Qualcomm Technologies, Inc.

Samsung portable handset (FCC ID: A3LSMN976V) RF Exposure Compliance Test Report

(Part 2: Test Under Dynamic Transmission Condition)

80-W5681-2 Rev. F

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Revision history

Revision	Date	Description
A	June 13, 2019	Initial release
B	June 28, 2019	Corrected typos and revised plots in Section 9.2.1 and 9.2.2, and added a side by side validation / SPEAG certificate calibration plot in E.2.2
C	June 28, 2019	Corrected typos in SAR values listed in Table 5-2, and revised the corresponding plots in Section 6.2.1, 6.2.3, 6.3, 6.4, and 6.5.
D	July 1, 2019	Updated text in Sections 3.2.1, 3.2.4, 8.2, and corrected typo in legend of all PD plots in Section 8.2.
E	July 3, 2019	Updated plots in Section 6 and 7
F	July 12, 2019	Updated Tables 5-1 & 6-1 to be consistent with Part 0 & Part 1 reports. Moved setup pictures to Appendix G.

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1 Introduction

The equipment under test (EUT) is Samsung portable handset (FCC ID: A3LSMN976V), it contains the Qualcomm SM8150 modem supporting 2G/3G/4G technologies and SDX50 modem supporting mmW 5G NR bands. Both of these modems are enabled with Qualcomm Smart Transmit feature to control and manage transmitting power in real time and to ensure at all times the time-averaged RF exposure is in compliance with the FCC requirement.

This purpose of the Part 2 report is to demonstrate the EUT complies with FCC RF exposure requirement under Tx varying transmission scenarios, thereby validity of Qualcomm Smart Transmit feature for FCC equipment authorization of Samsung portable handset (FCC ID: A3LSMN976V).

The P_{limit} and *input.power.limit* used in this report is determined and listed in Part 0 report.

Refer to Compliance summary report for product description and terminology used in this report.

2 Tx Varying Transmission Test Cases and Test Proposal

To validate time averaging algorithm and demonstrate the compliance in Tx varying transmission conditions, the following transmission scenarios are covered in Part 2 test:

1. During a time-varying Tx power transmission: To prove that the Smart Transmit algorithm accounts for Tx power variations in time accurately.
2. During a call disconnect and re-establish scenario: To prove that the Smart Transmit algorithm accounts for history of past Tx power transmissions accurately.
3. During technology/band handover: To prove that the Smart Transmit algorithm functions correctly during transitions in technology/band.
4. During DSI (Device State Index) change: To prove that the Smart Transmit algorithm functions correctly during transition from one device state (DSI) to another.
5. During antenna (or beam) switch: To prove that the Smart Transmit algorithm functions correctly during transitions in antenna (such as AsDiv scenario) or beams (different antenna array configurations).
6. SAR vs. PD exposure switching during sub-6+mmW transmission: To prove that the Smart Transmit algorithm functions correctly and ensures total RF exposure compliance during transitions in SAR dominant exposure, SAR+PD exposure, and PD dominant exposure scenarios.

As described in Part 0 report, the RF exposure is proportional to the Tx power for a SAR- and PD-characterized wireless device. Thus, algorithm validation in Part 2 can be effectively performed through conducted (for $f < 6$GHz) and radiated (for $f \geq 6$GHz) power measurement. Therefore, the validation is done in power measurement setup for transmission scenario 1 through 6.

To add confidence in the algorithm validation, the time-averaged SAR and PD measurements are also performed but only performed for transmission scenario 1 to avoid the complexity in SAR and PD measurement (such as, for scenario 3 requiring change in SAR probe calibration file to accommodate different bands and/or tissue simulating liquid).

The strategy for testing in Tx varying transmission condition is outlined as follows:

- Demonstrate the total RF exposure averaged over FCC defined time windows does not exceed FCC's SAR and PD limits, through <u>time-averaged power</u> measurements
  - Measure conducted Tx power (for $f < 6$GHz) versus time, and radiated Tx power (EIRP for $f > 10$GHz) versus time.
  - Convert it into RF exposure and divide by respective FCC limits to get normalized exposure versus time.
  - Perform running time-averaging over FCC defined time windows.

- Demonstrate that the total normalized time-averaged RF exposure is less than 1 for all transmission scenarios (i.e., transmission scenarios 1, 2, 3, 4, 5, and 6) at all times.

  Mathematical expression:

  – For sub-6 transmission only:

$$1g\_or\_10gSAR(t) = \frac{conducted\_Tx\_power(t)}{conducted\_Tx\_power\_P_{limit}} * 1g\_or\_10gSAR\_P_{limit} \quad (1a)$$

$$\frac{\frac{1}{T_{SAR}}\int_{t-T_{SAR}}^{t} 1g\_or\_10gSAR(t)dt}{FCC\ SAR\ limit} \leq 1 \quad (1b)$$

  – For sub-6+mmW transmission:

$$1g\_or\_10gSAR(t) = \frac{conducted\_Tx\_power(t)}{conducted\_Tx\_power\_P_{limit}} * 1g\_or\_10gSAR\_P_{limit} \quad (2a)$$

$$4cm^2PD(t) = \frac{radiated\_Tx\_power(t)}{radiated\_Tx\_power\_input.power.limit} * 4cm^2PD\_input.power.limit \quad (2b)$$

$$\frac{\frac{1}{T_{SAR}}\int_{t-T_{SAR}}^{t} 1g\_or\_10gSAR(t)dt}{FCC\ SAR\ limit} + \frac{\frac{1}{T_{PD}}\int_{t-T_{PD}}^{t} 4cm^2PD(t)dt}{FCC\ 4cm^2\ PD\ limit} \leq 1 \quad (2c)$$

  where, $conducted\_Tx\_power(t)$, $conducted\_Tx\_power\_P_{limit}$, and $1g\_or\_10gSAR\_P_{limit}$ correspond to the measured instantaneous conducted Tx power, measured conducted Tx power at P_{limit}, and measured *1gSAR or 10gSAR* values at P_{limit} corresponding to sub-6 transmission. Similarly, $radiated\_Tx\_power(t)$, $radiated\_Tx\_power\_input.power.limit$, and $4cm^2PD\_input.power.limit$ correspond to the measured instantaneous radiated Tx power, radiated Tx power at *input.power.limit* (i.e., radiated power limit), and $4cm^2$PD value at *input.power.limit* corresponding to mmW transmission. Both P_{limit} and *input.power.limit* are the parameters pre-defined in Part 0 and loaded via Embedded File System (EFS) onto the EUT. T_{SAR} is the FCC defined time window for sub-6 radio; T_{PD} is the FCC defined time window for mmW radio.

- Demonstrate the total RF exposure averaged over FCC defined time windows does not exceed FCC's SAR and PD limits, through time-averaged SAR and PD measurements. Note as mentioned earlier, this measurement is performed for transmission scenario 1 only.
  - For sub-6 transmission only, measure instantaneous SAR versus time; for LTE + mmW transmission, measure instantaneous E-field versus time for mmW radio and instantaneous conducted power versus time for LTE radio.
  - Convert it into RF exposure and divide by respective FCC limits to obtain normalized exposure versus time.
  - Perform time averaging over FCC defined time window.
  - Demonstrate that the total normalized time-averaged RF exposure is less than 1 for transmission scenario 1 at all times.

    Mathematical expression:

– For sub-6 transmission only:

$$1g\_or\_10gSAR(t) = \frac{pointSAR(t)}{pointSAR\_P_{limit}} * 1g\_or\_10gSAR(t)\_P_{limit} \qquad (3a)$$

$$\frac{\frac{1}{T_{SAR}}\int_{t-T_{SAR}}^{t} 1g\_or\_10gSAR(t)dt}{FCC\ SAR\ limit} \leq 1 \qquad (3b)$$

– For LTE+mmW transmission:

$$1g\_or\_10gSAR(t) = \frac{conducted\_Tx\_power(t)}{conducted\_Tx\_power\_P_{limit}} * 1g\_or\_10gSAR\_P_{limit} \qquad (4a)$$

$$4cm^2PD(t) = \frac{[pointE(t)]^2}{[pointE\_input.power.limit]^2} * 4cm^2PD\_input.power.limit \qquad (4b)$$

$$\frac{\frac{1}{T_{SAR}}\int_{t-T_{SAR}}^{t} 1g\_or\_10gSAR(t)dt}{FCC\ SAR\ limit} + \frac{\frac{1}{T_{PD}}\int_{t-T_{PD}}^{t} 4cm^2PD(t)dt}{FCC\ 4cm^2PD\ limit} \leq 1 \qquad (4c)$$

where, $pointSAR(t)$, $pointSAR\_P_{limit}$, and $1g\_or\_10gSAR\_P_{limit}$ correspond to the measured instantaneous point SAR, measured point SAR at P_{limit}, and measured *1gSAR* or 10gSAR values at P_{limit} corresponding to sub-6 transmission. Similarly, $pointE(t)$, $pointE\_input.power.limit$, and $4cm^2PD\_input.power.limit$ correspond to the measured instantaneous E-field, E-field at *input.power.limit*, and $4cm^2$PD value at *input.power.limit* corresponding to mmW transmission.

NOTE: cDASY6 measurement system by Schmid & Partner Engineering AG (SPEAG) of Zurich, Switzerland measures relative E-field, and provides ratio of $\frac{[pointE(t)]^2}{[pointE\_input.power.limit]^2}$ versus time. See Appendix D for time-averaged PD measurement details.

3 SAR Time Averaging Validation Test Procedures

This chapter provides the test plan and test procedure for validating Qualcomm Smart Transmit algorithm for sub-6 transmission.

3.1 Test sequence determination for validation

Following the FCC recommendation, two test sequences having time-variation in Tx power are predefined for sub-6 (f < 6 GHz) validation:

- Test sequence 1: requesting EUT to transmit at maximum power, measured P_{max}†, for 80s, then requesting for half of the maximum power, i.e., measured $P_{max}/2$, for the rest of the time.
- Test sequence 2: requesting EUT to transmit at time-varying Tx power levels. This sequence is generated relative to measured P_{max}, measured P_{limit} and calculated $P_{reserve}$ (= measured P_{limit} in dBm - *Reserve_power_margin* in dB) of EUT based on measured P_{limit}.

The details for generating these two test sequences is described and listed in Appendix A.

NOTE: For test sequence generation, "measured P_{limit}" and "measured P_{max}" are used instead of the "P_{limit}" specified in EFS entry and "P_{max}" specified for the device, because Smart Transmit algorithm operates against the actual power level of the "P_{limit}" that was calibrated for the EUT. The "measured P_{limit}" accurately reflects what the algorithm is referencing to, therefore, it should be used during algorithm validation testing. The RF tune up and device-to-device variation are already considered in Part 0 report prior to determining P_{limit}.

3.2 Test configuration selection criteria for validating smart transmit algorithm

3.2.1 Test configuration selection for time-varying Tx power transmission

The Smart Transmit time averaging algorithm operation is independent of bands, modes, and channels for a given technology. Hence, validation of Smart Transmit in one band/mode/channel per technology is sufficient. Two bands per technology are proposed and selected for this testing to provide high confidence in this validation.

The criteria for the selection are based on the P_{limit} values determined in Part 0 report. Select two bands* in each supported technology that correspond to least** and highest*** P_{limit} values for validating Smart Transmit.

* If one P_{limit} level applies to all the bands within a technology, then only one band needs to be tested. In this case, within the bands having the same P_{limit}, the radio configuration (e.g., # of RBs, channel#) and device position that correspond to the highest *measured* 1gSAR at P_{limit} shown in Part 1 report is selected.

** In case of multiple bands having the same least P_{limit} within the technology, then select the band having the highest *measured* 1gSAR at P_{limit}.

*** The band having a higher P_{limit} needs to be properly selected so that the power limiting enforced by Smart Transmit can be validated using the pre-defined test sequences. If the highest P_{limit} in a technology is too high where the power limiting enforcement is not needed when testing with the pre-defined test sequences, then the next highest level is checked. This process is continued within the technology until the second band for validation testing is determined.

3.2.2 Test configuration selection for change in call

The criteria to select a test configuration for call-drop measurement is:

- Select technology/band with least P_{limit} among all supported technologies/bands, and select the radio configuration (e.g., # of RBs, channel#) in this technology/band that corresponds to the highest *measured* 1gSAR at P_{limit} listed in Part 1 report.
- In case of multiple bands having same least P_{limit}, then select the band having the highest *measured* 1gSAR at P_{limit} in Part 1 report.

This test is performed with the EUT being requested to transmit at maximum power, the above band selection will result in Tx power enforcement (i.e., EUT forced to transmit at $P_{reserve}$) for longest duration in one FCC defined time window. The call change (call drop/reestablish) is performed during the Tx power enforcement duration (i.e., during the time when EUT is forced to transmit at $P_{reserve}$). One test is sufficient as the algorithm operation is independent of technology and band.

3.2.3 Test configuration selection for change in technology/band

The selection criteria for this measurement is, for a given antenna, to have EUT switch from a technology/band with lowest P_{limit} within the technology group (in case of multiple bands having the same P_{limit}, then select the band with highest *measured* 1gSAR at P_{limit}) to a technology/band with highest P_{limit} within the technology group, in case of multiple bands having the same P_{limit}, then select the band with lowest *measured* 1gSAR at P_{limit} in Part 1 report, or vice versa.

This test is performed with the EUT being requested to transmit at maximum power, the technology/band switch is performed during Tx power enforcement duration (i.e., during the time when EUT is forced to transmit at $P_{reserve}$).

3.2.4 Test configuration selection for change in antenna

The criteria to select a test configuration for antenna switch measurement is:

- Whenever possible and supported by the EUT, first select antenna switch configuration within the same technology/band (i.e., same technology and band combination).

- Then, select any technology/band that supports multiple Tx antennas, and has the highest difference in P_{limit} among all supported antennas.
- In case of multiple bands having same difference in P_{limit} among supported antennas, then select the band having the highest *measured* 1gSAR at P_{limit} in Part 1 report.

This test is performed with the EUT being requested to transmit at maximum power in selected technology/band, and antenna change is conducted during Tx power enforcement duration (i.e., during the time when EUT is forced to transmit at $P_{reserve}$).

3.2.5 Test configuration selection for change in DSI

The criteria to select a test configuration for DSI change test is

- Select a technology/band having the lowest P_{limit} within any technology and DSI group, and for the same technology/band having a different P_{limit} in any other DSI group. Note that the selected DSI transition need to be supported by the device.

This test is performed with the EUT being requested to transmit at maximum power in selected technology/band, and DSI change is conducted during Tx power enforcement duration (i.e., the duration that EUT is forced to transmit at $P_{reserve}$).

3.3 Test procedures for conducted power measurements

Perform conducted power measurement to validate Smart Transmit time averaging algorithm in the transmission scenarios described in Section 2.

3.3.1 Time-varying Tx power transmission scenario

This test is performed with the two pre-defined test sequences described in Section 3.1 for all the technologies and bands selected in Section 3.2.1. The purpose of the test is to demonstrate the effectiveness of power limiting enforcement and that the time-averaged SAR (corresponding time-averaged transmit power) does not exceed the FCC limit at all times (see Eq. (1a) and (1b)).

Test procedure

1. Measure P_{max}, measure P_{limit} and calculate $P_{reserve}$ (= measured P_{limit} in dBm – *Reserve_power_margin* in dB) and follow Section 3.1 to generate the test sequences for all the technologies and bands selected in Section 3.2.1. Both test sequence 1 and test sequence 2 are created based on measured P_{max} and measured P_{limit} of the EUT. Test condition to measure P_{max} and P_{limit} is:
   - Measure P_{max} with Smart Transmit <u>disabled</u> and callbox set to request maximum power.
   - Measure P_{limit} with Smart Transmit <u>enabled</u> and *Reserve_power_margin* set to 0 dB, callbox set to request maximum power.
2. Set *Reserve_power_margin* to actual (intended) value (3dB for this EUT based on Part 1 report) and reset power on EUT to enable Smart Transmit, establish radio link in desired radio configuration, with callbox requesting the EUT to transmit at pre-defined test sequence 1, measure and record Tx power versus time, and then convert the conducted Tx power into 1gSAR or 10gSAR value (see Eq. (1a)) using measured P_{limit} from above Step 1. Perform 100s running average to determine time-averaged power and 1gSAR or 10gSAR versus time as illustrated in Figure 3-1.

NOTE: In Eq.(1a), instantaneous Tx power is converted into instantaneous 1gSAR or 10gSAR value by applying the measured worst-case 1gSAR or 10gSAR value at P_{limit} for the corresponding technology/band/antenna/DSI reported in Part 1 report.

NOTE: For an easier computation of the 100s running average, 0 dBm for 100s can be added at the beginning of the test sequences, so the 100s running average can be directly performed starting with the first 100-seconds data using excel spreadsheet. This technique also applies to all tests performed in this Part 2 report for easier time-averaged computation using excel spreadsheet.

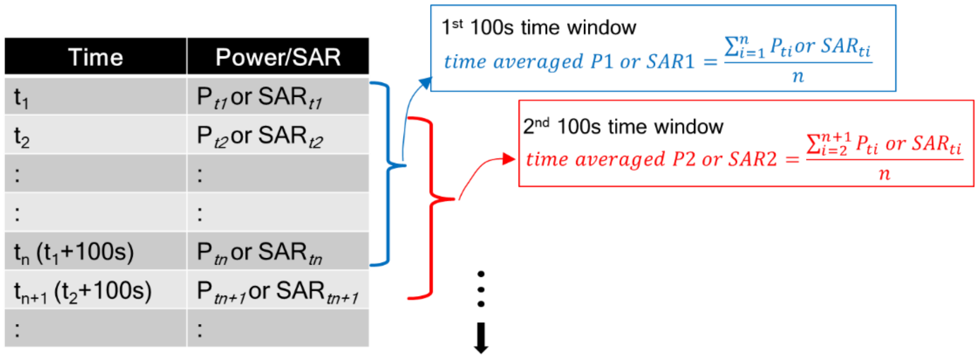


Figure 3-1 100s running average illustration

3. Make one plot containing:
    a. Instantaneous Tx power versus time measured in Step 2,
    b. Requested transmit power used in Step 2 (test sequence 1),
    c. Computed time-averaged power versus time determined in Step 2,
    d. Time-averaged power limit (corresponding to FCC SAR limit of 1.6 W/kg for 1gSAR or 4.0W/kg for 10gSAR) given by

$$Time\ avearged\ power\ limit = meas.P_{limit} + 10 \times \log\left(\frac{FCC\ SAR\ limit}{meas.SAR\_Plimit}\right) \qquad (5a)$$

    where $meas.P_{limit}$ and $meas.SAR\_Plimit$ correspond to measured power at P_{limit} and measured SAR at P_{limit}.

4. Make another plot containing:
    a. Computed time-averaged 1gSAR or 10gSAR versus time determined in Step 2
    b. FCC $1gSAR_{limit}$ of 1.6W/kg or FCC $10gSAR_{limit}$ of 4.0W/kg.
5. Repeat Steps 2 ~ 4 for pre-defined test sequence 2 and replace the requested Tx power (test sequence 1) in Step 2 with test sequence 2.
6. Repeat Steps 2 ~ 5 for all the selected technologies and bands.

The validation criteria are, at all times, the time-averaged power versus time shown in Step 3 plot shall not exceed the time-averaged power limit (defined in Eq. (5a)), in turn, the time-averaged 1gSAR or 10gSAR versus time shown in Step 4 plot shall not exceed the FCC limit of 1.6 W/kg for 1gSAR or 4.0 W/kg for 10gSAR (i.e., Eq. (1b)).

3.3.2 Change in call scenario

This test is to demonstrate that Smart Transmit algorithm accurately accounts for the past Tx powers during time-averaging when a new call is established.

The call disconnect and re-establishment needs to be performed during power limit enforcement, i.e., when the EUT transmits at $P_{reserve}$ level, to demonstrate the continuity of RF exposure management and limiting in call change scenario. In other words, the RF exposure averaged over any FCC defined time window (including the time windows containing the call change) doesn't exceed FCC limit of 1.6 W/kg for 1gSAR or 4.0 W/kg for 10gSAR.

Test procedure

1. Measure P_{limit} for the technology/band selected in Section 3.2.2. Measure P_{limit} with Smart Transmit enabled and *Reserve_power_margin* set to 0 dB, callbox set to request maximum power.
2. Set *Reserve_power_margin* to actual (intended) value and reset power on EUT to enable Smart Transmit.
3. Establish radio link with callbox in the selected technology/band.
4. Request EUT to transmit at 0 dBm for at least 100 seconds, followed by requesting EUT to transmit at maximum Tx power for about ~60 seconds, and then drop the call for ~10 seconds. Afterwards, re-establish another call in the same radio configuration (i.e., same technology/band/channel) and continue callbox requesting EUT to transmit at maximum Tx power for the remaining time of at least another 100 seconds. Measure and record Tx power versus time. Once the measurement is done, extract instantaneous Tx power versus time, convert the measured conducted Tx power into 1gSAR or 10gSAR value using Eq. (1a), and then perform 100s running average to determine time-averaged power and 1gSAR or 10gSAR versus time.

   NOTE: In Eq.(1a), instantaneous Tx power is converted into instantaneous 1gSAR or 10gSAR value by applying the measured worst-case 1gSAR or 10gSAR value at P_{limit} for the corresponding technology/band/antenna/DSI reported in Part 1 report.

5. Make one plot containing: (a) instantaneous Tx power versus time, (b) requested power, (c) computed time-averaged power, (d) time-averaged power limit calculated using Eq.(5a).
6. Make another plot containing: (a) computed time-averaged 1gSAR or 10gSAR versus time, and (b) FCC limit of 1.6 W/kg for 1gSAR or 4.0 W/kg for 10gSAR.

The validation criteria are, at all times, the time-averaged power versus time shall not exceed the time-averaged power limit (defined in Eq.(5a)), in turn, the time-averaged 1gSAR or 10gSAR versus time shall not exceed the FCC limit of 1.6 W/kg for 1gSAR or 4.0 W/kg for 10gSAR (i.e., Eq. (1b)).

3.3.3 Change in technology and band

This test is to demonstrate the correct power control by Smart Transmit during technology switches and/or band handovers.

Similar to the change in call test in Section 3.3.2, to validate the continuity of RF exposure limiting during the transition, the technology and band handover needs to be performed when

EUT transmits at $P_{reserve}$ level (i.e., during Tx power enforcement) to make sure that the EUT transmits from previous $P_{reserve}$ level to the new $P_{reserve}$ level (corresponding to new technology/band). Since the P_{limit} could vary with technology and band, Eq. (1a) can be written as follows to convert the instantaneous Tx power in 1gSAR or 10gSAR exposure for the two given radios, respectively:

$$1g\_or\_10gSAR_1(t) = \frac{conducted\_Tx\_power\_1(t)}{conducted\_Tx\_power\_P_{limit\_1}} * 1g\_or\_10gSAR\_P_{limit\_1} \quad (6a)$$

$$1g\_or\_10gSAR_2(t) = \frac{conducted\_Tx\_power\_2(t)}{conducted\_Tx\_power\_P_{limit\_2}} * 1g\_or\_10gSAR\_P_{limit\_2} \quad (6b)$$

$$\frac{\frac{1}{T_{SAR}}\left[\int_{t-T_{SAR}}^{t_1} 1g\_or\_10gSAR_1(t)dt + \int_{t1}^{t} 1g\_or\_10gSAR_2(t)dt\right]}{FCC\ SAR\ limit} \leq 1 \quad (6c)$$

where, *conducted_Tx_power_1(t), conducted_Tx_power_*P_{limit_1}, and *1g_or_10gSAR_*P_{limit_1} correspond to the measured instantaneous conducted Tx power, measured conducted Tx power at P_{limit}, and measured *1gSAR* or *10gSAR* value at P_{limit} of technology1/band1; *conducted_Tx_power_2(t), conducted_Tx_power_*P_{limit_2}*(t)*, and *1g_or_10gSAR_*P_{limit_2} correspond to the measured instantaneous conducted Tx power, measured conducted Tx power at P_{limit}, and measured *1gSAR* or *10gSAR* value at P_{limit} of technology2/band2.

Test procedure

1. Measure P_{limit} for both the technologies and bands selected in Section 3.2.3. Measure P_{limit} with Smart Transmit enabled and *Reserve_power_margin* set to 0 dB, callbox set to request maximum power.
2. Set *Reserve_power_margin* to actual (intended) value and reset power on EUT to enable Smart Transmit
3. Establish radio link with callbox in first technology/band selected.
4. Request EUT to transmit at 0 dBm for at least 100 seconds, followed by requesting EUT to transmit at maximum Tx power for about ~60 seconds, and then switch to second technology/band selected. Continue with callbox requesting EUT to transmit at maximum Tx power for the remaining time of at least another 100 seconds. Measure and record Tx power versus time for the full duration of the test.
5. Once the measurement is done, extract instantaneous Tx power versus time, and convert the conducted Tx power into 1gSAR or 10gSAR value using Eq. (6a) and (6b) and corresponding measured P_{limit} values from Step 1 of this section. Perform 100s running average to determine time-averaged power and 1gSAR or 10gSAR versus time.

   NOTE: In Eq.(6a) & (6b), instantaneous Tx power is converted into instantaneous 1gSAR or 10gSAR value by applying the measured worst-case 1gSAR or 10gSAR value at P_{limit} for the corresponding technology/band/antenna/DSI reported in Part 1 report.

6. Make one plot containing: (a) instantaneous Tx power versus time, (b) requested power, (c) computed time-averaged power, (d) time-averaged power limit calculated using Eq.(5a).
7. Make another plot containing: (a) computed time-averaged 1gSAR or 10gSAR versus time, and (b) FCC limit of 1.6 W/kg for 1gSAR or 4.0 W/kg for 10gSAR.

The validation criteria are, at all times, the time-averaged 1gSAR or 10gSAR versus time shall not exceed the FCC limit of 1.6 W/kg for 1gSAR or 4.0 W/kg for 10gSAR (i.e., Eq. (6c)).

3.3.4 Change in antenna

This test is to demonstrate the correct power control by Smart Transmit during antenna switches from one antenna to another. The test procedure is identical to Section 3.3.3, by replacing technology/band switch operation with antenna switch. The validation criteria are, at all times, the time-averaged 1gSAR or 10gSAR versus time shall not exceed FCC limit of 1.6 W/kg for 1gSAR or 4.0 W/kg for 10gSAR.

NOTE: If the EUT does not support antenna switch within the same technology/band, but has multiple antennas to support different frequency bands, then the antenna switch test is included as part of change in technology and band (Section 3.3.3) test.

3.3.5 Change in DSI

This test is to demonstrate the correct power control by Smart Transmit during DSI switches from one DSI to another. The test procedure is identical to Section 3.3.3, by replacing technology/band switch operation with DSI switch. The validation criteria are, at all times, the time-averaged 1gSAR or 10gSAR versus time shall not exceed FCC limit of 1.6 W/kg for 1gSAR or 4.0 W/kg for 10gSAR.

3.4 Test procedure for SAR measurements

To perform the validation through SAR measurement for transmission scenario 1 described in Section 2, the “path loss” between callbox antenna and EUT needs to be calibrated to ensure that the EUT Tx power reacts to the requested power from callbox in a radiated call. It should be noted that when signaling in closed loop mode, protocol-level power control is in play, resulting in EUT not solely following callbox TPC (transmit power control) commands. In other words, EUT response has many dependencies (RSSI, quality of signal, path loss variation, fading, etc.,) other than just TPC commands. These dependencies have less impact in conducted setup (as it is a controlled environment and the path loss can be very well calibrated) but have significant impact on radiated testing in an uncontrolled environment, such as SAR test setup. Therefore, the deviation in EUT Tx power from callbox requested power is expected, however the time-averaged SAR should not exceed FCC SAR requirement at all times as Smart Transmit controls Tx power at EUT.

The following steps are for time averaging algorithm validation through SAR measurement:

1. “Path Loss” calibration: Place the EUT against the phantom in the worst-case position determined based on Section 3.2.1. For each band selected, prior to SAR measurement, perform “path loss” calibration between callbox antenna and EUT. Since the SAR test environment is not controlled and well calibrated for OTA (Over the Air) test, extreme care needs to be taken to avoid the influence from reflections. The test setup is described in Section 7.1 and the step-by-step test procedure for “path loss” calibration is provided in Appendix B.
2. Time averaging algorithm validation:
   i For a given radio configuration (technology/band) selected in Section 3.2.1, enable Smart Transmit and set *Reserve_power_margin* to 0 dB, with callbox to request maximum power, perform area scan, conduct pointSAR measurement at peak location of the area scan. This point SAR value, $pointSAR\_P_{limit}$, corresponds to point SAR at the measured P_{limit} (i.e., measured P_{limit} from the EUT in Step 1 of Section 3.3.1).

ii Set *Reserve_power_margin* to actual (intended) value and reset power on EUT to enable Smart Transmit. Note, if *Reserve_power_margin* cannot be set wirelessly, care must be taken to re-position the EUT in the exact same position relative to the SAM phantom as in above Step 2.i. Establish radio link in desired radio configuration, with callbox requesting the EUT to transmit at power levels described by test sequence 1 generated in Step 1 of Section 3.3.1, conduct point SAR measurement versus time at peak location of the area scan determined in Step 2.i of this section. Once the measurement is done, extract instantaneous point SAR vs time data, *pointSAR(t)*, and convert it into instantaneous 1gSAR or 10gSAR vs. time using Eq. (3a), re-written below:

$$1g\_or\_10gSAR(t) = \frac{pointSAR(t)}{pointSAR\_P_{limit}} * 1g\_or\_10gSAR\_P_{limit}$$

where, $pointSAR\_P_{limit}$ is the value determined in Step 2.i, and *pointSAR(t)* is the instantaneous point SAR measured in Step 2.ii, $1g\_or\_10gSAR\_P_{limit}$ is the measured 1gSAR or 10gSAR value listed in Part 1 report.

iii Perform 100s running average to determine time-averaged 1gSAR or 10gSAR versus time.

iv Make one plot containing: (a) time-averaged 1gSAR or 10gSAR versus time determined in Step 2.iii of this section, (b) FCC limit of 1.6 W/kg for 1gSAR or 4.0 W/kg for 10gSAR.

v Repeat 2.ii ~ 2.iv for test sequence 2 generated in Step 1 of Section 3.3.1.

vi Repeat 2.i ~ 2.v for all the technologies and bands selected in Section 3.2.1.

The time-averaging validation criteria for SAR measurement is that, at all times, the time-averaged 1gSAR or 10gSAR versus time shall not exceed FCC limit of 1.6 W/kg for 1gSAR or 4.0 W/kg for 10gSAR (i.e., Eq. (3b)).

4 PD Time Averaging Validation Test Procedures

This chapter provides the test plan and test procedures for validating Qualcomm Smart Transmit algorithm for mmW transmission. For this EUT, millimeter wave (mmW) transmission is only in non-standalone mode, i.e., it requires an LTE link as anchor.

4.1 Test sequence for validation in mmW NR transmission

In 5G mmW NR transmission, the test sequence for validation is with the callbox requesting EUT to transmit in 5G mmW NR at maximum power all the time.

4.2 Test configuration selection criteria for validating smart transmit algorithm

4.2.1 Test configuration selection for time-varying Tx power transmission

The Smart Transmit time averaging algorithm operation is independent of bands, modes, channels, and antenna configurations (beams) for a given technology. Hence, validation of Smart Transmit in any one band/mode/channel per technology is sufficient.

4.2.2 Test configuration selection for change in antenna configuration (beam)

The Smart Transmit time averaging algorithm operation is independent of bands, modes, channels, and antenna configurations (beams) for a given technology. Hence, validation of Smart Transmit with beam switch between any two beams is sufficient.

4.2.3 Test configuration selection for SAR vs. PD exposure switch during transmission

The Smart Transmit time averaging algorithm operation is independent of the nature of exposure (SAR vs. PD) and ensures total time-averaged RF exposure compliance. Hence, validation of Smart Transmit in any one band/mode/channel/beam for mmW + sub-6 (LTE) transmission is sufficient, where the exposure varies among SAR dominant scenario, SAR+PD scenario, and PD dominant scenario.

4.3 Test procedures for mmW radiated power measurements

Perform conducted power measurement (for f < 6GHz) and radiated power measurement (for f > 6GHz) for LTE + mmW transmission to validate Smart Transmit time averaging algorithm in the various transmission scenarios described in Section 2.

4.3.1 Time-varying Tx power scenario

The purpose of the test is to demonstrate the effectiveness of power limiting enforcement and that the time-averaged transmit power when converted into RF exposure values does not exceed the FCC limit at all times (see Eq. (2a), (2b) & (2c) in Section 2).

Test procedure:

1. Measure conducted Tx power corresponding to P_{limit} for LTE in selected band, and measure radiated Tx power corresponding to *input.power.limit* in desired mmW band/channel/beam by following below steps:
    a. Measure radiated power corresponding to mmW *input.power.limit* by setting up the EUT to transmit in desired band/channel/beam at *input.power.limit* in Factory Test Mode (FTM). This test is performed in a calibrated anechoic chamber. Rotate the EUT to obtain maximum radiated Tx power, keep the EUT in this position and do not disturb the position of the EUT inside the anechoic chamber for the rest of this test.
    b. Reset EUT to place in online mode and establish radio link in LTE, measure conducted Tx power corresponding to LTE P_{limit} with Smart Transmit enabled and *Reserve_power_margin* set to 0 dB, callbox set to request maximum power.
2. Set *Reserve_power_margin* to actual (intended) value and reset power on EUT to enable Smart Transmit. With EUT setup for a mmW NR call in the desired/selected LTE band and mmW NR band, perform the following steps:
    a. Establish LTE and mmW NR connection in desired band/channel/beam used in Step 1. As soon as the mmW connection is established, immediately request all-down bits on LTE link. With callbox requesting EUT to transmit at maximum mmW power to test predominantly PD exposure scenario (as SAR exposure is less when LTE transmits at low power).
    b. After 120s, request LTE to go all-up bits for at least 100s. SAR exposure is dominant. There are two scenarios:
        i If $P_{limit} < P_{max}$ for LTE, then the RF exposure margin (provided to mmW NR) gradually runs out (due to high SAR exposure). This results in gradual reduction in the 5G mmW NR transmission power and eventually seized 5G mmW NR transmission when LTE goes to $P_{reserve}$ level.
        ii If $P_{limit} \geq P_{max}$ for LTE, then the 5G mmW NR transmission's averaged power should gradually reduce but the mmW NR connection can sustain all the time (assuming TxAGC uncertainty = 0dB).
    c. Record the conducted Tx power of LTE and radiated Tx power of mmW for the full duration of this test of at least 300s.
3. Once the measurement is done, extract instantaneous Tx power versus time for both LTE and mmW links. Convert the conducted Tx power for LTE into 1gSAR or 10gSAR value using Eq. (2a) and P_{limit} measured in Step 1.b, and then divide by FCC limit of 1.6 W/kg for 1gSAR

or 4.0 W/kg for 10gSAR to obtain instantaneous normalized 1gSAR or 10gSAR versus time. Perform 100s running average to determine normalized 100s-averaged 1g or 10gSAR versus time.

NOTE: In Eq.(2a), instantaneous Tx power is converted into instantaneous 1gSAR or 10gSAR value by applying the measured worst-case 1gSAR or 10gSAR value at P_{limit} for the corresponding technology/band/antenna/DSI reported in Part 1 report.

4. Similarly, convert the radiated Tx power for mmW into $4cm^2$PD value using Eq. (2b) and the radiated Tx power limit (i.e., radiated Tx power at *input.power.limit*) measured in Step 1.a, then divide by FCC $4cm^2$PD limit of $10W/m^2$ to obtain instantaneous normalized $4cm^2$PD versus time. Perform 4s running average to determine normalized 4s-averaged $4cm^2$PD versus time.

NOTE: In Eq.(2b), instantaneous radiated Tx power is converted into instantaneous $4cm^2$PD by applying the worst-case $4cm^2$PD value measured at *input.power.limit* for the selected band/beam in Part 1 report.

5. Make one plot containing: (a) instantaneous conducted Tx power for LTE versus time, (b) computed 100s-averaged conducted Tx power for LTE versus time, (c) instantaneous radiated Tx power for mmW versus time, as measured in Step 2, (d) computed 4s-averaged radiated Tx power for mmW versus time, and (e) time-averaged conducted and radiated power limits for LTE and mmW radio using Eq. (5a) & (5b), respectively:

$$Time\ avearged\ LTE\ power\ limit = meas.P_{limit} + 10 \times \log\left(\frac{FCC\ SAR\ limit}{meas.SAR\_Plimit}\right) \quad (5a)$$

$$Time\ avearged\ mmW\ NR\ power\ limit = meas.EIRP_{input.power.limit} + 10 \times \log\left(\frac{FCC\ PD\ limit}{meas.PD\_input.power.limit}\right) \quad (5b)$$

where $meas.EIRP_{input.power.limit}$ and $meas.PD\_input.power.limit$ correspond to measured EIRP at *input.power.limit* and measured power density at *input.power.limit*.

6. Make another plot containing: (a) computed normalized 100s-averaged 1gSAR or 10gSAR versus time determined in Step 3, (b) computed normalized 4s-averaged $4cm^2$PD versus time determined in Step 4, and (c) corresponding total normalized time-averaged RF exposure (sum of steps (6.a) and (6.b)) versus time.

The validation criteria are, at all times, the total normalized time-averaged RF exposure versus time determined in Step 6.c shall not exceed the normalized limit of 1.0 of FCC requirement (i.e., Eq. (2c)).

4.3.2 Switch in SAR vs. PD exposure during transmission

This test is to demonstrate that Smart Transmit algorithm is independent of the nature of exposure (SAR vs. PD), accurately accounts for switching in exposures among SAR dominant, SAR+PD, and PD dominant scenarios, and ensures total time-averaged RF exposure compliance.

Test procedure:

1. Measure conducted Tx power corresponding to P_{limit} for LTE in selected band, and measure radiated Tx power corresponding to *input.power.limit* in desired mmW band/channel/beam by following below steps:
   a. Measure radiated power corresponding to *input.power.limit* by setting up the EUT to transmit in desired band/channel/beam at *input.power.limit* in FTM. This test is performed in a calibrated anechoic chamber. Rotate the EUT to obtain maximum radiated Tx power, keep the EUT in this position and do not disturb the position of the EUT inside the anechoic chamber for the rest of this test.
   b. Reset EUT to place in online mode and establish radio link in LTE, measure conducted Tx power corresponding to LTE P_{limit} with Smart Transmit enabled and *Reserve_power_margin* set to 0 dB, callbox set to request maximum power.
2. Set *Reserve_power_margin* to actual (intended) value and reset power in EUT, with EUT setup for LTE + mmW call, perform the following steps:
   a. Establish LTE (sub-6) and mmW NR connection with callbox.
   b. As soon as the mmW connection is established, immediately request all-down bits on LTE link. Continue LTE (all-down bits) + mmW transmission for more than 100s duration to test predominantly PD exposure scenario (as SAR exposure is negligible from all-down bits in LTE).
   c. After 120s, request LTE to go all-up bits, mmW transmission should gradually run out of RF exposure margin if LTE's $P_{limit} < P_{max}$ and seize mmW transmission (SAR only scenario); or mmW transmission should gradually reduce in Tx power and will sustain the connection if LTE's $P_{limit} > P_{max}$.
   d. After 75s, request LTE to go all-down bits, mmW transmission should start getting back RF exposure margin and transmit again.
   e. Record the conducted Tx power of LTE and radiated Tx power of mmW for the entire duration of this test of at least 300s.
3. Once the measurement is done, extract instantaneous Tx power versus time for both LTE and mmW links. Convert the conducted Tx power for LTE into 1gSAR or 10gSAR value using Eq. (2a) and P_{limit} measured in Step 1.b, and then divide by FCC limit of 1.6 W/kg for 1gSAR or 4.0 W/kg for 10gSAR to obtain instantaneous normalized 1gSAR or 10gSAR versus time. Perform 100s running average to determine normalized 100s-averaged 1gSAR or 10gSAR versus time.

   NOTE: In Eq.(2a), instantaneous Tx power is converted into instantaneous 1gSAR or 10gSAR value by applying the measured worst-case 1gSAR or 10gSAR value at P_{limit} for the corresponding technology/band/antenna/DSI reported in Part 1 report.

4. Similarly, convert the radiated Tx power for mmW into $4cm^2$PD value using Eq. (2b) and the radiated Tx power limit (i.e., radiated Tx power at *input.power.limit*) measured in Step 1.a, then divide this by FCC $4cm^2$PD limit of $10W/m^2$ to obtain instantaneous normalized $4cm^2$PD versus time. Perform 4s running average to determine normalized 4s-averaged $4cm^2$PD versus time.

NOTE: In Eq.(2b), instantaneous radiated Tx power is converted into instantaneous $4cm^2$PD by applying the worst-case $4cm^2$PD value measured at *input.power.limit* for the selected band/beam in Part 1 report.

5. Make one plot containing: (a) instantaneous conducted Tx power for LTE versus time, (b) computed 100s-averaged conducted Tx power for LTE versus time, (c) instantaneous radiated Tx power for mmW versus time, as measured in Step 2, (d) computed 4s-averaged radiated Tx power for mmW versus time, and (e) time-averaged conducted and radiated power limits for LTE and mmW radio using Eq. (5a) & (5b), respectively.
6. Make another plot containing: (a) computed normalized 100s-averaged 1gSAR or 10gSAR versus time determined in Step 3, (b) computed normalized 4s-averaged $4cm^2$PD versus time determined in Step 4, and (c) corresponding total normalized time-averaged RF exposure (sum of steps (6.a) and (6.b)) versus time.

The validation criteria are, at all times, the total normalized time-averaged RF exposure versus time determined in Step 6.c shall not exceed the normalized limit of 1.0 of FCC requirement (i.e., Eq. (2c)).

4.3.3 Change in antenna configuration (beam)

This test is to demonstrate the correct power control by Smart Transmit during changes in antenna configuration (beam). Since the *input.power.limit* varies with beam, the Eq. (2a), (2b) and (2c) in Section 2 are written as below for transmission scenario having change in beam,

$$1g\_or\_10gSAR(t) = \frac{conducted\_Tx\_power(t)}{conducted\_Tx\_power\_P_{limit}} * 1g\_or\_10gSAR\_P_{limit} \quad (8a)$$

$$4cm^2PD_1(t) = \frac{radiated\_Tx\_power\_1(t)}{radiated\_Tx\_power\_input.power.limit\_1} * 4cm^2PD\_input.power.limit\_1 \quad (8b)$$

$$4cm^2PD_2(t) = \frac{radiated\_Tx\_power\_2(t)}{radiated\_Tx\_power\_input.power.limit\_2} * 4cm^2PD\_input.power.limit\_2 \quad (8c)$$

$$\frac{\frac{1}{T_{SAR}}\int_{t-T_{SAR}}^{t} 1g\_or\_10gSAR(t)dt}{FCC\ SAR\ limit} + \frac{\frac{1}{T_{PD}}\left[\int_{t-T_{PD}}^{t_1} 4cm^2\mathrm{PD}_1(t)dt + \int_{t1}^{t} 4cm^2\mathrm{PD}_2(t)dt\right]}{FCC4cm^2\ PD\ limit} \leq 1 \quad (8d)$$

where, $conducted\_Tx\_power(t)$, $conducted\_Tx\_power\_P_{limit}$, and $1g\_or\_10gSAR\_P_{limit}$ correspond to the measured instantaneous conducted Tx power, measured conducted Tx power at P_{limit}, and measured *1gSAR or 10gSAR* values at P_{limit} corresponding to LTE transmission. Similarly, *radiated_Tx_power_1(t), radiated_Tx_power_input.power.limit_1*, and *$4cm^2$PD_input.power.limit_1* correspond to the measured instantaneous radiated Tx power, radiated Tx power at *input.power.limit*, and *$4cm^2$PD* value at *input.power.limit* of beam 1; *radiated_Tx_power_2(t), radiated_Tx_power_input.power.limit_2*, and *$4cm^2$PD_input.power.limit_2* correspond to the measured instantaneous radiated Tx power, radiated Tx power at *input.power.limit*, and *$4cm^2$PD* value at *input.power.limit* of beam 2 corresponding to mmW transmission.

Test procedure:

1. Measure conducted Tx power corresponding to P_{limit} for LTE in selected band, and measure radiated Tx power corresponding to *input.power.limit* in desired mmW band/channel/beam by following below steps:
    a. Measure radiated power corresponding to mmW *input.power.limit* by setting up the EUT in FTM and to transmit in desired band/channel at *input.power.limit* of beam 1. Do not disturb the position of the EUT inside the anechoic chamber for the rest of this test. Repeat this Step 1.a for beam 2.
    b. Reset EUT to place in online mode and establish radio link in LTE, measure conducted Tx power corresponding to LTE P_{limit} with Smart Transmit enabled and *Reserve_power_margin* set to 0 dB, callbox set to request maximum power.
2. Set *Reserve_power_margin* to actual (intended) value and reset power in EUT, With EUT setup for LTE + mmW connection, perform the following steps:
    a. Establish LTE (sub-6) and mmW NR connection in beam 1. As soon as the mmW connection is established, immediately request all-down bits on LTE link with the callbox requesting EUT to transmit at maximum mmW power.
    b. After beam 1 transmits for at least 20s, request the EUT to change from beam 1 to beam 2, and continue transmitting with beam 2 for at least 20s.
    c. Record the conducted Tx power of LTE and radiated Tx power of mmW for the entire duration of this test.
3. Once the measurement is done, extract instantaneous Tx power versus time for both LTE and mmW links. Convert the conducted Tx power for LTE into 1gSAR or 10gSAR value using the similar approach described in Step 3 of Section 4.3.2. Perform 100s running average to determine normalized 100s-averaged 1gSAR versus time.
4. Similarly, convert the radiated Tx power for mmW NR into $4cm^2$PD value using Eq. (8b), (8c) and the radiated Tx power limits (i.e., radiated Tx power at *input.power.limit*) measured in Step 1.a for beam 1 and beam 2, respectively, and then divide the resulted PD values by FCC $4cm^2$PD limit of $10W/m^2$ to obtain instantaneous normalized $4cm^2$PD versus time for beam 1 and beam 2. Perform 4s running average to determine normalized 4s-averaged $4cm^2$PD versus time.

    NOTE: In Eq.(8b) and (8c), instantaneous radiated Tx power of beam 1 and beam 2 is converted into instantaneous $4cm^2$PD by applying the worst-case $4cm^2$PD value measured at the *input.power.limit* of beam 1 and beam 2 in Part 1 report, respectively.

5. Since the measured radiated powers for beam 1 and beam 2 in Step 1.a were performed at an arbitrary rotation of EUT in anechoic chamber, repeat Step 1.a of this procedure by rotating the EUT to determine maximum radiated power at *input.power.limit* in FTM mode for both beams separately. Re-scale the measured instantaneous radiated power in Step 2.c by the delta in radiated power measured in Step 5 and the radiated power measured in Step 1.a for plotting purposes in next Step. In other words, this step essentially converts measured instantaneous radiated power during the measurement in Step 2 into maximum instantaneous radiated power for both beams. Perform 4s running average to compute 4s-avearged radiated Tx power. Additionally, use these EIRP values measured at *input.power.limit* at respective peak locations to determine the EIRP limits (using Eq. (5b)) for both these beams.

6. Make one plot containing: (a) instantaneous conducted Tx power for LTE versus time, (b) computed 100s-averaged conducted Tx power for LTE versus time, (c) instantaneous radiated Tx power for mmW versus time, as obtained in Step 5, (d) computed 4s-averaged radiated Tx power for mmW versus time, as obtained in Step 5, and (e) time-averaged conducted and radiated power limits for LTE and mmW radio, respectively.
7. Make another plot containing: (a) computed normalized 100s-averaged 1gSAR versus time determined in Step 3, (b) computed normalized 4s-averaged 4cm^{2}PD versus time determined in Step 4, and (c) corresponding total normalized time-averaged RF exposure (sum of steps (6.a) and (6.b)) versus time.

The validation criteria are, at all times, the total normalized time-averaged RF exposure versus time determined in Step 6.c shall not exceed the normalized limit of 1.0 of FCC requirement (i.e., (8d)).

4.4 Test procedure for PD measurements

The following steps are used to perform the validation through PD measurement for transmission scenario 1 described in Section 2:

1. Place the EUT on the cDASY6 platform to perform PD measurement in the worst-case position/surface for the selected mmW band/beam. In PD measurement, the callbox is set to request maximum Tx power from EUT all the time. Hence, "path loss" calibration between callbox antenna and EUT is not needed in this test.
2. Time averaging algorithm validation:
    a. Measure conducted Tx power corresponding to P_{limit} for LTE in selected band, and measure point E-field corresponding to *input.power.limit* in desired mmW band/channel/beam by following the below steps:
        i. Measure conducted Tx power corresponding to LTE P_{limit} with Smart Transmit enabled and *Reserve_power_margin* set to 0 dB, with callbox set to request maximum power.
        ii. Measure point E-field at peak location of fast area scan corresponding to *input.power.limit* by setting up the EUT to transmit in desired mmW band/channel/beam at *input.power.limit* in FTM Mode. Do not disturb the position of EUT and mmW cDASY6 probe.
    b. Set *Reserve_power_margin* to actual value (i.e., intended value) and reset power on EUT, place EUT in online mode. With EUT setup for LTE (sub-6) + mmW NR call, as soon as the mmW NR connection is established, request all-down bits on LTE link. Continue LTE (all-down bits) + mmW transmission for more than 100s duration to test predominantly PD exposure scenario. After 120s, request LTE to go all-up bits, mmW transmission should gradually reduce. Simultaneously, record the conducted Tx power of LTE transmission using power meter and point E-field (in terms of ratio of $\frac{[pointE(t)]^2}{[pointE\_input.power.limit]^2}$) of mmW transmission using cDASY6 E-field probe at peak location identified in Step 2.a.ii for the entire duration of this test of at least 300s.
    c. Once the measurement is done, extract instantaneous conducted Tx power versus time for LTE transmission and $\frac{[pointE(t)]^2}{[pointE\_input.power.limit]^2}$ ratio versus time from cDASY6 system for mmW transmission. Convert the conducted Tx power for LTE into 1gSAR or

10gSAR value using Eq. (4a) and P_{limit} measured in Step 2.a.i, and then divide this by FCC limit of 1.6 W/kg for 1gSAR or 4.0 W/kg for 10gSAR to obtain instantaneous normalized 1gSAR or 10gSAR versus time. Perform 100s running average to determine normalized 100s-averaged 1gSAR or 10gSAR versus time

NOTE: In Eq.(4a), instantaneous Tx power is converted into instantaneous 1gSAR or 10gSAR value by applying the measured worst-case 1gSAR or 10gSAR value at P_{limit} for the corresponding technology/band reported in Part 1 report.

d. Similarly, convert the point E-field for mmW transmission into $4cm^2$PD value using Eq. (4b) and radiated power limit measured in Step 2.a.ii, and then divide this by FCC $4cm^2$PD limit of $10W/m^2$ to obtain instantaneous normalized $4cm^2$PD versus time. Perform 4s running average to determine normalized 4s-averaged $4cm^2$PD versus time.

e. Make one plot containing: (i) computed normalized 100s-averaged 1gSAR or 10gSAR versus time determined in Step 2.c, (ii) computed normalized 4s-averaged $4cm^2$PD versus time determined in Step 2.d, and (iii) corresponding total normalized time-averaged RF exposure (sum of steps (2.e.i) and (2.e.ii)) versus time.

The validation criteria are, at all times, the total normalized time-averaged RF exposure versus time determined in Step 2.e.iii shall not exceed the normalized limit of 1.0 of FCC requirement (i.e., Eq. (4c)).

5 Test Configurations

5.1 WWAN (sub-6) transmission

The P_{limit} values, corresponding to 1.0 mW/g of *SAR_design_target*, for technologies and bands supported by EUT are derived in Part 0 report and summarized in Table 5-1. Note all P_{limit} power levels entered in Table 5-1 correspond to average power levels after accounting for duty cycle in the case of TDD modulation schemes (for e.g., GSM & LTE TDD).

Table 5-1: P_{limit} for supported technologies and bands

Exposure scenario		head	body worn	hotspot	extremity	extremity	extremity	Maximum tune up output power*
avg. vol:		1g	1g	1g	10g	10g	10g	
spacing:		0mm	15mm	10mm	0mm	0mm	6,8,11mm	
DSI:		2	0	3	1	4	0	
Tech/Band	Antenna	**Plimit corresponding to 1mW/g (SAR_design_target)**						
GSM/GPRS/EDGE 850 MHz	A	33.9	31.5	27.4	27.2	27.2	31.5	25.5
GSM/GPRS/EDGE 1900 MHz	A	33.2	25.7	**17.7**	22.1	22.1	25.7	22.0
UMTS B5	A	32.8	30.5	27.2	26.9	26.9	30.5	24.5
UMTS B2	A	32.9	24.7	**17.4**	19.7	19.7	24.7	24.0
CDMA/EVDO BC0	A	33.7	32.4	27.6	26.1	26.1	32.4	25.3
CDMA/EVDO BC1	A	33.3	25.5	**18.0**	19.8	19.8	25.5	24.0
LTE FDD B12	A	34.7	32.9	30.6	27.6	27.6	32.9	24.8
LTE FDD B13	A	33.5	32.3	28.4	25.5	25.5	32.3	24.8
LTE FDD B26	A	34.3	31.9	27.8	27.3	27.3	31.9	24.8
LTE FDD B5	A	31.7	32.6	27.3	25.3	25.3	32.6	24.8
LTE FDD B66/4	A	33.2	24.6	19.8	20.6	20.6	24.6	24.0
LTE FDD B2	A	33.9	26.2	**18.0**	**20.2**	20.2	26.2	24.0
LTE FDD B7	B	33.8	27.4	**20.8**	20.8	20.8	27.4	23.0
LTE TDD B48	B	37.2	27.9	23.1	20.1	20.1	27.9	20.0
LTE TDD B38	B	33.2	26.6	20.0	20.0	20.0	26.6	19.5
LTE TDD B41 (PC3)	B	33.2	26.6	20.0	20.0	20.0	26.6	21.5

* Maximum tune up output power, P_{max}, is used to configure EUT during RF tune up procedure. The maximum allowed output power is equal to maximum tune up output power + 1dB device uncertainty.

Based on selection criteria described in Section 3.2, the selected technologies/bands and test configurations are highlighted in yellow in Table 5-1. The corresponding 1gSAR or 10gSAR values and relevant information extracted from Part 1 report are listed in Table 5-2. As per Part 1 report, the bottom surface (i.e., S6 as shown in Figure 5-1) of the EUT is the worst-case position for the selected test configurations. Additionally, per Part 1 report, the *Reserve_power_margin* (dB) for Samsung portable handset (FCC ID: A3LSMN976V) is set to 3dB in EFS, and is used in Part 2 test.

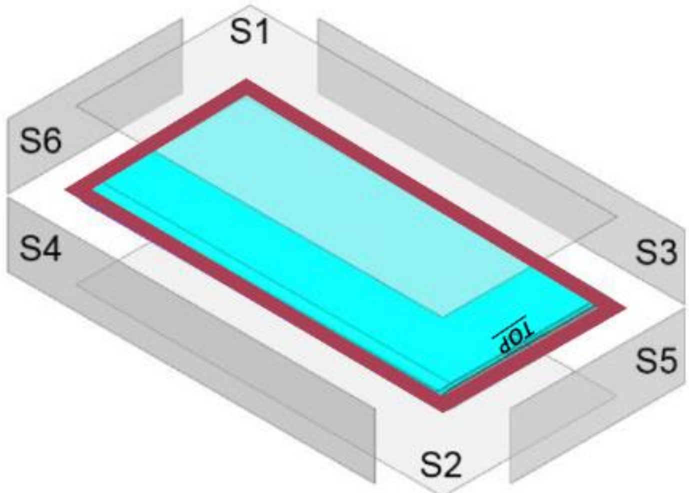


Figure 5-1: Samsung EUT position description: S1 = front, S2 = back, S3 = left, S4 = right, S5 = top, S6 = bottom

Table 5-2: Radio configurations selected for Part 2 test

Test Case #	Test scenario	Tech	Band	Ant	DSI	Channel	RB/offset	freq (MHz)	mode	device position	detail	measured 1g or 10gSAR at Plimit (W/kg)
1	time-varying Tx power transmission	WCDMA	II (1900)	A	3	9400	-	1880	RMC	bottom	hotspot/1g/10mm	1.090
2		CDMA	BC1	A	3	600	-	1880	EVDO Rev. 0	bottom	hotspot/1g/10mm	0.901
3		GSM	1900	A	3	810	-	1909.8	GPRS/ 3 slots	bottom	hotspot/1g/10mm	0.758
4		LTE	B2	A	3	18900	50/50/20MHz	1880	QPSK	bottom	hotspot/1g/10mm	0.840
5			B7	B	3	21350	50/0/20MHz	2560	QPSK	bottom	hotspot/1g/10mm	0.740
6	tech/band/ ant switch	WCDMA	II (1900)	A	3	9400	-	1880	RMC	bottom	hotspot/1g/10mm	1.090
		LTE	B7	B	3	21350	50/0/20MHz	2560	QPSK	bottom	hotspot/1g/10mm	0.740
7	call drop	WCDMA	II (1900)	A	3	9400	-	1880	RMC	bottom	hotspot/1g/10mm	1.090
8	DSI switch	LTE	B2	A	3	19100	50/50/20MHz	1900	QPSK	bottom	hotspot/1g/10mm	0.840
		LTE	B2	A	1	18700	50/50/20MHz	1860	QPSK	bottom	extremity-grip-sensor/10g/0mm	2.570

Note that the EUT has a proximity sensor to manage extremity exposure, which is represented using DSI = 1; the head exposure can be distinguished through audio receiver mode, represented as DSI = 2; similarly, the hotspot exposure is distinguished via hotspot mode, represented as DSI = 3; the exposure for headset jack active scenario is represented using DSI = 4 and is managed as the same exposure condition as extremity exposure at 0 mm; DSI = 0 represents all other exposures which cannot be distinguished, thus, in this case, the maximum 1gSAR and/or 10gSAR among all remaining exposure scenarios or the minimum P_{limit} among all remaining exposure scenarios (i.e., body worn 1gSAR evaluation at 15mm spacing, phablet 10gSAR extremity evaluation at 6~11mm spacing, phablet 10gSAR extremity evaluation at 0mm spacing for left and right surfaces) is used in Smart Transmit algorithm for time averaging operation.

Based on the selection criteria described in Section 3.2, the radio configurations for the Tx varying transmission test cases listed in Section 2 are:

1. Technologies and bands for time-varying Tx power transmission: The test case 1~5 listed in Table 5-2 are selected to test with the test sequences defined in Section 3.1 in both time-varying conducted power measurement and time-varying SAR measurement. Note that only one GSM, one CDMA EVDO and one WCDMA bands were selected as the second band for these technologies has P_{limit} greater than P_{max}, requiring no Tx power limitation.

2. Technology and band for change in call test: WCDMA Band II having the least P_{limit} among all technologies and bands (test case 7 in Table 5-2) is selected for performing the call drop test in conducted power setup.
3. Technologies and bands for change in technology/band/antenna test: Following the guidelines in Section 3.3.3 and 3.3.4, test case 6 in Table 5-2 is selected for handover test from a technology/band/antenna with lowest P_{limit} within the technology group (WCDMA II hotspot/antenna A), to a technology/band with highest P_{limit} within the technology group (LTE Band 7 hotspot/antenna B) in conducted power setup.
4. Technologies and bands for change in DSI: Based on selection criteria in Section 3.3.5, for a given technology and band, test case 8 in Table 5-2 is selected for DSI switch test by establishing a call in LTE B2 in hotspot condition (i.e., DSI=3), and then handing over to DSI = 1 with grip sensor triggered exposure scenario in conducted power setup.

5.2 LTE + mmW NR transmission

Based on the selection criteria described in Section 4.2, the selections for LTE and mmW NR validation test are listed in Table 5-3. The radio configurations used in this test are listed in Table 5-4.

Table 5-3 Selections for LTE + mmW NR validation measurements

Transmission Scenario	Test	Technology and Band	mmW Beam
Time-varying Tx power test	1. Cond. & Rad. Power meas. 2. PD meas.	LTE Band 2 and n261	Beam ID 41
		LTE Band 2 and n260	Beam ID 4
Switch in SAR vs. PD	1. Cond. & Rad. Power meas.	LTE Band 2 and n261	Beam ID 41
		LTE Band 2 and n260	Beam ID 4
Beam switch test	1. Cond. & Rad. Power meas.	LTE Band 2 and n261	Beam ID 27 to Beam ID 1
		LTE Band 2 and n260	Beam ID 39 to Beam ID 1

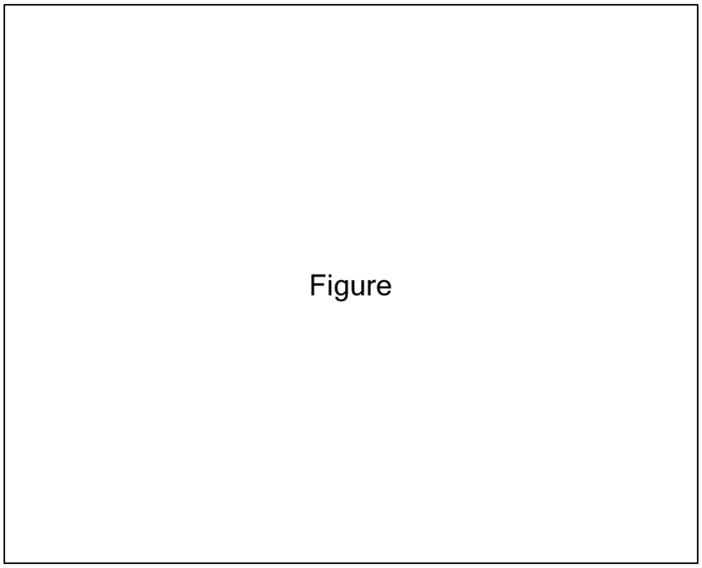
Table 5-4: Test configuration for LTE + mmW NR validation

Tech	Band	Antenna	DSI	Channel	RB/Offset	Freq (MHz)	Mode	UL Duty Cycle
LTE	B2	A	3	18900	50	1880	QPSK	100%
mmW NR	N261	J	--	2071821	1	27559.32	CP-OFDM, QPSK	75.6%
	N260	J	--	2230029	1	37051.8	CP-OFDM, QPSK	75.6%

6 Conducted Power Test Results for Sub-6 Smart Transmit Algorithm Validation

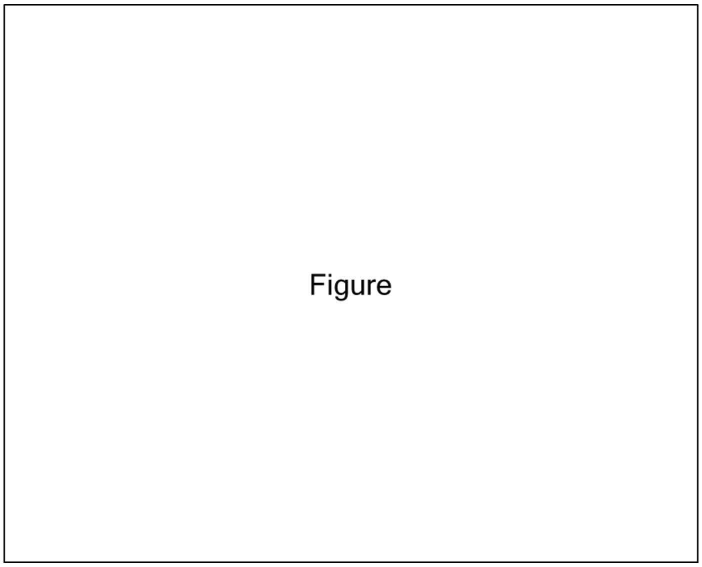
6.1 Measurement setup

The Rohde & Schwarz CMW500 callbox is used in this test. The test setup picture and schematic are shown in Figures 6-1a & 6-1c for measurements with a single antenna of EUT, and in Figures 6-1b & 6-1d for measurements involving antenna switch (see Appendix G for missing figures). For single antenna measurement, one port (RF1 COM) of the callbox is connected to the RF port of the EUT using a directional coupler. For antenna & technology switch measurement, two ports (RF1 COM and RF3 COM) of the callbox used for signaling two different technologies are connected to a combiner, which is in turn connected to a directional coupler. The other end of the directional coupler is connected to a splitter to connect to two RF ports of the EUT corresponding to the two antennas of interest. In both the setups, power meter is used to tap the directional coupler for measuring the conducted output power of the EUT. For time averaging validation test (Section 3.3.1), call drop test (Section 3.3.2), and DSI switch test (Section 3.3.4), only RF1 COM port of the callbox is used to communicate with the EUT. For technology/band switch measurement (Section. 3.3.3), both RF1 COM and RF3 COM port of callbox are used to switch from one technology communicating on RF1 COM port to another technology communicating on RF3 COM port. Note that for this EUT, antenna switch test (Section 3.3.4) is included within technology/band switch test as the selected technology/band combinations for the technology/band switch test are on two different antennas. All the path losses from RF port of EUT to the callbox RF COM port and to the power meter are calibrated and manually entered as offsets in the callbox and the power meter, respectively.



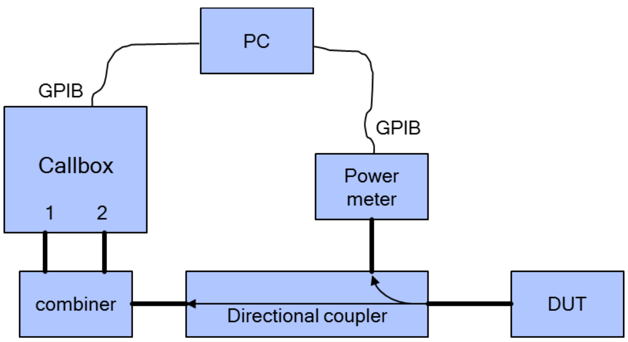
Figure

(a)

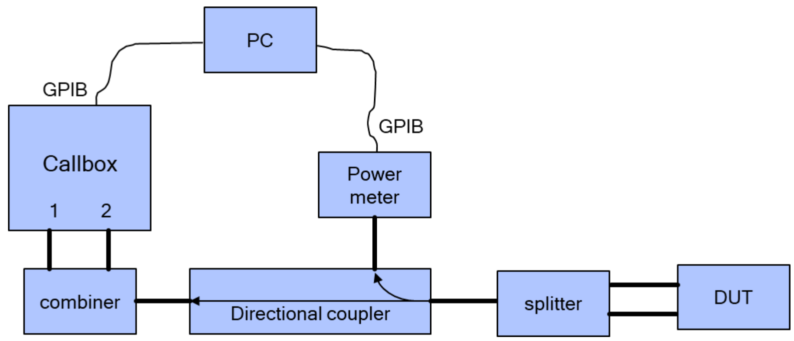


Figure

(b)


PC
GPIB
GPIB
Callbox
1
2
Power
meter
combiner
Directional coupler
DUT

(c)



(d)

Figure 6-1 Conducted power measurement setup (see Appendix G for missing figures)

Both the callbox and power meter are connected to the PC using GPIB cables. Two test scripts are custom made for automation, and the test duration set in the test scripts is 500 seconds.

For time-varying transmit power measurement, the PC runs the 1st test script to send GPIB commands to control the callbox's requested power versus time, while at the same time to record the conducted power measured at EUT RF port using the power meter. The commands sent to the callbox to request power are:

- 0dBm for 100 seconds
- test sequence 1 or test sequence 2 (defined in Section 3.1 and generated in Section 3.2.1), for 360 seconds
- stay at the last power level of test sequence 1 or test sequence 2 for the remaining time.

Power meter readings are periodically recorded every 100ms. A running average of this measured Tx power over 100 seconds is performed in the post-data processing to determine the 100s-time averaged power.

For call drop, technology/band/antenna switch, and DSI switch tests, after the call is established, the callbox is set to request the EUT to transmit at 0dBm for 100 seconds while simultaneously starting the 2nd test script runs at the same time to start recording the Tx power measured at EUT RF port using the power meter. After the initial 100 seconds since starting the Tx power recording, the callbox is set to request maximum power from the EUT for the rest of the test. Note that the call drop/re-establish, or technology/band/antenna switch or DSI switch is manually performed when the Tx power of EUT is at $P_{reserve}$ level. See Section 3.3 for detailed test procedure of call drop test, technology/band/antenna switch test and DSI switch test.

6.2 Time-varying transmit power measurement results

The measurement setup is shown in Figures 6-1(a) and 6-1(c). The measured P_{max} and measured P_{limit} of each selected radio configuration are listed in Table 6-1 and used for generation of test sequences following the test procedures in Section 3.1.

Table 6-1: Measured P_{limit} and P_{max} of selected radio configurations

Test Case #	Test scenario	Tech	Band	Ant	DSI	Channel	RB/offset	freq (MHz)	mode	device position	detail	Tune up power Pmax (dBm) (avg power)	Plimit EFS setting (dBm)	measured Plimit (dBm)	measured Pmax (dBm)
1	time-varying Tx power transmission	WCDMA	II (1900)	A	3	9262	-	1852.4	RMC	bottom	hotspot/1g/10mm	24	17.4	18.1	24.1
2		CDMA	BC1	A	3	600	-	1880	EVDO Rev. 0	bottom	hotspot/1g/10mm	24	18.0	17.82	22.91
3		GSM	1900	A	3	810	-	1909.8	GPRS/ 4 slots	bottom	hotspot/1g/10mm	21	17.7	17.12	19.85
4		LTE	B2	A	3	18900	50/50/20MHz	1880	QPSK	bottom	hotspot/1g/10mm	24	18.0	18.98	23.45
5			B7	B	3	21350	50/0/20MHz	2560	QPSK	bottom	hotspot/1g/10mm	23.0	20.8	21.58	23.02

Note: the device uncertainty of P_{max} is +1dB/-1.5dB as provided by manufacturer.

The purpose of the time-varying transmit power measurement is to demonstrate the effectiveness of power limiting enforcement and that the time-averaged transmit power when represented in time-averaged 1gSAR or 10gSAR values does not exceed FCC limit as shown in Eq. (1a) and (1b), rewritten below:

$$1g\_or\_10gSAR(t) = \frac{conducted\_Tx\_power(t)}{conducted\_Tx\_power\_P_{limit}} * 1g\_or\_10gSAR\_P_{limit} \quad (1a)$$

$$\frac{\frac{1}{T_{SAR}}\int_{t-T_{SAR}}^{t} 1g\_or\_10gSAR(t)dt}{FCC\ SAR\ limit} \leq 1 \quad (1b)$$

where, $conducted\_Tx\_power(t)$, $conducted\_Tx\_power\_P_{limit}$, and $1g\_or\_10gSAR\_P_{limit}$ correspond to the measured instantaneous conducted Tx power, measured conducted Tx power at P_{limit}, and measured *1gSAR* and *10gSAR* values at P_{limit} reported in Part 1 test (listed in Table 5-2 of this report as well).

Following the test procedure in Section 3.3, the conducted Tx power measurement for all selected configurations are reported in this section. In all the conducted Tx power plots, the dotted line represents the requested power by callbox (test sequence 1 or test sequence 2), the blue curve represents the instantaneous conducted Tx power measured using power meter, the green curve represents time-averaged power and red line represents the conducted power limit that corresponds to FCC limit of 1.6 W/kg for 1gSAR or 4.0 W/kg for 10gSAR.

Similarly, in all the 1g or 10gSAR plots (when converted using Eq. (1a)), the green curve represents the 100s-time averaged 1gSAR or 10gSAR value calculated based on instantaneous 1gSAR or 10gSAR; and the red line limit represents the FCC limit of 1.6 W/kg for 1gSAR or 4.0 W/kg for 10gSAR.

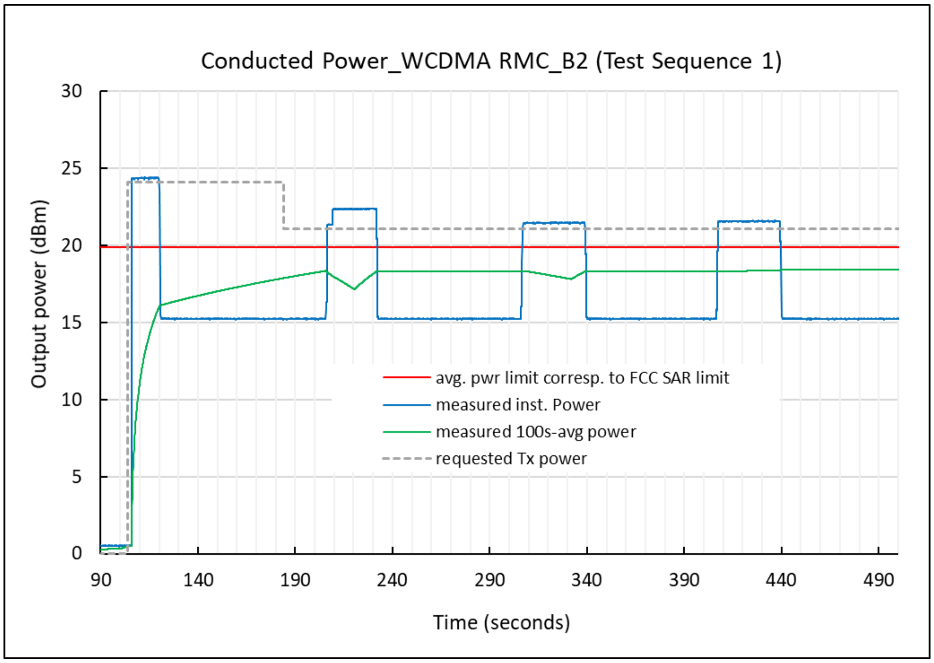
6.2.1 WCDMA Band II (test case 1 in Table 5-2)

Test sequence 1:

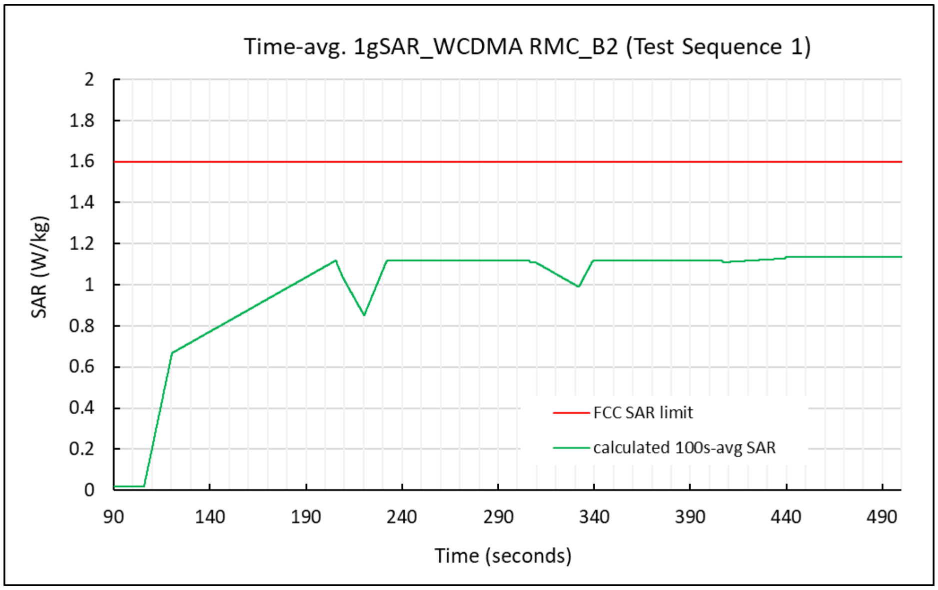
Table 6-2 Test sequence 1 for WCDMA Band II measurement

Duration (seconds)	Tx_power (dBm)	Notes
100	0.0	
80	24.10	meas. P_{max}
at least 120	21.10	meas. P_{max} - 3dB

Test result for test sequence 1:



Above time-averaged conducted Tx power is converted/calculated into time-averaged 1gSAR using Equation (1a) and plotted below to demonstrate that the time-averaged 1gSAR versus time does not exceed the FCC limit of 1.6 W/kg for 1gSAR:



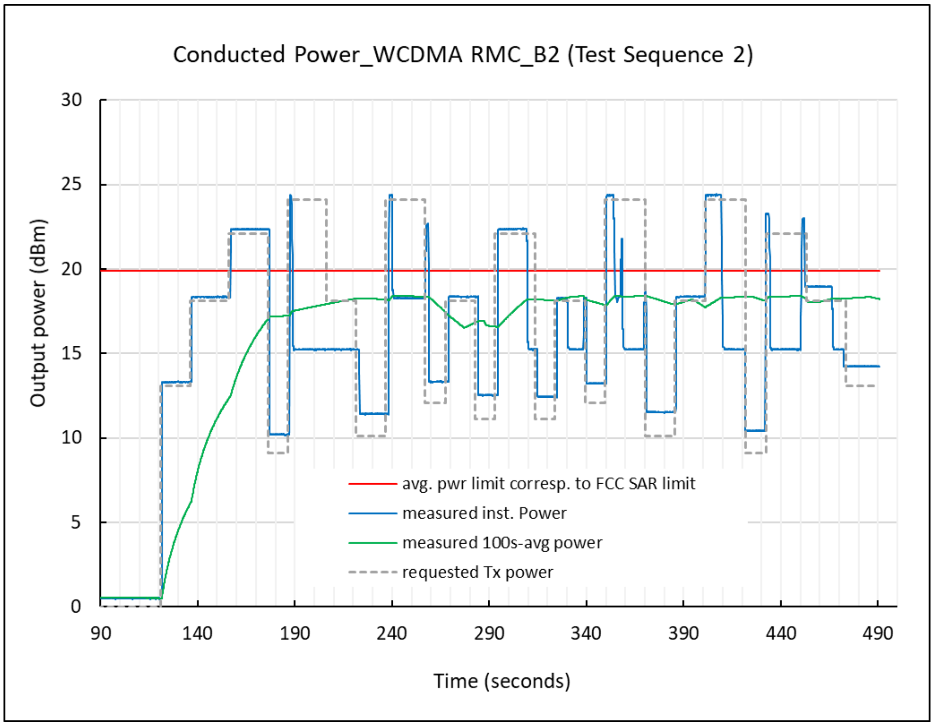
	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged 1gSAR (green curve)	1.134
Validated	

Test sequence 2:

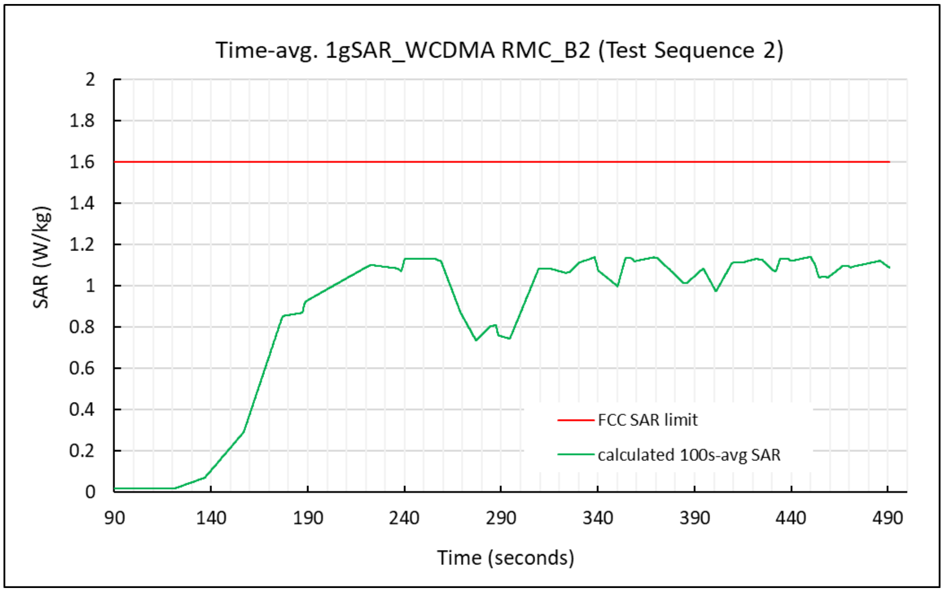
Table 6-3 Test sequence 2 for WCDMA Band II measurement

Duration*(seconds)	Tx_power(dBm)	Notes
100	0.0	
15	13.1	meas. P_{limit} – reserve_power_margin - 2dB
20	18.1	meas. P_{limit}
20	22.1	(meas. P_{limit} + meas. P_{max})/2 rounded to 0.1dB step
10	9.1	meas. P_{limit} - reserve_power_margin - 6dB
20	24.1	meas. P_{max}
15	18.1	meas. P_{limit}
15	10.1	meas. P_{limit} - reserve_power_margin - 5dB
20	24.1	meas.P_{max}
10	12.1	meas. P_{limit} - reserve_power_margin - 3dB
15	18.1	meas. P_{limit}
10	11.1	meas. P_{limit} - reserve_power_margin - 4dB
20	22.1	(meas. P_{limit} + meas. P_{max})/2 rounded to 0.1dB step
10	11.1	meas. P_{limit} - reserve_power_margin - 4dB
15	18.1	meas. P_{limit}
10	12.1	meas. P_{limit} - reserve_power_margin - 3dB
20	24.1	meas.P_{max}
15	10.1	meas. P_{limit} - reserve_power_margin - 5dB
15	18.1	meas. P_{limit}
20	24.1	meas.P_{max}
10	9.1	meas. P_{limit} - reserve_power_margin - 6dB
20	22.1	(meas. P_{limit} + meas.P_{max})/2 rounded to 0.1dB step
20	18.1	meas. P_{limit}
15	13.1	meas. P_{limit} - reserve_power_margin - 2dB

Test result for test sequence 2:



Above time-averaged conducted Tx power is converted/calculated into time-averaged 1gSAR using Equation (1a) and plotted below to demonstrate that the time-averaged 1gSAR versus time does not exceed the FCC limit of 1.6 W/kg for 1gSAR:



	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged 1gSAR (green curve)	1.141
Validated	

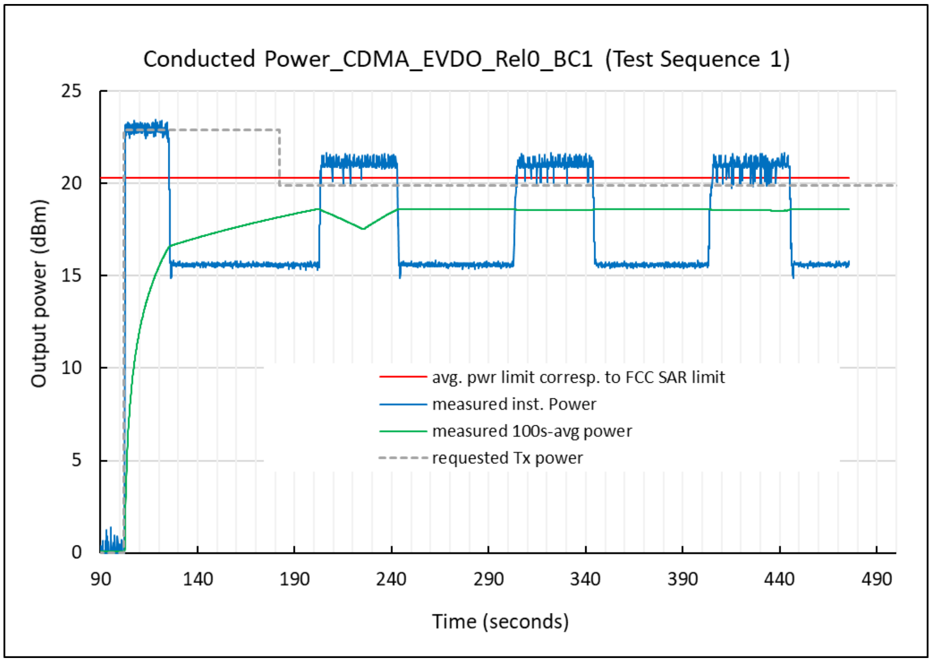
6.2.2 CDMA BC1 (test case 2 in Table 5-2)

Test sequence 1:

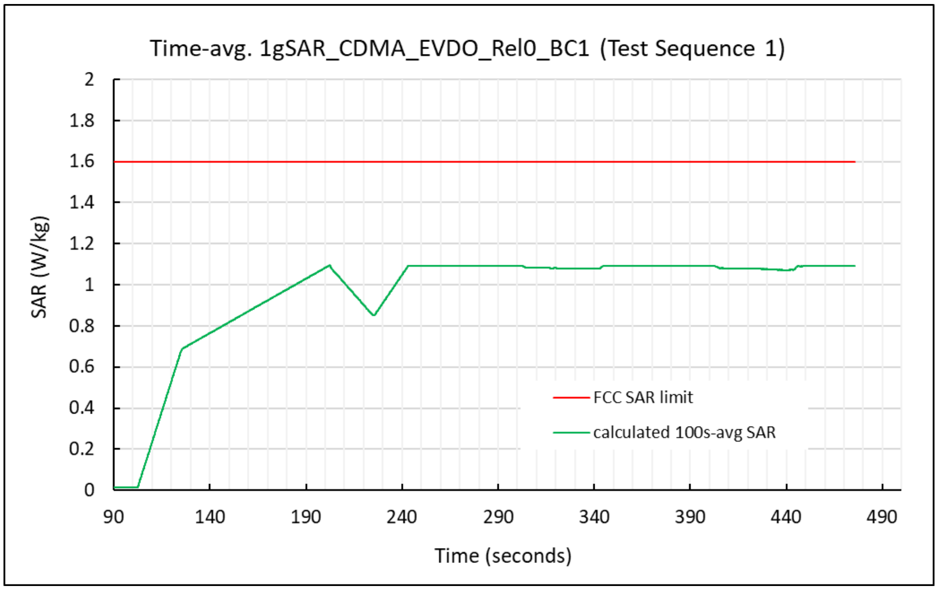
Table 6-4 Test sequence 1 for CDMA BC1 measurement

Duration (seconds)	Tx_power (dBm)	Notes
100	0.0	
80	22.91	meas. P_{max}
at least 120	19.91	meas. P_{max} - 3dB

Test result for test sequence 1:



Above time-averaged conducted Tx power is converted/calculated into time-averaged 1gSAR using Equation (1a) and plotted below to demonstrate that the time-averaged 1gSAR versus time does not exceed the FCC limit of 1.6 W/kg for 1gSAR:



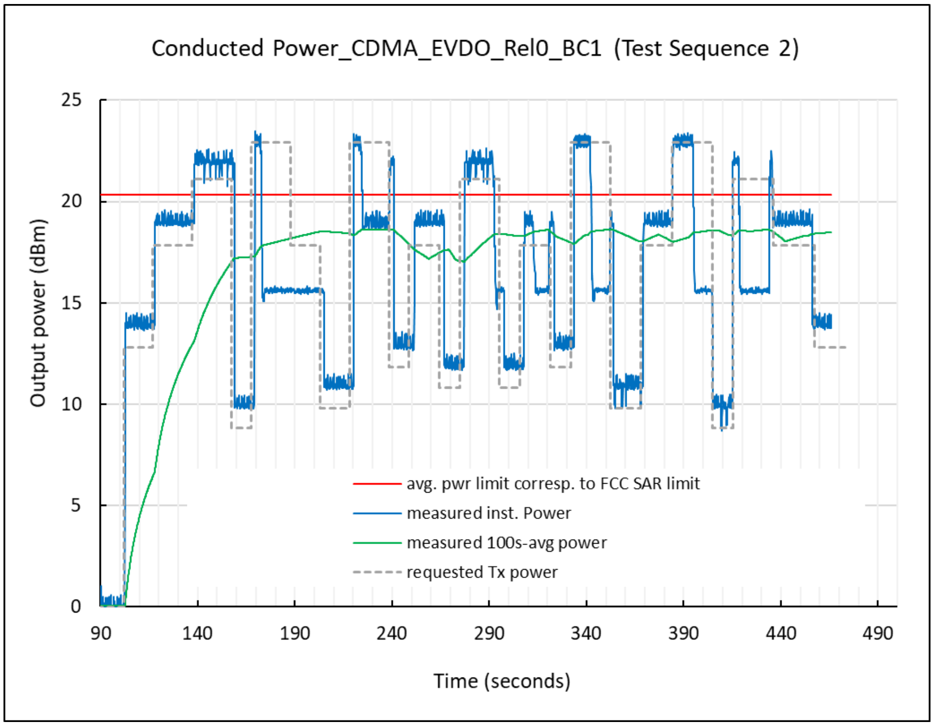
	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged 1gSAR (green curve)	1.084
Validated	

Test sequence 2:

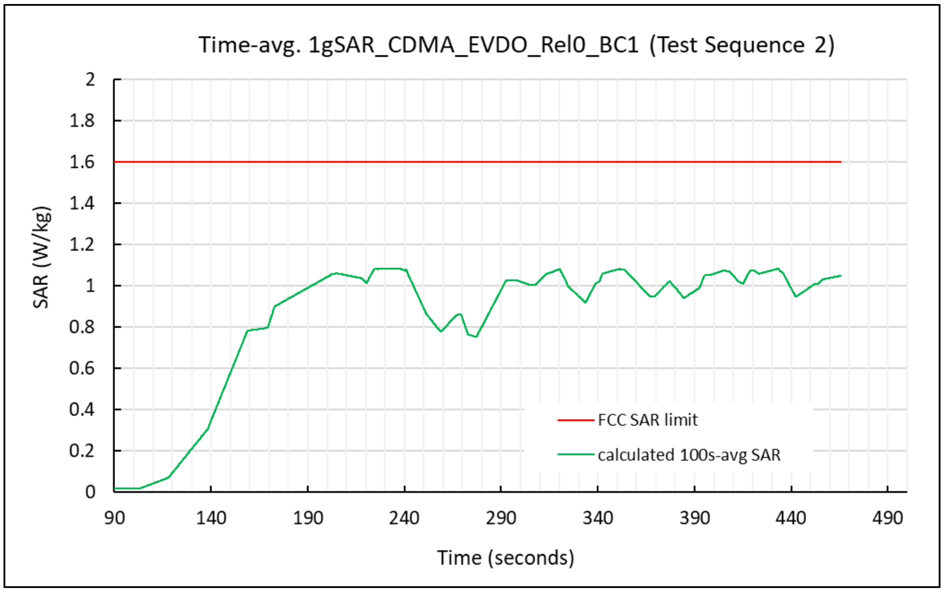
Table 6-5 Test sequence 2 for CDMA BC1 measurement

Duration*(seconds)	Tx_power(dBm)	Notes
100	0.0	
15	12.8	meas. P_{limit} – reserve_power_margin - 2dB
20	17.8	meas. P_{limit}
20	21.1	(meas. P_{limit} + meas. P_{max})/2 rounded to 0.1dB step
10	8.8	meas. P_{limit} - reserve_power_margin - 6dB
20	22.9	meas. P_{max}
15	17.8	meas. P_{limit}
15	9.8	meas. P_{limit} - reserve_power_margin - 5dB
20	22.9	meas.P_{max}
10	11.8	meas. P_{limit} - reserve_power_margin - 3dB
15	17.8	meas. P_{limit}
10	10.8	meas. P_{limit} - reserve_power_margin - 4dB
20	21.1	(meas. P_{limit} + meas. P_{max})/2 rounded to 0.1dB step
10	10.8	meas. P_{limit} - reserve_power_margin - 4dB
15	17.8	meas. P_{limit}
10	11.8	meas. P_{limit} - reserve_power_margin - 3dB
20	22.9	meas.P_{max}
15	9.8	meas. P_{limit} - reserve_power_margin - 5dB
15	17.8	meas. P_{limit}
20	22.9	meas.P_{max}
10	8.8	meas. P_{limit} - reserve_power_margin - 6dB
20	21.1	(meas. P_{limit} + meas.P_{max})/2 rounded to 0.1dB step
20	17.8	meas. P_{limit}
15	12.8	meas. P_{limit} - reserve_power_margin - 2dB

Test result for test sequence 2:



Above time-averaged conducted Tx power is converted/calculated into time-averaged 1gSAR using Equation (1a) and plotted below to demonstrate that the time-averaged 1gSAR versus time does not exceed the FCC limit of 1.6 W/kg for 1gSAR:



	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged 1gSAR (green curve)	1.083
Validated	

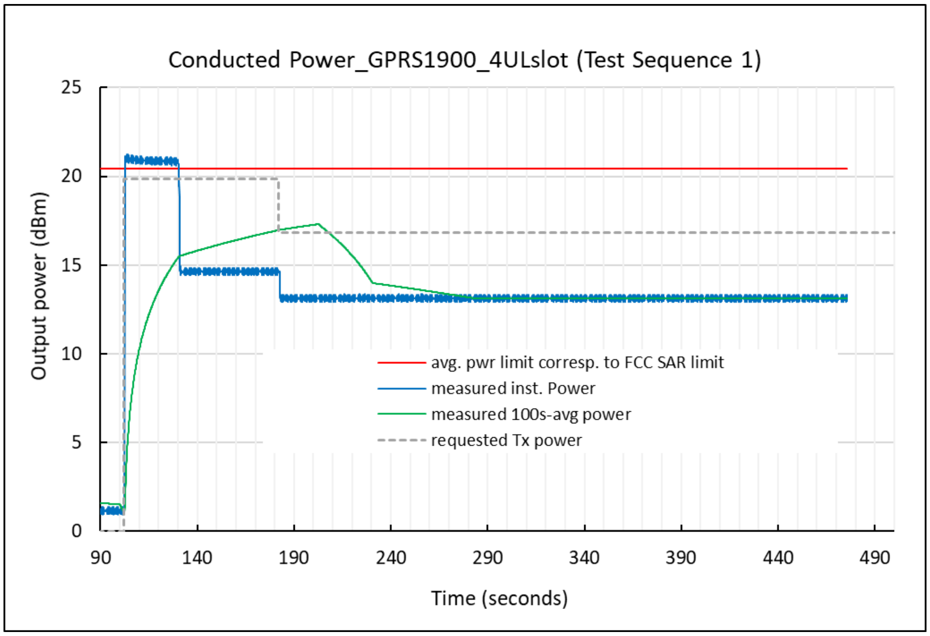
6.2.3 GSM1900 (test case 3 in Table 5-2)

Test sequence 1:

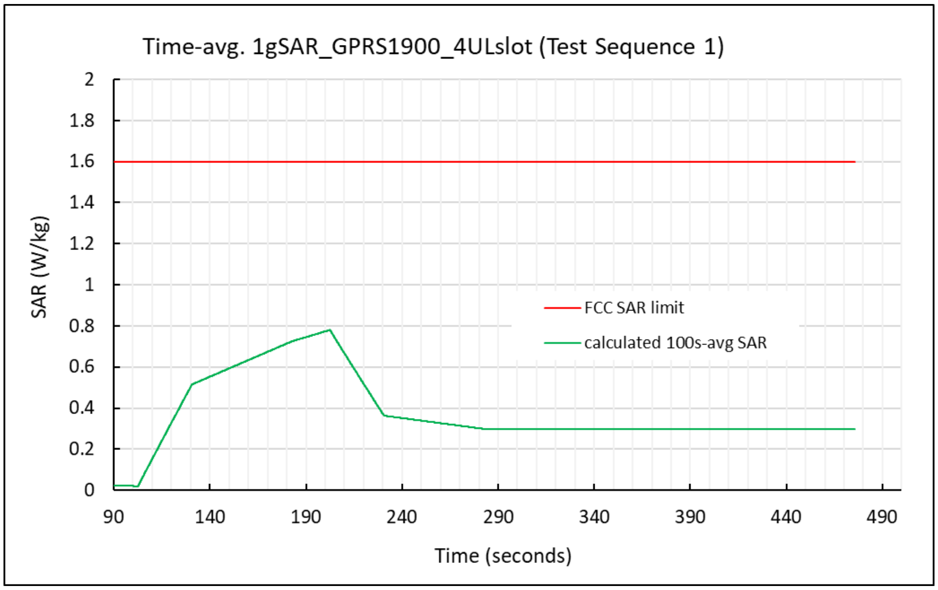
Table 6-6 Test sequence 1 for GSM1900 measurement

Duration (seconds)	Tx_power (dBm)	Notes
100	0.0	
80	19.85	meas. P_{max}
at least 120	16.85	meas. P_{max} - 3dB

Test result for test sequence 1:



Above time-averaged conducted Tx power is converted/calculated into time-averaged 1gSAR using Equation (1a) and plotted below to demonstrate that the time-averaged 1gSAR versus time does not exceed the FCC limit of 1.6 W/kg for 1gSAR:



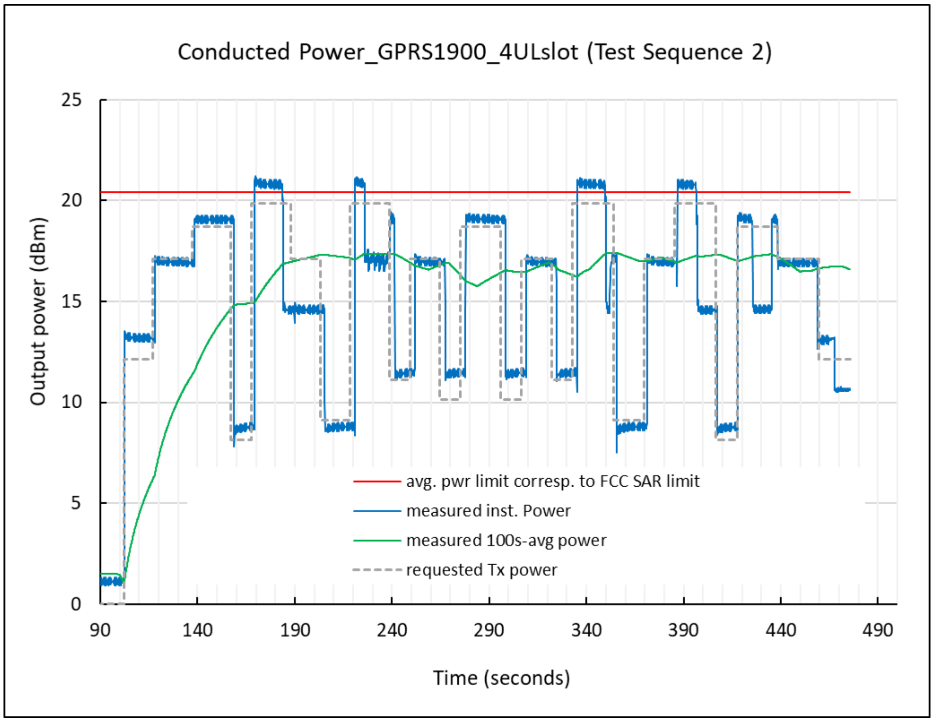
	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged 1gSAR (green curve)	0.791
Validated	

Teste sequence 2:

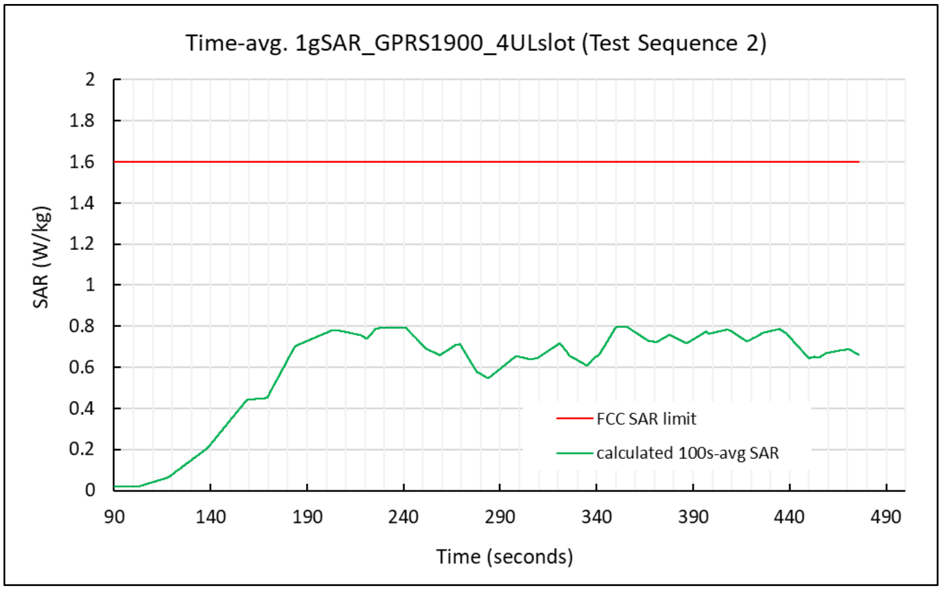
Table 6-7 Test sequence 2 for GSM1900 measurement

Duration*(seconds)	Tx_power(dBm)	Notes
100	0.0	
15	12.1	meas. P_{limit} – reserve_power_margin - 2dB
20	17.1	meas. P_{limit}
20	18.7	(meas. P_{limit} + meas. P_{max})/2 rounded to 0.1dB step
10	8.1	meas. P_{limit} - reserve_power_margin - 6dB
20	19.9	meas. P_{max}
15	17.1	meas. P_{limit}
15	9.1	meas. P_{limit} - reserve_power_margin - 5dB
20	19.9	meas.P_{max}
10	11.1	meas. P_{limit} - reserve_power_margin - 3dB
15	17.1	meas. P_{limit}
10	10.1	meas. P_{limit} - reserve_power_margin - 4dB
20	18.7	(meas. P_{limit} + meas. P_{max})/2 rounded to 0.1dB step
10	10.1	meas. P_{limit} - reserve_power_margin - 4dB
15	17.1	meas. P_{limit}
10	11.1	meas. P_{limit} - reserve_power_margin - 3dB
20	19.9	meas.P_{max}
15	9.1	meas. P_{limit} - reserve_power_margin - 5dB
15	17.1	meas. P_{limit}
20	19.9	meas.P_{max}
10	8.1	meas. P_{limit} - reserve_power_margin - 6dB
20	18.7	(meas. P_{limit} + meas.P_{max})/2 rounded to 0.1dB step
20	17.1	meas. P_{limit}
15	12.1	meas. P_{limit} - reserve_power_margin - 2dB

Test result for test sequence 2:



Above time-averaged conducted Tx power is converted/calculated into time-averaged 1gSAR using Equation (1a) and plotted below to demonstrate that the time-averaged 1gSAR versus time does not exceed the FCC limit of 1.6 W/kg for 1gSAR:



	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged 1gSAR (green curve)	0.811
Validated	

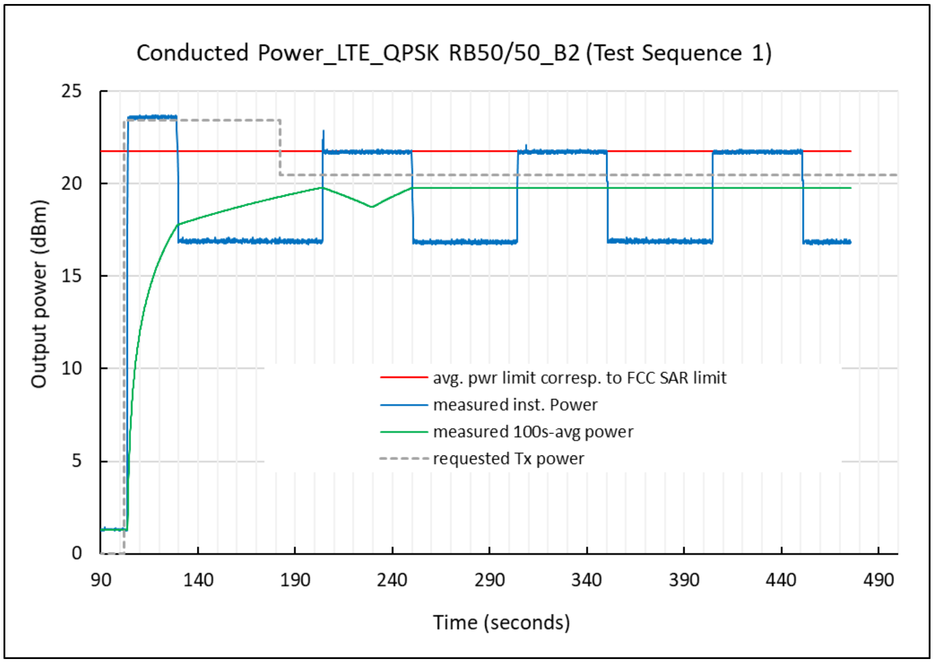
6.2.4 LTE Band 2 (test case 4 in Table 5-2)

Test sequence 1:

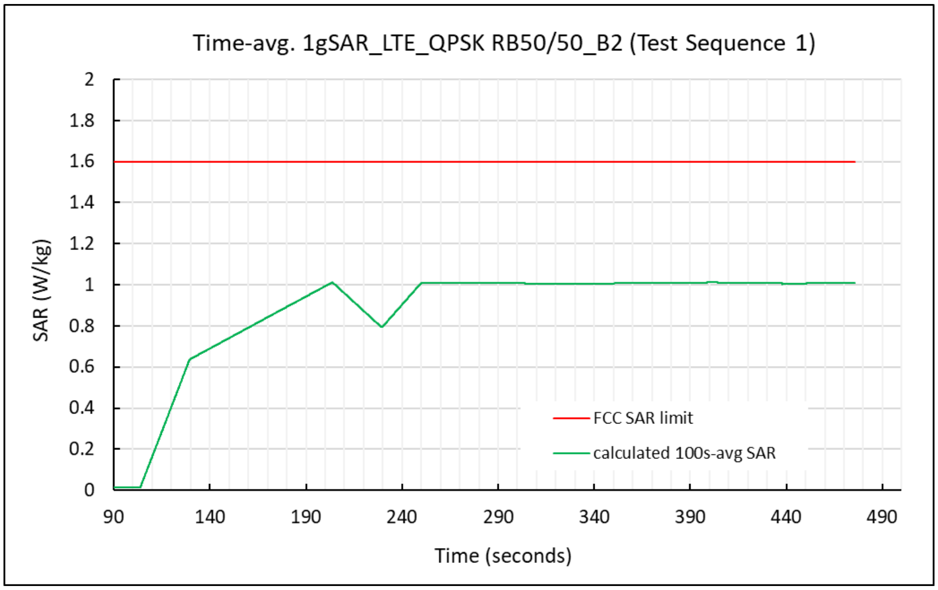
Table 6-8 Test sequence 1 for LTE Band 2 measurement

Duration (seconds)	Tx_power (dBm)	Notes
100	0.0	
80	23.45	meas. P_{max}
at least 120	20.45	meas. P_{max} - 3dB

Test result for test sequence 1:



Above time-averaged conducted Tx power is converted/calculated into time-averaged 1gSAR using Equation (1a) and plotted below to demonstrate that the time-averaged 1gSAR versus time does not exceed the FCC limit of 1.6 W/kg for 1gSAR:



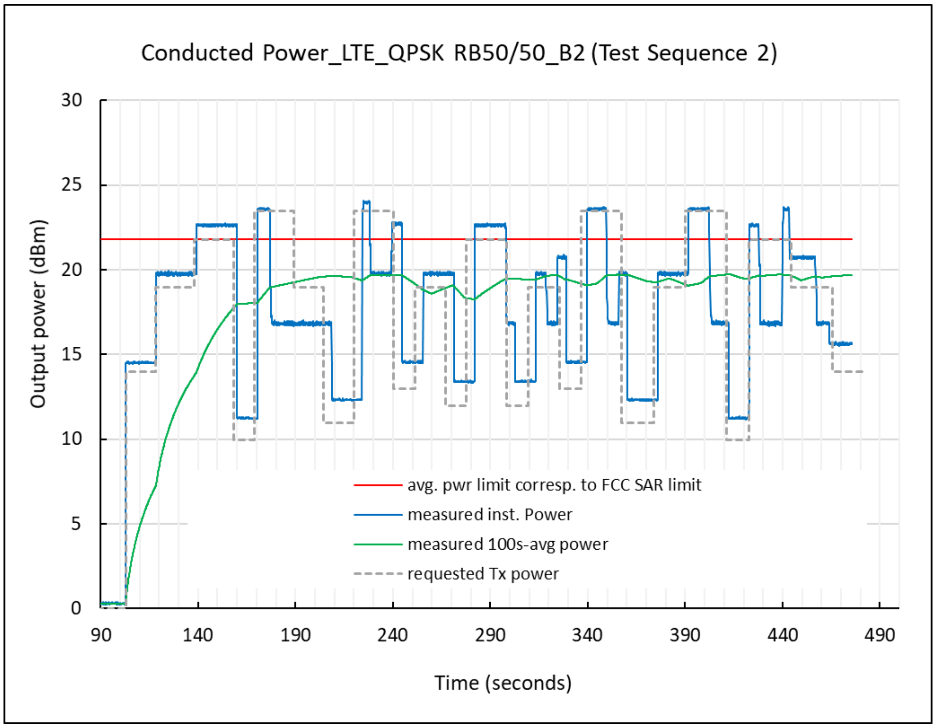
	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged 1gSAR (green curve)	1.012
Validated	

Test sequence 2:

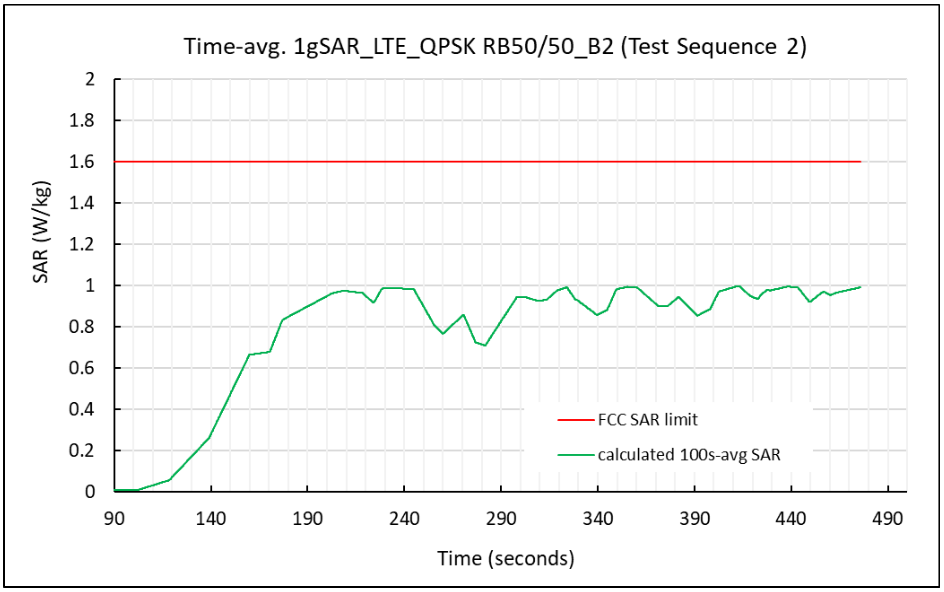
Table 6-9 Test sequence 2 for LTE Band 2 measurement

Duration*(seconds)	Tx_power(dBm)	Notes
100	0.0	
15	14.0	meas. P_{limit} – reserve_power_margin - 2dB
20	19.0	meas. P_{limit}
20	21.8	(meas. P_{limit} + meas. P_{max})/2 rounded to 0.1dB step
10	10.0	meas. P_{limit} - reserve_power_margin - 6dB
20	23.5	meas. P_{max}
15	19.0	meas. P_{limit}
15	11.0	meas. P_{limit} - reserve_power_margin - 5dB
20	23.5	meas.P_{max}
10	13.0	meas. P_{limit} - reserve_power_margin - 3dB
15	19.0	meas. P_{limit}
10	12.0	meas. P_{limit} - reserve_power_margin - 4dB
20	21.8	(meas. P_{limit} + meas. P_{max})/2 rounded to 0.1dB step
10	12.0	meas. P_{limit} - reserve_power_margin - 4dB
15	19.0	meas. P_{limit}
10	13.0	meas. P_{limit} - reserve_power_margin - 3dB
20	23.5	meas.P_{max}
15	11.0	meas. P_{limit} - reserve_power_margin - 5dB
15	19.0	meas. P_{limit}
20	23.5	meas.P_{max}
10	10.0	meas. P_{limit} - reserve_power_margin - 6dB
20	21.8	(meas. P_{limit} + meas.P_{max})/2 rounded to 0.1dB step
20	19.0	meas. P_{limit}
15	14.0	meas. P_{limit} - reserve_power_margin - 2dB

Test result for test sequence 2:



Above time-averaged conducted Tx power is converted/calculated into time-averaged 1gSAR using Equation (1a) and plotted below to demonstrate that the time-averaged 1gSAR versus time does not exceed the FCC limit of 1.6 W/kg for 1gSAR:



	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged 1gSAR (green curve)	0.998
Validated	

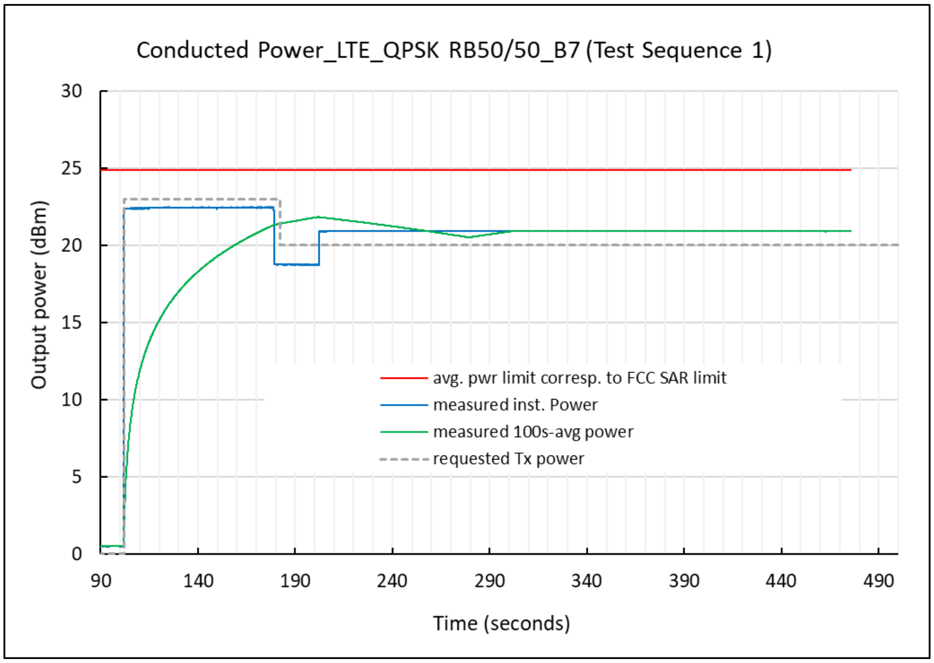
6.2.5 LTE Band 7 (test case 5 in Table 5-2)

Test sequence 1:

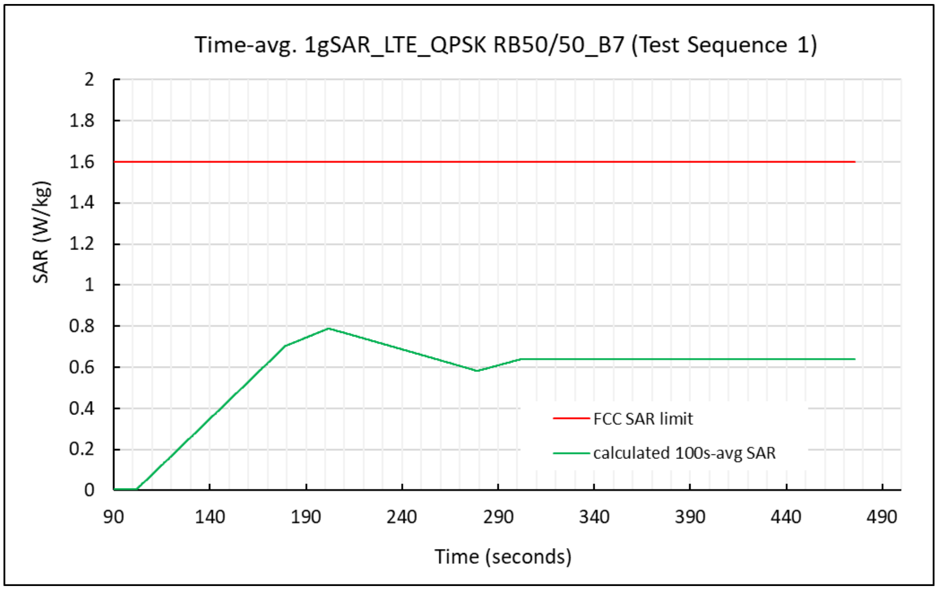
Table 6-10 Test sequence 1 for LTE Band 7 measurement

Duration (seconds)	Tx_power(dBm)	Notes
100	0.0	
80	23.02	meas. P_{max}
at least 120	20.02	meas. P_{max} - 3dB

Test result for test sequence 1:



Above time-averaged conducted Tx power is converted/calculated into time-averaged 1gSAR using Equation (1a) and plotted below to demonstrate that the time-averaged 1gSAR versus time does not exceed the FCC limit of 1.6 W/kg for 1gSAR:



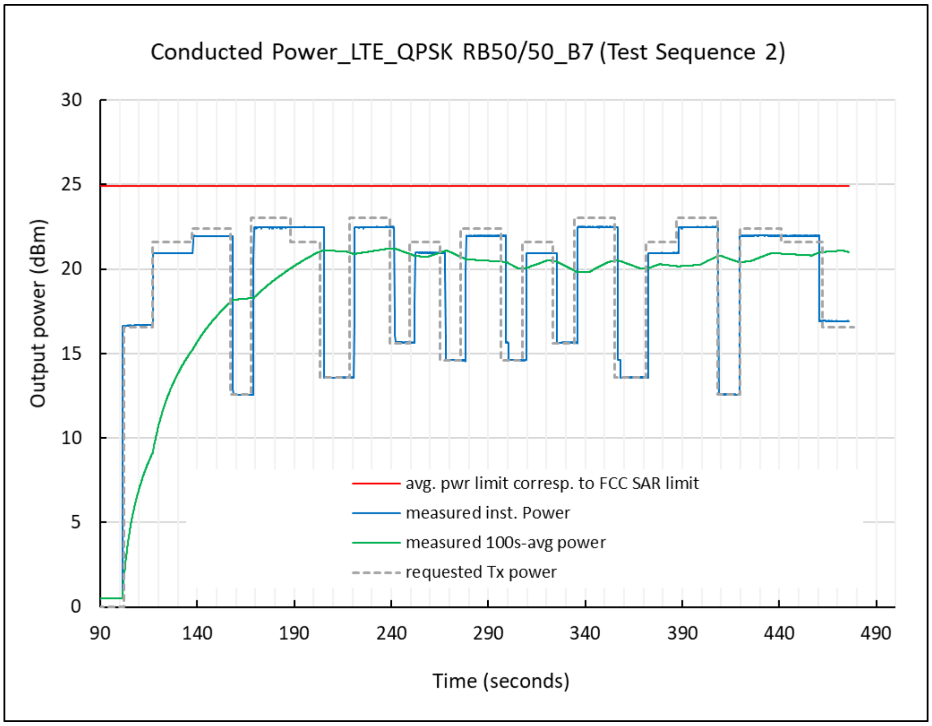
	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged 1gSAR (green curve)	0.789
Validated	

Test sequence 2:

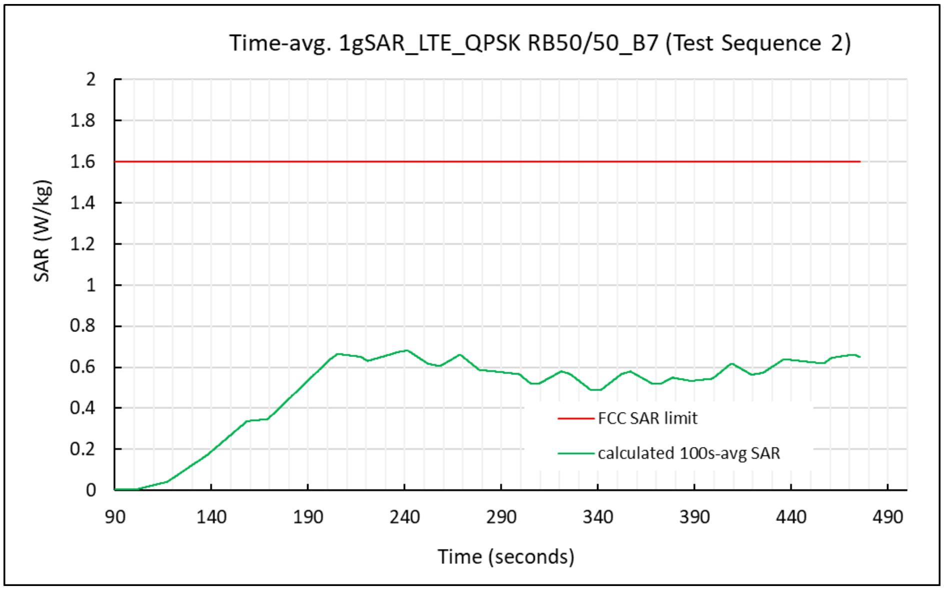
Table 6-11 Test sequence 2 for LTE Band 7 measurement

Duration*(seconds)	Tx_power(dBm)	Notes
100	0.0	
15	16.6	meas. P_{limit} – reserve_power_margin - 2dB
20	21.6	meas. P_{limit}
20	22.4	(meas. P_{limit} + meas. P_{max})/2 rounded to 0.1dB step
10	12.6	meas. P_{limit} - reserve_power_margin - 6dB
20	23.0	meas. P_{max}
15	21.6	meas. P_{limit}
15	13.6	meas. P_{limit} - reserve_power_margin - 5dB
20	23.0	meas. P_{max}
10	15.6	meas. P_{limit} - reserve_power_margin - 3dB
15	21.6	meas. P_{limit}
10	14.6	meas. P_{limit} - reserve_power_margin - 4dB
20	22.4	(meas. P_{limit} + meas. P_{max})/2 rounded to 0.1dB step
10	14.6	meas. P_{limit} - reserve_power_margin - 4dB
15	21.6	meas. P_{limit}
10	15.6	meas. P_{limit} - reserve_power_margin - 3dB
20	23.0	meas. P_{max}
15	13.6	meas. P_{limit} - reserve_power_margin - 5dB
15	21.6	meas. P_{limit}
20	23.0	meas. P_{max}
10	12.6	meas. P_{limit} - reserve_power_margin - 6dB
20	22.4	(meas. P_{limit} + meas. P_{max})/2 rounded to 0.1dB step
20	21.6	meas. P_{limit}
15	16.6	meas. P_{limit} - reserve_power_margin - 2dB

<u>Test result for test sequence 2:</u>



Above time-averaged conducted Tx power is converted/calculated into time-averaged 1gSAR using Equation (1a) and plotted below to demonstrate that the time-averaged 1gSAR versus time does not exceed the FCC limit of 1.6 W/kg for 1gSAR::



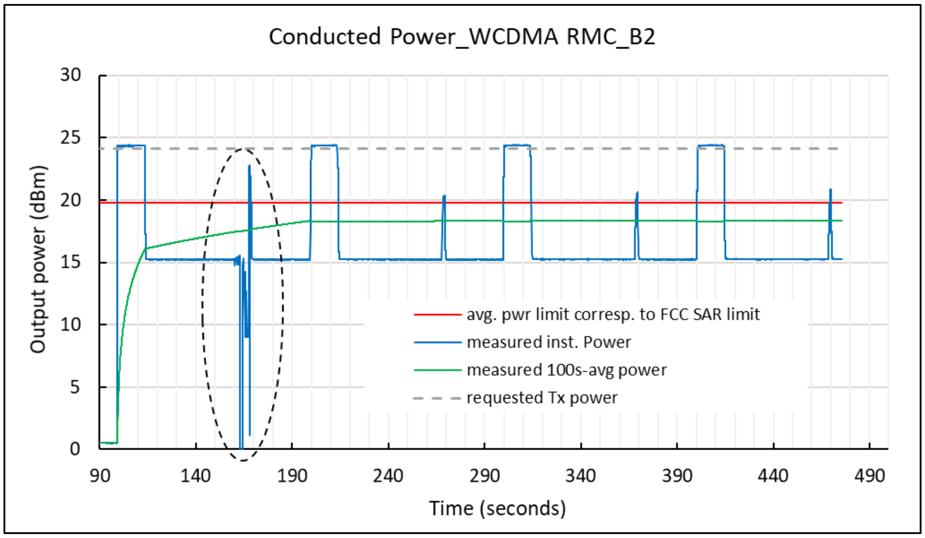
	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged 1gSAR (green curve)	0.681
Validated	

6.3 Call Drop Test Results (test case 7 in Table 5-2)

This test was measured with WCDMA Band II and with callbox requesting maximum power. The call drop was manually performed when the EUT is transmitting at $P_{reserve}$ level as shown in the plot below (dotted black region). The measurement setup is shown in Figure 6-1(a) and (c). The detailed test procedure is described in Section 3.3.2.

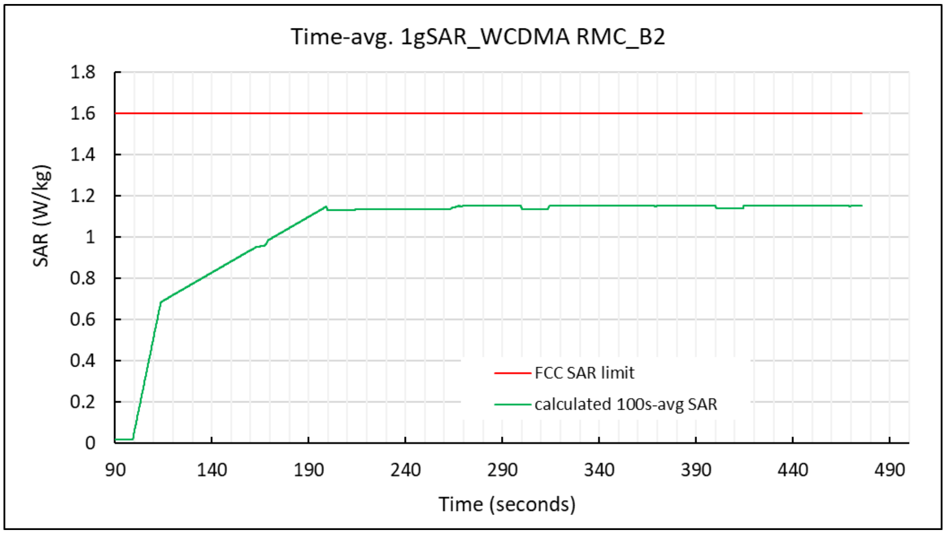
Call drop test result:

Plot 1: Measured Tx power (dBm) versus time shows that the transmitting power kept the same $P_{reserve}$ level of WCDMA Band II after the call was re-established:



Note: The power level after the change in call kept the same $P_{reserve}$ level of WCDMA B2. The conducted power plot shows expected Tx transition.

Plot 2: Above time-averaged conducted Tx power is converted/calculated into time-averaged 1gSAR using Equation (1a) and plotted below to demonstrate that the time-averaged 1gSAR versus time does not exceed the FCC limit of 1.6 W/kg for 1gSAR:



	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged 1gSAR (green curve)	1.156
Validated	

The test result validated the continuity of power limiting in call change scenario.

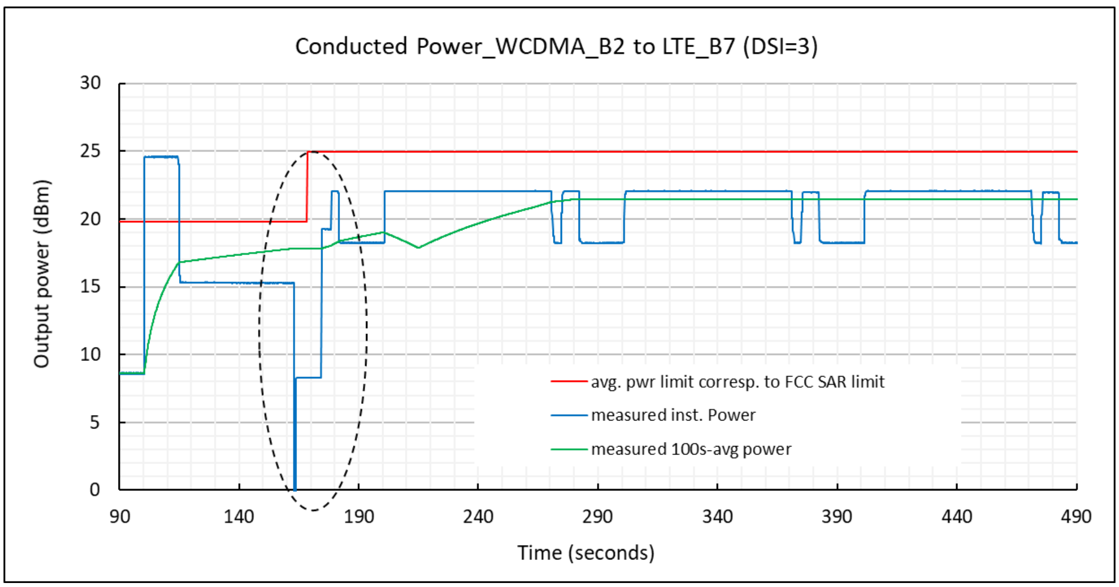
6.4 Change in technology/band/antenna test results (test case 6 in Table 5-2)

This test was conducted with callbox requesting maximum power, and with antenna & technology switch from WCDMA Band II, Antenna A, DSI = 3 (hotspot) to LTE Band 7, Antenna B, DSI =3 (hotspot). Following procedure detailed in Section 3.3.3 and Section 3.3.4, and using the measurement setup shown in Figure 6-1(b) and (d), the technology/band/antenna switch was performed when the EUT is transmitting at $P_{reserve}$ level as shown in the plot below (dotted black region).

The power meter path loss setting was manually entered, path loss setting corresponding to WCDMA Band II (13.1dB for 1880MHz) was used for the entire measurement. Since the path loss setting is different for LTE Band 7 (15.9dB for 2560MHz), during post-data processing, all the recorded power meter readings after technology/band/antenna was switched from WCDMA Band II to LTE Band 7, were adjusted by the 2.8 dB difference in path loss.

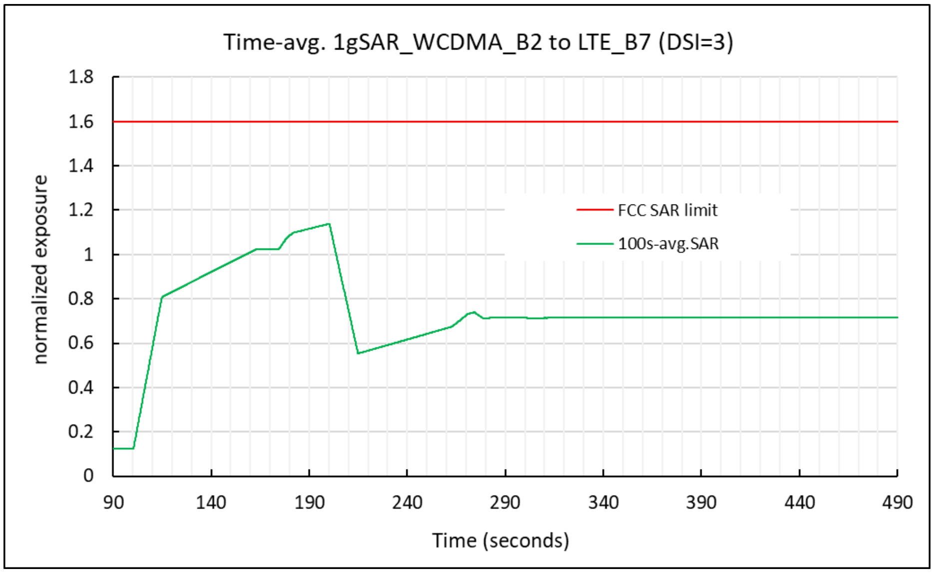
<u>Test result for change in technology/band:</u>

Plot 1: Measured Tx power (dBm) versus time shows that the transmitting power changed from WCDMA Band 2, Antenna A, DSI =3 (hotspot) $P_{reserve}$ level to LTE Band 7, Antenna B, DSI = 3 (hotspot) $P_{reserve}$ level:



Note: As per Part 1 report, *Reserve_power_margin* = 3dB. Based on Table 5-1, EFS P_{limit} = 17.4dBm for WCDMA B2 (DSI=3), and EFS P_{limit} = 20.8dBm for LTE Band 7 (DSI=3), it can be seen from above plot that the difference in $P_{reserve}$ (= P_{limit} – *3dB Reserve_power_margin*) power level corresponds to the expected difference in P_{limit} levels of 3.4dB (within 1dB of sub6 radio design related uncertainty). Therefore, the conducted power plot shows expected transition in Tx power.

Plot 2: All the time-averaged conducted Tx power measurement results were converted into time-averaged 1gSAR values using Equation (6a) and (6b), and plotted below to demonstrate that the time-averaged 1gSAR versus time does not exceed the FCC limit of 1.6 W/kg for 1gSAR:



	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged 1gSAR (green curve)	1.139
Validated	

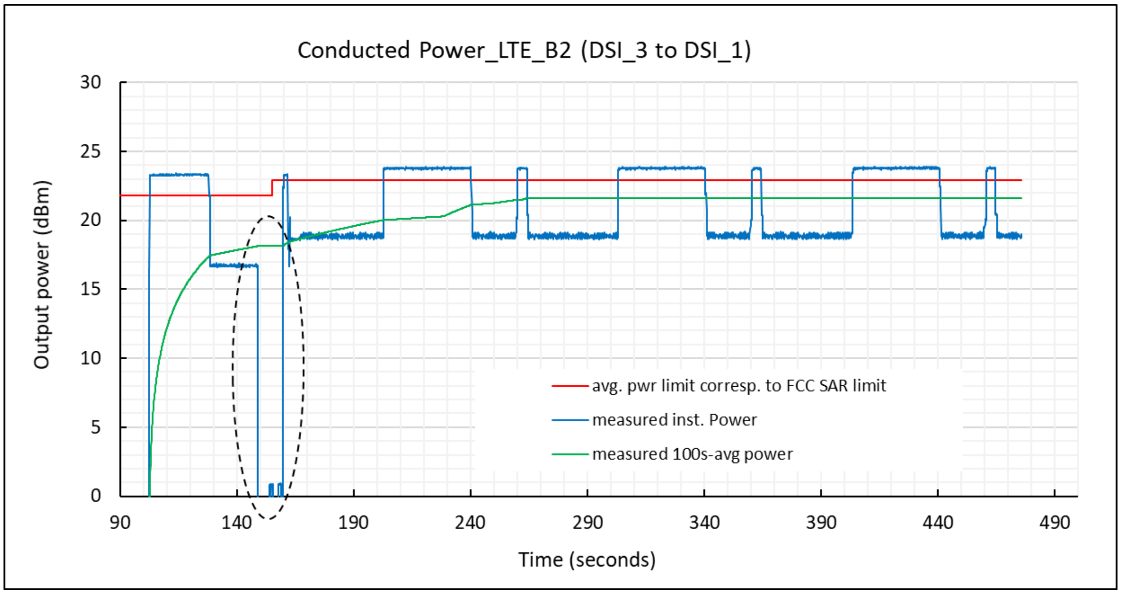
The test result validated the continuity of power limiting in technology/band/antenna switch scenario.

6.5 Change in DSI test results (test case 8 in Table 5-2)

This test was conducted with callbox requesting maximum power, and with DSI switch from LTE Band 2 DSI = 3 (hotspot, P_{limit} = 18.0dBm in EFS setting, measured P_{limit} = 18.98dBm) to DSI = 1 (extremity sensor triggered, P_{limit} = 20.2dBm in EFS setting, measured P_{limit} = 21.0dBm). Following procedure detailed in Section 3.3.5 using the measurement setup shown in Figure 6-1(a) and (c), the DSI switch was performed when the EUT is transmitting at $P_{reserve}$ level as shown in the plot below (dotted black circle).

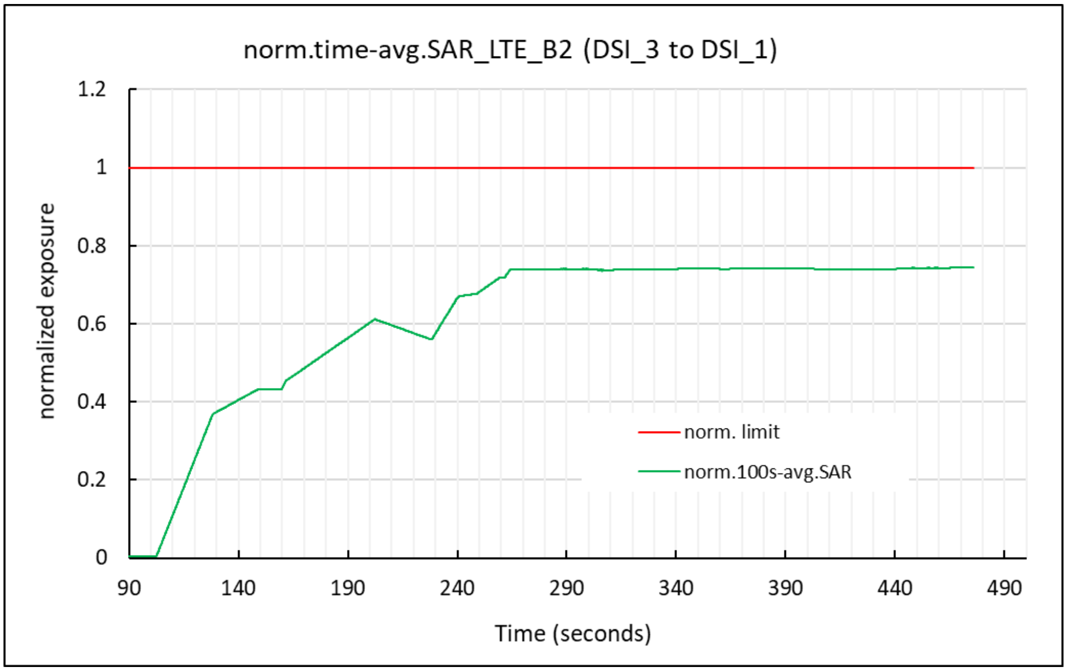
<u>Test result for change in DSI:</u>

Plot 1: Measured Tx power (dBm) versus time shows that the transmitting power changed when DSI = 3 switches to DSI = 1:



Note: As per Part 1 report, *Reserve_power_margin* = 3dB. Based on Table 5-1, EFS P_{limit} = 18.0dBm for LTE Band 2 hotspot DSI = 3, and EFS P_{limit} = 20.2dBm for LTE B2 extremity DSI = 1. The conducted power plot shows expected Tx power transition, i.e., from $P_{reserve}$ for the first DSI (=3) to the $P_{reserve}$ for the second DSI (=1) at the switch time of around ~160s in the plot above. The difference in $P_{reserve}$ (= P_{limit} – *3dB Reserve_power_margin*) level corresponds to the expected different in P_{limit} levels of 2.2dB (within 1dB of sub6 radio design related uncertainty). Therefore, the conducted power plot shows expected transition in Tx power.

Plot 2: All the time-averaged conducted Tx power measurement results were converted into time-averaged normalized SAR values using Equation (6a), (6b) and (6c), and plotted below to demonstrate that the time-averaged normalized SAR versus time does not exceed the FCC limit of 1 unit.



	(W/kg)
FCC normalized total exposure limit	1.0
Max 100s-time averaged normalized SAR (green curve)	0.743
Validated	

The test result validated the continuity of power limiting in DSI switch scenario

7 SAR Test Results for Sub-6 Smart Transmit Algorithm Validation

7.1 Measurement setup

The measurement setup is similar to normal SAR measurements. The difference in SAR measurement setup for time averaging algorithm validation is that the callbox is signaling in close loop power control mode (instead of requesting maximum power in open loop control mode) and callbox is connected to the PC using GPIB so that the test script executed on PC can send GPIB commands to control the callbox's requested power over time (test sequence). The same test script used in conducted setup for time-varying transmit power measurements is also used in this section for running the test sequences during SAR measurements, and the recorded values from the disconnected power meter by the test script were discarded.

As mentioned in Section 3.4, for EUT to follow TPC command sent from the callbox wirelessly, the "path loss" between callbox antenna and the EUT needs to be very well calibrated. Since the SAR chamber is in uncontrolled environment, precautions must be taken to minimize the environmental influences on "path loss". Detailed procedure to calibrate the "path loss" is provided in Appendix B.

The EUT is placed in worst-case position according to Table 5-2.

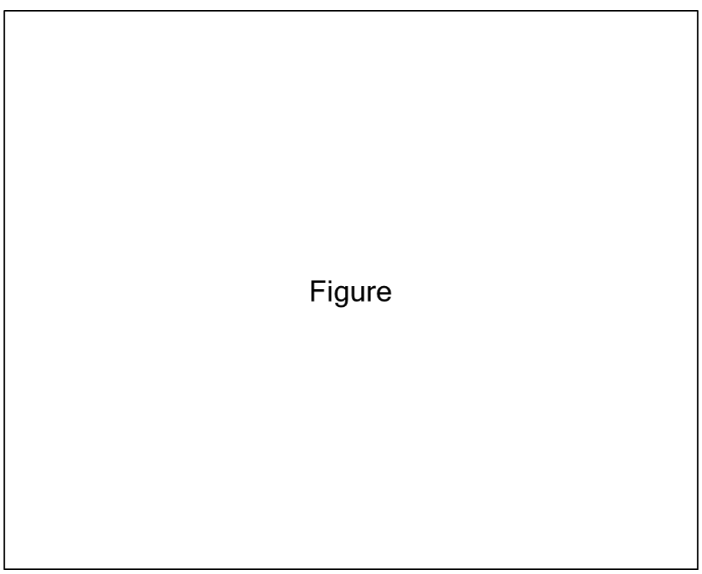


Figure 7-1 SAR measurement setup

7.2 SAR measurement results for time-varying Tx power transmission scenario

Following Section 3.4 procedure, time-averaged SAR measurements are conducted using EX3DV4 probe at peak location of area scan over 500 seconds. Appendix C furthermore detailed the steps for conducting time-averaged SAR measurements using cDASY6 SAR measurement system used for this validation. cDASY6 system validation for SAR measurement is provided in Appendix E, and the associated SPEAG certificates are attached in Appendix F.

Probe integration times depend on the communication signal being tested. Integration times used by SPEAG for their probe calibrations can be downloaded from here (integration time is listed on the bottom of the first page for each tech):

https://www.speag.com/assets/downloads/services/cs/UIDSummary171205.pdf

Since the sampling rate used by cDASY6 for pointSAR measurements is not in user control, the number of points in 100s interval is determined from the scan duration setting in cDASY6 time-average pointSAR measurement by (100s / cDASY6_scan_duration * total number of pointSAR values recorded). Running average is performed over these number of points in excel spreadsheet to obtain 100s-averaged pointSAR.

Following Section 3.4 and Appendix C procedures, for each of selected technology/band (listed in Table 5-2):

1. With *Reserve_power_margin* set to 0 dB, area scan is performed at P_{limit}, and time-averaged pointSAR measurements are conducted to determine the pointSAR at P_{limit} at peak location, denoted as *point*SAR$_{Plimit}$.
2. With *Reserve_power_margin* set to actual (intended) value, two more time-averaged pointSAR measurements are performed at the same peak location for test sequences 1 and 2.

To demonstrate compliance, all the pointSAR measurement results were converted into 1gSAR or 10gSAR values by using Equation (3a), rewritten below:

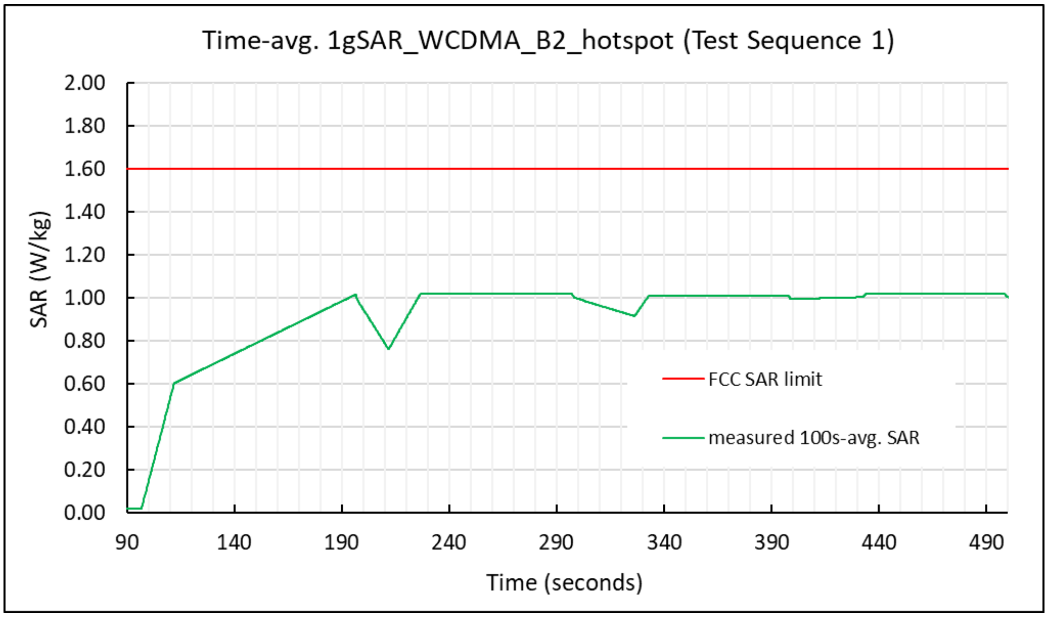
$$1g\_or\_10gSAR(t) = \frac{pointSAR(t)}{pointSAR\_P_{limit}} * 1g\_or\_10gSAR\_P_{limit} \qquad (3a)$$

where, $pointSAR(t)$, $pointSAR\_P_{limit}$, and $1g\_or\_10gSAR\_P_{limit}$ correspond to the measured instantaneous point SAR, measured point SAR at P_{limit} from above step 1 and 2, and measured *1gSAR* or 10gSAR values at P_{limit} obtained from Part 1 report and listed in Table 5-2 in Section 5.1 of this report.

7.2.1 WCDMA Band II SAR test results

Test sequence 1: Same as shown in Table 6-2.

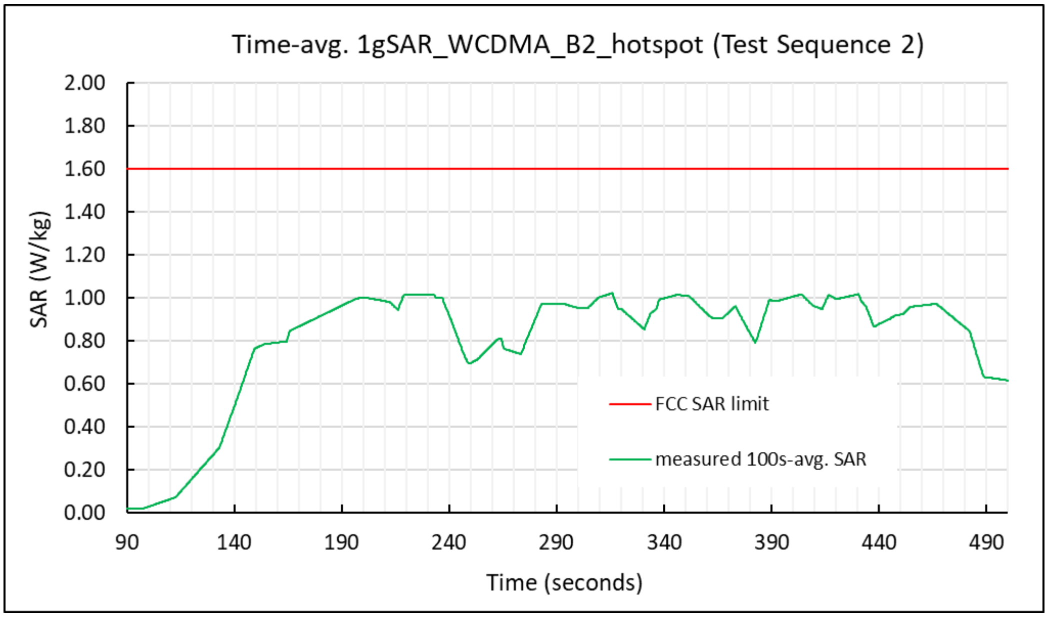
SAR test results for test sequence 1:



	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged point 1gSAR (green curve)	1.018
Validated	

Test sequence 2: same as shown in Figure 6-3.

SAR test results for test sequence 2:

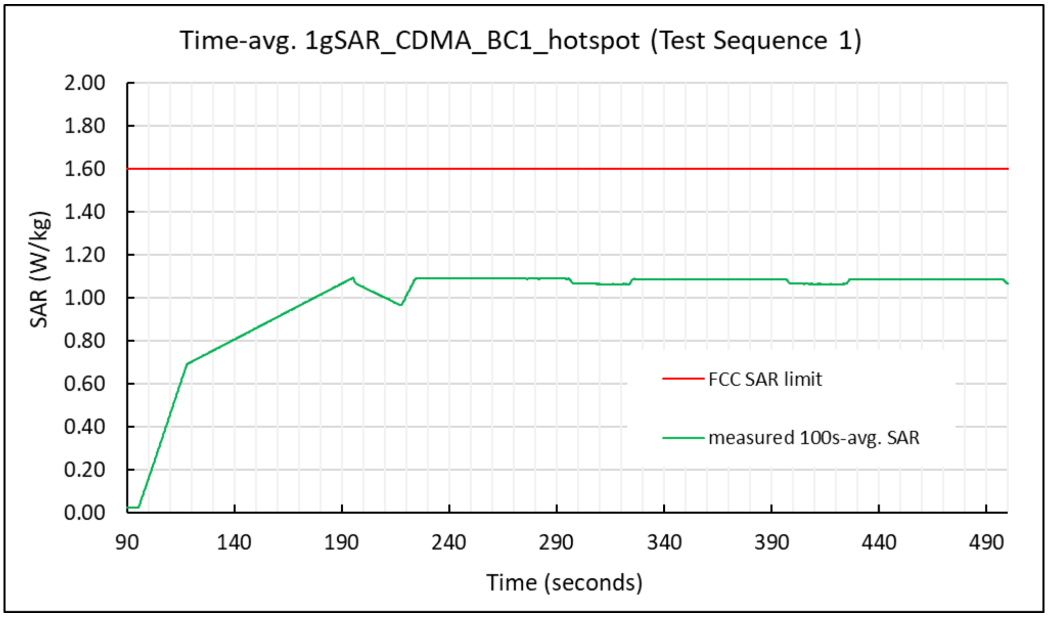


	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged point 1gSAR (green curve)	1.022
Validated	

7.2.2 CDMA BC1 SAR test results

Test sequence 1: Same as shown in Table 6-4.

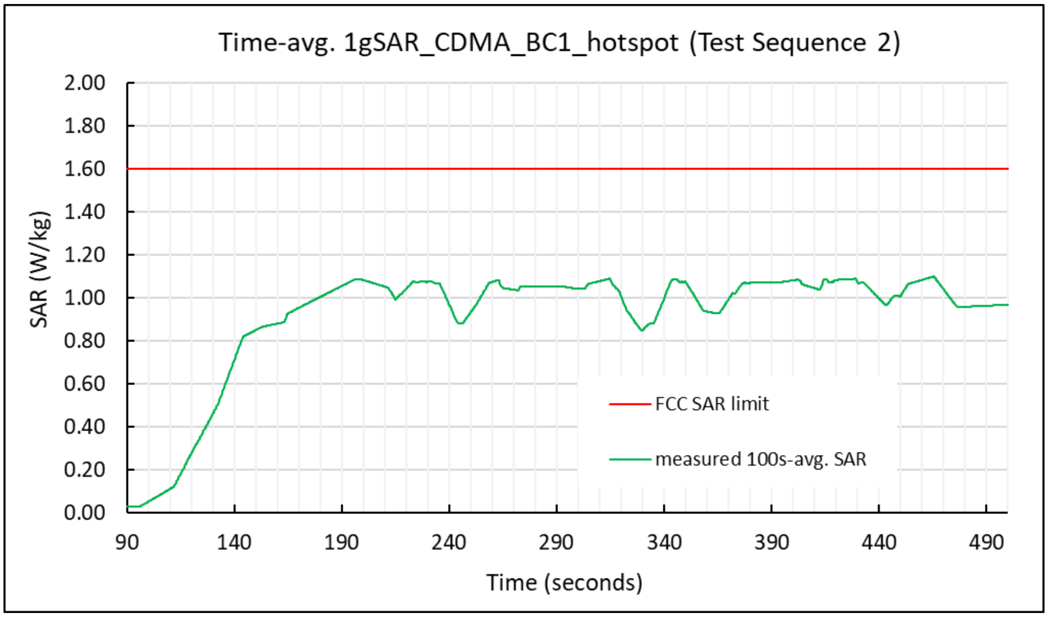
SAR test results for test sequence 1:



	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged point 1gSAR (green curve)	1.094
Validated	

Test sequence 2: same as shown in Figure 6-5.

SAR test results for test sequence 2:

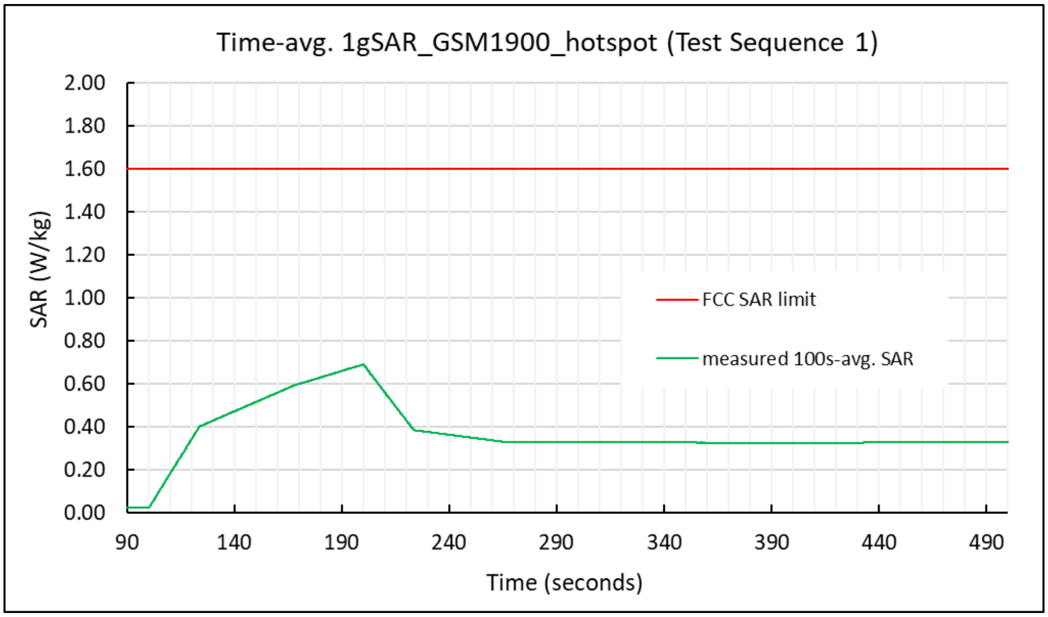


	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged point 1gSAR (green curve)	1.10
Validated	

7.2.3 GSM1900 SAR test results

Test sequence 1: Same as shown in Table 6-6.

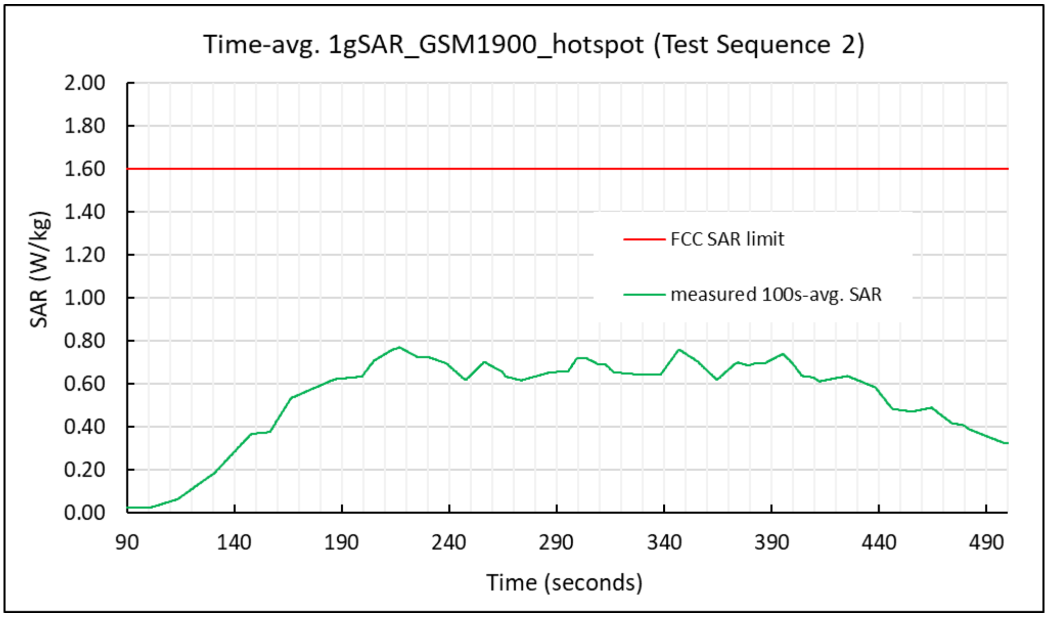
SAR test results for test sequence 1:



	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged point 1gSAR (green curve)	0.69
Validated	

Test sequence 2: same as shown in Figure 6-7.

SAR test results for test sequence 2:

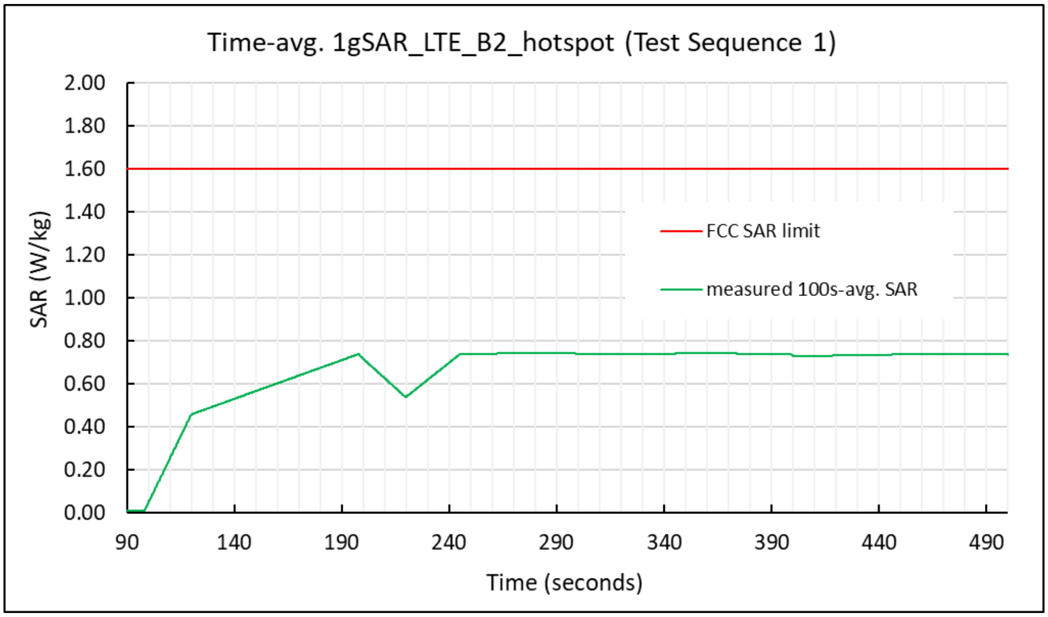


	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged point 1gSAR (green curve)	0.77
Validated	

7.2.4 LTE Band 2 SAR test results

Test sequence 1: Same as shown in Table 6-8.

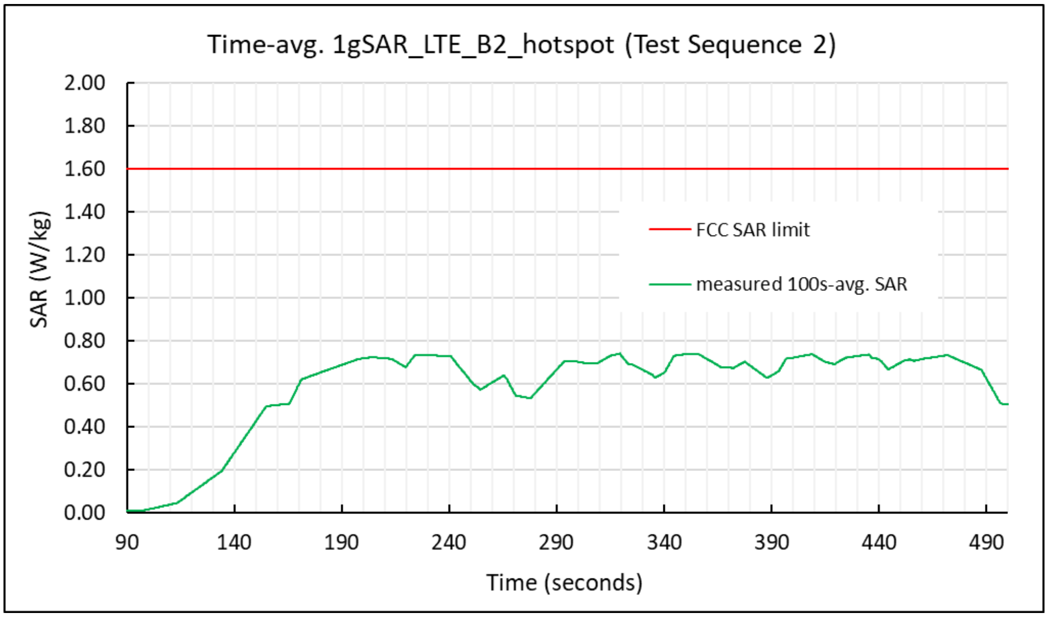
SAR test results for test sequence 1:



	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged point 1gSAR (green curve)	0.745
Validated	

Test sequence 2: same as shown in Table 6-9.

SAR test results for test sequence 2:

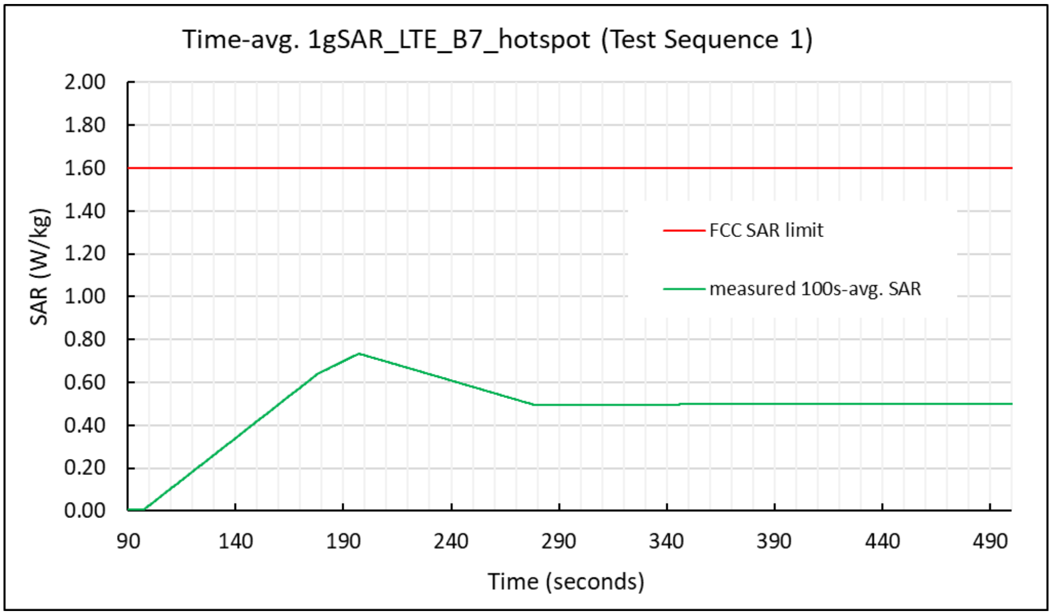


	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged 1gSAR (green curve)	0.741
Validated	

7.2.5 LTE Band 7 SAR test results

Test sequence 1: Same as shown in Table 6-10.

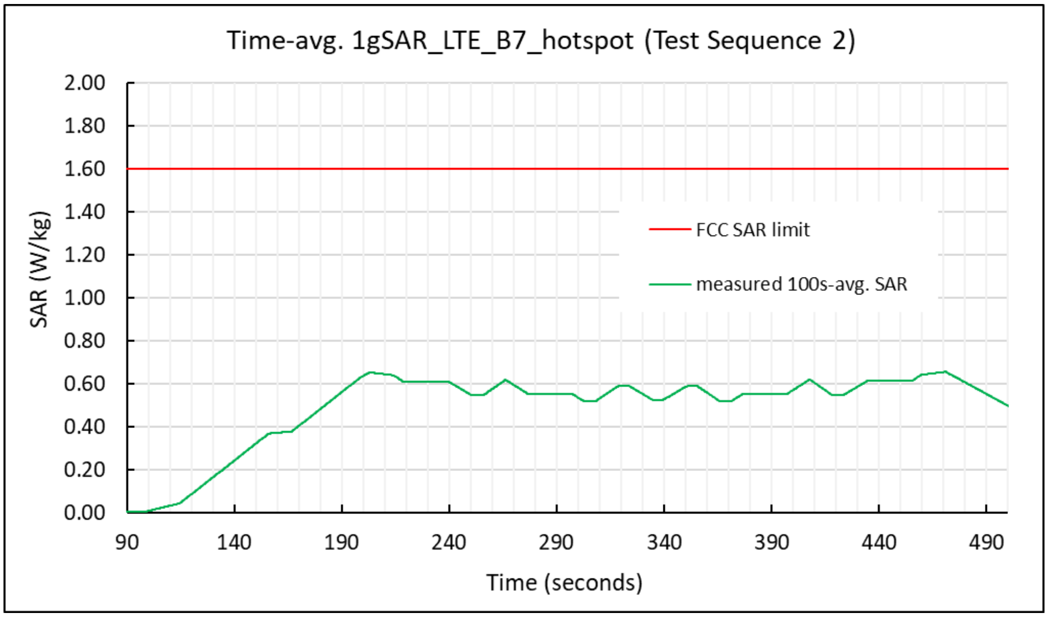
SAR test results for test sequence 1:



	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged point 1gSAR (green curve)	0.734
Validated	

<u>Test sequence 2:</u> same as shown in Table 6-11.

<u>SAR test results for test sequence 2:</u>



	(W/kg)
FCC 1gSAR limit	1.6
Max 100s-time averaged 1gSAR (green curve)	0.656
Validated	

8 Radiated Power Test Results for mmW Smart Transmit Algorithm Validation

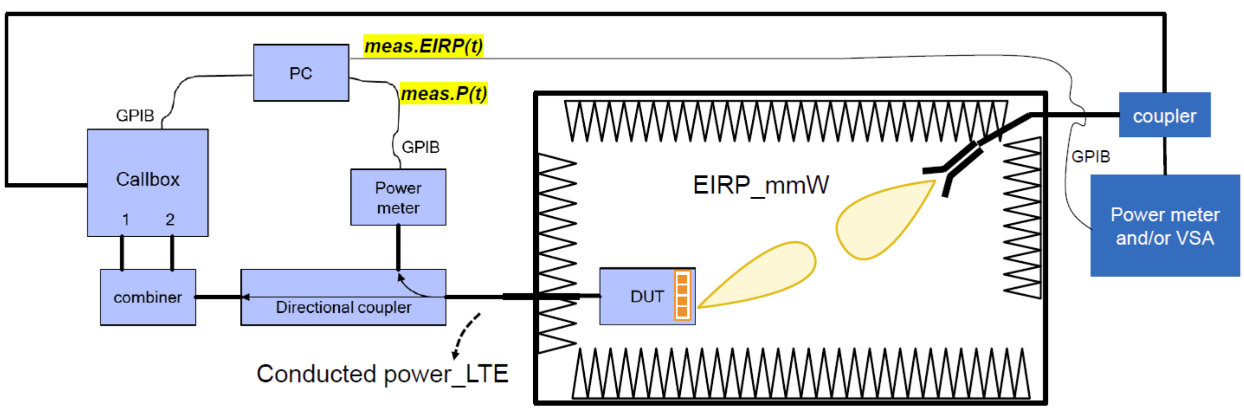
8.1 Measurement Setup

The Keysight Technologies E7515B UXM callbox is used in this test. The test setup is shown in Figure 8-1a and the schematic of the setup is shown in Figure 8-1b (see Appendix G for missing figures). The UXM callbox has two RF radio heads to up/down convert IF to mmW frequencies, which in turn are connected to two horn antennas for V- and H-polarizations for downlink communication. In the uplink, a directional coupler is used in the path of one of the horn antennas to measure and record radiated power using a Rohde & Schwarz NR50S power sensor and NRP2 power meter. Note here that the isolation of the directional coupler may not be sufficient to attenuate the downlink signal from the callbox, which will result in high noise floor masking the recording of radiated power from EUT. In that case, either lower the downlink signal strength emanating from the RF radio heads of callbox or add an attenuator between callbox radio heads and directional coupler. Additionally, note that since the measurements performed in this validation are all relative, measurement of EUT's radiated power in one polarization is sufficient. The EUT is placed inside an anechoic chamber with V- and H-pol horn antennas to establish the radio link as shown in Figure 8-1. The callbox's LTE port is directly connected to the EUT's RF port via a directional coupler to measure the EUT's conducted Tx power using a Rohde & Schwarz NR8S power sensor and NRP2 power meter. Additionally, EUT is connected to the PC via USB connection for sending beam switch command. Care is taken to route the USB cable and RF cable (for LTE connection) away from the EUT's mmW antenna modules.

Setup in Figure 8-1 is used for the test scenario 1, 4 and 5 described in Section 2. The test procedures described in Section 4 are followed. The path losses from the EUT to both the power meters are calibrated and used as offset in the power meter.

Figure

(a)



(b)

Figure 8-1 mmW NR radiated power measurement setup (see Appendix G for missing figures)

Both the callbox and power meters are connected to the PC using USB cables. Test scripts are custom made for automation of establishing LTE + mmW call, conducted Tx power recording for LTE and radiated Tx power recording for mmW. These tests are manually stopped after desired time duration. Test script is programmed to set LTE Tx power to all-down bits on the callbox immediately after the mmW link is established, and programmed to set toggle between all-up and all-down bits depending on the transmission scenario being evaluated. Similarly, test script is also programmed to send beam switch command manually to the EUT via USB connection. For all the tests, the callbox is set to request maximum Tx power in mmW NR radio from EUT all the time.

Test configurations for this validation are detailed in Section 5.2. Test procedures are listed in Section 4.3.

8.2 mmW NR radiated power test results

To demonstrate the compliance, the conducted Tx power of LTE B2 in DSI = 3 (hotspot mode) is converted to 1gSAR exposure by applying the corresponding worst-case 1gSAR value at P_{limit} as reported in Part 1 report and listed in Table 5-2 of this report.

Similarly, following Step 4 in Section 4.3.1, radiated Tx power of mmW Band n261 and n260 for the beams tested is converted by applying the corresponding worst-case 4cm^{2}PD values measured in Qualcomm lab, and listed in below Table 8-1. Qualcomm Smart Transmit algorithm operates based on time-averaged transmit power reported on a per symbol basis, which is independent of modulation, channel and bandwidth (RBs), therefore the worst-case 4cm^{2}PD was conducted with the EUT in FTM mode, with CW modulation and 100% duty cycle. cDASY6 system verification for power density measurement is provided in Appendix E, and the associated SPEAG certificates are attached in Appendix F.

Both the worst-case 1gSAR and 4cm^{2}PD values used in this section are listed in Table 8-1. The measured EIRP at *input.power.limit* for the beams tested in this section are also listed in Table 8-1.

Table 8-1: Worst-case 1gSAR, 4cm^2 avg. PD and EIRP measured at *input.power.limit* for the selected configurations

					meas. 4cm2PD		
Tech	**Band**	**Antenna**	**Beam ID**	**input.power.limit (dBm)**	**at input.power.limit (W/m2)**	**configuration**	**meas. EIRP at input.power.limit (dBm)**
mmW NR	n261	J	41	0.7	2.64	back	12.57
			27	0.7	2.73	back	12.10
			1	6.1	**4.18**	back	7.70
mmW NR	n260	J	4	2.9	1.76	back	9.10
			39	4.6	**4.13**	back	13.00
			1	6.5*	2.21	back	8.14

					meas. 1gSAR	
		Antenna	**DSI**	**Plimit (dBm)**	**at Plimit (W/kg)**	**configuration**
LTE	B2	A	3	18.0	0.84	bottom

* The *input.power.limit* for n260 beam 1 is 9.25dBm. However, the maximum input power of SDX50/QTM052 for n260 CP-OFDM modulation is 6.5dBm, thus the PD measurement was done with *input.power.limit* of 6.5dBm.

The 4cm2-averaged PD distributions for the highest PD value per band, as listed in Table 8-1, are plotted below:

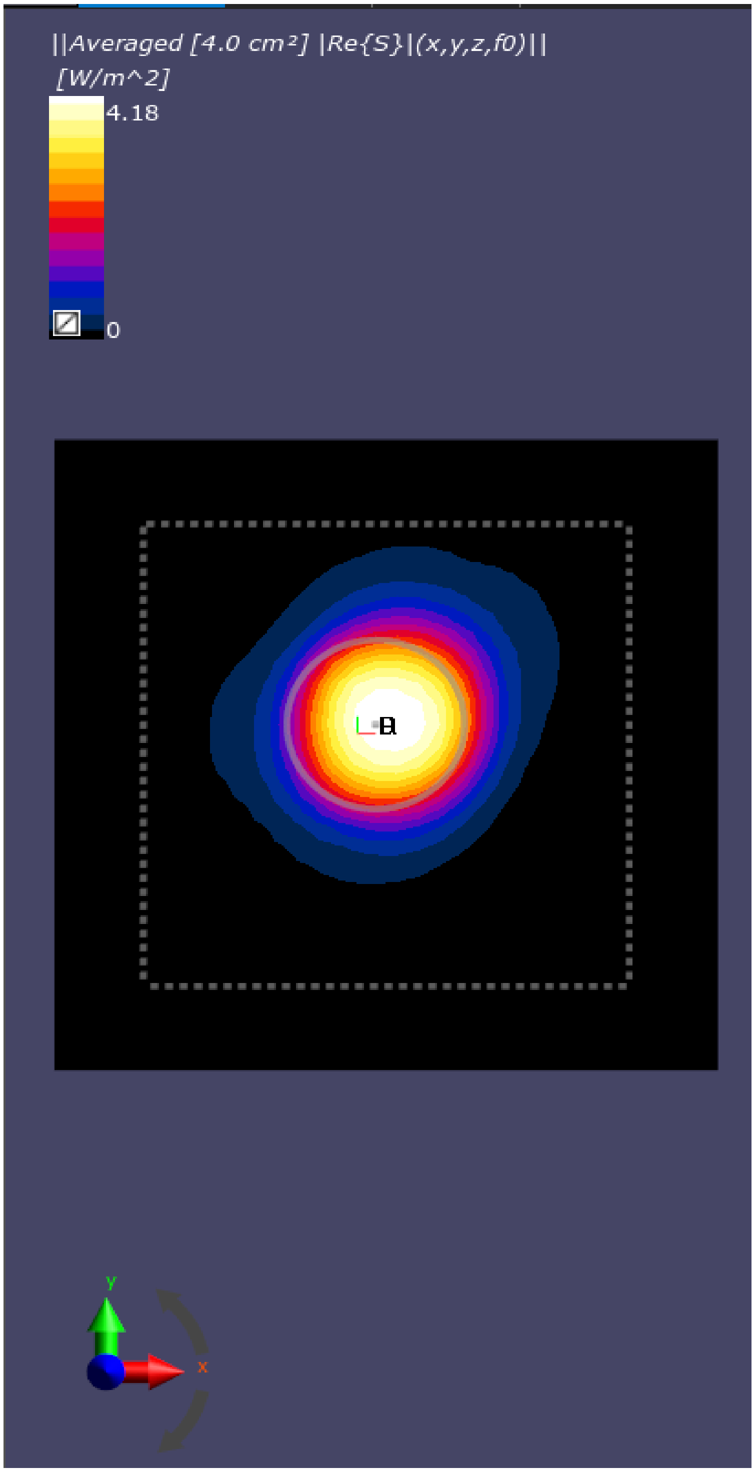


Figure 8-2: 4cm2-averaged power density distribution measured at input.power.limit of 6.1dBm and back surface (S2 as shown in Figure 5-1) for n261 beam 1

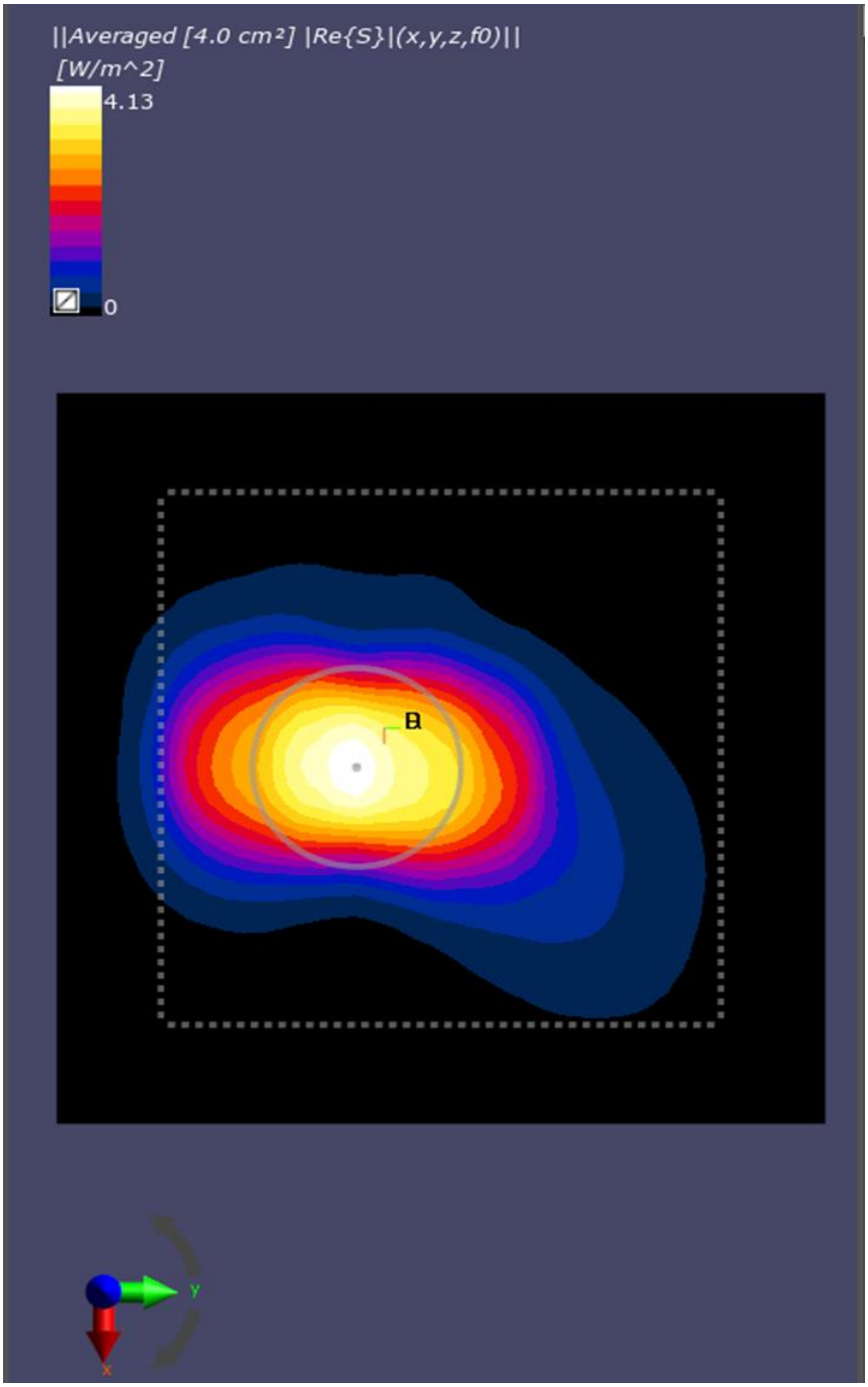
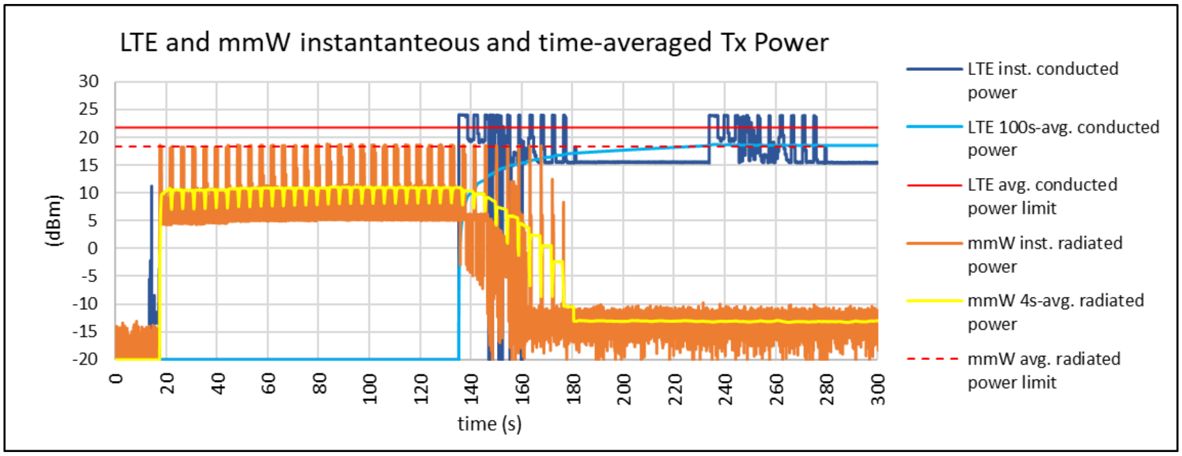


Figure 8-3**: 4cm2-averaged power density distribution measured at input.power.limit of *4.6*dBm and back surface (S2 as shown in Figure 5-1) for n26*0* beam *39***

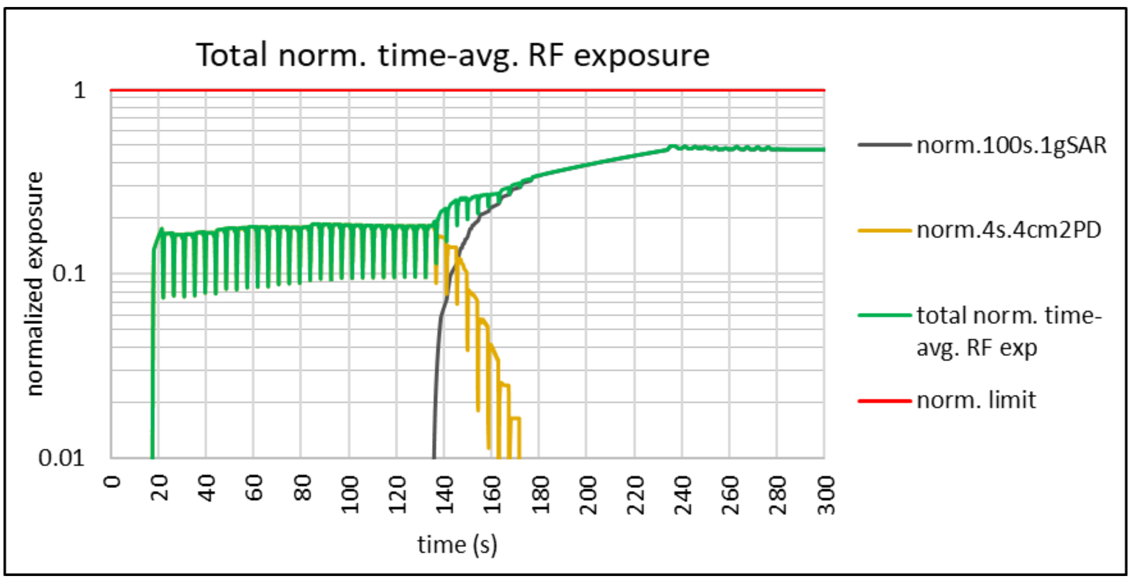
8.2.1 Maximum transmit power test results for n261

This test was measured with LTE B2 (DSI = 3) and mmW Band n261 Beam ID 41, by following the detailed test procedure described in Section 4.3.1.

Instantaneous and 100s-averaged conducted LTE Tx power versus time, instantaneous and 4s-averaged radiated mmW Tx power versus time, time-averaged conducted LTE Tx power limit and time-averaged radiated mmW Tx power limit:



Above time-averaged conducted Tx power for LTE B2 and radiated Tx power for mmW NR n261 beam 41 are converted into time-averaged 1gSAR and time-averaged 4cm^{2}PD using Equation (2a) and (2b), which are divided by FCC 1gSAR limit of 1.6 W/kg and 4cm^{2}PD limit of 10 W/m^2, accordingly, to obtain normalized exposures versus time. Below plot shows (a) normalized time-averaged 1gSAR versus time, (b) normalized time-averaged 4cm2-avg.PD versus time, (c) sum of normalized time-averaged 1gSAR and normalized time-averaged 4cm^2-avg.PD:



FCC requirement for total RF exposure (normalized)	1.0
Max total normalized time-averaged RF exposure (green curve)	0.495
Validated	

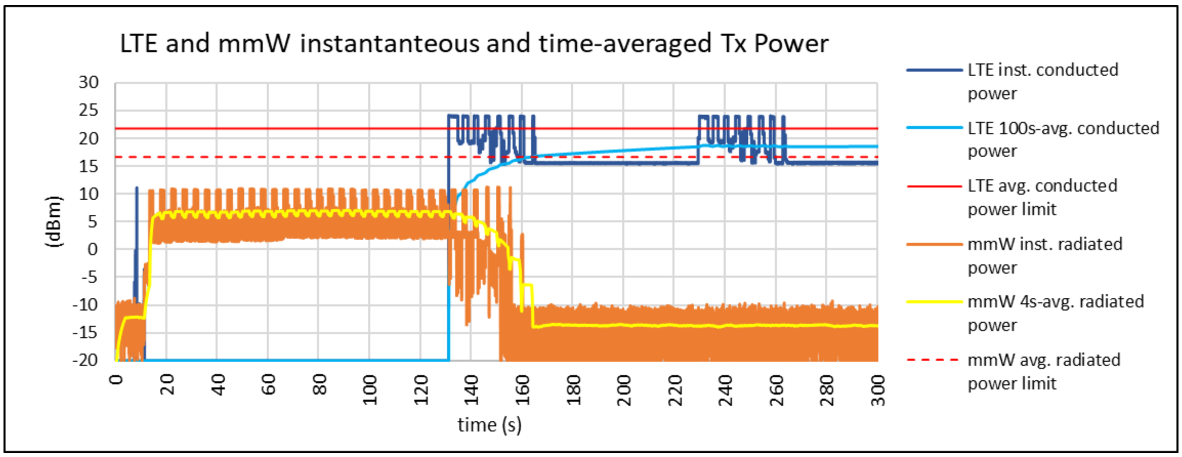
Plot notes: 5G mmW NR call was established at ~20s time mark and LTE was placed in all-down bits immediately after 5G mmW NR call was established. Between 20s~140s, mmW exposure is the dominant contributor. Here, Smart Transmit algorithm allocates a maximum of 75% for mmW (based on the 3dB reserve setting in Part 1 report). From Table 8-1, this corresponds to a normalized 4cm^{2}PD exposure value for Beam ID 41 of (75% * 2.64 W/m^2)/(10 W/m^2) = 19.8% ± 2.4dB device related uncertainty (see green/orange curve between 20s~140s). At ~140s time mark, LTE is set to all-up bits, taking away margin from mmW exposure gradually. Towards the end of test, LTE is the dominant contributor towards RF exposure, i.e., corresponding normalized 1gSAR exposure value of (100% * 0.84 W/kg)/(1.6 W/kg) = 52.5% ± 1dB design related uncertainty (see black curve approaching this level towards end of the test).

As can be seen, the power limiting enforcement is effective and the total normalized time-averaged RF exposure does not exceed 1.0. Therefore, Qualcomm® Smart Transmit time averaging algorithm is validated.

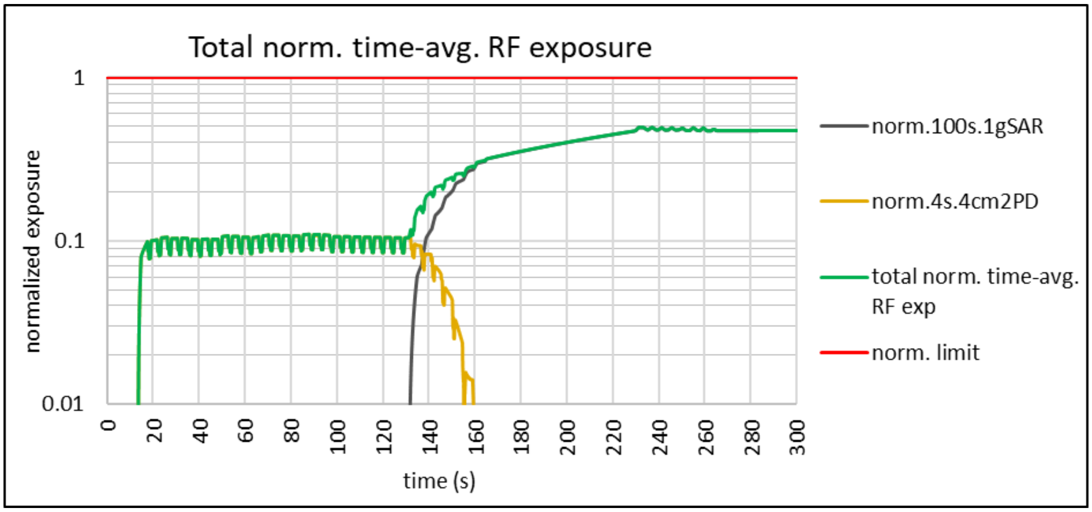
8.2.2 Maximum transmit power test results for n260

This test was measured with LTE B2 (DSI = 3) and mmW Band n260 Beam ID 4, by following the detailed test procedure described in Section 4.3.1.

Instantaneous and 100s-averaged conducted LTE Tx power versus time, instantaneous and 4s-averaged radiated mmW Tx power versus time, time-averaged conducted LTE Tx power limit and time-averaged radiated mmW Tx power limit:



Above time-averaged conducted Tx power for LTE B2 and radiated Tx power for mmW NR n260 beam 4 are converted into time-averaged 1gSAR and time-averaged 4cm^{2}PD using Equation (2a) and (2b), which are divided by FCC 1gSAR limit of 1.6 W/kg and 4cm^{2}PD limit of 10 W/m^2, accordingly, to obtain normalized exposures versus time. Below plot shows (a) normalized time-averaged 1gSAR versus time, (b) normalized time-averaged 4cm2-avg.PD versus time, (c) sum of normalized time-averaged 1gSAR and normalized time-averaged 4cm^2-avg.PD:



FCC requirement for total RF exposure (normalized)	1.0
Max total normalized time-averaged RF exposure (green curve)	0.494
Validated	

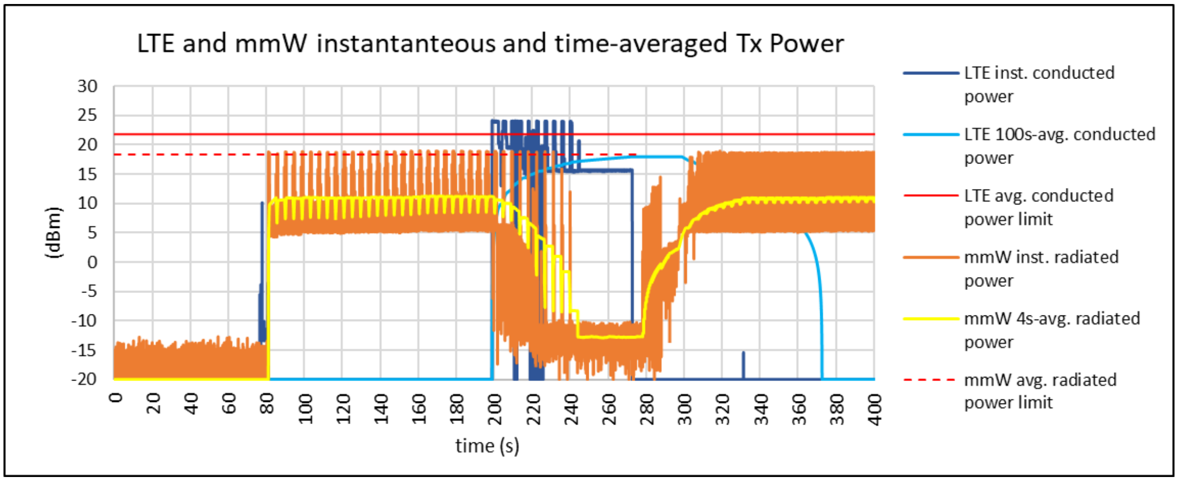
Plot notes: 5G mmW NR call was established at ~10s time mark and LTE was placed in all-down bits immediately after 5G mmW NR call was established. Between 10s~130s, mmW exposure is the dominant contributor. Here, Smart Transmit algorithm allocates a maximum of 75% for mmW (based on the 3dB reserve setting in Part 1 report). From Table 8-1, this corresponds to a normalized $4cm^2$PD exposure value for Beam ID 4 of (75% * 1.76 W/m^2)/(10 W/m^2) = 13.2% ± 2.4dB device related uncertainty (see orange/green curve between 10s~130s). At ~130s time mark, LTE is set to all-up bits, taking away margin from mmW exposure gradually. Towards the end of test, LTE is the dominant contributor towards RF exposure, i.e., corresponding normalized 1gSAR exposure value of (100% * 0.84 W/kg)/(1.6 W/kg) = 52.5% ± 1dB design related uncertainty (see black curve approaching this level towards end of the test).

As can be seen, the power limiting enforcement is effective and the total normalized time-averaged RF exposure does not exceed 1.0. Therefore, Qualcomm® Smart Transmit time averaging algorithm is validated

8.2.3 Switch in SAR vs. PD exposure test results for n261

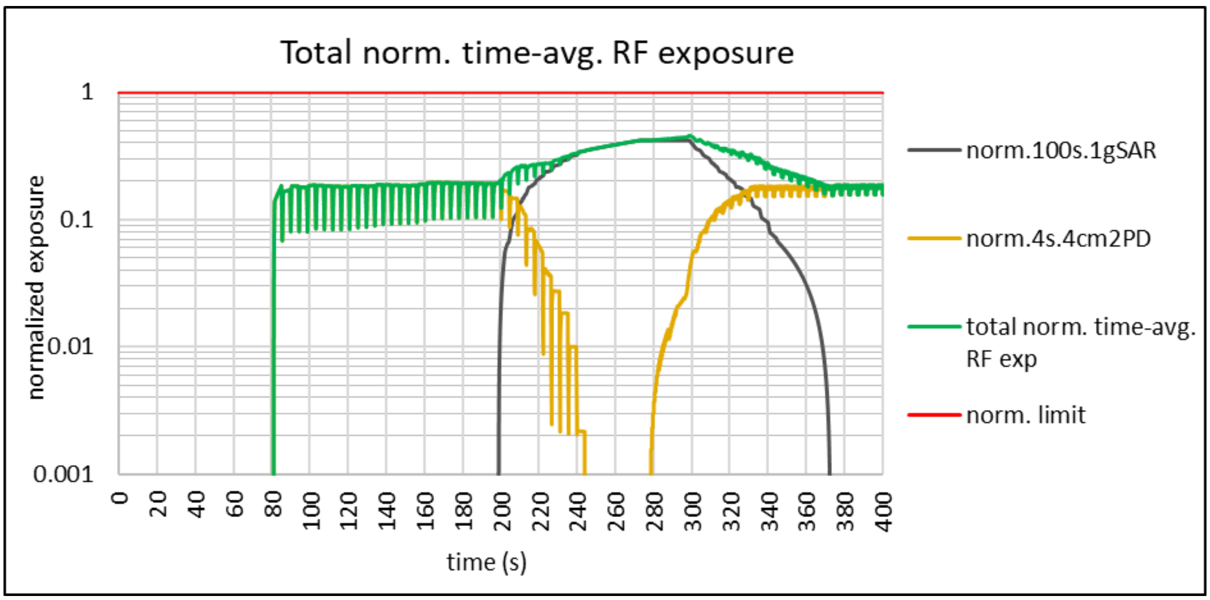
This test was measured with LTE Band 2 (DSI =3) and mmW Band n261 Beam ID 41, by following the detailed test procedure is described in Section 4.3.2.

Instantaneous and 100s-averaged conducted LTE Tx power versus time, instantaneous and 4s-averaged radiated mmW Tx power versus time, time-averaged conducted LTE Tx power limit and time-averaged radiated mmW Tx power limit:



From the above plot, it can be seen that between 80s ~ 200s, it is predominantly instantaneous PD exposure, between 200s ~ 240s, it is instantaneous SAR+PD exposure, between 240s ~ 270s, it is predominantly instantaneous SAR exposure, and above 270s, it is predominantly instantaneous PD exposure.

Normalized time-averaged exposures for LTE (1gSAR) and mmW ($4cm^2$PD), as well as total normalized time-averaged exposure versus time:



FCC requirement for total RF exposure (normalized)	1.0
Max total normalized time-averaged RF exposure (green curve)	0.455
Validated	

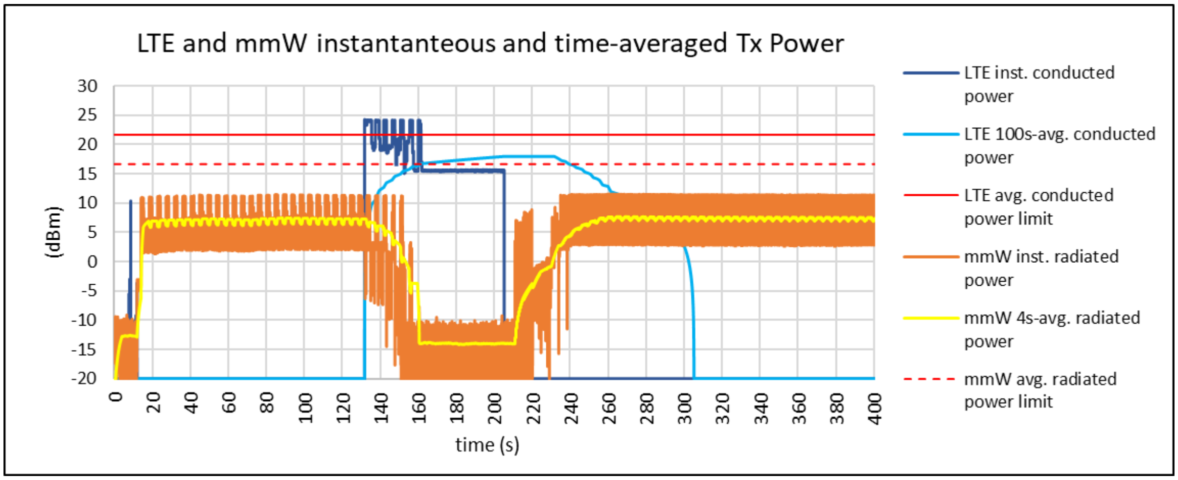
Plot notes: 5G mmW NR call was established at ~80s time mark and LTE was placed in all-down bits immediately after 5G mmW NR call was established. Between 80s~200s, mmW exposure is the dominant contributor. Here, Smart Transmit algorithm allocates a maximum of 75% for mmW (based on 3dB reserve setting in Part 1 report). From Table 8-1, this corresponds to a normalized $4cm^2$PD exposure value for Beam ID 41 of (75% * 2.64 W/m^2)/(10 W/m^2) = 19.8% ± 2.4dB device related uncertainty (see orange/green curve between 80s~200s). At ~200s time mark, LTE is set to all-up bits, taking away margin from mmW exposure gradually (orange curve for mmW exposure goes down while black curve for LTE exposure goes up). At ~270s time mark, LTE is set to all-down bits, which results in mmW getting back RF margin slowly as seen by gradual increase in mmW exposure (orange curve for mmW exposure goes up while black curve for LTE exposure goes down). The calculated maximum RF exposure from LTE corresponds to normalized 1gSAR exposure value of (100% * 0.84 W/kg)/(1.6 W/kg) = 52.5% ± 1dB design related uncertainty (note that this level will be achieved by green and black curves if LTE remains in all-up bits for longer time duration which was already demonstrated in maximum transmit power test in Section 8.2.1). Total normalized time-averaged exposure (green curve) for this test should be within the calculated range between 19.8% ± 2.4dB device related uncertainty (only PD exposure) and 52.5% ± 1dB design related uncertainty (only SAR exposure).

As can be seen, the power limiting enforcement is effective during transmission when SAR and PD exposures are switched, and the total normalized time-averaged RF exposure does not exceed 1.0. Therefore, Qualcomm® Smart Transmit time averaging algorithm is validated.

8.2.4 Switch in SAR vs. PD exposure test results for n260

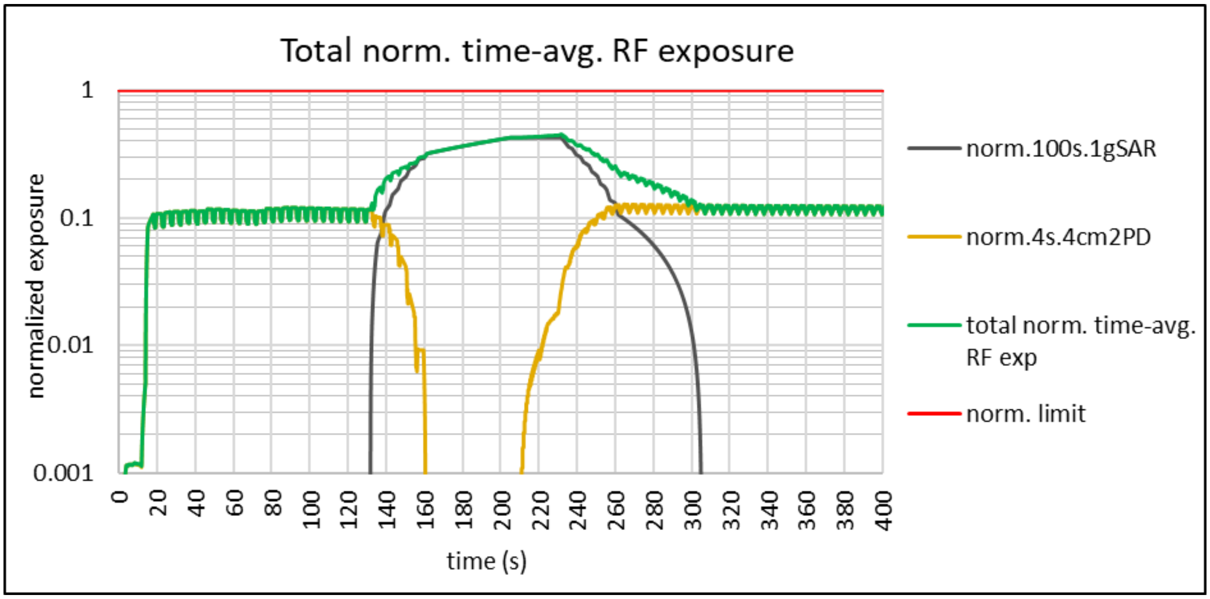
This test was measured with LTE Band 2 (DSI =3) and mmW Band n260 Beam ID 4, by following the detailed test procedure is described in Section 4.3.2.

Instantaneous and 100s-averaged conducted LTE Tx power versus time, instantaneous and 4s-averaged radiated mmW Tx power versus time, time-averaged conducted LTE Tx power limit and time-averaged radiated mmW Tx power limit:



From the above plot, it can be seen that between 15s ~ 130s, it is predominantly instantaneous PD exposure, between 130s ~ 160s, it is instantaneous SAR+PD exposure, between 160s ~ 210s, it is predominantly instantaneous SAR exposure, and above 210s, it is predominantly instantaneous PD exposure.

Normalized time-averaged exposures for LTE (1gSAR) and mmW ($4cm^2$PD), as well as total normalized time-averaged exposure versus time:



FCC requirement for total RF exposure (normalized)	1.0
Max total normalized time-averaged RF exposure (green curve)	0.451
Validated	

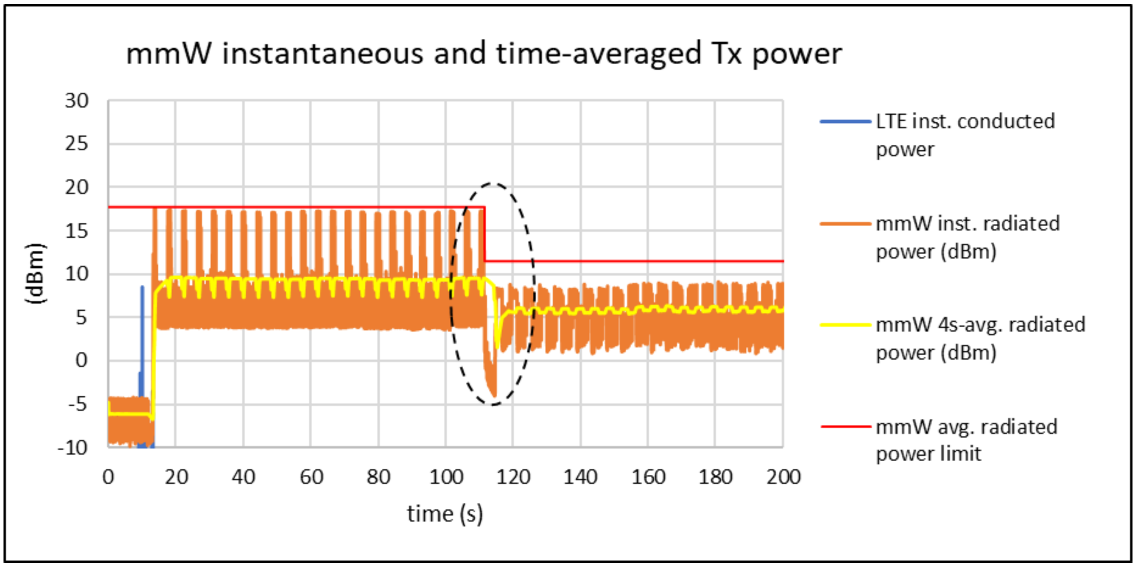
Plot notes: 5G mmW NR call was established at ~15s time mark and LTE was placed in all-down bits immediately after 5G mmW NR call was established. Between 15s~130s, mmW exposure is the dominant contributor. Here, Smart Transmit algorithm allocates a maximum of 75% for mmW (based on 3dB reserve setting in Part 1 report). From Table 8-1, this corresponds to a normalized $4cm^2$PD exposure value for Beam ID 4 of (75% * 1.76 W/m^2)/(10 W/m^2) = 13.2% ± 2.4dB device related uncertainty (see orange/green curve between 15s~130s). At ~130s time mark, LTE is set to all-up bits, taking away margin from mmW exposure gradually (orange curve for mmW exposure goes down while black curve for LTE exposure goes up). At ~210s time mark, LTE is set to all-down bits, which results in mmW getting back RF margin slowly as seen by gradual increase in mmW exposure (orange curve for mmW exposure goes up while black curve for LTE exposure goes down). The calculated maximum RF exposure from LTE corresponds to normalized 1gSAR exposure value of (100% * 0.84 W/kg)/(1.6 W/kg) = 52.5% ± 1dB design related uncertainty (note that this level will be achieved by green and black curves if LTE remains in all-up bits for longer time duration which was already demonstrated in maximum transmit power test in Section 8.2.2). Total normalized time-averaged exposure (green curve) for this test should be within the calculated range between 13.2% ± 2.4dB device related uncertainty (only PD exposure) and 52.5% ± 1dB design related uncertainty (only SAR exposure).

As can be seen, the power limiting enforcement is effective during transmission when SAR and PD exposures are switched, and the total normalized time-averaged RF exposure does not exceed 1.0. Therefore, Qualcomm® Smart Transmit time averaging algorithm is validated

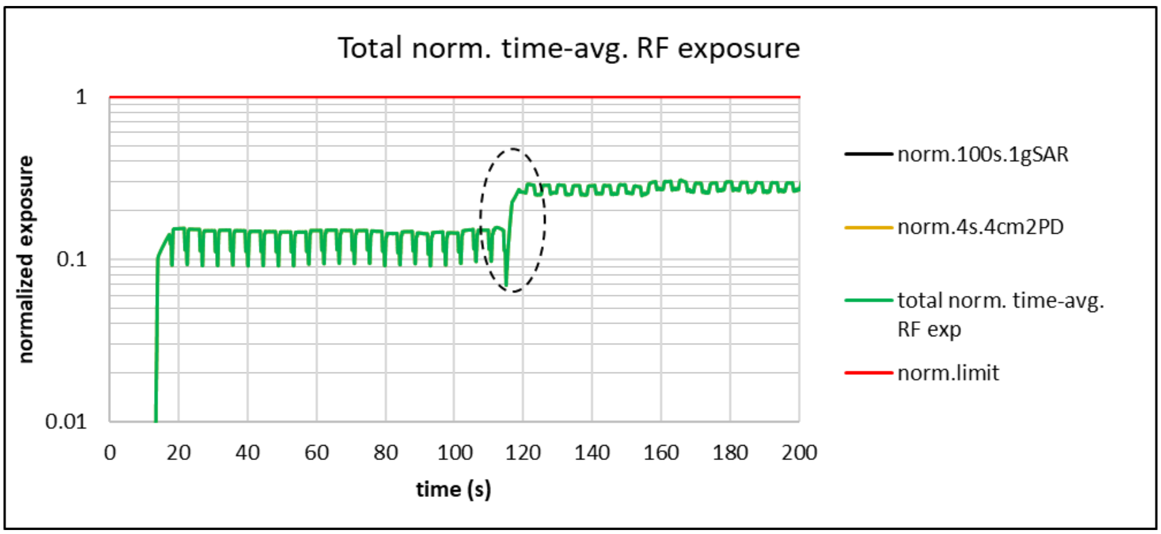
8.2.5 Change in Beam test results for n261

This test was measured with LTE Band 2 (DSI = 3) and mmW Band n261, with beam switch from Beam ID 27 to Beam ID 1, by following the test procedure is described in Section 4.3.3.

Instantaneous conducted LTE Tx power versus time, instantaneous and 4s-averaged radiated mmW Tx power versus time, time-averaged radiated mmW Tx power limits for beam 27 and beam 1:



Normalized time-averaged exposures for LTE and mmW (4cm^{2}PD), as well as total normalized time-averaged exposure versus time:



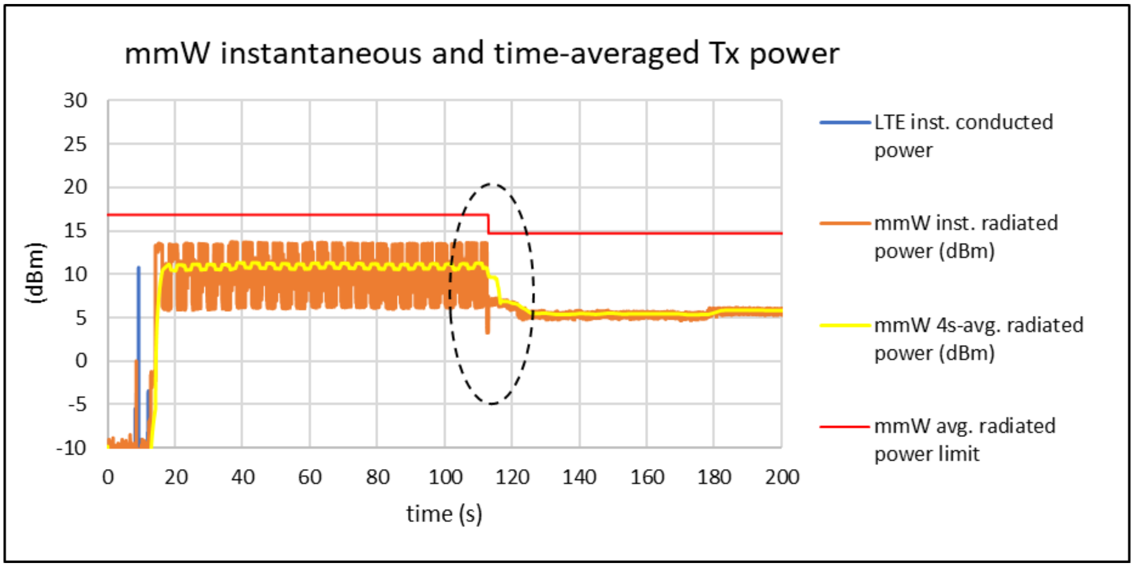
FCC requirement for total RF exposure (normalized)	1.0
Max total normalized time-averaged RF exposure (green curve)	0.31
Validated	

Plot notes: 5G mmW NR call was established at ~10s time mark and LTE was placed in all-down bits immediately after 5G mmW NR call was established. For the rest of this test, mmW exposure is the dominant contributor as LTE is left in all-down bits. Here, Smart Transmit algorithm allocates a maximum of 75% for mmW (based on 3dB reserve setting in Part 1 report). From Table 8-1, exposure between 10s ~110s corresponds to a normalized 4cm^{2}PD exposure value for Beam ID 27 of (75% * 2.73 W/m^2)/(10 W/m^2) = 20.5% ± 2.4dB device related uncertainty. At ~110s time mark (shown in black dotted ellipse), beam was switched to Beam ID 1 resulting in a normalized $4cm^2$PD exposure value of (75% * 4.18 W/m^2)/(10 W/m^2) = 31.4% ± 2.4dB device related uncertainty. Additionally, during the switch, the ratio between the averaged radiated powers of the two beams (yellow curve) should correspond to the difference in EIRPs measured at each corresponding *input.power.limit* for these beams listed in Table 8-1, i.e., 4.4dB ± 2.4dB device uncertainty.

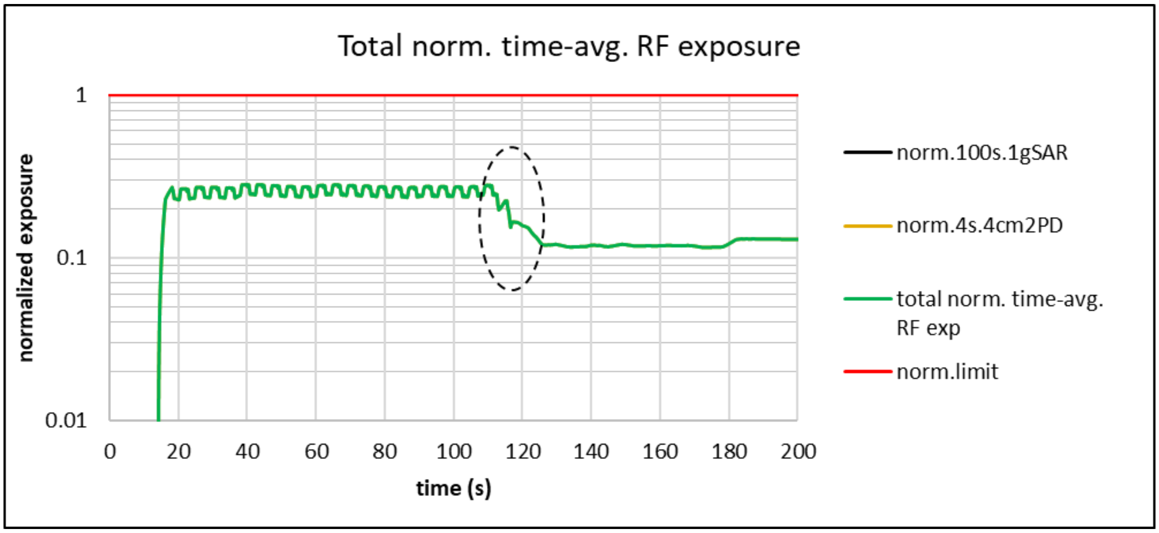
8.2.6 Change in Beam test results for n260

This test was measured with LTE Band 2 (DSI = 3) and mmW Band n260, with beam switch from Beam ID 39 to Beam ID 1, by following the test procedure is described in Section 4.3.3.

Instantaneous conducted LTE Tx power versus time, instantaneous and 4s-averaged radiated mmW Tx power versus time, time-averaged radiated mmW Tx power limits for beam 39 and beam 1:



Normalized time-averaged exposures for LTE (1gSAR) and mmW ($4cm^2$PD), as well as total normalized time-averaged exposure versus time:



FCC requirement for total RF exposure (normalized)	1.0
Max total normalized time-averaged RF exposure (green curve)	0.28
Validated	

Plot notes: 5G mmW NR call was established at ~10s time mark and LTE was placed in all-down bits immediately after 5G mmW NR call was established. For the rest of this test, mmW exposure is the dominant contributor as LTE is left in all-down bits. Here, Smart Transmit algorithm allocates a maximum of 75% for mmW (based on 3dB reserve setting in Part 1 report). From Table 8-1, exposure between 10s ~110s corresponds to a normalized $4cm^2$PD exposure value for Beam ID 39 of (75% * 4.13 W/m^2)/(10 W/m^2) = 31% ± 2.4dB device related uncertainty between 10s~110s). At ~110s time mark (shown in black dotted ellipse), beam was switched to Beam ID 1 resulting in a normalized $4cm^2$PD exposure value of (75.6% duty cycle * 2.21 W/m^2)/(10 W/m^2) = 16.7% ± 2.4dB device related uncertainty. Note that the input.power.limit for Beam ID 1 is 9.5dBm, however the maximum input power for n260 CP-OFDM modulation is capped at 6.5dBm, therefore, there is no power limiting required when n260 Beam ID 1 transmits, resulting in flat line in power plot for instantaneous radiated power after switch. Additionally, during the switch, the ratio between the averaged radiated powers of the two beams (yellow curve) should correspond to the difference in EIRPs measured at each corresponding *input.power.limit* for these beams listed in Table 8-1, i.e., 4.86dB ± 2.4dB device uncertainty.

9 PD Test Results for mmW Smart Transmit Algorithm Validation

9.1 Measurement setup

The measurement setup is similar to normal PD measurements, the EUT is positioned on cDASY6 platform, and is connected with the callbox (conducted for LTE and wirelessly for mmW). Keysight UXM callbox is set to request maximum mmW Tx power from EUT all the time. Hence, "path loss" calibration between callbox antenna and EUT is not needed in this test. The callbox's LTE port is directly connected to the EUT's RF port via a directional coupler to measure the EUT's conducted Tx power using a Rohde & Schwarz NR8S power sensor and NRP2 power meter. Additionally, EUT is connected to the PC via USB connection for toggling between FTM and online mode with Smart Transmit enabled following the test procedures described Section 4.4.

Worst-surface of EUT (for the mmW beam being tested) is positioned facing up for PD measurement with cDASY6 mmW probe as shown in Figure 9-1. Figure 9-2 shows the schematic of this measurement setup.

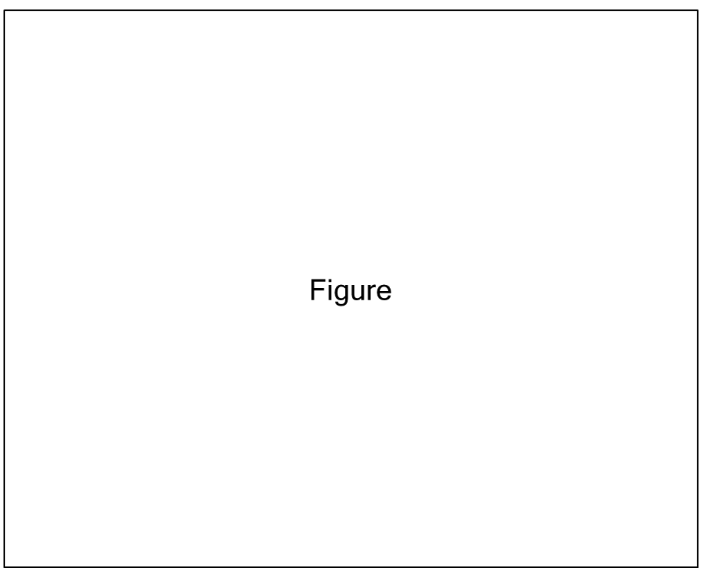


Figure 9-1 Worst-surface of EUT positioned facing up for the mmW beam being tested (see Appendix G for missing figures)

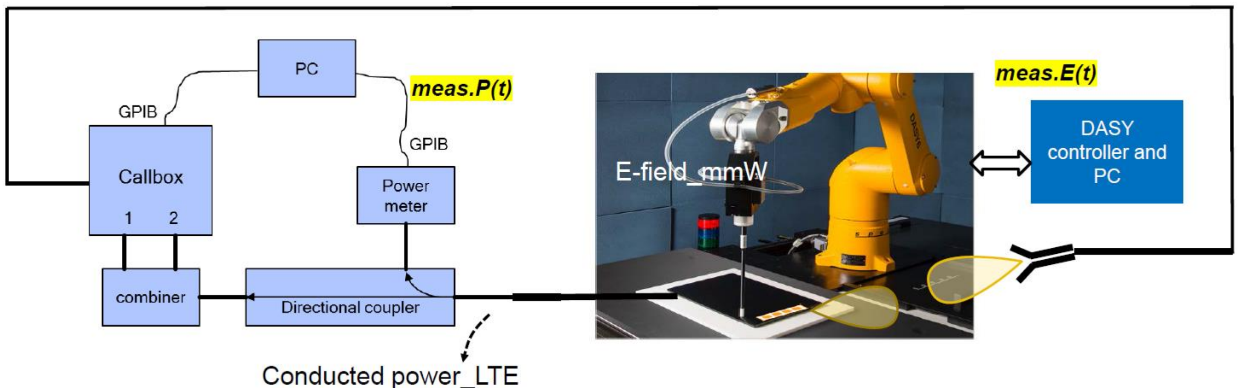


Figure 9-2 PD measurement setup

Both callbox and power meters are connected to the PC using USB cables. Test scripts are custom made for automation of establishing LTE + mmW call, and for conducted Tx power recording of LTE transmission. These tests are manually stopped after desired time duration. Once the mmW link is established, LTE Tx power is programmed to toggle between all-up and all-down bits on the callbox. For all the tests, the callbox is set to request maximum Tx power in mmW NR radio from EUT all the time. Therefore, the calibration for the pathloss between the EUT and the horn antenna connected to the remote radio head of the callbox is not required.

Power meter readings are periodically recorded every 10ms on NR8S power sensor for LTE conducted Tx power. Time-averaged E-field measurements are performed using EUmmWV2 mmW probe at peak location of fast area scan. The distance between EUmmWV2 mmW probe tip to EUT surface is ~0.5 mm, and the distance between EUmmWV2 mmW probe sensor to probe tip is 1.5 mm. Appendix D furthermore detailed the steps for performing time-averaged E-field measurements using cDASY6 measurement system used for this validation. cDASY6 records relative point E-field (i.e., ratio $\frac{[pointE(t)]^2}{[pointE\_input.power.limit]^2}$) versus time for mmW NR transmission.

9.2 PD measurement results for maximum power transmission scenario

The following configurations were measured by following the detailed test procedure is described in Section 4.4:

1. LTE Band 2 (DSI =3) and mmW Band n261 Beam ID 41
2. LTE Band 2 (DSI =3) and mmW Band n260 Beam ID 4

The measured conducted Tx power of LTE and ratio of $\frac{[pointE(t)]^2}{[pointE\_input.power.limit]^2}$ of mmW is converted into 1gSAR and $4cm^2$PD value, respectively, using Eq. (4a) and (4b), rewritten below:

$$1g\_or\_10gSAR(t) = \frac{conducted\_Tx\_power(t)}{conducted\_Tx\_power\_P_{limit}} * 1g\_or\_10gSAR\_P_{limit} \quad (4a)$$

$$4cm^2PD(t) = \frac{[pointE(t)]^2}{[pointE\_input.power.limit]^2} * 4cm^2PD\_input.power.limit \quad (4b)$$

$$\frac{\frac{1}{T_{SAR}}\int_{t-T_{SAR}}^{t} 1g\_or\_10gSAR(t)dt}{FCC\ SAR\ limit} + \frac{\frac{1}{T_{PD}}\int_{t-T_{PD}}^{t} 4cm^2PD(t)dt}{FCC\ 4cm^2PD\ limit} \le 1 \qquad (4c)$$

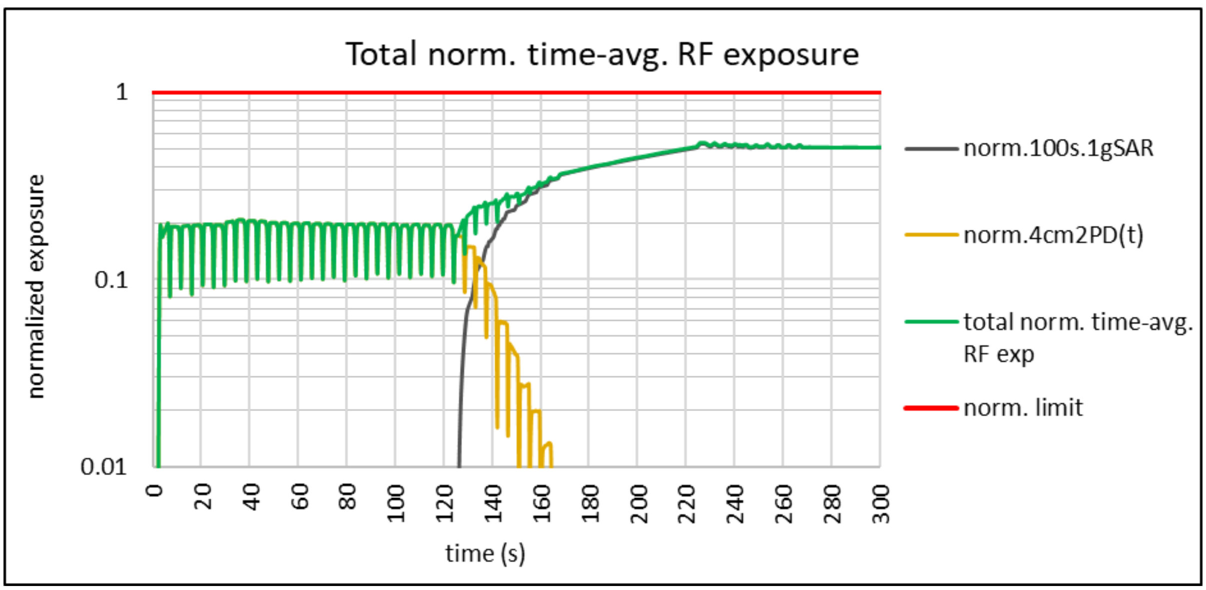
where, $conducted\_Tx\_power(t)$, $conducted\_Tx\_power\_P_{limit}$, and $1g\_or\_10gSAR\_P_{limit}$ correspond to the measured instantaneous conducted Tx power, measured conducted Tx power at P_{limit}, and measured 1gSAR or 10gSAR values at P_{limit} corresponding to LTE transmission. Similarly, $pointE(t)$, $pointE\_input.power.limit$, and $4cm^2PD@input.power.limit$ correspond to the measured instantaneous E-field, E-field at *input.power.limit*, and $4cm^2$PD value at *input.power.limit*. corresponding to mmW transmission.

NOTE: cDASY6 system measures relative E-field, and provides ratio of $\frac{[pointE(t)]^2}{[pointE\_input.power.limit]^2}$ versus time. See Appendix D for measurement details.

The radio configurations tested are described in Table 5-3 and 5-4. The 1gSAR at P_{limit} for LTE B2 DSI = 3, the measured $4cm^2$PD at *input.power.limit* of mmW n261 beam 41 and n260 beam 4, are all listed in Table 8-1.

9.2.1 PD test results for n261

Step 2.e plot (in Section 4.4) for normalized instantaneous and time-averaged exposures for LTE and mmW n261 beam 41:



FCC limit for total RF exposure (normalized)	1.0
Max total normalized time-averaged RF exposure (green curve)	0.536
Validated	

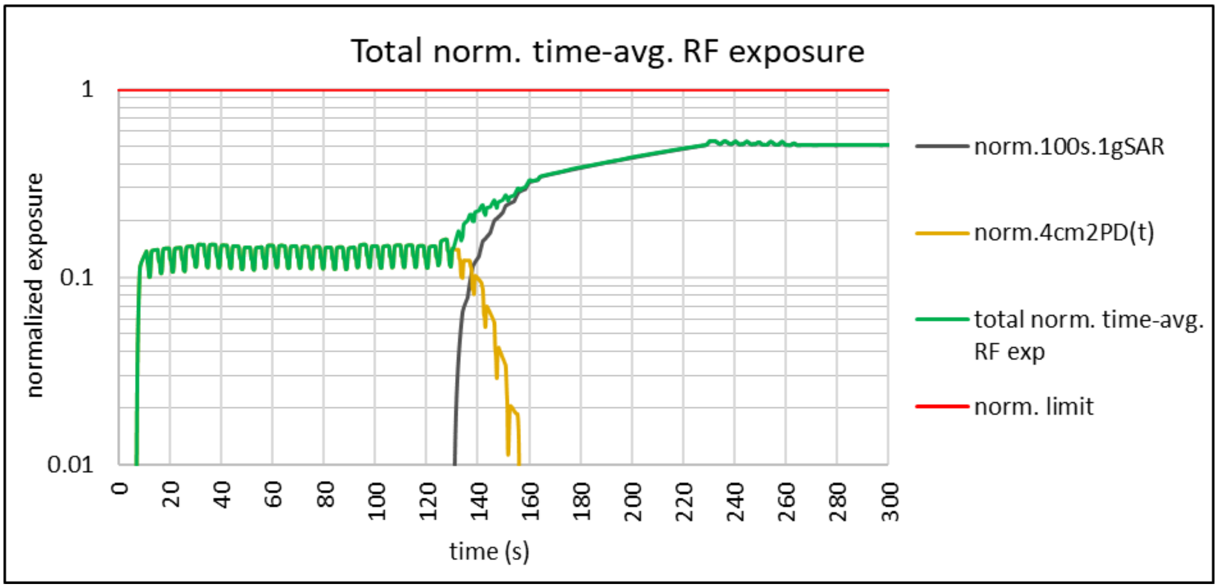
Plot notes: LTE was placed in all-down bits immediately after 5G mmW NR call was established. Between 5s~125s, mmW exposure is the dominant contributor. Here, Smart Transmit algorithm allocates a maximum of 75% for mmW (based on the 3dB reserve setting in Part 1 report). From Table 8-1, this corresponds to a normalized $4cm^2$PD exposure value for Beam ID 41 of (75% *

2.64 W/m^2)/(10 W/m^2) = 19.8% ± 2.4dB device related uncertainty (see orange/green curve between 10s~120s). Around 120s time mark, LTE is set to all-up bits, taking away margin from mmW exposure gradually. Towards the end of the test, LTE is the dominant contributor towards RF exposure, i.e., corresponding normalized 1gSAR exposure value of (100% * 0.84 W/kg)/(1.6 W/kg) = 52.5% ± 1dB design related uncertainty (see black curves approaching this level towards end of the test).

As can be seen, the power limiting enforcement is effective and the total normalized time-averaged RF exposure does not exceed 1.0. Therefore, Qualcomm® Smart Transmit time averaging algorithm is validated.

9.2.2 PD test results for n260

Step 2.e plot (in Section4.4) for normalized instantaneous and time-averaged exposures for LTE and mmW n260 beam 4:



FCC limit for total RF exposure	1.0
Max total normalized time-averaged RF exposure (green curve)	0.531
Validated	

Plot notes: LTE was placed in all-down bits immediately after 5G mmW NR call was established. Between 10s~130s, mmW exposure is the dominant contributor. Here, Smart Transmit algorithm allocates a maximum of 75% for mmW (based on the 3dB reserve setting in Part 1 report). From Table 8-1, this corresponds to a normalized 4cm^{2}PD exposure value for Beam ID 4 of (75% * 1.76 W/m^2)/(10 W/m^2) = 13.2% ± 2.4dB device related uncertainty (see orange/green curve between 10s~130s). Around 130s time mark, LTE is set to all-up bits, taking away margin from mmW exposure gradually. Towards the end of the test, LTE is the dominant contributor towards RF exposure, i.e., corresponding normalized 1gSAR exposure value of (100% * 0.84 W/kg)/(1.6 W/kg) = 52.5% ± 1dB design related uncertainty (see black curves approaching this level towards end of the test).

As can be seen, the power limiting enforcement is effective and the total normalized time-averaged RF exposure does not exceed 1.0. Therefore, Qualcomm® Smart Transmit time averaging algorithm is validated

10 Conclusions

Qualcomm Smart Transmit feature employed in Samsung portable handset (FCC ID: A3LSMN976V) has been validated through the conducted/radiated power measurement (as demonstrated in Chapters 6 and 8), as well as SAR and PD measurement (as demonstrated in Chapters 7 and 9).

As demonstrated in this report, the power limiting enforcement is effective and the total normalized time-averaged RF exposure does not exceed 1.0 for all the transmission scenarios described in Section 2. Therefore, the EUT complies with FCC RF exposure requirement.

A Test Sequences

1. Test sequence is generated based on below parameters of the EUT:
   a. Measured maximum power (P_{max})
   b. Measured Tx_power_at_SAR_design_target (P_{limit})
   c. Reserve_power_margin (dB)
      - $P_{reserve}$ (dBm) = measured P_{limit} (dBm) – Reserve_power_margin (dB)
   d. *SAR_time_window* (100s for FCC)
2. Test Sequence 1 Waveform:

   Based on the parameters above, the Test Sequence 1 is generated with one transition between high and low Tx powers. Here, high power = P_{max}; low power = $P_{max}/2$, and the transition occurs after 80 seconds at high power P_{max}. This 80s duration makes sure that EUT is enforced to limit power first before the transition from high (P_{max}) to low ($P_{max}/2$) occurs. If 80s is not long enough for power limiting enforcement (transition) to take place, then the high power duration needs to be increased accordingly. The Test sequence 1 waveform is shown below:

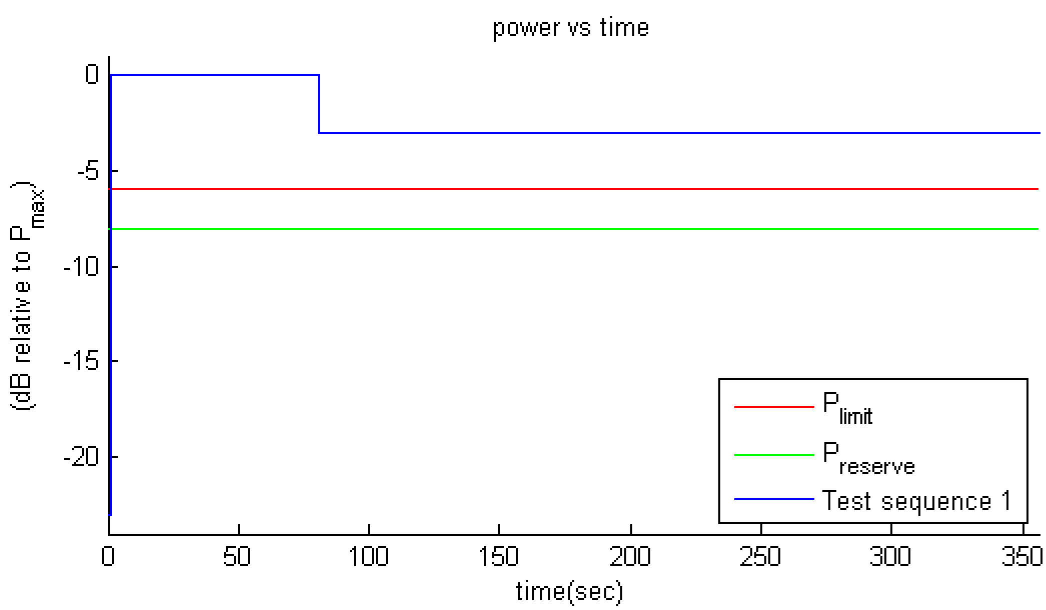


Figure A-1 Test sequence 1 waveform

3. Test Sequence 2 Waveform:

Based on the parameters in A-1, the Test Sequence 2 is generated as described in Table 10-1, which contains two 170 second-long sequences (yellow and green highlighted rows) that are mirrored around the center row of 20s, resulting in a total duration of 360 seconds:

Table A-1 Test Sequence 2

Time duration (seconds)	dB relative to P_{limit} or $P_{reserve}$
15	$P_{reserve}$ – 2
20	P_{limit}
20	(P_{limit} + P_{max})/2 averaged in mW and rounded to nearest 0.1 dB step
10	$P_{reserve}$ – 6
20	P_{max}
15	P_{limit}
15	$P_{reserve}$ – 5
20	P_{max}
10	$P_{reserve}$ – 3
15	P_{limit}
10	$P_{reserve}$ – 4
20	(P_{limit} + P_{max})/2 averaged in mW and rounded to nearest 0.1 dB step
10	$P_{reserve}$ – 4
15	P_{limit}
10	$P_{reserve}$ – 3
20	P_{max}
15	$P_{reserve}$ – 5
15	P_{limit}
20	P_{max}
10	$P_{reserve}$ – 6
20	(P_{limit} + P_{max})/2 averaged in mW and rounded to nearest 0.1 dB step
20	P_{limit}
15	$P_{reserve}$ – 2

The Test Sequence 2 waveform is shown in Figure A-2.

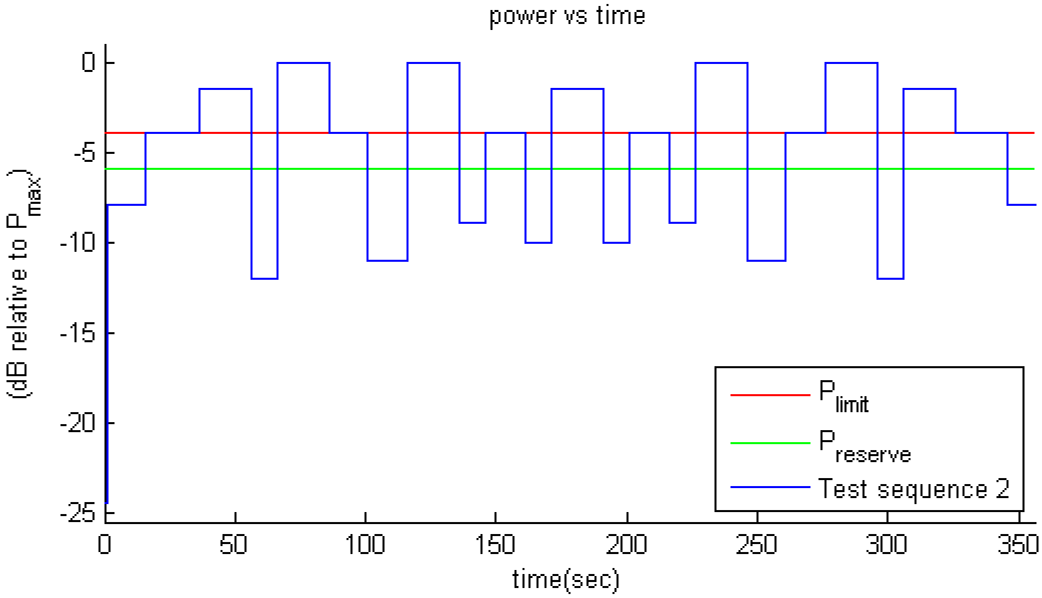


Figure A-2 Test Sequence 2 waveform

B Test Procedure for Calibrating Setup Loss Between Callbox and EUT Positioned Against Flat Section of SAM Phantom

Path loss estimation and callbox setup for time-averaged SAR measurement is described in this appendix.

The purpose for this setup is to have enough dynamic range for time-averaging SAR measurement, otherwise if path loss between callbox and EUT is set too low (or too high) on the callbox, EUT will transmit at maximum power (or low power) most of time (or all the time) in the time averaging measurement regardless of various Tx power level requests from callbox. Note that the path loss determined here is not for the purpose of Tx power measurement, but to vary the Tx power of EUT corresponding to callbox requests in a radiated call. Therefore, the absolute accuracy of path loss in this estimation is not a concern as long as the estimated path loss setting in the callbox results in varying EUT's Tx power upon request from the callbox.

Prior to estimating the path loss, the EUT should be in call with the callbox in "close loop power control" mode. If using the Rohde & Schwarz CMW500 callbox, Figure B-1 and Figure B-2 show settings for closed loop power control.

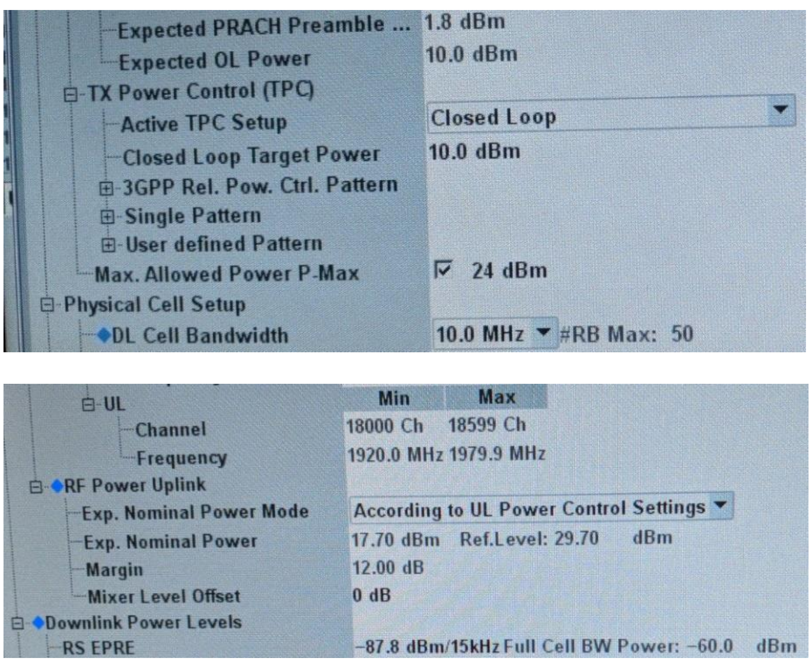


Figure B-1 Configuration settings for LTE technology

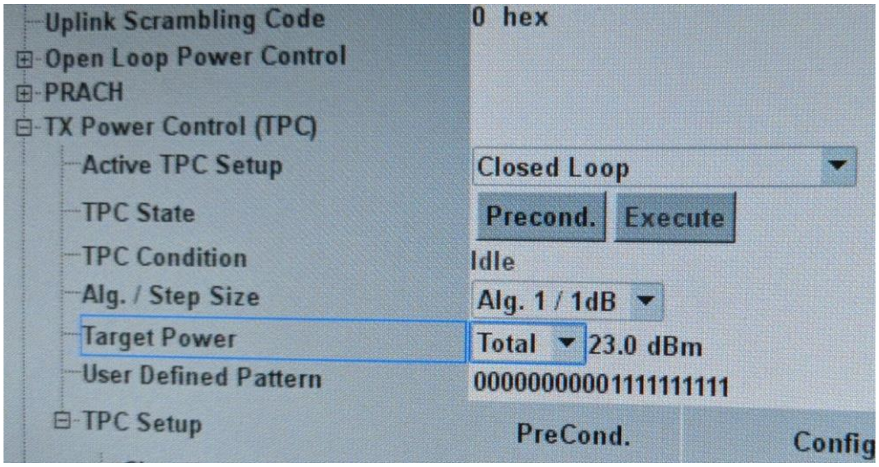


Figure B-2 Configuration setting for WCDMA technology

Path loss between callbox and EUT (positioned against the flat section of the SAM Twin phantom during SAR test) is estimated by adjusting the path loss setting on the callbox (for Rohde & Schwarz CMW500, this setting can be found under “Routing -> External Attenuation” as shown in Figure B-3, where both “External Attenuation (Input)” and “External Attenuation (Output)” settings must be set to the same number).

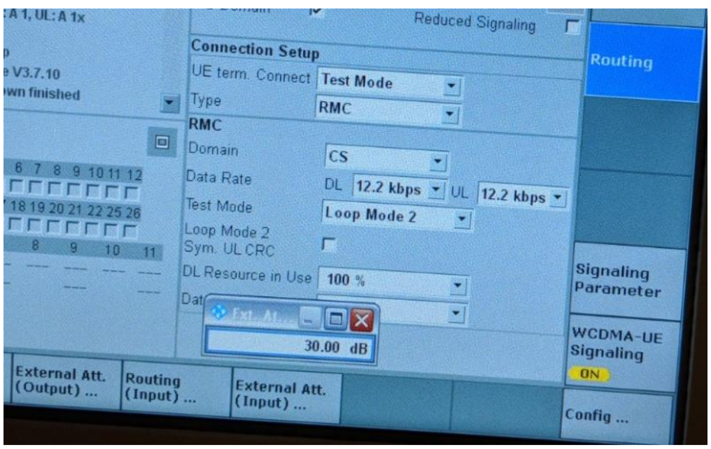


Figure B-3 Settings found under Routing -> External Attenuation

This path loss setting in the callbox is adjusted (highlighted in blue box in Figure B-4) such that the RSSI (received signal strength indicator) by the EUT (found under "UE measurement report" setting in Rohde & Schwarz CMW500 callbox as shown inside red box in Figure B-4) is similar to the requested setting in the callbox (indicated by green box in Figure B-4).

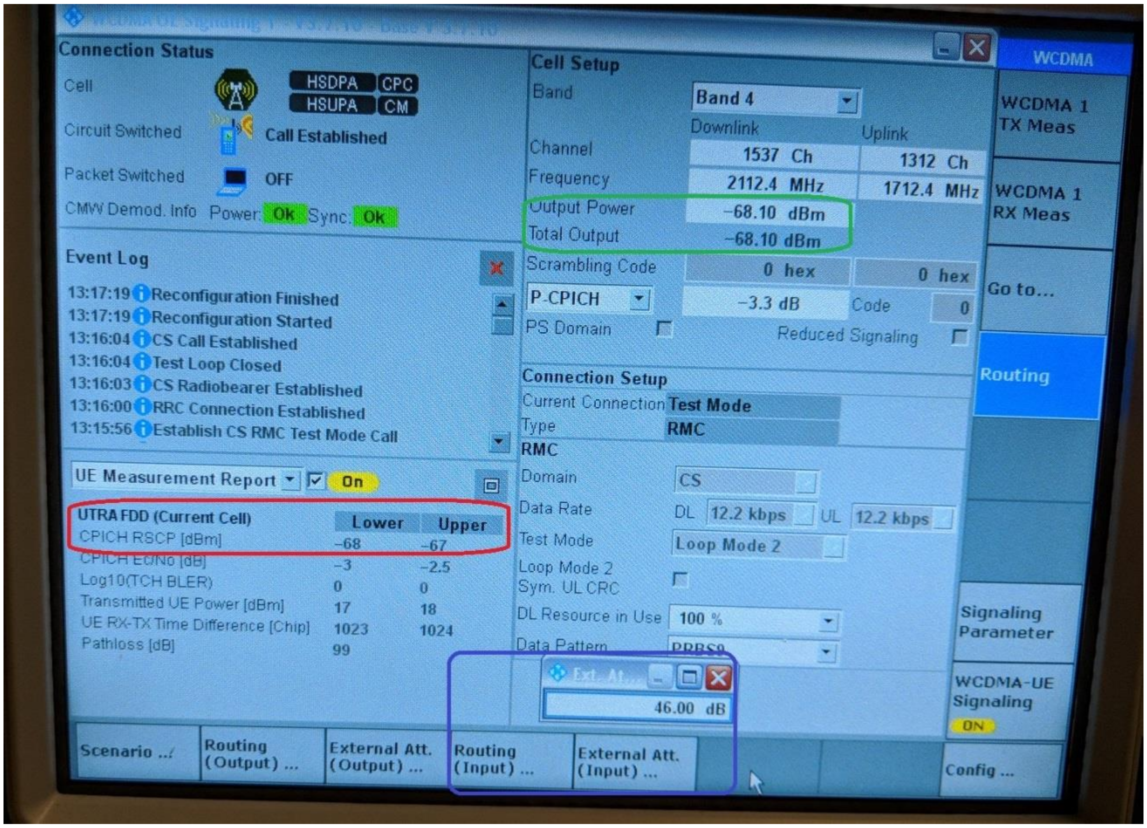


Figure B-4 UE measurement report setting in Rohde & Schwarz CMW500 callbox

By following this procedure thus far, it gives a reasonable estimate for path loss. Additional fine tuning of path loss needs to be done to ensure that EUT's maximum power indicated on the callbox matches with maximum conducted power (P_{max}). Callbox should be set to request maximum power from EUT (in this case, it was set to 30 dBm*, as shown in green box in Figure B-5). The path loss setting (under Routing>External attenuation in Rohde & Schwarz CMW500 callbox) should be further adjusted such that the EUT's power shown on the callbox matches with measured maximum conducted power (meas. P_{max}) for this tech/band. The EUT's power can be found against "UE Tx power" level under "Tx Measurement" tab (as shown in red box in Figure B-5) in Rohde & Schwarz CMW500 callbox.

Figure B-5 Rohde & Schwarz CMW500 callbox settings

NOTE: During path loss calibration, 30 dBm, was intentionally requested in the callbox setting instead of maximum conducted power (P_{max}). This is because the initial estimation of path loss from matching RSSI could still be off by few dB so the EUT might not transmit at maximum power even if indicated so by the UE Tx measurement report in the callbox. Requesting higher power than EUT capable of transmitting (in this case, 30 dBm) during fine tuning of path loss calibration confirms the calibration is accurate if the UE Tx measurement report in callbox corresponds to P_{max} of EUT. Otherwise, UE Tx measurement report will indicate lower reading (if path loss setting is too low) or higher reading than P_{max} (if path loss setting is too high).

C Test Procedure for Time-Averaged SAR Validation Using cDASY6

Test procedures for time-averaged SAR algorithm validation with cDASY6 measurement system:

1. With Smart Transmit enabled and *Reserve_power_margin* set to 0 dB, establish radio link with a callbox in desired operational technology, band and channel
2. In cDASY6, enable checkbox for time-averaged SAR measurement option (this is equivalent to multimeter option in DASY5) after Area Scan in Measurement Setup settings (see Figure C-1), and set the duration of the scan to 500s (greater than duration of test sequence in the "Scan Duration" field).

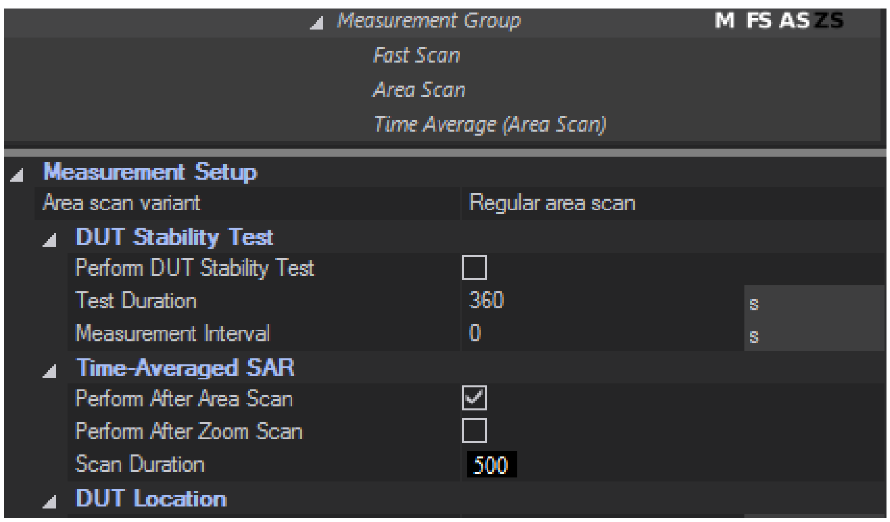
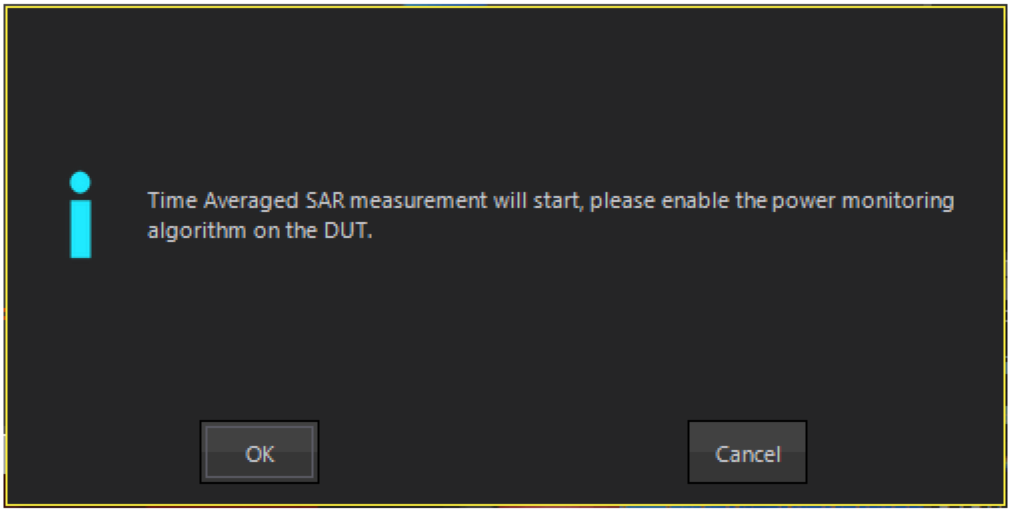


Figure C-1 cDASY6 system measurement setup

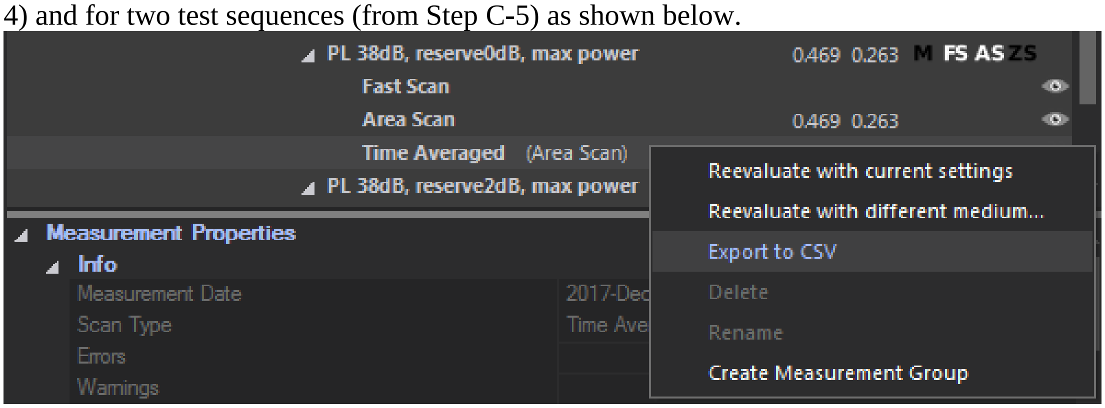
3. Perform path loss calibration as described in Appendix B.
4. Request EUT to transmit at maximum power and perform the area scan. After the area scan, cDASY6 will pause for time-averaged SAR measurement (this is equivalent to multimeter option in DASY5) as shown in below screen shot:



Without changing the *Reserve power margin* setting, continue with performing pointSAR measurements versus time (under "Time-averaged SAR" measurement label in cDASY6) with callbox requesting max power. Wireless device will transmit at P_{limit}, and average of extracted data indicates the pointSAR value corresponding to measured P_{limit}.

After the completion of time-averaged SAR measurement, cDASY6 will pause asking if user would like to perform additional time-average SAR measurements, continue with next step.

5. To measure time-average SAR for test sequences: First, set *Reserve_power_margin* to the actual (intended) value without disturbing the wireless device position relative to the flat section of the SAM Twin phantom. Perform the 2nd time-averaged SAR measurement, resume cDASY6 pointSAR measurement with callbox requesting EUT to transmit Test Sequence1 described in Appendix A. After this step, cDASY6 prompts if user would like to measure additional time-averaged SAR measurement. Resume cDASY to perform 3rd time-averaged SAR measurement with callbox requesting EUT to transmit Test sequence 2 described in Appendix A.
6. Extract pointSAR versus time data from time-averaged SAR measurement at P_{limit} (from Step 4) and for two test sequences (from Step C-5) as shown below.



7. Average of extracted pointSAR data for first time-averaged SAR measurement indicates the pointSAR value corresponding to measured Plimit, i.e., denoted as *pointSAR_Plimit*. Convert the pointSAR data versus time, denoted as *pointSAR(t)*, for the two test sequences into 1gSAR values by using equation (3a), re-written below:

$$1g\_or\_10gSAR(t) = \frac{pointSAR(t)}{pointSAR\_P_{limit}} * 1g\_or\_10gSAR\_P_{limit} \qquad (3a)$$

and by applying the measured worst-case 1gSAR value for each technology/band at P_{limit}.

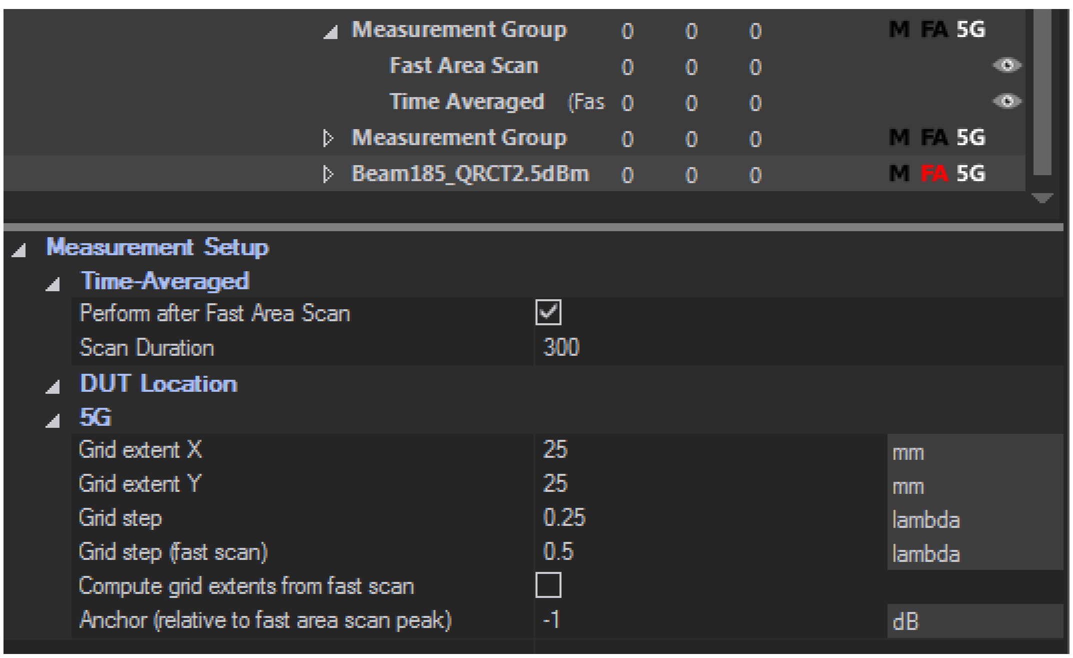
8. For the For Smart Transmit validation, this time-averaged 1gSAR or 10gSAR should be less than the FCC limit of 1.6W/m^2 for 1gSAR and 4.0W/kg for 10gSAR at all times.
9. Repeat Steps 1~6 in this Appendix to complete the validation for all the selected technologies/bands.

Note that during the time-averaging SAR measurements, the entire lab environment surrounding cDASY6 system should be motionless (including the operator) as it would significantly affect the estimated path loss which will result in different EUT response. Since these tests are performed in uncalibrated and uncontrolled wireless environment, the time variation of SAR measurement may not be repeatable. However, Smart Transmit ensures that the time averaged SAR will always comply.

D Test Procedure for Time-Averaged PD Validation Using cDASY6

Test procedures for time-averaged PD algorithm measurement with cDASY6 system:

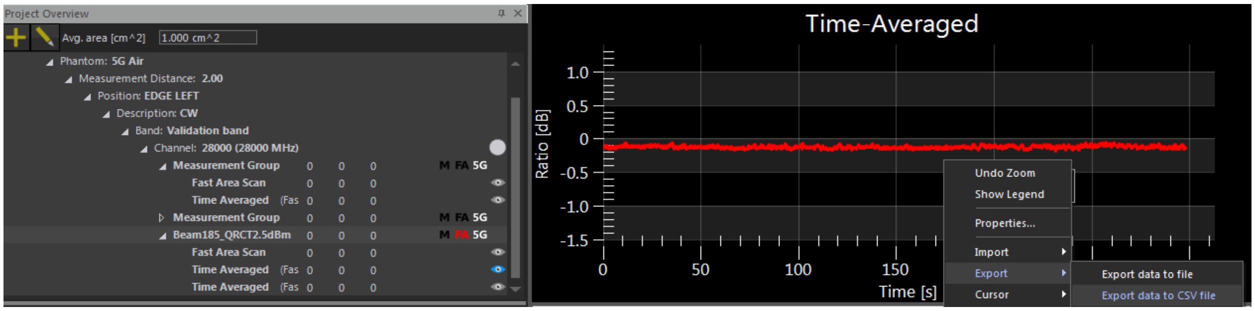
1. Setup the EUT to transmit in the desired band, channel and beam configuration at *input.power.limit*.
2. In cDASY6, enable checkbox for time-averaged measurement option after Fast Area Scan in Measurement Setup settings (see screen capture below), and set the duration of the scan to 300s. Fast area scan quickly scans the area to identify the hotspot location with highest E-field along the polarization of the sensor inside the mmW probe.



3. For tests where the callbox requesting EUT to transmit at maximum power at all times, mmW path loss between EUT and the callbox need not be calibrated.
4. Setup EUT to transmit at *input.power.limit* via Factory Test Mode (FTM) and perform the fast area scan with time-average scan enabled. After the fast area scan, cDASY6 will pause for time-average measurement at the peak location of fast area scan.
5. To measure time-average PD for maximum power test sequences: place EUT in online mode without disturbing the wireless device position relative to the mmW probe. Start the cDASY6 time-averaged measurement and simultaneously start recording LTE conducted Tx power.

Establish mmW call with the callbox requesting maximum power from the EUT in mmW link at all times. After this step, user should click 'no' on the prompt for an additional cDASY6 time-averaged measurements.

6. Extract recorded data (i.e., point E-field data versus time normalized to the E-field at peak location from fast area scan in Step 4) from time-averaged measurement as shown below by first viewing the data in field viewer, and then right-click on the plot to export data in csv format.



7. Exported data is in terms of linear ratios given by $\frac{[pointE(t)]^2}{[pointE\_input.power.limit(t)]^2}$, which indicates the PD value versus time is relative to the 4cm2.PD measured at *input.power.limit*, as given by below equation, i.e.,

$$4cm^2PD(t) = \frac{[pointE(t)]^2}{[pointE\_input.power.limit]^2} * 4cm^2PD\_input.power.limit \quad (4b)$$

where, $\frac{[pointE(t)]^2}{[pointE\_input.power.limit]^2}$ is a ratio between E-field for time-varying mmW Tx power and E-field measured at *input.power.limit*.

E cDASY6 System Validation

E.1 SAR system verification and validation

Table E-1 provides the list of calibrated equipment for SAR measurement system verification.

Table E-1 List of calibrated equipment

Equipment Manufacturer and Type	Serial number	Last Calibrated	Next Calibration
Schmid & Partner Engineering AG Dosimetric E-field Probe, ES3DV4	3618	4/15/2019	4/15/2020
Schmid & Partner Engineering AG dipole validation kit, D2600V2	1159	4/24/2019	4/24/2020
Schmid & Partner Engineering AG dipole validation kit, D1900V2	5d096	12/17/2018	12/17/2019
Schmid & Partner Engineering AG Data Acquisition Electronics, DAE3	400	2/13/2019	2/13/2020
Rohde & Schwarz NR50S Power Sensor	101085	5/6/2019	2/18/2020
Agilent N5230A PNA	MY45000533	1/23/2019	1/23/2020

The system verification was performed using a dipole antenna against the flat section of the SAM phantom. Table E-2 shows the verification test results and the relevant plots are provided in Figure E-1 and Figure E-2. The measured SAR values for the frequency bands of interest were within ±10% of the corresponding target SAR levels.

Table E-2 System validation results

Validation dipole	S/N	Frequency (MHz)	1W Target 1gSAR (mW/g)	Measured 1gSAR scaled to 1W (mW/g)	Deviation (%)	Date
D2600V2	1159	2600	53	50.2	-5.31%	6/15/2019
D1900V2	5d098	1900	39.8	43.6	9.53%	6/17/2019

The broad-band solution MBBL600-6000V6 is used for body tissue-simulating liquid. Table E-3 list the tissue dielectric properties.

Table E-3 Tissue dielectric properties at the time of testing

		Permittivity (ε_r)				Conductivity (σ)			
Test Date	Frequency (MHz)	Measured Values	Target Values	Deviation (%)	Limit	Measured Values	Target Values	Deviation (%)	Limit
6/15/2019	2600	53.73	52.5	2.30%	±10%	2.27	2.16	5.09%	±10
6/17/2019	1900	55.72	53.3	4.30%	±10%	1.59	1.52	4.61%	±10

NOTE: The deviation should be controlled within ±5%. If the deviation is between ±5% to ±10%, the correction will be made in the corresponding SAR result to compensate the additional deviation.

Appendix F provides the calibration certificates for SAR the measurement equipment used in this report.

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Measurement Report

Exposure Conditions

Phantom Section, TSL	Position, Test Distance [mm]	Band	Group, UID	Frequency [MHz], Channel Number	Modulation	TSL Conductivity [S/m]	TSL Permittivity
Flat, MSL	Flat, 1.0 cm	--	0--	1900.0, --	CW	1.59	55.7

Hardware Setup

Phantom	TSL, Measured Date	Probe, Calibration Date	DAE, Calibration Date
Twin-SAM V4.0 (30deg probe tilt) - 209	MBBL-600-6000 Batch: 171204-1, 2019-Jun-17	EX3DV4 - SN3618, 2019-04-15	DAE3 Sn400, 2019-02-13

Scan Setup

	Area Scan	Zoom Scan
Grid Extents [mm]	56.0 x 84.0	30.0 x 30.0 x 30.0
Grid Steps [mm]	14.0 x 14.0	5.0 x 5.0 x 5.0
Sensor Surface [mm]	3.0	1.4

Measurement Results

	Area Scan	Zoom Scan
Date	2019-06-17, 13:59	2019-06-17, 14:05
psSAR1g [W/Kg]	0.428	0.432
psSAR10g [W/Kg]	0.215	0.220
Power Drift [dB]	-0.02	0.03

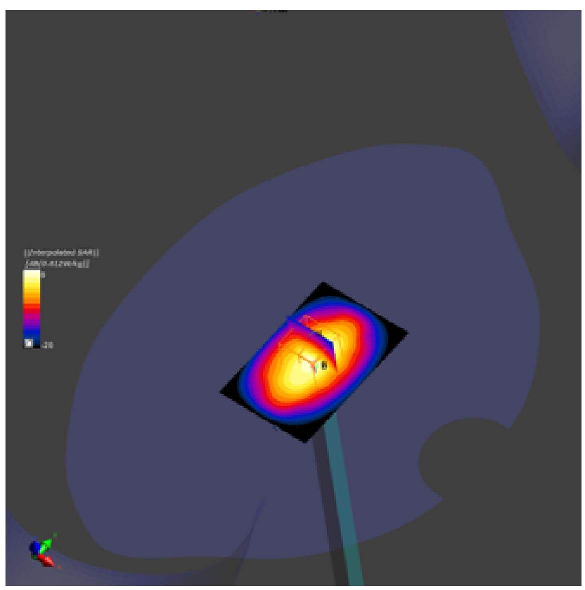


Figure E-1 SAR measurement system verification plot for 1900MHz. Input power = 9.91mW.

QualcommTechnologies Inc.

Measurement Report

Exposure Conditions

Phantom Section, TSL	Position, Test Distance [mm]	Band	Group, UID	Frequency [MHz], Channel Number	Modulation	TSL Conductivity [S/m]	TSL Permittivity
Flat, MSL	Flat, 1.0 cm		0--	2600.0, 0	CW	2.27	53.7

Hardware Setup

Phantom	TSL, Measured Date	Probe, Calibration Date	DAE, Calibration Date
Twin-SAM V4.0 (30deg probe tilt) - 209	MBBL-600-6000 Batch: 171204-1, 2019-Jun-15	EX3DV4 - SN3618, 2019-04-15	DAE3 Sn400, 2019-02-13

Scan Setup

	Area Scan	Zoom Scan
Grid Extents [mm]	48.0 x 96.0	30.0 x 30.0 x 30.0
Grid Steps [mm]	12.0 x 12.0	5.0 x 5.0 x 5.0
Sensor Surface [mm]	3.0	1.4

Measurement Results

	Area Scan	Zoom Scan
Date	2019-06-15, 10:55	2019-06-15, 11:00
psSAR1g [W/Kg]	0.594	0.546
psSAR10g [W/Kg]	0.261	0.243
Power Drift [dB]	-0.03	-0.01

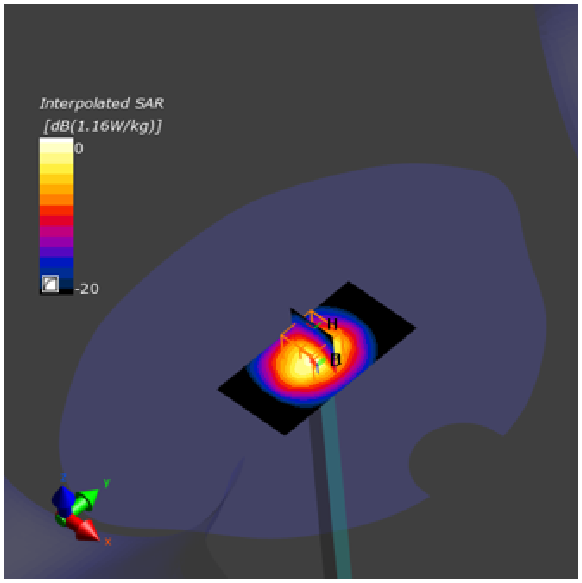


Figure E-2 SAR measurement system verification plot for 2600MHz. Input power = 10.88mW.

E.2 Power density measurement system verification

Table E-4 provides the list of calibrated equipment for power density measurement system verification.

Table E-4 List of calibrated equipment

Equipment Manufacturer and Type	Serial number	Last Calibrated	Next Calibration
Schmid & Partner Engineering AG mm-Wave E-field Probe, EummWV3	9367	9/26/2018	9/26/2019
Schmid & Partner Engineering AG 5G Verification Source 30GHz	1006	5/3/2019	5/3/2020

E.2.1 Power density probe

The novel EUmmWV2 probe is used in the power density measurement. It is designed for precise near-field measurements in the mm-wave range by SPEAG. The specifications are:

- Frequency range: 0.75 ~ 110 GHz
- Dynamic range: <50 – 3000 V/m (up to 10000 V/m with additional PRE-10 voltage divider)
- Linearity: < ± 0.2 dB
- Supports sensor model calibration (SMC)
- ISO17025 accredited calibration

E.2.2 Power density system verification

The power density system verification is performed using the SPEAG verification device. It consists of a ka-band horn antenna with a corresponding gun oscillator packaged within a cube-shaped housing.

The specification of the verification device is

- Calibrated frequency: 30 GHz at 10 mm from the case surface
- Frequency accuracy: ± 100 MHz
- E-field polarization: linear
- Harmonics: -20 dBc (typ)
- Total radiated power: 14 dBm (typ)
- Power stability: 0.05 dB
- Power consumption: 5 W (max)
- Size: 100 × 100 × 100 mm
- Weight: 1 kg

Table E-5 shows the verification test results. The measured power density (PD) value is within 0.6dB of target level. Note that the uncertainty of 5G verification source is 1.28dB (k=2).

Table E-5 System validation results

Validation kit	S/N	Frequency (GHz)	14dBm Target PD (W/m^2)	14dBm Meas. PD (W/m^2)	Deviation (dB)	Test Date
Ka-band source	1006	30	40.8 (4cm^2)	41.8 (4cm^2)	0.11dB (4cm^2)	6/12/2019
Ka-band source	1006	30	40.8 (4cm^2)	46.6 (4cm^2)	0.58dB (4cm^2)	6/13/2019
Ka-band source	1006	30	40.8 (4cm^2)	41.6 (4cm^2)	0.08dB (4cm^2)	6/14/2019

Scan Setup

Scan Type	5G Scan
Grid Extents [mm]	60 x 60
Grid Steps [lambda]	0.25 x 0.25
Sensor Surface [mm]	5.55

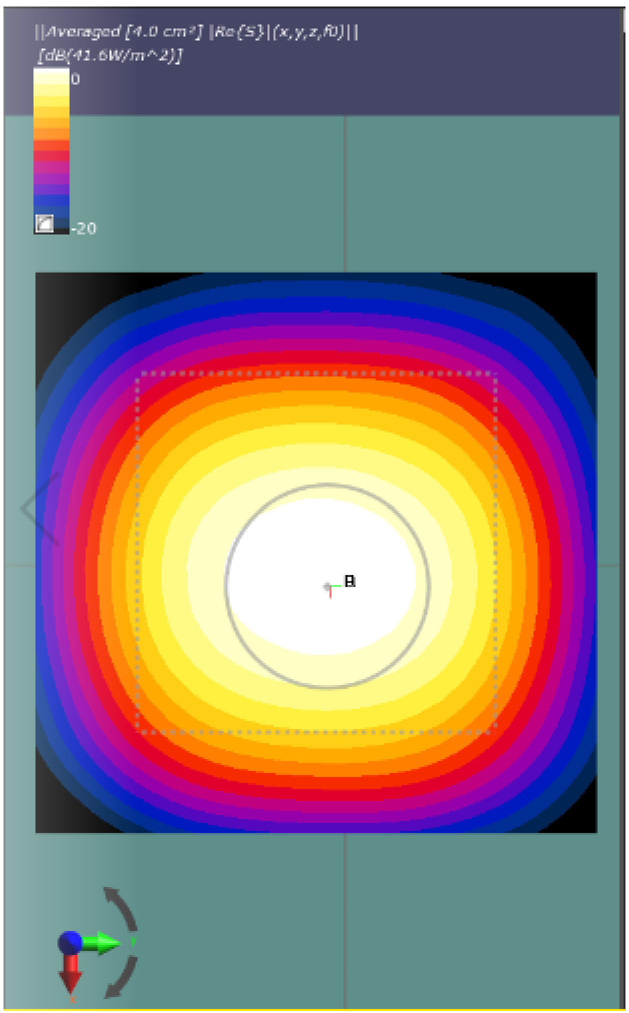
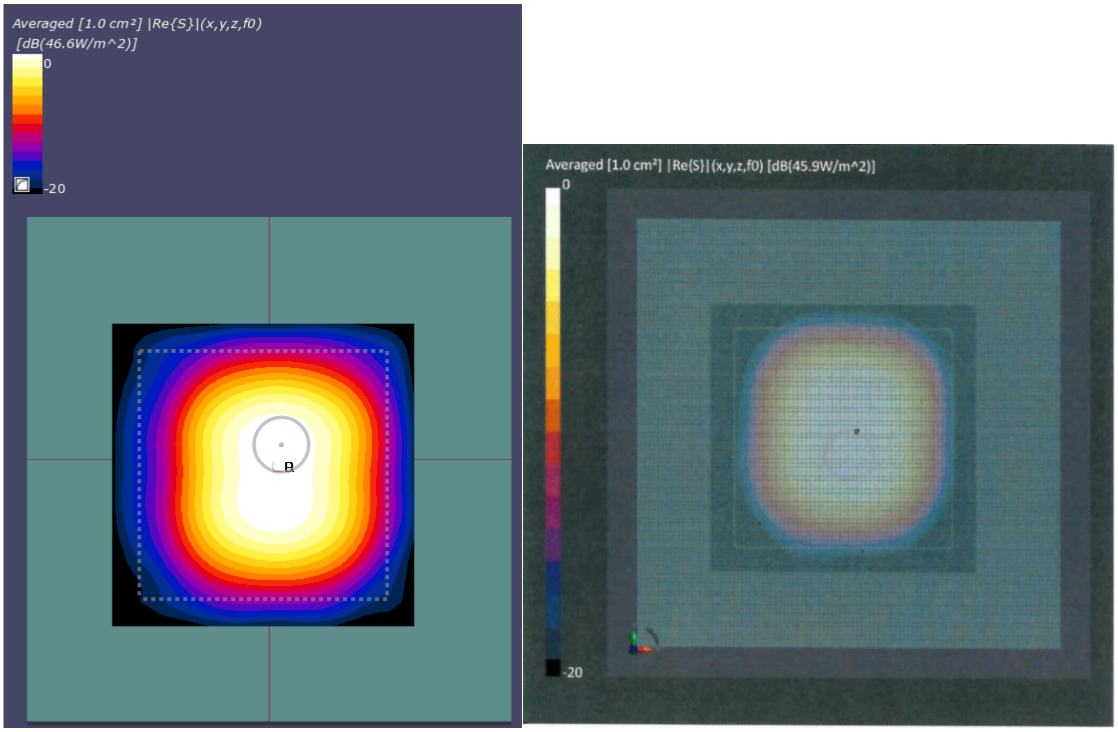


Figure E-3 4cm^{2}PD for source validation on 6/14/2019

Figure E-4 provides the side by side 1cm2 PD distributions of Qualcomm validation performed on 6/24/2019 and SPEAG 5G verification source 30GHz (SN: 1006) calibration plot.



(a) (b)

Figure E-4 1cm2 PD distributions: (a) Qualcomm validation performed on 6/24/2019; (b) SPEAG 5G verification source 30GHz – SN:1006 calibration plot for 1cm2 averaged PD.

Appendix F provides the calibration certificates for SAR the measurement equipment used in this report.

F SPEAG Certificates of cDASY6 SAR Probe, DAE, Dipole, mmW Probe and mmW Verification Source