Intel® Model: 13110NGW

FCC ID: PD913110NG

IC: 1000M-13110NG

Intel® Model 13110NGW Embedded Inside an HTC Virtual RealityHDMA Model 2Q4L100

WiGig Subsystem with RFEM 3

16 April 2018

MPE Simulation Report

Revision 1.4

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List of Abbreviations

Table 1 – Abbreviations

Abbreviation	Definition
Ant	Antenna
Az	Azimuth
BB	Base Band
BF	Beam Forming
BT	Bluetooth
BW	Bandwidth
CPU	Central Processing Unit
El	Elevation
EM	Electro-Magnetic
GHz	Gigahertz
IF	Intermediate Frequency
MAC	Media Access Control
M.2	M2: Formerly known as Next Generation Form Factor (NGFF); used as specification for connectors of the expansion cards mounted on computer
mm-Wave	Millimeter Wave
PC	Personal Computer
PCIe	Peripheral Component Interconnect Express; a PCI Special Interest Group standard
R&D	Research and Development
RF	Radio Frequency

Abbreviation	Definition
RFEM 3	Third-generation Radio Front End Module
RFIC	Radio Frequency Integrated Circuit
RX	Receive
SKU	Stock Keeping Unit, specific product model version
SoC	System-on-Chip
TDM	Time Division Multiplexing
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.

Terms and Definitions

Sub-array: A predefined group of radiating elements that are excited simultaneously with same amplitude and possibly different phases. There are three sub-arrays, and each one of them includes between 10 to 12 of the 24 elements of RFEM 3.

1 Document Scope

1.1 Introduction

This document is submitted to support the compliance with the FCC rule located in Title 47 of the Code of Federal Regulations (CFR), parts §2.1093 and §15.255(g), of Intel 13110NG WiGig module (FCC ID: PD913110NG, IC: 1000M-13110NG), including two separate active antenna arrays, embedded inside the VR HMDA model 2Q4L100.

Per the location of the active RFEM 3 antenna arrays (RFEM 3-A and RFEM 3-B) in the Intel 13110NGW module embedded inside the VR HMDA model 2Q4L100, the distance between the RFEM 3 arrays to the head or body of an end user, at the closest contact point, may be in the near field.

The determination of the near-field average power density is performed using EM simulations and a near field measurements. EM simulations that include the RFEM 3 arrays model embedded inside the VR HMDA model 2Q4L100 is used to determine subsets of the worst case configuration and the correspondent near field power density.

Due to the range of variations and uncertainty introduced by measurement and simulation, both results are applied to supplement each other, to establish conservative compliance information at the evaluation surfaces.

The simulation method and simulation results are described in this document. The near field measurement system details are described in document [2] and the comparison between simulation and measurement is shown in [3].

Chapter 2 provides relevant background on Intel 13110NGW module. Chapter 3 describes the simulation methodology to determine the worst case configuration and shows the power density simulation results.

1.2 Associated documents

This 'MPE Simulation Report' and the called references [2] and [3] are not confidential; relevant details and explanations that qualify for confidentiality are included separately in the operational description document called reference [1]

[1] 180215-VR HTC VIVE - Theory of Operation Report

[2] 180215-VR HTC VIVE - Near Field Measurement Report

[3] 180215-VR HTC VIVE - Simulations and Measurements Comparisons and Compliance Descriptions Report

1.3 Remarks and Comments

Previous filings for similar devices (PD9, RFEM) showed on order of 3 dB differences when only the normal component of the Poynting vector was used to determine power density, vs. using all three vector components. In this filing, the simulations used three components of the Poynting vector (consistent with FCC procedures), whereas the version of the measurement system available at this time used only the normal component to determine maximum power density results. Intel is collaborating with the measurement system vendor so that future filings for similar devices may use other methods for power density calculations, and as consistent with technical considerations in the IEEE/IEC measurement standards working group. The highest reported power density results (0.553 mW/cm^2 simulated, 0.497 mW/cm^2; 11% relative difference) are on the order of half of the FCC limit (1 mW/cm^2). Additional margins for RF exposure compliance are provided by that the evaluations planes are selected relatively close to the device enclosure at 9.3 mm spacing, with closest portions of user's head at 12.1 mm.

2 Background – WiGig System Operation

2.1 System block diagram

The Intel 13110NGW Virtual Reality HMDA module is a solution for WiGig connectivity for VR Wireless Headset such as VR HMDA model 2Q4L100.

The client solution for Intel 13110NGW VR HMDA includes the 13110NGW WiGig module (FCC ID: PD913110NG, IC:1000M-13110NG) connected to two beamforming antenna arrays, RFEM 3-A and RFEM 3-B, using two IF coaxial cables. Only one array can be operational at a given time.

The WiGig module (FCC ID: PD913110NG, IC:1000M-13110NG) is a PCIe M.2 module consisting of 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. Intel calls this module SNK. (Note that SNK uses the same WiGig baseband silicon as Maple Peak)

RFEM 3-A and RFEM 3-B (10101RRFW) are active antenna arrays modules, which convert the IF signal to a 60GHz signal. They also performs the beamforming functionality by phase [1] shifting the RF signal that goes to each antenna. The RFEM 3 is slave to the WiGig BB chip since all module control and algorithms run on the BB chip.

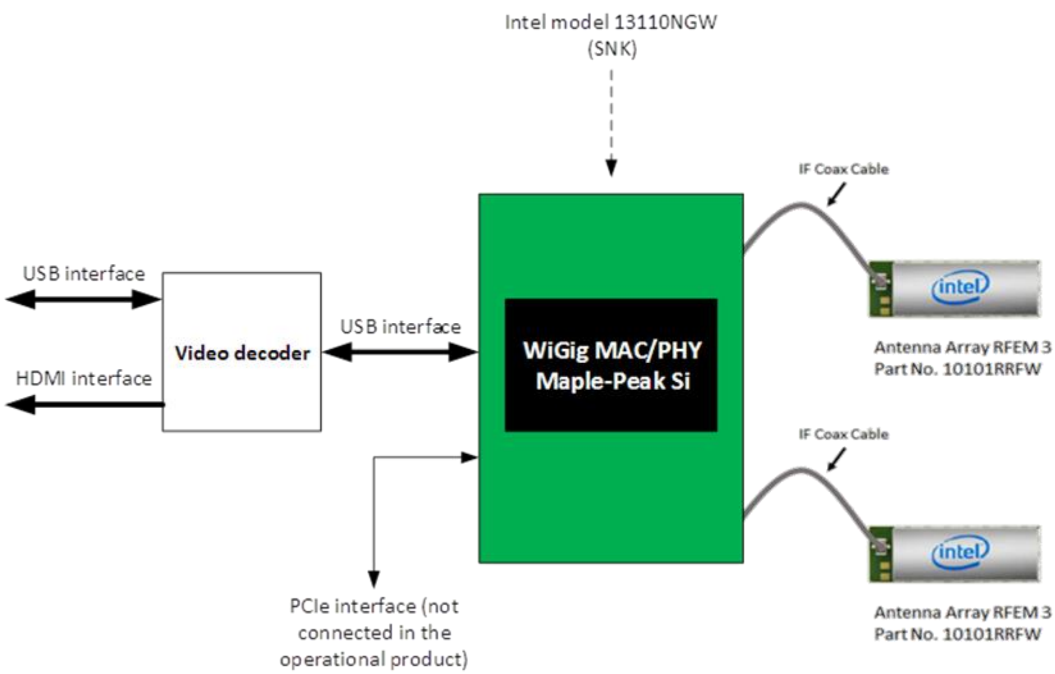


Figure 1 – Intel 13110NGW module system block diagram

Note: Also known by the Intel internal project code name "SNK," the above-described WiGig module solution still uses the "Maple Peak" Intel chipset (MAC/BB chip). The RFEM3 uses "Buckwell Peak" radio chipset

[1] *Each antenna is excited by an amplitude at a defined phase angle. RFEM 3 feeding circuit has 2 bit phase shifter. Therefore, the phase's values can be 0, 90, 180, or 270 degrees.*

2.2 TX duty cycle

The maximum TX duty cycle of the Intel Wireless Gigabit Sink-M 13110 VR module over a 10-second period is limited to 55%, independent of user activity and link conditions; therefore, it adheres to the source-based time-averaging definition in Title 47 of the Code of Federal Regulations (CFR) 2.1093(d)(5).

3 Numerical Modeling for RF Exposure Power Density Evaluation

3.1 Simulation methodology

3.1.1 Assessment considerations

During the system operation mode, it is challenging to define a practical system worst-case scenario in which the user is exposed to the highest emission level. To ensure coverage of the highest emission, the analysis of subsets of the worst-case conditions is used and is emphasized in the following:

1. Device orientation with respect to human body – In most of the cases, when the energy is directed to the human body, the human body will attenuate the signal. In this case, a reliable link can't be achieved. In normal mode, the system will transmit a low-duty cycle. However, in the analysis done for this document, the system is simulated in operational mode operating at 55% maximum duty cycle, which is much higher than the typical normal mode.

2. Energy direction, beam forming – In order to avoid human body attenuation or object blockage of a reliable link, the system beam forming will automatically search for a path that will establish a more reliable link. So, in real life, in most of the cases the EM path will not be directed towards the human body.

Please note that the above worst-case assessment description is very conservative in that it is very unlikely that this case would happen under normal usage conditions.

3.1.2 Near-field analysis

Finding the worst-case emission in the near field across the evaluation plane requires searching on two orthogonal domains. One domain is the location – the need to find the place that has the worst-case energy. The other domain that has to be searched is the antenna phases' configuration, i.e., search, over the various antenna phases, and find the antenna phase combination that gives the worst-case value. Section 3.1.4 explains how these two worst-case (location and phase) searches are investigated.

After the completion of the worst-case phase analysis, the phases found during this analysis are used to find the worst-case spatially averaged power density across a $1cm^2$, for RF exposure evaluation purposes. EM simulation is used for this analysis.

3.1.3 Simulation tool

3.1.3.1 Tool description

For the EM simulation, the commercially-available ANSYS Electronics Desktop 2017 (HFSS) is used. The ANSYS HFSS tool is used in the industry for simulating 3D, full-wave electromagnetic fields. Intel uses this EM simulation tool due to its gold-standard accuracy, advanced solver, and high-performance computing technology capabilities for doing accurate and rapid design of high-frequency components.

3.1.3.2 Solver description

The HFSS simulation is performed 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.

3.1.3.3 Convergence criteria and power density calculations

The HFSS uses a volume air box containing the simulated area to calculate the EM fields. The box is truncated by a Perfect Match Layer (PML) boundary condition. The simulation uses the adaptive mesh technique meet the exit criteria of delta S < 0.02. The delta S is the change in the magnitude of the S-parameters between two consecutive passes; if the magnitude and phase of all S-parameters change by an amount less than the Maximum-Delta-S-per-Pass value from one iteration to the next, the adaptive analysis stops.

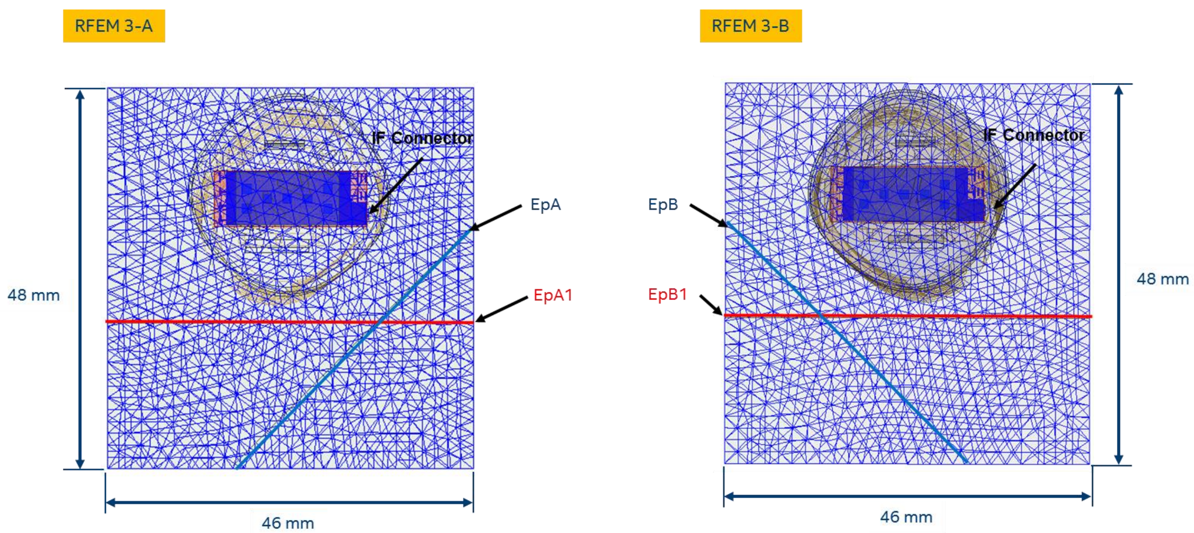


Figure 2 – Illustration of the adaptive mesh technique

After having the simulated electrical and magnetic (E and H) fields. The spatially-averaged power density (P_{av}) on a given surface (A) is calculated as the surface integral of the Poynting vector:

$$P_{av} = \frac{1}{2A}\int_A \left|Re(\vec{E} \times \vec{H}^*)\right| \cdot dS$$

Note: HFSS phasors in the field calculator are peak phasors, which leads to the ½ factor in the Poynting vector calculation.

3.1.4 Finding the near-field, worst-case simulation configuration

As explained previously, near-field analysis requires finding the worst-case location (along the searched plane) and antenna phase values. As further explained, the search should be done on two domains:

1) Look for the worst-case positions (across the search plane)
2) Look for the two worst-case antenna phases

The RFEM 3 antenna is intended to operate according to one of three predefined sub-arrays[2]. The search planes are defined as the planes used for the calculation, for each sub-array, of the worst-cases antenna phase combinations. In the case of the VR HMDA model HTC VIVE, two RFEM 3 antennas (called RFEM 3-A and RFEM 3-B) are used but only one RFEM 3 is operational at a given time and they never operate simultaneously.

The initial evaluation plane are defined for each RFEM 3 array, corresponding to the head tangential plane. These planes noted EpA, EpB are shown in blue at Figure 3. Considering that the HMDA device can rotate on top of the user's head, additional evaluation planes are defined to find the worst cases. These planes noted EpA1, EpB1 are shown in red at the Figure 3. For these planes, the HMDA device is in the position where the planes are parallel to the RFEM 3 array edge.

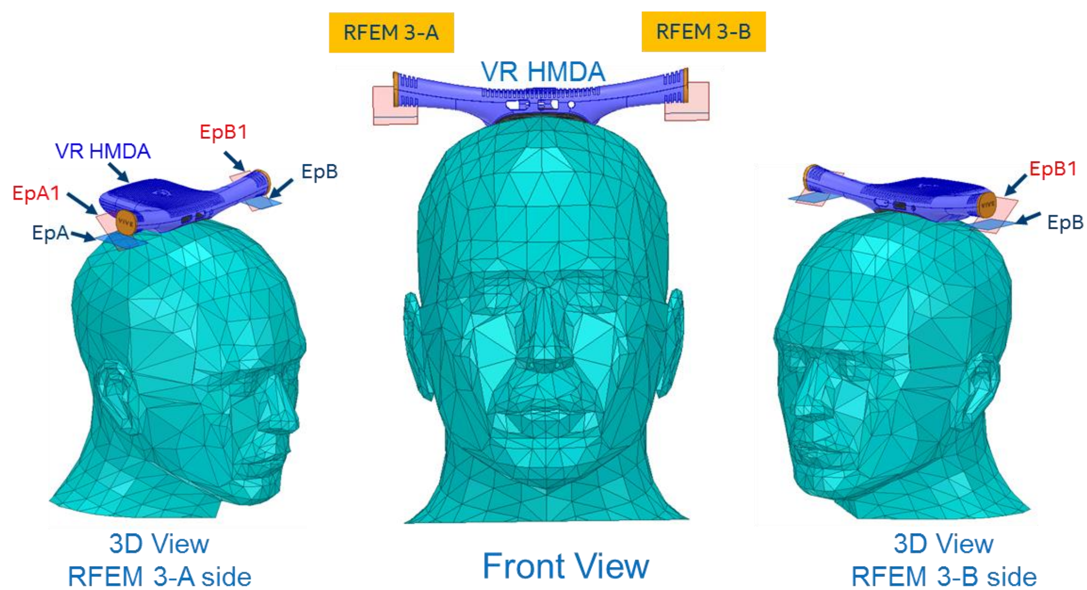


Figure 3 – The worst case search on the evaluation planes

The two domains described in 1) and 2) are applied separately for each sub-array of RFEM 3-A and RFEM 3-B in order to find worst case power density.

Note: the head shown in Figure 3 and all similar figures in this report is for general illustration purposes only of device positioning, but in-tissue energy or fields are not evaluated and the head is not included in any simulations.

[2] *A sub-array is a group of radiating elements which are excited simultaneously with the same amplitude. In RFEM 3, the number of sub-arrays is three.*

3.1.4.1 Terminology

- Element – Each one of the radiating elements that are used in the system. We denote the antenna element with index **k** in this explanation. N – Number of chains (RFEM 3 includes 24 radiated antenna elements – **N**=24). As described in the previous section, there are three sub-arrays in RFEM 3. These sub-arrays, named sub-array 1, sub-array 2 and sub-array 3, are composed of 12, 11 and 11 active elements respectively. For each sub-array, a set of elements from the 24 radiating antennas is activated).
- Point – Each point on the grid that is used for searching for the worst- case position. They are spaced 0.1mm from each other. The grid point would be denoted as **g** in this explanation.
- Complex E-field vector generated by the k^{th} antenna element at point g:

$$\overrightarrow{E_{k,g}} = \vec{x}\left(\mathrm{Re}\left[E_{kx,g}\right] + j\mathrm{Im}\left[E_{kx,g}\right]\right) + \vec{y}\left(\mathrm{Re}\left[E_{ky,g}\right] + j\mathrm{Im}\left[E_{ky,g}\right]\right) + \vec{z}\left(\mathrm{Re}\left[E_{kz,g}\right] + j\mathrm{Im}\left[E_{kz,g}\right]\right)$$

- Complex H-field vector generated by the k^{th} antenna element at point g:

$$\overrightarrow{H_{k,g}} = \vec{x}\left(\mathrm{Re}\left[H_{kx,g}\right] + j\mathrm{Im}\left[H_{kx,g}\right]\right) + \vec{y}\left(\mathrm{Re}\left[H_{ky,g}\right] + j\mathrm{Im}\left[H_{ky,g}\right]\right) + \vec{z}\left(\mathrm{Re}\left[H_{kz,g}\right] + j\mathrm{Im}\left[H_{kz,g}\right]\right)$$

- $\hat{x}$, $\hat{y}$, $\hat{z}$ – unit direction vectors having unit magnitude and mutually orthogonal to each other.
- $\hat{x}$, $\hat{y}$, $\hat{z}$ forms the coordinate system relative to each evaluation plane where $\hat{z}$ is always considered as the normal vector to the plane. The equations of this section are therefore applicable for each evaluation plane using its proper coordinate system.

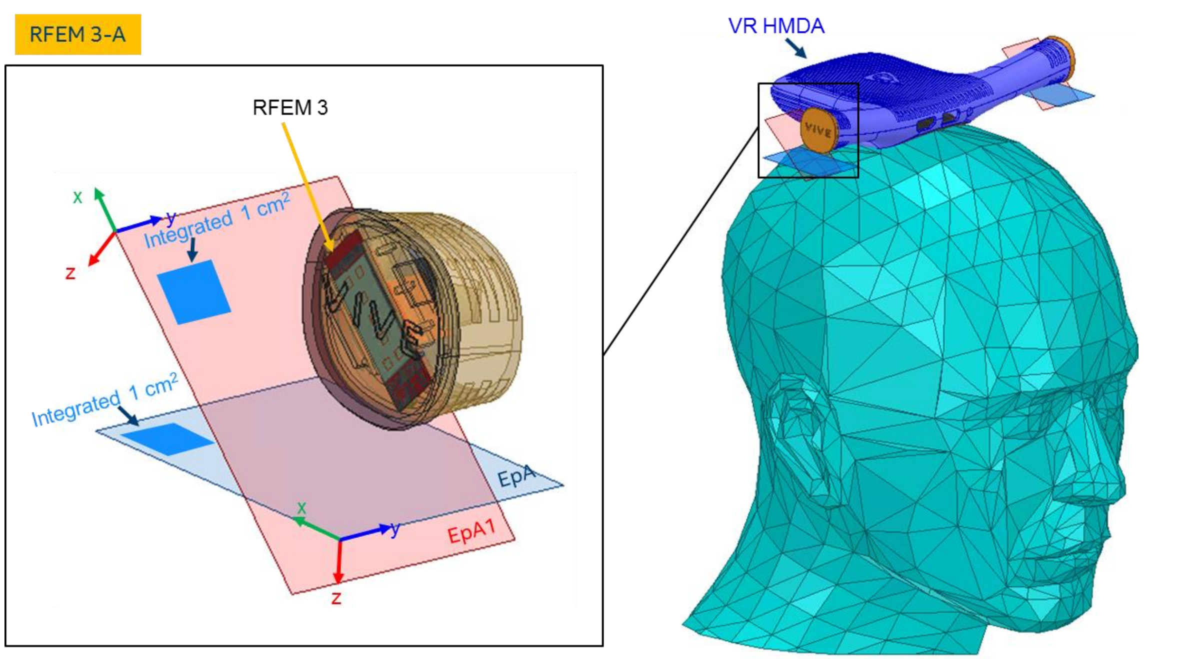


Figure 4 – Near field worst-case terminology and orientation

3.1.4.2 Primer on field vector representation

For each sub-array, *E* and *H* fields generated by the k chain are

$$\overrightarrow{E_k} = \vec{x}(\mathrm{Re}[E_{kx}] + j\mathrm{Im}[E_{kx}]) + \vec{y}(\mathrm{Re}[E_{ky}] + j\mathrm{Im}[E_{ky}]) + \vec{z}(\mathrm{Re}[E_{kz}] + j\mathrm{Im}[E_{kz}])$$

$$\overrightarrow{H_k} = \vec{x}(\mathrm{Re}[H_{kx}] + j\mathrm{Im}[H_{kx}]) + \vec{y}(\mathrm{Re}[H_{ky}] + j\mathrm{Im}[H_{ky}]) + \vec{z}(\mathrm{Re}[H_{kz}] + j\mathrm{Im}[H_{kz}])$$

For each sub-array, *E* and *H* fields generated by all *N* chains (only sub-array elements are activated) are

$$\overrightarrow{E_{\mathrm{All}}} = \vec{x}\sum_{k=1}^{N}(\mathrm{Re}[E_{kx}] + j\mathrm{Im}[E_{kx}]) + \vec{y}\sum_{k=1}^{N}(\mathrm{Re}[E_{ky}] + j\mathrm{Im}[E_{ky}]) + \vec{z}\sum_{k=1}^{N}(\mathrm{Re}[E_{kz}] + j\mathrm{Im}[E_{kz}])$$

$$\overrightarrow{H_{\mathrm{All}}} = \vec{x}\sum_{k=1}^{N}(\mathrm{Re}[H_{kx}] + j\mathrm{Im}[H_{kx}]) + \vec{y}\sum_{k=1}^{N}(\mathrm{Re}[H_{ky}] + j\mathrm{Im}[H_{ky}]) + \vec{z}\sum_{k=1}^{N}(\mathrm{Re}[H_{kz}] + j\mathrm{Im}[H_{kz}])$$

The Poynting vector generated by all *N* chains is

$$\begin{aligned}
\overrightarrow{P_{\mathrm{General,All}}} = \frac{1}{2}\overrightarrow{E_{\mathrm{All}}} \times \overrightarrow{H_{\mathrm{All}}^{*}} \\
= \frac{1}{2}\langle \vec{x}\Bigg\{\sum_{k=1}^{N}(\mathrm{Re}[E_{ky}] + j\mathrm{Im}[E_{ky}])\sum_{k=1}^{N}(\mathrm{Re}[H_{kz}] - j\mathrm{Im}[H_{kz}]) \\
- \sum_{k=1}^{N}(\mathrm{Re}[E_{kz}] + j\mathrm{Im}[E_{kz}])\sum_{k=1}^{N}(\mathrm{Re}[H_{ky}] - j\mathrm{Im}[H_{ky}])\Bigg\} \\
+ \vec{y}\Bigg\{\sum_{k=1}^{N}(\mathrm{Re}[E_{kz}] + j\mathrm{Im}[E_{kz}])\sum_{k=1}^{N}(\mathrm{Re}[H_{kx}] - j\mathrm{Im}[H_{kx}]) \\
- \sum_{i=1}^{N}(\mathrm{Re}[E_{kx}] + j\mathrm{Im}[E_{kx}])\sum_{k=1}^{N}(\mathrm{Re}[H_{kz}] - j\mathrm{Im}[H_{kz}])\Bigg\} \\
+ \vec{z}\Bigg\{\sum_{k=1}^{N}(\mathrm{Re}[E_{kx}] + j\mathrm{Im}[E_{kx}])\sum_{k=1}^{N}(\mathrm{Re}[H_{ky}] - j\mathrm{Im}[H_{ky}]) \\
- \sum_{k=1}^{N}(\mathrm{Re}[E_{ky}] + j\mathrm{Im}[E_{ky}])\sum_{k=1}^{N}(\mathrm{Re}[H_{kx}] - j\mathrm{Im}[H_{kx}])\Bigg\}\rangle
\end{aligned}$$

Power flow is

$$
\begin{aligned}
\mathrm{Re}\left[\overrightarrow{P_{\text{General,All}}}\right] = \frac{1}{2}\langle \vec{x} & \left\{\sum_{k=1}^{N} \mathrm{Re}\left[E_{ky}\right] \sum_{k=1}^{N} \mathrm{Re}[H_{kz}] + \sum_{k=1}^{N} \mathrm{Im}\left[E_{ky}\right] \sum_{k=1}^{N} \mathrm{Im}[H_{kz}] - \sum_{k=1}^{N} \mathrm{Re}[E_{kz}] \sum_{k=1}^{N} \mathrm{Re}\left[H_{ky}\right] \right. \\
& \left. - \sum_{k=1}^{N} \mathrm{Im}[E_{kz}] \sum_{k=1}^{N} \mathrm{Im}\left[H_{ky}\right]\right\} \\
& + \vec{y}\left\{\sum_{k=1}^{N} \mathrm{Re}[E_{kz}] \sum_{k=1}^{N} \mathrm{Re}[H_{kx}] + \sum_{k=1}^{N} \mathrm{Im}[E_{kz}] \sum_{k=1}^{N} \mathrm{Im}[H_{kx}] - \sum_{k=1}^{N} \mathrm{Re}[E_{kx}] \sum_{k=1}^{N} \mathrm{Re}[H_{kz}] \right. \\
& \left. - \sum_{k=1}^{N} \mathrm{Im}[E_{kx}] \sum_{k=1}^{N} \mathrm{Im}[H_{kz}]\right\} \\
& + \vec{z}\left\{\sum_{k=1}^{N} \mathrm{Re}[E_{kx}] \sum_{k=1}^{N} \mathrm{Re}\left[H_{ky}\right] + \sum_{k=1}^{N} \mathrm{Im}[E_{kx}] \sum_{k=1}^{N} \mathrm{Im}\left[H_{ky}\right] - \sum_{k=1}^{N} \mathrm{Re}\left[E_{ky}\right] \sum_{k=1}^{N} \mathrm{Re}[H_{kx}] \right. \\
& \left. - \sum_{k=1}^{N} \mathrm{Im}\left[E_{ky}\right] \sum_{k=1}^{N} \mathrm{Im}[H_{kx}]\right\}\rangle
\end{aligned}
$$

3.1.4.3 Domain search for worst-case direction

For each evaluation plane, the two-domain search is completed (for each sub-array) as follows:

A. First find a direction (location) for the worst-case $1cm^2$ square averaging area using upper-bound methods.

   The basic concept behind the upper-bound method is to assume that there could be an "ideal beam forming" mechanism that could align the phases of all the elements for both E and H fields. When this ideal mechanism is used, then all the complex phasors are aligned to the same phase, hence the phasor absolute value can be used instead of the phasor. The E (and H) field for any direction is the sum of the magnitude of the fields.

   This method provides the worst-case position independent of the antenna phases. It allows finding the worst-case location with this "ideal beam forming" mechanism.

B. After the worst-case direction is found using the upper-bound method for each sub-array, the antenna phases are aligned to this direction. The antenna phases are aligned to maximize the power across the $1cm^2$ averaging area that was found using the upper-bound method. The method that is used to find the required antenna phases is as follows: first order the antennas of the sub-array according to the power contribution on the found $1cm^2$ from the highest to the lowest. Then start by activating the antenna that contributes the most, set its phase to 0, and then activate the 2^{nd} antenna and search over the phases for the 2^{nd} antenna. Choose the phase that maximizes the power of the two antenna elements. To find the phase for the third antenna, fix antenna 1's phase to zero and antenna 2's phase to the value that was found before. Then search for the phases for the third antenna that maximize the power. Continue with the same process until you reach the last sub-array element.

C. The same process is used to find the required antenna phases of the second worst case and described as follows: As in the first worst case (item B), order the sub-array antenna elements according to the power contribution on the found $1cm^2$ from the highest to the lowest. Then start by activating the first antenna element that contributes the most, set the phase of the first element to 0. Then, activate the 2^{nd} antenna and search over the phases, except the phase value found in the first worst case, for the 2^{nd} antenna element. Choose the phase that maximizes the power of the two antenna elements. Then, activate the third antenna elements, search for the phases for the third antenna that maximize the power. Continue with the same process until you reach the last sub-array element

D. Calculate the power density with the antenna phases that were found in the previous items (item B and item C) for the first and second worst cases.

The above process can be written as the following algorithm:

1. A grid is defined with 0.1mm spacing.
2. At each point in the grid, the complex E and H fields are calculated using each one of all radiating elements in the involved sub-array, separately. Each one of the calculated E and H fields are 3D complex vectors, so the simulation output from this stage is 12, 11,

11 3D complex E field strength vectors and 12, 11, 11 3D complex H field strength vectors for the three sub-arrays respectively . The vectors are defined as:

$$\overrightarrow{E_{k,g}} = \vec{x}\left(\mathrm{Re}\left[E_{kx,g}\right] + j\mathrm{Im}\left[E_{kx,g}\right]\right) + \vec{y}\left(\mathrm{Re}\left[E_{ky,g}\right] + j\mathrm{Im}\left[E_{ky,g}\right]\right) + \vec{z}\left(\mathrm{Re}\left[E_{kz,g}\right] + j\mathrm{Im}\left[E_{kz,g}\right]\right) \text{ and}$$

$$\overrightarrow{H_{k,g}} = \vec{x}\left(\mathrm{Re}\left[H_{kx,g}\right] + j\mathrm{Im}\left[H_{kx,g}\right]\right) + \vec{y}\left(\mathrm{Re}\left[H_{ky,g}\right] + j\mathrm{Im}\left[H_{ky,g}\right]\right) + \vec{z}\left(\mathrm{Re}\left[H_{kz,g}\right] + j\mathrm{Im}\left[H_{kz,g}\right]\right)$$

3. Upper-bound assumption is used to derive the E and H field on each one of the grid points. The following items describe the upper-bound method that is used:
   a. The calculation is made separately for E field and H field.
   b. For E field, the following calculation is made independently for each one of the grid points:

$$\overrightarrow{E_{\mathrm{UB,g}}} = \vec{x}\sum_{k=1}^{N}\sqrt{\mathrm{Re}\left[E_{kx,g}\right]^2 + \mathrm{Im}\left[E_{kx,g}\right]^2} + \vec{y}\sum_{k=1}^{N}\sqrt{\mathrm{Re}\left[E_{ky,g}\right]^2 + \mathrm{Im}\left[E_{ky,g}\right]^2} + \vec{z}\sum_{k=1}^{N}\sqrt{\mathrm{Re}\left[E_{kz,g}\right]^2 + \mathrm{Im}\left[E_{kz,g}\right]^2} = \vec{x}\sum_{k=1}^{N}\left|E_{kx}\right| + \vec{y}\sum_{k=1}^{N}\left|E_{ky,g}\right| + \vec{z}\sum_{k=1}^{N}\left|E_{kz,g}\right|$$

   The magnitude of the complex E vector is summed over the antenna elements in a sub-array. The summation is done for each one of the grid points, and for each one of the elements in each direction, independently.
   c. The output of the previous item is the 3D real vector of the E field on each one of the simulated grid points in each direction. The physical implementation is that an ideal beam forming was done for the E field for each one of the points.
   d. The same process as described in item b is done for the H field.

$$\overrightarrow{H_{\mathrm{UB,g}}} = \vec{x}\sum_{k=1}^{N}\sqrt{\mathrm{Re}\left[H_{kx,g}\right]^2 + \mathrm{Im}\left[H_{kx,g}\right]^2} + \vec{y}\sum_{k=1}^{N}\sqrt{\mathrm{Re}\left[H_{ky,g}\right]^2 + \mathrm{Im}\left[H_{ky,g}\right]^2} + \vec{z}\sum_{k=1}^{N}\sqrt{\mathrm{Re}\left[H_{kz,g}\right]^2 + \mathrm{Im}\left[H_{kz,g}\right]^2} = \vec{x}\sum_{k=1}^{N}\left|H_{kx,g}\right| + \vec{y}\sum_{k=1}^{N}\left|H_{ky,g}\right| + \vec{z}\sum_{k=1}^{N}\left|H_{kz,g}\right|$$

   e. At each point in the grid, the Poynting vector is calculated by vector multiplication of the E and H fields, which are added up in items b and d. As explained before, without a loss of generality, we assume that the search plane is the x/y plane. All three (xyz) components of the Poynting vector are added, and not just the component that is normal to the x/y plane:

$$P_g = \frac{1}{2}Re\{(\vec{E} \times \vec{H}^*)\} = \frac{1}{2}Re\left\{\left(\left(\left(E_y H_z^* - E_z H_y^*\right)\right)\hat{x} + \left((E_z H_x^* - E_x H_z^*)\right)\hat{y} + \left(E_x H_y^* - E_y H_x^*\right)\hat{z}\right)\right\}$$

$$P_{g,x} = \frac{1}{2}Re\{E_y H_z^* - E_z H_y^*\}$$

$$P_{g,y} = \frac{1}{2}Re\{(E_z H_x^* - E_x H_z^*)\}$$

$$P_{g,z} = \frac{1}{2}Re\{E_x H_y^* - E_y H_x^*\}$$

$$PUpperBound_g = \sqrt{{P_{g,x}}^2 + {P_{g,y}}^2 + {P_{g,z}}^2}$$

4. The above calculated Poynting vectors are used to estimate the power across 1cm^2 area.

$$P1cm2 = \iint_{1cm^2} PUpperBound_{g\ x,y,z}$$

5. The 1cm^2 area with the highest power value is used as the worst-case direction of a sub-array. The antenna phases are aligned to maximize the energy in this 1cm^2 area, as explained below in order to find the 2 worst cases:
    a. Turn on each element one-by-one to find order of power intensity in the 1cm^2 window. (Find the order of contribution)
    b. Sort in the power order from the highest to the lowest, #0 to #(12, 11, 11) for the involved sub-arrays 1,2 and 3 respectively .
    c. Turn on #0 with phase P0=0. (reference)
    d. Turn on #1 and change the phase to maximize the power and find the phase P1.
    e. Keep P0 and P1 on, then turn on #2 and do same.
    f. Repeat for the rest of the antennas.
6. Using the antenna phases that were calculated in step 5, the power density is calculated along the evaluation plane and then spatially averaged across a 1cm^2 area using the equation $1cm2 = \iint_{1cm^2} \left| Poynting_{\ x,y,z} \right|$.

3.1.5 3D models used in the simulation

3.1.5.1 Worst-case operating conditions

The Intel 13110NGW module and RFEM 3 antennas are simulated inside the VR HMDA model HTC VIVE. Figure 5 shows the two RFEM 3 antennas (RFEM 3-A and RFEM 3-B), which are located on both sides of the VR headset. The evaluation planes EpA, EpB, EpA1 and EpB1 are illustrated in the Figure 5.

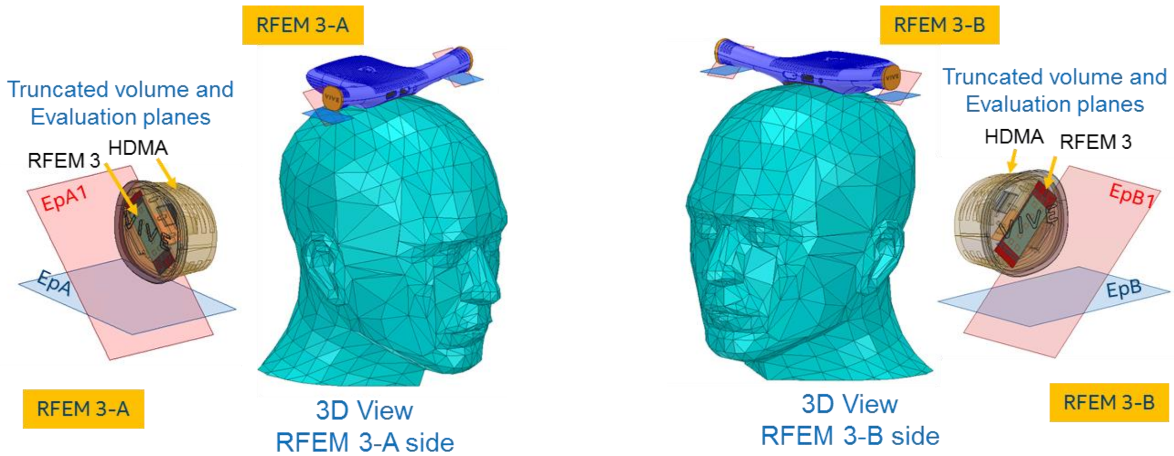


Figure 5 – Worst-case evaluation planes for VR HDMA model HTC VIVE

3.1.5.2 RFEM 3 housing

Figure 6 shows the position of the two RFEM 3 antennas in the device which are separated by a distance of 198 mm.

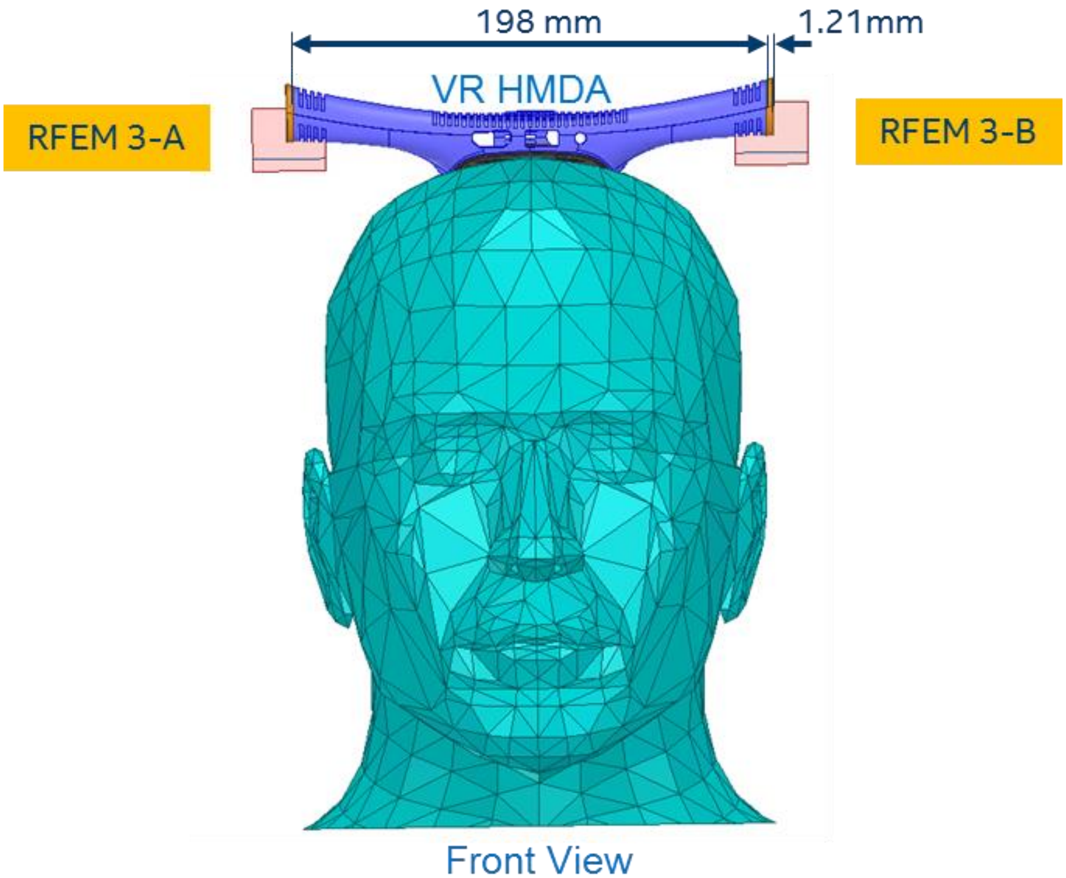


Figure 6 – VR HMDA with RFEM 3 location

3.1.5.3 Closest distance to the evaluation planes

In operating mode, the closest distance between the RFEM 3 antennas and the ‘EpA and EpB’ evaluation planes is 9.3 mm and the closet distance to the ‘EpA1 and EpB1’ is 12.1 mm.

Figure 7 shows the distances from the RFEM 3 antennas and the VR HMDA device to the EpA, EpB, EpA1 and EpB1 evaluation planes.

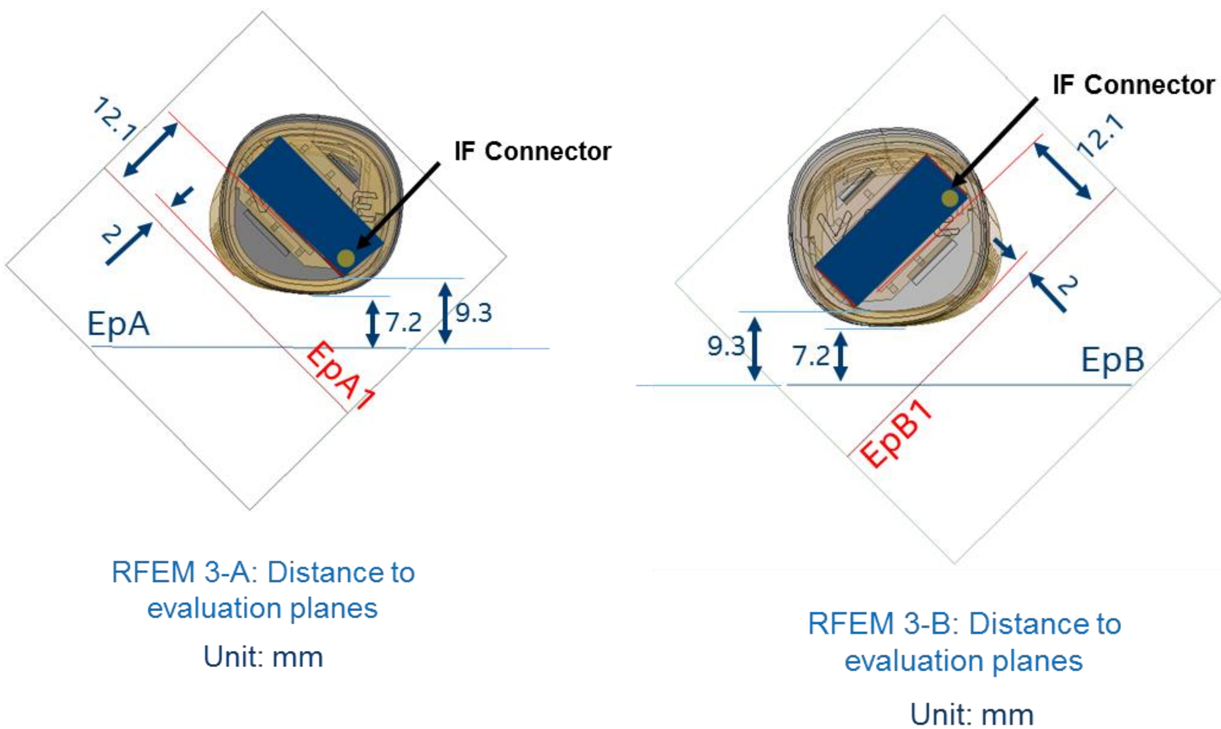


Figure 7 – Closet distances to the evaluation planes

3.1.5.4 Metals in proximity of the RFEM 3

All the metals that are in the RFEM 3 region were included in the simulation.

3.1.6 Antenna feed

This section provides a general description of the numerical simulations. The EM simulation uses an accurate 3D model of the RFEM 3 antenna. The model includes the antenna elements as well as their feeding lines.

In the simulation, each antenna element is fed independently, and we excite the antennas at the origin of the antenna structure on the RFEM 3. The antenna structure includes the silicon chip, the solder bumps, the vias, traces, and actual antenna element. The phases of the elements are controlled by the silicon ship using a 2 bits phase shifter.

As described previously, the RFEM 3 antenna will be operated according to one of three predefined sub-arrays. For the operational sub-array, signals of equal amplitude are applied to the feed-points of individual array elements, and the aggregate equivalent conducted power to all sub-array elements *c*orresponds to the sum of all elements' powers. In the worst-case power density the sub-array 3 is the operational sub-array with an equivalent conducted power of 13 dBm; thus each element is fed by 2.59 dBm (13 dBm divided over 11 elements).

The total power (same per element) is used to build the pattern of radiated power through beam forming. The same power is used per element, while phase is changed per element. Phases are derived for each excitation separately, to simulate the worst-case condition. Section 3.1.4 explains how the phases are derived to find the worst-case condition.

3.2 Power density simulation results

3.2.1 Introduction

The evaluation planes (EpA, EpB) and (EpA1, EpB1) of both RFEM 3-A and RFEM 3-B antenna arrays presented in Section 3.1.5.2 has been simulated according to the methodology described in Section 3.1. The simulation results for all sub-arrays in these evaluation planes are presented in this section.

The power density has been simulated over three channels with frequencies listed in Table 2. For each channel, we'll present the resulting details according to the methodology explained in Section 3.1.4.

- Simulation results of the **upper-bound**, single-point power density for each single-point across the mesh ($PUpperBound_g$). This value represents single-point power density, and not spatially-averaged power density over 1cm^2.
- Antenna **phases' configurations** of the first- and second-worst cases spatially averaged power density over 1cm^2.
- Simulation results of the **single-point power density** using the antenna phases corresponding to the first- and second-worst cases.
- Simulation results of the **spatially averaged power density over 1cm^2** of the first- and second-worst cases. These results present the spatially averaged power density across 1cm^2 using the xyz components of the 'Poynting' vector.
- All simulation results in the evaluation planes, for all channels and sub-arrays are normalized to the target maximum conducted power of 13 dBm.

Table 2 – WiGig channel frequencies

	Channel 1	Channel 2	Channel 3
Frequency (GHz)	58.32	60.48	62.64

Table 3 summarizes all the simulation configurations as well as the result types presented in the following sections.

Table 3 – Power density simulation configuration and result details

Sub-arrays & channels	Evaluation Planes	Results types	Count	Reference			
				EpA	EpB	EpA1	EpB1
1, 2, and 3	EpA, EpB, EpA1, and EpB1	Upper-bound power density	3 channels x 3 sub-arrays x 4 evaluation plane	Table 4 Row #2	Table 8 Row #2	Table 13 Row #2	Table 17 Row #2
		1st worst-case antenna phases	3 channels x 3 sub-arrays x 4 evaluation plane	Table 4 Row #1	Table 8 Row #1	Table 13 Row #1	Table 17 Row #1
		1st worst-case single point power density	3 channels x 3 sub-arrays x 4 evaluation plane	Table 4 Row #3	Table 8 Row #3	Table 13 Row #3	Table 17 Row #3
		1st worst-case spatially averaged power density	3 channels x 3 sub-arrays x 4 evaluation plane	Table 4 Row #4	Table 8 Row #4	Table 13 Row #4	Table 17 Row #4
		2nd worst-case antenna phases	3 channels x 3 sub-arrays x 4 evaluation plane	Table 5 Row #1	Table 9 Row #1	Table 14 Row #1	Table 18 Row #1
		2nd worst-case single point power density	3 channels x 3 sub-arrays x 4 evaluation plane	Table 5 Row #3	Table 9 Row #3	Table 14 Row #3	Table 18 Row #3
		2nd worst-case spatially averaged power density	3 channels x 3 sub-arrays x 4 evaluation plane	Table 5 Row #4	Table 9 Row #4	Table 14 Row #4	Table 18 Row #4
		Worst-case distribution [3]	[3 plots] / 1 channel x 1 sub-array x 4 evaluation plane	Section 3.2.2.2	Section 3.2.2.4	Section 3.2.3.2	Section 3.2.3.4

[3] *The distribution of the worst-case, spatially-averaged power density found among the 18 calculated worst cases in the evaluation plane corresponding to each RFEM 3*

3.2.2 Simulation results in the EpA and EpB evaluation planes

3.2.2.1 Worst-cases power density value's in the EpA evaluation plane

Table 4 and Table 5 summarizes, for all sub-arrays and channels, the simulation results in the **EpA evaluation plane** for the first and second worst cases respectively. In these tables, the following results are presented:

- The maximum values of the calculated upper bound single point power density values in the evaluation plane. The worst-case position is calculated using all the power density single-points issued from the upper-bound simulation results. We leverage the phase conditions for each antenna element that resulted in these worst-case conditions to evaluate final spatially averaged power density.
- The phases' configuration, a.k.a. "beamforming codes" of each sub-array elements (marked in grey) for the first and second worst cases. The white cells with phase ("-") correspond to the non-active elements of the sub-array. For instance, for sub-array 1, the active elements are 5, 6, 7, 8; 17 to 24, and the worst case occurs for each channel with the indicated phases. "Ph #" indicates the number of the attributed phase combination for each worst case.
- The maximum calculated single-point power density values using the first- and the second-worst-case sub-array antenna phases.
- The maximum calculated spatially-averaged power density over 1 cm^2. These values are calculated in the evaluation plane using the first and the second worst-case sub-array antenna phases.

Note: All simulation results are presented at 100% duty cycle and all power density values are shown in [mW/cm^2].

Table 4 – Simulation results for the first-worst case in the EpA plane

Row #		Sub-array	Sub-array 1			Sub-array 2			Sub-array 3		
		Channel	CH1	CH2	CH3	CH1	CH2	CH3	CH1	CH2	CH3
1	Phases configuration [degrees]	Ant. index	Ph1 #1	Ph1 #2	Ph1 #3	Ph1 #4	Ph1 #5	Ph1 #6	Ph1 #7	Ph1 #8	Ph1 #9
		1	-	-	-	-	-	-	270	0	90
		2	-	-	-	-	-	-	270	0	90
		3	-	-	-	-	-	-	180	270	0
		4	-	-	-	90	90	180	-	-	-
		5	0	0	270	180	90	90	-	-	-
		6	90	90	0	270	180	180	-	-	-
		7	180	0	0	-	-	-	-	-	-
		8	180	270	180	-	-	-	-	-	-
		9	-	-	-	90	0	0	-	-	-
		10	-	-	-	0	270	270	-	-	-
		11	-	-	-	270	270	270	-	-	-
		12	-	-	-	270	0	0	-	-	-
		13	-	-	-	0	270	0	180	270	0
		14	-	-	-	0	0	90	180	270	180
		15	-	-	-	0	0	90	0	90	180
		16	-	-	-	270	270	0	0	90	180
		17	0	90	90	-	-	-	-	-	-
		18	180	270	0	-	-	-	-	-	-
		19	180	0	0	-	-	-	-	-	-
		20	180	0	0	-	-	-	-	-	-
		21	0	0	270	-	-	-	0	0	90
		22	0	0	270	-	-	-	0	0	90
		23	270	270	180	-	-	-	270	270	0
		24	270	270	180	-	-	-	270	270	0
2	Upper Bound PD[4]		6.686	6.564	5.850	7.878	9.081	7.982	7.680	7.151	5.340
3	Single point PD[5]		1.453	1.331	0.935	1.282	1.626	2.000	2.163	1.849	1.450
4	Average PD[6]		0.658	0.620	0.446	0.570	0.732	0.762	0.652	0.533	0.414

[4] *Upper bound single point power density without phase difference between sub-array element's*

[5] *Single point power density with phases' configuration shown in row #1 for the corfresponding case (For example, the single power density of sub-array1, channel 1 is obtained using the phase configuration Ph1 #1)*

[6] *Spatially averaged over 1 cm^2 of the single point power density with phases' configuration shown in row #1 for the corfresponding case*

Table 5 – Simulation results for the second-worst case in the EpA plane

Row #	Sub-array		Sub-array 1			Sub-array 2			Sub-array 3		
	Channel		CH1	CH2	CH3	CH1	CH2	CH3	CH1	CH2	CH3
1	Phases configuration [degrees]	Ant. index	Ph1 #10	Ph1 #11	Ph1 #12	Ph1 #13	Ph1 #14	Ph1 #15	Ph1 #16	Ph1 #17	Ph1 #18
		1	-	-	-	-	-	-	0	270	90
		2	-	-	-	-	-	-	0	270	90
		3	-	-	-	-	-	-	270	180	0
		4	-	-	-	180	90	90	-	-	-
		5	0	0	180	180	0	0	-	-	-
		6	90	180	0	270	90	180	-	-	-
		7	180	0	0	-	-	-	-	-	-
		8	180	270	90	-	-	-	-	-	-
		9	-	-	-	180	0	0	-	-	-
		10	-	-	-	0	180	180	-	-	-
		11	-	-	-	0	180	270	-	-	-
		12	-	-	-	180	0	0	-	-	-
		13	-	-	-	270	180	0	180	180	270
		14	-	-	-	90	0	90	270	180	270
		15	-	-	-	0	0	90	90	0	180
		16	-	-	-	270	270	0	90	0	90
		17	0	90	90		-	-	-	-	-
		18	180	270	270		-	-	-	-	-
		19	180	0	0	-	-	-	-	-	-
		20	180	0	0	-	-	-	-	-	-
		21	90	0	180	-	-	-	0	0	180
		22	0	0	180	-	-	-	0	0	180
		23	270	270	90	-	-	-	270	270	90
		24	270	270	90	-	-	-	270	270	90
2	Upper Bound PD[4]		6.686	6.564	5.850	7.878	9.081	7.982	7.680	7.151	5.340
3	Single point PD[5]		1.276	1.120	1.026	1.258	1.258	1.258	2.172	1.767	1.526
4	Average PD[6]		0.582	0.583	0.400	0.477	0.494	0.572	0.648	0.529	0.390

[4] *Upper bound single point power density without phase difference between sub-array element's*

[5] *Single point power density with phases' configuration shown in row #1 for the corfresponding case. (For example, the single power density of sub-array1, channel 1 is obtained using the phase configuration Ph1 #10)*

[6] Spatially averaged over 1 cm^2 of the single point power density with phases' configuration shown in row #1 for the corresponding case

Table 6 presents, for all channels and all sub-arrays, the spatially-averaged power density over 1 cm^2 in the EpA evaluation plane using the first and the second worst-case sub-array antenna phases presented in tables above.

Table 6 – Maximum spatially averaged power density over 1cm^2 [mW/cm^2]

	First worst case			Second worst case		
	Channel 1	**Channel 2**	**Channel 3**	**Channel 1**	**Channel 2**	**Channel 3**
Sub-array 1	0.658	0.620	0.446	0.582	0.583	0.400
Sub-array 2	0.570	**0.732**	**0.762**	0.477	0.494	0.572
Sub-array 3	0.652	0.533	0.414	0.648	0.529	0.390

Table 6 shows that the worst case in **EpA evaluation plane** is found for **sub-array 2 at channel 3** (marked in orange) with spatially averaged power density of **0.762 mW/cm^2** at 100 % duty cycle. The next section presents all power density distributions for this worst cases.

3.2.2.2 Worst-case power density distribution in the EpA evaluation plane

As described in the previous section, the worst-case, spatially-averaged power density over 1 cm^2 among the eighteen calculated worst cases is found for sub-array 2, channel 3.

This section present for this worst case the distribution of the following listed items:

- Upper bound single point power density distribution
- Single-point power density distribution
- One dimensional cut of the single-point power density distribution
- Spatially averaged power density over 1 cm^2

- **Upper-bound power density distribution**

Figure 8 presents the upper-bound, single-point power density at 100% duty cycle of sub-array 2, channel 3 which is the worst case among the two simulated worst cases of the three sub-arrays of the RFEM 3-A evaluation plane (Figure 5). The upper-bound, single-point power density shown in the figure below is normalized to a total conducted power of 13 dBm.

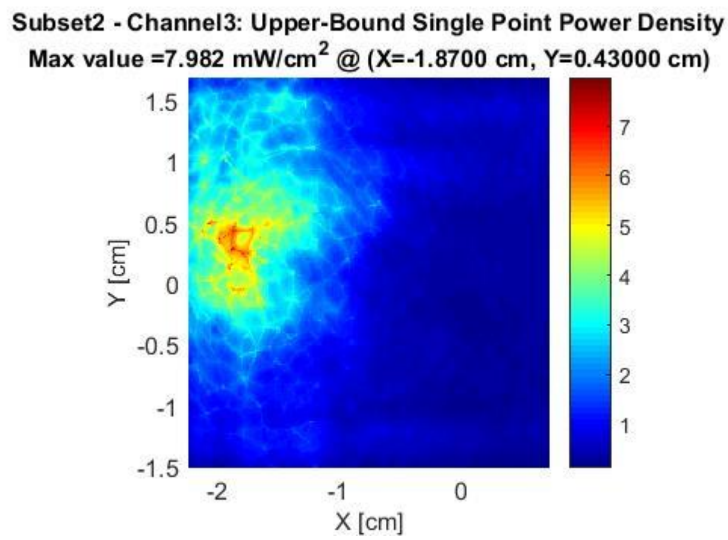


Figure 8 – Upper-bound, single-point power density in the EpA evaluation plane

Figure 9 shows the upper-bound, single-point power density distribution with the footprint of the RFEM 3-A antenna array and the EpA evaluation plane.

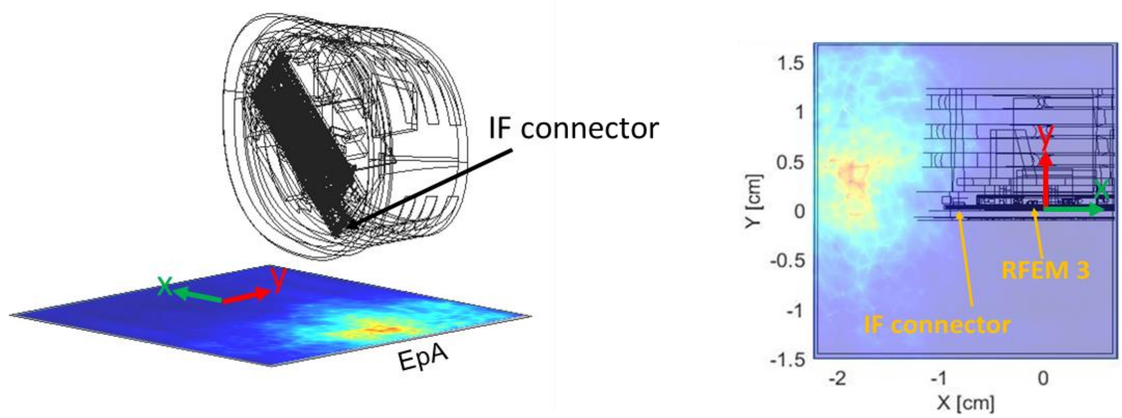


Figure 9 – Upper-bound, single-point power density in the EpA evaluation plane with footprint of the RFEM 3-A antenna and EpA plane

- **Single-point power density distribution – phase configuration [Ph1 #6]**

Figure 10 presents the single-point power density distribution at 100 % duty cycle of sub-array 2, channel 3 in the evaluation plane of RFEM 3-A using the worst-case antenna phases of sub-array 2, channel 3 (see ‘Ph1 #6’ in Table 4). The single-point power density shown in the figure below is normalized to a total conducted power of 13 dBm.

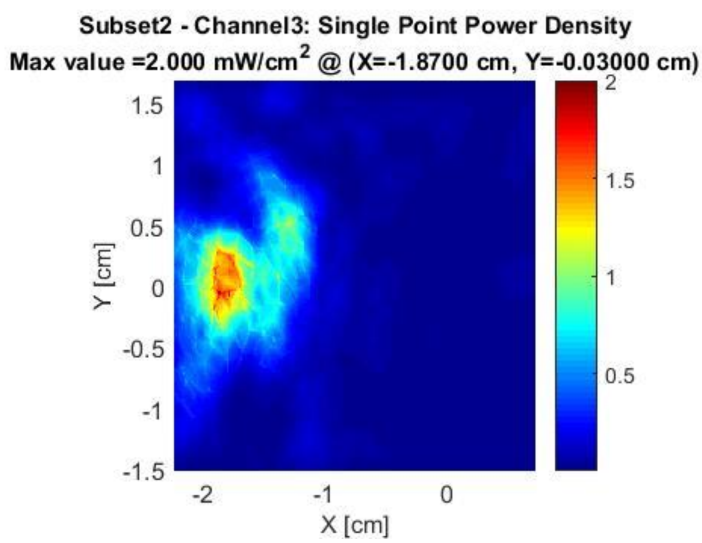


Figure 10 – Single-point power density in the EpA evaluation plane

Figure 11 shows the single-point power density distribution with the footprint of the RFEM 3-A antenna array and the EpA evaluation plane

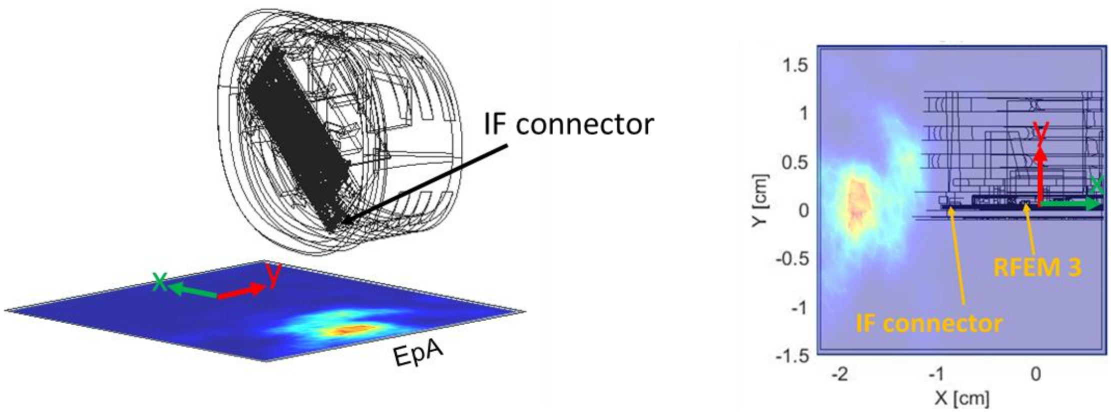


Figure 11 – Single-point power density in the EpA evaluation plane with footprint of the RFEM 3-A antenna and EpA plane

The footprint of RFEM 3-A antenna with the EpA evaluation plane for power density representation is shown in Figure 12

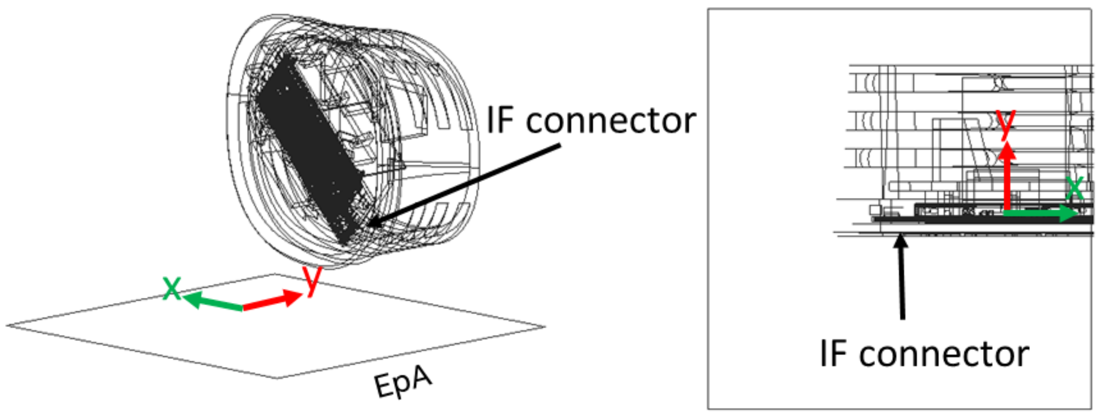


Figure 12 – Footprint of the EpA evaluation plane

- **One-dimensional cut of the single-point power density distribution**

In Figure 13 and Figure 14, we present the simulation results from the xyz components of single-point power density values with worst-case antenna phases of sub-array 2, channel 3 which is the worst case among the three sub-arrays in the EpA evaluation. These figures represent the 1-dimensional cut in the x-axis and y-axis that shows the behavior of the near field power density at the evaluation plane.

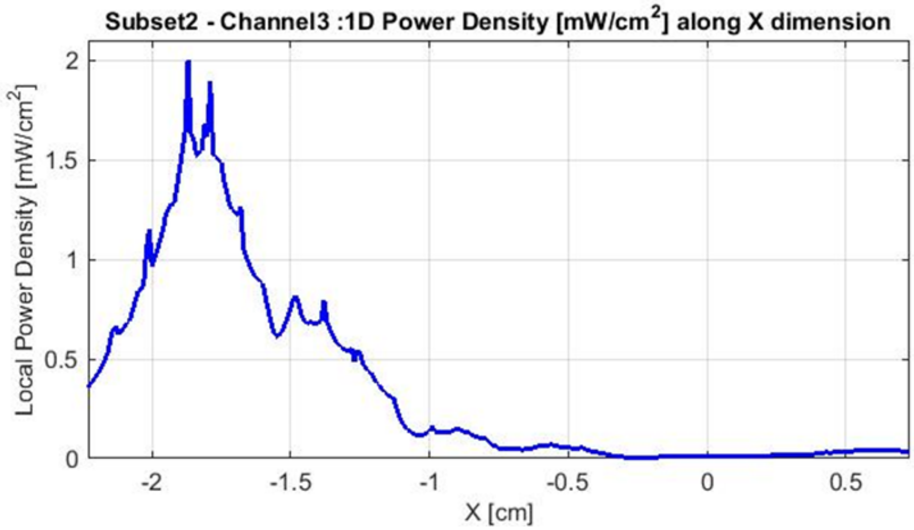


Figure 13 – 1-dimensional plots of the power density along x dimension

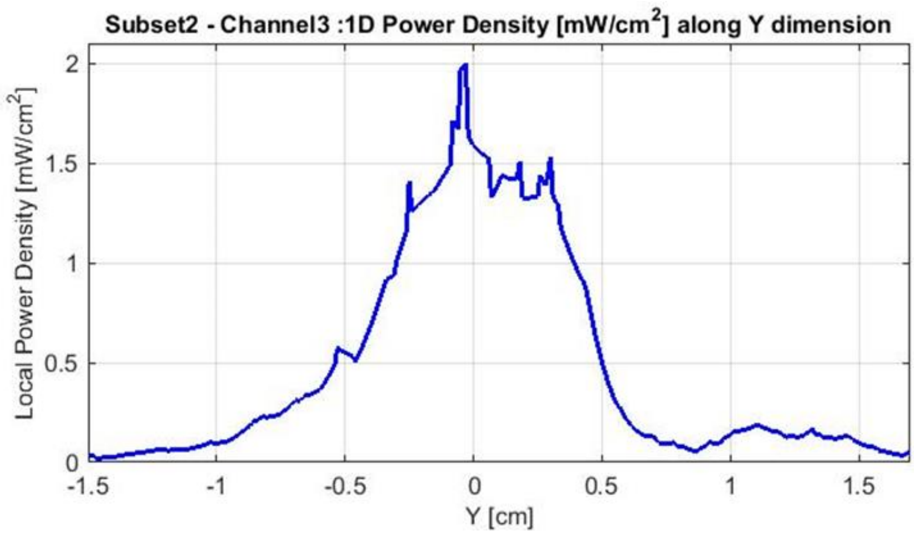


Figure 14 – 1-dimensional plots of the power density along y dimension

- **Distribution of spatially-averaged power density over 1 cm^2 - phase configuration [Ph1 #6]**

Figure 15 presents the spatially-averaged power over 1cm^2 at 100% duty cycle for the worst-case scenario of sub-array 2, channel 3. The 1cm^2 square location correspondent to the maximum of spatially averaged power density value is plotted in Figure 15 for the channel 3.

The spatially averaged power density shown in the figure below is normalized to a total conducted power of 13 dBm.

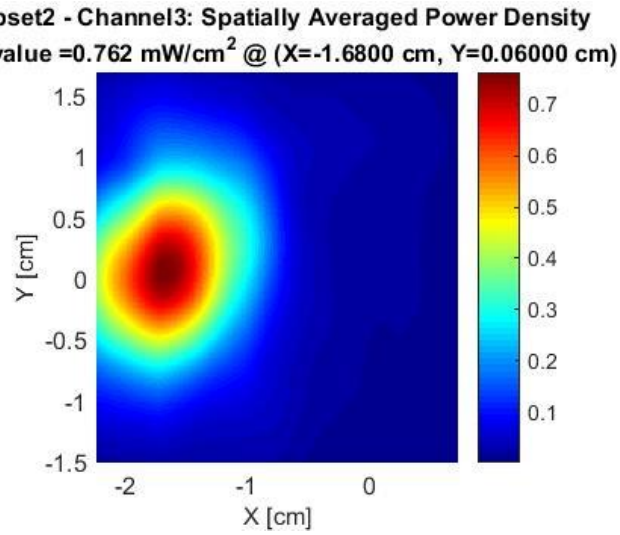


Figure 15 – Spatially-averaged power density over 1cm^2 in the EpA evaluation plane

The Table 7 shows the simulated worst-case power density, for sub-array 2 – channel 3, in the EpA evaluation plane.

Table 7 – Worst-case power density in the EpA evaluation plane

Highest power density	Sub-array 2 - Channel 3
Total conducted power	13 dBm
55% duty cycle	0.419 mW/cm^2
100% duty cycle	0.762 mW/cm^2

Notes for Table 7:

1. The worst-case power density is found for channel 3 on sub-array 2.
2. The Maximum power density (spatially averaged over worst 1cm^2) achieved in the EpA evaluation plane equals 0.762 mW/cm^2 over 100% duty cycle.
3. The Intel 13110NGW module is limited to transmit at a duty cycle of 55% over 10 seconds. Therefore the maximum spatially-integrated and time-averaged power density over 1cm^2 is 0.762x 0.55 = 0.419 mW/cm^2.

3.2.2.3 Worst-case power density value’s in the EpB evaluation plane

Table 8 and Table 9 summarizes, for all sub-arrays and channels, the simulation results in the **EpB evaluation plane** for the first and second worst cases respectively. In these tables, the following results are presented:

- The maximum values of the calculated upper bound single point power density values in the evaluation plane. The worst-case position is calculated using all the power density single-points issued from the upper-bound simulation results. We leverage the phase conditions for each antenna element that resulted in these worst-case conditions to evaluate final spatially averaged power density.
- The phases’ configuration, a.k.a. “beamforming codes” of each sub-array elements (marked in grey) for the first and second worst cases. The white cells with phase (“-“) correspond to the non-active elements of the sub-array. For instance, for sub-array 1, the active elements are 5, 6, 7, 8; 17 to 24, and the worst case occurs for each channel with the indicated phases. “Ph #” indicates the number of the attributed phase combination for each worst case.
- The maximum calculated single-point power density values using the first- and the second-worst-case sub-array antenna phases.
- The maximum calculated spatially-averaged power density over 1 cm^2. These values are calculated in the evaluation plane using the first and the second worst-case sub-array antenna phases.

Note: All simulation results are presented at 100% duty cycle and all power density values are shown in [mW/cm^2].

Table 8 – Simulation results for the first-worst case in the EpB evaluation plane

Row #		Sub-array	Sub-array 1			Sub-array 2			Sub-array 3		
		Channel	CH1	CH2	CH3	CH1	CH2	CH3	CH1	CH2	CH3
1	Phases configuration [degrees]	Ant. index	Ph2 #1	Ph2 #2	Ph2 #3	Ph2 #4	Ph2 #5	Ph2 #6	Ph2 #7	Ph2 #8	Ph2 #9
		1	-	-	-	-	-	-	270	270	180
		2	-	-	-	-	-	-	0	270	180
		3	-	-	-	-	-	-	180	180	0
		4	-	-	-	0	0	90	-	-	-
		5	270	0	270	0	180	270	-	-	-
		6	270	90	0	90	270	0	-	-	-
		7	270	0	270	-	-	-	-	-	-
		8	0	180	0	-	-	-	-	-	-
		9	-	-	-	0	180	270	-	-	-
		10	-	-	-	270	90	180	-	-	-
		11	-	-	-	180	0	90	-	-	-
		12	-	-	-	180	90	270	-	-	-
		13	-	-	-	180	270	0	180	90	0
		14	-	-	-	90	270	0	90	90	0
		15	-	-	-	0	90	180	0	270	180
		16	-	-	-	180	270	0	180	180	0
		17	0	270	270	-	-	-	-	-	-
		18	270	180	90	-	-	-	-	-	-
		19	90	90	0	-	-	-	-	-	-
		20	0	90	0	-	-	-	-	-	-
		21	270	90	90	-	-	-	180	180	90
		22	180	0	0	-	-	-	90	90	0
		23	0	270	180	-	-	-	270	270	180
		24	0	0	270	-	-	-	0	0	270
2	Upper Bound PD[4]		9.409	9.754	8.375	6.421	6.579	7.010	10.532	9.979	9.399
3	Single point PD[5]		2.068	2.237	1.702	1.814	1.697	1.754	4.494	3.407	3.302
4	Average PD[6]		0.708	0.631	0.453	0.654	0.540	0.628	**1.006**	0.997	0.945

[4] *Upper bound single point power density without phase difference between sub-array element's*

[5] *Single point power density with phases' configuration shown in row #1 for the corfresponding case (For example, the single power density of sub-array1, channel 1 is obtained using the phase configuration Ph2 #1)*

[6] Spatially averaged over 1 cm^2 of the single point power density with phases' configuration shown in row #1 for the corresponding case

Table 9 – Simulation results for the second-worst case in the EpB evaluation plane

Row #	Sub-array		Sub-array 1			Sub-array 2			Sub-array 3		
	Channel		CH1	CH2	CH3	CH1	CH2	CH3	CH1	CH2	CH3
1	Phases configuration [degrees]	Ant. index	Ph2 #10	Ph2 #11	Ph2 #12	Ph2 #13	Ph2 #14	Ph2 #15	Ph2 #16	Ph2 #17	Ph2 #18
		1	-	-	-	-	-	-	90	90	90
		2	-	-	-	-	-	-	90	90	90
		3	-	-	-	-	-	-	270	270	270
		4	-	-	-	270	0	0	-	-	-
		5	180	270	180	90	180	180	-	-	-
		6	270	0	270	180	270	270	-	-	-
		7	180	270	180	-	-	-	-	-	-
		8	0	90	0	-	-	-	-	-	-
		9	-	-	-	90	180	270	-	-	-
		10	-	-	-	0	90	180	-	-	-
		11	-	-	-	270	0	90	-	-	-
		12	-	-	-	270	90	270	-	-	-
		13	-	-	-	180	270	0	0	0	0
		14	-	-	-	180	180	0	270	0	0
		15	-	-	-	0	90	180	180	180	180
		16	-	-	-	270	270	0	0	0	0
		17	180	180	270		-	-	-	-	-
		18	0	90	90		-	-	-	-	-
		19	0	0	0	-	-	-	-	-	-
		20	0	0	270	-	-	-	-	-	-
		21	270	270	180	-	-	-	270	270	270
		22	180	180	90	-	-	-	180	180	180
		23	0	90	270	-	-	-	0	0	90
		24	0	0	0	-	-	-	0	0	0
2	Upper Bound PD[4]		9.409	9.754	8.375	6.421	6.579	7.010	10.532	9.979	9.399
3	Single point PD[5]		2.254	1.830	1.519	1.693	1.688	1.730	3.189	2.798	2.034
4	Average PD[6]		0.700	0.556	0.420	0.544	0.533	0.584	0.935	0.706	0.686

[4] *Upper bound single point power density without phase difference between sub-array element's*
[5] *Single point power density with phases' configuration shown in row #1 for the corfresponding case (For example, the single power density of sub-array1, channel 1 is obtained using the phase configuration Ph2 #10)*
[6] Spatially averaged over 1 cm^2 of the single point power density with phases' configuration shown in row #1 for the corresponding case

Table 10 presents, for all channels and all sub-arrays, the spatially-averaged power density over 1 cm^2 in the EpB evaluation plane using the first and the second worst-case sub-array antenna phases presented in tables above.

Table 10 – Maximum spatially-averaged power density over 1cm^2 [mW/cm^2]

	First worst case			Second worst case		
	Channel 1	**Channel 2**	**Channel 3**	**Channel 1**	**Channel 2**	**Channel 3**
Sub-array 1	0.708	0.631	0.453	0.700	0.556	0.420
Sub-array 2	0.654	0.540	0.628	0.544	0.533	0.584
Sub-array 3	**1.006**	**0.997**	**0.945**	**0.935**	0.706	0.686

Table 10 shows that the very worst case is found for **sub-array 3 at channel 1** (marked in orange) with a spatially-averaged power density of **1.006 mW/cm^2** at 100% duty cycle. The next section presents all power density distributions for this worst cases.

3.2.2.4 Worst-case power density distribution in EpB evaluation plane

As described in the previous section, the worst-case, spatially-averaged power density over 1 cm^2 among the eighteen calculated worst cases is found for sub-array 3, channel 1.

This section present for this worst case the distribution of the following listed items:

- Upper-bound, single-point power density distribution
- Single-point power density distribution
- One-dimensional cut of the single-point power density distribution
- Spatially-averaged power density over 1 cm^2

- **Upper-bound power density distribution**

Figure 16 presents upper-bound, single-point power density at 100 % duty cycle of sub-array 3, channel 1, which is the worst case among the two simulated worst cases of the three sub-arrays in the EpB evaluation plane (Figure 5). The upper-bound, single-point power density shown in the figure below is normalized to a total conducted power of 13 dBm.

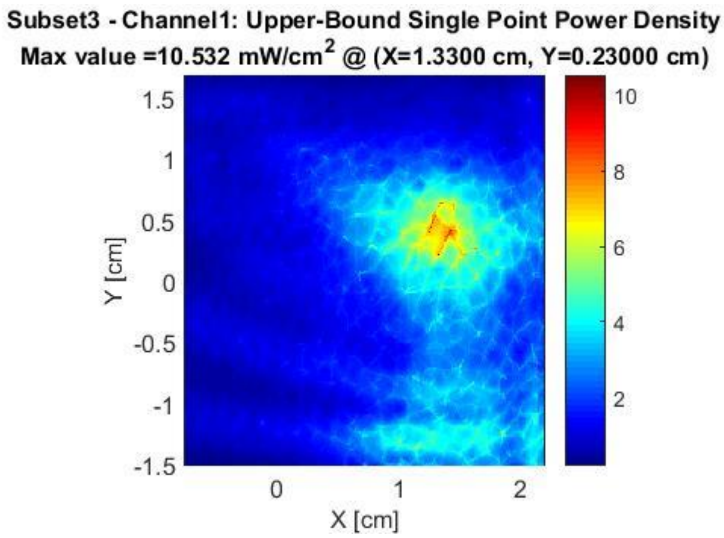


Figure 16 – Upper-bound, single-point power density in the EpB evaluation plane

Figure 17 shows the upper-bound, single-point power density distribution with the footprint of the RFEM 3-B antenna array and the EpB evaluation plane.

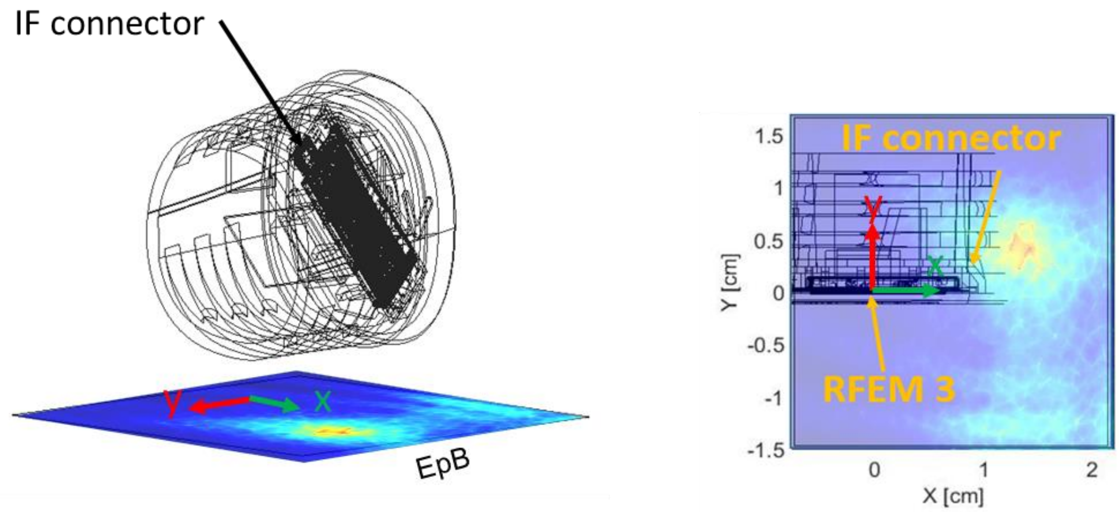


Figure 17 – Upper-bound, single-point power density in the EpB evaluation plane with footprint of the RFEM 3-B antenna and EpB plane

- **Single point power density distribution - phase configuration [Ph2 #7]**

Figure 18 presents the single-point power density distribution at 100% duty cycle of sub-array 3, channel 1 in the EpB evaluation plane of RFEM 3-B using the worst-case antenna phases of sub-array 3, channel 1 (see 'Ph2 #7' in Table 8). The single-point power density shown in the figure below is normalized to a total conducted power of 13 dBm.

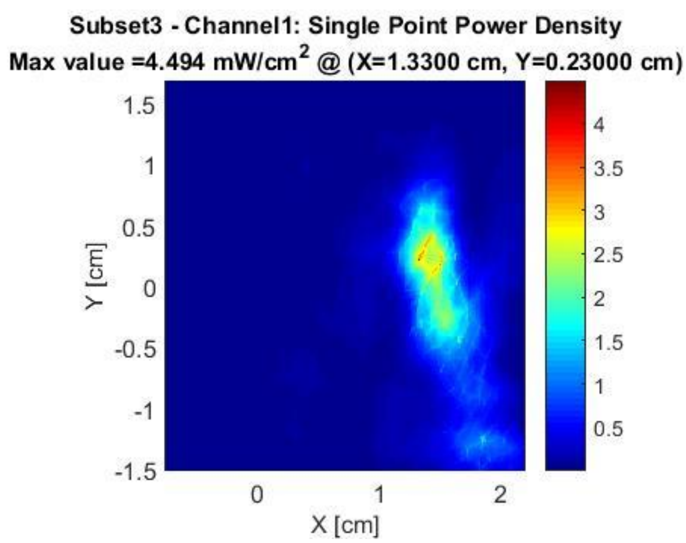


Figure 18 – Single-point power density in the EpB evaluation plane

Figure 19 shows the single-point power density distribution with the footprint of the RFEM 3-B antenna array and the EpB evaluation plane

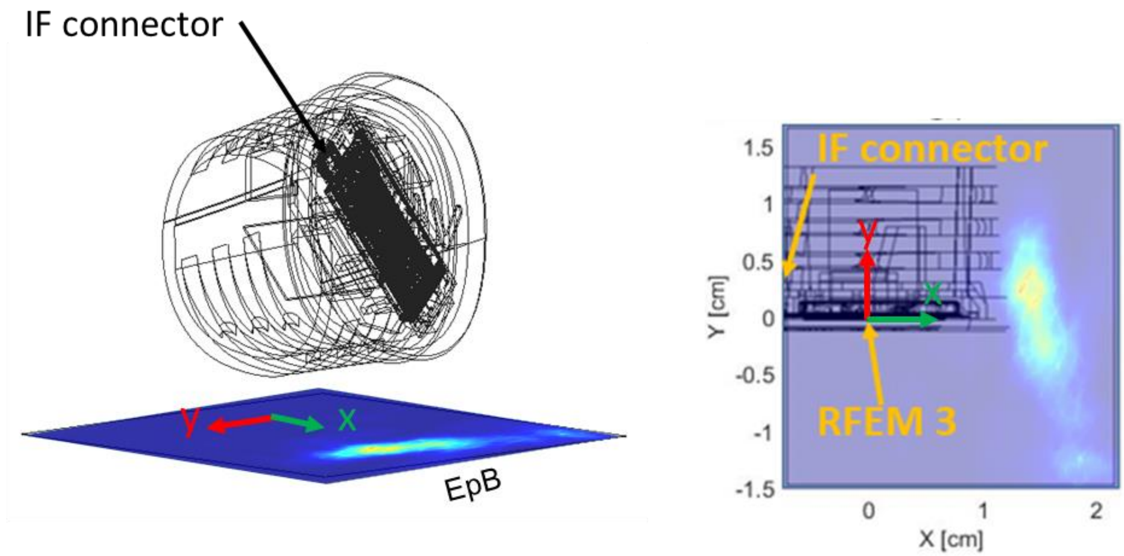


Figure 19 – Single-point power density in the EpB evaluation plane with footprint of the RFEM 3-B antenna and EpB plane

The footprint of the RFEM 3-B antenna with the EpB evaluation plane for power density representation is shown in Figure 20.

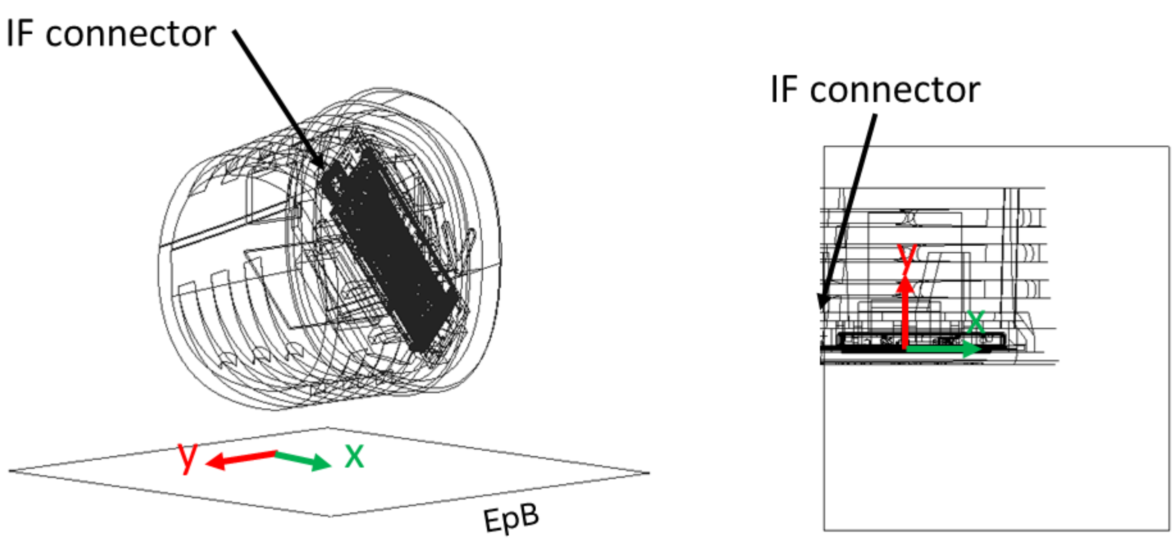


Figure 20 – Footprint of the EpB evaluation plane

- **One dimensional cut of the single-point power density distribution**

In Figure 21 and Figure 22, we present the simulation results from the xyz components of single-point power density values with worst-case antenna phases of sub-array 3, channel 1, which is the worst case among the three sub-arrays in the EpB evaluation plane. These figures represent a 1-dimensional cut in the x-axis and y-axis that shows the behavior of the near field power density at the evaluation plane.

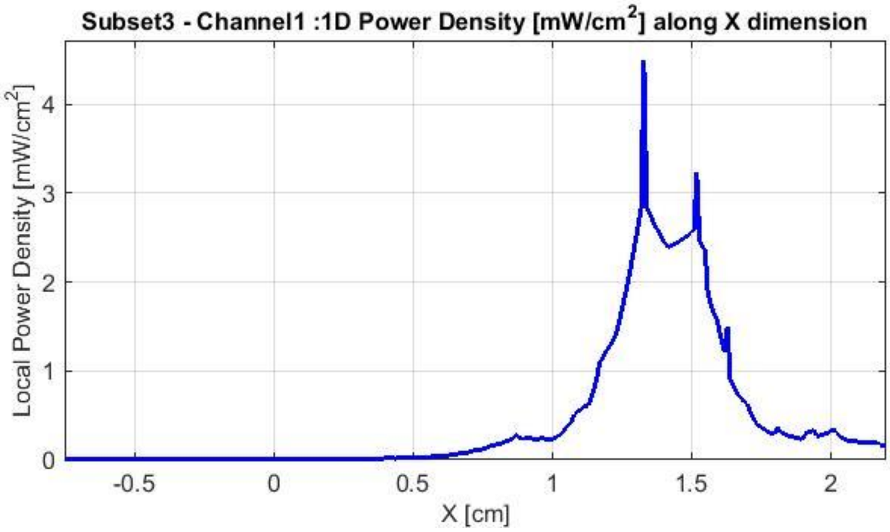


Figure 21 – 1-dimensional plots of the power density along x dimension

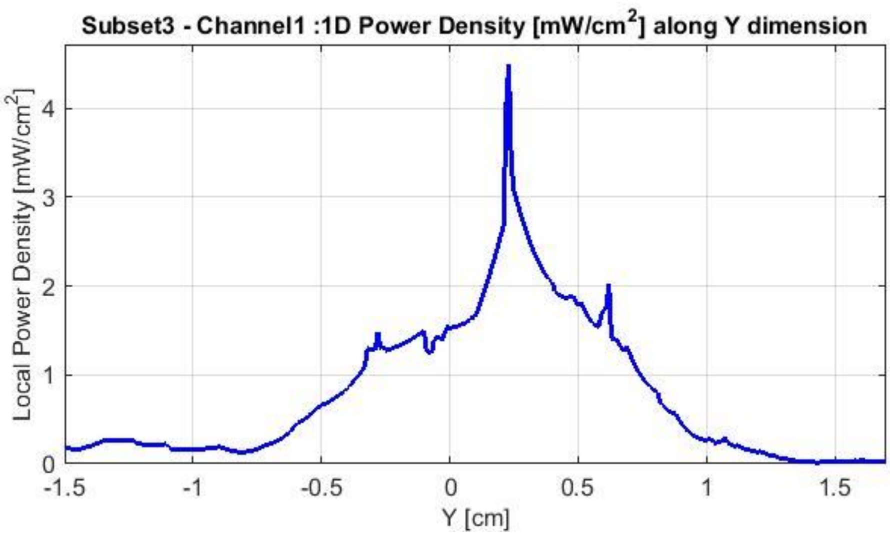


Figure 22 – 1-dimensional plots of the power density along y dimension

- **Distribution of spatially-averaged power density over 1 cm^2 - phase configuration [Ph2 #7]**

Figure 23 presents the spatially-averaged power over 1cm^2 at 100% duty cycle for the worst-case scenario of sub-array 3, channel 1. The 1cm^2 square location correspondent to the maximum of spatially-averaged power density value is plotted in Figure 23 for the channel 1.

The spatially averaged power density shown in the figure below is normalized to a total conducted power of 13 dBm.

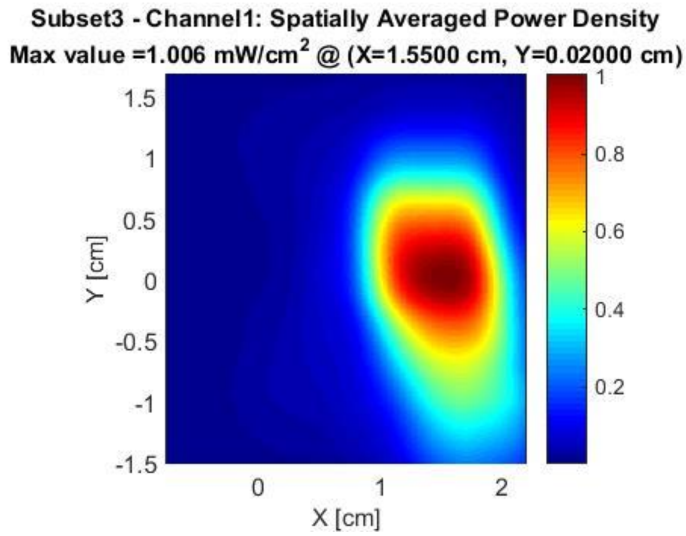


Figure 23 – Spatially- averaged power density over 1cm^2 in the EpB evaluation plane

Table 11 shows the simulated worst-case power density, for sub-array 3 – channel 1, in the EpB evaluation plane.

Table 11 – Worst-case power density in the EpB evaluation plane

Highest power density	Sub-array 3 - Channel 1
Total conducted power	13 dBm
55% duty cycle	0.553 mW/cm^2
100% duty cycle	1.006 mW/cm^2

Notes for Table 11:

1. The worst-case power density is found for channel 1 on sub-array 3.
2. The maximum power density (spatially averaged over worst 1cm^2) achieved in the EpB evaluation plane equals to 1.006 mW/cm^2 over 100% duty cycle.
3. The Intel 13110NGW module is limited to transmit at a duty cycle of 55% over 10 seconds. Therefore the maximum spatially-integrated and time-averaged power density over 1cm^2 is 1.006x 0.55 = 0.553 mW/cm^2.

3.2.2.5 Field and power density distributions for the six highest worst cases in the EpA and EpB evaluation planes

This section shows the E-field, H-field, local power density, and spatially-averaged power density distribution at the corresponding RFEM 3 evaluation plane of the six highest worst cases' spatially-averaged power density, calculated for both EpA and EpB evaluation planes and marked in bold in Table 6 and Table 10.

Table 12 lists the identified highest six spatially-averaged power density worst cases.

Table 12 – Highest six worst-cases of spatially-averaged power density

	Evaluation plane	Sub-array	Channel	Worst case	Simulated AVG. PD	Phase config.	Plot
Worst Case #1	EpB	3	1	1	1.006	Ph2 #7	Plot #1
Worst Case #2	EpB	3	2	1	0.997	Ph2 #8	Plot #2
Worst Case #3	EpB	3	3	1	0.945	Ph2 #9	Plot #3
Worst Case #4	EpB	3	1	2	0.935	Ph2 #16	Plot #4
Worst Case #5	EpA	2	3	1	0.762	Ph1 #6	Plot #5
Worst Case #6	EpA	2	2	1	0.732	Ph1 #5	Plot #6

The distribution plot of the six highest worst cases listed in Table 12 are shown in the Figures below. Note that the color scale for each plot is presented according to the maximum value obtained for each case.

Plot #1: Worst Case 1 – Sub-array 3 – Channel 1

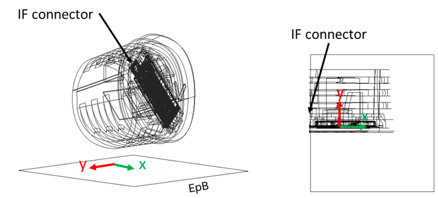
<table>
<tr>
<td>

Evaluation Plane: EpB

Frequency: 58320 MHz

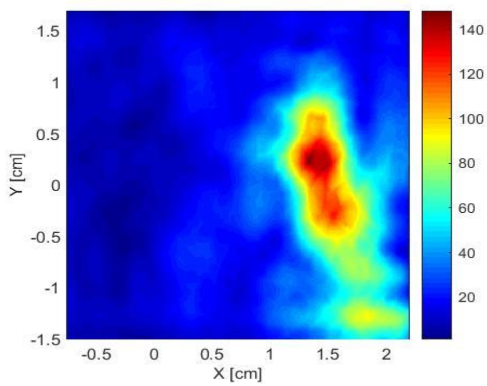
Distance: 0mm

</td>
<td>



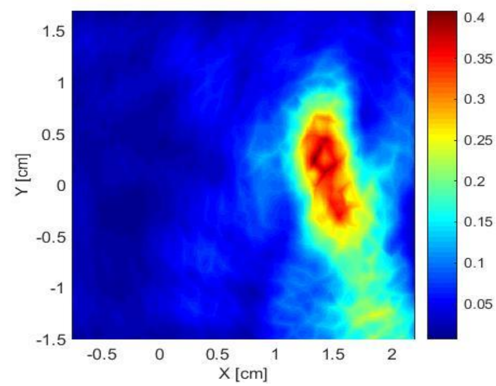
</td>
</tr>
<tr>
<td>

Simulated E-field
Maximum value = 148.490 V/m - Peak



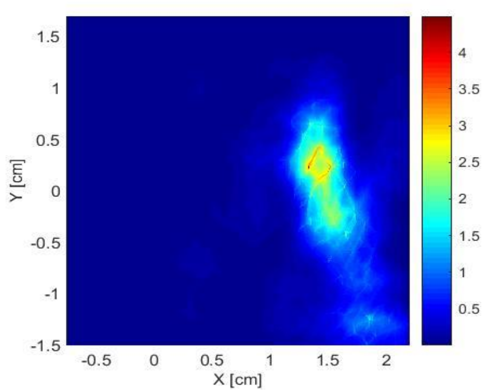
</td>
<td>

Simulated H-field
Maximum value = 0.408 A/m - Peak



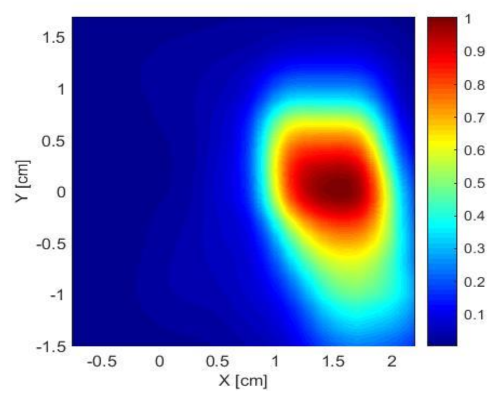
</td>
</tr>
<tr>
<td>

Simulated localized free space power density
Maximum value = 4.494 mW/cm²



</td>
<td>

Simulated spatially-averaged power density
Maximum value = 1.006 mW/cm²



</td>
</tr>
</table>

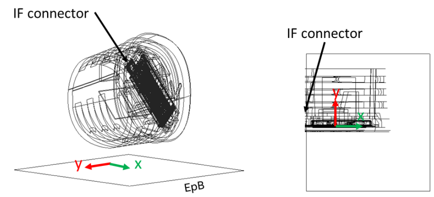
Figure 24 – Plot #1: EpB – Worst Case 1 – Sub-array 3 – Channel 1

Plot #2: Worst Case 1 – Sub-array 3 – Channel 2

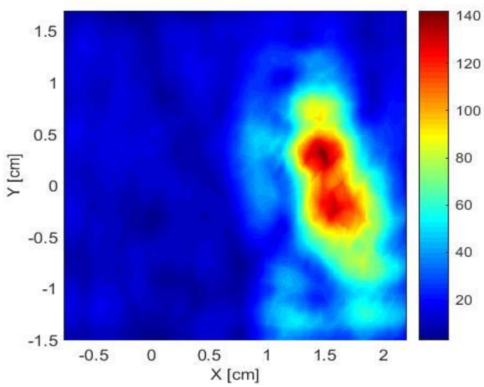
Evaluation Plane: EpB

Frequency: 60480 MHz

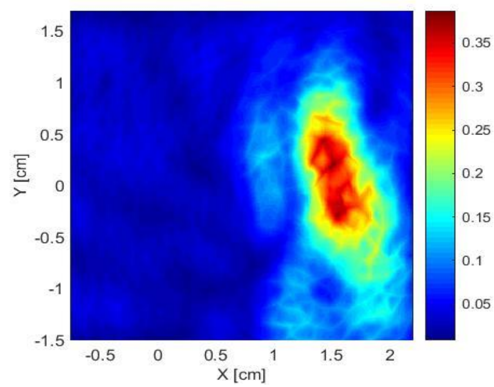
Distance: 0mm



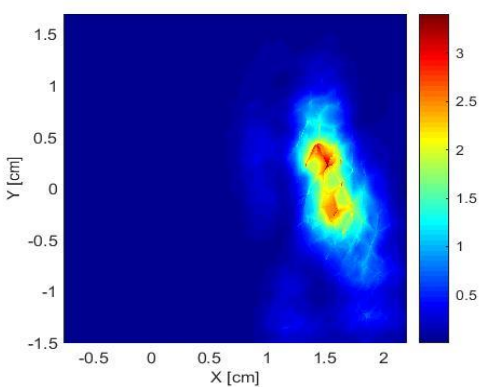
Simulated E-field
Maximum value = 142.226 V/m - Peak



Simulated H-field
Maximum value = 0.387 A/m - Peak



Simulated localized free space power density
Maximum value = 3.407 mW/cm²



Simulated spatially-averaged power density
Maximum value = 0.997 mW/cm²

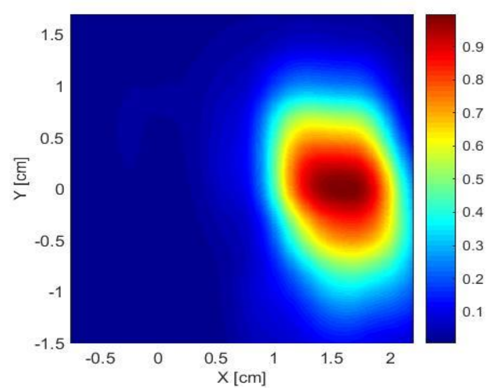
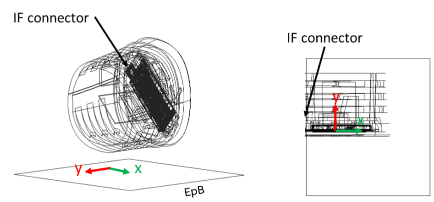
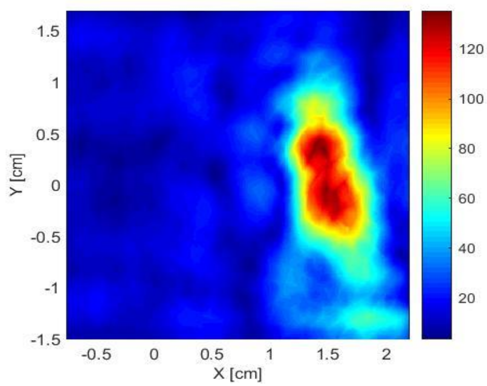


Figure 25 – Plot #2: EpB – Worst Case 1 – Sub-array 3 – Channel 2

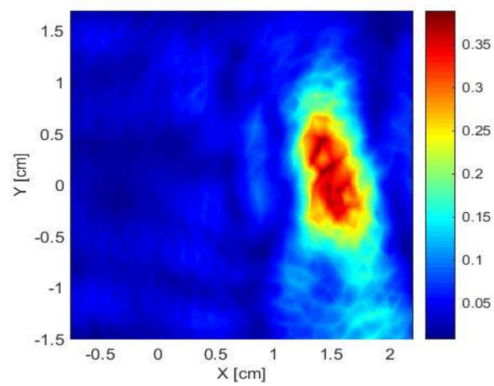
Plot #3: Worst Case 1 – Sub-array 3 – Channel 3

Evaluation Plane: EpB **Frequency: 62640 MHz** **Distance: 0mm**	

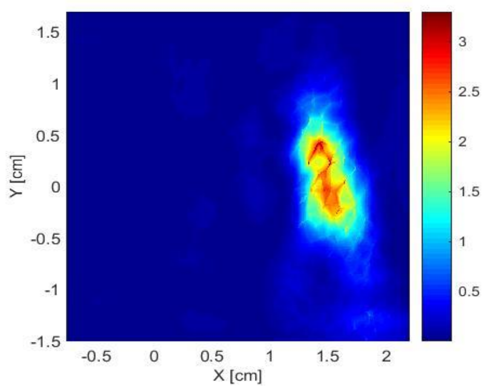
Simulated E-field
Maximum value = 135.421 V/m - Peak



Simulated H-field
Maximum value = 0.389 A/m - Peak



Simulated localized free space power density
Maximum value = 3.302 mW/cm^2



Simulated spatially-averaged power density
Maximum value = 0.945 mW/cm^2

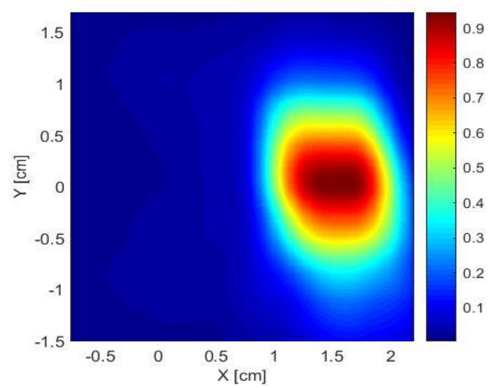


Figure 26 – Plot #3: EpB – Worst Case 1 – Sub-array 3 – Channel 3

Plot #4: Worst Case 2 – Sub-array 3 – Channel 1

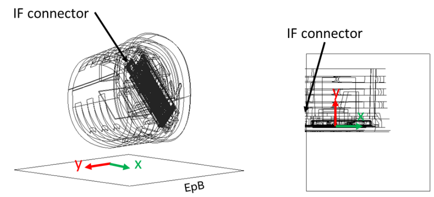
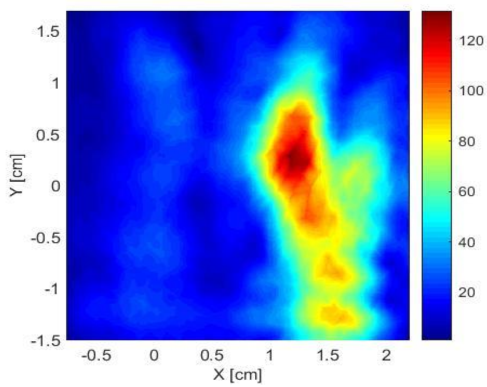
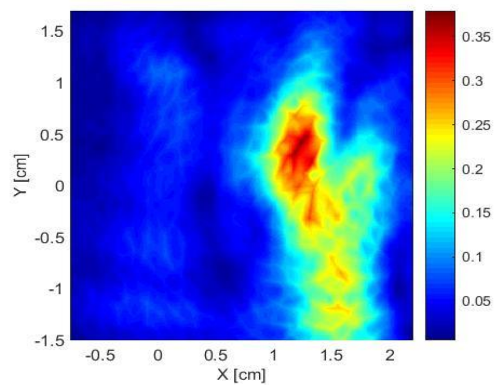
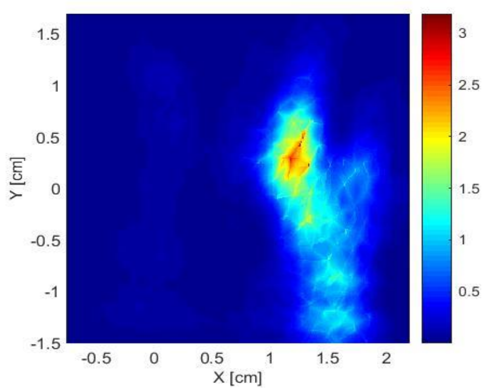
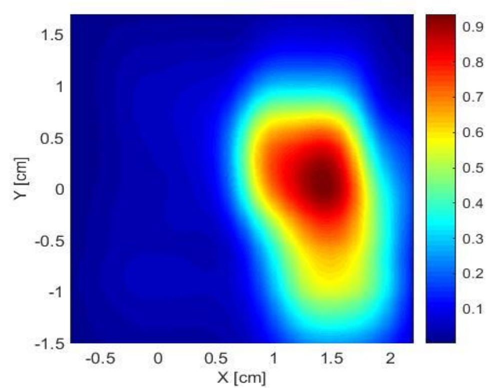
Evaluation Plane: EpB **Frequency: 58320 MHz** **Distance: 0mm**	
Simulated E-field Maximum value = 131.648 V/m - Peak 	**Simulated H-field** Maximum value = 0.379 A/m - Peak 
Simulated localized free space power density Maximum value = 3.189 mW/cm^2 	**Simulated spatially-averaged power density** Maximum value = 0.935 mW/cm^2 

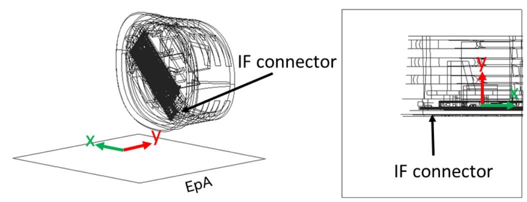
Figure 27 – Plot #4: EpB – Worst Case 2 – Sub-array 3 – Channel 1

Plot #5: Worst Case 1 – Sub-array 2 – Channel 3

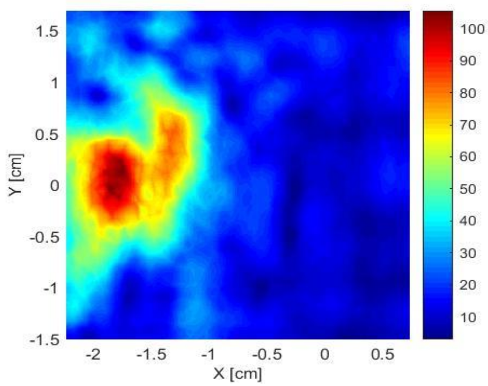
Evaluation Plane: EpA

Frequency: 62640 MHz

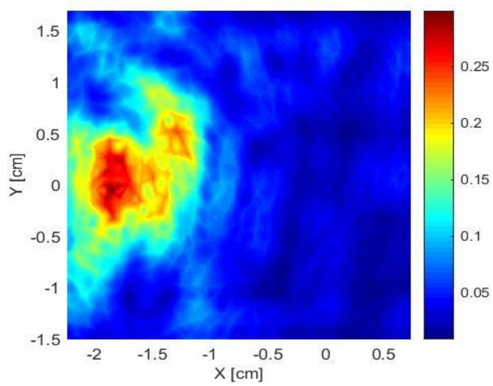
Distance: 0mm



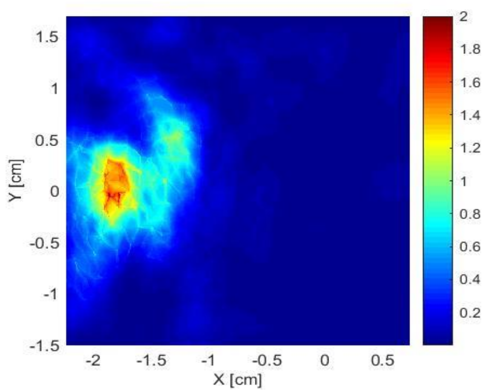
Simulated E-field
Maximum value = 105.568 V/m - Peak



Simulated H-field
Maximum value = 0.300 A/m - Peak



Simulated localized free space power density
Maximum value = 2.000 mW/cm²



Simulated spatially-averaged power density
Maximum value = 0.762 mW/cm²

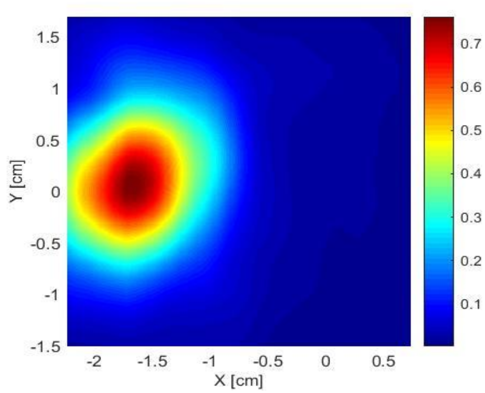


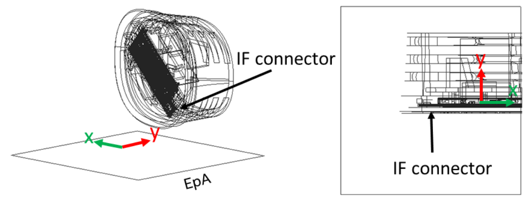
Figure 28 – Plot #5: EpA – Worst Case 1 – Sub-array 2 – Channel 3

Plot #6: Worst Case 1 – Sub-array 2 – Channel 2

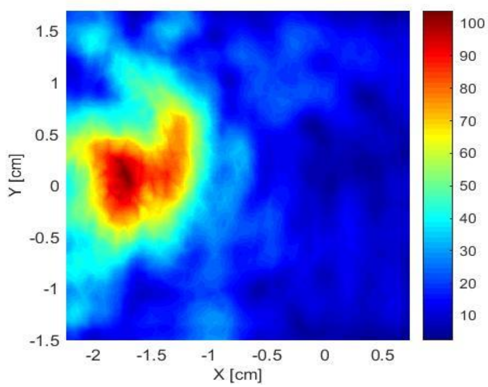
Evaluation Plane: EpA

Frequency: 60480 MHz

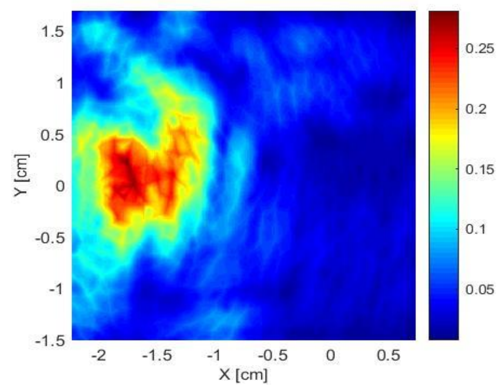
Distance: 0mm



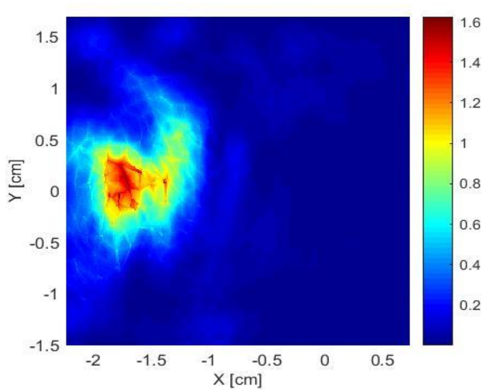
Simulated E-field
Maximum value = 103.897 V/m - Peak



Simulated H-field
Maximum value = 0.282 A/m - Peak



Simulated localized free space power density
Maximum value = 1.626 mW/cm^2



Simulated spatially-averaged power density
Maximum value = 0.732 mW/cm^2

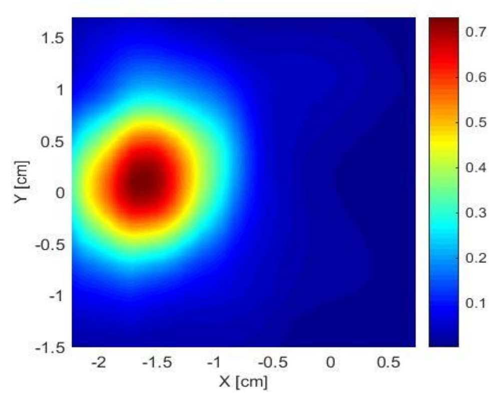


Figure 29 – Plot #6: EpA – Worst Case 1 – Sub-array 2 – Channel 2

3.2.3 Simulation results in the EpA1 and EpB1 evaluation planes

3.2.3.1 Worst-cases power density value's in the EpA1 evaluation plane

Table 13 and Table 14 summarizes, for all sub-arrays and channels, the simulation results in the **EpA1 evaluation plane** for the first and second worst cases respectively. In these tables, the following results are presented:

- The maximum values of the calculated upper bound single point power density values in the evaluation plane. The worst-case position is calculated using all the power density single-points issued from the upper-bound simulation results. We leverage the phase conditions for each antenna element that resulted in these worst-case conditions to evaluate final spatially averaged power density.
- The phases' configuration, a.k.a. "beamforming codes" of each sub-array elements (marked in grey) for the first and second worst cases. The white cells with phase ("-") correspond to the non-active elements of the sub-array. For instance, for sub-array 1, the active elements are 5, 6, 7, 8; 17 to 24, and the worst case occurs for each channel with the indicated phases. "Ph #" indicates the number of the attributed phase combination for each worst case.
- The maximum calculated single-point power density values using the first- and the second-worst-case sub-array antenna phases.
- The maximum calculated spatially-averaged power density over 1 cm^2. These values are calculated in the evaluation plane using the first and the second worst-case sub-array antenna phases.

Note: All simulation results are presented at 100% duty cycle and all power density values are shown in [mW/cm^2].

Table 13 – Simulation results for the first-worst case in the EpA1 evaluation plane

Row #	Sub-array		Sub-array 1			Sub-array 2			Sub-array 3		
	Channel		CH1	CH2	CH3	CH1	CH2	CH3	CH1	CH2	CH3
1	Phases configuration [degrees]	Ant. index	Ph3 #1	Ph3 #2	Ph3 #3	Ph3 #4	Ph3 #5	Ph3 #6	Ph3 #7	Ph3 #8	Ph3 #9
		1	-	-	-	-	-	-	180	90	180
		2	-	-	-	-	-	-	180	90	180
		3	-	-	-	-	-	-	180	90	0
		4	-	-	-	180	180	0	-	-	-
		5	180	90	90	90	90	180	-	-	-
		6	180	0	90	180	180	270	-	-	-
		7	90	180	180	-	-	-	-	-	-
		8	180	0	270	-	-	-	-	-	-
		9	-	-	-	0	0	0	-	-	-
		10	-	-	-	270	270	270	-	-	-
		11	-	-	-	180	180	90	-	-	-
		12	-	-	-	180	180	270	-	-	-
		13	-	-	-	180	270	270	0	270	90
		14	-	-	-	90	0	270	0	270	90
		15	-	-	-	0	90	90	180	90	270
		16	-	-	-	180	270	0	90	0	90
		17	270	90	0	-	-	-	-	-	-
		18	90	270	90	-	-	-	-	-	-
		19	270	90	180	-	-	-	-	-	-
		20	180	0	0	-	-	-	-	-	-
		21	180	0	0	-	-	-	0	270	0
		22	0	180	180	-	-	-	0	0	270
		23	180	0	0	-	-	-	0	0	180
		24	180	0	270	-	-	-	0	0	180
2	Upper Bound PD[4]		12.617	11.128	8.166	5.027	4.795	4.725	9.301	8.408	7.194
3	Single point PD[5]		2.354	2.459	1.712	1.213	1.353	1.255	2.699	2.540	2.108
4	Average PD[6]		0.999	0.804	0.619	0.517	0.501	0.418	0.767	0.688	0.697

4 *Upper bound single point power density without phase difference between sub-array element's*

5 *Single point power density with phases' configuration shown in row #1 for the corfresponding case (For example, the single power density of sub-array1, channel 1 is obtained using the phase configuration Ph3 #1)*

6 Spatially averaged over 1 cm^2 of the single point power density with phases' configuration shown in row #1 for the corresponding case

Table 14 – Simulation results for the second-worst case in the EpA1 plane

Row #	Sub-array		Sub-array 1			Sub-array 2			Sub-array 3		
	Channel		CH1	CH2	CH3	CH1	CH2	CH3	CH1	CH2	CH3
1	Phases configuration [degrees]	Ant. index	Ph3 #10	Ph3 #11	Ph3 #12	Ph3 #13	Ph3 #14	Ph3 #15	Ph3 #16	Ph3 #17	Ph3 #18
		1	-	-	-	-	-	-	180	90	180
		2	-	-	-	-	-	-	180	90	180
		3	-	-	-	-	-	-	90	90	0
		4	-	-	-	90	270	0	-	-	-
		5	180	90	90	0	90	180	-	-	-
		6	180	90	0	90	270	270	-	-	-
		7	0	270	180	-	-	-	-	-	-
		8	180	0	270	-	-	-	-	-	-
		9	-	-	-	0	0	0	-	-	-
		10	-	-	-	180	270	270	-	-	-
		11	-	-	-	90	180	90	-	-	-
		12	-	-	-	90	270	270	-	-	-
		13	-	-	-	90	270	270	0	270	90
		14	-	-	-	0	0	180	0	270	90
		15	-	-	-	270	90	90	180	90	270
		16	-	-	-	90	270	270	0	0	90
		17	180	90	270		-	-	-	-	-
		18	0	180	0		-	-	-	-	-
		19	180	90	180	-	-	-	-	-	-
		20	90	0	0	-	-	-	-	-	-
		21	180	90	270	-	-	-	270	270	0
		22	0	270	90	-	-	-	0	0	180
		23	180	90	270	-	-	-	0	90	90
		24	180	90	180	-	-	-	0	0	90
2	Upper Bound PD[4]		12.617	11.128	8.166	5.027	4.795	4.725	9.301	8.408	7.194
3	Single point PD[5]		2.182	2.146	1.360	1.096	1.098	0.958	2.601	2.480	2.143
4	Average PD[6]		0.847	0.708	0.577	0.466	0.453	0.352	0.671	0.684	0.536

4 Upper bound single point power density without phase difference between sub-array element's

5 Single point power density with phases' configuration shown in row #1 for the corfresponding case (For example, the single power density of sub-array1, channel 1 is obtained using the phase configuration Ph3 #10)

6 Spatially averaged over 1 cm^2 of the single point power density with phases' configuration shown in row #1 for the corresponding case

Table 15 presents, for all channels and all sub-arrays, the spatially-averaged power density over 1 cm^2 in the EpA1 evaluation plane using the first and the second worst-case sub-array antenna phases presented in tables above.

Table 15 – Maximum spatially averaged power density over 1cm^2 [mW/cm^2]

	First worst case			Second worst case		
	Channel 1	**Channel 2**	**Channel 3**	**Channel 1**	**Channel 2**	**Channel 3**
Sub-array 1	**0.999**	0.804	0.619	0.847	0.708	0.577
Sub-array 2	0.517	0.501	0.418	0.466	0.453	0.352
Sub-array 3	0.767	0.688	0.697	0.671	0.684	0.536

Table 15 shows that the worst case in **EpA1 evaluation plane** is found for **sub-array 1 at channel 1** (marked in orange) with spatially averaged power density of **0.999 mW/cm^2** at 100 % duty cycle. The next section presents all power density distributions for this worst cases.

3.2.3.2 Worst-case power density distribution in the EpA1 evaluation plane

As described in the previous section, the worst-case, spatially-averaged power density over 1 cm^2 among the eighteen calculated worst cases is found for sub-array 1, channel 1.

This section present for this worst case the distribution of the following listed items:

- Upper bound single point power density distribution
- Single-point power density distribution
- One dimensional cut of the single-point power density distribution
- Spatially averaged power density over 1 cm^2

- **Upper-bound power density distribution**

Figure 30 presents thed upper-bound, single-point power density at 100% duty cycle of sub-array 1, channel 1 which is the worst case among the two simulated worst cases of the three sub-arrays of the EpA1 evaluation plane (Figure 5). The upper-bound, single-point power density shown in the figure below is normalized to a total conducted power of 13 dBm.

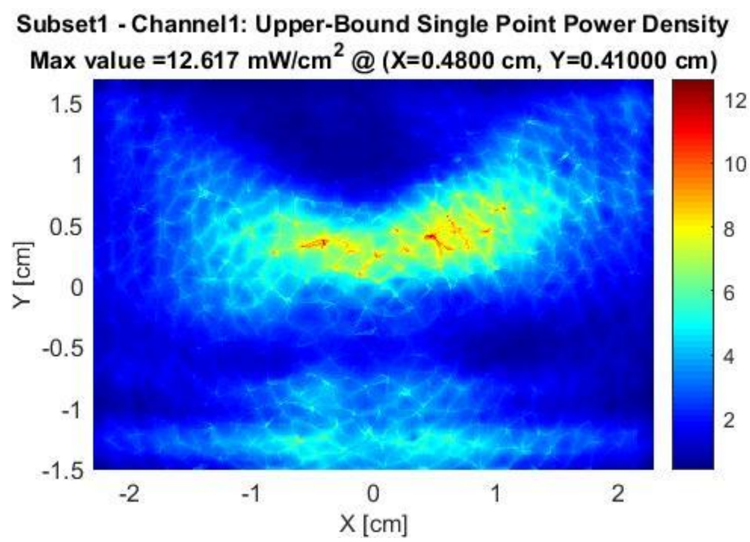


Figure 30 – Upper-bound, single-point power density in the EpA1 evaluation plane

Figure 31 shows the upper-bound, single-point power density distribution with the footprint of the RFEM 3-A antenna array and the EpA1 evaluation plane

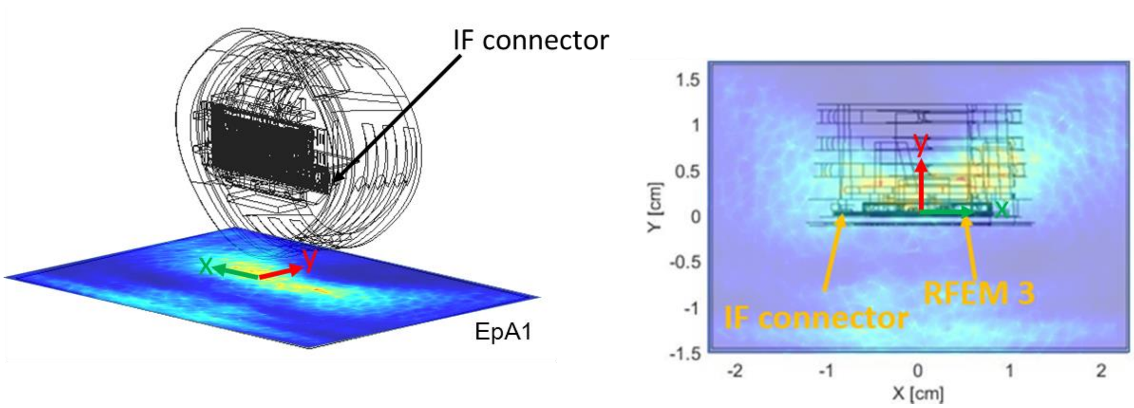


Figure 31 – Upper-bound, single-point power density in the EpA1 evaluation plane with footprint of the RFEM 3-A antenna and EpA1 plane

- **Single-point power density distribution - phase configuration [Ph3 #1]**

Figure 32 presents the single-point power density distribution at 100% duty cycle of sub-array 1, channel 1 in the EpA1 evaluation plane using the worst-case antenna phases of sub-array 1, channel 1 (see 'Ph3 #1' in Table 13). The single-point power density shown in the figure below is normalized to a total conducted power of 13 dBm.

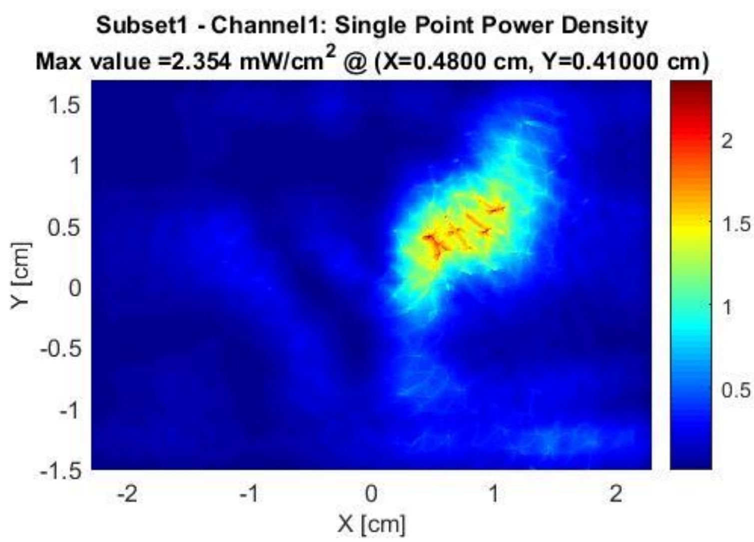


Figure 32 – Single-point power density in the EpA1 evaluation plane

Figure 33 shows the single-point power density distribution with the footprint of the RFEM 3-A antenna array and the EpA1 evaluation plane

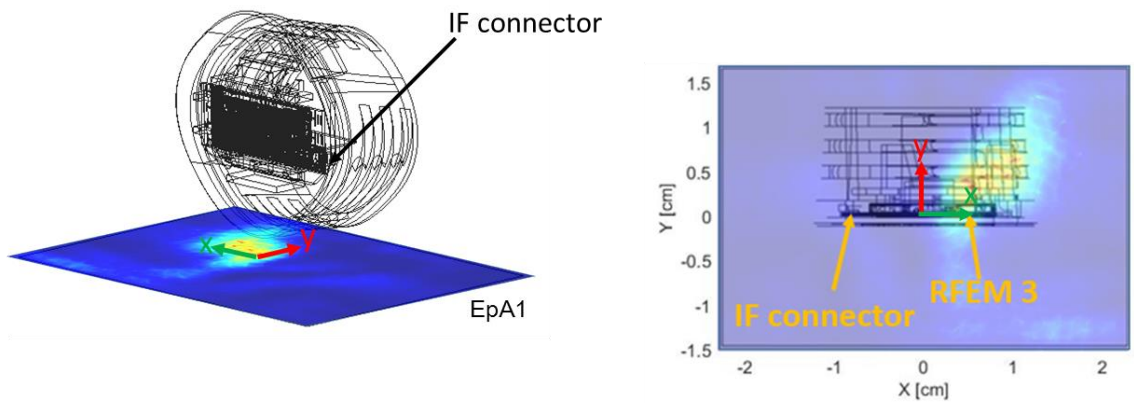


Figure 33 – Single-point power density in the EpA1 evaluation plane with footprint of the RFEM 3-A antenna and EpA1 plane

The footprint of the RFEM 3-A antenna with the EpA1 evaluation plane for power density representation is shown in Figure 34.

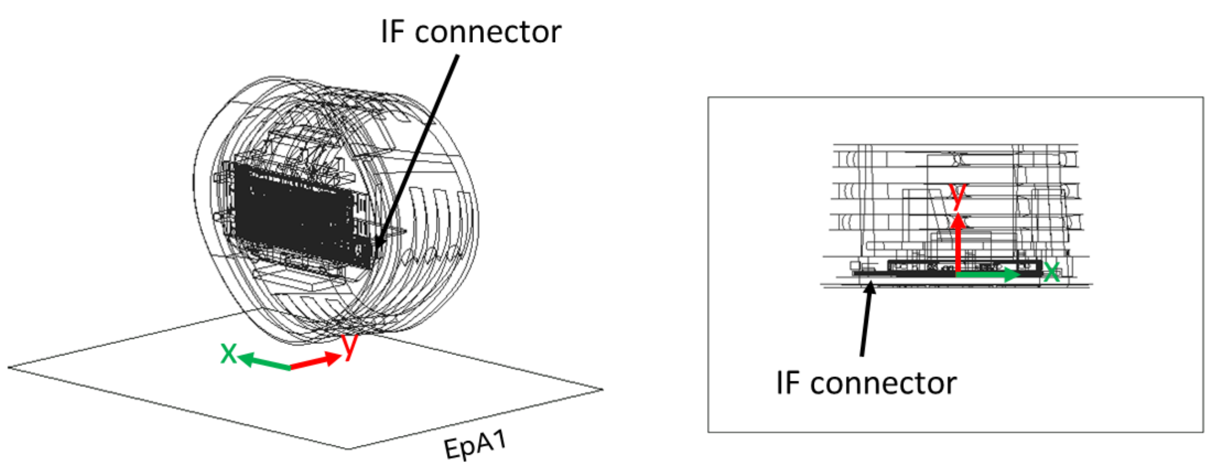


Figure 34 – Footprint of the EpA1 evaluation plane

- **One-dimensional cut of the single-point power density distribution**

In Figure 35 and Figure 36, we present the simulation results from the xyz components of single-point power density values with worst-case antenna phases of sub-array 1, channel 1 which is the worst case among the three sub-arrays in the EpA1 evaluation plane. These figures represent the 1dimensional cut in the x-axis and y-axis that shows the behavior of the near field power density at the evaluation plane.

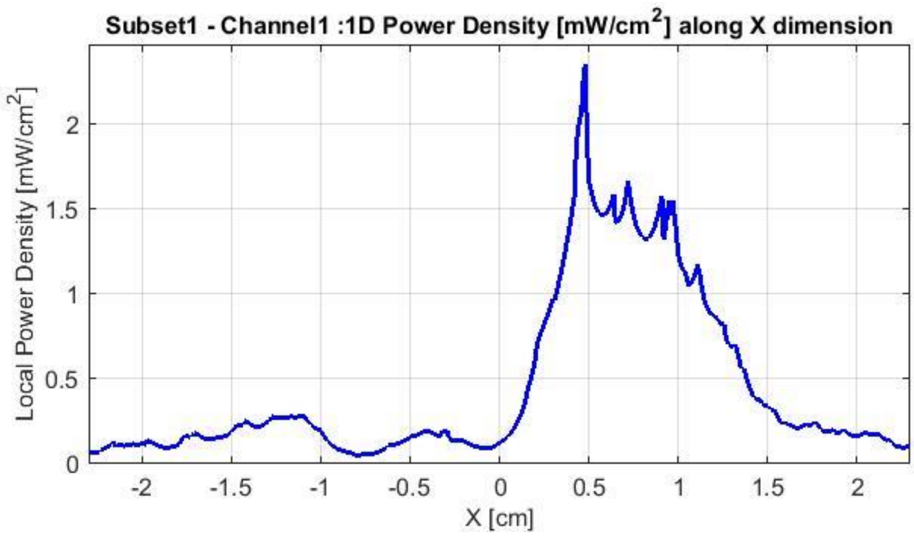


Figure 35 – 1-dimensional plots of the power density along x dimension

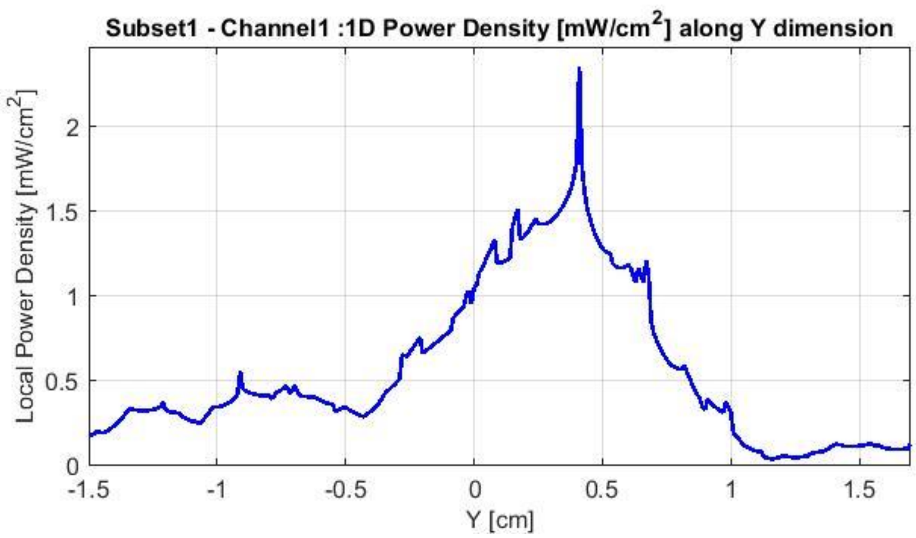


Figure 36 – 1-dimensional plots of the power density along y dimension

- **Distribution of spatially-averaged power density over 1 cm^2 - phase configuration [Ph3 #1]**

Figure 37 presents the spatially-averaged power over 1cm^2 at 100% duty cycle for the worst-case scenario of sub-array 1, channel 1. The 1cm^2 square location correspondent to the maximum of spatially averaged power density value is plotted in Figure 37 for the channel 1.

The spatially averaged power density shown in the figure below is normalized to a total conducted power of 13 dBm.

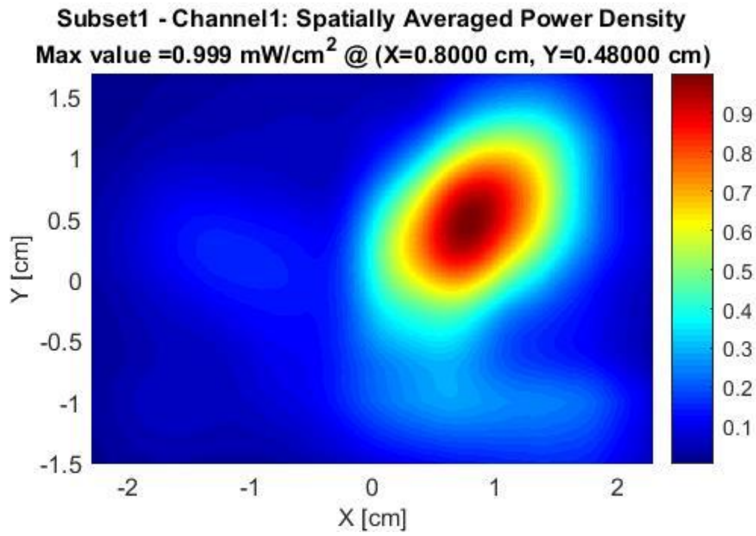


Figure 37 – Spatially-averaged power density over 1cm^2 in the EpA1 evaluation plane

The Table 16 shows the simulated worst-case power density, for sub-array 1 – channel 1, in the EpA1 evaluation plane.

Table 16 – Worst-case power density in the EpA1 evaluation plane

Highest power density	Sub-array 1 - Channel 1
Total conducted power	13 dBm
55% duty cycle	0.549 mW/cm^2
100% duty cycle	0.999 mW/cm^2

Notes for Table 16:

1. The worst-case power density is found for channel 1 on sub-array 1.
2. The Maximum power density (spatially averaged over worst 1cm^2) achieved in the EpA1 evaluation plane equals 0.999 mW/cm^2 over 100% duty cycle.
3. The Intel 13110NGW module is limited to transmit at a duty cycle of 55% over 10 seconds. Therefore the maximum spatially-integrated and time-averaged power density over 1cm^2 is 0.999x 0.55 = 0.549 mW/cm^2.

3.2.3.3 Worst-cases power density value's in the EpB1 evaluation plane

Table 17 and Table 18 summarizes, for all sub-arrays and channels, the simulation results in the **EpB1 evaluation plane** for the first and second worst cases respectively. In these tables, the following results are presented:

- The maximum values of the calculated upper bound single point power density values in the evaluation plane. Please note that since the worst-case conditions are searched over a plane for near field, then the azimuth and the elevation are not relevant. The worst-case position is calculated using all the power density single-points issued from the upper-bound simulation results. We leverage the phase conditions for each antenna element that resulted in these worst-case conditions to evaluate final spatially averaged power density.
- The phases' configuration, a.k.a. "beamforming codes" of each sub-array elements (marked in grey) for the first and second worst cases. The white cells with phase ("-") correspond to the non-active elements of the sub-array. For instance, for sub-array 1, the active elements are 5, 6, 7, 8; 17 to 24, and the worst case occurs for each channel with the indicated phases. "Ph #" indicates the number of the attributed phase combination for each worst case.
- The maximum calculated single-point power density values using the first- and the second-worst-case sub-array antenna phases.
- The maximum calculated spatially-averaged power density over 1 cm^2. These values are calculated in the evaluation plane using the first and the second worst-case sub-array antenna phases.

Note: All simulation results are presented at 100% duty cycle and all power density values are shown in [mW/cm^2].

Table 17 – Simulation results for the first-worst case in the EpB1 plane

Row #		Sub-array	Sub-array 1			Sub-array 2			Sub-array 3		
		Channel	CH1	CH2	CH3	CH1	CH2	CH3	CH1	CH2	CH3
1	Phases configuration [degrees]	Ant. index	Ph4 #1	Ph4 #2	Ph4 #3	Ph4 #4	Ph4 #5	Ph4 #6	Ph4 #7	Ph4 #8	Ph4 #9
		1	-	-	-	-	-	-	180	180	180
		2	-	-	-	-	-	-	180	180	180
		3	-	-	-	-	-	-	0	0	0
		4	-	-	-	270	270	0	-	-	-
		5	0	0	90	180	180	180	-	-	-
		6	0	0	90	270	270	270	-	-	-
		7	270	180	180	-	-	-	-	-	-
		8	0	270	0	-	-	-	-	-	-
		9	-	-	-	0	0	0	-	-	-
		10	-	-	-	270	270	270	-	-	-
		11	-	-	-	270	270	270	-	-	-
		12	-	-	-	270	270	270	-	-	-
		13	-	-	-	0	270	0	90	90	90
		14	-	-	-	270	0	90	90	0	90
		15	-	-	-	90	180	180	270	270	270
		16	-	-	-	270	90	180	90	90	90
		17	180	180	180	-	-	-	-	-	-
		18	0	0	0	-	-	-	-	-	-
		19	180	180	180	-	-	-	-	-	-
		20	90	0	0	-	-	-	-	-	-
		21	0	270	0	-	-	-	0	0	0
		22	180	90	180	-	-	-	270	270	270
		23	0	270	0	-	-	-	90	90	90
		24	0	270	270	-	-	-	90	90	90
2	Upper Bound PD[4]		13.408	12.175	9.971	4.658	5.326	4.895	8.551	7.954	6.859
3	Single point PD[5]		2.144	2.624	2.407	0.961	0.952	0.871	3.224	2.492	2.156
4	Average PD[6]		0.962	0.944	0.762	0.433	0.387	0.357	0.998	0.852	0.712

[4] *Upper bound single point power density without phase difference between sub-array element's*

[5] *Single point power density with phases' configuration shown in row #1 for the corfresponding case (For example, the single power density of sub-array1, channel 1 is obtained using the phase configuration Ph4 #1)*

[6] Spatially averaged over 1 cm^2 of the single point power density with phases' configuration shown in row #1 for the corresponding case

Table 18 – Simulation results for the second-worst case in the EpB1 plane

Row #	Sub-array		Sub-array 1			Sub-array 2			Sub-array 3		
	Channel		CH1	CH2	CH3	CH1	CH2	CH3	CH1	CH2	CH3
1	Phases configuration [degrees]	Ant. index	Ph4 #10	Ph4 #11	Ph4 #12	Ph4 #13	Ph4 #14	Ph4 #15	Ph4 #16	Ph4 #17	Ph4 #18
		1	-	-	-	-	-	-	180	90	90
		2	-	-	-	-	-	-	180	90	90
		3	-	-	-	-	-	-	0	0	0
		4	-	-	-	270	0	270	-	-	-
		5	0	90	90	270	270	90	-	-	-
		6	0	90	90	0	0	180	-	-	-
		7	180	270	180	-	-	-	-	-	-
		8	0	90	0	-	-	-	-	-	-
		9	-	-	-	0	0	0	-	-	-
		10	-	-	-	270	270	270	-	-	-
		11	-	-	-	0	0	270	-	-	-
		12	-	-	-	0	0	90	-	-	-
		13	-	-	-	90	180	0	0	0	0
		14	-	-	-	270	0	90	0	0	0
		15	-	-	-	270	270	90	180	180	180
		16	-	-	-	270	180	0	0	0	0
		17	270	90	90		-	-	-	-	-
		18	90	270	270		-	-	-	-	-
		19	270	90	180	-	-	-	-	-	-
		20	180	0	0	-	-	-	-	-	-
		21	0	90	0	-	-	-	0	0	270
		22	180	270	180	-	-	-	180	180	180
		23	0	90	0	-	-	-	0	0	0
		24	0	90	270	-	-	-	0	0	0
2	Upper Bound PD[4]		13.408	12.175	9.971	4.658	5.326	4.895	8.551	7.954	6.859
3	Single point PD[5]		2.320	2.614	1.885	0.822	0.758	0.949	1.781	1.668	1.388
4	Average PD[6]		0.853	0.853	0.740	0.342	0.342	0.343	0.806	0.650	0.532

[4] *Upper bound single point power density without phase difference between sub-array element's*

[5] *Single point power density with phases' configuration shown in row #1 for the corfresponding case (For example, the single power density of sub-array1, channel 1 is obtained using the phase configuration Ph4 #10)*

[6] Spatially averaged over 1 cm^2 of the single point power density with phases' configuration shown in row #1 for the corresponding case

Table 19 presents, for all channels and sub-arrays, the spatially-averaged power density over 1 cm^2 in the EpB1 evaluation plane using the first and the second worst-case sub-array antenna phases presented in tables above.

Table 19 – Maximum spatially averaged power density over 1cm^2 [mW/cm^2]

	First worst case			Second worst case		
	Channel 1	**Channel 2**	**Channel 3**	**Channel 1**	**Channel 2**	**Channel 3**
Sub-array 1	**0.962**	**0.944**	0.762	**0.853**	**0.853**	0.740
Sub-array 2	0.433	0.387	0.357	0.342	0.342	0.343
Sub-array 3	**0.998**	0.852	0.712	0.806	0.650	0.532

Table 19 shows that the worst case in **EpB1 evaluation plane** is found for **sub-array 3 at channel 1** (marked in orange) with spatially averaged power density of **0.998 mW/cm^2** at 100 % duty cycle. The next section presents all power density distributions for this worst cases.

3.2.3.4 Worst-case power density distribution in the EpB1 evaluation plane

As described in the previous section, the worst-case, spatially-averaged power density over 1 cm^2 among the eighteen calculated worst cases is found for sub-array 3, channel 1.

This section present for this worst case the distribution of the following listed items:

- Upper bound single point power density distribution
- Single-point power density distribution
- One dimensional cut of the single-point power density distribution
- Spatially averaged power density over 1 cm^2

- **Upper-bound power density distribution**

Figure 38 presents the upper-bound, single-point power density at 100% duty cycle of sub-array 3, channel 1 which is the worst case among the two simulated worst cases of the three sub-arrays of the EpB1 evaluation plane (Figure 5). The upper-bound, single-point power density shown in the figure below is normalized to a total conducted power of 13 dBm.

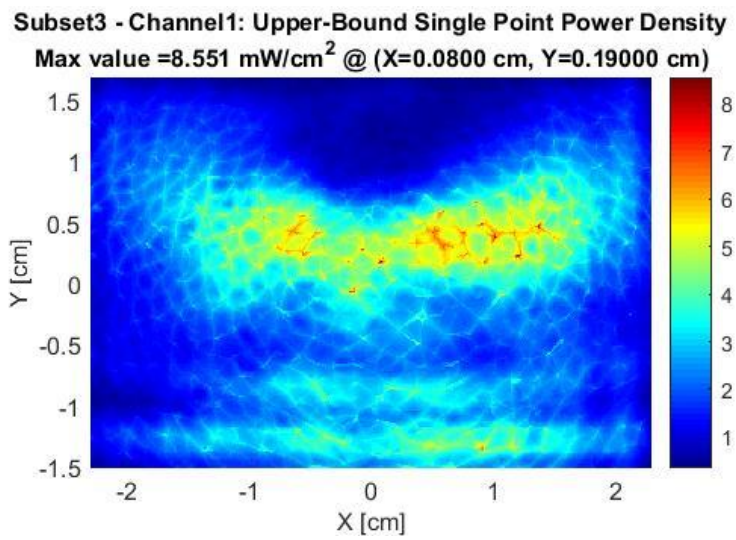


Figure 38 – Upper-bound, single-point power density in the EpB1 evaluation plane

Figure 39 shows the upper-bound, single-point power density distribution with the footprint of the RFEM 3-B antenna array and the EpB1 evaluation plane

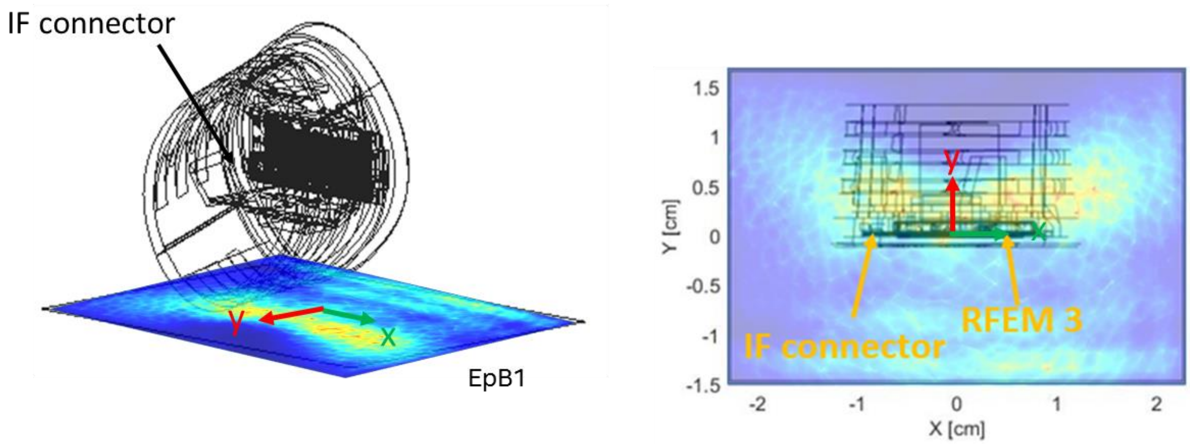


Figure 39 – Upper-bound, single-point power density in the EpB1 evaluation plane with footprint of the RFEM 3-B antenna and EpB1 plane

- **Single-point power density distribution - phase configuration [Ph4 #7]**

Figure 40 presents the single-point power density distribution at 100% duty cycle of sub-array 3, channel 1 in the EpB1 evaluation plane using the worst-case antenna phases of sub-array 3, channel 1 (see 'Ph4 #7' in Table 17). The single-point power density shown in the figure below is normalized to a total conducted power of 13 dBm.

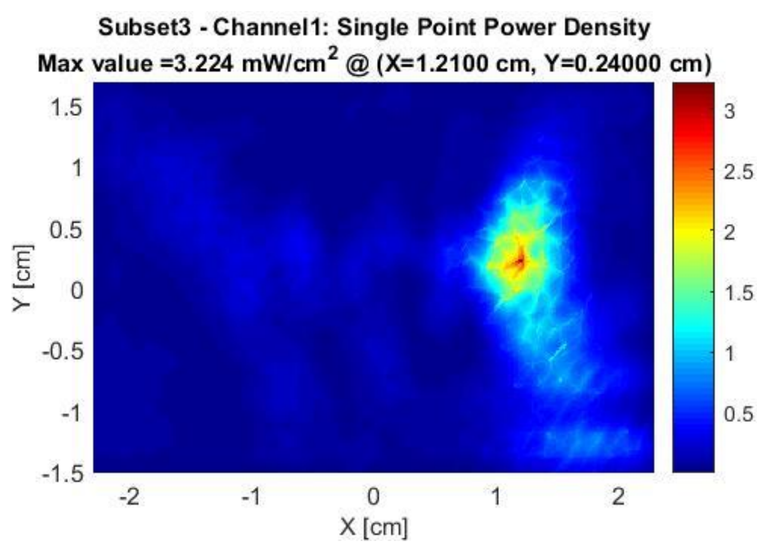


Figure 40 – Single-point power density in the EpB1 evaluation plane

Figure 41 shows the upper-bound, single-point power density distribution with the footprint of the RFEM 3-B antenna array and the EpB1 evaluation plane

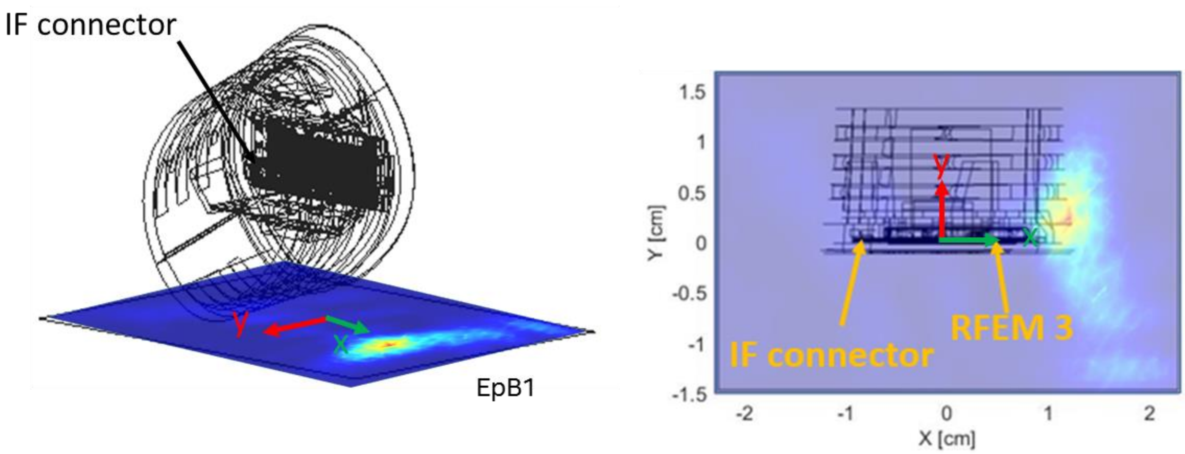


Figure 41 – Single-point power density in the EpB1 evaluation plane with footprint of the RFEM 3-B antenna and EpB1 plane

The footprint of the RFEM 3-B with the EpB1 evaluation plane for power density representation is shown in Figure 42.

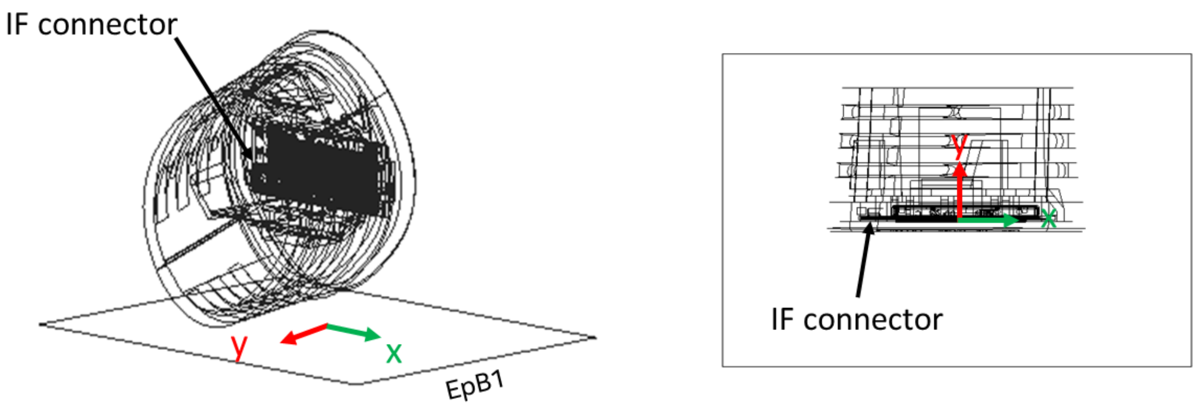


Figure 42 – Footprint of the EpB1 evaluation plane

- **One-dimensional cut of the single-point power density distribution**

In Figure 43 and Figure 44, we present the simulation results from the xyz components of single-point power density values with worst-case antenna phases of sub-array 3, channel 1 which is the worst case among the three sub-arrays in the EpB1 evaluation plane. These figures represent the 1-dimensional cut in the x-axis and y-axis that shows the behavior of the near field power density at the evaluation plane.

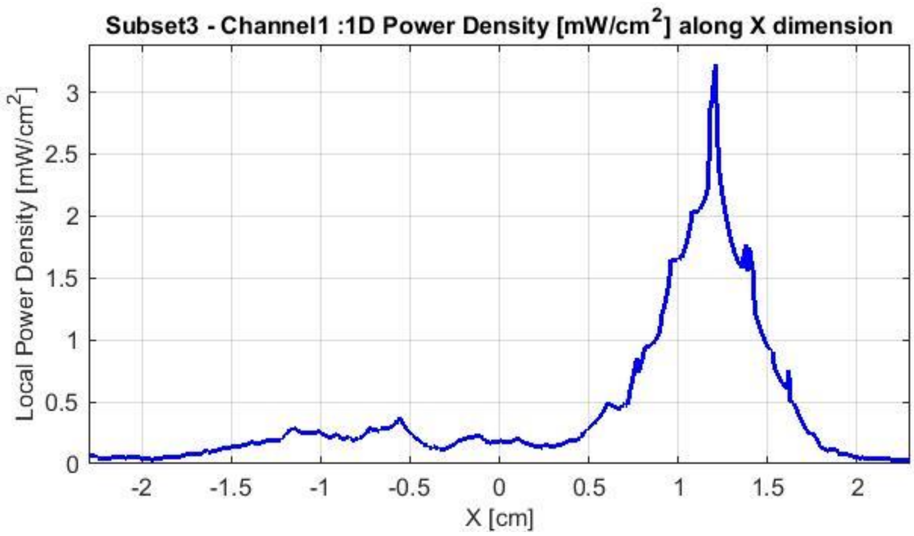


Figure 43 – 1-dimensional plots of the power density along x dimension

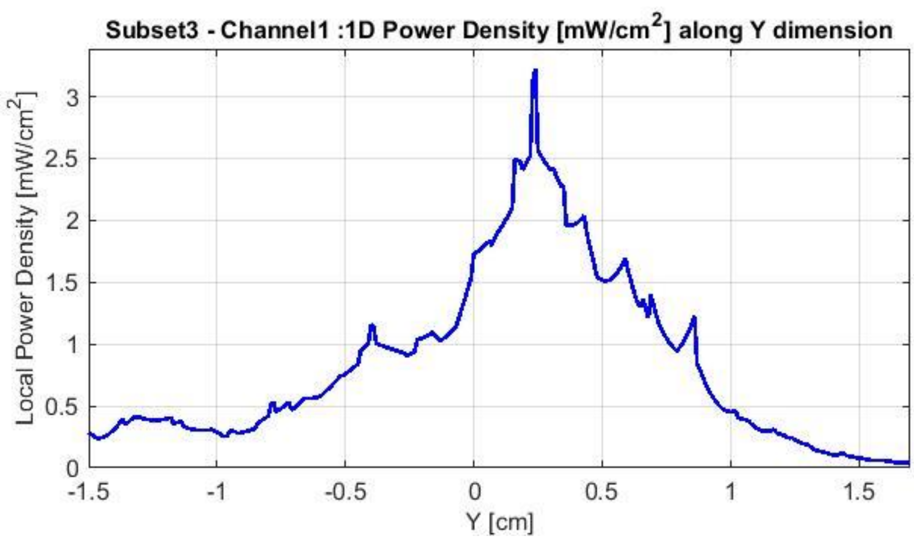


Figure 44 – 1-dimensional plots of the power density along y dimension

- **Distribution of spatially-averaged power density over 1 cm² - phase configuration [Ph4 #7]**

Figure 45 presents the spatially-averaged power over 1cm² at 100% duty cycle for the worst-case scenario of sub-array 3, channel 1. The 1cm² square location correspondent to the maximum of spatially averaged power density value is plotted in Figure 45 for the channel 1.

The spatially averaged power density shown in the figure below is normalized to a total conducted power of 13 dBm.

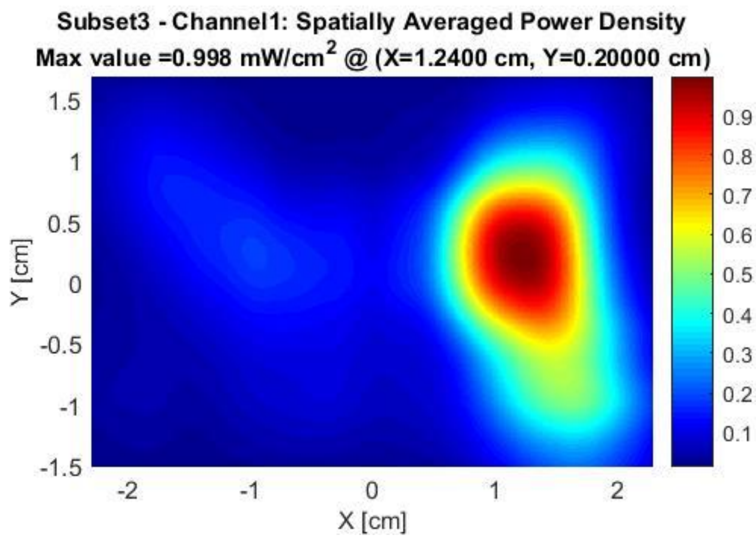


Figure 45 – Spatially-averaged power density over 1cm² in the EpB1 evaluation plane

The Table 20 shows the simulated worst-case power density, for sub-array 3 – channel 1, in the EpB1 evaluation plane.

Table 20 – Worst-case power density in the EpB1 evaluation plane

Highest power density	Sub-array 3 - Channel 1
Total conducted power	13 dBm
55% duty cycle	0.548 mW/cm²
100% duty cycle	0.998 mW/cm²

Notes for Table 20:

1. The worst-case power density is found for channel 1 on sub-array 3.
2. The Maximum power density (spatially averaged over worst 1cm²) achieved in the EpB1 evaluation plane equals 0.998 mW/cm² over 100% duty cycle.
3. The Intel 13110NGW module is limited to transmit at a duty cycle of 55% over 10 seconds. Therefore the maximum spatially-integrated and time-averaged power density over 1cm² is 0.998x 0.55 = 0.548 mW/cm².

3.2.3.5 Field and power density distributions for the six highest worst cases in the EpA1 and EpB1 planes

This section shows the E-field, H-field, local power density, and spatially-averaged power density distribution at the corresponding RFEM 3 evaluation plane of the six highest worst cases' spatially-averaged power density, calculated for both EpA1 and EpB1 evaluation planes and marked in bold in Table 15 and Table 19.

Table 21 lists the identified highest six spatially-averaged power density worst cases.

Table 21 – Highest six worst-cases of spatially-averaged power density

	Evaluation plane	Sub-array	Channel	Worst case	Simulated AVG. PD	Phase config.	Plot
Worst Case #1	EpA1	1	1	1	0.999	Ph3 #1	Plot #1
Worst Case #2	EpB1	3	1	1	0.998	Ph4 #7	Plot #2
Worst Case #3	EpB1	1	1	1	0.962	Ph4 #1	Plot #3
Worst Case #4	EpB1	1	2	1	0.944	Ph4 #2	Plot #4
Worst Case #5	EpB1	1	1	2	0.853	Ph4 #10	Plot #5
Worst Case #6	EpB1	1	2	2	0.853	Ph4 #11	Plot #6

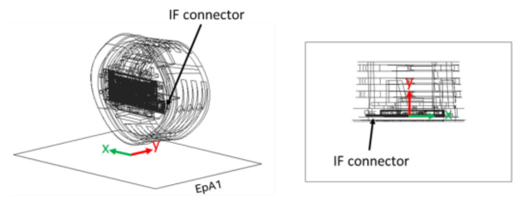
The distribution plot of the six highest worst cases listed in Table 21 are shown in the Figures below. Note that the color scale for each plot is presented according to the maximum value obtained for each case.

Plot #1: Worst Case 1 – Sub-array 1 – Channel 1

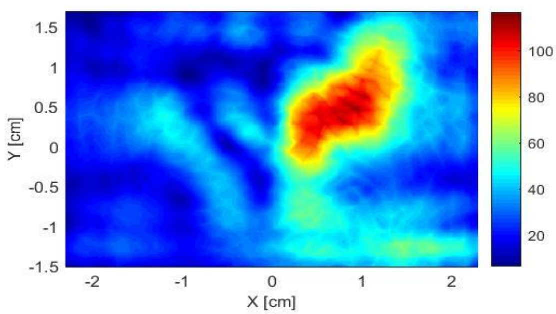
Evaluation Plane: EpA1

Frequency: 58320 MHz

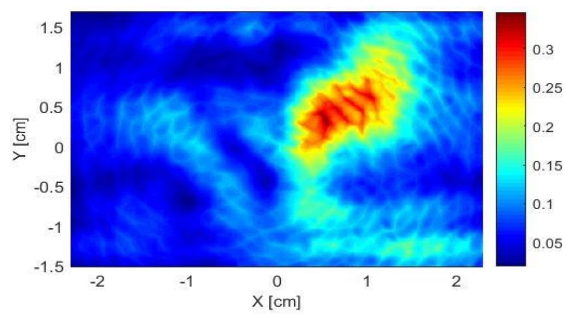
Distance: 0mm



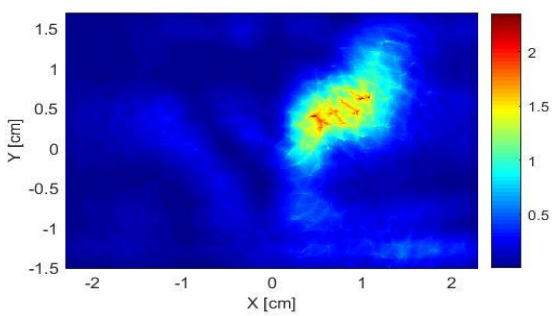
Simulated E-field
Maximum value = 116.679 V/m - Peak



Simulated H-field
Maximum value = 0.347 A/m - Peak



Simulated localized free space power density
Maximum value = 2.354 mW/cm²



Simulated spatially Averaged power density
Maximum value = 0.999 mW/cm²

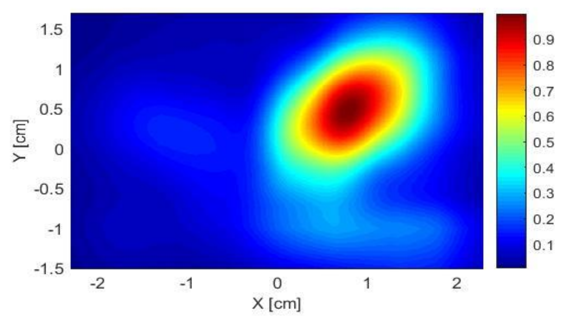


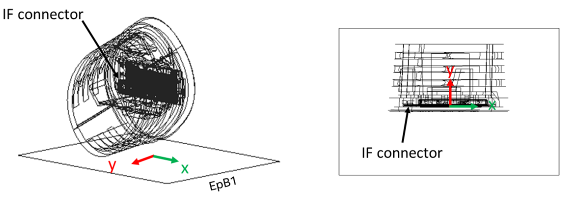
Figure 46 – Plot #1: EpA1 – Worst Case 1 – Sub-array 1 – Channel 1

Plot # 2: Worst Case 1 - Sub-array 3 – Channel 1

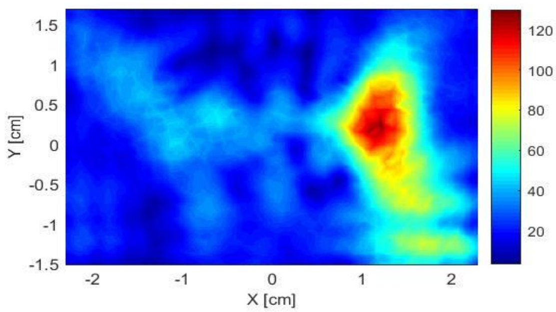
Evaluation Plane: EpB1

Frequency: 58320 MHz

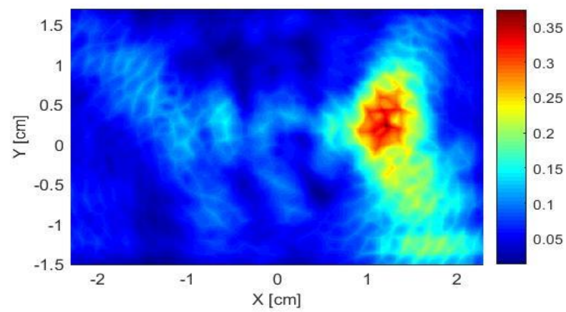
Distance: 0mm



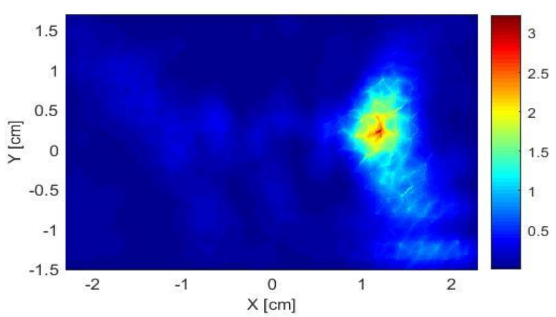
Simulated E-field
Maximum value = 130.026 V/m - Peak



Simulated H-field
Maximum value = 0.374 A/m - Peak



Simulated localized free space power density
Maximum value = 3.224 mW/cm²



Simulated spatially Averaged power density
Maximum value = 0.998 mW/cm²

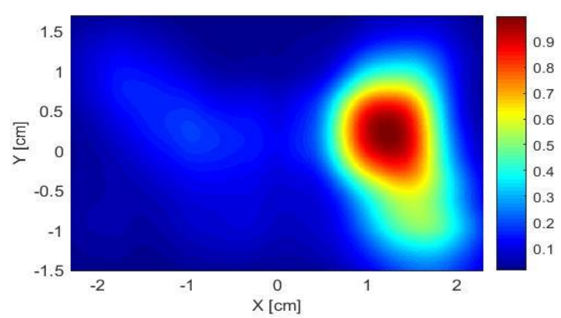


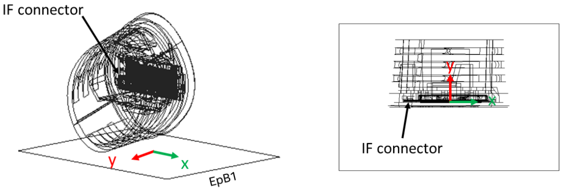
Figure 47 – Plot #2: EpB1 – Worst Case 1 – Sub-array 3 – Channel 1

Plot # 3: Worst Case 1 - Sub-array 1 – Channel 1

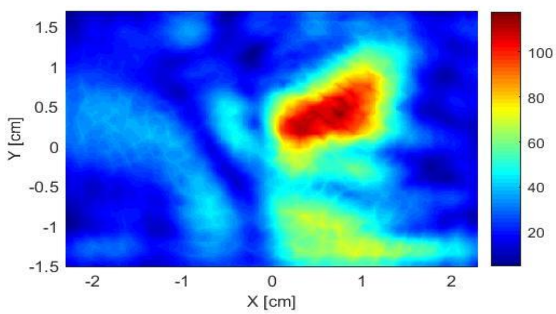
Evaluation Plane: EpB1

Frequency: 58320 MHz

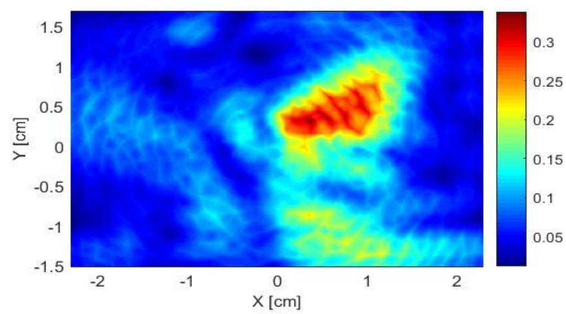
Distance: 0mm



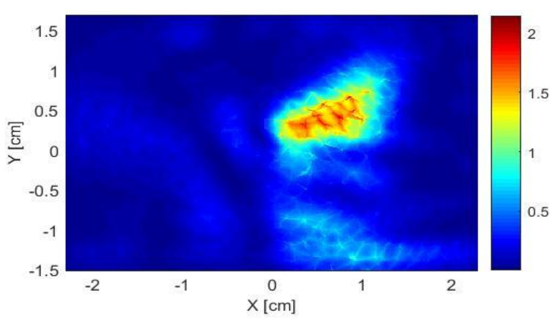
Simulated E-field
Maximum value = 117.887 V/m - Peak



Simulated H-field
Maximum value = 0.338 A/m - Peak



Simulated localized free space power density
Maximum value = 2.144 mW/cm^2



Simulated spatially Averaged power density
Maximum value = 0.962 mW/cm^2

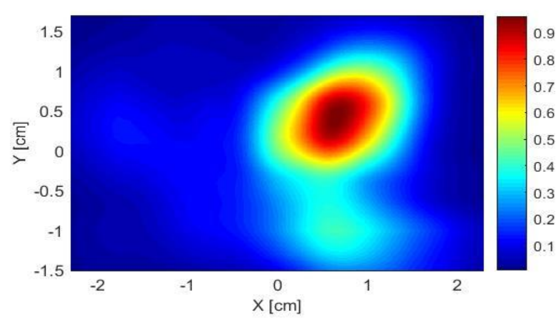


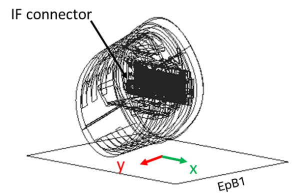
Figure 48 – Plot #3: EpB1 – Worst Case 1 – Sub-array 1 – Channel 1

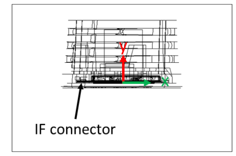
Plot # 4: Worst Case 1 - Sub-array 1 – Channel 2

Evaluation Plane: EpB1

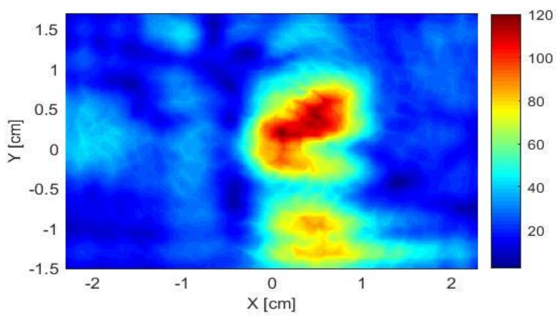
Frequency: 60480 MHz

Distance: 0mm

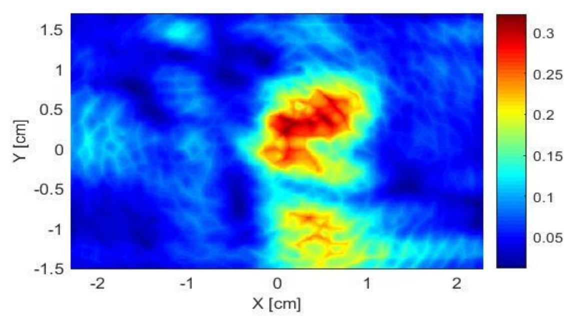




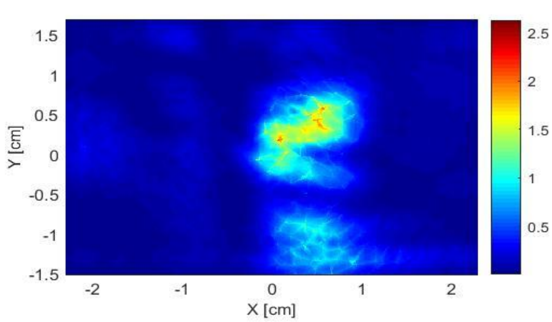
Simulated E-field
Maximum value = 120.221 V/m - Peak



Simulated H-field
Maximum value = 0.322 A/m - Peak



Simulated localized free space power density
Maximum value = 2.624 mW/cm^2



Simulated spatially Averaged power density
Maximum value = 0.944 mW/cm^2

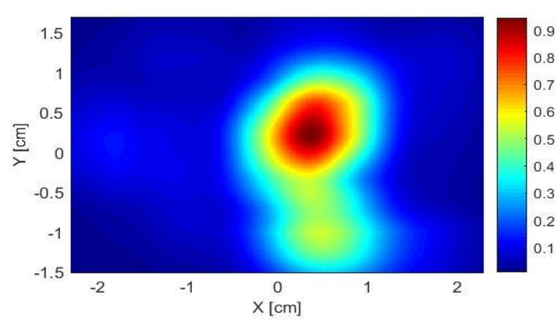


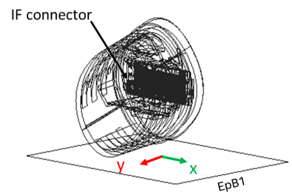
Figure 49 – Plot #4: EpB1 – Worst Case 1 – Sub-array 1 – Channel 2

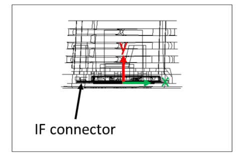
Plot # 5: Worst Case 2 - Sub-array 1 – Channel 1

Evaluation Plane: EpB1

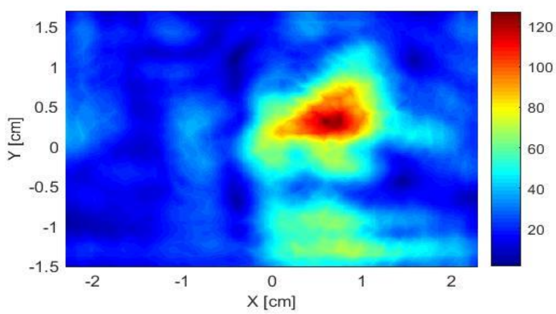
Frequency: 58320 MHz

Distance: 0mm

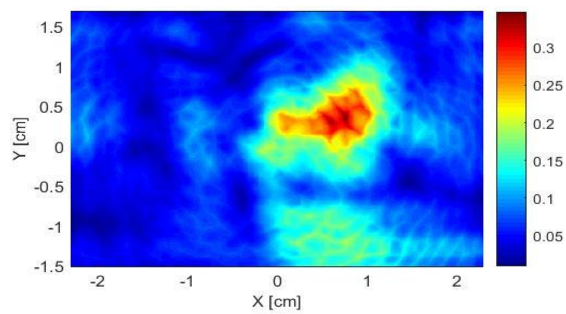




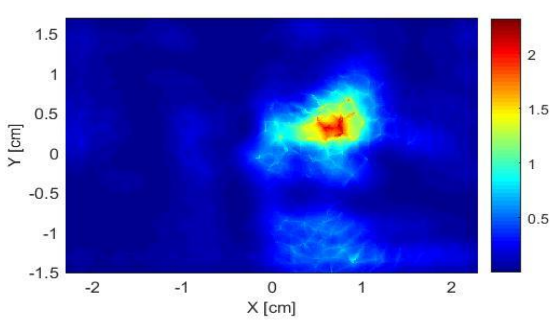
Simulated E-field
Maximum value = 127.167 V/m - Peak



Simulated H-field
Maximum value = 0.348 A/m - Peak



Simulated localized free space power density
Maximum value = 2.320 mW/cm^2



Simulated spatially Averaged power density
Maximum value = 0.853 mW/cm^2

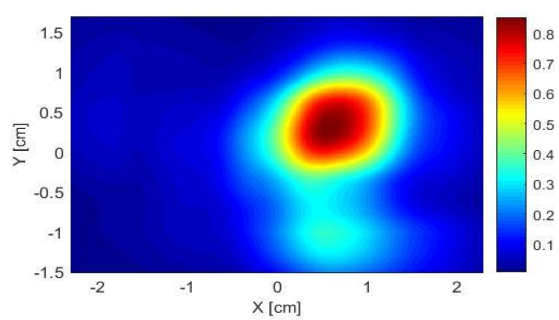


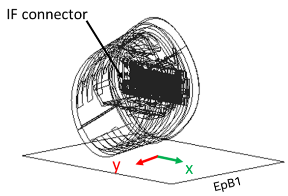
Figure 50 – Plot #5: EpB1 – Worst Case 2 – Sub-array 1 – Channel 1

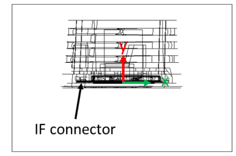
Plot # 6: Worst Case 2 - Sub-array 1 – Channel 2

Evaluation Plane: EpB1

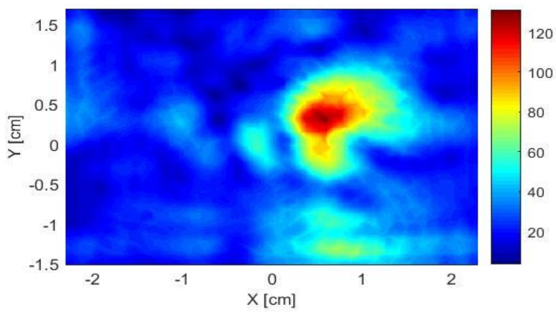
Frequency: 60480 MHz

Distance: 0mm

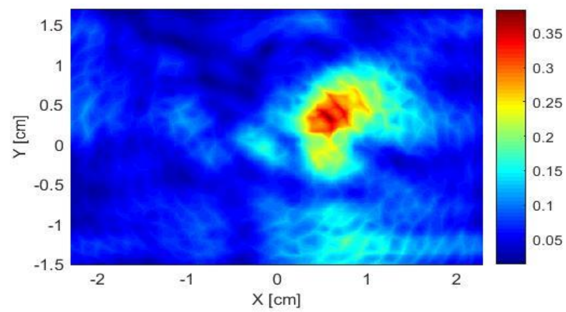




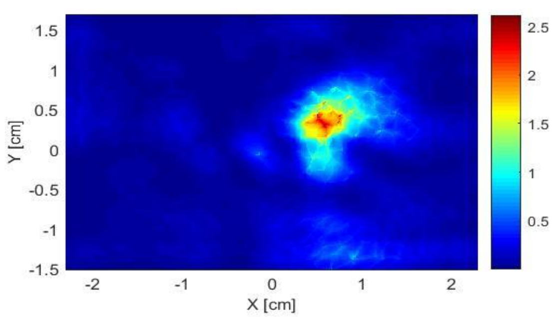
Simulated E-field
Maximum value = 131.346 V/m - Peak



Simulated H-field
Maximum value = 0.384 A/m - Peak



Simulated localized free space power density
Maximum value = 2.614 mW/cm^2



Simulated spatially Averaged power density
Maximum value = 0.853 mW/cm^2

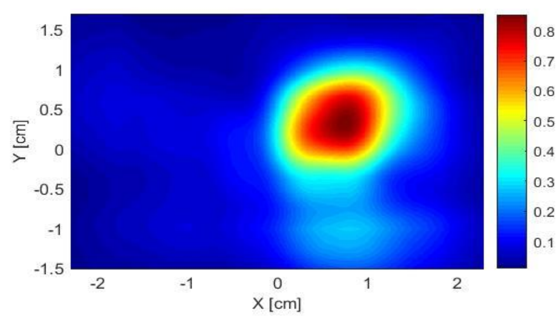


Figure 51 – Plot #6: EpB1 – Worst Case 2 – Sub-array 1 – Channel 2

3.2.4 Conclusion

The simulation results for the three sub-arrays in the four evaluation planes EpA, EpB, EpA1 and EpB1 for three channels were presented in this report. The worst case is observed on channel 1 for sub-array 3 in the EpB evaluation plane, with the maximum total spatially averaged power density of 0.553 mW/cm^2. Note that the applicable FCC limit is 1 mW/cm^2.