Intel® Model: 18260NGW, FCC ID: PD918260NG

Intel model 18260NGW embedded inside Hewlett-Packard model HSTNN-I72C

WiGig subsystem – Power Density Simulation Report

February 2016

Revision 1.2

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Table 1 – Acronyms

ABS	Acrylonitrile butadiene styrene
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 Isotropic 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 18260NGW WiGig module (FCC ID: PD918260NG), including an active antenna array, embedded inside the portable device Hewlett-Packard model HSTNN-I72C. This portable device is convertible two-in-one laptop, the screen can be detached from the keyboard and can work in standalone mode.

Please note, Hewlett-Packard model HSTNN-I72C is the regulatory model number.

Per the location of the active antenna array (a.k.a. RFEM) in the Hewlett-Packard model HSTNN-I72C 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.

As the near field power density measurement cannot be performed, we used an EM simulation that includes the 18260NGW transmitter model, embedded inside the Hewlett-Packard model HSTNN-I72C 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, to lab measurements of the Intel 18260NGW module inside the Hewlett-Packard model HSTNN-I72C platform, for transition field to far field distances, where the theoretical far field boundary is calculated for reference. The near field simulation results are also presented in this document.

The 2nd chapter provides relevant background on the Intel 18260NGW module. The 3rd chapter describes the simulation methodology to determine RF exposure (power density) levels. The 4th chapter includes simulation results, and 5th chapter provides the correlation between simulation and lab measurements in transition field to 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 this report.

2 Background – WiGig System Operation

2.1 System block diagram

The Intel 18260NGW module is a solution for WiGig connectivity for various platforms. The Intel 18260NGW module can be embedded in a conventional clamshell PC as well as modern 2 in 1 platforms (detachable platforms, e.g., like Hewlett-Packard model HSTNN-I72C).

Intel's 18260NGW WiGig module is made of an M.2 module connected to the RFEM using one IF coaxial cable. The internal Intel code name of this solution is "Douglas Peak", which consists of the Maple Peak Silicon and the 8260 Silicon.

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, which converts between the IF signal and 60GHz signal. It also performs the beam forming functionality by phase shifting the RF signal that goes to each antenna. The RFEM is slave to the WiGig BB chip – all module control and algorithms run on the BB chip.

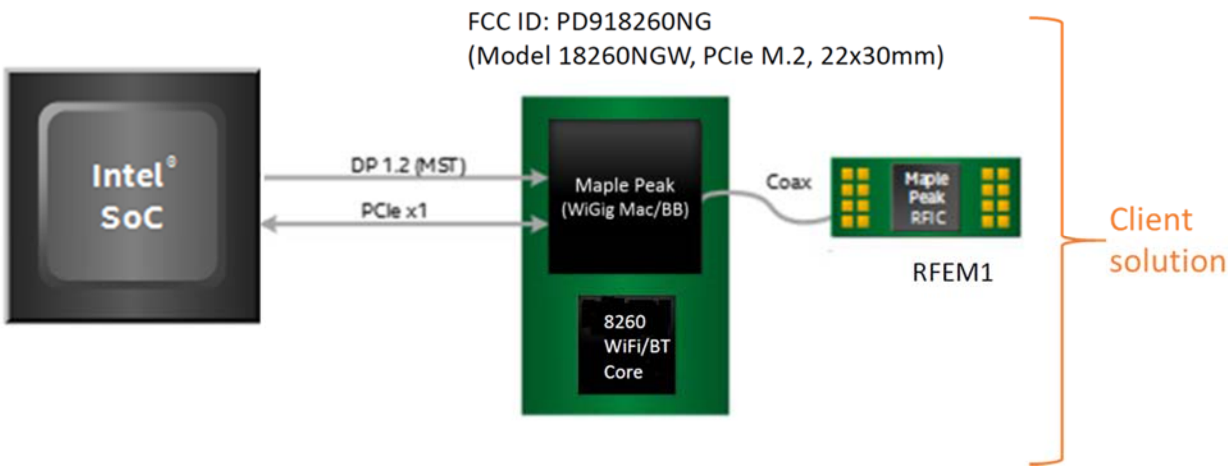


Figure 1 – Intel 18260NGW module system block diagram

In a 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 Hewlett-Packard model HSTNN-I72C platform, both the M.2 module and the RFEM are located inside the same section of the PC platform, meaning both units are in the detachable part of the 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 antennas are not practical, and electronically steerable antenna are usually used.

In the Intel 18260NGW module, such an 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). The Intel 18260NGW 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.

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).

In addition, the Intel 18260NGW module was measured to obtain maximal TX-Duty-Cycle in a fully loaded system, resulting in a maximal TX-Duty-Cycle of 58% over any 10 seconds period, lower than the upper bound derived from the analysis in this section.

2.4 Intel 18260NGW module in Hewlett-Packard model HSTNN-I72C

Intel produces several HW SKUs (variations) of the Intel 18260NGW module, which target different types of customer platform products.

Hewlett-Packard uses the Intel 18260NGW module inside the Hewlett-Packard model HSTNN-I72C 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 **3.5 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

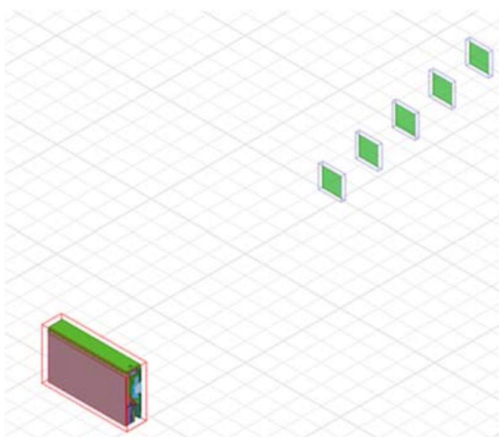
The HFSS simulation is done using the Finite Element Method which operates in the frequency domain. The HFSS is based on an accurate direct solver with first order basis functions.

3.1.3 Evaluting Near Field Power

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

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

The power density is calculated in the relevant places (in front of the RFEM outside the Hewlett-Packard model HSTNN-I72C platform) on surfaces of 1cm^2.



Intel 18260NGW 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. The figure below depicts an example of the overall power density of the RFEM at a given distance.

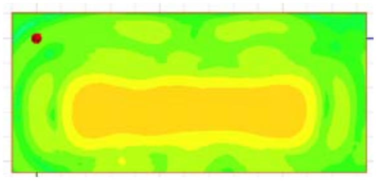


Figure 3 - Example of Power Density results

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 a convergence precision to 2%. (The convergence precision is better than 0.18 dB).

The RFEM active antenna is located behind the cover glass shown on the Figure 4. The antenna inside the HSTNN-I72C platform is not parallel to the platform cover. The distance between an end user holding the platform and the antenna surface of the RFEM is comprised between 2.713 mm and 4.693 mm. Therefore, the 1cm x 1cm Mesh used to calculate the power density is taken on the front glass surface. An example of this Mesh can be seen in the Figure 5.

Figure 4 - Hewlett-Packard model HSTNN-I72C

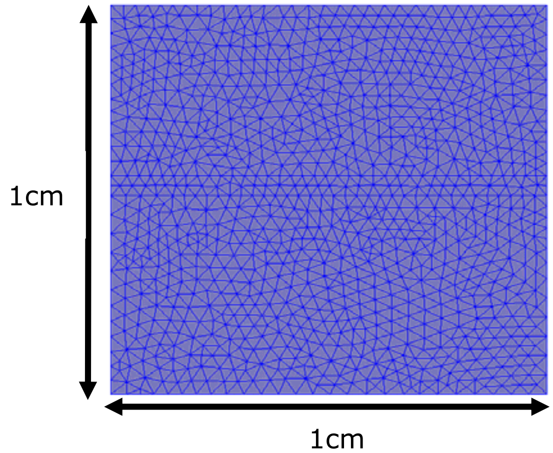


Figure 5 – Example Mesh visualization of $1cm^2$ test plane

3.1.5 Finding worst case value

To find the maximum power density, a 1cm2 square is placed in the simulation in-front of the RFEM at the minimum distance, parallel to the front glass.

Figure 6 gives sample results of few possible locations of the square with respect to the RFEM.

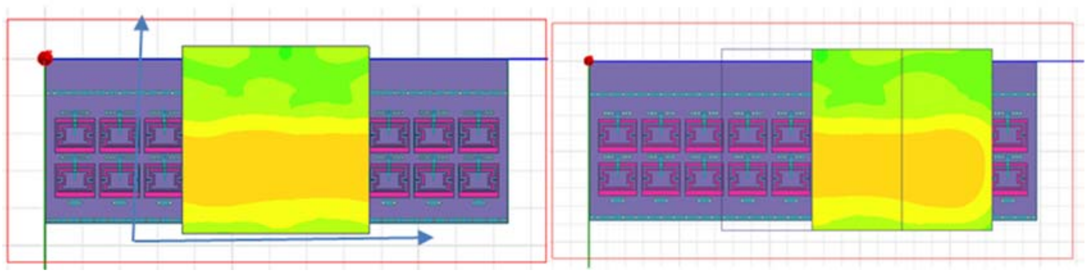


Figure 6 - Examples of integration windows of 1cm²

To assure that the maximum value, the 1cm² square is moved in both X & Y dimension across the entire RFEM size. The power density is calculated for each location point and the maximum is used as the maximal power density. The resolution of the power density is better than 0.1mm across all the area, this same resolution is used to find the 1cm² maximum power density.

Figure 7 present an example of the integrated power density across 1cm² where each point in the diagram represent the center of the 1cm² square used to integrate the power. Please note that the diagram resolution is better than 0.1mm.

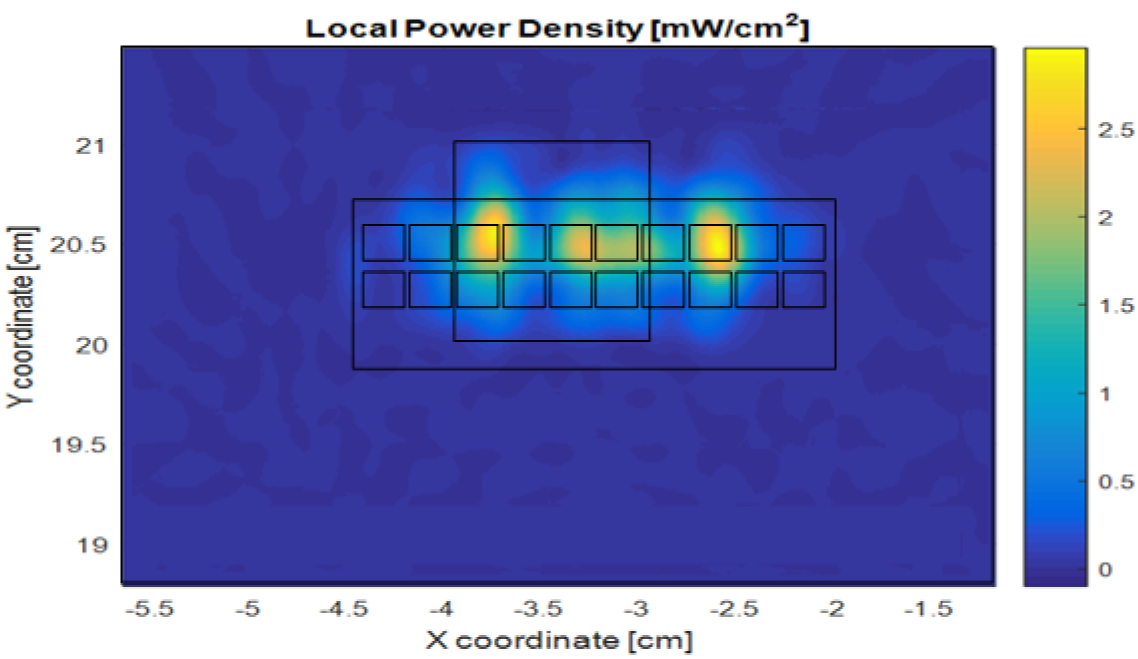


Figure 7 – Integrated power density as function of location

3.2 3D Models used in the simulation

3.2.1 RFEM housing inside Intel 18260NGW module

HP model HSTNN-I72C CAD files including the Intel model 18260NGW are used in the EM simulation to allow correct exposure level simulation.

Figure 8– 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 is holding the unit and touching the glass cover (behind the screen). For this case, the distance between a hand or body to the active antenna is between 2.713 mm and 4.693 mm.

3.2.3 Metals In Proximity Of The RFEM

Four metal elements are located close to the RFEM active antenna, the closest element is the Psensor located at a lateral distance of about 2mm from RFEM edge. The other elements close to the active antenna are the slate cover at 2.6mm, the WWAN antenna at 5.15mm, and the PCB Microphone at 2.88mm. All metals within the truncated area as shown on the Figure 9 have been included in the simulation. The power that goes to the sides of the truncated simulation model has been evaluated in the simulation and showed that most of the energy is bound within the simulated model and the possible effect of the truncation area is minimal and cannot change the simulation results.

3.3 Antenna Feed

The EM simulation uses a 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 3.5 dBm. This via feed point is used as the interface point for the simulation. 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.

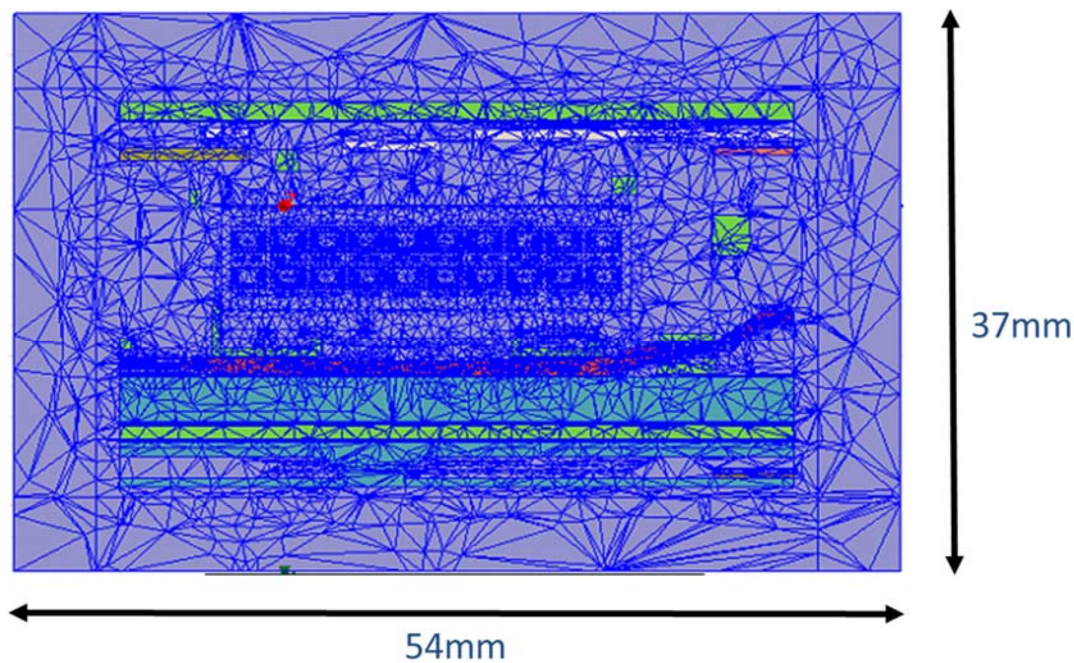


Figure 9 – Simulation mesh for RFEM module

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 3.5 dBm. In addition, the simulation is conducted using 100% TX duty cycle.

4 Simulation Results

4.1 Simulated Power over the search plane

Figure 10 and Figure 11 below present the magnitude of the complex E-field and H-field for the worst case 1cm^2 test plane located at the front glass level in front of the RFEM. Channel 1 and Channel 2 are shown as they represent the worst case scenario. More information on this can be found in section 4.2.

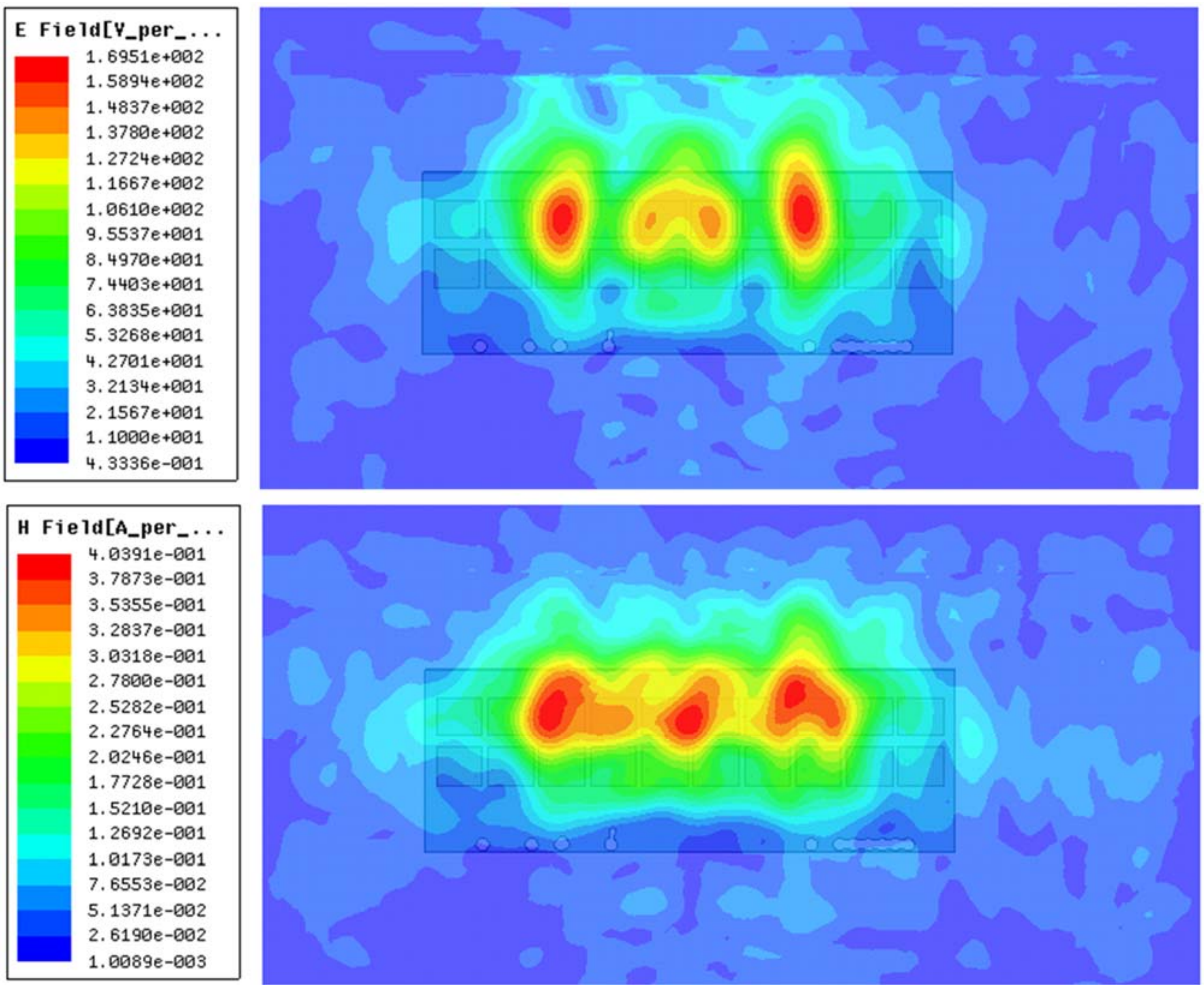


Figure 10 – Magnitude of E-field & H-field (spot values) with 100% duty cycle on Channel 1

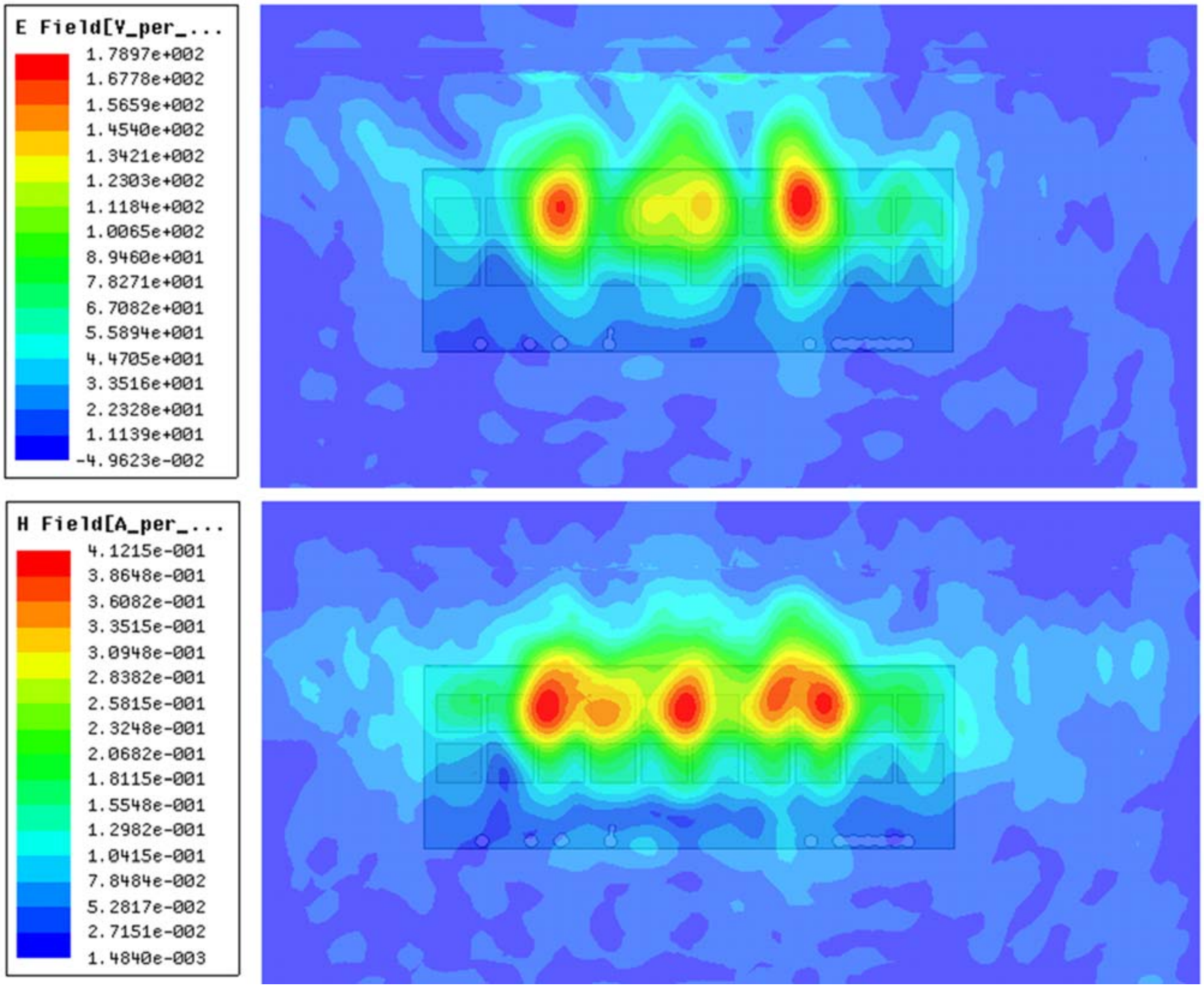


Figure 11 - Magnitude of E-field & H-field (spot values) with 100% duty cycle on Channel 2

We can deduce from the figures above 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 figures below, the black square in the diagrams represent the worst case $1cm^2$.

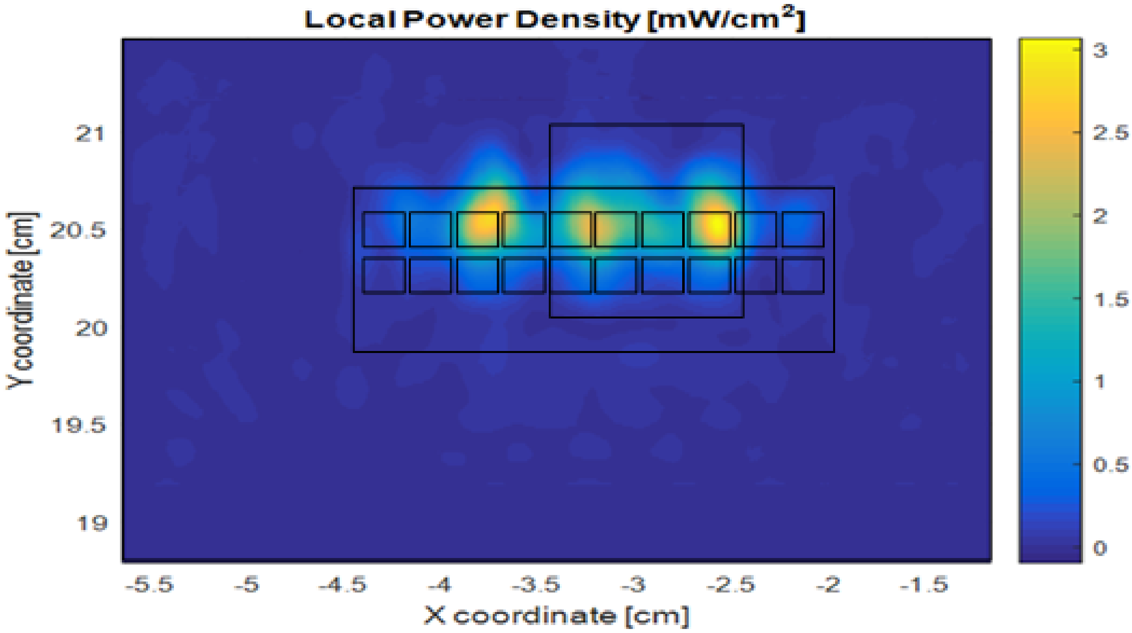


Figure 12 - Power Density mesh test plane at 100% duty cycle in front of the antenna at ABS level, Channel 1.

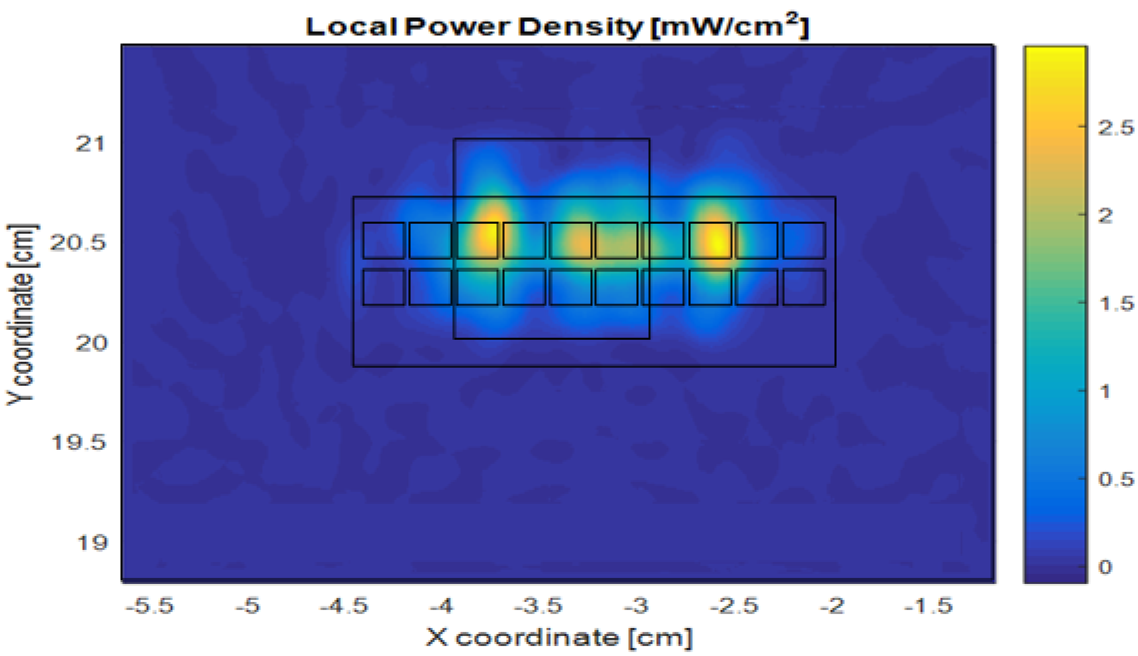


Figure 13 - Power Density mesh test plane at 100% duty cycle in front of the antenna at ABS level, Channel 2.

Figure 12 and Figure 13 were calculated with a resolution of 0.1mm (10,000 points in 1cm^2). The HFSS resolution is even finer.

In Figure 14 and Figure 15 below, we present a subset of the simulation results presented in Figure 12 and Figure 13. The subset is a 1 dimensional cut in the X axis and Y axis that shows the behavior of the near field power density at zero distance from the front glass surface.

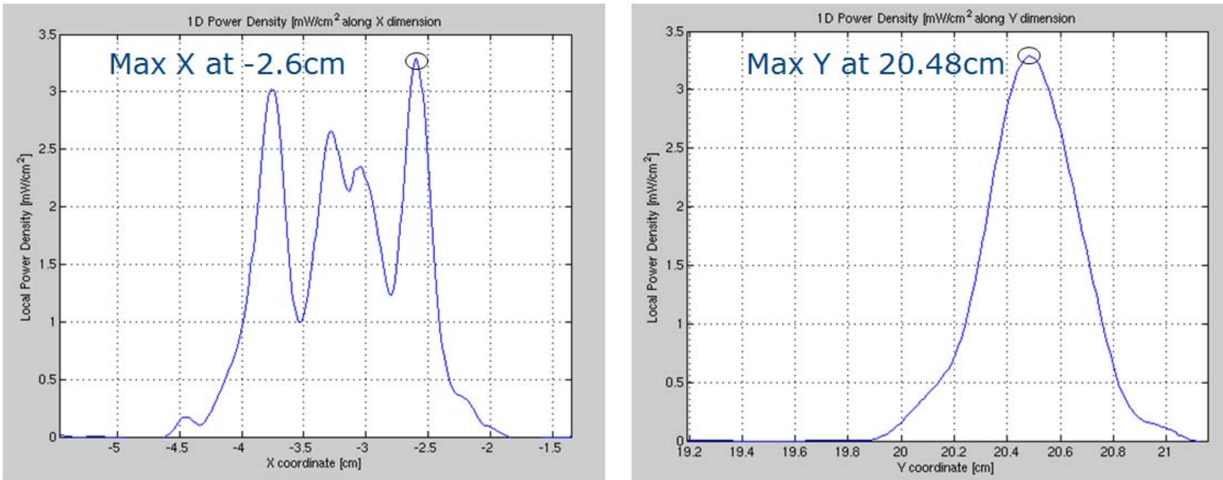


Figure 14 - One dimensional plots of the power density on Channel 1

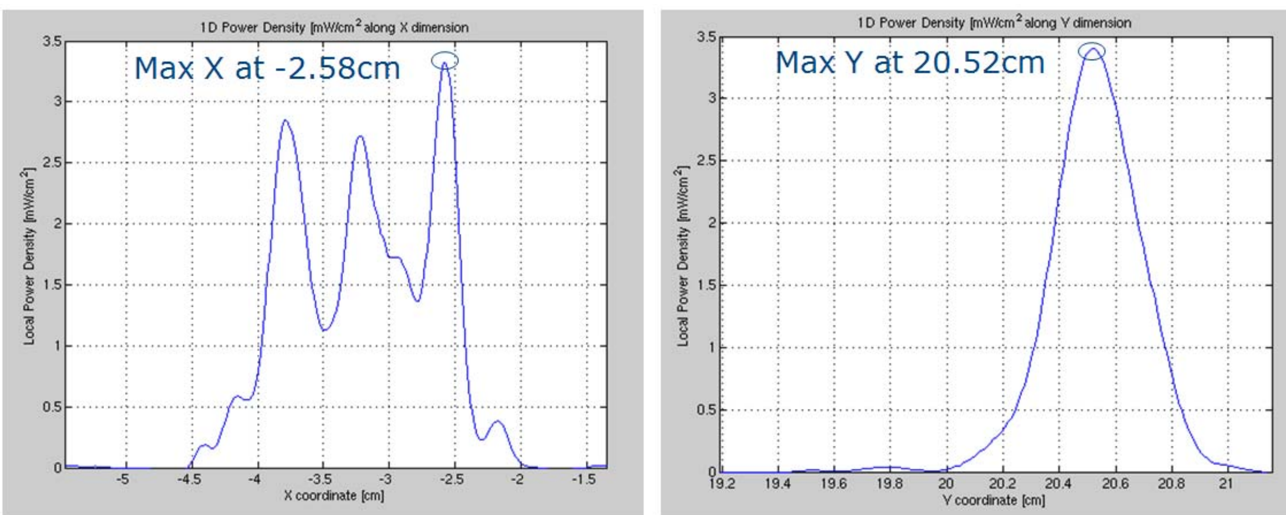


Figure 15 - One dimensional plots of the power density on Channel 2

Figure 14 and Figure 15 show the power density at the position which gives the highest energy.

Please note that Figure 10 to Figure 15 in this section are the simulation results of in the near field at zero distance from the front glass surface. We would like to note that as there is no established methods for measuring near field power density at zero distance, the simulation results that can be verified (and are verified), are the emission level at transition to far field. More data on correlating simulation results can be found in section 5.1.

4.2 Power Density

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

Please note that that worst case analysis method is used for this analysis. Following this method, the worst case channels are presented. Worst case channels are chosen based on the simulation (the worst case is channel 1) and lab measurements (the worst case is channel 2). Channel 3 was not included in this document because this is not the worst case. Channel 1, 2 and 3 measurement data can be found in the lab test report 15112601.TR01 Rev 01.

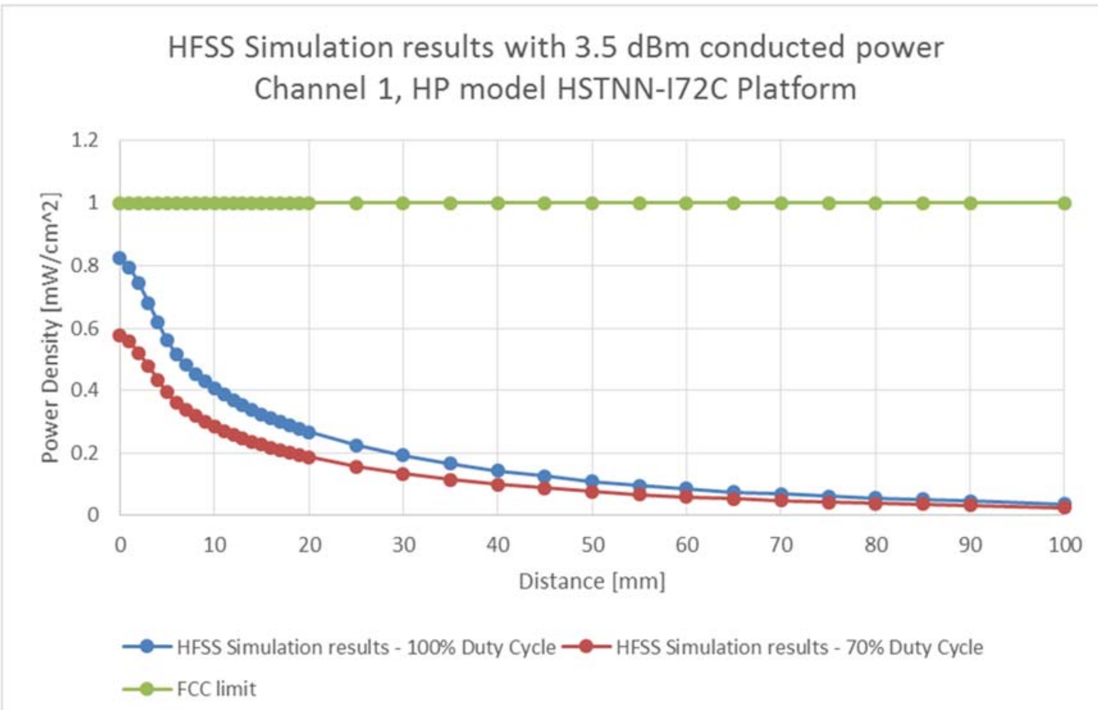


Figure 16 – HFSS Simulation results in Channel 1

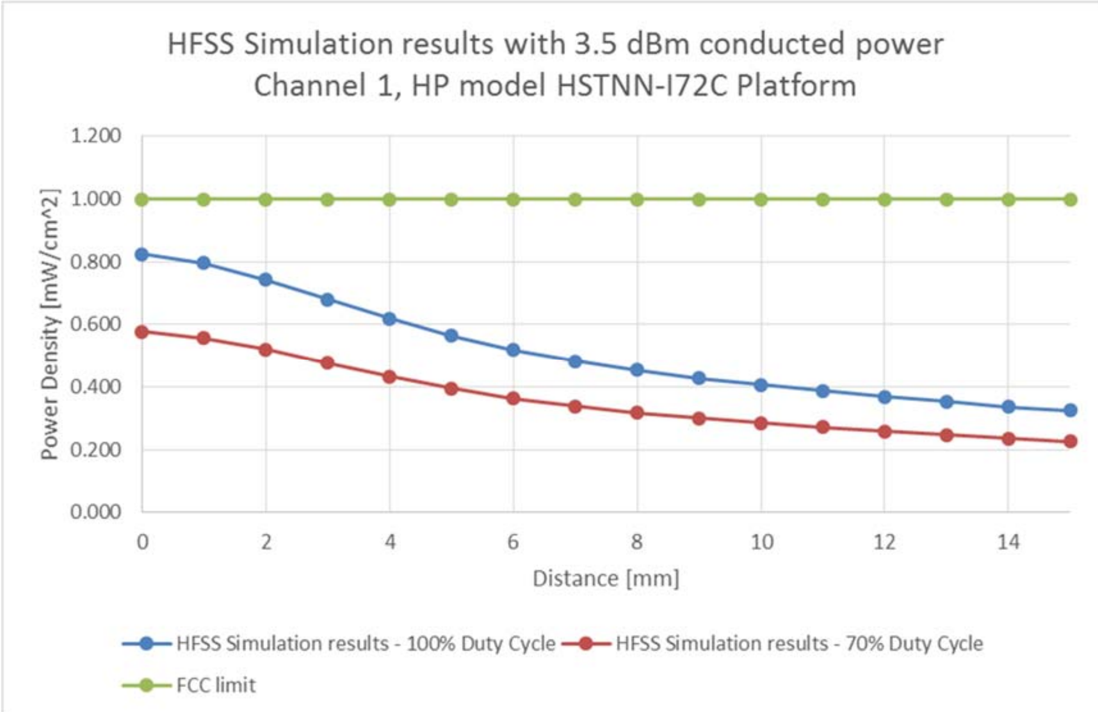


Figure 17 - – HFSS Simulation results in Channel 1 (Zoom view)

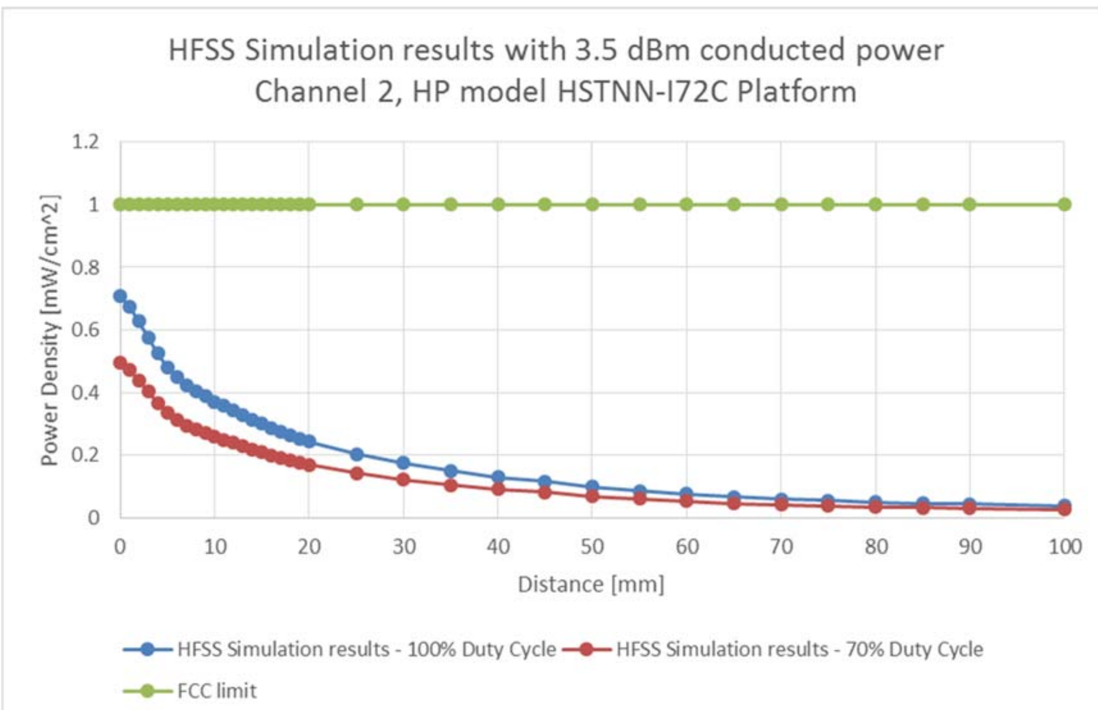


Figure 18 – HFSS Simulation results in Channel 2

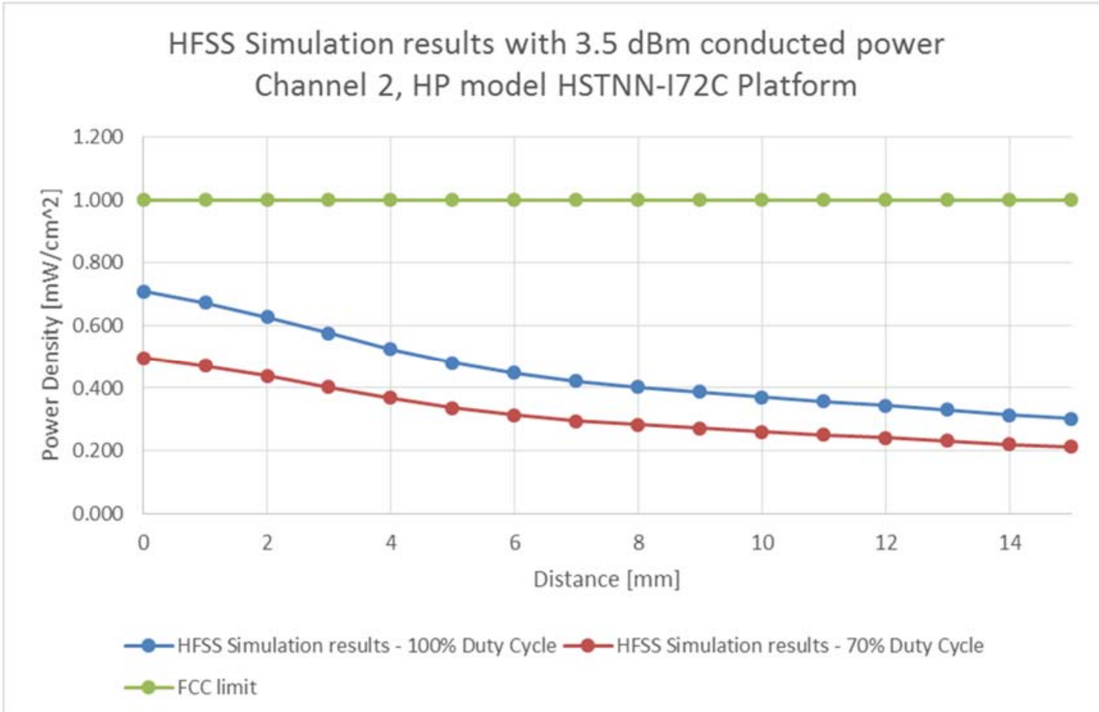


Figure 19 – HFSS Simulation results in Channel 2 (Zoom view)

Notes for the figures:

1. The minimal distance shown is 0 mm from the front glass, which is the smallest possible distance to the end user, achieved when touching the Hewlett-Packard model HSTNN-I72C platform lid in the nearest point to the RFEM. This 0 mm distance is the reference at the front glass cover of the platform in front of the RFEM.
2. The maximal power density (spatially integrated over worst $1cm^2$) in the HFSS simulation is achieved at 0mm, and equals to $0.824mW/cm^2$ for the channel 1 and equals to $0.708mW/cm^2$ for the channel 2 and $0.332mW/cm^2$ for the channel 3 over 100% duty cycle
3. As explained in section 2.3, the Intel 18260NGW module is limited to Transmit at a duty cycle of 70% over 10sec. Therefore the maximal integrated spatial and averaged time power density over $1cm^2$ is $0.824 * 0.7 = 0.577$ mW/cm^2 for channel 1 and $0.708 * 0.7 = 0.496$ mW/cm^2 for the channel 2.
4. According to HFSS simulation, the worst case was found on Channel 1 whilst the Lab tests (Intel regulatory lab report number 15112601.TR01 Rev 01) found that the emission in far field is higher in Channel 2. In the report we include simulation and measurement results for Channel 1 and Channel 2. The Channel 3 is not reported, as the simulated power density is 4 dB less than the worst case.

5 Validation of Simulation Model

Due to the lack of standardized code validation, benchmarking and uncertainty of the simulation software, the transition field to 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, including correlation of the simulated power density in transition field to far-field against lab measurements. The same simulation was used for both power density estimation in near field (previous chapter) and transition field to far field correlation (this chapter).

5.1 Correlation of Power Density In transition field to Far Field

Note – the power level that is used in chapter 4 is 3.5dBm. 3.5dBm is the maximum output power that Intel is reporting for final approval. Note that initial lab measurement correlation and the supporting simulation was done using 4dBm maximum output power as the starting point. Based on the correlation margin from the measurement and simulation at 4dBm Intel calculated the 3.5dBm requested power that is reported in this document

5.1.1 Far Field Boundary Calculation

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

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

Equation 2 – Far field boundary calculation

The housing may have an impact on the far field boundary. The housing was included in the simulation and as a first approximation we used the RFEM dimension to determine the far field boundary.

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

λ (wave length) = 5.144mm for channel 1, so the far field boundary is at distance 14.0 cm from the RFEM.

λ (wave length) = 4.96mm for channel 2, so the far field boundary is at distance 14.5cm from the RFEM.

In the measurement report 15112601.TR01 Rev 01, the convergence to far field data starts at ~7-9cm.

5.1.2 Lab Measurements

Intel Regulatory Lab, Sophia-Antipolis, France

Measurements were taken on November 23, 2015 to November 26, 2015 & Jan 18th 2016 on Hewlett-Packard model HSTNN-I72C platform with 18260NGW module. Data can be found in report number: 15112601.TR01 Rev 01.

5.1.3 Correlation Of Measurements And Simulation

The correlation between measurements and simulation have been done at 4dBm conducted power. The power density and E.I.R.P. graphs are normalized to 100% duty cycle.

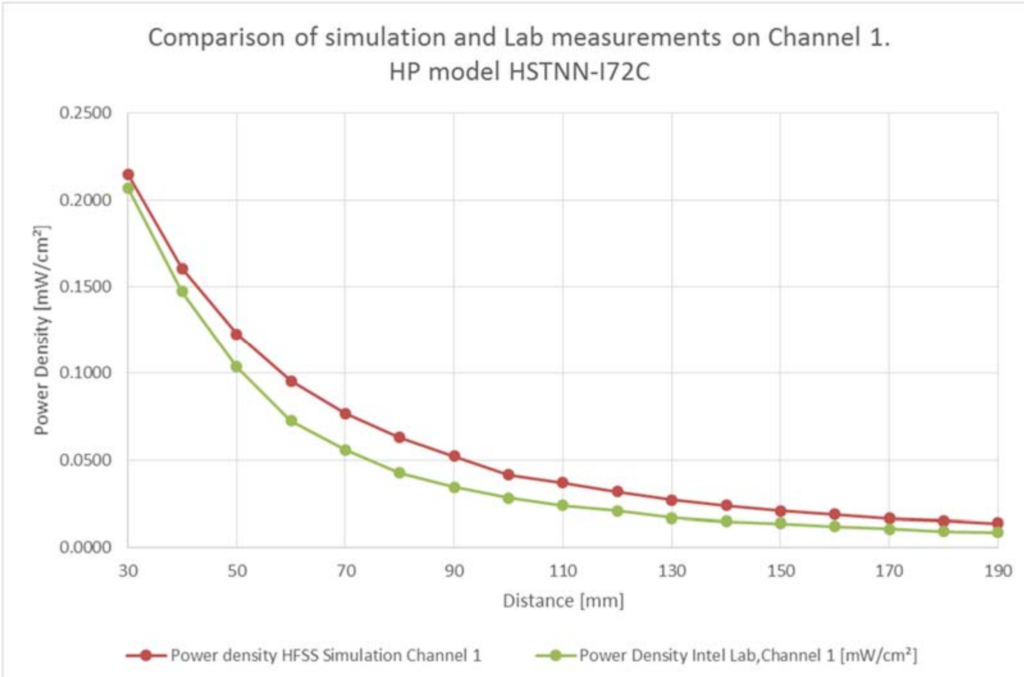


Figure 20 - Comparison of Power Density simulation to lab measurements on Channel 1 (Normalized for 100% duty cycle)

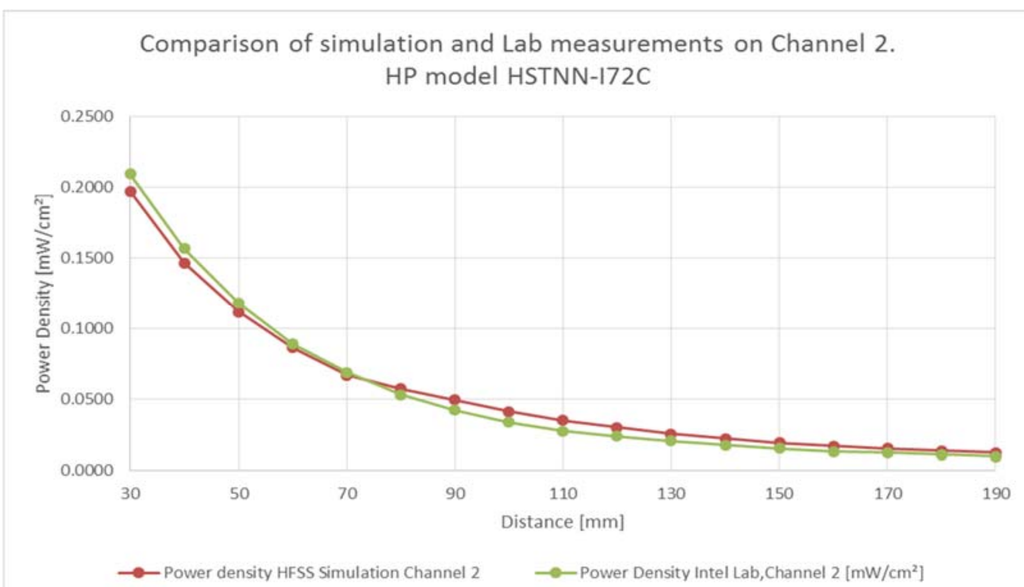


Figure 21 - Comparison of Power Density simulation to lab measurements on Channel 2 (Normalized for 100% duty cycle)

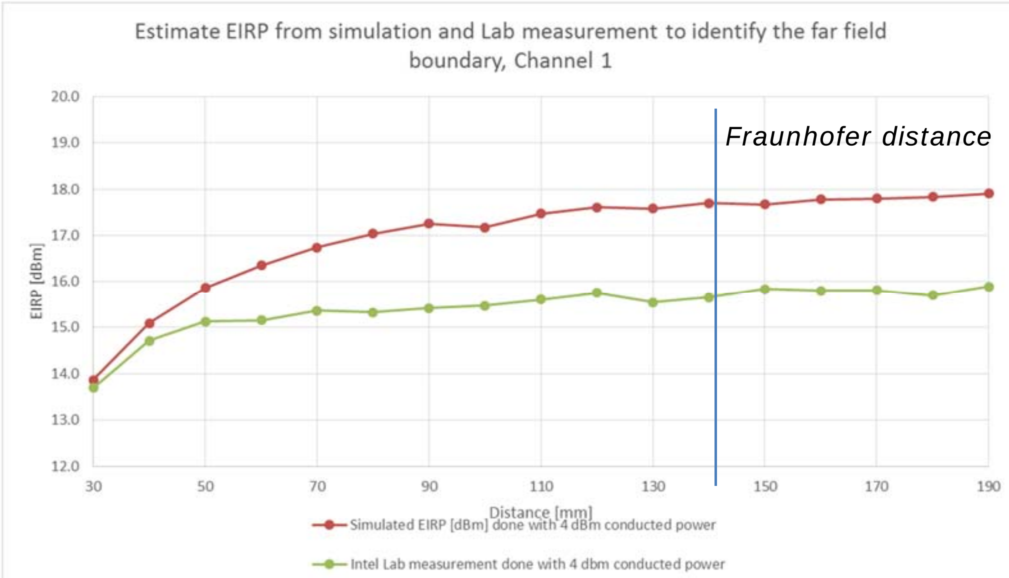


Figure 22 - Estimate EIRP of Simulation vs. lab measurements and far field boundary (Ch1) (Normalized for 100% duty cycle)

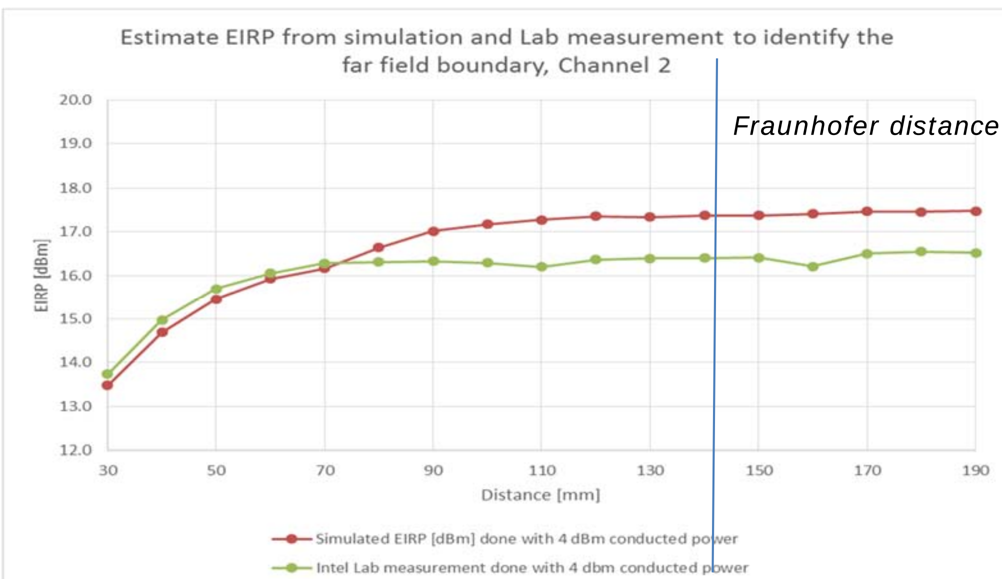


Figure 23 - Estimate EIRP of Simulation vs lab measurements and far field boundary (Ch2) (Normalized for 100% duty cycle)

Discussion – correlation results:

The following observations can be made by looking at Figure 22 & Figure 23:

1. EIRP increased to a steady state, demonstrating we are in the near/transition field below 7-9cm (shorter than the Fraunhofer distance).
2. Very good correlation can be seen in the graph shape and trends between lab measurements and simulation results.
3. Good correlation can be seen in the far field results between lab measurements to measured data. In both cases the simulation predict higher value then the measured data (reasonable results), where in channel 1 the simulation is higher by up to 2dB while in channel 2 the simulation is higher by ~1dB.

Summary – as explained, good to very good correlation can be seen between measured to simulated data.

5.1.4 Estimating conducted power level

Measured EIRP signal power can be also used to estimate the conducted equivalent power that is fed to the antenna array. The estimation is done by subtracting the antenna gain from the estimated EIRP level. Note that below 7 centimeters the conducted power estimation is inapplicable due to the inherent properties of the near field.

The EIRP level is the same as reported in previous section while the antenna gain is the antenna gain that is used in the RFEM modular approval.

Channel 1 antenna gain is – 15.3dBi, Channel 2 antenna gain is – 15.45dBi.

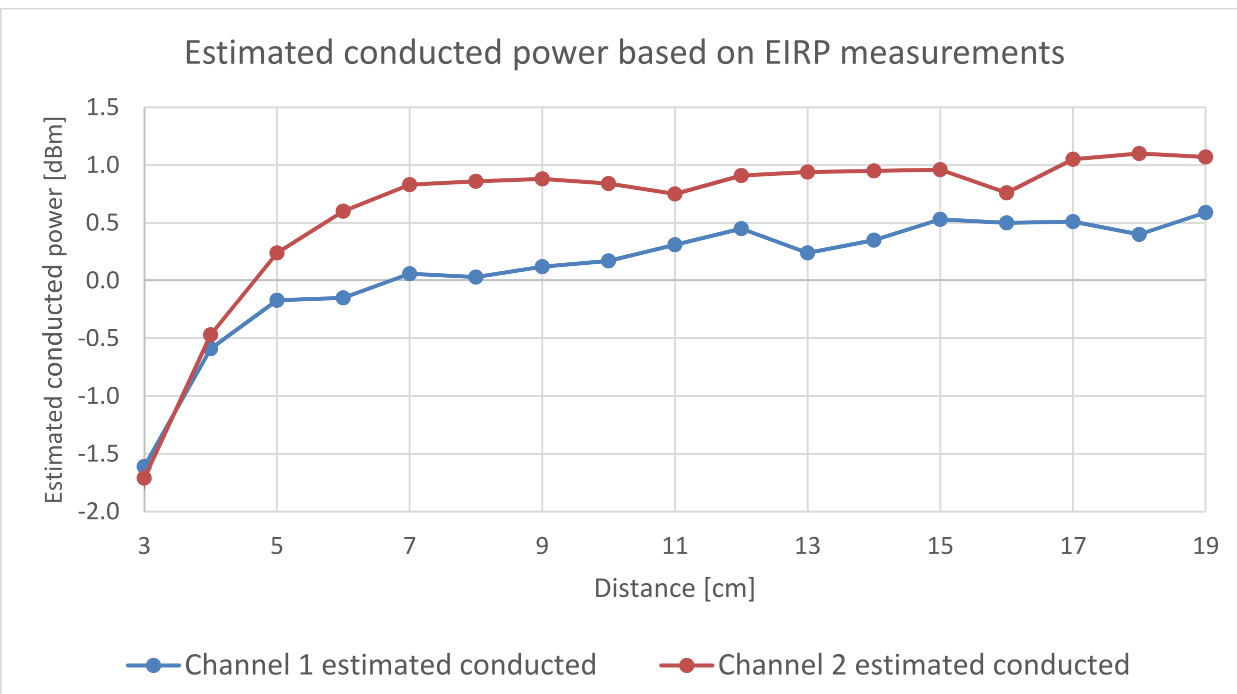


Figure 24 - Estimate conducted power from EIRP data

Discussion – correlation results:

Looking at Figure 24 one can see that the estimated conducted power is lower than the actual power level that was used. The tests were done with a conducted power of 4dBm while the estimated power is 0.5dBm-1dBm. The difference in the power is due to the following factors:

1. Looking at the EIRP vs simulation results reveal that the simulation is optimistic than the actual values by ~1-2dB.
2. The antenna gain that is used for this estimation is the modular antenna gain (antenna in free space). However the antenna that is embedded inside a platform has a platform loss that is typically in the vicinity of ~1.5dB.
3. Lower estimated conducted power can be seen at short distances (up to about 7cm) as coupling with the measuring device or other near objects. In addition at this range (3-7cm) the antenna gain is lower than the far field antenna gain, hence EIRP is lower and the predicted power is lower.

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.

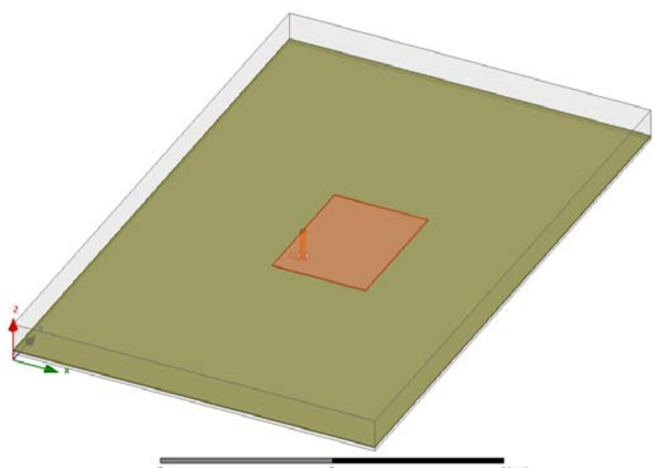


Figure 25 - Simulation of a single Patch antenna

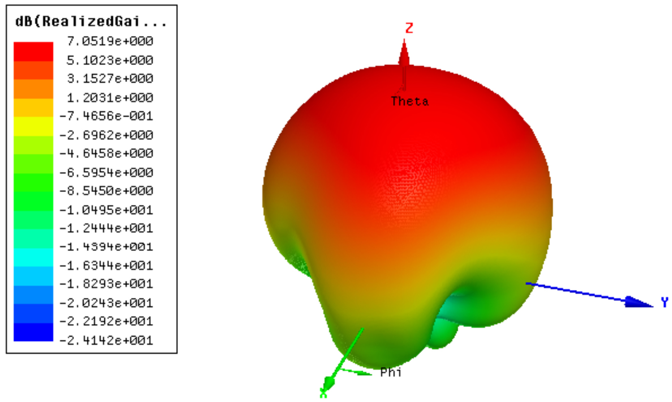


Figure 26 – Patch Antenna Gain

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:

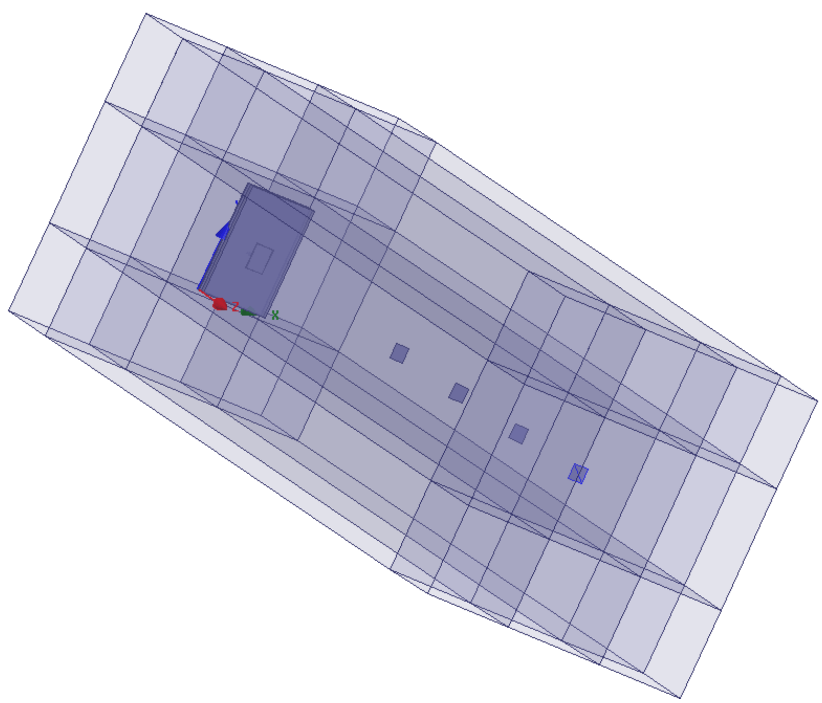


Figure 27 – Simulation 3D structure

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:

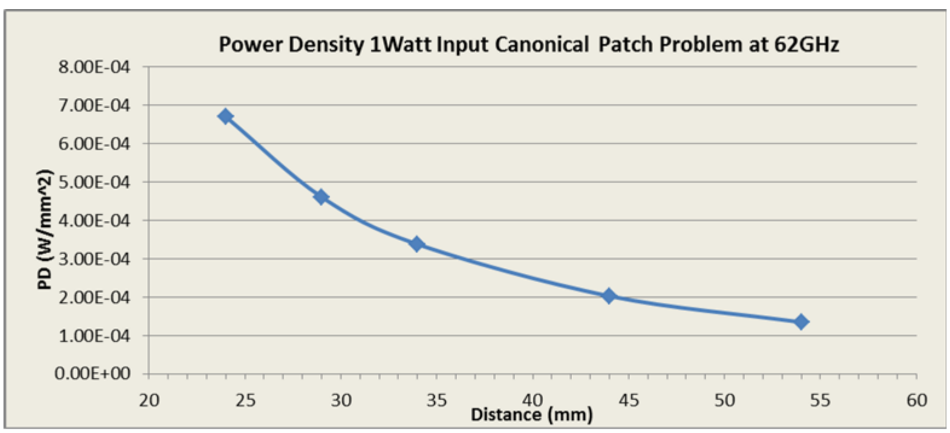


Figure 28– Power Density of Canonical Patch Antenna

6 Summary

Due to the lack of standardized code validation, benchmarking and uncertainty of the simulation software, the transition field/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 simulation gives far field results slightly higher than the measurement for the Channel 1 and Channel 2, suggesting that the simulation results are conservative. The error margins of all test results will be considered collectively by the FCC to establish confidence for the accuracy of the near field simulation.

The following table summarizes the simulation results in the near field of Intel 18260NGW module, embedded in Hewlett-Packard model HSTNN-I72C:

Parameter	**Value**
Total conducted power	3.5 dBm
Maximal TX duty-cycle	70%
Maximal spatially integrated and time averaged power density, over 1cm^2 and 10 seconds	0.577 mW/cm^2

Table 3 – Summary of simulation results for RF exposure compliance

Therefore Intel 18260NGW module, embedded in Hewlett-Packard model HSTNN-I72C, complies with FCC rule parts §2.1093 and §15.255(g).