

## APPENDIX D: TOTAL EXPOSURE RATIO

The Total Exposure Ratio (TER) is calculated by combining all SAR measurements and power density measurements after normalizing to their respective limits. The general expression is below.

$$TER = \sum_{a=1}^A \frac{SAR_a}{SAR_{a, limit}} + \sum_{b=1}^B \frac{SAPD_b}{SAPD_{b, limit}} < 1$$

The TER shall be less than unity to ensure compliance with the limits.

$$\sum_{n=1}^N \frac{4G SAR_n}{4G SAR_{n, limit}} + \sum_{m=1}^M \frac{5G mmW NR SAPD_m}{5G mmW NR SAPD_{m, limit}} + \sum_{p=1}^P \frac{WLAN SAR_p}{WLAN SAR_{p, limit}} < 1$$

Qualcomm® Smart Transmit algorithm for WWAN adds directly the time-averaged RF exposure from 4G and time-averaged RF exposure from 5G mmW NR. Smart Transmit algorithm controls the total RF exposure from both 4G and 5G mmW NR to not exceed FCC limit. Therefore, per FCC guidance, TER does not need to be evaluated directly for the 4G and 5G simultaneous compliance via summation. The following equations are derived in Appendix D page 4. The validation of the time-averaging algorithm and compliance under the Tx varying transmission scenario for WWAN technologies are reported in Part 2 report. The report SN could be found in Bibliography section.

$$\sum_{n=1}^N \frac{4G SAR_n}{4G SAR_{n, limit}} + \sum_{p=1}^P \frac{WLAN SAR_p}{WLAN SAR_{p, limit}} < 1$$

$$\sum_{m=1}^M \frac{5G mmW NR SAPD_m}{5G mmW NR SAPD_{m, limit}} + \sum_{p=1}^P \frac{WLAN SAR_p}{WLAN SAR_{p, limit}} < 1$$

For 5G mmW NR, since there is total design-related uncertainty arising from TxAGC and device-to-device variation, the worst-case RF exposure should be determined by accounting for this device uncertainty of 2.8 dB. Smart Transmit algorithm limits PD exposure to 75% of maximum to provide at least 25% margin allocated for 4G LTE anchor due to the 3 dB reserve power margin used in the device. Therefore, 5G mmW NR RF exposure for this DUT is evaluated by reported PSPD calculated as:

$$reported\_psPD = 75\% \times PD\_design\_target + 2.8 dB = 7.5 W/m^2$$

Note that since not all the beams supported by this EUT are measured, *reported\_PSPD* cannot be computed based on limited *measured PSPD* data. Alternatively, since *measured PSPD* for all the beams will be  $\leq PD\_design\_target + 2.8$  dB uncertainty, *reported\_PSPD* is computed based on this worst-case PSPD as shown above.

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The compliance analysis for simultaneous transmission scenarios of WWAN (4G LTE & 5G mmW NR) with Smart Transmit and 4G & WLAN can be found in two reports indicated in the table below. This appendix demonstrates compliance for the 5G + WLAN scenarios. The report SNs can be found in Bibliography section.

	<b>Simultaneous Scenario</b>	<b>Evaluation Report</b>
1.	4G LTE WWAN + WLAN	FCC SAR Evaluation Report (Part 1)
2.	4G LTE WWAN + 5G mmW NR WWAN	RF Exposure Part 2 Test Report

RF exposure compliance with 5G mmW NR WWAN+WLAN simultaneous transmission scenarios is demonstrated for various radio configurations below.

Note that the above *reported PSPD* applies to the worst-surface of the DUT at 2mm evaluation distance. For this DUT, the worst-surface(s) are listed in Table 1-9.

Worst-case PD on other surfaces of the DUT are calculated from simulated PD data (see Section 4.6 of Power Density Simulation Report, report SN could be found in Section 1.7 - Bibliography), by multiplying reported PSPD with the highest proportion out of all beams and out of all three channels in each band, where the adjustment for each beam/channel is computed as the proportion of “simulated PD on desired surface” to “simulated PD on worst-surface”. For example, to determine worst-case PD on front surface (needed for Head RF Exposure evaluation during simultaneous transmission), highest proportion of (simulated PD on front surface)/(simulated PD on worst surface) was determined out of all supported beams and out of all three channels by the DUT in each band.

In some cases, the simulation vs measurement for some surfaces can exceed the device's total uncertainty. In those cases, if the measured psPD > simulated adjusted psPD (assuming a linear congruency of the psPD across surfaces), then 75% of the measured value (based on the 3 dB reserve power margin) should be used towards the simultaneous TX analysis. Table D-1 lists the relevant worst-case reported psPD values based on the additional surfaces and evaluation distances needed to perform the TER analysis. The highest of the adjusted Reported\_psPD and Measured Total psPD\* 0.75 was chosen for TER analysis and the chosen values are indicated by bolded psPD values.

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**Table D-1  
5G mmW NR psPD**

NR Band	Surface	Evaluation Distance (mm)	Adjustment Factor due to Simulation	Adjusted Reported psPD (W/m2)	Measured Total psPD (W/m2)	Reported Total psPD x 0.75 (W/m2)
n261	Back	2	1.000	<b>7.500</b>	-	-
	Front	2	0.637	<b>4.778</b>	2.39	1.793
	Top	2	0.136	<b>1.020</b>	1.16	0.870
	Right	2	1.000	<b>7.500</b>	-	-
	Left	2	0.967	<b>7.253</b>	2.53	1.898
n260	Back	2	1.000	<b>7.500</b>	-	-
	Front	2	0.456	<b>3.420</b>	1.74	1.305
	Top	2	0.132	<b>0.990</b>	0.753	0.565
	Right	2	1.000	<b>7.500</b>	-	-
	Left	2	1.000	<b>7.500</b>	1.6	1.200

Note: Adjusted factor is (simulated PD on desired exposure plane)/(PD on worst-surface at 2mm evaluation distance) out of all beams and out of all channels. See Power Density Simulation Report, report SN could be found in Section 1.7 – Bibliography.

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**Table D-2  
5G mmW NR Head Total Exposure Ratio**

	psPD	2.4 GHz WLAN Ant1 at 15.5 dBm	2.4 GHz WLAN Ant2 at 15.5 dBm	2.4 GHz WLAN MIMO at 15.5 dBm	Bluetooth	5 GHz WLAN Ant1 at 18 dBm	5 GHz WLAN Ant2 at 18 dBm	5 GHz WLAN MIMO at 18 dBm	psPD + 2.4 GHz WLAN Ant1	psPD + 2.4 GHz WLAN Ant2	psPD + 2.4 GHz WLAN MIMO	psPD + 2.4 GHz WLAN Ant2 + BT	psPD + 5 GHz WLAN Ant1	psPD + 5 GHz WLAN Ant2	psPD + BT + 5 GHz WLAN MIMO	psPD + 2.4 GHz WLAN MIMO + 5 GHz WLAN MIMO
		W/m <sup>2</sup>	W/kg	W/kg	W/kg	W/kg	W/kg	W/kg	W/kg							
Applicable Limit	10.0	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Reported Value	4.778	0.498	0.308	0.512	0.159	0.365	0.219	0.305								
Ratio to Limit	0.478	0.311	0.193	0.320	0.099	0.228	0.137	0.191	0.789	0.670	0.798	0.770	0.706	0.615	0.768	0.988

**Table D-3  
5G mmW NR Body-Worn Total Exposure Ratio - Back Side at 10 mm**

	psPD	2.4 GHz WLAN Ant1 at 20.5 dBm	2.4 GHz WLAN Ant2 at 20.5 dBm	2.4 GHz WLAN MIMO at 15.5 dBm	Bluetooth	5 GHz WLAN Ant1 at 18 dBm	5 GHz WLAN Ant2 at 18 dBm	5 GHz WLAN MIMO at 15 dBm	psPD + 2.4 GHz WLAN Ant1	psPD + 2.4 GHz WLAN Ant2	psPD + 2.4 GHz WLAN Ant1 + 2.4 GHz WLAN Ant2	psPD + 2.4 GHz WLAN Ant2 + BT	psPD + 5 GHz WLAN Ant1	psPD + 5 GHz WLAN Ant2	psPD + BT + 5 GHz WLAN MIMO	psPD + 2.4 GHz WLAN MIMO + 5 GHz WLAN MIMO
		W/m <sup>2</sup>	W/kg	W/kg	W/kg	W/kg	W/kg	W/kg	W/kg							
Applicable Limit	10.0	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Reported Value	7.500	0.116	0.053	0.039	0.014	0.219	0.277	0.266								
Ratio to Limit	0.750	0.073	0.033	0.024	0.009	0.137	0.173	0.166	0.823	0.783	0.856	0.792	0.887	0.923	0.925	0.941

**Table D-4  
5G mmW NR Hotspot Total Exposure Ratio**

	psPD	2.4 GHz WLAN Ant1 at 20.5 dBm	2.4 GHz WLAN Ant2 at 20.5 dBm	2.4 GHz WLAN MIMO at 15.5 dBm	Bluetooth	5 GHz WLAN Ant1 at 18 dBm	5 GHz WLAN Ant2 at 18 dBm	5 GHz WLAN MIMO at 15 dBm	psPD + 2.4 GHz WLAN Ant1	psPD + 2.4 GHz WLAN Ant2	psPD + 2.4 GHz WLAN Ant1 + 2.4 GHz WLAN Ant2	psPD + 2.4 GHz WLAN Ant2 + BT	psPD + 5 GHz WLAN Ant1	psPD + 5 GHz WLAN Ant2	psPD + BT + 5 GHz WLAN MIMO	psPD + 2.4 GHz WLAN MIMO + 5 GHz WLAN MIMO
		W/m <sup>2</sup>	W/kg	W/kg	W/kg	W/kg	W/kg	W/kg	W/kg							
Applicable Limit	10.0	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Reported Value	7.500	0.116	0.053	0.039	0.014	0.219	0.277	0.266								
Ratio to Limit	0.750	0.073	0.033	0.024	0.009	0.137	0.173	0.166	0.823	0.783	0.856	0.792	0.887	0.923	0.925	0.941
Back Side at 10mm	Reported Value	7.500	0.116	0.053	0.039	0.014	0.219	0.266								
Ratio to Limit	0.750	0.073	0.033	0.024	0.009	0.097	0.144	0.114	0.823	0.783	0.856	0.792	0.847	0.894	0.873	0.889
Front Side at 10mm	Reported Value	4.778	0.358*	0.13*	0.066	0.020	0.037	0.015								
Ratio to Limit	0.478	0.224	0.081	0.041	0.013	0.023	0.009	0.018	0.702	0.559	0.783	0.572	0.501	0.487	0.508	0.537
Top Edge at 10mm	Reported Value	1.020	0.358*	0.13	0.101*	0.016	0.173*	0.231*								
Ratio to Limit	0.102	0.224	0.081	0.063	0.010	0.108	0.144	0.114	0.326	0.183	0.407	0.193	0.210	0.246	0.226	0.280
Right Edge at 10mm	Reported Value	7.500	0	0	0	0	0	0								
Ratio to Limit	0.750	0	0	0	0	0	0	0	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750
Left Edge at 10mm	Reported Value	7.500	0.358	0.015	0.101	0.047	0.173	0.231*								
Ratio to Limit	0.750	0.224	0.009	0.063	0.029	0.108	0.144	0.114	0.974	0.759	0.983	0.789	0.858	0.894	0.894	0.928

\* Note: For test positions that were not required to be evaluated for WLAN SAR per FCC KDB publication 248227, the worst-case WLAN SAR result for the applicable exposure conditions was used for simultaneous transmission analysis.

**Table D-5  
5G mmW NR Phablet Total Exposure Ratio**

	psPD	5 GHz WLAN Ant1 at 18 dBm	5 GHz WLAN Ant2 at 18 dBm	5 GHz WLAN MIMO at 15 dBm	psPD + 5 GHz WLAN Ant1	psPD + 5 GHz WLAN Ant2	psPD + 5 GHz WLAN MIMO
	W/m <sup>2</sup>	W/kg	W/kg	W/kg			
Applicable Limit	10.0	4.0	4.0	4.0	1.0	1.0	1.0
Reported Value	7.500	0.694	0.98	0.962			
Ratio to Limit	0.750	0.174	0.245	0.241	0.924	0.995	0.991

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**Notes:**

1. Worst-case power density results for each test configuration among all antenna arrays (QTM-0, QTM-1, QTM-2) and among all supported bands (n261, n260) were considered for TER analysis.
2. For back side, front side, top edge, left edge, and right edge, power density results at 2 mm were considered as a more conservative evaluation for 10 mm body-worn/hotspot.
3. Per FCC guidance, the bands/modes that are not required to be evaluated for Phablet SAR are not considered for TER analysis.
4. Per FCC guidance, for power density measurements, a test separation distance of 2 mm was used for phablet configuration due to probe restraints.
5. Worst-case front side reported psPD was considered for Head TER analysis.
6. The worst-case between Adjusted Reported\_psPD and Measured Total psPD x 0.75 was chosen for TER analysis. The bolded psPD values in Table D-1 indicate the worst-case Reported psPD used in TER analysis.

The above numerical summed PD and SAR for all the worst-case simultaneous transmission conditions were below the Total Exposure Ratio. Therefore, the above analysis is sufficient to determine no further test cases are required and that simultaneous transmission is compliant to the FCC RF Exposure Limit.

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## Mathematical Derivation of TER Compliance

$$\text{Total Normalized RFx} = \text{Normalized RFx}_{\text{Time Averaged WWAN}} + \text{Normalized RFx}_{\text{WLAN}} \leq 1.0 \quad (1)$$

Since WWAN Smart Transmit algorithm adds directly the time-averaged RF exposure from 4G and time-averaged RF exposure from 5G mmW NR, per chipset manufacturer's guidance, Normalized RF exposure from 4G and from 5G mmW NR could be assumed as

$$\text{Normalized RFx}_{\text{Time Averaged WWAN}} = \frac{4G \text{ SAR}}{4G \text{ SAR Limit}} + \frac{5G \text{ mmW NR SAPD}}{5G \text{ mmW NR SAPD Limit}} \leq 1.0 \quad (2)$$

Smart Transmit algorithm assumes that 4G and 5G mmW NR hotspots are co-located and therefore:

$$\text{Time Averaged WWAN} = [x(t) \times A] + [(1-x(t)) \times B] \leq 1.0 \text{ Normalized Limit} \quad (3)$$

$A = \text{Max normalized time-averaged SAR exposure from 4G}$

$B = \text{Max normalized time-averaged PD exposure from 5G mmW NR}$

$x(t) = \text{Ranges between } [0,1]$

$x(t) \times A = \text{Percentage of normalized time-averaged RF exposure from 4G}$

$(1-x(t)) \times B = \text{Remaining percentage of RF exposure contribution from 5G mmW NR}$

Smart Transmit controls "x" in real time such that the sum of these exposures never exceeds 1.0 Normalized Limit. If the equations below (4a, 4b) are proven, then, mathematically equation (5) would be proven.

$$A + \text{norm. SAR from WLAN} \leq 1.0 \text{ normalized limit} \quad (4a)$$

$$B + \text{norm. SAR from WLAN} \leq 1.0 \text{ normalized limit} \quad (4b)$$

$$[x(t) \times A] + [(1-x(t)) \times B] + \text{norm. SAR from WLAN} \leq 1.0 \text{ normalized limit} \quad (5)$$

Without 5G mmW NR, Smart Transmit limits the maximum RF exposure contributed from 4G to 100% normalized exposure. With 5G mmW NR, Smart Transmit limits the maximum RF exposure contributed from 5G mmW NR to 75% normalized exposure to guarantee at least 25% margin allocated to 4G LTE anchor to maintain the link. Therefore,

$$\text{Smart Tx WWAN: } A = \max(\text{normalized SAR exposure from 4G}) \leq 1.0 \text{ normalized limit} \quad (6a)$$

$$\text{Smart Tx WWAN: } B = 0.75 \times \max(\text{normalized PD exposure from 5G mmW NR}) \leq 1.0 \text{ normalized limit} \quad (6b)$$

To demonstrate simultaneous transmission compliance in equation (1), below equations (7a & 7b) obtained by combining equations (4a & 4b) and (6a & 6b), should be proven for simultaneous transmission compliance:

$$\text{Total Normalized RFx} = \text{Normalized SAR}_{4G \text{ WWAN}} + \text{Normalized SAR}_{\text{WLAN}} < 1.0 \quad (7a)$$

$$\text{Total Normalized RFx} = 0.75 \times \text{Normalized SAPD}_{5G \text{ mmW NR WWAN}} + \text{Normalized SAR}_{\text{WLAN}} < 1.0 \quad (7b)$$

which are re-written as:

$$\text{Total Normalized RFx} = \frac{4G \text{ SAR}}{4G \text{ SAR Limit}} + \frac{\text{WLAN SAR}}{\text{WLAN SAR Limit}} < 1 \quad (8a)$$

$$\text{Total Normalized RFx} = 0.75 * \frac{5G \text{ mmW NR SAPD}}{5G \text{ mmW NR SAPD Limit}} + \frac{\text{WLAN SAR}}{\text{WLAN SAR Limit}} < 1 \quad (8b)$$

Analysis for equation (8a) is performed in Section 12 of FCC SAR Evaluation Report (Part 1). Analysis for equation (8b) is performed in this appendix, Tables D-2 to D-5.

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