	7	M7	7.70	0.8	10	75	-13	1	0.074	25	-0.4	1.5	Y
D1450	10	M11	5.73	3.0	5	255	-28	-20	0.169	25	-0.1	1.5	Y
D1750	22	M18	5.67	20.0	25	30	-40	-2	0.611	25	-0.4	1.5	Y
D1750	22	M18	5.67	20.0	5	255	-22	39	3.780	25	0.3	1.5	Y
D1950	5	M18	5.67	20.0	5	45	38	19	0.097	25	0.2	1.5	Y
D1950	24	M8	5.76	1.4	25	0	39	-58	1.040	25	-0.0	1.5	Y
D2300	6	M3	11.96	0.2	10	45	10	48	0.093	25	0.0	1.5	Y
D2300	25	M1	0.00	0.0	5	165	-1	59	10.280	25	-0.4	1.5	Y
D2450	2	M23	8.90	80.0	5	90	-18	-28	0.064	25	0.1	1.5	Y
D2450	22	M23	8.90	80.0	25	120	0	-79	0.702	25	0.5	1.5	Y
D2600	18	M18	5.67	20.0	25	0	-27	-10	0.216	25	-0.2	1.5	Y
D2600	8	M18	5.67	20.0	5	150	-36	78	0.268	25	-0.1	1.5	Y
D3700	14	M21	8.43	25.0	25	120	-25	-14	0.081	30	0.2	1.6	Y
D3700	22	M2	10.00	0.0	10	135	-10	-35	4.028	30	0.2	1.6	Y
D4200	12	M1	0.00	0.0	10	195	-32	-62	0.320	30	-0.4	1.6	Y
D4200	17	M6	7.93	0.4	25	315	-37	-37	0.139	30	-0.2	1.6	Y
D4600	11	M21	8.43	25.0	10	180	2	-6	0.284	30	0.2	1.6	Y
D4600	13	M21	8.43	25.0	5	90	23	10	1.207	30	0.1	1.6	Y
D5200	0	M19	9.38	20.0	5	300	-11	-39	0.053	30	-0.3	1.6	Y
D5200	16	M23	8.90	80.0	25	210	32	38	0.158	30	-0.0	1.6	Y
D5200	11	M20	10.12	20.0	5	105	30	28	0.665	30	-0.3	1.6	Y
D5500	14	M22	8.91	40.0	5	225	26	19	1.606	30	0.0	1.6	Y
D5600	7	M19	9.38	20.0	5	285	4	-64	0.335	30	0.3	1.6	Y
D5600	13	M19	9.38	20.0	10	210	-33	57	0.439	30	-0.1	1.6	Y
D5600	21	M19	9.38	20.0	10	300	-6	-44	3.076	30	0.3	1.6	Y
D5800	9	M3	11.96	0.2	25	60	-4	-71	0.042	30	-0.3	1.6	Y
D5800	14	M22	8.91	40.0	10	150	-3	-75	0.573	30	0.2	1.6	Y
V750	23	M17	6.59	10.0	2	345	17	72	0.669	30	-0.6	1.6	Y

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Table 7 Test configurations and measurement outcomes for 10-gram average SAR – continued from previous page

antenna	P_f (dB)	Mod	PAPR (dB)	BW (MHz)	s (mm)	θ (°)	x (mm)	y (mm)	SAR (W/kg)	u_s (%)	ΔSAR (dB)	mpe (dB)	Pass ?
V750	28	M15	5.75	5.0	2	240	-21	15	2.321	30	-0.2	1.6	Y
V835	20	M17	6.59	10.0	2	165	34	-47	0.343	30	-0.5	1.6	Y
V835	29	M8	5.76	1.4	2	270	8	-30	3.298	30	0.4	1.6	Y
V1950	25	M18	5.67	20.0	2	285	20	-56	1.108	30	-0.1	1.6	Y
V3700	14	M2	10.00	0.0	2	135	11	-17	0.103	30	-0.0	1.6	Y
V3700	27	M1	0.00	0.0	2	15	-15	24	2.262	30	0.4	1.6	Y
V3700	27	M7	7.70	0.8	2	75	28	4	1.988	30	-0.2	1.6	Y
C2450A	19	M10	10.26	1.4	7	105	16	65	0.241	25	-0.2	1.5	Y
C2450A	30	M10	10.26	1.4	7	330	-9	-23	2.774	25	-0.6	1.5	Y
C2450B	28	M6	7.93	0.4	7	270	-30	45	1.715	25	0.1	1.5	Y
C2450B	29	M22	8.91	40.0	7	0	37	42	2.063	25	-0.1	1.5	Y