EMF compliance assessment based on a mixed approach of Measurements and numerical Simulations

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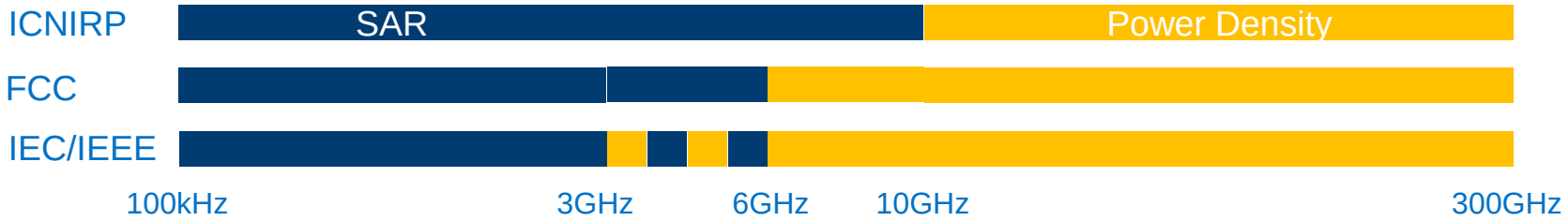
Exposure to EMF – Regulatory Compliance Limits

- ✓ Human Body > 20cm to any radiator: MPE (Max Permissible Exposure) calculation
- ✓ Human Body < 20cm to radiator up to 6GHz : SAR (Specific Absorption rate) $SAR = \frac{\sigma |E|^2}{2\rho}$
- ✓ Human Body to radiator > 6GHz : PD (Power Density) $S_{av} = \frac{1}{AT}\int\int (\mathcal{E} \times \mathcal{H}) \cdot \hat{\mathbf{n}} \, dA dT$.

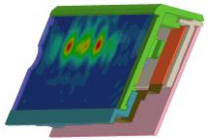


Regulatory Body	Power Density Limit	Averaging Area
FCC	1 mW/cm^2	1 cm^2
ETSI		20 cm^2

Power Density Assesment Procedure

1 - Near-field simulation of the industrial design

- Numerical Model Definition: CAD File, simulation Domain
- Definition of:
  - Evaluation planes
  - Dielectric coefficients of materials



2 – Post-Processing : Calculation of phase combinations leading to the highest exposure

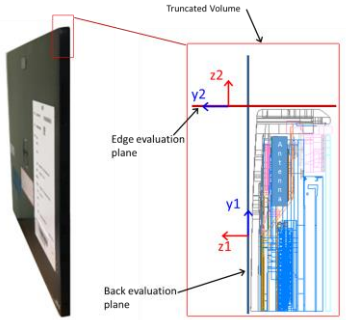
3 - Validation of simulated PD @ worst exposure plane

- E-field measurement using near-field probe, H-field reconstruction and power density calculation
- Correlation between near-field measurement and simulation at exposure plane

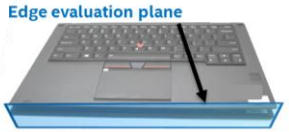
Evaluation Plane Definition -Examples

1 – Form Factors

- Tablets

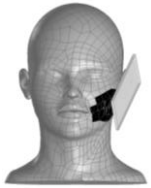


- Convertibles

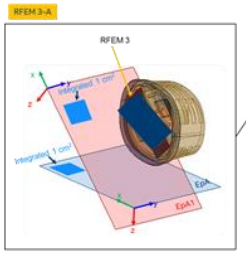


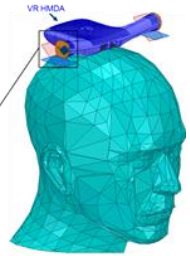
- Clam Shell

- Mobile



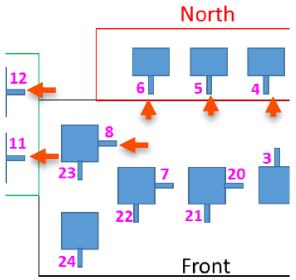
- Other





Worst Case Phase Combination Assessment

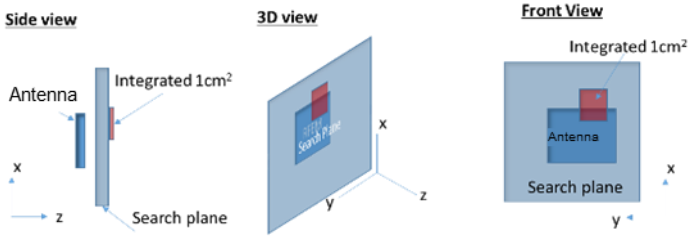
1. Find the location of maximum power density on the evaluation surface in each evaluation configuration using an upper bound method.
2. The antenna phases are then adjusted to maximize the power density across the spatial averaging area that was found using the upper-bound method.
3. Calculate the power density with the antenna phases. Repeat the steps for all needed configurations (Channels, sub-arrays…)
4. Validate the simulation by measurement at distances supported by the measurement method.



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

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

$$P_g = \frac{1}{2}Re\{(\vec{E} \times \vec{H}^*)\}$$



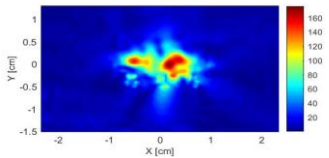
Phase Combination and Power Density Values

General example- WiGig 60 GHz- 3 Subsets – 3 Channels

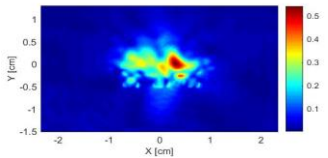
	First worst case			Second worst case		
	Channel 1	**Channel 2**	**Channel 3**	**Channel 1**	**Channel 2**	**Channel 3**
Subset 1	**0.842**	0.744	0.630	**0.840**	0.739	0.628
Subset 2	**0.427**	0.385	0.340	0.305	**0.355**	0.300
Subset 3	**0.612**	0.534	0.450	**0.592**	0.486	0.419

Antenna index	Subset 1 – Back plane Phases [Degrees]			Subset 2 – Edge plane Phases [Degrees]			Subset 3 – Back plane Phases [Degrees]		
	CH1	CH2	CH3	CH1	CH2	CH3	CH1	CH2	CH3
	Ph #10	Ph #11	Ph #12	Ph #13	Ph #14	Ph #15	Ph #16	Ph #17	Ph #18
1	-	-	-	-	-	-	180	0	270
2	-	-	-	-	-	-	0	180	90
3	-	-	-	-	-	-	0	0	0
4	-	-	-	270	270	270	-	-	-
5	-	-	-	0	0	0	-	-	-
6	-	-	-	180	270	0	-	-	-
7	0	90	90	-	-	-	-	-	-
8	270	270	90	-	-	-	-	-	-
9	-	-	-	180	0	180	-	-	-
10	-	-	-	90	180	270	-	-	-
11	-	-	-	180	270	180	-	-	-
12	-	-	-	0	270	0	-	-	-
13	-	-	-	180	180	0	270	90	0
14	-	-	-	0	180	0	90	0	0
15	-	-	-	270	90	270	90	0	0
16	-	-	-	90	180	270	0	270	270
17	270	180	270		-	-	-	-	-
18	270	180	180		-	-	-	-	-
19	0	180	180	-	-	-	-	-	-
20	270	0	0	-	-	-	-	-	-
21	270	0	0	-	-	-	270	90	0
22	0	90	90	-	-	-	0	180	90
23	270	180	90	-	-	-	0	270	180
24	90	180	270	-	-	-	180	90	0

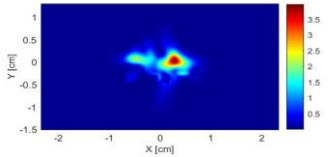
Simulated E-field
Maximum value = 176.837 V/m - Peak



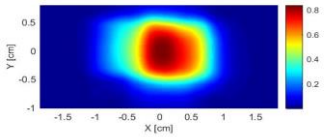
Simulated H-field
Maximum value = 0.544 A/m - Peak



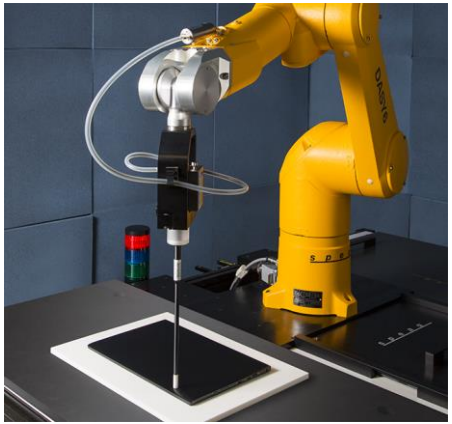
Simulated localized free space power density
Maximum value = 3.987 mW/cm^2

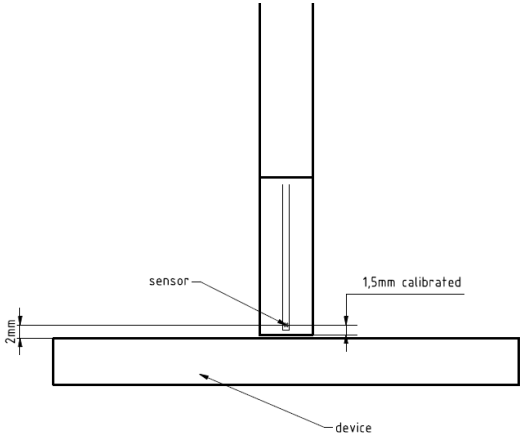


Simulated spatially Averaged power density
Maximum value = 0.842 mW/cm^2



Near field Measurement

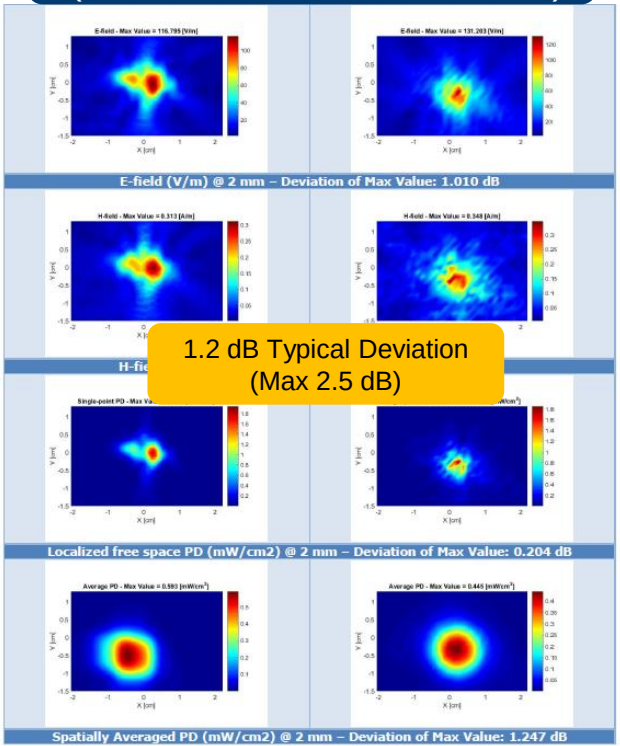




- The probe consist of two dipoles optimally arranged with different angles (γ1 and γ2) to obtain pseudo-vector information, printed on glass substrate protected by high density foam that allows low perturbation of the measured field.
- Near-field probe measuring at 2 mm minimum distance to the device
- H-field reconstruction and power density calculation

Measurement Accuracy & Uncertainty (WiGig @60GHz)

PD @2mm Distance
(Simulation vs. Measurement)

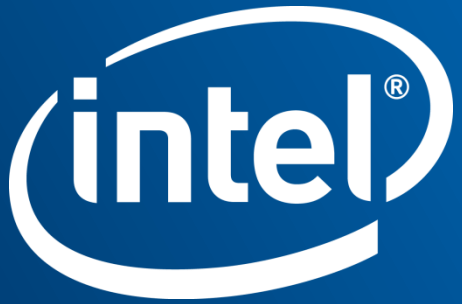


1.2 dB Typical Deviation
(Max 2.5 dB)

Uncertainty Budget						
Error Description	Uncertainty Value (±dB)	Probability Distribution	Div.	(ci)	Std. Unc. (±dB)	(vi) Veff
Measurement System						
Probe Calibration	0.43	N	1	1	0.43	∞
Hemispherical Isotropy	0.60	R	√3	1	0.35	∞
Linearity	0.20	R	√3	1	0.12	∞
System Detection Limits	0.04	R	√3	1	0.02	∞
Modulation Response*	0.17	R	√3	1	0.10	∞
Readout Electronics	0.01	N	1	1	0.01	∞
Response Time	0.03	R	√3	1	0.02	∞
Integration Time	0.11	R	√3	1	0.06	∞
RF Ambient Noise	0.04	R	√3	1	0.02	∞
RF Ambient Reflections	0.21	R	√3	1	0.12	∞
Probe Positioner	0.04	R	√3	1	0.02	∞
Probe Positioning	0.11	R	√3	1	0.06	∞
S_{avg} Reconstruction	0.61	R	√3	1	0.35	∞
Test Sample Related						
Power Drift	0.57	R	√3	1	0.33	∞
Power Scaling	0.00	R	√3	1	0.00	∞
Combined Std. Uncertainty					0.77	∞
Expanded Std. Uncertainty					**1.54**	

RF exposure Considerations at mm-Waves:

- Metrics : Averaging Area / Averaging Time
- Evaluation plane Definition
- Material Characteristics
- Antenna Array Phase combinations
- Fields Post-processing
- Measurement Distance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