Qualcomm Technologies, Inc.

Requirements for Human Exposure Assessment of Wireless Electric Vehicle Charging (WEVC) Systems

Qualcomm Regulatory Group

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Executive Summary

- Human exposure to electromagnetic fields generated by WEVC systems considers two distinct effects that must be assessed separately:
    - Localized Induced effects in the human body and the different tissue types (muscle, brain, skin etc.)
    - Localized Induced effects in electronic devices implanted in the human body (Implantable medical devices)
- The acceptable limits for induced effects in the human body are defined by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and transposed into regulation by more than 100 countries.
    - The induced effects are referred to in the standard as "The Basic Restrictions" and have defined limits based on biological studies.
    - Demonstrating compliance with the "Basic Restrictions" for the WEVC applications can only be achieved through use of well-established computational techniques with associated validation measurements. This approach has been validated and accepted by the Regulators including the FCC in the US, who have the most stringent exposure requirements.
- The acceptable limits for induced effects in implantable medical devices is defined by the International Standard ANSI/AAMI/ISO 14117 for Implantable Medical Device (IMD) immunity assessment.
    - The electromagnetic fields generated by a WEVC system must be lower than the immunity limit used in the design of IMD when considering the use case for driver/passenger and the pedestrian bystander.
    - Consideration for lower probability events should also be assessed such as a bystander with IMD who may have fallen next to the WEVC activated vehicle.
- This document clarifies the applicable regulatory limits for WEVC when considering the induced effects in the human body and the field strength limits for interference with implanted medical devices (IMD)
    - Regulatory limits for WEVC @ 85kHz = 170mA/m^2 (averaged over 1cm^2 area) **or** 11.5 V/m (averaged over 2x2x2mm^3 volume) depending on market
    - Interference limit for IMD compatibility with WEVC @ 85kHz =
        - 11.9 A/m (15uT) rms for driver/passenger and bystander use case - ***IMD operation unaffected***
        - 23.4 A/m (29.4uT) rms for lower probability occurrences such as fallen bystander - ***IMD operation may be reversion mode with no permanent damage***

Introduction to ICNIRP

In 1974, the International Radiation Protection Association (IRPA) formed a working group on non-ionizing radiation (NIR), which, after many years of development, has been established as an independent scientific organization—the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The functions of the ICNIRP are to investigate the hazards that may be associated with the different forms of NIR, develop international guidelines on NIR exposure limits, and deal with all aspects of NIR protection.

ICNIRP has two major guidelines for limiting RF exposure:

- 1998 GUIDELINES FOR LIMITING EXPOSURE TO TIME-VARYING ELECTRIC, MAGNETIC AND ELECTROMAGNETIC FIELDS (UP TO 300 GHz)
- 2010 ICNIRP GUIDELINES FOR LIMITING EXPOSURE TO TIME-VARYING ELECTRIC AND MAGNETIC FIELDS (1 Hz – 100 kHz)

The ICNIRP 1998 basic restrictions are defined to prevent whole-body heat stress, excessive localized tissue heating, and nerve stimulation. The ICNIRP 2010 basic restrictions are established based on the most recent biologic studies to address nerve stimulation in the 1Hz ~ 100kHz frequency range. The ICNIRP 2010 guidelines specify the limits in induced electric field E (V/m) for both the Central Nervous System (CNS) and the Peripheral Nervous System (PNS), while the ICNIRP 1998 limits were based on effects seen in the CNS from biological studies and are specified in induced current density (A/m^2).

In the 2010 guidelines, the limit for non-thermal effects was relaxed over the frequency range of 1 Hz to 100 kHz and replaces the low-frequency part of the 1998 guidelines (ICNIRP 1998). ICNIRP is currently revising the guidelines for the high-frequency portion of the spectrum (above 100 kHz).

ICNIRP Limits Transposed into Regulation Worldwide

Many countries have transposed the ICNIRP guidelines into regulations. As of today, ICNIRP 2010 guidelines have not been fully adopted by all countries. In those countries where ICNIRP 2010 guidelines have not been adopted, human exposure assessment is pursuant to ICNIRP 1998 guidelines or requires a direct engagement with the regulator on the applicability of ICNIRP 2010 to WEVC systems operating below 100 kHz.

- EU: Most Member States have adopted the Council Recommendation 1999/519/EC, which is based on ICNIRP, into their regulations. These regulations are the legally binding measures to control EMF exposure of the general public. Member States can elect to apply more stringent limits on a precautionary basis. Reference documents below:
    - Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz).
    - Report on the implementation of the Council Recommendation on the limitation of exposure of the general public to electromagnetic fields (0 Hz – 300 GHz) (1999/519/EC) in the EU Member States, European Commission, Brussels, 2008.

- **USA: FCC: 47 CFR Part 1.1310 and Part 2.1093.**
    - The limits are based on guidelines of the National Council on Radiation Protection and 1992 IEEE C95.1.
        - While the FCC has no defined RF exposure limit or methodology below 100 kHz, the FCC will accept a combination of computational analysis and validation measurements to demonstrate compliance for operation below 100 kHz.
- **China**: China has implemented standard YD/T 2653 for short range devices (SRD) and similar applications related to human exposure to electromagnetic fields (1OHz~30MHz). The standard is based on the 2010 ICNIRP guidelines.
- **Japan**: Japan's Radio-radiation Protection Guidelines are based upon ICNIRP guidelines

Table 1 Regulation adopting ICNIRP guidelines

Countries	Human exposure rules	ICNIRP Revision
Canada	SC-6	Basic Restrictions defined by ICNIRP 2010
EU	1999/519/EC	Basic Restrictions defined by ICNIRP 1998
China	YD/T 2653-2013	Basic Restrictions defined by ICNIRP 2010
Japan	MIC Council Report No. 2035	Basic Restrictions defined by ICNIRP 2010

Definition of the Basic Restriction Limits

Several different criteria were used in the development of the basic restriction limits in the ICNIRP 1998 guidelines for the various frequency ranges:

- Between 1 Hz and 10 MHz, basic restrictions are expressed as a current density limit (Induced J measured in A/m^2) to prevent effects on nervous system functions;
- Between 100 kHz and 10 GHz, basic restrictions are expressed as a SAR limit which is provided to prevent whole-body heat stress and excessive localized tissue heating. In the 100 kHz to 10 MHz range a current density limit also applies.
- Between 10 MHz and 300 GHz, basic restrictions are expressed as a power density to prevent excessive heating in tissue at or near the body surface.

The 2010 Fact sheet from ICNIRP outlines the following main changes between the ICNIRP 1998 guidelines and the ICNIRP 2010 guidelines:

1. The induced internal electric fields (induced E) "is the physical quantity that determines biological effects" and that induced current density (induced J) specified in ICNIRP 1998 should no longer be used.

2. The ICNIRP 1998 guidelines were set to limit the induced current density in the CNS tissue only, while the ICNIRP 2010 guidelines consider effects on the CNS and PNS which covers the whole body.

Table 2 details the basic restrictions from the ICNIRP 1998 guidelines. The yellow highlights the applicable limits for 85 kHz WEVC.

Table 2: ICNIRP 1998 basic restrictions for EMF for frequencies up to 10 GHz

Exposure characteristics	Frequency range	Current density for head and trunk ($mA\ m^{-2}$) (rms)	Whole-body average SAR ($W\ kg^{-1}$)	Localized SAR (head and trunk) ($W\ kg^{-1}$)	Localized SAR (limbs) ($W\ kg^{-1}$)
Occupational exposure	up to 1 Hz	40	—	—	—
	1–4 Hz	40/*f*	—	—	—
	4 Hz–1 kHz	10	—	—	—
	1–100 kHz	*f*/100	—	—	—
	100 kHz–10 MHz	*f*/100	0.4	10	20
	10 MHz–10 GHz	—	0.4	10	20
General public exposure	up to 1 Hz	8	—	—	—
	1–4 Hz	8/*f*	—	—	—
	4 Hz–1 kHz	2	—	—	—
	1–100 kHz	*f*/500	—	—	—
	100 kHz–10 MHz	*f*/500	0.08	2	4
	10 MHz–10 GHz	—	0.08	2	4

[a] Note:

1. *f* is the frequency in hertz.
2. Because of electrical inhomogeneity of the body, current densities should be averaged over a cross-section of 1 cm^2 perpendicular to the current direction.
3. For frequencies up to 100 kHz, peak current density values can be obtained by multiplying the rms value by $\sqrt{2}$ (~1.414). For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$.
4. For frequencies up to 100 kHz and for pulsed magnetic fields, the maximum current density associated with the pulses can be calculated from the rise/fall times and the maximum rate of change of magnetic flux density. The induced current density can then be compared with the appropriate basic restriction.
5. All SAR values are to be averaged over any 6-min period.
6. Localized SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for the estimation of exposure.
7. For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$. Additionally, for pulsed exposures in the frequency range 0.3 to 10 GHz and for localized exposure of the head, in order to limit or avoid auditory effects caused by thermoelastic expansion, an additional basic restriction is recommended. This is that the SA should not exceed 10 mJ kg^{-1} for workers and 2mJ kg^{-1} for the general public, averaged over 10 g tissue.

The ICNIRP 2010 guidelines replace the low-frequency part of the ICNIRP 1998 guidelines. Table 3 details the basic restrictions from the ICNIRP 2010 guidelines.

Table 3: ICNIRP 2010 basic restrictions for human exposure to EMF

Exposure characteristic	Frequency range	Internal electric field ($V m^{-1}$)
Occupational exposure		
CNS tissue of the head	1–10 Hz	0.5/f
	10 Hz–25 Hz	0.05
	25 Hz–400 Hz	2×10^{-3}f
	400 Hz–3 kHz	0.8
	3 kHz–10 MHz	2.7×10^{-4}f
All tissues of head and body	1 Hz–3 kHz	0.8
	3 kHz–10 MHz	2.7×10^{-4}f
General public exposure		
CNS tissue of the head	1–10 Hz	0.1/f
	10 Hz–25 Hz	0.01
	25 Hz–1000 Hz	4×10^{-4}f
	1000 Hz–3 kHz	0.4
	3 kHz–10 MHz	1.35×10^{-4}f
All tissues of head and body	1 Hz–3 kHz	0.4
	3 kHz–10 MHz	1.35×10^{-4}f

Notes:
- f is the frequency in Hz.
- All values are rms.
- In the frequency range above 100 kHz, RF specific basic restrictions need to be considered additionally.

The table below defines the applicable limits for WEVC operating at 85 kHz.

Table 4: Basic Restriction Limits at 85 kHz

ICNIRP Revision	Basic restrictions	
	Induced current density for head and trunk (mA/m^2) (averaged over 1 cm^2 area)	Internal electric field (V/m) (averaged over 2x2x2 mm^3 volume)
ICNIRP 1998	170	
ICNIRP 2010		11.5

Procedure for Assessing WEVC Compliance with Basic Restrictions

Regulatory Limits

Assessment of human exposure to WEVC systems should be assessed against applicable ICNIRP basic restriction limits as the exposure from WEVC systems results from very localized fields.

The computational techniques have reached a level of maturity and standardization which allows their use in EMF exposure assessments of most wireless technologies including WEVC. IEEE 1528.x and IEEE C95.3.1 have standardized the computational methods with established recommendations and definitions:

- Anatomical models for exposure assessments (Virtual Family).
- Numerical techniques to determine the induced fields in the human body.
- Validation approach and uncertainty analysis.

Regulatory authorities have been encouraging the combination of numerical simulation combined with validation mesurements where the measurement equipment and techniques are not available or cannot yield the required level of accuracy e.g. B-field measurements of WEVC using loop probes in close proximity to metal structures where field gradients are steep.

- FCC 47 CFR Part 2.1093: “Compliance with SAR limits can be demonstrated by either laboratory measurement techniques or by computational modeling.” The OET 65 supplement C provides the guidance for SAR measurement and computation.
- Technical norms for the correct application of numerical methods in compliance testing have been developed by IEC/IEEE 62704-1, 2012.

Numerical simulations with anatomical human models may be time-consuming, and so conducting such simulations in various body orientations and positions relative to the WEVC may not be practical. Therefore, we recommend to: (a) perform numerical simulations using homogeneous body and limb models that represent bulk coupling in anatomical models, and (b) apply worst-case body enhancement factors to account for the conservativeness of homogeneous tissue phantoms relative to the localized exposures in inhomogeneous anatomical models. A body enhancement factor is the worst-case RF exposure ratio in anatomical human models to homogeneous phantoms. The body enhancement factor determined for an RF source representing a WEVC system can be re-used for assessing RF exposure from different WEVC systems.

The following steps are recommended to assess WEVC compliance with respect to human exposure limits:

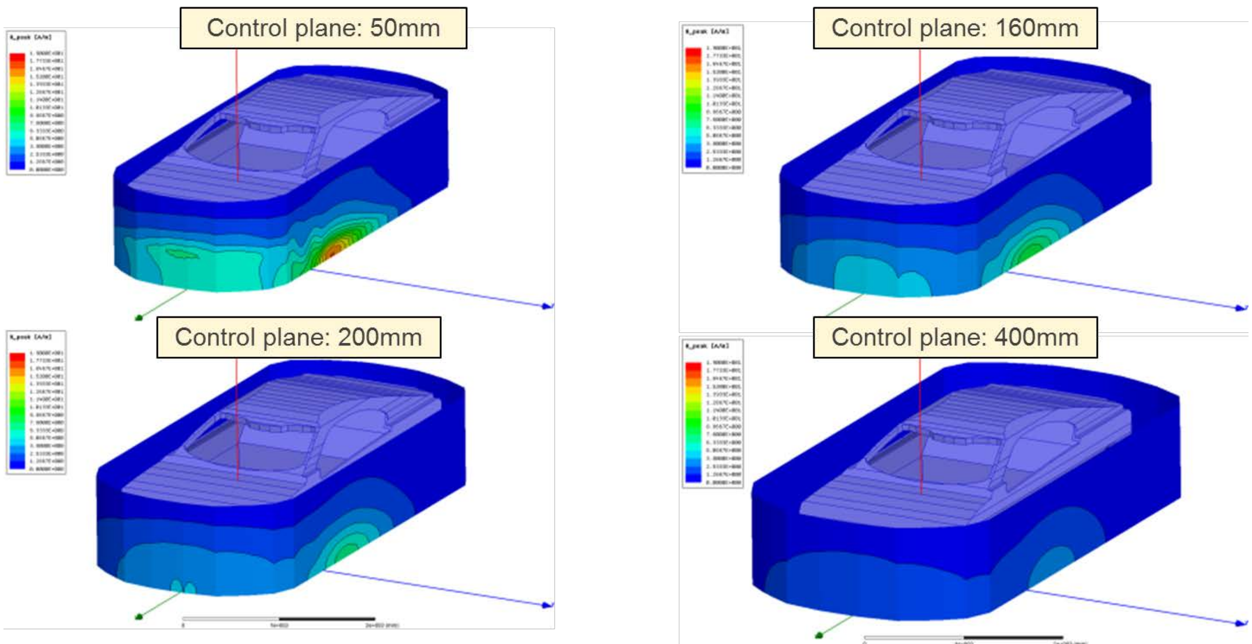
1. Model the wireless power transfer system, including:
    - Geometry of the coil structures
    - Operating frequency
    - Maximum coil currents

- Worst base pad coil to vehicle pad coil relative phases condition

2. Characterize worst case magnetic fields using computational technique(s) recommended in IEEE C95.3. 1 and/or IEEE 1528.x.

- Car form factor
- Worst case ground condition
- Worst case offset condition
- Highest air gap between base pad and vehicle pad

Figure 1: Example of H/B field simulation aound a car



3. Validate that the WEVC configuration is representative

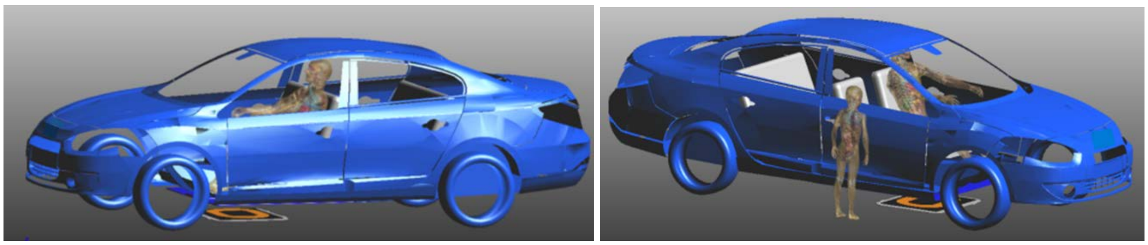
- Perform uncertainty analysis, and calculate the combined extended uncertainty of measurement and simulation
- Compare the simulated results of the magnetic field with measured validation data points. If the error delta is within the combined extended uncertainty, the simulation model is a good representative of WEVC. Otherwise, an improved model is needed.

4. Assess human exposure to the applicable limits when considering standard usage models, i.e. driver/passenger and bystander use cases.

- Induced J in CNS and/or induced E in bystanders, driver or passenger(s) while they are in typical use case position(s).

- Consideration for lower probability events should also be assessed such as a bystanders who may have fallen next to the WEVC activated vehicle.

Figure 2: Example of use case simulations



5. Determine the compliance distances to cover the 95th percentile of the human population and various usage conditions by using homogeneous phantoms and applying a body enhancement factor.

- Homogeneous phantoms
  - **Body phantom:** The Foundation for Research on Information Technologies in Society (IT'IS) has recently developed a body phantom to represent the 95th percentile RF exposure for the human population using the statistical data of weight, height, and body-mass index of the human population.
  - **Limb phantoms:** These phantoms represent wrist and thigh dimensions of the 95th percentile of the human population.
    - Arm phantom: length = 810mm; square cross-section width = 48mm
    - Leg phantom: length = 910mm; circular cross-section diameter = 220mm

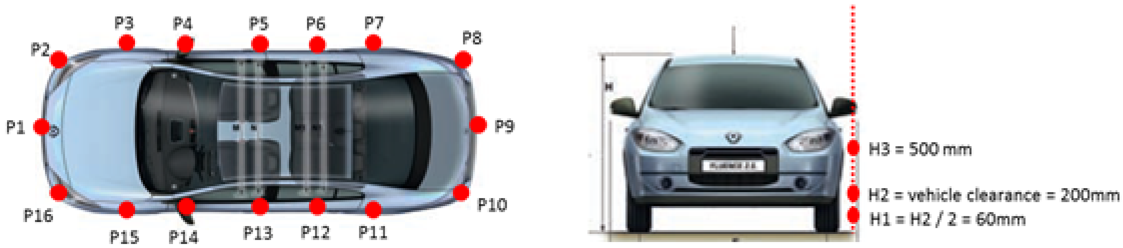
- The dielectric properties of the homogeneous phantom should be representative of human tissue and not underestimate the exposure levels in humans.
  - Muscle tissue with adequate cross-section simulates worst-case bulk coupling for body tissue.
  - Body phantom with brain (grey matter) conductivity is used to assess the induced current density in CNS.

- Apply pre-determined worst-case body enhancement factor to determine RF exposure in humans.

  Evaluate the exposure at various orientations and distances to determine the minimum separation distance(s) required for compliance.

6. Simulation provides a practical way to evaluate all the variables to identify the worst case, and results in a conservative assessment. Validation of simulation by measurements are needed and required by regulators. Validation points should always be selected to minimize the uncertainties associated with the probe being used i.e not used in proximity to metal structures. See Figure 3.

Figure 3: Example of validation points

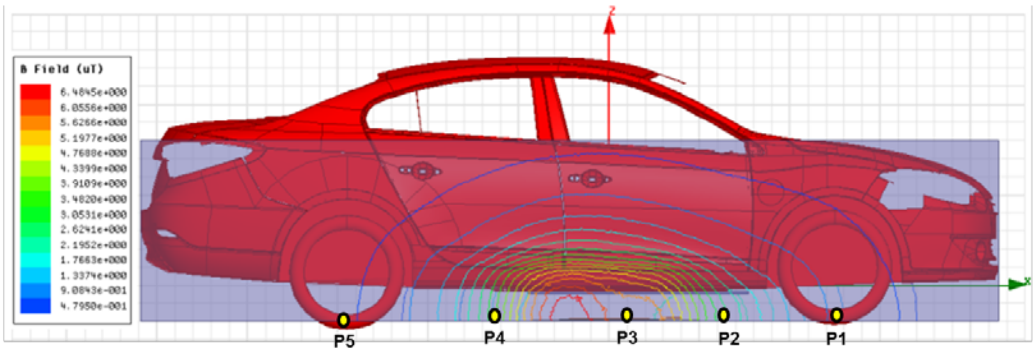


P1	front, center	P14	left, mirror	P3	right, front axle	P7	right, rear axle
P2	front, right	P13	left, center EV pad	P4	right, mirror	P8	back, right
P16	front, left	P12	left, center rear door	P5	right, center EV pad	P9	back, center
P15	left, front axle	P11	left, rear axle	P6	right, center rear door	P10	back, left

Uncertainty Analysis

Without simulation and depending on the number of points tested, the hot spot could be completely missed when relying entirely on probe based measurements (see example in figure 4). Therefore, we recommend using a simulation approach in combination with measurements for validation in order to demonstrate compliance. The correlation between measured and simulated values should be within the combined uncertainty of simulation and measurement (see example below in tables 5-7).

Figure 4: Example of simulation with measurement validation



Test Location		P3	P4	P5	Worst Pt	P6	P7
Measured B (uT) at evenly spaced points		1.12	2.32	4.76	missed	2.02	0.7
Simulated B (uT)	At rated electrical parameters	1.34	2.62	5.62	6.91	2.60	0.91
Simulated B (uT)	Under the condition of ±10% operation range				4.61 ~ 7.38		

Table 5: Example of measurement uncertainty budget

H-field	error(%)	Prob. Distr.	distr. Factor	correction	Unc.	
1.Narda probe:						
Calibration				1	8.0%	
Frequency Response				1	8.6%	
Non-linearity				1	3.4%	
resolution				1	1.4%	
Temperature				1	2.3%	
repeatability				1	2.0%	
2.Positioning:						
Sensor displacement	1.0%	Rect.	1.73	1	0.6%	
Probe displacement	10.0%	Norm.	1.00	1	10.0%	
Anisotropy	5.0%	Rect.	1.00	1	5.0%	
3.Current Source:						
Repeatability	5.0%	Rect.	1.73	1	2.9%	
Stability	10.0%	Norm.	1.00	1	10.0%	
Ground influence	60.0%	Norm.	1.00	1	60.0%	
Std. Uncertainty (k=1)					63%	(4.3 dB)
Expanded Uncert (k=2)					126%	(7.1 dB)

1. Uncertainty values for calibration, frequency response, non-linearity, resolution, temperature, and repeatability were obtained from a Narda uncertainty report [G. Basso. Uncertainty in the measurement of electromagnetic field with isotropic broadband sensor and selective E&H field analyzer. Revision 3. Narda Safety Test Solution. [Online]. Available: www.nardasts.com/pdf/fachartikel/EHP-200_uncertainty_rev03.pdf.]

2. As the sensor locations inside the Narda probe were known to be approximately located along the 3 (out of 6) faces of the probe, the probe was moved +/- 5cm to obtain sensor displacement uncertainty. For probe displacement uncertainty, the Narda probe was positioned +/- 10cm accounting for uncertainty in probe positioning. For anisotropy uncertainty, the Narda probe was rotated 360 degrees about the sensor axis.

3. The WEVC system was turned on and off repeatedly to record the variation in transmitter coil current for repeatability uncertainty. The stability uncertainty was obtained by monitoring current variation over 2 hours. The ground influence was obtained by measuring the WEVC system in various ground conditions.

Table 6: Example of simulation uncertainty budget

Error Description	Uncert.	Prob. Dist.	Div.	Std. Unc.	
FEM Mesh Density[1]	18.0%	Rect	sqrt(3)	10.4%	
Boundary Condition[2]	0.64%	Norm	1	0.6%	
WEVC Coil Modeling Accuracy[3]	5.62%	Norm	1	5.6%	
Convergence of the numerical method[4]	0.25%	Norm	1	0.3%	
Relative phase relationship[5]	33.43%	Norm	1	33.4%	
Combined Std. Unc.				35.5%	(2.6dB)
Expanded Std. Unc.				70.9%	(4.7dB)

1. Mesh density with max length of 20mm around coils region was compared with auto mesh function in Ansoft HFSS v15.0.

2. Boundaries set at 50m away from the edge of the simulation model were moved by ±20%.

3. Base pad and vehicle coils contain many turns made up of litz wire. Simplified numerical model turns were increased from 1 to 4 turns for base pad and from 1 to 2 turns for vehicle pad.

4. Convergence setting was increased from 3 to 4 number of passes with max energy delta set to <0.1

5. Base pad and vechicle pad phase variation +/= 30 deg from their norminal value

Table 7: Example of combined uncertainty budget

Error Description	Uncert.	Std. Unc.	
Simulation	35.5%	35.5%	
Measurement	63.0%	63.0%	
Combined Std. Unc.		72.3%	(4.7dB)
Expanded Std. Unc.		144.6%	(7.8dB)

Implantable Medical Devices (IMDs)

In addition to the human exposure to EMF of WEVC, it is reasonable to expect that patients with IMDs, especially active implantable cardiovascular devices (pacemakers and implantable cardioverter defibrillators, or ICDs) will be exposed to EMF from the WEVC. The interaction between the WEVC and IMDs is a concern of patients, industry and regulators, given the potential life-sustaining nature of these devices.

The requirements for WEVC compatibility with IMDs is derived from the immunity standards by which these devices are designed. Compatibility can be claimed and achieved when the fields associated with WEVC for given use cases are below the immunity levels defined for IMDs.

ANSI/AAMI/ISO 14117 is an international standard for IMD immunity assessment. It specifies performance limits of pacemakers and ICDs, which are subject to interactions with EMF emitters operating across frequency spectrum within 0 – 3000 MHz. This international standard also specifies requirements for the protection of these devices from EM fields encountered in a therapeutic environment and defines their required accompanying documentation, providing manufacturers of EM emitters with information about their expected level of immunity.

The incidence of EMI with medical devices is usually very low in the population, although some interference has been demonstrated in laboratory studies. This is a consequence of two factors. First, the signals from most interfering sources are rejected by medical devices. Second, the improved design of devices over time has resulted in higher immunity of medical devices to many interfering sources due to immunity requirements.

Figure 5: Magnetic field zones for pacemakers and ICDs

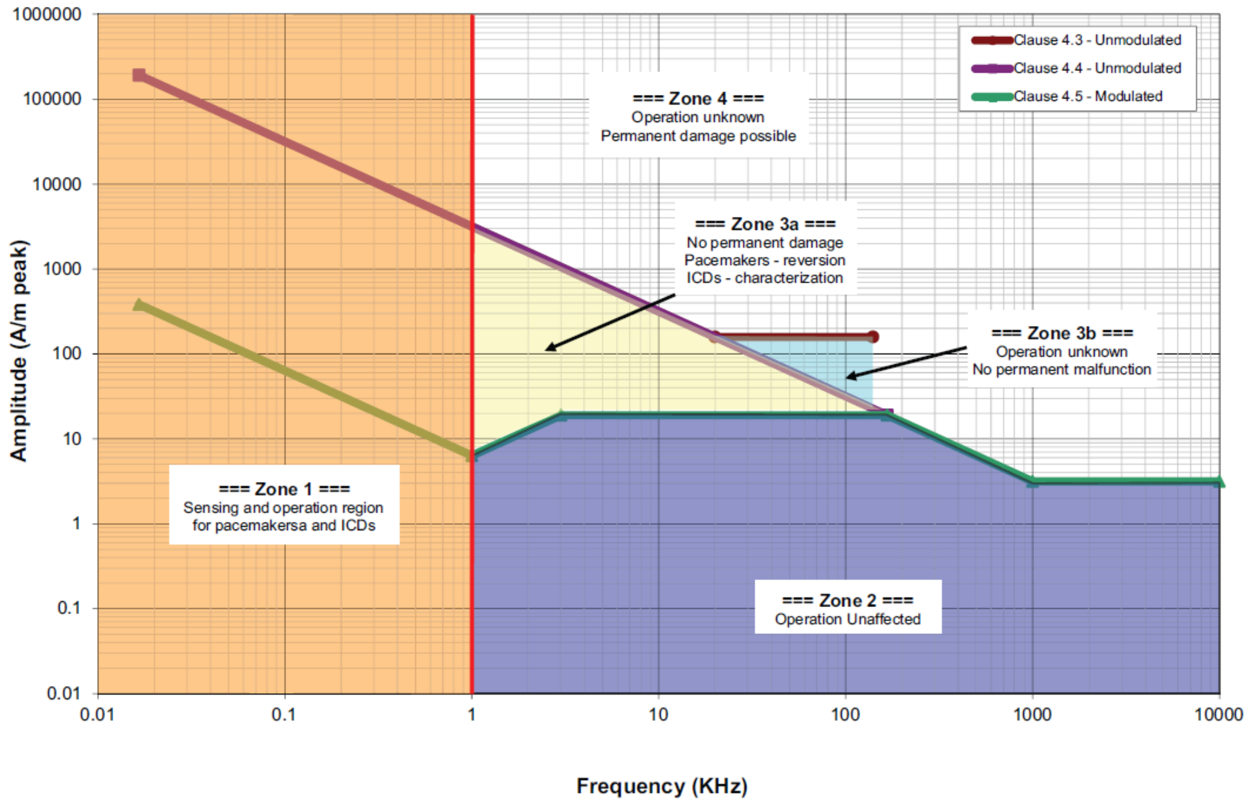


Figure 5 illustrates magnetic limits of different magnetic field zones for pacemakers and ICDs. Using this chart the magnetic field limits for WEVC systems can be defined and compliance can be demonstrated when considering the specific use cases for which humans with IMD's will be in the vicinity of a charging vehicle. The limits for a WEVC system operating at 85 kHz are defined as follows:

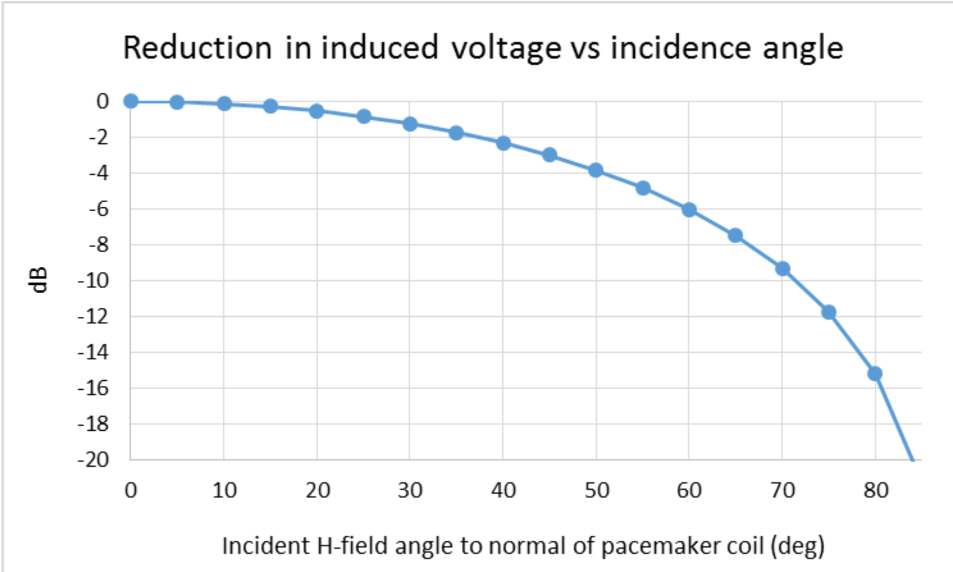
- Interference limit for IMD compatibility with WEVC @ 85kHz =

    1. 11.9 A/m (15uT) rms for driver/passenger and bystander use cases - <u>IMD operation unaffected</u>

    2. 23.4 A/m (29.4uT) rms for lower probability occurrences such as fallen bystander - IMD <u>operation may be reversion mode with no permanent damage</u>

When considering the scenario for a fallen bystander with an implantable medical device, the risk of interference to the IMD should consider the orientation of the IMD relative to the incident H-field and uncertainty analysis. The graph in Figure 6 shows the reduction in induced voltage relative to the incident angle. It should be noted that in measuring the magnetic field using a probe, it is the total H-field (in uT) that is measured while the interference risk (induced voltage in IMD) is only associated with the normal component of the field.

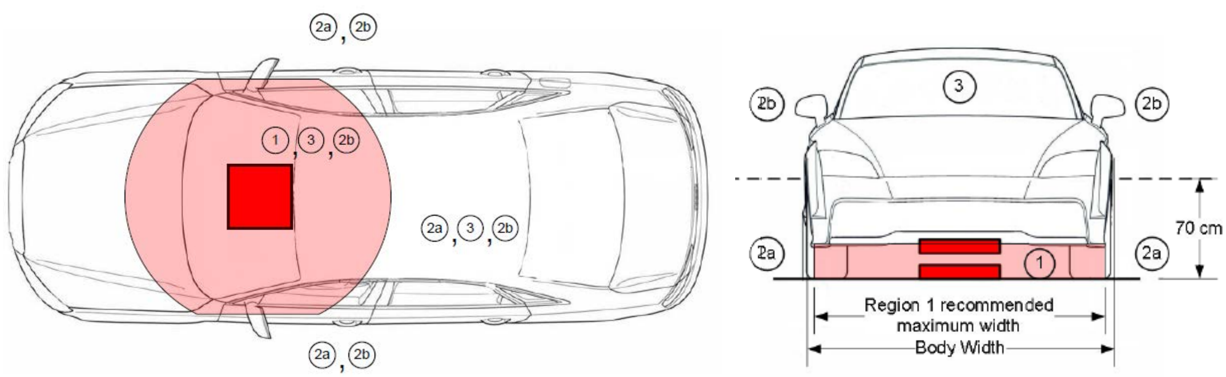
Figure 6: Reduction due to IMD orientation relative to the incident H-field



Measurement Locations for Assessing Potential for Interference to IMD

The following diagrams derived in SAE 2945 are useful for defining the locations for assessing the magnetic fields and determining compliance with the applicable limits above.

Figure 7 : Locations for measuring magnetic fields required to assess potential for interference to IMD (ref: SAE 2945 May 2016)



- Region 1 – is the entire area underneath the vehicle, including and surrounding the wireless power assemblies. In this region, the magnetic fields are high and therefore reasonable measures should be taken to prevent human access to this region.

- Region 2a - is the region around the vehicle, at heights less than 70 cm above ground. Region 2a may additionally include areas under the vehicle. This region would present risk of exposure to lower leg extremities in standard use cases and should be considered for other low probability scenarios such as bystanders who may have fallen next to the vehicle. For IMD assessment, this region should also be considered for this low probability case.

- Region 2b - is the region around the vehicle at heights equal to or greater than 70 cm above ground. The interference risk to humans with implantable medical devices is a key consideration given the bystander use case.
- Region 3 - is the vehicle interior where magnetic fields must meet the IMD immunity levels at the locations, defined by design, where an IMD (in the body) would be positioned.

Certification Process

In addition to human exposure, a WEVC system also needs to meet relevant radio and EMC requirements before it can get an FCC authorization for marketing. Subsystem radios such as LOP, Bluetooth, Magnetic Vectoring, and FOD can obtain modular certification per their applicable rules respectively.

In the U.S., to obtain an authorization for a WEVC subsystem, or a vehicle level system, a DoC or certification process can be used per FCC Part 18. MP5 or the upcoming ANSI 63.30 measurement procedure shall be observed for emission measurement. Individual KDB inquiries must be filed for each type of equipment to obtain further guidance for compliance assessment including emission and human exposure.

Regulatory bodies will accept exposure assessments using the combination of numerical simulation combined with validation mesurements where the measurement equipment and techniques are not available or cannot yield the required level of accuracy e.g. B-field measurements of WEVC using loop probes in close proximity to metal structures where field gradients are steep.

Conclusions

The ICNIRP defined basic restrictions are the limits used for regulatory compliance in a majority of developed markets and are based directly on established health effects. Reference levels are provided for practical and convenient exposure assessment purposes.

This document clarifies the applicable regulatory limits for WEVC when considering the induced effects in the human body and the field strength limits for interference with implanted medical devices (IMDs)

- Regulatory limits for WEVC @ 85kHz = 170mA/m^2 (averaged over 1cm^2 area) **or** 11.5 V/m (averaged over 2x2x2mm^3 volume) depending on market
- Interference limit for IMD compatibility with WEVC @ 85kHz =
  - 11.9 A/m (15uT) rms for driver/passenger and bystander use cases - ***IMD operation unaffected***

- 23.4 A/m (29.4uT) rms for lower probability occurrences such as fallen bystander - *IMD operation may be reversion mode with no permanent damage*

Reference documents

1. ICNIRP PUBLICATION – 1998, ICNIRP GUIDELINES FOR LIMITING EXPOSURE TO TIME-VARYING ELECTRIC, MAGNETIC AND ELECTROMAGNETIC FIELDS (UP TO 300 GHZ),

2. ICNIRP PUBLICATION – 2010, ICNIRP GUIDELINES FOR LIMITING EXPOSURE TO TIME-VARYING ELECTRIC AND MAGNETIC FIELDS (1 HZ – 100 kHz)

3. CFR 47 FCC Part 1 and Part 2

4. EU Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz), July 1999.

5. DIRECTIVE 2013/35/EU, on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents and repealing Directive 2004/40/EC, Official Journal of the European Union, June 2013

6. ANSI/AAMI/ISO 14117, Active implantable medical devices - Electromagnetic compatibility - EMC test protocols for implantable cardiac pacemakers, implantable cardioverter defibrillators and cardiac resynchronization devices.

7. SAE J2954 TIR, Wireless Power Transfer for Light-Duty Plug-In/ Electric Vehicles and Alignment Methodology, May 2016

8. YD/T 2653-2013, Product standard to demonstrate the compliance of short range devices(SRD) and similar applications related to human exposure to electromagnetic fields (1OHz~30MHz)

9. Japan MIC, Information and Communications Council Report No. 2035 (March 2015)