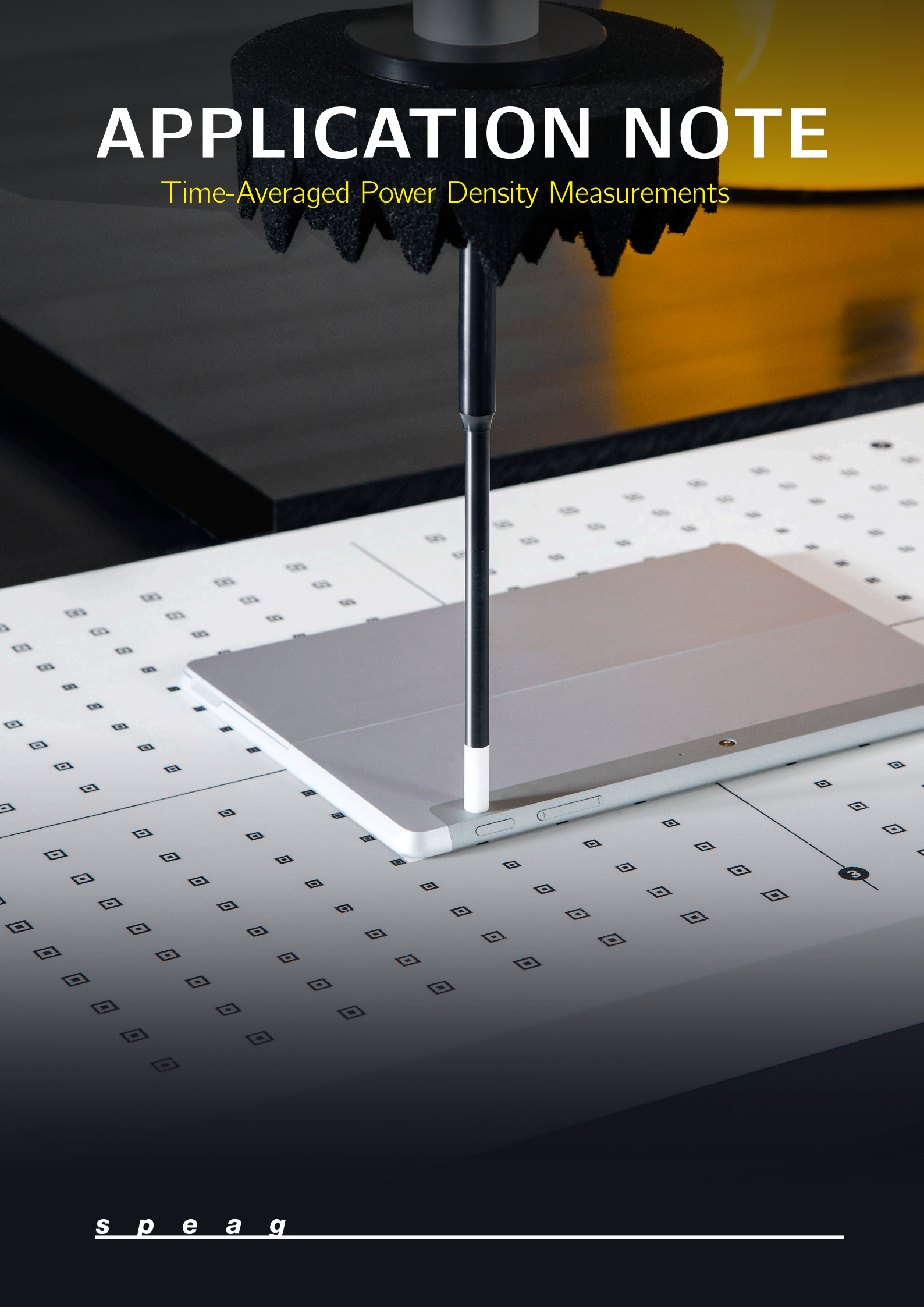


# APPLICATION NOTE

Time-Averaged Power Density Measurements



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# Time-Averaged Power Density Measurements

## 1 Introduction

The purpose of this application note is to provide guidance to end users on performing of time-averaged power density (TA-PD) measurements, i.e., time-averaged incident power density (TA-IPD) measurements with DASY8 Module mmWave and time-averaged absorbed power density (TA-APD) measurements with DASY8 Module APD. In Section 2, the theory in the context of the relevant standards is discussed. In Section 3, example TA-IPD and TA-APD measurements performed with DASY8 Module mmWave V4.0 and DASY8 Module APD V3.0, are demonstrated.

## 2 Theory

In this section, we consider the theory behind time-averaged power density measurements, which is applicable to both time-averaged incident power density (TA-IPD) and time-averaged absorbed power density (TA-APD).

### 2.1 Background

Modern user equipment (UE) may rely on dynamic power control and exposure time-averaging (DPC-ETA) to modulate the transmit power over time for compliance with exposure limits. With DPC-ETA, the average exposure is intentionally reduced while communication performance is maintained. Exposure limits may be defined by over a time-averaging window specified by international guidelines – e.g., those published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [1] – or national regulations. Taking time averaging into account prevents exposure limits from becoming overly conservative due to reliance on peak transmit power measurements. For frequencies below 6 GHz, standardized time-averaged specific absorption rate (SAR) measurement procedures have been developed [2], [3]: these rely on measurements of conducted or radiated power, or on single point near-field measurements, to assess the time-varying power and, together with a reference SAR scan, the time-averaged SAR. At mmWave frequencies, conducted power measurements may not be possible due to the lack of conducted ports in this frequency range, and array systems currently lack the resolution to accurately resolve the resulting field distributions. Therefore, at mmWave frequencies, near-field power density is a good measure for characterization of DPC-ETA. In the following sections, the term power density (PD) is used as placeholder for both incident power density (IPD) and absorbed power density (APD): the measurement procedures for both are the same.

Reconstruction of the power density in an area, in particular the peak-spatial power density (psPD), requires knowledge regarding the electric field in that area. Single-probe measurement systems, such as DASY8 Module mmWave and DASY8 Module APD, scan the electric (E-) field in one or more planes: e.g., in DASY8 Module mmWave, a 5G scan this is implemented using the 5G scan. During such a scan, the E-field is assumed to be constant over time, therefore devices using DPC-ETA algorithms cannot be measured directly with a scanning probe system.

## 2.2 Measurement Procedure

To address the measurement of devices based on DPC-ETA algorithms, a multi-step procedure is used: first, an “anchor scan” – a full PD measurement at a constant power level – is performed to capture the spatial distribution of the field; second, a “time-averaged scan” – measurement of the time-resolved field – is performed at a single location, and the anchor scan is scaled accordingly to obtain the time-averaged PD; third, the results are scaled in a post-processing step. This approach leverages the spatial information from the anchor scan while accounting for temporal variations in power. This multi-step procedure is analogous to that defined in the International Electrotechnical Commission (IEC) Technical Report (TR) 63424-1[3] for measurements at frequencies <6 GHz.

In more detail, the procedure for measurement of devices based on DPC-ETA algorithms is:

### 1. Anchor Scan

- (a) The UE is configured to transmit at a constant power  $P_{\text{ref}}$ , which can be arbitrary, in the desired configuration; according to IEC TR 63424-1[3],  $P_{\text{ref}} = P_{\text{limit}}$  should be chosen.
- (b) The reference anchor scan over the device is performed at constant  $P_{\text{ref}}$  to obtain the reference peak-spatial power density  $psPD_{\text{Pref}}$ .

### 2. Time-Averaged Scan

- (a) The DPC-ETA algorithm on the UE is enabled, which must be done without moving the UE.
- (b) The time-averaged scan over the acquisition duration  $T_{\text{acq}}$  is started; the probe moves to the location where the E-field is maximal to optimize the signal-to-noise ratio of the time-averaged scan. If the power variation of the UE is periodic, the acquisition duration  $T_{\text{acq}}$  can be chosen as a multiple of the averaging period  $T_{\text{avg}}$  to obtain the steady-state time-averaged power density over  $T_{\text{avg}}$ .

### 3. Scaling

- (a) The power density ratio  $R_{\text{PD}}$  is calculated according to Equation 1.1:

$$R_{\text{PD}}(t) = \frac{|E|_{\text{point}}^2(t)}{|E|_{\text{point,Pref}}^2(t)} \quad (1.1)$$

- (b) The time-averaged peak-spatial power density is given by Equation 1.2:

$$\overline{psPD} = \overline{R_{\text{PD}}} \times psPD_{\text{Pref}} \quad (1.2)$$

In the case of IPD measurements, the scaling is applied to all variants  $psIPD_{\text{n+}}$ ,  $psIPD_{\text{tot+}}$ ,  $psIPD_{\text{mod+}}$ . The averaging is performed over the entire acquisition period  $T_{\text{acq}}$ , according to Equation 1.3:

$$\overline{R_{\text{PD}}} = \int_0^{T_{\text{acq}}} R_{\text{PD}}(t) dt \quad (1.3)$$

For some applications, e.g., DPC-ETA algorithm validation, the psPD will have been assessed before or is not relevant, and only relative power changes are of interest. In such cases, an anchor scan is not necessary, and the time-averaged scan can be performed directly.

## 2.3 Post-Processing

### Exposure Ratio Scaling

With DASY8 Modules mmWave and APD, the time-averaged psPD and the time-averaged power density ratio  $\overline{R_{\text{PD}}}$  – averaged over the entire acquisition duration – are automatically reported. In the case of a periodic time-varying power, where  $T_{\text{acq}} = T_{\text{avg}}$  and  $P_{\text{ref}} = P_{\text{limit}}$ , the reported  $\overline{R_{\text{PD}}}$  corresponds to the expression for the exposure ratio  $R(t = T_{\text{avg}})$  defined by IEC TR 63424-1[3]. If  $P_{\text{ref}}$  is different, the power density ratio must be scaled according to Equation 1.4 to obtain the exposure ratio:

$$R(t = T_{\text{avg}}) = \overline{R_{\text{PD}}} \times \frac{P_{\text{limit}}}{P_{\text{ref}}} \quad (1.4)$$

### Change of the Averaging Period

For non-periodic power changes – e.g., a transition between operating modes, or when the averaging period should be changed – the time-averaged power density ratio, and with it the time-averaged power density, are themselves functions of time. In such a case, the user can export the time series  $R_{PD}(t)$  and calculate the time-averaged quantities with an external tool. The time-dependent time-averaged power density ratio is defined in Equation 1.5:

$$\overline{R_{PD, T_{avg}}}(t) = \int_{t-T_{avg}}^t R_{PD}(t') dt' \quad (1.5)$$

### 3 Example Measurements

#### 3.1 TA-IPD Measurement with DASY8 Module mmWave

To illustrate the measurement procedure, an example device was measured with DASY8 Module mmWave V4.0. More details about how to set up the individual scans can be found in the DASY8 Module mmWave V4.0 System Handbook [4]. The example measurement was performed in the 5G NR n258 band at 24.275 GHz. With the DPC-ETA algorithm enabled, the device switches periodically between two power levels with an averaging period of  $T_{\text{avg}} = 100$  s. When the DPC-ETA algorithm is disabled, the device transmits constantly at the higher power level.

##### 3.1.1 Anchor Scan

The device is fixed in position, and the DPC-ETA algorithm is disabled. A fast area scan is performed to align the detailed 5G scan to the maximum IPD region, and then a 5G scan is performed over the area close to this maximum to produce the anchor scan. The result is shown in Figure 1.1. When the DPC-ETA algorithm is disabled, the peak spatial power density is  $psIPD_{n+, \text{Pref}} = 28.8 \text{ W/m}^2$  over a  $4 \text{ cm}^2$  rotating square averaging area.

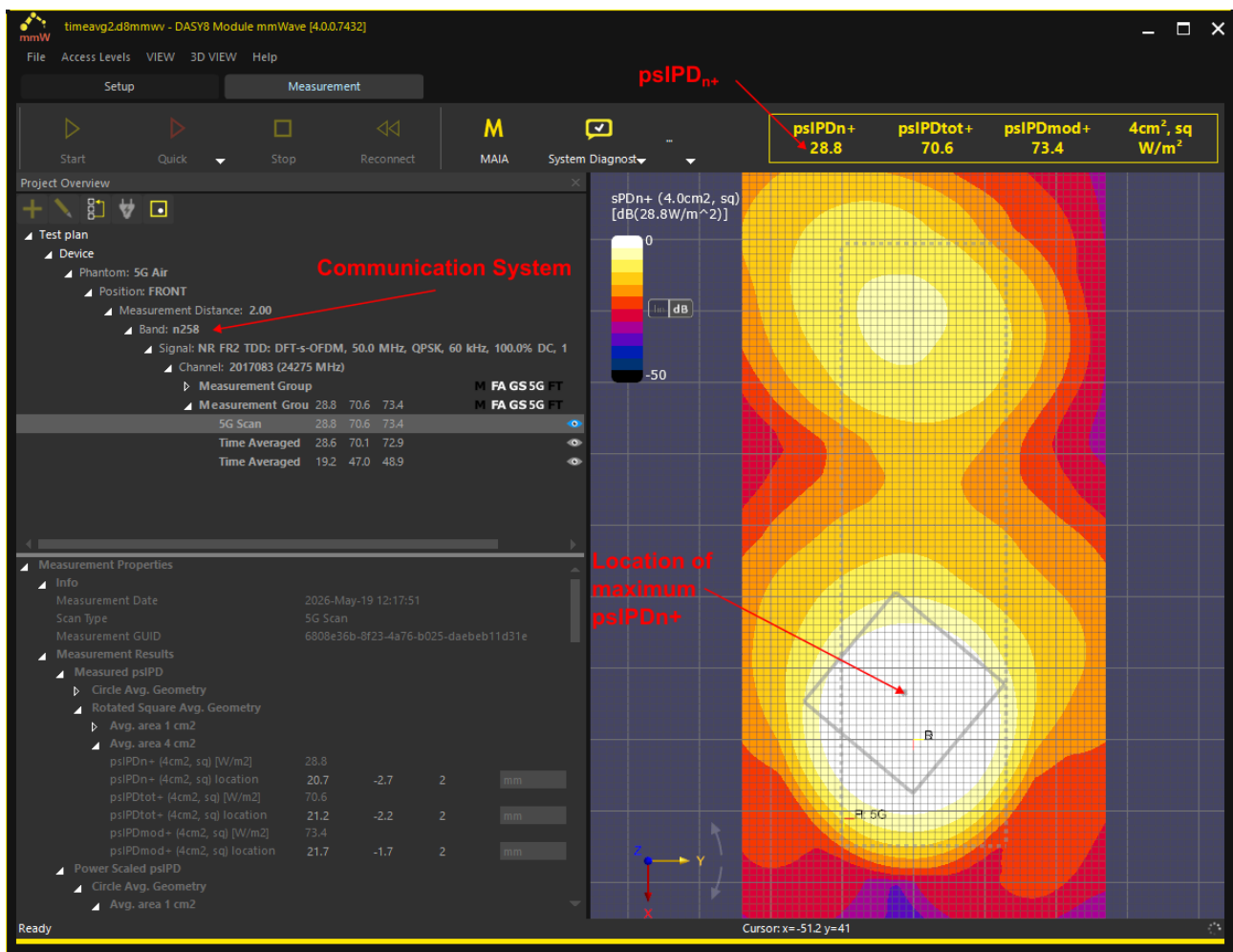


Figure 1.1: An example IPD anchor scan performed at  $P_{\text{ref}}$

### 3.1.2 Time-Averaged Scan

The DPC-ETA algorithm is enabled without moving the device; this is important, since DASY8 Module mmWave moves the probe to the anchor point, i.e., the maximum identified by the anchor scan, and references the field value measured in the anchor scan, and moving the device would disrupt this referencing. The time-averaged scan is anchored to the previous 5G scan, and the acquisition time is set to  $T_{\text{acq}} = 200\text{ s}$  to capture two power cycle periods. The result is shown in Figure 1.2. The power density ratio is  $\overline{R}_{\text{IPD}} = 0.6654$ , the time-averaged psIPD is given by Equation 1.2 as  $\overline{psIPD}_{n+} = 19.2\text{ W/m}^2$ .

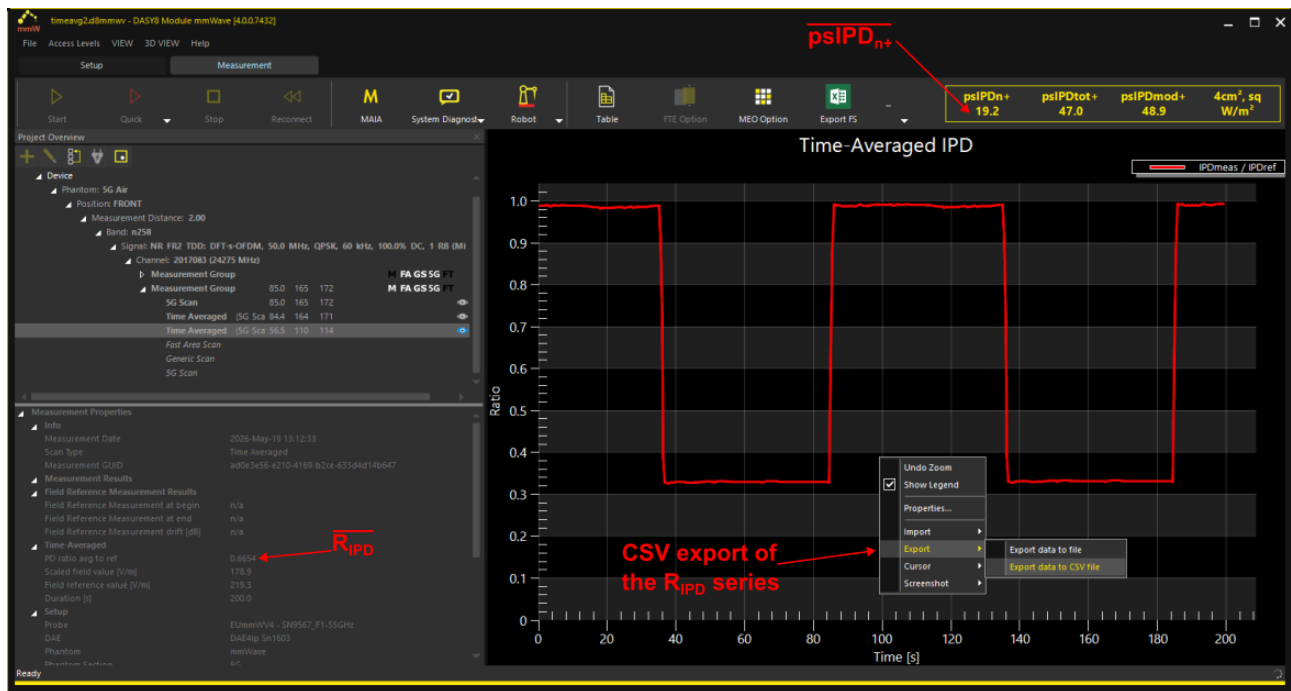


Figure 1.2: An example time-averaged IPD scan performed over  $T_{\text{acq}} = 2T_{\text{avg}} = 200\text{ s}$

### 3.1.3 Post-Processing

Since  $T_{\text{acq}}$  is a multiple of  $T_{\text{avg}}$  and the power is periodic, the reported  $\overline{psIPD_{n+}}$  corresponds to the steady-state  $\overline{psIPD_{n+,T_{\text{avg}}}}(t)$ . To verify this, the data can be exported and re-evaluated with an averaging period of  $T_{\text{avg}} = 100$  s. The data is exported to a csv file by right-clicking in the plot area, as shown in Figure 1.2. The resulting file can be opened in Excel and evaluated according to Equation 1.5. The resulting  $R_{\text{IPD}}(t)$  and  $\overline{R_{\text{IPD},T_{\text{avg}}}}(t)$  are shown in Figure 1.3. After 100 s, the time-averaged power density ratio stays constant at 0.667, corresponding to the value reported above for  $\overline{R_{\text{IPD}}}$ . The exported csv file contains only the time stamps and the corresponding  $R_{\text{IPD}}$  values. The averaging according to Equation 1.5, reported in column “TA-Ratio” in Figure 1.3), must be calculated by the user.

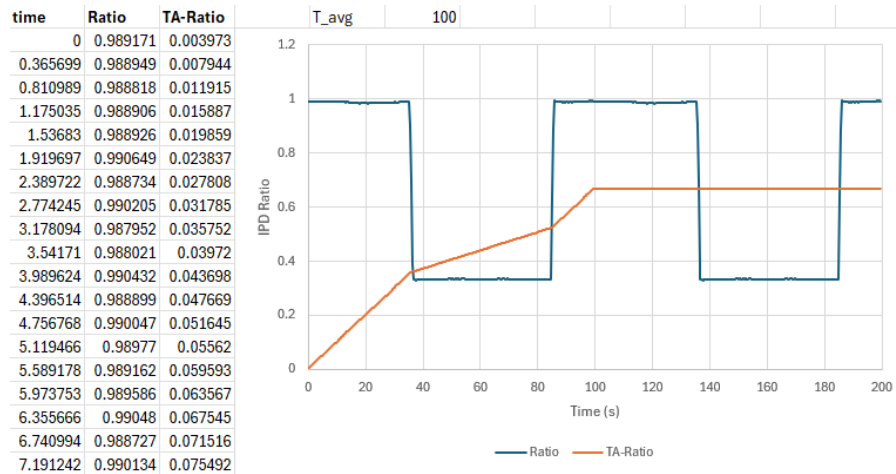


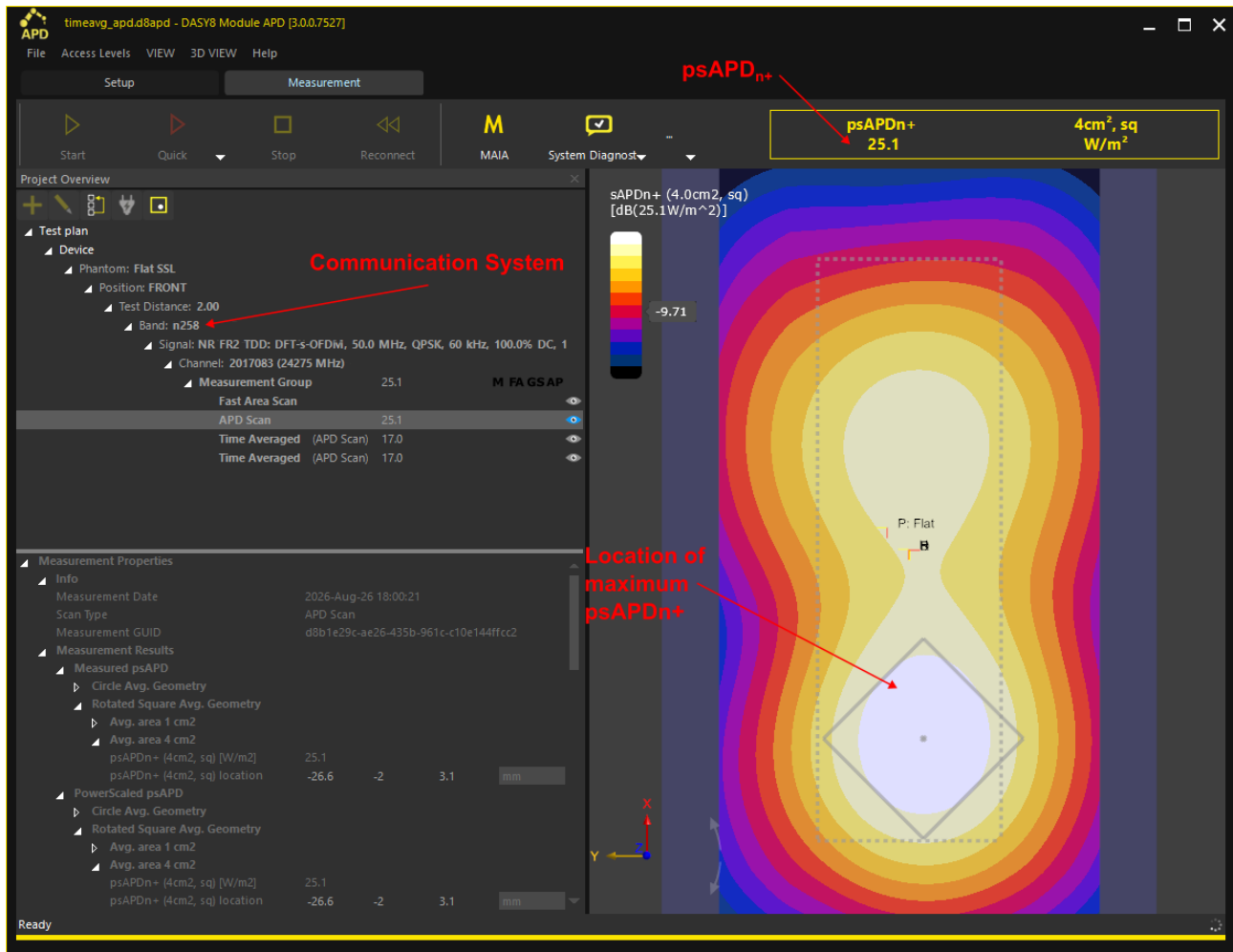
Figure 1.3: An example post-processing result for a custom averaging period

## 3.2 TA-APD Measurement with DASY8 Module APD

A similar measurement of the the same device and communication system was conducted with DASY8 Module APD V3.0. More details about how to set up the individual scans can be found in the DASY8 Module APD V3.0 System Handbook [5].

### 3.2.1 Anchor Scan

The device is fixed in position, and the DPC-ETA algorithm is disabled. A fast area scan is performed to align the detailed APD scan to the maximum, and then an APD scan is performed over the area close to the maximum to produce the anchor scan. The result is shown in Figure 1.4. With the DPC-ETA algorithm disabled, the maximum is  $psAPD_{n+, \text{Pref}} = 25.1 \text{ W/m}^2$  over a  $4 \text{ cm}^2$  rotating square averaging area.

Figure 1.4: An example APD anchor scan performed at  $P_{ref}$ 

### 3.2.2 Time-Averaged Scan

As in the IPD example measurement, the DPC-ETA algorithm is enabled without moving the device, prompting DASY8 Module APD to reference the field value measured in the anchor scan. The time-averaged scan is anchored to the previous APD scan, and the acquisition time is set to  $T_{acq} = 200$  s to capture two power cycle periods. The result is shown in Figure 1.5. The power density ratio is  $\bar{R}_{APD} = 0.6798$ , and the time-averaged APD is given by Equation 1.2 as  $\overline{psAPD}_{n+} = 17.0$  W/m². The curves of  $R_{APD}(t)$  and  $R_{IPD}(t)$  are very similar apart from a phase shift; consequently,  $\bar{R}_{APD}$  and  $\bar{R}_{IPD}$  differ by only 0.1 dB, demonstrating good agreement between both systems.

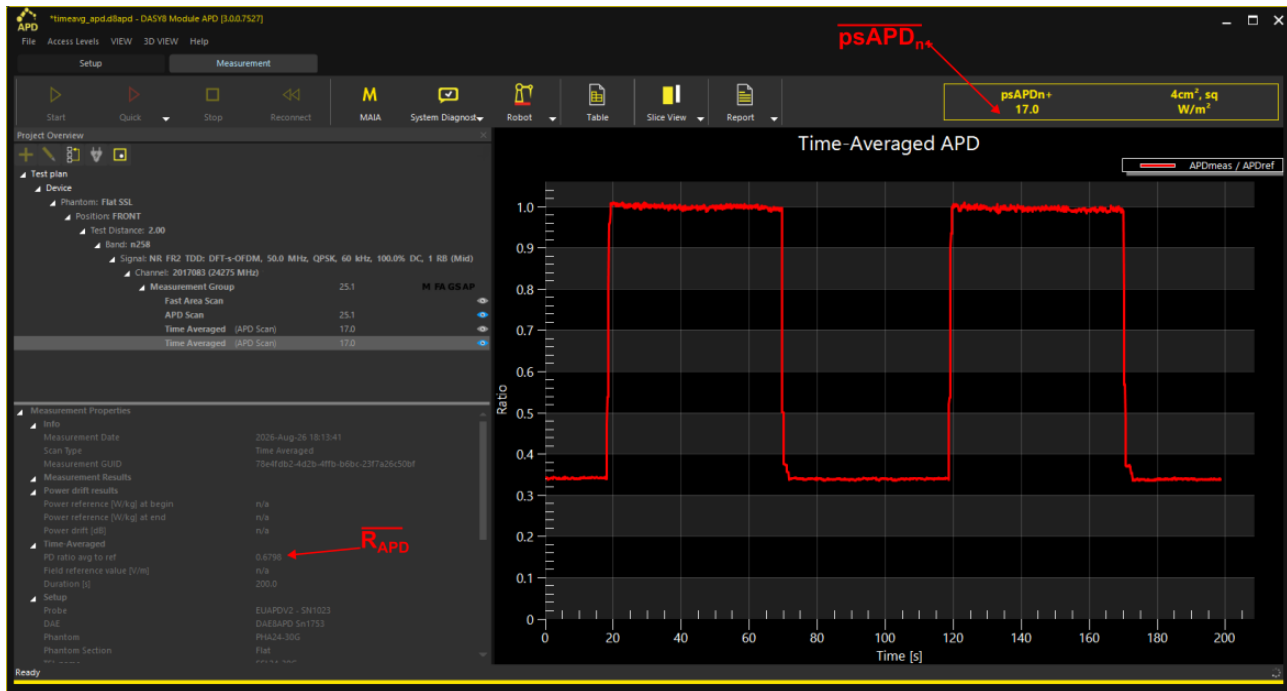


Figure 1.5: An example APD time-averaged scan performed over  $T_{\text{acq}} = 2T_{\text{avg}} = 200$  s

### 3.2.3 Post-Processing

As with the IPD measurement, the APD ratio can be exported to a csv file by clicking in the plot area in DASY8 Module APD and then evaluated over a custom averaging period in Excel according to Equation 1.5. In this case, the averaging period has been chosen as  $T_{\text{avg}} = 60$  s, which is different from the power cycle period of the device under test. This demonstrates that, when the averaging period and power cycle period do not agree or the power is not periodic, the time-averaged power density  $\overline{R_{\text{PD}, T_{\text{avg}}}}(t)$ , according to Equation 1.5 is also a time-varying quantity.

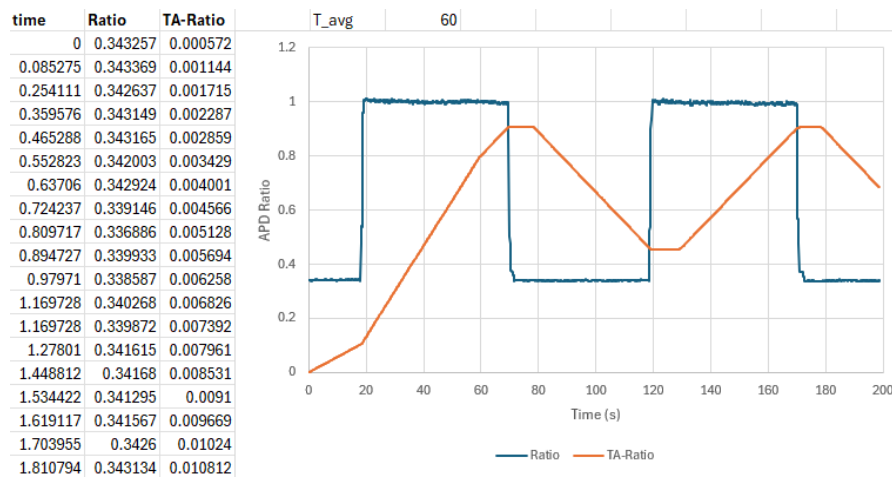


Figure 1.6: An example post-processing result for a custom averaging period that does not correspond to the power cycle period

# Bibliography

- [1] International Commission on Non-Ionizing Radiation Protection (ICNIRP). "Guidelines for Limiting Exposure to Electromagnetic Fields (up to 300 GHz)". In: *Health Physics* 118.5 (May 2020), pp. 483–524.
- [2] *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 - Human models, instrumentation and procedures (Frequency range of 4 MHz to 10 GHz)*. Oct. 2020.
- [3] International Electrotechnical Commission (IEC). *IEC 63424 ED1 – Validation of Dynamic Power Control and Exposure Time-Averaging Algorithms – Part 1: Cellular network implementations for SAR at frequencies up to 6 GHz*. 2024.
- [4] SPEAG. *DASY8 Module mmWave V4.0 System Handbook*.
- [5] SPEAG. *DASY8 Module APD V3.0 System Handbook*.