IEC/IEEE 63195-2 XFdtd 7.9.2 Verification

Final Draft International Standard (FDIS), Assessment of power density of human exposure to radio frequency fields from wireless devices in close proximity to the head and body - Part 2: Computational procedure, (Frequency range 6 GHz to 300 GHz). 2021.

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1 Overview

XFdtd 7.9.2 is compliant with and passes all tests outlined in the international power density standard determined by the International Electrotechnical Commission (IEC) and the Institute of Electrical and Electronics Engineers (IEEE). The standard, including full problem descriptions, is detailed in the IEC/IEEE standard [1].

The verification tests described in the standard are summarized below, presented with references to the corresponding IEC draft section, and followed by XFdtd's results.

Unless indicated otherwise, IEC sections, tables, and equations are referenced as [1].

2 Code Verification (IEC Annex A)

Several test problems are presented in the standard for the verification of interpolation and superposition algorithms, metallic losses, anisotropic dielectrics, and the calculation of the peak spatial-average power density (psPD). Those tests and their results using XFdtd are described in this section.

2.1 General (IEC Section A.1)

XFdtd 7.9.2 is compliant with and passes all tests outlined in the international Specific Absorption Rate (SAR) standard determined by the International Electrotechnical Commission (IEC) and the Institute of Electrical and Electronics Engineers (IEEE) [2], [3].

2.2 Interpolation and Superposition of Vector Field Components (IEC Section A.2)

Combined fields from three $\lambda/2$ dipoles were used to determine the code's accuracy regarding interpolation and superposition algorithms. The dipoles operate at 24 GHz and were excited consecutively. The x-, y- and z-vector components of the electric and magnetic fields were evaluated on two cubical surfaces with edge lengths of 10 mm and 16 mm centered around the origin. The field values were superimposed with different amplitudes and phase offsets and compared against reference data at a 0.5 mm spacing. The maximum permissible deviation from the reference results is 10%. XFdtd's results are summarized in Table 1.

Amplitudes & phases	**Maximum deviation on 10 mm cube**		**Maximum deviation on 16 mm cube**	
	Electric field amplitude (%)	Magnetic field amplitude (%)	Electric field amplitude (%)	Magnetic field amplitude (%)
Configuration 1 D_1: A = 1V, $\phi = 0°$ D_2: A = 0.5V, $\phi = 90°$ D_3: A = 2V, $\phi = 180°$	2.12	2.6	8.52	5.12
Configuration 2 D_1: A = 2V, $\phi = 0°$ D_2: A = 2V, $\phi = 90°$ D_3: A = 2V, $\phi = 0°$	2.93	2.31	8.27	5.38
Configuration 3 D_1: A = 1V, $\phi = 180°$ D_2: A = 0.5V, $\phi = 90°$ D_3: A = 2 V, $\phi = 180°$	2.17	2.72	8.52	5.04

Table 1: XFdtd's results of both electric and magnetic field values on the cube surface.

2.3 Calculation of the Far Field Pattern and the Radiated Power (IEC Section A.3)

Far zone patterns and radiated power for the dipole configurations in Table 1 were calculated. Far zone fields were collected over the full 3-D sphere at θ and ϕ increments of 10°. Results were compared against reference data and the maximum permissible deviation from the reference results is 10%. XFdtd's results are summarized in Table 2.

Amplitudes & phases	**Calculated power (W)**	**Reference power (W)**	**Maximum deviation of the amplitude of the far field pattern from reference (%)**
D_1: A = 1V, $\phi = 0°$ D_2: A = 0.5V, $\phi = 90°$ D_3: A = 2V, $\phi = 180°$	0.0227	0.023	1.38
D_1: A = 1V, $\phi = 0°$ D_2: A = 0.5V, $\phi = 90°$ D_3: A = 2V, $\phi = 0°$	0.0519	0.0527	1.32
D_1: A = 1V, $\phi = 0°$ D_2: A = 0.5V, $\phi = 90°$ D_3: A = 2 V, $\phi = 180°$	0.0227	0.023	1.38

Table 2: XFdtd's results of both radiated power and far zone fields.

2.4 Implementation of Lossy Conductors (IEC Section A.4)

The complex propagation constant of an R320 waveguide was computed over the frequency range from 25 GHz to 40 GHz with a step size of 250 MHz. The TE_{10} mode excited the waveguide and the waveguide walls were modeled as conductors with conductivities of 10^5 S/m, 10^6 S/m, and 10^7 S/m. The waveguide was filled with a lossless dielectric with relative permittivities of 1 and 2. The waveguide axis was oriented along all three axes of the coordinate system, for two different orientations around the waveguide axis (the waveguide was rotated by 90°). Fine and coarse meshes discretized the space and the maximum permissible deviation of the attenuation constant from the reference results is 10% and 15%, respectively. XFdtd's results are summarized in Tables 3 to 8.

	Limit for code compliance						
Waveguide axis (direction of propagation) and orientation around waveguide axis	Waveguide axis = Z, TE_{10} orientation = Y						
ϵ_r		1	2	1	2	1	2
σ [S/m]		10^5	10^5	10^6	10^6	10^7	10^7
maximum deviation of simulated α from reference fine mesh	± 10 %	2.98	4.98	2.91	5.16	4.88	5.23
maximum deviation of simulated α from reference coarse mesh	± 15 %	3.23	7.28	3.69	7.52	4.11	7.55

Table 3: XFdtd's results of the evaluation of the numerical dispersion characteristics. Waveguide axis along Z, TE_{10} field oriented along Y.

	Limit for code compliance						
Waveguide axis (direction of propagation) and orientation around waveguide axis	Waveguide axis = Z, TE_{10} orientation = X						
ϵ_r		1	2	1	2	1	2
σ [S/m]		10^5	10^5	10^6	10^6	10^7	10^7
maximum deviation of simulated α from reference fine mesh	$\pm$ 10 %	3.06	4.98	2.89	5.17	4.91	5.23
maximum deviation of simulated α from reference coarse mesh	$\pm$ 15 %	3.22	7.28	3.69	7.52	4.14	7.57

Table 4: XFdtd's results of the evaluation of the numerical dispersion characteristics. Waveguide axis along Z, TE_{10} field oriented along X.

	Limit for code compliance						
Waveguide axis (direction of propagation) and orientation around waveguide axis	Waveguide axis = Y, TE_{10} orientation = Z						
ϵ_r		1	2	1	2	1	2
σ [S/m]		10^5	10^5	10^6	10^6	10^7	10^7
maximum deviation of simulated α from reference fine mesh	$\pm$ 10 %	2.88	4.98	2.91	5.17	4.74	5.22
maximum deviation of simulated α from reference coarse mesh	$\pm$ 15 %	3.22	7.28	3.68	7.52	4.12	7.56

Table 5: XFdtd's results of the evaluation of the numerical dispersion characteristics. Waveguide axis along Y, TE_{10} field oriented along Z.

	Limit for code compliance						
Waveguide axis (direction of propagation) and orientation around waveguide axis	Waveguide axis = Y, TE_{10} orientation = X						
ϵ_r		1	2	1	2	1	2
σ [S/m]		10^5	10^5	10^6	10^6	10^7	10^7
maximum deviation of simulated α from reference fine mesh	$\pm$ 10 %	2.99	4.98	2.91	5.16	5.03	5.23
maximum deviation of simulated α from reference coarse mesh	$\pm$ 15 %	3.22	7.28	3.69	7.52	4.07	7.55

Table 6: XFdtd's results of the evaluation of the numerical dispersion characteristics. Waveguide axis along Y, TE_{10} field oriented along X.

	Limit for code compliance						
Waveguide axis (direction of propagation) and orientation around waveguide axis	Waveguide axis = X, TE_{10} orientation = Y						
ϵ_r		1	2	1	2	1	2
σ [S/m]		10^5	10^5	10^6	10^6	10^7	10^7
maximum deviation of simulated α from reference fine mesh	$\pm$ 10 %	2.97	4.98	2.90	5.16	4.75	5.24
maximum deviation of simulated α from reference coarse mesh	$\pm$ 15 %	3.23	7.28	3.70	7.52	4.14	7.56

Table 7: XFdtd's results of the evaluation of the numerical dispersion characteristics. Waveguide axis along X, TE_{10} field oriented along Y.

	Limit for code compliance						
Waveguide axis (direction of propagation) and orientation around waveguide axis	Waveguide axis = X, TE_{10} orientation = Z						
ϵ_r		1	2	1	2	1	2
σ [S/m]		10^5	10^5	10^6	10^6	10^7	10^7
maximum deviation of simulated α from reference fine mesh	± 10 %	2.98	4.98	2.95	5.17	4.82	5.23
maximum deviation of simulated α from reference coarse mesh	± 15 %	3.22	7.28	3.69	7.52	4.15	7.56

Table 8: XFdtd's results of the evaluation of the numerical dispersion characteristics. Waveguide axis along X, TE_{10} field oriented along Z.

2.5 Implementation of Anisotropic Dielectrics (IEC Section A.5)

The waveguide from Section 2.4 was filled with a uniaxial anisotropic dielectric with the following properties:

a. ϵ_r = 3, σ = 0.01 S/m along the x- and y-axis, ϵ_r = 1, σ = 0 along the z-axis

b. ϵ_r = 3, σ = 0.01 S/m along the x- and z-axis, ϵ_r = 1, σ = 0 along the y-axis

c. ϵ_r = 3, σ = 0.01 S/m along the y- and z-axis, ϵ_r = 1, σ = 0 along the x-axis

The waveguide was oriented along all three axes of the coordinate system. The complex numerical propagation constant was compared to reference results with a maximum permissible deviation of 5% or 10%. XFdtd's results are summarized in Tables 9 to 11.

	Limit for code compliance			
axis, direction of propagation and orientation	z			
Uniaxial dielectric as specified in A.5		a)	b)	c)
maximum deviation of simulated Re{k_z} from reference fine mesh	± 5 %	0.09	0.03	0.09
maximum deviation of simulated Im{k_z} from reference fine mesh	± 10 %	0.27	n.a.	0.27
maximum deviation of simulated Re{k_z} from reference coarse mesh	± 10 %	1.81	0.39	1.81
maximum deviation of simulated Im{k_z} from reference coarse mesh	± 15 %	5.67	n.a.	5.66

Table 9: XFdtd's results of the evaluation of the representation of anisotropic dielectric. Waveguide oriented along Z.

	Limit for code compliance			
axis, direction of propagation and orientation	y			
Uniaxial dielectric as specified in A.5		a)	b)	c)
maximum deviation of simulated Re{k_z} from reference fine mesh	± 5 %	0.09	0.09	0.03
maximum deviation of simulated Im{k_z} from reference fine mesh	± 10 %	0.27	0.27	n.a.
maximum deviation of simulated Re{k_z} from reference coarse mesh	± 10 %	1.81	1.81	0.39
maximum deviation of simulated Im{k_z} from reference coarse mesh	± 15 %	5.66	5.67	n.a.

Table 10: XFdtd's results of the evaluation of the representation of anisotropic dielectric. Waveguide oriented along Y.

	Limit for code compliance			
axis, direction of propagation and orientation	x			
Uniaxial dielectric as specified in A.5		a)	b)	c)
maximum deviation of simulated Re$\{k_z\}$ from reference fine mesh	± 5 %	0.03	0.09	0.09
maximum deviation of simulated Im$\{k_z\}$ from reference fine mesh	± 10 %	n.a.	0.29	0.27
maximum deviation of simulated Re$\{k_z\}$ from reference coarse mesh	± 10 %	0.46	1.87	1.87
maximum deviation of simulated Im$\{k_z\}$ from reference coarse mesh	± 15 %	n.a.	5.76	5.76

Table 11: XFdtd's results of the evaluation of the representation of anisotropic dielectric. Waveguide oriented along X.

2.6 Planar Surfaces (IEC Section A.6.2)

The distribution of the spatial power density (sPD) was evaluated on the vertices of a square evaluation surface of 20 cm x 20 cm. The incident field distribution across the evaluation surface is provided in IEC Formulas A.4 and A.5. sPD was evaluated according to the three definitions of the PD in IEC Formulas 4, 5, and 8 for the two averaging areas of 1 cm^2 and 4 cm^2. The maximum permissible deviation of sPD values is 2%. XFdtd's results are summarized in Table 12.

	Maximum deviation of sPD from reference for 1 cm^2 averaging area (%)	Maximum deviation of sPD from reference for 4 cm^2 averaging area (%)
IEC Formula 4	0.68	0.26
IEC Formula 5	0.68	0.20
IEC Formula 8	1.31	0.49

Table 12: XFdtd's results of the evaluation of the planar averaging algorithm.

2.7 Non-Planar Surfaces (IEC Section A.6.3)

The distribution of the sPD and the psPD was evaluated on the surfaces of four testing geometries:

a. Three SAR Star geometries with different notch lengths.

b. SAM head phantom.

The incident field distribution across the evaluation surface is provided in IEC Formulas A.4 and A.5. sPD was evaluated according to the three definitions of the PD in IEC Formulas 4, 5, and 8 for the two averaging areas of 1 cm^2 and 4 cm^2. The following deviations from the reference results are permitted:

a. For the SAM phantom and for the SAR Star geometries, the maximum permissible deviation of the psPD from the reference results is 1%.

b. For the SAM phantom, the maximum permissible deviation of the sPD from the reference results is 5% normalized to the psPD.

c. For the SAR Star geometries, the maximum permissible deviation of the sPD from the reference results is 40% for a maximum of 2,000 vertices and 5% for the remaining vertices normalized to the psPD.

The evaluation script provided in IEC Annex I was run 24 times (two averaging areas, three formulas, and four geometries) in order to compare XF's results to the reference results supplied online. For each case, the evaluation script returned `STATUS: PASS`.

References

[1] International Electrotechnical Commission (IEC) and the Institute of Electrical and Electronics Engineers (IEEE), *IEC/IEEE 63195-2 Final Draft International Standard (FDIS), Assessment of Power Density of Human Exposure to Radio Frequency Fields from Wireless Devices in Close Proximity to the Head and Body - Part 2: Computational Procedure, (Frequency range 6 GHz to 300 GHz)*, 2021.

[2] International Electrotechnical Commission (IEC) and the Institute of Electrical and Electronics Engineers (IEEE), *IEC/IEEE 62704-1, Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Body from Wireless Communications Devices, 30 MHz - 6 GHz- Part 1: General Requirements for using the Finite Difference Time Domain (FDTD) Method for SAR Calculations*, 2017.

[3] Remcom, Inc., *IEC/IEEE 62704-1 XFdtd 7.9.2 Verification*, 2021.