APPENDIX C: TOTAL EXPOSURE RATIO

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PY7-57441Y				Quality Manager
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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.

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

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

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

Qualcomm® Smart Transmit algorithm for WWAN adds directly the time-averaged RF exposure from 4G and time-averaged RFexposure 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 later in Appendix C. 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.

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

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

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 device uncertainty. 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:

$$reported\_psPD = 75\% \times PD\_design\_target + PD\_uncertainty = 0.75\ mW/cm^2$$

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 ≤ *PD_design_target + PD_uncertainty* 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.

	Simultaneous Scenario	Evaluation Report
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-case surfaces of the DUT at 2mm evaluation distance.

Worst-case PD on other surfaces of the DUT are calculated from simulated PD data (see Power Density Simulation Report), 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 C-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 C-1
5G mmW NR psPD

NR Band	Surface	Evaluation Distance (mm)	Adjustment Factor due to Simulation	Adjusted Reported psPD (mW/cm²)	Measured Total psPD (mW/cm²)	Measured Total psPD x 0.75 (mW/cm²)	Final Reported psPD (mW/cm²)
n261	Back	2	0.659	0.494	0.266	0.200	**0.494**
n261	Front	2	0.627	0.470	0.333	0.250	**0.470**
n261	Top	2	1.000	0.750	0.452	0.339	**0.750**
n261	Bottom	2	1.000	0.750	0.468	0.351	**0.750**
n261	Right	2	1.000	0.750	0.430	0.323	**0.750**
n261	Left	2	1.000	0.750	0.463	0.347	**0.750**
n260	Back	2	0.820	0.615	0.369	0.277	**0.615**
n260	Front	2	0.617	0.463	0.307	0.230	**0.463**
n260	Top	2	1.000	0.750	0.476	0.357	**0.750**
n260	Bottom	2	1.000	0.750	0.377	0.283	**0.750**
n260	Right	2	1.000	0.750	0.441	0.331	**0.750**
n260	Left	2	1.000	0.750	0.462	0.347	**0.750**

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.

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Table C-2
5G mmW NR Head Total Exposure Ratio

		psPD	2.4 GHz WLAN Chain 0 Reported SAR	2.4 GHz WLAN Chain 1 Reported SAR	2.4 GHz WLAN MIMO Reported SAR	Bluetooth Reported SAR	5 GHz WLAN Chain 0 Reported SAR	5 GHz WLAN Chain 1 Reported SAR	5 GHz WLAN MIMO Reported SAR	psPD + 2.4 GHz WLAN MIMO	psPD + 5 GHz WLAN MIMO	psPD + 2.4 GHz MIMO + 5 GHz MIMO	psPD + BT	psPD + BT + 5GHz WLAN MIMO
		mW/cm²	W/kg	W/kg	W/kg	W/kg	W/kg	W/kg	W/kg					
		1	2	3	4	5	6	7	8	1 + 4	1 + 8	1 + 4 + 8	1 + 5	1 + 5 + 8
Applicable Limit		1.0	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.0	1.0	1.0	1.0	1.0
Front Side	Reported Value	0.470	0.267	0.039	0.306	0.357	0.466	0.024	0.490					
	Ratio to Limit	0.470	0.167	0.024	0.191	0.223	0.291	0.015	0.306	0.661	0.776	0.968	0.693	0.999

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

		psPD	2.4 GHz WLAN Chain 0 Reported SAR	2.4 GHz WLAN Chain 1 Reported SAR	2.4 GHz WLAN MIMO Reported SAR	Bluetooth Reported SAR	5 GHz WLAN Chain 0 Reported SAR	5 GHz WLAN Chain 1 Reported SAR	5 GHz WLAN MIMO Reported SAR	psPD + 2.4 GHz WLAN MIMO	psPD + 5 GHz WLAN MIMO	psPD + 2.4 GHz MIMO + 5 GHz MIMO	psPD + BT	psPD + BT + 5GHz WLAN MIMO
		mW/cm²	W/kg	W/kg	W/kg	W/kg	W/kg	W/kg	W/kg					
		1	2	3	4	5	6	7	8	1 + 4	1 + 8	1 + 4 + 8	1 + 5	1 + 5 + 8
Applicable Limit		1.0	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.0	1.0	1.0	1.0	1.0
Back Side	Reported Value	0.615	0.057	0.025	0.082	0.084	0.035	0.075	0.110					
	Ratio to Limit	0.615	0.036	0.016	0.051	0.053	0.022	0.047	0.069	0.666	0.684	0.698	0.668	0.736

Table C-4
5G mmW NR Hotspot Total Exposure Ratio

		psPD	2.4 GHz WLAN Chain 0 Reported SAR	2.4 GHz WLAN Chain 1 Reported SAR	2.4 GHz WLAN MIMO Reported SAR	Bluetooth Reported SAR	psPD + 2.4 GHz WLAN MIMO	psPD + BT
		mW/cm²	W/kg	W/kg	W/kg	W/kg		
		1	2	3	4	5	1 + 4	1 + 5
Applicable Limit		1.0	1.6	1.6	1.6	1.6	1.0	1.0
Back Side	Reported Value	0.615	0.057	0.025	0.082	0.084		
	Ratio to Limit	0.615	0.036	0.016	0.051	0.053	0.666	0.668
Front Side	Reported Value	0.470	0.078	0.025	0.103	0.072		
	Ratio to Limit	0.470	0.049	0.016	0.064	0.045	0.534	0.515
Top Edge	Reported Value	0.750	0.078	0.000	0.078	0.061		
	Ratio to Limit	0.750	0.049	0.000	0.049	0.038	0.799	0.788
Bottom Edge	Reported Value	0.750	0.000	0.000	0.000	0.000		
	Ratio to Limit	0.750	0.000	0.000	0.000	0.000	0.750	0.750
Right Edge	Reported Value	0.750	0.078	0.000	0.078	0.121		
	Ratio to Limit	0.750	0.049	0.000	0.049	0.076	0.799	0.826
Left Edge	Reported Value	0.750	0.000	0.025	0.025	0.000		
	Ratio to Limit	0.750	0.000	0.016	0.016	0.000	0.766	0.750

Table C-5
5G mmW NR Phablet Total Exposure Ratio

		psPD	5 GHz WLAN Chain 0 Reported SAR	5 GHz WLAN Chain 1 Reported SAR	5 GHz WLAN MIMO Reported SAR	psPD + 5 GHz WLAN MIMO
		mW/cm²	W/kg	W/kg	W/kg	
		1	2	3	4	1 + 4
Applicable Limit		1.0	4.0	4.0	4.0	1.0
Back Side	Reported Value	0.615	0.205	0.233	0.438	
	Ratio to Limit	0.615	0.051	0.058	0.110	0.725
Front Side	Reported Value	0.470	0.205	0.233	0.438	
	Ratio to Limit	0.470	0.051	0.058	0.110	0.580
Top Edge	Reported Value	0.750	0.205	0.000	0.205	
	Ratio to Limit	0.750	0.051	0.000	0.051	0.801
Bottom Edge	Reported Value	0.750	0.000	0.000	0.000	
	Ratio to Limit	0.750	0.000	0.000	0.000	0.750
Right Edge	Reported Value	0.750	0.205	0.000	0.205	
	Ratio to Limit	0.750	0.051	0.000	0.051	0.801
Left Edge	Reported Value	0.750	0.000	0.233	0.233	
	Ratio to Limit	0.750	0.000	0.058	0.058	**0.808**

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Notes:

1. Worst-case power density results for each test configuration among all antenna arrays and among all supported bands were considered for TER analysis.
2. 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, as indicated in the above tables in blue.
3. Per KDB Publication 248227 D01v02r02, SAR for MIMO was evaluated by following the simultaneous SAR provisions from KDB Publication 447498 D01v06 by evaluating the sum of the 1g SAR values of each antenna transmitting independently, as indicated in the above tables in green.
4. For back side, power density results at 2 mm were considered as a more conservative evaluation for 10 mm body-worn and 10 mm hotspot.
5. For front side, top edge, bottom edge, left edge, and right edge, power density results at 2 mm were considered as a more conservative evaluation for 10 mm hotspot.
6. Per FCC guidance, the bands/modes that are not required to be evaluated for Phablet SAR are not considered for TER analysis.
7. Per FCC guidance, for power density measurements, a test separation distance of 2 mm was used for phablet configuration due to probe restraints.
8. Worst-case front side reported psPD was considered for Head TER analysis.
9. 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 C-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

$$Total\ Normalized\ RFx\ =\ Normalized\ RFx\ _{Time\ Averaged\ WWAN} + Normalized\ RFx\ _{WLAN}\ \leq\ 1.0 \tag{1}$$

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

$$Normalized\ RFx\ _{Time\ Averaged\ WWAN} = \frac{4G\ SAR}{4G\ SAR\ Limit} + \frac{5G\ mmW\ NR\ psPD}{5G\ mmW\ NR\ psPD\ Limit} \leq\ 1.0 \tag{2}$$

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

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

$A = Max\ normalized\ time\text{-}averaged\ SAR\ exposure\ from\ 4G$
$B = Max\ normalized\ time\text{-}averaged\ PD\ exposure\ from\ 5G\ mmW\ NR$

$x(t) = Ranges\ between\ [0,1]$
$x(t)\times A = Percentage\ of\ normalized\ time\text{-}averaged\ RF\ exposure\ from\ 4G$
$(1\text{-}x(t))\times B = Remaining\ percentage\ of\ RF\ exposure\ contribution\ from\ 5G\ mmW\ NR$

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.

$$A + norm.\ SAR\ from\ WLAN\ \leq\ 1.0\ normalized\ limit \tag{4a}$$

$$B + norm.\ SAR\ from\ WLAN\ \leq\ 1.0\ normalized\ limit \tag{4b}$$

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

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,

$$Smart\ Tx\ WWAN:\ A = max\ (normalized\ SAR\ exposure\ from\ 4G)\leq 1.0\ normalized\ limit \tag{6a}$$
$$Smart\ Tx\ WWAN:\ B = 0.75\ \times\ max\ (normalized\ PD\ exposure\ from\ 5G\ mmW\ NR)\leq 1.0\ normalized\ limit \tag{6b}$$

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:

$$Total\ Normalized\ RFx\ =\ Normalized\ SAR\ _{4G\ WWAN} + Normalized\ SAR\ _{WLAN} < 1.0 \tag{7a}$$
$$Total\ Normalized\ RFx\ =\ 0.75\ \times\ Normalized\ psPD\ _{5G\ mmW\ NR\ WWAN} + Normalized\ SAR\ _{WLAN} < 1.0 \tag{7b}$$

which are re-written as:

$$Total\ Normalized\ RFx\ =\ \frac{4G\ SAR}{4G\ SAR\ Limit} + \frac{WLAN\ SAR}{WLAN\ SAR\ Limit} < 1 \tag{8a}$$

$$Total\ Normalized\ RFx\ =\ 0.75 * \frac{5G\ mmW\ NR\ psPD}{5G\ mmW\ NR\ psPD\ Limit} + \frac{WLAN\ SAR}{WLAN\ SAR\ Limit} < 1 \tag{8b}$$

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 C-2 to C-5.

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