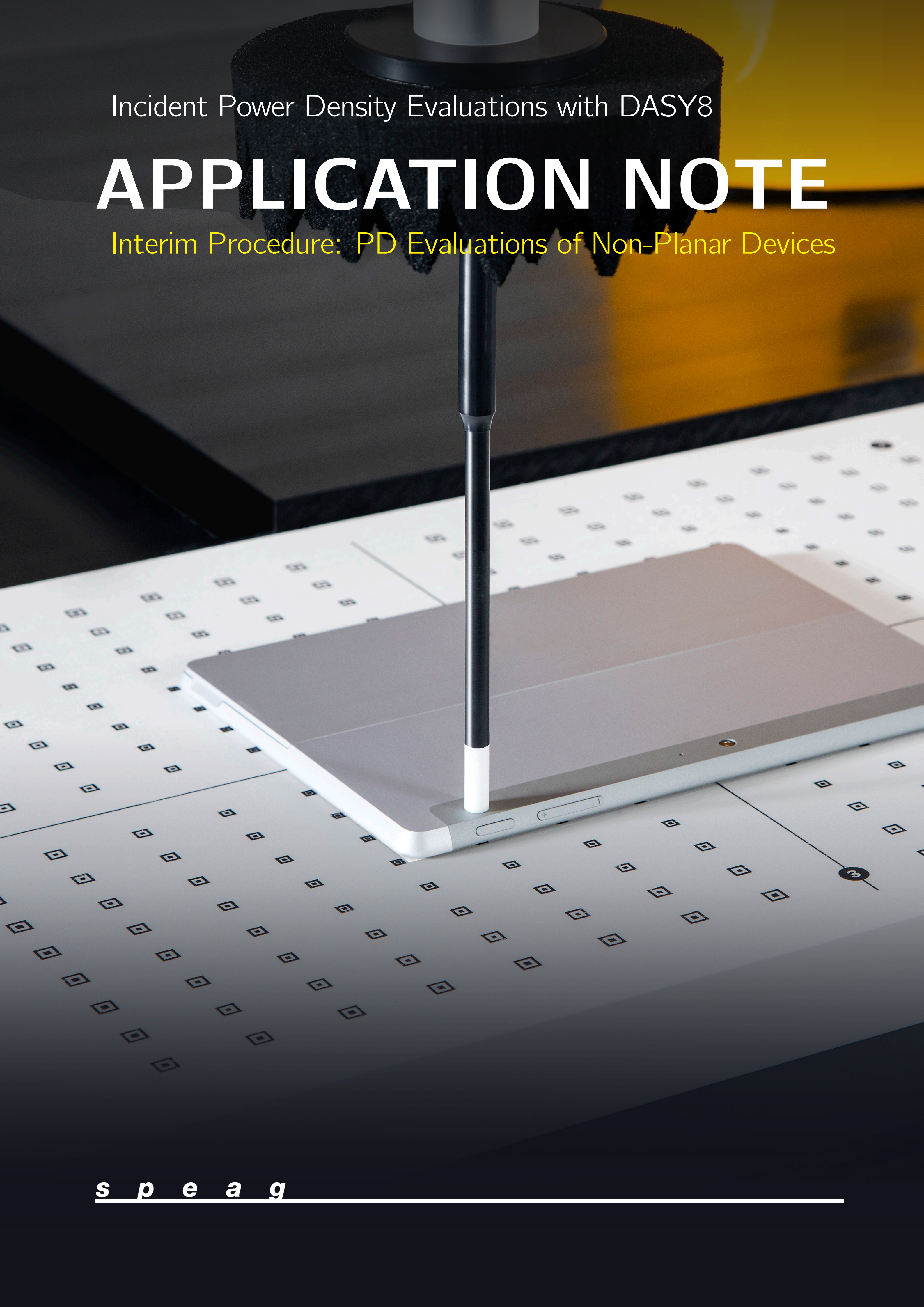
Incident Power Density Evaluations with DASY8

APPLICATION NOTE

Interim Procedure: PD Evaluations of Non-Planar Devices



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Interim Procedure: Incident Power Density Evaluations of Non-Planar Devices, e.g., Camera Modules

1 Introduction

Modern wireless devices that transmit at frequencies above 6 GHz (Wi-Fi 6E, 5G NR FR2...) must be tested for compliance with the peak spatial incident power density ($psPD$) regulatory limits with DASY8 Module mmWave.

The purpose of this Application Note is to provide additional guidance for testing compliance of devices that have non-planar outer shells. The measurement procedure is illustrated with a smartphone that has an extruding camera module as an example, but it can be applied to any device. The proposed method is illustrated with a subset of the validation sources listed in the IEC/IEEE 63195-1 standard [1].

The measurement procedure described in this Application Note also applies to DASY6 users.

2 Equivalent Source Reconstruction Algorithm

Recently, SPEAG and IT'IS achieved a breakthrough by developing a novel equivalent source reconstruction (ESR) algorithm that can model 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 on the basis of advanced non-linear optimizers.. 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 has been published [2] and implemented in DASY8 Module mmWave V3.2.2.

The ESR algorithm offers major improvements compared to the previously used plane-to-plane phase reconstruction (PTP-PR) method:

- The uncertainty of the reconstruction (REC term in [1]) for $psPD$ assessments is 0.6 dB for evaluation distances as close as $\lambda/25$ to the device under test (DUT).
- The method enables not only forward but also backward transformations in the near-field as well as spatial incident power density (sPD) evaluations along non-planar surfaces, e.g., conformal surfaces.

The full set of features developed for evaluation of the sPD on any arbitrary surface will become available with V4.0, the release of which had to be postponed until Q32024. We are releasing this Application Note describing an interim procedure to provide a solution for the most important applications before the release of V4.0.

3 Typical Applications

Most modern smartphones are thin and have an extruding camera module. In cases where the antenna is operating at mmWave frequencies and is located near the camera module, the *sPD* evaluation surface needs to follow the geometry of the DUT.

Figure 1.1 shows the *sPD* evaluation surface for a smartphone with a typical form factor. The antenna (black patch) is located near the camera module. The evaluation surface (red line) is located 2 mm from and follows the contour of the smartphone surface.

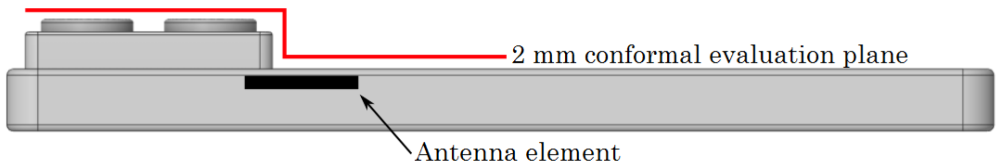


Figure 1.1: *sPD* evaluations conformal to the surface of the DUT.

4 Hardware and Software Requirements

This section lists the hardware and software components required for implementation of the measurement procedure described in this Application Note.

Required Component	Compatible Model	Remarks
Hardware		
Probe	EUmmWVx	Calibrated from 0.75 – 110 GHz
Phantom	mmWave	–
Verification Source	5G Verification Source	Calibrated at transmit frequency
Software		
Module	Module mmWave V3.2.2+	Includes PD evaluations with equivalent source reconstruction
Option	B/FTE	Enables backward/forward projections

Table 1.1: Hardware and software components required for incident *PD* measurements.

5 Interim Measurement Procedures

Conformal evaluations of DUTs are complex, since they require an accurate computer-aided design (CAD) model of the DUT and Module mmWave V4.0 and higher. As an interim procedure, SPEAG recommends that two evaluation measurements be performed 2 mm above the surface of the DUT:

- evaluation of the *sPD* at 2 mm above the camera module ($psPD_{2\,\text{mm from camera}}$)
- evaluation via Option B/FTE of the *sPD* at 2 mm above the back shell ($psPD_{2\,\text{mm from shell}}$)

The two measurement procedures are described below. Section 5.1 describes the most accurate approach, which requires the use of external tools when performed in DASY8 Module mmWave V3.2.2; this approach will be fully automated in DASY8 Module mmWave V4.0 and will include evaluation of the sPD values on the side walls. Section 5.2 describes an easier-to-apply approach performed with DASY8 Module mmWave V3.2.2 that requires no external tools but leads to overestimation of the *psPD* in most cases.

5.1 Interim Evaluation with Least Overestimation

A realistic approach is to exclude from the $sPD_{2\,mm\,from\,shell}$ plane the area that overlaps with the camera module, since this area is unlikely to ever contact the human body. The testing laboratory can perform the procedure manually by:

- exporting the sPD distributions in .csv format; this feature is included by default in DASY8 Module mmWave
- setting the value to zero in the area that overlaps the camera module for $sPD_{2\,\mathrm{mm\,from\,shell}}$
- setting the value to zero in the area not on top of the camera module for $sPD_{2\,\mathrm{mm\,from\,camera}}$

The $psPD$ is defined as the maximum of the two $psPD$ values determined on the two evaluation planes.

Figure 1.2 shows the two evaluation planes from a side view of the DUT. The red area is evaluated at 5 mm above the back shell, i.e., 2 mm above the camera module, and the blue area is evaluated at 2 mm above the back shell.

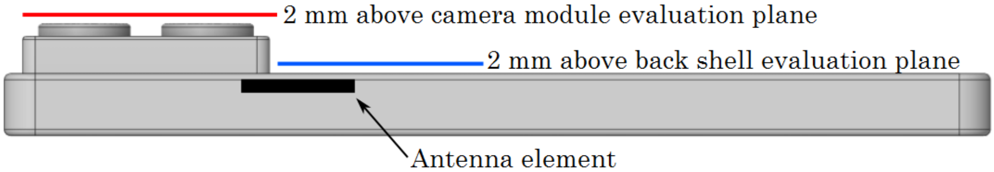


Figure 1.2: sPD evaluations performed in the plane located 5 mm above the surface of the DUT shell, i.e., 2 mm above the camera module (red) and in the plane 2 mm from the DUT shell (blue). For evaluation of the plane at 2 mm, the area under the camera module is not taken into consideration, i.e., the $sPD_{2\,\mathrm{mm\,from\,camera}}$ is set to 0). The area outside the camera module is not taken into consideration for the 5 mm plane, i.e., the $sPD_{2\,\mathrm{mm\,from\,shell}}$ is set to zero.

Figure 1.3 shows the two evaluation planes from a top view of the DUT. The red area is evaluated at 5 mm above the back shell, i.e., 2 mm above the camera module, and the blue area is evaluated at 2 mm above the back shell.

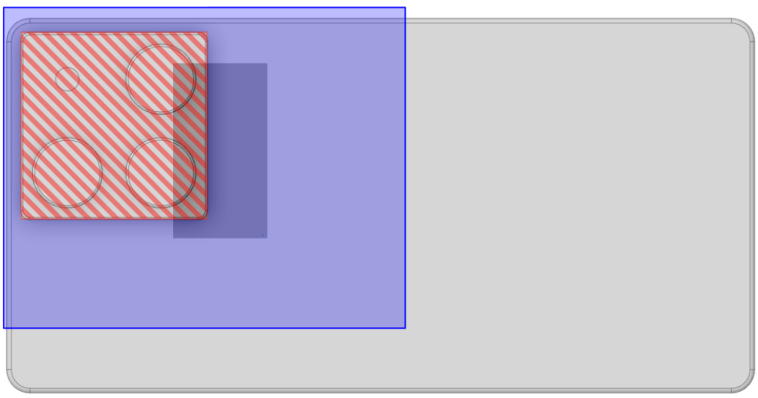


Figure 1.3: sPD evaluations performed at 2 mm above the Camera Module (red) and 2 mm from the DUT Shell (blue).

Note: Accurate evaluations that are performed outside DASY8 Module mmWave in V3.2.2, e.g., with Excel or Python, will be automated in DASY8 Module mmWave V4.0. and higher.

5.2 Simplified Interim Solution with Overestimation of Exposure

This procedure has been developed for DASY8 Module mmWave V3.2.2 as a simplified method that doesn't require external tools. The $psPD$ values determined are more conservative than those determined by the approach described in Section 5.1. When the larger $psPD$ is located on the $psPD_{2\,\text{mm from shell}}$ plane and at the camera module location, the $psPD$ is overestimated.

Figure 1.4 shows the two evaluation planes from a side view of the DUT. The red area is evaluated at 5 mm above the back shell, i.e., 2 mm above the camera module, and the blue area is evaluated at 2 mm above the back shell Note that the 5 mm plane extends over the back shell and that the 2 mm plane extends under the camera module. The $psPD$ is defined as the higher of the two $psPD$ values determined on the two evaluation planes, however without nullifying the area from the $sPD_{2\,\text{mm from shell}}$ located under the camera module or the area from the $sPD_{2\,\text{mm from camera}}$ corresponding to the back shell.

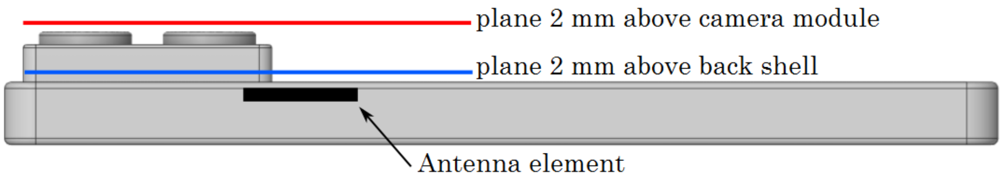


Figure 1.4: sPD evaluations at 2 mm from the camera module (red) and 2 mm from the back shell of the DUT (blue)

This method is more conservative, since, although the user cannot physically access the 2 mm layer above the back shell under the camera module, the evaluation can be performed directly in DASY8 Module V3.2.2.

6 Example

6.1 Test Setup

The measurement procedure described in Section 5 has been validated with the 10 GHz pyramidal horn antenna with slot arrays described in [1]. The antenna was placed in a smartphone model having a form factor shell of 160 mm height (y-axis) and 80 mm width (x-axis) at an offset of −10 mm on the x-axis and −45 mm on the y-axis relative to the center of the DUT. The camera module has been modeled as a low permittivity Rohacell cubic form of $35 \times 35 \times 3$ mm, located at offsets of −17.5 mm on the x-axis and −52.5 mm on the y-axis relative to the center of the shell.

Note: In this example, only the $psPD_{n+,4\text{cm}^2,\text{sq}}$ (surface-normal propagation-direction peak power density into the evaluation surface averaged over $4cm^2$ using a square averaging geometry) is considered; the procedure should be repeated for all quantities that need to be reported for compliance testing.

6.2 Measurement System

The DASY8 system elements used in the measurements are listed in Table 1.2.

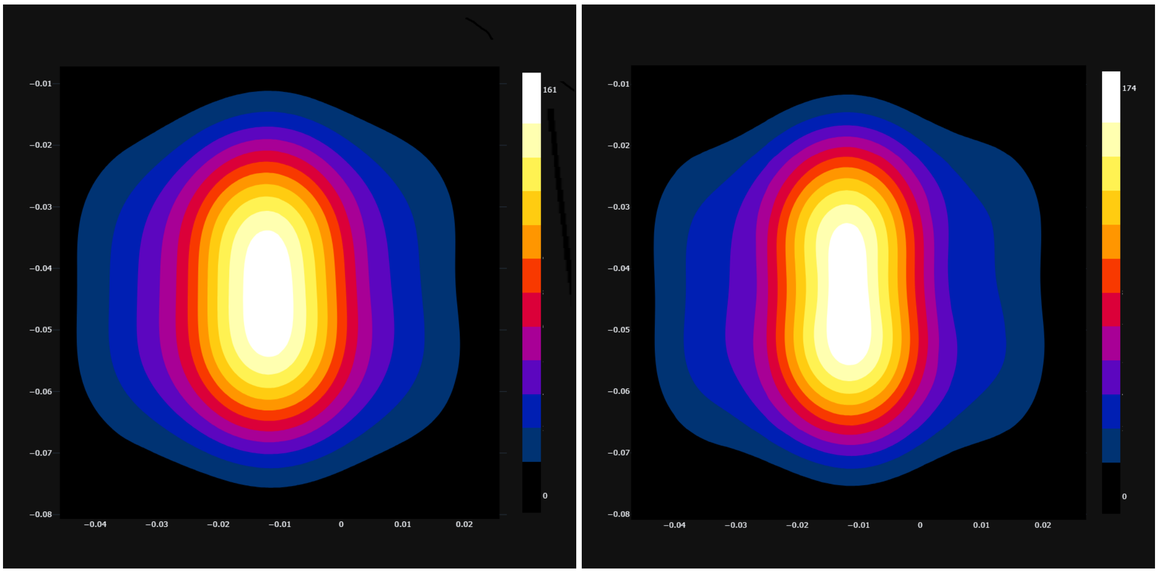
System	Type:	DASY8
	Software Version:	Module mmWave V3.2.2
	Manufacturer:	Schmid & Partner Engineering AG, Switzerland
Positioner	Robot:	TX2-60 L
	Serial No:	F/19/0014438/A/001
	Controller:	CS9
	Serial No:	F/19/0014438/C/001
	Manufacturer:	Stäubli, France
Data Acquisition System	Type:	DAE4ip
	Serial No:	355
	Calibrated On:	November 17, 2023
	Manufacturer:	Schmid & Partner Engineering AG, Switzerland
Probe	Type:	EUmmWV4
	Serial Number:	9477
	Calibrated On:	June 12, 2023
	Manufacturer:	Schmid & Partner Engineering AG, Switzerland
Validation Source	Type:	HSA 10 GHz
	Serial Number:	HSA 10:01
	Manufacturer:	Schmid & Partner Engineering AG, Switzerland

Table 1.2: Measurement system used to perform the incident power density measurements.

6.3 Results

A forward transform (FT) scan was performed at 5 mm from the DUT back shell, i.e., 2 mm from the top of the camera module, and the $sPD_{n+,4\text{cm}^2,\text{sq}}$ was evaluated on the same measurement plane. The B/FTE option is used to assess the $sPD_{n+,4\text{cm}^2,\text{sq}}$ at 2 mm from the back shell.

Figure 1.5 shows the $sPD_{n+,4\text{cm}^2,\text{sq}}$ distributions at 5 mm (Fig. 1.5a) and 2 mm (Fig. 1.5b) from the back shell. The $psPD_{n+,4\text{cm}^2,\text{sq},2\text{mm}}$ is 174 W/m^2 and the $psPD_{n+,4\text{cm}^2,\text{sq},5\text{mm}}$ is 161 W/m^2. According to the procedure described in Section 5.2, the $psPD$ is reported as 174 W/m^2.



(a) Measurement plane 5 mm from the back shell

(b) Measurement plane 2 mm from the back shell with B/FTE option

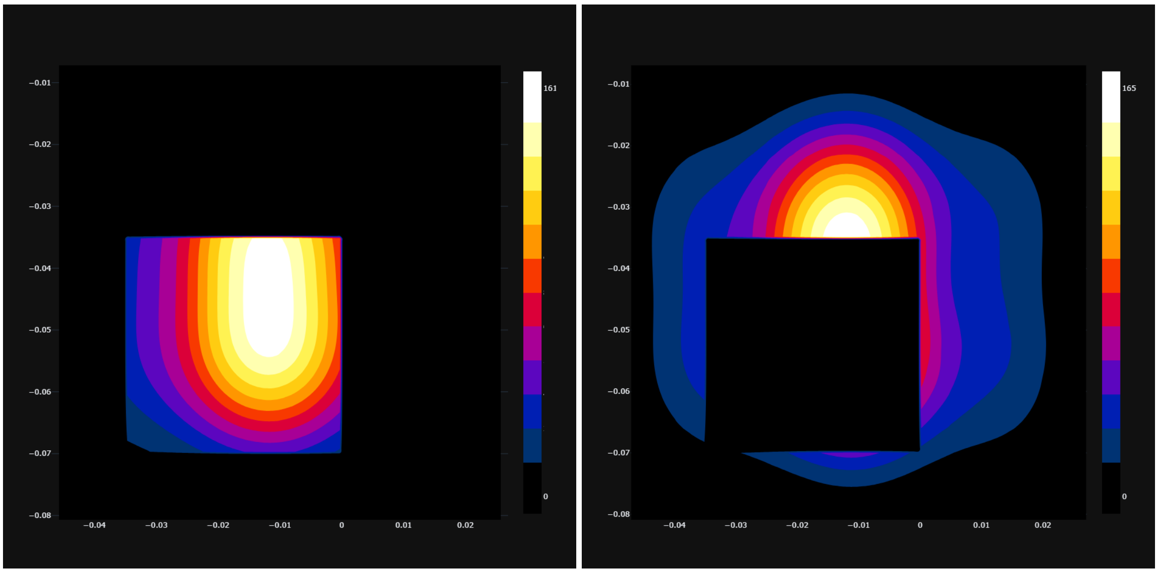
Figure 1.5: Evaluations of $sPD_{n+,4\text{cm}^2,\text{sq}}$ at 5 mm and 2 mm from the back shell.

Alternatively, the $psPD_{n+,4cm^2,sq}$ is evaluated according to the less conservative procedure described in Section 5.1. For this purpose, a Python script was developed to:

- set the $sPD_{n+,4\text{cm}^2,\text{sq}}$ values located below the camera module on the 2 mm evaluation plane to 0
- set the $sPD_{n+,4\text{cm}^2,\text{sq}}$ values that are not above the camera module on the 5 mm evaluation plane to 0

The Python script used for this purpose is given in Appendix 1. Please note that the same procedure can be developed with other tools, e.g., Excel.

Figure 1.6 shows the $sPD_{n+,4\text{cm}^2,\text{sq}}$ distributions at 5 mm (1.6a) and 2 mm (1.6b) from the back shell. The $psPD_{n+,4\text{cm}^2,\text{sq},2\text{mm}}$ is 165 W/m^2 and the $psPD_{n+,4\text{cm}^2,\text{sq},2\text{mm}}$ is 161 W/m^2. According to the procedure described in Section 5.1, the $psPD$ is reported as 165 W/m^2, which is less than the 174 W/m^2 found above according the conservative approach but greater than evaluating the $psPD_{n+,4\text{cm}^2,\text{sq}}$ at 5 mm only.



(a) Measurement plane 5 mm from the back shell with mask corresponding to the area not beneath the camera module applied

(b) Measurement plane 2 mm from the back shell with B/FTE option and mask corresponding to the area beneath the camera module applied

Figure 1.6: Evaluations of $sPD_{n+,4\text{cm}^2,\text{sq}}$ at 5 mm and 2 mm from the back shell, with masks applied to limit the evaluation plane to the meaningful areas.

7 Conclusions

This Application Note describes easy-to-implement measurement procedures for evaluating the $psPD$ on non-planar devices. The $psPD$ values provided are more conservative and accurate than those based on evaluations only on the highest plane above the DUT.

These procedures will be fully automated in DASY8 Module mmWave V4.0, whereby no external tools will be required.

Bibliography

[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] 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, September 2022, doi: 10.1109/TAP.2022.3177564.

1 Data Extraction for Accurate Evaluations

The Python script below, developed for masking data on the 2 mm evaluation plane that collide with the camera module, performs these three steps:

- reads the sPD distribution exported from DASY8 Module mmWave in .csv format
- masks (i.e., sets to 0) the sPD values under the camera module
- determines the $psPD$ from the masked sPD distribution

The script below is given as an example. The testing laboratory will need to update it based on the procedure described in this application note and the device being tested.

```
import csv
import numpy
import plotly.graph_objects as go

with open(r'C:\Users\dasy\Desktop\NonPlanarEvaluations\5G_2.00mm_BACK-sPDn+ (4.0cm2,
    sq).csv') as csv_file:
    sPD_reader = csv.reader(csv_file, delimiter='\t')
    # skip the header lines
    for i in range(7):
        next(sPD_reader)
    # store the sPD distribution in a numpy array
    data = []
    for sPD_point in sPD_reader:
        data.append([float(v) for v in sPD_point[:-1:2]])
    data = numpy.array(data)
    x_coordinates = data[:, 1]
    y_coordinates = data[:, 2]
    sPD = data[:, 0]

    # set the data under the camera module to 0 and display the psPD
    mask = numpy.where(
        (x_coordinates < 0.0) & (x_coordinates > -0.035) &
        (y_coordinates < -0.035) & (y_coordinates > -0.07)

    )
    sPD[mask] = 0
    print('The psPD is:', numpy.max(sPD), 'W/m2')

    # plot the sPD distribution
    fig = go.Figure(
        go.Contour(
            x=x_coordinates,
            y=y_coordinates,
            z=sPD,
            contours=dict(
                start=0,
                end=numpy.ceil(numpy.nanmax(data[:, 0])),
                size=numpy.nanmax(data[:, 0])/12),
            line_width=0
        ),
    )
    fig.update_layout(template='plotly_dark')
    fig.update_yaxes(
        scaleanchor="x",
        scaleratio=1,
    )
    fig.show()
```