FCC 47 CFR § 2.1093

RF EXPOSURE EVALUATION REPORT
(TAS validation Report)

FOR

GSM/WCDMA/LTE/5G NR Phone + BT/BLE, DTS/UNII a/b/g/n/ac/ax, and NFC

MODEL NUMBER: SM-A546V

FCC ID: A3LSMA546V

REPORT NUMBER: 4790632299-S1V1

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Prepared for

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TL-637

Revision History

Rev.	Date	Revisions	Revised By
V1	1/19/2023	Initial Issue	--

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Attestation of Test Results

Applicant Name	SAMSUNG ELECTRONICS CO.,LTD.
FCC ID	A3LSMA546V
Model Number	SM-A546V
Applicable Standards	FCC 47 CFR § 2.1093
Date Tested	1/4/2023 to 1/19/2023
Test Results	Pass

UL Korea, Ltd. tested the above equipment in accordance with the requirements set forth in the above standards. All indications of Pass/Fail in this report are opinions expressed by UL Korea, Ltd. based on interpretations and/or observations of test results. Measurement Uncertainties were not taken into account and are published for informational purposes only. The test results show that the equipment tested is capable of demonstrating compliance with the requirements as documented in this report.

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Approved & Released By:	Prepared By:
	
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1. Introduction

The equipment under test (EUT) is SM-A546V (FCC ID : A3LSMA546V), it contains S.LSI chipset supporting 4G/5G NR Sub6 technologies and 5G NR mmW. these chipsets are enabled with Samsung S.LSI proprietary TAS (Time Average SAR) algorithm has been designed to meet the compliance limits over the required duration, while still allowing dynamic control of transmit power for meeting system performance.

This document consists of TAS algorithm description, algorithm parameters, validation methodology, test cases, test procedures and test results. In order to demonstrate that TAS algorithm meets FCC requirements for SAR/PD exposure.

2. Tx Varying Transmission Test Cases and Test Proposal

The following scenarios are covered in this report to demonstrate compliance with FCC RF exposure in Tx varying transmission conditions.

1. During a time-varying Tx power transmission – to prove that TAS feature accounts for Tx power variations in time accurately.
2. During a call disconnect and re-establish scenario – to prove that the TAS feature accounts for history of Tx power from past accurately.
3. During a technology/band handover – to prove that TAS feature accounts for history across transitions in band/technology.
4. During RSI (Radio SAR index) change – to prove that TAS feature functions correctly to meet compliance limits across RSI changes.
5. During time averaging window change – to prove that TAS feature properly handles the change from one time averaging window to another as specified by FCC, and meets the normalized FCC limit of 1.0 at all time.
6. During SAR exposure switch – to prove that TAS feature accounts for history across transitions in ENDC power sharing.
7. During TAS to non TAS Handover – to prove that TAS feature properly handles the change from TAS support band to non TAS support band.

As described in linearity analysis in SAR/PD characterization report, the RF exposure is proportional to the Tx power for both FR1(2G/3G/LTE/NR Sub6) and FR2(NR mmW). Thus, we rely on conducted power measurements (FR1) and radiated power measurements (FR2) in each dynamic case to demonstrate that overall RF exposure is within the FCC limit. The overall procedure for validating the test is summarized below:

1. Measure conducted power (FR1) over time , denoted as $TxPower(t)$, and radiated power EIRP (FR2) over time, denoted $EIRP(t)$, with time index t

2. Convert measured powers to RF exposure values using linear relationship shown below. In below expression, $Plimit,FR1$ would be the measured power at which FR1 technology meets measured SAR level of SAR_design_target. Similarly, $Plimit,FR2$ would be the measured EIRP at which FR2 technology meets measured PD level of PD$_design_target$.

$$SAR(t) = \frac{TxPower(t)}{P_{limit,FR1}} \times SAR\_design\_target \quad \text{(equation : 2.1)}$$

$$PD(t) = \frac{EIRP(t)}{P_{limit,FR2}} \times PD\_design\_target \quad \text{(equation : 2.2)}$$

3. Compute the average RF exposure over the most recent measurement duration which are denoted as $TSAR$ and TPD for FR1 and FR2, respectively. These durations are as specified by FCC. This measurement duration interval is then given by [$t - TSAR$, t] and [$t - TPD$, t] for FR1 and FR2, respectively

4. Divide the RF exposure for FR1 and FR2 by corresponding FCC limits and ensure the sum denoted as TER (total exposure ratio) is less than 1 for all t. Please refer following to following equations which describe the calculation of TER and its target constraint. The expressions below is general considering a number of FR1 and FR2 radios in general denoted by $LSAR$ and LPD .

- For FR1 transmissions only:

$$\sum_{l_{SAR}=0}^{L_{SAR}-1} \frac{\frac{1}{T_{SAR}} \int_{t-T_{SAR}}^{t} SAR_{l_{SAR}}}{FCC\ \ SAR_{limit}} \leq 1 \quad \text{(equation : 2.3)}$$

- For sub-6 mmWave transmission:

$$\sum_{l_{SAR}=0}^{L_{SAR}-1} \frac{\frac{1}{T_{SAR}} \int_{t-T_{SAR}}^{t} SAR_{l_{SAR}}}{FCC\ \ SAR_{limit}} + \sum_{l_{PD}=0}^{L_{PD}-1} \frac{\frac{1}{T_{PD}} \int_{t-T_{PD}}^{t} PD_{l_{PD}}}{FCC\ \ PD_{limit}} \leq 1 \quad \text{(equation : 2.4)}$$

3. SAR Time Averaging Validation Test Procedures

In this section, we cover the test plan and test procedure for validating Samsung S.LSI TAS feature for FR1(2G/3G/LTE/NR Sub6) scenarios.

3.1. Test sequence determination for validation

Two sequences for time varying Tx power are pre-defined as given below for FR1 case.

1. Test Sequence A is generated with two power levels. One is maximum power level Pmax and the other is lower power level. The lower power level is defined as 3dB lower value than maximum power level. At first, maximum power level is applied for 100 seconds ($1.0 * TSAR$). After this, lower power level is used until this test is finished.

2. Test Sequence B is generated at multiple power levels that are specified in the Appendix as a function of Pmax and Plimit.

3.2. Test configuration selection criteria for validating TAS

This section provides general guidance for selecting test cases in TAS feature validation. Modifications of the test cases are possible to study other specific scenarios.

3.2.1 Test configuration selection for time-varying Tx power transmission

The Samsung S.LSI TAS algorithm is independent of band, modes or channel of any technology. Hence, we can validate using one or two combinations of band/mode/channel per technology. The criteria for selecting these would be based on the relative value of Plimit and Pmax. Essentially, we need to pick this combination such that Plimit is less than Pmax so that the TAS algorithm will enforce power restriction. Two bands can be selected to different values of Plimit - one corresponding to lowest value and another being highest but still less than Pmax.

3.2.2 Test configuration selection for change in call

The criteria to select the technology/band for transition between call setup and call drop is to choose the one with least Plimit. The test is performed with DUT requested power at Pmax so that the Samsung S.LSI TAS feature enforces power restriction for longest duration. The call change is performed when the DUT is operating with restricted power. One such test is sufficient since behavior is not dependent on band/technology.

3.2.3 Test configuration for change in technology/Band/window

FCC specifies different measurement durations for time averaging based on operating frequency. The change of operating frequency can result in change of time window for averaging, for e.g. change from 100s averaging for frequency below 3GHz to 60s averaging for frequency above 3GHz in FR1. The criteria for selecting test case to demonstrate compliance across time window change is to pick a technology/band corresponding to each time window such that Plimit is less than Pmax.

3.2.4 Test configuration for change in RSI (Radio SAR Index)

The criteria for selecting test case to demonstrate compliance across RSI change within a radio. The two RSI states are chosen by pick a technology/band such that Plimit is less than Pmax for both states.

3.2.5 Test configuration for SAR exposure switching

The criteria for selecting test case is to pick an LTE band and a NR band with Plimit lower than Pmax in each case. The test is performed with both RATs connected in an EN-DC scenario. In the first portion of the test, DUT is requested to transmit at maximum power for NR and minimum power for LTE. In the second portion of the test, DUT is requested to transmit at maximum power for both NR and LTE. In the final portion of the test, DUT is requested to transmit at minimum power for NR and maximum power for LTE.

3.2.6 Test configuration for TAS to non TAS Handover

This test scenario is similar section 3.2.3. The difference is that one tech support TAS feature and the other tech does not support TAS feature. This test is conducted according to the test procedures provided in Samsung S.LSI.

3.3 Test procedures for conducted power measurements

This section provides general conducted power measurement procedures to perform compliance test under dynamic scenarios described in Section 2.

3.3.1 Time-varying Tx power transmission scenario

This test is performed with two pre-defined test sequences as described in Section 3.1 for all technologies operating on sub-6GHz applying to both LTE and NR as selected in Section 3.2.1. The purpose of the test is to demonstrate the maximum power limiting enforcement and that the time-averaged SAR does not exceed the FCC limit at all times.

Test procedure:

1. Using the Pmax and Plimit, generate the test sequence of power levels for each selected technology/band. Both test sequences A and B are generated. Maximum power can be changed according to DUT test results.

2. Establish the connection of the DUT to the call box in the selected RAT, with the call box requesting the DUT Tx power to be according to the sequence determined in Step 1. An initial value of Tx power will be set to 0dBm for 100s before the desired test sequence starts to help with post-processing of the time-average value with the very first value in the sequence. This is illustrated in the figure below.

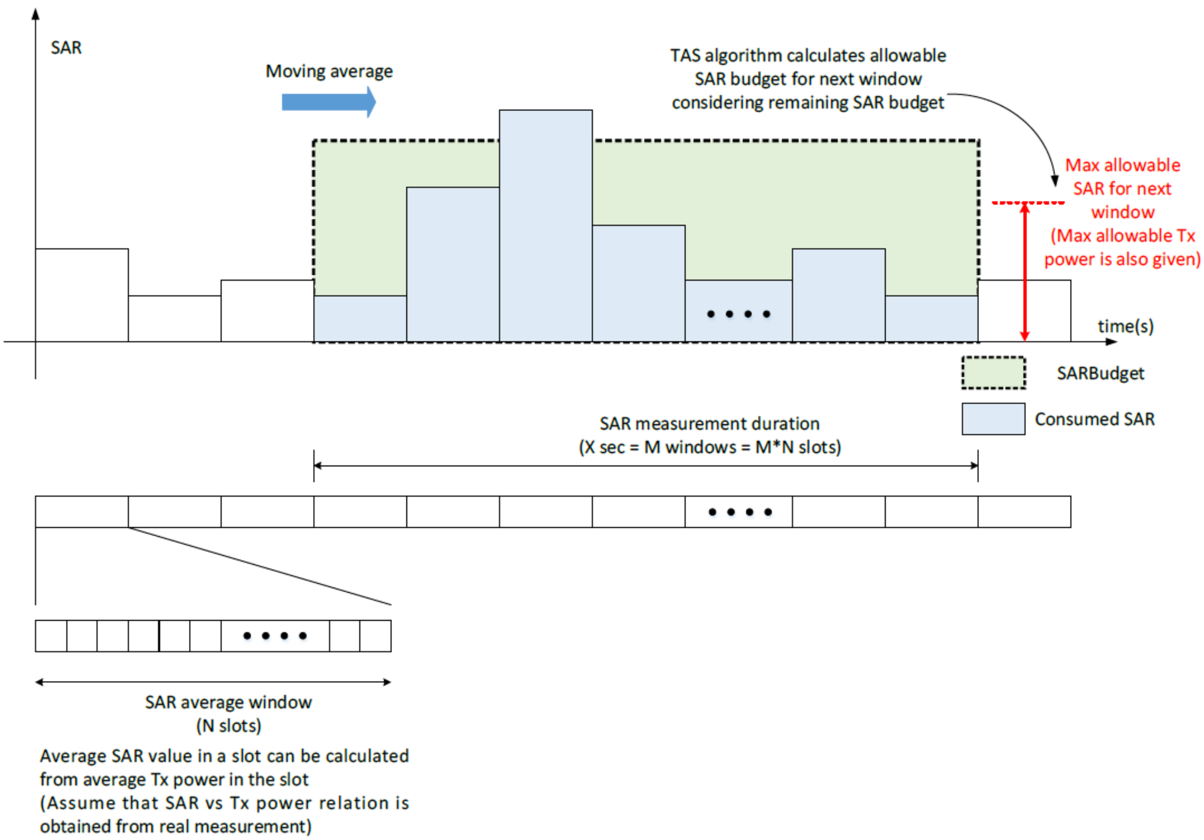


Figure 3.3-1 SAR measurement from Tx power using block-wise processing

3. Release connection

4. After the completion of the test, prepare one plot with the following information;

   a. Instantaneous Tx power versus time measured in Step 2.
   b. Requested Tx power versus time used in Step 2.
   c. Time-averaged power over 100s using instantaneous values from Step 2.
   d. Power level Plimit which is determined as meeting SAR target.

5. Make a second plot containing the following information:
   a. Computed time-averaged 1gSAR versus time determined in Step 2.
   b. FCC 1gSAR limit of 1.6W/kg.

The pass condition is to demonstrate time-averaged 1gSAR versus time shown in Step 5 value versus time does not exceed the FCC limit of 1.6 W/kg throughout the test duration. We would also demonstrate that time-averaged power does not exceed the Plimit at any time in the plot in Step 4.

3.3.2 Change in call scenario

This test is to demonstrate that Samsung S.LSI TAS feature correctly accounts for past Tx powers during time-averaging when a new call is established. The call change has to be carried out when the power limit enforcement is ongoing.

Test procedure:

1. Establish radio connection of DUT with call box e.g. using LTE technology.
2. Configure call box to set DUT Tx power to a low value of -10dBm for 100s.
3. Configure call box to send “ALL UP” power control commands and continue LTE transmission from DUT so that maximum power of Pmax is achieved.
4. After 60s of transmission at Pmax power level, release the call from call box.
5. After 10s, re-establish the LTE connection from call box to DUT and repeat sending “ALL UP” power control command to bring the Tx power to Pmax level again.
6. Continue LTE transmission at Pmax level for another 400s.
7. Release LTE connection.
8. After the completion of the test, prepare one plot with the following information (a) Instantaneous Tx power versus time (b) Requested Tx power versus time (c) Time-averaged power over 100s using instantaneous values and (d) Power level Plimit which is determined as meeting SAR target
9. Make a second plot containing the following information (a) Computed time-averaged 1gSAR versus time and (b) FCC 1gSAR limit of 1.6W/kg

Pass condition is to demonstrate time-averaged 1gSAR value versus time does not exceed the FCC limit of 1.6 W/kg throughout the test duration. It is required to check if SAR calculation is accounting for call drop and connection. Current TAS algorithm software makes the UE estimate the exact amount of Tx power and average SAR even during call drop and call re-establishment event. The UE stores time information when it goes into a sleep mode and wake-up to calculate Tx power on / off duration.

3.3.3 Change in technology/band/window

This test is to demonstrate that Samsung S.LSI TAS feature can properly handle change of technology/band and consequently time window as necessary during handover scenarios. Since both Plimit and window duration can change across bands, we have to use separate equations below for converting Tx power to SAR as well as apply some combined SAR exposure criteria as shown below.

$$SAR_1(t) = \frac{TxPower_1(t)}{P_{limit,1,FR1}} * SAR\_design\_target_1$$ (equation : 3.3.3.1)

$$SAR_2(t) = \frac{TxPower_2(t)}{P_{limit,2,FR1}} * SAR\_design\_target_2$$ (equation : 3.3.3.2)

where $Plimit$,1,FR1 would correspond to measured power at which first technology/band meets measured SAR level of SAR_design_target1 as described in Table 6.2.1 with time-averaging duration of T1,SAR . Similarly, $Plimit$,FR2 would be the measured EIRP at which FR2 technology meets measured PD level of PD_$design_target$ as described in Table 6.2.1. Similarly, the quantities $Plimit$,2,FR1 , SAR_design_target2 , T2,SAR are defined for the second technology/band. When first band is chosen below 3GHz, we would have T1,SAR = 100s, and by choosing second band to be above 3GHz, we would use T2,SAR = 60s. On the other hand, when first band is chosen above 3GHz and second band below 3GHz, we would use T1,SAR = 60s and T1,SAR = 100s.

Test procedure for switching from 100s to 60s and vice-versa :

1. Establish radio connection of DUT with call box e.g. using LTE technology in band A (e.g B2) which has 100s averaging duration.
2. Configure call box to set DUT Tx power to a low value of -10dBm for 160s.
3. Configure call box to send “ALL UP” power control commands and continue LTE transmission From DUT so that maximum power of Pmax is achieved. Continue transmission at the maximum power for at least 140s.
4. Change band from band A (B2) to another LTE band B (e.g. B48), which should correspond to a change in averaging duration from 100s to 60s. Continue call in band B with call box requesting maximum power for at least 200s.
5. Change band from band B(B48) back to the first band A(B2) and continue call at maximum power for at least 120s.
6. Release LTE connection.
7. After the completion of the test, prepare one plot with the following information for each band (a) Instantaneous Tx power versus time (b) Time-averaged power for each band according to their averaging duration and (c) Plimit corresponding to each band.
8. Make a second plot containing the following information (a) Computed time-averaged 1gSAR versus time for each band (b) Sum of time-averaged SAR computed according to Eqn (3.3.3.1) and (3.3.3.2), and (c) FCC 1gSAR limit of 1.6W/kg.

Pass condition is to demonstrate total time-averaged 1gSAR value versus time does not exceed the FCC limit of 1.6 W/kg throughout the test duration. It is required to check if power limiting enforcement is operated as expected when band change occurs in-between.

Test procedure for switching from 60s to 100s and vice-versa :

1. Establish radio connection of DUT with call box e.g. using LTE technology in band B (B48) which has 60s averaging duration.
2. Configure call box to set DUT Tx power to a low value of -10dBm for 160s.
3. Configure call box to send “ALL UP” power control commands and continue LTE transmission from DUT so that maximum power of Pmax is achieved. Continue transmission at the maximum power for at least 140s.
4. Change band from band B (B48) to another LTE band A (B2), which should correspond to a change in averaging duration from 60s to 100s. Continue call in band A with call box requesting maximum power for at least 120s
5. Change band from band A(B2) back to the first band B(B48) and continue call at maximum power for at least 180s.
6. Release LTE connection
7. After the completion of the test, prepare one plot with the following information for each band (a) Instantaneous Tx power versus time (b) Time-averaged power for each band according to their averaging duration and (c) Plimit corresponding to each band
8. Make a second plot containing the following information (a) Computed time-averaged 1gSAR versus time for each band (b) Sum of time-averaged SAR computed according to Eqn (3.3.3.1) and (3.3.3.2), and (c) FCC 1gSAR limit of 1.6W/kg.

Pass condition is to demonstrate total time-averaged 1gSAR value versus time does not exceed the FCC limit of 1.6 W/kg throughout the test duration. It is required to check if power limiting enforcement is operated as expected when band change occurs in-between.

3.3.4 Change in RSI (Radio SAR Index)

This test is to demonstrate that Samsung S.LSI TAS feature can properly handle change of RSI resulting from different SAR index state detected by host platform software. It involves changing the Plimit value during the test for the same technology to emulate RSI change, while the SAR_design_target remains the same. Note that the DUT has a proximity sensor to manage extremity exposure, which is represented using RSI (number = related proximity senor scenario) ; the head exposure can be distinguished through audio receiver mode, represented as RSI (number = related head exposure scenario); similarly, the body worn with 15mm distance exposure is represented as RSI (number = related head exposure scenario); the other exposure would be updated and defined as other RSI numbers.

Test procedure :

1. Establish radio connection of DUT with call box.
2. Configure DUT to send at low Tx power of 0dBm for 110s and set the RSI index corresponding to Plimit.
3. Configure call box to send “ALL UP” power control commands and continue transmission from DUT so that maximum power of Pmax is achieved. Continue the transmission for 200s.
4. Change the RSI index corresponding to lower value of (Plimit - 3dB) and continue the transmission for another 300s
5. Release the connection.

Pass condition is to demonstrate time-averaged 1gSAR value versus time does not exceed the FCC limit 1.6 W/kg throughout the test duration. It is required to check if power limiting enforcement is operated as expected when RSI index is changed during the test.

3.3.5 SAR exposure switching

This test is to demonstrate that Samsung S.LSI TAS feature can properly handle change of dominant SAR exposure radio in the case of two simultaneous active RATs. It involves changing the required power of both radios such that either one or both of the RATs becomes dominant contributor to total exposure ratio at different times of the test.

Test procedure :

1. Establish LTE and NR radio connection in NSA case with both call boxes, e.g. LTE band and NR band.
2. Configure the LTE call box to send “ALL DOWN” power control commands for LTE and configure the NR call box to send “ALL UP” power control commands. This would correspond to NR dominant SAR scenario and continue this stage for about 220s.
3. In the second part of test, configure the LTE call box to sent “ ALL UP” power control commands and all transmissions are continued, resulting in maximum power requested from DUT for both LTE and NR. This stage of test is continued for another 110s.
4. In the third part of test, configure the NR call box to send “ALL DOWN” power control commands so that LTE becomes the dominant SAR radio. This stage is continued for another 110s.
5. Finally, both LTE and NR connections are released.

3.3.6 Change in TAS to non TAS Handover

This test is to demonstrate that Samsung S.LSI TAS feature can properly handle change of TAS to non TAS handover scenarios. Since Both Plimits can change across bands, we have to use below equations below for converting Tx power to SAR as well as apply some combined SAR exposure criteria as shown below.

$$SAR_1(t) = \frac{TxPower_1(t)}{P_{limit,1,FR1}} * SAR\_design\_target_1$$ (equation : 3.3.3.1)

$$SAR_2(t) = \frac{TxPower_2(t)}{P_{limit,2,FR1}} * SAR\_design\_target_2$$ (equation : 3.3.3.2)

where $Plimit$,1,FR1 would correspond to measured power at which first supported TAS band meets measured SAR level of SAR_design_target1 as described in Table 6.2.1 with time-averaging duration of T1,SAR . Similarly, the quantities $Plimit$,2,FR1 , SAR_design_target2 , T2,SAR are defined for the second Non-TAS band.

Test procedure for switching from TAS to Non TAS Handover :

1. Establish radio connection of DUT with call box e.g. using TAS technology in band A which has 100s averaging duration.
2. Configure call box to set DUT Tx power to a low value of -10dBm for 110s.
3. Configure call box to send “ALL UP” power control commands and continue TAS technology transmission From DUT so that maximum power of Pmax is achieved. Continue transmission at the maximum power for at least 110s.
4. Change band from TAS technology band A to Non TAS technology band B. Continue call in Non TAS technology band B with call box requesting maximum power for at least 390s..
5. Release WCDMA connection.
6. After the completion of the test, prepare one plot with the following information for each band (a) Instantaneous Tx power versus time (b) Time-averaged power for each band according to their averaging duration and (c) Plimit corresponding to each band.
7. Make a second plot containing the following information (a) Computed time-averaged 1gSAR versus time for each band (b) Sum of time-averaged SAR computed according to Eqn (3.3.3.1) and (3.3.3.2), and (c) FCC 1gSAR limit of 1.6W/kg.

Pass condition is to demonstrate total time-averaged 1gSAR value versus time does not exceed the FCC limit of 1.6 W/kg throughout the test duration. It is required to check if power limiting enforcement is operated as expected when band change occurs in-between.

4. PD Time Averaging Validation Test Procedures

In this section, we cover the test plan and test procedure for validating Samsung S.LSI TAS feature for FR2 scenarios. For this DUT, FR2 transmissions are only in non-standalone mode, so it requires LTE as an anchor, and both SAR for LTE and PD for FR2 will be accounted.

4.1 Test sequence determination for validation

In FR2 transmissions, the test sequence for validation is with the callbox requested maximum power for FR2 at all time.

4.2 Test configuration selection criteria for validating TAS

4.2.1 Test configuration selection for time-varying Tx power transmission

Since the TAS feature is independent of band and beams for a given technology, demonstration with one band will be sufficient.

4.2.2 Test configuration selection for SAR vs PD exposure switch during transmission

The TAS feature works for both types of exposure (SAR or PD) and ensures total time-averaged exposure ratio meets the FCC limit of 1.0. One scenarios of LTE band and FR2 band is sufficient, while exposure condition can be varied between SAR dominant, SAR+PD scenario and PD dominant scenarios for demonstration.

4.2.3 Test configuration selection for change of beam

Since the TAS feature is independent of band and beams for a given technology, demonstration with one pair of beams for switching between them will be sufficient.

4.3 Test procedures for FR2 radiated power measurements

For FR2 testing, we need to perform conducted power measurements for LTE and radiated power measurements for FR2. This section provides general procedures for test setup to validate the compliance in dynamic scenarios outlines in Section 4.

4.3.1 FR2 max power transmission

Test procedure :

1. Set the phone in an anechoic chamber for FR2 radiated transmission. In a non-signaling transmission mode for FR2 at maximum target EIRP, adjust the position of the DUT via rotation within the chamber to obtain the maximum measured radiated EIRP using the fixed test antenna. Keep the DUT in this fixed position for the remainder of the test.
2. Reset the DUT state to normal signaling mode and establish both LTE and FR2 connections with the call box.

3. Immediately send “ALL DOWN” power control commands from LTE call box to send LTE to the lowest transmission power. Next, configure the FR2 call box to send “ALL UP” power control commands to send FR2 radio to maximum EIRP condition. In this case, the FR2 radio will comprise the dominant exposure condition using PD metric.
4. After 120s, configure LTE call box to send “ALL UP” power control commands and continue transmission.
5. Record the conducted power of LTE and radiated EIRP of FR2 radio at all times during the test.
6. After 200s, release LTE and FR2 connection.
7. After the end of the test, convert the instantaneous LTE Tx power into 1gSAR value using Plimit and Eqn (2.1), and then divide by FCC limit of 1.6W/Kg to obtain normalized SAR versus time. Perform 100s time averaging to determine normalized average 1gSAR versus time.
8. Similar to Step 7, convert the instantaneous radiated FR2 EIRP into PD value using Plimit and Eqn (2.2), and then divide by FCC limit of 10W/m^2 for 4cm^2 spatial averaging to obtain instantaneous normalized PD versus time. Perform 4s time averaging to determine normalized average PD versus time.
9. Make one plot containing (a) Instantaneous conducted power for LTE, (b) computed 100s time averaged power for LTE, (c) Instantaneous EIRP for FR2, (d) computed 4s time averaged EIRP for FR2 and (e) Plimit for each of LTE and FR2
10. Make a second plot containing (a) normalized 100s time-averaged SAR for LTE computed in Step 7 (b) normalized 4s time-averaged PD for FR2, (c) TER (Total Exposure Ratio) corresponding total normalized time-averaged RF exposure (using sum of 10(a) and 10(b)) versus time.

Pass condition is to demonstrate that TER is kept under 1.0 throughout the test. This ensures that criteria defined in is met at all times.

4.3.2 SAR vs PD exposure switch during transmission

This test is to ensure that Samsung S.LSI TAS feature works for any nature of exposure (SAR or PD) and accurately accounts for switching among SAR dominant, SAR+PD, and PD dominant scenarios, and ensured total time-averaged RF exposure compliance at all times.

Test procedure :

1. Set the phone in an anechoic chamber for FR2 radiated transmission. In a non-signaling transmission mode for FR2 at maximum target EIRP, adjust the position of the DUT via rotation within the chamber to obtain the maximum measured radiated EIRP using the fixed test antenna. Keep the DUT in this fixed position for the remainder of the test.
2. Reset the DUT state to normal signaling mode and establish both LTE and FR2 connections with the call box.
3. Immediately send “ALL DOWN” power control commands from LTE call box to send LTE to the lowest transmission power. Next, configure the FR2 call box to send “ALL UP” power control commands to send FR2 radio to maximum EIRP condition. In this case, the FR2 radio will comprise the dominant exposure condition using PD metric.
4. After 120s, configure LTE call box to send “ALL UP” power control commands and continue transmission. Now, the RF exposure margin for FR2 should begin to reduce and could cause reduction in EIRP or stopping of FR2 transmissions.

5. After 120s, configure LTE call box to send “ALL DOWN” power control commands and continue transmission. Now, the FR2 radio should begin to obtain more RF exposure margin and start its transmission at higher power again.
6. Record the conducted power of LTE and radiated EIRP of FR2 radio at all times during the test.
7. Release LTE and FR2 connection.
8. After the end of the test, convert the instantaneous LTE Tx power into 1gSAR value using Plimit and (2.1), and then divide by FCC limit of 1.6W/Kg to obtain normalized SAR versus time. Perform 100s time averaging to determine normalized average 1gSAR versus time.
9. Similar to Step 7, convert the instantaneous radiated FR2 EIRP into PD value using Plimit and Eqn(2.2), and then divide by FCC limit of 10W/m^2 for 4cm^2 spatial averaging to obtain instantaneous normalized PD versus time. Perform 4s time averaging to determine normalized average PD versus time.
10. Make one plot containing (a) Instantaneous conducted power for LTE, (b) computed 100s time averaged power for LTE, (c) Instantaneous EIRP for FR2, (d) computed 4s time averaged EIRP for FR2 and (e) Plimit for each of LTE and FR2
11. Make a second plot containing (a) normalized 100s time-averaged SAR for LTE computed in Step 7 (b) normalized 4s time-averaged PD for FR2, (c) TER (Total Exposure Ratio) corresponding total normalized time-averaged RF exposure (using sum of 10(a) and 10(b)) versus time.

Pass condition is to demonstrate that TER is kept under 1.0 throughout the test. This ensures that criteria defined in is met at all times.

4.3.3 Change of beam

This test is to demonstrate that Samsung S.LSI TAS feature can account for change of beam in FR2 and still meet total RF exposure compliance.

Test procedure :

1. Set the phone in an anechoic chamber for FR2 radiated transmission. In a non-signaling transmission mode for FR2 at maximum target EIRP with beam 1, adjust the position of the DUT via rotation within the chamber to obtain the maximum measured radiated EIRP using the fixed test antenna.
2. Reset the DUT state to normal signaling mode and establish both LTE and FR2 connections with the call box.
3. Immediately send “ALL DOWN” power control commands from LTE call box to send LTE to the lowest transmission power. Next, configure the FR2 call box to send “ALL UP” power control commands to send FR2 radio to maximum EIRP condition. In this case, the FR2 radio will comprise the dominant exposure condition using PD metric.
4. After 20s, the test equipment turns the DUT by 90 degrees (horizontal=90, vertical=0) to change best module and correspondingly a beam change.
5. After 20s, the test equipment turns the DUT by 90 degrees (horizontal=270, vertical=0) to change best module again and correspondingly a beam change.
6. Continue the LTE and FR2 transmissions for another 20s
7. Record the conducted power of LTE and radiated EIRP of FR2 radio and per beam at all times during the test.
8. Release LTE and FR2 connection.

9. After the end of the test, convert the instantaneous LTE Tx power into 1gSAR value using Plimit and Eqn (2.1), and then divide by FCC limit of 1.6W/Kg to obtain normalized SAR versus time. Perform 100s time averaging to determine normalized average 1gSAR versus time.
10. Similar to Step 9, convert the instantaneous radiated FR2 EIRP into PD value using Plimit and Eqn (2.2), and then divide by FCC limit of 10W/m^2 for 4cm^2 spatial averaging to obtain instantaneous normalized PD versus time for each beam. Perform 4s time averaging to determine normalized average PD versus time. Note that for each beam, we have to use the corresponding Plimit values before converting to the PD values.
11. Make one plot containing (a) Instantaneous conducted power for LTE, (b) computed 100s time averaged power for LTE, (c) Instantaneous EIRP for FR2 per beam, (d) computed 4s time averaged EIRP for FR2 per beam and (e) Plimit for each of LTE and FR2
12. Make a second plot containing (a) normalized 100s time-averaged SAR for LTE computed in Step 7 (b) normalized 4s time-averaged PD for FR2 per beam, (c) TER (Total Exposure Ratio) corresponding total normalized time-averaged RF exposure (using sum of 12(a) and 12(b)) versus time as computed in left hand side of equation below;

$$\frac{\frac{1}{T_{SAR}}\int_{t-T_{SAR}}^{t} SAR(t')dt'}{FCC\ \ SAR_{limit}} + \frac{\frac{1}{T_{PD}}\int_{t-T_{PD}}^{t} PD_1(t')dt'}{FCC\ \ PD_{limit}} + \frac{\frac{1}{T_{PD}}\int_{t-T_{PD}}^{t} PD_2(t')dt'}{FCC\ \ PD_{limit}} \leq 1 \qquad \text{(equation : 4.3.3.1)}$$

Pass condition is to demonstrate time-averaged 1gSAR value and 4cm2 PD versus time does not exceed the FCC limits of 1.6 W/kg and 10W/m2 throughout the test duration. And TER (Total Exposure Ratio) as in Eqn (4.3.3.1) should be kept under 1.0 throughout the test. It is required to check if power limiting enforcement is operated as expected during the test.

5. Test Configurations

5.1 Test case list for sub-6GHz transmissions

To validate TAS algorithm in various sub-6GHz conditions, the chosen TC (Test Case) list is defined as in Table 5.1.1.

Table 5.1.1 Sub-6GHz TAS validation test case list

No.	Test Scenarios	Test cases	Test configurations
F_TC 01	Time-varying Tx Power transmission	LTE_Time_Varying_Tx_Power_Case_1	Selected two LTE Bands, Test Seq.A
F_TC 02		SA_FR1_Time_Varying_Tx_Power_Case_1	Selected two NR Bands, Test Seq.A
F_TC 03		LTE_Time_Varying_Tx_Power_Case_2	Selected two LTE Bands, Test Seq.B
F_TC 04		SA_FR1_Time_Varying_Tx_Power_Case_2	Selected two NR Bands, Test Seq.B
F_TC 05	Change in call	LTE_Call_Disconnect_Reestablishment	Selected one LTE Band
F_TC 06	Re-selection in call	SA_FR1_to_LTE_RAT_Re-selection	Selected one LTE Band and one NR Band
F_TC 07	Change in band / time window	LTE_Averaging_Time_Window_Change	Switched LTE Band A to LTE Band B
F_TC 08		LTE_Averaging_Time_Window_Change 2	Switched LTE Band B to LTE Band A
F_TC 09	SAR exposure switch	NSA_FR1_Dominant_Power_Switching	Selected one LTE Band and one NR Band
F_TC 13	Change in RSI	SA_FR1_RF_SAR_Index_Change	Selected one NR Band
F_TC 14	TAS to nonTAS H.O.	LTE_to_WCDMA_Hand Over	Selected one LTE Band and one WCDMA Band

5.2 Test case list for LTE+FR2 transmissions

To validate TAS algorithm in scenarios including FR2, the chosen TC (Test Case) list is defined as in Table 5.2.1.

Table 5.2.1 LTE+FR2 TAS validation test case list

No.	Test Scenarios	Test cases	Test configurations
F_TC 10	Time-varying Tx Power transmission	mmWave_Max_Tx_Power	Selected one LTE Band and one NR Band
F_TC 11	SAR exposure Switch	mmWave_Dominant_Power_Switching	Selected one LTE Band and one NR Band
F_TC 12	Change of beam	mmWave_Module_Beam_Change	Selected one LTE Band and one NR Band FR2 Module 0 to 1 switch

6. Conducted Power Test Results for Sub-6 TAS validation

6.1 Measurement set-up

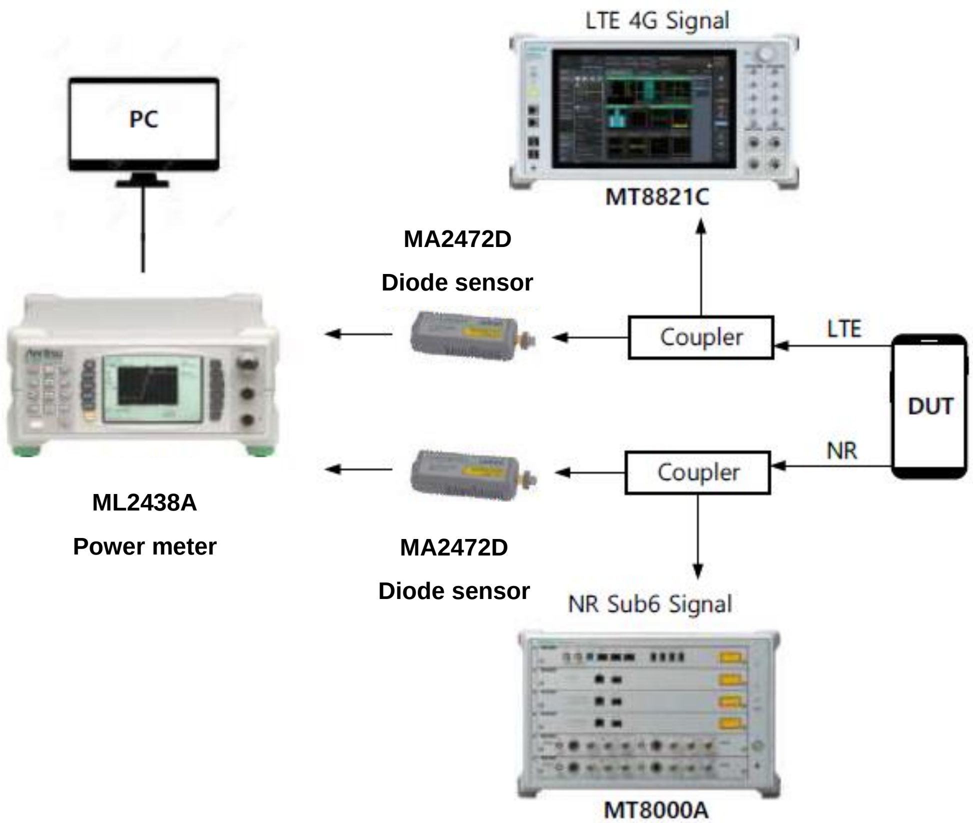


Figure 6.1-1 Test set-up for legacy and sub 6GHz

The test setup for TAS validation with sub-6GHz RATs only is shown in Figure 6.1-1. Normally, a power sensor would measure total power in the entire frequency of its specification e.g. 10MHz to 18GHz for the MA2472D unit. However, when two radios are active, we need to measure their powers separately for using the corresponding SAR mapping table. Therefore, this test setup considers scenarios where two radios would be transmitting from different ports of the DUT so that separate power sensors measure them individually. A common power meter is able to display and record the readings for each sensor at the same time for postprocessing at a PC. The signaling call boxes MT8000A and MT8821C are used to establish the call and data connection to the DUT on those same ports for NR and LTE, respectively. The couplers are able to provide the transmit signal from DUT to power sensors while uplink and downlink signaling messages exchanged with the call boxes on the same paths. We can build scripts to program a certain sequence of power control commands from the call boxes to the DUT which can essentially instruct the DUT to change its transmit power. Thus, if we want DUT to transmit at maximum power in LTE, then continuous power up commands are sent by MT8821C. Similarly, continuous power up commands from MT8000A will try to increase NR power up to its maximum limit. Other power control scenarios which mimic real field behavior such as sequence of power up followed by power down are also possible as described in Section 5.1 and Section 6.1. All the path losses from RF port of DUT to the callbox and the power meters are calibrated and automatically entered as offsets in the callbox and power meter, which are also connected to the control PC used in the test setup. We use an Anritsu AMS tool, which is capable of executing the entire test sequence including requested power variation over time and call setup/disconnect scenarios based on pre-configured test case definition.

Power readings for each active technology are recorded every 100ms and dumped in an excel file. A postprocessing tool is used to extract data from the excel file and plot the required metrics such as time-averaged power, SAR and TER values versus time as described in Section 3.3. In summary, the tests have to be executed as following procedure.

1. Measure conduction sub 6GHz Tx power corresponds to SAR regulation.
2. Set sub 6GHz power level with some margin. And start the test
3. Execute time-varying test scenarios. And record sub 6GHz power using sub 6GHz power meter equipment.
4. Plot the recorded results over measurement time. And evaluate the results for validation.

Note that Plimit is different according to the used OEM, so it is necessary to set the Plimit suitable for each terminal.

6.2 P_{limit} and P_{max} measurement results

The measured $Plimit$ for all the selected radio configurations are listed in Table 6.2.1. $Pmax$ was also measured for radio configurations selected for testing time-varying Tx power transmission scenario in order to generate test sequences following the test procedures. Note that Table 6.2.1 is not actual Plimit corresponding to 1W/kg SAR, but our measured averaged power when forcing Plimit in our SW.

Table 6.2.1 Measured P_{limit} and P_{max} of selected radio configurations

TC #	Test Scenarios	Tech	Band	RSI	RB/offset	Mode	Detail	Plimit setting (dBm)	Pmax setting (dBm)	Measured Plimit (dBm)	Measured Pmax (dBm)
1	Time varying Tx power case (Test Sequence.A)	LTE	B7	3	1/0/20 MHz	QPSK	1g/10mm/Hotspot_Rear	20.00	23.00	20.02	23.30
			B48	4	1/0/20 MHz	QPSK	1g/0mm/Head_Right Touch	17.50	21.00	17.68	21.10
2		FR1	Bn2	3	1/1/40 MHz	DFT-s OFDM QPSK	1g/10mm/Hotspot_Edge 3	22.00	24.00	22.13	24.30
			Bn48	4	1/53/40 MHz	DFT-s OFDM QPSK	1g/0mm/Head_Right Touch	13.00	17.00	13.61	17.06
3	Time varying Tx power case (Test Sequence.B)	LTE	B7	3	1/0/20 MHz	QPSK	1g/10mm/Hotspot_Rear	20.00	23.00	20.02	23.30
			B48	4	1/0/20 MHz	QPSK	1g/0mm/Head_Right Touch	17.50	21.00	17.68	21.10
4		FR1	Bn2	3	1/1/40 MHz	DFT-s OFDM QPSK	1g/10mm/Hotspot_Edge 3	22.00	24.00	22.13	24.30
			Bn48	4	1/53/40 MHz	DFT-s OFDM QPSK	1g/0mm/Head_Right Touch	13.00	17.00	13.61	17.06
5	Change in call (Disconnect-Re-establishment)	LTE	B48	4	1/0/20 MHz	QPSK	1g/0mm/Head_Right Touch	17.50	21.00	17.68	21.10
6	FR1 to LTE IRAT Re-selection	FR1	Bn2	3	1/1/40 MHz	DFT-s OFDM QPSK	1g/10mm/Hotspot_Edge 3	22.00	24.00	22.13	24.30
		LTE	B7	3	1/0/20 MHz	QPSK	1g/10mm/Hotspot_Rear	20.00	23.00	20.02	23.30
7	Window change case 1	LTE	B2	3	1/99/20 MHz	QPSK	1g/10mm/Hotspot_Edge 3	22.00	24.00	21.92	23.98
			B48	3	1/99/20MHz	QPSK	1g/10mm/Hotspot_Edge 4	17.50	21.00	17.68	21.10
8	Window change case 2	LTE	B2	3	1/99/20 MHz	QPSK	1g/10mm/Hotspot_Edge 3	22.00	24.00	21.92	23.98
			B48	3	1/99/20MHz	QPSK	1g/10mm/Hotspot_Edge 4	17.50	21.00	17.68	21.10
9	Switch in SAR exposure (FR1 dominant power change)	NSA FR1	B13	3	1/0/10 MHz	QPSK	1g/10mm/Hotspot_Edge 2	24.00	24.00	23.89	23.89
			Bn2	3	1/1/40 MHz	DFT-s OFDM QPSK	1g/10mm/Hotspot_Edge 3	22.00	24.00	22.13	24.30
10	mmWave Max Tx power	LTE	B4	3	1/0/20 MHz	QPSK	1g/10mm/Hotspot	22.00	24.00	21.65	23.99
		FR2	n261	-	66/0/100 MHz	DFT-s OFDM QPSK	V+H / 3,10	11.00	-	12.11	-
			n260	-	66/0/100 MHz	DFT-s OFDM QPSK	V+H / 2,9	11.00	-	11.35	-
11	mmWave dominant power switching	LTE	B4	3	1/0/20 MHz	QPSK	1g/10mm/Hotspot	22.00	24.00	21.65	23.99
		FR2	n261	-	66/0/100 MHz	DFT-s OFDM QPSK	V+H / 3,10	11.00	-	12.11	-
			n260	-	66/0/100 MHz	DFT-s OFDM QPSK	V+H / 2,9	11.00	-	11.35	-
12	mmWave module beam change	LTE	B4	3	1/0/20 MHz	QPSK	1g/10mm/Hotspot	22.00	24.00	21.65	23.99
		FR2	n261	-	66/0/100 MHz	DFT-s OFDM QPSK	V+H / 3,10	11.00	-	12.11	-
			n260	-	66/0/100 MHz	DFT-s OFDM QPSK	V+H / 2,9	11.00	-	11.35	-
13	RSI change	FR1	Bn48	3	1/53/40 MHz	DFT-s OFDM QPSK	1g/10mm/Hotspot_Edge 4	14.00	17.00	14.43	17.06
				4	1/53/40 MHz	DFT-s OFDM QPSK	1g/0mm/Head_Right Touch	13.00	17.00	13.61	17.06
14	TAS to Non TAS	LTE	B2	3	1/99/20 MHz	QPSK	1g/10mm/Hotspot_Edge 3	22.00	24.00	22.13	24.30
		WCDMA	5	3	-	Rel 99	1g/10mm/Hotspot_Rear	24.00	24.00	23.87	23.87

Even if the same SAR_design_target is set, the Plimit will be changed according to the used OEM.

*Plimit and Pmax for LTE TDD Bands in the table above were written with Frame average power.

**Plimit and Pmax for NR FR1 TDD Bands in the table above were written with Frame average power at 88.5% duty cycle using Call box.

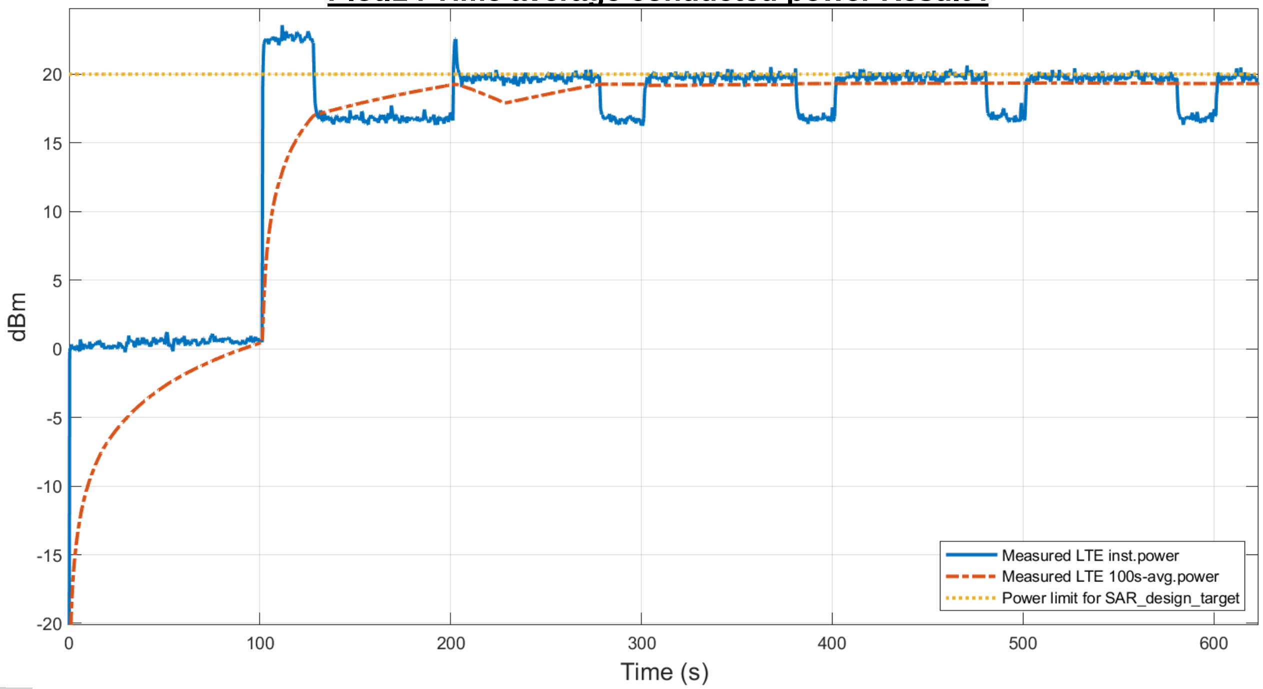
6.3 TC01-04: Time-varying Tx power measurement results

Following the test procedure in Section 3.3.1, the conducted Tx power measurement results for all selected test cases are listed in this section. In all conducted Tx power plots, the blue line shows the measured instantaneous power using the power meter, the red line shows the time-averaged Tx power and yellow line shows the Plimit value corresponding to design target. In all SAR plots, the dotted blue line shows the time-averaged 1gSAR while the red line shows the corresponding FCC limit of 1.6W/Kg. Time-varying Tx power measurements were conducted for TC #01-04 in Table 6.2.1 by generating the test sequence A or B given in Section A.

6.3.1 LTE Band 7

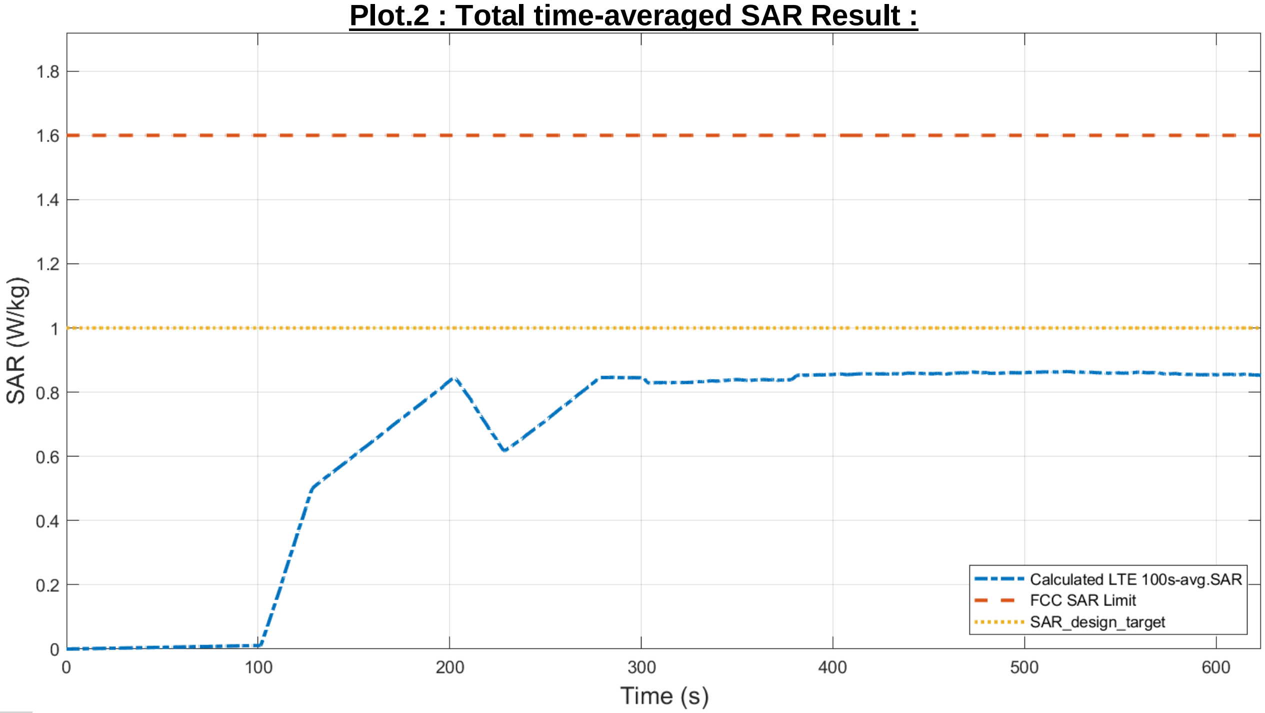
(TC01: LTE Band_Time_Varying_Tx_Power_Case_1)

Plot.1 : Time average conducted power Result :



Plot.1 shows the conducted Tx power plot with calculated time-averaged power based on the measured instantaneous Tx power with 1gSAR FCC Limit value. As shown in Plot.1, it is confirmed for time average Tx power that the FCC limit was not exceeded, and that the averaged Tx power is smaller than the target power, and it will saturate to target power with little margin.

Plot.2 : Total time-averaged SAR Result :

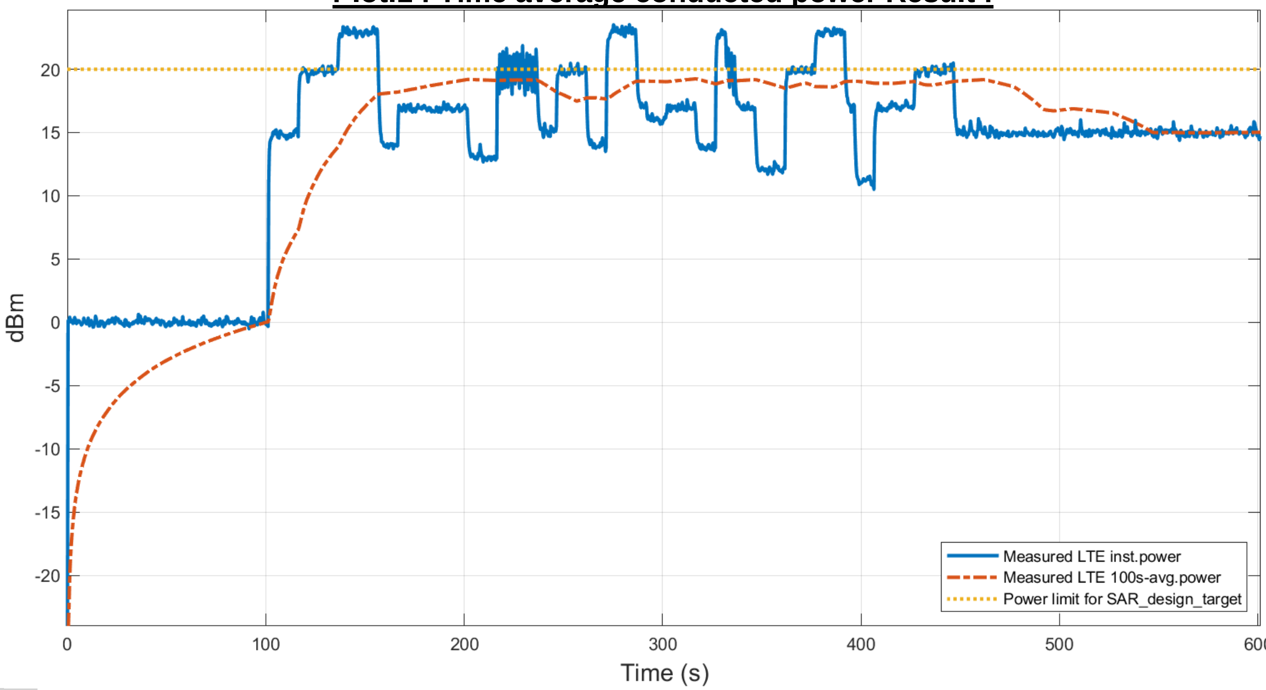


Plot.2 shows the plot of calculated time-averaged 1gSAR for this test demonstrating that exposure is well below the FCC limit of 1.6W/Kg.

FCC1g SAR limit	**1.6**	W/kg
Max 100s-time averaged 1gSAR (blue curve)	**0.864**	W/kg
Device uncertainty	**1.0**	dB

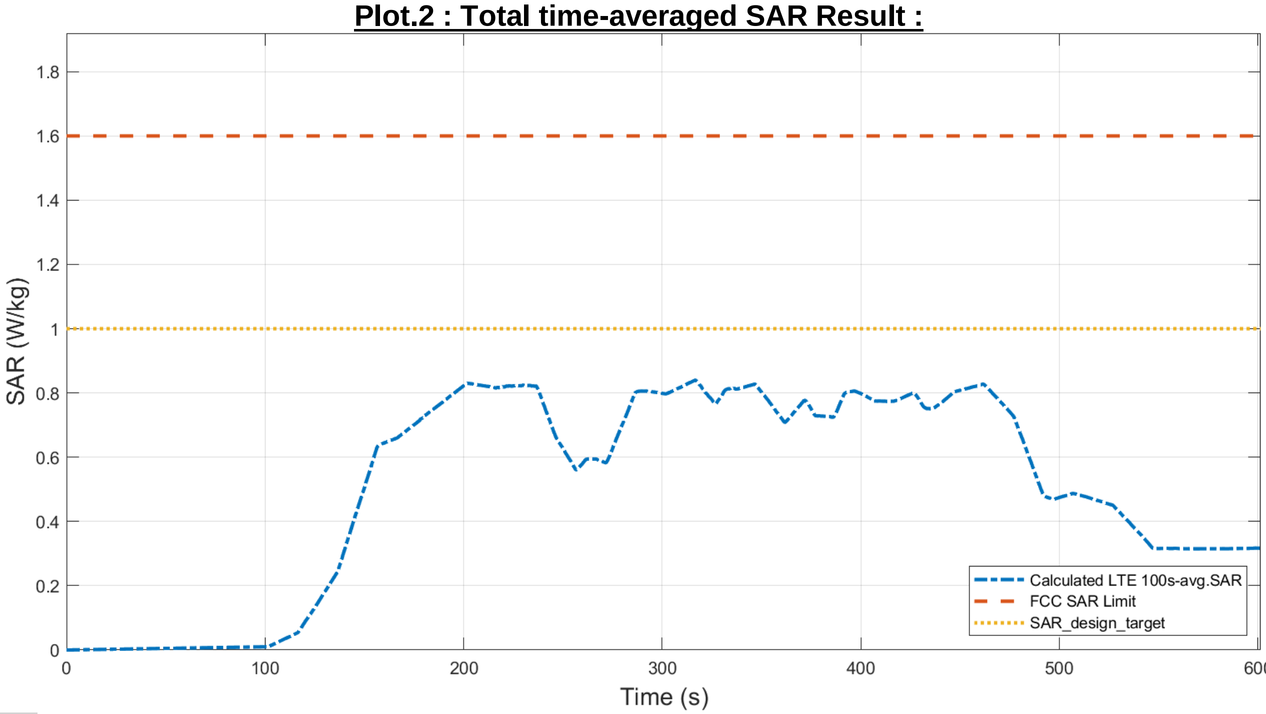
(TC03: LTE Band_Time_Varying_Tx_Power_Case_2)

Plot.1 : Time average conducted power Result :



Plot.1 shows the instantaneous and time-averaged Tx power with test sequence B.

Plot.2 : Total time-averaged SAR Result :



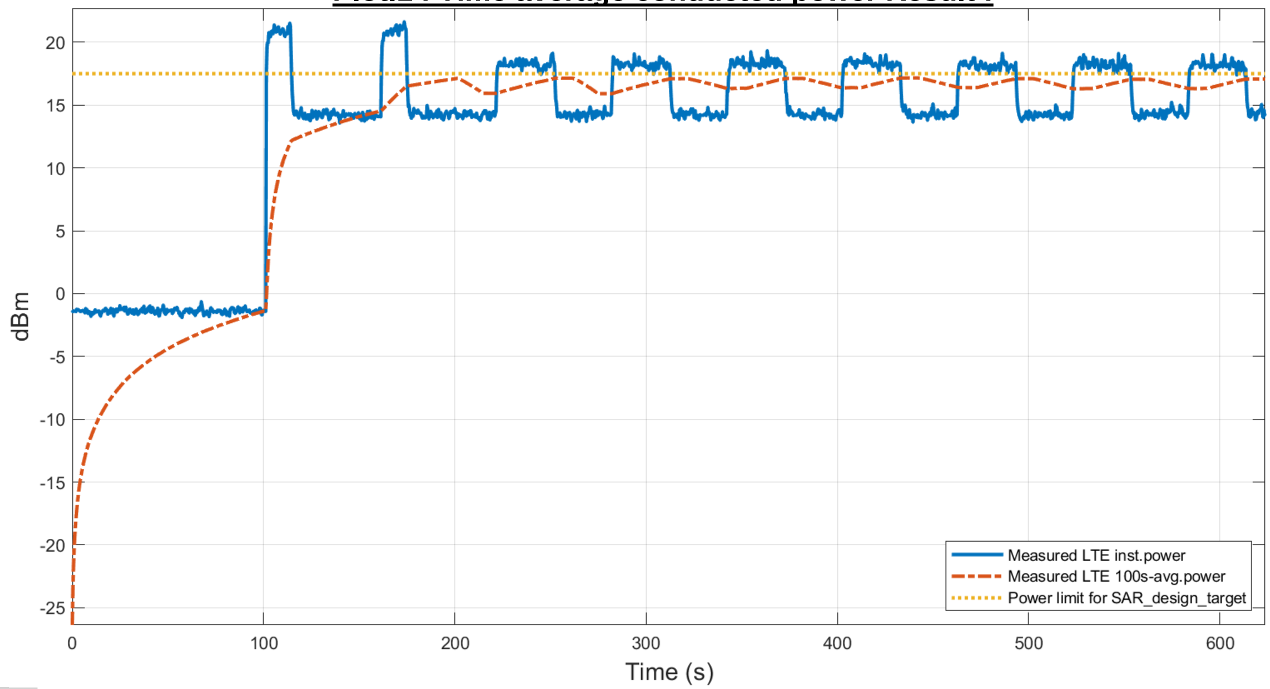
Plot.2 shows the plot of calculated time-averaged 1gSAR for this test demonstrating that exposure is well below the FCC limit of 1.6W/Kg.

FCC1g SAR limit	**1.6**	W/kg
Max 100s-time averaged 1gSAR (blue curve)	**0.841**	W/kg
Device uncertainty	**1.0**	dB

6.3.2 LTE Band 48

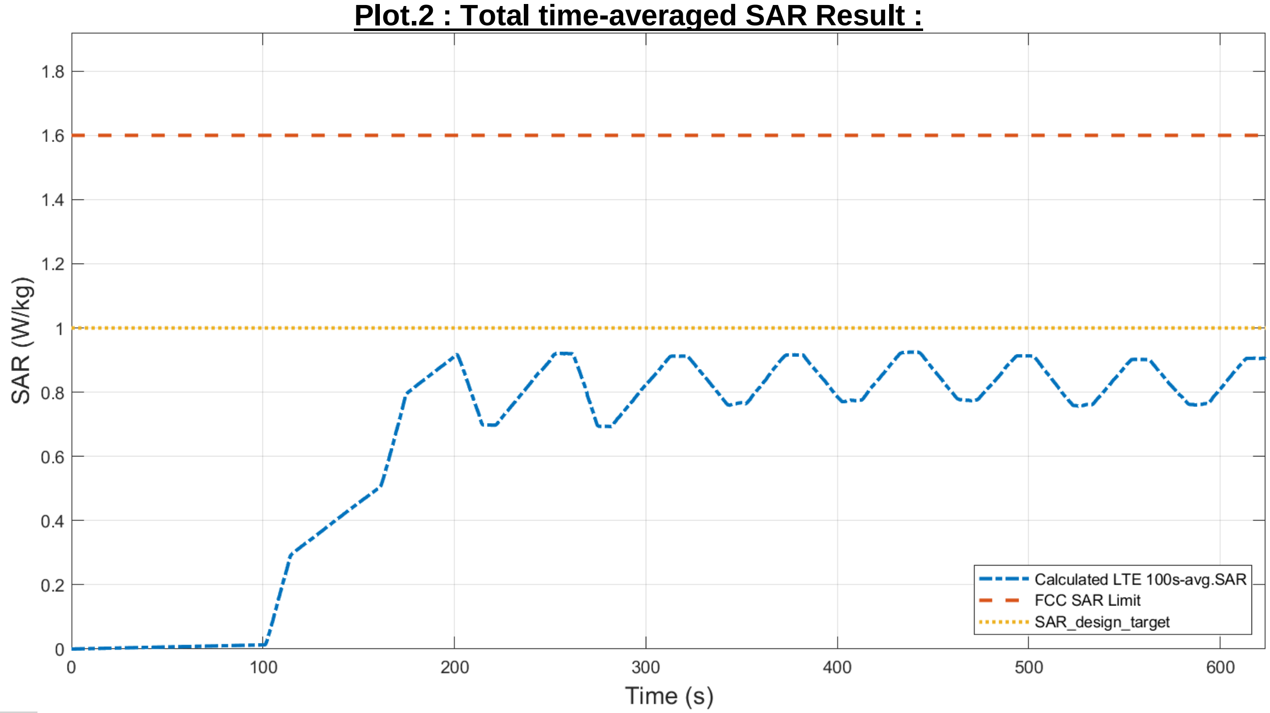
(TC01: LTE Band_Time_Varying_Tx_Power_Case_1)

Plot.1 : Time average conducted power Result :



Plot.1 shows the conducted Tx power plot with calculated time-averaged power based on the measured instantaneous Tx power with 1gSAR FCC Limit value. As shown in Plot.1, it is confirmed for time average Tx power that the FCC limit was not exceeded, and that the averaged Tx power is smaller than the target power, and it will saturate to target power with little margin.

Plot.2 : Total time-averaged SAR Result :

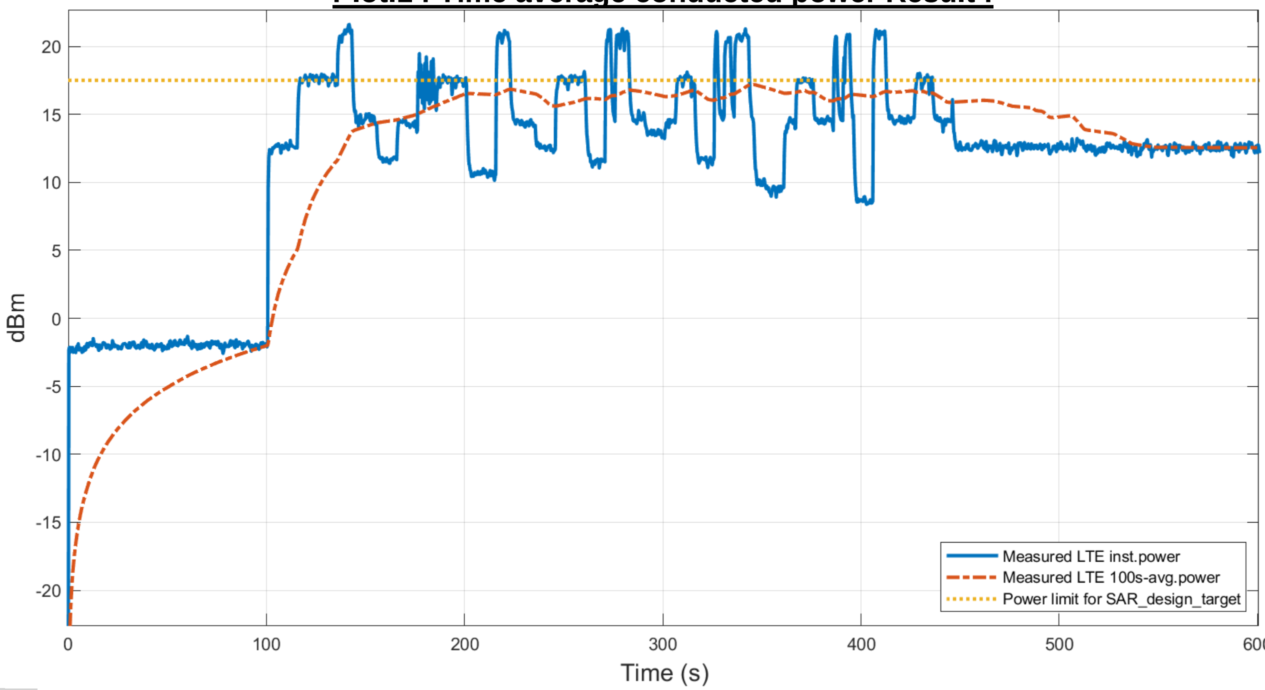


Plot.2 shows the plot of calculated time-averaged 1gSAR for this test demonstrating that exposure is well below the FCC limit of 1.6W/Kg.

FCC1g SAR limit	**1.6**	W/kg
Max 100s-time averaged 1gSAR (blue curve)	**0.925**	W/kg
Device uncertainty	**1.0**	dB

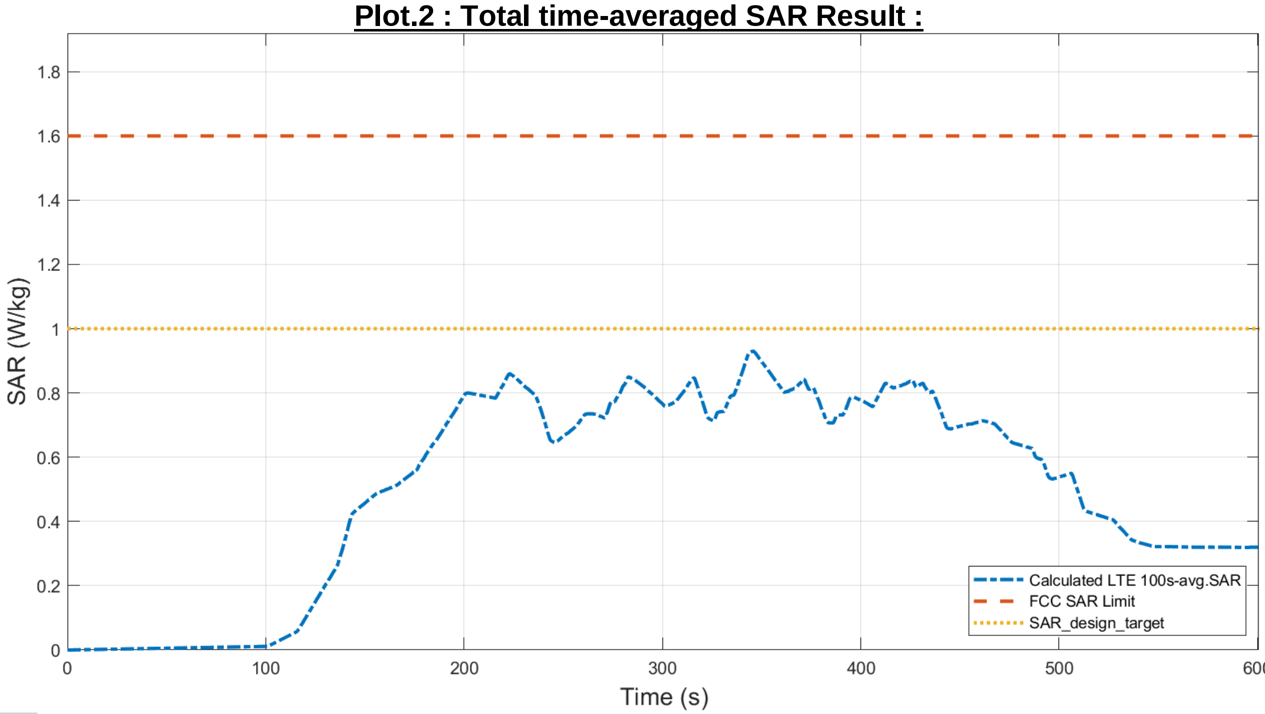
(TC03: LTE Band_Time_Varying_Tx_Power_Case_2)

Plot.1 : Time average conducted power Result :



Plot.1 shows the instantaneous and time-averaged Tx power with test sequence B.

Plot.2 : Total time-averaged SAR Result :



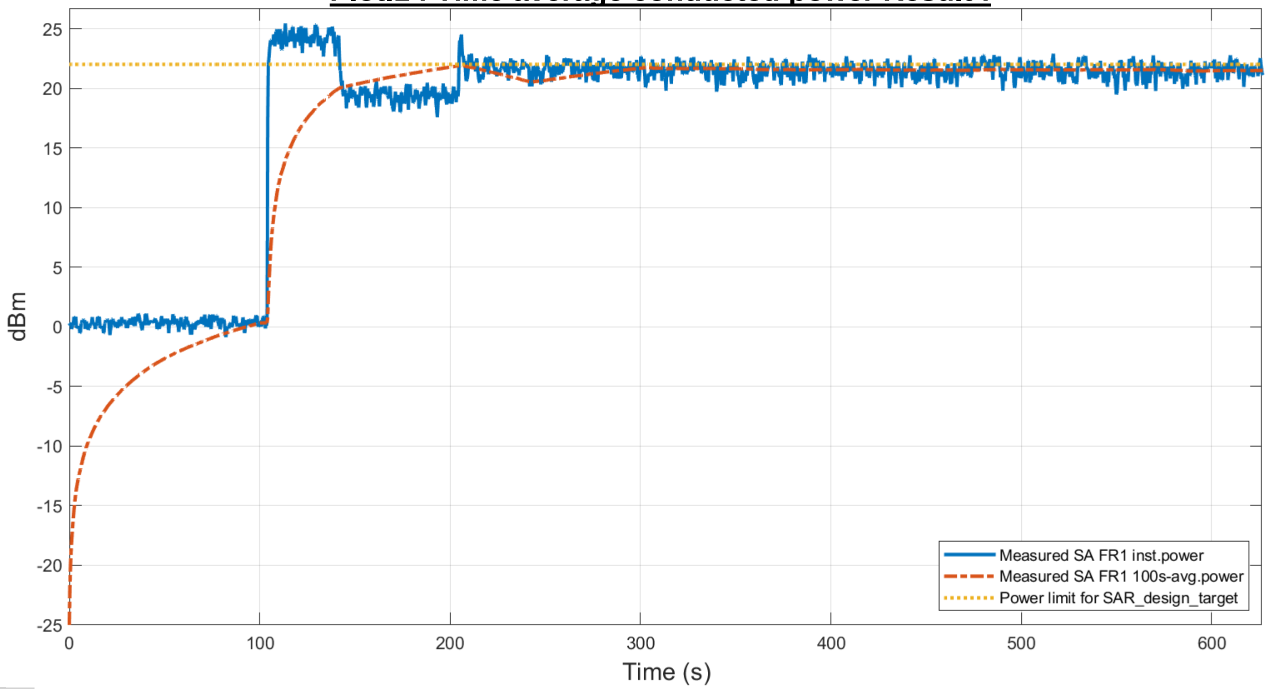
Plot.2 shows the plot of calculated time-averaged 1gSAR for this test demonstrating that exposure is well below the FCC limit of 1.6W/Kg.

FCC1g SAR limit	**1.6**	W/kg
Max 100s-time averaged 1gSAR (blue curve)	**0.930**	W/kg
Device uncertainty	**1.0**	dB

6.3.3 NR Band n2

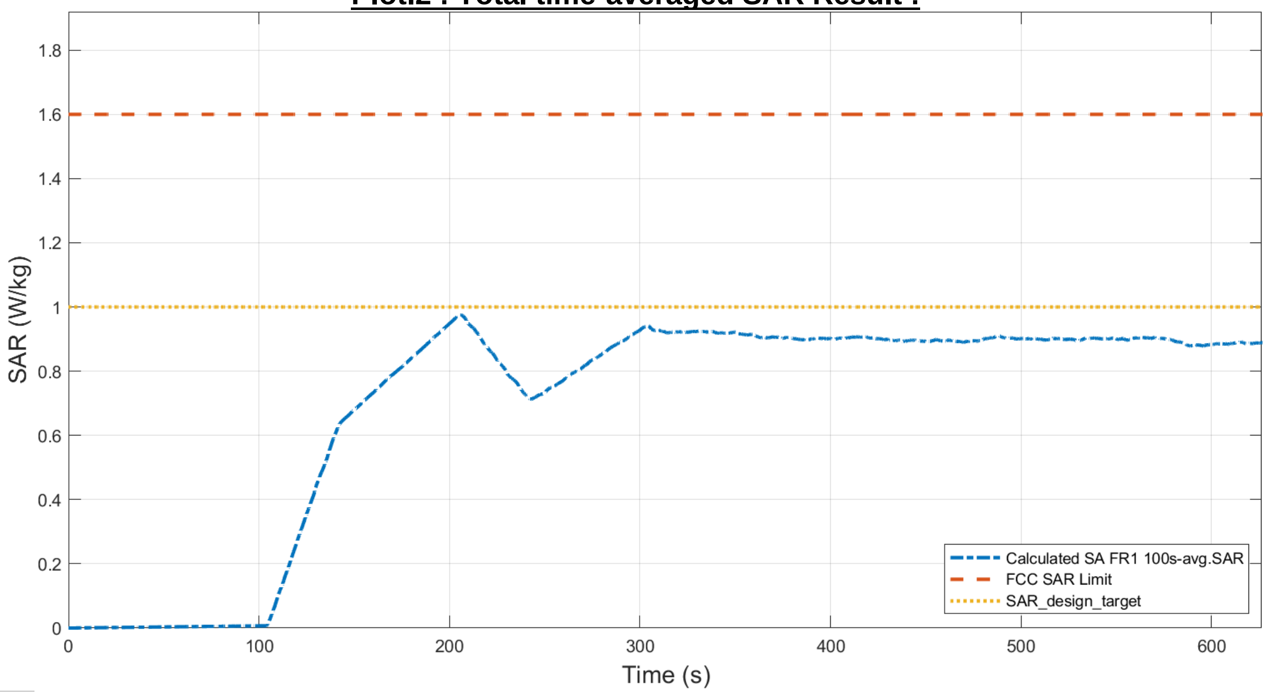
(TC02: SA_FR1_NR Band_Time_Varying_Tx_Power_Case_1)

Plot.1 : Time average conducted power Result :



Plot.1 shows the conducted Tx power plot with calculated time-averaged power based on the measured instantaneous Tx power with 1gSAR FCC Limit value. As shown in Plot.1, it is confirmed for time average Tx power that the FCC limit was not exceeded, and that the averaged Tx power is smaller than the target power, and it will saturate to target power with little margin.

Plot.2 : Total time-averaged SAR Result :

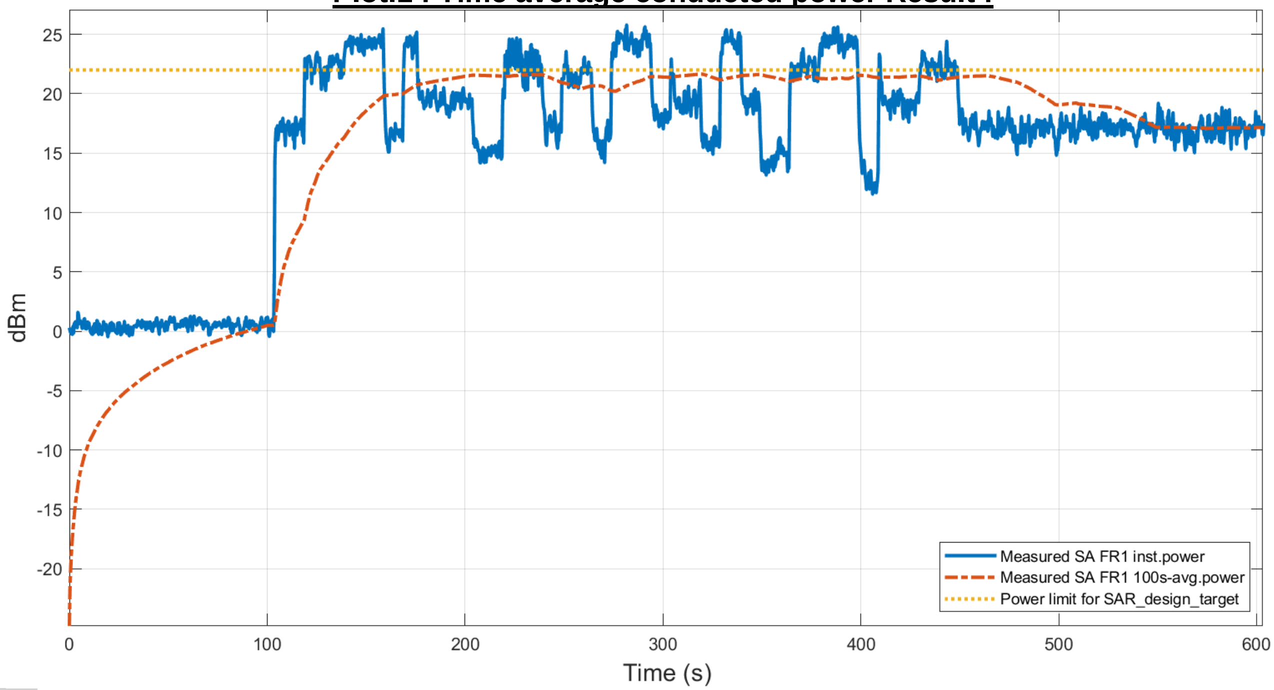


Plot.2 shows the plot of calculated time-averaged 1gSAR for this test demonstrating that exposure is well below the FCC limit of 1.6W/Kg.

FCC1g SAR limit	**1.6**	W/kg
Max 100s-time averaged 1gSAR (blue curve)	**0.976**	W/kg
Device uncertainty	**1.0**	dB

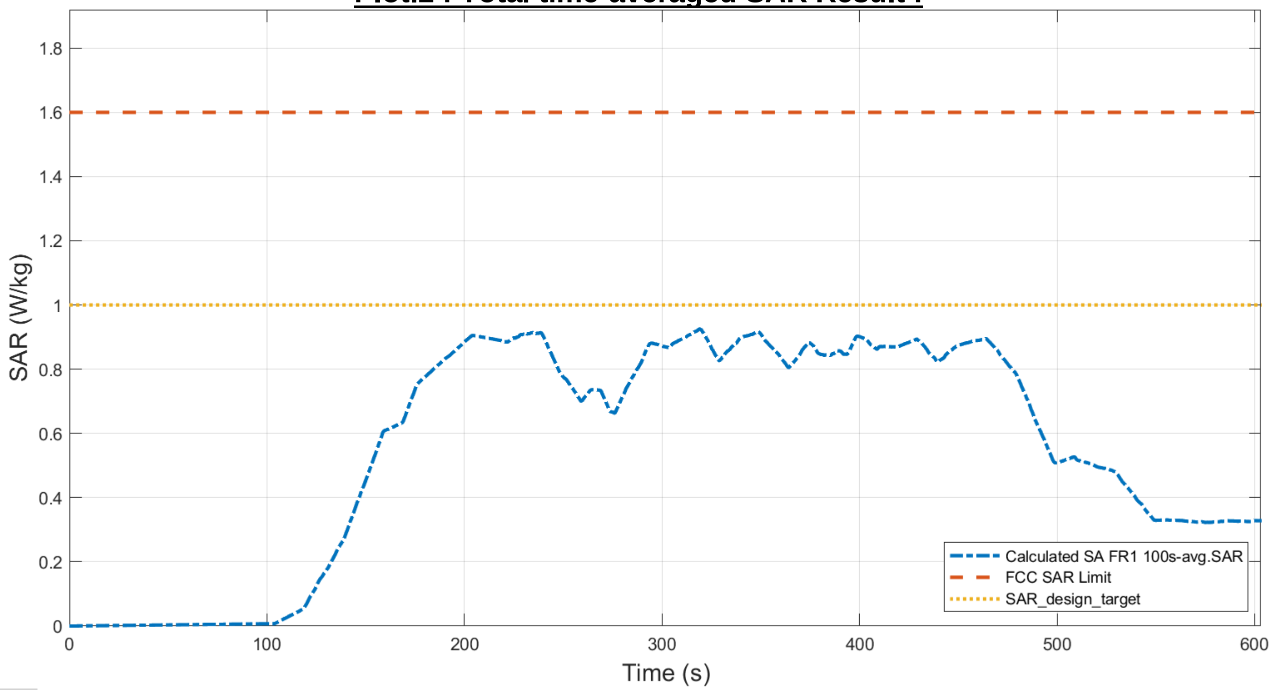
(TC04: SA_FR1_NR Band_Time_Varying_Tx_Power_Case_2)

Plot.1 : Time average conducted power Result :



Plot.1 shows the instantaneous and time-averaged Tx power with test sequence B.

Plot.2 : Total time-averaged SAR Result :



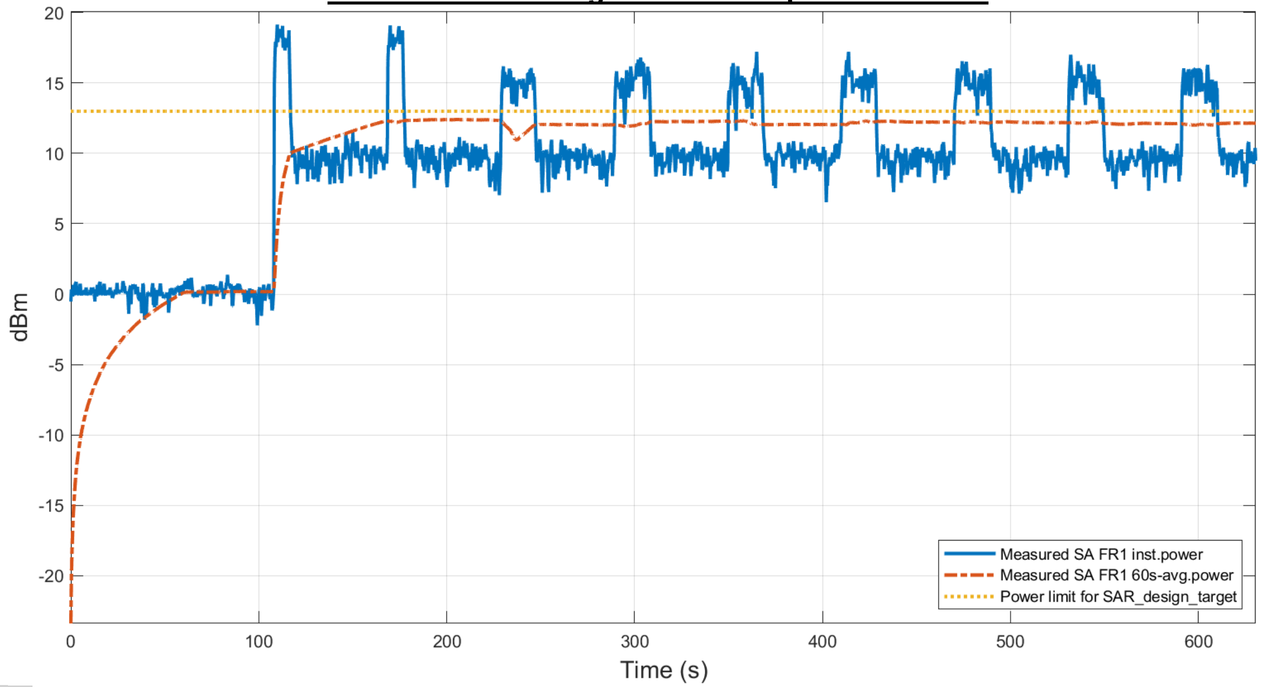
Plot.2 shows the plot of calculated time-averaged 1gSAR for this test demonstrating that exposure is well below the FCC limit of 1.6W/Kg.

FCC1g SAR limit	**1.6**	W/kg
Max 100s-time averaged 1gSAR (blue curve)	**0.925**	W/kg
Device uncertainty	**1.0**	dB

6.3.4 NR Band n48

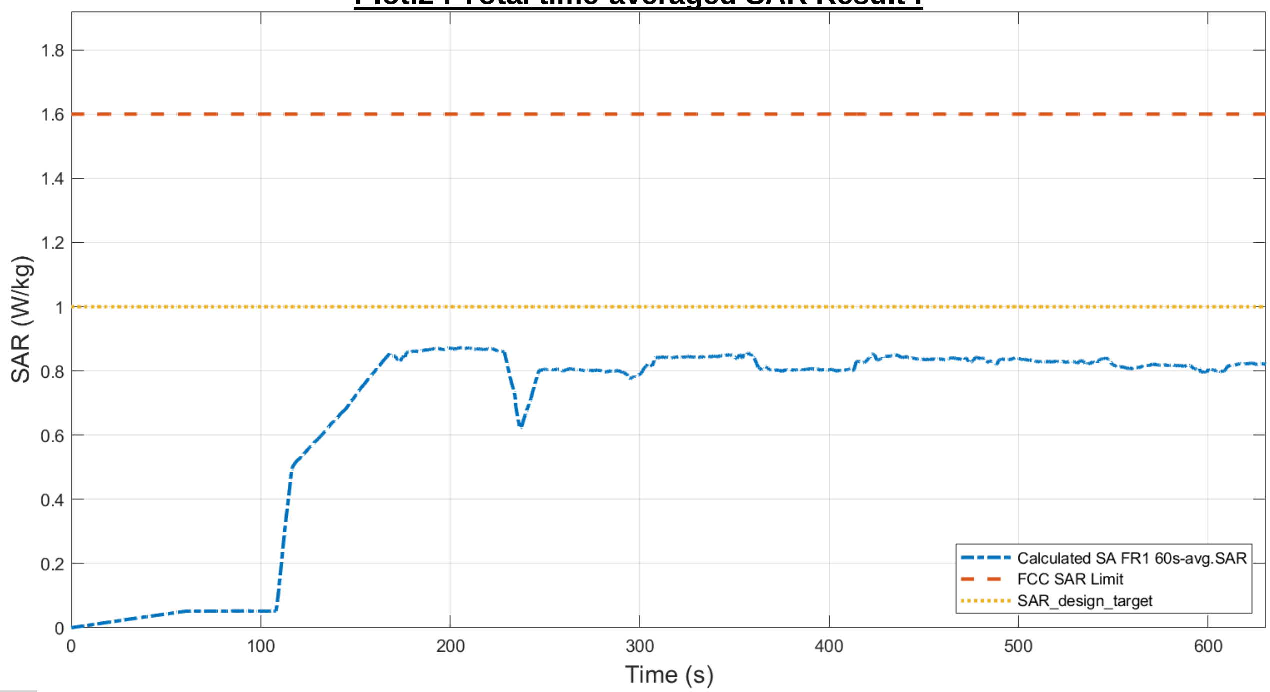
(TC02: SA_FR1_NR Band_Time_Varying_Tx_Power_Case_1)

Plot.1 : Time average conducted power Result :



Plot.1 shows the conducted Tx power plot with calculated time-averaged power based on the measured instantaneous Tx power with 1gSAR FCC Limit value. As shown in Plot.1, it is confirmed for time average Tx power that the FCC limit was not exceeded, and that the averaged Tx power is smaller than the target power, and it will saturate to target power with little margin.

Plot.2 : Total time-averaged SAR Result :

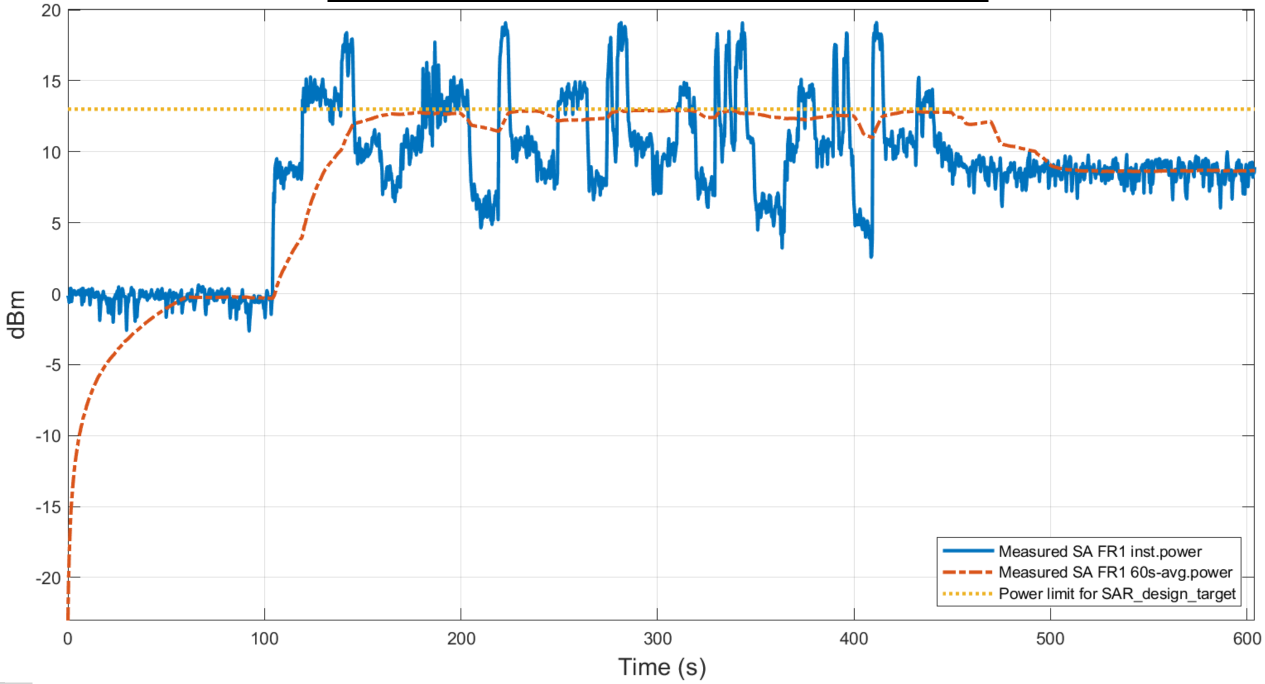


Plot.2 shows the plot of calculated time-averaged 1gSAR for this test demonstrating that exposure is well below the FCC limit of 1.6W/Kg.

FCC1g SAR limit	**1.6**	W/kg
Max 100s-time averaged 1gSAR (blue curve)	**0.873**	W/kg
Device uncertainty	**1.0**	dB

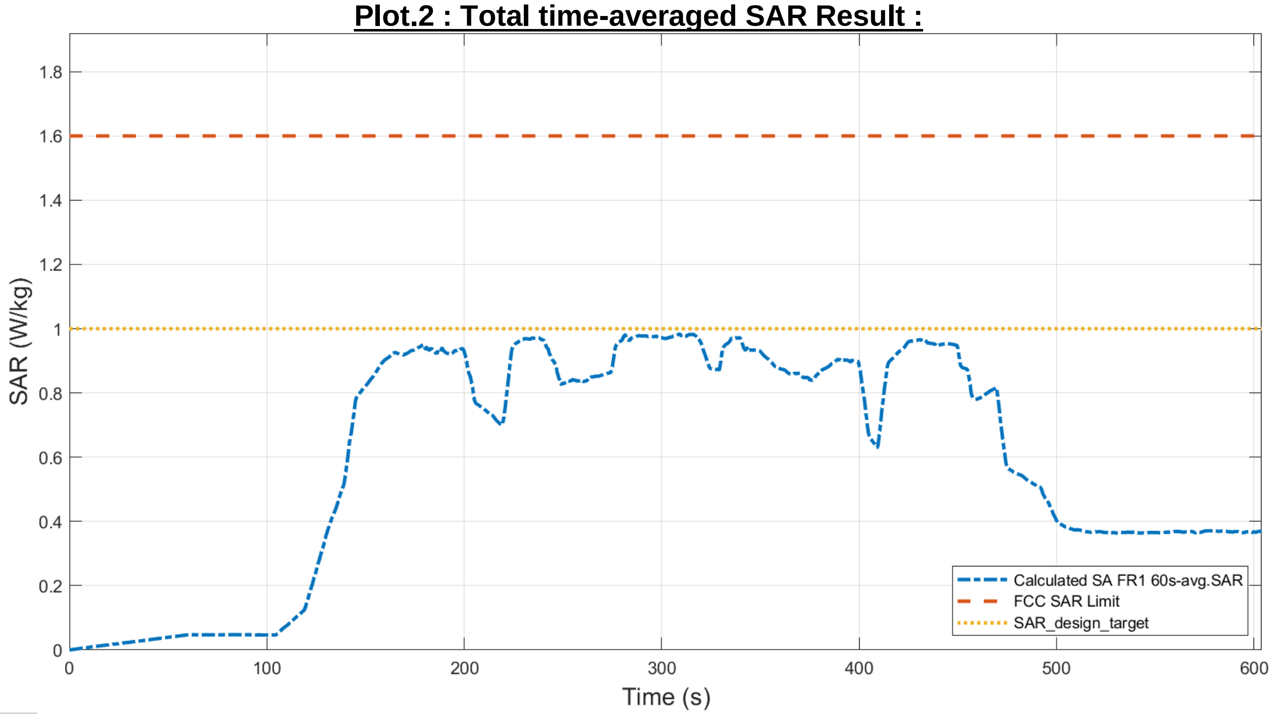
(TC04: SA_FR1_NR Band_Time_Varying_Tx_Power_Case_2)

Plot.1 : Time average conducted power Result :



Plot.1 shows the instantaneous and time-averaged Tx power with test sequence B.

Plot.2 : Total time-averaged SAR Result :



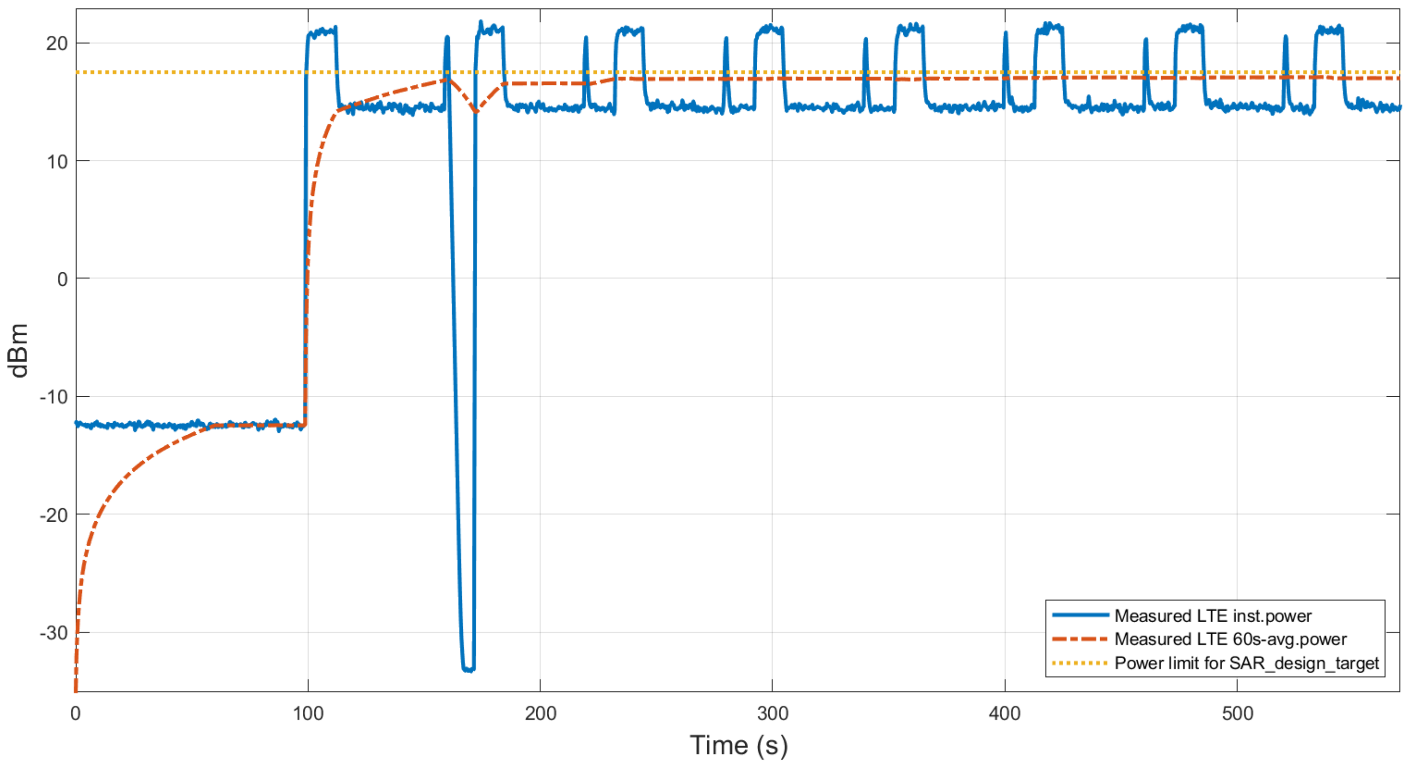
Plot.2 shows the plot of calculated time-averaged 1gSAR for this test demonstrating that exposure is well below the FCC limit of 1.6W/Kg.

FCC1g SAR limit	**1.6**	W/kg
Max 100s-time averaged 1gSAR (blue curve)	**0.984**	W/kg
Device uncertainty	**1.0**	dB

6.4 TC05: Change in call test results

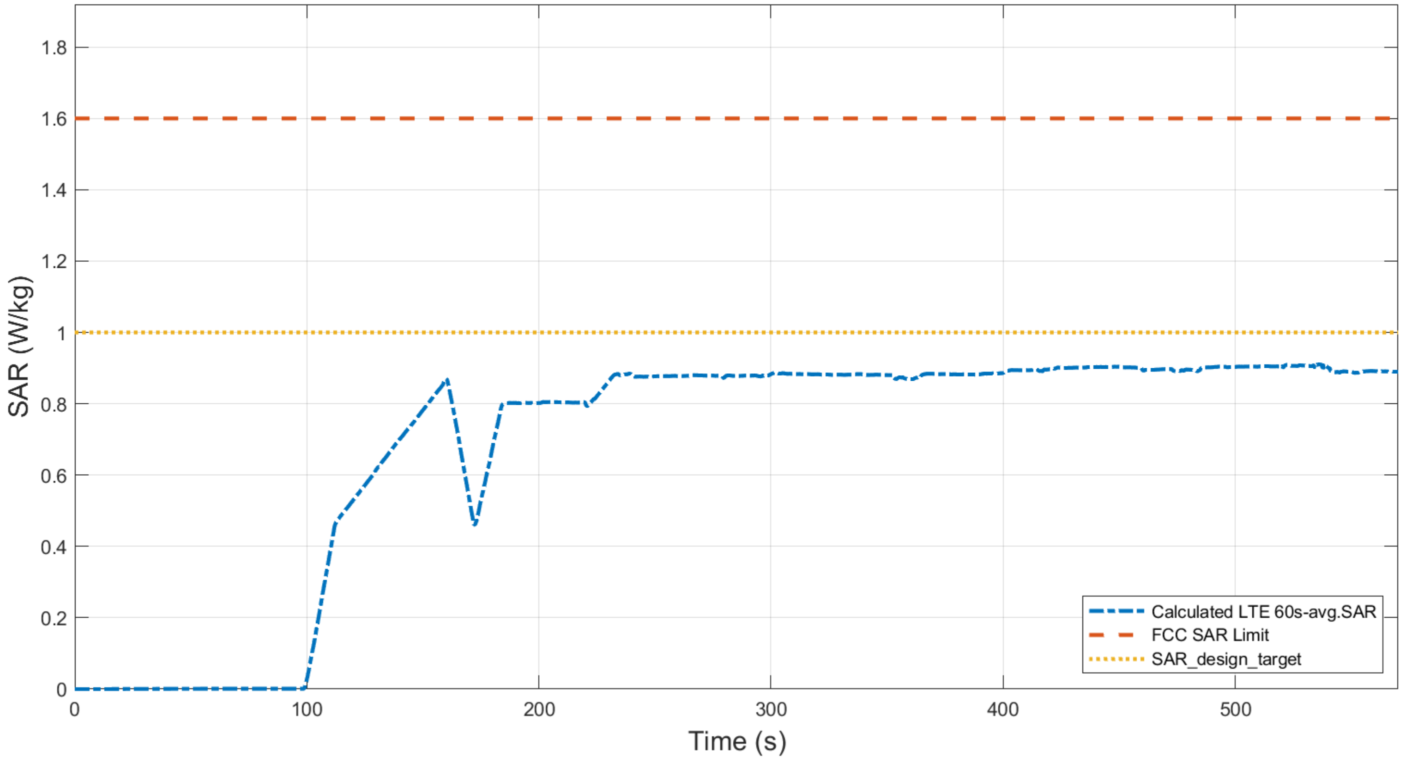
The test results in this section are obtained following the procedure in Section 3.3.2. The test case corresponds to TC05 in Table 6.2.1.

Plot.1 : Conducted Tx power in Call_Disconnect_Re-establishment :



Plot.1 shows the instantaneous and time-averaged Tx power for this test. The call disconnected around 160s and resumed after 10s. It is confirmed for time-average Tx power that the FCC limit was not exceeded, and that the averaged Tx power is lower than the value of Plimit.

Plot.2 : Total time-averaged SAR Result :



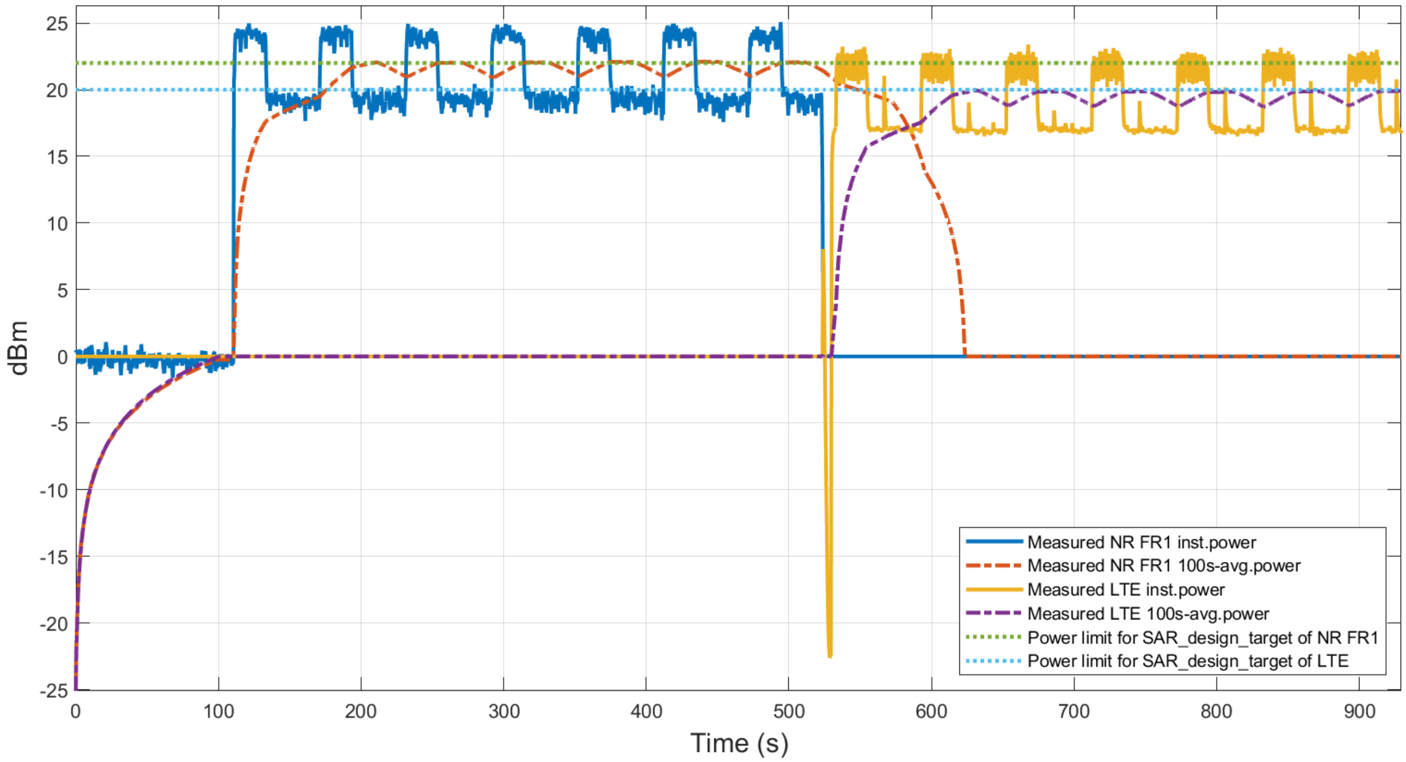
Plot.2 shows calculated time-averaged 1gSAR for this test demonstrating that exposure is well below the FCC limit of 1.6W/Kg. Looking at the results, it can be seen that even if transmission is stopped due to a call drop, the SAR value measured for a period of time window is stored in the window section and is continuously checked.

FCC1g SAR limit	**1.6**	W/kg
Max 100s-time averaged 1gSAR (blue curve)	**0.911**	W/kg
Device uncertainty	**1.0**	dB

6.5 TC06: Re-selection in call test results

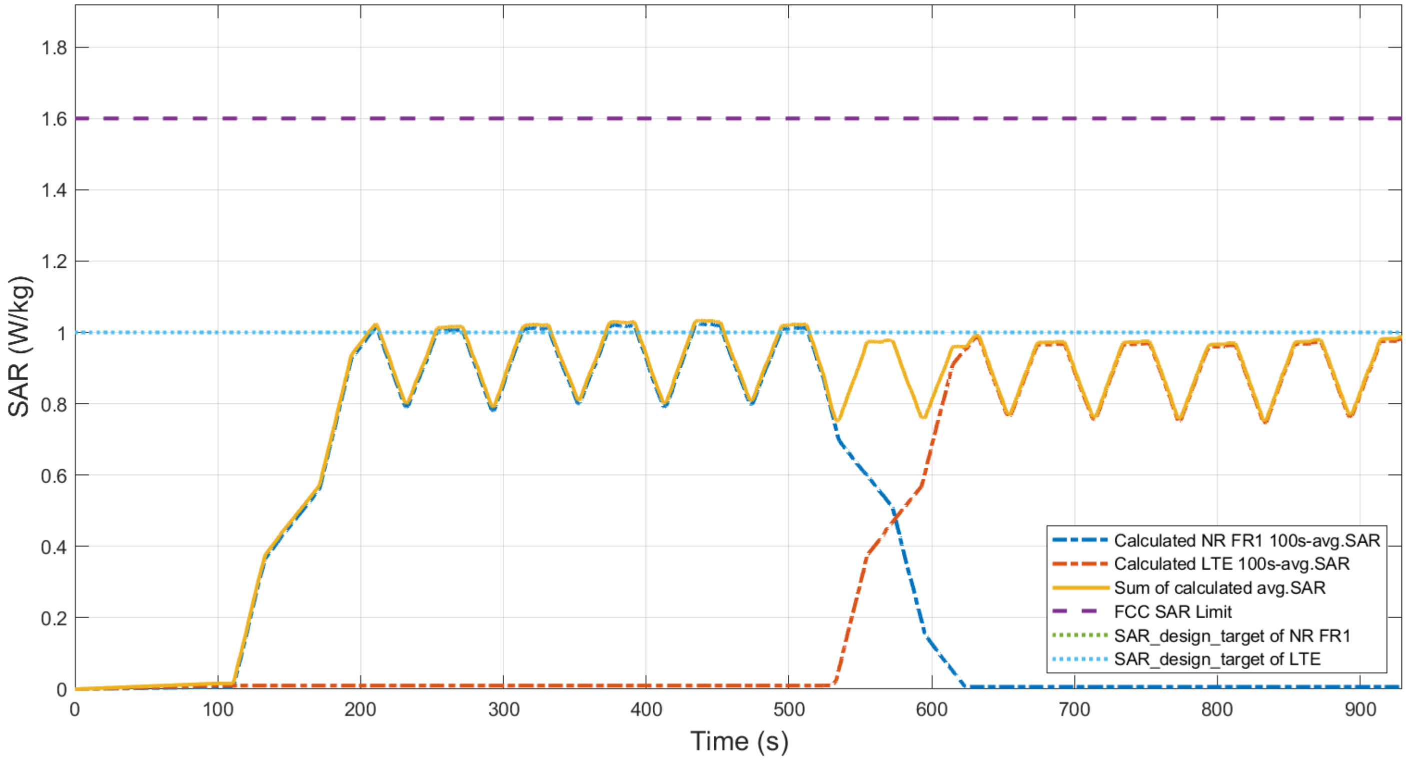
The test results in this section are obtained following the procedure in Section 3.3.3. The test cases correspond to TC06 in Table 6.2.1.

Plot.1 : Conducted Tx power for SAR IRAT re-selection :



Plot.1 shows the instantaneous and time-averaged conducted Tx power for both LTE Band and NR FR1 Band for the duration of the test. Around time stamp of ~510s, a RAT re-selection from LTE Band to NR FR1 Band was executed, resulting in reduction of time-averaged power of LTE Band and simultaneous increase in time-averaged power of NR FR1 Band.

Plot.2 : Total time-averaged SAR Result :



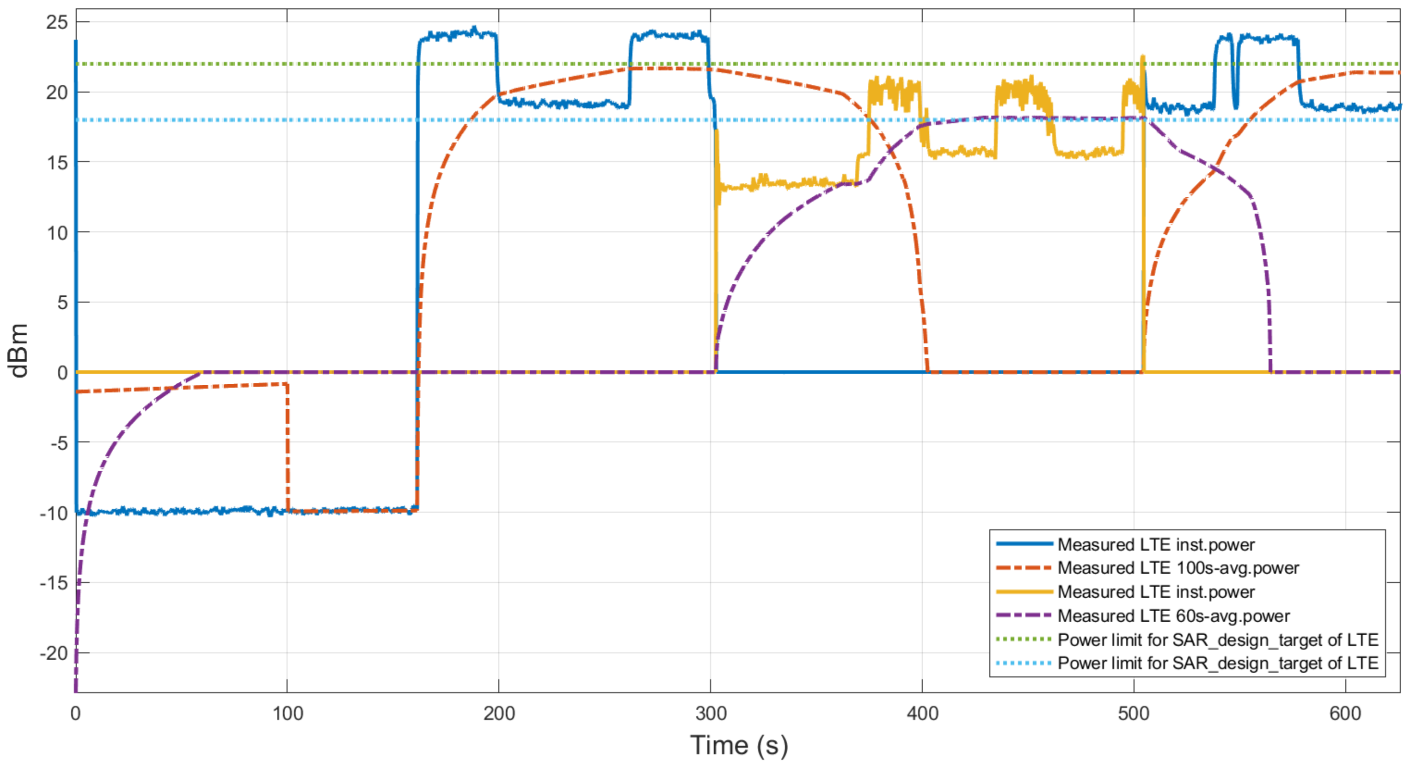
Plot.2 shows the time-averaged 1gSAR value for each of LTE Band and NR FR1 Band, as well as the total SAR value. We can see that the total 1gSAR is higher during the band transitions, but is always under the total FCC limit of 1.6W/Kg.

FCC1g SAR limit	**1.6**	W/kg
Max 100s-time averaged 1gSAR (blue curve)	**1.034**	W/kg
Device uncertainty	**1.0**	dB

6.6 TC07 : Change in band/time-window (100s-60s-100s) test results

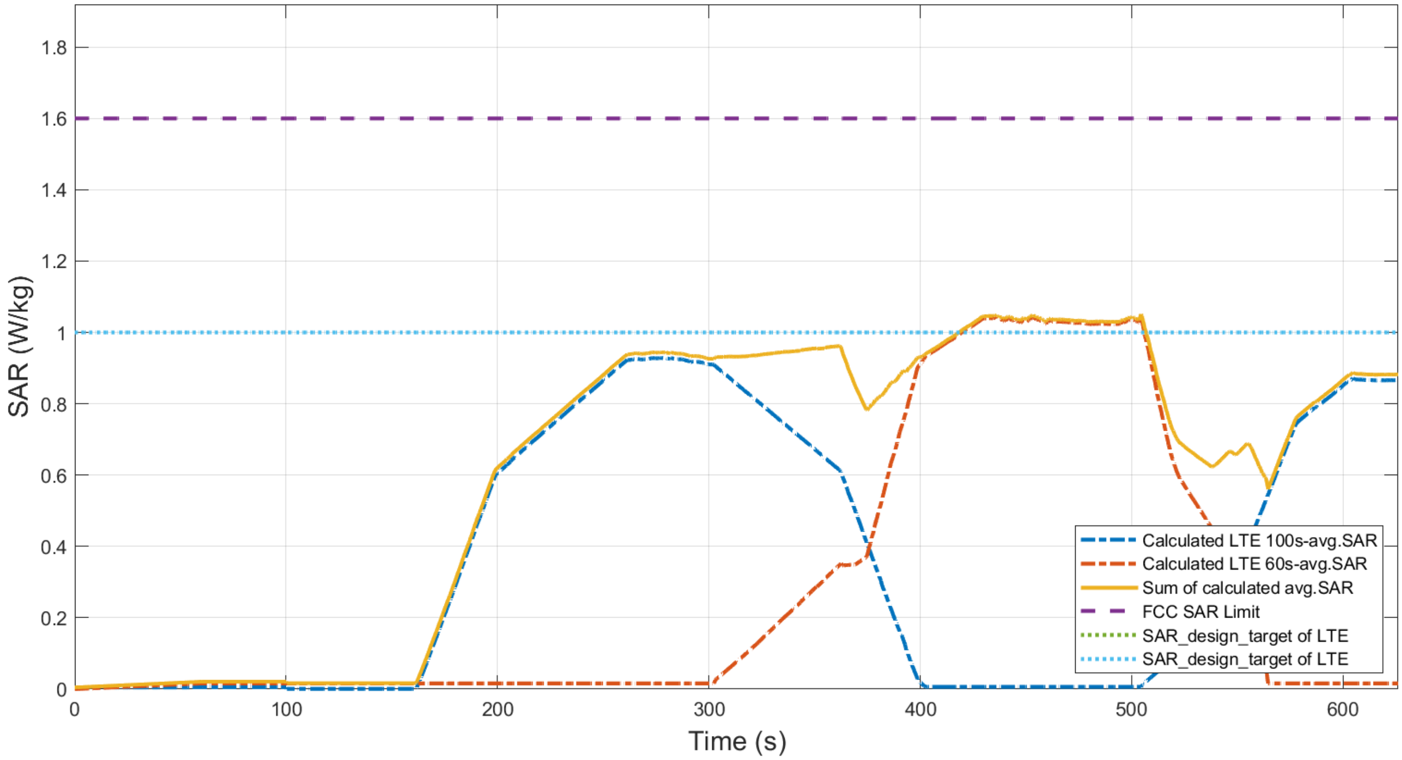
The test results in this section are obtained following the procedure in Section 3.3.3. The test cases correspond to TC07 in Table 6.2.1.

Plot.1 : Conducted Tx power for SAR window change :



Plot.1 shows the instantaneous and time-averaged conducted Tx power for both LTE Band 2 and Band 48 for the duration of the test. Around time stamp of ~300s, a handover from Band 2 to Band 48 was executed, resulting in reduction of time-averaged power of Band 2 and simultaneous increase in time-averaged power of Band 48. Around time stamp of ~500s, handover back to Band 2 was executed, resulting in reduction of time-averaged power of Band 48 and increase of time-averaged power of Band 2. It can be seen that transition time of time-averaged values for Band 2 is longer than Band 48, which is the consequence of 100s time averaging for Band 2 versus shorter 60s averaging for Band 48. Plot.2 shows the time-averaged 1gSAR value for each of Band 2 and Band 48, as well as the total SAR value. We can see that the total 1gSAR is higher during the band transitions, but is always under the total FCC limit of 1.6W/Kg.

Plot.2 : Total time-averaged SAR Result :



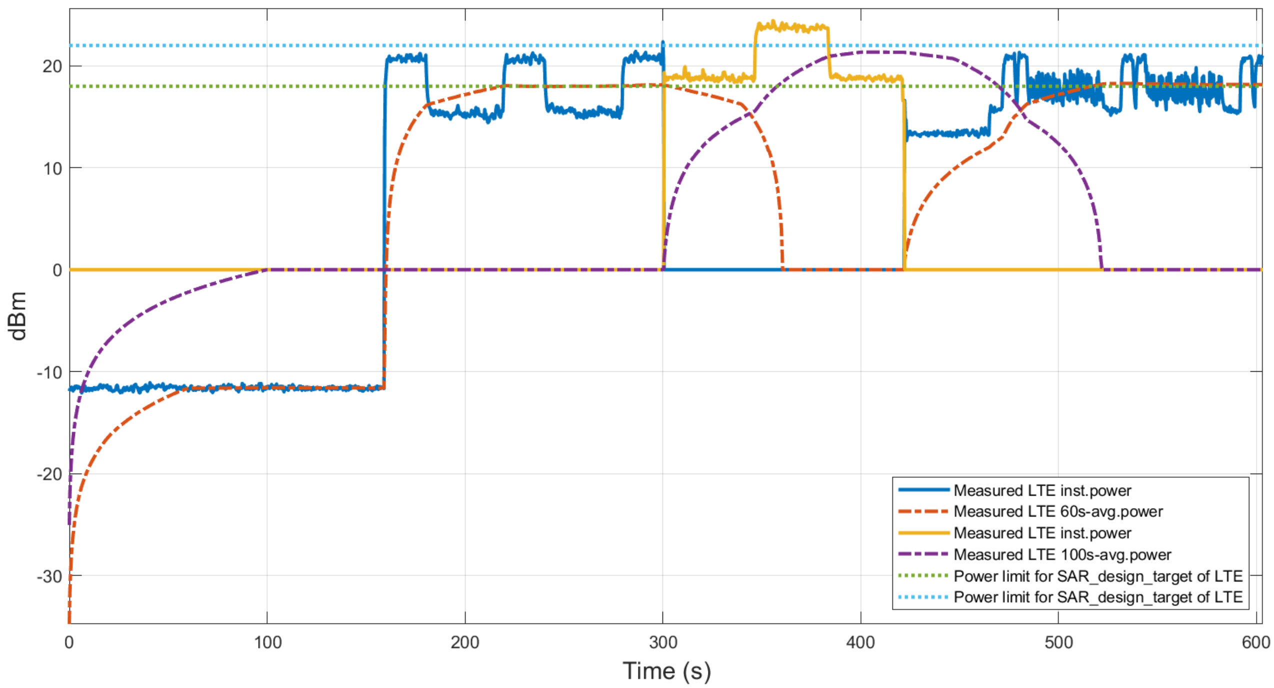
Plot.2 shows the time-averaged 1gSAR value for each of Band 2 and Band 48, as well as the total SAR value. We can see that the total 1gSAR is higher during the band transitions, but is always under the total FCC limit of 1.6W/Kg.

FCC1g SAR limit	**1.6** W/kg
Max 100s-time averaged 1gSAR (blue curve)	**1.051** W/kg
Device uncertainty	**1.0** dB

6.7 TC08 : Change in band/time-window (60s-100s-60s) test results

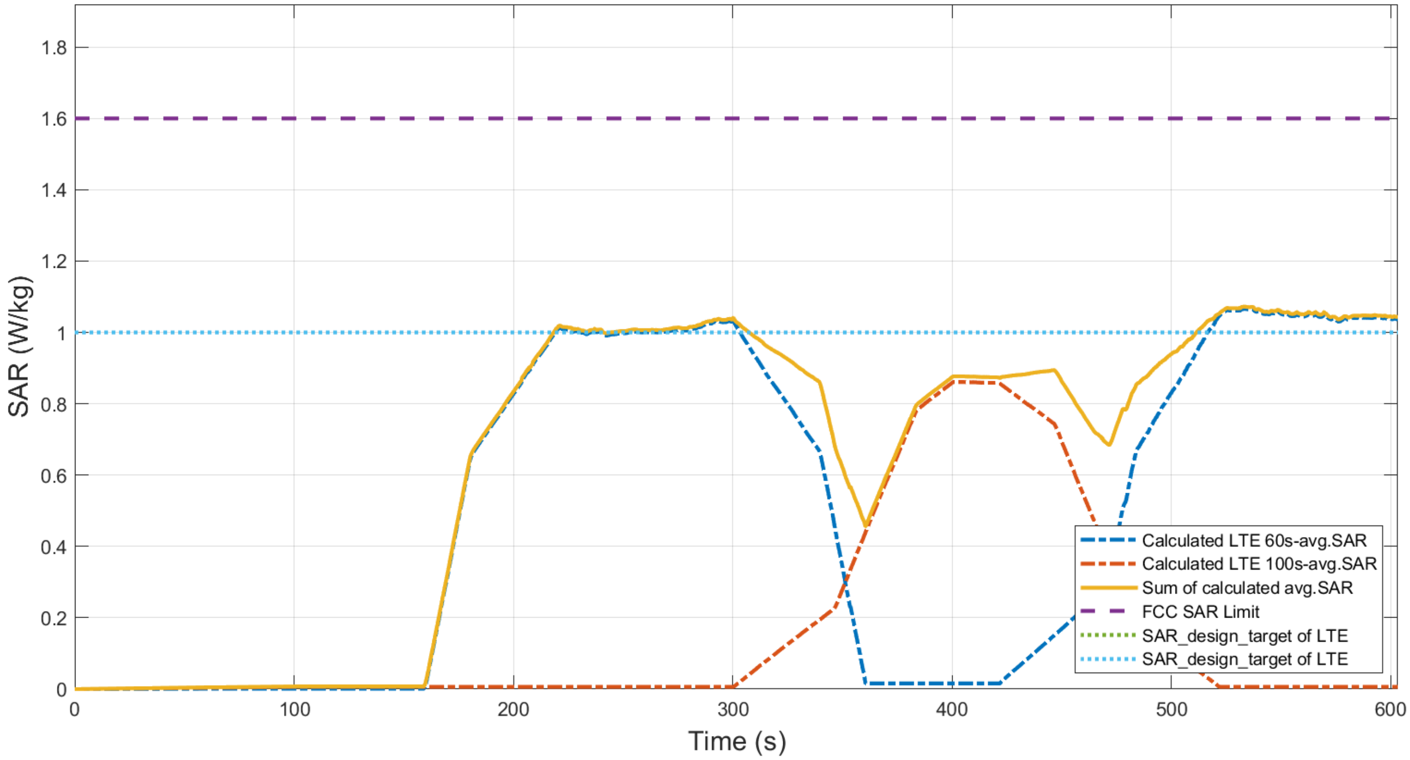
The test results in this section are obtained following the procedure in Section 3.3.3. The test cases correspond to TC08 in Table 6.2.1.

Plot.1 : Conducted Tx power for SAR window change :



Plot.1 shows the instantaneous and time-averaged conducted Tx power for both LTE Band 2 and Band 48 for the duration of the test. Around time stamp of ~300s, a handover from Band 48 to Band 2 was executed, resulting in reduction of time-averaged power of Band 48 and simultaneous increase in time-averaged power of Band 2. Around time stamp of ~420s, handover back to Band 48 was executed, resulting in reduction of time-averaged power of Band 2 and increase of time-averaged power of Band 48. It can be seen that transition time of time-averaged values for Band 2 is longer than Band 48, which is the consequence of 100s time averaging for Band 2 versus shorter 60s averaging for Band 48.

Plot.2 : Total time-averaged SAR Result :



Plot.2 shows the time-averaged 1gSAR value for each of Band 2 and Band 48, as well as the total SAR value. We can see that the total 1gSAR is higher during the band transitions, but is always under the total FCC limit of 1.6W/Kg.

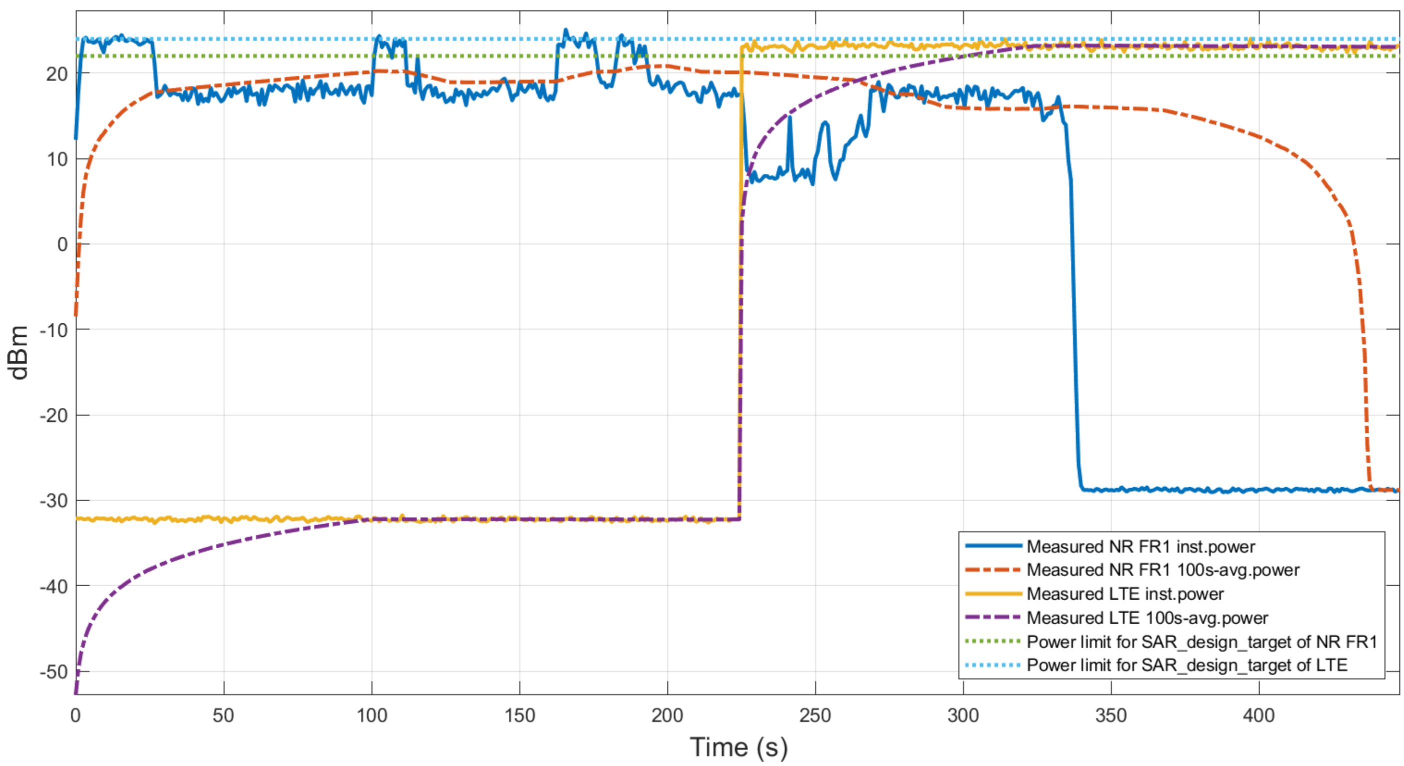
FCC1g SAR limit	**1.6** W/kg
Max 100s-time averaged 1gSAR (blue curve)	**1.072** W/kg
Device uncertainty	**1.0** dB

6.8 TC09 : Switch in SAR exposure test results

The test results in this section are obtained following the procedure in Section 3.3.5. The test cases correspond to TC09 in Table 6.2.1.

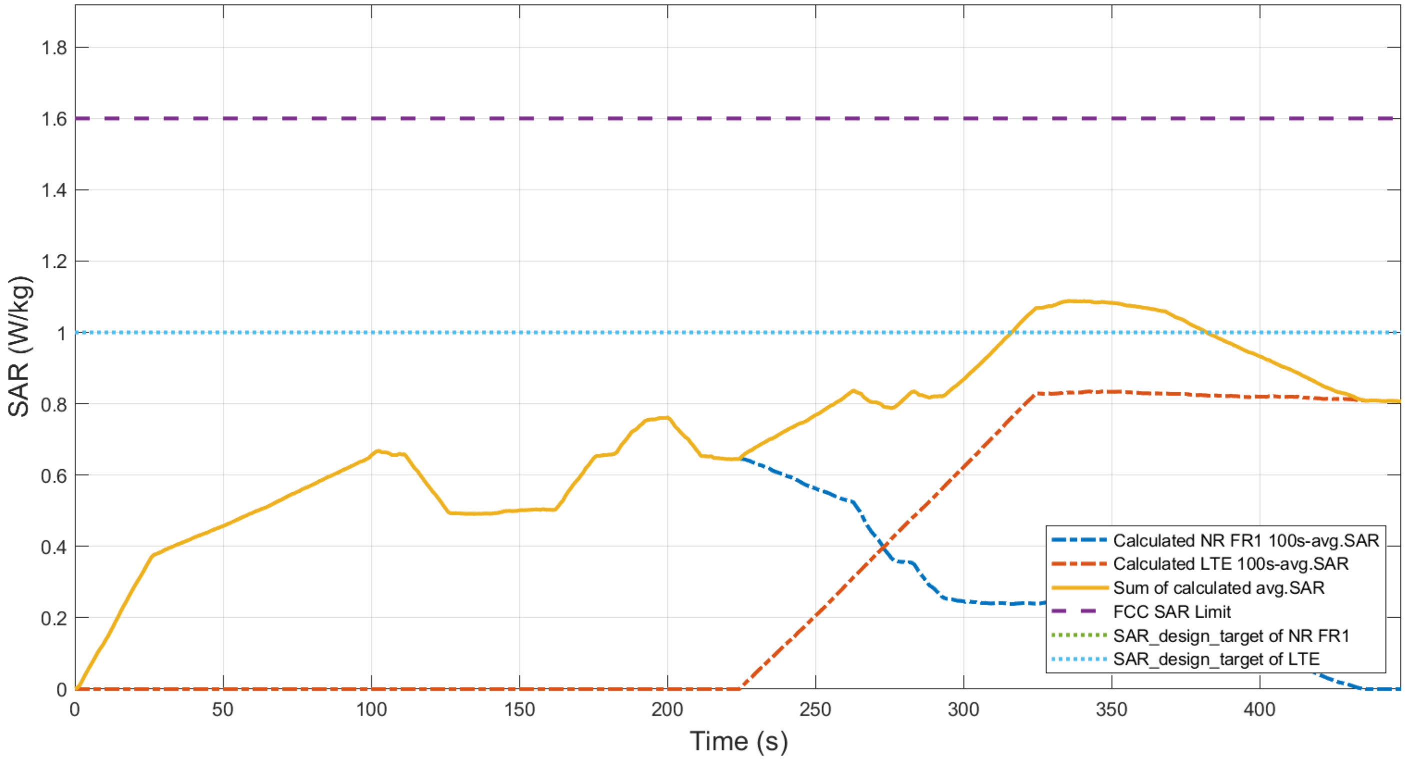
In this LTE+FR1 NSA scenario, we first establish LTE and NR call. In the first part of test, LTE is sent to lowest transmit power using "ALL DOWN" power control commands from call box while NR is sent to maximum power using "ALL UP" power control commands from call box. This would correspond to FR1 dominant SAR scenario and lasts about 220s. In the second part of test, LTE is sent "ALL UP" commands and transmissions are continued, resulting in LTE+FR1 SAR scenario lasting another 110s. In the third part of test, NR is sent "ALL DOWN" power control commands so that it becomes an FR1 dominant SAR scenario for 110s. Finally, both LTE and NR connections are released.

<u>Plot.1 :Time average SAR of LTE and FR1 in EN-DC case :</u>



Plot.1 shows the instantaneous and time-averaged Tx power for both LTE band and NR FR1 band versus time. When both LTE and FR1 operate, the SAR value was the highest instantaneously, but it can be seen that sum of average power in LTE and FR1 decreases again as soon as it is turned off. Plot.2 shows the computed time-averaged SAR value for LTE and FR1 as well as the sum. It was confirmed that algorithm operated under the total SAR design target limit of 1.2W/Kg, while also being under the FCC limit of 1.6W/Kg at all times. After the operation of FR1 is turned off, it can also be seen that the average power of LTE increases.

Plot.2 : Total time-averaged SAR Result :



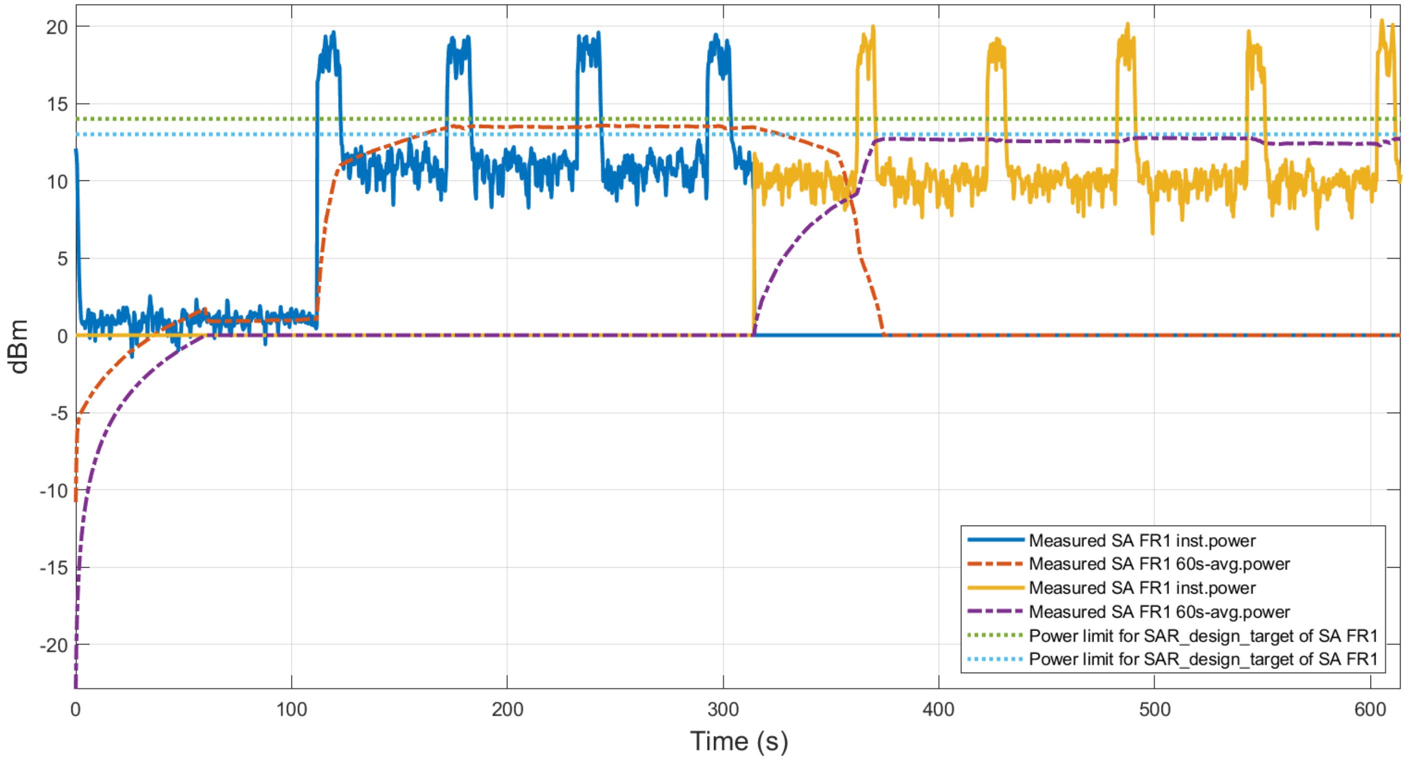
Plot.2 shows the computed time-averaged SAR value for LTE and FR1 as well as the sum. It was confirmed that algorithm operated under the total SAR design target limit of 1.2W/Kg, while also being under the FCC limit of 1.6W/Kg at all times. After the operation of FR1 is turned off, it can also be seen that the average power of LTE increases.

FCC1g SAR limit	**1.6** W/kg
Max 100s-time averaged 1gSAR (blue curve)	**1.088** W/kg
Device uncertainty	**1.0** dB

6.9 TC13 : Change in RSI value results

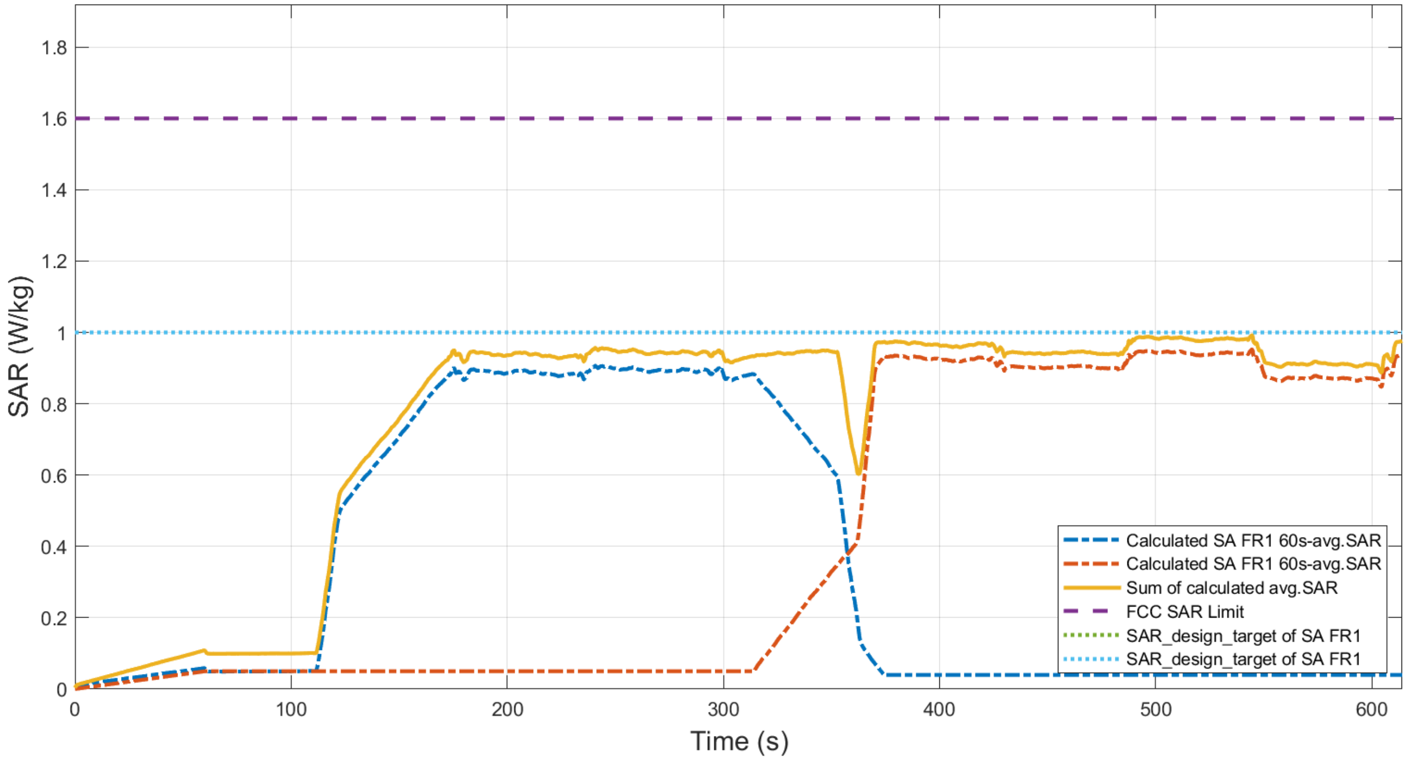
The test results in this section are obtained following the procedure in Section 3.3.4. The test cases correspond to TC13 in Table 6.2.1.

Plot.1 : Conducted Tx power for SAR RSI change :



Plot.1 shows the instantaneous and time-averaged conducted Tx power for both SA FR1 Band n48 for the duration of the test. Around time stamp of ~310s, the RSI value is changed from RSI=3 to RSI=4, resulting in reduction of target time-averaged power of SA FR1 Band n48. It can be seen that Plimit value of RSI=4 is lower than that of RSI=3, so in RSI=3 region, more Tx power is limited compared to RSI=4 region. Figure 8.8-2 shows the time-averaged 1gSAR value for each of RSI value, as well as the total SAR value. We can see that the total 1gSAR is higher during the band transitions, but is always under the total FCC limit of 1.6W/Kg.

Plot.2 : Total time-averaged SAR Result :



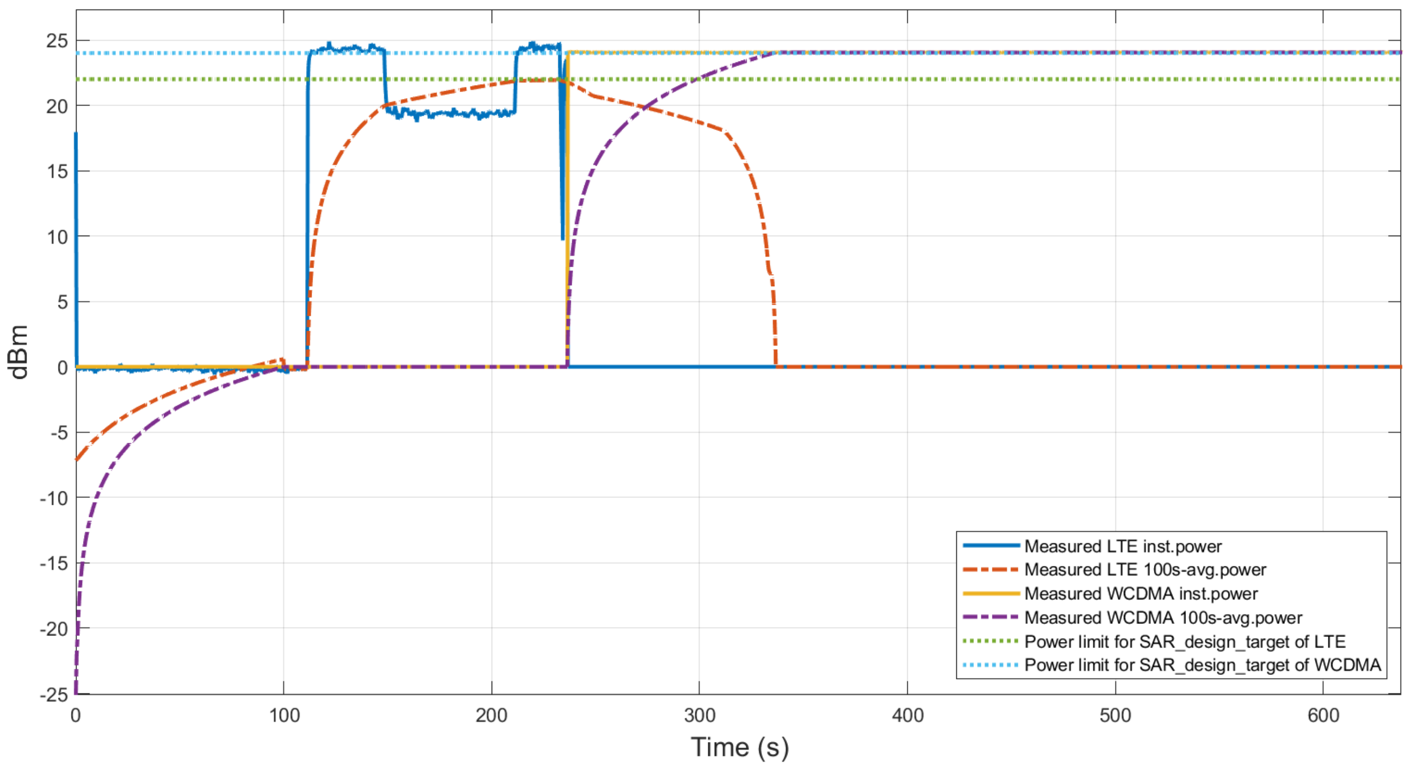
Plot.2 shows the time-averaged 1gSAR value for each of RSI values, as well as the total SAR value. We can see that the total 1gSAR is higher during the band transitions, but is always under the total FCC limit of 1.6W/Kg.

FCC1g SAR limit	**1.6**	W/kg
Max 100s-time averaged 1gSAR (blue curve)	**0.992**	W/kg
Device uncertainty	**1.0**	dB

6.10 TC14 : TAS to non TAS H.O. test results

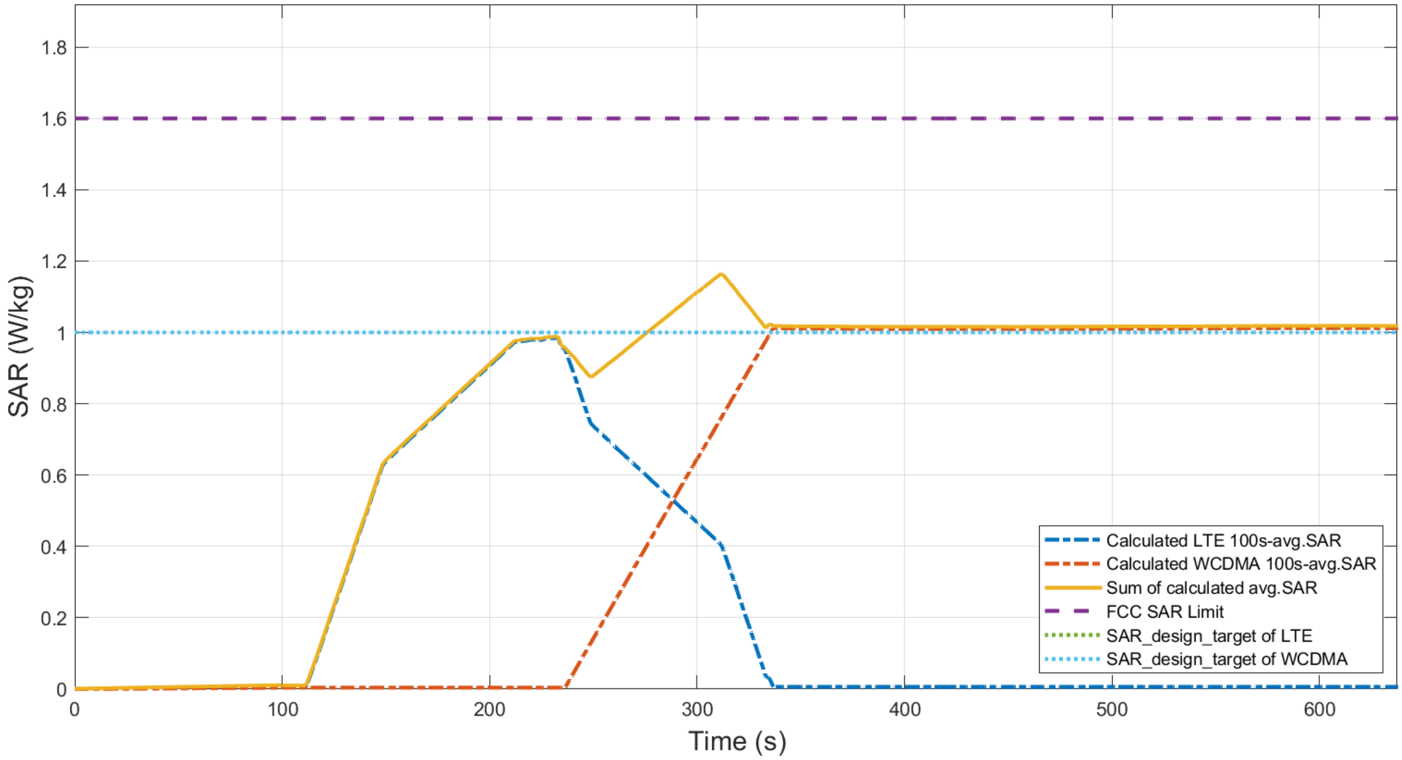
The test results in this section are obtained following the procedure in Section 3.3.6. The test cases correspond to TC14 in Table 6.2.1.

<u>Plot.1 : Conducted Tx power for SAR TAS to non TAS H.O. :</u>



Plot.1 shows the instantaneous and time-averaged conducted Tx power for both LTE Band and WCDMA Band for the duration of the test. Around time stamp of ~220s, a handover from LTE Band to WCDMA Band was executed, resulting in reduction of time-averaged power of LTE Band and simultaneous increase in time averaged power of WCDMA Band. Because WCDMA is nonTAS RAT, it always transmits maximum power. But when remaining SAR value is low after handover, nonTAS would limit the Tx power for a second to satisfy SAR Compliance.

Plot.2 : Total time-averaged SAR Result :



Plot.2 shows the time-averaged 1gSAR value for each of LTE Band and WCDMA Band, as well as the total SAR value. We can see that the total 1gSAR is higher during the band transitions, but is always under the total FCC limit of 1.6W/Kg.

FCC1g SAR limit	**1.6** W/kg
Max 100s-time averaged 1gSAR (blue curve)	**1.165** W/kg
Device uncertainty	**1.0** dB

7. Radiated Power Test Results for mmWave(FR2) TAS validation

7.1 Measurement set-up

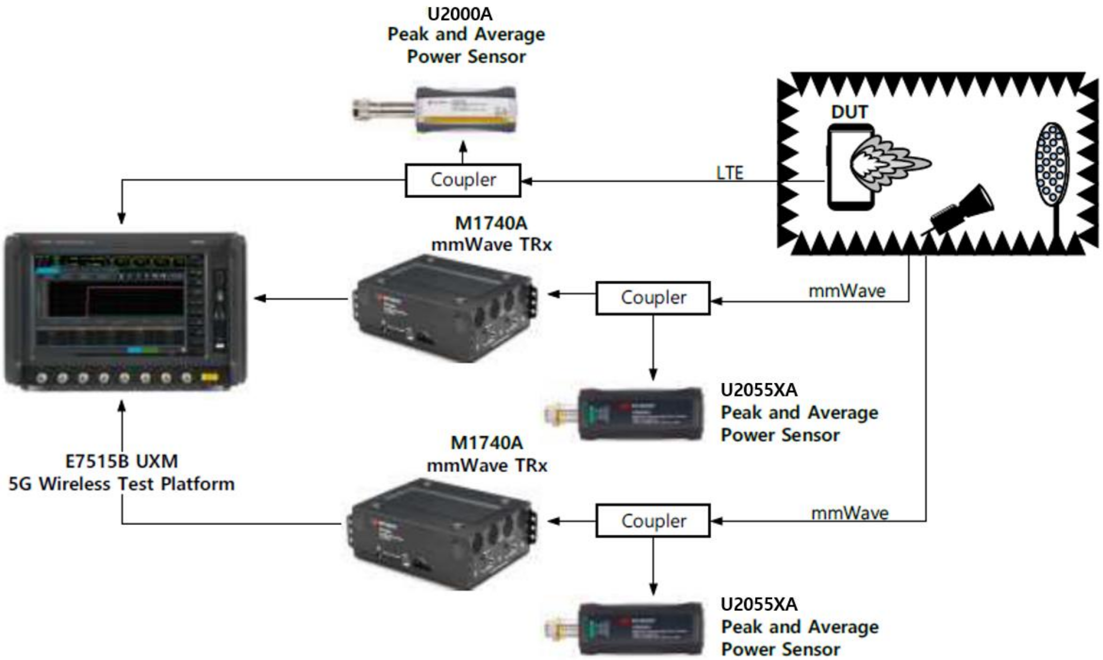


Figure 7.1-1 Test set-up for mmWave(FR2)

In mmWave technology, we are not able to measure conducted power at antenna, so only radiated power in the form of EIRP (equivalent isotropically radiated power) will be measured in an anechoic chamber. The test setup is illustrated in Figure 7.1-1. For NSA (non-standalone) operation, legacy LTE technology will also be active and this connection can be done via a connected port of the DUT. A power sensor can be coupled to the LTE transmission. There is a concept of two orthogonal polarization measurements (horizontal and vertical) in mmWave, and so two additional power sensors are needed to measure both. There are remote radio-heads required to performance up/down-conversion of the mmWave signal from/to the call box. The Keysight UXM call box is capable of establishing both LTE and FR2 connections. The coupled power sensors in mmWave uplink will be logged along with the LTE power simultaneously for post-processing on the PC. The LTE power is then mapped to SAR, while the mmWave power readings will be mapped to PD using the characterization data. The direction of DUT is set to see the worst case corresponding to module and beam showing the highest PD in characterization as described in Section 4.3. By validation in this conservative worst PD case, all other cases can be regarded as to be validated as well.
In summary, PD test has to be executed as following procedure (detailed procedure in Section 4.3).

1. Measure conduction sub 6GHz Tx power corresponds to SAR regulation and measure Tx EIRP corresponds to PD regulation. For mmWave, E-field PD measurement TE is used instead of EIRP measurements.
2. Set sub 6GHz and mmWave power level with some margin. And start the test.
3. Execute time-varying test scenarios. And record sub 6GHz power using sub 6GHz power meter equipment and EIRP value using mmWave power meter.
4. Plot the recorded results over measurement time. And evaluate the results for validation.

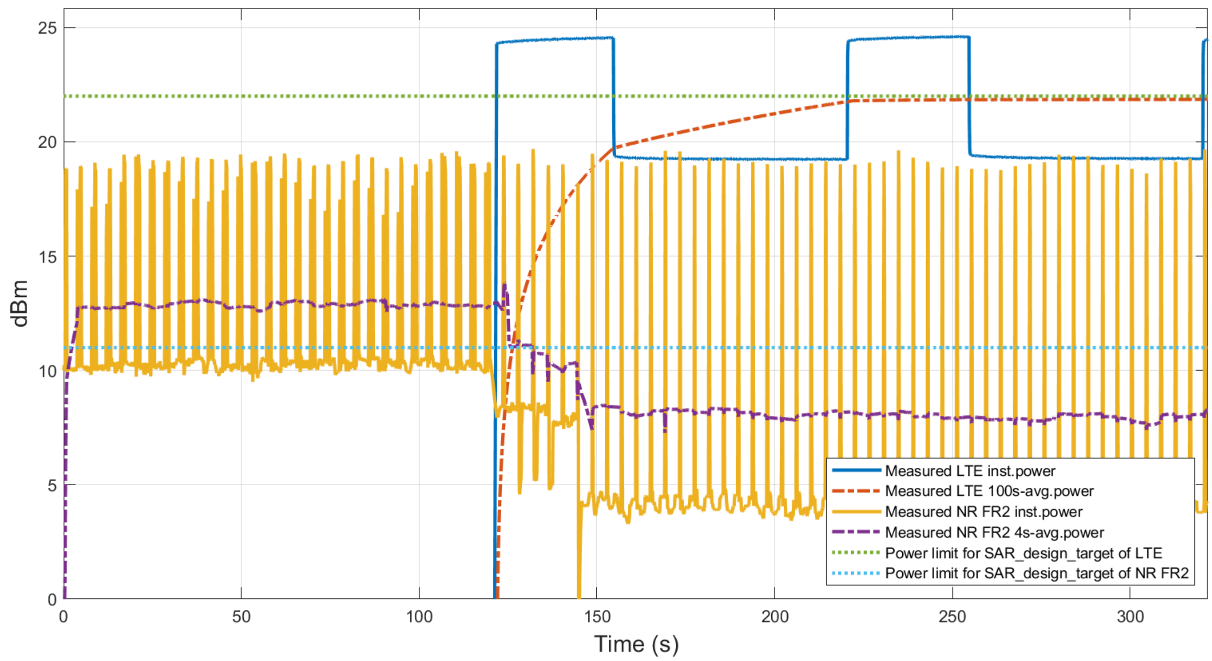
Note that Plimit is different according to the used OEM, so it is necessary to set the Plimit suitable for each terminal.

7.2 Time-varying Tx power measurement results

The results in this section were obtained following the procedure in Section 4.3.1 and corresponds to the test case TC10 in Table 7.2.1.

7.2.1 TC10 : mmWave_n261_Max_Tx_Power results

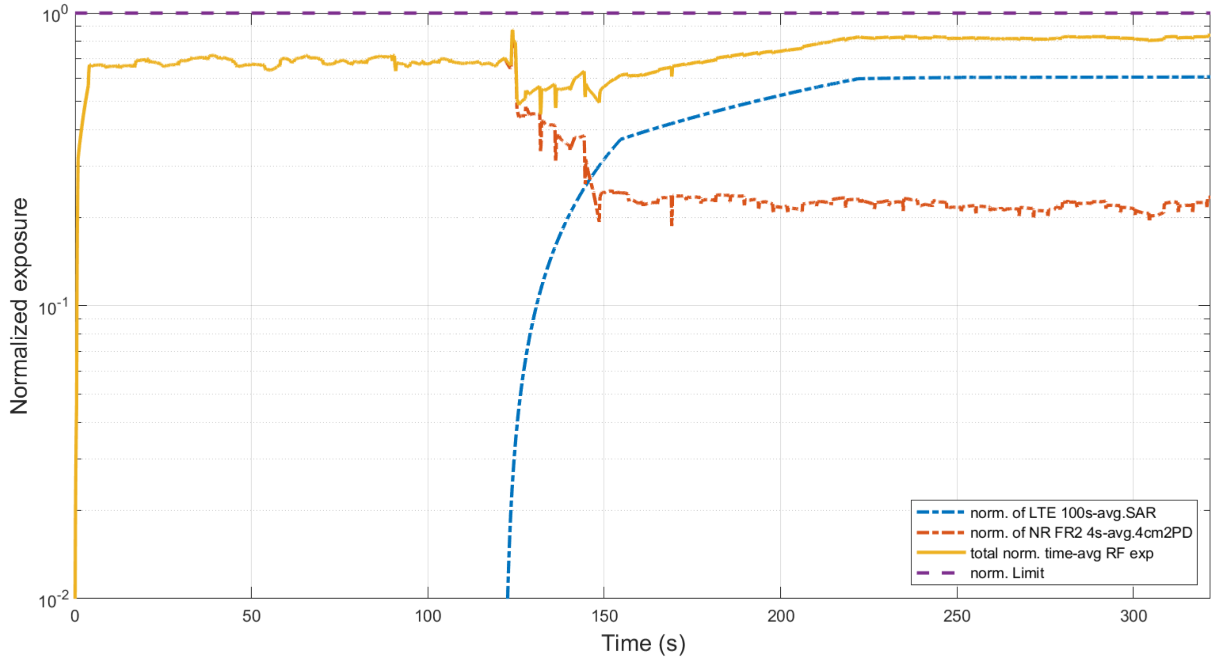
Plot.1 : Conducted power of LTE band and radiated EIRP of FR2 band in EN-DC :



Plot.1 shows the instantaneous and time-averaged conducted power for LTE and radiated power for NR FR2. When LTE is operated, FR2 power would be decreased to maintain TER value. After the average power of LTE is saturated as target power, the average power of FR2 is not decreased any more. As a result, although LTE is turned on, the TER value doesn't increase or decrease.

Band	Plimit (dBm)	PD or SAR_Design target	
LTE Band 4	22.0	SAR	1.0 W/kg
FR2 Band n261	11.0	PD	4.42 W/m^2

Plot.2 : Total normalized time-averaged RF exposure Result :

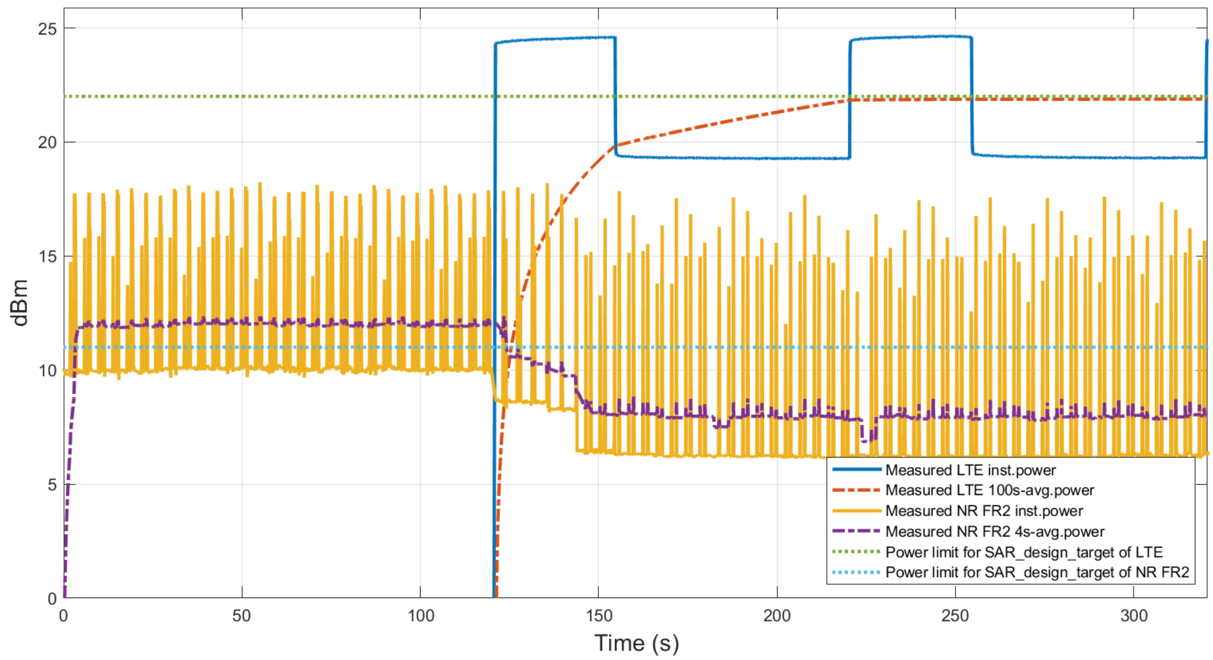


Plot.2 shows the computed normalized and time-averaged SAR and PD values for LTE and NR FR2, respectively, as well as their sum which is the TER value. We can see that the TER is always under the FCC compliance limit of 1.0, thus validating the TAS feature in this test case.

FCC requirement for total RF exposure (normalized)	**1.0**
Max total normalized time-averaged RF exposure (yellow curve)	**0.878**
Validated	

7.2.2 TC10 : mmWave_n260_Max_Tx_Power results

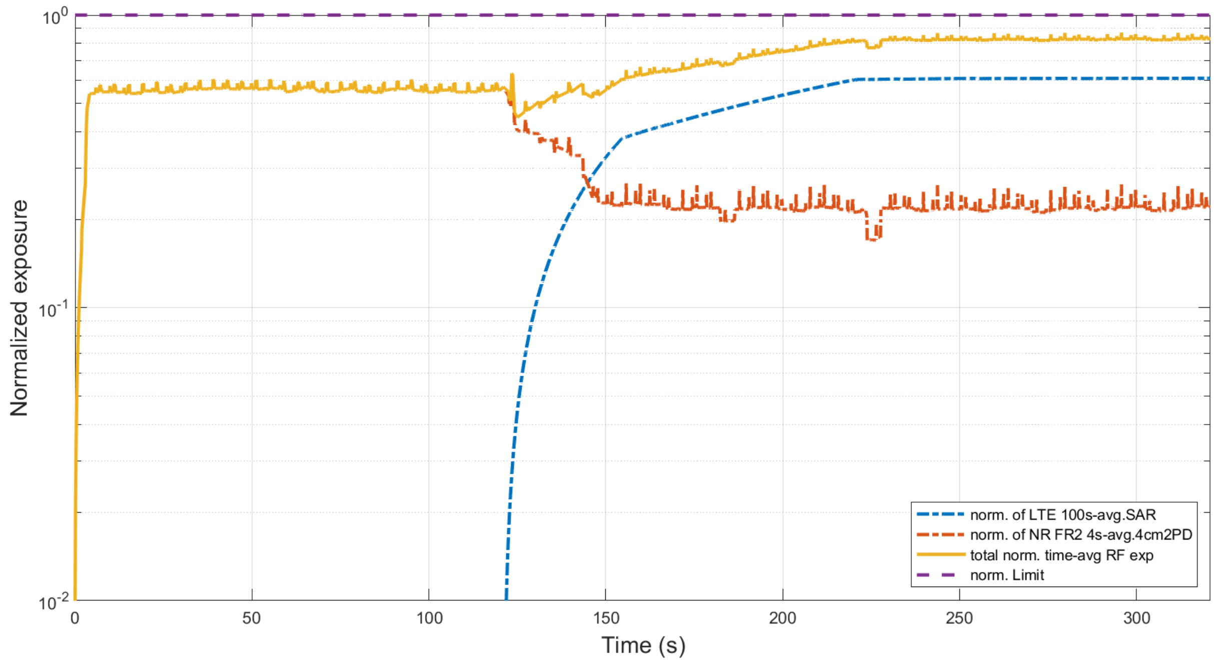
Plot.1 : Conducted power of LTE band and radiated EIRP of FR2 band in EN-DC :



Plot.1 shows the instantaneous and time-averaged conducted power for LTE and radiated power for NR FR2. When LTE is operated, FR2 power would be decreased to maintain TER value. After the average power of LTE is saturated as target power, the average power of FR2 is not decreased any more. As a result, although LTE is turned on, the TER value doesn't increase or decrease.

Band	Plimit (dBm)	PD or SAR_Design target	
LTE Band 4	22.0	SAR	1.0 W/kg
FR2 Band n260	11.0	PD	4.42 W/m^2

Plot.2 : Total normalized time-averaged RF exposure Result :



Plot.2 shows the computed normalized and time-averaged SAR and PD values for LTE and NR FR2, respectively, as well as their sum which is the TER value. We can see that the TER is always under the FCC compliance limit of 1.0, thus validating the TAS feature in this test case.

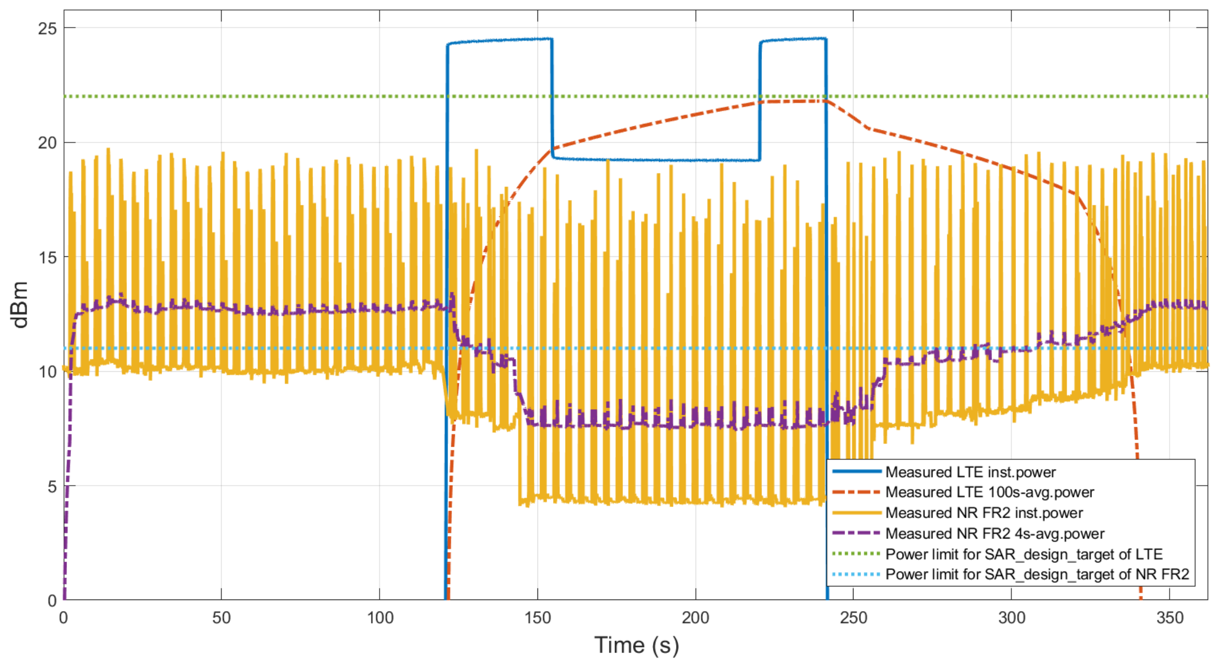
FCC requirement for total RF exposure (normalized)	**1.0**
Max total normalized time-averaged RF exposure (yellow curve)	**0.872**
Validated	

7.3 SAR vs. PD exposure switch test results

The results in this section were obtained following the procedure in Section 4.3.2 and corresponds to the test case TC11 in Table 7.2.1.

7.3.1 TC11 : mmWave_n261_Dominant_Power_Switching results

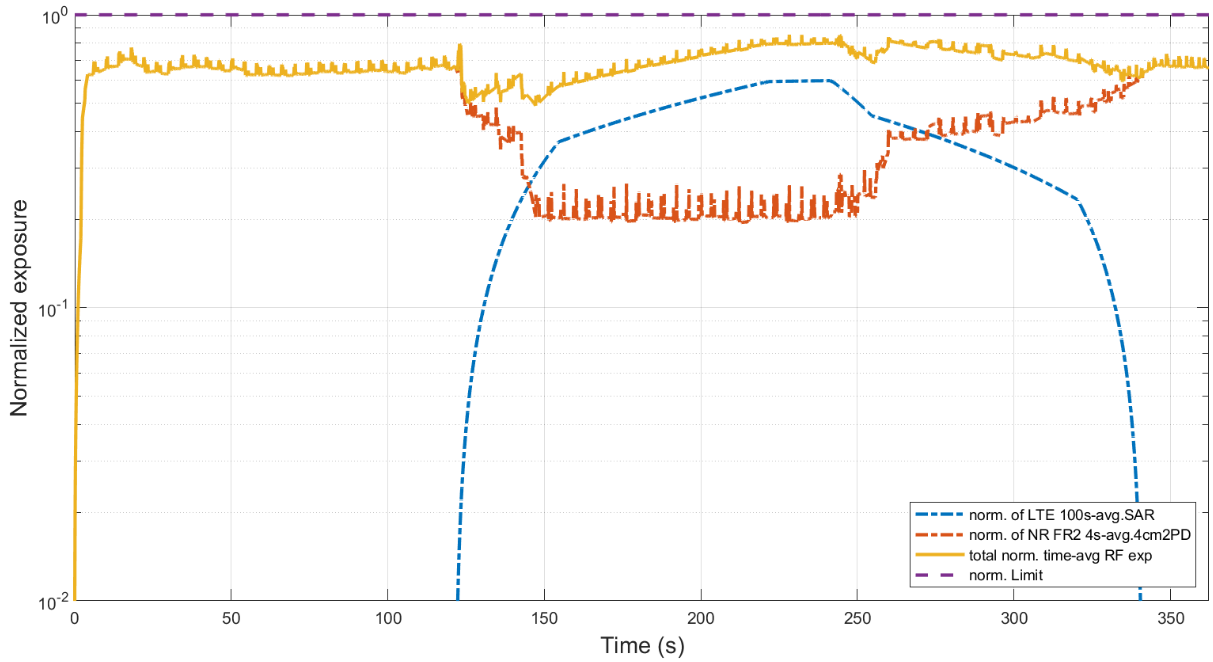
Plot.1 : Conducted power of LTE band and radiated EIRP of FR2 band in EN-DC :



Plot.1 shows the instantaneous and time-averaged conducted power for LTE and radiated power for NR FR2. When LTE is operated, FR2 power would be decreased to maintain TER value. After the average power of LTE is saturated as target power, the average power of FR2 is not decreased any more. After LTE is turned off, the average power of FR2 is increased to restore the original target power. As a result, whether LTE is turned on or not, the TER value dramatically doesn't increase or decrease.

Band	Plimit (dBm)	PD or SAR_Design target	
LTE Band 4	22.0	SAR	1.0 W/kg
FR2 Band n261	11.0	PD	4.42 W/m^2

Plot.2 : Total normalized time-averaged RF exposure Result :

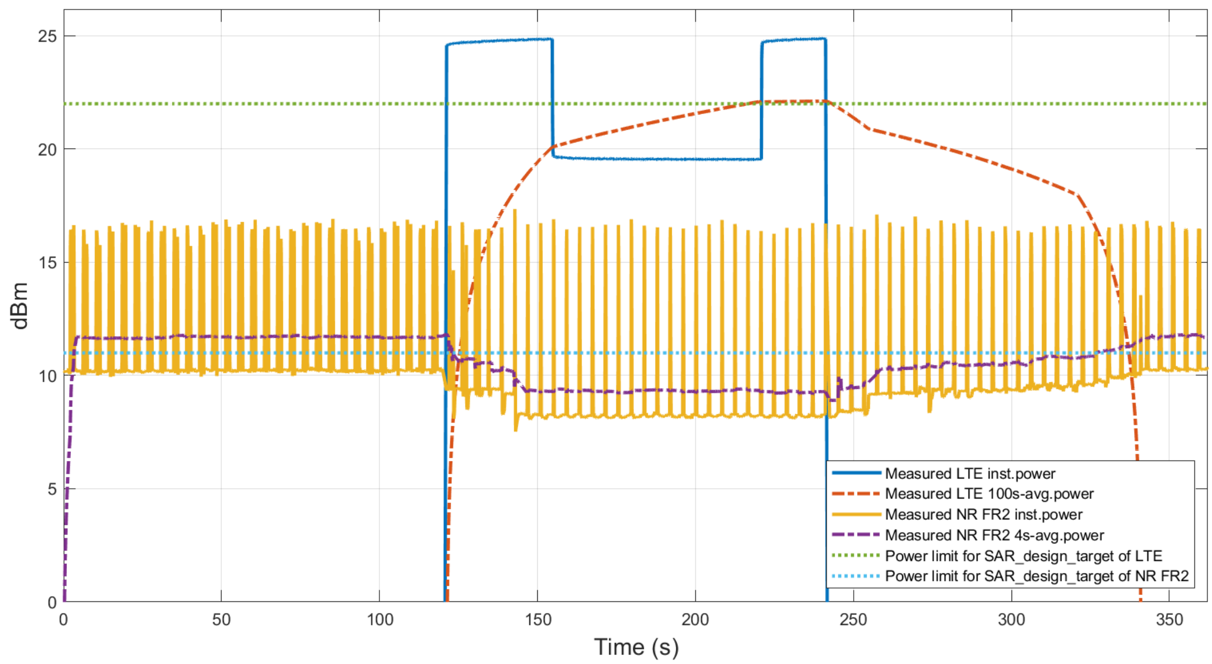


Plot.2 shows the computed normalized and time-averaged SAR and PD values for LTE and NR FR2, respectively, as well as their sum which is the TER value. We can see that the TER is always under the FCC compliance limit of 1.0, thus validating the TAS feature in this test case.

FCC requirement for total RF exposure (normalized)	**1.0**
Max total normalized time-averaged RF exposure (yellow curve)	**0.856**
Validated	

7.3.2 TC11 : mmWave_n260_Dominant_Power_Switching results

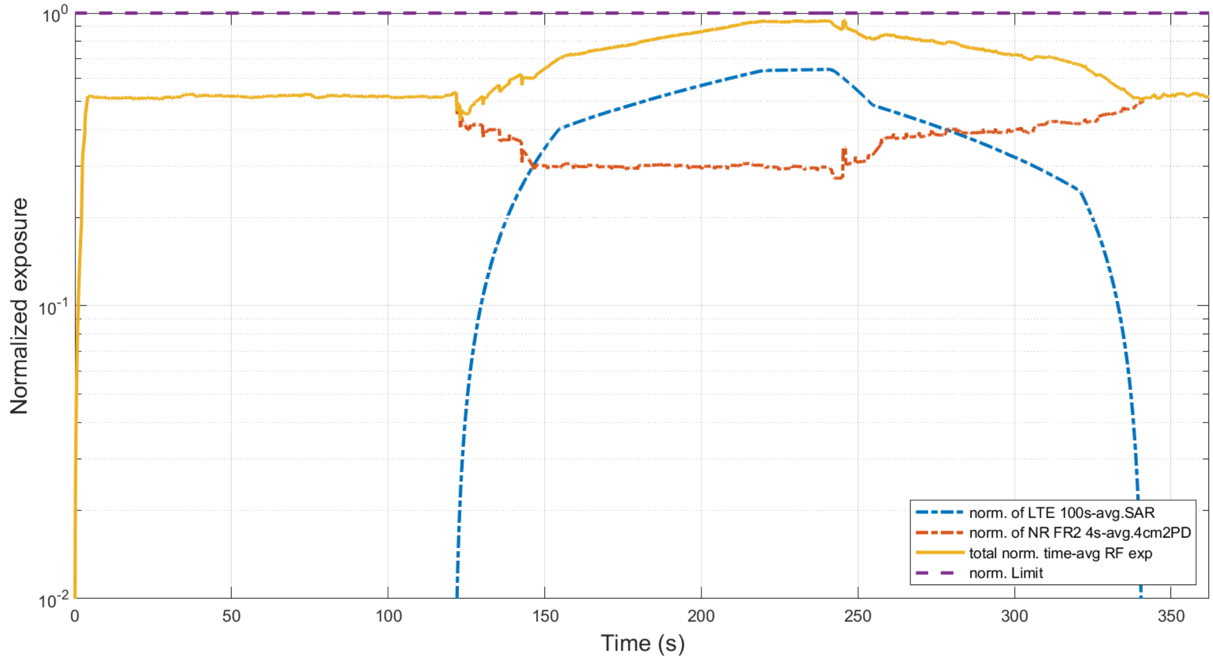
Plot.1 : Conducted power of LTE band and radiated EIRP of FR2 band in EN-DC :



Plot.1 shows the instantaneous and time-averaged conducted power for LTE and radiated power for NR FR2. When LTE is operated, FR2 power would be decreased to maintain TER value. After the average power of LTE is saturated as target power, the average power of FR2 is not decreased any more. After LTE is turned off, the average power of FR2 is increased to restore the original target power. As a result, whether LTE is turned on or not, the TER value dramatically doesn't increase or decrease.

Band	Plimit (dBm)	PD or SAR_Design target	
LTE Band 2	22.0	SAR	1.0 W/kg
FR2 Band n260	11.0	PD	4.42 W/m^2

Plot.2 : Total normalized time-averaged RF exposure Result :



Plot.2 shows the computed normalized and time-averaged SAR and PD values for LTE and NR FR2, respectively, as well as their sum which is the TER value. We can see that the TER is always under the FCC compliance limit of 1.0, thus validating the TAS feature in this test case.

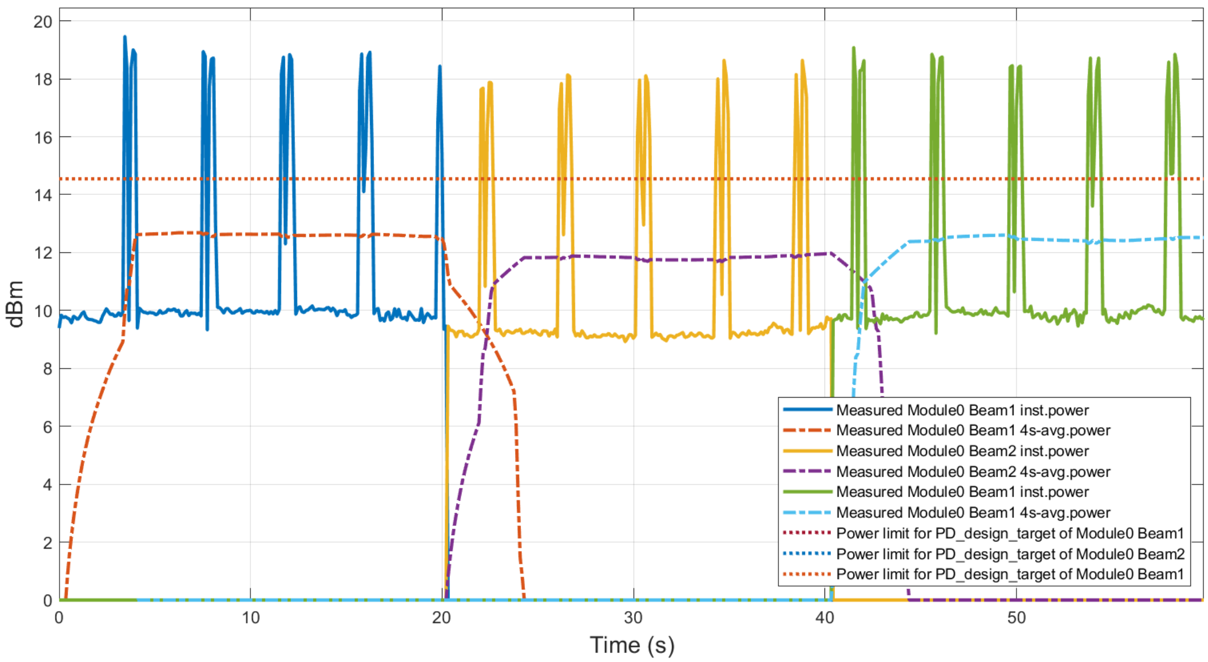
FCC requirement for total RF exposure (normalized)	**1.0**
Max total normalized time-averaged RF exposure (yellow curve)	**0.946**
Validated	

7.4 FR2 beam change

The results in this section were obtained following the procedure in Section 4.3.3 and corresponds to the test case TC12 in Table 7.2.1.

7.4.1 TC12 : mmWave_n261_Module_Beam_change results

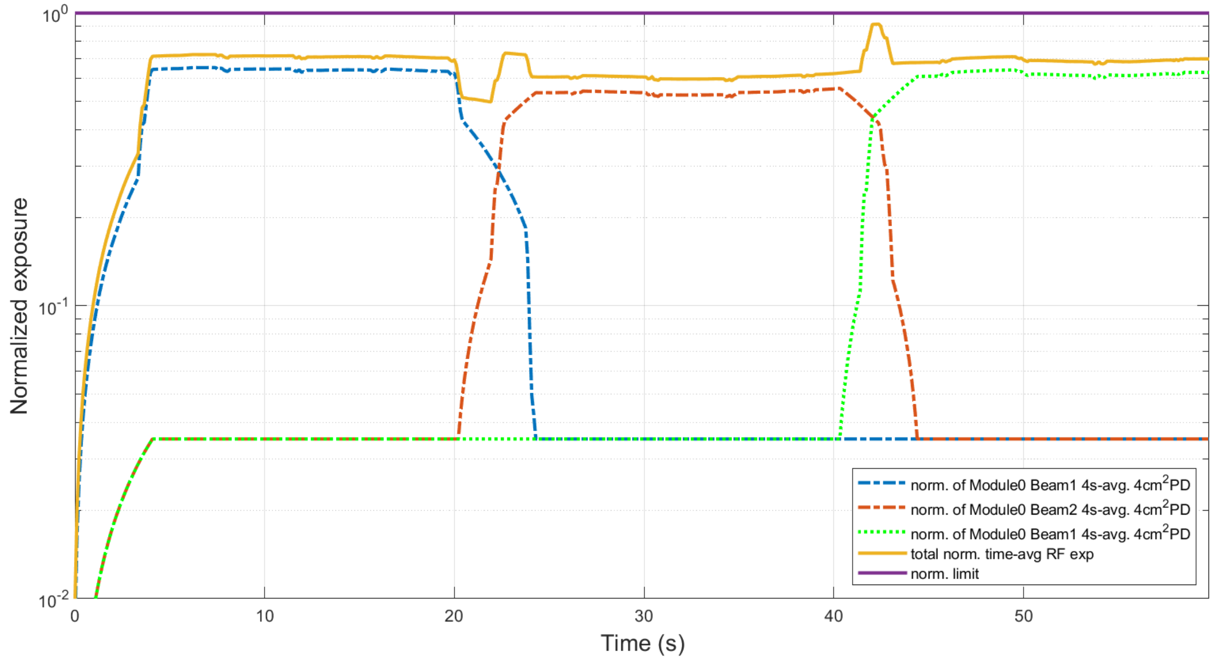
Plot.1 : Measured radiated EIRP of FR2 n261 in mmWave Module beam change :



Plot.1 shows the instantaneous and time-averaged radiated power for NR FR2. We don’t show the LTE transmit power, since it would be at the lowest level and doesn’t meaningfully contribute to the TER.

Band	Plimit (dBm)	PD or SAR_Design target	
FR2 Band n261	11.0	PD	4.42 W/m^2

Plot.2 : Total normalized time-averaged RF exposure Result :

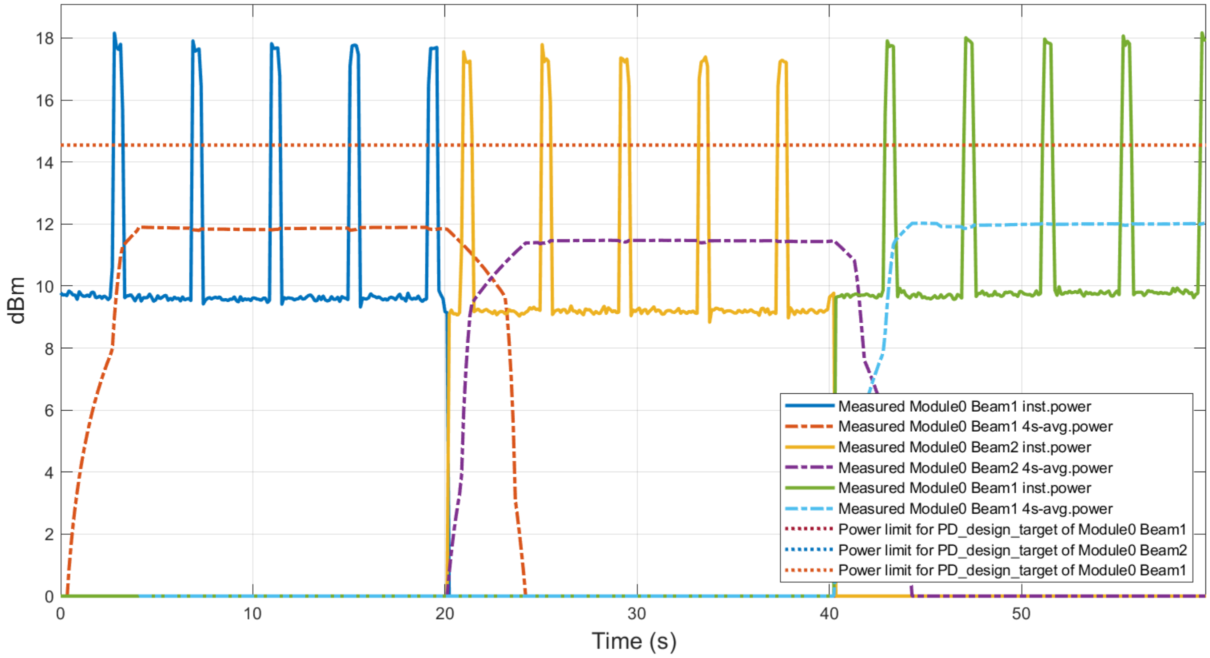


Plot.2 shows the computed time-averaged PD for each selected module/beam setting as well as the total sum. When beam or module of FR2 would be changed, the sum of each beam/module is not higher than the target power limit. As a result, whether beam/module is changed or not, the TER value dramatically doesn't increase.

FCC requirement for total RF exposure (normalized)	**1.0**
Max total normalized time-averaged RF exposure (yellow curve)	**0.917**
Validated	

7.4.2 TC12 : mmWave_n260_Module_Beam_change results

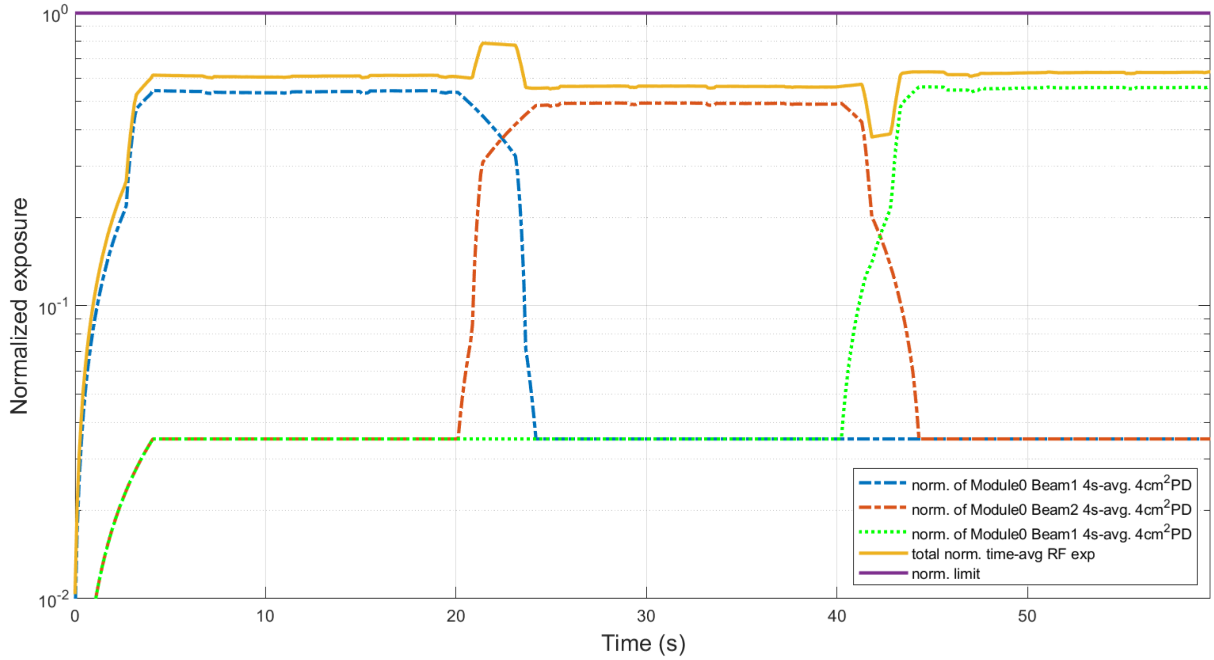
Plot.1 : Measured radiated EIRP of FR2 n261 in mmWave Module beam change :



Plot.1 shows the instantaneous and time-averaged radiated power for NR FR2. We don't show the LTE transmit power, since it would be at the lowest level and doesn't meaningfully contribute to the TER.

Band	Plimit (dBm)	PD or SAR_Design target	
FR2 Band n260	11.0	PD	4.42 W/m^2

Plot.2 : Total normalized time-averaged RF exposure Result :



Plot.2 shows the computed time-averaged PD for each selected module/beam setting as well as the total sum. When beam or module of FR2 would be changed, the sum of each beam/module is not higher than the target power limit. As a result, whether beam/module is changed or not, the TER value dramatically doesn't increase.

FCC requirement for total RF exposure (normalized)	**1.0**
Max total normalized time-averaged RF exposure (yellow curve)	**0.789**
Validated	

8. Test Equipment

The measuring equipment used to perform the tests documented in this report has been calibrated in accordance with the manufacturers' recommendations, and is traceable to recognized national standards.

Conducted test

Name of Equipment	Manufacturer	Type/Model	Serial No.	Cal. Due Date
Power Sensor	Anritsu	MA2472D	2014271	9-8-2023
Power Sensor	Anritsu	MA2472D	2014291	9-8-2023
Power Meter	Anritsu	MT8821C	2212002	9-8-2023
Directional Coupler	KRYTAR	100318010	215541	1-5-2024
Directional Coupler	KRYTAR	100318010	215542	1-5-2024
Band Pass Filter	MINI-CIRCUITS	VBFZ-3590-S+	S0242	1-6-2024
Band Pass Filter	MINI-CIRCUITS	VBFZ-2000-S+	S0238	1-6-2024
Resistive Power Splitter	WEINSCHEL	1534	S0244	1-5-2024
Radio Communication Test Station	Anritsu	MT8000A	6272466165	9-8-2023
Radio Communication Analyzer	Anritsu	MT8821C	6161094351	11-29-2023

Radiated test

Name of Equipment	Manufacturer	Type/Model	Serial No.	Cal. Due Date
Base Station Simulator	R & S	CMW500	150314	8-2-2023
UXM 5G Wireless Test Platform	Keysight	E7515B	MY59150850	1-9-2024
mmWave Transceiver(RRH)	Keysight	M1740A	MY58270356	1-9-2024
mmWave Transceiver(RRH)	Keysight	M1740A	MY58270541	1-9-2024
Common Interface Unit	Keysight	E7770A	MY58290155	-
Power Sensor	Keysight	U2000A	MY54260010	8-3-2023
Average Power Sensor	Keysight	U2055XA	MY60000072	8-4-2023
Average Power Sensor	Keysight	U2055XA	MY60000073	8-4-2023
Coupler	KRYTAR	1850	164428	8-1-2023
Directional Coupler	Keysight	87301C	US55330276	8-3-2023
Directional Coupler	Keysight	87301C	US55330277	8-3-2023

9. Conclusions

Samsung Time-Averaging SAR (TAS) feature employed in A has been validated through conducted power measurement as well as SAR measurement. As demonstrated in this report, TAS feature limit the transmit power effectively and shows that SAR value does not exceed 1.6 W/Kg and the TER value does not exceed 1.0 for all the transmission scenarios described in Section 2.

Section A. Test Sequences

A.1 Test sequence is generated based on below parameters of the DUT :

1. Measured maximum power (P_{max})
2. Measured Tx power (P_{limit}) to satisfy SAR Compliance
3. Setup time to make SAR Remaining be full
4. Do test according to test sequence

A.2 Test sequence A waveform :

Based on the parameters above, the Test Sequence A is generated with two power levels.
One is maximum power level and the other is lower power level. The lower power level is defined as 3dB lower value than maximum power level. At first, maximum power level is applied for 100 seconds (SAR_time_window x 1.0). After then, lower power level is used until this test is finished.

A.3 Test sequence B waveform :

Based on the parameters above, the Test Type B is generated with pre-defined power levels, which is described in Table A.3.1.

Table A.3.1 Table of test sequence B

Time duration (second)	Power level (dB)
15	P_{limit} - 5
20	P_{limit}
20	P_{limit} + 5
10	P_{limit} – 6
20	P_{max}
15	P_{limit}
15	P_{limit} -7
20	P_{max}
10	P_{limit}-5
15	P_{limit}
10	P_{limit}-6
20	P_{limit} + 5
10	P_{limit} – 4
15	P_{limit}
10	P_{limit} – 6
20	P_{max}
15	P_{limit}-8
15	P_{limit}
20	P_{max}
10	P_{limit} – 9
20	P_{limit} + 5
20	P_{limit}
15	P_{limit} – 5

Section B. References

The following documents contain reference in this technical document.

[1] 3GPP TR 37.815: Study on high power User Equipment (UE) (power class 2) for E-UTRA (Evolved Universal Terrestrial Radio Access) – NR Dual Connectivity (EN-DC) (1 LTE FDD band + 1 NR TDD band)

Appendixes

Refer to separated files for the following appendixes.

4790632299-S1 FCC Report SAR Part2_App A_Test setup photos

End OF REPORT