Intel® Model: 17265NGW, FCC ID: PD917265NG

Intel model 17265NGW embedded inside Dell model P58G

WiGig subsystem – Power Density Test Report

August 2015

Revision 1.5

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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

El	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 WiGig module (FCC ID: PD917265NG), including an active antenna array, embedded inside the Dell Model P58G platform.

Please note, Dell model P58G is the regulatory model number. This identical host is also marketed under the name Dell Latitude 7350. In the report we refer only to P58G model.

Per the location of the active antenna array (a.k.a. RFEM) in the Dell Model P58G 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 Dell Model P58G platform 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 module inside the Dell Model P58G platform.

The 2nd chapter provides relevant background on Intel 17265NGW 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.

Please note that this document covers non confidential parts, relevant details and explanations that qualify for confidentiality are included separately in the Operational Descriptions document/exhibit; therefore, not included in the this reports.

2 Background – WiGig System Operation

2.1 System Block Diagram

Intel 17265NGW module is a solution for WiGig connectivity for various platforms. Intel 17265NGW module can be embedded in conventional clamshell PC as well as modern 2 in 1 platforms (detachable platforms, e.g., like Dell Model P58G platform.).

Intel 17265NGW 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.

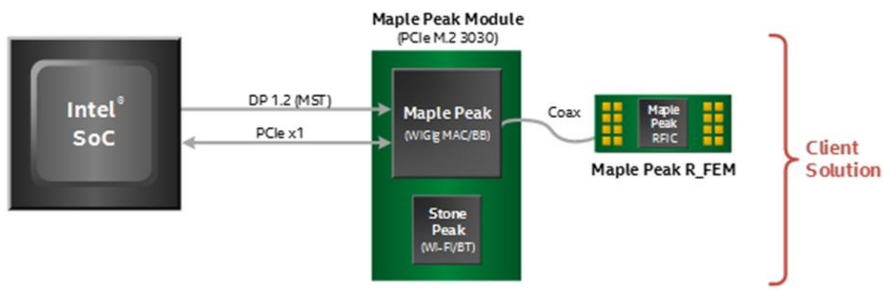


Figure 1 – Intel 17265NGW module system block diagram

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 Dell Model P58G platform. Both the M.2 module and the RFEM are located inside the same section of the PC platform.

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 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 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 Dell Model P58G

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

Dell uses Intel 17265NGW module inside the Dell Model P58G platform. This SKU is characterized by:

1. supporting channels **1+2+3**
2. Reduced power emission, which translates to:
    a. Maximal transmit conducted power of **4.0 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 Evaluting 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:

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

The power density is calculated in the relevant places (in front of the RFEM outside the Dell Model P58G platform) on surfaces of cm^2. For each distance, the $1cm^2$ with the maximum spatial-average power density is chosen as the power for that distance.

Intel 17265NGW

module 3D model

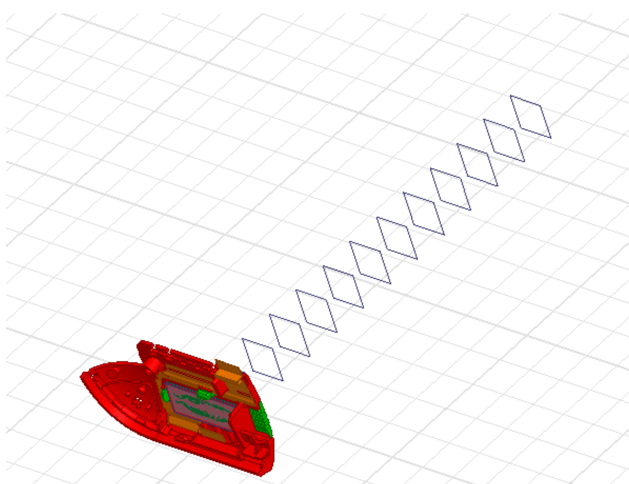


Figure 2 - Illustration of evaluation of near field power

3.1.4 Power Averaging

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

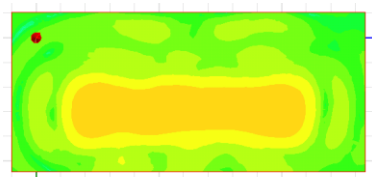


Figure 3 - Example of Power Density results

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 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 1.526mm. Therefore, the 1cm x 1cm Mesh used to calculate the power density is taken at a distance of 1.526mm. An example of this Mesh can be seen in the figure below.

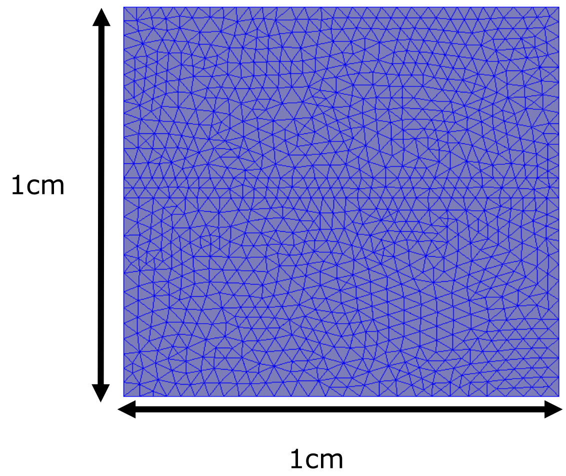


Figure 4 - Example Mesh visualization of 1cm^2 test plane at 1.526mm distance from RFEM

3.1.5 Finding worst case value

To find the maximum emission level 1cm^2 square is placed in the simulation in-front of the RFEM at 1.526mm.

Figure 14 gives sample results of few possible locations of the square with respect to the RFEM.

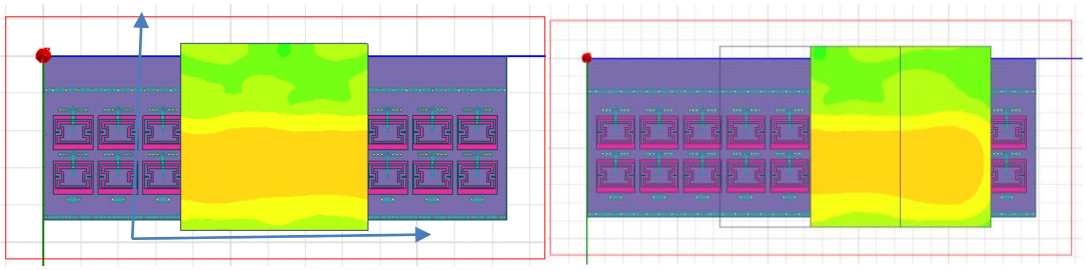


Figure 5 - Examples of integration windows of 1cm^2

To assure that the maximum value is find the 1cm2 square is moved in both X & Y dimension across the entire RFEM size. The resolution used to find the maximum emission is better than 0.1mm. The emission level is calculated for each location point and the maximum is used as the maximal emission level.

Figure 6 present the average power across 1cm^2 (each point in the diagram represent the center of the 1cm^2 square used to measure the power). As can be seen in the diagram the center of the highest power density 1cm^2 is at coordinates 1.9420, 2.1776.

Using this method the maximum power density was found to be 0.9062mW/cm2 (before duty cycle correction).

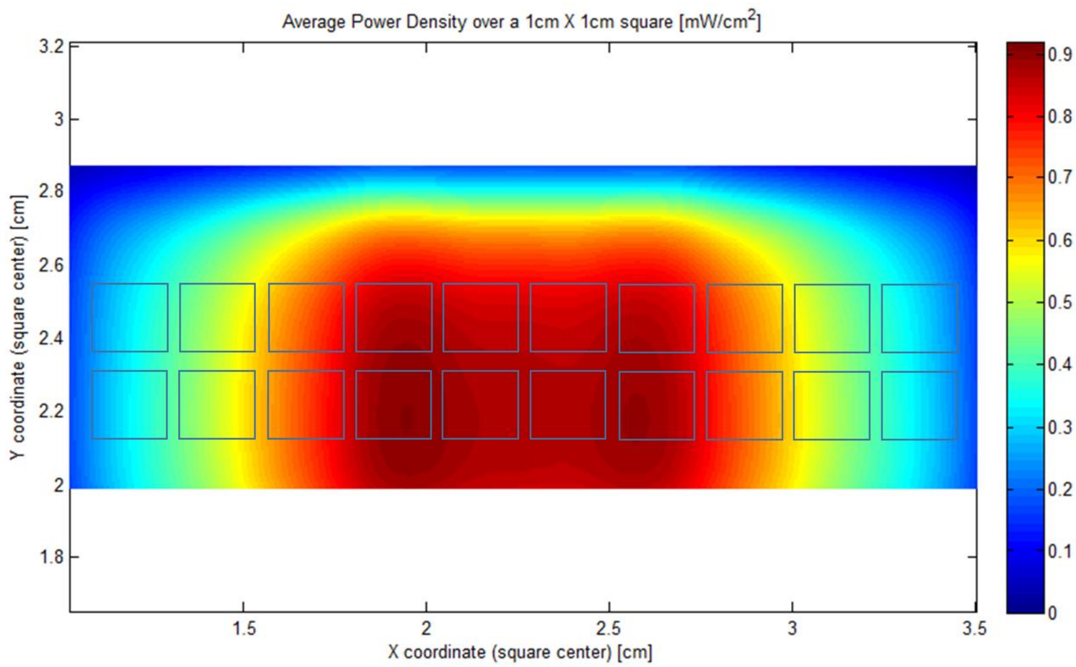


Figure 6 – Average power density as function of location

3.1.6 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, tanδ=0.01. The source for this coefficients is the material manufacturer.
2. The ABS plastic that is used in the Intel 17265NGW module platform build, the dielectric constants parameters for the ABS material are: Permittivity =3, tanδ=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). The following dielectric properties are used for the copper:

   Relative permeability – 1.0.
   Bulk conductivity - 58000000 siemens/m

3.2 3D Models Used In The Simulation

3.2.1 RFEM Housing Inside Intel 17265NGW Module

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

Please refer to the following figure to see RFEM placement inside the Dell Model P58G platform.

Figure 7– Active antenna inside the 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 1.526mm.

3.2.3 Metals In Proximity Of The RFEM

The closest metal to the active antenna is ground plane for the WWAN antenna. The metal is placed ~4mm form the active antenna and mostly behind it.

The metal effect was tested in simulation and found that it has no effect on the exposure data.

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). Signals of equal phase and amplitude are applied to the feed-points of individual array elements and the aggregate power to all array elements is 4.0 dBm. 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.

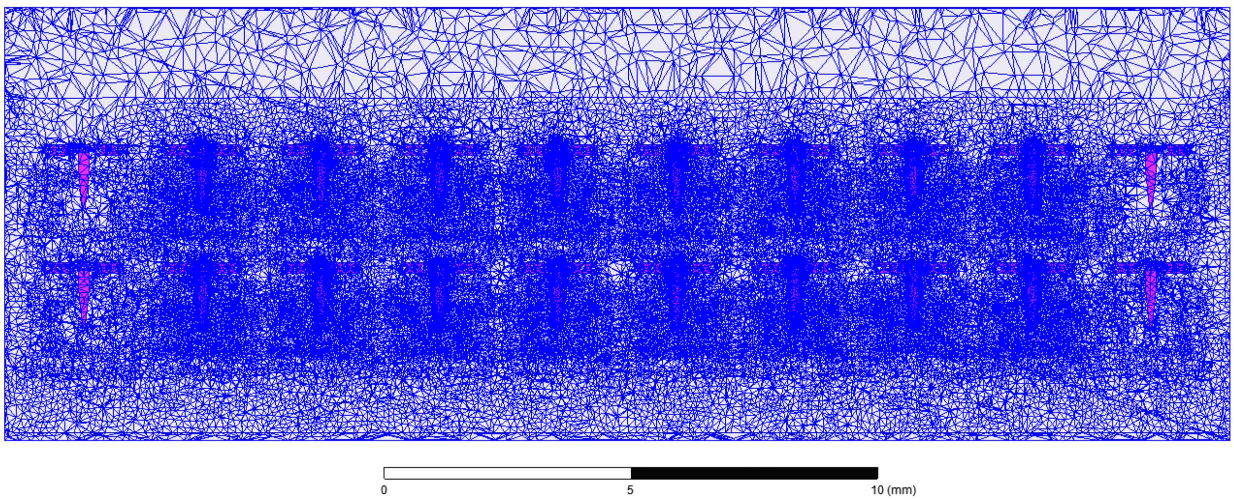


Figure 8 – Simulation mesh for RFEM module

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 4.0dBm. 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 1cm^2 test plane located at 1.526mm from the RFEM, located inside Dell Model P58G platform.

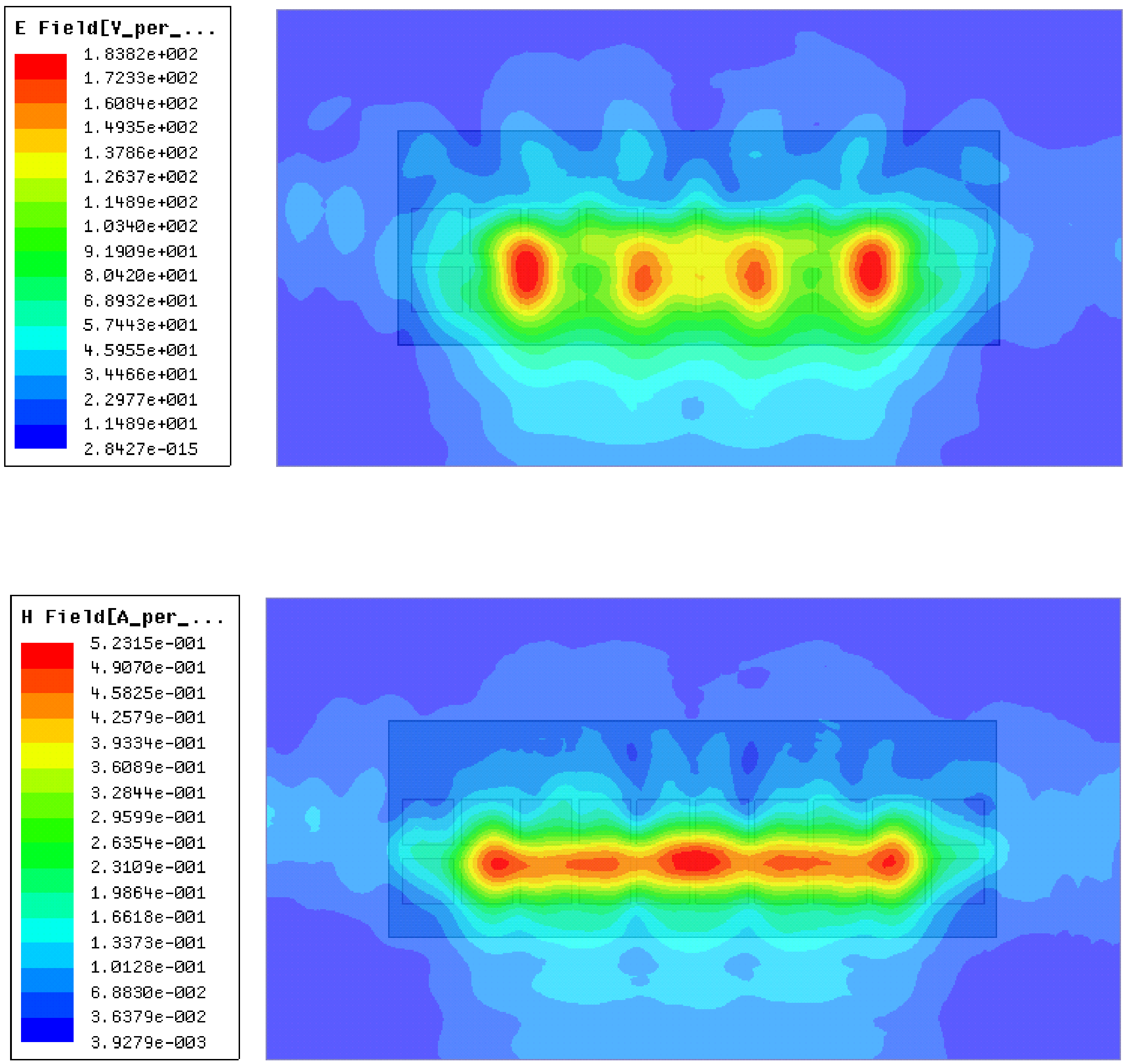


Figure 9 – Maximum complex E-field and H-field over 1cm^2 with 100% duty cycle at 1.526mm distance

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, the pink square in the diagram represent the worst case 1cm^2.

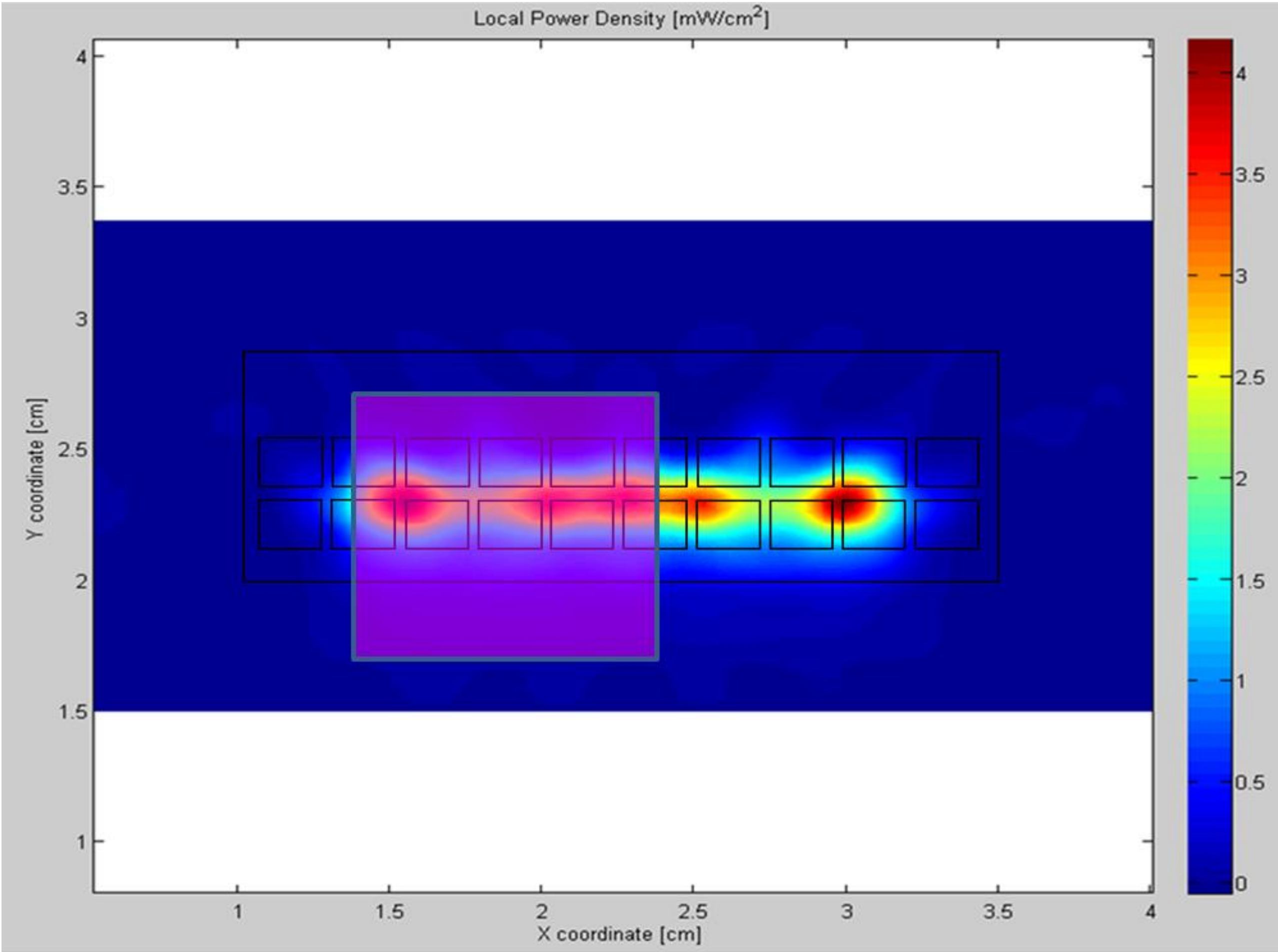


Figure 10 - Power Density mesh for maximum 1cm^2 test plane at 100% duty cycle and distance of 1.526mm

Figure 10 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.

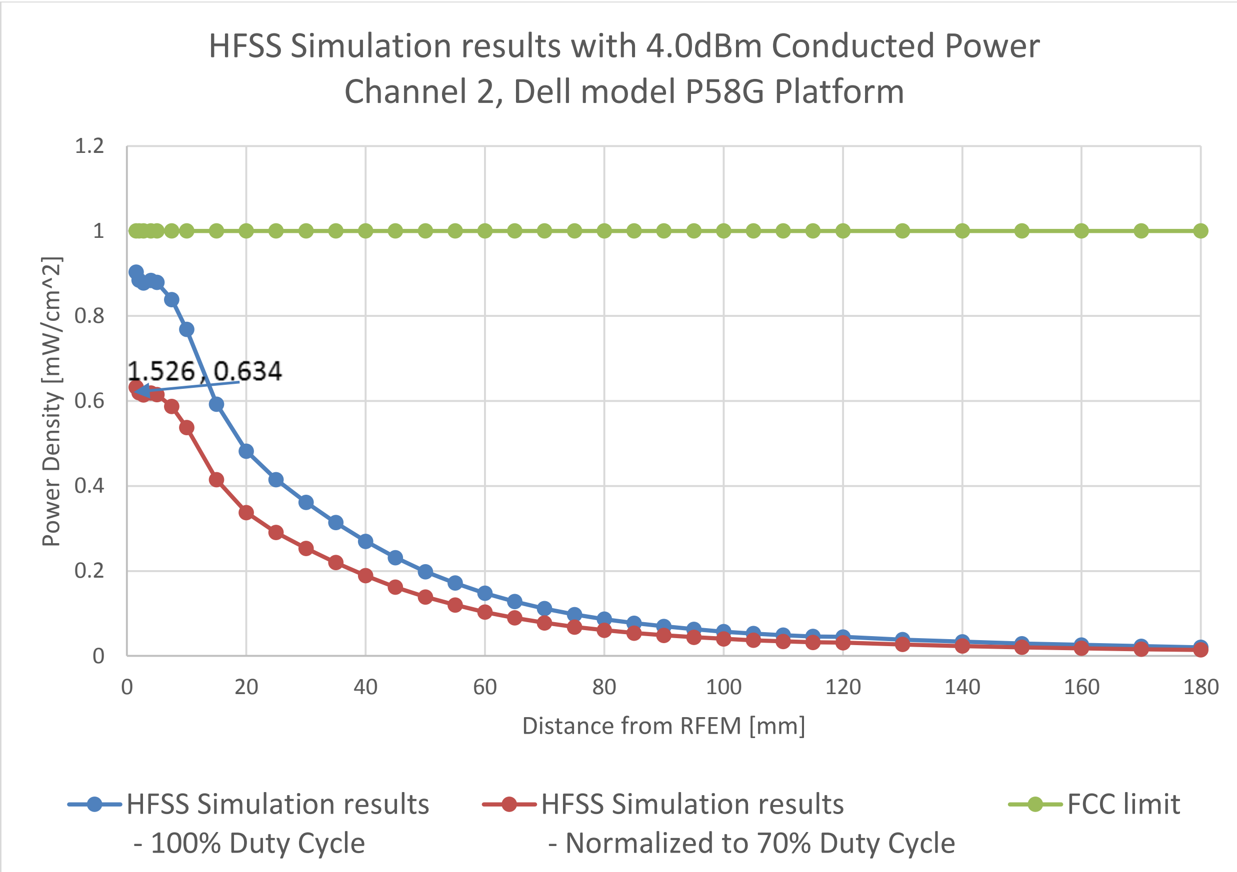


Figure 11 – HFSS Simulation results in Ch2

Notes for the figure:

1. The minimal distance shown is 1.526mm, which is the smallest possible distance to the end user, achieved when touching the Dell Model P58G platform lid in the nearest point to the RFEM.
2. The maximal power density (spatially averaged over worst 1cm^2) in the HFSS simulation is achieved at 1.526mm, and equals to 0.906mW/cm^2 over 100% duty cycle.
3. As explained in section 2.3, the Intel 17265NGW module is limited to Transmit at a duty cycle of 70% over 10sec. Therefore the maximal average (spatial and time) power density over 1cm^2 is 0.9062 * 0.7 = 0.63434mW/cm^2.
4. According to HFSS simulation, the EIRP and Power-Density on Channels 1 & 3 are lower than those of Channel 2. Lab tests (Intel regulatory lab report number 15052702.TR01 rev03 and UL lab report number 15U19818-E2, Revision C) also found that the emission in far field is higher in channel 2 compared to channels 1 & 3. Here we present the results for Channel 2, which is the worst-case for RF Exposure.

5 Validation Simulation Model in Far-Field

Due to the lack of standardized code validation, benchmarking and uncertainty of the simulation software, the far field results are included for the purpose of providing confidence for the software simulation model used and that the results produced were within an acceptable range when compared with the measured results. The error margins of all test results have been considered collectively by the FCC to determine compliance.

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. The same simulation was used for both power density estimation (previous chapter) and far field correlation (this chapter).
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 5dBm. This value was used for both lab measurements and simulation results.

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

The system duty cycle was set by the SW to 50%, this 50% is thermal duty cycle (also referred to by "Duty Cycle Over Burst Period" in both Intel and UL test reports) that set the time that the unit is on (however – the system does not transmit in all the "on" time). This 50% thermal duty cycle was measured by UL lab (table in section 10.1.2) and also by Intel lab (table in section B.1) and found to be about 49.7-49.8%. In the "on" time there is also duty cycle – this is packet to packet duty cycle (the system transmit packet, goes to idle and transmit again. This other duty cycle is referred to as "Duty Cycle within Burst" in both Intel and UL test reports). This duty cycle is set to the maximum allowed one – and measured in both Intel and UL lab to be about 97-98%. The reported duty cycle in the report is the product of those = 48.8% (as reported in both Intel and UL reports).In other words, the ultimate ~48% duty cycle in both Intel and UL reports represent the combination of both the "Duty Cycle Over Burst Period" and the "Duty Cycle within Burst" as measured in both Intel and UL reports.

The beam forming direction was set to boresight (azimuth & elevation =0°)

Intel Regulatory Lab, Sophia-Antipolis, France

Measurements were taken May 26th 2015 to June 19th 2015 on Dell Model P58G platform with 17265NGW module. Please note that these tests were done after Intel regulatory lab received A2LA accreditation (received on May 18th). Data can be found in report number: 15052702.TR01 rev 03.

UL Verification Services Inc.

Measurements were taken on Feb 17th, 23rd & March 31st 2015 on the same Dell Latitude 7350 platform with 17265NGW module. Report number: 15U19818-E2, Revision C.

5.1.3 Correlation Of Measurements And Simulation

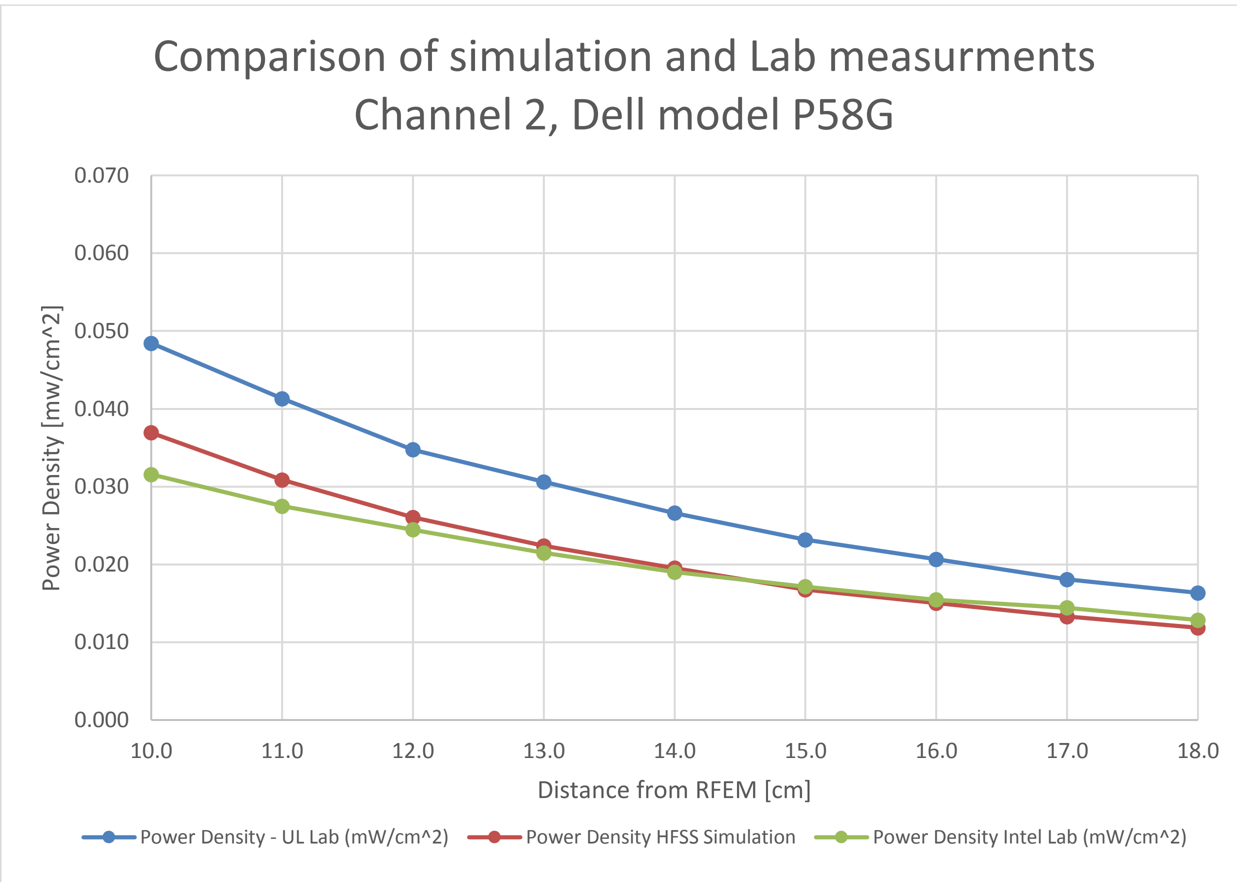


Figure 12 - Comparison of Power Density simulation to lab measurements

Please see section 5.1.4 Lab to Lab differences for explanation of the data.

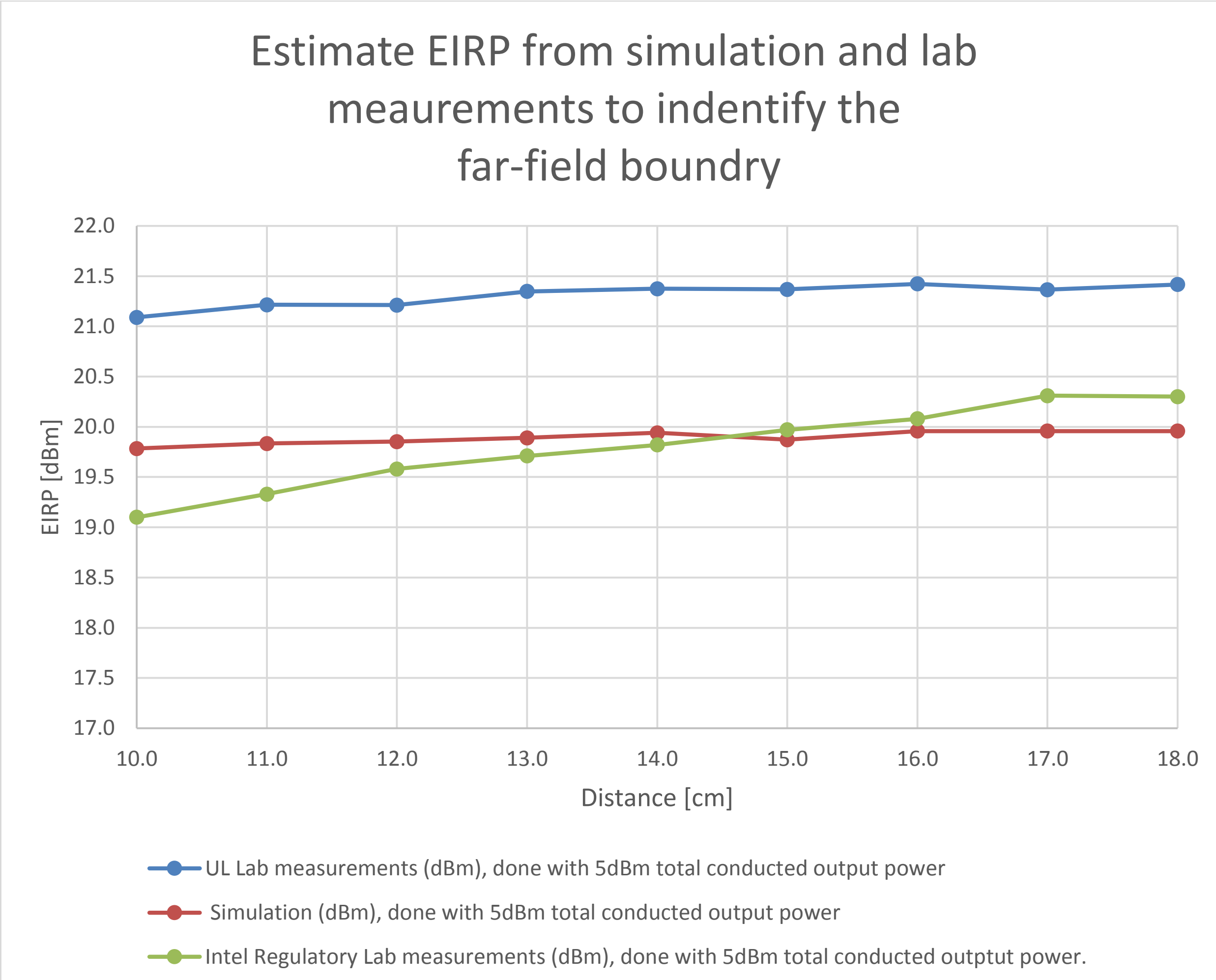


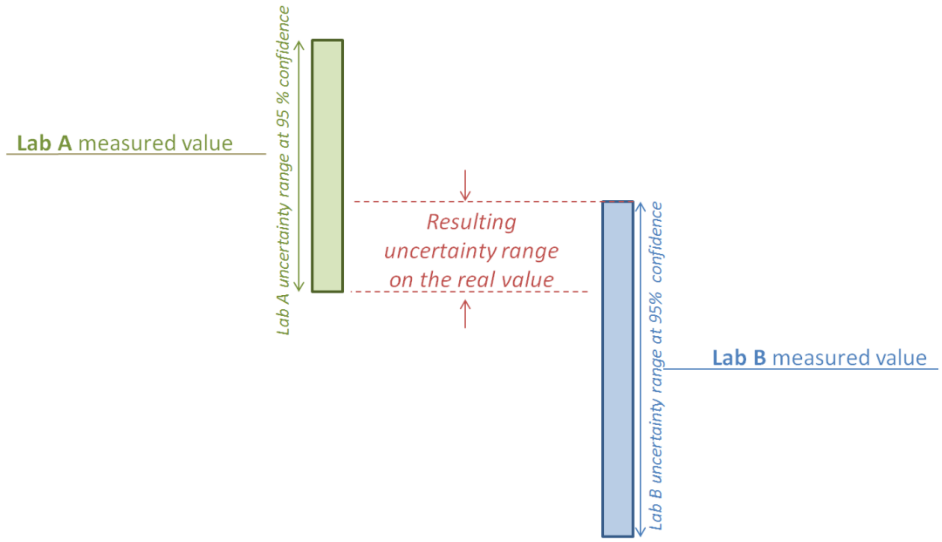
Figure 13 – Estimate EIRP of Simulation vs. lab measurements and far field boundary (Ch2)

Please see section 5.1.4 Lab to Lab differences for explanation of the data.

5.1.4 Lab to Lab Variance

Please note that two different labs having different test measurement setups are expected to have some variation in measured values, although labs are expected to measures values within their respective uncertainty ranges. With different measurement setups it is expected that the uncertainty values will also vary between labs. We have listed in this section the obvious measurement setup differences between UL Lab and Intel Lab.

Please consider there will always be an overlapping uncertainty ranges between labs even when the same test methods, traceability requirements and confidence levels are common between them. Please see figure below as an example.



Below are the measurement setup differences observed:

- Technology of the power sensors: the power sensor utilized by UL Lab is a diode power sensor whereas Intel Lab utilizes a thermal power sensor.
- UL Lab used an external Low Noise Amplifier (LNA) in their measurement chain since there was a specific need from the power sensor's sensitivity, whereas Intel Lab did not use an LNA since the sensitivity of its power sensor was sufficient to measure the signal of concern.
- Differences in chamber construction, as an example the use of different absorber types.

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.

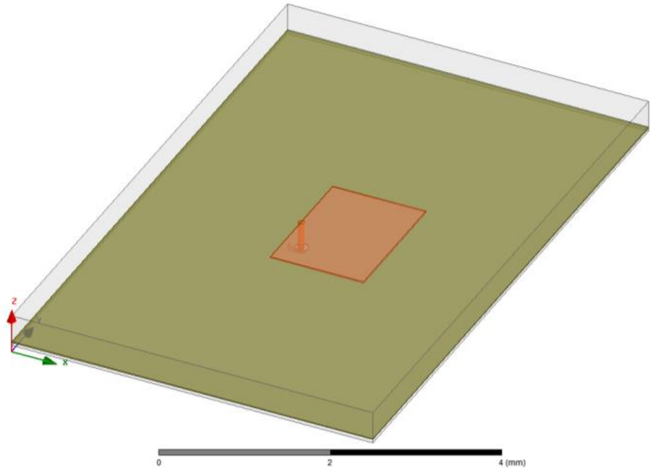


Figure 14 - Simulation of a single Patch antenna

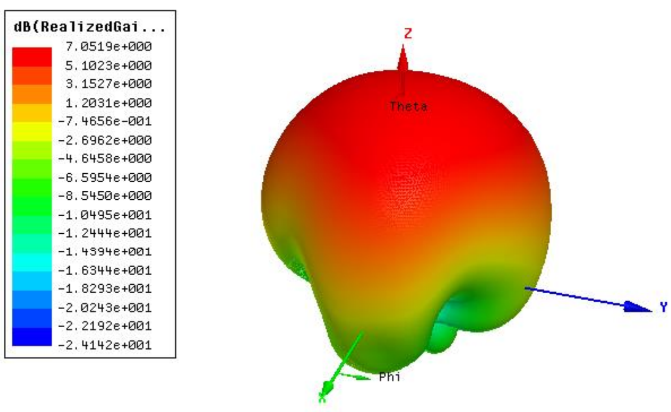


Figure 15 – Patch Antenna Gain

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:

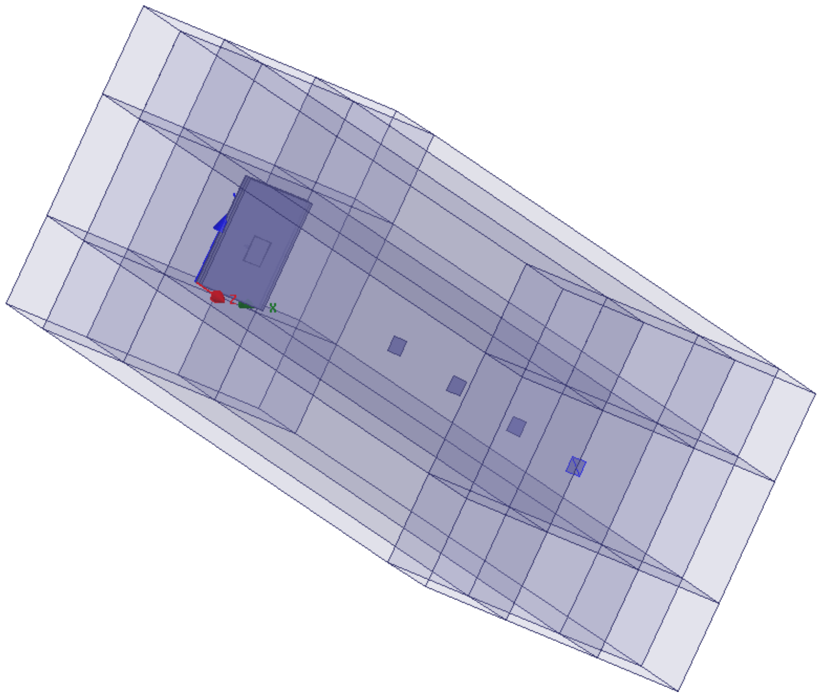


Figure 16 – Simulation 3D structure

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 2 – 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:

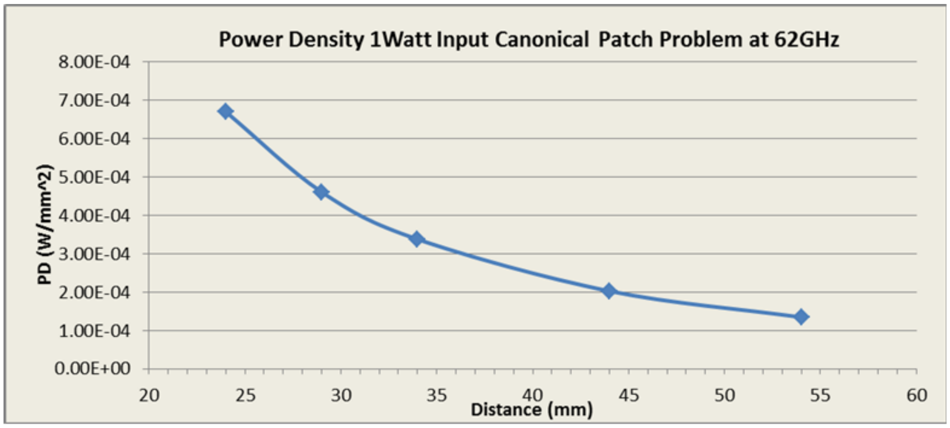


Figure 17– Power Density of Canonical Patch Antenna

6 Summary

Due to the lack of standardized code validation, benchmarking and uncertainty of the simulation software, the far field results are included for the purpose of providing confidence for the software simulation model used and that the results produced were within an acceptable range when compared with the measured results. The error margins of all test results have been considered collectively by the FCC to establish confidence for the accuracy of the HFSS simulation.

The following table summarizes the simulation results in the near field of Intel 17265NGW module, embedded in Dell Model P58G:

Parameter	**Value**
Total conducted power	4.0 dBm
Maximal TX duty-cycle	70%
Maximal (spatial and time) average power density, over $1cm^2$ and 10 seconds	$0.63434mW/cm^2$

Table 3 – Summary of simulation results for RF exposure compliance

Therefore Intel 17265NGW module, embedded in Dell Model P58G, complies with FCC rule parts §2.1093 and §15.255(g).