Motorola Model: MD1005G
FCC ID: IHDT56XL1

Appendix for Power Density Simulation and Measurement Report

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1. Table of Contents

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.

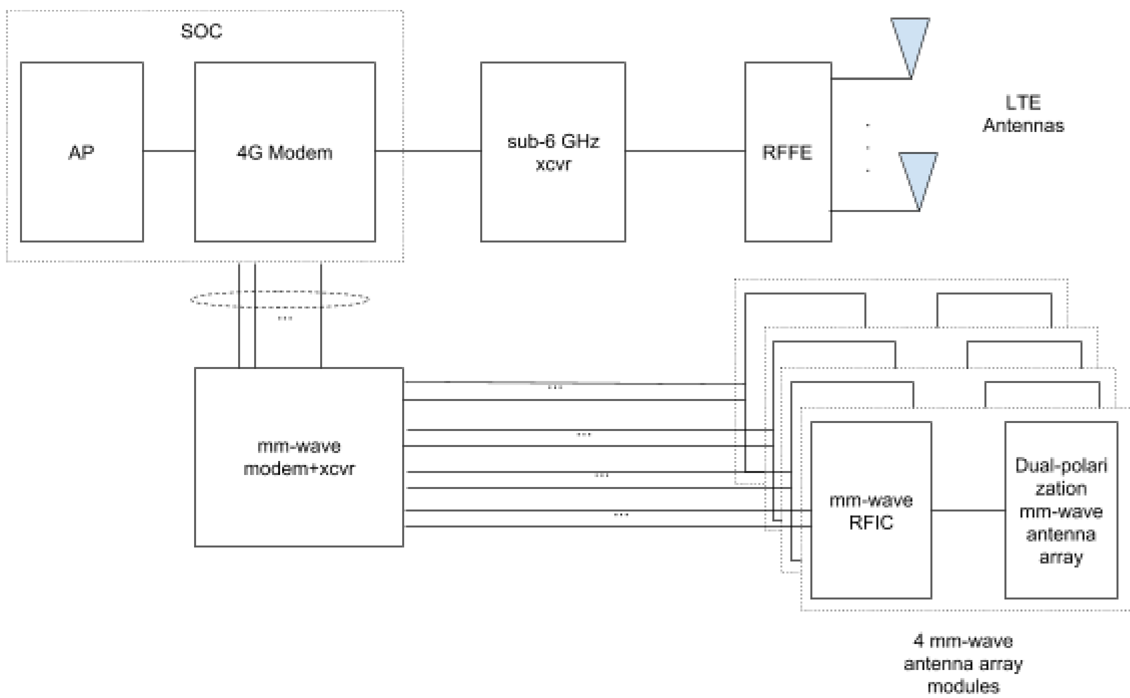

Figure 5.1.1: RF block diagram of the device.

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.

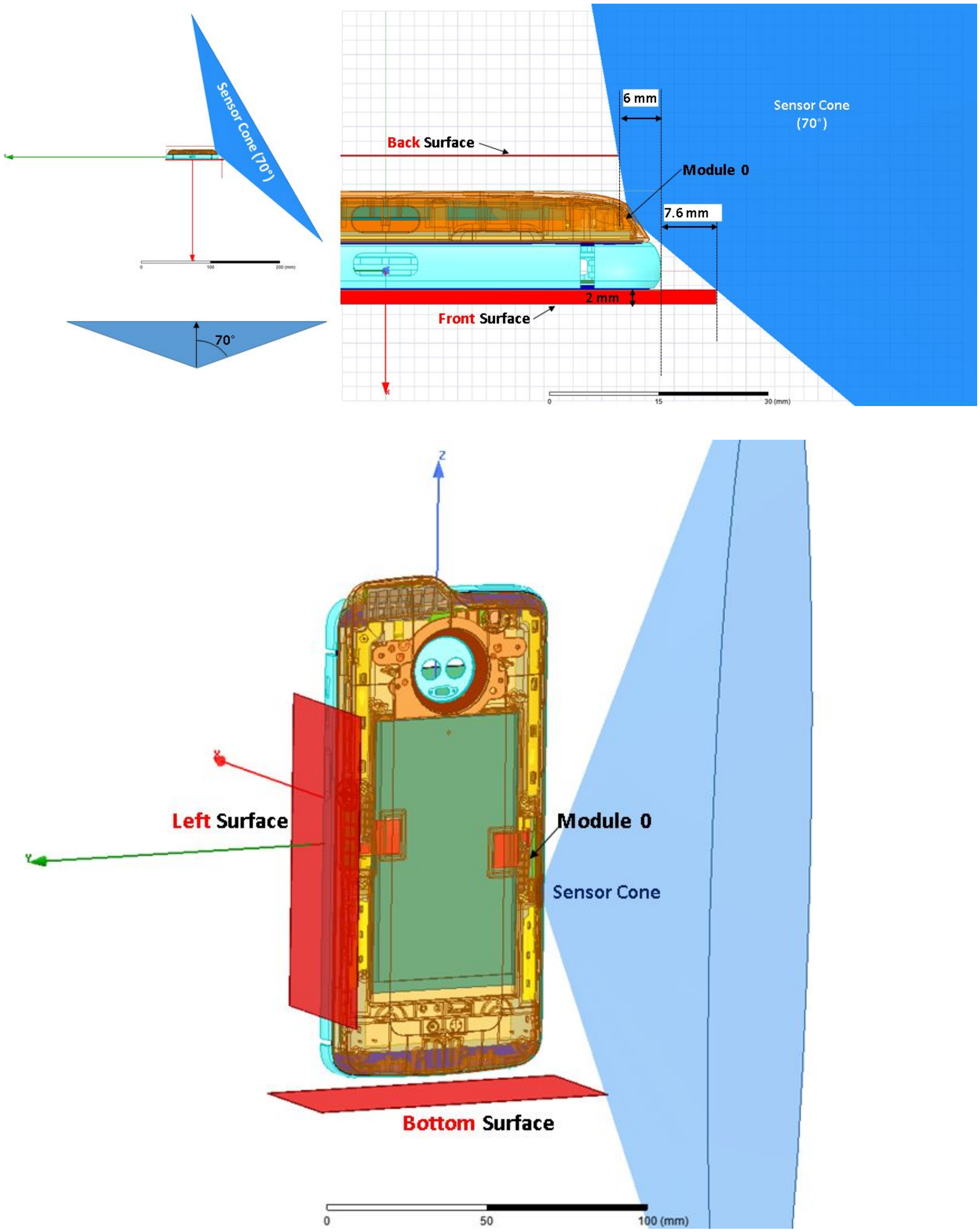

Figure 5.2.4.1 Measurement planes for Module 0.

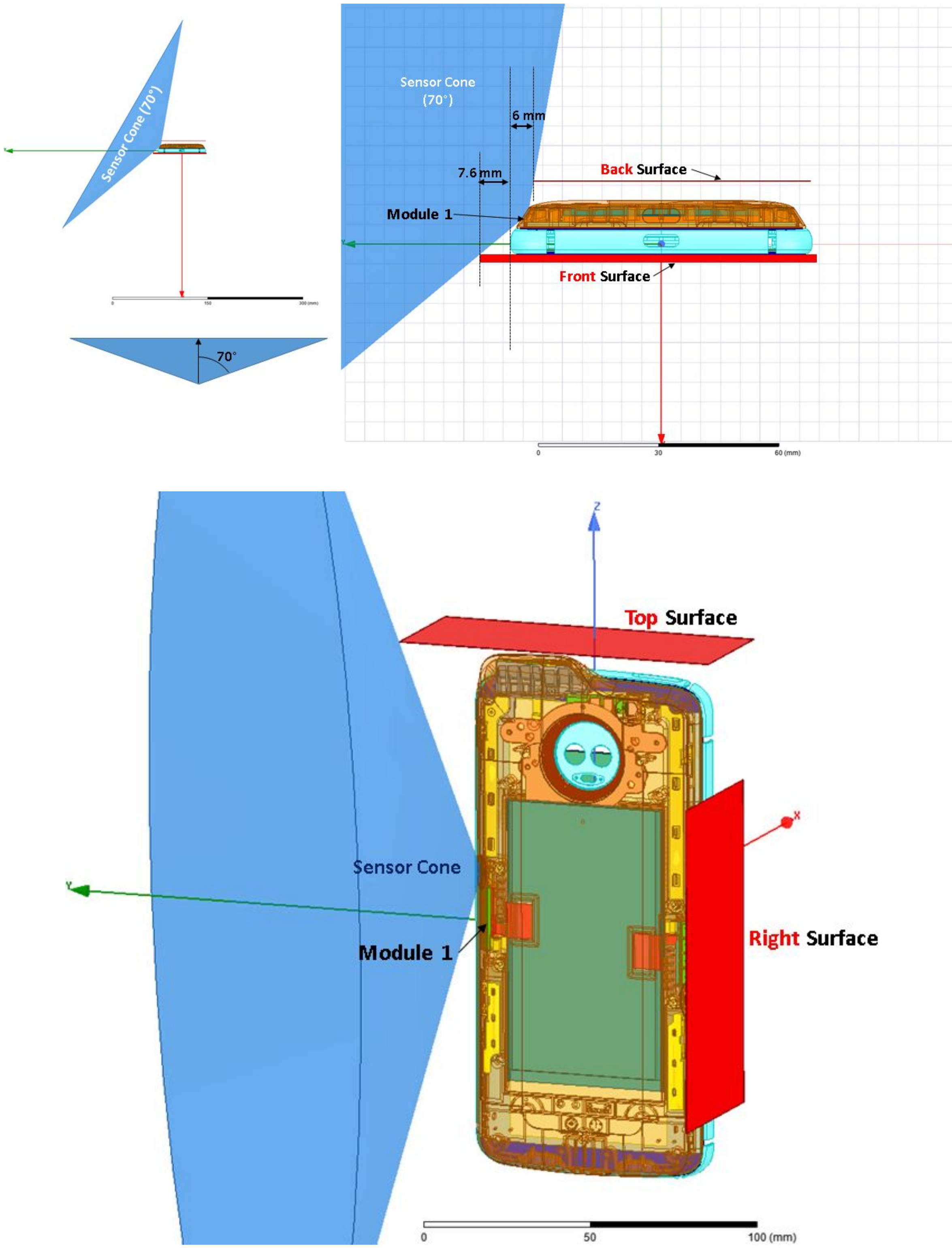

Figure 5.2.4.2 Measurement planes for Module 1.

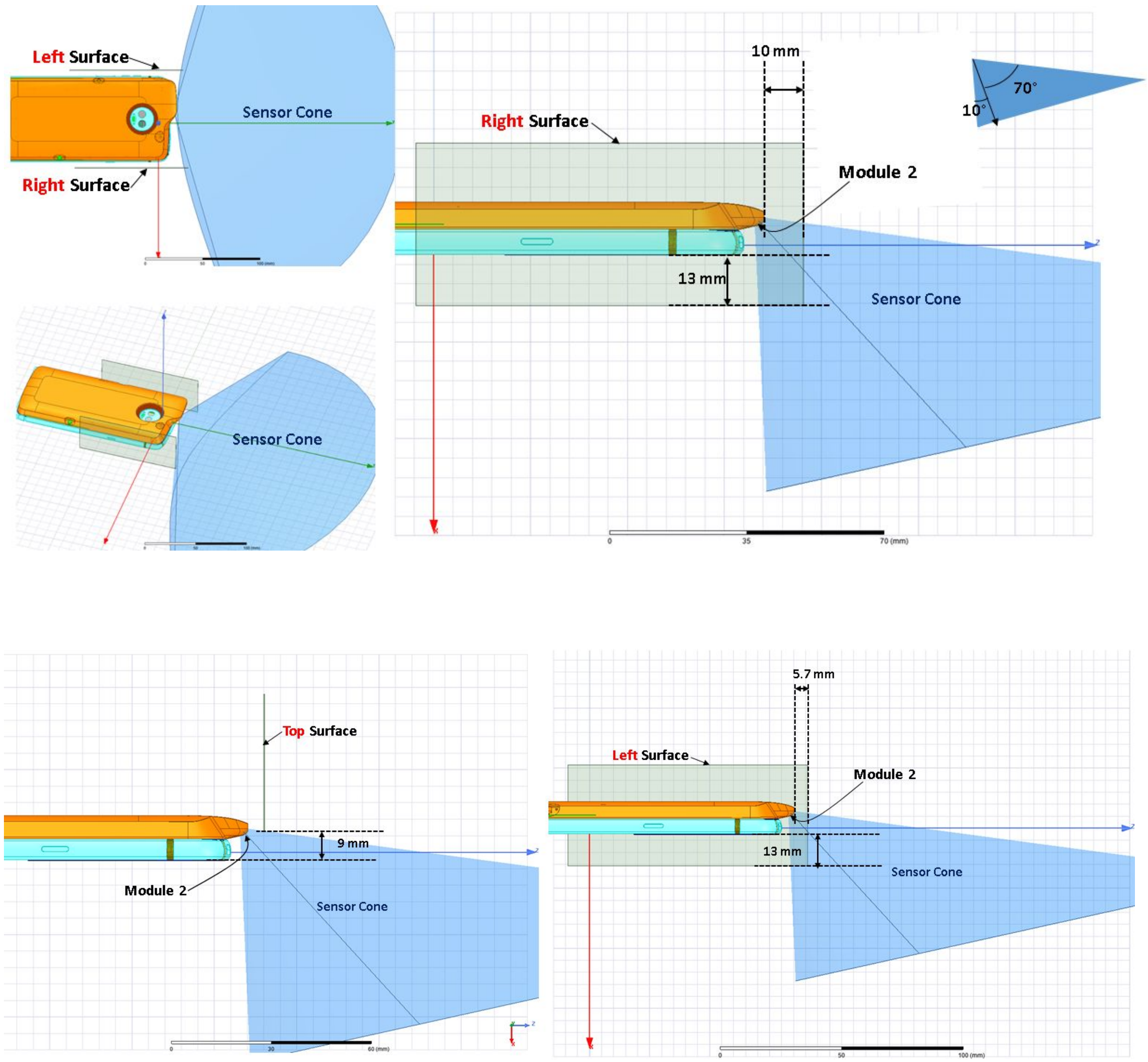

Figure 5.2.4.3 Measurement planes for Module 2.

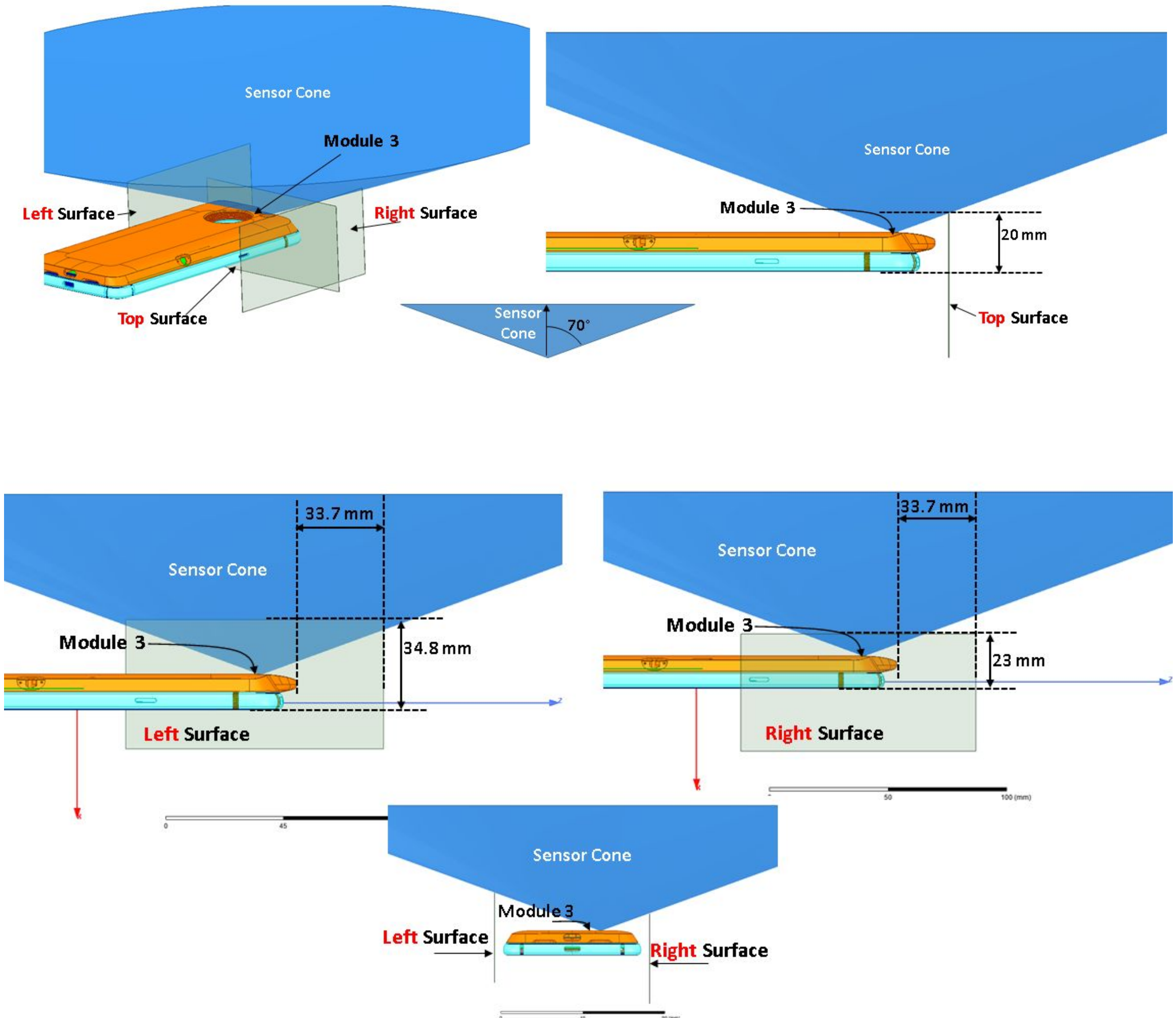

Figure 5.2.4.4 Measurement planes for Module 3.

Simulation Models

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

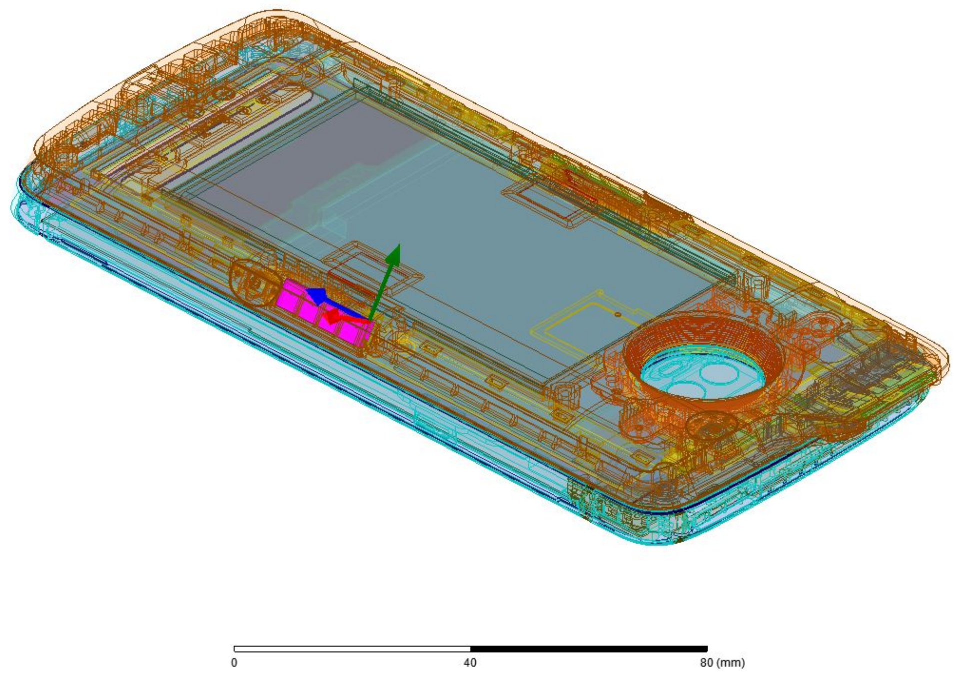

Figure 6.3.4-1: 3D model used for Module 0 (Right Array), the antenna array is highlighted

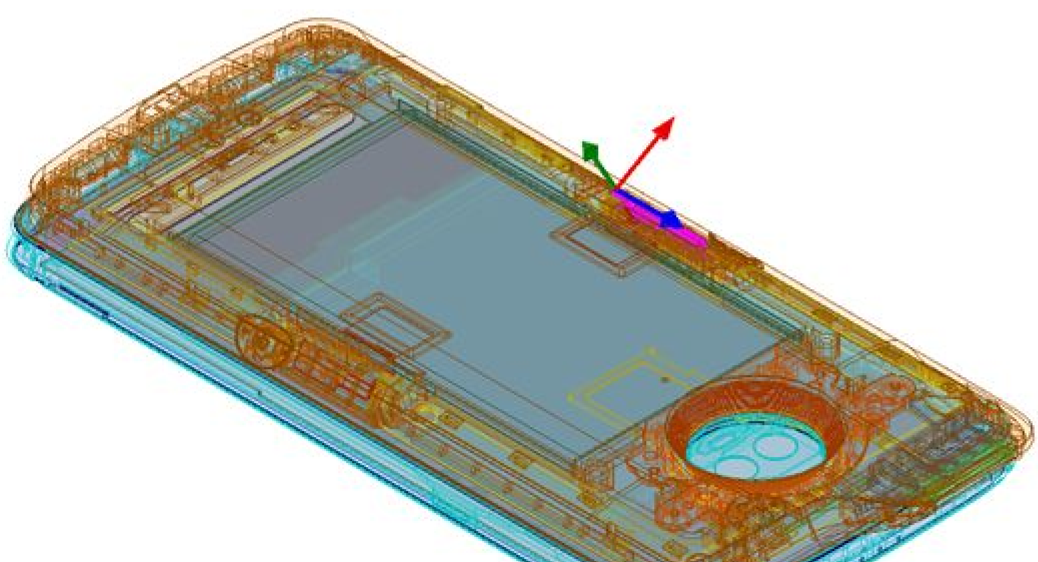

Figure 6.3.4-2: 3D model used for Module 1 (Left Array), the antenna array is highlighted

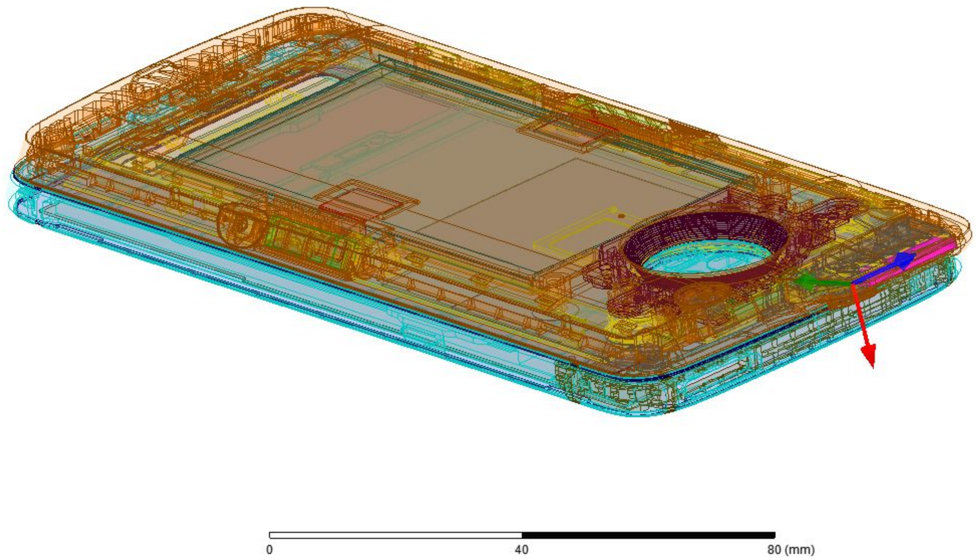

Figure 6.3.4-3: 3D model used for Module 2 (Front Array), the antenna array is highlighted

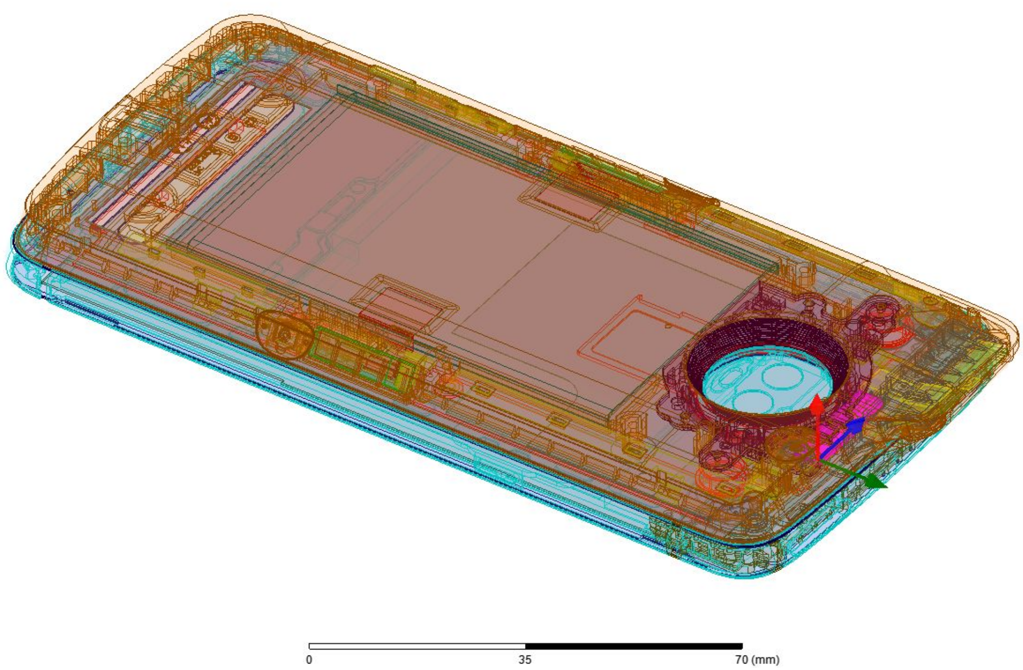

Figure 3.3.4-4: 3D model used for Module 3 (Back Array), the antenna array is highlighted

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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 10 beam pairs per module instead of 16.

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 section 5.2.4 for the module, 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
4. respective worst-case beam pair identified via simulation in Step 2.
5. 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.
6. 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 to do the power density measurement.

Note that for some modules and measurement planes, where the simulated power density values of the worst two beams were similar, both of the two worst beam pairs were measured.

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.

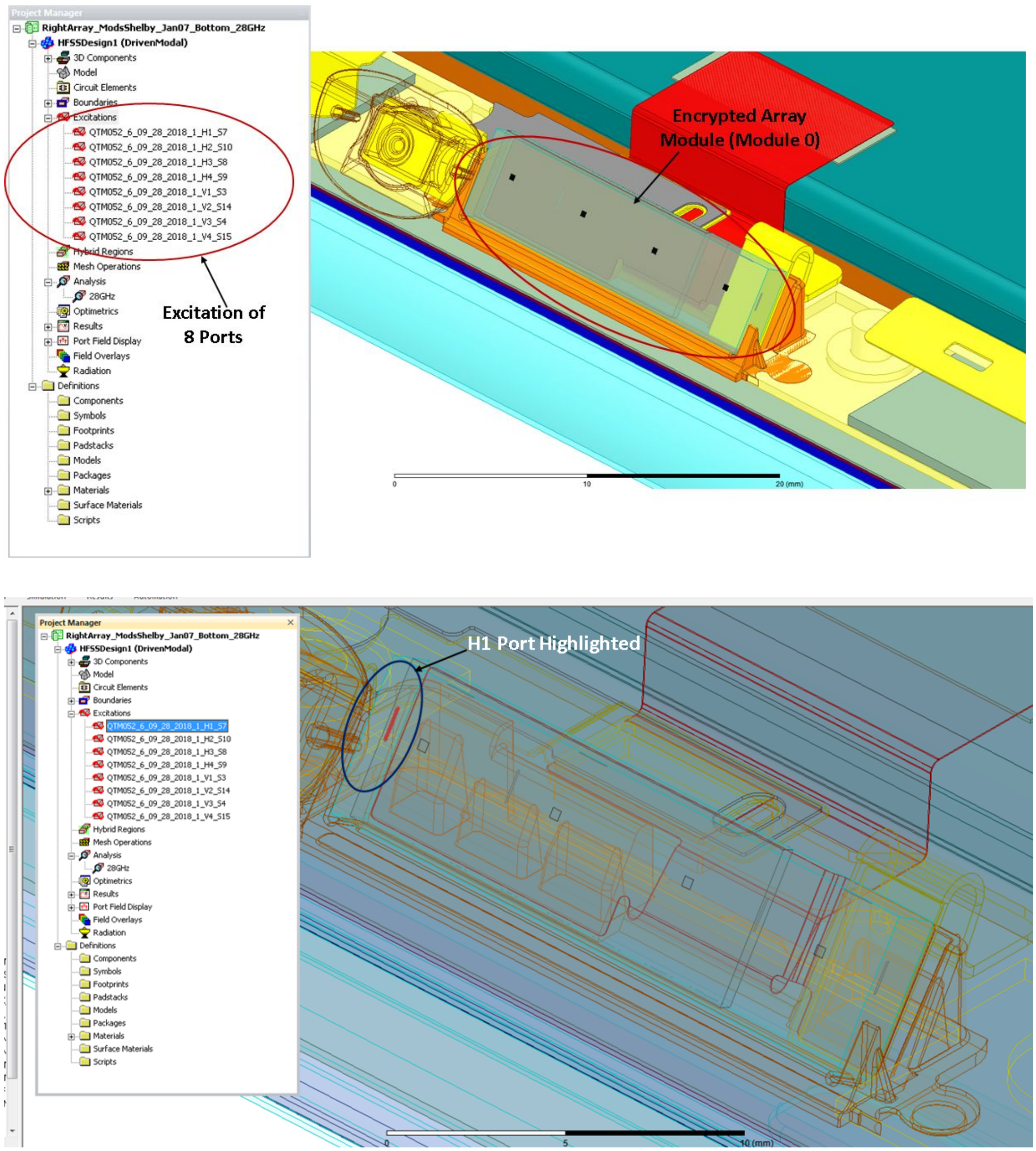

Figure 7.1.1-1: All 8 ports and the highlighted H1 port (Horizontal) in HFSS.

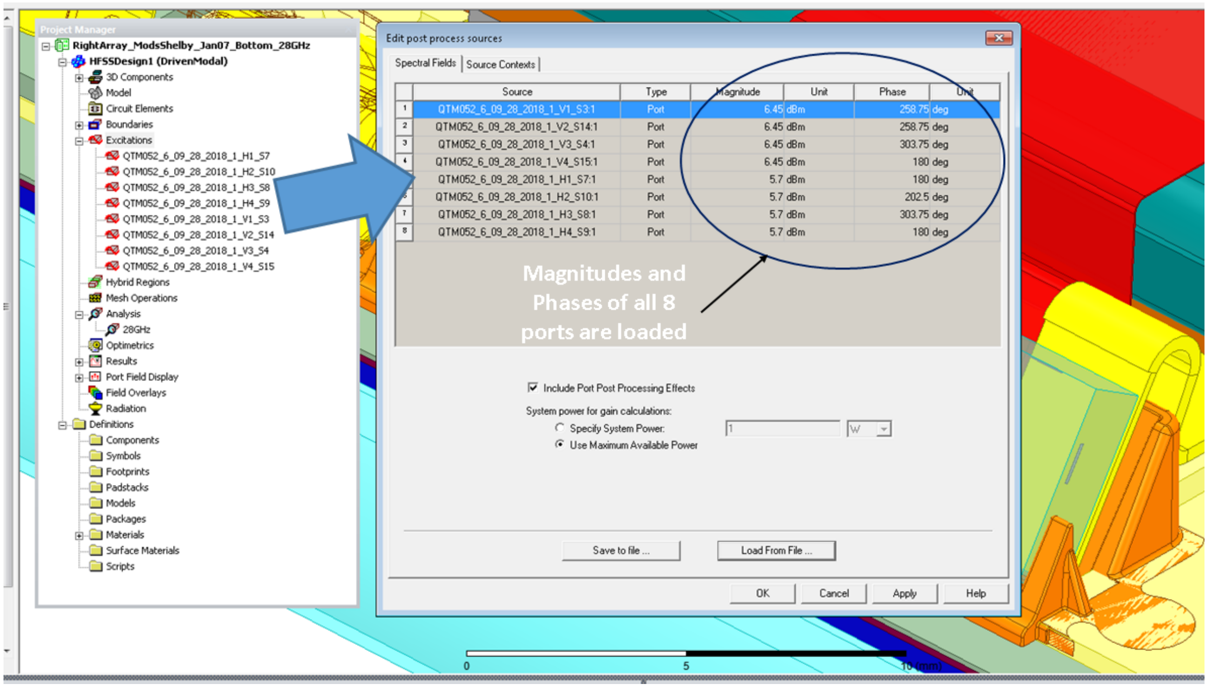

Figure 7.1.1-2: Magnitudes and phases of a beam pair are loaded in HFSS.

5. Appendix B2: Material Properties in HFSS

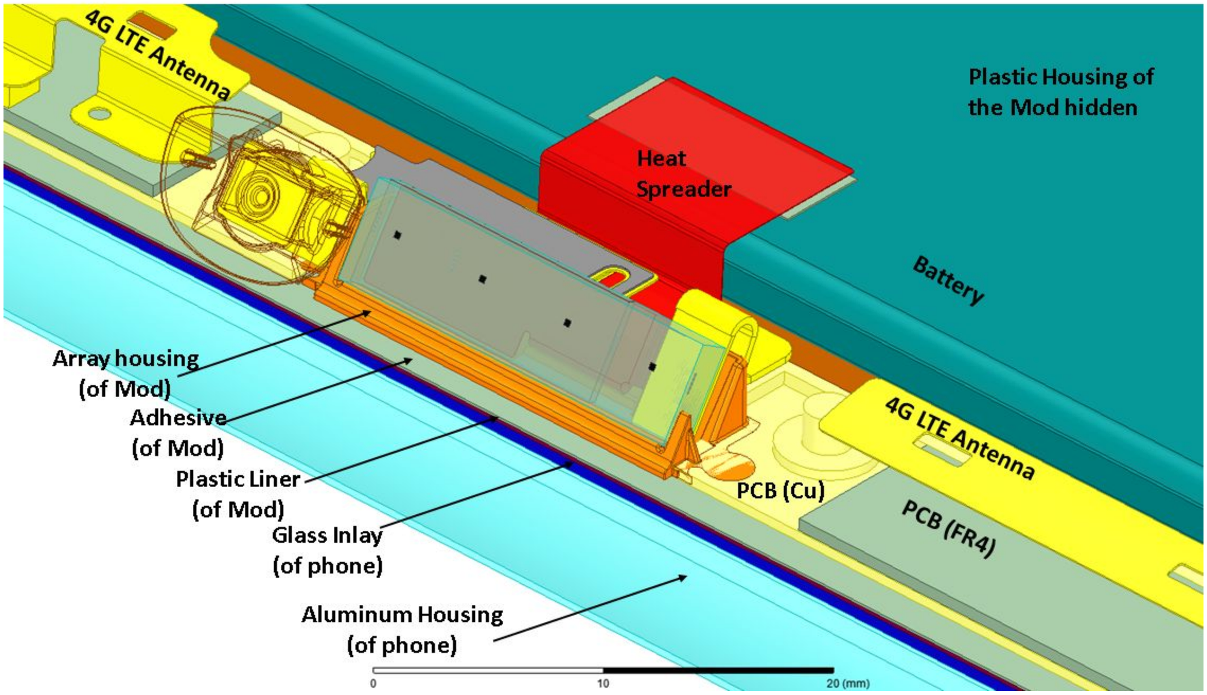

Figure 8.1.1-1: Parts/materials near an array module (Module 0).

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 for all the beampairs in each of the modules is in the tables below:

Module 0 (Right Array)			Simulated Avg Power Density (W/m²)			
#	BeamPair	Ant Group	Left @5 mm	Bottom @5 mm	Back @5 mm	Front @2 mm
1	29-160	AG0 + AG1	0.32	0.19	6.60	1.69
2	30-159	AG0 + AG1	0.11	0.15	4.22	4.80
3	31-161	AG0 + AG1	0.39	0.61	7.70	3.51
4	32-158	AG0 + AG1	0.21	0.44	6.26	1.57
5	33-157	AG0 + AG1	0.21	0.29	7.18	2.99
6	48-178	AG0 + AG1	0.20	0.31	5.33	1.31
7	49-177	AG0 + AG1	0.20	0.34	10.22	5.98
8	50-179	AG0 + AG1	0.20	0.46	4.96	3.74
9	51-176	AG0 + AG1	0.38	0.47	7.13	1.62
10	61-189	AG0 + AG1	0.24	0.86	7.40	2.61
11	1-129	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 10 beam pairs per module instead of 16.			
12	7-137	AG0 + AG1				
13	8-136	AG0 + AG1				
14	9-135	AG0 + AG1				
15	18-147	AG0 + AG1				
16	19-146	AG0 + AG1				

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

Module 1 (Left Array)			Simulated Avg Power Density (W/m²)			
#	Beam Pair	Ant Group	Right @5 mm	Top @5 mm	Back @5 mm	Front @2 mm
1	24-152	AG0 + AG1	0.25	0.28	4.28	0.99
2	25-156	AG0 + AG1	0.14	0.20	3.40	2.10
3	26-153	AG0 + AG1	0.23	0.17	8.54	3.00
4	27-154	AG0 + AG1	0.13	0.17	4.03	1.07
5	28-155	AG0 + AG1	0.20	0.15	4.02	1.05
6	44-172	AG0 + AG1	0.26	0.28	4.43	0.96
7	45-175	AG0 + AG1	0.21	0.29	4.22	1.49
8	46-173	AG0 + AG1	0.16	0.13	3.22	2.32
9	47-174	AG0 + AG1	0.26	0.15	4.85	1.38
10	60-188	AG0 + AG1	0.14	0.43	4.69	1.34
11	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 10 beam pairs per module instead of 16.			
12	4-132	AG0 + AG1				
13	5-133	AG0 + AG1				
14	6-134	AG0 + AG1				
15	16-144	AG0 + AG1				
16	17-145	AG0 + AG1				

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

Module 2 (Front Array)			Simulated Avg Power Density (W/m²)			
#	Beam Pair	Ant Group	Right @5 mm	Left @5 mm	Top @5 mm	Back @5 mm
1	39-171	AG0 + AG1	0.19	2.75	3.07	2.20
2	40-170	AG0 + AG1	0.12	2.87	4.23	2.83
3	41-168	AG0 + AG1	0.33	1.40	2.95	2.60
4	42-169	AG0 + AG1	0.89	1.49	2.85	2.34
5	43-167	AG0 + AG1	0.51	0.94	5.51	4.15
6	56-187	AG0 + AG1	0.12	2.98	2.98	2.16
7	57-185	AG0 + AG1	0.72	1.07	2.64	2.24
8	58-184	AG0 + AG1	0.23	1.20	2.50	2.84
9	59-186	AG0 + AG1	0.75	2.41	3.24	2.09
10	63-191	AG0 + AG1	0.31	1.34	2.69	2.03
11	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 10 beam pairs per module instead of 16.			
12	13-143	AG0 + AG1				
13	14-142	AG0 + AG1				
14	15-141	AG0 + AG1				
15	22-151	AG0 + AG1				
16	23-150	AG0 + AG1				

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

Module 3 (Back Array)			Simulated Avg Power Density (W/m²)			
#	Beam Pair	Ant Group	Right @5 mm	Left @5 mm	Top @5 mm	Front @2 mm
1	34-162	AG0 + AG1	1.41	0.66	3.99	0.33
2	35-163	AG0 + AG1	1.51	0.66	3.70	0.24
3	36-164	AG0 + AG1	2.46	1.14	2.65	0.55
4	37-166	AG0 + AG1	0.54	0.66	3.85	0.27
5	38-165	AG0 + AG1	0.84	1.23	2.54	0.29
6	52-180	AG0 + AG1	2.34	1.10	3.02	0.24
7	53-181	AG0 + AG1	2.38	1.12	3.06	0.24
8	54-182	AG0 + AG1	2.52	1.45	2.67	0.42
9	55-183	AG0 + AG1	0.63	1.01	3.16	0.32
10	62-190	AG0 + AG1	1.57	0.59	4.03	0.28
11	2-130	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 10 beam pairs per module instead of 16.			
12	10-138	AG0 + AG1				
13	11-139	AG0 + AG1				
14	12-140	AG0 + AG1				
15	20-148	AG0 + AG1				
16	21-149	AG0 + AG1				

Table 6.3.5-4 Simulated avg. power density data 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: 27.925 GHz**	**49**	**177**	**Front Surface**	**2 mm**	**0.12**	**5.98**
	49	**177**	**Back Surface**	**5 mm**	**2.47**	**10.22**
	31	**161**	**Left Surface**	**5 mm**	**0.17**	**0.39**
	61	**189**	**Bottom Surface**	**5 mm**	**0.48**	**0.86**

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: 27.925 GHz**	**26**	**153**	**Front Surface**	**2 mm**	**0.26**	**3**
	26	**153**	**Back Surface**	**5 mm**	**1.13**	**8.54**
	26	**153**	**Right Surface**	**5 mm**	**0.06**	**0.23**
	44	**172**	**Top Surface**	**5 mm**	**0.52**	**0.28**

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: 27.925 GHz**	**43**	**167**	**Back Surface**	**5 mm**	**1.29**	**4.15**
	42	**169**	**Right Surface**	**5 mm**	**0.15**	**0.89**
	56	**187**	**Left Surface**	**5 mm**	**1.49**	**2.98**
	43	**167**	**Top Surface**	**5 mm**	**1.25**	**5.51**

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: 27.925 GHz**	**36**	**164**	**Front Surface**	**2 mm**	**0.39**	**0.55**
	54	**182**	**Right Surface**	**5 mm**	**0.90**	**2.52**
	38	**165**	**Left Surface**	**5 mm**	**0.82**	**1.23**
	37	**166**	**Top Surface**	**5 mm**	**3.23**	**3.85**

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

In all cases, the absolute values of the simulated power density are substantially higher than the measured values. This is due to some conservative assumptions in the simulation model and in the per-beam EIRP normalization process. Since the purpose of the simulation process is to make relative assessments of which beam is worst-case in the various measurement planes, it was not deemed necessary to investigate this systematic offset in detail.

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 2077083, Frequency: 27875.04 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	33	157	24.4
0	31	161	24.0
0	49	177	23.3
0	29	160	23.3
0	51	176	23.1
0	30	159	22.7
0	32	158	22.4
0	61	189	22.2
0	50	179	21.5
0	48	178	20.9
0	8	136	19.3
0	18	147	19.2
0	7	137	19.1
0	9	135	19.0
0	19	146	18.5
0	1	129	15.0
1	28	155	20.9
1	25	156	20.6
1	26	153	20.6
1	47	174	20.4
1	24	152	20.0
1	44	172	19.8
1	45	175	19.4
1	60	188	18.6
1	46	173	18.6
1	16	144	18.2
1	5	133	18.1
1	27	154	17.3
1	6	134	17.3
1	17	145	16.4
1	4	132	15.9

1	0	128	12.3
2	59	186	20.8
2	41	168	20.3
2	57	185	19.2
2	58	184	18.9
2	40	170	18.9
2	63	191	18.8
2	42	169	18.6
2	13	143	18.1
2	43	167	18.0
2	56	187	17.7
2	22	151	17.7
2	39	171	17.4
2	14	142	16.1
2	23	150	16.1
2	15	141	16.0
2	3	131	12.8
3	35	163	21.4
3	52	180	21.1
3	54	182	20.7
3	34	162	20.5
3	36	164	20.3
3	37	166	20.3
3	53	181	19.8
3	38	165	19.6
3	62	190	19.5
3	55	183	19.0
3	11	139	17.4
3	20	148	17.1
3	10	138	17.0
3	12	140	16.9
3	21	149	15.5
3	2	130	13.3

Table 7.1 Measured EIRP for all beampairs