



**Intel® Model: 17265NGW LC, FCC ID:
PD917265NG**

HP PC model HSTNN-I22C Power Density report for FCC

January 2015

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Table of Contents

1	Document scope	6
2	Background – WiGig system operation	7
2.1	System block diagram	7
2.2	Beam forming	7
2.3	Tx Duty Cycle	7
2.4	Intel 17265NGW module in HP PC model HSTNN-I22C	8
3	Simulation Methodology	9
3.1	Electromagnetic Simulation	9
3.1.1	Tool description	9
3.1.2	Solver description	9
3.1.3	Evaluating near field power	9
3.1.4	Power averaging	10
3.1.5	Dielectric parameters	10
3.2	3D Models used in the simulation	11
3.2.1	RFEM housing inside Intel 17265NGW LC module	11
3.2.2	Closest distance to the body of an end user	11
3.2.3	Metals in proximity of the RFEM	11
3.3	Antenna feed	11
4	Simulation results	13
4.1	Power averaging	13
4.2	Power Density	15
5	Validation of Simulation results	16
5.1	Correlation of power density in far field	16
5.1.1	Far field boundary calculation	16
5.1.2	Lab measurements	16
5.1.3	Correlation of measurements and simulation	17
5.2	Simulating a canonical antenna design	20
6	Summary	23



List of Figures

Figure 1 – Intel 17265NGW LC module system block diagram.....	7
Figure 2 - Illustration of evaluation of near field power	9
Figure 3 - Example of Power Density results	10
Figure 4 - Example Mesh visualization of 1cm ² test plane at 2.48mm distance from RFEM.....	10
Figure 5 – Simulation mesh for RFEM module	12
Figure 6 – Maximum complex E-field and H-field over 1cm ² with 100% duty cycle at 2.48mm distance.....	13
Figure 7 - Power Density mesh for maximum 1cm ² test plane at 100% duty cycle and distance of 2.48mm	14
Figure 8 – HFSS Simulation results in Ch2.....	15
Figure 9 - Comparison of Power Density simulation to lab measurements.....	17
Figure 10 – Zoom-in on the comparison of simulation to lab measurements	18
Figure 11 – Estimate EIRP of Simulation vs. lab measurements and far field boundary (Ch2)	19
Figure 12 - Simulation of a single Patch antenna.....	20
Figure 13 – Patch Antenna Gain	20
Figure 14 – Simulation 3D structure	21
Figure 15– Power Density of Canonical Patch Antenna	22

List of Tables

Table 1 – Acronyms	4
Table 2 - Setup parameters and measurement results, Intel Regulatory Lab.....	17
Table 3 – Gain calculation from power density per several distances.....	21
Table 4 – Summary of simulation results for RF exposure compliance	23

Table 1 – Acronyms

ABS	Acrylonitrile butadiene styrene – the plastic type from which the HP model HSTNN-I22C is built
Ant	Antenna
Az	Azimuth
BB	Base Band
BF	Beam Forming
BT	Bluetooth
BW	Band Width
CAD	Computer Aided Design
CPU	Central Processing Unit
EIRP	Equivalent Isotropically Radiated Power



Document scope

EI	Elevation
EM	Electro-Magnetic
GHz	Giga Hertz (10^9 Hz)
IF	Intermediate Frequency
MAC	Media Access Control
mmWave	Milli-Meter Wave
OTP	One Time Programmable memory
PC	Personal Computer
R&D	Research and Development
RF	Radio Frequency
RFEM	Radio Front End Module
RFIC	Radio Frequency Integrated Circuit
RX	Receive
SKU	Stock Keeping Unit, specific product model version
TPC	Transmit Power Control
T/R SW	Transmit / Receive Switch
TX	Transmit
WiGig	Wireless Gigabit Alliance – the alliance that promoted the 60GHz into 802.11ad standard.



1 Document scope

This report is submitted to support the compliance to FCC rule parts §2.1093 and §15.255(g), of Intel 17265NGW LC WiGig module (FCC ID: PD917265NG), including an active antenna array, embedded inside the HP PC model HSTNN-I22C.

Per the location of the active antenna array (a.k.a. RFEM) in the HP PC model HSTNN-I22C platform, the distance between the antenna array to the body of an end user, at the closest contact point, will be in the near field, and consequently accurate power density measurements are not possible.

Therefore, to obtain accurate near field power density results, we used an EM simulation that includes the RFEM transmitter model, embedded inside the HP PC model HSTNN-I22C 3D model. These results are documented in the following sections of this report.

To prove the validity of these results, we will show how the results of the same simulation are well correlated, for far field distances, to lab measurements of Intel 17265NGW LC module inside the HP PC model HSTNN-I22C platform.

The 2nd chapter provides relevant background on Intel 17265NGW LC module. The 3rd chapter describes the simulation methodology to determine RF exposure (power density) levels. The 4th chapter includes simulation results, and 5th chapter the correlation between simulation and lab measurements in far field. Chapter 6 summarizes the RF-Exposure analysis.

2 Background – WiGig system operation

2.1 System block diagram

Intel 17265NGW LC module is a solution for WiGig connectivity for various platforms. Intel 17265NGW LC module can be embedded in conventional clamshell PC as well as modern 2 in 1 platforms (detachable platforms, e.g., like HP PC model HSTNN-I22C).

Intel 17265NGW LC WiGig module solution is made of an M.2 module connected to an RFEM using one IF coaxial cable.

M.2 Module: a combo board, including a Wi-Fi / BT chip as well as a WiGig BB chip, which implements the WiGig MAC, Modem, BF algorithm, and active antenna array module control, as well as the BB + IF stage circuitry.

RFEM: an active antenna array module, which converts between the IF signal and 60GHz signal. It also performs the beam forming functionality. The RFEM is slave to the WiGig BB chip – all module control and algorithms run on the BB chip.

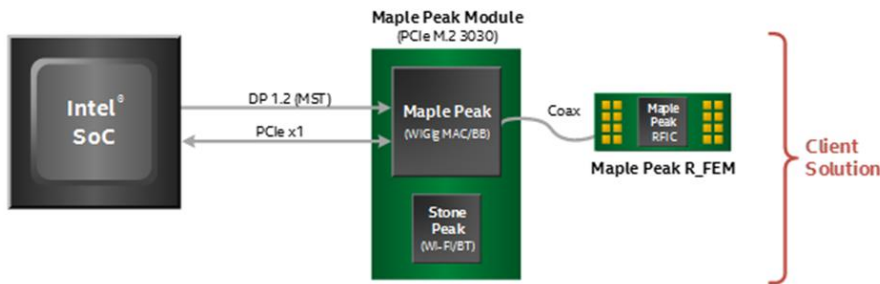


Figure 1 – Intel 17265NGW LC module system block diagram

In typical application the RFEM is located at the top of the lid of a notebook PC, in order to improve the RF propagation of the communication link.

Due to the detachable nature of the HP PC model HSTNN-I22C platform, both the M.2 module and the RFEM are located inside the same section of the PC platform. The following picture shows the location of the M.2 and RFEM module inside the HP PC model HSTNN-I22C platform with a (white) coax cable connection between them. Please refer to figure 1 in the test setup photos document.

2.2 Beam forming

Achieving high bandwidth communication over 60GHz channels usually requires directional antenna at the transmitter and receiver sides. In consumer electronics, fixed directional or mechanically rotated antenna are not practical and electronically steerable antenna are usually used.

In Intel 17265NGW LC module, such electronic steerable antenna array is being used. Beam forming protocol (defined in the IEEE 802.11ad standard) is used to find the right direction for setting both the RX and TX antenna directions.

Due to the antenna structure the highest antenna gain is achieved when directing the antenna to the antenna origin $(Az, El)=(0,0)$.

2.3 Tx Duty Cycle

The WiGig protocol, as defined in IEEE 802.11ad, is packet based with time division multiplexing (TDM). Intel 17265NGW LC module is configured to guarantee that the Tx-Duty-Cycle, defined as the ratio of



the duration of all transmissions to the total time, is at most 70% over any 10 seconds period. This was established by worst case analysis, as derived from full system simulation, and verified by measurements.

The limited Tx-Duty-Cycle is established based on HW and FW implementation with ~100 ms (102.4 ms) measurement duration and 10 seconds averaging. The 70% duty cycle limitation is guaranteed independent of user activity, and therefore it adheres to the source-based time-averaging definition in 2.1093(d)(5).

2.4 Intel 17265NGW module in HP PC model HSTNN-I22C

Intel produces several HW SKUs (variations) of Intel 17265NGW module, which target different types of customer platform products.

HP uses Intel 17265NGW LC module inside the HP PC model HSTNN-I22C platform. This SKU is characterized by:

1. supporting only channels **2+3**
2. Reduced power emission, which translates to:
 - a. Maximal transmit conducted power of **6.4 dBm** aggregated conducted power at the antenna ports.
 - b. Maximal TX duty-cycle of **70%**.

3 Simulation Methodology

3.1 Electromagnetic Simulation

3.1.1 Tool description

For the EM simulation we use the commercially available ANSYS HFSS tool 2014 version. ANSYS HFSS tool is used in industry for simulating 3-D full-wave electromagnetic fields.

3.1.2 Solver description

The HFSS simulation is done using the Finite Element Method which operates in the frequency domain. The HFSS is based on an accurate direct solver with first order basis functions.

Time domain WiGig packets can't be simulated in HFSS simulation due to two reasons:

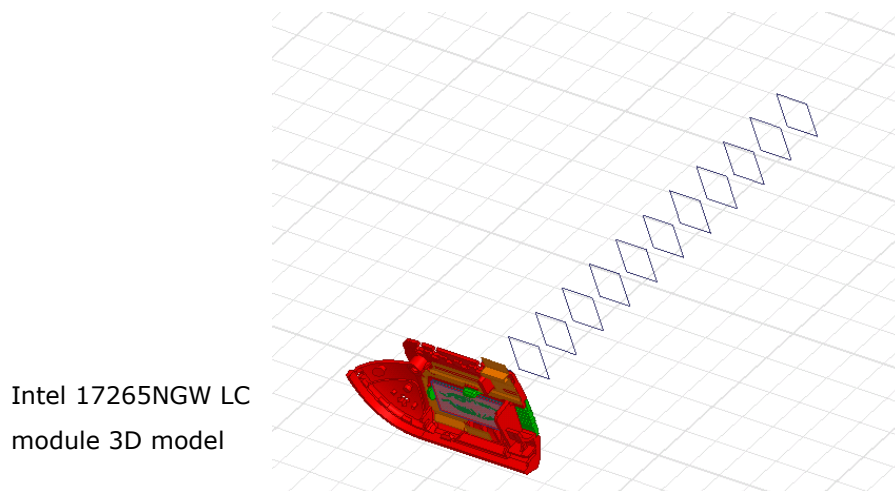
1. The simulation is done in frequency domain, problematic to add time domain packets.
2. Simulation time would explode if long time domain packets (10's-100's uSec) would be added to the electromagnetic solver that runs on 60GHz simulation.

3.1.3 Evaluating near field power

The simulation calculates the electric and magnetic fields in a fine mesh of points. The average power density on a given surface is calculated as the surface integral of the Poynting vector:

$$W = \frac{1}{2} \operatorname{Re} \int_S (\vec{E} \times \vec{H}^*) \cdot \vec{n} dS$$

The power density is calculated in the relevant places (in front of the RFEM outside the HP PC model HSTNN-I22C platform) on surfaces of 1cm * 1cm. For each distance, the 1cm² with the maximum power is chosen as the power for that distance.



Intel 17265NGW LC
module 3D model

Figure 2 - Illustration of evaluation of near field power

3.1.4 Power averaging

In the simulation we simulate the power density. Figure 3 below depicts an example of the the overall power density of the RFEM at a given distance.

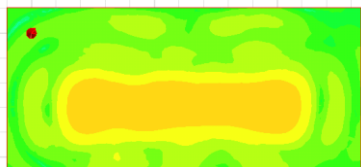


Figure 3 - Example of Power Density results

We integrate over the worst case (spatial and channel wise) 1cm^2 , and use this value. Later, in chapter 4, we use this worst case in determining the RF exposure level.

HFSS employs the finite element method which the geometric model is automatically divided into a large number of Tetrahedra in 3D objects or triangles in 2D objects. The value of a vector field quantity (E field or H field) at point inside each tetrahedron/triangle is interpolated from the vertices and midpoint of selected edges. HFSS uses iterative process in which the mesh is automatically refined in critical regions to meet the 2% accuracy criteria (accuracy is better than 0.18 dB).

In the Intel 17265NGW LC module platform, the RFEM is located inside the platform chassis and covers. The shortest distance between an end user holding the platform and the antenna surface of the RFEM is 2.48mm. Therefore, the $1\text{cm} \times 1\text{cm}$ Mesh used to calculate the power density is taken at a distance of 2.48mm. An example of this Mesh can be seen in the figure below.

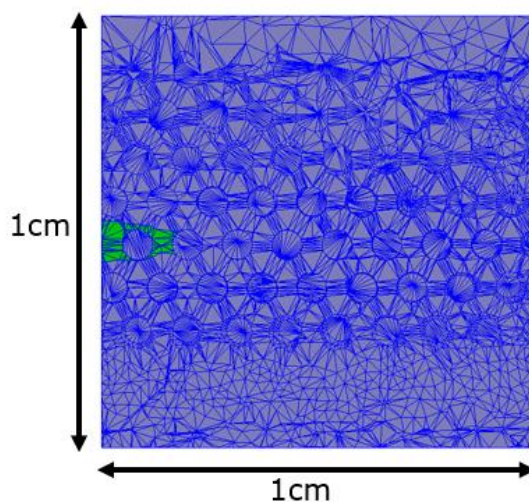


Figure 4 - Example Mesh visualization of 1cm^2 test plane at 2.48mm distance from RFEM

3.1.5 Dielectric parameters

Three material types are used in the simulation:

1. The PCB that is used for the antenna module. The dielectric constant parameters that are used for this material are: Permittivity =3.7, $\tan\delta=0.01$. The source for this coefficients is the material manufacturer.
2. The ABS plastic that is used in the Intel 17265NGW LC module platform build, the dielectric constants parameters for the ABS material are: Permittivity =3, $\tan\delta=0.01$. These are the industry used parameters for ABS plastic at the 60GHz frequency bands.



3. Metal (copper) that is used in the active antenna module. The metal is used for the antenna structure, feed lines, vias etc. In addition metal is used for antenna ground plane (the same structure in the simulation and the actual module).

3.2 3D Models used in the simulation

3.2.1 RFEM housing inside Intel 17265NGW LC module

3D Intel 17265NGW LC module CAD files are used in the EM simulation to allow correct exposure level simulation.

Please refer to figure 2 in the test setup photos document to see RFEM placement inside the HP HSTNN-I22C platform.

3.2.2 Closest distance to the body of an end user

The closest distance between the active antennas to the skin of an end user is when the person holding the unit and touching the plastic grill. At this case the distance between a hand or body to the active antenna is 2.48mm.

3.2.3 Metals in proximity of the RFEM

The closest metal to the active antenna is the WWAN antenna, the antenna is located at a lateral distance of about 2mm from RFEM edge (~5mm from the active element) at a plane that is slightly behind the RFEM.

Since the WWAN antenna is relatively far away and behind the WiGig antenna ground plane (wavelength wise @ 60GHz) we don't foresee the WWAN antenna impacting the WiGig antenna performance, hence WWAN antenna was not included in the simulation.

3.3 Antenna feed

The EM simulation uses an accurate 3D model of the WiGig antenna. The model includes the antenna elements as well as their feeding lines.

In the simulation, we excite the antennas at the origin of the antenna structure on the RFEM (the antenna structure includes the vias, traces and actual antenna element). This via feed point is used as the interface point for the simulation – and is marked in green in the above diagram. Antenna layers are fully simulated, including all parts of the PCB and antennas: conducted traces, feeds, antenna elements and dielectrics. The modeling (mesh resolution) is automatically defined by the simulation tool to assure better than 2% accuracy. The picture below shows the feeding layer inside the antenna and the selected mesh resolution.

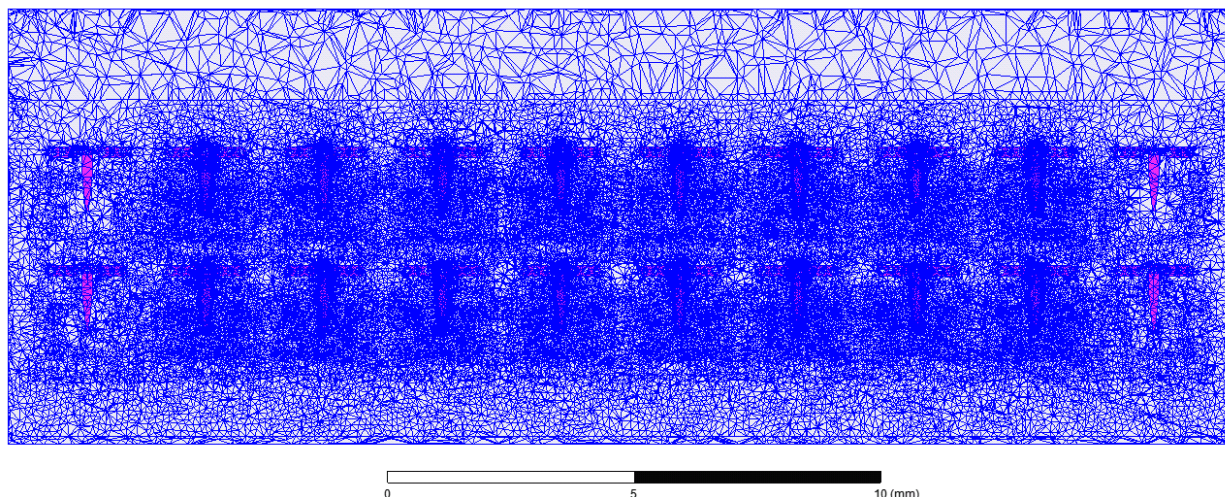


Figure 5 – Simulation mesh for RFEM module

The trace loss from the Si to the antenna feed point (including trace loss and vias) is incorporated by the power level at the antenna feed point

In the simulation, all the antenna are excited at the same phase – hence forming a forward looking beam (boresight direction, $(Az,El)=(0,0)$). This is the direction that yields the highest antenna gain.

Note: the lab tests also use the same predefined steering (values of the phase shifters) in order to create the forward looking beam bore sight direction, $(Az,El)=(0,0)$, the direction with the maximum antenna gain.

The simulation uses a fixed power feed per element, such that the aggregated conducted output power at the antenna feed points is 6.4dBm. In addition, the simulation is conducted using 100% TX duty cycle.

4 Simulation results

4.1 Power averaging

The figures below present the Magnitude of the complex E-field and H-field for the worst case 1cm² test plane located at 2.48mm from the RFEM, located inside HP PC model HSTNN-I22C.

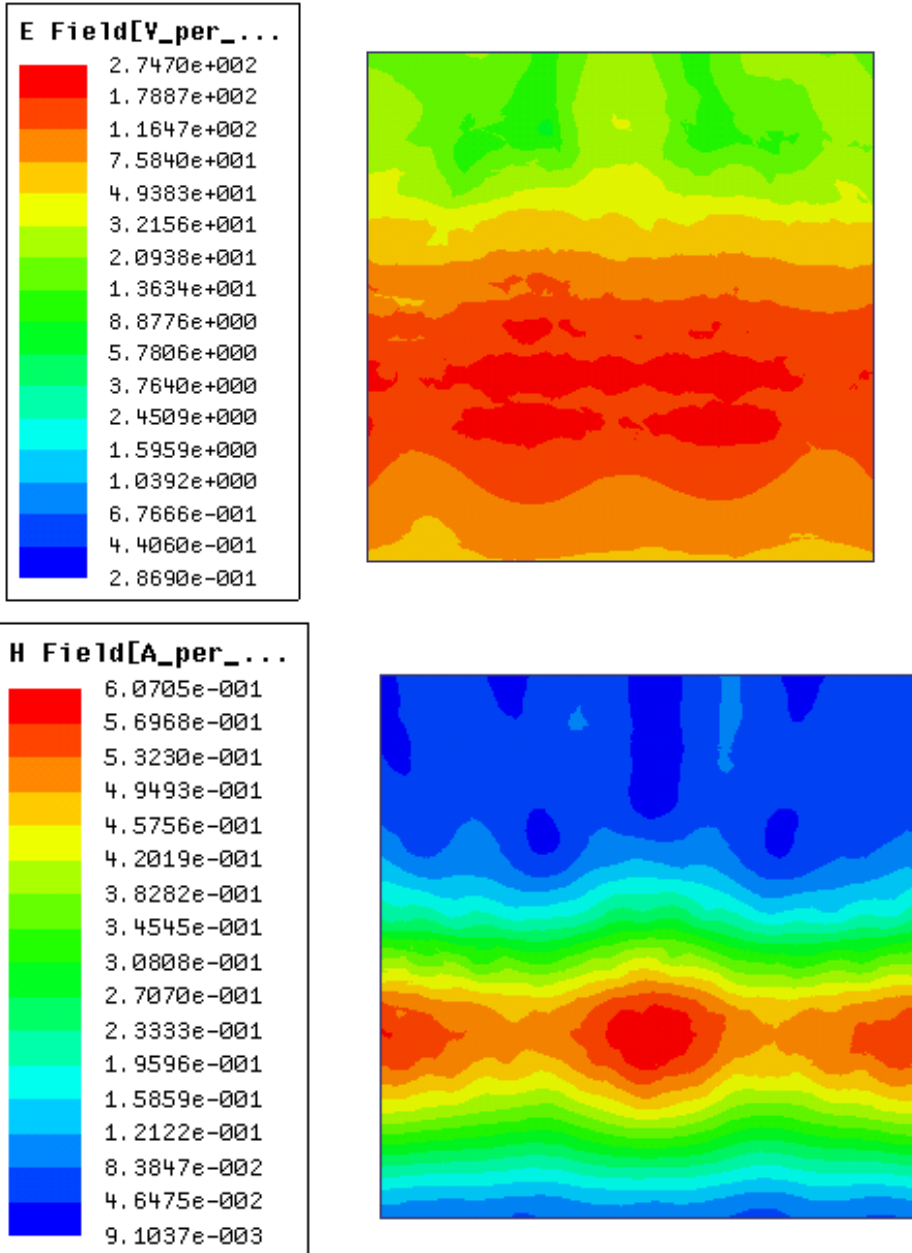


Figure 6 – Maximum complex E-field and H-field over 1cm² with 100% duty cycle at

2.48mm distance

We can deduce from the figure that the resolution of the HFSS simulation at this distance is very high, hence able to identify the 1cm^2 with the worst case (highest) power density.

From the E-Field and H-Field we calculate the power density using the Poynting equation. The result is shown in the figure below:

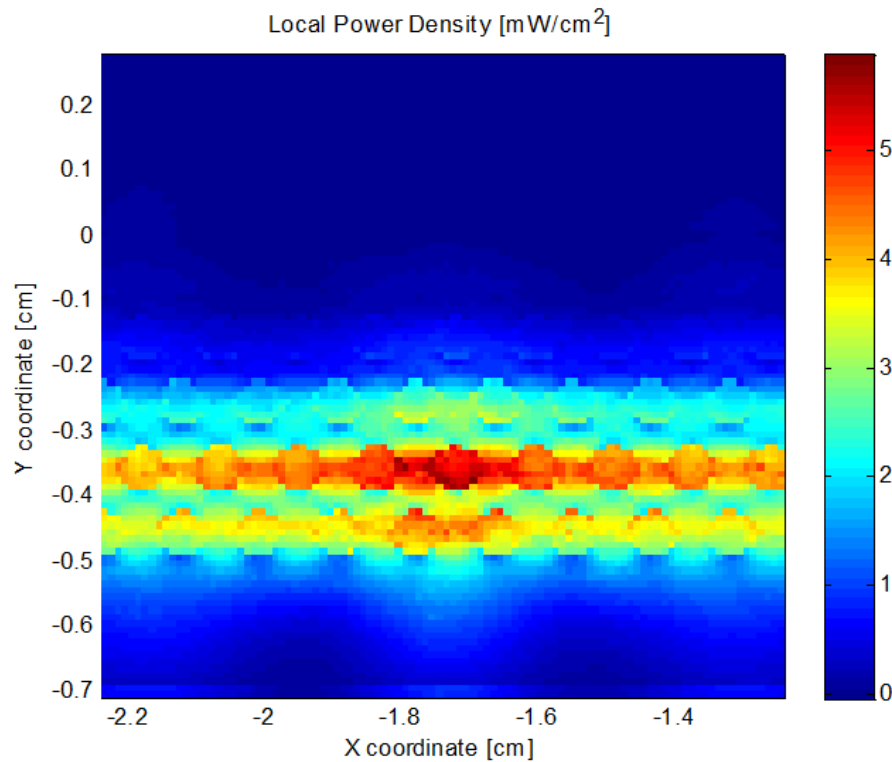


Figure 7 - Power Density mesh for maximum 1cm^2 test plane at 100% duty cycle and distance of 2.48mm

Figure 7 was calculated with a resolution of 0.1mm (10,000 points in 1cm^2). The HFSS resolution is even finer.



4.2 Power Density

The following figure shows the worst case power-density (over X-Y position and channels) computed by the simulation versus the distance from the RFEM.

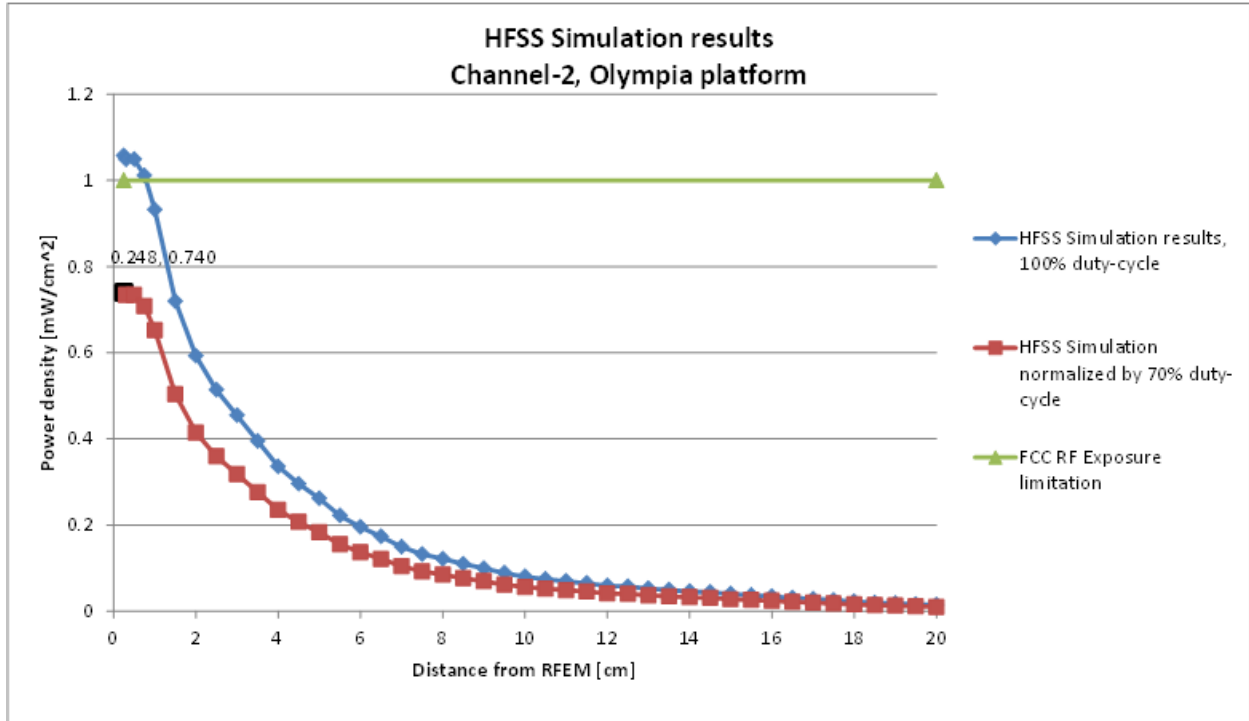


Figure 8 – HFSS Simulation results in Ch2

Notes for the figure:

1. The minimal distance shown is 0.248 cm, which is the smallest possible distance to the end user, achieved when touching the HP HSTNN-I22C Platform lid in the nearest point to the RFEM.
2. The maximal power density (spatially averaged over worst 1cm²) in the HFSS simulation is achieved at 0.248cm, and equals to 1.06mW/cm² over 100% duty cycle.
3. As explained in section 2.3, the Intel 17265NGW LC module is limited to Transmit at a duty cycle of 70% over 10sec. Therefore the maximal average (spatial and time) power density over 1cm² is $1.06 * 0.7 = 0.74\text{mW/cm}^2$.
4. According to HFSS simulation, the EIRP and Power-Density on Channel-3 are lower than those of Channel-2. Here we present the results for Channel-2, which is the worst-case for RF Exposure.

5 Validation of Simulation results

In order to validate the accuracy of the simulation we took a few measures, presented in this chapter:

1. Correlation of simulated power density in far-field to lab measurements
2. Simulating a simpler “canonical” antenna design
3. Comparison between simulation results and lab measurements

5.1 Correlation of power density in far field

Note – the correlation of power density in far field was done with conducted output power of 7.5dBm & 42.4% Duty cycle. Those values (both power and duty cycle) were used for both lab measurements and simulation results. After doing UL Fremont lab tests we found that output power level and duty cycle adjustments are needed. However Intel believes that far field correlation is agnostic to small output power and correlation adjustments, hence the correlation can be used as is.

5.1.1 Far field boundary calculation

Far field boundary can be estimated using *Fraunhofer distance* equation:

Equation 2 – Far field boundary calculation

$$\text{FarFieldBoundary} = \frac{2d^2}{\lambda}$$

In the RFEM, d (largest antenna dimension) = 19mm (counting only the antenna elements that actually transmit).

λ (wave length) = 4.96mm for channel 2.

So the far field boundary is at distance 14.5cm from the RFEM.

5.1.2 Lab measurements

Measurements setup:

In both lab tests below, both duty cycle and beam forming direction were manually set.

The Duty cycle was set to 42% and the beam forming direction was set to boresight (azimuth & elevation =0°)

UL Verification Services Inc.

Measurements were taken on December 17th on HP HSTNN-I22C platform with 17265NGW LC module. Report number: **14U19637-1, Revision B.**

Intel Regulatory Lab, Sophia-Antipolis, France

Measurements were taken December 11th on HP HSTNN-I22C platform with 17265NGW LC module, , detailed in the below pages. Please refer to figure 3 in the test setup photos document.

In this setup, an average power meter sensor was directly connected to the measuring antenna.

The power meter sensor was wrapped inside absorbing material (as shown on the picture) to avoid reflections.



The table below concentrates the parameters used, and the measurement results:

Parameters:		Measurement Distance (cm)	Meas Avg Power (dBm)	Estimated EIRP (dBm)	Averaged power density (mW/cm ²)
Freq (GHz)	60.48	7.248	-20.47	18.87	0.052
Small Aperture Probe Gain (dBi)	10.29	8.248	-20.85	19.65	0.047
waveguide-to-coax Loss (dB)	0.8	9.248	-21.31	20.21	0.042
Duty Cycle (%)	41.16	10.248	-21.82	20.62	0.038
		11.248	-22.35	20.92	0.033
		12.248	-22.9	21.12	0.029
		13.248	-23.38	21.34	0.026
		14.248	-23.8	21.56	0.024
		20.248	-26.67	21.79	0.012

Table 2 - Setup parameters and measurement results, Intel Regulatory Lab

5.1.3 Correlation of measurements and simulation

The figure below shows the power density comparison:

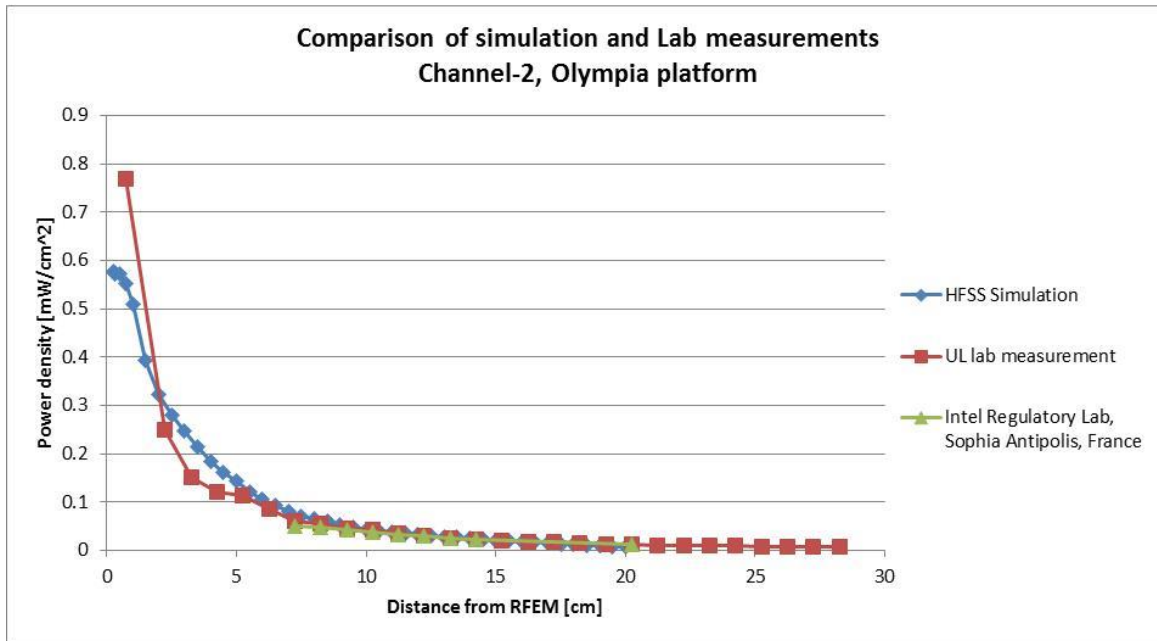


Figure 9 - Comparison of Power Density simulation to lab measurements

The figure on the next page shall zoom-in inside this graph.

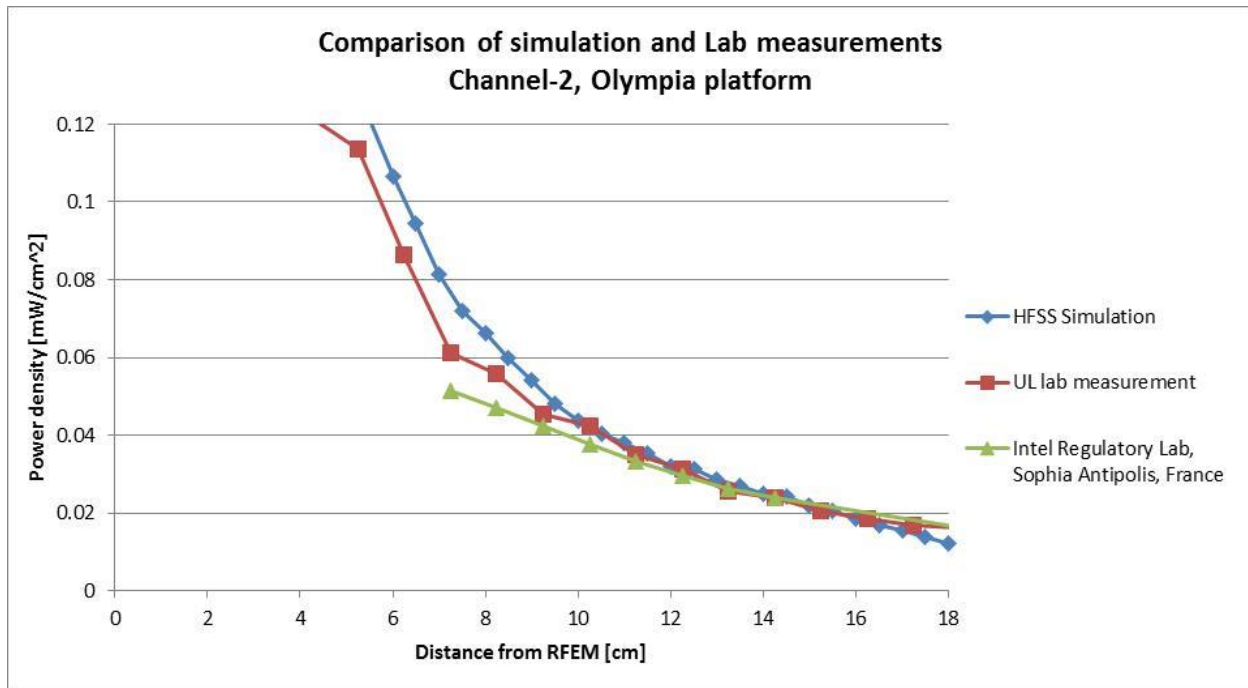


Figure 10 – Zoom-in on the comparison of simulation to lab measurements

We see an excellent correlation in the far-field between the HFSS simulation and 2 independent lab measurements. According to measurements, the far-field boundary is at distance of 13-15cm, in accordance with the prediction, as can be seen in the EIRP Plot in the UL Verification Services test report. For distances above 17cm there is a slight mismatch between the simulation and measurements, and it is due to the inaccuracy of the simulation near its boundaries.

The figure on the next page shows the EIRP correlation between the EIRP estimate from simulation and the lab measurements, to identify the far-field boundary.

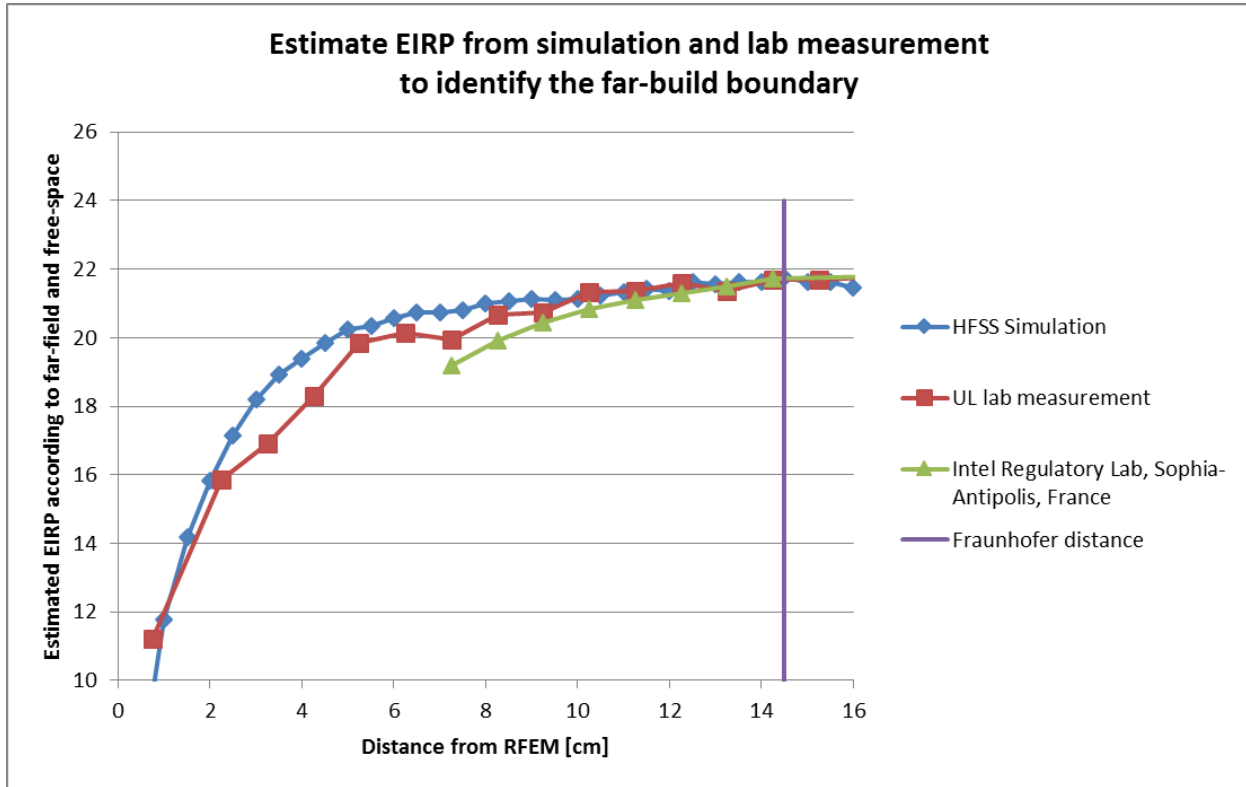


Figure 11 – Estimate EIRP of Simulation vs. lab measurements and far field boundary (Ch2)

We see an excellent correlation in the EIRP of the simulation vs. both lab measurements, as from already from 10cm distance, the deviation between the EIRPs is less than dB. From this we can deduce that the far-field boundary is at distance of 12-15cm, in accordance with the prediction.

5.2 Simulating a canonical antenna design

A simple patch antenna with Length = 7.5mm (GND plane length), and Lambda = 4.8mm, and was designed to work at 62.5GHz, as can be seen in the figure below.

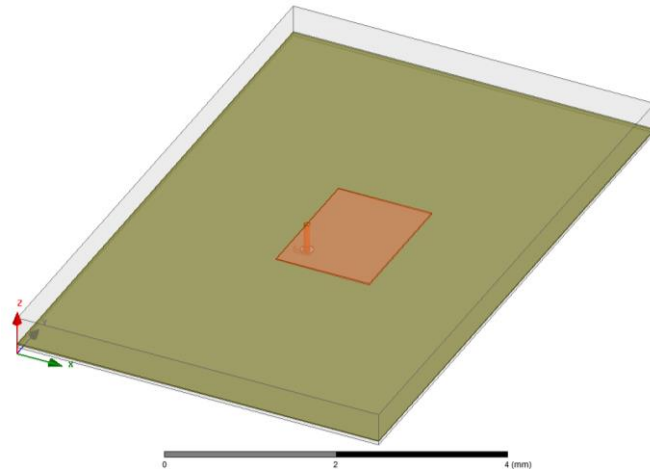


Figure 12 - Simulation of a single Patch antenna

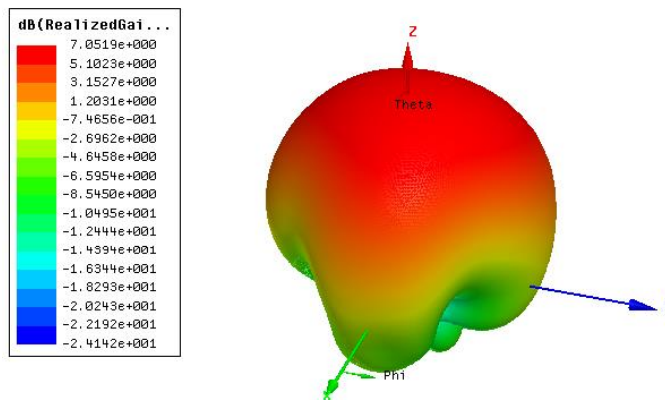


Figure 13 - Patch Antenna Gain

The simulated Far-Field Max Realized Gain [dBi] is 7.05[dBi], as simulated by far field simulation. The 7.05dBi gain was obtained using HFSS simulation using Far Field Gain option.

Theoretically patch antenna gives ~7-9dBi gain. The simulated patch antenna in the HFSS simulation is not a theoretical patch, it includes several "real life" non-idealities (width, size, feeding point etc). The 7.05 dBi Max Realized Gain is the gain obtained from HFSS simulation including those non-idealities.

A few test planes were integrated into the simulation at different far-field distances from the patch (shown below) for power density calculations:

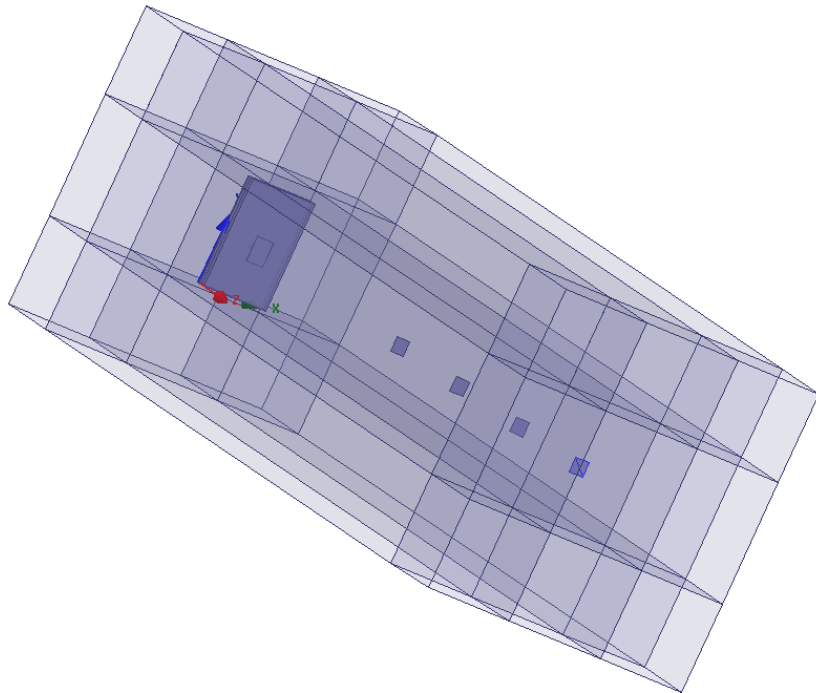


Figure 14 – Simulation 3D structure

The distances between the patch and the test planes range from 24mm to 54mm.

To validate the numerical tool, the power density results at the test planes are translated into gain using omnidirectional power propagation and compared to far field gain according to simulation (table below).

The table below summarizes the results:

Far Field Distance	$P_{omni} = \frac{P}{4\pi R^2} \left[\frac{W}{mm^2} \right]$	Power Density from simulation $\left[\frac{W}{mm^2} \right]$	Gain calculation from power density [dBi]
24mm	1.34e-4	6.70e-4	6.99
29mm	9.11e-5	4.61e-4	7.04
34mm	6.59e-5	3.38e-4	7.10
44mm	3.91e-5	2.03e-4	7.15
54mm	2.59e-5	1.35e-4	7.17

Table 3 – Gain calculation from power density per several distances

Where P is the simulated radiated power and R is the distance from the patch to the test plane.

The table above shows excellent correlation between the Patch antenna gain calculated from power density, to the Far-Field Max realized gain (7.05[dBi]). This is also depicted in the figure below:

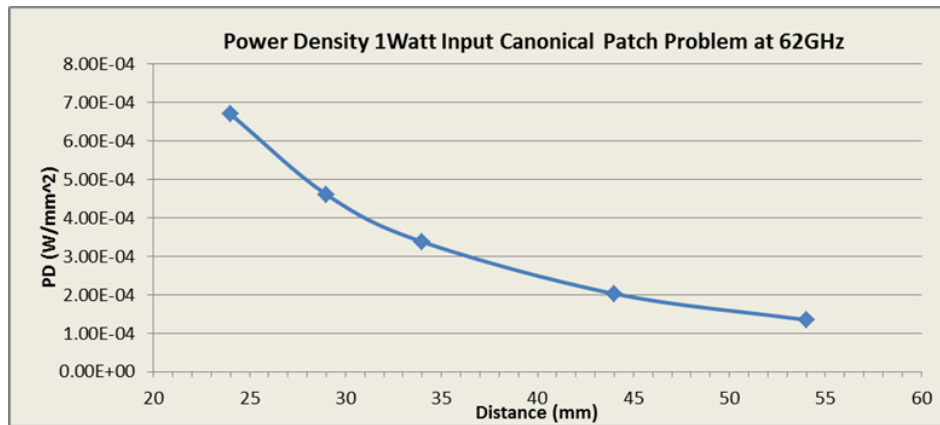


Figure 15- Power Density of Canonical Patch Antenna



6 Summary

We validated the accuracy of the HFSS simulation in several ways, including excellent correlation of measurements in far-field performed in 2 different labs, to HFSS simulation results

In the near-field the following table summarizes the results of Intel 17265NGW LC module, embedded in HP PC model HSTNN-I22C:

Parameter	Value
Total conducted power	6.4 dBm
Maximal TX duty-cycle	70%
Maximal (spatial and time) average power density, over 1cm ² and 10 seconds	0.74 mW/cm ²
Margin from FCC requirement on maximal allowed power density (1 mW/cm ²)	1.3 dB

Table 4 – Summary of simulation results for RF exposure compliance

Therefore Intel 17265NGW LC module, embedded in HP PC model HSTNN-I22C, complies with FCC rule parts §2.1093 and §15.255(g).