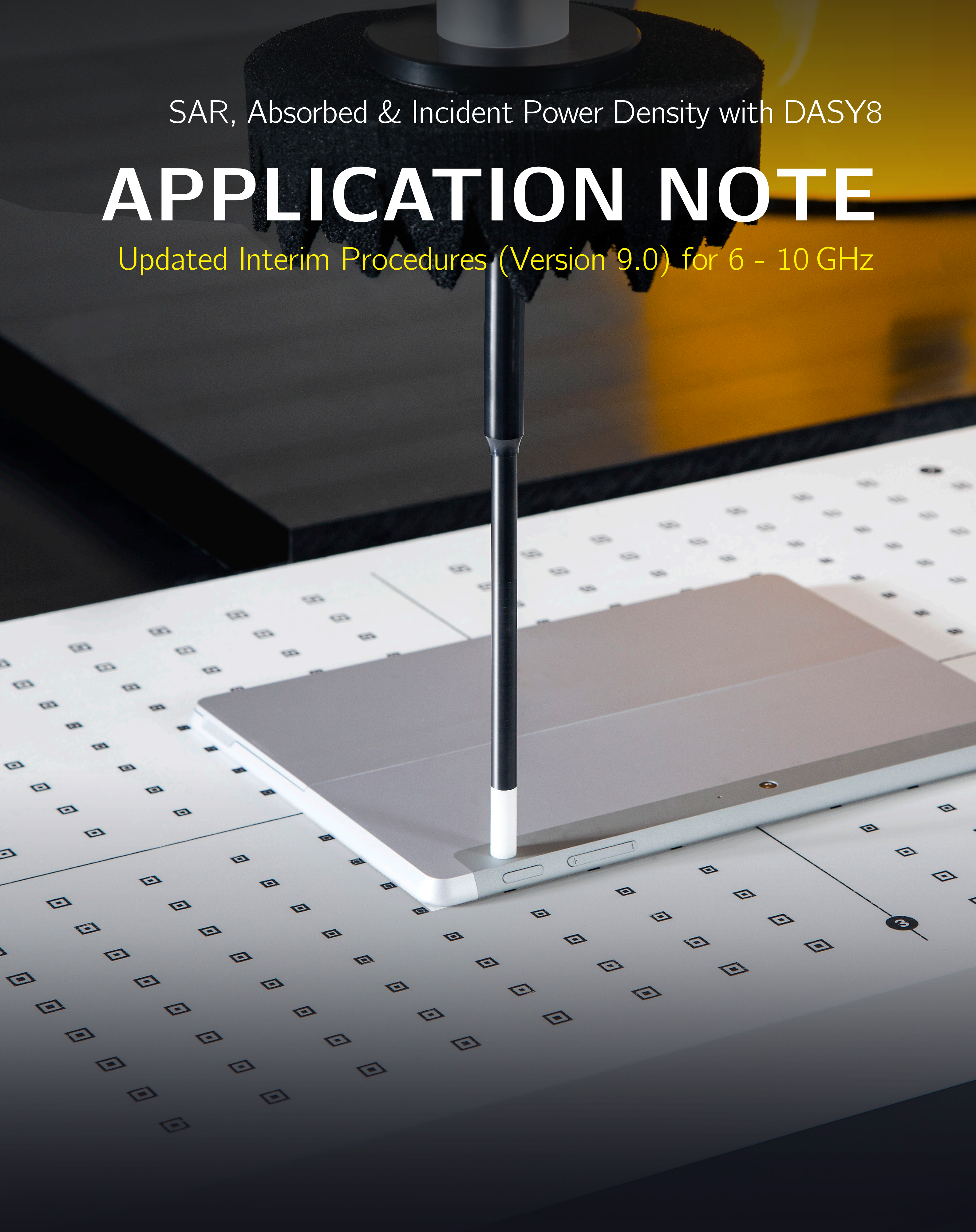
SAR, Absorbed & Incident Power Density with DASY8

APPLICATION NOTE

Updated Interim Procedures (Version 9.0) for 6 - 10 GHz



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Demonstrating Compliance of Devices Operating between 6 – 10 GHz: Updated Interim Procedures (Version 9.0)

1 Introduction

With the opening of the Unlicensed National Information Infrastructure (U-NII) bands above 6 GHz, procedures for assessing the *peak spatial incident Power Density* (*psPD*) compliance testing in the reactive near-field, i.e., at distances smaller than $\lambda/5$, is required. SPEAG and the IT'IS Foundation (Zurich, Switzerland) have joined forces in a research collaboration to develop novel methods for compliance testing of devices operating between 6 – 10 GHz. The first report was published in October 2020 and provided a workaround for distances smaller than $\lambda/5$ [6] using the developed Plane-to-Plane Phase Reconstruction (PTP-PR) Algorithm used in Module mmWave V2.x. However, the required measurement effort and the resulting uncertainties were not satisfactory.

Recently, SPEAG and IT'IS achieved a breakthrough by developing a novel equivalent source reconstruction (ESR) algorithm, that models an unknown and inaccessible transmitter as a set of distributed known auxiliary sources below the surface of the device enclosure. The positions, amplitudes, and phases of these sources are then determined to reconstruct the measured near-fields optimally. As a result, the transmitters inside any enclosure can be replaced with these equivalent sources in any radiation problem, including exposure assessment scenarios. This method is published [9] and implemented in DASY8 Module mmWave V3.2 and Sim4Life V7.2.

In parallel to this development, regulators have started to use the dosimetric quantity *peak spatial Absorbed Power Density* (psAPD) instead of the incident psPD [8] as a limit. Within a short time, the International Electrotechnical Commission (IEC) reacted and developed the Publicly Available Specifications (PAS) entitled "Conversion Method of Specific Absorption Rate (SAR) to Absorbed Power Density for the Assessment of Human Exposure to Radio Frequency Electromagnetic Fields from Wireless Frequency Electromagnetic Fields from Wireless Devices in Close Proximity to the Head and Body-Frequency Range of 6 GHz to 10 GHz.".

This application note describes practical guidelines and testing procedures for demonstrating compliance of devices transmitting at frequencies between 6 – 10 GHz. They are consistent with the interim procedures introduced by the Federal Communications Commission (FCC) during the Telecommunications Certification Body (TCB) workshop in October 2020 and last updated in October 2022.

The measurement procedures described in this Application Note also apply to DASY6 users.

2 Hardware & Software Requirements

2.1 SAR / APD

Required Component	Compatible Model	Remarks
Hardware		
Probe	EX3DV4	Additional calibration required for 6 – 10 GHz (frequency validity extended to ±700 MHz)
Phantoms	SAM & ELI	–
Tissue Simulating Liquid	HBBL600-10000V6	–
Dipoles	D6.5GHzV2, D7GHzV2 D8GHzV2 and D9GHzV2	Calibrated for HSL at respective frequencies
Software		
Software	Module SAR V16.2+	Includes advanced extrapolation and APD

Table 1.1: Hardware and software components required for SAR / APD measurements at 6 – 10 GHz

2.2 PD

Required Component	Compatible Model	Remarks
Hardware		
Probe	EUmmWVx	Calibrated from 0.75 – 110 GHz
Phantom	mmWave	–
Verification Source	5G Verification Source 10 GHz	Calibrated at 10 GHz
Software		
Software	Module mmWave V3.2.2+	Includes PD evaluations with equivalent source reconstruction

Table 1.2: Hardware and software components required for *PD* measurements at 6 – 10 GHz

3 Interim Procedures for FCC Radiofrequency Exposure Evaluations

The interim procedure for FCC radiofrequency (RF) exposure evaluations of U-NII 6–7 GHz band portable devices have been made available during the TCB workshop in October 2020. The procedure is summarized below:

- evaluate SAR / APD with DASY8 Module SAR V16.2 or higher according to [3]. The configurations to be tested are defined in the relevant Knowledge Database (KDB). The peak spatial averaged SAR (psSAR) and the peak spatial averaged absorbed Power Density (psAPD) are reported.
- for the configuration with the highest SAR / APD, evaluate the PD with DASY8 Module mmWave V3.2.2 or higher.

4 SAR / APD Measurements with DASY8 Module SAR

This section describes how to perform SAR / APD measurements according to the IEC/IECC 62209-1528:2020 [3]. It is the first step of the interim procedure for FCC RF exposure evaluations of U-NII 6–7 GHz band portable devices. The procedure is very similar to the one used for devices operating below 6 GHz.

4.1 Tissue Simulating Liquid (TSL)

Frequency (MHz)	**Permittivity (ε)**	**Conductivity (S/m)**
6500	34.5	6.07
7000	33.9	6.65
8000	32.7	7.84
9000	31.6	9.08

Table 1.3: Dielectric target values for Head Simulating Liquid (HSL) media according to [3]

SPEAG's head broad band liquid 600–10000 (HBBL600–10000Vx) meets the outlined dielectric parameters (Table 1.3) with a maximum deviation of less than $\pm 10\%$.

4.2 Probe Calibration

At frequencies above 6 GHz, the probe conversion factor is valid over a large frequency range (typically ± 700 MHz) and the dielectric parameters of the TSL are changing rapidly with the frequency. In the 6 - 10 GHz frequency range, the dielectric parameters (ε, σ) range for which the probe conversion factor is valid is adjusted to the measurement frequency as described in Equation 1.1:

$$\begin{aligned} 0.9*(\sigma+1.23*\Delta_f) < \sigma < 1.1*(\sigma+1.23*\Delta_f) \\ 0.9*(\varepsilon-1.18*\Delta_f) < \varepsilon < 1.1*(\varepsilon-1.18*\Delta_f) \end{aligned} \tag{1.1}$$

where:

σ = conductivity of the TSL in S/m
ε = permittivity of the TSL
Δ_f = measurement frequency - calibration frequency in GHz

4.3 System Performance Check and System Validation

Four dipoles and the P6500 antenna have been developed for system check purposes. The sipoles are suited for SAR system verification checks and validation while the P6500 offers a dual purpose for SAR as well as mmWave systems checks and validation measurements.

4.3.1 Dipole System Check and Validation Sources

The dipoles consist of: D6.5GHzV2, D7GHzV2, D8GHzV2, and D9GHzV2 (see Figure 1.1). The spacer, which has a nominal thickness of 5 mm ±0.1 mm in the 6 – 10 GHz frequency range, is integral to the antenna. The updated numerical psSAR / psAPD target values for these dipoles are summarized in Table 1.4.

Freq (MHz)	**Shell (mm)**	**psSAR1g (W/kg)**	**psSAR8g (W/kg)**	**psSAR10g (W/kg)**	**psAPD$^{SAR}_{1cm^2}$ (W/m^2)**	**psAPD$^{SAR}_{4cm^2}$ (W/m^2)**	**psAPD$^{sqr}_{1cm^2}$ (W/m^2)**	**psAPD$^{sqr}_{4cm^2}$ (W/m^2)**
6500	2.0	298	64.6	52.8	$2.98 \cdot 10^3$	$1.29 \cdot 10^3$	$3.32 \cdot 10^3$	$1.30 \cdot 10^3$
7000	2.0	286	59.7	48.7	$2.86 \cdot 10^3$	$1.19 \cdot 10^3$	$3.15 \cdot 10^3$	$1.20 \cdot 10^3$
8000	2.0	273	54.6	44.5	$2.73 \cdot 10^3$	$1.09 \cdot 10^3$	$2.93 \cdot 10^3$	$1.09 \cdot 10^3$
9000	2.0	240	49.0	39.3	$2.40 \cdot 10^3$	$0.98 \cdot 10^3$	$2.55 \cdot 10^3$	$0.96 \cdot 10^3$

Table 1.4: Updated numerical target psSAR / psAPD derived from the SAR (psAPD^{SAR}), and the directly determined numerical psAPD^{sqr} target values for the 6 – 10 GHz system-check dipoles at the nominal distance to the Flat phantom. The psAPD^{sqr} is evaluated using a rotating square as averaging area as specified in [4] whereby the numerical modeling uncertainty is 0.34 dB (the deviations compared to the previous values are less than 0.17 dB). Calibrated values are provided in the calibration certificate.

Figure 1.1: Two of the four dipoles (i.e., D7GHzV2 and the D9GHzV2) used for system performance checks in the frequency range between 6 – 10 GHz

System performance checks are performed with the dipole which operates at the closest frequency of the measurement frequency following the procedures defined in [3], see Section A.2 / A.5.

System validation is performed using the procedures of [3] except for the measurement with a 2 cm transverse offset from the feed-point, as the exposure is too localized to provide meaningful results at that offset, i.e., local SAR <<-20 dB of peak SAR (see Section A.3.5 b) of [3]).

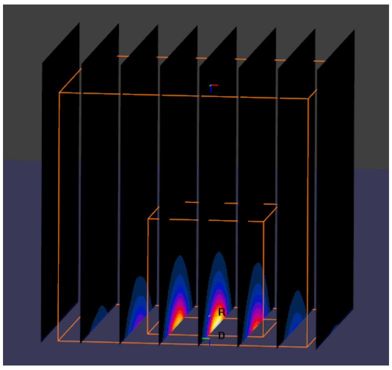


Figure 1.2: SAR Distribution of a D6.5GHzV2 system dipole

4.3.2 P6500V2 Verification and Validation Source

After the release of the WiFi bands above 6 GHz, customers and regulators asked for a more universal system check/validation source that:

- is more representative of actual transmitter structures in this frequency range.
- is suited for both SAR/APD and PD.

To meet this demand, SPEAG developed a new coaxial-fed rectangular patch source operated at 6500 MHz (P6500V2)[1]. The psSAR and psAPD are measured at 5 mm using the designated spacer. The numerical target values for the P6500V2 are given in [10].

Figure 1.3: P6500V2 positioned under the Flat phantom for SAR/APD system check

[1]Note: The source is not yet part of the standards, but the design and the target values will be forwarded to the corresponding IEC working groups as well as to the regulatory bodies.

4.4 Measurement Procedure

The measurement procedure used to assess the SAR below 6 GHz remains valid for frequencies up to 10 GHz. The following scans are performed:

- a Fast Area Scan to define the most appropriate location for the power reference point used in the subsequent scans
- an Area Scan to determine the location of the maximum SAR
- a Zoom Scan anchored at the maximum location of the Area Scan. SPEAG recommends using the *Smart Zoom Scan* as the measurement grid will be refined on the fly to fulfill the Zoom Scan grid resolution described in [3].

For frequencies above 6 GHz, the DASY8 Module SAR Zoom Scan results provide the *psSAR* averaged over 1g, 8g, and 10 g ($psSAR1g/8g/10g$) as well as the absorbed *psAPD* averaged over $1cm^2$ and $4cm^2$ ($psAPD1cm^2/4cm^2$). Both quantities must be reported to the regulators.

4.5 Experimental Uncertainty for APD Evaluations

4.5.1 APD System Check and Validation

System check and validation are performed with dipoles. Their numerical targets have been computed following the requirements described in [3].

The uncertainty of the experimental evaluation of the psAPD of Table 1.5 is assessed according to [3, 5] for DASY8. The expanded standard uncertainty of the experimental evaluations is ±29.0% (1 cm^2) and ±28.8% (4 cm^2), which corresponds to 1.1 dB. Note that the SAR assessment uncertainty for 8 g is the same as for 10 g.

Uncertainty Budget for psSAR / psAPD System Check
(Frequency band: 6 – 10 GHz range)

Symbol	Error Description	Uncert.	Prob. Dist.	Div.	c_i (1g) / (1 cm^2)	c_i (8 g/10 g) / (4 cm^2)	Std. Unc. (1 g) / (1 cm^2)	Std. Unc. (8 g/10 g) / (4 cm^2)
psSAR	Module SAR V16.2 (Table 6.2.3)	±13.2%	N	1	1	1	±13.2%	±13.2%
PDC	Power Density Conversion	±13.5%	R	$\sqrt{3}$	0.8^D	0.8^D	±6.2%	±6.2%
u(ΔSAR)	Combined Uncertainty						±14.6%	±14.6 %
U	**Expanded Uncertainty**						±29.2%	±29.2%

Table 1.5: Uncertainty of a system validation (6 – 10 GHz) using DASY8 Module SAR V16.2 or higher according to [5]. The RF ambient noise uncertainty has been reduced to ±1.0, considering input power levels are ≥250 mW. All listed error components have v_{eff} equal to ∞.
Footnote details: ^{D} valid for system check dipoles.

4.6 APD Assessments

The uncertainty of the experimental evaluation of the psAPD of Table 1.6 is assessed according to [3, 5] for DASY8. The expanded standard uncertainty of the experimental assessment of any device under test (DUT) is 1.2 dB.

Uncertainty Budget for psSAR / psAPD Assessments
(Frequency band: 6 – 10 GHz range)

Symbol	Error Description	Uncert.	Prob. Dist.	Div.	c_i (1g) / (1 cm^2)	c_i (8 g/10 g) / (4 cm^2)	Std. Unc. (1 g) / (1 cm^2)	Std. Unc. (8 g/10 g) / (4 cm^2)
psSAR	Module SAR V16.2 (Table 6.3.3)	±14.2/14.1%	N	1	1	1	±14.2%	±14.1%
PDC	Power Density Conversion	±13.5%	R	$\sqrt{3}$	1	1	±7.8%	±7.8%
u(ΔSAR)	Combined Uncertainty						±16.2%	±16.1 %
U	**Expanded Uncertainty**						±32.4%	±32.2%
	in dB						±*1.2 dB*	±*1.2 dB*

Table 1.6: Uncertainty of psAPD assessments for devices operating between 6 – 10 GHz using DASY8 Module SAR V16.2 or higher according to [5]. All listed error components have v_{eff} equal to ∞.

5 PD Measurements with DASY8 Module mmWave

The incident PD must be measured for the test configuration producing the highest SAR value. It involves the following procedure:

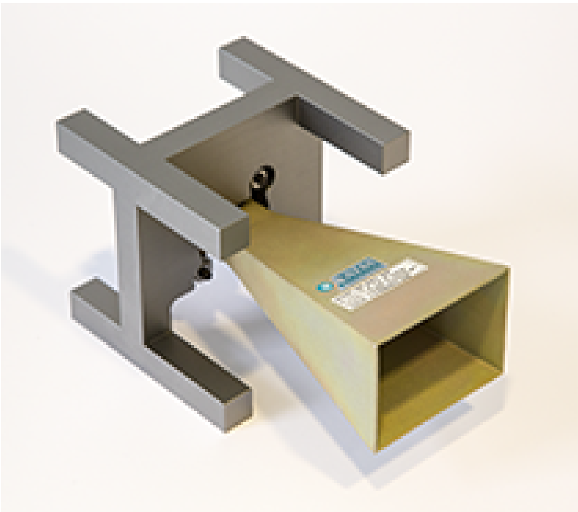
- perform a system performance check at the chosen frequency
- measure the DUT at the required test distances

Note that there is no need to adjust the incident psPD results since the total uncertainty is below 2 dB for test distances larger than $\lambda/25$.

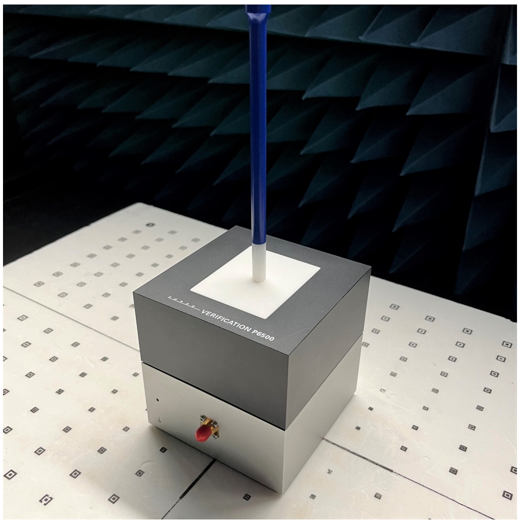
5.1 System Performance Check

System checks are performed with the 5G Verification Source 10 GHz (see Figure 1.4a) or with the P6500[2] (see Figure 1.4b). The measurement procedure is described in Section A.3 of [4].

System checks are usually performed with an input power to the antenna of 20 dBm. The automatic grid step calculated from the test distance and measurement frequency is used. SPEAG recommends using the auto-extend feature to cover - 15 dB from the maximum E-field.



(a) Verification Source 10 GHz



(b) P6500V2

Figure 1.4: System Check Antennas for U-NII bands above 6 GHz

5.2 Incident PD Assessment

In Module mmWave V3.2.2 and higher, the default grid step is calculated from the measurement distance and test frequency. The grid extents should be -15 dB from the maximum E-field, which can easily be achieved using the auto-extend feature.

In V3.2.2 and above, users can choose between two reconstruction modes. The mode selection is available under Application Preferences » Post Processing Settings (see Figure 1.5):

- Hybrid: the ESR algorithm will be used for measurements $\leq$ 24 GHz and the PTP-PR algorithm above $>$ 24 GHz
- ESR: the ESR algorithm will be used at any measurement frequency.

[2] Note: The source is not yet part of the standards, but the design and the target values will be forwarded to the corresponding IEC working groups as well as to the regulatory bodies.

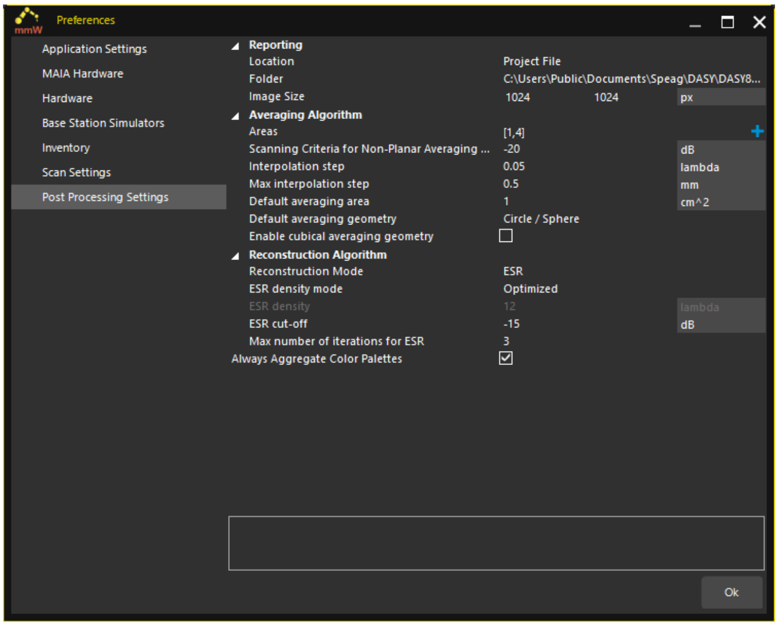


Figure 1.5: Reconstruction Mode Selection

The selection is irrelevant in the 6-10 GHz range since ESR will be used in both modes.

6 Conclusion

This application note illustrates how to use DASY8 for FCC RF exposure evaluations of U-NII 6–7 GHz band portable devices or according to the procedures presented during the TCB workshop in October 2022.

Bibliography

[1] IEEE PC95.1/D3.3 *Draft Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic and Electromagnetic Fields, 0 Hz to 300 GHz*, 2019

[2] ICNIRP, *Draft ICNIRP Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz)*, Health Physics, 2019

[3] IEC/IEEE 62209-1528:2020, *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 - Part 1528: Human models, instrumentation and procedures (Frequency range of 4 MHz to 10 GHz)*, October 2020.

[4] 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*, CFDIS, September 2021.

[5] IEC PAS 63446:2022 ED1, *Conversion method of specific absorption rate to absorbed power density for the assessment of human exposure to radio frequency electromagnetic fields from wireless devices in close proximity to the head and body - Frequency range of 6 GHz to 10 GHz.*

[6] Kristian Cujia, Leif Klysner, Arya Fallahi, Andreas Christ, Niels Kuster, *Solutions for Testing Compliance of Devices Operating between 6 – 10 GHz with DASY6*, preliminary report, October 2020.

[7] E. Carrasco, D. Colombi, K. R. Foster, M. C. Ziskin, Q. Balzano, Exposure Assessment of Portable Wireless Devices above 6 GHz. Radiat Prot Dosimetry. 2019 Jun 1;183(4):488-495. doi: 10.1093/rpd/ncy177. PMID: 30289490.

[8] Supplementary Procedure for Assessing Specific Absorption Rate & Absorbed Power Density Compliance of Portable Devices in the 6 GHz Band (5925-7125 MHz), ISED SPR-APD, Issue 1, November 2021.

[9] K. S. Cujia, A. Fallahi, S. Reboux and N. Kuster, "Experimental Exposure Evaluation From the Very Close Near- to the Far-Field Using a Multiple-Multipole Source Reconstruction Algorithm," in IEEE Transactions on Antennas and Propagation, vol. 70, no. 9, pp. 8461-8472, Sept. 2022, doi: 10.1109/TAP.2022.3177564..

[10] Validation of DASY8/6 Module mmWAVE V3.2 and Module SAR V16.2 at 6500MHz with P6500V2, Including Establishment of Target Values.

Appendix

ITIS FOUNDATION	Project	Document Name	Rev.
	I20211013	**IRR-20211013**	**6**

Numerical Target Values of System Check and Validation Dipole Antennas 6.5 GHz to 9 GHz

	Name	**Function**	**Date**	**Signature**
Author	Andreas Christ	External Consultant	Oct 21, 2021	
Approval	Niels Kuster	Quality Manager. Director	Oct 21, 2021	

IT'IS FOUNDATION
Foundation for Research on Information Technologies in Society

Prof. Dr. Niels Kuster
Director, IT'IS Foundation
Professor, Swiss Federal Institute of Technology – ETH Zurich
Phone +41 44 245 9690 · kuster@itis.swiss

Numerical Target Values of System Check and Validation Dipole Antennas 6.5 GHz to 9 GHz

conducted by

Andreas Christ, Erdem Ofli and Theodore Samaras

Zurich, October 21th, 2021

Executive Summary

Recently, a method was proposed to obtain the peak spatial average absorbed power density (psAPD) at the surface of a lossy medium from the evaluation of the peak spatial average SAR. The method was validated using dipole antennas from 6.5 GHz to 9.0 GHz as well as dipole and slot array antennas. The target values were obtained for a circular averaging area. As the final draft of [1] specifies a rotating square as averaging area, the psAPD values were reevaluated. The deviations of the reevaluated results with respect to the previous ones using the circular averaging area are found to be less than 0.04 dB. The maximum deviations from the results converted from psSAR are 0.43 dB, which are in-line with the values reported in [2]. The expanded numerical standard uncertainty has been evaluated as 0.34 dB. The expanded experimental standard uncertainty for the APD assessment of the system check dipoles has been reassessed to 1.1 dB.

Contents

1 Objectives

The objective of this short report is to provide validated numerical target results for the absorbed power densities for the dipoles for system performance check and validation operating at 6.5, 7, 8 and 9 GHz that are compliant with the performance specifications of the standards [3, 4]. The dipoles are evaluated numerically, and the peak average spatial absorbed power density (psAPD) at the phantom bottom is evaluated following [1,4]. The numerical evaluations are complemented by measurements using the dosimetric assessment system DASY8 (SPEAG, Zurich, Switzerland). The numerical uncertainty is evaluated by adapting the methods of [1,5], and the assessment of the experimental uncertainty follows [4].

2 Methods

2.1 Numerical Model and Simulations

Numerical models of the dipoles for system check and validation specified for the frequencies from 6.5 GHz to 9.0 GHz in [3] are generated based on the original drawings. These models consider the feed of the dipole through the dipole leg made of coaxial semi-rigid. The models are simulated at a flat phantom with a lossless dielectric shell ($\varepsilon_r = 3.7$) and the dielectric spacer according to the manufacturer's specifications. All simulations are carried out using the finite-difference time-domain method [6] and the simulation platform Sim4Life, Versions 5.0.0 and 6.2.1 (ZMT Zurich MedTech AG (ZMT), Switzerland).

The impact of the numerical parameters, such as mesh resolution, simulated time, distance to absorbing boundary conditions, etc., was adapted iteratively until convergence of the numerical results was reached. The peak spatial average specific absorption rate (psSAR) was evaluated according to [5]. The peak spatial average absorbed power density (psAPD) at the tissue surface was integrated over circular averaging areas of 1 cm^2 and 4 cm^2 following the dimensions given in [7, 8] using the implementation of Sim4Life Version 5.0.0. The circular averaging area was used as the averaging algorithm of the final draft of [1] had not been finalized at the time of the evaluation. Additional results applying the rotating square as averaging area that is defined in the final draft of [1] have been evaluated with Sim4Life Version 6.2.1 and added to this report (Section 3).

2.2 Evaluation of the psAPD Based on the psSAR

The efficient evaluation of the psAPD from psSAR results has recently been demonstrated in [2]. Conversion factors (CF) can be applied to calculate the psAPD from the psSAR provided that the psSAR is evaluated in a cube with the same surface area as the averaging area for the psAPD. Conversion factors of $\mathrm{CF}_{1\mathrm{g}} = 10\,\mathrm{kg/m}^2$ and $\mathrm{CF}_{8\mathrm{g}} = 20\,\mathrm{kg/m}^2$ to calculate the 1 cm^2 and 4 cm^2 from the 1 g psSAR and the 8 g psSAR, respectively. The uncertainty of this conversion has been quantified with less than 0.55 dB [2]. Based on this method, JWG12 of the IEC TC106 has initiated the development of a Publicly Available Specification for the assessment of the psAPD using SAR measurements for the frequency range from 6 GHz to 10 GHz.

3 Results

Table 1 shows the simulated results of for the psAPD of the dipole antennas for the frequency range from 6.5 GHz to 9.0 GHz in comparison to the values obtained from the psSAR according to [2]. The maximum deviation of the converted results from the simulated ones is 0.47 dB. The psSAR results according to [5] are given in Table 2.

Updated psAPD results that have been determined applying the rotating square as averaging area as specified in [1] are given in Table 3. Differences between these and the results evaluated with the circular averaging volume (Table 1) are less than 0.04 dB. The deviations with respect to the values converted from the psSAR are also within 0.47 dB. In general, a reduction of the uncertainty of the evaluation of the psAPD by conversion from the psSAR according to [4] can be observed when the frequency increases, which is due to the higher penetration depth. I.e., an increasing part of the electromagnetic energy is absorbed in the psSAR averaging volume.

The experimental results are within the mutual uncertainty of the applied numerical and experimental methods (Sections 4 and 5). They are not reported here.

Table 1: psAPD evaluated from the psSAR according to [2,4] and integrated from the surface power density of the numerical simulation results

	converted from psSAR		simulated, circular		deviations	
frequency /(GHz)	1 cm^2 /($kW/m^2/W$)	4 cm^2 /($kW/m^2/W$)	1 cm^2 /($kW/m^2/W$)	4 cm^2 /($kW/m^2/W$)	1 cm^2 /(dB)	4 cm^2 / (dB)
6.5	2.98	1.29	3.32	1.30	0.47	0.02
7.0	2.86	1.19	3.15	1.20	0.41	0.00
8.0	2.73	1.09	2.93	1.09	0.31	-0.01
9.0	2.40	0.98	2.55	0.96	0.27	-0.07

Table 2: psSAR evaluated according to [5] for the same dipoles. The values in brackets shows the values reported earlier in [3]. The deviation of up to 0.17 dB corresponds to the numerical modeling uncertainty of 0.34 dB.

frequency /(GHz)	1 g psSAR /(W/kg)	8 g psSAR /(W/kg)	10 g psSAR /(W/kg)
6.5	298.4	64.6	52.8
7.0	286.0 (275.0)	59.7	48.7 (47.0)
8.0	273.1	54.6	44.5
9.0	239.5 (243.0)	49.0	39.3 (40.0)

Table 3: psAPD evaluated using a rotating square as averaging area specified in [1]

	converted from psSAR		simulated, rotating square		deviations	
frequency /(GHz)	$1\,cm^2$ /(kW/m^2/W)	$4\,cm^2$ /(kW/m^2/W)	$1\,cm^2$ /(kW/m^2/W)	$4\,cm^2$ /(kW/m^2/W)	$1\,cm^2$ /(dB)	$4\,cm^2$ / (dB)
6.5	2.98	1.29	3.30	1.29	0.43	0.00
7.0	2.86	1.19	3.12	1.19	0.38	-0.01
8.0	2.73	1.09	2.92	1.09	0.29	-0.03
9.0	2.40	0.98	2.54	0.96	0.25	-0.08

4 Numerical Uncertainty for Target Values

The uncertainty of the numerical psAPD of Table 3 is estimated with methods that generally follow [1, 5] and have been adapted to the particular requirements of the numerical setup of the dipole antennas and the phantom. The uncertainty budget is given in Table 4. The expanded standard uncertainty of the numerical evaluations is ±8% (0.34 dB).

As the numerical uncertainty is assumed to increase for higher frequencies, the uncertainty assessment is carried out for the dipole and phantom setup for 9 GHz. For the evaluation of the uncertainty components, the deviations of the 1 cm^2 and 4 cm^2 psAPD are evaluated separately. The maximum deviation is reported in Table 4 to achieve a conservative estimate of the uncertainty. In detail, the uncertainty components are evaluated as follows:

- **Mesh resolution:** The maximum mesh steps of the dipole antenna and of the area in which the psSAR and the psAPD are averaged are reduced to 50% of their default values.
- **Positioning:** The distance between dipole and phantom is changed by ±1 mesh step.
- **Phantom dimensions:** The overall length and width of the phantom are increased by 25% with respect to their default dimensions.
- **Shorting cylinder:** The length of the shorting cylinder of the dipole has been modified by $\lambda/4$ and terminated both in free space and in the absorbing boundary conditions of the computational domain.
- **Absorbing boundary conditions:** The computational domain has been increased by $\lambda/4$ in all directions with respect to its original dimensions.
- **Power budget:** The deviation of the sum of the radiated and total dissipated power from the antenna feedpoint power is reported.
- **Convergence:** The total simulated time has been reduced by 30% with respect to the reference simulation. The deviation is reported.
- **Power density averaging:** [4] does not specify a method for the calculation of the psAPD. The values in Table 4 are calculated by evaluating the $\mathrm{psPD_{n+}}$ at the interface of the tissue simulant and the phantom shell according to [1]. This calculation is affected by interpolation uncertainties due to the finite mesh spacing. These interpolation uncertainties are assessed by comparing $\mathrm{psPD_{n+}}$ to $\mathrm{psPD_{tot+}}$. An average value for the observed deviations is reported.

Numerical Uncertainty Budget

Error Description	Uncert. value	Prob. Dist.	Div.	(c_i)	Std. Unc. (max. of 1 cm^2 and 4 cm^2)	(v_i) v_{eff}
Mesh resolution phantom	2.0%	N	1	1	2.0%	∞
Mesh resolution dipole	0.1%	N	1	1	0.1%	∞
Positioning (dist. dipole - phantom)	4.0%	R	$\sqrt{3}$	1	2.3%	∞
Phantom dimensions	0.2%	R	$\sqrt{3}$	1	0.1%	∞
Shorting cylinder	0.1%	N	1	1	0.1%	∞
Absorbing boundary conditions	0.3%	R	$\sqrt{3}$	1	0.2%	∞
Power budget	2.7%	N	1	1	2.7%	∞
Convergence	0.3%	R	$\sqrt{3}$	1	0.2%	∞
Power density averaging	6.6%	N	1	1	6.6%	∞
Combined Std. Uncertainty					±4 %	∞
Expanded STD Uncertainty					**±8 % (0.34 dB)**	∞

Table 4: Numerical uncertainty budget of the evaluation of the psAPD (Table 3) adapted from [1, 5].

5 Experimental Uncertainty for APD System Check

The uncertainty of the experimental evaluation of the psAPD of Table 5 is assessed according to [3, 4] for DASY8/6. The expanded standard uncertainty of the experimental evaluations is ±29.0% (1 g) and ±28.8% (8 g), which corresponds to 1.1 dB .

Uncertainty Budget for APD System Check
(Frequency band: 6 GHz–10 GHz **range)**

Symbol	Error Description	Uncert. value	Prob. Dist.	Div.	c_i (1 g)	c_i (10 g)	Std. Unc. (1 g)	Std. Unc. (8 g)
psSAR	Module SAR V16.2 (Table 6.2.3)	±13.1%	N	1	1	1	±13.1%	±13.0%
PDC	Power Density Conversion	±13.5%	R	$\sqrt{3}$	0.8 ^{D}	0.8 ^{D}	±6.2%	±6.2%
u(ΔSAR)	Combined Uncertainty						±14.5%	±14.4%
U	**Expanded Uncertainty**						±29.0%	±28.8%

Table 5: Uncertainty of a system validation (6 GHz–10 GHz) using DASY8/6 Module SAR V16.2 or higheraccording to [4]. The RF ambient noise uncertainty has been reduced to ±1.0, considering input power levels are ≥250 mW. All listed error components have v_{eff} equal to ∞.
Footnote details: ^{D} valid for system check dipoles.

6 Conclusions

The 1 cm^2 and 4 cm^2 psAPD of the dipole antennas for system check and validation for frequencies from 6.5 GHz to 9.0 GHz [3] has been reevaluated applying the average algorithm for the power density using a rotating square area as specified in [1]. The new results are compared to those converted from the numerical psSAR evaluation proposed in [2]. The deviations with respect to the previous evaluation using a circular averaging area are found to be less than 0.04 dB. The maximum deviations from the results converted from psSAR are 0.47 dB, which corresponds to the values reported in [2], previously.

The numerical uncertainty has been evaluated as 0.34 dB, and the experimental uncertainty has been evaluated as 1.1 dB. It should be noted that one of the major contributing factors of the numerical uncertainty budget is the power density averaging according to [1]. This method has originally been specified for the averaging of the incident power density in free space. It is expected that the numerical uncertainty due to the averaging can be reduced when [4] specifies an averaging algorithm with improved interpolation at the dielectric interface of the phantom shell and the tissue simulant.

Andreas Christ, Erdem Ofli and Theodore Samaras, Zurich, October 21th, 2021

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