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Validation of *DASY8/6 Module mmWAVE V3.2Beta* and *Module SAR V16.2* at 6500 MHz including Target Values of RP6500V1

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Validation of *DASY8/6 Module mmWAVE V3.2Beta* and *Module SAR V16.2* at 6500 MHz including Target Values of RP6500V1

conducted by

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Zurich, August 31, 2022

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Executive Summary

The software versions *Module mmWAVE V3.2Beta* and *Module SAR V16.2*, available for DASY8 and DASY6 and compliant with IEC/IEEE 63195-1 [1], IEC/IEEE 62209-1528 [2], and IEC PAS APD [3], have been validated over the frequency range between 6 and 9 GHz. The validation was performed with the new coaxial-fed rectangular patch verification source operated at 6500 MHz (RP6500V1). Evaluation of the peak spatial averaged power density (psPD) in free space, and the peak spatial SAR (psSAR)/ peak spatial averaged absorbed power density (psAPD) values in the liquid filled flat phantom, were performed with calibrated DASY8 systems. Details of the DASY8 measurement system configuration used for these measurements are specified in Section 2.

The RP6500V1 source and its target values are documented in Appendix A), and have an estimated standard uncertainty of 0.7 dB. The source was also independently evaluated by *Thessaloniki Software Solutions S.A.* (see Appendix F). The differences between the two evaluations are less than 0.1 dB.

The spatial averaged power density (psPD) measurements were performed at the distances 2, 5, 10, 20, 50, 100 and 150 mm from the source. The measured data were evaluated with the equivalent source reconstruction (ESR) of *Module mmWAVE V3.2Beta*, the results of which are summarized in Table 1 for the square averaged area. The maximum deviation from the target values is 0.73 dB, which is well within the combined expanded uncertainty of 1.6 dB. In addition, the psPD values of the plane-to-plane phase reconstruction (PTP-PR) evaluations are provided in Appendix B, verifying that ESR is a much more reliable method than PTP-PR when in the very close near-field of sources.

The measurement results of psSAR and psAPD of the same antenna using *Module SAR V16.2* at 5 and 10 mm distances from the standard flat phantom are summarized in Table 2 and Table 3, respectively. The maximum deviation is 0.31 dB while the combined expanded uncertainty is 1.4 dB.

A second copy of the same antenna has been evaluated by *BNNSPEAG*, the results of which are summarized in Appendix C. The results well correspond to those measured at *IT'IS Foundation*.

Frequency [GHz]	Distance [mm]	$\Delta psPD_{n+,1cm^2}$ [dB]	$\Delta psPD_{tot+,1cm^2}$ [dB]	$\Delta psPD_{n+,4cm^2}$ [dB]	$\Delta psPD_{tot+,4cm^2}$ [dB]	Combined Unc. (k=2) [dB]	Pass (y/n)
6.5	2	-0.51	-0.19	-0.44	-0.40	1.6	y
	5	-0.68	-0.59	-0.49	-0.53	1.6	y
	10	-0.45	-0.45	-0.30	-0.30	1.6	y
	20	-0.23	-0.20	-0.17	-0.14	1.6	y
	50	0.20	0.20	0.19	0.18	1.6	y
	100	-0.49	-0.42	-0.46	-0.40	1.6	y
	150	-0.73	-0.68	-0.69	-0.63	1.6	y

Table 1: Comparison of the measured peak spatial-average power densities (based on the square averaging geometry and evaluated with ESR algorithm) with the numerical target values for the RP6500V1 source.

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Frequency [GHz]	Distance [mm]	$\Delta psSAR_{1g}$ [dB]	$\Delta psSAR_{10g}$ [dB]	Combined Unc. (k=2) [dB]	Pass (y/n)
6.5	5	0.17	0.21	1.4	y
	10	-0.17	-0.19	1.4	y

Table 2: Comparison of the measured peak spatial average specific absorption rate (psSAR) with the numerical target values for the RP6500V1 source.

Frequency [GHz]	Distance [mm]	$\Delta psAPD_{1cm^2}$ [dB]	$\Delta psAPD_{4cm^2}$ [dB]	Combined Unc. (k=2) [dB]	Pass (y/n)
6.5	5	0.04	0.20	1.4	y
	10	-0.31	-0.21	1.4	y

Table 3: Comparison of the measured peak spatial average power density (psAPD) with the numerical target values for the RP6500V1 source.

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In conclusion:

- All APD values measured with *Module SAR V16.2* are within the combined expanded uncertainty of 1.4 db (k=2),
- All psPD results measured and assessed with ESR using software versions *Module mmWAVE V3.2Beta* are within the combined expanded uncertainty of 1.6 db (k=2),
- The psPD values assessed with PTP-PR are only with the combined uncertainty for distances larger than 20 mm.

Therefore the software versions *Module mmWAVE V3.2Beta* (ESR) and *Module SAR V16.2* (APD) can be considered validated for evaluating devices in the WiFi 6E band, meeting all requirements of IEC/IEEE 63195-1 [1], IEC/IEEE 62209-1528 [2] and IEC PAS APD [3].

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1 Objectives

The objective of this report is to validate the DASY8 and DASY6 software versions *Module mmWAVE V3.2Beta* and *Module SAR V16.2*, following the validation protocol as defined in the latest drafts of IEC/IEEE 63195-1 [1], IEC/IEEE 62209-1528 [2], and IEC PAS APD [3], which includes:

- measurement of the spatial averaged power densities(psPD) of the coaxial-fed rectangular patch antenna at 6.5 GHz (RP6500V1) at seven distances (i.e., 2, 5, 10, 20, 50, 100 and 150 mm)
- measurement of the peak spatial averaged absorbed power densities (psAPD) and the peak spatial SAR (psSAR) of the coaxial-fed rectangular patch antenna at 6.5 GHz (RP6500V1) at two distances (5 and 10 mm)
- numerical target values
- comparison of the measurement results with the numerical target values.

The acceptance criterion is that 95% of all deviation values are within the combined expanded uncertainty of the measurement and the numerical target values. If so, the software version *Module mmWAVE V3.2Beta* and *Module SAR V16.2* can be considered validated for evaluating devices in the WiFi 6E band, meeting all requirements of IEC/IEEE 63195-1 [1], IEC/IEEE 62209-1528 [2] and IEC PAS APD [3].

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2 Measurement System

The DASY8 system elements used in the measurements for validating *Module mmWAVE V3.2Beta* are listed in Table 4.

System	Type:	DASY8
	Software Version:	*Module mmWAVE V3.2Beta*
	Manufacturer:	Schmid & Partner Engineering AG, Switzerland
Positioner	Robot:	TX2-60L
	Serial No:	F/19/0014438/A/001
	Controller:	CS9
	Serial No:	F/19/0014438/C/001
	Manufacturer:	Stäubli, France
Data Acquisition System	Type:	DAE4ip
	Serial No:	1603
	Calibrated On:	Jun. 06, 2022
	Manufacturer:	Schmid & Partner Engineering AG, Switzerland
Probe	Type:	EUmmWV4
	Serial Number:	9477
	Calibrated On:	Aug. 11, 2022
	Manufacturer:	Schmid & Partner Engineering AG, Switzerland

Table 4: Measurement system used in the measurements for the validation of *Module mmWAVE V3.2Beta*.

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3 Coaxial-fed Patch Antenna and Instruments

Coaxial-fed Patch Antenna and instruments used in the measurements for validating *Module mmWAVE V3.2Beta* are listed in Table 5.

6.5 GHz Validation Sources	Validation-source Unit No.:	1000/1002
	Validation-source Evaluated On:	Aug. 22, 2022 / Apr. 6, 2022
	Validation-source Manufacturer:	Schmid & Partner Engineering AG, Switzerland
	Power-source Type:	Signal generator
	Power-source Model Name:	SMA100B
	Power-source Serial No.:	1419.8888K02-101071-VX
	Power-source Output Freq.:	6.5 GHz
	Power-source Manufacturer:	Rohde & Schwarz GmbH & Co. KG, Germany
Phantom	Type:	mmWave phantom
	Part No.:	QD 015 025 CA
	Serial No.:	1002
	Manufacturer:	Schmid & Partner Engineering AG, Switzerland

Table 5: Validation sources and corresponding instruments used in the measurements for the validation of *Module mmWAVE V3.2Beta* and *Module SAR V16.2*.

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4 Measurements

In this section, the measurement results of the RP6500V1 source are provided, and the results are compared with their target values. A complete list of numerical target values is provided in Appendix A. The target values are independently verified by *Thessaloniki Software Solutions S.A.* (Appendix F). The averaged power density measurements were performed with the default post-processing settings of the DASY8/6 system.

4.1 Result - Peak Spatial Average Power Density (psPD)

4.1.1 Comparison of Peak Spatial Average Power Density Target Values with Measurement Results Based on ESR Method

Date	Sample	Cond. power [dBm]	Resolution [λ]	Deviation Metric	Distance [mm] 2	5	10	20	50	100	150
22.08.2022	SN1000	20.0	0.0434, 0.125	$\Delta psPD_{circular}$ [dB]	-0.54	-0.70	-0.47	-0.24	0.20	-0.49	-0.72
22.08.2022	SN1000	20.0	0.0434, 0.125	$\Delta psPD_{rotating-square}$ [dB]	-0.51	-0.68	-0.45	-0.23	0.20	-0.49	-0.73

Table 6: Deviations of $psPD_{n+,1cm^2}$. Resolutions of 0.0434λ and 0.125λ were used in measurements at 2 mm and >2 mm, respectively.

Date	Sample	Cond. power [dBm]	Resolution [λ]	Deviation Metric	Distance [mm] 2	5	10	20	50	100	150
22.08.2022	SN1000	20.0	0.0434, 0.125	$\Delta psPD_{circular}$ [dB]	-0.27	-0.61	-0.47	-0.21	0.20	-0.42	-0.67
22.08.2022	SN1000	20.0	0.0434, 0.125	$\Delta psPD_{rotating-square}$ [dB]	-0.19	-0.59	-0.45	-0.20	0.20	-0.42	-0.68

Table 7: Deviations of $psPD_{tot+,1cm^2}$. Resolutions of 0.0434λ and 0.125λ were used in measurements at 2 mm and >2 mm, respectively.

Date	Sample	Cond. power [dBm]	Resolution [λ]	Deviation Metric	Distance [mm] 2	5	10	20	50	100	150
22.08.2022	SN1000	20.0	0.0434, 0.125	$\Delta psPD_{circular}$ [dB]	-0.54	-0.50	-0.33	-0.19	0.19	-0.47	-0.68
22.08.2022	SN1000	20.0	0.0434, 0.125	$\Delta psPD_{rotating-square}$ [dB]	-0.44	-0.49	-0.30	-0.17	0.19	-0.46	-0.69

Table 8: Deviations of $psPD_{n+,4cm^2}$. Resolutions of 0.0434λ and 0.125λ were used in measurements at 2 mm and >2 mm, respectively.

Date	Sample	Cond. power [dBm]	Resolution [λ]	Deviation Metric	Distance [mm] 2	5	10	20	50	100	150
22.08.2022	SN1000	20.0	0.0434, 0.125	$\Delta psPD_{circular}$ [dB]	-0.49	-0.57	-0.32	-0.15	0.18	-0.40	-0.63
22.08.2022	SN1000	20.0	0.0434, 0.125	$\Delta psPD_{rotating-square}$ [dB]	-0.40	-0.53	-0.30	-0.14	0.18	-0.40	-0.63

Table 9: Deviations of $psPD_{tot+,4cm^2}$. Resolutions of 0.0434λ and 0.125λ were used in measurements at 2 mm and >2 mm, respectively.

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4.2 Result - Peak Spatial Specific Absorption Rate (psSAR)

4.2.1 Comparison of psSAR Target Values with Measurement Results

Date	Sample	Cond. power [dBm]	Distance [mm]	$\Delta psSAR_{1g}$ [dB]	$\Delta psSAR_{10g}$ [dB]
06.04.2022	SN1002	20.0	5	0.17	0.21
06.04.2022	SN1002	20.0	10	-0.17	-0.19

Table 10: Comparison of the measured peak spatial average specific absorption rate (psSAR) with the numerical target values for the RP6500V1 source.

4.3 Result - Peak Spatial Absorbed Power Density (psAPD)

4.3.1 Comparison of pSAPD Target Values with Measurement Results

Date	Sample	Cond. power [dBm]	Distance [mm]	$\Delta psAPD_{1cm^2}$ [dB]	$\Delta psAPD_{4cm^2}$ [dB]
06.04.2022	SN1002	20.0	5	0.04	0.20
06.04.2022	SN1002	20.0	10	-0.31	-0.21

Table 11: Comparison of the measured peak spatial absorbed power density (psAPD) with the numerical target values for the RP6500V1 source.

5 Combined Uncertainty

Combined uncertainty is derived based on model uncertainty, numerical uncertainty and measurement uncertainty. The model uncertainty deals with parameters of the antenna model in Sim4Life, such as its dimensions and materials. The numerical uncertainty involves parameters specifying the simulation execution (namely the simulation-related uncertainty source) and result extraction (namely the extraction-related uncertainty source), such as meshing, convergence and the interpolation resolution of evaluation planes. Detailed descriptions of all parameters studied for assessing the model uncertainty and the numerical uncertainty are provided in Appendix D for the coaxial-fed rectangular microstrip patch antenna. A detailed budget for the measurement uncertainty can be found in the DASY8 manuals [4], [5] and application note [6].

Uncertainty Parameter	psSAR	psAPD	psPD (ESR)	psPD (PTP) Distance $\geq \lambda/5$
Model uncertainty ($k = 2$) [dB]	0.61	0.61	0.58	0.58
Numerical uncertainty ($k = 2$) [dB]	0.29	0.30	0.30	0.30
Measurement uncertainty ($k = 2$) [dB]	1.20	1.20	1.50	1.50
Combined uncertainty ($k = 2$) **[dB]**	1.38	1.38	1.64	1.64

Table 12: Combined uncertainty of the 6.5 GHz coaxial-fed rectangular microstrip patch antenna.

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6 Conclusions

This report provides the measurement results of the coaxial-fed rectangular microstrip patch antenna (RP6500V1), and compares them with the numerical target values. The measurements have been conducted with the software version *Module mmWAVE V3.2Beta* and *Module SAR V16.2*. Since all deviation values are within the combined uncertainty of the measurement and the numerical target values, the software version *Module mmWAVE V3.2Beta* and *Module SAR V16.2* can be considered validated for evaluating devices in the WiFi 6E band meeting all requirements of IEC/IEEE 63195-1 [1], IEC/IEEE 62209-1528 [2] and IEC PAS APD [3].

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References

[1] IEC/IEEE 63195-1 ED1, Assessment of power density of human exposure to radio frequency fields from wireless devices in close proximity to the head and body (frequency range of 6 GHz to 300 GHz) – Part 1: Measurement procedure, May 2022.

[2] IEC/IEEE 62209-1528, Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-worn wireless communication devices — Human models, instrumentation and procedures (Frequency range of 4MHz to 10 GHz), 2020.

[3] IEC PAS APD, "Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure", Draft, 2022.

[4] Schmid & Partner Engineering AG, DASY8 Module mmWave manual, February 2022.

[5] Schmid & Partner Engineering AG, DASY8 Module SAR manual, August 2022.

[6] Schmid & Partner Engineering AG, Interim Procedures for Devices Operating at 6 - 10 GHz, August 2022.

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A Numerical Target Values

A.1 Target Values with *psPD* Derived Based on Circular Averaging Geometry

Target values of the RP6500V1 source are listed in Table 13. All values are normalized to 20-dBm conducted power. Peak spatial-average power densities are derived based on the circular averaging geometry. The values are independently verified by a third-party lab and the results are shown in Appendix F.

d [mm]	E_{max} [V/m]	H_{max} [A/m]	max(S_{tot}) [W/m^2]	max(S_n) [W/m^2]	$psPD_{n+,1cm^2}$ [W/m^2]	$psPD_{n+,4cm^2}$ [W/m^2]	$psPD_{tot+,1cm^2}$ [W/m^2]	$psPD_{tot+,4cm^2}$ [W/m^2]	$psPD_{mod+,1cm^2}$ [W/m^2]	$psPD_{mod+,4cm^2}$ [W/m^2]
2	830.1	2.42	654.2	633.8	329.4	177.9	417.9	242.9	508.5	399.1
5	398.4	1.06	274.9	272.7	218.6	137.9	229.0	158.4	259.6	201.9
10	240.5	0.63	148.2	147.9	130.4	91.8	133.7	100.9	138.2	109.0
20	146.2	0.39	56.9	56.9	53.0	43.6	53.8	46.0	54.1	46.8
50	56.4	0.15	8.64	8.63	8.51	8.16	8.55	8.31	8.56	8.32
100	29.1	0.08	2.28	2.13	2.14	2.12	2.38	2.36	2.38	2.36
150	18.8	0.05	0.97	0.93	1.01	0.99	1.09	1.07	1.09	1.07

Table 13: Numerical target values of the RP6500V1 source normalized to a conducted power of 20 dBm. *psPD* values are derived based on the circular averaging geometry.

A.2 Target Values with *psPD* Derived Based on Rotating Square Averaging Geometry

Target values of the RP6500V1 source are listed in Table 14. All values are normalized to 20-dBm conducted power. Peak spatial-average power densities are derived based on the rotating square averaging geometry. The values are independently verified by a third-party lab and the results are shown in Appendix F.

d [mm]	E_{max} [V/m]	H_{max} [A/m]	max(S_{tot}) [W/m^2]	max(S_n) [W/m^2]	$psPD_{n+,1cm^2}$ [W/m^2]	$psPD_{n+,4cm^2}$ [W/m^2]	$psPD_{tot+,1cm^2}$ [W/m^2]	$psPD_{tot+,4cm^2}$ [W/m^2]	$psPD_{mod+,1cm^2}$ [W/m^2]	$psPD_{mod+,4cm^2}$ [W/m^2]
2	830.1	2.42	654.2	633.8	330.3	177.2	414.6	241.3	516.4	398.9
5	398.4	1.06	274.9	272.7	217.5	136.7	228.0	157.0	259.2	200.9
10	240.5	0.63	148.2	147.9	129.9	90.9	133.2	100.0	137.9	108.2
20	146.2	0.39	56.9	56.9	52.8	43.2	53.6	45.7	54.0	46.5
50	56.4	0.15	8.64	8.63	8.50	8.15	8.55	8.30	8.55	8.31
100	29.1	0.08	2.28	2.13	2.14	2.11	2.38	2.36	2.38	2.36
150	18.8	0.05	0.97	0.93	1.01	1.00	1.09	1.07	1.10	1.07

Table 14: Numerical target values of the RP6500V1 source normalized to a conducted power of 20 dBm. *psPD* values are derived based on the rotating square averaging geometry.

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A.3 Target Values with *psAPD* and *psSAR*

Table shows the target values of psAPD and psSAR of the RP6500V1 source. All values are normalized to 20-dBm conducted power. Peak spatial-average absorbed power densities are derived based on the rotated square averaging geometry. The values are independently verified by a third-party lab and the results are shown in Appendix F.

d [mm]	$psSAR_{1g}$ [W/kg]	$psSAR_{8g}$ [W/kg]	$psSAR_{10g}$ [W/kg]	peak SAR [W/kg]	$psAPD_{1cm^2}$ [W/m^2]	$psAPD_{4cm^2}$ [W/m^2]
5	14.9	4.0	3.4	80.0	153.7	79.8
10	9.6	3.2	2.8	44.3	99.2	65.0

Table 15: Numerical target values of the 6.5 GHz coaxial-fed rectangular microstrip patch antenna normalized to a conducted power of 20 dBm. *psAPD* values are derived based on the rotated square averaging geometry.

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B Evaluation of psPD Values of the Plane-to-Plane Phase Reconstruction (PTP-PR)

Frequency [GHz]	Distance [mm]	$\Delta psPD_{n+,1cm^2}$ [dB]	$\Delta psPD_{tot+,1cm^2}$ [dB]	$\Delta psPD_{n+,4cm^2}$ [dB]	$\Delta psPD_{tot+,4cm^2}$ [dB]	Combined Unc. (k=2) [dB]
	2	-2.96	-3.82	-2.92	-3.78	
	5	-3.48	-3.54	-2.72	-3.00	
	10	-3.05	-3.06	-2.44	-2.62	
6.5	20	-1.81	-1.47	-1.54	-1.30	1.6
	50	0.23	0.23	0.22	0.19	1.6
	100	-0.08	-0.46	-0.07	-0.48	1.6
	150	-0.22	-0.55	-0.35	-0.64	1.6

Table 16: Comparison of the measured peak spatial-average power densities (based on the square averaging geometry and evaluated with PTP-PR algorithm) with the numerical target values for the RP6500V1 source. Note that measurement grid and extend resolutions recommended for ESR were used in PTP measurements violating the conditions mentioned in uncertainty budget evaluation section in [4].

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C Evaluation of RP6500V1 Antenna by BNNSPEAG

C.1 Measurement System

The DASY8 system used in the measurements for validating *Module mmWAVE V3.2Beta* are listed in Table 17.

System	Type:	DASY8
	Software Version:	*Module mmWAVE V3.2Beta*
	Manufacturer:	Schmid & Partner Engineering AG, Switzerland
Positioner	Robot:	TX2-60L
	Serial No:	F/20/0021574/A/001
	Controller:	CS9
	Serial No:	F/20/0021574/C/001
	Manufacturer:	Stäubli, France
Data Acquisition System	Type:	DAE4ip
	Serial No:	1640
	Calibration Due:	Nov. 30, 2022
	Manufacturer:	Schmid & Partner Engineering AG, Switzerland
Probe	Type:	EUmmWV4
	Serial Number:	9509
	Calibration Due:	Dec. 02, 2022
	Manufacturer:	Schmid & Partner Engineering AG, Switzerland

Table 17: Measurement system used in the measurements for the validation of *Module mmWAVE V3.2Beta*.

C.2 Coaxial-fed Patch Antenna and Instruments

Coaxial-fed Patch Antenna and instruments used in the measurements for validating *Module mmWAVE V3.2Beta* are listed in Table 18.

6.5 GHz Validation Soource	Validation-source Unit No.:	1002
	Validation-source Evaluated On:	Jun. 15, 2022
	Validation-source Manufacturer:	Schmid & Partner Engineering AG, Switzerland
	Power-source Type:	Signal generator
	Power-source Model Name:	N5173B
	Power-source Serial No.:	MY57280560
	Power-source Output Freq.:	6.5 GHz
	Power-source Manufacturer:	Keysight Technologies
Phantom	Type:	mmWave phantom
	Part No.:	QD 015 045 AC
	Serial No.:	1004
	Manufacturer:	Schmid & Partner Engineering AG, Switzerland

Table 18: Validation sources and corresponding instruments used in the measurements for the validation of *Module mmWAVE V3.2Beta* and *Module SAR V16.2*.

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C.3 Comparison of Peak Spatial Average Power Density Target Values with Measurement Results based on ESR Method

All measurements were performed with 24-dBm conducted power. The results are normalized to 20-dBm conducted power and presented in Table 19- Table 22.

Date	Sample	Cond. power [dBm]	Resolution [λ]	Deviation Metric	Distance [mm] 2	5	10	20	50	100	150
15.06.2022	SN1002	20.0	0.0434, 0.125	$\Delta psPD_{circular}$ [dB]	-0.35	-0.36	-0.84	-0.63	-0.01	-0.11	0.20
15.06.2022	SN1002	20.0	0.0434, 0.125	$\Delta psPD_{rotating-square}$ [dB]	-0.36	-0.32	-0.82	-0.62	-0.01	-0.11	0.20

Table 19: Deviations of $psPD_{n+,1cm^2}$. Resolutions of 0.0434λ and 0.125λ were used in measurements at 2 mm and >2 mm, respectively.

Date	Sample	Cond. power [dBm]	Resolution [λ]	Deviation Metric	Distance [mm] 2	5	10	20	50	100	150
15.06.2022	SN1002	20.0	0.0434, 0.125	$\Delta psPD_{circular}$ [dB]	-0.24	-0.42	-0.82	-0.62	0.00	-0.08	0.26
15.06.2022	SN1002	20.0	0.0434, 0.125	$\Delta psPD_{rotating-square}$ [dB]	-0.18	-0.39	-0.80	-0.61	0.01	-0.08	0.25

Table 20: Deviations of $psPD_{tot+,1cm^2}$. Resolutions of 0.0434λ and 0.125λ were used in measurements at 2 mm and >2 mm, respectively.

Date	Sample	Cond. power [dBm]	Resolution [λ]	Deviation Metric	Distance [mm] 2	5	10	20	50	100	150
15.06.2022	SN1002	20.0	0.0434, 0.125	$\Delta psPD_{circular}$ [dB]	-0.37	-0.09	-0.77	-0.55	-0.09	-0.11	0.21
15.06.2022	SN1002	20.0	0.0434, 0.125	$\Delta psPD_{rotating-square}$ [dB]	-0.32	-0.05	-0.75	-0.53	-0.08	-0.11	0.20

Table 21: Deviations of $psPD_{n+,4cm^2}$. Resolutions of 0.0434λ and 0.125λ were used in measurements at 2 mm and >2 mm, respectively.

Date	Sample	Cond. power [dBm]	Resolution [λ]	Deviation Metric	Distance [mm] 2	5	10	20	50	100	150
15.06.2022	SN1002	20.0	0.0434, 0.125	$\Delta psPD_{circular}$ [dB]	-0.44	-0.13	-0.71	-0.55	-0.06	-0.08	0.34
15.06.2022	SN1002	20.0	0.0434, 0.125	$\Delta psPD_{rotating-square}$ [dB]	-0.41	-0.11	-0.68	-0.52	-0.05	-0.08	0.31

Table 22: Deviations of $psPD_{tot+,4cm^2}$. Resolutions of 0.0434λ and 0.125λ were used in measurements at 2 mm and >2 mm, respectively.

Date	Sample	Cond. power [dBm]	Resolution [λ]	Deviation Metric	Distance [mm] 2	5	10	20	50	100	150
15.06.2022	SN1002	20.00	0.083, 0.125	$\Delta psPD_{circular}$ [dB]	-0.46	-0.22	-0.80	-0.57	0.02	-0.08	0.27
15.06.2022	SN1002	20.00	0.083, 0.125	$\Delta psPD_{rotating-square}$ [dB]	-0.52	-0.21	-0.79	-0.56	0.02	-0.08	0.26

Table 23: Deviations of $psPD_{mod+,1cm^2}$. Resolutions of 0.0434λ and 0.125λ were used in measurements at 2 mm and >2 mm respectively.

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Date	Sample	Cond. power [dBm]	Resolution [λ]	Deviation Metric	Distance [mm] 2	5	10	20	50	100	150
15.06.2022	SN1002	20.00	0.0434, 0.125	$\Delta psPD_{circular}$ [dB]	-0.54	-0.27	-0.74	-0.49	-0.04	-0.07	0.33
15.06.2022	SN1002	20.00	0.0434, 0.125	$\Delta psPD_{rotating-square}$ [dB]	-0.52	-0.25	-0.73	-0.51	-0.03	-0.07	0.31

Table 24: Deviations of $psPD_{mod+,4cm^2}$. Resolutions of 0.0434λ and 0.125λ were used in measurements at 2 mm and >2 mm respectively.

C.4 Comparison of psSAR Target Values with Measurement Results

All measurements were performed with 24-dBm conducted power. The results are normalized to 20-dBm conducted power and presented in Table 25.

Date	Sample	Cond. power [dBm]	Distance [mm]	$\Delta psSAR_{1g}$ [dB]	$\Delta psSAR_{10g}$ [dB]
10.06.2022	SN1002	20.0	5	-0.36	-0.35
10.06.2022	SN1002	20.0	10	-0.54	-0.50

Table 25: Comparison of the measured peak spatial average specific absorption rate (psSAR) with the numerical target values for the RP6500V1 source.

C.5 Comparison of pSAPD Target Values with Measurement Results

All measurements were performed with 24-dBm conducted power. The results are normalized to 20-dBm conducted power and presented in Table 26.

Date	Sample	Cond. power [dBm]	Distance [mm]	$\Delta psAPD_{1cm^2}$ [dB]	$\Delta psAPD_{4cm^2}$ [dB]
10.06.2022	SN1002	20.0	5	-0.44	-0.30
10.06.2022	SN1002	20.0	10	-0.62	-0.46

Table 26: Comparison of the measured peak spatial absorbed power density (psAPD) with the numerical target values for the RP6500V1 source.

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D Uncertainty Assessment for Coaxial-fed Patch Antenna Source

D.1 Model Uncertainty Source

Seven uncertainty factors stemming from the simulation model are studied, as listed in Table 27.

Parameter studied	Value used in reference simulation	Value used in simulation for uncertainty assessment	Remarks
Substrate permittivity	3.66	3.66±0.05	±0.05 is the uncertainty of the permittivity of RO4350B. 3.66 is the design permittivity of RO4350B.
Substrate thickness	60 mil	60 mil±4.0 mil	±4.0 mil is the uncertainty of the thickness of 60-mil RO4350B.
Patch length	10.93 mm	10.93 mm±0.05 mm	±0.05 mm is the uncertainty of the dimensions of the patch length.
Patch width	10.93 mm	10.93 mm±0.05 mm	±0.05 mm is the uncertainty of the dimensions of the patch width.
Coaxial line fed location	2.01 mm	2.01 mm±0.05 mm	±0.05 mm is the uncertainty of the position of the coaxial line fed w.r.t. the center of the patch.
Positioning			Distance between antenna and phantom is changed by ±1 grid step.
Phantom dimensions			Overall length and width of the phantom are increased by 25 % withe respect to thier default dimenions.

Table 27: Parameters belong to model uncertainty source.

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D.2 Numerical Uncertainty Source

Four uncertainty factors related to the simulation setup are studied, as listed in Table 28.

Parameter studied	**Value used in reference simulation**	**Value used in simulation for uncertainty assessment**	**Remarks**
Convergence	Simulated time: 65 periods	Simulated time reduced by 30 %	
Grid resolution	Manual settings for patch, ground; Automatic (Very Fine) for all other objects	Maximum grid steps of manual settings reduced 50% of their default values; Automatic (Very Fine) for all other objects	
Absorbing boundary conditions	Default padding values	Padding increased by $\lambda/4$ in all directions	
Power budget			Deviation of the sum of the radiated and total dissipated power from the antenna feedpoint power reported
Power density averaging			Uncertainty due to interpolation resolution of evaluation plane

Table 28: Parameters belong to numerical uncertainty source.

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E Measurement Results of $psPD_{mod+}$ (ESR Method)

Date	Sample	Cond. power [dBm]	Resolution [λ]	Deviation Metric	Distance [mm] 2	5	10	20	50	100	150
22.08.2022	SN1000	20.0	0.0434, 0.125	$\Delta psPD_{circular}$ [dB]	-0.22	-0.53	-0.47	-0.22	0.21	-0.42	-0.68
22.08.2022	SN1000	20.0	0.0434, 0.125	$\Delta psPD_{rotating-square}$ [dB]	-0.21	-0.50	-0.46	-0.21	0.21	-0.42	-0.68

Table 29: Deviations of $psPD_{mod+,1cm^2}$. Resolutions of 0.0434λ and 0.125λ were used in measurements at 2 mm and >2 mm respectively.

Date	Sample	Cond. power [dBm]	Resolution [λ]	Deviation Metric	Distance [mm] 2	5	10	20	50	100	150
22.08.2022	SN1000	20.0	0.0434, 0.125	$\Delta psPD_{circular}$ [dB]	-0.62	-0.62	-0.38	-0.17	0.18	-0.40	-0.63
22.08.2022	SN1000	20.0	0.0434, 0.125	$\Delta psPD_{rotating-square}$ [dB]	-0.56	-0.60	-0.34	-0.16	0.18	-0.40	-0.64

Table 30: Deviations of $psPD_{mod+,4cm^2}$. Resolutions of 0.0434λ and 0.125λ were used in measurements at 2 mm and >2 mm respectively.

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F Report on the Validation of a Patch Antenna Used as a 6.5GHz Standard Antenna

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REPORT SUBSTANTIATION PAGE	
1. REPORT NUMBER **20220714_101**	2. RECIPIENT LIST NUMBER **1**
3. TITLE (and subtitle) **Report on the validation of a patch antenna used as a 6.5GHz standard antenna.**	4. REPORT TYPE **Technical**
5. AUTHORS **(1) Mariana Rouni (2) Ioannis Markakis**	6. STATUS **Draft**
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9. DISTRIBUTION INFORMATION AND STATUS **IT'IS FOUNDATION / COMMERCIAL-IN-CONFIDENCE**	10. REPORT DATE **14/07/2022**
11. ADDITIONAL NOTES The names of THESS S.A. and any of the researchers involved may be mentioned only in connection with statements or results from this report. The mention of names to third parties other than certification bodies is allowed only after written approval from the authors.	12. PAGES NUMBER **5**
12. KEY WORDS **Patch antenna; 5G standard antenna; 6.5GHz**	
18. SUMMARY **The current report contains the values of power density and peak spatial Specific Absorption Rate calculated from a patch antenna which will be used as a standard antenna for SAR, Absorbed Power-Density (APD) and surface averaged Power-Density (PD) evaluations. The patch antenna operates at 6.5Gz.**	

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1 Objective

The objective of the current document is to report on the SAR and power density values which were calculated from the 5G patch antenna at 6.5GHz. These results will be used for the validation of the antenna as a standard antenna for SAR and power density evaluations.

2 Methodology

The simulations were based on the CAD files of the antenna which were sent to THESS. Figure 1 shows the different views of the antenna and Figure 2 shows the simulation setup which includes the flat phantom in Sim4Life 7.0 Model view.

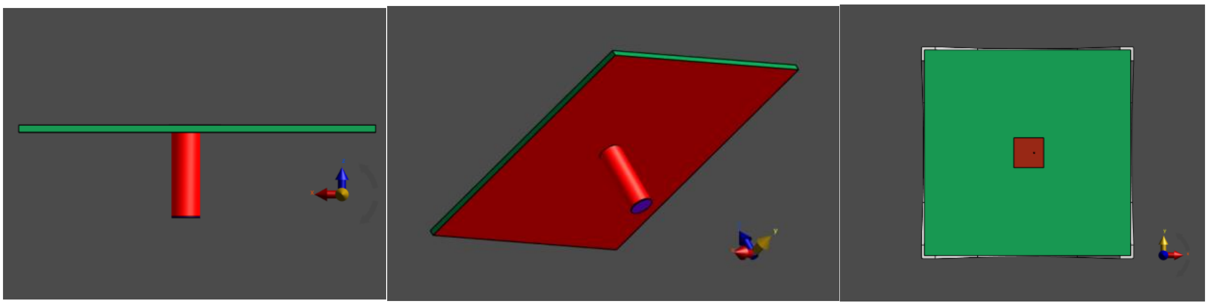

Figure 1 Sideview, bottom and top view of the antenna.

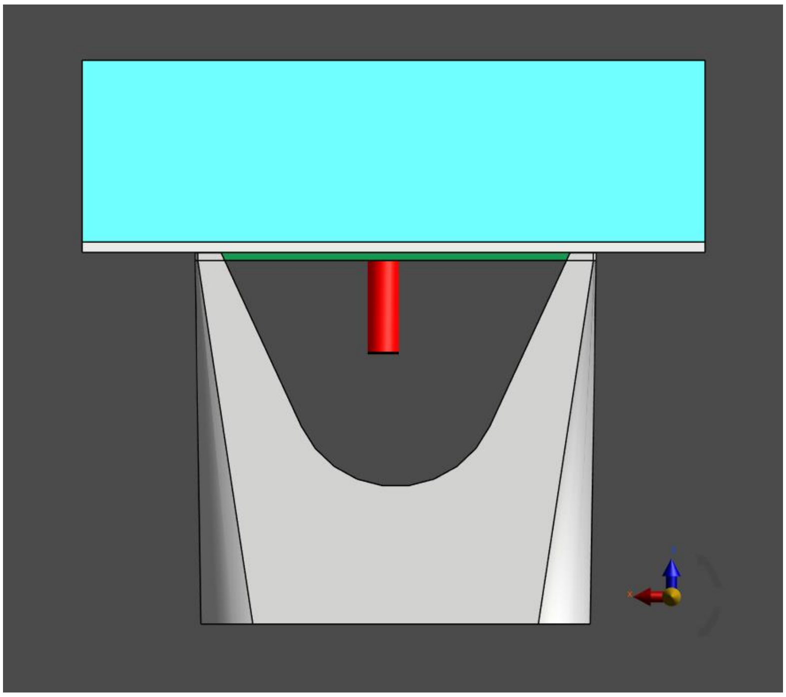

Figure 2. Full simulation setup: antenna (with holder) and flat phantom.

The patch antenna consists of a 75mm x 75mm x 0.035mm ground plane, a dielectric substrate of 1.524mm height and a patch of 10.93mm x 10.93mm x 0.035mm. The flat phantom was placed at three different distances above the antenna, namely 0.0mm, 5.0mm and 10.0mm away. The dimensions of the flat phantom were 120mm x 120mm x 35mm (the shell thickness was 2mm). All metallic objects were assigned as PEC. The dielectric properties of all other materials used in the simulations are presented in Table 1.

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Table 1 Dielectric properties of model entities.

Model entity	Conductivity (S/m)	Relative Permittivity
Substrate	0.00432	3.66
Liquid Phantom	6.07	34.5
Phantom Shell	0	3.7

The antenna's operating frequency was set at 6.5GHz and the total simulation time was 65 periods. Moreover, in order to calculate surface averaged power density (sPD), an additional simulation ran having the antenna in free space. This simulation ran at several frequencies in a 3GHz bandwith, from 5GHz to 8GHz.

In Table 2, the max grid step for every object in the simulations is shown. The total number of grid cells for our computational domain was about 200MCells. All simulations and post processing of the results were performed in Sim4Life v7.0 computational platform.

Table 2. Max grid step in mm for each object in simulation.

Object			
Flat Phantom	Patch	Antenna's ground plane	Other
0.2 x 0.2 x 0.2 (mm)	0.1 x 0.1 x 0.05 (mm)	0.25 x 0.2 x 0.05 (mm)	Automatic Grid (refinement : very fine)

The boundary conditions were UPML/CPML, whereas the type of the boundary settings was set, as usual, to ABC and the strength was high for all planes.

3 Numerical results

In this section, the results from the simulations are presented in three tables (one for SAR and two for sPD values). In Table 3, the peak SAR and the peak spatial SAR values averaged over a volume of 1g, 10g and 8g of the flat phantom is extracted at 3 different distances between the flat phantom and the patch antenna. In Table 4 and Table 5 the averaged power density is calculated at different distances from the patch antenna in free space using two different averaging algorithms (circle and rotating square) for two cases of averaging area ($1cm^2$ and $4cm^2$). The surface discretization was set to 0.1mm. All results were normalized to 20dBm conducted power.

Table 3 Peak spatial SAR and peak SAR values in liquid phantom for three distance-from-antenna cases.

Distance from the antenna	Frequency	Conducted Power	1g SAR	10g SAR	8g SAR	peak SAR
(mm)	GHz	dBm	W/kg	W/kg	W/kg	W/kg
10.0	6.5	20	9.6	2.8	3.2	44.3
5.0	6.5	20	14.9	3.4	4.0	80.1
0.0	6.5	20	16.7	3.2	3.8	102.11

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Table 4 Surface power density at different distances from the antenna as the average over a circular area of 1 cm^2 and 4 cm^2.

	sPD_1.0 cm^2			sPD_4.0cm^2		
Distance (mm)	**sPD_n+**	**sPD_tot+**	**sPD_mod+**	**sPD_n+**	**sPD_tot+**	**sPD_mod+**
2	329.514	418.040	508.631	177.981	242.957	399.276
5	218.685	229.059	259.692	137.907	158.458	201.997
10	130.488	133.715	138.293	91.877	100.922	109.083
20	53.004	53.775	54.073	43.588	46.057	46.816
50	8.509	8.555	8.559	8.166	8.313	8.319
100	2.138	2.378	2.379	2.117	2.357	2.358
150	1.008	1.093	1.093	0.993	1.065	1.065

Table 5 Surface power density at different distances from the antenna as max of a square averaging area 1cm^2 and 4cm^2 which rotates in 5-degree steps.

	sPD_1.0 cm^2			sPD_4.0cm^2		
Distance (mm)	**sPD_n+**	**sPD_tot+**	**sPD_mod+**	**sPD_n+**	**sPD_tot+**	**sPD_mod+**
2	330.412	414.763	516.583	177.256	241.414	399.018
5	217.578	228.055	259.312	136.717	157.100	200.936
10	129.946	133.250	137.927	90.959	100.060	108.275
20	52.867	53.664	53.970	43.245	45.766	46.535
50	8.505	8.552	8.556	8.151	8.302	8.309
100	2.138	2.378	2.379	2.115	2.356	2.357
150	1.008	1.095	1.095	0.996	1.071	1.071

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G Backward field and psPD evaluations for the RP6500V1 source based on the ESR method.

The ESR method enables field propagation on the space surrounding the source. This capability offers a solution for power density evaluations at locations where measurements are restricted due to e.g. geometrical constraints. To validate this capability, ESR is performed using simulated noisy measurement data (-30dB noise level) at a distance of 5mm from the RP6500V1 source, and the reconstructed fields are then evaluated at distances of 2, 3, 4, 5 and 10mm (Fig. 1).

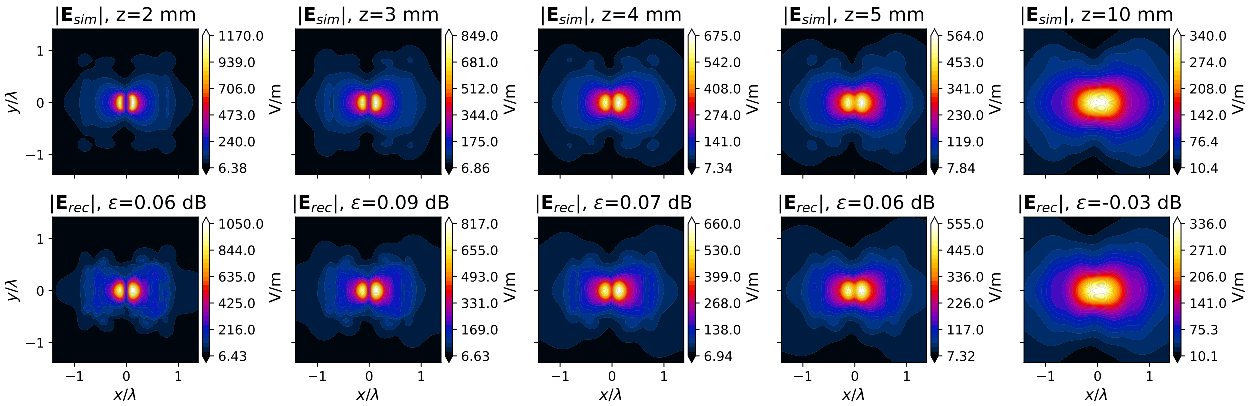

Figure 1: Simulated and reconstructed E-field magnitude at distances of 2, 3, 4, 5 and 10mm from the source. All fields are reconstructed upon application of the ESR method on simulated noisy measurement data (-30dB noise level) at a distance of 5mm from the source. The reported uncertainty ε corresponds to $\Delta psPD_{tot+,1cm^2}$.

Tables 31 and 32 summarize the resulting uncertainty in peak spatial-average power densities derived from these field evaluations and calculated on a circular and a rotating-square averaging geometry, respectively.

Frequency [GHz]	Distance [mm]	$\Delta psPD_{n+,1cm^2}$ [dB]	$\Delta psPD_{tot+,1cm^2}$ [dB]	$\Delta psPD_{mod+,1cm^2}$ [dB]	$\Delta psPD_{n+,4cm^2}$ [dB]	$\Delta psPD_{tot+,4cm^2}$ [dB]	$\Delta psPD_{mod+,4cm^2}$ [dB]
	2	0.16	0.06	0.03	0.15	0.14	-0.04
	3	0.08	0.09	0.13	0.04	0.15	0.06
	4	0.06	0.07	0.12	-0.01	0.11	0.05
	5	0.04	0.06	0.09	-0.03	0.06	0.02
6.5	10	-0.03	-0.03	-0.02	-0.08	-0.06	-0.06
	20	-0.07	-0.07	-0.06	-0.12	-0.1	-0.08
	50	-0.85	-0.18	-0.16	-0.85	-0.18	-0.16
	100	0.49	0.53	0.53	0.43	0.39	0.4
	150	0.15	0.08	0.09	-0.05	-0.1	-0.09

Table 31: Comparison of the evaluated peak spatial-average power densities using a circular averaging geometry w.r.t. the numerical target values for the RP6500V1 source. All fields are reconstructed upon application of the ESR method on simulated noisy measurement data (-30dB noise level) at a distance of 5mm from the source.

ESR also supports non-planar field evaluations. To illustrate this, Figure 2 shows the simulated and reconstructed E-field magnitude on the surface of a phone featuring a camera module. The RP6500V1 source is placed inside the phone case (red block, left plot). The camera module sticks out of the phone surface by 2mm, thereby restricting access to the antenna. All fields are reconstructed upon application of the ESR

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Frequency [GHz]	Distance [mm]	$\Delta psPD_{n+,1cm^2}$ [dB]	$\Delta psPD_{tot+,1cm^2}$ [dB]	$\Delta psPD_{mod+,1cm^2}$ [dB]	$\Delta psPD_{n+,4cm^2}$ [dB]	$\Delta psPD_{tot+,4cm^2}$ [dB]	$\Delta psPD_{mod+,4cm^2}$ [dB]
	2	0.13	0.06	0.08	0.19	0.2	-0.06
	3	0.08	0.09	0.16	0.09	0.21	0.07
	4	0.06	0.06	0.14	0.03	0.14	0.06
	5	0.04	0.05	0.1	-0	0.08	0.03
6.5	10	-0.03	-0.03	-0.02	-0.08	-0.05	-0.05
	20	-0.07	-0.07	-0.06	-0.12	-0.1	-0.08
	50	-0.85	-0.18	-0.17	-0.85	-0.18	-0.17
	100	0.49	0.54	0.54	0.45	0.44	0.45
	150	0.19	0.11	0.12	0	-0.06	-0.05

Table 32: Comparison of the evaluated peak spatial-average power densities using a rotating-square averaging geometry w.r.t. the numerical target values for the RP6500V1 source. All fields are reconstructed upon application of the ESR method on simulated noisy measurement data (-30dB noise level) at a distance of 5mm from the source.

method on simulated noisy measurement data (-30dB noise level) at a distance of 5mm from the phone. The evaluated uncertainties $\Delta psPD_{n+,1cm^2}$, $\Delta psPD_{tot+,1cm^2}$, $\Delta psPD_{mod+,1cm^2}$ using a spherical averaging geometry ($r = 1/\sqrt{\pi}$ cm) are $\{0.19, 0.21, 0.22\}$ dB. The uncertainties $\Delta psPD_{n+,4cm^2}$, $\Delta psPD_{tot+,4cm^2}$ and $\Delta psPD_{mod+,4cm^2}$ using a spherical averaging geometry ($r = 2/\sqrt{\pi}$ cm) are $\{0.05, 0.17, 0.02\}$ dB.

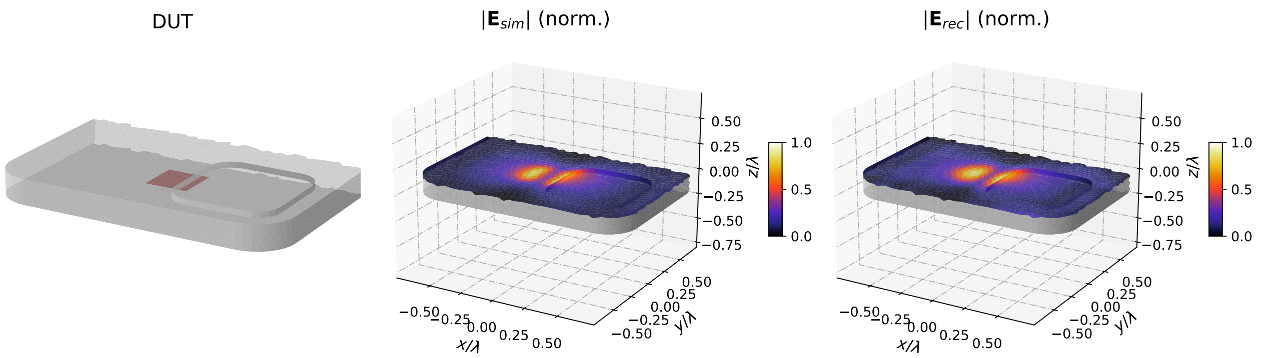

Figure 2: Simulated and reconstructed E-field magnitude (normalized color scale) on the surface (offset by 2mm) of a phone featuring a 2mm thick camera module. The RP6500V1 is located inside the phone case (red block, left plot) and close access to it is restricted by the camera module. All fields are reconstructed upon application of the ESR method on simulated noisy measurement data at a distance of 5mm from the phone.