Motorola Model: MD1005G
FCC ID: IHDT56XL1

Appendix for 39 GHz Power Density Simulation and Measurement Report

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Note on Right-Left Convention: Throughout this Simulation Appendix document, references to “right” or “left” side of the Mod device are given from the perspective of viewing the device from the back.

2. Appendix A: Block Diagram, Sensor-Based Measurement Planes, and 3D Simulation Models

Block Diagram

The RF block diagram of the device is shown in Figure 5.1.1, below.

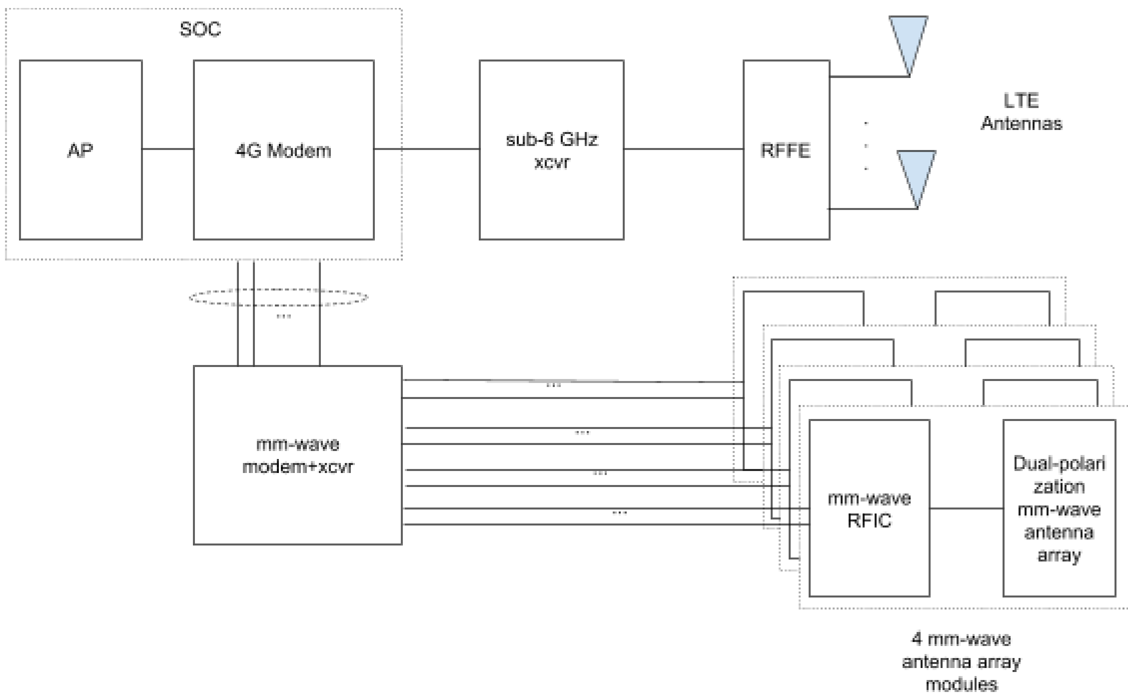

Figure 5.1.1: RF block diagram of the device.

Measurement Planes

In the following group of figures, the reduced measurement planes for each of the four mm-wave array modules, for each of the 5 mm-spaced or 2 mm-spaced overall measurement planes on the six sides of the device, are shown. These reduced measurement planes are the regions in which power density measurements are performed for each individual module, based on the operational characteristics of the proximity detection system, as described in the main report and Appendix B.

The overall measurement planes are at a test separation distance of 5 mm on the six surfaces of the device, and at a 2 mm test separation distance (relative the host phone device) on the front surface. As discussed in the previous lab KDB inquiry, the 5 mm overall measurement planes are relevant to body-worn conditions, while the front-only 2 mm overall measurement plane is relevant to the at-head talk mode condition. As described in the main report, each module’s power density is measured in the applicable portions of those overall measurement planes, which are not excluded by the operation of the proximity sensor and power management system. For some modules (back, left, and right modules), the front surface measurements were performed only on the 2 mm-spaced plane, since meeting the requirement at 2 mm implies also meeting the requirement at a larger spacing of 5 mm.

For the back, left, and right modules, one respective 5mm-spaced overall measurement plane directly in front of the module, was excluded entirely from measurement, due to broad coverage of the proximity detection system in this "principal plane." That is, the back 5 mm plane is excluded for the back module, left 5 mm plane is excluded for the left module, and right 5 mm plane is excluded for the right module. For the front-facing module, the 5 mm overall measurement plane is included in the measurement, since the detector cone for this module is not as broad due to partial blocking by the host phone device. However, for the front module, the plane at 2 mm spacing was excluded entirely, because the power management algorithm (as explained in Section 1.4.3.2 and Figure 1-4-10 of the Operational Description) entirely disables the front-facing module whenever the phone is operational in a talk-mode condition at the head (which is the use condition that the 2 mm-spaced front plane represents).

Other than these excluded-per-module principal planes each module is measured in the non-excluded portions of the other overall measurement planes as shown in the figures below.

In addition to the measurements on these 2mm- and 5mm-spaced planes, each module is measured in an entire plane at 70 mm spacing in its broadside direction, demonstrating compliance at a conservative distance representing the non-detect threshold distance of the proximity detector.

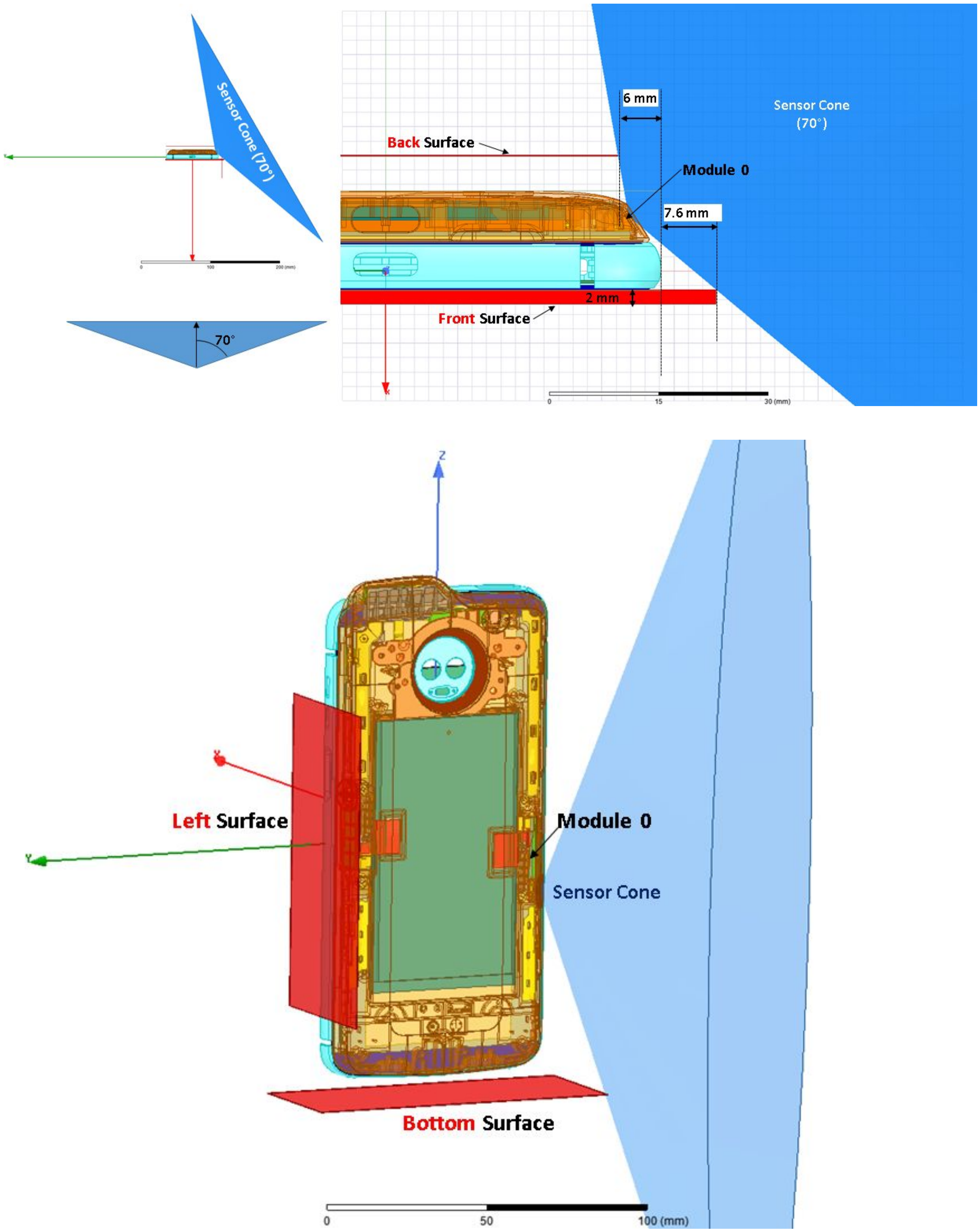

Figure 5.2.4.1 Measurement planes for Module 0.

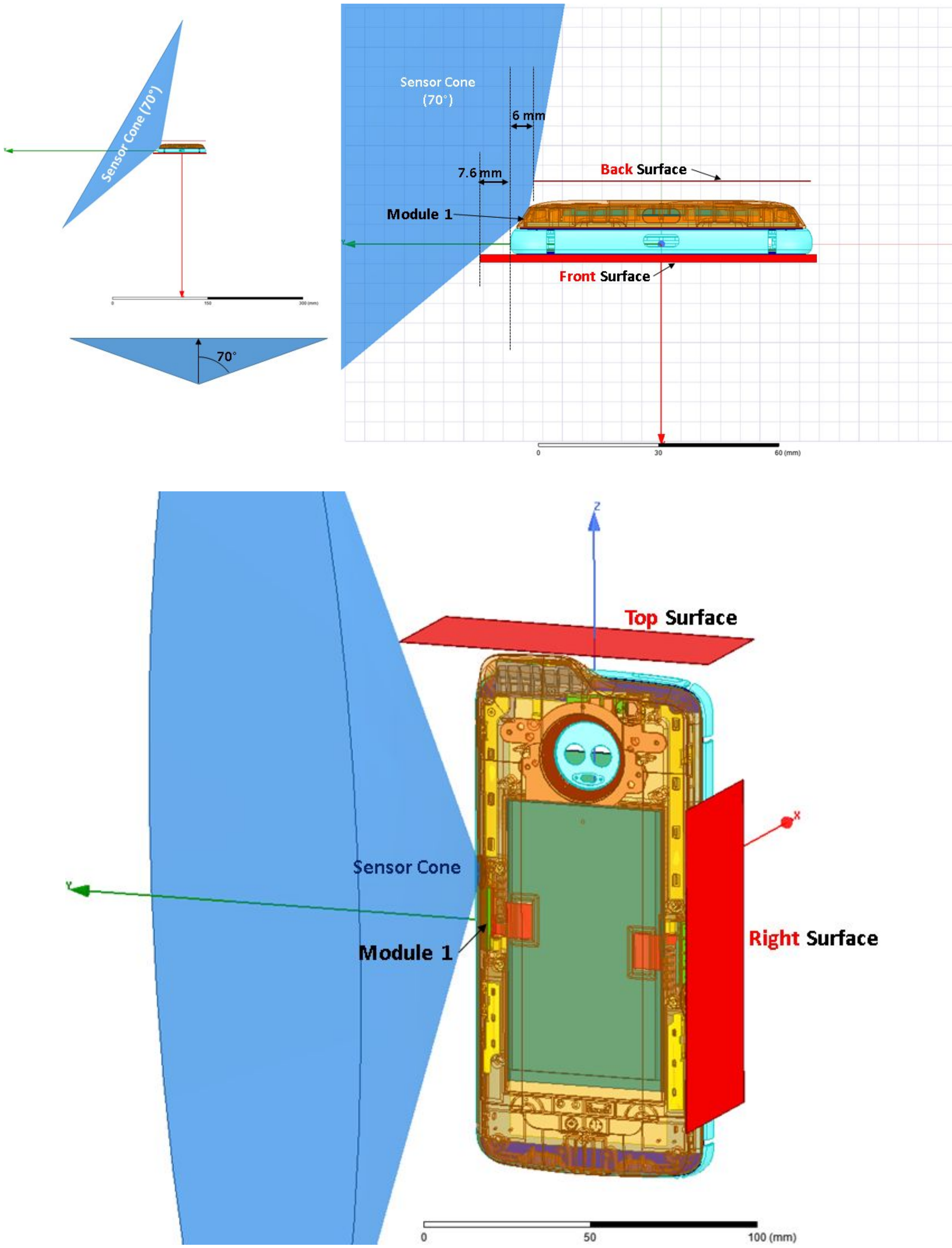

Figure 5.2.4.2 Measurement planes for Module 1.

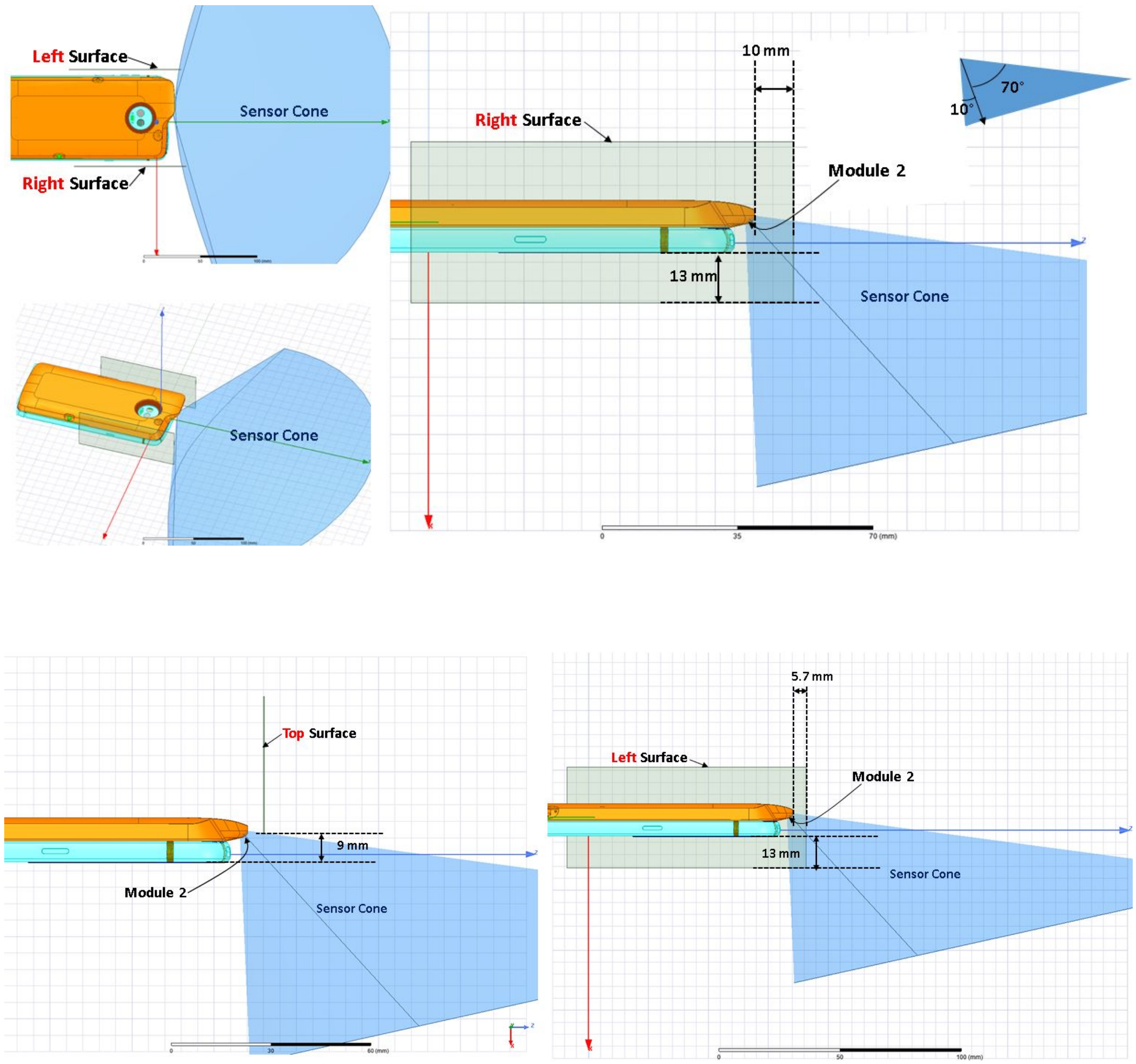

Figure 5.2.4.3 Measurement planes for Module 2.

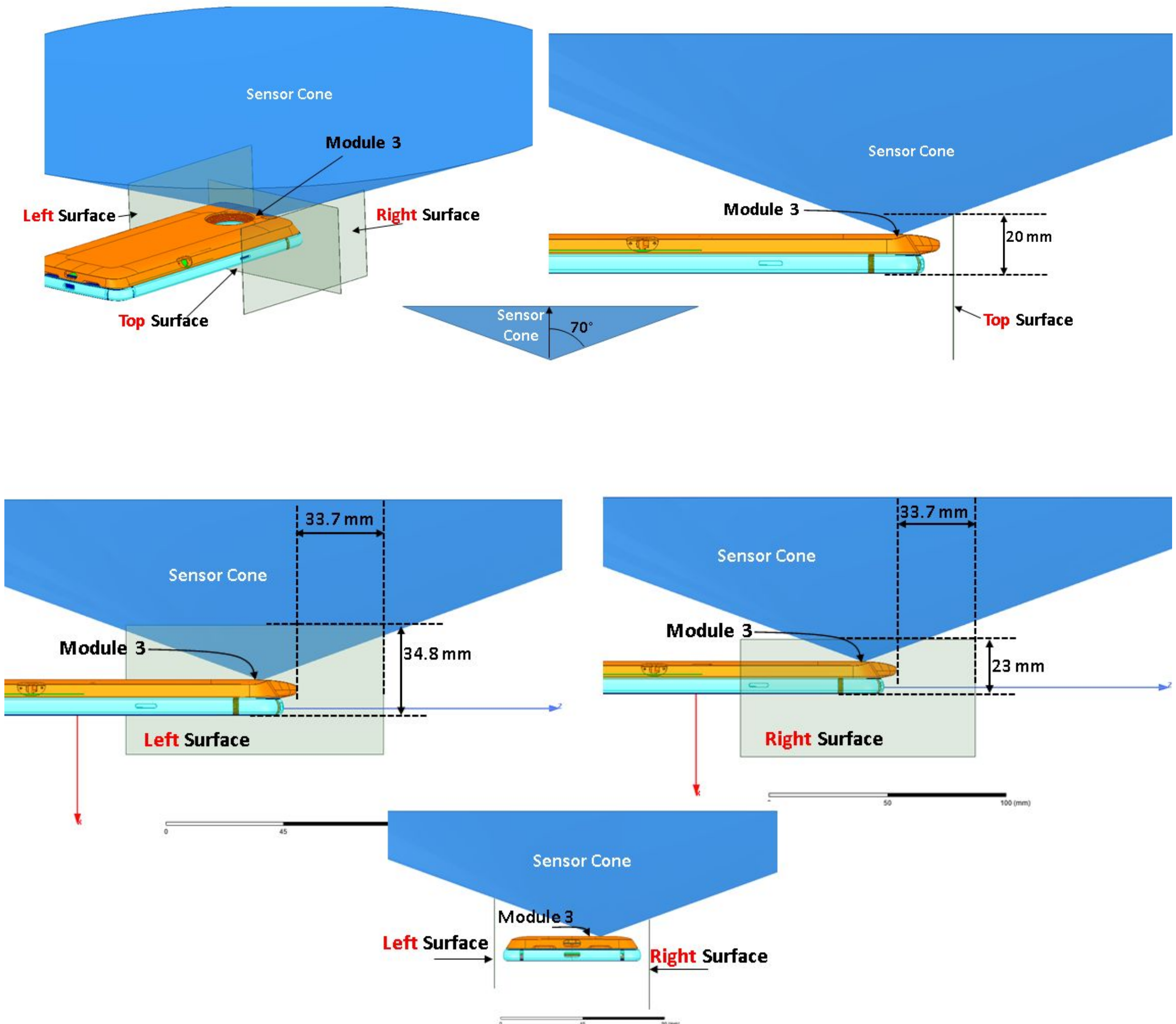

Figure 5.2.4.4 Measurement planes for Module 3.

Simulation Models

In the following group of figures, the detailed simulation models employed for each module's analysis are illustrated.

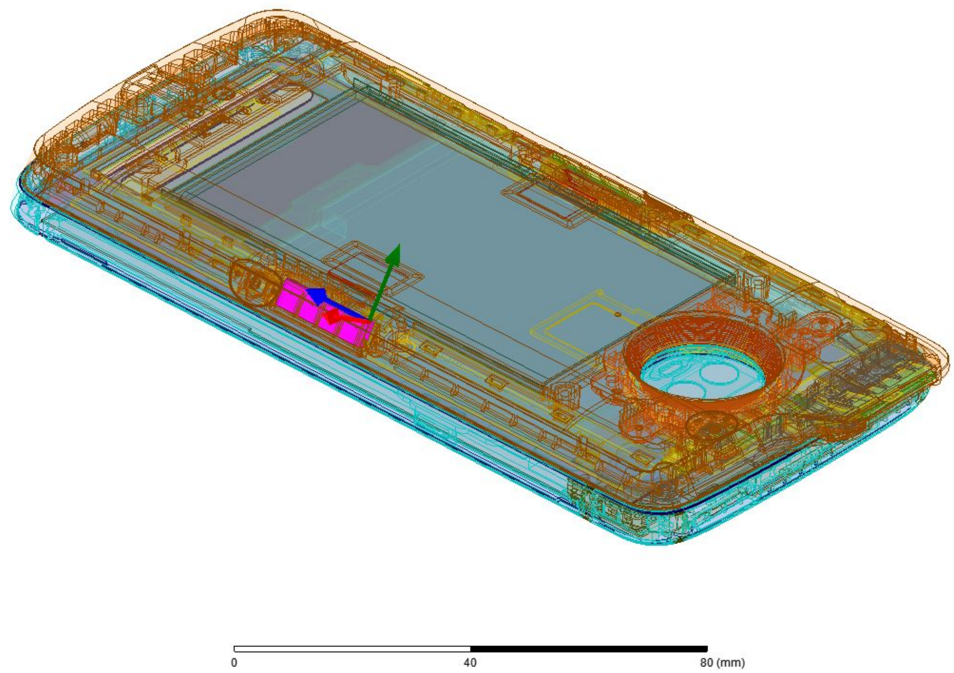

Figure 6.3.4-1: 3D model used for Module 0 (Right Array), the antenna array is highlighted

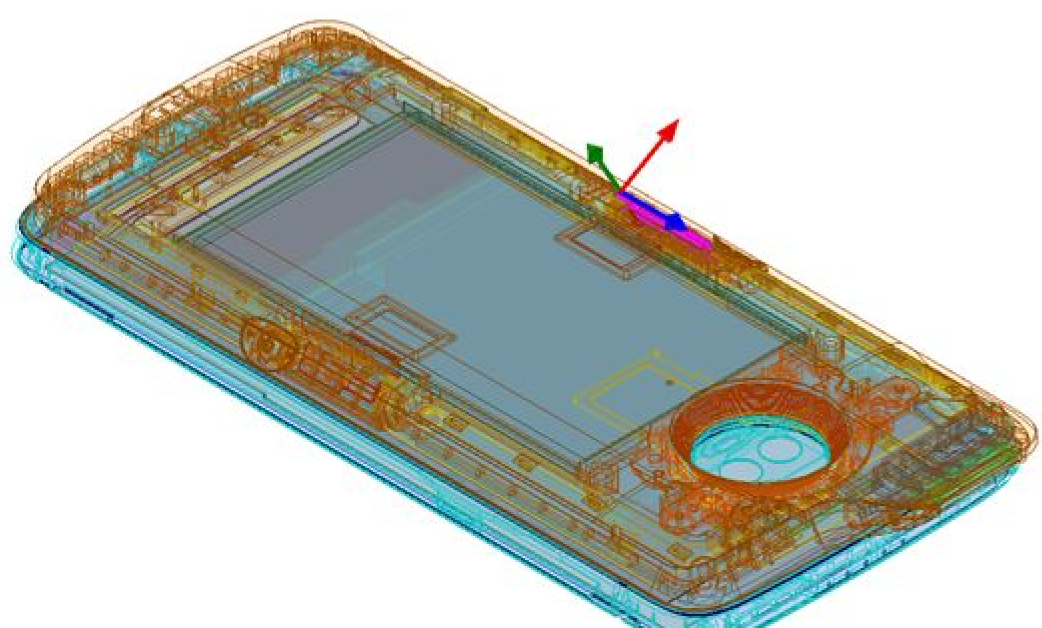

Figure 6.3.4-2: 3D model used for Module 1 (Left Array), the antenna array is highlighted

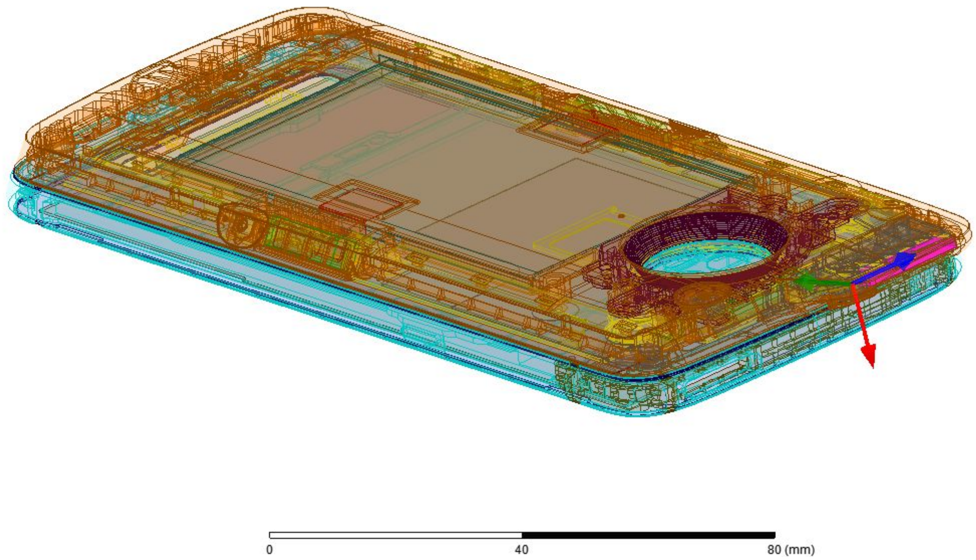

Figure 6.3.4-3: 3D model used for Module 2 (Front Array), the antenna array is highlighted

Figure 6.3.4-4: 3D model used for Module 3 (Back Array), the antenna array is highlighted

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3. Appendix B: Detailed Strategy for Finding Worst Case Beams

More details of finding the worst-case near field results are described below:

Full-power beams are beams in which all four antenna array elements are excited with the full available power from their respective PAs. The simulations excluded those few beams that are not full-power; these are beams where less than all four (generally only one or two) of the antenna array elements are excited. Since the PA power per antenna port is limited to the same nominal value regardless of how many ports/elements are excited, these beams have substantially lower total power and hence lower emissions. Typically, excluding these beams with fewer than four elements excited results in around 9 beam pairs per module instead of 15.

The detailed step-by-step process to accomplish this search is as follows:

1. For each full-power beam pair for each module, simulate in HFSS that beam pair's power density at each x-y-z point in each of the reduced measurement planes for that module (i.e. the planes defined in Figures 5.2.4 for the modules, which exclude those regions which are within the proximity detector system's effective region of operation for the module in question).
   a. The phase weights applied to each antenna element's port for the simulation of each beam pair are taken from the codebook defined in the modem, wherein the beam pair was originally defined at design time.
   b. The magnitude weights applied to each antenna element's port for the simulation of each individual beam comprising the beam pair are back-calculated from the measured EiRP pattern of that beam. This is necessary because there is no means to perform a conducted power measurement of these port powers on the module. The only means to perform an amplitude normalization of the simulated result is via normalization to the measured EiRP pattern. Essentially, this step calibrates the amplitude of the power applied in the simulation such that the simulated far-field EiRP is forced to correspond to the measured one.
2. For each of the reduced measurement planes for each module, identify from Step 1 the beam pair having the worst-case power density in that plane.
3. Measure the power density in each of the reduced measurement planes for each module, for the respective worst-case beam pair identified via simulation in Step 2[1].
4. For each *overall* measurement plane defined around the device (for example, the entire measurement plane at 5 mm spacing from the "back" side of the device), considering all of the results from Step 3 for reduced measurement planes that fall within that *overall* measurement plane, select the highest power density value. This is the worst-case power density for that *overall* measurement plane.
5. Considering all of the *overall* measurement planes comprising a use condition (for example, body-worn accessory condition is comprised of the planes 5 mm from the front and rear surfaces of the device), select for those planes the worst-case power density value found in Step 4. This is the reported power density value for the use case in question.

The above steps are repeated for each of the two mm-wave frequency bands (n261 and n260, i.e. 28 GHz and 39 GHz) that the device supports.

One exception to the above process is for the selection of worst case beam pair at 70 mm distance (i.e. at the conservative transition distance of sensor's detect/undetect distance). For the 70 mm distance, we use the measured EIRP and pick the highest EIRP beam pair and the beam pair with highest total radiated power to do the power density measurements.

[1] In practice, for most module/plane combinations, the worst two or three beam pairs were measured (rather than only one), particularly when simulated PD results for the worst beam pairs were close in values, e.g. comparable to measurement tolerance, and of significant magnitude. In this way, the search outcomes were made more conservative.

4. Appendix B1: Port Excitations in HFSS

The encrypted array module has the predefined 8 ports for horizontal and vertical feed excitations. These ports are shown in Figure 7.1.1-1 below. The locations of these ports can not be modified by the OEM. Although it is not possible to display the internal feeding structure of the module in the figure below, a representation of the locations of all eight feed points on the antennas is provided in the Operational Description document. The excitation magnitudes and phases for these ports can be loaded from a csv file using the "Edit Sources" option in HFSS. An example of the edited sources (loaded magnitudes & phases) is shown in Figure 7.1.1-2. Note that since HFSS is a frequency-domain finite element method solver, the excitation waveform can be considered as sinusoidal.

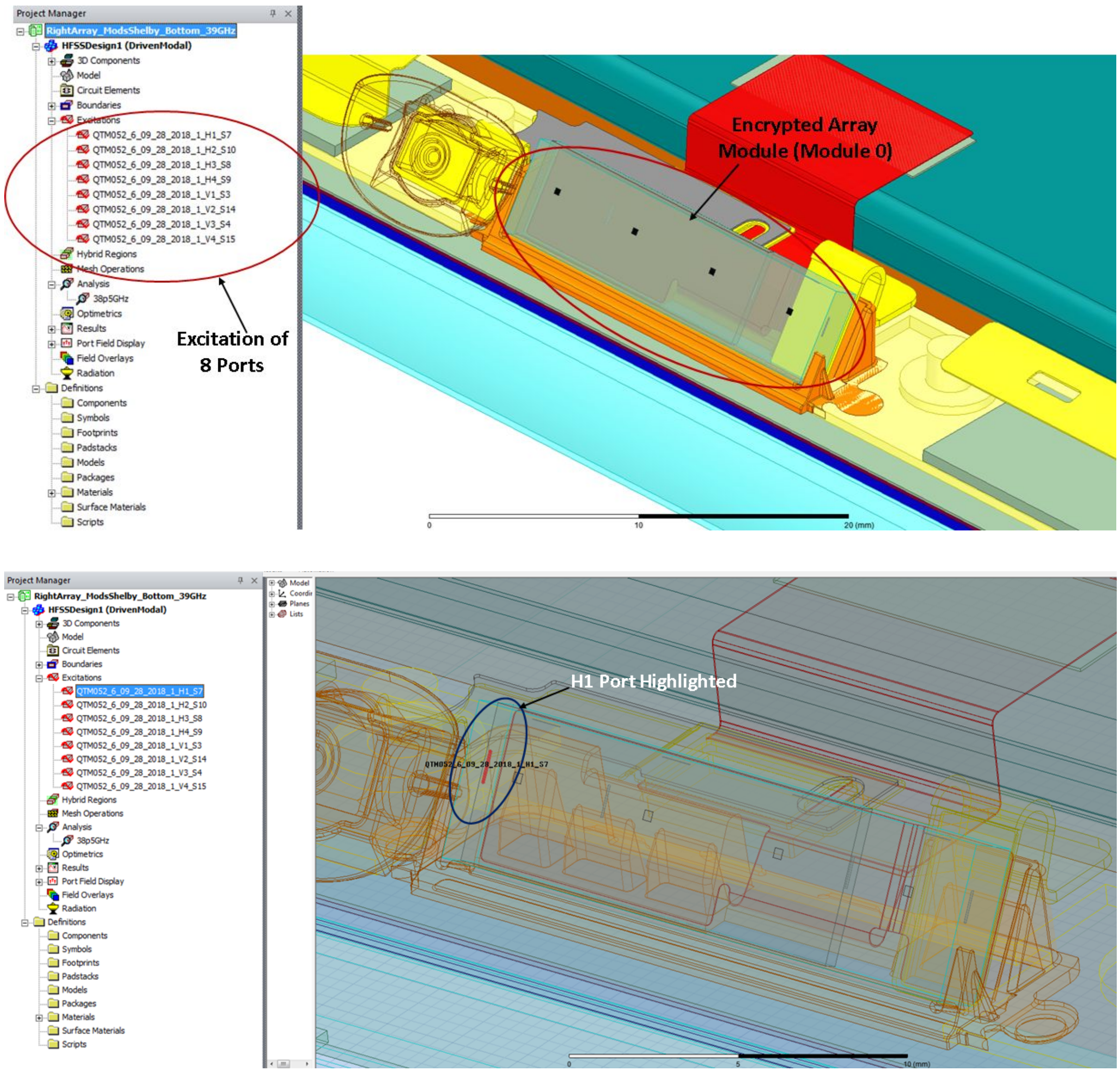

Figure 7.1.1-1: All 8 ports and the highlighted H1 port (Horizontal) in HFSS.

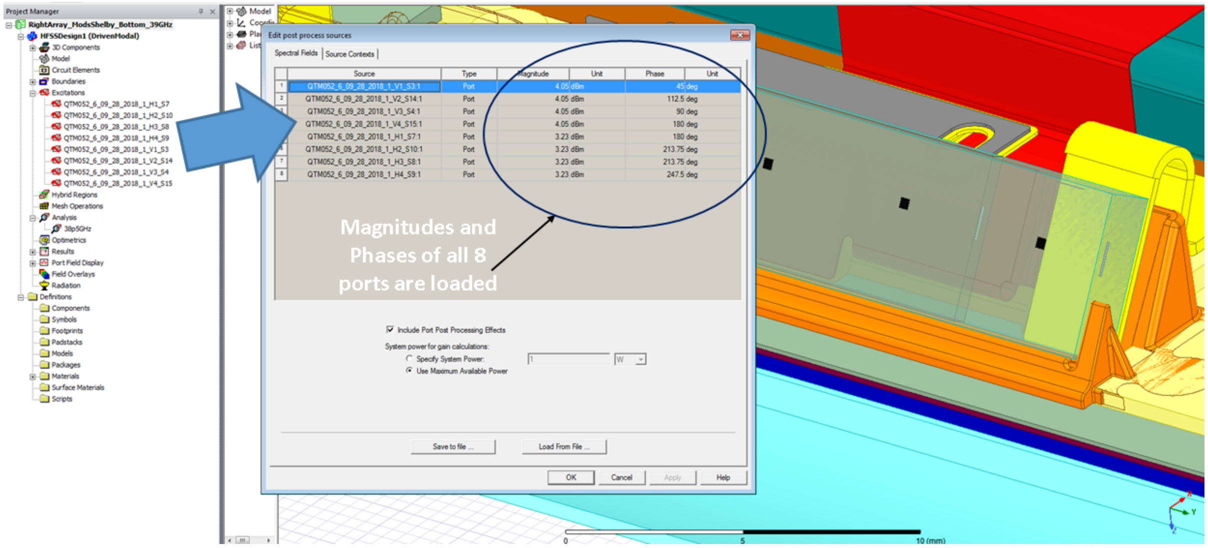

Figure 7.1.1-2: Magnitudes and phases of a beam pair are loaded in HFSS.

5. Appendix B2: Material Properties in HFSS

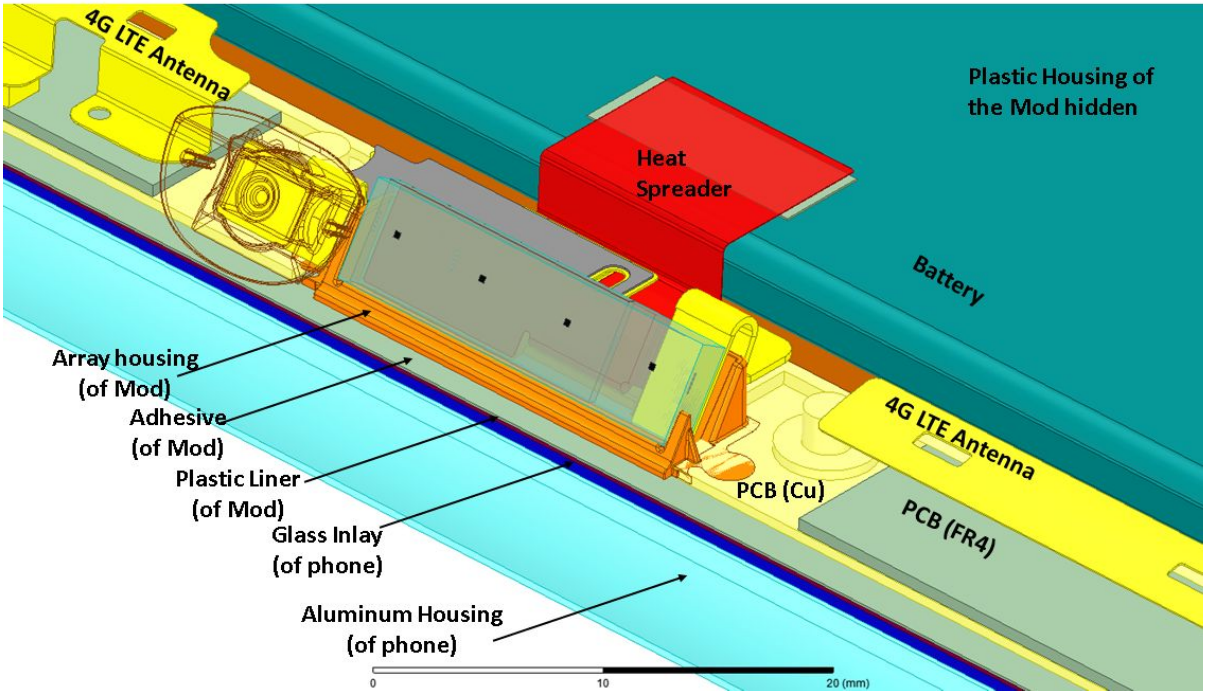

Figure 8.1.1-1: Parts/materials near an array module (Module 0).

Parts	Material	Dielectric Constant	Loss Tangent	Conductivity (S/m)
Housing of Mod, Array Housing, Liner	**Plastic**	**2.7**	**0.007**	
Adhesive	**Adhesive**	**3.2**	**0.04**	
Glass Inlay	**Glass**	**7.3**	**0.015**	
PCB (FR4)	**FR4**	**3.5**	**0.02**	
Housing of phone, Battery	**Aluminum**			**33000000**
PCB (Cu), Heat Spreader, 4G LTE Antenna	**Copper**			**40000000**

Table 5.1.1-1 Parts and material properties around Module 0.

6. Appendix C: Power Density and EiRP Results

Power Density Simulated and Measured Results

The simulated average power density at 38.5 GHz for all the beampairs in each of the modules is in the tables below:

<table>
<tr><th colspan="3">N260 (38.5 GHz)
Module 0 (Right Array)</th><th>Simulated Avg Pd (W/m^2)</th><th>Simulated Avg Pd (W/m^2)</th><th>Simulated Avg Pd (W/m^2)</th><th>Simulated Avg Pd (W/m^2)</th></tr>
<tr><th>#</th><th>Beam Pair</th><th>Ant Group</th><th>Left @5 mm</th><th>Bottom @5 mm</th><th>Back @5 mm</th><th>Front @2 mm</th></tr>
<tr><td>1</td><td>29-161</td><td>AG0 + AG1</td><td>0.11</td><td>0.27</td><td>3.55</td><td>1.07</td></tr>
<tr><td>2</td><td>30-160</td><td>AG0 + AG1</td><td>0.09</td><td>0.32</td><td>4.19</td><td>1.53</td></tr>
<tr><td>3</td><td>31-159</td><td>AG0 + AG1</td><td>0.13</td><td>0.62</td><td>3.99</td><td>1.07</td></tr>
<tr><td>4</td><td>32-158</td><td>AG0 + AG1</td><td>0.12</td><td>0.56</td><td>4.32</td><td>0.89</td></tr>
<tr><td>5</td><td>33-157</td><td>AG0 + AG1</td><td>0.11</td><td>0.27</td><td>3.25</td><td>1.33</td></tr>
<tr><td>6</td><td>48-179</td><td>AG0 + AG1</td><td>0.08</td><td>0.25</td><td>3.85</td><td>1.51</td></tr>
<tr><td>7</td><td>49-177</td><td>AG0 + AG1</td><td>0.10</td><td>0.14</td><td>3.11</td><td>1.20</td></tr>
<tr><td>8</td><td>50-178</td><td>AG0 + AG1</td><td>0.10</td><td>0.42</td><td>3.77</td><td>1.59</td></tr>
<tr><td>9</td><td>51-176</td><td>AG0 + AG1</td><td>0.15</td><td>0.58</td><td>4.02</td><td>0.79</td></tr>
<tr><td>10</td><td>1-129</td><td>AG0 + AG1</td><td colspan="4" rowspan="6">The simulations excluded these beams that are not full-power; these are beams where less than all four (generally only one or two) of the antenna array elements are excited. Since the PA power per antenna port is limited to the same nominal value regardless of how many ports/elements are excited, these beams have substantially lower total power and hence lower emissions. Typically, excluding these beams with fewer than four elements excited results in the above 9 beam pairs per module instead of 15.</td></tr>
<tr><td>11</td><td>7-135</td><td>AG0 + AG1</td></tr>
<tr><td>12</td><td>8-136</td><td>AG0 + AG1</td></tr>
<tr><td>13</td><td>9-137</td><td>AG0 + AG1</td></tr>
<tr><td>14</td><td>18-146</td><td>AG0 + AG1</td></tr>
<tr><td>15</td><td>19-147</td><td>AG0 + AG1</td></tr>
</table>

Table 6.3.5-1 Simulated avg. power density data at **38.5 GHz** for **Module 0** (Right Array).

N260 (38.5 GHz) Module 1 (Left Array)			Simulated Avg Pd (W/m²)	Simulated Avg Pd (W/m²)	Simulated Avg Pd (W/m²)	Simulated Avg Pd (W/m²)
#	Beam Pair	Ant Group	Right @5 mm	Top @5 mm	Back @5 mm	Front @2 mm
1	24-152	AG0 + AG1	0.10	0.48	4.39	0.79
2	25-153	AG0 + AG1	0.08	0.08	3.62	1.46
3	26-154	AG0 + AG1	0.11	0.53	2.98	0.98
4	27-156	AG0 + AG1	0.25	0.28	4.74	1.46
5	28-155	AG0 + AG1	0.10	0.53	3.87	1.25
6	44-173	AG0 + AG1	0.11	0.19	4.10	1.23
7	45-172	AG0 + AG1	0.13	0.11	2.44	1.09
8	46-174	AG0 + AG1	0.10	0.33	3.84	1.75
9	47-175	AG0 + AG1	0.11	0.62	3.77	0.95
10	0-128	AG0 + AG1	The simulations excluded these beams that are not full-power; these are beams where less than all four (generally only one or two) of the antenna array elements are excited. Since the PA power per antenna port is limited to the same nominal value regardless of how many ports/elements are excited, these beams have substantially lower total power and hence lower emissions. Typically, excluding these beams with fewer than four elements excited results in the above 9 beam pairs per module instead of 15.			
11	4-133	AG0 + AG1				
12	5-132	AG0 + AG1				
13	6-134	AG0 + AG1				
14	16-144	AG0 + AG1				
15	17-145	AG0 + AG1				

Table 6.3.5-2 Simulated avg. power density data at **38.5 GHz** for **Module 1** (Left Array).

N260 (38.5 GHz) Module 2 (Front Array)			Simulated Avg Pd (W/m²)	Simulated Avg Pd (W/m²)	Simulated Avg Pd (W/m²)	Simulated Avg Pd (W/m²)	Simulated Avg Pd (W/m²)
#	Beam Pair	Ant Group	Top @5 mm	Back @ 5 mm	Left @5 mm	Right @5 mm	Front @5 mm
1	39-168	AG0 + AG1	3.63	2.66	2.99	0.35	2.45
2	40-167	AG0 + AG1	4.16	2.91	1.94	0.14	2.56
3	41-171	AG0 + AG1	4.04	2.49	1.27	0.39	3.11
4	42-170	AG0 + AG1	3.56	2.67	1.31	0.36	2.38
5	43-169	AG0 + AG1	3.84	2.40	1.76	0.14	3.07
6	56-185	AG0 + AG1	3.92	2.70	1.72	0.45	2.71
7	57-184	AG0 + AG1	4.92	2.85	2.53	0.08	2.22
8	58-186	AG0 + AG1	5.13	3.65	0.64	0.16	2.97
9	59-187	AG0 + AG1	4.85	3.99	1.91	0.47	2.23
10	3-131	AG0 + AG1	The simulations excluded these beams that are not full-power; these are beams where less than all four (generally only one or two) of the antenna array elements are excited. Since the PA power per antenna port is limited to the same nominal value regardless of how many ports/elements are excited, these beams have substantially lower total power and hence lower emissions. Typically, excluding these beams with fewer than four elements excited results in the above 9 beam pairs per module instead of 15.				
11	13-142	AG0 + AG1					
12	14-141	AG0 + AG1					
13	15-143	AG0 + AG1					
14	22-150	AG0 + AG1					
15	23-151	AG0 + AG1					

Table 6.3.5-3 Simulated avg. power density data at **38.5 GHz** for **Module 2** (Front Array).

<table>
<tr><th colspan="3">N260 (38.5 GHz)
Module 3 (Back Array)</th><th>Simulated Avg Pd (W/m^2)</th><th>Simulated Avg Pd (W/m^2)</th><th>Simulated Avg Pd (W/m^2)</th><th>Simulated Avg Pd (W/m^2)</th></tr>
<tr><th>#</th><th>Beam Pair</th><th>Ant Group</th><th>Right @ 5 mm</th><th>Left @5 mm</th><th>Top @5 mm</th><th>Front @2 mm</th></tr>
<tr><td>1</td><td>34-163</td><td>AG0 + AG1</td><td>0.59</td><td>0.89</td><td>1.32</td><td>0.90</td></tr>
<tr><td>2</td><td>35-162</td><td>AG0 + AG1</td><td>0.68</td><td>1.02</td><td>2.03</td><td>0.66</td></tr>
<tr><td>3</td><td>36-165</td><td>AG0 + AG1</td><td>0.57</td><td>0.84</td><td>1.78</td><td>0.77</td></tr>
<tr><td>4</td><td>37-166</td><td>AG0 + AG1</td><td>0.61</td><td>1.28</td><td>1.69</td><td>0.60</td></tr>
<tr><td>5</td><td>38-164</td><td>AG0 + AG1</td><td>0.58</td><td>0.79</td><td>1.33</td><td>0.68</td></tr>
<tr><td>6</td><td>52-180</td><td>AG0 + AG1</td><td>0.81</td><td>1.08</td><td>2.01</td><td>1.08</td></tr>
<tr><td>7</td><td>53-182</td><td>AG0 + AG1</td><td>0.58</td><td>0.84</td><td>1.07</td><td>0.36</td></tr>
<tr><td>8</td><td>54-183</td><td>AG0 + AG1</td><td>0.61</td><td>0.37</td><td>1.52</td><td>0.87</td></tr>
<tr><td>9</td><td>55-181</td><td>AG0 + AG1</td><td>0.57</td><td>0.65</td><td>1.38</td><td>0.94</td></tr>
<tr><td>10</td><td>2-130</td><td>AG0 + AG1</td><td colspan="4" rowspan="6">The simulations excluded these beams that are not full-power; these are beams where less than all four (generally only one or two) of the antenna array elements are excited. Since the PA power per antenna port is limited to the same nominal value regardless of how many ports/elements are excited, these beams have substantially lower total power and hence lower emissions. Typically, excluding these beams with fewer than four elements excited results in the above 9 beam pairs per module instead of 15.</td></tr>
<tr><td>11</td><td>10-140</td><td>AG0 + AG1</td></tr>
<tr><td>12</td><td>11-139</td><td>AG0 + AG1</td></tr>
<tr><td>13</td><td>12-138</td><td>AG0 + AG1</td></tr>
<tr><td>14</td><td>20-148</td><td>AG0 + AG1</td></tr>
<tr><td>15</td><td>21-149</td><td>AG0 + AG1</td></tr>
</table>

Table 6.3.5-4 Simulated avg. power density data at **38.5 GHz** for **Module 3** (Back Array).

A comparison between the simulated and measured average power density for the worst beam pair of each surface is tabulated below. The worst beam pair here refers to the measured worst beam pair at each surface for each module.

Test Config	Beam ID 1	Beam ID 2	Exposure Conditions	Test separation	Measured Avg. PD (W/m²) avg. area: 4 cm²	Simulated Avg. PD (W/m²) avg. area: 4 cm²
Module 0 (Right Array) Freq: 38.5 GHz	**30**	**160**	**Front Surface**	**2 mm**	**0.49**	**1.53**
	32	**158**	**Back Surface**	**5 mm**	**4.28**	**4.32**
	51	**176**	**Left Surface**	**5 mm**	**0.38**	**0.15**
	31	**159**	**Bottom Surface**	**5 mm**	**0.43**	**0.62**

Table 6.3.5-9 Simulated and measured avg. power density data for Module 0 (Right Array).

Test Config	Beam ID 1	Beam ID 2	Exposure Conditions	Test separation	Measured Avg. PD (W/m²) avg. area: 4 cm²	Simulated Avg. PD (W/m²) avg. area: 4 cm²
Module 1 (Left Array) Freq: 38.5 GHz	**46**	**174**	**Front Surface**	**2 mm**	**0.55**	**1.75**
	27	**156**	**Back Surface**	**5 mm**	**4.17**	**4.74**
	27	**156**	**Right Surface**	**5 mm**	**0.19**	**0.25**
	47	**175**	**Top Surface**	**5 mm**	**0.27**	**0.62**

Table 6.3.5-10 Simulated and measured avg. power density data for Module 1 (Left Array).

Test Config	Beam ID 1	Beam ID 2	Exposure Conditions	Test separation	Measured Avg. PD (W/m²) avg. area: 4 cm²	Simulated Avg. PD (W/m²) avg. area: 4 cm²
Module 2 (Front Array) Freq: 38.5 GHz	**59**	**187**	**Back Surface**	**5 mm**	**2.55**	**3.99**
	59	**187**	**Right Surface**	**5 mm**	**0.727**	**0.47**
	39	**168**	**Left Surface**	**5 mm**	**3.01**	**2.99**
	59	**187**	**Top Surface**	**5 mm**	**5.2**	**4.85**
	41	**171**	**Front Surface**	**5 mm**	**1.63**	**3.11**

Table 6.3.5-11 Simulated and measured avg. power density data for Module 2 (Front Array).

Test Config	Beam ID 1	Beam ID 2	Exposure Conditions	Test separation	Measured Avg. PD (W/m²) avg. area: 4 cm²	Simulated Avg. PD (W/m²) avg. area: 4 cm²
Module 3 (Back Array) Freq: 38.5 GHz	**52**	**180**	**Front Surface**	**2 mm**	**0.68**	**1.08**
	52	**180**	**Right Surface**	**5 mm**	**0.67**	**0.81**
	37	**166**	**Left Surface**	**5 mm**	**0.93**	**1.28**
	52	**180**	**Top Surface**	**5 mm**	**3.11**	**2.01**

Table 6.3.5-12 Simulated and measured avg. power density data for Module 3 (Back Array).

The measurement vs. simulation agreement for power density is very good. In 12 of the 17 cases presented, the disagreement is 2 dB or less. The remaining five cases, where the delta exceeds 2 dB, are cases where the power density value is insignificant (low relative the limit, in fact < 1.6 W/m^2 in all of these cases). Furthermore, in all cases with the highest power density values (values of 4 W/m^2 or greater, which determine the compliance level of the device), the agreement is within 0.6 dB. The increased delta for the very low field value regions is speculated to be due to the combined impacts of uncertainty in the measurement and less mesh refinement in the simulation (in these areas of lower energy). In any case, the validity of the simulation for rank-ordering the beam pairs is well demonstrated.

Measured EiRP Results

The table 7.1 below summarizes the EIRP of all beam pairs measured in Motorola's development labs utilizing Keysight CATR (Compact Antenna Test Range) Model 230. This testing is done at NR - ARFCN 2254166, Frequency: 38500.02 MHz for the 100 MHz Bandwidth with 66 RB starting @0 for QPSK CP-OFDM Modulation. The highlighted rows correspond to beampairs with maximum EIRP for each of the modules and are used to determine the beampair for PD measurement at 70 mm distance (threshold of sensor detection distance) in the principal plane direction for each module.

Note that these EiRP data are measured in a different test environment than are the official reported EiRP results measured at Sporton's lab for Part 2/Part 30 compliance. It can be expected that these results will differ from each other. The results presented in this section are non-official and are not reported for Part 2/Part 30 compliance. They are presented here because they are representative of the results used in the worst-case-beam selection process as described in this appendix and the accompanying reports.

Antenna Module	Beam ID1	Beam ID2	EIRP Total (dBm)
0	31	159	21.9
0	49	177	21.44
0	51	176	20.71
0	50	178	20.67
0	32	158	20.46
0	48	179	19.69
0	33	157	19.16
0	18	146	18.81
0	30	160	18.57
0	29	161	18.04
0	8	136	17.52
0	7	135	16.73
0	19	147	16.67
0	9	137	16.01
0	1	129	13.96
1	45	172	21.96
1	47	175	21.3
1	27	156	21.18
1	44	173	21.09
1	46	174	20.36
1	26	154	20.33
1	25	153	20.17
1	28	155	20.12
1	24	152	19.27
1	4	133	18.72
1	6	134	17.9
1	5	132	17.71
1	17	145	17.62
1	16	144	17.58
1	0	128	13.36

2	59	187	21.71
2	56	185	21.59
2	43	169	21.51
2	58	186	21.47
2	57	184	20.86
2	42	170	20.67
2	39	168	20.57
2	40	167	20.22
2	41	171	18.88
2	23	151	18.03
2	15	143	17.83
2	14	141	17.04
2	22	150	16.86
2	13	142	16.51
2	3	131	12.81
3	53	182	23.11
3	52	180	22.83
3	55	181	22.67
3	36	165	22.57
3	38	164	21.88
3	37	166	20.94
3	34	163	20.9
3	35	162	20.84
3	54	183	20.73
3	20	148	18.85
3	21	149	18.34
3	11	139	17.82
3	12	138	17.44
3	10	140	16.84
3	2	130	13.09

Table 7.1 Measured EIRP for all beampairs