Testing WPT with MAGPy V2.4+

APPLICATION NOTE

Testing Compliance with FCC KDB 447498/680106

speag

Testing Compliance of WPT Devices with MAGPy V2.4+ According to FCC KDB 447498/680106

1 Scope of this Document

This application note provides guidance on how to apply MAGPy V2.4+ for demonstration of compliance with the US Federal Communications Commission (FCC) Knowledge Database (KDB) 447498 D01 [1] and FCC KDB 680106 D01 [2]. MAGPy V2.4+ can be used in the following scenarios:

- demonstration of compliance with the limits of the specific absorption rate (SAR) for inductive wireless power transfer (WPT) devices operating at frequencies ≥100 kHz with coil structures larger than 100 mm, according to Tier 3 of Draft IEC/IEEE 63184 [3] (for coils smaller than 100 mm, MAGPy V2.4+ provides reliable but not conclusive results of compliance),
- demonstration of compliance with the maximum permissible exposure (MPE) limits of the incident electric (E-) and magnetic (H-) fields for inductive WPT devices operating at frequencies < 100 kHz, according to Tier 2 of Draft IEC/IEEE 63184 [3],
- validation of the numerical models of inductive WPT devices for simulation-based assessments.

The MAGPy V2.4+ system supports two compliance evaluation locations: probe center and probe tip. It is the only system that can accurately assess the fields at the probe tip (i.e., at the flat surface of the probe) with a reliable field extrapolation, as the probe not only measures the amplitude but also the gradient of the H-field. This enables the assessment at the surface of the device under test (DUT).

However, the more accurate measurements are in the probe center, i.e., 18.5 mm from the flat surface of the probe. These measurements are direct measurements without extrapolation. Hence, it is advised to set the evaluation location to:

- the probe tip, if the compliance location is < 18.5 mm from the DUT, and
- the probe center, if the compliance location is ≥18.5 mm from the DUT.

Note: The most accurate method with the least overestimation to demonstrate compliance is DASY8/6 Module WPT V2.4+, whereby guidance is provided in [4]. This requires testing in a dedicated laboratory whereas MAGPy V2.4+ can also be applied *in situ*.

2 FCC KDB 680106 D01 Exposure Assessment Requirements

2.1 Scope and Method

General radiofrequency (RF) exposure test requirements are described in FCC KDB 447498 D01 [1]. FCC KDB 680106 D01 [2] provides specific guidance for RF exposure compliance evaluations of WPT devices with respect to FCC equipment authorization for electromagnetic exposure.

The FCC has adopted SAR limits for RF exposure from 100 kHz to 6 GHz, as specified in §1.1310 of Title 47 of the US Code of Federal Regulations [5]. As an alternative to SAR, the guidelines described in [2] also permit evaluation of the incident electric (E-) and magnetic (H-) field strengths against the MPE limits summarized in Table 1 of KDB 447498 [6]. As stated in Section 3.2 of FCC KDB 680106 D01 [2]: *"In addition, present limitations of RF exposure evaluation systems prevent an accurate evaluation of SAR below 4 MHz. For these reasons, a specific MPE-based RF Exposure compliance procedure for devices operating in the aforementioned low-frequency ranges has been set in place."*

It is important to note that the FCC has not established limits to prevent nerve stimulation due to locally induced E-fields at frequencies below 10 MHz[1].

SPEAG has developed the technology to fill these gaps to enable evaluations of SAR, induced E-field, and incident fields from 3 kHz to 10 GHz and beyond.

2.2 Compliance Testing Requirements

Section 3 of FCC KDB 680106 D01 [2] sets out the requirements for compliance testing of WPT devices.

Section 3.1 of KDB 680106 D01 defines the output power, separation distance, and use-case requirements, including justifications for the chosen minimum separation distance for specific use cases.

Section 3.2 of KDB 680106 D01 defines the requirements for situations where SAR cannot be measured and extends the MPE limits to frequencies below 300 kHz. For operating frequencies between 100 kHz and 300 kHz, the values at 300 kHz – i.e., E_{inc} = 614 V/m, H_{inc} = 1.63 A/m, which are root-mean-square (rms) values – apply[2]. For operating frequencies below 100 kHz, MPE limits are temporal peak values[3] of E_{inc} = 83 V/m, H_{inc} = 90 A/m (see Figures 1.1 and 1.2). Section 3.2 of KDB 680106 D01 exempts incident E-field measurements from the compliance testing for devices under test (DUTs) that operate at low frequencies (typically below 1 MHz) and use coil-type emitting structures that have H-fields as the dominant near field.

Section 3.3 of KDB 680106 D01 describes the requirements for measurement validation when probes with a greater than 5 mm sensor offset (i.e., the spacing between the sensor center and the probe outer surface) are used. The fields at positions that cannot be reached must be estimated via either a numerical calculation or an analytical model. The FCC also requests validation of the estimate by comparing the model prediction and the measurement result at the closest reachable positions. For a successful validation, the agreement should be better than 30%.

Section 4 of FCC KDB 680106 D01 provides guidance for the setup of instrumentation to test compliance of WPT devices that are co-located with other RF devices. The principle is that a WPT transmitter should be tested in the presence of a WPT receiver, given that the receiver structure can alter the field strength patterns.

2.3 KDB Submission

In this section, we summarize situations where a KDB Inquiry is needed to demonstrate compliance of WPT devices. As stated in FCC KDB 680106 D01 [2]: *"WPT equipment manufacturers may have to use the KDB Inquiry process to provide documentation demonstrating how the device meets the requirements of this guidance, and only proceed with device authorization upon receiving concurrence from the FCC."*

The following are topics listed in FCC KDB 680106 D01 for submitting a KDB Inquiry:

[1] Adoption of limits on induced E-field (in the frequency range 3 kHz to 10 MHz) at present remains under consideration in the open rulemaking proceeding FCC docket no. 19 226 (NPRM FCC-19-126) [7].

[2] For § 2.1091 mobile devices and § 2.1093 portable devices intended for use by consumers in the general population / uncontrolled environments, only "source-based" time averaging per an inherent property of the RF source is permitted for determining exposure levels (6 min and 30 min time averaging provisions of § 1.1310, based on device maximum duty factor, are not applicable to consumer devices).

[3] Consistent with considerations in FCC-19-126 [7], transient or very short-term peak fields are taken as instantaneous values not to be time-averaged. These limits are applicable in uncontrolled exposure situations; higher limits might be acceptable in controlled exposure situations but require a KDB Inquiry.

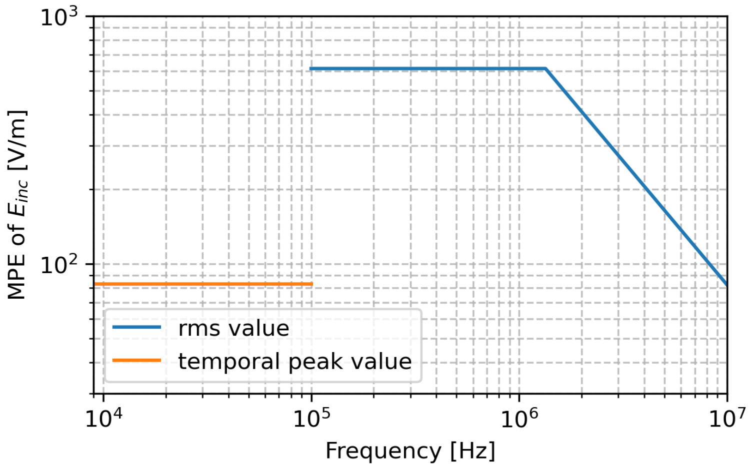

Figure 1.1: MPE limits of the incident E-field defined by the FCC. Note that the limits at frequencies ≥100 kHz are defined in terms of the *rms* value, while those at <100 kHz are defined in terms of the temporal peak value.

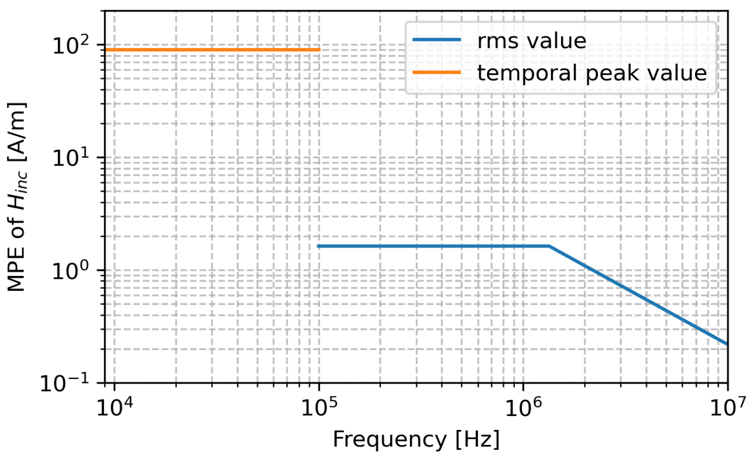

Figure 1.2: MPE limits of the incident H-field defined by the FCC. Note that the limits at frequencies ≥100 kHz are defined in terms of the *rms* value, while those at <100 kHz are defined in terms of the temporal peak value.

– **Distance:** If the WPT device does not comply with RF exposure limits for some unlikely use conditions, a KDB Inquiry is needed (in accordance also with Section 3.3 of KDB 951290 D01 [8]). Information to be covered in the KDB Inquiry includes the selection of the minimum distance, an explanation for why this minimum distance was chosen, and reassurance that any non-compliant use conditions (e.g., getting closer than the minimum distance selected) are highly unlikely to occur.

– **Part 18 WPT devices:** For a WPT device whose charging function is intended for operation under 47 CFR Part 18 (industrial, scientific, and medical equipment), the KDB Inquiry process is required to obtain FCC concurrence, unless exception criteria in Section 5.2 (1) through (6) of KDB 680106 [2] are met. Information to be covered in the KDB Inquiry includes the operating frequency, the conducted power for each radiating structure, operation scenarios, RF exposure compliance information, and the maximum charging distance between the load and the WPT transmitter.

– **WPT "at a distance":** Part 18 WPT transmitters that can provide power to a load beyond a separation distance of 1 m require a KDB Inquiry, in accordance also with Section 3.2 of KDB 951290 D01 [8].

Note: FCC KDB 680106 [2] requires submitting an KDB Inquiry to FCC for compliance testing of WPT devices in most cases. We recommend stating in the inquiry that *"The evaluation is performed according to the attached Application Note "Testing Compliance of WPT Devices with MAGPy V2.4+ According to FCC KDB 447498/680106" issued by SPEAG."*

3 Compliance of MAGPy V2.4+ with FCC KDB 680106 D01

3.1 Measurement of the Incident H-Field

For field measurements at distances <18.5 mm, the compliance location in MAGPy V2.4+ shall be set to probe tip. MAGPy V2.4+ enables assessment of the H-field at the surface of the probe as the probe has information of the field gradient and considers the averaging over the sensor size when the extrapolation function is determined using the measured fields of all eight isotropic sensors and the measured gradient. Hence, MAGPy V2.4+ can be applied to determine the incident H-field at the surface of the DUT. The H-field value at the probe surface (also called probe tip in the MAGPy software) including the associated uncertainty can be directly used to validate the DUT model for simulation-based assessments [9]. For field measurements at distances $\geq$ 18.5 mm, the compliance location in MAGPy V2.4+ shall be set to probe center.

3.2 Measurement of the Incident E-Field

The centers of the isotropic E-field sensors (implemented as dipole/monopole) are in the probe center. The dipole/monopole arms have been designed to provide maximal sensitivity and enable determining if the incident E-field from a source is local or not. The sensors are calibrated for uniform E-field or fields with linear gradients.

3.3 Determination If the E-Field Exposure Can Be Neglected

In case of inductive sources, the fields induced in the human body or its surrogate phantom are dominated by the incident H-field. It can be evaluated if the incident E-field is local and can be neglected with the following procedure:

- demonstrate that the field impedance at 30 mm from the DUT is $< 37.7\,\Omega$ for all cases where the H-field is higher than RL,
- demonstrate that the maximum induced fields due to the incident E-field (determined at the location of the maximum incident E-field, and estimated with the approximation published in [10] after taking the 23 dB worst-case underestimation of the incident E-field into account [11]) are much smaller than the induced fields due to the incident H-field there.

3.4 Assessment of Compliance with BR

MAGPy V2.4+ has the big advantage that it offers direct demonstration of compliance with BR for devices with coil structures larger than 100 mm at any distance (including $d_{meas} \leq 18.5$ mm) and any DUT at distances $d_{meas} > 18.5$ mm.

3.5 Differences between Evaluations with DASY Modules and MAGPy V2.4+

The DASY8/6 Module SAR V16.2+ and Module WPT V2.4+ offer the most accurate methods to determine compliance of WPT devices in accordance with FCC KDB 680106 [2] but require a laboratory environment. DASY8/6 based evaluations are performed according to Tier 4 of [3] without overestimation, and can be performed for any WPT devices with coil structures not larger than 900 mm×900 mm. For details about how to make the compliance testing with DASY8/6 Module SAR and Module WPT, see the Application Note [4].

MAGPy V2.4+ is the most accurate instrument to evaluate WPT devices *in situ*. It is suited for devices with coil structures larger than 100 mm (double the probe diameter). It may be used for smaller devices if the uncertainty is properly developed and assessed for the specific DUT.

4 Compliance Evaluation Procedures from 100 kHz to 10 MHz

4.1 Assessment of psSAR1g/10g

The workflow to demonstrate compliance with SAR limits is illustrated in Figure 1.3. More information/illustration about the relevant operations can be found in Section 3 of the MAGPy Manual [12] and Figure 1.5–1.6. This procedure corresponds to Tier 3 of [3].

Prepare system

- Select the relevant standard (incl. health effect (electrostimulation/thermal/combined) and exposure scenario (general-public/occupational)) (Manual Section 3.4)
- Check the H-field spectrum of the DUT and set the peak frequency search range (Manual Section 3.3)
- Perform a preliminary scan to find a location with high incident fields
- Check default parameters of time-domain slicing and adjust if needed (Figure 1.5a)
- Confirm the multifrequency assessment is enabled (If other frequency components are at least 30 dB lower than the fundamental frequency component and/or are below the probe sensitivity, they will automatically be neglected) (Figure 1.5b)
- Confirm the total induced field evaluation is enabled (Figure 1.5b)

Search for the worst-case probe location and orientation

- Display results in ABS mode (Manual Section 3.7)
- Select the probe tip or probe center as the compliance location for distances $\leq$18.5 mm and $>$18.5 mm respectively (Figure 1.5b)
- Clear the display (Manual Section 3.7)
- Scan the exposure characterization space around the DUT and rotate the probe axis in all directions along which a user or bystander may approach the DUT (note that the body surface is always normal to the probe axis, see Figure 1.6) to find the probe location and orientation resulting in the maximum psSAR1g/10g (Manual Section 3.5) (it is recommended to rotate the probe around its axis by 45 degree to confirm the maximum SAR values)

Extract compliance evaluation results

- Display results in REL mode (Manual Section 3.7)
- Note the maximum relative value for psSAR1g/10g at the worst-case location and orientation; if it is negative (i.e., the maximum psSAR1g/10g is below the corresponding safety limit), then the compliance of the DUT has been successfully demonstrated (Manual Section 3.5)
- Investigate if the E-field exposure local and can be neglected by checking if the E/H ratio at 30 mm from the DUT are much smaller than the free-space wave impedance $377\,\Omega$ and the E-field induced by the maximum incident E-field is much smaller than that induced by the incident H-field there. If the E-field exposure cannot be neglected, a rigorous compliance testing should be made with DASY8/6 Module SAR.
- Save results by taking screenshots and/or exporting data in terms of CSV/JSON files (Manual Section 3.9)

Investigate the transient behavior of the emissions during receiver removal

- Check the incident fields in the time domain at the worst-case location and orientation (Figure 1.7), and scale the compliance evaluation results if appropriate

Figure 1.3: Step-by-step measurement procedure of MAGPy for compliance evaluation against SAR limits. If the demonstration of compliance fails, it is recommended to evaluate the compliance of the device using the more accurate procedures based on DASY8/6 offering less overestimation in SAR [4].

4.2 Uncertainty

As the assessment of the induced fields using the generic gradient source mode (GGSM) method [13] had been designed to be always conservative if the contribution by the incident E-field can be neglected, the uncertainty of the assessment does not need to be considered.

5 Compliance Evaluation Procedures from 3 kHz to 100 kHz

5.1 Assessment of Peak Incident Fields

The workflow to demonstrate compliance with MPE is illustrated in Figure 1.4. More information/illustration about the relevant operations can be found in Section 3 of the MAGPy Manual [12] and Figure 1.5–1.6. This procedure corresponds to Tier 2 of [3].

5.2 Uncertainty

The uncertainties ($k = 2$) of the incident H-fields measured with MAGPy V2.4+ at the probe tip and probe center are typically $< 35.7\%$ and $< 13.9\%$ respectively. The uncertainty ($k = 2$) of the incident E-field measured with MAGPy V2.4+ is typically $< 24.4\%$ (valid for uniform E-field or fields with linear gradients). Detailed uncertainty budgets can be found in Section 8 of the MAGPy Manual [12].

6 Model Validation Procedures from 3 kHz to 10 MHz

6.1 Assessment of Incident H-Field

The workflow to validate the DUT model which can be used in simulation-based assessments against SAR limits is illustrated in Figure 1.8. More information can be found in Section 3.5 of [9].

6.1.1 Uncertainty

The uncertainties of the measured incident H-field and E-field are the same as those presented in Section 5.2.

Prepare system

- Select the relevant standard (incl. health effect (electrostimulation/thermal/combined) and exposure scenario (general-public/occupational)) (Manual Section 3.4)
- Check the H-field spectrum of the DUT and set the peak frequency search range (Manual Section 3.3)
- Perform a preliminary scan to find a location with high incident fields
- Check default parameters of time-domain slicing and adjust if needed (Figure 1.5a)
- Confirm the multifrequency assessment is enabled (If other frequency components are at least 30 dB lower than the fundamental frequency component and/or are below the probe sensitivity, they will automatically be neglected) (Figure 1.5b)

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Search for the worst-case probe location

- Display results in ABS mode (Manual Section 3.7)
- Select the probe tip or probe center as the compliance location for distances $\leq$18.5 mm and $>$18.5 mm respectively (Figure 1.5b)
- Clear the display (Manual Section 3.7)
- Scan the exposure characterization space around the DUT to find the probe location resulting in the maximum H-field (Manual Section 3.6) (it is recommended to rotate the probe around its axis by 45 degree to confirm the maximum H-field value)
- FCC may allow incident E-field measurement to be exempt for DUTs which operate at low frequencies (typically below 1 MHz) and use coil-type emitting structures

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Extract compliance evaluation results

- Display results in REL mode (Manual Section 3.7)
- Note the maximum relative value for the incident H-field at the worst-case probe location; if it is negative (i.e., the maximum H-field at the probe tip is below the corresponding safety limit), the compliance of the DUT has been successfully demonstrated (Manual Section 3.6)
- Investigate if the E-field exposure is local and can be neglected by checking if the E/H ratios at 30 mm from the DUT surface are much smaller than the free-space wave impedance 377 Ω and if the E-field induced by the maximum incident E-field is much smaller than that induced by the incident H-field there. If the above conditions are met, compliance is conclusively demonstrated.
- If the E-field exposure cannot be neglected, measure the incident E-field and extrapolate the field to the DUT surface and estimate the total uncertainty.
- Save results by taking screenshots and/or exporting data in terms of CSV/JSON files (Manual Section 3.9)

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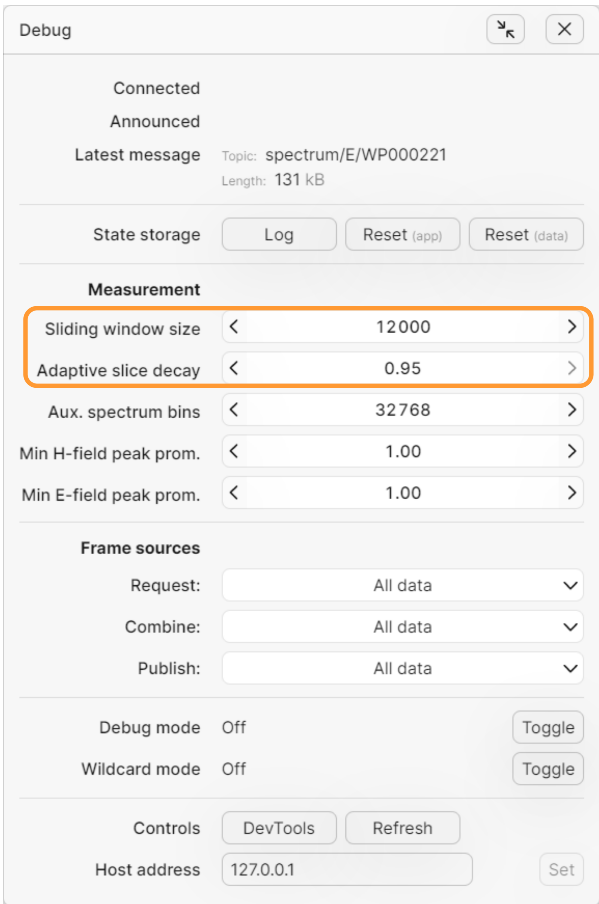
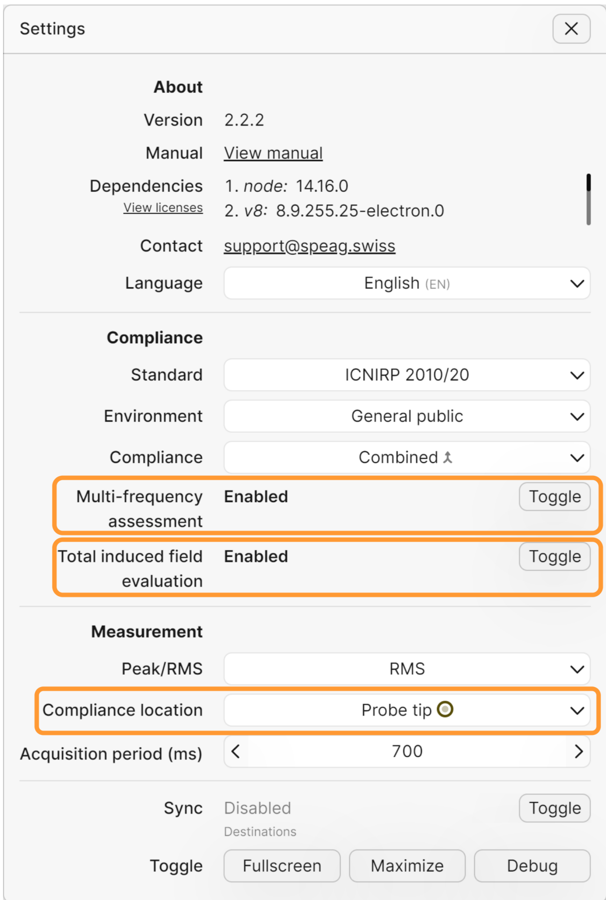
Investigate the transient behavior of the emissions during receiver removal

- Check the incident fields in the time domain at the worst-case probe location (Figure 1.7), and scale the compliance evaluation results if appropriate

Figure 1.4: Step-by-step measurement procedure of MAGPy for compliance evaluation against MPE. If the demonstration of compliance fails, it is recommended to evaluate the compliance of the device using the more accurate procedures based on DASY8/6 offering less overestimation in the incident H-field [4].

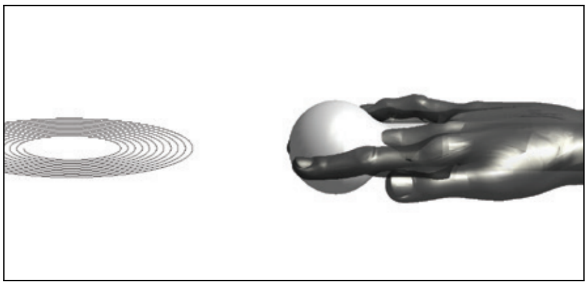


(a) Time-domain slicing setting

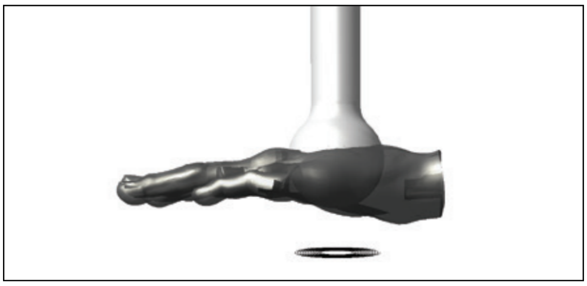


(b) Multi-freq. assessment, total field evaluation and compliance location setting

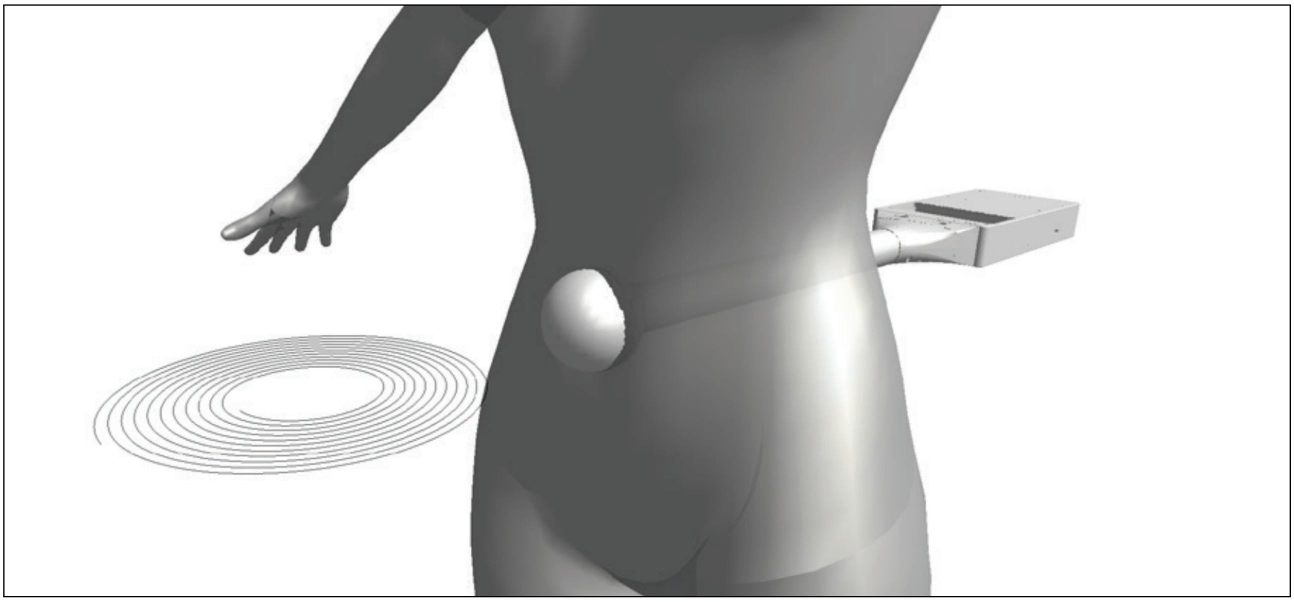
Figure 1.5: Settings of the time-domain slicing parameters, the multifrequency assessment option, the total field evaluation option, and the compliance location



(a) The hand reaches towards a magnetic field source from the side.



(b) The hand is placed on top of a magnetic field source (e.g., mobile charger).



(c) The whole body is in close proximity to the field source.

Figure 1.6: Exposure evaluation scenarios

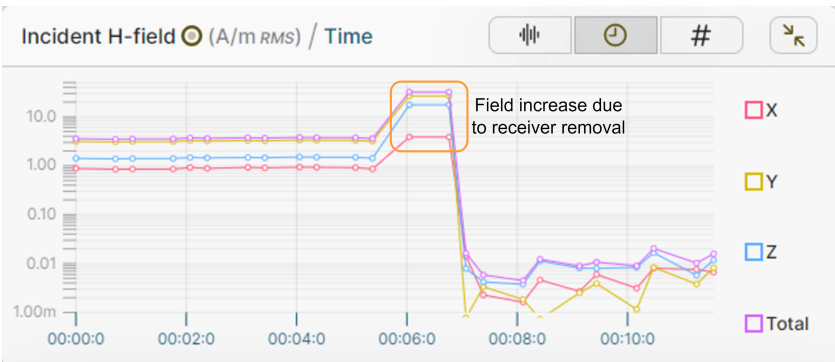


Figure 1.7: The time-domain plot of the incident H-field in the MAGPy graphical user interface. The data were recorded from a commercial wireless charger while removing the smartphone placed on the charger. The same procedure can also be used to monitor the stability of the source.

Prepare system

- Check the H-field spectrum of the DUT and set the peak frequency search range (Manual Section 3.3)
- Perform a preliminary scan to find a location with high incident fields
- Check default parameters of time-domain slicing and adjust if needed (Figure 1.5a)

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Measure incident fields at validation points

- Determine the validation points according to [9]
- Display results in ABS mode (Manual Section 3.7)
- Select the probe tip or probe center as the compliance location for distances ≤18.5 mm and >18.5 mm respectively (Figure 1.5b)
- Clear the display (Manual Section 3.7)
- Mark down the incident H-field measured at each validation point (it is recommended to rotate the probe around its axis by 45 degree to confirm the H-field value)
- Repeat the above steps to obtain results for all validation points

Figure 1.8: Step-by-step measurement procedure of MAGPy for the validation of the numerical DUT model.

7 Conclusion

This application note provides guidance on how MAGPy V2.4+ is used for measurement-based assessments against SAR and MPE limits as required by FCC KDB 447498 D01 [1] and FCC KDB 680106 [2], and the validation of the DUT model for simulation-based assessments. A separate Application Note is available for DASY8/6 Module SAR V16.2+ and WPT V2.4+ [4].

Bibliography

[1] FCC KDB 447498 D01 v06, *RF exposure procedures and equipment authorization policies for mobile and portable devices*, October 2015.

[2] FCC KDB 680106 D01 v04, *Equipment authorization of wireless power transfer devices*, October 2023.

[3] IEC/IEEE 63184, *Assessment methods of the human exposure to electric and magnetic fields from wireless power transfer systems – Models, instrumentation, measurement and computational methods and procedures (Frequency range of 3 kHz to 30 MHz)*, CDV, August 2023.

[4] SPEAG, *Testing compliance of WPT devices with DASY8/6 Module WPT V2.4+ according to FCC KDB 447498/680106*, January 2024.

[5] United States Code of Federal Regulations (CFR), Title 47, Section 1.1310, *Radiofrequency radiation exposure limits*, https://www.ecfr.gov/current/title-47/chapter-I/subchapter-A/part-1/subpart-I/section-1.1310.

[6] FCC KDB 447498 D01 DR05, *RF exposure procedures and equipment authorization policies for mobile and portable devices*, draft for review, August 2022, https://apps.fcc.gov/oetcf/kdb/reports/ExpiredDocumentList.cfm (Accessed: 12-Dec-2023).

[7] FCC-19-126, ET Docket No. 19-226, *Targeted changes to the Commission's rules regarding human exposure to radiofrequency electromagnetic fields*, December 2019, https://docs.fcc.gov/public/attachments/FCC-19-126A1$_$Rcd.pdf, (Accessed: 12-Dec-2023).

[8] FCC KDB 951290 D01 v01, *Equipment compliance review (ECR) inquiries*, August 2023.

[9] SPEAG Application Note, *Testing WPT devices by simulations: Guidance for best practice*, January 2024.

[10] Christ, Andreas and Fallahi, Arya and Neufeld, Esra and Balzano, Quirino and Kuster, Niels, *Mechanism of Capacitive Coupling of Proximal Electromagnetic Sources With Biological Bodies*, Bioelectromagnetics, vol. 43, no. 7, pp. 404–412, 2022.

[11] SPEAG Application Note, *Characterization of MAGPy's electric field sensor for highly localized sources* $<$ 10 *MHz*, January 2024.

[12] SPEAG, *MAGPy V2.4 manual*, February 2024.

[13] Liorni, I., Lisewski, T., Capstick, M. H., Kuehn, S., Neufeld, E., and Kuster, N., *Novel method and procedure for evaluating compliance of sources with strong gradient magnetic fields such as wireless power transfer systems*, IEEE Transactions on Electromagnetic Compatibility, 62(4), 1323-1332, 2019.