International Telecommunication Union

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Radiocommunication Sector of ITU

Report ITU-R SM.2451-1

(07/2022)

Assessment of impact on radiocommunication services from wireless power transmission for electric vehicle operating below 30 MHz

SM Series

Spectrum management

International Telecommunication Union

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

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***Note**: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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REPORT ITU-R SM.2451-1

Assessment of impact on radiocommunication services from wireless power transmission for electric vehicle operating below 30 MHz

(2019-2022)

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Acronyms and abbreviations

AM	Amplitude modulation
ATS	Automatic Train Stop systems
BBC	British Broadcasting Corporation
CEPT	European Conference of Postal and Telecommunications Administrations/Conférence européenne des administrations des postes et des télécommunications
CISPR	Comité International Spécial des Perturbations Radioélectriques
EBU	European Broadcasting Union
ERC	European Radiocommunications Committee
EV	Electric vehicle
IEC	International Electrotechnical Commission
ITRS	Inductive Train Radio System
ITU-R	ITU Radiocommunication Sector
LF	Low frequency
LORAN	Long-range navigation
MF	Medium frequency
MF-WPT	Magnetic field wireless power transfer
OATS	Open Area Test Site
PHEV	Plug-in hybrid electric vehicle
RR	Radio Regulations
SAE	Society of Automotive Engineers
SDO	Standards Development Organization
SFTS	Standard frequency and time signal
SPICE	Simulation Program with Integrated Circuit Emphasis
SRD	Short range device
TC	Technical Committee
WPT	Wireless power transmission
WPT-EV	Wireless power transmission for electric vehicles
WRC	World Radiocommunication Conference

Related ITU Recommendations, Reports

Recommendation ITU-R P.372

Recommendation ITU-R SM.329

Recommendation ITU-R SM.1056

Recommendation ITU-R SM.1753

Recommendation ITU-R SM.1896

Recommendation ITU-R SM.2110

Recommendation ITU-R SM.2129

Report ITU-R SM.2153

Report ITU-R SM.2303

Report ITU-R SM.2452

NOTE – The other relevant ITU-R Recommendations and Reports should be considered for the protection of radiocommunication services.

1 Introduction

There are various wireless power transmission (WPT) applications in use, in experimental, or in implementation phase throughout the world. The frequencies used for WPT for electric vehicle charging (WPT-EV) are used also by radiocommunication systems or services. The impact of WPT-EV applications on existent radiocommunication services were not sufficiently known. In order to examine this possible impact of WPT-EV on the radiocommunication services operating in the same or adjacent/larger separation frequencies, WRC-15 agreed that ITU-R should study this impact via its Resolution **958 (WRC-15)** as of *Annex 1 a) and b)* as one of the urgent studies required in preparation for the 2019 World Radiocommunication Conference (WRC-19). Agenda item 9.1 issue 9.1.6 was included in the agenda of WRC-19 for this purpose.

Resolution **958 (WRC-15)** also asks to study suitable harmonized frequency ranges which would minimize the impact on radiocommunication services from WPT-EV. When considering potential candidate frequency bands, impact studies on services already having allocations in these frequency bands and in adjacent or larger separation bands are necessary. These studies should take into account the current and planned use of these frequencies by existing services and their necessary protection from WPT-EV emissions.

This Report covers the impact assessment of the WPT-EV on the radiocommunication services operating in the same or adjacent/larger separation frequencies in order to provide necessary protection to the radiocommunication services. It is also intended to provide guidance to the administrations wishing to allow implementation of WPT-EV technologies in the proposed ranges[1] in order to minimize the potential impact of WPT-EV on radiocommunication services.

2 Technical characteristics and protection requirements of radio services

There are potentially a large number of radio services that could be impacted by operation of WPT-EV. The impact can be on the same frequency, adjacent frequencies or frequencies with larger separations (i.e. harmonic frequencies). Information on the technical characteristics and protection requirements for radio services used in impact studies is provided in Table 1.

[1] Frequency recommendations for WPT-EV are contained in Recommendation ITU-R SM.2110, and some protection criteria are still under study.

TABLE 1

Radiocommunications service/system technical characteristics and protection requirements for use in impact studies

Frequency range	Service/System	Application	Characteristics and protection requirements (reference)
50 Hz-10 kHz	T-Coil systems	Hearing Aids	Annex 11
5-200 kHz	Metrological Radio Aids	Lightning detection system	
10-250 kHz 425-524 kHz	Automatic Train Stop Systems (ATS)	Railway safety applications	Annex 7
14-19.95 kHz	FIXED MARITIME MOBILE		
14-19.95 kHz	Standard Frequency and Time Signal Service	RR Article **5.56** "Such stations shall be afforded protection from harmful interference"	
19.95-20.05 kHz (20 kHz)	Standard Frequency and Time Signal Service		Annex 1
19.5-21.5 kHz (20.5 kHz)	Standard Frequency and Time Signal Service	20.5 kHz time signal used in Russian Federation	(Future work)
20.05-70 kHz	FIXED MARITIME MOBILE		
20.05-70 kHz	Standard Frequency and Time Signal Service	RR Article **5.56** "Such stations shall be afforded protection from harmful interference"	
39-41 kHz (40 kHz)	Standard Frequency and Time Signal Service	40 kHz time signal used in Japan	Annex 1
59-61 kHz (60 kHz)	Standard Frequency and Time Signal Service	60 kHz time signal used in Japan, United Kingdom and United States of America	Annex 1
68.25-68.75 kHz (68.5 kHz)	Standard Frequency and Time Signal Service	68.5 kHz time signal used in China	Annex 2
77.25-77.75 kHz (77.5 kHz)	Standard Frequency and Time Signal Service	77.5 kHz time signal used in Germany	Annex 1 and Annex 2

TABLE 1 *(end)*

Frequency range	Service/System	Application	Characteristics and protection requirements (reference)
72-84 kHz 86-90 kHz	Standard Frequency and Time Signal Service	In Region 1 only. RR. Article **5.56** "Such stations shall be afforded protection from harmful interference"	
90-110 kHz	RADIONAVIGATION Maritime Radio	Loran-C	Annex 5
99.75-102.5 kHz (100 kHz)	Standard Frequency and Time Signal Service	100 kHz time signal used in China	Annex 2
128.6-129.6 kHz	Fixed	Radio Ripple control	
130-535 kHz	Aeronautical	Non-directional beacons	
135.7 kHz-137.8 kHz	Amateur		Annex 10
157.5-166.5 kHz	Standard Frequency and Time Signal Service		Annex 2
148.5-283.5 kHz	Broadcasting	Low Frequency (LF) AM sound broadcasting	Annex 1 and Annex 8
255-405 kHz	AERONAUTICAL RADIONAVIGATION		
424, 490, 518 kHz and 495-505 kHz	Maritime		
472-479 kHz	Amateur		Annex 10
525-1 705 kHz	Broadcasting	Medium Frequency (MF) AM sound broadcasting	Annex 1, Annex 5 and Annex 8
1 800-2 000 kHz	Amateur		Annex 10
< 30 MHz	Services have indicated concerns on the levels of unwanted emissions. In particular, Aeronautical, Maritime, Broadcasting and Amateur		Annex 1

3 System characteristics of WPT-EV applications

3.1 Radio characteristics of WPT-EV

The radio characteristics of typical WPT-EV are summarized in Table 2 based on the available information in ITU-R and general parameters of typical WPT-EV are summarized in Table 3 and have been used in impact studies. Details on emission levels, including unwanted emissions can be found in Annex 2. Details on draft limits being proposed by Standards Development Organisations (SDOs) can be found in Annex 3.

The limits under discussion in CISPR/B have been used in some impact studies and are contained in Tables A3-1 and A3-2 in Annex 3. The CISPR Subcommittee B is working to introduce emission limits and their measurement methods for WPT charger for EV into the next edition (Edition 7) of the standard CISPR 11.

Also, Table A7-1 in Annex 7 introduces emission limits for WPT for EV applications in Japan, which was obtained from Japan's domestic impact study results.

TABLE 2

Radio characteristics of example of emission levels of WPT-EV in impact studies

Frequency band (kHz)	Centre frequency (kHz)	Emission mask	Frequency stability (Hz)	Power level (kW)	Emission level of the fundamental at 10 m (dBμA/m)	Emission level of the third harmonic at 10 m (dBμA/m)	Unwanted emission levels	Usage
19-21/ 55-57[2] 63-65	19-21 (Note 1)	Annex 3	Note 1	22-120	Annex 2	Annex 2	Annex 2	Heavy duty
79-90	79-90 (Note 1)	Annex 3	Note 1	1-22	Annex 2	Annex 2	Annex 2	Light duty

NOTE 1 – Not standardized yet. Dependent on product design. Refer to appropriate SDOs for frequency requirements.

TABLE 3

General parameters of typical WPT-EV

Parameter/input	19-21 kHz/55-65 kHz WPT- EV	79-90 kHz WPT- EV
Application area	Heavy duty electric vehicle (buses, trucks, etc.)	Light duty passenger electric vehicle
Power levels	22-120 kW	1-22 kW
Typical power level	100 kW for bus systems	11 kW for passenger vehicle
Frequency use within the operating frequency band	– Variable tuning searching and choosing the operating frequency for best efficiency – dedicated discrete operating frequencies – fixed operating frequency	
Sources of radiated emissions	– Power electronics generating transmitting energy – Cables coupling the energy to the charging pad – Magnetic elements (Ferrite antennas) of the charging pad	
Coupling mechanism	Inductive, Resonant	

[2] This frequency range is the third harmonic of fundamental in the 19-21 kHz frequency range. Both the fundamental and third harmonic are used together to achieve a higher power transfer efficiency for some inductive systems.

TABLE 3 *(end)*

Parameter/ input	19-21 kHz/55-65 kHz WPT- EV	79-90 kHz WPT- EV
Coupling situation (air gap between vehicle and charging pad)	Near field 0.2 .. 0.35	Near field 0.08 .. 0.3 metres
Efficiency of the coupling system	80% .. 85%	80% .. 95%
Use-cases	– At bus garage – At bus terminal	Private parking – At home – At the office In public locations – Open parking lots – Open parking lots on the street – Multi stories parking lots – Underground parking lots
Charging direction	Unidirectional/bidirectional	
Expected density for WPT-EV charging pads	1 unit/100 m² – At bus garage – At bus terminal	5 units/100 m² In parking garage: same density on each floor

3.2 19-21 kHz/55-65 kHz WPT-EV usage scenario

The main usage scenario envisaged for heavy vehicle WPT-EV operating in the 19-21 kHz/ 55-65 kHz frequency ranges is for buses. The usage scenarios are shown in Table 4.

TABLE 4

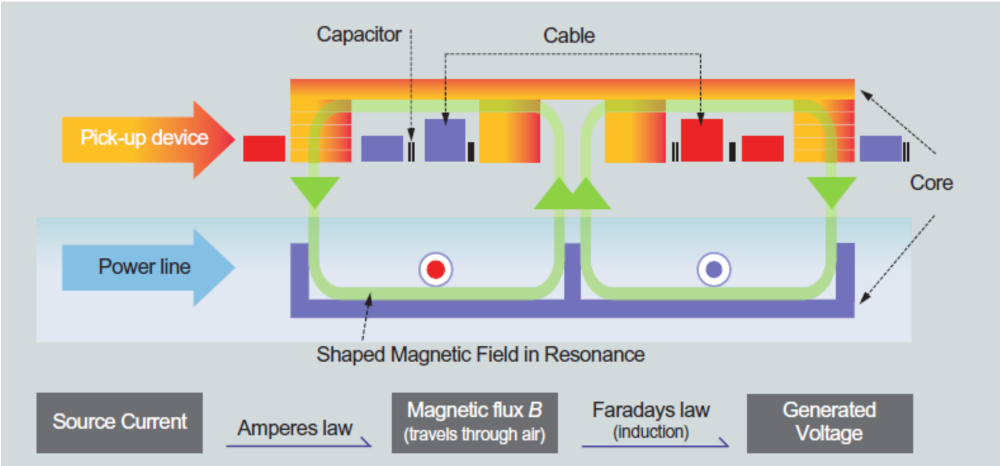
Usage scenarios for 19-21 kHz/55-65 kHz WPT-EV used for bus systems

Scenarios	Charging time per vehicle	Number of buses on a bus route	Number of vehicles that can charge simultaneously	Charging power	Efficiency
Depot based WPT-EV for heavy vehicles (e.g. at bus terminus/ depot/garage)	15-20 mins	6 buses on route, 45 min between WPT-EV terminals, 90 min round trip	4 (1-2 typical)	100 kW	85%
On-street WPT-EV for heavy vehicles (e.g. bus stops)	Not currently envisaged				
Dynamic charging (when vehicle is in motion)	This is considered not feasible and there is no use case				

The basic configuration of typical WPT-EV is shown in Fig. 1. In order to charge vehicles, the power supply system (primary device) may be embedded under the ground or placed on the ground that magnetically transfer energy to battery-powered vehicles above. The bus can be charged at the bus garage without stopping.

FIGURE 1

System structure of typical WPT-EV



Wireless power transfer between an AC power supply and EV is based on the principle of power transfer via magnetic field. A power supply system (e.g. IEC TC69-Primary device) and a pickup device (e.g. IEC TC69-Secondary device) are used for this purpose. Such a WPT-EV system may incorporate one or more coils. Two devices are coupled inductively resonant.

NOTE – The length unit in the following two Figures is mm.

FIGURE 2

Typical cases of charging for WPT-EV

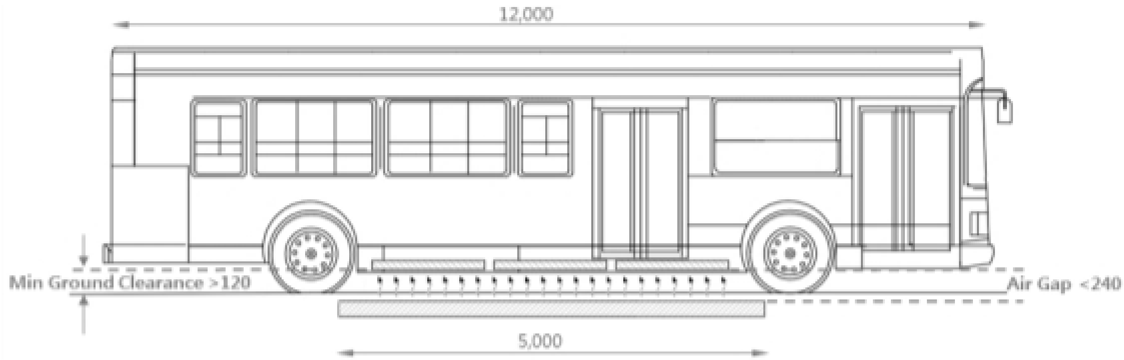


FIGURE 3

Power supplying system (primary device)

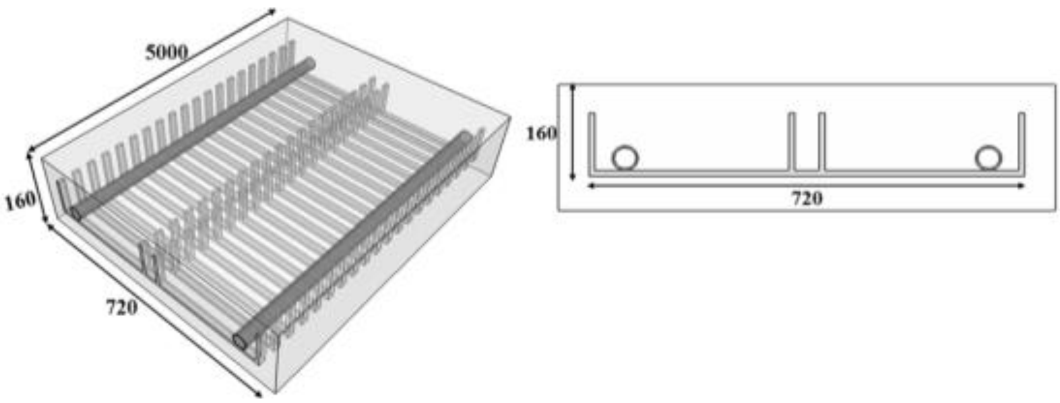
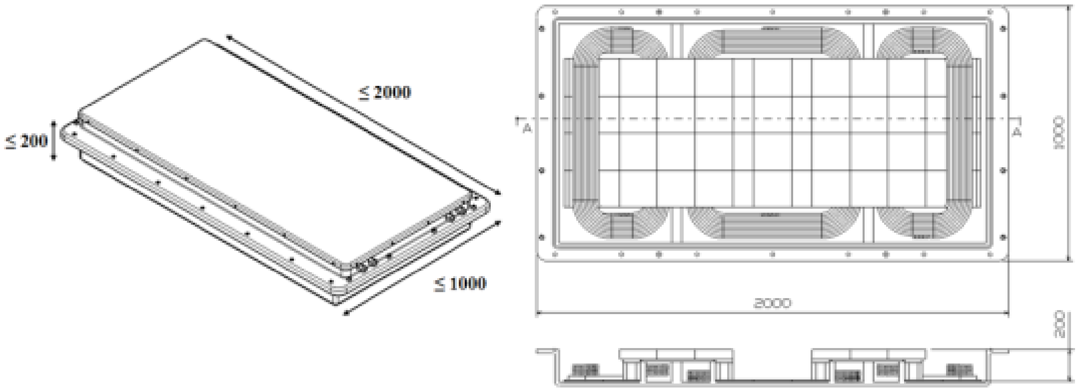


FIGURE 4

Typical pickup device (secondary device)



3.3 79-90 kHz WPT-EV usage scenario

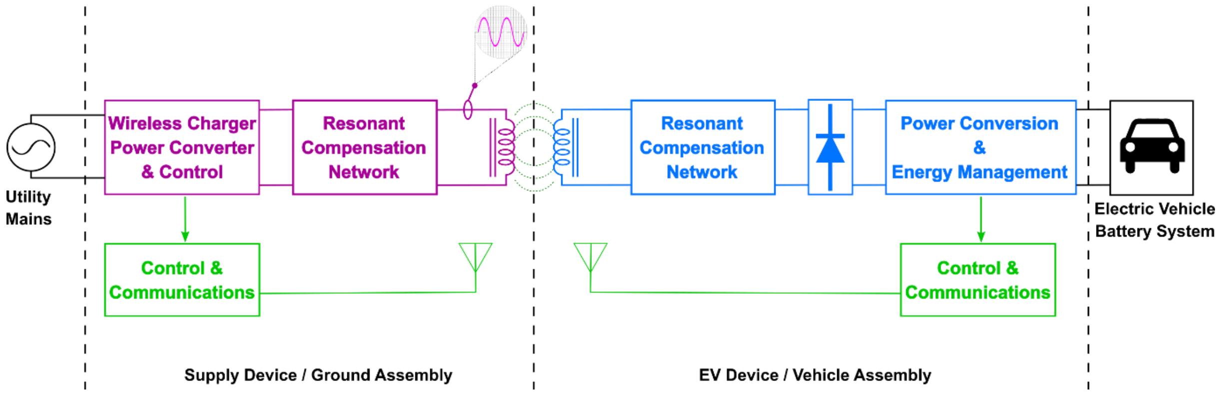
3.3.1 Brief explanation of WPT systems being standardized by SDOs

WPT-EV systems are being actively pursued across the globe in support of global initiatives for utilization of electric vehicles. WPT-EV systems are seen by the SDOs as being a critical part of the infrastructure for static and dynamic charging of electric vehicles. There are three primary SDOs with publications for Systems of Wireless Power Transfer for Electric Vehicles (WPT-EV). These are IEC/TC69/WG7, ISO/TC22/SC37/JPT19363 and SAE J2954. Through coordination, these three SDOs are harmonizing the requirements for these systems to help ensure world-wide interoperability.

WPT-EV systems are designed to transfer energy wirelessly, with measured efficiency between 85% and 93%, from a coil assembly on the ground (primary device) to a coil assembly placed underneath the electric vehicle (secondary device). The wireless transfer occurs by means of a magnetic field using near-field magnetic properties and resonance. Figure 5 shows a block diagram of such a system.

FIGURE 5

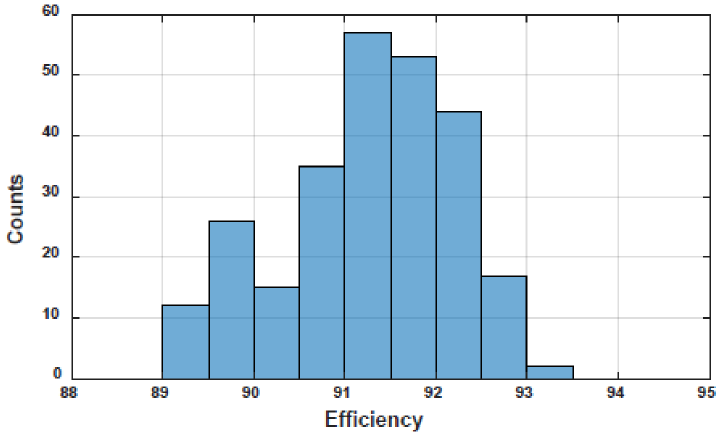
Typical block diagram of a WPT-EV system from SDOs



In general, there are two main subsystems in the WPT-EV system, namely the Supply Device (from IEC and ISO)/Ground Assembly (GA) (in SAE) and the EV device (IEC and ISO)/Vehicle Assembly (VA) (in SAE J2954). The Supply Device's responsibility is to generate a magnetic field at the desired operating frequency, while the EV Device converts the magnetic field into a DC power that can be used by the EV.

FIGURE 6

WPT efficiency distribution over operating range



Based on extensive research and review; IEC, ISO, and SAE have determined that the fundamental operating frequency of the WPT-EV system for light duty applications should be within 79-90 kHz. While a frequency band is provided, it is generally expected that a given system will operate nominally at a fixed frequency within this range and not adjust its frequency during power transfer. These systems are expected to operate at efficiencies greater than 80% though measurements have shown typical efficiencies are ~90% AC input to DC output, see Figure 6. All energy transfer only occurs at the fundamental frequency.

During operation, the voltage generated by the Power Converter excites the Compensation Network that operates using resonance with the Primary Device coil. A resultant near sinusoidal current in the Primary Device coil then induces a proportional magnetic field. The energy is coupled between the Primary Device and the Secondary Device through the means of this magnetic field. Both coils can be described using a model of a loosely coupled transformer structure. Because the current generated in the Primary Device coil is sinusoidal and not modulated during power transfer, the field produced is a Continuous Wave (CW).

As of June 2019, the WPT-EV systems for power classes up to 11.1 kW are being standardized by the relevant SDOs. The frequency range of 79-90 kHz is expected to be used for all light-duty vehicles.

SAE J2954 has done studies on several interoperable systems and has published a subset of their data in a Technical paper presented at SAE World Congress in April 2019 titled "Validation of Wireless Power Transfer up to 11 kW Based on SAE J2954 with Bench and Vehicle Testing" (https://www.sae.org/publications/technical-papers/content/2019-01-0868/). Additional testing is included in Annex 12.

Standards for WPT-EV systems have been in development since 2010. Standards such as SAE J2954, ISO 19363, and IEC 61980 have active development for WPT-EV systems and have all collaborated to ensure some degree of harmonization. Most of these standard's bodies have committed to releasing a full standard in 2020 or 2021 such as SAE J2954 which was released in October of 2020. These standards are established to ensure interoperability between various manufacturers' systems, but they also contain important information about human and cardiac implantable electronic device (CIED) EMF safety as well as recommendations for electromagnetic compatibility (EMC) and appropriate conditions for emissions testing to meet global requirements. In 2017, SAE J2954 setup a cooperative research programme, which has been actively testing systems since inception and making recommendations based on that testing for harmonized standard adoption.

In 2018 and 2019, SAE J2954 sent liaison letters to ITU-R outlining EMC related requirements, indicated that emissions studies had been underway since 2010, and provided the results of those studies. Furthermore, the general characteristics of standardized WPT-EV systems were provided.

WPT-EV systems based on the aforementioned standards:

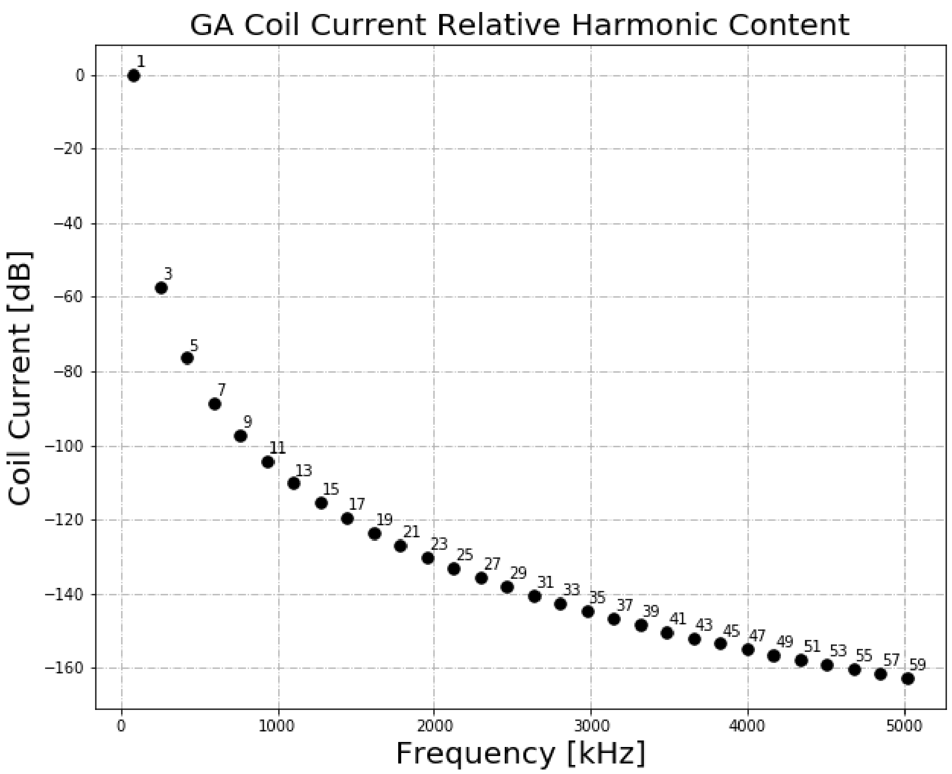
– Use near-field magnetic resonance to transfer energy wirelessly between a loosely coupled ground coil assembly and a vehicle coil assembly by means of evanescent magnetic field coupling.
– Utilize filtered sinusoidal currents in the ground assembly coil to generate a local magnetic field for transferring power.
– Have an efficiency from AC mains input to DC output greater than 80% though measured values have shown typical efficiencies at 89% to 93%.
– Operate in the range of 79-90 kHz (nominally 85 kHz) but do so at a fixed frequency across the full charging cycle of a vehicle.
– Do not modulate the wireless energy between the ground and vehicle coil assemblies in any way for communication but instead utilize out-of-band wireless communications (such as Wi-Fi), which follow well-established global radio requirements.
– Meet set requirements for human and CIED EMF safety based on ICNIRP 2010 guidelines for human exposure and ISO 14117 guidelines for CIED magnetic field compatibility.
– Meet interoperability requirements for light duty vehicles and power levels starting from 3.7 kW (WPT1 power class) to 11.1 kW (WPT3 power class).
– Meet minimum alignment tolerance requirements as ±75 mm in the direction of vehicle travel and ±100 mm in the lateral direction.
– Meet requirements for foreign object detection to prevent unsafe metallic object heating.
– Meet general interoperability requirements including defined controls and communications standards.

Although radiated emissions are not based solely on the current characteristics in the coil, it is useful to understand the expected harmonic content of the current in the ground assembly coil which transfers the power wirelessly via evanescent coupling to the vehicle assembly coil.

The image shown below shows calculated relative harmonic content based on Fourier Series calculations to derive the expected ground assembly coil current for a standardized system.

FIGURE 7

Calculated relative harmonic content of WPT-EV coil current in ground assembly



Additionally, SPICE simulations show expected time domain and frequency domain plots of the current in the ground assembly coil.

FIGURE 8

SPICE simulated time-domain current waveform of coil current in WPT-EV ground assembly

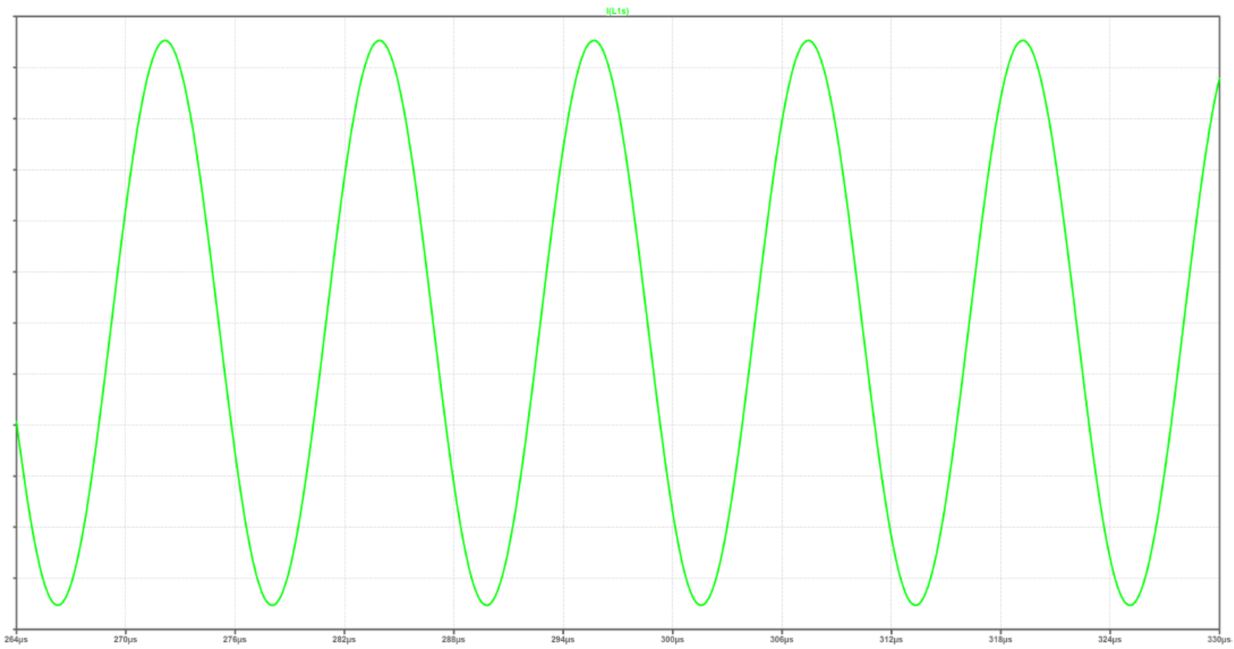
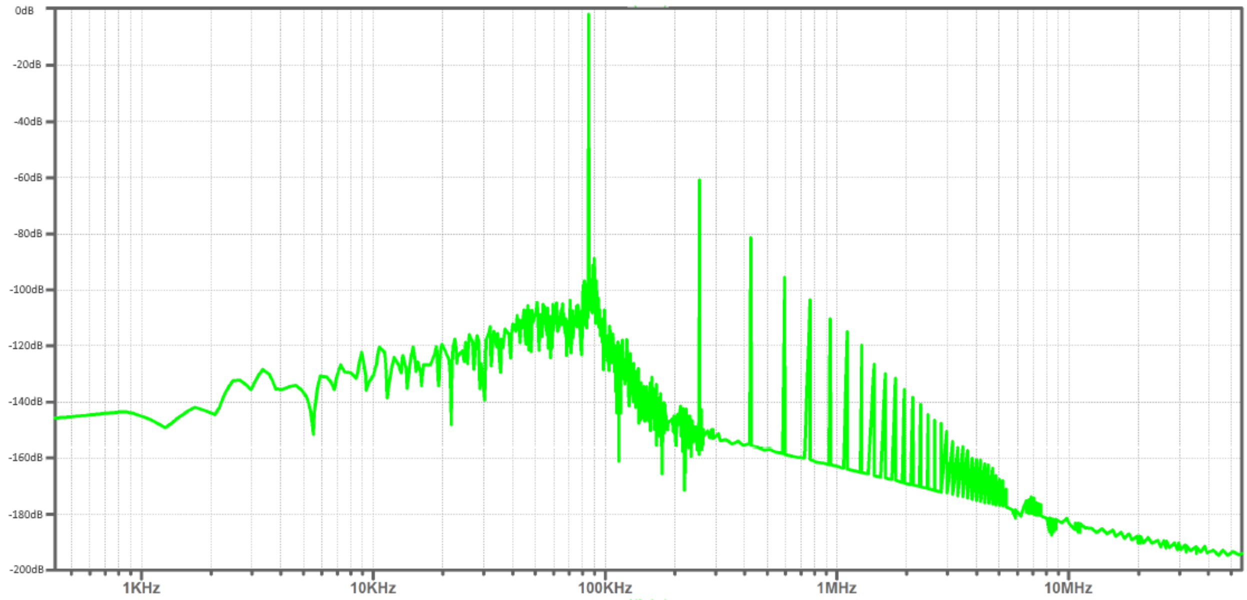


FIGURE 9

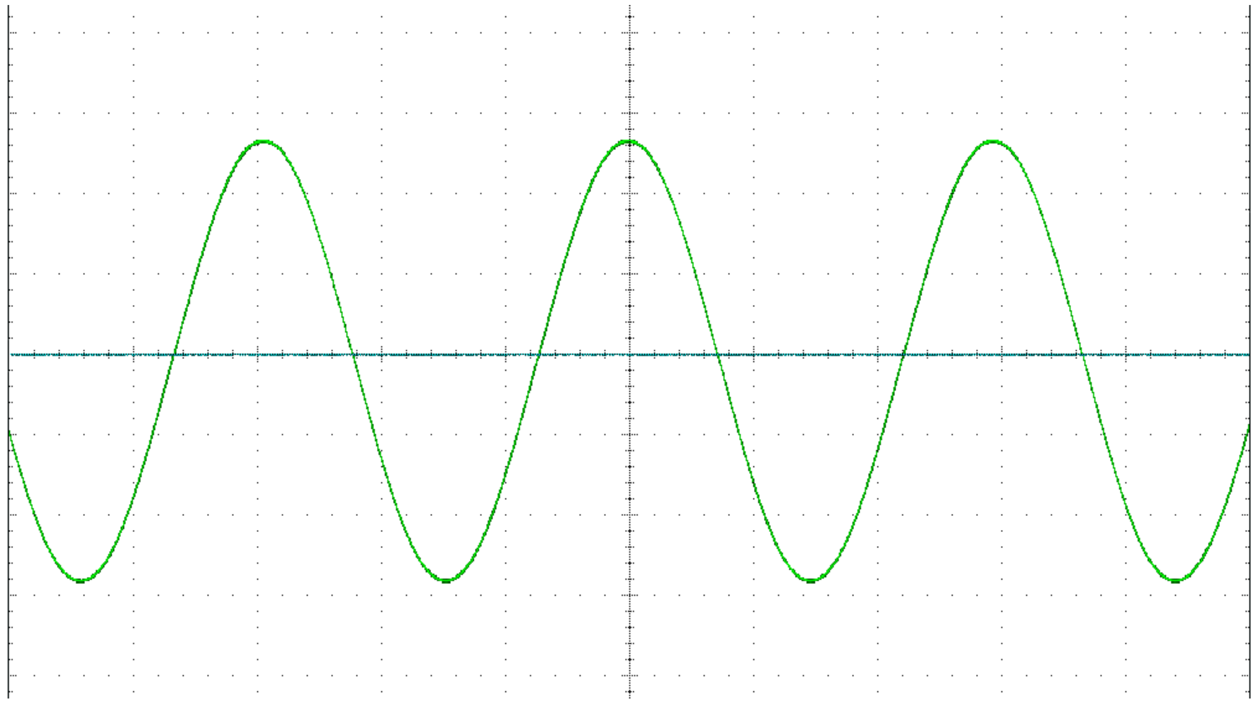
SPICE simulated relative frequency-domain spectrum of coil current in WPT-EV ground assembly



Finally, the resultant coil current was measured using a standard current probe and oscilloscope with the waveform shown below.

FIGURE 10

Actual coil current measured in the time-domain with oscilloscope



The magnetic field emanating directly from ground assembly coil is not the only possible source of emissions. The analysis represents the best-case of emissions from differential-mode currents in the

WPT-EV system. Standard text[3] shows that in power electronics design, emissions from common-mode currents, which may be unrelated to an intentional emission source, can dominate far-field emissions in many cases.

3.3.2 Estimations of growth of the number of WPT-EV systems

The project STILLE in Germany has made an estimation of 17.1 units /km^2 for the estimated real case in urban areas and a population of WPT-EV charging devices of 0.7 units /km^2 on the rural areas.

The values from the project STILLE are given until 2025. The extrapolation of these values until 2030 are: real case for urban areas are 64.2 units /km^2 and for rural areas are 2.5 units /km^2.

The project STILLE has defined a realistic charging time of one hour per day and WPT-EV charging station. It is interesting to notice, that this value remains stable over time. The reason is that the expected number of cars increases every year, on the other hand, the drive profile remains and the number of WPT-EV charge stations increase in the same ratio.

Considering all the data from the project STILLE, it is possible to extrapolate the given data and calculate the total amount of vehicles that will have the optional WPT-EV system mounted in the year 2030.

TABLE 5

Extrapolation of the total amount of vehicles with optional WPT-EV system mounted

Year	European Total Number of EV (million)	WPT deployment rate of WPT-EV of all vehicles with take rate	European Number of WPT-EV equipped vehicle with take rate (million)
Number of vehicles in 2020	4	0.71%	0.03
Increase 2021 => 2025	24	1.72%	0.4
Increase 2026 => 2030	43	2.83%	1.2
Total Number of vehicles in 2030	71	2.33%	1.7

From: “ECC report 289 page 103” which was extrapolated from “STILLE – Forecast of EU market development of inductive systems until 2025” October 2018.

3.4 Estimated activity factor per charging pad

In Table 6, the activity factor describes the operating time of a charging pad per day.

[3] Introduction to Electromagnetic Compatibility, Clayton R. Paul, John Wiley & Sons, Inc., 1992 states on page 301, “… a small common-mode current can produce the same level of radiated electric field as a much larger value of differential-mode current. In short, common-mode currents have a much higher potential for producing radiated emissions than do differential-mode currents! … the predominant mechanisms for producing radiated electric fields in practical products are the common-mode currents on the conductors!”

TABLE 6

Estimated activity factor per charging pad

Type of charging	Location	Power levels (kW)	Charging for unidirectional charging (hours)	Activity factor Unidirectional charging	Activity factor Bidirectional charging
19-21 kHz/55-65 kHz WPT-EV					
Long-time charging	Bus garage	22-120	0.25-6	10 – 80%	N/A
79-90 kHz WPT-EV					
Long-time charging	Home	3.7-11	0.25-6	1 – 25%	10 – 80%
Long-time charging	Work	3.7-11	0.25-6	1 – 25%	5 – 40%
Opportunistic charging	Public parking places	11-22	2-12	10 – 50%	20 – 70%

4 Summary of the studies on the impact of WPT-EV on radiocommunication services

This section summarizes impact study results for WPT-EV operating in 19-21 kHz, 55-65 kHz, and 79-90 kHz frequency ranges. Radiocommunication services and systems considered were standard frequency and time signal service, ripple control, train protection automatic warning systems, maritime radio (Loran-C), AM sound broadcasting, amateur radio, aeronautical service, lightning detection systems, maritime mobile service, differential GPS service, and non-directional beacons in the radionavigation service. In addition, required limits of WPT-EV radiated emission for the protection of AM broadcasting and impact of spurious and harmonic radiated emissions on the amateur service and relevant protection requirements were discussed and summarized.

4.1 Impact studies for WPT-EV operating in the 19-21 kHz frequency range

In the studies presented in relevant annexes, measurements were taken with a 10 m distance between the loop antenna and the charger; the measurement environments are detailed in Report ITU-R SM.2303. Measurements were taken, but were not compared with the values presented by the service requiring protection; as such no conclusion can be drawn.

4.1.1 Impact studies on standard frequency and time signal service

Annex 6 include a study on 20 kHz SFTS which conducted field measurements. The standard frequency and time signals considered in the study are systems operating at 20 kHz. However, no SFTS operations on 20 kHz were identified in this study. Measurements were taken but were not compared with the values presented by the service requiring protection, as such no conclusion can be drawn.

The Annex to Recommendation ITU-R TF.768 lists six radio stations operating 20.5 kHz SFTS service in the Russian Federation. Any study of impact of WPT-EV on these services also needed to be conducted. Therefore, the study of impact of WPT-EV on these radiocommunication services is still uncompleted.

4.1.2 Impact studies on ripple control

In the studies presented in Annex 2, a study on 129.1 kHz and 139 kHz of ripple control was conducted by both simulation and field measurements. Measurements were taken but were not compared with the values presented by the service requiring protection; as such no conclusions can be drawn.

4.1.3 Impact studies on train protection automatic warning systems

In the studies presented in Annex 7, the study concludes that a 5 m separation distance is necessary to protect Automatic Train Stop Systems (ATS).

4.1.4 Impact studies on some maritime radio

In the study presented in Annex 2, some measured harmonic emission levels of heavy duty WPT-EV bus system were provided. Testing results show that harmonic emission levels of heavy duty WPT-EV bus system (with fundamental frequency of 19-21 kHz) in frequency range of LORAN system is 26.73 dBμA/m @ 10 m @ 100.2 kHz, in frequency range of NAVTEX system is about −11 dBμA/m @ 10 m around 490 kHz, and in frequency range of NAVDAT system is −11.5 dBμA/m @ 10 m around 500 kHz. See Table A2-1 for more detail.

No conclusion is included in this study.

4.1.5 Impact studies on AM sound broadcasting

The frequency range from 19 to 21 kHz does not overlap with any broadcasting band and so it is only harmonic emissions from such systems that would have any impact. It may also be that harmonics are used in the power transfer process. Harmonics between the 8^{th} (of 21 kHz) and the 14^{th} (of 19 kHz) will lie within the LF broadcasting band (148.5-283.5 kHz) while harmonics between the 25^{th} (of 21 kHz) and the 89^{th} (of 19 kHz) will lie within the MF broadcasting band (525-1 705 kHz). Detailed studies are presented in § 4.4 and in Annex 8, which describe analyses based on the protection criteria for AM broadcast reception and on possible separation distances between WPT-EV chargers and radio receivers. In the case of WPT-EV chargers used specifically for heavy-duty electric vehicles (e.g. bus, tram, truck) it is likely that WPT-EV for such vehicles would be located at a minimum separation distance of 10 m from an AM broadcast receiver. The studies also found that mitigation would be required to protect AM broadcasting in cases where the unwanted emissions would need to be reduced and/or WPT-EV would need to operate, with enhanced stability and purity, on specific frequencies such that the corresponding harmonics fall in frequencies that reduce the impact on AM broadcast reception, taking into account the AM channel rasters. Please refer to § 4.4 for further information on protection requirements of AM sound broadcasting.

4.1.6 Impact studies on amateur radio

The amateur frequency bands 135.7-137.8 kHz and 472-479 kHz are unlikely to be affected by the emissions from WPT-EV at 19-21 kHz as they do not overlap with the WPT operating frequencies. The impact of harmonic interference from WPT-EV operating at 19-21 kHz has not been studied.

Limited information is available about the harmonic radiated emissions from WPT-EV operating at this frequency. The matter of harmful interference from harmonic radiated emissions is covered by § 4.5.

4.1.7 Study on the impact of WPT-EV to aeronautical service

Studies in aeronautical service bands were not conducted for 190-535 kHz (Recommendation ITU-R SM.1535) and 2 800-22 000 kHz (Recommendation ITU-R M.1458). Measurements were taken of WPT-EV systems in several annexes but were not compared with the values presented by the service requiring protection; as such no conclusions can be drawn.

4.1.8 Study on the impact of WPT-EV to lightning detection systems

Studies for lightning detection systems that operate at 5-200 kHz were not conducted. Measurements were taken of WPT-EV systems in several annexes but were not compared with the values presented by the service requiring protection as such no conclusions can be drawn.

4.1.9 Study on the impact of WPT-EV to maritime mobile service

Impact from WPT-EV to the maritime mobile service requires study.

4.2 Impact studies for WPT-EV operating in the 55-65 kHz frequency range (also including the third harmonic originated by WPT-EV operating in the 19-21 kHz frequency range)

4.2.1 Impact studies on the standard frequency and time signal (SFTS) service

In the study presented in Annex 4 it was found that WPT-EV operating anywhere in the 55-65 kHz frequency range at the proposed CISPR limits (see Annex 3) will cause harmful interference to SFTS operating at 60 kHz. All scenarios studied show a large negative margin between −120 dB and −47 dB. When considering measurements from a WPT-EV system at 34.18 dBμA/m at 10 m (see Annex 2) the baseline analysis shows that the on-street WPT-EV usage scenario, with separation distances of 10 to 20 metres will cause harmful interference for all cases studied. For depot based WPT-EV usage scenario co-existence may be feasible for frequency separations of greater than 4 kHz (e.g. outside 56-64 kHz) provided that the separation distance is greater than 50 m. It is noted that the measurements are based on one particular WPT-EV system and this may not be representative of all equipment types.

60 kHz SFTS stations are operated in Japan, the United States of America, and the United Kingdom with millions using the service.

The study presented in Annex 6 considered that interference to 60 kHz SFTS could be mitigated if the fundamental frequency could be shifted to 21 kHz which in turn would shift the third harmonic to 63 kHz. It further considered it was sufficient if WPT-EV did not operate ±1.5 kHz (58.5 kHz to 61.5 kHz) from the 60 kHz SFTS frequency. However, this was not based on calculations to determine the compatibility between the two systems (co-existence analysis).

4.2.2 Impact studies on ripple control

The study presented in Annex 2 on 129.1 kHz and 139 kHz of ripple control was conducted by both simulation and field measurements. Measurements were taken but were not compared with the values presented by the service requiring protection; as such no conclusions can be drawn.

4.2.3 Impact studies on train protection automatic warning systems

In the studies presented in Annex 2 and Annex 7, a 5 m separation distance is needed to protect ATS.

4.2.4 Impact studies on maritime radio including navigation system

Testing results in the study presented in Annex 2 show the harmonic emission levels of heavy duty WPT-EV bus system (with fundamental frequency of 19-21 kHz, and its third harmonic in the 55-65 kHz frequency range which is used as part of the power transfer). See Table A2-1 for more detail.

No conclusion is included in this study. However, interference is unlikely because the third harmonic does not fall in the bands and there is significant frequency separation.

Impact from WPT-EV with the third harmonic at 55-65 kHz to the maritime mobile service requires study.

4.2.5 Impact studies on AM sound broadcasting

The frequency range from 55 to 65 kHz does not overlap with any broadcasting band and so it is only harmonic emissions from such systems that would have any impact. It may also be that harmonics are used in the power transfer process. Harmonics between the 3rd (of 55 kHz) and the 5th (of 55 kHz) will lie within the LF broadcasting band (148.5-283.5 kHz) while harmonics between the 9th (of

65 kHz) and the 31st (of 55 kHz) will lie within the MF broadcasting band (525-1 705 kHz). Detailed studies are presented in § 4.4 and Annex 8 which describe analyses based on the protection criteria for AM broadcast reception and on possible separation distances between WPT-EV chargers and radio receivers. In the case of WPT-EV chargers used specifically for heavy-duty electric vehicles (e.g. bus, tram, truck) it is likely that WPT-EV for such vehicles would be located at a minimum separation distance of 10 m from an AM broadcast receiver. The studies also found that mitigation would be required to protect AM broadcasting in cases where the unwanted emissions would need to be reduced and/or WPT-EV would need to operate, with enhanced stability and purity, on specific frequencies such that the corresponding harmonics fall in frequencies that reduce the impact on AM broadcast reception, taking into account the AM channel rasters. Refer to § 4.4 for further information on protection requirements of AM sound broadcasting.

4.2.6 Impact studies on amateur radio

Limited information is available about the harmonic radiated emissions from WPT-EV operating at this frequency. The matter of harmful interference from harmonic radiated emissions is covered in § 4.5.

4.3 Impact studies for WPT-EV operating in the 79-90 kHz frequency range

4.3.1 Impact studies to standard frequency and time signal service

4.3.1.1 Impact studies to standard frequency and time signal service using 40 and 60 kHz

The study in Annex 7 on the impact to SFTS services at 40-60 kHz from WPT-EV was completed.

Separation distance of 10 m was agreed and used to assess the impact to those devices. In addition, operation time range of the device to receive the SFTS service which is not overlapping with WPT-EV operation, diversity of SFTS wave propagation direction, and expecting receiver performance improvement in the future of those devices were taken into assessment. In conclusion, the impact of WPT systems to radio-controlled clocks/watches has been confirmed that the study shows it does not cause harmful interference.

4.3.1.2 Impact studies to standard frequency and time signal service using 77.5 kHz

In the studies presented on DCF 77 (Annex 4), taking into account a WPT-EV field strength of 68.5 dBμA/m at 10 m, shows that a maximum of 50% blocking of the considered standard clock radio receivers using 77.5 kHz (DCF77) will only occur within a distance of 18 m of a WPT-EV charging installation. In order to account for the possible field strength increase to a maximum of 82 dBμA/m at 10 m, this distance would be extended to 31 m. This impact can be reduced by restricting the transmission power of the WPT-EV charging installation and carefully selecting its centre frequency within 79-90 kHz and potentially by other mitigation techniques (e.g. periodically interrupting the charging process).

4.3.2 Impact to specific railway radiocommunication system

The studies presented in Annex 7 considered and discussed harmful interference to railway communication systems in actual operational use cases through simulations and measurements. Specifically, the ATS system, which is used globally, was studied operating at 10-250 kHz. The results of the study establish that a minimum 5-metre separation distance is required to not produce harmful interference.

4.3.3 Impact studies to maritime radio including navigation system

4.3.3.1 Loran-C systems in 79-90 kHz

In the studies presented in Annex 5 between Loran-C systems and WPT-EV, the emission and field strength of the proposed frequency range 79-90 kHz, including the 2nd harmonics of WPT-EV charging applications, refer to the CISPR proposed limits. The Loran-C system protection criterion refers to Recommendations ITU-R M.589-3 and ITU-R P.372-13.

According to the coexistence study, for single and multiple WPT-EV applications, there would be no risk of interference with Loran receivers under marine coverage by the charging emissions of WPT-EV. The results of the study indicate that the coexistence between WPT-EVs and Loran-C systems is feasible, provided the frequency range 79-90 kHz is identified for medium-power WPT-EV.

4.3.3.2 Study on the impact of WPT-EV to maritime mobile service

Impact from WPT-EV operating at 79-90 kHz to the maritime mobile service requires study.

4.3.4 Impact studies to AM sound broadcasting

The frequency range from 79 to 90 kHz does not overlap with any broadcasting band and so it is only harmonic emissions from such systems that would have any impact. It may also be that harmonics are used in the power transfer process. The 2nd and 3rd harmonics of any frequency between 79 kHz and 90 kHz will lie within the LF broadcasting band (148.5-283.5 kHz) while harmonics between the 6th (of 90 kHz) and the 21st (of 79 kHz) will lie within the MF broadcasting band (525-1 705 kHz). Detailed studies are presented in § 4.4 and in Annex 8, which describe analyses based on the protection criteria for AM broadcast reception and on possible separation distances between WPT-EV chargers and radio receivers. In the case of WPT-EV chargers used for generic light-duty electric vehicles, the studies concluded that it is likely that minimum separation distances between 1 and 3 metres are likely. The studies also found that mitigation would be required to protect AM broadcasting in cases where the unwanted emissions would need to be reduced and/or WPT-EV would need to operate, with enhanced stability and purity, on specific frequencies such that the corresponding harmonics fall in frequencies that reduce the impact on AM broadcast reception, taking into account the AM channel rasters. Refer to § 4.4 for further information on protection requirements of AM sound broadcasting.

Other studies are found in Annexes 5 and 7.

One study in Annex 5 – including a field interference test, a theoretical analysis, and Monte Carlo simulations – was performed in some urban areas with high levels of both wanted broadcast signal and environment noise floor. This interference test in the Annex 5 showed that there will be no interference with AM radio in some urban areas. For other scenarios, such as suburban and rural areas, mitigating the interference would require increased separation distances between the WPT-EV equipment and the AM broadcast receiver. For more details, please refer to § A5.1. Refer to § 4.4 for further information on protection requirements of AM sound broadcasting. See also Annex 9 for analysis to reconcile results of some studies with the required limits in § 4.4.

NOTE – Regarding the abovementioned results provided in Annex 9, further interference testing studies may be needed for verification.

The other study in Annex 7 presented the impact study based on the environment noise level as derived by Recommendation ITU-R P.372-13. By keeping the adequate separation distances between the WPT-EV equipment and the AM broadcast receiver, the radiated emission level from WPT-EV was found to be below the environment noise level; and then, it concluded that radiated emission from WPT-EV will not cause harmful interference to AM broadcast receivers.

4.3.5 Impact studies for the amateur service

In the studies presented in Annex 7 field measurements were conducted for the 135.7-137.8 kHz and 472-479 kHz amateur frequency bands. These frequencies allocated to the amateur service on a primary or secondary basis are unlikely to be affected by the emissions at the operating frequency of WPT-EV.

Limited information is available about the harmonic radiated emissions from WPT-EV operating at this frequency other than measurements shown in Annex 12. Annex 10 models the level of harmonic radiated emissions with distance, based on a WPT device operating at the limits defined in Recommendation ITU-R SM.329 and draws conclusions about protection levels based on this modelling, the median noise levels set out in Recommendation ITU-R P.372, and the median amateur service signals measured in Annex 13.

In the studies presented in Annex 12, field measurements were conducted for the 3.50-4.00 MHz, 7.00-7.30 MHz, 10.10-10.15 MHz, and 14.00-14.35 MHz bands. The study was performed on an accredited Open Area Test Site (OATS) in a residential and lite commercial area. While general conclusions cannot be drawn about every ambient environment or type of amateur radio equipment, Annex 12 concludes that the amateur service is not significantly impacted even though, in one specific condition, the WPT-EV signal was measurable and visible on the amateur radio at a 10 m distance where an amateur service signal was also present at similar levels.

Annex 13 notes that the mean level of amateur service signals measured is such that WPT emissions measured in Annex 12 exceed the level of the median signal by a considerable amount at 10 m from the WPT device. Of course, the degree to which WPT-EV will disturb amateur service communications will depend *inter alia* on the pre-existing background noise levels at the specific reception sites as well as the characteristics of the specific WPT-EV system with a harmonic located at the same frequency. The tests in Annex 12 included many qualitative tests in the amateur bands, but only one qualitative test showed interference including reception of one amateur service signal in the presence of an operating WPT-EV system. This study represents work to correlate commonly performed EMC testing of systems to EMC limits in various regulations with existing ambient noise levels and their impact on radio services, with WPT-EV emissions and amateur radio service serving as convenient examples. This single study, however, allows conclusions to be drawn only for the referenced conditions and further studies of impact are required. The matter of harmful interference from harmonic radiated emissions is also covered in § 4.5.

4.3.6 Impact study for Differential GPS

Impact from WPT-EV to the Differential GPS application in the RADIONAVIGATION service requires study.

4.3.7 Impact study for Non-Directional Beacons

Impact from WPT-EV to the Non-Directional Beacons in the RADIONAVIGATION service requires study.

4.4 Limits of WPT-EV radiated emission for the protection of AM broadcasting

Various limits have been proposed for absolute maximum levels for the electric and magnetic field strengths for inductive applications operating over short ranges and at implied, though not specified, low power levels. There are proposals to adapt or extend these same limits to medium/high power inductive power transfer applications such as WPT-EV, which will operate at powers of the order of tens to hundreds of kilowatts. However, from studies based on practical modelling in Annex 8, adherence to existing or suggested field strength limits (CISPR 11) might not offer adequate protection to avoid interference to radio services. These limits are tens of dB higher than may be needed to protect a broadcast radio receiver in close proximity of an inductive power transfer device.

It should be noted, however, that impact studies such as those in Annex 12 show that the type and directional alignment of the receiving antenna along with its distance can make a difference in the results.

Please see also § 4.3.4, where several other studies have been referred to. Other studies on the compatibility between WPT-EV equipment and the AM broadcast receivers could be carried out in the future.

It is assumed that interference into an AM broadcast receiver will be a single sinusoid, harmonic of the WPT fundamental frequency that falls within an (approximately[4]) 10 kHz wide AM Broadcast channel and hence into the acceptance bandwidth of the receiver. In addition to the studies and tests[5] carried out on this subject, Further studies are in progress to understand how such a single sinusoid affects an AM broadcast receiver and if this is different from an interfering broadcast station for which Recommendation ITU-R BS.560 provides protection criteria. Annex 8 uses provisions of Recommendation ITU-R BS.703 Characteristics of AM sound broadcasting reference receivers for planning purposes; however, it must be recognized that the planning signal strengths have a stated Audio Frequency (AF) signal-to-noise ratio of 26 dB. The AF signal-to-noise ratio will improve linearly to at least 40 dB, with increasing input signal level. In Annex 8, using the worst-case 56 dB protection ratio (40 dB baseline +16 dB worst-case offset) as specified in Recommendation ITU-R BS.560, would give rise to a tolerable level of interference at the receiver operating in the MF broadcast band of:

- −47.5 dBμA/m. – at the location of the receiver

A more thorough derivation of this along with an equivalent figure for the LF Broadcast band is given in Annex 8. This figure is ‘worst case’ and dependent on the precise frequency of the interfering harmonic; there being a 20 dB variation across the circa 5 kHz audio bandwidth of a typical receiver. Subsequent work carried out by the BBC and reported in Attachment 6 to Annex 8 shows that this figure can be relaxed (using the same noted assumptions indicated above) to:

- −43.0 dBμA/m. – at the location of the receiver

The tolerable interference level is valid at the location of the receiver itself. In any generic formulation of limits for a ‘device’ the interference level must be specified at a standardised distance from the device itself. In many existing standards (e.g. in CISPR) the standard measurement distance is often specified as being 10 m from the device. It is possible that a victim receiver might not be found at the standardised measurement distance and so a correction may need to be applied. When converting between measurement distances in the near field, a conversion of 60 dB of distance decade is often applied.

A study[6] shows that if the frequency of the interfering harmonic can be tightly constrained (in both frequency and stability) a relaxation of about 30 dB can be applied to the above figures, resulting in a limit of:

- **−13 dBμA/m** – at the location of the receiver.

More detail on the reasons for this and the necessary constraints are given in § 5.4.1 and considerable detail on the derivation of all the figures in this section are given in Annex 8.

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[4] 9 kHz In Regions 1 and 3 and 10 kHz in Region 2.

[5] BBC WHP332 “Wireless Power Transfer: Plain Carrier Interference to AM Reception” – https://www.bbc.co.uk/rd/publications/wireless-power-transfer-plain-carrier-interference-to-am-reception.

[6] BBC WHP332 “Wireless Power Transfer: Plain Carrier Interference to AM Reception” – https://www.bbc.co.uk/rd/publications/wireless-power-transfer-plain-carrier-interference-to-am-reception.

4.5 Impact of spurious and harmonic radiated emissions on the amateur service and relevant protection requirements

The three frequency ranges being considered for WPT-EV do not overlap with, and have reasonable separation from, the 135.7-137.8 kHz and 472 kHz amateur frequency bands. Therefore, receiver sensitivity suppression (out-of-band) has not been considered a problem.

Amateur frequency bands from 472 kHz upwards are potentially affected by harmonic radiation from WPT-EV operating at 79-90 kHz and possibly from WPT-EV systems operating at 20 kHz and 60 kHz.

Report ITU-R SM.2303 states that interference to amateur services was not studied. Subsequent papers submitted to ITU-R by IARU in Annex 10 have suggested that the harmonic radiated emissions limits, as defined or suggested by ITU-R and/or CISPR could, by themselves, fall short of providing adequate protection from potential harmonic interference to amateur services from WPT-EV operating in the 79-90 kHz frequency range. In addition to the purpose of correlating EMC measurements with ambient noise levels, Annex 12 also serves as an additional datapoint to assess the impact of WPT-EV harmonics on stations operating in the amateur service.

Protection levels for the amateur service, which are set out in Recommendations ITU-R F.240 and ITU-R M.1044, together with the results of studies in Annex 10 and Annex 13, can be used to guide the development of appropriate protection criteria though these recommendations do not apply to a continuous single-carrier interferer specifically.

Annex 12 also contains an impact study of WPT-EV harmonic emissions emanating from a system following the requirements in industry standards for systems operating in the 79-90 kHz band, measured using the standardized EMC test methodology and equipment as well as amateur radio equipment. Impact is dependent on distance, antenna type, and other factors such as background ambient noise and the environment in which different radio services and WPT-EV systems may be located. Issues of wideband noise from WPT-EV systems has not been studied, but the developed protection requirements could be applicable to such radiation, which may also be common to typical power electronics such as switch-mode power supplies and are not harmonically related to WPT-EV specifically. The expected separation distance WPT-EV systems operating at 20 and 60 kHz is likely to provide reasonable protection from harmonic radiated emissions from the WPT-EV systems, although this remains to be validated.

The high duty cycle of 79-90 kHz WPT-EV systems, their planned location close to or inside dwellings (and therefore close to amateur service antennas), and their anticipated deployment density show that harmonic radiated emissions from WPT-EV systems in this frequency range need to be properly controlled if harmful interference is to be avoided.

Specifically, the adoption of radiated emission limits from inductive device limits for other applications and devices by themselves is one option but might not provide the level of protection required. Annexes 10, 11, 12 and 13 provide more details.

The studies in Annexes 10 and 13 model the protection needs of the amateur service and note that the mean level of amateur service signals measured is such that WPT emissions measured in Annex 12 exceed the level of the median signal by a considerable amount at 10 m from the WPT device. This conclusion is based on protection ratios from Recommendation ITU-R F.240, which do not include unmodulated single-carrier interference (type "N0N"), which represents a harmonic interferer from a WPT-EV system. Based on the data in these annexes, the radiated emission limit suggested by this study to provide reasonable protection is in the order of:

−46 dBμA/m at 300 kHz reducing by 7 dB per frequency decade to −60 dBμA/m at 30 MHz.

Measurements conducted at 10 m distance in a 10 kHz bandwidth.

However, according to Annex 10, the necessary limits for harmonic radiated emissions from WPT-EV systems can be relaxed from this level by about 20 dB if:

a) all WPT-EV systems adopt a harmonized, tightly tolerance frequency of operation; and

b) the phase noise and noise sidebands from WPT-EV are no higher than the above limit.

Some harmonic radiated emission data has been provided for WPT-EV systems operating at 79-90 kHz. Annex 12 represents some of this data collected with a WPT-EV system that follows previously noted SDO requirements highlighted in § 3.3.1. The single-carrier harmonic emissions from the WPT-EV system shown are higher than levels suggested in Annex 10 and do not show harmful interference for the conditions stated in Annex 12.

5 Harmonization and mitigation measures to minimize the impact of WPT-EV on the radiocommunication services

5.1 Global harmonization

The term harmonization in this Report encompasses two considerations:

1 The frequency ranges to be used by WPT-EV equipment.

2 The characteristics of WPT-EV equipment related to protection of other Radiocommunication services.

Both harmonization considerations above can help mass production and deployment of WPT-EV while preserving the operation of radiocommunication services from any potential interference from WPT-EV equipment.

Regarding the harmonized frequency ranges, Recommendation ITU-R SM.2110 indicates the recommended frequency bands for WPT-EV.

Regarding the characteristics of WPT-EV equipment, several annexes to this Report provide the field strength measurements of WPT-EV equipment in different frequency bands that can be used as a basis for consideration of potential interference to different concerned radiocommunication services.

5.2 Mitigation measures

5.2.1 Mitigation strategies to reduce the impact on the broadcasting service

The operation of AM broadcast transmitters is covered by the Radio Regulations. In Regions 1 and 3 the relevant instrument is the Geneva 1975 Frequency Plan (GE75) and in Region 2 the Rio de Janeiro 1981 Frequency Plan (RJ81). These international agreements allocate operating frequencies to LF and MF transmitters such that they do not cause interference to each other based on factors such as geographical separation, transmitter power and antenna characteristics. The underlying basis for the plans is Recommendations ITU-R BS.703 and ITU-R BS.560. Importantly, the regional assignment plans set the transmitter operating frequencies on a grid or raster; under the GE75 Plan each (carrier) frequency is a multiple of 9 kHz and under the RJ81 Plan a multiple of 10 kHz

A significant benefit of having all the carriers on a common raster is that co-channel interference is up to 16 dB less intrusive than if the frequencies were chosen randomly. This can be seen in Fig. 1 of Recommendation ITU-R BS.560.

A similar principle can be applied to a WPT-EV system if its operating frequency can be chosen and fixed to be a multiple of 9 kHz or 10 kHz. If the operating frequency is chosen in this way any harmonics will also (automatically) lie on the broadcast frequency raster. Studies to investigate the subjective effects of interference from an un-modulated carrier situated on or off the raster were carried out by the BBC in November 2017 and are described in BBC Research and Development

White Paper WHP 332, November 2017 – Wireless Power Transfer: Plain Carrier Interference to AM Reception, which is reproduced as Attachment 6 to Annex 8.

The technique and its potential application are described in detail in Annex 8 and could form the basis of a mitigation strategy. For 'on raster' operation, the tolerable level of interference can, as stated in § 4.4 above, be relaxed by 30 dB.

5.2.2 Other factors

5.2.2.1 Modulation of the charging 'field'

As indicated by § 3.3.1, standardized WPT-EV systems are not expected to modulate the field level and do not transfer data through modulation of the charging field. Communication is typically carried out by standard and well-characterized out-of-band radio interfaces such as Wi-Fi.

5.2.2.2 Disturbance to the amateur service

It should also be noted that locking the WPT operating frequency to the broadcasting raster has a beneficial impact on disturbance to the amateur service, as all harmonics are on specific 'spot' frequencies, rather than spread across the entire spectrum.

This keeps the bulk of the spectrum clear of harmful interference and so would allow a significant relaxation in the required harmonic radiated emission levels.

6 Conclusions

This Report has considered the impact on radiocommunication services operating below 30 MHz of radiation emanating from equipment and systems used for Wireless Power Transmission for Electric Vehicle charging (WPT-EV).

Studies have considered those services which operate at, or close to, the proposed WPT-EV operating frequencies, and also those services which might be affected by radiation from WPT-EV systems on other frequencies, particularly those harmonically related to the nominal operating frequency. Further work is planned in ITU-R to consider limits on radiation from WPT-EV systems necessary to protect radiocommunications services.

WPT-EV systems have no defined or implied status that gives precedence over radiocommunication services, certainly with respect to causing harmful interference (see RR Nos. **15.12** and **15.13**). The operating frequencies, power levels, and radiation arising from WPT-EV operation should therefore be set in a way that avoids harmful interference to radiocommunication services.

In terms of impact to services operating at or near to the operating frequency of the WPT-EV, the principal area of concern is related to the impact on SFTS services operating at 60 kHz and 77.5 kHz.

It should be noted that the impact of WPT-EV (operating in 19-21 kHz) on SFTS services and WPT-EV (operating in all bands) on Maritime mobile services have not been studied so far.

One study regarding SFTS on 60 kHz shows that WPT-EV operating anywhere in the 55-65 kHz at the proposed CISPR limits (see Annex 3) or a third harmonic from WPT-EV operating at 20 kHz will cause harmful interference to SFTS operating at 60 kHz. It was also found that for an on-street WPT-EV usage scenario, with separation distances of 10 to 20 metres, WPT-EV will cause harmful interference in all cases studied. For depot based WPT-EV usage scenario co-existence may be feasible for frequency separations of greater than ±4 kHz provided that the separation distance is greater than 50 m and the field strength is 34 dBμA/m at 10 m. On the other hand, if the distance between the WPT-EV and the SFTS receiver can be secured at 100 m or more, it is calculated that no harmful interference will occur if the emission limit is set to a level that does not exceed 44 dBμA/m at 10 m. Another study considered that interference to 60 kHz SFTS could be mitigated if the fundamental frequency could be shifted to 21 kHz which in turn would shift the third harmonic to 63 kHz but this was not based on co-existence analysis.

Although the analysis shows that a frequency separation of ±4 kHz is required. If a separation distance of 100 m between WPT-EV and SFTS can be guaranteed then the frequency separation can be relaxed to ±3 kHz and the field strength can be 44 dBµA/m at 10 m.

One study regarding SFTS operating on 77.5 kHz shows that WPT-EV operating in the band 79-90 kHz with a limit of 68.5 dBµA/m for the main emission impacts SFTS receiving at the wanted minimum field strength of 50 dBµV/m when operating in 10 metres distance. The protection distance for SFTS operating on 77.5 kHz depends on the wanted field strength, the interfering radiation and frequency offset.

The studies indicate that the operation of WPT-EV in the 19-21 kHz, 55-65 kHz, and 79-90 kHz frequency bands (see Table A8-1) require tight control of the radiation from WPT-EV systems to make it compatible with radiocommunication services with allocations in other frequency bands particularly in harmonically related bands. In the studies, concern was identified about the impact of radiation from WPT-EV systems on the broadcasting service and the amateur service. Some studies show that the current emission limits for WPT-EV systems could result in harmful interference to these radiocommunication services. The basis for this conclusion is set out in the individual studies.

Several aspects of the Report are still under critical review, notably how the "radiated disturbance" limits used in some of the studies have been carried over from those limits established for a variety of ISM and SRD applications that, when originally devised, had a low chance of interfering with radio services. These limits have now been pressed into service as a reference for WPT-EV limits when the original assumptions and methodology can no longer be accepted as representing the electromagnetic environment in which the generality of domestic electronic and electrical products are used nowadays, let alone being valid for the projected use of much higher power WPT-EV chargers.

In the case of the aeronautical service, ripple control and lightning detection systems among others, relevant impact studies from WPT-EV are still needed.

Limits on radiation and mitigation techniques, as well as other relevant matters, including guidance to administrations, are best promulgated through ITU-R Recommendations and Reports, supplemented by further studies and documentation as considered necessary. The current and planned documentation relevant to WPT-EV use includes:

– frequencies suited to WPT-EV, which are specified in Recommendation ITU-R SM.2110 (the Table below is Table 1 from Recommendation ITU-R SM.2110-1); and
– results of related studies and examples of national approaches to regulation, provided in the Annexes of this Report.

The ITU-R will need to collaborate closely with SDOs in order to ensure that appropriate frequency ranges and technical limits are incorporated into standards as necessary to protect radiocommunication services.

TABLE 7

Frequency bands and power levels for WPT-EV

Categories	Power level	Frequency band	WPT applications
High power WPT-EV	More than 22 kW	19-21 kHz	Specific heavy-duty electric vehicles (e.g. bus, tram, truck)
	More than 22 kW	55-57 kHz*	Specific heavy-duty electric vehicles (e.g. bus, tram, truck)
	More than 22 kW	63-65 kHz (1)	Specific heavy-duty electric vehicles (e.g. bus, tram, truck)
Medium power WPT-EV	Up to 22 kW	79-90 kHz	Generic light-duty electric vehicles

(1) Not to be used for the fundamental frequency of WPT-EV. Assuming a minimum separation distance of 50 m between WPT-EV and SFTS receivers, the third harmonic must fall within the 64-65 kHz and 55-56 kHz frequency range and the WPT emission be limited to 35 dBµA/m at 10 m. Where a separation distance of greater than 100 m between WPT-EV and SFTS receivers can be guaranteed, the third harmonic may fall within the 63-65 kHz and 55-57 kHz and the WPT emission be limited to 44 dBµA/m at 10 m.

Annex 1

Technical characteristics and protection requirements of radiocommunication services for use in WPT-EV impact studies

A1.1 Maritime services

Technical characteristics for the frequency bands 190-535 kHz and 285-325 kHz can be found in Appendix **12** of the Radio Regulations, while technical characteristics for 2.8-22 MHz can be found in Appendix **27** of the Radio Regulations.

TABLE A1-1

Technical characteristics of Maritime services

Frequency bands	Recommendation	Title	Relevant sections
90-110 kHz (1)	ITU-R M.589	Technical characteristics of methods of data transmission and interference protection for radionavigation services in the frequency bands between 70 and 130 kHz	Annex 1 section 2
285-325 kHz(1)	ITU-R M.823	Technical characteristics of differential transmissions for global navigation satellite systems from maritime radio beacons in the frequency band 283.5-315 kHz in Region 1 and 285-325 kHz in Regions 2 and 3	Annex 1 section 1
490-518 kHz(1)	ITU-R M.2010	Characteristics of a digital system, named Navigational Data for broadcasting maritime safety and security related information from shore-to-ship in the 500 kHz band	Annex 3 Table 1

TABLE A1-1 (*end*)

Frequency bands	Recommendation	Title	Relevant sections
1.6-3.8 MHz[(1)]	ITU-R M.1173	Technical characteristics of single-sideband transmitters used in the maritime mobile service for radiotelephony in the bands between 1 606.5 kHz (1 605 kHz Region 2) and 4 000 kHz and between 4 000 kHz and 27 500 kHz	Annex 1
	ITU-R M.1171	Radiotelephony procedures in the maritime mobile service	Annex 1 section 2 and section 3
4-27.5 MHz[(1), (2)]	ITU-R M.1173	Technical characteristics of single-sideband transmitters used in the maritime mobile service for radiotelephony in the bands between 1 606.5 kHz (1 605 kHz Region 2) and 4 000 kHz and between 4 000 kHz and 27 500 kHz	Annex 1
	ITU-R M.1171	Radiotelephony procedures in the maritime mobile service	Annex 1 section 2 and section 3

(1) Items considered as safety service under Recommendation ITU-R SM.1535.

(2) Items to be considered in the studies for the frequency band 6 765-6 795 kHz.

TABLE A1-2

Technical characteristics of Aeronautical Services

Frequency bands	Recommendation	Title	Relevant sections
190-535 kHz [(1)]	ITU-R SM.1535	The protection of safety services from unwanted emissions	Annex 4
2.8-22 MHz [(1), (2)]	ITU-R M.1458	Use of the frequency bands between 2.8-22 MHz by the aeronautical mobile (R) service for data transmission using class of emission J2D	Annex 1

(1) Items considered as safety service under Recommendation ITU-R SM.1535.

(2) Items to be considered in the studies for the frequency band 6 765-6 795 kHz.

A1.2 Amateur service

TABLE A1-3

Technical characteristics of Amateur Service

Frequency bands	Recommendations	Title	Relevant sections
All	ITU-R M.1732	Characteristics of systems operating in the amateur and amateur-satellite services for use in sharing studies	Body text (*recommends*) and Table 1A
F < 30 MHz	ITU-R M.1044	Frequency sharing criteria in the amateur and amateur-satellite services	Section 5
F < 30 MHz	ITU-R F.240	Signal-to-interference protection ratios for various classes of emission in the fixed service below about 30 MHz	Table 1

A1.3 Standard frequency and time signal service[7]

TABLE A1-4

Standard frequency and time signal (SFTS) service stations

Station (call signs)	Coordinates	Frequency (kHz)	Radiated power (kW)
ALS162	47° 10’ 05” N, 02° 12’ 02” E	162	800
BPC	34° 27' 25’’ N, 115° 50’ 13’’E	68.5	100
BPL	34° 56' N, 109° 32' E	100	-
DCF77	50° 01’ N 09° 00’ E	77.5	30
JJY40	37° 22’ N 140° 51’ E	40	10
JJY60	33° 28 N 130° 11’ E	60	20
MSF	54° 55’ N 03° 15’ W	60	16
RBU	56° 44'N 37° 40'E	66.6	50
RTZ	52° 26'N 103° 41'E	50	10
WWVB	40° 40’ N 105° 03’ W	60	70

[7] A detailed study on protection criteria for SFTS systems can be found in Report ITU-R TF.2487 which should be used for studies regarding the sharing/compatibility with other services and systems, e.g. non-beam WPT systems.

The band 19.95-20.05 kHz is allocated to the standard frequency and time signal service on a primary basis in the Table of Frequency Allocations. RR No. **5.56** also states that stations of services to which the bands 14-19.95 kHz and 20.05-70 kHz and in Region 1 also the bands 72-84 kHz and 86-90 kHz are allocated may transmit standard frequency and time signals. Such stations shall be afforded protection from harmful interference.

TABLE A1-5

Minimum usable field strength of ALS 162 standard frequency and time signal services

	Minimum usable field strength
Electric field strength	50 dBμV/m
Magnetic field strength	−1.5 dBμA/m

TABLE A1-6

Minimum usable field strength of BPL standard frequency and time signal services

	Minimum usable field strength
Electric field strength	25 dBμV/m
Magnetic field strength	−26.5 dBμA/m

TABLE A1-7

Minimum usable field strength of BPC, MSF, WWVB and DCF77 standard frequency and time signal services

	Minimum usable field strength
Electric field strength	40 dBμV/m (100 μV/m)
Magnetic field strength	−11.50 dBμA/m

TABLE A1-8

Minimum usable field strength of JJY standard frequency and time signal services

	Minimum usable field strength
Electric field strength	60 dBμV/m

TABLE A1-9

Minimum usable field strength of RBU and RTZ standard frequency and time signal services

	Minimum usable field strength
Electric field strength	42 dBμV/m
Magnetic field strength	−9.5 dBμA/m

TABLE A1-10

Co-frequency protection criteria for ALS 162

	Protection ratio	Maximum permissible near field or far field interfering signal (E field)	Maximum permissible near field or far field interfering signal (H field)
Minimum protection criteria	21 dB	50 dBμV/m	−1.5 dBμA/m

TABLE A1-11

Co-frequency protection criteria for BPC

	Protection ratio	Maximum permissible near field or far field interfering signal (E field)	Maximum permissible near field or far field interfering signal (H field)
Minimum protection criteria	12dB	40 dBμV/m	−11.5 dBμA/m

TABLE A1-12

Co-frequency protection criteria for MSF, WWVB and DCF77 SFTS

	Protection ratio	Maximum permissible near field or far field interfering signal (E field)	Maximum permissible near field or far field interfering signal (H field)
Minimum protection criteria	25 dB	15 dBμV/m	−36.5 dBμA/m

FIGURE A1-1

MSF and WWVB selectivity curve protection criteria for SFTS

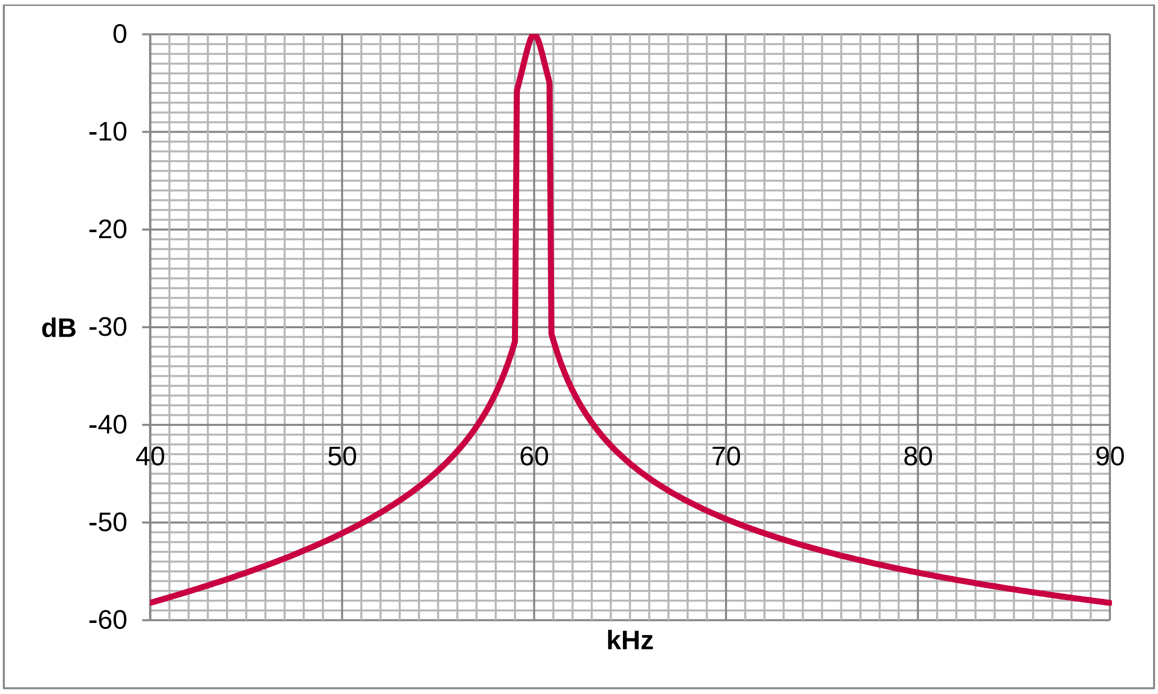


TABLE A1-13

Radiated emission limits of WPT systems to protect SFTS services for JJY

Frequency range of fundamental frequency	Protection criteria	Comments
10-79 kHz	The radiated emission limit for WPT for EV device is 23.1 dBμA/m measured at a distance of 10 metres. (1) Any WPT-EV device should make an individual application to the Minister of Internal Affairs and Communications and use it only if it is authorized	It is not permitted at 40 kHz and 60 kHz where SFTS (JJY) services are operated
79-90 kHz	The radiated emission limit for WPT for EV device (maximum power output 7.7 kW) is 68.4 dBμA/m measured at a distance of 10 metres	In the WPT device manual or on the WPT product, the following instruction or equivalent should be indicated: “Possible harmful electro-magnetic interference to the radio-controlled watch/clock devices receiving SFTS."
90-150 kHz	The radiated emission limit for WPT for EV device is 23.1 dBμA/m measured at a distance of 10 metres. Any WPT for EV device should make an individual application to the Minister of Internal Affairs and Communications and use it only if it is authorized	

(1) This emission level is the same as for ‘Industrial facilities emitting radio waves’ in Japan.

TABLE A1-14

Co-frequency protection criteria for RBU and RTZ

	Protection ratio	Maximum permissible near field or far field interfering signal (E field)	Maximum permissible near field or far field interfering signal (H field)
Minimum protection criteria	12 dB	42 dBμV/m	−9.5 dBμA/m

The use of WPT for EV in relation to SFTS is as follows:

WPT for EV devices shall not cause harmful interference defined by *Carrier to Interference* ratio derived from the minimum receiver sensitivity of the radio-controlled watch/clock devices in agreed use cases. Separation distance of 10 m shall be used as a coexistence criterion. Additional measures on operation time non-overlapping between WPT and the radio-controlled watch/clock, radio propagation direction variation, and possible performance improvement were taken into consideration.

Usage of WPT-EV

These standard frequency and time signal service stations provide a valuable service in disseminating accurate and precise atomic time over 3 continents. They are often used to provide a precise time standard in astronomical observatories. In addition to the scientific uses of these signals, receivers for these stations are in widespread domestic use.

Today several administrations operate standard frequency and time signal services in these LF bands and could be affected by WPT transmissions. The coverage areas of some of those LF transmissions are shown below in Figs A1-2 to A1-6. Signal levels in the red areas exceed 100 μV/m. Within those red areas tens of million devices use those transmissions for time including radio-controlled clocks, wrist-watches and other devices, many seeking traceability to legal time.

FIGURE A1-2

Radio station DCF77 operating at 77.5 kHz

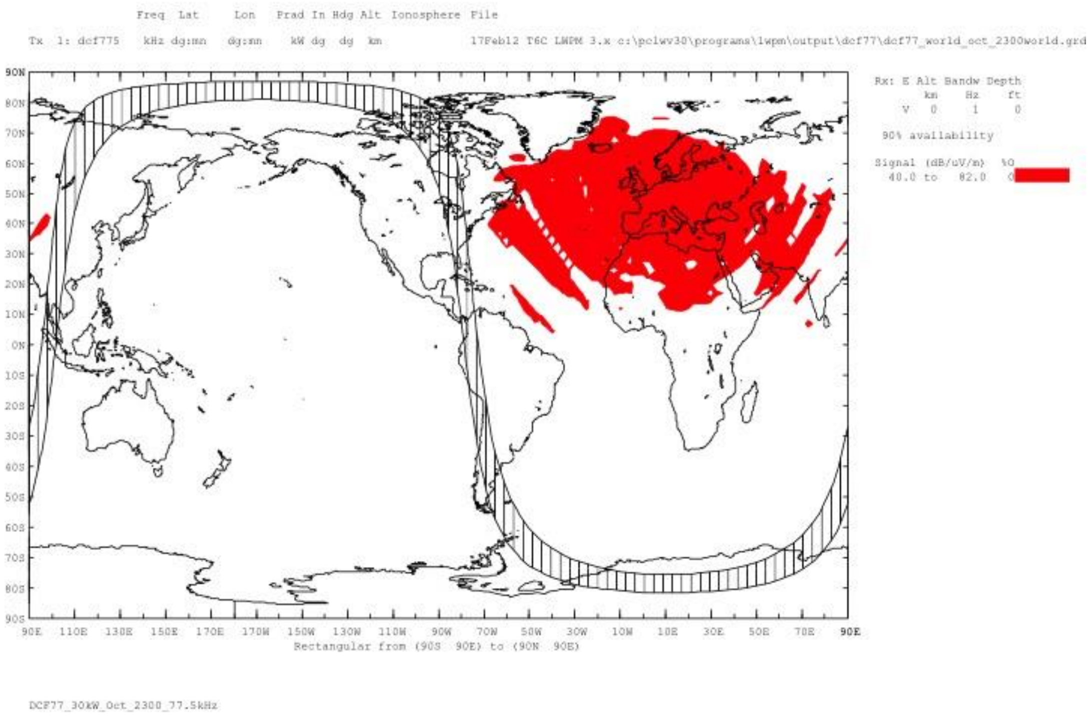


FIGURE A1-3

Radio station JJY operating at 40 kHz

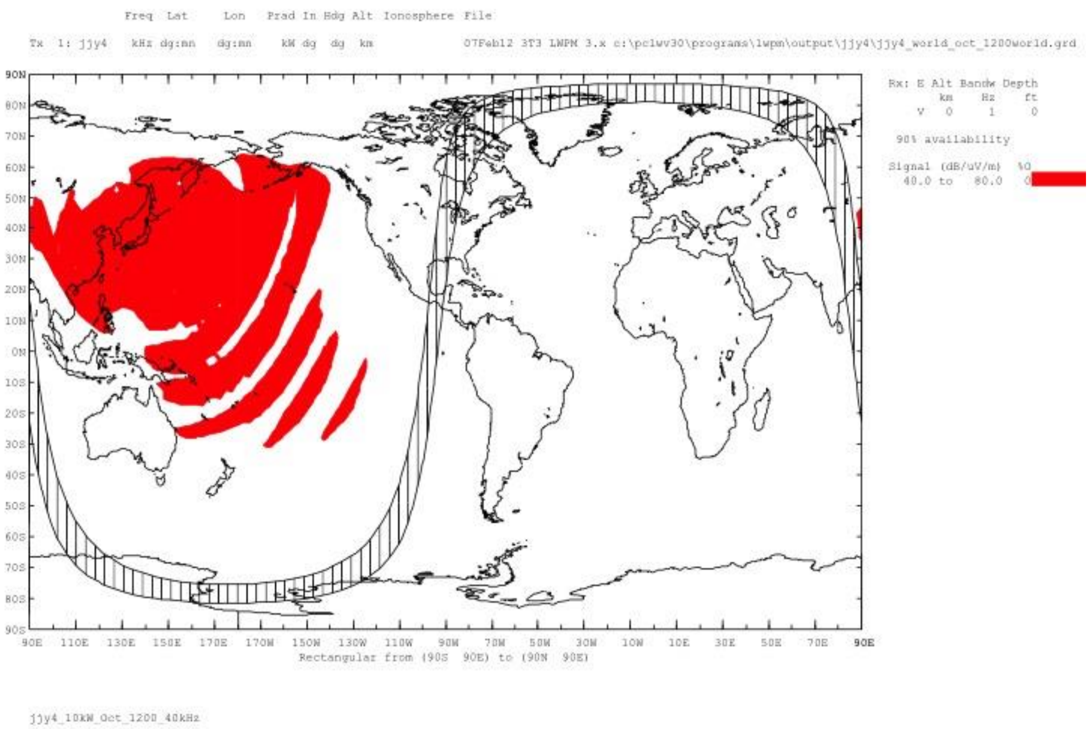


FIGURE A1-4

Radio station JJY operating at 60 kHz

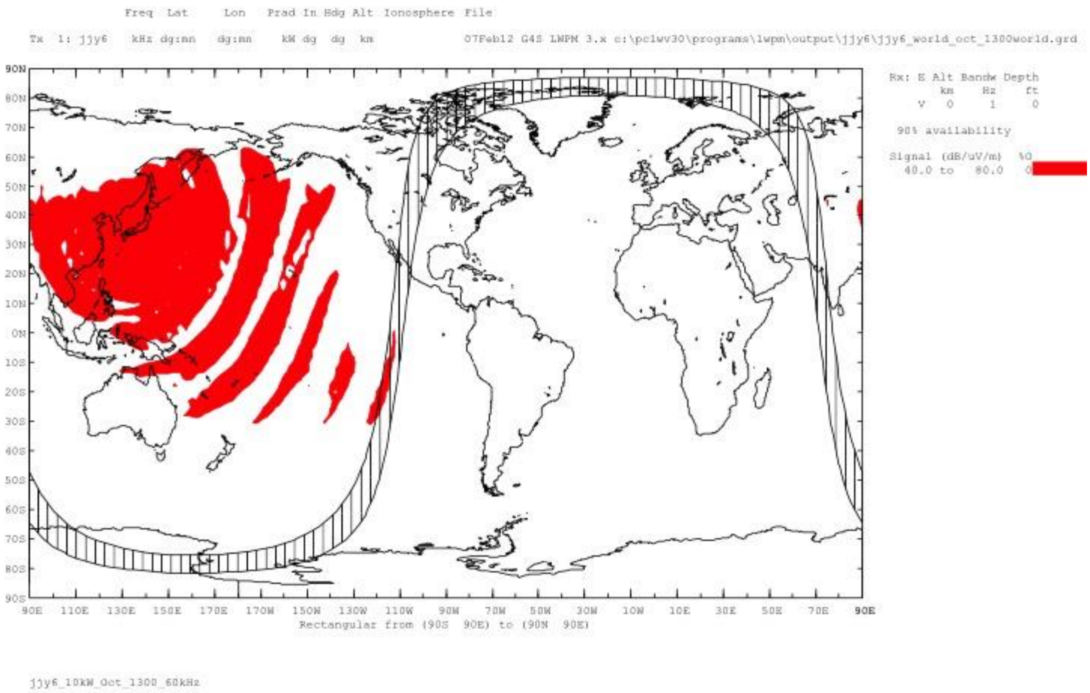


FIGURE A1-5

Radio station MSF operating at 60 kHz

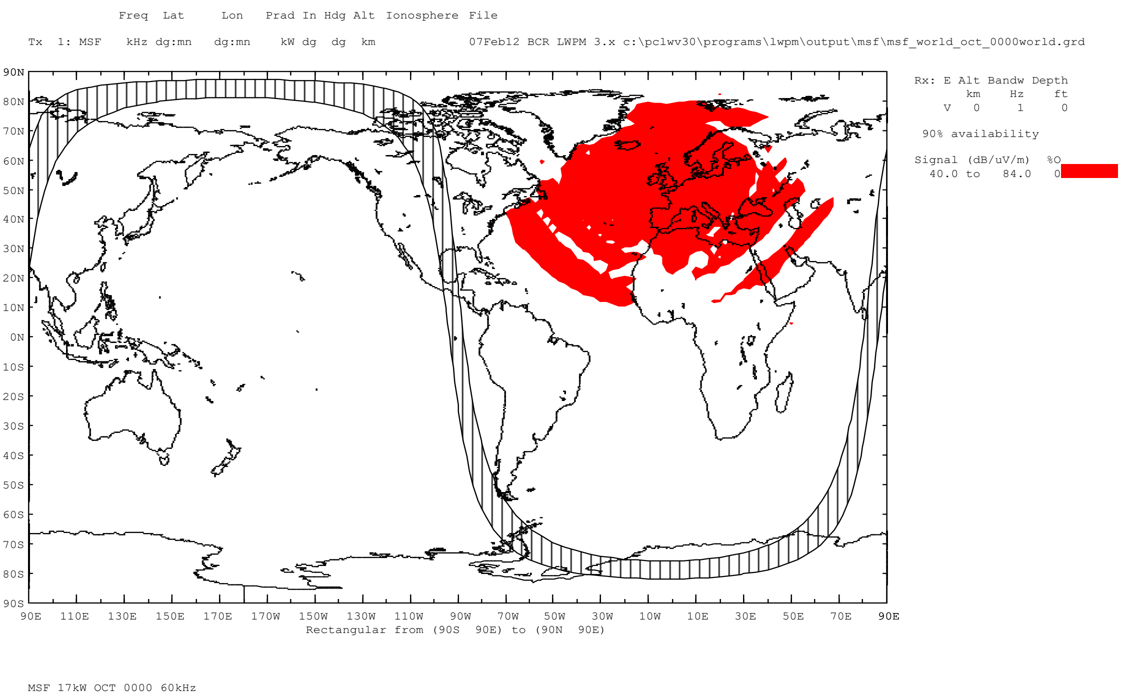
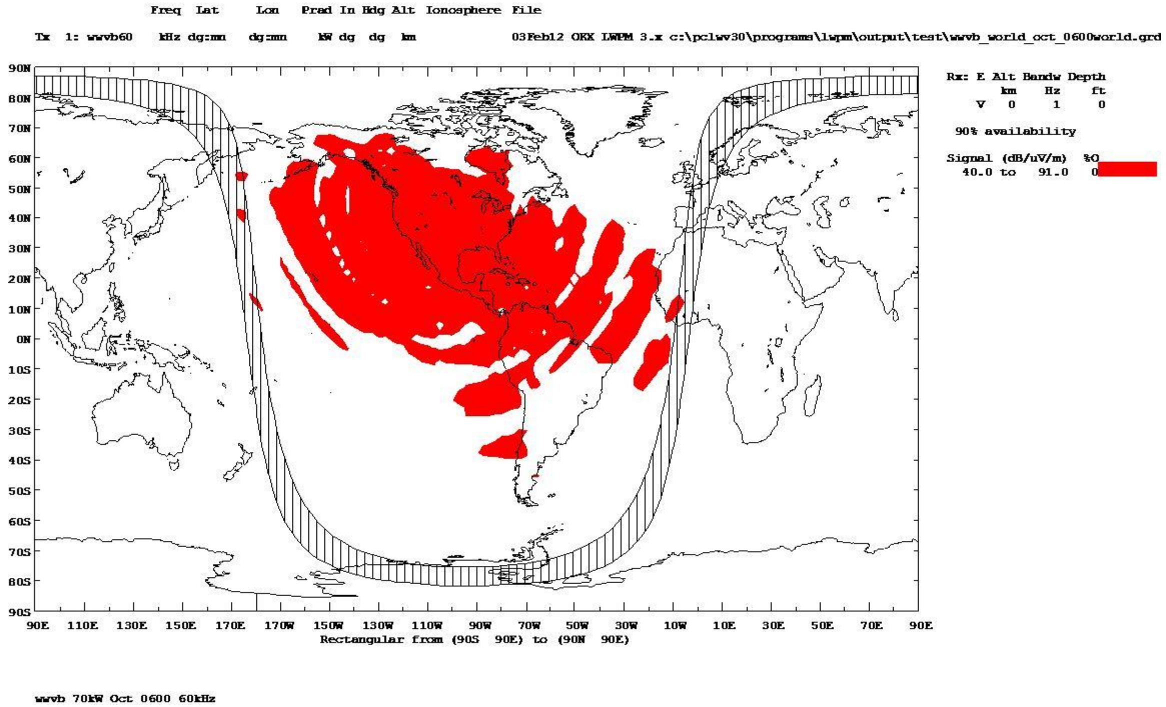


FIGURE A1-6

Radio station WWVB operating at 60 kHz



A1.4 Sound broadcasting service

WPT-EV is expected to produce harmonics in the bands 148.5 to 283.5 kHz, 525 to 1 705 kHz and 2 300-26 100 kHz and can interfere with the reception of LF, MF and HF sound broadcasting. The following ITU-R deliverables (Recommendations, Reports, Planning Agreements) are relevant for the impact studies.

TABLE A1-15

Technical characteristics of sound broadcasting service

Frequency bands	Document	Title	Relevant sections
LF MF HF	Rec. ITU-R BS.703	Characteristics of AM sound broadcasting reference receivers for planning purposes	All
LF MF HF	Rec. ITU-R BS.560	Radio frequency protection ratios in LF, MF and HF broadcasting	All
All	Rec. ITU-R BS./BT.1895	Protection criteria for terrestrial broadcasting systems	All
	Rec. ITU-R BS.216-2	Protection ratio for sound broadcasting in the Tropical Zone	All
LF MF	Rec. ITU-R BS.415-2	Minimum performance specifications for low-cost sound-broadcasting receivers	2 and 3
LF MF HF	Rec. ITU-R BS.559-2	Objective measurement of radio frequency protection ratios in LF, MF and HF broadcasting	All
MF	Rec. ITU-R BS.598-1	Factors influencing the limits of amplitude-modulation sound-broadcasting coverage in band 6 (MF)	All

TABLE A1-15 (*end*)

Frequency bands	Document	Title	Relevant sections
All	Rec. ITU-R P.372-13	Radio noise	
All	Rep. ITU-R SM.2303	Wireless power transmission using technologies other than radio frequency beam	Section 7.2.1 and Annex 6
LF MF	GE75 Agreement	Assignment plan for MF broadcasting in Regions 1 and 3 and LF broadcasting in Region 1 (Geneva 1975)	All
MF	RJ81 Agreement	Assignment plan for MF broadcasting in Region 2 (Rio de Janeiro 1981)	All
MF	RJ88 Agreement	Assignment plan for MF broadcasting in Region 2 (Rio de Janeiro 1988)	All

Information on the current situation of broadcasting transmitters in the LF and MF bands are provided in Annex 8.

Protection criteria for the LF, MF and HF sound BC services are given in Table A8-1 (off raster working) and Table A8-2 (on raster working) in Annex 8.

A1.5 Meteorological service

WPT-EV could have an impact on lightning detection networks operating in the 20-350 kHz range which needs to be protected.

Annex 2

Example emission levels of WPT-EV

This Annex contains details on measured emission levels for example WPT-EV systems used in the some of the impact studies. This only contains a very limited sample of equipment. It is noted that some of this equipment may be pre-production equipment.

A2.1 19-21 kHz/55-65 kHz WPT-EV

Measurements were conducted on a heavy duty WPT-EV bus system in Gumi City, Korea. The system operates with its fundamental in the 19-21 kHz frequency range and has a third harmonic in the 55-65 kHz frequency range which is used as part of the power transfer. Details of the emission measurements are contained in Table A2-1.

TABLE A2-1

Measured emission levels of a 100 kW heavy duty WPT-EV bus system used in impact studies

Radiocommunication services and systems	**Frequency bands**		**Test results (dBuA/m) at 10 m**
Standard frequency and time signal	19.95 kHz – 20.05 kHz (20 kHz, Global)		85.30 (20.28 kHz)
	39 kHz – 41 kHz (40 kHz, Japan)		22.02 (39.31 kHz)
	49.25 kHz – 50.75 kHz (50 kHz, Russia)		17.29 (49.66 kHz)
	59 kHz – 61 kHz (60 kHz, UK, US and Japan)		34.18 (60.23 kHz)
	65.85 kHz – 67.35 kHz (66.6 kHz, Russia)		21.88 (65.87 kHz)
	68.25 kHz – 68.75 kHz (68.5 kHz, China)		21.55 (68.69 kHz)
	77.25 kHz – 77.75 kHz (77.5 kHz, Germany)		19.45 (77.62 kHz)
	99.75 kHz – 102.5 kHz (100 kHz, China)		26.73 (100.2 kHz)
	157.5 kHz – 166.5 kHz (162 kHz, France)		−5.8 (166 kHz)
Ripple Control	128.6 kHz – 129.6 kHz (129.1 kHz, Europe)		9.554 (129.3 kHz)
	138.5 kHz – 139.5 kHz (139 kHz, Europe)		6.886 (138.7 kHz)
Train protection automatic warning system	Automatic Train Stop (ATS) Systems	10 kHz – 250 kHz (Japan)	85.30 (20.28 kHz)
		425 kHz – 524 kHz (Japan)	−10.1 (441 kHz)
	Inductive Train Radio Systems (ITRS)	100 kHz – 250 kHz (Japan)	26.73 (100.2 kHz)
		80 kHz, 92 kHz (Japan, only one route)	15.8 (79.97 kHz) 14.77 (92.19 kHz)
Amateur radio	135.7 kHz – 137.8 kHz		4.659 (136.6 kHz)
	472 kHz – 479 kHz		−10.6 (476 kHz)
Maritime radio	90 kHz – 110 kHz (LORAN)		26.73 (100.2 kHz)
	424 kHz, 490 kHz, 518 kHz (NAVTEX)		−10.7 (423 kHz) −10.8 (488 kHz) −11.3 (518 kHz)
	495 kHz – 505 kHz (NAVDAT)		−11.5 (500 kHz)
AM broadcasting	148.5 kHz – 283.5 kHz (Region 1)		−5 (148.5 kHz)
	525 kHz – 526.5 kHz (Region 2)		−11 (525-526.5 kHz)
	526.5 kHz – 1 606.5 kHz (Global)		−10.1 (548 kHz)
	1 605.5 kHz – 1 705 kHz (Region 2)		−13.2 (1646 kHz)

A2.2 79-90 kHz WPT-EV

Radiated emissions of a WPT system for EV using 85 kHz band were measured in 2011 to 2014. Details of the WPT equipment, the measurement method and the measured data are already described in Annex 3, Report ITU-R SM.2303. Table A2-2 shows the measured emission levels of the WPT-EV system using 85 kHz band. The radiated emission level at each frequency range of the related radiocommunication services and system is described in this Table. At some of those frequency ranges, the radiated emission levels are lower than the noise level of measuring receiver in which the standard resolution bandwidth is settled which does not represent the noise floor.

Measured emissions of a WPT system using 85 kHz are described in Figs A2-2 and A2-3. Figure A2-1 shows the configuration of Transmit and Receive coils of the WPT system. The WPT equipment is different from the equipment measured in the above Annex 3, Report ITU-R SM.2303. Table A2-2. Figures A2-2 and A2-3, the radiated emission level in the spurious region is –40 dB or lower from the emission level of WPT frequency.

TABLE A2-2

Measured emission levels of a 3 kW WPT-EV system using 85 kHz band

Radiocommunication services and systems		**Frequency bands**	**Test results (dBuA/m) at 10 m**
Standard frequency and time signal		19.95 kHz – 20.05 kHz (20 kHz, Global)	Less than measuring receiver noise level (<−15)
		39 kHz – 41 kHz (40 kHz, Japan)	Less than measuring receiver noise level (<−23)
		49.25 kHz – 50.75 kHz (50 kHz, Russia)	Less than measuring receiver noise level (<−25)
		59 kHz – 61 kHz (60 kHz, UK, US and Japan)	Less than measuring receiver noise level (<−27)
		65.85 kHz – 67.35 kHz (66.6 kHz, Russia)	Less than measuring receiver noise level (< −27)
		68.25 kHz – 68.75 kHz (68.5 kHz, China)	Less than measuring receiver noise level (<−25)
		77.25 kHz – 77.75 kHz (77.5 kHz, Germany)	Less than measuring receiver noise level (<−30)
		99.75 kHz – 102.5 kHz (100 kHz, China)	Less than measuring receiver noise level (<−33)
		157.5 kHz – 166.5 kHz (162 kHz, France)	Less than measuring receiver noise level (<−18)
Ripple control		128.6 kHz – 129.6 kHz (129.1 kHz, Europe)	Less than measuring receiver noise level (<−33)
		138.5 kHz – 139.5 kHz (139 kHz, Europe)	Less than measuring receiver noise level (<−34)
Train protection automatic warning system	Automatic Train Stop (ATS) Systems	10 kHz – 250 kHz (Japan)	71.3 (85.1 kHz; WPT frequency) 14.4 (176.2 kHz; 2nd harmonic) Less than measuring receiver noise level (Other frequency band)
	Inductive Train Radio (ITRS) Systems	100 kHz – 250 kHz (Japan)	14.4 (176.2 kHz; 2nd harmonic)
		80 kHz, 92 kHz (Japan, only one route)	71.3 (85.1 kHz; WPT frequency)
Amateur radio		135.7 kHz – 137.8 kHz	Less than measuring receiver noise level (< −33)
		472 kHz – 479 kHz	Less than measuring receiver noise level (<−28)

TABLE A2-2 *(end)*

Radiocommunication services and systems	**Frequency bands**	**Test results (dBuA/m) at 10 m**
Ripple control	128.6 kHz – 129.6 kHz (129.1 kHz, Europe) 138.5 kHz – 139.5 kHz (139 kHz, Europe)	Less than measuring receiver noise level (<−33) Less than measuring receiver noise level (<−34)
Maritime radio	90 kHz – 110 kHz (LORAN)	Less than measuring receiver noise level (<−33)
	424 kHz, 490 kHz, 518 kHz (NAVTEX)	−11.8 (425.5 kHz; 5th harmonic) Less than measuring receiver noise level (Other frequency band)
	495 kHz – 505 kHz (NAVDAT)	Less than measuring receiver noise level (< −28)
AM broadcasting	148.5 kHz – 283.5 kHz (Region 1) 525 kHz – 526.5 kHz (Region 2) 526.5 kHz – 1 606.5 kHz (Global) 1 605.5 kHz – 1 705 kHz (Region 2)	14.4 (176.2 kHz; 2nd harmonic) −15.6 (595.7 kHz; 7th harmonic) * More than 8th harmonics cannot be detected. Less than measuring receiver noise level (Other frequency band)

FIGURE A2-1

Configuration of transmit and receive coils of WPT system

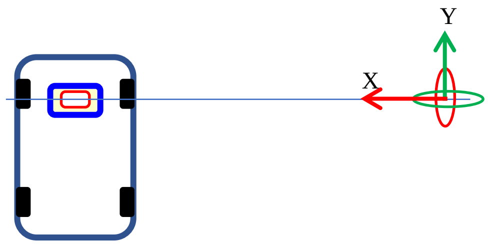


FIGURE A2-2

Measured emission of a WPT system using 85 kHz (Loop antenna direction: X)

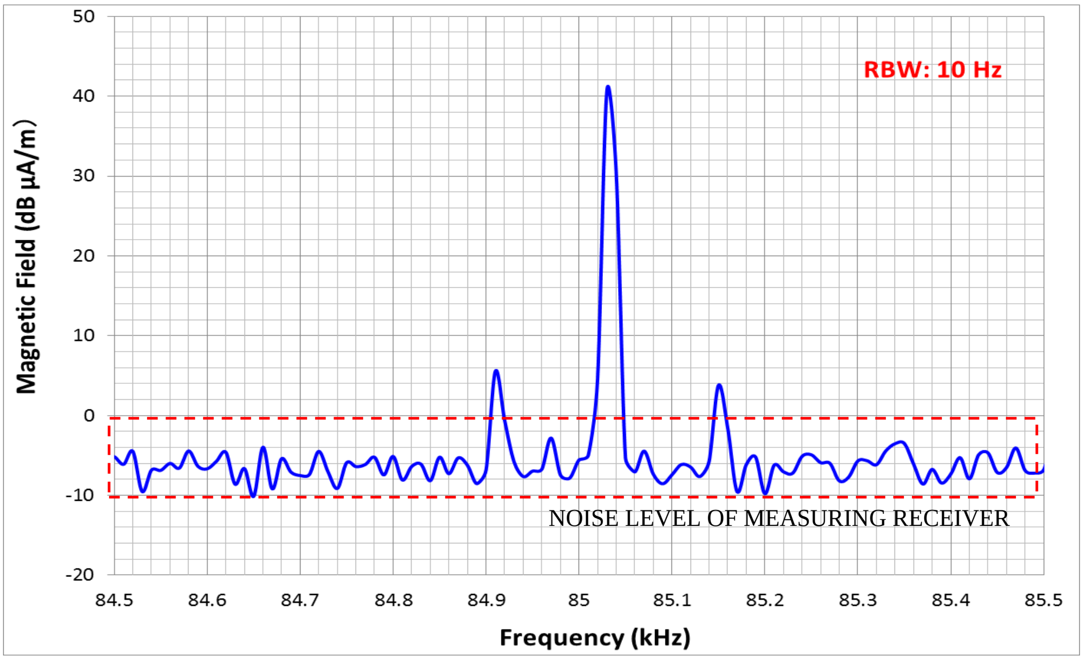
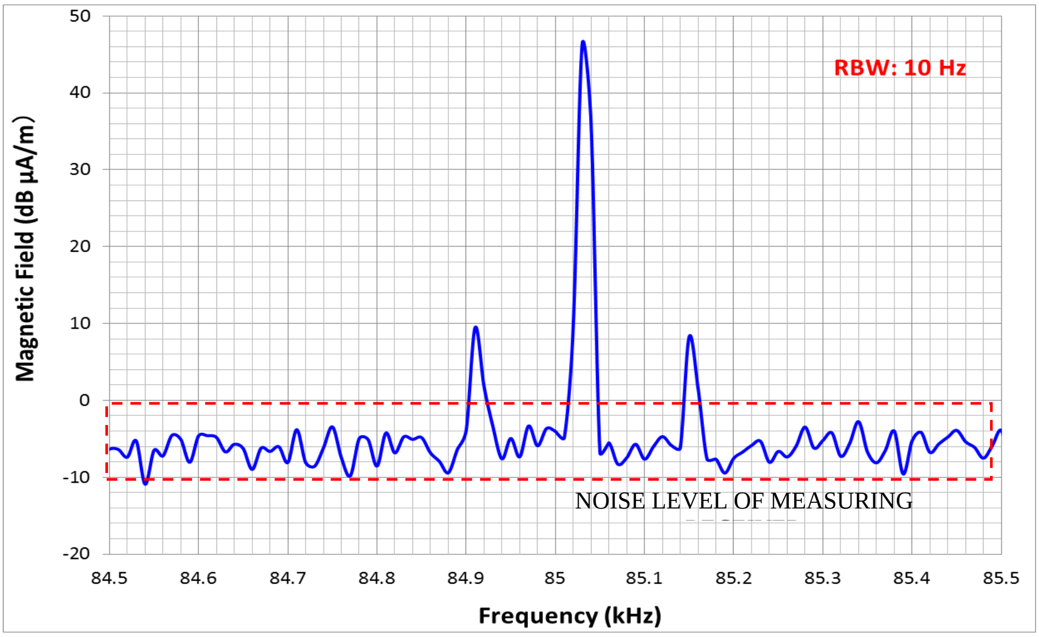


FIGURE A2-3

Measured emission of a WPT system using 85 kHz (Loop antenna direction: Y)



Annex 3

Proposed emission limits for WPT-EV from standards development organisations

A3.1 Proposed draft CISPR limits[8]

During 2017, CISPR was working to develop radiated emission limits for WPT-EV in the CISPR/B subcommittee. This led to consideration of the amendments to CISPR 11 Ed. 6 contained in the Committee Draft for Vote document CIS/B/687/CDV: "Industrial, scientific and medical equipment – Radio-frequency disturbance characteristics – Limits and methods of measurement – Requirements for air-gap wireless power transfer (WPT)". The amendment failed in the vote and in December 2017 and was rejected. A new amendment to CISPR 11 was subsequently under consideration, the Committee Draft document was developed in the AHG4 meeting in April 2019 and was circulated as a CDV in the spring of 2019. The result of the voting of this CIS/B/737/CDV also failed. The changed points on the limits from the CIS/B/687/CDV to the CIS/B/737/CDV are follows:

– The measuring distance is selected only 10 m from the EUT volume because in order to keep wider dynamic range of measurement and to avoid any inconsistency come from the measurement in the transition range between far-field and near-field.

– The sub-power classes for Class B were simplified to "(≤ 1 kW)" and (> 1 kW), and the limit values of fundamental frequencies for > 1 kW sub-class WPT in the range 79-90 kHz is limited to 67.8 dBµA/m.

– The limit values for harmonics ranges are reconsidered by evaluating the calculation by using CISPR TR16-4-4 as follows:

– 150 kHz – 5.62 MHz: 14.5 dBµA/m decreasing linearly with logarithm of frequency to −10 dBµA/m;

– 5.62-30 MHz: −10 dBµA/m.

The limits from CIS/B/687/CDV and CIS/B/737/CDV have been used in some impact studies. Limits from the failed CIS/B/737/CDV are contained in Tables A3-1 and A3-2.

Since the failed voting of CIS/B/737/CDV, CISPR B AHG4 has undertaken the work of testing procedures and limits for WPT-EV systems in fragments. In 2021, CIS/B/763/CDV, which contains the details for testing procedures for WPT-EV systems, passed voting and is planned for inclusion in CISPR 11 edition 7. Future work of CISPR B AHG4 will consider incorporating additional limits for WPT-EV below 150 kHz and subsequently above 150 kHz in future amendments of CISPR 11.

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[8] The website for relevant documents from CIS/B could be found in https://www.iec.ch/ords/f?p=103:30:500124287282098::::FSP_ORG_ID,FSP_LANG_ID:1412,25 .

TABLE A3-1

Electromagnetic radiation disturbance limits for class B group 2 WPT equipment for EVs measured on a test site

Frequency range (kHz)	Limits for a measuring distance *D* = 10 m	
	Class B (≤ 1 kW) (1)	Class B (> 1 kW) (1)
	Magnetic field quasi-peak (dB(μA/m))	Magnetic field quasi-peak (dB(μA/m))
9-19	27-23.8	27-23.8
19-25	57	72
25-36	22.6-21.1	22.6-21.1
36-40 (2)	56.2	71.2
40-55	20.6-19.3	20.6-19.3
55-65 (2)	54.4	69.4
65-79	18.6-17.7	18.6-17.7
79-90	52.8	67.8 (3)
90-150	17.2-15	17.2-15

At the transition frequency, the more stringent limit shall apply. Where the limit varies with the frequency, it decreases linearly with the logarithm of the increasing frequency.

On a test site, class B equipment should be measured at a nominal distance of 10 m.

National authorities can request additional suppression of emissions within specific frequency bands used by sensitive radio services at designated installations, for example by imposing the limits in Table E.2.

(1) Selection of the appropriate set of limits shall be based on the rated a.c. mains power stated by the manufacturer.

(2) In some countries, these bands are not available.

(3) WPT systems with a rated a.c. mains power of > 3.6 kW, if not meeting the limit for the rated a.c. mains power of > 1 kW specified in this Table, shall at least meet the relaxed-by-15-dB limit. In this case, the documentation for the user and the instructions for use accompanying the equipment shall contain the following caution note:

Caution: This equipment is not intended for use in environments where sensitive devices and/or radiocommunication devices like short range devices (SRD) used e.g. in railway signaling applications are allocated and operated in a distance of less than 10 m from the equipment. In such circumstances, it may not provide adequate protection to radio reception.

TABLE A3-2

Electromagnetic radiation disturbance limits for class B group 2 WPT equipment measured on a test site

Frequency range (MHz)	Limits for a measuring distance D = 10 m
	Magnetic Field
	Quasi-Peak (dB(μA/m))
0.15-5.62	14.5 decreasing linearly with logarithm of frequency to –10
5.62-30	–10

Annex 4

Impact studies on the Standard Frequency and Time Signal Service

A4.1 Impact study on the 60 kHz Standard Frequency and Time Signal Service

This Annex gives the study on the Impact of WPT-EV on the 60 kHz Standard Frequency and Time Signal (SFTS) Service for WPT-EV operating in the 55-65 kHz frequency range.

A4.1.1 Baseline protection criteria of the SFTS service

The minimum usable field strength (MUFS) provided in Annex 1 of 100 µV/m (40 dBµV/m) is used in this study. Table A4-1 gives the minimum usable electric and magnetic field strengths. It is noted that these are in the far field of the SFTS transmissions but will usually be in the near field of WPT sources as the wavelength at the fundamental of 60 kHz is 5 000 m.

TABLE A4-1

Baseline minimum usable far field strength of the SFTS service

	Minimum usable field strength
Electric field strength (dBµV/m)	40
Magnetic field strength (dBµA/m)	−11.50

A4.1.1.1 Protection criteria for the SFTS service

The protection criteria for SFTS is provided in Annex 1 which includes a protection ratio of +25 dB and the receiver selectivity curve.

Measurements were performed in the United Kingdom on a 60 kHz SFTS receiver to verify earlier the theoretical assumptions on SFTS protection requirements. Based on these measurements a protection criteria of +24 dB has been used in this study (see Table A4-2) noting that this is 1 dB more relaxed than protection criteria in Annex 1.

TABLE A4-2

Co-frequency protection criteria for SFTS used in this study[9]

	Protection ratio	Maximum permissible near field or far field interfering signal (E field)	Maximum permissible near field or far field interfering signal (H field)
Protection criteria used in this study	24 dB	16 dBµV/m	−35.5 dBµA/m

TABLE A4-3

Adjacent frequency protection criteria for SFTS

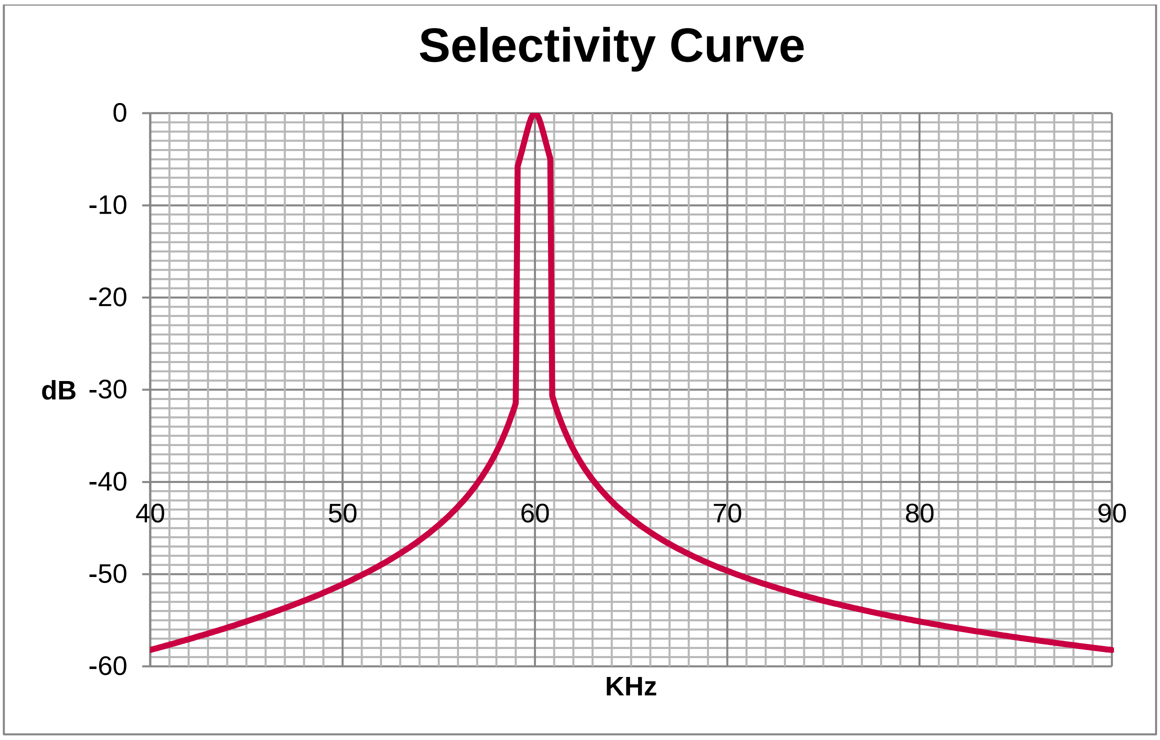
Frequency separation/offset (kHz)	Relative selectivity (dB)	Protection criteria based on measurements		
		Basic SFTS protection ratio (dB)	Maximum permissible interfering signal (dBµV/m) at the SFTS receiver	Maximum permissible interfering signal (dBµA/m) at the SFTS receiver
Protection criteria for 100% On/Off keying modulation				
−10	−51.1	−27.1	67.1	15.6
−9	−50.1	−26.1	66.1	14.6
−8	−48.99	−24.99	64.99	13.49
−7	−47.74	−23.74	63.74	12.24
−6	−46.33	−22.33	62.33	10.83
−5	−44.68	−20.68	60.68	9.18
−4	−42.69	−18.69	58.69	7.19
−3	−40.17	−16.17	56.17	4.67
−2	−36.74	−12.74	52.74	1.24
−1	−31.45	−7.45	47.45	−4.05
1	−31.34	−7.34	47.34	−4.16
2	−36.47	−12.47	52.47	0.97
3	−39.75	−15.75	55.75	4.25
4	−42.12	−18.12	58.12	6.62
5	−43.96	−19.96	59.96	8.46
6	−45.46	−21.46	61.46	9.96
7	−46.73	−22.73	62.73	11.23
8	−47.82	−23.82	63.82	12.32
9	−48.78	−24.78	64.78	13.28
10	−49.64	−25.64	65.64	14.14

[9] It should be noted that 60 kHz is an RF signal wavelength of 5 000 m.

The selectivity of the SFTS receiver is determined by the ferrite rod antenna (Q value) and the narrow band crystal filter. If the crystal filter is placed after the first pre-amplifier then particularly strong signals may overload this pre-amplifier. However, overloading is not considered in this study only the overall selectivity.

FIGURE A4-1

Selectivity curve of SFTS receiver



A4.1.2 Background noise

Recommendation ITU-R P.372-13 provides a background on radio noise. Atmospheric noise usually dominates for the worst case and this is closely associated with thunderstorms/lightning activity so in different geographic areas around the world the levels may be significantly lower on average in some areas than others. The UK is in a temperate zone with relatively low levels of thunderstorm activity throughout the year.

The P.372 level for 99.5% time background noise signal is around −13 dBμV/m (-64 dBμA/m). This is well below the maximum permissible interfering signal levels given in the protection criteria. This provides a good margin for users of the signal to place receivers with allowance for orientation coupling loss and building penetration loss, together with scope for manufactures to use cost effective techniques in their designs.

A4.1.3 Usage scenarios for 55-65 kHz WPT-EV

Use of the 55-65 kHz frequency range (in conjunction with 19-21 kHz as a third harmonic) is intended for heavy vehicles, lorries and buses. It is expected that WPT-EV charging stations may be at depots and in the future it could be at traffic lights and bus stops. WPT-EV use in dynamic roads has been highlighted as a potential usage scenario but this is not analysed. Using the example of central and suburban London, it is likely that WPT-EV could be used in close proximity to SFTS usage. The separation distances between WPT-EV and SFTS receivers are estimated to be between 10-20 m for on-street WPT-EV and 20-50 m for WPT-EV located at depots. WPT-EV will also have a high duty cycle of 100% when charging. This means that WPT-EV must not cause interference within these distances. The scenarios are given in Table A4-4.

TABLE A4-4

Usage scenarios and separation distances for 55-65 kHz WPT-EV

Usage scenario	**Separation distance from SFTS receivers**
On-street WPT-EV for heavy vehicles (e.g. bus stops)	10-20 metres
Depot based WPT-EV for heavy vehicles (e.g. at bus terminus/depot)	20-50 metres

A4.1.4 Impact analysis of 55-65 kHz WPT-EV with respect to standard frequency and time signal service reception

This impact analysis looks at both the necessary distance and frequency separations between WPT-EV and SFTS so that harmful interference does not occur. The analysis uses the measurements in Annex 2 and the proposed CISPR 11 limits in Annex 3. It is noted that measurements are for one specific type of WPT-EV system on a specific frequency which may not be representative or typical for all WPT-EV systems operating in the band. This analysis assumes that the same measured level value would apply for different frequency offsets. It is also noted that there have been different measurements provided on WPT-EV systems which show higher levels of field strength than what is used in this study. The study also assumes that the WPT-EV has no unwanted emissions. However, measurements provided indicate that there are unwanted emissions and side bands. In which case larger frequency and distance separations than calculated in this analysis would be required.

The analysis applies the protection criteria in Tables A4-2 and A4-3 to calculate frequency and separations distances. The calculation of the frequency offsets is for the edge of the WPT-EV emission and the edge of the SFTS receiver bandwidth. The results of this analysis are given below.

TABLE A4-5

Limits and measured values used in the analysis

Proposed CISPR limit at 10 m	**Measured level of a WPT-EV system at 10 m**
84.4 dBμA/m	34.18 dBμA/m

A4.1.4.1 Impact analysis of the proposed 55-65 kHz CISPR WPT-EV limits on SFTS

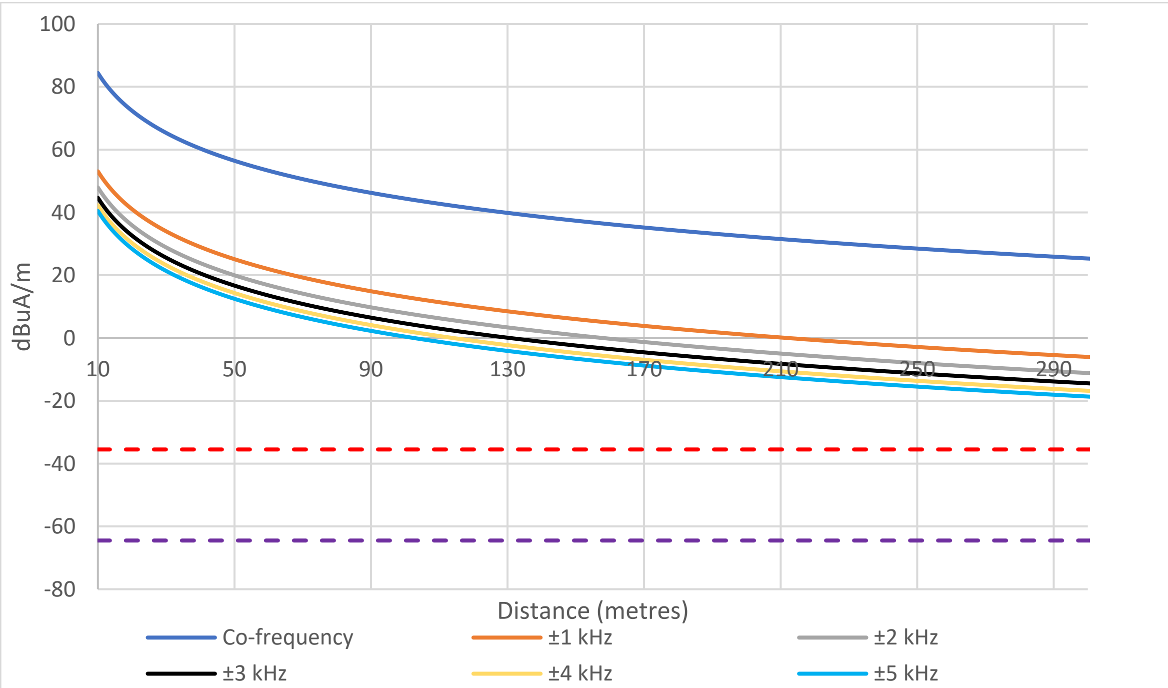
TABLE A4-6

Frequency and distance separation analysis on 55-65 kHz CISPR WPT-EV proposed limits

Frequency offset (kHz)	Maximum permitted interfering signal at the SFTS receiver (dBμA/m)	10 m separation distance		20 m separation distance		50 m separation distance	
		Field strength of WPT-EV (dBμA/m)	Margin (dB)	Field strength of WPT-EV (dBμA/m)	Margin (dB)	Field strength of WPT-EV (dBμA/m)	Margin (dB)
−5	9.18	84.40	−75.22	72.36	−63.18	56.44	−47.26
−4	7.19	84.40	−77.21	72.36	−65.17	56.44	−49.25
−3	4.67	84.40	−79.73	72.36	−67.69	56.44	−51.77
−2	1.24	84.40	−83.16	72.36	−71.12	56.44	−55.20
−1	−4.05	84.40	−88.45	72.36	−76.41	56.44	−60.49
Cofrequency	−35.50	84.40	−119.90	72.36	−107.86	56.44	−91.94
1	−4.16	84.40	−88.56	72.36	−76.52	56.44	−60.60
2	0.97	84.40	−83.43	72.36	−71.39	56.44	−55.47
3	4.25	84.40	−80.15	72.36	−68.11	56.44	−52.19
4	6.62	84.40	−77.78	72.36	−65.74	56.44	−49.82
5	8.46	84.40	−75.94	72.36	−63.90	56.44	−47.98

FIGURE A4-2

Frequency and distance separation analysis on proposed CISPR WPT-EV limits to 60 kHz SFTS



The analysis shows that 60 kHz SFTS will receive harmful interference from WPT-EV operating at the proposed 55-65 kHz CISPR limits for all frequency and distance separations analysed. For both on-street and depot based WPT-EV usage scenarios (given in Table A4-4) all frequency and distance separations show a large negative margin.

A4.1.4.2 Impact analysis of a measured 55-65 kHz WPT-EV system on SFTS

This analysis uses the measurements results currently contained in Annex 2. The limitations of these measurements mentioned in § A4.4 apply in this analysis.

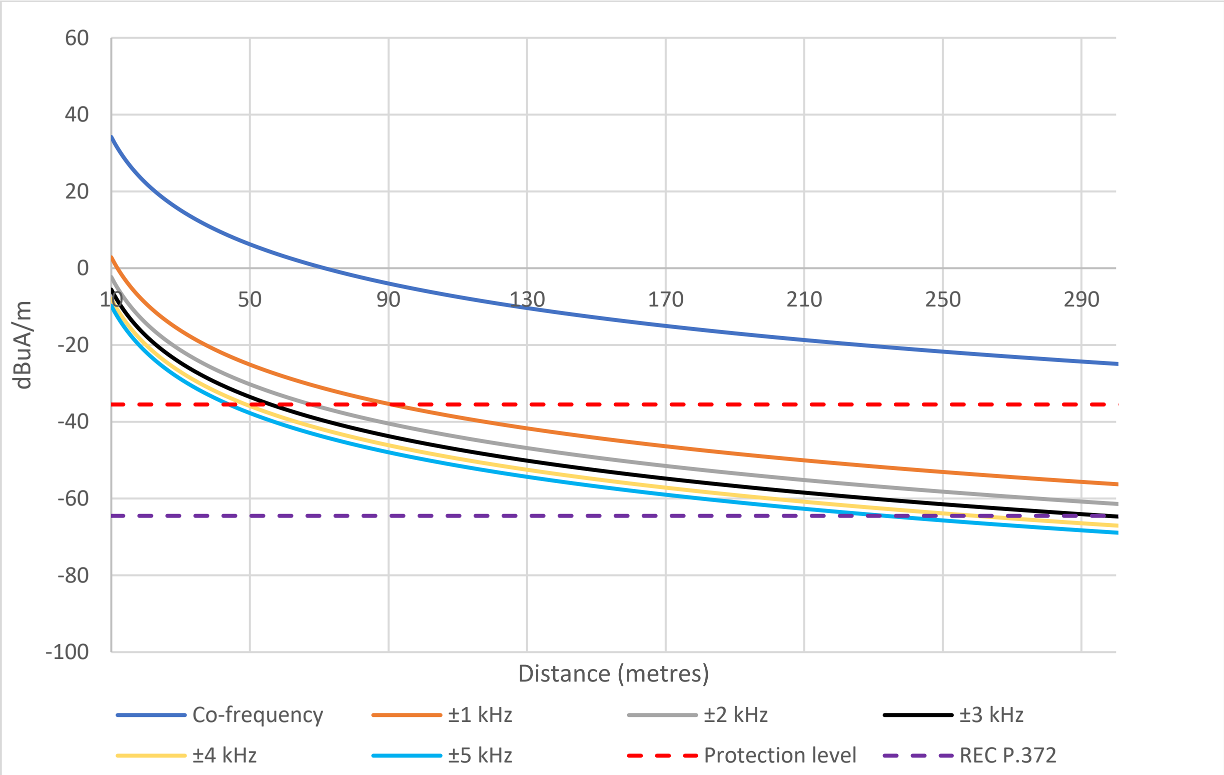
TABLE A4-7

Frequency and distance separation analysis on a measured 55-65 kHz WPT-EV system

Frequency offset (kHz)	Maximum permitted interfering signal at the SFTS receiver (dBμA/m)	10 m separation distance		20 m separation distance		50 m separation distance	
		Field strength of WPT-EV (dBμA/m)	Margin (dB)	Field strength of WPT-EV (dBμA/m)	Margin (dB)	Field strength of WPT-EV (dBμA/m)	Margin (dB)
−5	9.18	34.18	−25	22.14	−12.96	6.22	2.96
−4	7.19	34.18	−26.99	22.14	−14.95	6.22	0.97
−3	4.67	34.18	−29.51	22.14	−17.47	6.22	−1.55
−2	1.24	34.18	−32.94	22.14	−20.90	6.22	−4.98
−1	−4.05	34.18	−38.23	22.14	−26.19	6.22	−10.27
Co-frequency	−35.5	34.18	−69.68	22.14	−57.64	6.22	−41.72
+1	−4.16	34.18	−38.34	22.14	−26.30	6.22	−10.38
+2	0.97	34.18	−33.21	22.14	−21.17	6.22	−5.25
+3	4.25	34.18	−29.93	22.14	−17.89	6.22	−1.97
+4	6.62	34.18	−27.56	22.14	−15.52	6.22	0.40
+5	8.46	34.18	−25.72	22.14	−13.68	6.22	2.24

FIGURE A4-3

Frequency and distance separation analysis on a measured WPT-EV system to 60 kHz SFTS



The analysis shows 60 kHz SFTS will receive harmful interference from the measured WPT-EV system operating at the 55-65 kHz frequency range for the on-street usage scenario (given in Table A4-4). All frequency and distance separations show a large negative margin. For the depot based WPT-EV usage scenario frequency separations of 4 kHz or greater (i.e. lower than 56 kHz and above 64 kHz) with a distance separations of 50 m show that co-existence may be feasible.

A4.1.4.3 Sensitivity analysis

A sensitivity analysis was conducted to look at cases where the field strength may be higher than the minimum usable field strength in Table A4-1. This case looks at central London where many SFTS receivers are used and there may be future use of WPT-EV. A basic calculation is used to estimate the field strength received in London from the MSF transmitter located in Anthorn (latitude 54° 55' N, longitude 3° 15' W), which is shown in Table A4-6. It should be noted that, this field strength is likely to overestimate the signal received, since there are many buildings and objects in London which will attenuate the signal. Many receivers may be operating at or close to the minimum usable field strength between steel framed/steel reinforced concrete buildings.

TABLE A4-8

Approximate field strength received in central London without building losses, etc.

Location	Distance from transmitter	Field Strength (E Field) (dBμV/m)	Field Strength (H Field) (dBμA/m)
Central London	450 km	53.87	2.37

This analysis uses the measurements results currently contained in Annex 2. The limitations of these measurements mentioned in § 4 apply in this analysis.

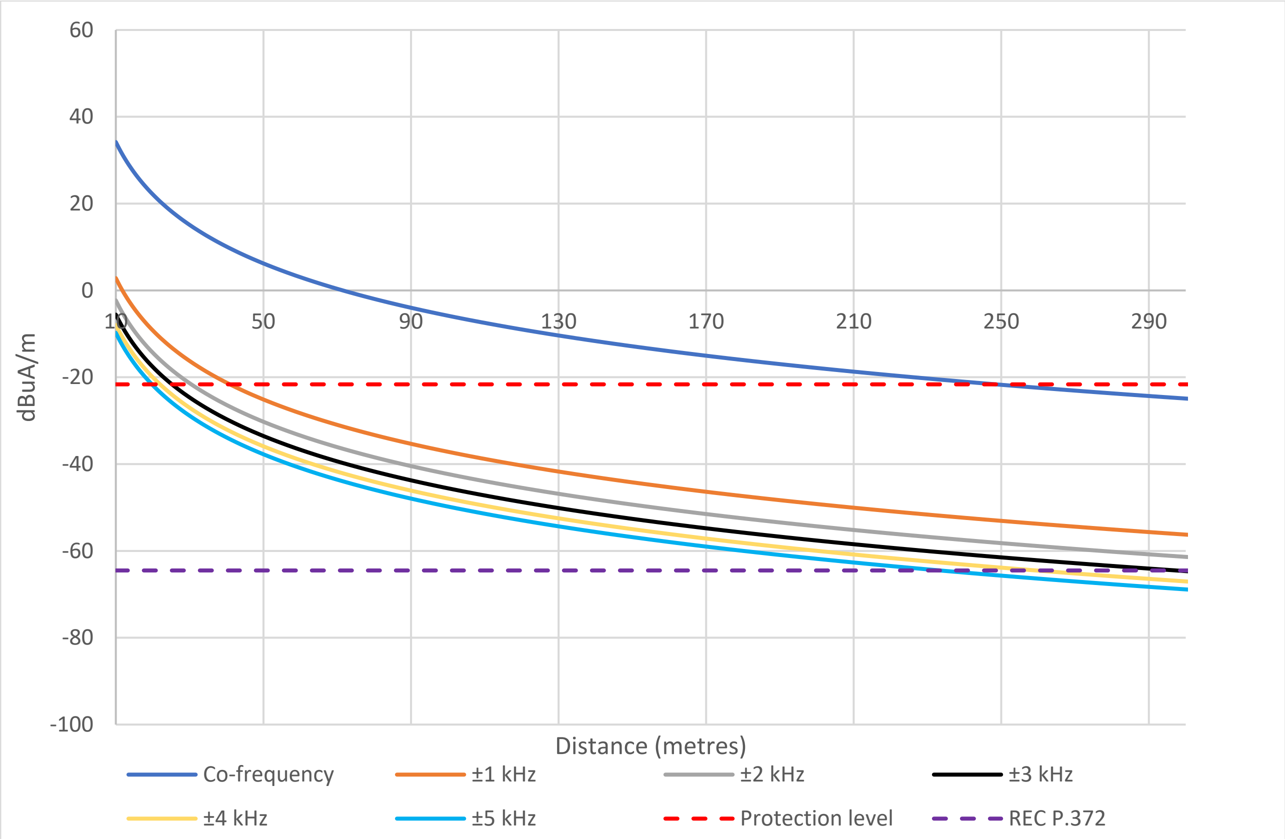
TABLE A4-9

Frequency and distance separation analysis on a measured 55-65 kHz WPT-EV system and using higher estimated SFTS field strength levels

Frequency offset (kHz)	Maximum permitted interfering signal at the SFTS receiver (dBµA/m)	10 m separation distance		20 m separation distance		50 m separation distance	
		Field strength of WPT-EV (dBµA/m)	Margin (dB)	Field strength of WPT-EV (dBµA/m)	Margin (dB)	Field strength of WPT-EV (dBµA/m)	Margin (dB)
−5	23.05	34.18	−11.13	22.14	0.91	6.22	16.83
−4	21.06	34.18	−13.12	22.14	−1.08	6.22	14.84
−3	18.54	34.18	−15.64	22.14	−3.60	6.22	12.32
−2	15.11	34.18	−19.07	22.14	−7.03	6.22	8.89
−1	9.82	34.18	−24.36	22.14	−12.32	6.22	3.60
Cofrequency	−21.63	34.18	−55.81	22.14	−43.77	6.22	−27.85
+1	9.71	34.18	−24.47	22.14	−12.43	6.22	3.49
+2	14.84	34.18	−19.34	22.14	−7.30	6.22	8.62
+3	18.12	34.18	−16.06	22.14	−4.02	6.22	11.90
+4	20.49	34.18	−13.69	22.14	−1.65	6.22	14.27
+5	22.33	34.18	−11.85	22.14	0.19	6.22	16.11

FIGURE A4-4

Frequency and distance separation analysis on a measured WPT-EV system to 60 kHz SFTS while assuming a higher SFTS wanted field strength



The analysis shows for the on-street based WPT-EV usage scenario (given in Table A4-4) frequency separations 5 kHz or greater (i.e. lower than 55 kHz and above 65 kHz) with a distance separation of 20 m show that co-existence may be feasible. For the depot based WPT-EV usage scenario frequency separations of greater than 1 kHz (i.e. lower than 59 kHz and above 61 kHz) with a distance separations of 50 m show that co-existence may be feasible. However, it is noted that this analysis is overly optimistic taking into account all of the best-case scenarios.

A.4.1.4.4 Aggregate interference

It is likely that multiple WPT-EV charging stations could be operating at the same time at nearby locations which will cause aggregate interference. For example, up to four WPT-EV bus charging stations either at bus stops or bus depots could be up to four WPT-EV systems operating simultaneously meaning that the interference levels will increase by 6 dB. The results of this analysis are shown in Table A4-10 and Fig. A4-5.

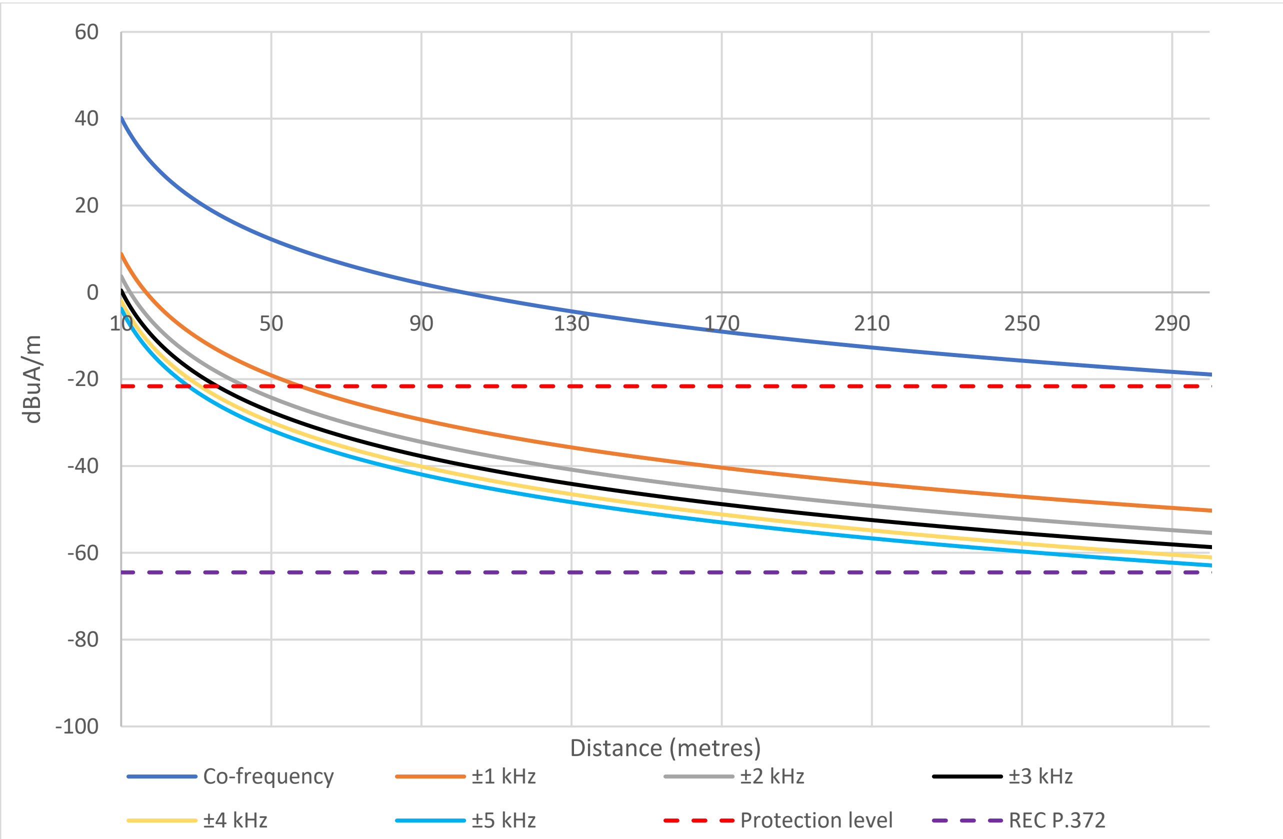
TABLE A4-10

Frequency and distance separation analysis on a measured 55-65 kHz WPT-EV system and using higher estimated SFTS field strength levels considering aggregate interference

Frequency offset (kHz)	Maximum permitted interfering signal (dBµA/m)	10 m separation distance		20 m separation distance		50 m separation distance	
		Field strength (dBµA/m)	Margin (dB)	Field strength (dBµA/m)	Margin (dB)	Field strength (dBµA/m)	Margin (dB)
−5	23.1	40.18	−17.13	28.14	−5.09	12.22	10.83
−4	21.1	40.18	−19.12	28.14	−7.08	12.22	8.84
−3	18.5	40.18	−21.64	28.14	−9.60	12.22	6.32
−2	15.1	40.18	−25.07	28.14	−13.03	12.22	2.89
−1	9.8	40.18	−30.36	28.14	−18.32	12.22	−2.40
Cofrequency	−21.6	40.18	−61.81	28.14	−49.77	12.22	−33.85
+1	9.7	40.18	−30.47	28.14	−18.43	12.22	−2.51
+2	14.8	40.18	−25.34	28.14	−13.30	12.22	2.62
+3	18.1	40.18	−22.06	28.14	−10.02	12.22	5.90
+4	20.5	40.18	−19.69	28.14	−7.65	12.22	8.27
+5	22.3	40.18	−17.85	28.14	−5.81	12.22	10.11

FIGURE A4-5

Frequency and distance separation analysis on a measured WPT-EV system to 60 kHz SFTS while assuming a higher SFTS wanted field strength considering aggregate interference



The analysis shows 60 kHz SFTS will receive harmful interference from the measured WPT-EV system operating at the 55-65 kHz frequency range for the on-street usage scenario (given in Table A4-4). All frequency and distance separations show a large negative margin. For the depot based WPT-EV usage scenario frequency separations of 2 kHz or greater (i.e. lower than 58 kHz and above 62 kHz) with a distance separations of 50 m show that co-existence may be feasible.

A.4.1.4.5 Mitigations

Mitigations may be required to use the 55-65 kHz frequency range for WPT-EV as many scenarios analysed show harmful interference and unwanted emissions have not been analysed. The level of mitigation needed would depend on the frequency separation and usage scenario for WPT-EV (i.e. if it is on-street or Depot based WPT-EV which are Table A4-4). This mitigation measure will be needed to ensure that SFTS remains protected. The suggested limits are given in Table A4-11 and Fig. A4-6.

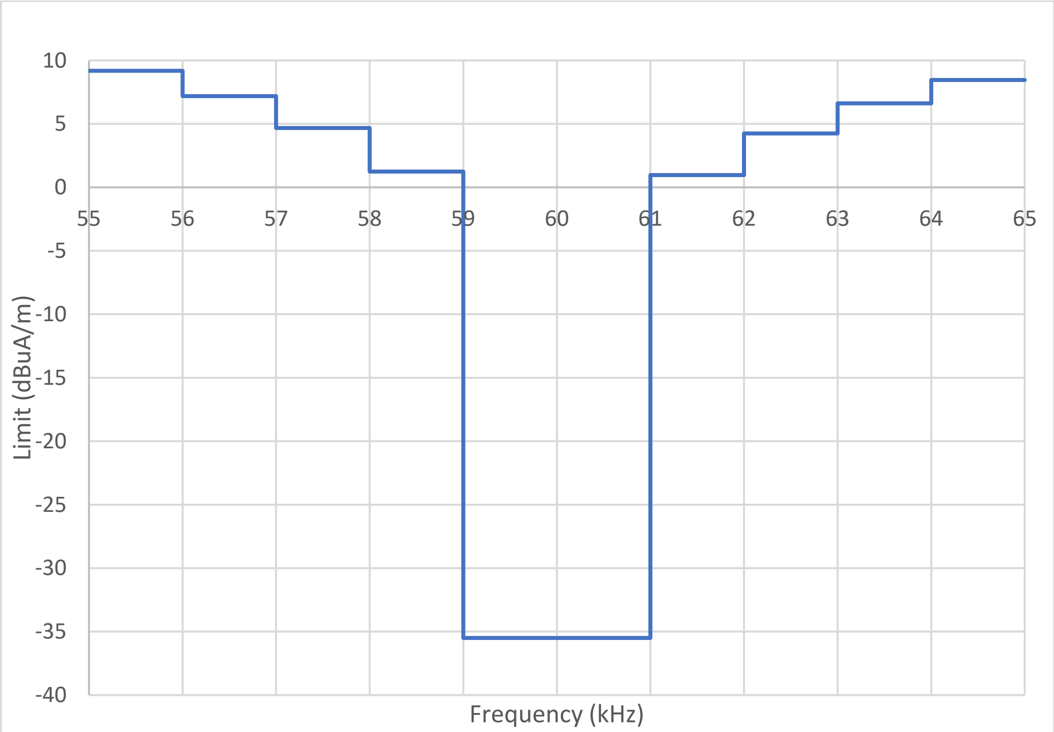
TABLE A4-11

Limits to protect SFTS from 55-65 kHz WPT-EV

Frequency range	Limit required to at the SFTS receiver for protection
55 to 56 kHz	9.18 dBμA/m at 10 m
56 to 57 kHz	7.19 dBμA/m at 10 m
57 to 58 kHz	4.67 dBμA/m at 10 m
58 to 59 kHz	1.24 dBμA/m at 10 m
59 to 61 kHz	−35.5 dBμA/m at 10 m
61 to 62 kHz	0.97 dBμA/m at 10 m
62 to 63 kHz	4.25 dBμA/m at 10 m
63 to 64 kHz	6.62 dBμA/m at 10 m
64 to 65 kHz	8.46 dBμA/m at 10 m

FIGURE A4-6

Limits to protect SFTS from 55-65 kHz WPT-EV



A4.1.5 Conclusions

Use of the 55-65 kHz frequency range for WPT-EV could cause harmful interference to SFTS unless particular frequency and distance separations can be ensured.

WPT-EV operating at the proposed CISPR limits will cause harmful interference in all the cases analysed. For both on-street and depot based WPT-EV usage scenarios analysed (given in Table 4) all frequency and distance separations show a large negative margin between −120 dB and −47 dB. The distance separations required to protect SFTS would be impractically large and all frequency offsets within the 55-65 kHz frequency range do not provide mitigation.

When considering measurements from a WPT-EV system the baseline analysis shows that on-street WPT-EV usage scenario, with separation distances of 10 to 20 metres will cause harmful interference in all cases studied. For depot based WPT-EV usage scenario co-existence may be feasible for frequency separations of greater than 4 kHz (e.g. outside 56-64 kHz) provided that the separation distance is greater than 50 m. It is noted that the measurements are based on one particular WPT-EV system and this may not be representative of all equipment types. Measurements provided in earlier contributions have indicated higher levels. This analysis has also not considered the unwanted emissions from WPT-EV, for which measurements indicate unwanted emissions and side bands.

The study shows that the proposed CISPR limits and street usage scenarios will cause harmful interference to SFTS. The study also indicated that unwanted emissions need to be controlled. Therefore, For WPT-EV to operate in the 55-65 kHz frequency range significant mitigation would be required. This could be through limits on maximum field strengths at 10 and 50 m depending on the usage scenario.

A4.2 Impact study on the 77.5 kHz Standard Frequency and Time Signal Service

A4.2.1 Introduction

For the wireless charging of electric vehicles (EV), one of the designated frequency bands is the range from 79 to 90 kHz. Being very close to the standard time and frequency signal of 77.5 kHz (DCF77), transmitted from Mainflingen located close to Frankfurt/Main in the centre of Germany. The subject of this study is to investigate whether the main charging signal, e.g. at 85 kHz, radiated by the wireless power transmission (WPT) stations may block the reception of radio controlled clocks in the vicinity. Measurements were carried out to determine the tolerable field strengths of WPT stations and to estimate the minimum required distance to DCF77 receivers.

FIGURE A4-7

Schematic view of the reach of the DCF77 transmission

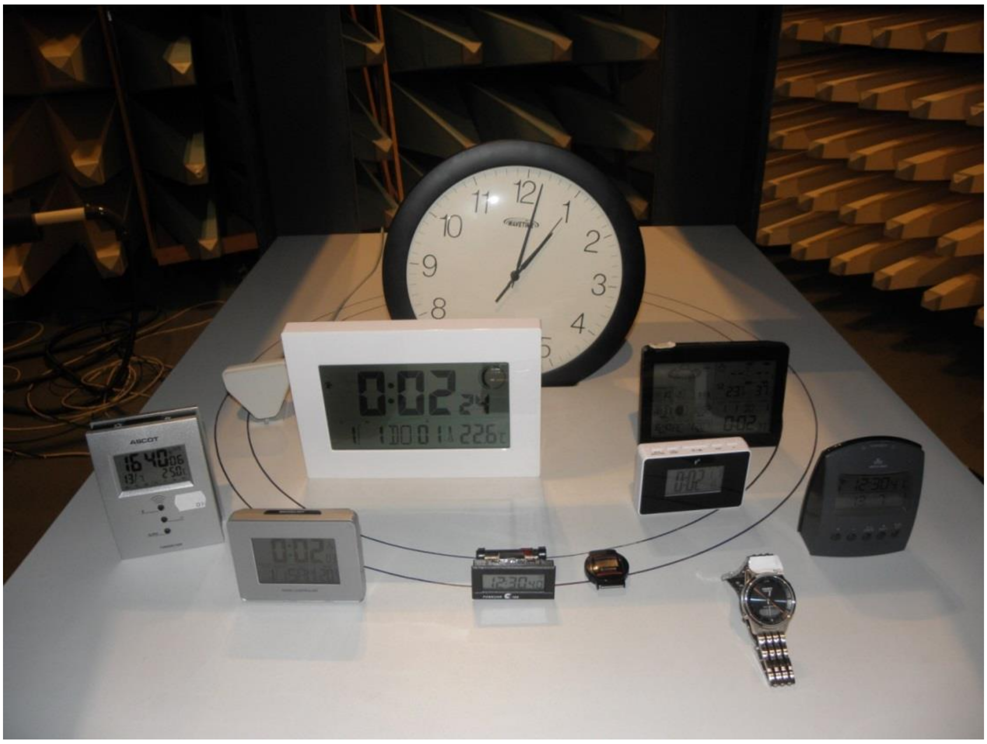
"With the longwave transmitter DCF77 … at 77.5 kHz, a reliable time signal and standard frequency transmitter has been available for many years, which can be received in many parts of Europe. Radio-controlled DCF77 clocks can be manufactured at low cost, and millions of them are in use. Today, approximately half of all "large electrical clocks" (table clocks, mounted clocks, wall clocks and alarm clocks) sold in the private sector are radio-controlled clocks. In addition, more than half a million of radio-controlled industrial clocks are in use … the number of DCF77 receivers produced from 2000 to 2008 is estimated to be about 100 million, whereby the largest portion by far falls into the "consumer-oriented" radio-controlled clock category...The carrier frequency of the DCF77 is used to calibrate or to automatically correct standard frequency generators. In traffic, e.g. in railway and air-traffic control, DCF77 plays an important role. Parking metres and traffic lights are synchronized by DCF77. In an ever increasing number of buildings, heating and ventilation systems are controlled by DCF77, and roller shutters are closed or opened by DCF77. In the telecommunication and energy-supply industries, DCF77 radio-controlled clocks are used to allow time-related tariffs to be correctly billed. Numerous NTP servers feed the time received from DCF77 into computer networks, and all radio and television stations receive the exact time from DCF77. These are just a few examples for the application of DCF77, but they make clear the considerable development that has been achieved in the past fifty years – also in the "old" technique and in the dissemination of time via longwave. And radio-controlled clocks are still used to an ever increasing extent."

The current version of ETSI EN 300 330 specifies a maximum magnetic field strength of 68.5 dBµA/m in 10 m distance, but a future limit of 72 dBµA/m is under discussion (in Draft EN 303 417) and measurements of a WPT system in 2015 showed that the actual emission may reach field strengths of up to 74 dBµA/m.

A total of 11 DCF77 clocks and watches of different design have been tested in the measurements presented here to establish criteria with WPT systems operating between 79 and 90 kHz. The measurements were conducted in the large anechoic and shielded chamber of the laboratory Kolberg of the Federal Network Agency (BNetzA), Germany, on the 23rd and 24th November 2017.

FIGURE A4-8

Devices under test



A4.2.2 DCF77 (wanted) signal

The DCF77 signal was produced by a signal generator (R&S SMU200). A programmed 10 minute long sequence of pulses was repeatedly sent out through a magnetic loop antenna (EMCO 6511) positioned at a distance of 10 m to the DUTs.

For the majority of the measurements the field strength of the DCF77 signal at the location of the DUTs was adjusted to 50 dBµV/m. This corresponds to the minimum outdoor field strength of the real DCF77 transmitter in 1 000 km distance.

To get indications on the nature of the interfering effect, additional measurements were made with a wanted field strength of 70 dBµV/m.

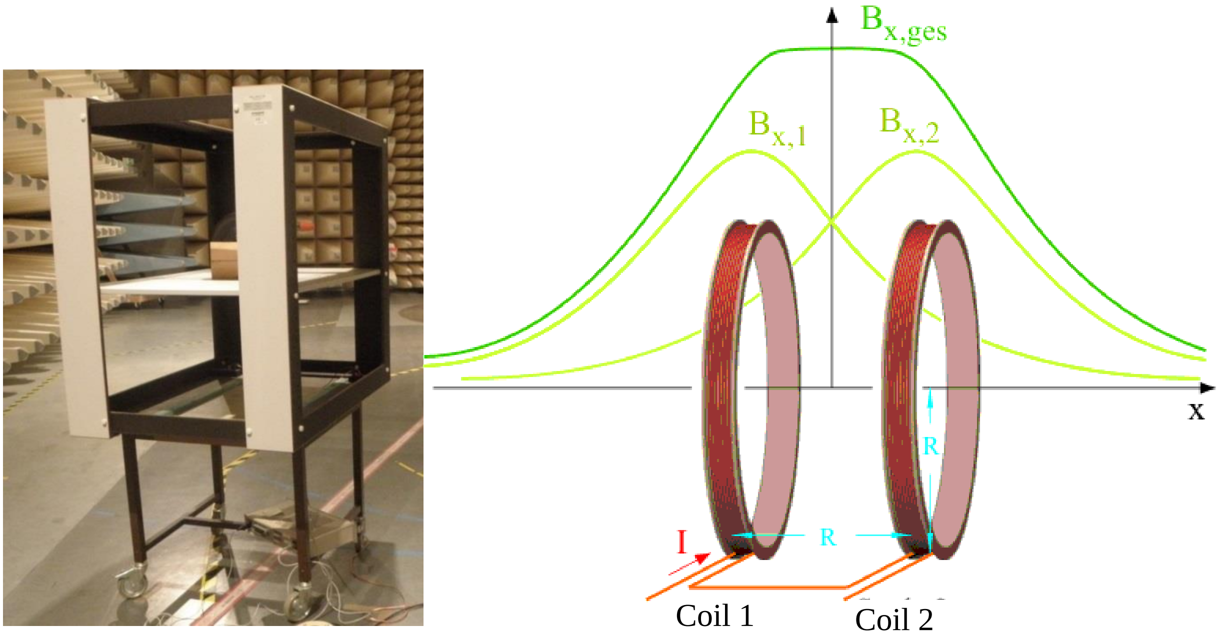
A sensitivity measurement has proven that except for Rx9, all clocks were able to synchronize at a minimum wanted field strength of 50 dBµV/m which was selected for the following interference measurements. Rx9 was excluded from following measurements because it could not synchronize at the wanted field strength.

A4.2.3 WPT (unwanted) signal

The unwanted WPT signal was emulated by an unmodulated carrier from a signal generator (HP 8648C) and transmitted by a "Helmholtz coil". This coil consists of two magnetic loops mounted in parallel to a wooden frame. Inside the frame, a homogeneous magnetic field is generated. The DUTs are placed in the centre of the frame (between the two coils).

FIGURE A4-9

Helmholtz coil with principle



The only possible interfering effects in these measurements are blocking/desensitization or overloading of the DCF77 receiver.

A4.2.3.1 Failure criterion

Without interferer, all clocks finished the synchronization process within three minutes after its start.

The failure criterion used for these measurements was any of the following effects:

1 No indication of received pulses (for clocks with pulse indicator).

2 Failure to synchronize to the transmitted date and time of the wanted signal.

3 Synchronisation to the transmitted time of the wanted DCF77 signal lasted more than one minute longer as in a situation without interferer.

A4.2.3.2 Measurement setup

To ensure that the DUTs received nothing but the signals used for this measurement, the setup was placed in an anechoic, shielded chamber. Especially important was the fact that the 'real' DCF77 signal from Mainflingen could not be received by the DUTs. This was ensured by measurement with a magnetic loop antenna (R&S HFH2-Z2) in the centre of the Helmholtz coil and a spectrum analyser (R&S ESU).

The DUTs were placed in the centre of the wooden frame with the Helmholtz coil. The wanted DCF77 signal was transmitted from a distance of 10 m. The direction of the DUTs was adjusted to receive a maximum of both wanted and unwanted signal.

FIGURE A4-10

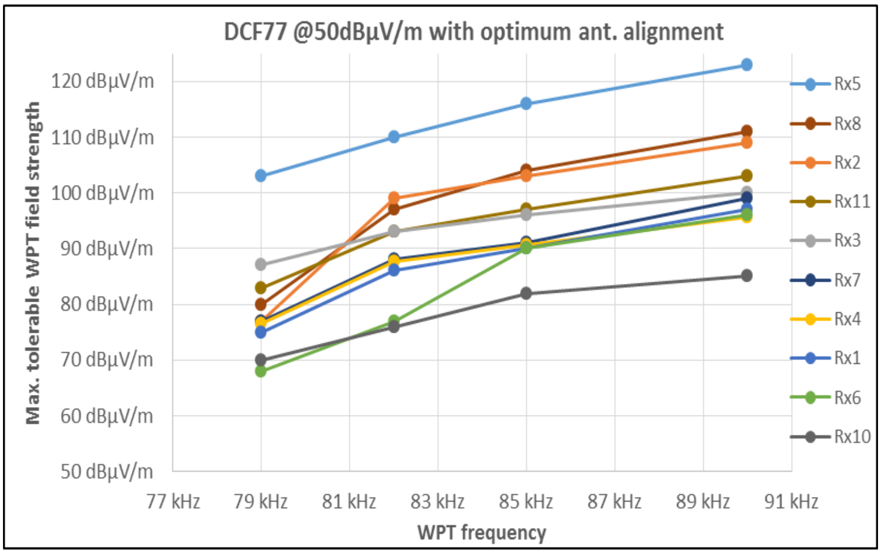
Measurement setup – Front: Wanted DCF77 signal generation, background: Helmholtz coil with DUT

A4.2.3.3 Interference measurements

The wanted DCF77 level was adjusted to 50 dBµV/m at the location of the DUTs. The unwanted WPT level was raised in steps of 3 dB. For every measurement the synchronisation process was started at all DUTs and the ability to synchronize was determined for each DUT until failure.

FIGURE A4-11

Measurement results for 50 dBµV/m wanted field strength and optimum antenna alignment

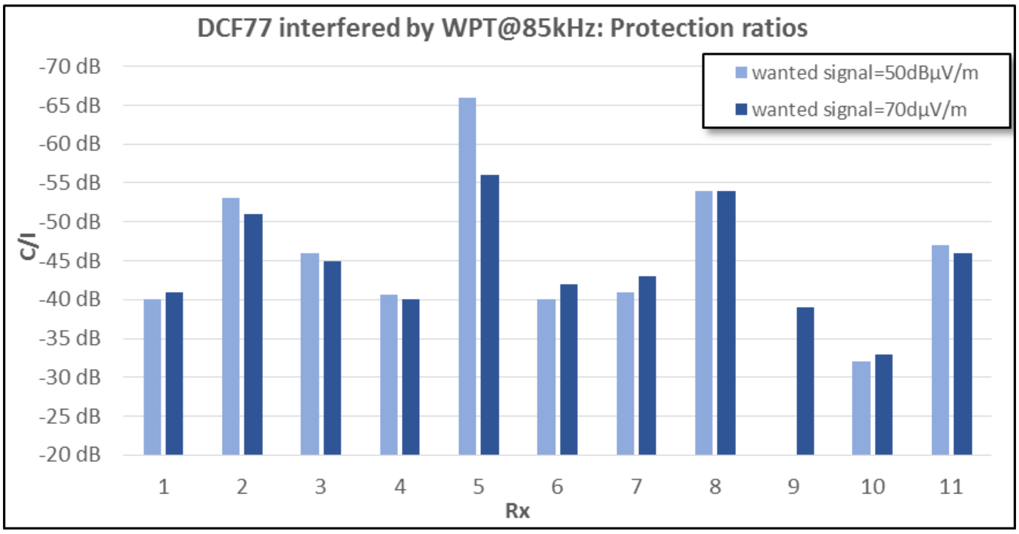


The results show a significant difference in the immunity against WPT signals between the different clocks. The most immune clock Rx5 still works with a WPT level that is about 35 dB higher as the least immune clock Rx10.

An additional measurement was made with a wanted DCF77 field strength of 70 dBµV/m. Figure A4-12 compares the measured carrier to interference ratio (*C*/*I*, difference between wanted and unwanted field strength) of both measurements.

FIGURE A4-12

Measured *C*/*I* for different wanted field strength



It can be seen that the *C*/*I* is nearly independent of the wanted level for all receivers except Rx5. So, generally, the interfering effect of high WPT field strengths can be compensated by raised DCF77 field strength. This indicates that the dominating effect is insufficient receiver selectivity or desensitization (blocking). Only Rx5 seems to be overloaded.

A4.2.3.4 Measurements with different antenna orientation

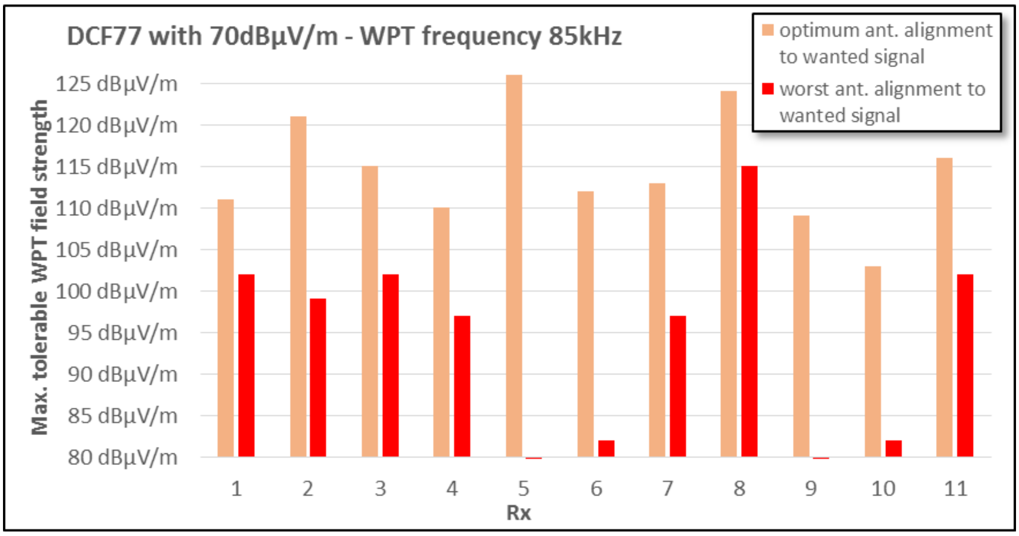
In all previous measurements, the receiving antennas were aligned with both wanted and unwanted signals. To assess the effect of non-optimal antenna alignments, additional measurements were made where the unwanted WPT signal still arrives in optimum receiving direction, but the wanted DCF77 signal arrives from a direction where the DUT antenna is least sensitive (90° offset). In so far, this setup could be regarded as a 'worst case' scenario.

With this setup, only Rx1 and Rx2 were able to synchronize at 50 dBµV/m wanted field strength (without interferer), but all receivers could synchronize at 70 dBµV/m.

The following graph compares the two measurements: The one with optimum antenna alignment is labelled 'optimum', the one with cross-alignment from this section is called 'worst'.

FIGURE A4-13

Comparison of results with different antenna alignment for high wanted field strength



From this measurement, it can be seen that the directivity of the receiving antennas varies considerably: while for Rx1 the directivity is only 9 dB, it is 30 dB for Rx6. It should be mentioned, however, that in an absolute homogeneous field the receiving minimum of the directional Rx antennas may be very sharp and needs exact positioning. This minimum position may not have been realized for all DUTs.

A4.2.4 Impact assessment

The results allow assessment of the required distance between WPT systems and DCF77 clocks to a certain extent to ensure that no harmful impact of WPT on DCF77 occurs. The following tables and figures may serve to estimate these distances for the three measured frequency offsets. For the underlying calculations the following assumptions were made:

All *C*/*I* values are taken from the results under optimum antenna alignments:

1 the maximum WPT field strength on the main frequency from ETSI EN 300 330 is 68.5 dBµA/m in 10 m distance which corresponds to an electrical field strength of 120 dBµV/m;

2 the WPT field strength in the near-field is assumed to follow a 60 dB/decade drop with distance;

3 the 90% and 10% curves are derived from the second best and second worst value of the measurement results.

The resulting compatibility distance then estimates according to following formula:

$$d\left(E_{DCF},\frac{C}{I}\right) = 10^{\left(\frac{120\frac{dB\mu V}{m}-E_{DCF}+\frac{C}{I}}{60\frac{dB}{dec}}+1\right)}$$

FIGURE A4-14

Protection distances at different wanted DCF77 field strength for a WPT at 79 kHz

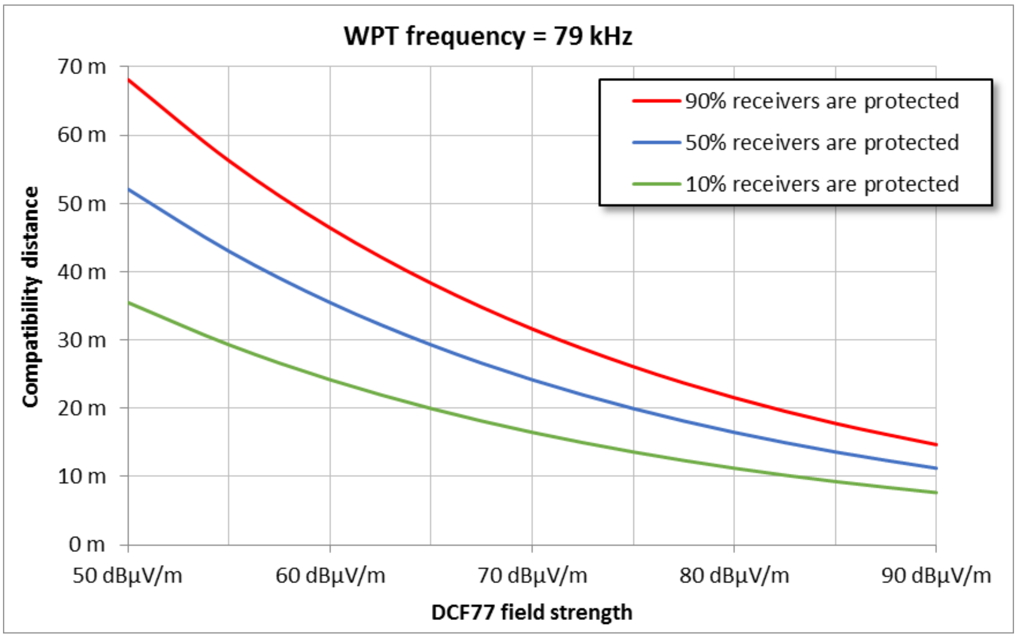


FIGURE A4-15

Protection distances at different wanted DCF77 field strength for a WPT at 85 kHz

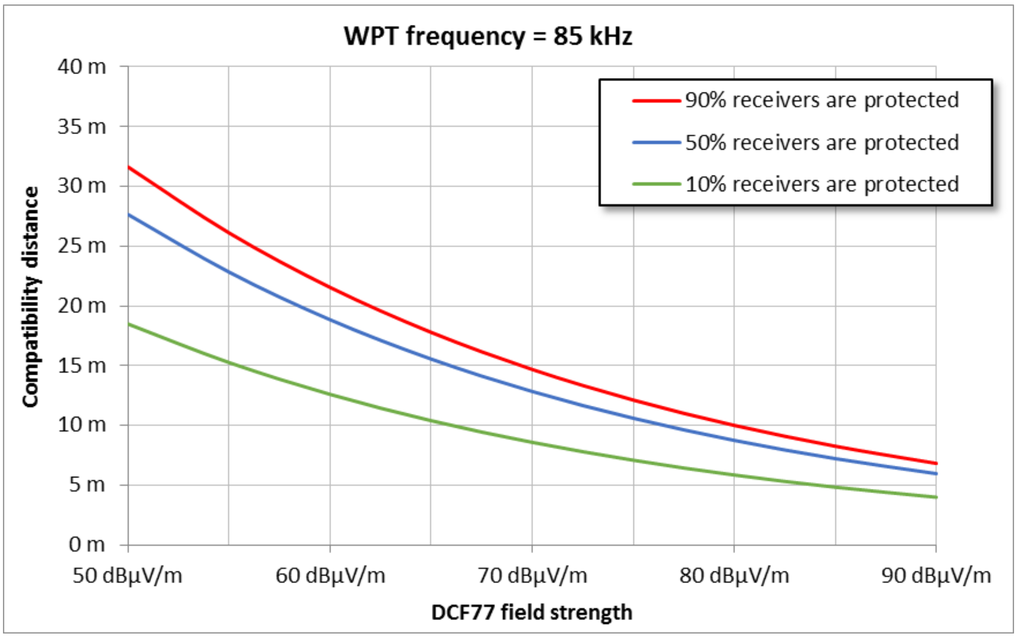
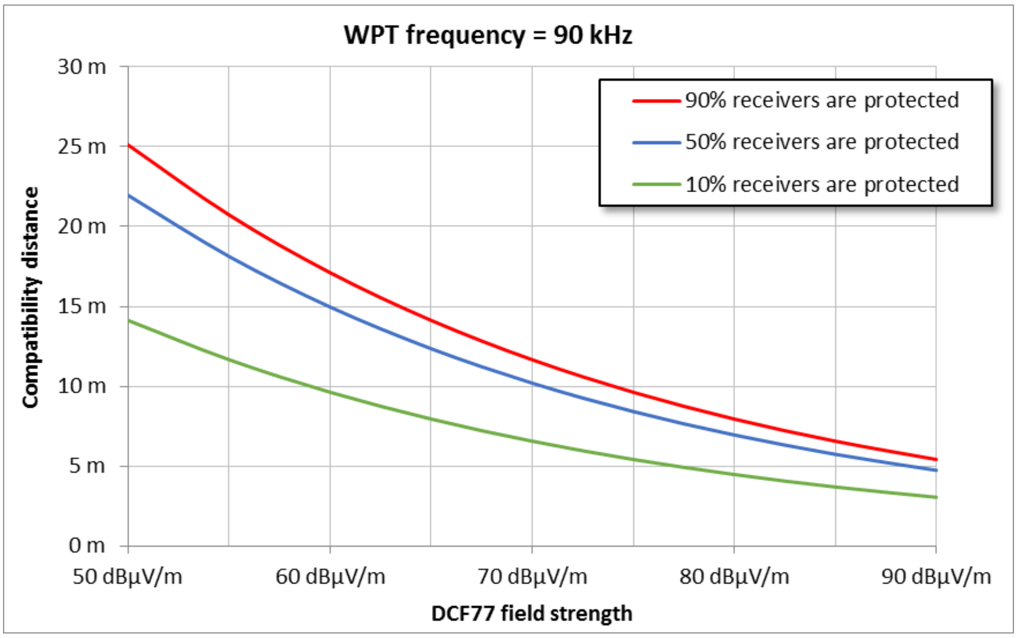


FIGURE A4-16

Protection distances at different wanted DCF77 field strength for a WPT at 90 kHz



A4.2.5 Conclusion on DCF measurement

Even if the current limit for WPT devices (inductive SRD) given in ERC/REC 70-03 Annex 9 of 68.5 dBµA/m for the main WPT emission is met, none of the tested DCF devices work in 10 m distance when receiving only the minimum required wanted field strength of 50 dBµV/m.

The actual protection distance depends on wanted field strength (DCF77) received by the radio clock, the interfering radiation of the WPT system and the frequency offset. For example, when the DCF77 level is 60 dBµV/m (which may be assumed throughout Germany), the WPT level is 68.5 dBµA/m at 10 m distance and the WPT frequency is in the middle of the band at 85 kHz, 50% of the DCF receivers need to be at more than 18 m away from the WPT station to avoid blocking. Increasing the WPT level to 82 dBµA/m by 13.5 dB would increase this distance to 31 m.

It should be distinguished between critical DCF-Receivers and non-critical DCF-Receivers.

Mobile non-critical DCF-Receivers (e.g. wristwatches) should be able to synchronise in general. For fixed non-critical DCF-Receivers (personal clocks, it can be assumed that one single WPT charging station within the distance 31 m would not cause harmful interference, because charging should not last for 24 h. So DCF device should be able to synchronise several times a day. An aggregation of several chargers within the distance of 31 m would reduce the possibility of synchronisation. A possible mitigation would be a minimum distance between charging stations.

For critical DCF-Receivers (e.g. traffic control, time related tariffs, military) a conclusion depends on the systems description. The switch to/from summer time is one possible important event which should be paid attention. A possible mitigation would be a pause of charging for a period of time. For critical DCF-Receivers a minimum distance between charging stations would be helpful.

It should be noted that there was no harmonised technical documentation for DCF-Receivers found. A possible future mitigation could be better receiver characteristics enforced by standardisation.

Annex 5

WPT-EV impact study from China

A5.1 The impact study of WPT-EV on the MF broadcast

This study addressed the potential impact of WPT-EV on broadcast reception in MF band. In China, MF broadcast service is in use and the frequency range is from 526.5-1 606.5 kHz. The purpose is to identify and quantify the risk of interference and separation distance to avoid the harmful interference. The radiated harmonic of WPT-EV and its impact on AM radio receivers in 526.5-1 606.5 kHz was analysed.

Regarding broadcast protection criteria, we refer to China national standard GB 2017-80, Recommendations ITU-R BS.560-4 and ITU-R BS.703. The field test was conducted to study and verify the minimum protection criteria in an urban area.

Regarding WPT-EV emission level, it is assumed that the harmonic emissions in the frequency range of 526.5-606.5 kHz are compliant to ETSI EN 303 417 defined spurious emission limits. H field to E field conversion is conducted by real E/H ratio based on the small loop model at an appropriate distance.

Besides numerical analysis, the field test was conducted to observe the subjective audio experience with the different separation distances. WPT-EV field strength and broadcast signal field strength was measured. The protection ratio according to subjective audio experience was verified.

Section A5.1.1 presented the MF broadcast technical characteristic and protection criteria according to ITU-R Recommendations.

Section A5.1.2 conducted the numerical analysis on the interference to broadcast receiver caused by WPT-EV operation harmonics and spurious emission.

Section A5.1.4 studied the impact to the subject audio experience by field test and experiment in an urban area, which is the typical deployment scenario of WPT-EV. The Monte Carlo simulation was conducted to evaluate the aggregated interference from multiple WPT-EV stations charging simultaneously.

The interference to MF broadcast reception from the harmonics from WPT-EV station operating in 79 kHz – 90 kHz frequency range was studied by theoretical analysis, field test and simulations in typical urban area. More field testing may be conducted for more scenarios if needed.

Annex 9 to this Report provided by EBU carried out studies to compare with this Annex 5, focusing on compatibility studies between WPT-EV and AM broadcasting system. China may further provide interference testing studies into this Annex 5 and update this Annex as appropriate.

Regarding to Table A5-4, a note has been provided in section § A5.1.3.4 for additional explanation to related data which did not seem rational. Please note that: (1) During the test carried out at the time this annex was made, the test audio programs in use are real commercial programs and randomly selected; (2) The question raised in Annex 9 on the possible different testing results between the phonetic and musical programs can be carried out separately in a future study.

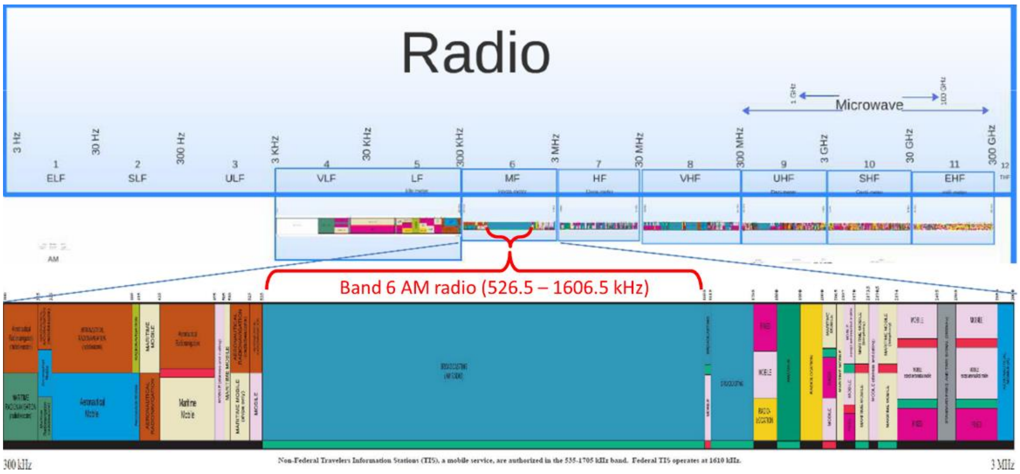
A5.1.1 MF broadcast technical characteristic and protection criteria

A5.1.1.1 MF AM broadcast technical characteristic

As shown in Fig. A5-1, the MF AM broadcast system frequency range in ITU Regions 1 and 3 is from 526.5-1 606.5 kHz. It is mainly for the wide coverage of AM audio service broadcasts.

FIGURE A5-1

AM broadcast frequency in MF band



The following key technical characteristics for MF AM DSB Broadcasting is specified by typical channel standard.

– Channel spacing: 9 kHz

– None audio slot with carrier between LSB (lower side band) and USB (upper side band)

– ITU 300 Hz

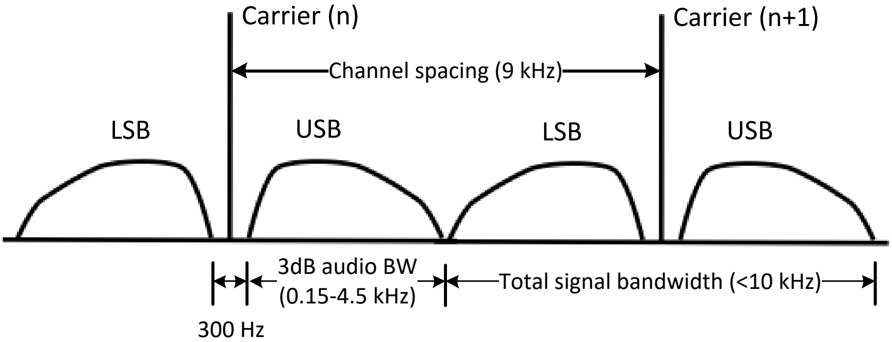
– Tx/Rx channel BW: <10 kHz

– Audio WB: 4.5 kHz.

DSB modulation frequency domain characteristic is demonstrated as Fig. A5-2.

FIGURE A5-2

Demonstration of DSB broadcast signal in frequency domain



Sensitivity should be presented as a single mean figure for each broadcasting band, from which the minimum usable field strength may be calculated considering other influences (e.g. man-made noise). The following values are suggested for the minimum sensitivity of an average receiver:

– Band 5 (LF): 66 dB(μV/m)

– Band 6 (MF): 60 dB(μV/m)

– Band 7 (HF): 40 dB(μV/m)

In this study, 60 dB(μV/m) is applied as the minimum sensitivity of MF broadcast signal and it was recommended in Recommendation ITU-R BS.703 in 1990. The environment noise since [1990]) has been increased significantly, especially in urban areas. The MF broadcast signal field strength in an urban area is usually much greater than the sensitivity level 60 dB(μV/m) defined by Recommendation ITU-R BS.703 to adapt to the existing environment noise, especially in urban areas. It is verified in the field measurement.

A5.1.1.2 MF broadcast protection criteria

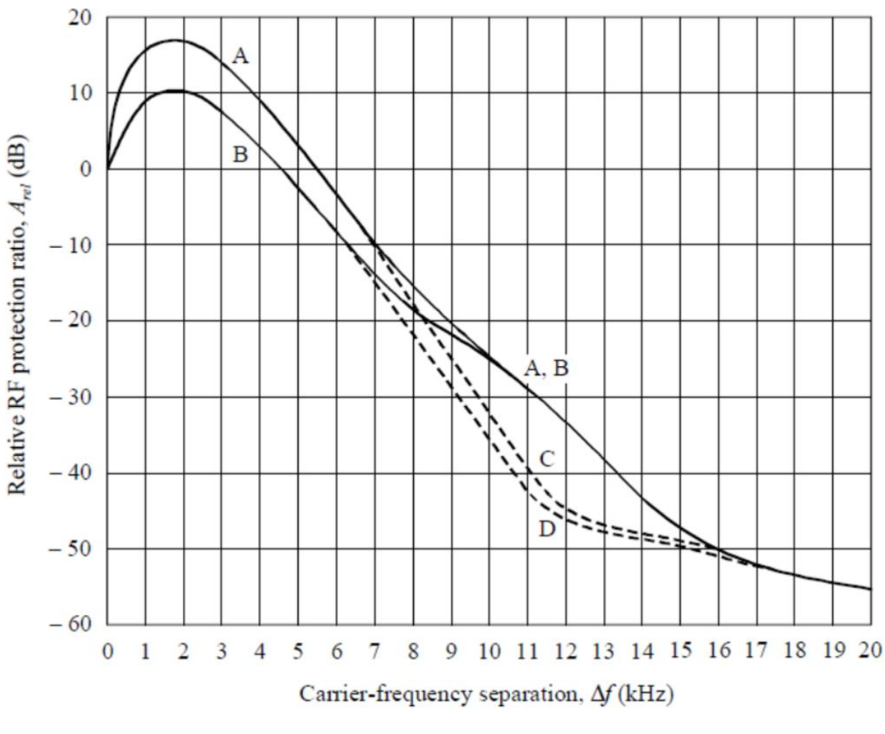
Recommendation ITU-R BS.560-4 recommends the radio-frequency (RF) protection ratios for sound broadcasting in bands 5 (LF), 6 (MF), and 7 (HF). A co-channel protection ratio of 26 dB was used by the Regional Administrative MF Broadcasting Conference (Region 2) (Rio de Janeiro, 1981) for both ground-wave and sky-wave services. Co-channel protection ratios of 30 and 27 dB were used by the Regional Administrative LF/MF Broadcasting Conference (Regions 1 and 3) (Geneva, 1975), for ground-wave and sky-wave services, respectively. China's national standard adopts co-channel protection ratio of 26 dB.

The relative RF protection ratio is the difference (dB) between the protection ratio when the carriers of the wanted and unwanted transmitters have a frequency difference of Δf (Hz or kHz) and the protection ratio when the carriers of these transmitters have the same frequency.

Once a value for the co-channel RF protection ratio (which is equal to the audio-frequency protection ratio) has been determined, then the RF protection ratio, expressed as a function of the carrier frequency spacing, as shown by looking at the curves of Fig. A5-3.

FIGURE A5-3

Relative value of the RF protection ratio as a function of the carrier-frequency separation



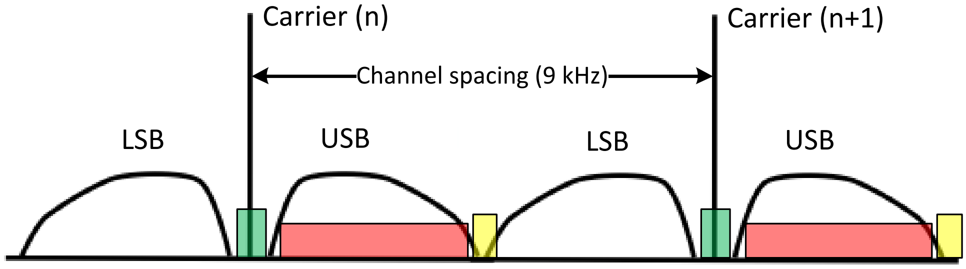
In terms of protection ratio in Recommendation ITU-R M.560-4, relative RF protection ratio (vs carrier) is to protect interference from other AM stations. Therefore, the unwanted signal was assumed to be AM audio modulation waveform.

According to China's national standard, the protection ratio of AM audio modulation waveform is specified to be 26 dB. If the unwanted signal is single tone or very narrow band noise, the protection radio of 26 dB is also sufficient. It is verified by the field test in Table A5-4.

Due to DSB modulation technical characteristics and the existence of the centre gap between the LSB and USB, the single tone or very narrow band interference falling into the centre gap (shown as green blocks in Fig. A5-4 in theory will not cause any harmful interference to the audio reception. For those yellow blocks in Fig. A5-4, it is at the edge of the audio carrier. Its protection criteria may not be as low as the centre green blocks, but its protection criteria can still be relaxed compared to the centre part of LSB and USB.

FIGURE A5-4

Single tone interference to DSB SIGNAL



A5.1.2 Numerical interference analysis

A5.1.2.1 WPT-EV harmonics with operation frequency and emission

Coexistence interference risk by WPT-EV harmonics is analysed and classified as follows.

– Low risk: harmonics inside the carrier slot (green portion in Fig. A5-4) and outside the audio band. Harmonics of WPT-EV operating frequency of 81/90 kHz will fall into the centre gap between LSB and USB of AM carriers.

– Medium risk: harmonics in slot between adjacent channels (yellow portion in Fig. A5-4). Half of harmonics will fall into the centre gap between USB and LSB. And half of harmonics fall at the edge of the USB or LSB, where the protection ratio can be lower than that of those harmonics falling into the central portion of USB/LSB.

– High risk: harmonics in audio bands, i.e. LSB or USB. WPT-EV operation frequency will be the frequency from 79 kHz to 90 kHz, except 85.5 kHz and 90 kHz.

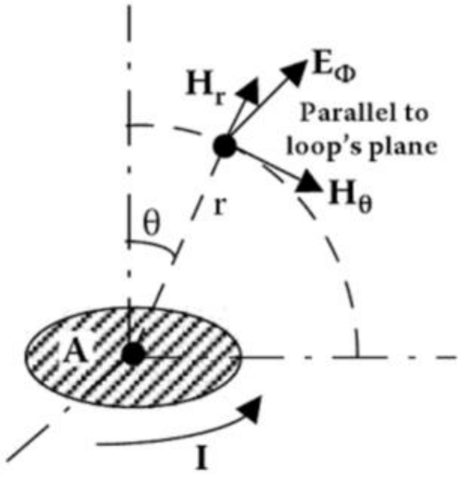
A5.1.2.2 H field conversion to E-field

Since the source of emission from WPT-EV is coil, H field will dominate the emission at the near field. The H fields decay differently depending on the ground conditions such as earth vs water and the varying distance. For a simple assessment, free space condition is the worst case. It can be shown that the H fields will decay from 60 dB/dec at near field region defined by $\lambda/2\pi$ gradually to 20 dB/dec at far field region.

The E/H ratio and emission is assessed based on loop model in free space. The model is verified by both measurement and simulation. The small loop antenna is a closed loop as shown in Fig. A5-5.

FIGURE A5-5

A small loop radiation



For the radiations by small loop model, the E and H can be described approximately as follows:

$$E_{\phi}(V/m) = \pi Z_0 \frac{IA}{\lambda^2 r}\sqrt{1+\left(\frac{\lambda}{2\pi r}\right)^2}\sin\theta \quad (1)$$

$$H_{\theta}(A/m) = \pi \frac{IA}{\lambda^2 r}\sqrt{1-\left(\frac{\lambda}{2\pi r}\right)^2+\left(\frac{\lambda}{2\pi r}\right)^4}\sin\theta \quad (2)$$

Where, I is loop current (A, ampere); A is loop area (m^2); λ is wavelength (m), λ = 300/f, f is the frequency(MHz); r is the distance to observation point (m); and Z_0 is the free space impedance, 377 Ω.

At each region, the E field strength from a WPT-EV station is converted by E/H ratio as shown in Fig. A5-6 (low channel of MF band), Fig. A5-7 (middle channel of MF band), and Fig. A5-8 (high channel of MF band).

FIGURE A5-6

***E*/*H* versus distance by loop source in free space at low end of MF band (530 kHz)**
Low channel in MF band

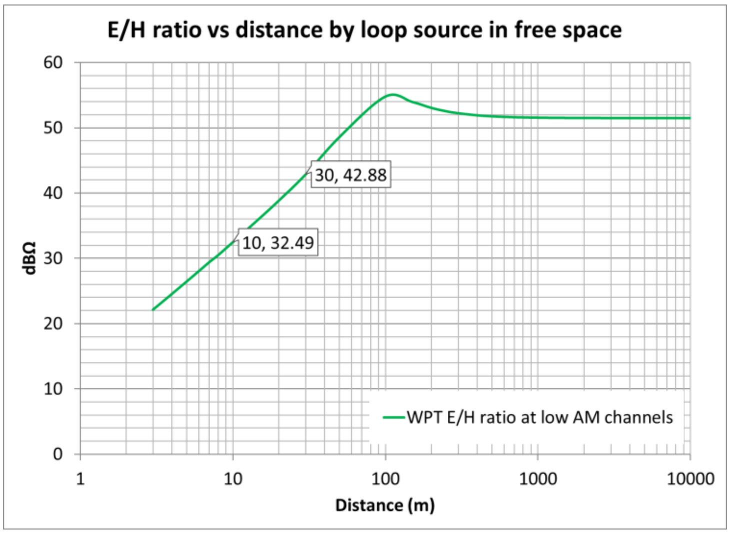


FIGURE A5-7

***E*/*H* versus distance by loop source in free space in middle of MF band (1 062 kHz)**
Middle channel in MF band

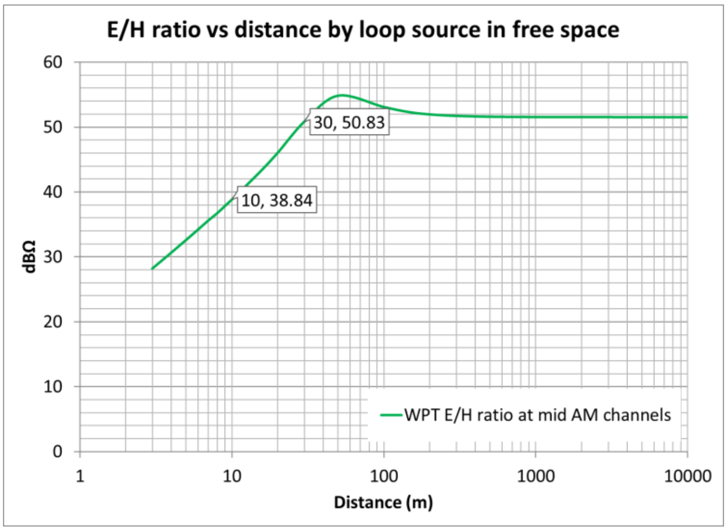
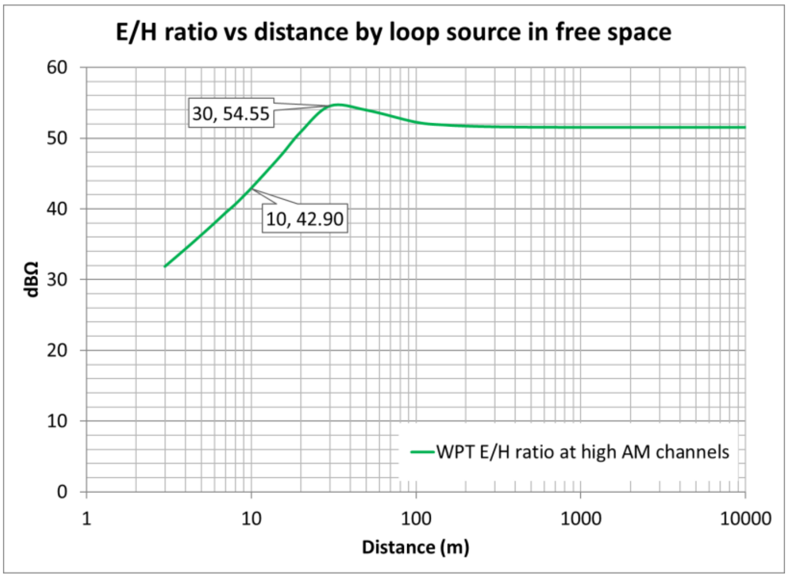


FIGURE A5-8

***E*/*H* versus distance by loop source in free space at high end of MF band (1 602 kHz)**
High channels in MF band



A5.1.2.3 Numerical analysis

Assume harmonics of WPT-EV meet ESTI EN 303 417 defined limits are assumed to be maximum emission from WPT-EV. Converted E field to be used to assess interference with AM. In Table A5-1, WPT-EV operating frequency is assumed to be within 79-90 kHz frequency range. Gap is defined as equation (3).

Gap = the protection ratio of 26 dB – (Min AM Rx sensitivity – WPT-EV harmonic E field strength) (3)

TABLE A5-1

E field analysis and protection gap analysis with 10 m free space

Frequency (MHz)	**EN 303 417 spurious limit (dBμA/m @ 10 m)**	***E*/*H* (dBΩ)**	**Converted E field limit (dBμV/m @ 10 m)**	**Minimum AM Rx sensitivity (dBμV/m)**	**Gap (dB)**
0.531	9.29	32.51	41.80	60.00	7.80
1.062	6.28	38.84	45.12	60.00	11.12
1.602	4.50	42.90	47.40	60.00	13.40

According to the analysis in Table A5-1, there is still a gap (7.80 dB to 13.4 dB) to meeting the stringent protection requirement of 26 dB at the minimum sensitivity level. Firstly, in the implementation of commercial production, there will be some margin to meet the standard minimum requirement. Therefore, the harmonics strength level of the commercial products will be less than the standard requirement. Secondly, the broadcast signal level is much higher than minimum sensitivity level in the urban area since the environment noise is usually high in urban. And radio receiver can resist much stronger interference in a good coverage area. Thirdly, there are usually walls between the underground garages and resident buildings. The wall penetration loss will introduce about additional 17 dB attenuation to WPT-EV signal level. It has been measured and verified by the field test. Since the greatest gap to meet the protection criteria is less than 17 dB, the coexistence between broadcast and WPT-EV charging can be feasible.

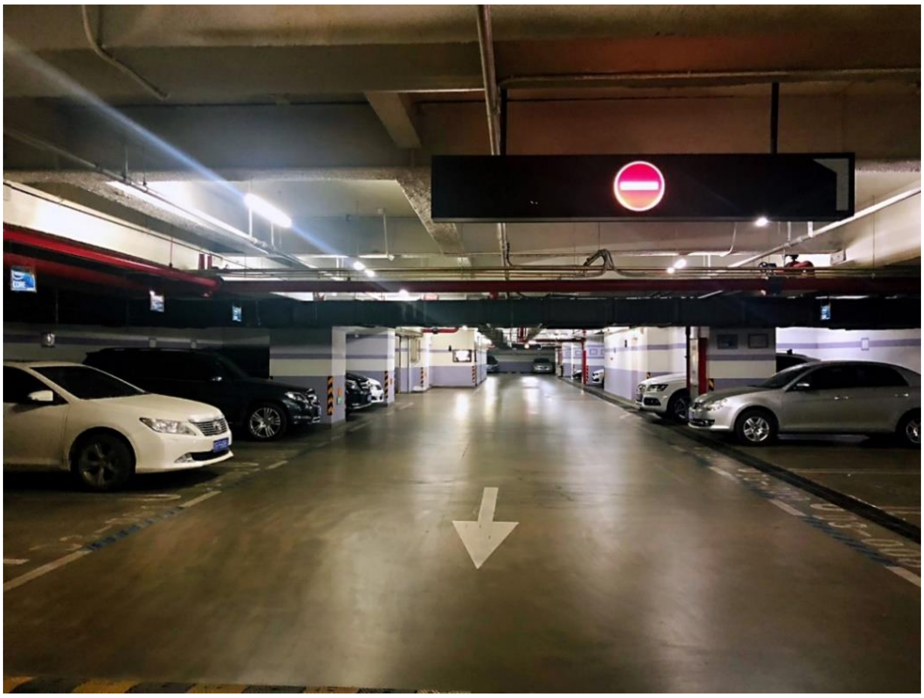
A5.1.3 Assessment with Field measurement

A5.1.3.1 Typical WPT-EV deployment scenarios in China

Underground parking garages are very popular in urban China, shown in Fig. A5-9. The general height of one layer of underground parking garage is usually 4~4.5 metres. The AM radio receivers are usually used on the ground floor, which is at least 1 metre high from the ground.

FIGURE A5-9

A picture of some underground parking garage in China



A5.1.3.2 Subjective assessment

Recommendation ITU-R BS.1284-1 is used for criteria of subjective assessment of sound quality. Five-grade scales are used for the subjective assessment of sound quality (SQ), shown as Table A5-2.

TABLE A5-2

Recommendation ITU-R BS.1284-1 subjective assessment merit

Sound Quality	Impairment
5 Excellent	5 Imperceptible
4 Good	4 Perceptible, but not annoying
3 Fair	3 Slightly annoying
2 Poor	2 Annoying
1 Bad	1 Very annoying

A5.1.3.3 Radio measurement setup

A field test was conducted in the Shanghai urban area in China. The measurement setup is demonstrated in Fig. A5-10. The measurement condition is summarized as follows:

– loop and rod antenna is used for H field measurement;

– measurement distance was setup as 5 m and 10 m. For an extreme case, 3.4 m was tested;

– charging frequency is set to 85.5 kHz, 85.68 kHz and 85.2 kHz respectively;

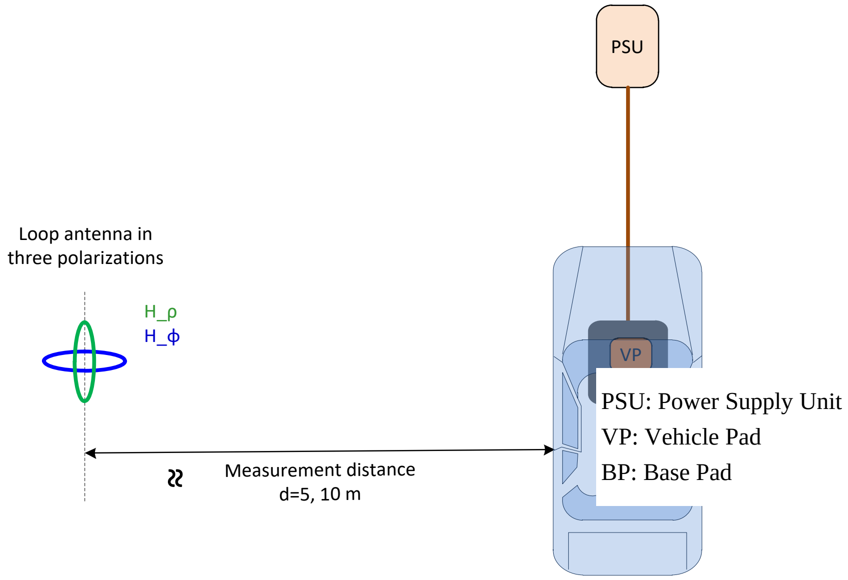
– charging power of the battery is 6.6 kW;

– the radio used in the test is Tecsun PL-380;

– compared radio subjective quality at the selected distance with/without WPT-EV charging.

FIGURE A5-10

The demonstration of radio setup of the field test



A5.1.3.4 Measurement results and analysis

There are in total 9 AM channels in Shanghai. The signal bandwidth of each channel is 9 kHz. Two MF channels were carefully selected to address the harmonic interference test, which are the channels the harmonics of the testing WPT-EV frequency can fall into. The broadcast radio signal levels and sound quality for the MF channels were measured without any WPT-EV interference as show in Table A5-3.

TABLE A5-3

Field signal levels of MF channels in Shanghai

MF channel (kHz)	Signal level	Sound quality score
855	Strong (94 dBμV/m)	5
1197	Strong (86.4 dBμV/m)	4

The H field environment noise measurement result is about –17 ~ –13 dBμA/m/15 Hz around 850 kHz in an urban area in Shanghai. H field strength of environment noise level in 9 kHz is about 10.8 ~ 14.8 dBμA/m. Convert H field strength to E field strength with E/H ratio of 51.5 dBΩ. E field strength of environment noise level in 9 kHz is about 62.3 ~ 66.3 dBμV/m.

Regarding AM broadcast field strength in urban area, it was tested in Shanghai. According to the field test, the AM broadcast field strength should be at least higher than 80 dBμV/m to keep radio sound quality score above 3 in typical urban area. Since the signal level of 855 kHz is measured to be about 94 dBμV/m, SIR of radio receiver in 855 kHz channel in the field with the environment noise is estimated to be around 27.7 dB ~ 31.7 dB.

The WPT-EV signal was measured at 1 metre from the base pad. The waveform is a CW wave with field strength of about 74.4 dBμA/m. The centre frequency was set at 85.5 kHz, 85.68 kHz or 85.2 kHz respectively. The 6 dB signal bandwidth is about 1 Hz, which is restricted by the test equipment resolution. And all harmonics are CW type of very narrow band noise.

The measured AM channel waveforms when WPT-EV charging is powered-off are shown in Figs A5-11 and A5-12 (Zoom-in AM channels (1197 kHz) measurement result without WPT-EV harmonic). The measured AM channel waveforms when WPT-EV charging is power-on are shown in Fig. A5-13 and Fig. A5-14 (Zoom-in AM channels (1 197 kHz) measurement result with WPT-EV harmonic (WPT-EV operation frequency 85.68 kHz) at 10 m). The orange trace indicates the output by the peak detection of the spectrum analyzer. The blue trace indicates the output by the average detection of the spectrum analyser. The broadcast signal field strength is much stronger than that of the WPT-EV harmonics. And the environment noise level in the urban area is high. No significant impact from WPT-EV charging was observed on the environment noise floor.

FIGURE A5-11

AM channels measurement result without WPT-EV harmonics

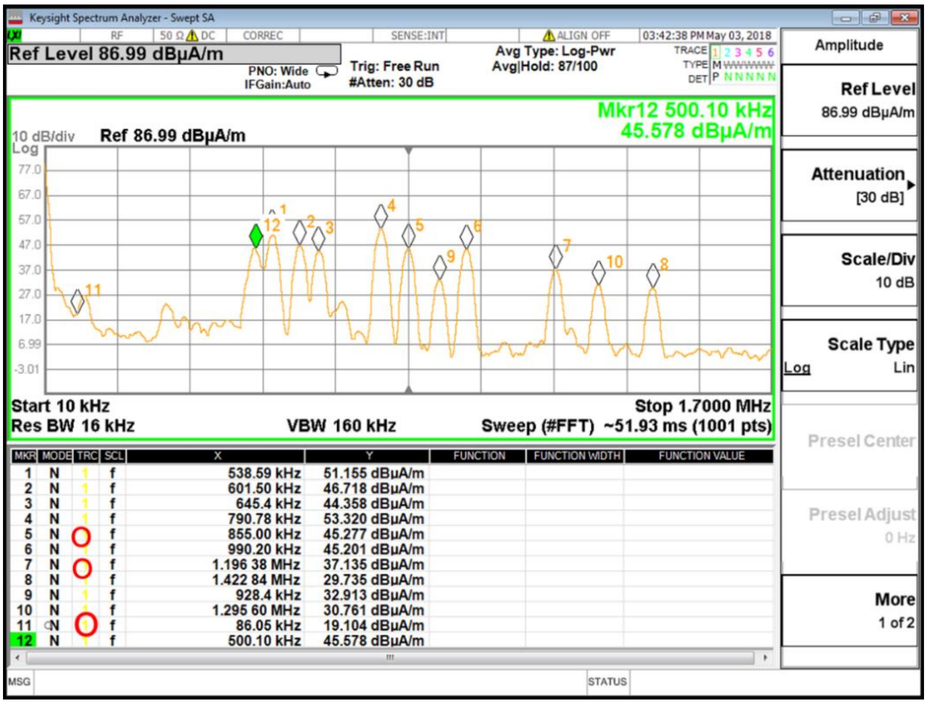


FIGURE A5-12

Zoom-in AM channels (855 kHz) measurement result without WPT-EV harmonic

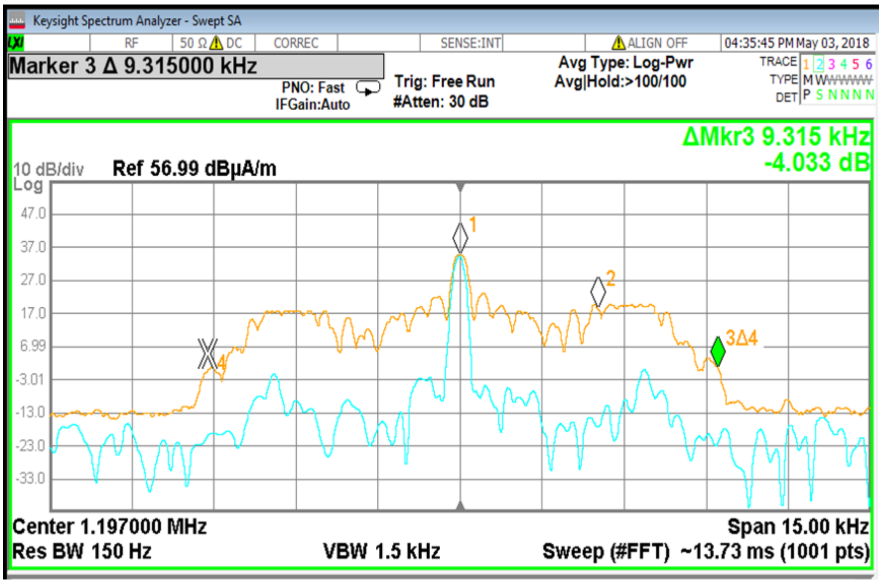


FIGURE A5-13

AM channel (855 kHz) measurement result with WPT-EV harmonic (WPT-EV operation frequency 85.68 kHz) at 10 m

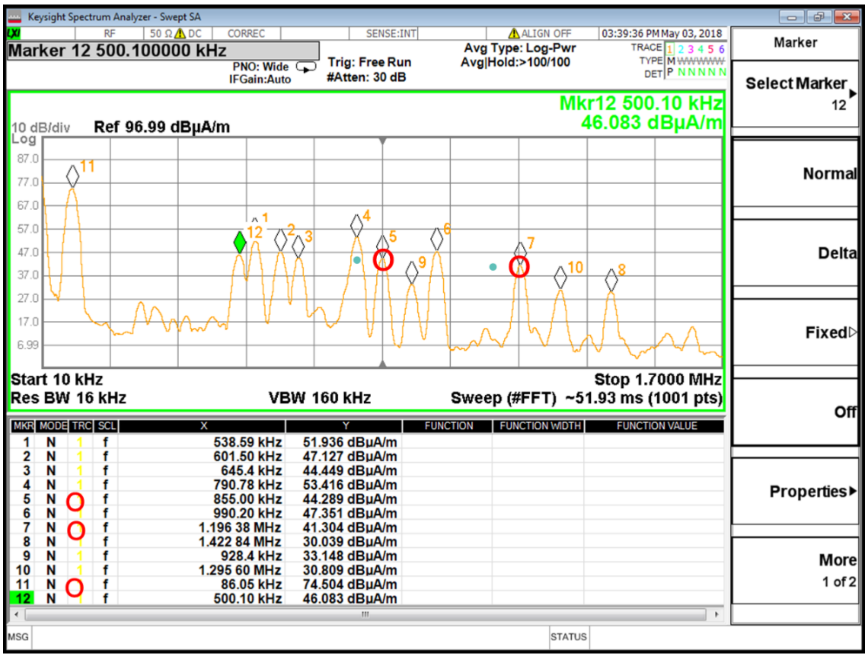


FIGURE A5-14

Zoom-in AM channel (1 197 kHz) measurement result with WPT-EV harmonic (WPT-EV operation frequency 85.68 kHz) at 10 m

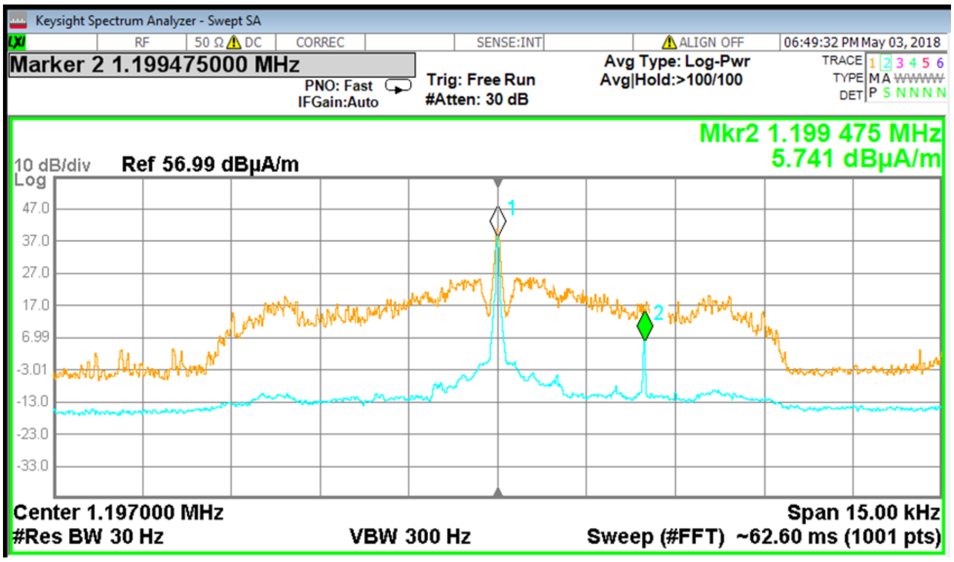
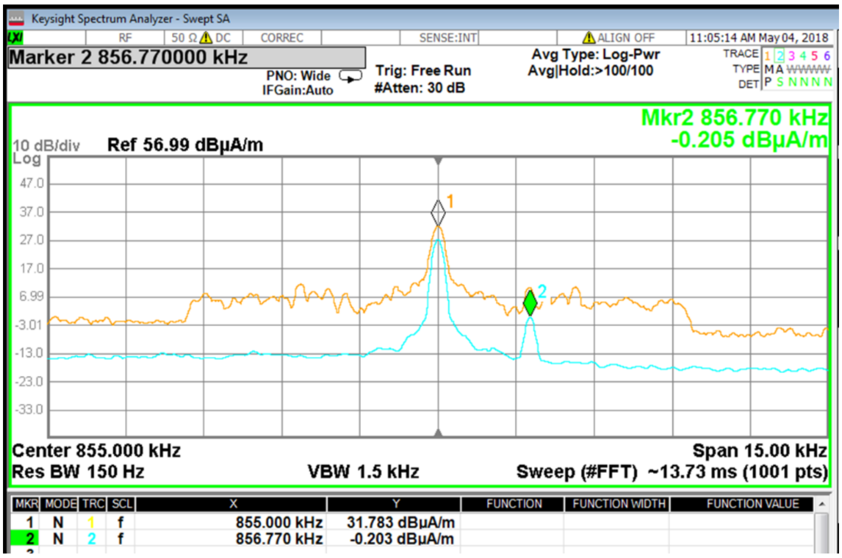


FIGURE A5-15

**AM channel (at 855 kHz) measurement result with WPT-EV harmonic|
(WPT-EV operation frequency of 85.68 kHz) at 4.3 m**



When the WPT-EV charging operating frequency is set to 85.5 kHz, the 10th order harmonic will be 855 kHz and it fell into the centre gap between LSB and USB of 855 kHz AM broadcast channel. According to Fig. A5-16, the width of centre gap of 9 kHz channel is approximately 100 Hz (±50 Hz from the centre frequency). The orange trace indicates the output by the peak detection of the spectrum analyser. The blue trace indicates the output by the average detection of the spectrum analyser.

The waveform of 855 kHz broadcast channel was measured when WPT-EV charging is powered on in Fig. A5-17 and it is the zoom-in figure of the spectrum analyser. Similarly, the orange trace indicates the output by the peak detection of the spectrum analyser. The blue trace indicates the output by the average detection of the spectrum analyser. It is shown that the harmonics falling into the centre gap had no impact on the LSB or USB audio signal demodulation. The sound quality was not impacted according to the subjective test.

FIGURE A5-16

AM channel (855 kHz) measurement result without WPT-EV harmonics

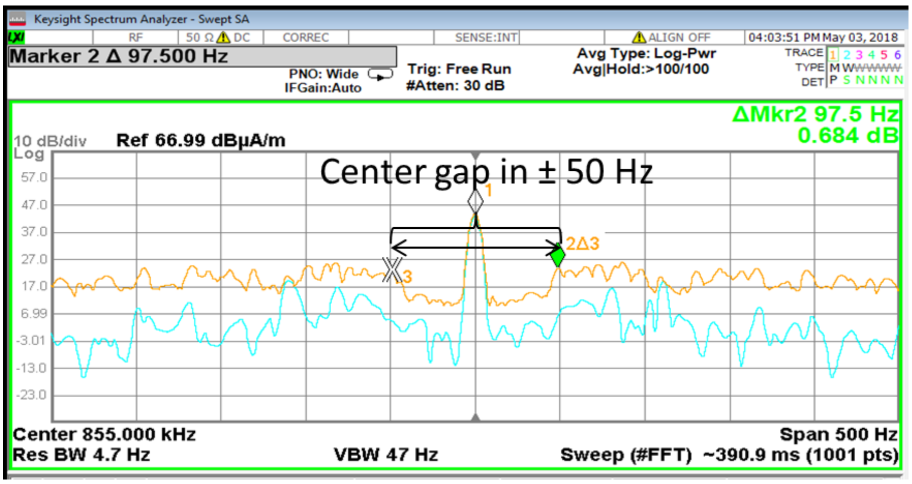
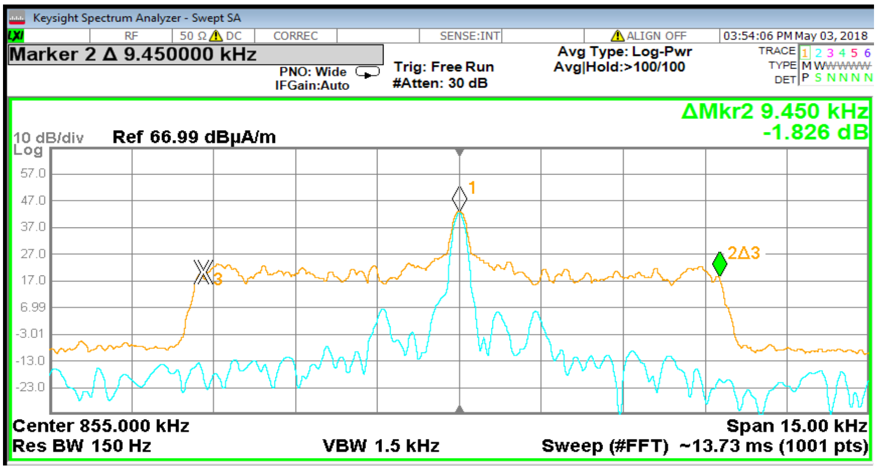


FIGURE A5-17

AM channel (855 kHz) measurement result with WPT-EV harmonic (WPT-EV operation frequency of 85.5 kHz)



In Table A5-4, the subjective test results are summarized for various configurations with different distances and different channels. A WPT-EV harmonic is narrow band noise and its interference could be perceptible when the harmonics are high enough in a broadcast channel, such as when the radio is very close to a powered-on charging vehicle (less than 3.4 m in the test). Since the broadcast signal is strong in urban areas, the harmonics caused no sound quality degradation as long as the distance is greater than 3.4 metres. For the operation frequency of 85.68 kHz, its 10th order harmonic falls into the USB of channel 855 kHz with the offset of 1.8 kHz from the centre of the 855 kHz channel, and its 14th order harmonic falls into USB of channel 1 197 kHz with the offset of 2.52 kHz from the centre of the 1 197 kHz channel.

For the worst case in the test, the operating frequency was 85.68 kHz and the observed AM channel is 1 197 kHz (E field of 86.6 dBµV/m). The radio was 3.4 m separated from the charging vehicle and S/N of AM signal to harmonic was around 23.9 dB. No sound quality degradation was observed. For WPT-EV 85.5 kHz operating frequency, even when the distance was 3 metres, no sound quality degradation was observed since the harmonics fall into the centre gap of the AM channels.

TABLE A5-4

The field test results summary

Frequency info					**Radio performance before charging**			**Radio performance during charging**		
Distance (m)	**WPT freq. (kHz)**	**CH No.**	**CH Freq. (kHz)**	**Offset from the centre of AM channel Freq. (kHz)**	**AM E-field (dBµV/m)**	**AM H-field (dBµA/m)**	**SQ of radio**	**Harm. H-field (dBµA/m)**	**SQ of radio**	***S/N* by H field (dB)**
10	85.2	37	855	−3	94.2	42.7	5	< 2	5	40.0
10	85.5	37	855	0	94.2	42.7	5	Inside AM carrier	5	Cannot identify
3	85.5	37	855	0	94.2	42.7	5	Inside AM carrier	5	Cannot identify

TABLE A5-4 (*end*)

Frequency info					**Radio performance before charging**			**Radio performance during charging**		
Distance (m)	**WPT freq (kHz)**	**CH No.**	**CH Freq. (kHz)**	**Offset from the centre of AM channel Freq. (kHz)**	**AM E-field (dBμV/m)**	**AM H-field (dBμA/m)**	**SQ of radio**	**Harm. H-field (dBμA/m)**	**SQ of radio**	***S/N* by H field (dB)**
10	85.5	75	1197	0	86.6	35.1	4	Inside AM carrier	4	Cannot identify
3	85.5	75	1197	0	86.6	35.1	4	Inside AM carrier	4	Cannot identify
10	85.68	37	855	1.8	94.2	42.7	5	6.3	5	36.4
5	85.68	37	855	1.8	94.2	42.7	5	14.0	5	28.7
4.3	85.68	37	855	1.8	83.3	31.8	5	5.3	5	26.5
10	85.68	75	1197	2.52	86.6	35.1	4	3.0	4	32.1
5	85.68	75	1197	2.52	86.6	35.1	4	6.2	4	28.9
4.6	85.68	75	1197	2.52	86.6	35.1	4	6.8	4	28.3
3.4	85.68	75	1197	2.52	86.6	35.1	4	11.2	4	23.9

NOTE – In field tests, some large random propagation fading was encountered resulting in both the level of AM signal and the level of WPT harmonic signal degrading significantly. However, the related signal-to-noise ratio can be still meaningful under this circumstance, since the fading on the wanted and unwanted signal were simultaneous.

During the field test, AM field strength was observed and it should be higher 80 dBμV/m to keep radio sound quality score above 3 in a typical urban area. Higher AM signals are needed in urban regions than rural areas due to higher environmental noise and propagation loss.

– AM signals in urban regions typically greater than 80 dBμV/m.

– AM signals in suburban regions typically span from 70 dBμV/m to 80 dBμV/m.

– AM signals in rural regions typically span from 60 dBμV/m to 70 dBμV/m.

The theoretical analysis is conducted with adjusted AM signal level, which is more realistic in terms of the environment noise levels in urban, suburban and rural areas. The results are shown in Table A5-5. The margin is defined as equation (4) and it is a negative of “gap” definition in equation (3).

Margin = Min AM Rx field strength with acceptable SQs – WPT-EV harmonic E filed strength – 26 dB (4)

TABLE A5-5

E field and protection margin analysis with 10 m free space in typical urban, suburban and rural coverages

Frequency (MHz)	EN 303 417 spurious limit (dBµA/m @ 10 m)	E/H ratio (dBΩ)	Converted E field limit (dBµV/m @ 10 m)	Min AM Rx field strength with acceptable SQ (dBµV/m)	Margin (dB)
0.531	9.29	32.51	41.80	80.00 (urban)	12.20
1.062	6.28	38.84	45.12		8.88
1.602	4.50	42.9	47.40		6.6
0.531	9.29	32.51	41.80	70.00 (suburban)	2.2
1.062	6.28	38.84	45.12		−1.12
1.602	4.50	42.9	47.40		−3.4
0.531	9.29	32.51	41.80	60.00 (rural)	−7.8
1.062	6.28	38.84	45.12		−11.12
1.602	4.50	42.9	47.40		−13.40

Since in urban conditions, all margin values are greater than 0, it means that WPT-EV harmonic meeting with ESTI EN 303 417 limit will not interfere with AM radio in urban areas. For suburban and rural scenarios, the field test was not conducted, and the analysis was done according to the predicted AM signal level. And in suburban and rural areas, since the margin value in some channels is less than 0, more attenuation may be needed and a maximum of 13.4 dB more attenuation may be required. It can be due to the wall penetration loss of the garage. The wall attenuation can be about 17 dB according to the field test in Shanghai.

A5.1.4 Multiple WPT-EV stations

The Monte Carlo simulation is conducted to evaluate the aggregated WPT-EV harmonic interference generated by multiple WPT-EV stations, which are charging simultaneously.

A5.1.4.1 Topology and assumptions

For the aggregated interference, the urban scenario is evaluated as the typical scenario. For suburban and rural areas, due to low deployment density of multiple WPT-EVs it is not necessary to be studied.

An underground garage in the basement is the typical scenario in an urban area in China. The radio receiver is placed on the ground floor. Multiple WPT-EV stations charging simultaneously are simulated. Shown in Fig. A5-18, there are two layers surrounding the centre car (shown in red circle, which is right below the radio), total 25 cars. A maximum of four layers surrounding the centre car are simulated, total 81 cars.

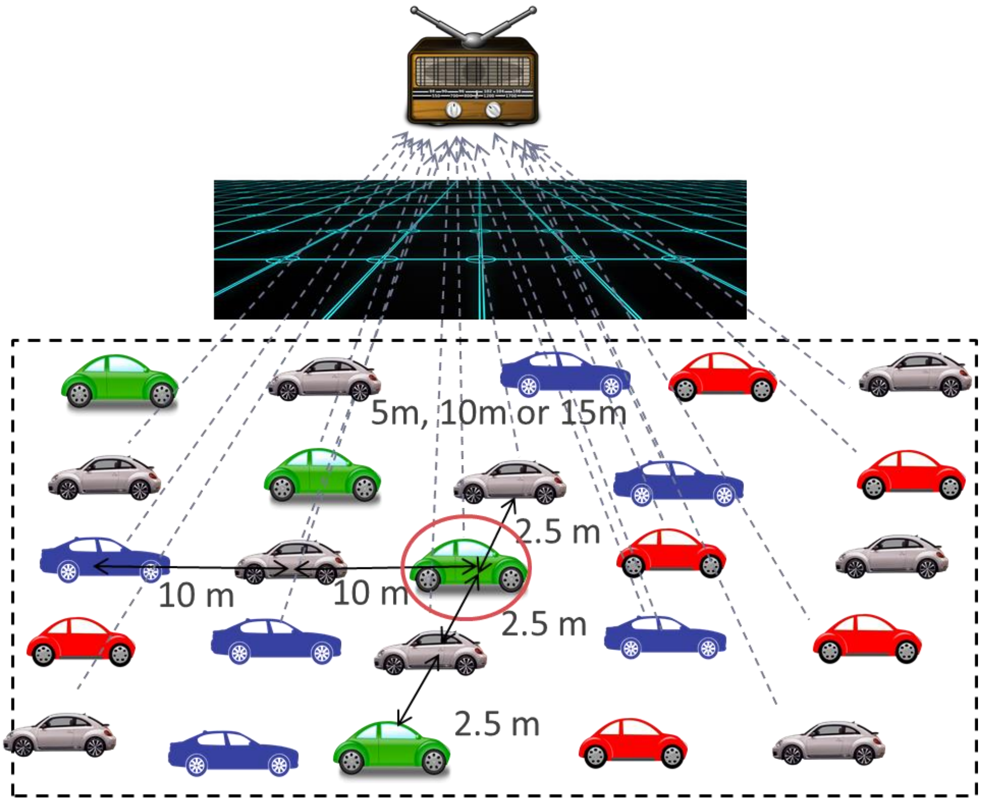
The parking space width is assumed to be 2.5 metres. The lane width is assumed be 5 metres. The vehicle length is assumed to be 5 metres. The minimum space between WPT-EV pads across the lane is 10 metres. The height between the radio and the first-floor basement is 5 metres. The height between the radio and the second floor basement is 10 metres. The height between radio and the third floor basement is 15 metres.

Since there are the cement floors for the basement garage, the cement floor penetrations will be considered. The penetration loss is lognormally distributed random $N(\mu, \sigma^2)$. μ is the mean value and it is assumed to 17 dB according to the field measurement. σ is the standard deviation and it is assumed to be 4 dB according to an academic study in other frequency ranges. The penetration loss of each floor will be added separately.

In the simulation, an extremely high deployment density is assumed since every parking slot is assumed to support WPT-EV and charging simultaneously. Considering the penetration rate and charging time difference, the density of the simultaneous charging WPT-EV stations should be lower than the simulation assumption. The interference should be less in reality.

FIGURE A5-18

Topology of multiple WPT-EV aggregated harmonic interference in the Monte Carlo simulation



A5.1.4.2 Monte Carlo simulation methodology

The simulation consists of many snapshots. The steps for each snapshot are provided in detail as follows.

Step 1: Set the E-field strength of the centre car to the limit according to Table A5-1. For example, it is 41.8 dBμV/m at 10 metres at frequency of 531 kHz and denote it as E_1 and make it in linear domain. Therefore,

$$E_1 = 10^{\frac{41.8}{20}} \quad (5)$$

For 1.062 MHz, $E_1 = 10^{45.12/20}$. For 1.602 MHz, $E_1 = 10^{47.4/20}$. E_1 is the reference E field strength in μV/m.

Step 2: For each WPT-EV station, calculate its distance d_n to the radio receiver according the certain topology, while n is the nth WPT-EV station. Set d_1 = 10 m and it is the reference distance.

Step 3: Calculate E field strength for each WPT-EV station E_n according to the distance and E-field of the centre car (with minimum distance). Since E field is a vector, add a random phase to it. φ is a uniformly distributed random between 0 degree and 360 degrees.

$$E_n = \frac{\frac{\sqrt{1+\left(\frac{\lambda}{2\pi d_n}\right)^2}}{d_n}}{\frac{\sqrt{1+\left(\frac{\lambda}{2\pi d_1}\right)^2}}{d_1}} \times E_1 \times (\cos(\varphi) + j\ \sin(\varphi)) \quad (6)$$

While, λ = 300/f, f is the frequency (MHz), and assuming free-space loss, from car to receiver;

Step 4: For each link, reduce the penetration loss of floors.

$$E_n = E_n * 10^{(-\ penertrationLoss\_dB)/20} \quad (7)$$

Step 5: Calculate the aggregated interference for the m_{th} snapshot.

$$E_{aggregate,m_{th\_}\,snapshot} = \sum_n E_n \quad (8)$$

$$E_{aggregate_{dB\mu V},m_{th\_}\,snapshot} = 20 \times \log_{10}(|\sum_n E_n|) \quad (9)$$

Step 6: Calculate the average $E_{avergae\_aggreate\_dB\mu V}$. Note that it should be added in linear domain for arithmetic average and then convert it to log domain.

$$E_{average\_aggreate\_dB\mu V} = 20 \times \log10\left(\frac{\sum_m\left[E_{aggregate,m_{th\_}\,snapshot}\right]}{total\_snapshot\_num}\right) \quad (10)$$

While, *total_snapshot_num* is the total snapshot number of the simulation.

A5.1.4.3 Simulation results

The aggregated interference of multiple WPT-EV stations when they are in B1, B2 and B3 garages are simulated separately. The simulation results are summarized in Tables A5-6, A5-7 and A5-8.

TABLE A5-6

Aggregated E field simulation results of WPT-EV harmonics in urban area for B1 floor

Frequency of the harmonic (MHz)	Number of charging WPT-EV stations	WPT-EV aggregated E field strength of harmonics at radio receiver (dBµV/m)	Min AM Rx field strength with acceptable SQ (dBµV/m)	SIR (signal to interference ratio) (Min AM Rx field strength-WPT-EV aggregated E field strength of harmonics) (dB)
0.531	25	30.6	80.00 (urban)	49.4
	49	31.3		48.7
	81	31.6		48.4
1.062	25	33.9	80.00 (urban)	46.1
	49	34.7		45.3
	81	35.0		45.0
1.602	25	36.3	80.00 (urban)	43.7
	49	37.0		43.0
	81	37.4		42.6

TABLE A5-7

Aggregated E field simulation results of WPT-EV harmonics in urban area for B2 floor

Frequency of the harmonic (MHz)	Number of charging WPT-EV stations	WPT-EV aggregated E field strength of harmonics at radio receiver (dBμV/m)	Min AM Rx field strength with acceptable SQ (dBμV/m)	SIR (signal to interference ratio) (Min AM Rx field strength-WPT-EV aggregated E field strength of harmonics) (dB)
0.531	25	18.6	80.00 (urban)	61.4
	49	20.3		59.7
	81	21.2		58.8
1.062	25	22.0	80.00 (urban)	58.0
	49	23.8		56.2
	81	24.7		55.3
1.602	25	24.4	80.00 (urban)	55.6
	49	26.3		53.7
	81	27.2		52.8

TABLE A5-8

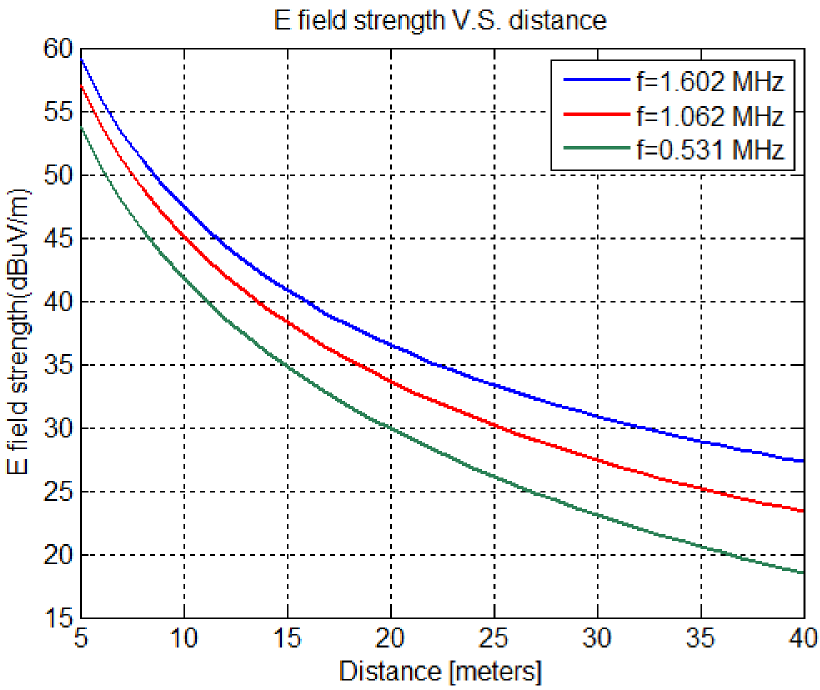
Aggregated E field simulation results of WPT-EV harmonics in urban area for B3 floor

Frequency of the harmonic (MHz)	Number of charging WPT-EV stations	WPT-EV aggregated E field strength of harmonics at radio receiver (dBμV/m)	Min AM Rx field strength with acceptable SQ (dBμV/m)	SIR (signal to interference ratio) (Min AM Rx field strength-WPT-EV aggregated E field strength of harmonics) (dB)
0.531	25	5.2	80.00 (urban)	74.8
	49	7.4		72.6
	81	8.7		71.3
1.062	25	8.7	80.00 (urban)	71.3
	49	10.9		69.1
	81	12.2		67.8
1.602	25	11.1	80.00 (urban)	68.9
	49	13.5		66.5
	81	14.8		65.2

At first, when the WPT-EV station is further away from the radio receiver, its E field strength of the harmonic will be naturally attenuated by the path loss of the longer distance according to Fig. A5-19.

FIGURE A5-19

E field strength attenuation with distance in near field



Secondly, the floor penetration loss introduced more attenuation. Due to the penetration loss of the cement floors, the aggregate interference in the upper floors will dominate the overall aggregated interference. For example, if there are B1/B2/B3 garages in a building, the aggregated interference of WPT-EV B1 garage are about 12 dB higher than that of B2 and about 22 dB higher than that of B3. In this case, the aggregated interference from B1 will dominate.

Taking 1.602 MHz as an example:

– B1 aggregated interference with 81 WPT-EV stations is 37.4 dBµV/m.

– B1 and B2 total aggregated interference of 162 WPT-EV stations is 39.7 dBµV/m.

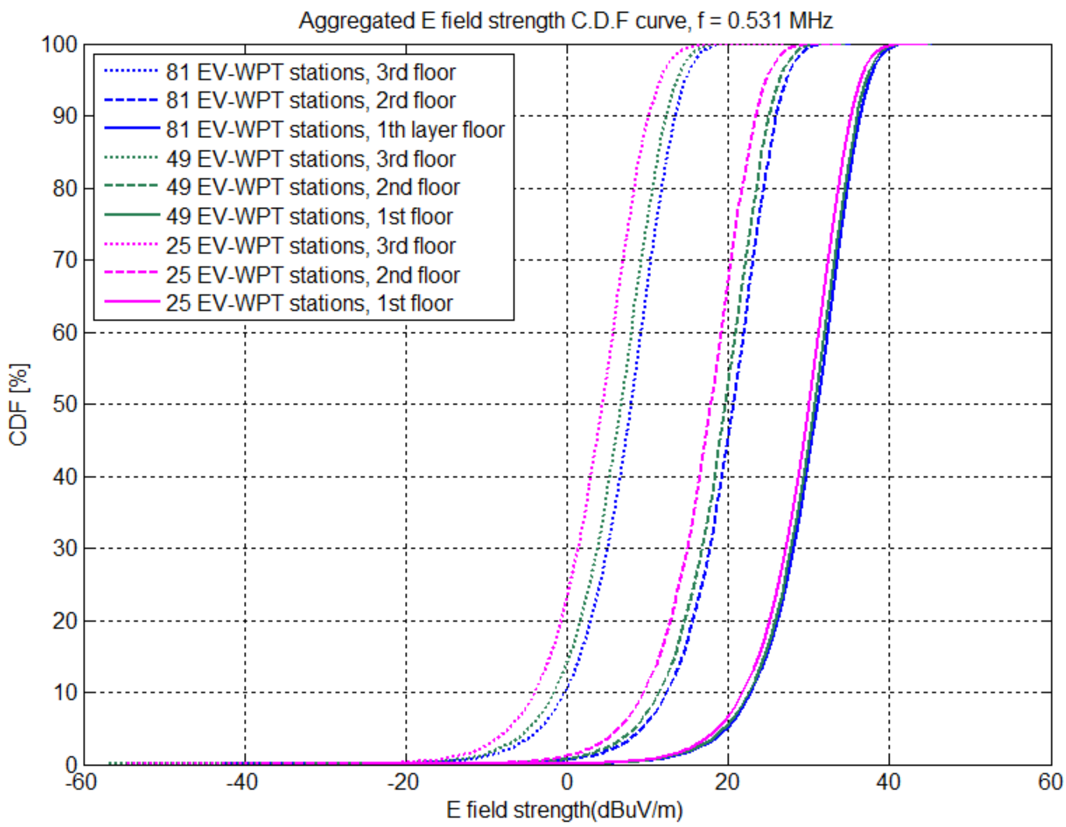
– B1, B2 and B3 total aggregated interference of 243 WPT-EV stations is 40.2 dBµV/m.

The SIR at the radio receiver B1/B2/B3 is about 39.8 dB and it is much greater than 26 dB. If the basement garages are located starting from B2 and lower floors, considering 1.602 MHz and 81 WPT-EV stations per each floor, B2 and B3 total aggregated interference of 162 WPT-EV stations is 29.1 dBµV/m. the SIR at the radio receiver B2/B3 is about 50.9 dB and it is much greater than 26 dB.

Figure A5-20 shows the CDF curve of the aggregated harmonic interference from WPT-EV and shows more statistics of the aggregated interferences. Even in the worst case (81 WPT-EV stations at B1), 99% of the aggregated interference is less than 40 dBµV/m and SIR is still more than 40 dB in urban area.

FIGURE A5-20

CDF curve of the aggregated harmonic interference from multiple WPT-EV stations



Therefore, it can be concluded that the aggregated multiple WPT-EV harmonic interference will not cause harmful interference to a radio receiver in urban areas.

A5.2 The impact study of WPT-EV on China Loran system

This study addressed the analysis of light duty vehicle EV-WPT emission and coexistence with Loran-C system at 90-110 kHz. Identify and quantify risk of interference with the Loran-C based incumbent service being used in China.

CCSA TC5 WG8 suggested that the technical characteristic and protection criteria of Loran-C/Chayka should be based on Recommendation ITU-R M.589-3 [8][9][10]. At the same time, [9] pointed out that eLoran research was under planning in China. This contribution is mainly supposed to study the coexistence between EV-WPT and Loran-C (or other systems with similar protection criteria).

The conservative assessment approach of extrapolation from H field to E field at far distance using E/H + H field roll-off by 60 dB/dec was applied. The assessment approach is widely used and adopted.

In the study, some several key factors are addressed. The charging frequency range 79-90 kHz including their 2nd harmonics would be investigated. The technical specifications in Recommendations ITU-R M.589-3 [8] and ITU-R P.372-13 [10], CCSA’s contribution on Locan-C and eLoran [9], etc. were used. The lowest signal level (45 dBuV/m) at coverage boundary where a Loran receiver would need is used.

The conclusion from the study is that there is no risk of interference with Loran receivers within marine coverage by EV-WPT stations, either single or multiple when the stations are operating in frequency range of 79-90 kHz. The EV-WPT stations must be in the power range defined by CIS/B/687/CDV and meet the H field radiated emission limits defined therewith.

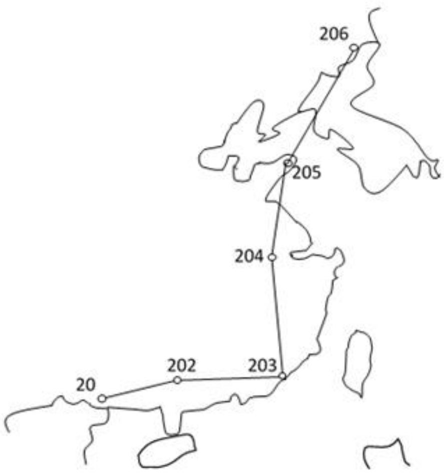
A5.2.1 China Loran system and receiver protection criteria

A5.2.1.1 Loran system overview

Transmitter locations of Loran-C systems are shown in Fig. A5-21 [9]. There are six Loran transmitters along east and south coastal lines. There are three chains to cover north, east, and south seas. The average Tx power is 40 kW (5 km onshore). Covering range is 900-1 300 nautical miles.

FIGURE A5-21

Locations of China Loran-C system stations

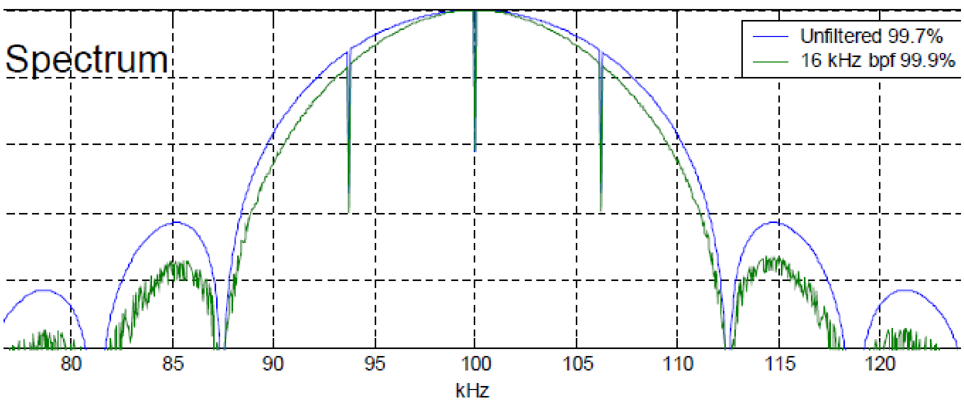


The technical characteristics of Loran-C signal is shown as Fig. A5-22. The signal is centred (>99%) at 100 kHz with BW 20 kHz. It can still work with ambient noise 10 dB over the signal.

It requires in-band *S*/*N* of 20 dB to keep the demodulation quality.

FIGURE A5-22

Loran-C signal wave form demonstration



A5.2.1.2 Protection criteria

In-band and out-of-band interference protection criteria is shown as Figs A5-23 and A5-24 [8]. Worst curve (near-synch) is used to estimate interference risk.

FIGURE A5-23

Loran-C/CWI protection criteria

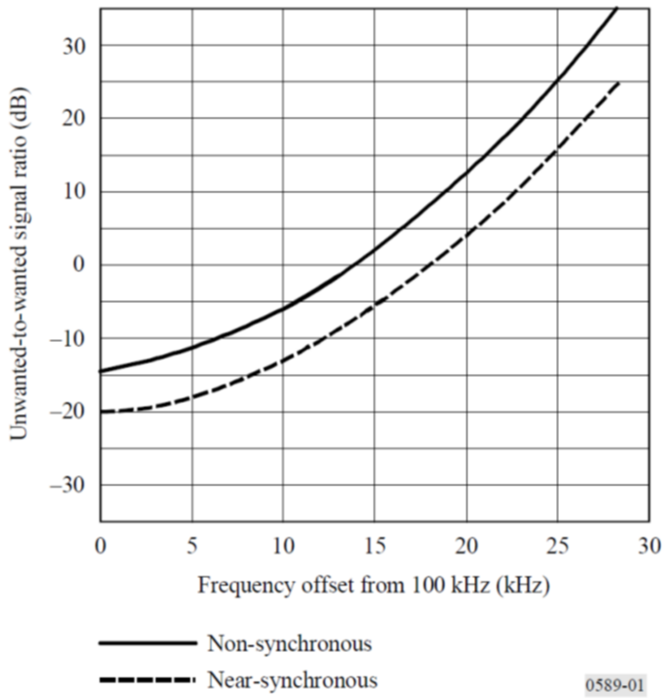
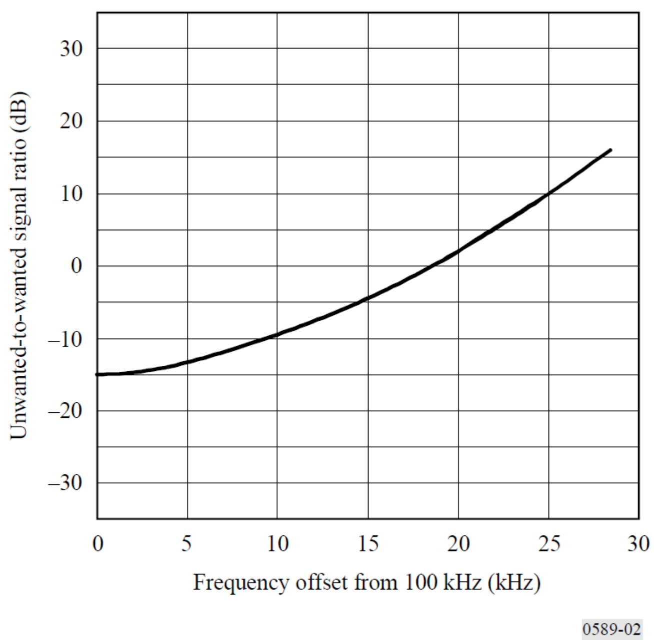


FIGURE A5-24

Loran-C/FSK protection criteria



A5.2.2 Coexistence study

A5.2.2.1 EV-WPT technical characteristic

CEC (China Electricity Council) made the frequency usage survey on WPT system frequency for passenger cars and light duty vehicles. As the result, the industry concluded that 79 kHz – 90 kHz is the most appropriate selection for those applications in China.

EV-WPT is not a radio service and its electrical power is mainly transferred from the charging station to the vehicle through local magnetic coupling at a very short distance. SRD or other radio regulation for radio services should not be applicable to WPT since there is no communications and data transfer in WPT process.

In our coexistence study, CISPR proposed limit 82.8 dBµA/m is applied as the peak magnitude strength at the operating frequency. According to the measurement results, the peak magnitude for other frequency offset is derived. The emission level of the real implementation should be less than CISPR limit. Therefore, our study addressed the worst case in terms of the emission.

A5.2.2.2 Loran signal attenuation along distance

Our study applied the isotropic emission model. Tx power of Loran signal is very strong and the system is able to cover thousands of kilometres. According to Recommendation ITU-R M.589-3 [8], min 45 dBµV/m should be achieved at coverage boundary in 90-110 kHz.

At 79-90 kHz, WPT emission needs to be below the Loran signal strength and meet the interference protection criteria in [12].

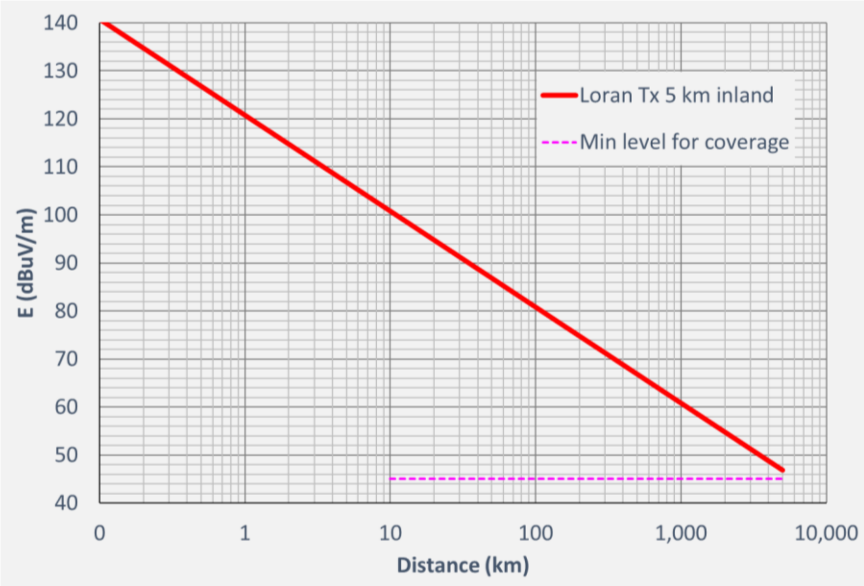
TABLE A5-9

Protection power level for Loran signal strength at various frequency

Frequency (kHz)	Coverage min E field (dBµV/m)	Loran-C/CWI Prot. criteria (near synch N/S)	Acceptable noise at Loran-C/CWI receiver (dBµV/m)
81.38	45	4	49
81	45	2	47
85	45	−5	40
88	45	−10	35
90	45	−13	32

FIGURE A5-25

Typical China Loran system field strength (40 kW)

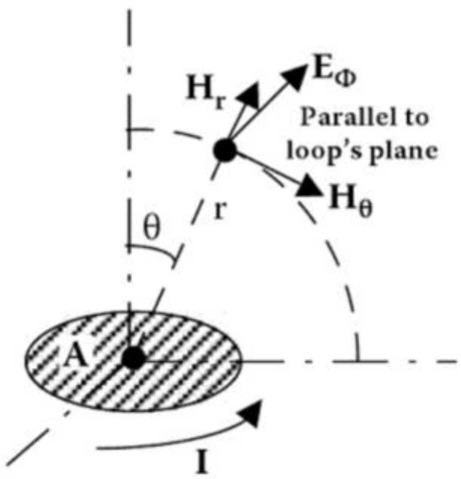


A5.2.2.3 Data analysis

Since the source of emission from EV-WPT is coil, H field will dominate the emission at the near field. The H fields decay differently with varied distance ground condition such as earth versus water. For simple assessment, free space condition is considered to be the worst case. It can be shown that the H fields will decay from 60 dB/dec at near field region defined by λ/2π gradually to 20 dB/dec at far field region. At each region, the E field strength from an EV-WPT station is converted by *E*/*H* as shown in Fig. A5-7. The *E*/*H* and emission is assessed based on loop model in free space. The model has verified by both measurement and simulation. The small loop antenna is a closed loop as shown in Fig. A5-25.

FIGURE A5-26

A small loop radiation



For the radiations by small loop model, the E and H can be described approximately as follows [14]:

$$E_{\varphi}(V/m) = \pi Z_0 \frac{IA}{\lambda^2 r}\sqrt{1+\left(\frac{\lambda}{2\pi r}\right)^2}\sin\theta \quad (11)$$

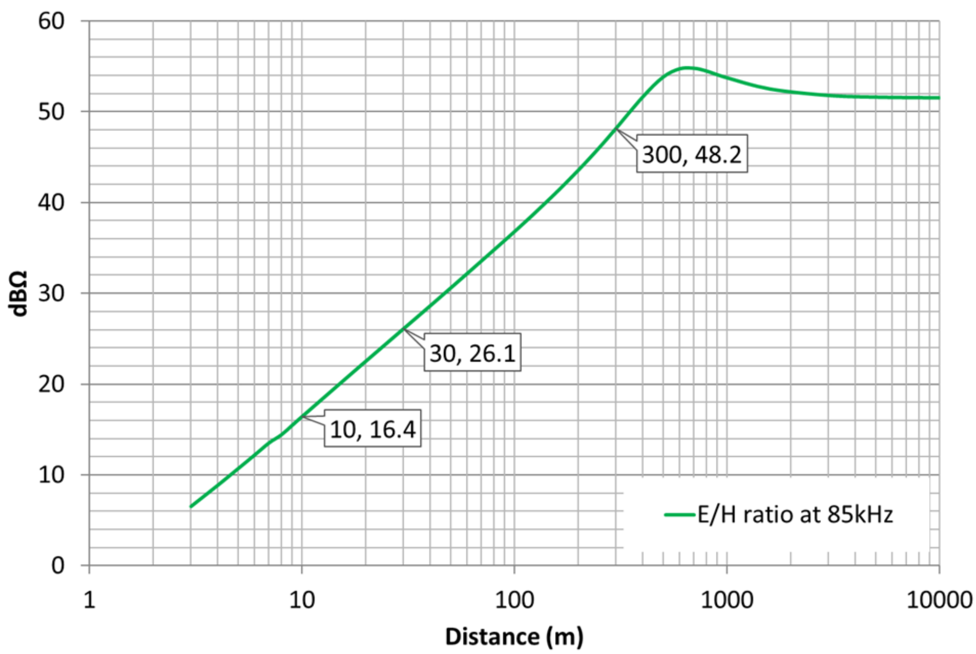
$$H_{\theta}(A/m) = \pi \frac{IA}{\lambda^2 r}\sqrt{1-\left(\frac{\lambda}{2\pi r}\right)^2+\left(\frac{\lambda}{2\pi r}\right)^4}\sin\theta \quad (12)$$

where:

- I : loop current (A, ampere)
- A : loop area (m^2)
- λ : wavelength (m), λ = 300/f, f : frequency (MHz)
- r : distance to observation point (m)
- Z_0 : free space impedance, 377 Ω.

FIGURE A5-27

E/H ratio vs distance by loop source in free space



From this model, it can be concluded that For H field which is dominated by the WPT, it decays per 60 dB/dec until near field region ends near λ/2 π, then through the transition region, the roll off gradually becomes 20 dB/dec at far field region. Since the sea water can be treated close to be conductive, its impact is between PEC (Perfect Electric Conductor) and free space so the overall decay of H field and E field is faster than in the pure free space model leading to a roll off between that of free space and PEC, as shown in Fig. A5-28.

FIGURE A5-28

E-field per unit AT (ampere-turn) from loop source

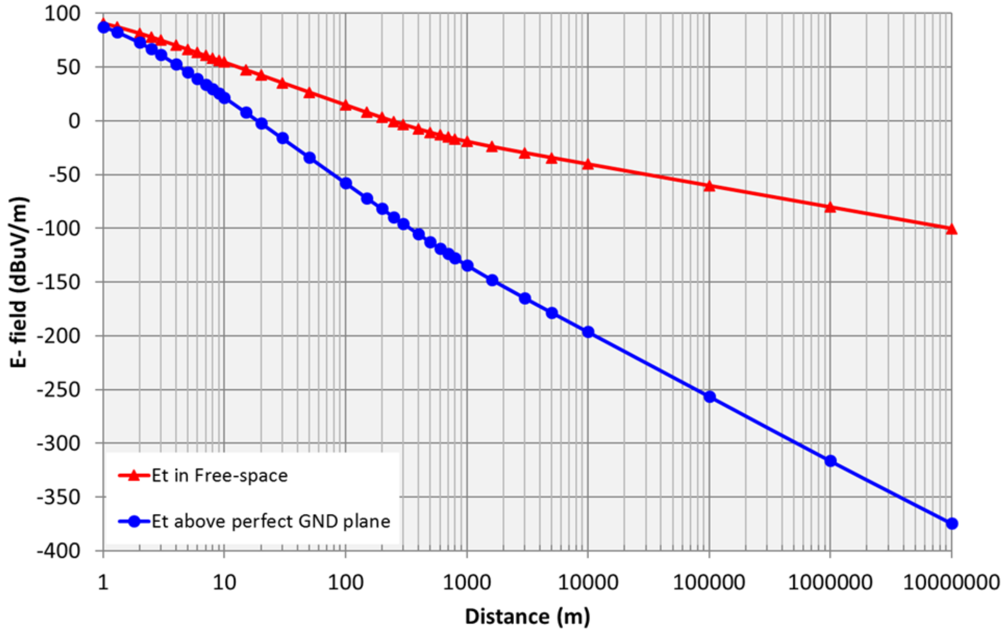


TABLE A5-10

EV-WPT signal strength at various frequency at various distance

Loran system parameters				coex@10m			
Freq (kHz)	Coverage min E field (dBuV/m)	Loran-C/CWI Prot. criteria (near synch N/S)	Acceptable E field at Loran-C/CWI reciver	E/H ratio @10m per loop model	H@10m (dBuA/m) (EV@7kW)	Converted E@10m (dBuV/m)	Margin at 10m (dB)
81.38	45	2	47	16.00	22	38.0	9.00
85	45	-5	40	16.42	22	38.4	1.58
88	45	-10	35	16.72	22	38.7	-3.72
90	**45**	**-13**	**32**	16.92	82	98.9	**-66.92**
95	**45**	**-18**	**27**	17.39	22	39.4	**-12.39**
100	**45**	**-20**	**25**	17.83	22	39.8	**-14.83**
170	45	60	105	22.45	52	74.5	30.55

Loran system parameters				coex@100m			
Freq (kHz)	Coverage min E field (dBuV/m)	Loran-C/CWI Prot. criteria (near synch N/S)	Acceptable E field at Loran-C/CWI reciver	E/H ratio @100m per loop model	H@100m (dBuA/m) (EV@7kW)	Converted E@100m (dBuV/m)	Margin at 100m (dB)
81.38	45	2	47	36.4	-38	-1.60	48.60
85	45	-5	40	36.8	-38	-1.20	41.20
88	45	-10	35	37.1	-38	-0.90	35.90
90	**45**	**-13**	**32**	37.3	22	59.30	**-27.30**
95	**45**	**-18**	**27**	37.8	-38	-0.20	27.20
100	**45**	**-20**	**25**	38.3	-38	0.30	24.70
170	45	60	105	43.6	-8	35.60	69.40

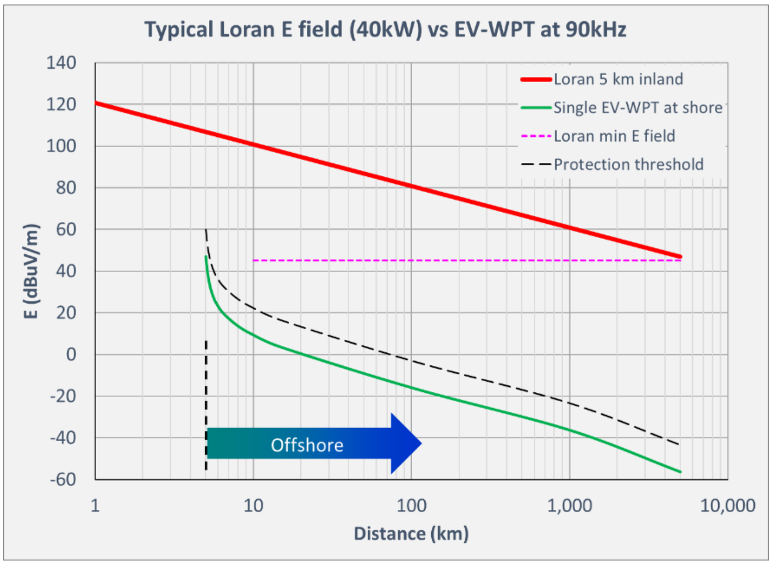
Freq (kHz)	Coverage min E field (dBuV/m)	Loran-C/CWI Prot. criteria (near synch N/S)	Acceptable E field at Loran-C/CWI reciver	E/H ratio @1km per loop model	H@1km (dBuA/m) (EV@7kW)	Converted E@1km (dBuV/m)	Margin at 1km (dB)
81.38	45	2	47	53.4	-98	-44.60	91.60
85	45	-5	40	53.7	-98	-44.30	84.30
88	45	-10	35	53.7	-98	-44.30	79.30
90	**45**	**-13**	**32**	53.6	-38	15.60	16.40
95	**45**	**-18**	**27**	53.4	-98	-44.60	71.60
100	**45**	**-20**	**25**	53.3	-98	-44.70	69.70
170	45	60	105	53.2	-68	-14.80	119.80

A5.2.3.3.1 Single EV-WPT

Loran signal (red) is much higher than a WPT signal at 79-90 kHz (green) in the entire offshore. Spurious and harmonics of WPT signal will be at least 40 dB lower than the WPT signal which meet the worst protection criteria at 90 kHz, thus there would be no risk of interference with offshore Loran receivers. Even the minimum Loran signal at coverage boundary is much higher than the protection criteria against the attenuated emission from EV-WPT, as shown in Fig. A5-29.

FIGURE A5-29

Typical China Loran system field strength and single EV-WPT emission

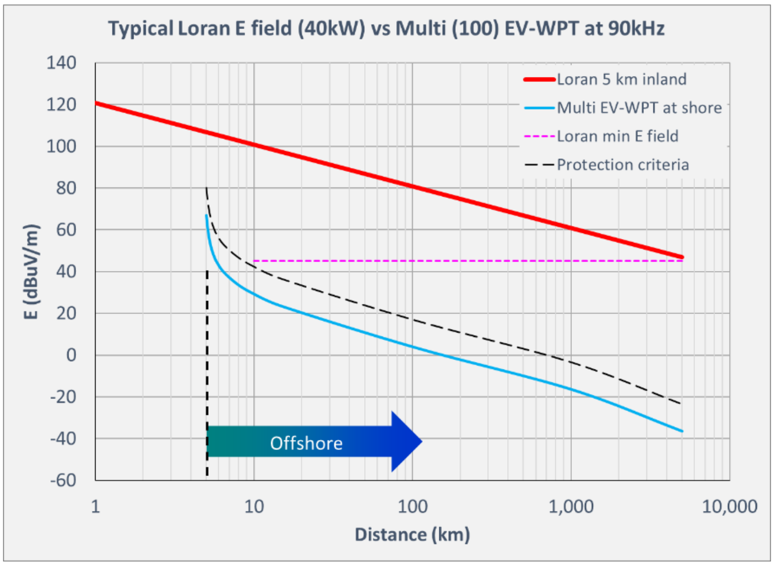


A5.2.3.3.2 Multiple EV-WPT

For worst case, assume 100 EV-WPTs in operation at the same site. The entire emissions are aggregated by all WPTs (actual aggregation should be much lower due to difference in distance, phase, and timing from each WPT). As shown in Fig. A5-30, Loran signal (red) is much higher (~70 dB) than combined emissions from multiple WPTs at 79-90 kHz (light blue) at all distances except near the WPT. In addition, combined spurious and harmonics of 79-90 kHz from multiple EV-WPTs will be at least 40 dB lower than the combined WPT signals, thus there would be no risk of interference with offshore Loran receivers.

FIGURE A5-30

Typical China Loran system field strength and multiple EV-WPT emission



A5.2.3 Conclusion

In the study, the emission and field strength of charging frequency range 79-90 kHz including their 2nd harmonics of EV WPT are investigated. Loran-C system protection criteria refers to Recommendations ITU-R M.589-3 and ITU-R P.372-13. The lowest signal level (45 dBμV/m) at coverage boundary where a Loran receiver would need is used. The following conclusions are reached from the study:

For single EV-WPT, there would be no risk of interference of with Loran receivers under marine coverage by the charging signal of EV-WPT.

Multiple EV-WPT: No risk of interference with Loran receivers under marine coverage from multiple EV-WPTs at either one site or multiple sites inland.

For single EV-WPT station, the spurious and harmonics of WPT signal will be at least 40 dB lower than the WPT signal, thus there would be no risk of interference with offshore Loran receivers by the spurious and harmonic emission of EV-WPT.

For multiple EV-WPT station, the combined spurious and harmonics of WPT signal will be at least 40 dB lower than the combined WPT signal, thus there would be no risk of interference with offshore Loran receivers by the combined spurious and harmonic emission of EV-WPT. The above conclusions apply to multiple EV-WPT stations with operating frequency of 79-90 kHz in the power range defined by CIS/B/687/CDV and meeting the H field radiated emission limits defined therewith.

A5.3 References

[1] Recommendation ITU-R BS.560-4 – Radio-frequency protection ratios in LF, MF and HF broadcasting

[2] Recommendation ITU-R BS.703 – Characteristics of AM sound broadcasting reference receivers for planning purpose

[3] China national standard, GB 2017-80, “MF broadcast network coverage technology”

[4] ESTI EN 303 417 V1.1.1 (2017) “Wireless power transmission systems, using technologies other than radio frequency beam, in the 19-21 kHz, 59-61 kHz, 79-90 kHz, 100-300 kHz, 6 765-6 795 kHz ranges; Harmonized Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU”

[5] Xingcun Colin Tong, “Advanced Materials and Design for Electromagnetic Interference Shielding”

[6] Recommendation ITU-R BS.1284-1 – General methods for the subjective assessment of sound quality

[7] SCHWENGLER, T.; GILBERT, M., “Propagation Models at 5.8 GHz – Path Loss & Building Penetration”, Radio and Wireless Conference, 2000. RAWCON 2000. 2000 IEEE

[8] Recommendation ITU-R M.589-3 – Technical characteristics of methods of data transmission and interference protection for radionavigation services in the frequency bands between 70 and 130 kHz

[9] TC5_WG8_2017_080, “Loran-C and e-Loran”

[10] Recommendation ITU-R P.372-13 – Radio noise

[11] Report ITU-R SM.2303 – Wireless power transmission using technologies other than radio frequency beam

[12] CISPR 11, “Industrial, scientific and medical equipment – Radio-frequency disturbance characteristics – Limits and methods of measurement”

[13] CIS/B/687/CDV, “Supplement of CISPR 11 with requirements for air-gap wireless power transfer (WPT) – Comments on the limit values for Class B equipment in frequency ranges of 9 kHz to 150 kHz”

[14] COLIN TONG, X., “Advanced Materials and Design for Electromagnetic Interference Shielding”

Annex 6

Impact studies in Korea for 19-21 kHz/55-65 kHz WPT-EV

A6.1 Studies on the impact to SFTS services from 19-21 kHz/55-65 kHz WPT-EV

A6.1.1 Introduction

The Republic of Korea has measured the emission levels for WPT equipment operating in the 20/60 kHz band in the frequency range of 9 kHz to 30 MHz. This section provides measurements and proposed mitigation techniques to protect SFTS services operating in the 60 kHz band.

A6.1.2 A mitigation in order to protect 60 kHz SFTS

According to Table 9 of ERC Recommendation 70-03, the frequency band of UK 60 kHz SFTS uses 250 Hz bandwidth (59.75 kHz ~ 60.25 kHz) and the maximum field strength at 10 m is 42 dBμA/m.

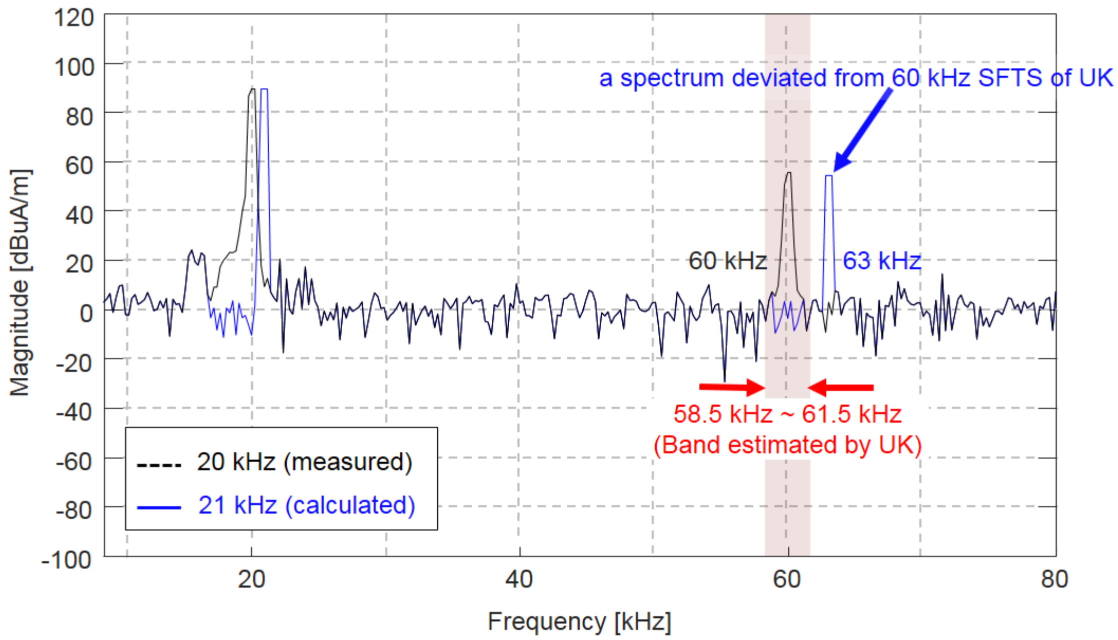
As the protection bandwidth of the SFTS is the wider, the protection condition is better, so the minimum protection band needs to be at least five to six times of 250 Hz bandwidth considering the coexistence with WPT heavy-duty system as the safety factor.

It could be approximately 1 500 Hz as six times of the safety factor.

Therefore, the Republic of Korea proposes that the X value would be 58.5 kHz and the Y value would be 61.5 kHz.

FIGURE A6-1

A mitigation approach



Apart of the above proposal, in order to avoid the interference effect safely between WPT system and UK 60 kHz SFTS, it would better to use a farther frequency such as 63 kHz in a country using 60 kHz SFTS.

Figure A6-1 shows the result of a mitigation approach with frequency shift of 63 kHz.

A6.1.3 Case study on the 60 kHz standard frequency and time signal (SFTS) service using AM

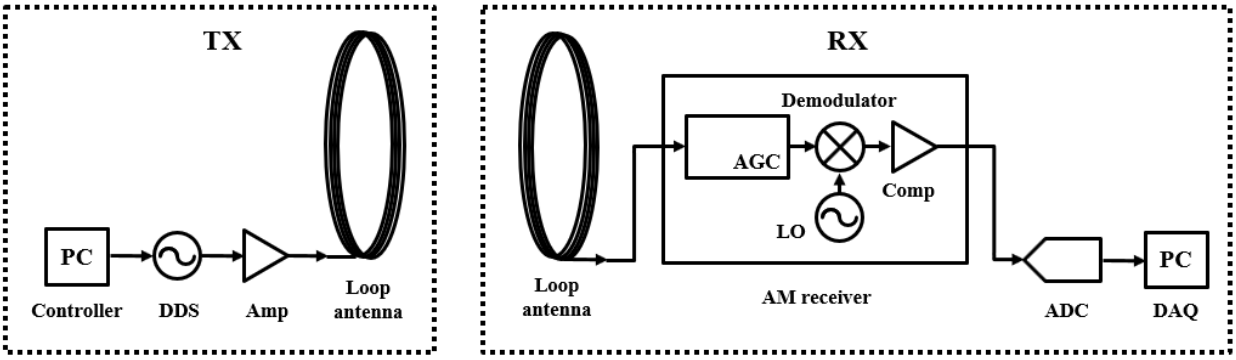
This section shows a case study results for heavy duty WPT-EV operating in 19 to 21 kHz ranges. The frequency range from 19 to 21 kHz does not affect any other communication system, but the harmonic frequencies may impact. The third harmonic frequency band of this system is 57 to 63 kHz, which has the potential to affect the SFTS service operating at 60 kHz. The AM communication system is composed of a transmitting (TX)/receiving (RX) antenna and each module for communication. The TX and RX antennas are fabricated resonance antennas, which are set at 60 kHz.

Direct digital synthesizer (DDS) board (AD9854) produces a message signal in AM modulated format and encodes the signal using Manchester code. The data rate of the message signal is set to be 5 Hz and carrier frequency is 60 kHz, which is corresponding to SFTS service. The message signal is fed into power amplifier and emitted from the TX antenna.

The RX antenna is designed with a high quality-factor to receive a 60 kHz signal with narrow bandwidth. The received signal is fed into atomic clock AM receiver module (CANADUINO). The AM receiver module consists of an auto gain controller (AGC), local oscillator (LO), demodulator, and comparator. The AGC keeps the proper magnitude of received signal. Output signal of AGC is demodulated with 60 kHz AC signal generated from LO and converted into well-limited voltage signal by comparator. Thereafter, output signal of AM receiver is transmitted to an analogue-to-digital converter (ADC) on the microcontroller (ATmega128). Microcontroller sends digital data to a PC through UART communication. The data acquisition (DAQ) software implements a synchronization and decoding process with digital data. Through digital processing series, transmitted message signal can completely be restored.

FIGURE A6-2

A structure for TX and RX system to implement 60 kHz SFTS



The DAQ software not only restores the message signal but also estimates the bit error rate (BER). The BER is a widely used criterion for quality and performance analysis of the digital communication system which is defined as the ratio of total number of received erroneous bits to the total number of received bits. The real-time BER estimation can be used to identify the reliability of communication system in order to maintain a desired quality of service (QoS). In this case study, BER is utilized as the metric for impact of electromagnetic field interference (EMI) to AM communication system.

As shown in Fig. A6-3, the TX system was located at a distance of 12 m from the heavy duty WPT-EV, and the RX system measured the BER according to the distance while moving in a direction gradually closer from a distance of 10 m to the heavy duty WTP-EV. At this time, the TX system was placed at a distance of 12 m because the TX and RX systems were perfectly communicated with and BER of 0 regardless of the charging status of the heavy duty WPT-EV at a distance 10 m or more.

FIGURE A6-3

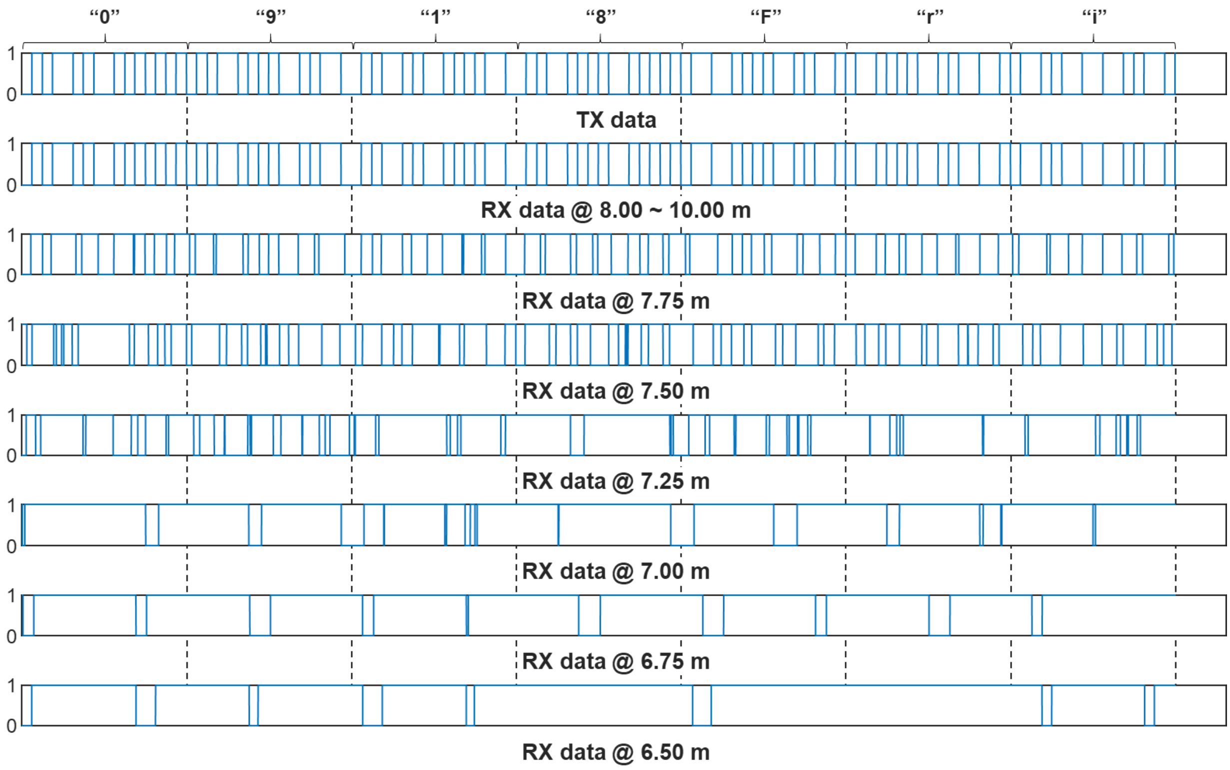
A measurement setup for impact study between 60 kHz AM communication system and the heavy duty WPT-EV system

The TX sent seven string data of "0918Fri" at 5 bit/s. The transmission time required to send the data string is 22.4 seconds, which is calculated as 16 bits × 7 string × 200 milliseconds, and a 16 bits terminator is added after the character string to accurately identify the data. In order to analyse the influence of RX by the heavy duty WPT-EV, the RX was positioned from 10 m to 6.5 m by moving closer to heavy duty WPT-EV at 0.25 m intervals. In the ambient environment where the heavy duty WPT-EV is not charging, the BER 0, which means there is no error in communication between the TX and RX systems, was confirmed within the location range of the RX. However, when the heavy duty WPT-EV is being charged, as the location of the RX is closer to the heavy duty WPT-EV, the electromagnetic interference increases, and thus the error increases.

As shown in Fig. A6-4, when the RX is located within 8 m from the heavy duty WPT-EV, an error occurred in the received data.

FIGURE A6-4

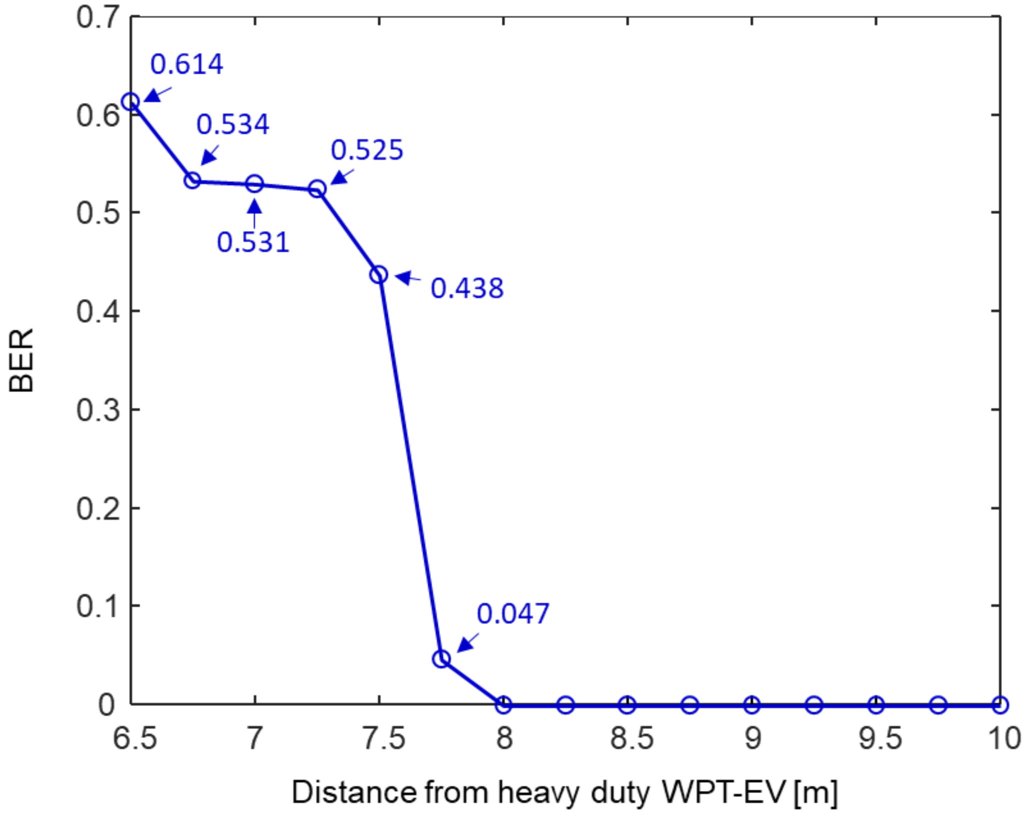
Measured TX and RX data at each distance



As in the received data, the BER was 0 at the point where the RX was placed more than 8 m away from the heavy duty WPT-EV, and the BER increased as the distance became closer.

FIGURE A6-5

Measurement results of BER between TX and RX at each distance



In addition, the EMI at each point where the antenna is located was measured. Figure A6-6 shows the measured electromagnetic field while the ambient condition, which is the environment where the heavy duty WPT-EV is not being charged, and the charging condition. The EMIs are measured at every distance where the TX and RX antennas are located, only the results at four representative distances are shown in Fig. A6-6. In addition, the Figure shows the peak values at 20 kHz and 60 kHz according to the distance.

FIGURE A6-6

Measurement results of EMI from the heavy duty WPT-EV at each distance

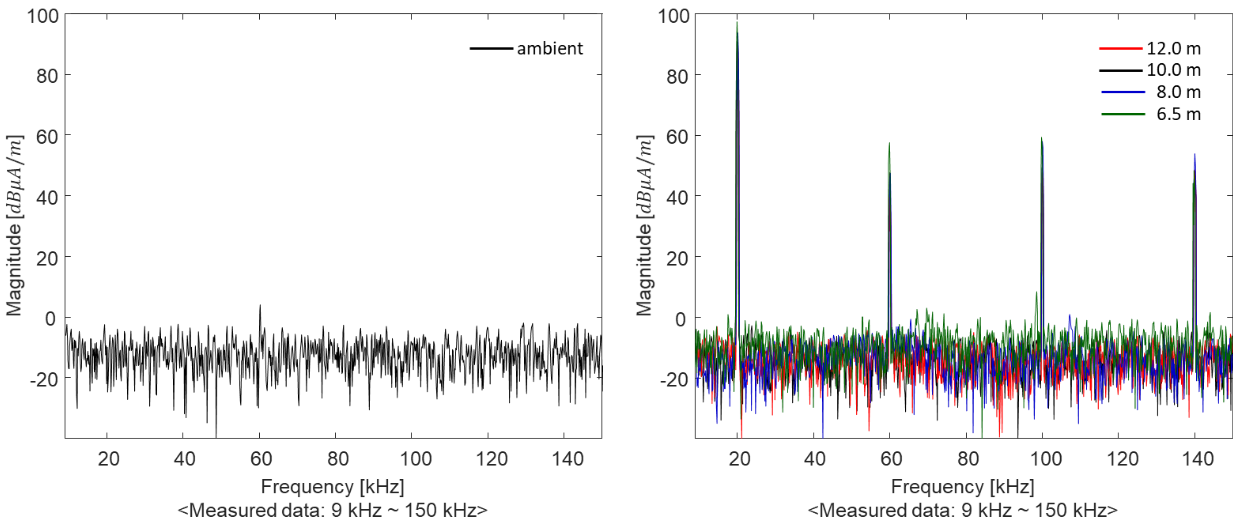
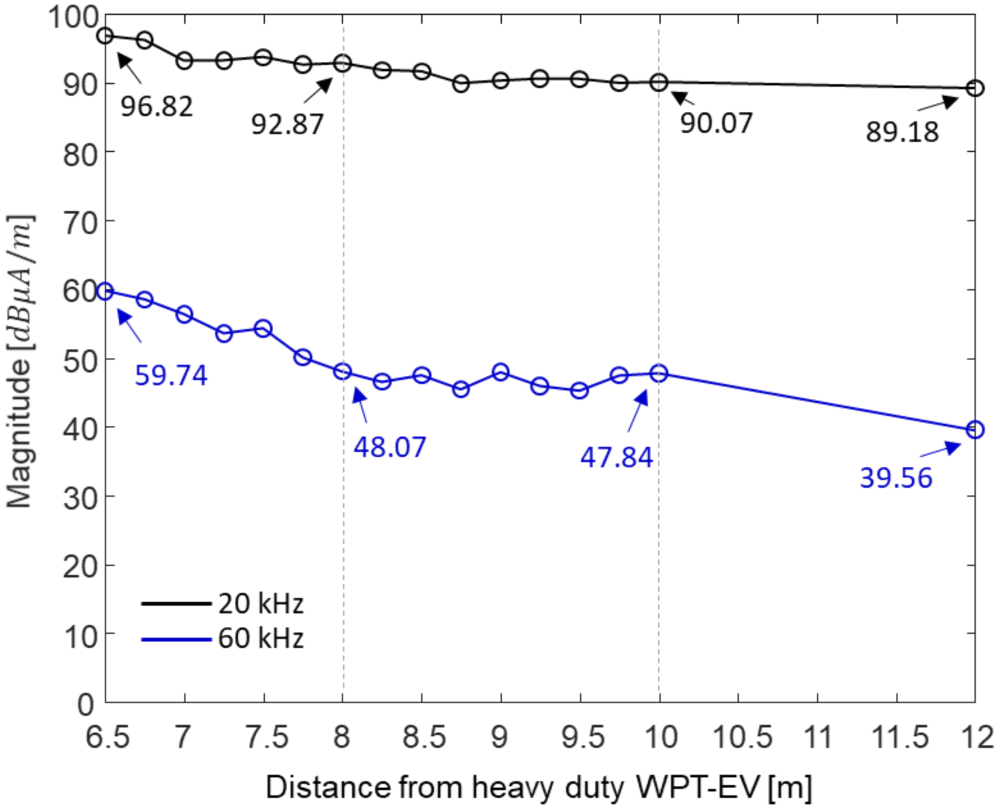


FIGURE A6-7

Measured peak value of 20 and 60 kHz component of EMI from the heavy duty WPT-EV at each distance



A6.2 Studies on the impact to AM sound broadcasting services from 19-21 kHz/55-65 kHz WPT-EV

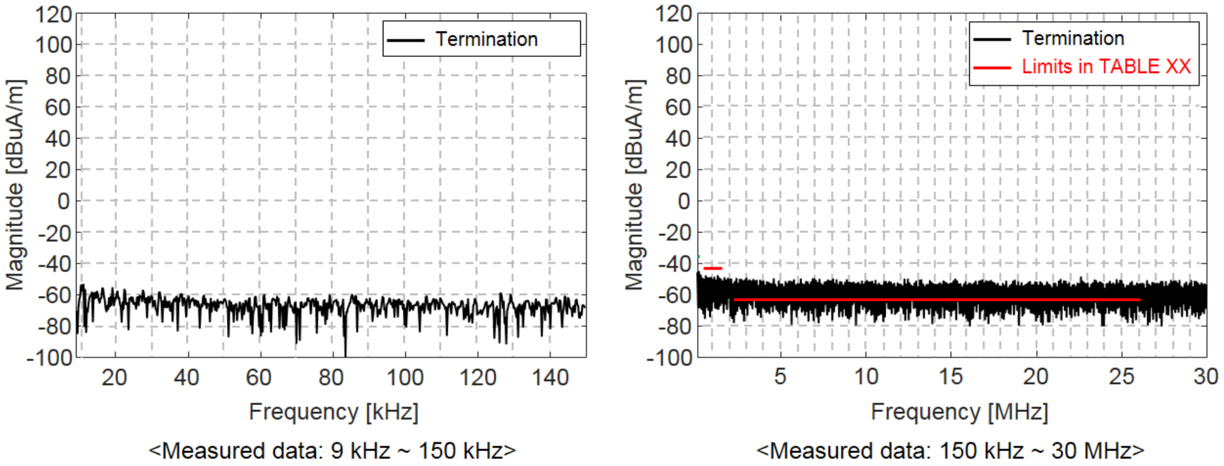
A6.2.1 Introduction

Since EBU suggested the limitation of the sound broadcasting as −47.5 dBμA/m, the Republic of Korea has studied the interference analysis between AM broadcasting and the heavy-duty WPT-EV system.

A6.2.2 An interference analysis between AM broadcasting and WPT-EV system

FIGURE A6-8

An interference analysis between AM broadcasting and the heavy-duty WPT-EV system (Termination of equipment)



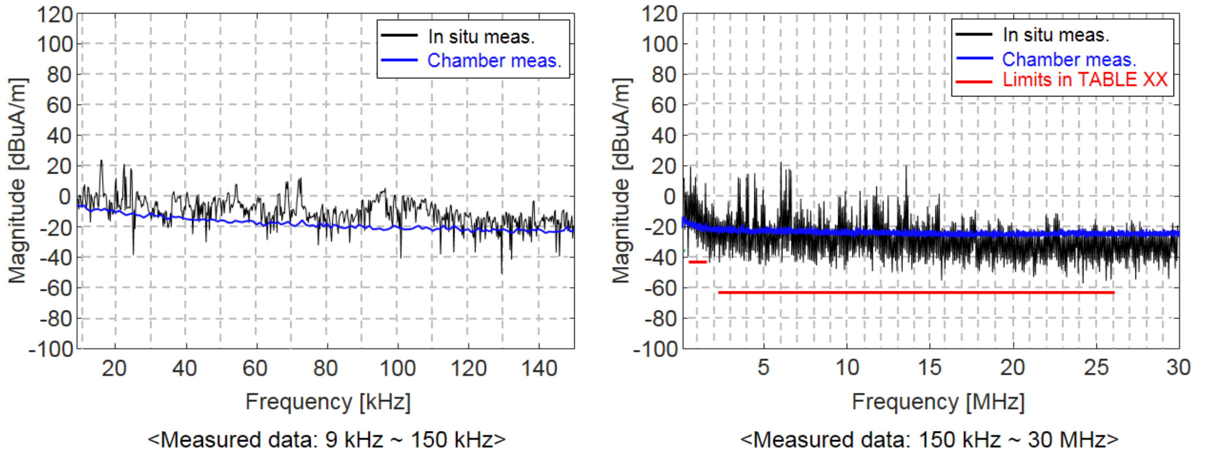
In order to trace the interference between AM broadcasting and the heavy-duty WPT-EV system, the EMI receiver (Keysight E4440A) is terminated to 50 [Ω] and it does not consider the antenna factor due to non-connecting to Loop antenna.

According to Table A8-1, the limit of WPT harmonics at high WPT power is the −37 dBµA/m at 10 m.

Although the EMI receiver is terminated, it seems that the values are similar to −56 dBµA and −60 dBµA. It means that the limit is almost same to the EMI receiver's own noise.

FIGURE A6-9

An interference analysis between AM broadcasting and the heavy-duty WPT-EV system (Ambient)



As the EMI receiver (Keysight E4440A) is connected to Loop antenna, it considers the antenna factor as about 20 dB. According to Table A8-2, the limit of WPT harmonics at high WPT power is the −7 dBµA/m at 10 m.

It seems that the values are similar to 0 dBµA and −20 dBµA under a real environment noise. Therefore, the results of measurement are significantly above the limit, regardless of the charging of the heavy-duty WPT system. It shows that the limit of Table A8-2 does not even meet a real environment noise.

A6.2.3 The mitigation analysis of AM sound broadcasting

AM sound broadcasting should be protected safely. The mitigation methodologies are as follows.

A6.2.3.1 The interference effect between WPT system and AM sound broadcasting

One recent published work on magnetic coupling, Fourier Analysis for Harmonic Signals in Electrical Power Systems[10], indicates that the third harmonic represents 20% of the available power, and the fifth harmonic represents 10%. Going on further, the seventh harmonic represents 6%, and the ninth harmonic represents 3%.

The heavy-duty WPT system uses 20 kHz as the fundamental frequency. The seventh harmonic of 20 kHz is 140 kHz. The lowest band of LF broadcasting is even 148.5-283.5 kHz. Therefore, it seems that there will be very little interference effect.

A6.2.3.2 The minimum separation distance between WPT system and AM sound broadcasting

According to Table A8-2, the minimum separation distance is 10 m and the limit is −7 dBμA/m.

In case of the heavy-duty WPT system, it would be proposed that the minimum separation distance is 30 m or more in order to avoid the interference effect safely between WPT system and AM sound broadcasting.

At the moment, AM broadcasting is not popular because there is a little mixed noise on sound signals. Furthermore, LF band is rarely used except for an emergency. Hence it can minimize the interference effect if enough separation distance is kept.

A6.2.4 Conclusion

AM sound broadcasting should be protected safely. The minimum separation distance of 30 m or more is required in order to avoid the interference effect safely between WPT system and AM sound broadcasting.

It seems that it is another wise alternative to approach as a national regulation policy together with the above mitigation methodologies.

A6.3 Additional measurements of WPT-EV systems for the heavy-duty vehicle

This section details measurements of WPT EV systems for the heavy-duty vehicle taken in Korea: test results of electromagnetic disturbance of heavy-duty WPT EV systems.

A6.3.1 Test conditions

A6.3.1.1 Circumstance of test site

Test environment of the heavy-duty WPT EV with the power inverter and power lines is shown in Fig. A6-10. Figure A6-11 shows four different measurement distances required for testing.

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[10] Authors: Emmanuel Hernández Mayoral, Miguel Angel Hernández López, Edwin Román Hernández, Hugo Jorge Cortina Marrero, José Rafael Dorrego Portela and Victor Ivan Moreno Oliva. Published: February 8th 2017 by IntechOpen.

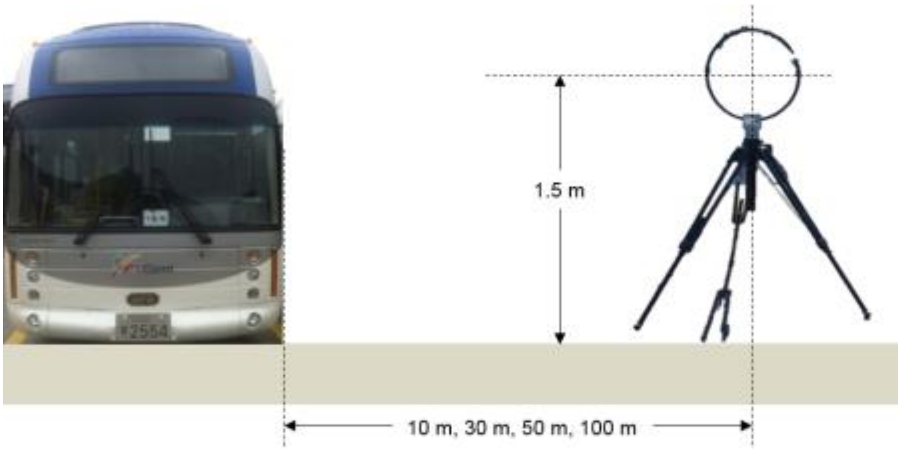
FIGURE A6-10

Surroundings of test site (in Gumi City)

H field intensities are measured with a loop antenna at four different distances from a WPT bus based on a fixed 1.5 m antenna height as shown in Fig. A6-11.

FIGURE A6-11

Measurement setup at four different distances adopted in our test



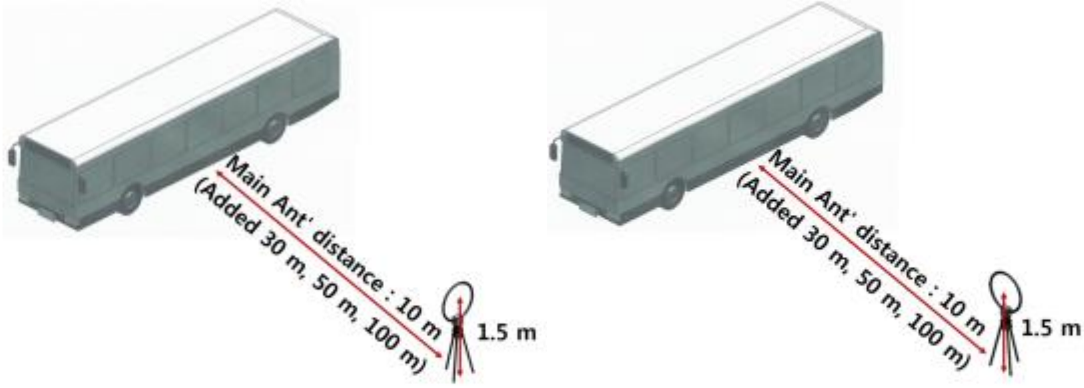
Ten metres is a reference distance provided by the test measurement method. However, the test was done at 30 m, 50 m and 100 m for checking the impact test conditions.

The reference is IEC 62236-2:2008, Railway applications -Electromagnetic Compatibility – Part 2.

The loop Antenna has frequency range 9 kHz to 30 MHz and additionally the antenna position can be a vertical x-axis and vertical y-axis (90^{o} to the x-axis) as shown in Fig. A6-12.

FIGURE A6-12

Antenna positions for vertical x-axis and y-axis

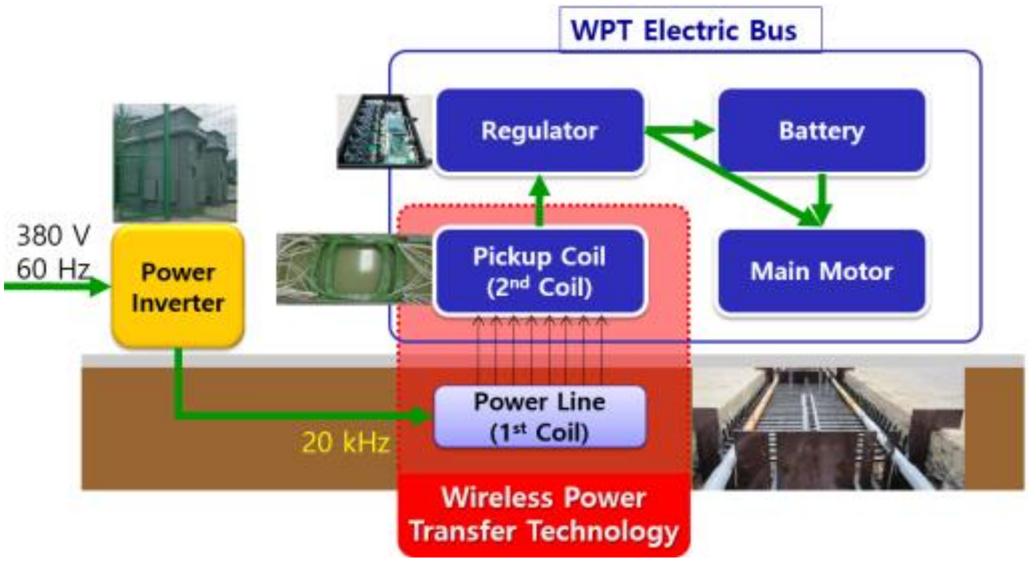


A6.3.1.2 Configuration of heavy-duty WPT EV system

The power inverter in the yellow-coloured block in Fig. A6-13 generates 20 kHz signals from 380 Vac @ 60 Hz and the signals are supplied to power line (first Coil). The pickup coil (second Coil) is capturing the strong magnetic fields. Then the induced currents are changed to DC current from 20 kHz currents by its built-in rectifier. The changed DC current feeds to a regulator to charge the batteries or runs the main motors.

FIGURE A6-13

Block-diagram of WPT bus charging system for test



A6.3.1.3 Operating conditions

Figure A6-14 shows the real charging site and on-charging heavy-duty WPT EV.

FIGURE A6-14

WPT bus and charging area (right hand side)

This test is carried out under the conditions of 125 A and 680 V (85 kW charging power), 99.26 kW main power, 85.6% charging efficiency and 20 kHz.

FIGURE A6-15

Power inverters (left hand side) and meter indicating the main power of the inverter when a series of measurements have been carried out

A6.3.1.4 Testing conditions

Measurement Devices are as follows:

① Antenna: Rhode & Schwarz, HFH2-Z2, Loop Antenna (calibrated on 8th March 2017)

② Receiver: Agilent E4440A, Spectrum Analyzer (Calibrated on 15th April 2016).

The weather conditions for testing are as follows:

① Test period: April 13 to April 14, 2017

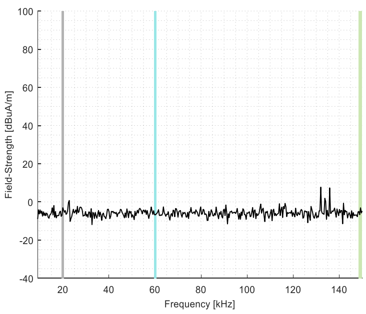
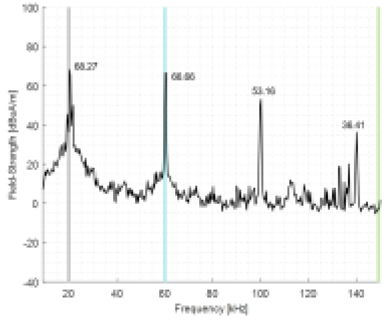
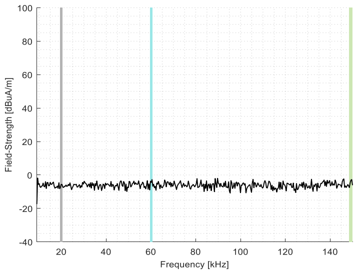
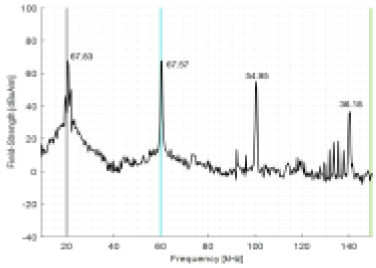
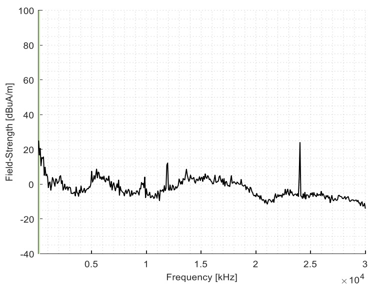
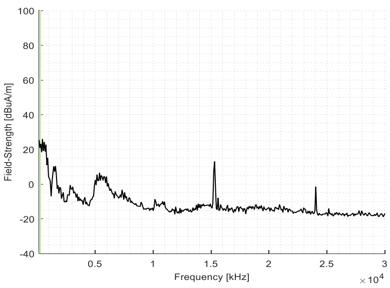
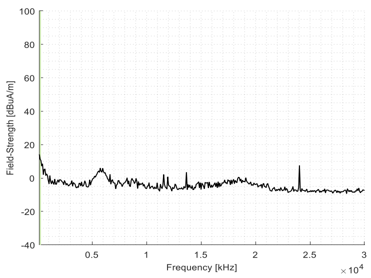
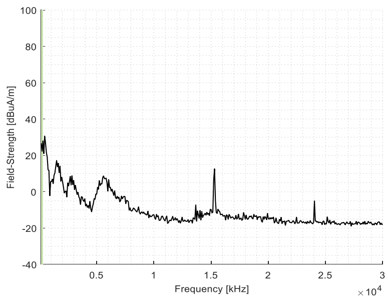
② Temperature: 12°C ~ 25°C (10:00 AM to 5:00 PM)

③ Humidity: 45% R.H. (Rainfall probability: 16%)

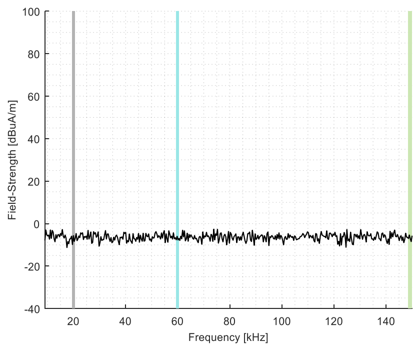
④ Wind speed: 4 m/s.

A6.3.2 Test results at different distances

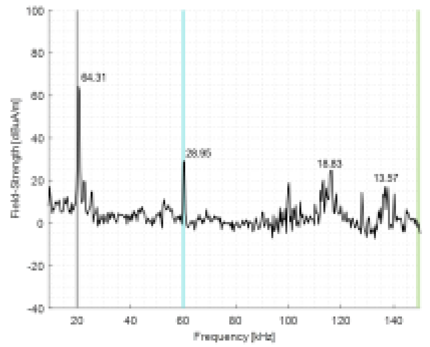
A6.3.2.1 10 m

	
Vertical X-axis 9 kHz ~ 150 kHz (Ambient)	Vertical X-axis 9 kHz ~ 150 kHz (Charging)
	
Vertical Y-axis 9 kHz ~ 150 kHz (Ambient)	Vertical Y-axis 9 kHz ~ 150 kHz (Charging)
	
Vertical X-axis 150 kHz ~ 30 MHz (Ambient)	Vertical X-axis 150 kHz ~ 30 MHz (Charging)
	
Vertical Y-axis 150 kHz ~ 30 MHz (Ambient)	Vertical Y-axis 150 kHz ~ 30 MHz (Charging)

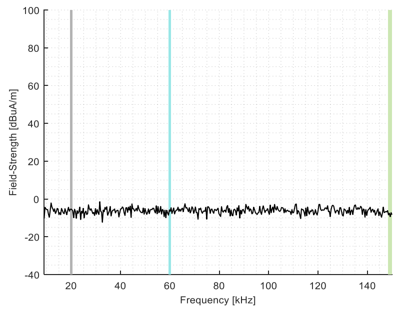
A6.3.2.2 30 m



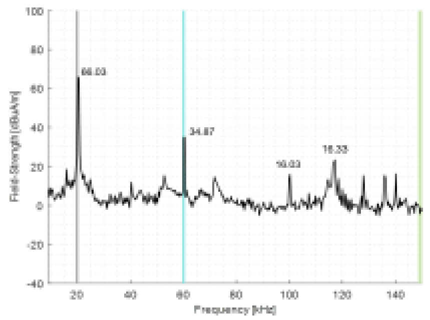
Vertical X-axis 9 kHz ~ 150 kHz (Ambient)



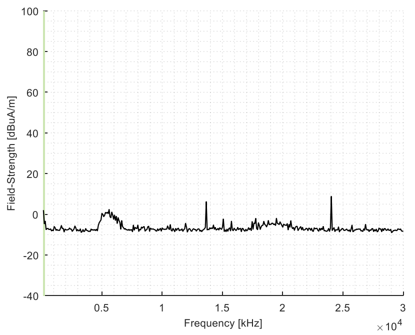
Vertical X-axis 9 kHz ~ 150 kHz (Charging)



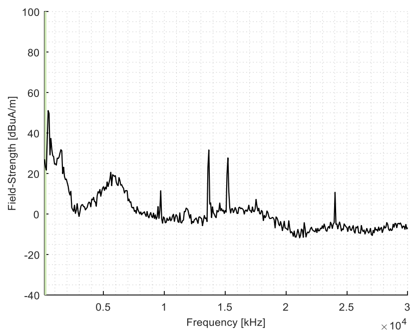
Vertical Y-axis 9 kHz ~ 150 kHz (Ambient)



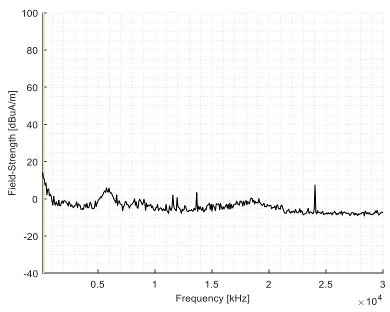
Vertical Y-axis 9 kHz ~ 150 kHz (Charging)



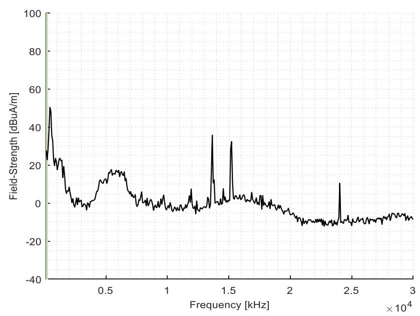
Vertical X-axis 150 kHz ~ 30 MHz (Ambient)



Vertical X-axis 150 kHz ~ 30 MHz (Charging)

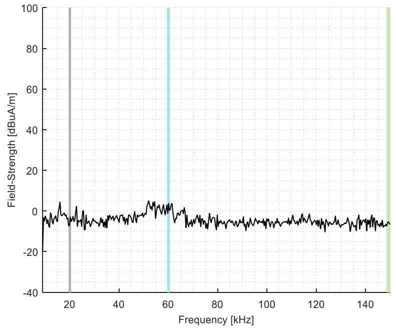
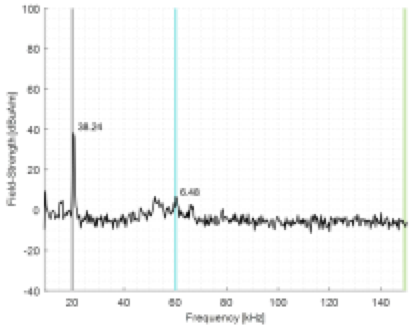
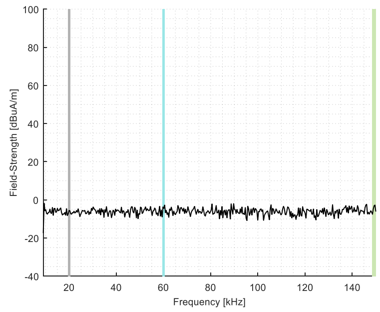
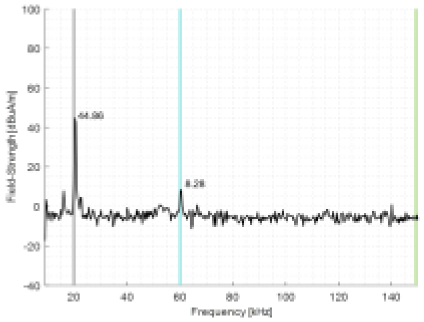
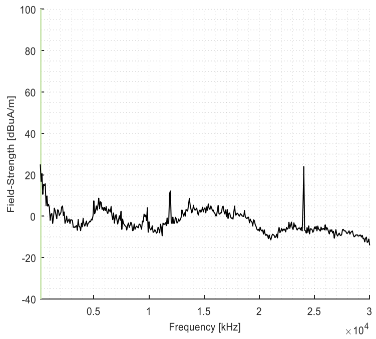
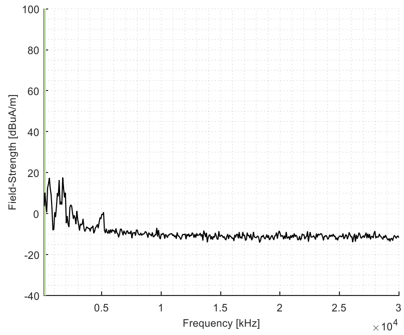
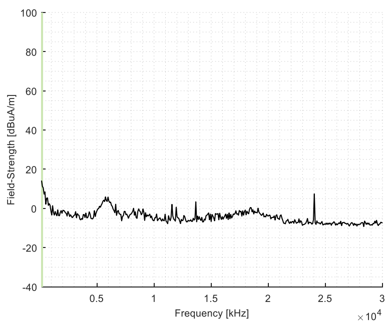
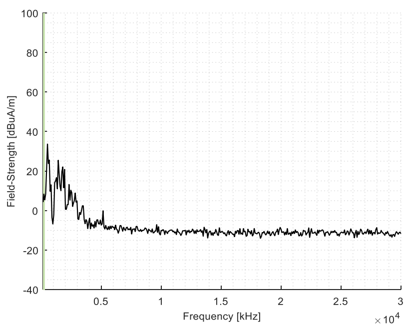


Vertical Y-axis 150 kHz ~ 30 MHz (Ambient)

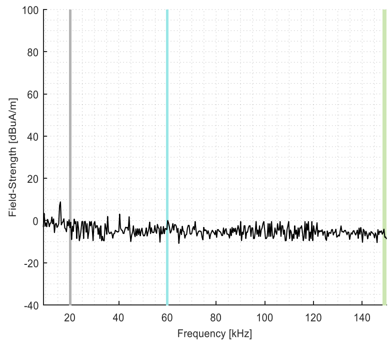


Vertical Y-axis 150 kHz ~ 30 MHz (Charging)

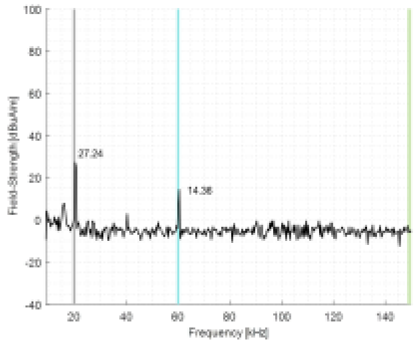
A6.3.2.3 50 m

	
Vertical X-axis 9 kHz ~ 150 kHz (Ambient)	Vertical X-axis 9 kHz ~ 150 kHz (Charging)
	
Vertical Y-axis 9 kHz ~ 150 kHz (Ambient)	Vertical Y-axis 9 kHz ~ 150 kHz (Charging)
	
Vertical X-axis 150 kHz ~ 30 MHz (Ambient)	Vertical X-axis 150 kHz ~ 30 MHz (Charging)
	
Vertical Y-axis 150 kHz ~ 30 MHz (Ambient)	Vertical Y-axis 150 kHz ~ 30 MHz (Charging)

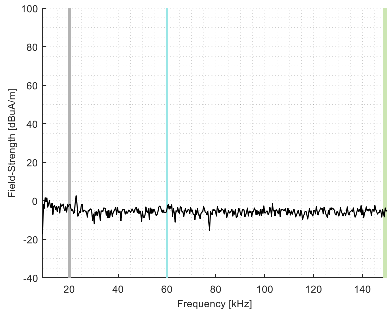
A6.3.2.4 100 m



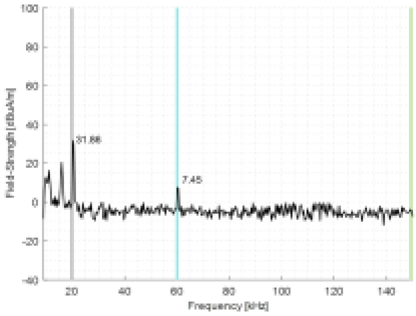
Vertical X-axis 9 kHz ~ 150 kHz (Ambient)



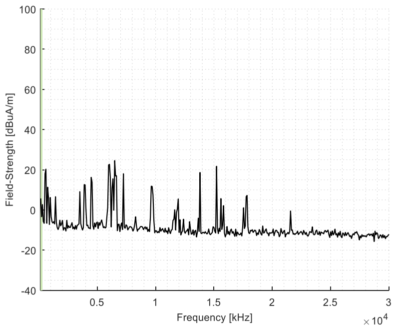
Vertical X-axis 9 kHz ~ 150 kHz (Charging)



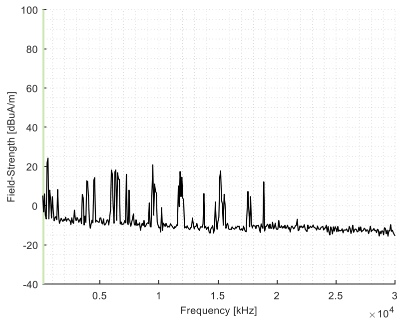
Vertical Y-axis 9 kHz ~ 150 kHz (Ambient)



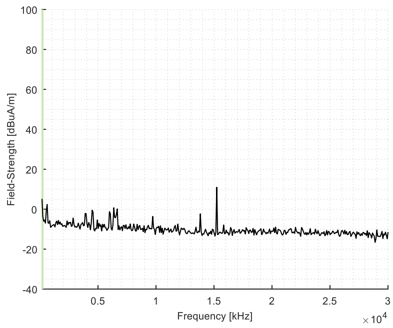
Vertical Y-axis 9 kHz ~ 150 kHz (Charging)



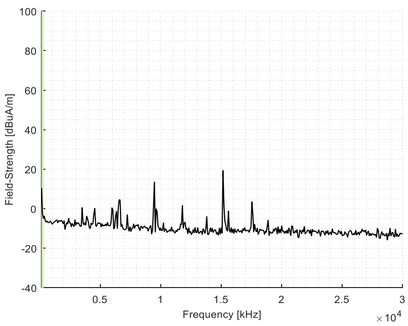
Vertical X-axis 150 kHz ~ 30 MHz (Ambient)



Vertical X-axis 150 kHz ~ 30 MHz (Charging)



Vertical Y-axis 150 kHz ~ 30 MHz (Ambient)

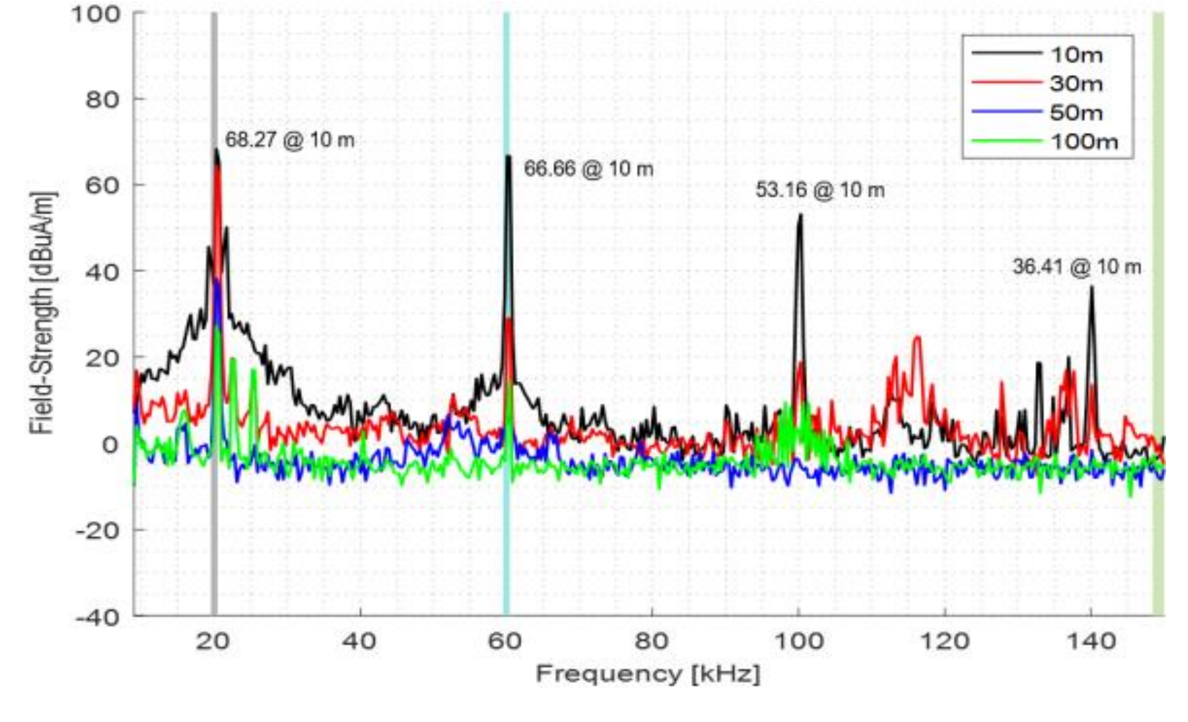


Vertical Y-axis 150 kHz ~ 30 MHz (Charging)

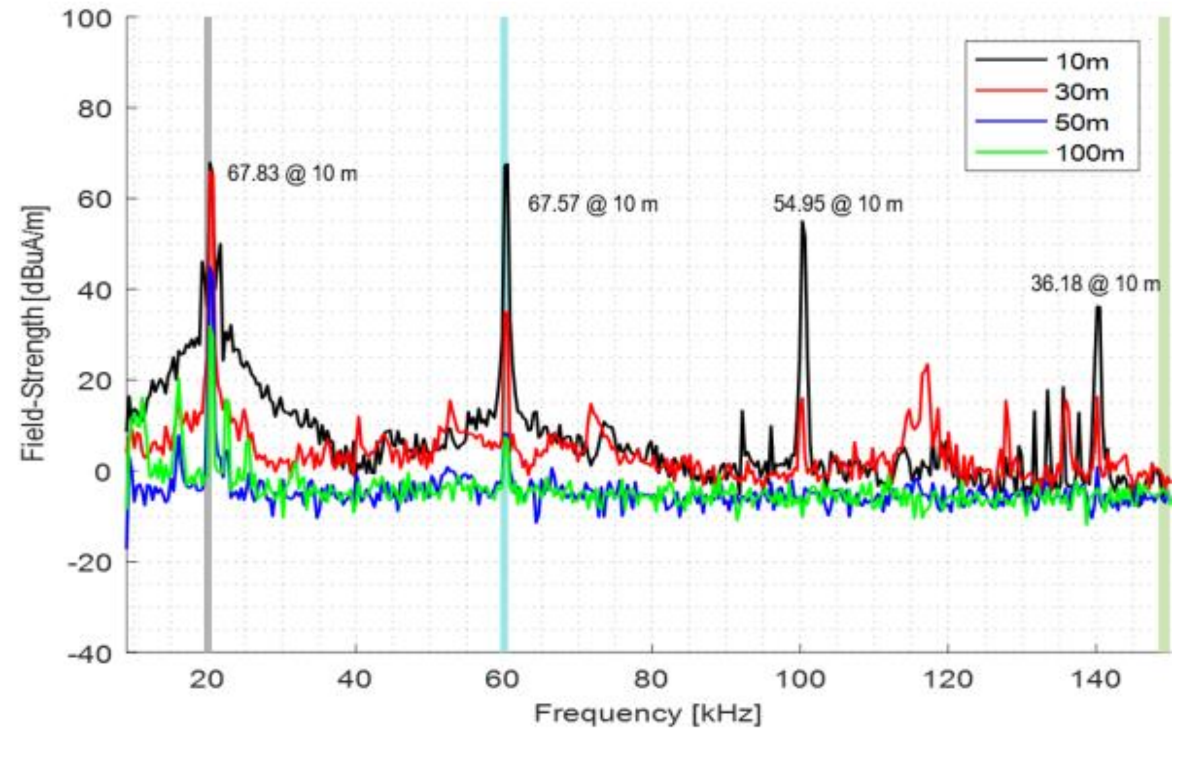
A6.3.2.5 Compared data I (9 kHz ~ 150 kHz)

FIGURE A6-16

Comparison of H field characteristics at each distance for 9 kHz ~ 150 kHz



Vertical X-axis 9 kHz ~ 150 kHz

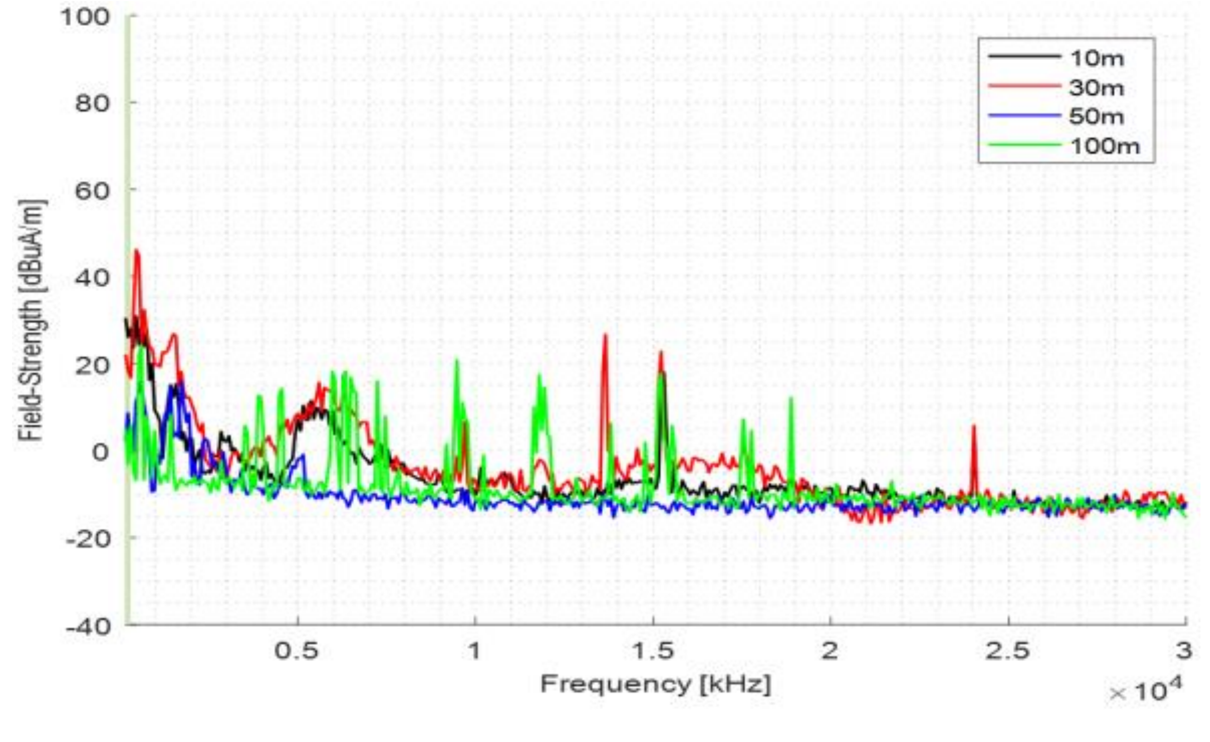


Vertical Y-axis 9 kHz ~ 150 kHz

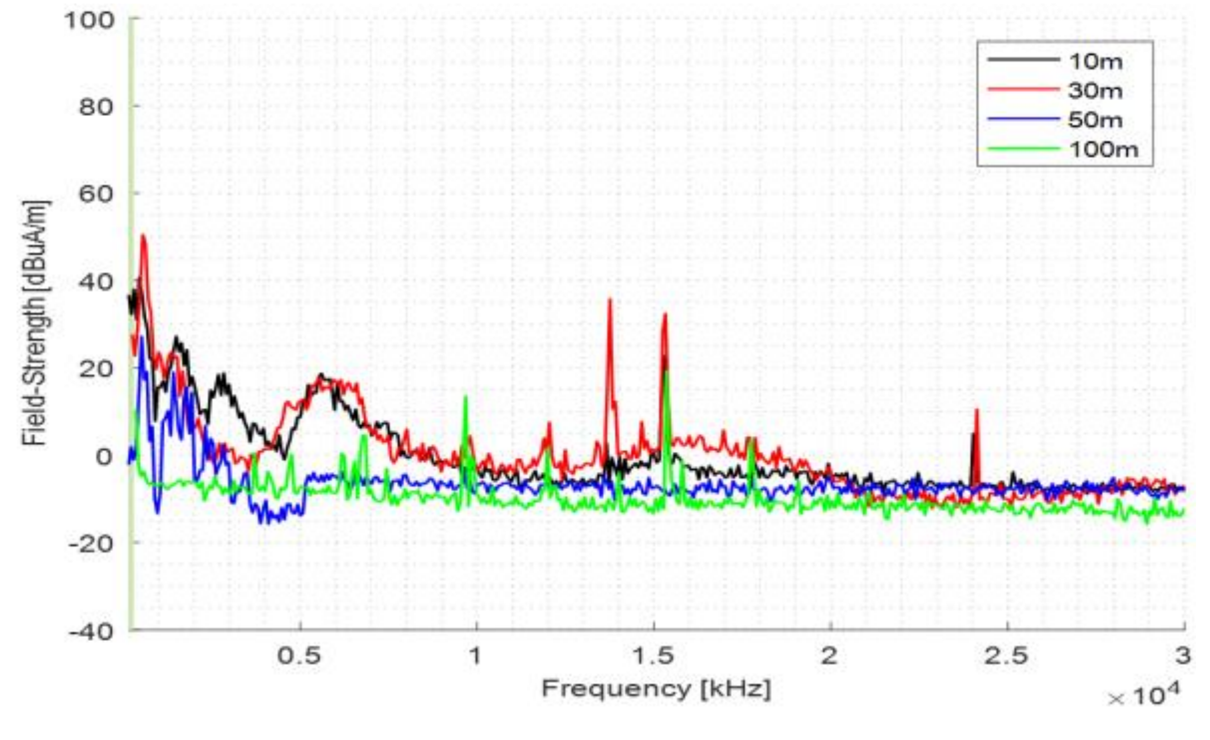
A6.3.2.6 Compared data II (150 kHz ~ 30 MHz)

FIGURE A6-17

Comparison of H field characteristics at each distance for 150 kHz ~ 30 MHz



Vertical X-Axis 150 kHz ~ 30 MHz



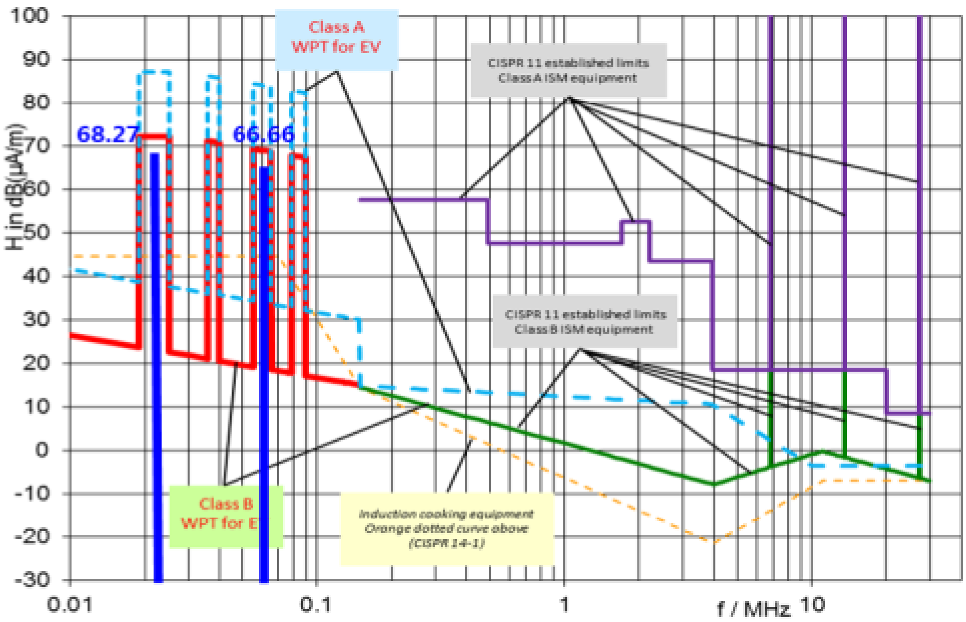
Vertical Y-axis 150 kHz ~ 30 MHz

A6.3.3 Conclusions

The test result at 10 m shows the maximum 68.27 dBμA/m @ 20 kHz and 66.66 dBμA/m @ 60 kHz under the condition of WPT EV being charged by the power line. The measurement value meets the H-field limitation proposed by CISPR B (not only "Class A" but "Class B" WPT for Electric Vehicle).

FIGURE A6-18

H-Field limits adopted in the CISPR B/TF-WPT meeting



A6.3.4 Impact study in Korea

A6.4.4.1 Introduction

Since Japan suggested an impact study for an interference between WPT EV frequencies and Japan Radio Standard time signal (60 kHz) in 2015, Korea has tried various impact case studies for many times.

The study items are as follows:

– 60 kHz interference from Japan NICT

– Harmonic frequencies interference for EBU (European Broadcasting Union) LF (148.5 ~ 283.5 kHz)

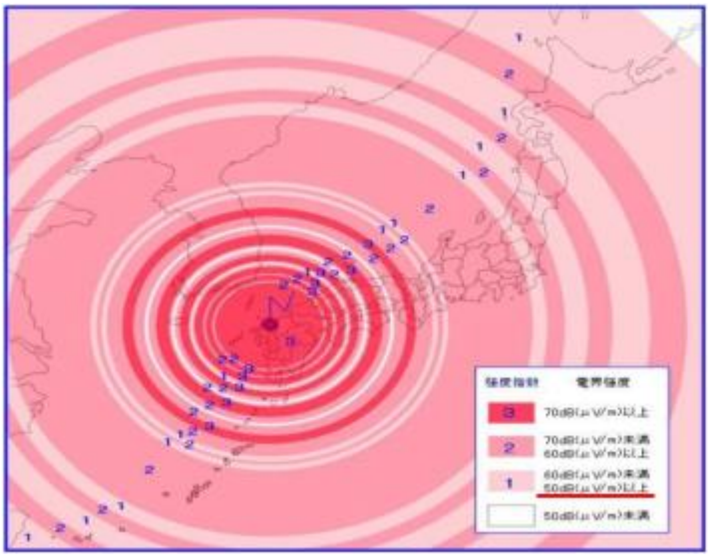
A6.3.4.2 The impact study for 60 kHz standard time signal from Japan (NICT)

Japan reported to ITU-R Study Group (SG) 1 the co-existence study internally between WPT EV and other electronic devices in Nov. 2014 written in Japanese language. It also included EMI and EMF issues.

Since June 2015, Japan delegation of ITU-R SG 1 introduced that NICT (Japan) uses 60 kHz as standard time signal from the Hagane-transmitting station located in Kitakyushu. Japan requested the interference and/or impact study between Korean heavy-duty WPT EV and Japanese standard time signal.

FIGURE A6-19

Electric field strength of 60 kHz standard time signal (source: NICT Homepage)



According to electric field strength table of the 60 kHz (source: NICT homepage), the lowest level is 50 dBμV/m. In this reason, the limitation of 60 kHz standard time signal is 50 dBμV/m.

The real clocks used 60 kHz time signal is shown in Fig. A6-20 and the test result is shown in Fig. A6-21.

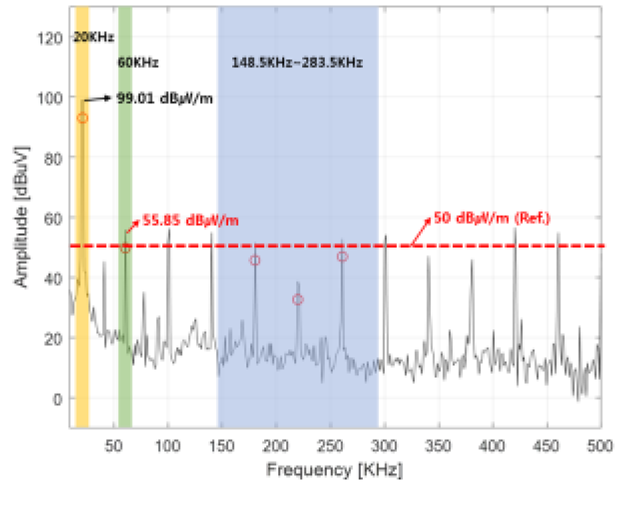
FIGURE A6-20

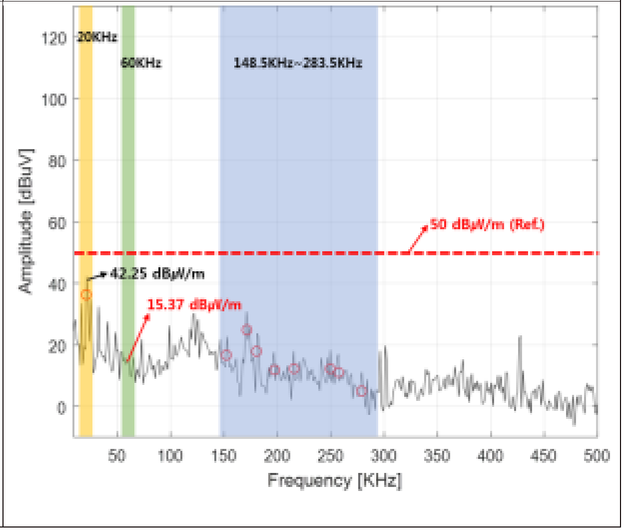
Real clocks used 60 kHz standard time signal

FIGURE A6-21

Test result at 10 m and 100 m based on 60 kHz standard time signal

10 m (charging)	100 m (charging)





At 10 m, the amplitude of 60 kHz is 55.85 dBµV/m and the value is greater than the limitation with 5.85 dB. At 100 m, the amplitude of 60 kHz is 15.37 dBµV/m and the limitation had a margin of 34.63 dB.

In a result, 100 m of separation distance is enough to protect the 60 kHz time signal clock from a heavy-duty WPT EV charging station. In practice, 50 m distance is acceptable to meet the 40 dBµV/m limitation.

A6.3.4.3 Impact study for broadcasting LF (148.5 ~ 283.5 kHz)

Since 2015, EBU (European Broadcasting Union) indicated that European countries are using the broadcasting radio signal for special emergency. The LF frequency range is 148.5 kHz ~ 283.5 kHz.

Therefore, EBU proposed that it needs to take an impact study or harmonizing interference study for WPT EV frequency band not only 20/60 kHz but also 85 kHz.

According to the liaison letter of ITU-R WP 6A on 4^{th} August 2015, the maximum acceptable interference level from receiver is summarized in Table A6-1.

TABLE A6-1

The limitation level of receiver at LF and MF

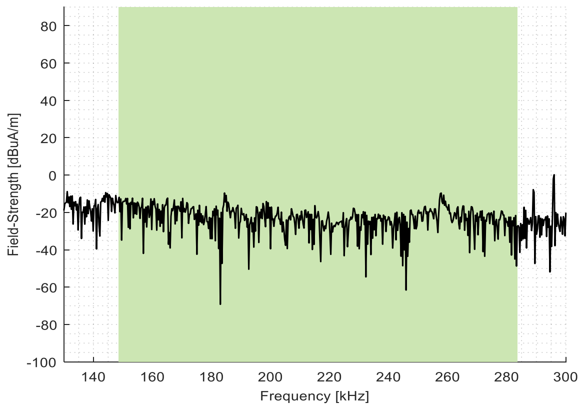
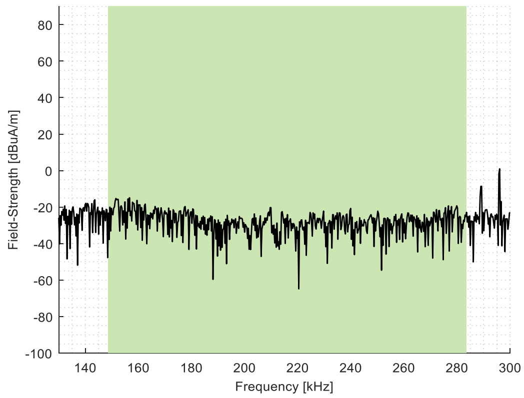
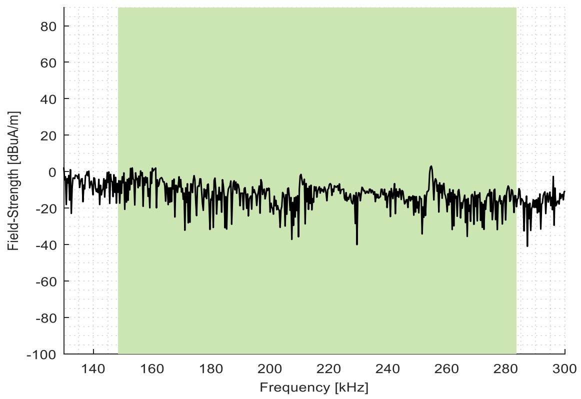
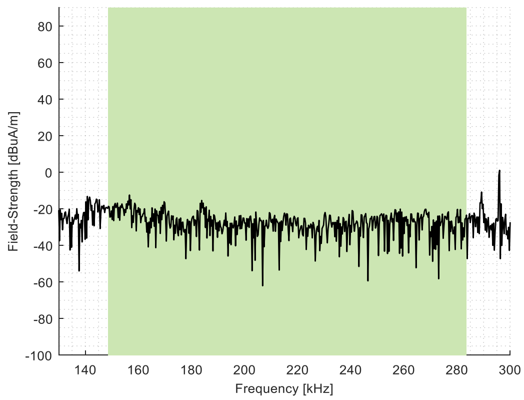
SG6 Liaison Letter (WP1A/86-1B/70, 4^{th} August 2015)	Receiver level	
	LF	MF
Frequency	148.5 kHz ~ 283.5 kHz	-
Sensitivity	66 dBµV/m (14.5 dBµV/m)	60 dBµV/m (8.5 dBµV/m)
Co-channel protection ratio	40 dB	40 dB
Non-co-channel protection ratio	16 dB	16 dB
Overall protection ratio	56 dB	56 dB
Maximum acceptable interference level	10 dBµV/m (−41.5 dBµV/m)	4 dBµV/m (−47.5 dBµV/m)

Test results are summarized in Fig. A6-22.

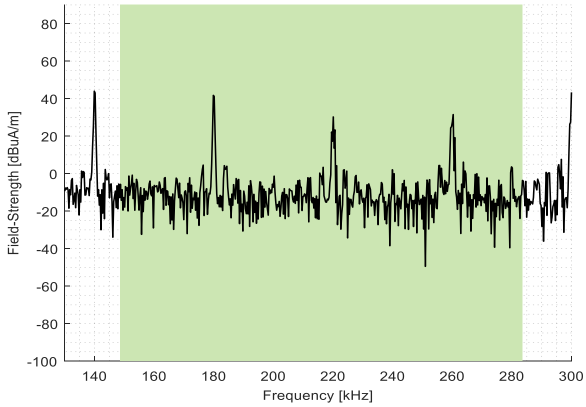
FIGURE A6-22

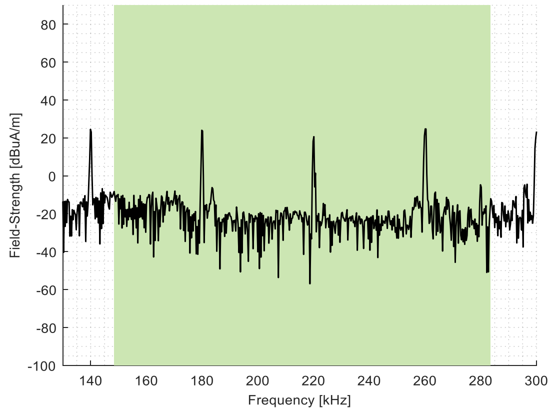
Test results

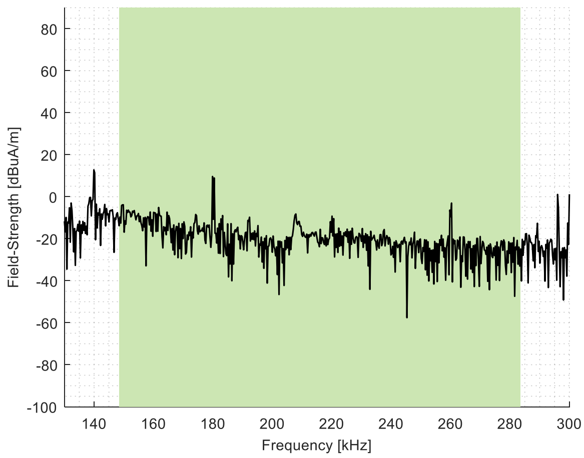
– Under ambient condition

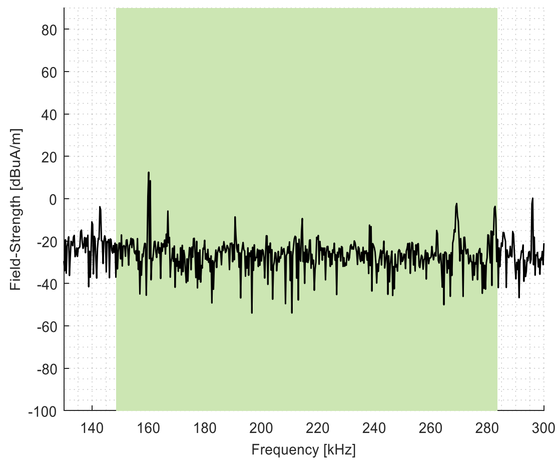
130 kHz to 300 kHz @ 10 m (Ambient)	**130 kHz to 300 kHz @ 30 m (Ambient)**
 PEAK: −9.58 DBµA/M @ 184.4 kHz	 PEAK: −15.23 DBµA/M @ 151.5 kHz
130 kHz to 300 kHz @ 50 m (Ambient)	**130 kHz to 300 kHz @ 100 m (Ambient)**
 PEAK: 3.1 DBµA/M @ 254.7 kHz	 PEAK: −12.48 DBµA/M @ 156.6 kHz

– Under charging condition

<table>
<tr><th>130 kHz to 300 kHz @ 10 m (Charging)</th><th>130 kHz to 300 kHz @ 30 m (Charging)</th></tr>
<tr><td>

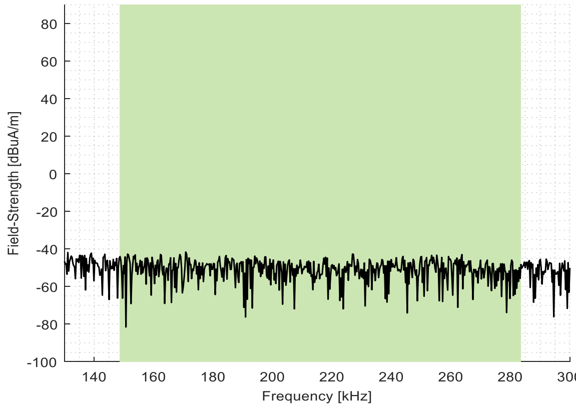
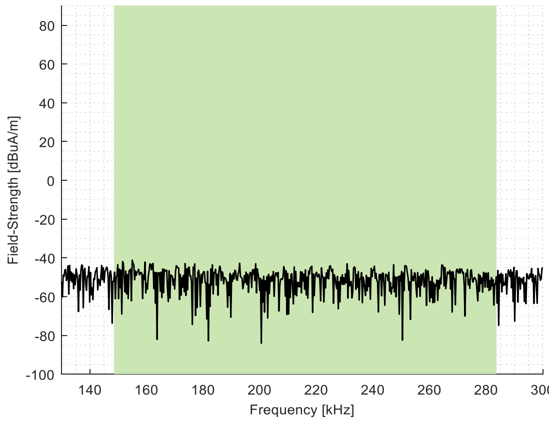
PEAK: 41.78 DBμA/M @ 179.9 kHz</td><td>

PEAK: 24.77 DBμA/M @ 260.1 kHz</td></tr>
<tr><th>130 kHz to 300 kHz @ 50 m (Charging)</th><th>130 kHz to 300 kHz @ 100 m (Charging)</th></tr>
<tr><td>

PEAK: 9.63 DBμA/M @ 179.9 kHz</td><td>

PEAK: 12.51 DBμA/M @ 160.0 kHz</td></tr>
</table>

– Without any antenna cable

150 kHz to 300 kHz @ 10 m (without Ant')	130 kHz to 300 kHz @ 100 m (without Ant')
 PEAK: −40.99 DBµA/M @ 170.8 kHz	 PEAK: −40.66 DBµA/M @ 154.93 kHz

Under the ambient condition, there is no charging on the heavy-duty WPT EV because the maximum value is already more than 3.1 dBµA/m @ 254.7 kHz at 50 m and the minimum value is −15.23 dBµA/m @ 151.5 kHz at 30 m. It means that any value never meets the given limitation from EBU.

At charging mode, the maximum value is 41.78 dBµA/m @ 179.9 kHz at 10 m and the minimum value is 9.63 dBµA/m @ 179.9 kHz at 50 m. Needless to say, it exceeds significantly the limitation more than 80 dB.

In conclusion, Korea reports to the impact study for EBU LF Band 148.5-283.5 kHz as two results.

1) It is impossible to meet the given EBU limitation under any urban circumstance regardless of WPT charging condition or not such as Fig. A6-22 (Test result).

   Because the limitation, 10 dBµV/m (= −41.4 dBµA/m), of Table A6-1 is very tight, itself noise level of equipment (the receiver, Agilent E4440A) system without any antenna connecting is already exceeded the limitation.

2) It needs to approach other compromise with a more realistic view from EBU.

   As it investigated the table of EBU LF audio broadcasting, two broadcasting frequencies are linked to 19-21 kHz. One is 173 kHz broadcasting station. The 9th harmonics of 173 kHz is 19.2 kHz. The other is 182 kHz broadcasting station. The 9th harmonics of 182 kHz is 20.2 kHz. If Korea does not use two pin point frequencies, 19.2 kHz and 20.2 kHz, it may not affect the inference between EBU LF band and heavy-duty WPT system. Korea is willing to avoid those pin point frequencies when EBU accepts this condition. It will use more other frequencies under the same 20 kHz band (19-21 kHz).

Annex 7

Impact Studies in Japan for WPT-EV using 79-90 kHz

A7.1 Introduction

This Annex provides impact studies carried out in the process of Japan’s new rule making for WPT-EV systems using 79-90 kHz. The study was conducted by a working group (WG) for WPT rule-making in the Ministry of Internal Affairs and Communications (MIC), Japan. The WG consisted of technology experts and representatives in the related fields including WPT industries, intended incumbent radio systems, EMC, radio wave exposure and academia. The study results were incorporated into Japanese radio regulation and guidelines for WPT operation; and then, the new rule became effective in March 2016.

A7.2 Emission limits on WPT for EVs

Emission limits for WPT for EV applications in Japanese radio regulation are shown in Table A7-1 in accordance with frequency ranges designated.

In specifying conductive and radiated emission limits in the WG, CISPR standards were referenced in light of international regulatory harmonization. For some specific use cases in incumbent radio system operations in the concerned spectrum, additional domestic coexistence conditions and requirements derived from impact studies were specified and incorporated into the emission limits upon stakeholders’ agreement.

The emission limits define allowable radio frequency power strength from WPT equipment in the new rules called the ‘type specification’, which exempt permission of individual equipment installation application for WPT.

TABLE A7-1

Emission limits for WPT for EV applications in Japan

WPT target application	Conductive emission limits		Radiated emission limits of fundamental wave	Radiated emission limits in other bands			
	9-150 kHz	150 kHz - 30 MHz	79-90 kHz	9-150 kHz	150 kHz - 30 MHz	30 MHz - 1 GHz	1-6 GHz
WPT for EV charging	Not specified	0.15-0.50 MHz: Quasi-peak 66-56 dBµV (linearly decreasing with log (f) Average 56-46 dBµV (linearly decreasing with log (f), 0.50-5 MHz: Quasi-peak 56 dBµV, Average 46 dBµV 5-30 MHz: Quasi-peak 60 dBµV, Average 50 dBµV, except ISM bands	68.4 dBµA/m at 10 m. (Quasi-peak)	23.1 dBµA/m at 10 m. (Quasi-peak), except 79-90 kHz	Taking basis on CISPR 11 Ed. 5.1, converting to values at 10 m distance, linearly decreasing with log (f) from 39 dBµA/m at 0.15 MHz to 3 dBµA/m at 30 MHz (1). Exception-1: For 158-180 kHz, 237-270 kHz, 316-360 kHz, and 3 965-450 kHz, emission limits are higher than (1) above by 10 dB. Exception-2: For 526.5-1 606.5 kHz, –2.0 dBµA/m (quasi-peak)	Taking basis on CISPR 11 Ed. 5.1, the following is applied: 30-80.872 MHz: 30 dBµV/m; 80.872-81.88 MHz: 50 dBµV/m; 81.88-134.786 MHz: 30 dBµV/m; 134.786-136.414 MHz: 50 dBµV/m; 136.414-230 MHz: 30 dBµV/m; 230-1 000 MHz: 37 dBµV/m	Not specified

A7.3 WPT-EV Standardization

The WPT-WG of the Broadband Wireless Forum, Japan (BWF) is taking responsibility for drafting WPT technical standards utilizing the ARIB (Association of Radio Industries and Businesses) drafting protocols. The ARIB Standard STD-T113 "Wireless power transmission systems" assumes to comprise WPT-EV technologies through BWF's standard-drafting process once a WPT specification for EV applications has been standardized in global basis in IEC 61980 and ISO 19363.

A7.4 Impact studies on the WPT using 79-90 kHz

A7.4.1 Impact assessment process and intended incumbent radiocommunication services/ systems in the study

The following steps were taken in the studies:

1 First step: Survey on spectrum use and determination of candidate frequency ranges.

Survey the spectrum usage of incumbent radiocommunication services in the proposed WPT operating frequency ranges, adjacent bands, and other frequency ranges in which WPT harmonics may fall. These services may have any possibility to suffer service quality degradation caused by WPT systems. Determine candidate bands for WPT from relatively vacant spectrum.

2 Second step: Selection of preferential incumbent radiocommunication systems to protect.

Pick up incumbent radiocommunication systems which might be suffered from WPT in the candidate band(s). Prioritize the systems to protect by clarifying attributes of services in accordance with the following condition and/or usage situations:

– The frequency range category in the Radio Regulations (RR)

– Justifications for protection from the WPT system

– Mechanism to avoid harmful interference from WPT systems

Above considerations lead to selection of the preferential incumbent radiocommunication systems.

3 Third step: Assessment of WPT emission impact to the incumbent radiocommunication services.

The impact of WPT systems to each selected incumbent radiocommunication services are assessed by simulation and/or measurement. In this step, the following points should be clarified.

– Frequency ranges of power transmission, power level, and any other parameters or characteristics that may influence to the incumbent radiocommunication services.

– Use cases of the incumbent systems with defining parameters including operation period/timing (in particular overlapped period in use with WPT), physical separation distance or positioning.

– Emission strength from WPT systems: The maximum emission strength should appropriately be determined for assessment referring to available regulations or draft document developed in CISPR/B.

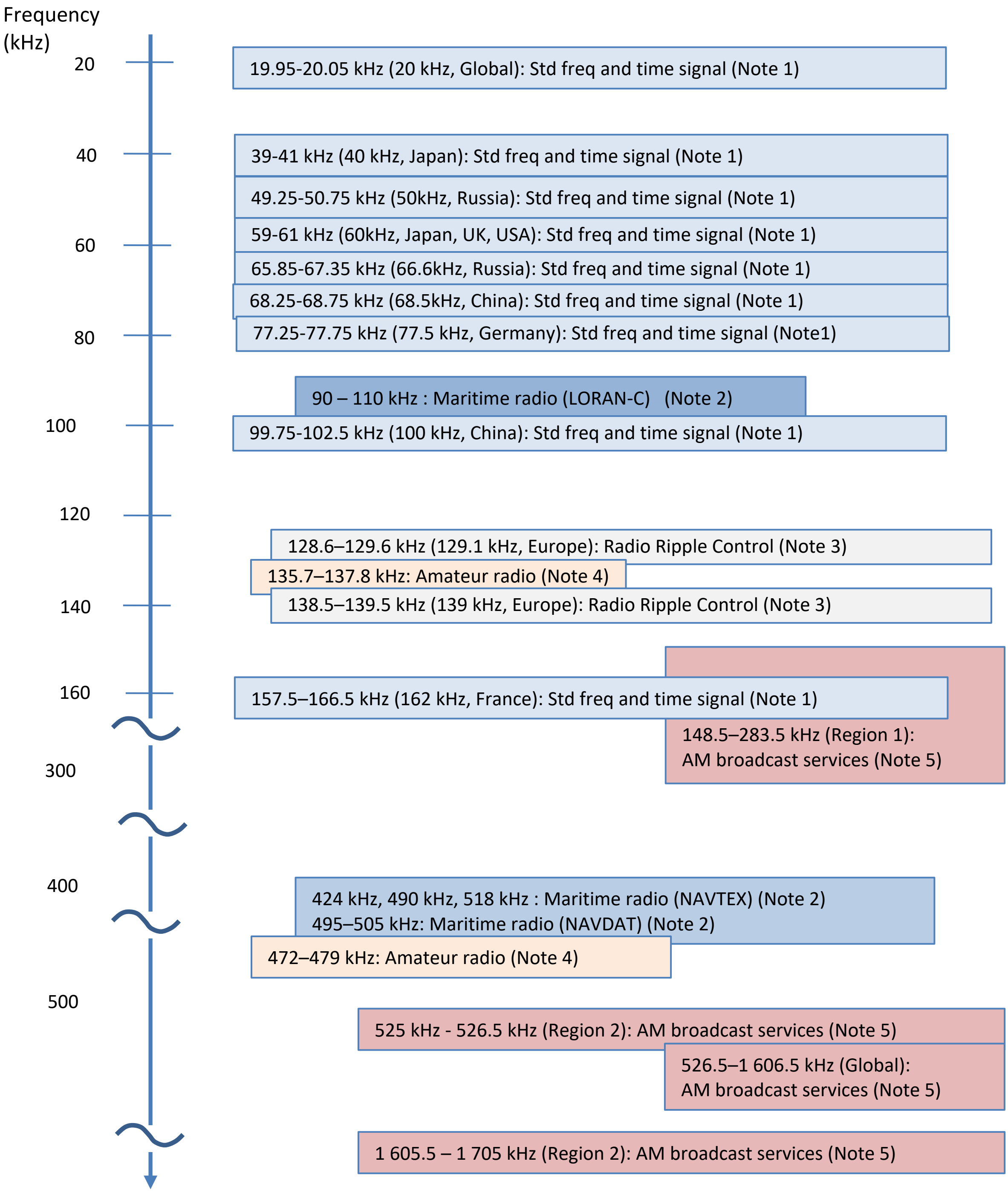
– Test and verification: Unwanted emission strength calculated or measured at the concerned receiver should not exceed the receiver sensitivity or should not cause any operational failure. In addition, use case conditions such as use-time distribution, time-overlapping of operations, and practical device locations should be taken into consideration.

The advisability to mitigate the impact should be discussed and judged by the result of the above-mentioned steps. Frequency ranges with an adequate mitigation of the impact verified and confirmed in the steps could be recommended to adopt as the candidate frequency ranges for non-beam WPT for EVs.

Frequency ranges for WPT for EVs are assumed to be in the frequency range below 150 kHz, considering discussions about worldwide WPT technology standards development in IEC TC 69/PT61980, ISO TC22/PAS 19363 and SAE J2954TF. Also, frequency ranges of harmonics were taken in consideration of frequency range selection. This survey covered frequency ranges below 1 MHz. The result of the survey of spectrum use is illustrated in Fig. A7-1 and listed in Table A7-2.

FIGURE A7-1

Spectrum of radio-communication services from 9 kHz to 3 MHz



Note 1: Amplitude modulation (BCD). The clocks and watches that periodically receive digital signals of the standard time transmitted from the standard-time-signal transmitting stations to synchronize and adjust own time.
Note 2: Pulse, FSK etc. Radio system that secures safety of vessel operation which is used at port and harbour or on the sea.
Note 3: A radio system used for load/demand control of electricity, which communicates over the electrical distribution system.
Note 4: Radio service with transmitter and receiver devices used for technology research and training of amateur radio operators.
Note 5: Amplitude modulation; Audio broadcasting service with receiver devices which use long wave or medium wave band.

TABLE A7-2

Spectrum of radio-communication services from 9 kHz to 3 MHz

Radio-communication services and systems		**Frequency bands**	**Modulation**	**Remarks**
Standard frequency and time signal		19.95 kHz – 20.05 kHz (20 kHz, Global) 39 kHz – 41 kHz (40 kHz, Japan) 49.25 kHz – 50.75 kHz (50 kHz, Russia) 59 kHz – 61 kHz (60 kHz, UK, US and Japan) 65.85 kHz – 67.35 kHz (66.6 kHz, Russia) 68.25 kHz – 68.75 kHz (68.5 kHz, China) 77.25 kHz – 77.75 kHz (77.5 kHz, Germany) 99.75 kHz – 102.5 kHz (100 kHz, China) 157.5 kHz – 166.5 kHz (162 kHz, France)	Amplitude Modulation (BCD)	Clocks and watches periodically receive digital signals transmitted from standard frequency and time signal stations to synchronize and adjust their own time
Ripple Control		128.6 kHz – 129.6 kHz (129.1 kHz, Europe) 138.5 kHz – 139.5 kHz (139 kHz, Europe)	–	Radio systems used for load/demand control of electricity, which communicates over the electrical distribution system
Train protection automatic warning system	Automatic Train Stop (ATS) Systems	10 kHz – 250 kHz (Japan)	–	Telecommunication systems which apply electric current to the coils installed along railroad tracks and detect electric current induced in the coils installed on train vehicles on the rail to control the trains.
		425 kHz – 524 kHz (Japan)	–	
	Inductive Train Radio Systems (ITRS)	100 kHz – 250 kHz (Japan)	–	Signal transmission systems which use inductive coupling between transmission line which is installed along the railroad track and so forth and antennae which are installed on train vehicles.
		80 kHz, 92 kHz (Japan, only one route)	–	
Amateur radio		135.7 kHz – 137.8 kHz	Amplitude Modulation, Frequency Modulation, Single Sideband, etc.	Systems for the amateur service as defined in No. **1.56** of the Radio Regulation, for the purpose of self-training intercommunication and technical investigations carried out by amateurs
		472 kHz – 479 kHz		
Maritime radio		90 kHz – 110 kHz (LORAN)	Pulse Modulation, Frequency Shift Keying etc.	Radio systems used at port and harbour or on the sea in order to secure safety of vessel operation, etc.
		424 kHz, 490 kHz, 518 kHz (NAVTEX)		
		495 kHz – 505 kHz (NAVDAT)		
AM broadcasting		148.5 kHz – 283.5 kHz (Region 1) 525 kHz – 526.5 kHz (Region 2) 526.5 kHz – 1 606.5 kHz (Global) 1 605.5 kHz – 1 705 kHz (Region 2)	Amplitude Modulation	Systems for audio broadcasting services with receivers which use LF and MF bands.

The survey on incumbent radiocommunication systems concluded that the following four incumbent systems/services should be selected for assessment of the impact of WPT for passenger EVs using 79-90 kHz:

– Standard frequency and time signal (SFTS) services.

– Train radio systems (10 kHz-250 kHz).

– Amateur radio services (135.7 kHz – 137.8 kHz).

– MF broadcasting services (526.5 kHz – 1 606.5 kHz).

Train radio systems are operated in a unique environment in Japan. They are not categorized clearly in Japan’s Radio Regulations. However, the WG (see § A7-1) decided to assess the train radio systems because it is a safety matter to prevent train service users from any accidents.

A7.4.2 Impact to broadcasting services

A7.4.2.1 Impact studies documented in Report ITU-R SM.2303

The following two approaches for the impact study on MF sound broadcasting services are described in § 7.2 of Report ITU-R SM.2303.

1 An approach proposed by EBU and ITU-R broadcasting experts: The approach is based on the protection criteria of broadcasting services specified in Recommendations ITU-R BS.560 and BS.703. The impact study focused on the radio environment where the minimum sensitivity of an AM sound broadcasting receiver for planning purposes is applied. The corresponding areas can be assumed to have low field strengths of radio broadcasting signals. The maximum tolerable magnetic fields at broadcasting receivers in the LF and MF bands were derived by using the RF protection criteria of broadcasting services shown in relevant ITU-R Recommendations and Reports. Details can be found in § 7.2.1 of Report ITU-R SM.2303.

2 An approach proposed by Japan: The impact study performed by Japan focuses on the radio environment in urban areas comparable to Environmental Category “City” in Recommendation ITU-R P.372-13, where high and medium environmental noise and high and medium field strengths of sound broadcasting signals can be assumed. Basic condition for coexistence in this impact study is to ensure that radiated interfering emission field strength from WPT systems should be less than the environment noise level described in Recommendation ITU-R P.372-13. The radiated emission limit has finally been determined to be −2.0 dBμA/m at 10 metres apart from WPT systems in Japan’s regulation, by considering a practical separation distance, propagation loss due to walls of houses and buildings and uncertainty budget in industries' design and test stage. This approach was validated through an analytical emission study, emission measurement and audibility test using WPT test equipment and MF broadcasting receivers. Details can be found in § 7.2.2 of Report ITU-R SM.2303.

A7.4.2.2 Conditions for coexistence between WPT systems for EVs and MF sound broadcasting services

The following points should carefully be taken into account to determine what conditions to coexist.

– Radiated interfering emission field strength from WPT systems should be less than the environment noise level derived by Recommendation ITU-R P.372-13, for different categories of radio environment, at the input of a radio receiver antenna.

– Each administration should determine the radiated emission limits when prescribing the required minimum separation distance(s) between WPT systems and broadcasting receivers, considering propagation loss due to walls of houses and buildings and other factors including uncertainty budget in industries' design and test stage.

Reasons of the above mentioned are described below.

Table A7-3 shows an example of different radio environment categories with conditions for coexistence between WPT systems and MF sound broadcasting services, which are characterized by separation distance, propagation loss by walls of houses or buildings, uncertainty budget in test and design, H-field strength from WPT systems, and environmental noise levels. The environmental noise levels in the bottom row in Table A7-3 were calculated referring to Recommendation ITU-R P.372-13 which categorizes “City”, “Residential”, “Rural” and “Quiet rural” radio environment.

The WG used “City” in the impact study assuming near future coexistence of WPT for EVs in MF broadcasting service environment, where the environmental noise level was calculated to be −25.5 dBμA/m. On the other hand, in “Quiet rural”, the environment noise level is calculated to be –48.5 dBμA/m, which is almost the same as the emission limit of –47.5 dBμA/m proposed by EBU/ITU-R broadcasting experts as shown in § 7.2.1 of Report ITU-R SM.2303. Although the two approaches from EBU and Japan are different, resultant radiated emission limits derived by the approaches are considered to be consistent in the quiet rural environment.

The required minimum separation distance for each radio environment can be derived in order that the emission H-field strength from WPT systems at a radio receiver should be less than the environment noise level. In the Japan’s study, the following conditions were assumed to develop the national regulation for WPT systems for EVs as described in § 7.2.2 of Report ITU-R SM.2303.

– Self-interference is out of scope of the impact study. Self-interference means that an owner’s WPT system interferes to the same owner’s MF sound broadcasting receiver.
– MF sound broadcasting receivers are located inside houses or buildings. On the other hand, a WPT system for EVs is located outside of the houses or buildings. Propagation loss due to house walls should be considered, which was estimated as 10 dB from the Japanese study results.
– The separation distance between a WPT system and a MF sound broadcasting receiver is 10 m, under the assumption that the nearest neighbourhood house is located more than 10 m apart from the WPT owner’s house in the City area.
– Uncertainty budget in manufacturers’ design and test stage is considered. This value was supported because manufacturers sensibly and commonly take account of uncertainty budget by 10 dB or more to guarantee their emission performance in their design and test stages in order to clear the regulation limits for 100% of their products. Uncertainty budget estimated here is 14 dB from measurement results of developed WPT systems.

Consequently, the radiated emission limits in Japan’s new regulation for WPT systems for EVs was determined as –2.0 dBμA/m at 10 m distance in the frequency range of MF sound broadcasting services.

This regulation can be applied to radio environment other than City area by taking an appropriate separation distance into account. WPT industries should continuously take appropriate interference mitigation measure to reduce the interference to lower than the allowable emission limits in order to avoid harmful disturbance to broadcasting services in suburban and rural areas. If the WPT system should cause unacceptable interference to the receivers, radio administrations shall provide necessary regulatory measures/orders to stop WPT system operation causing harmful interference to the other incumbent radio systems.

When adopting Japan’s regulation of −2.0 dBμA/m at 10 m distance and the other factors including propagation loss and uncertainty budget, the coexistence between WPT systems for EVs and broadcasting services can be achieved by setting the suitable separation distances of 13 metres, 16 metres and 35 metres for “Residential”, “Rural” and “Quiet rural” radio environment, respectively.

Study results show that the coexistence can be achieved for any radio environments by setting suitable separation distances between WPT systems for EVs and MF sound broadcasting receivers.

TABLE A7-3

Example of condition for coexistence between WPT systems and broadcasting services

Radio environment categories in Rec. ITU-R P.372-13	A (City)	B (Residetial)	C (Rural)	D (Quiet rural)	Remarks
(1) Radiated emission limits @ 10 m (dBuA/m)	-2.0	-2.0	-2.0	-2.0	Radiated emission limits in MF frequency range in Japan's regulations for WPT systems for EV.
Separation distance (m)	10	13	16	35	Separation distance 10m is defined as the comdistion of impact study in urban areas. Separation distance in residential, rural and quiet rural areas are described only as reference.
(2) Degradation due to separation distance (dB)	0	4.8	8.6	22.9	In Japan's radio raw, the diatance conversion factor from 10 m to 30 m is 1/10 (=20 dB) in the frequency range of MF broadcasting service. From this relationship (the 2.1-th power rule), the factor from 10 m to 15 m is 1/2.3 (=7.2 dB) the factor from 10 m to 20 m is 1/4.3 (=12.7 dB)
(3) Propagation loss due to walls of houses and buildings (dB)	10	10	10	10	Referred from Japan's report results of MIC's round-table conference concerning MF broadcasting pre-emphasis (Dec. 1983).
(4) Uncertainty budget in industries' design and test stage (dB)	14	14	14	14	Estimated by measured results of developmed WPT systems for EVs in Japan.
(5) Realized emission H-field strength at AM radio receiver (dBuA/m)	-26.0	-30.8	-34.6	-48.9	Calculated by (5) = (1) - (2) -(3) - (4)
Environment noise level (dBuA/m)	**-25.5**	**-30.5**	**-34.5**	**-48.5**	**Calculated at 500 kHz by Eq.(7) and Fig.10 in Rec. ITU-R P.372-13.**

A7.4.3 Impact to standard frequency and time signal (SFTS) services

WPT devices whose radiated emission are lower than the emission limits described in Table A7-4 will not cause harmful interference, which is defined by *C*/*I* derived from the minimum receiver sensitivity of the radio-controlled clock/watch devices using SFTS services in agreed use cases. Separation distance of 10 m was agreed and used to assess the impact to those devices. In addition, operation time range of the device to receive the SFTS service which is not overlapping with WPT operation, diversity of SFTS wave propagation direction, and expecting receiver performance improvement in the future of those devices were taken into assessment. Consequently, the impact of WPT systems to radio-controlled clocks/watches has been confirmed to be small enough not to cause harmful interference. Details are described in the following (a) – (d).

TABLE A7-4

Radiated emission limits of WPT systems for EV using 79-90 kHz in Japan's study

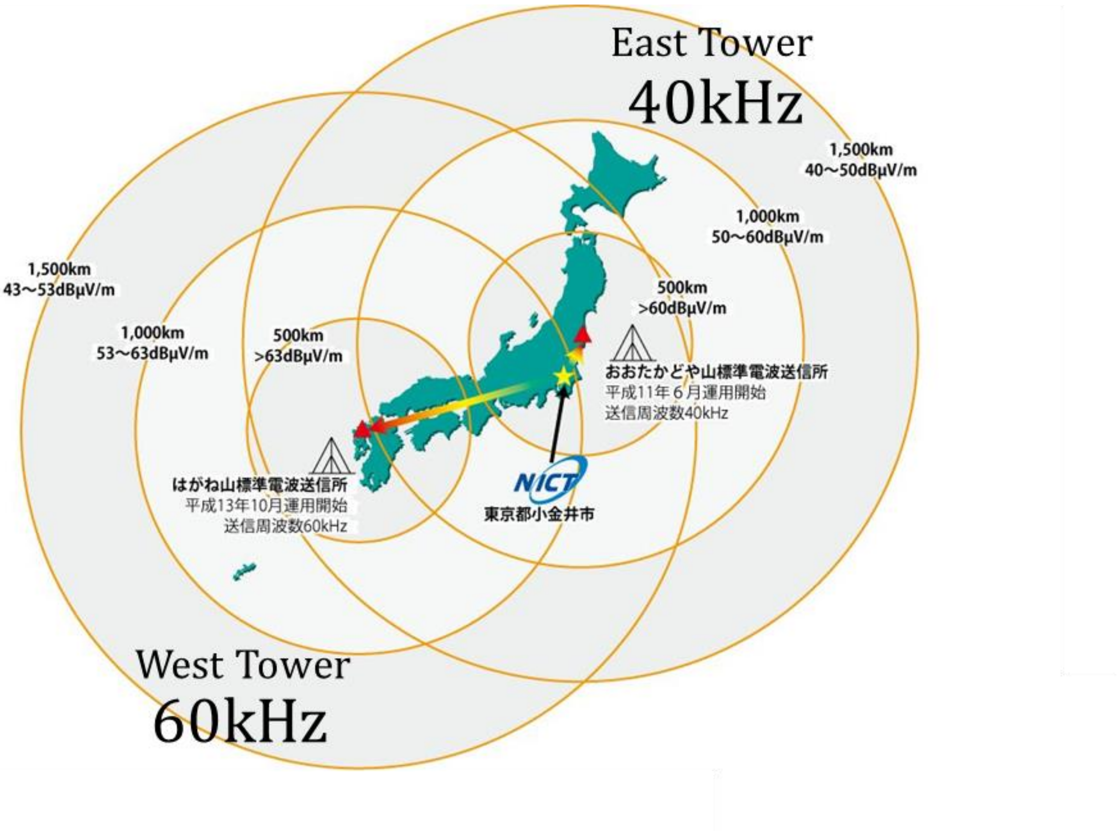
	Radiated emission limits
WPT frequency range (frequency range used for power transmission), 79-90 kHz	68.4 dBμA/m @ 10 m for 3 kW Tx Power 72.5 dBμA/m @ 10 m for 7.7 kW Tx Power
Frequency range from 526.5-1 606.5 kHz (MF broadcasting services frequency range)	−2.0 dBμA/m @ 10m
Other frequency ranges under 3 MHz expect for 526.5-1 606.5 kHz	23.1 dBμA/m @ 10 m

a) SFTS transmissions in Japan

Figure A7-2 shows SFTS transmission coverage with signal strength transmitted from two transmission towers located in eastern (the East Tower in Fukushima-Prefecture) and western (the West Tower in Saga-Prefecture) Japan. The East Tower transmits SFTS on 40 kHz and the West Tower does on 60 kHz. The SFTS can be received anywhere at your radio-controlled clock/watch devices anywhere in the country even if in islands far off in the ocean at signal strength higher than 50 dBμV/m, the minimum electric field strength.

FIGURE A7-2

SFTS transmissions covering all over Japan

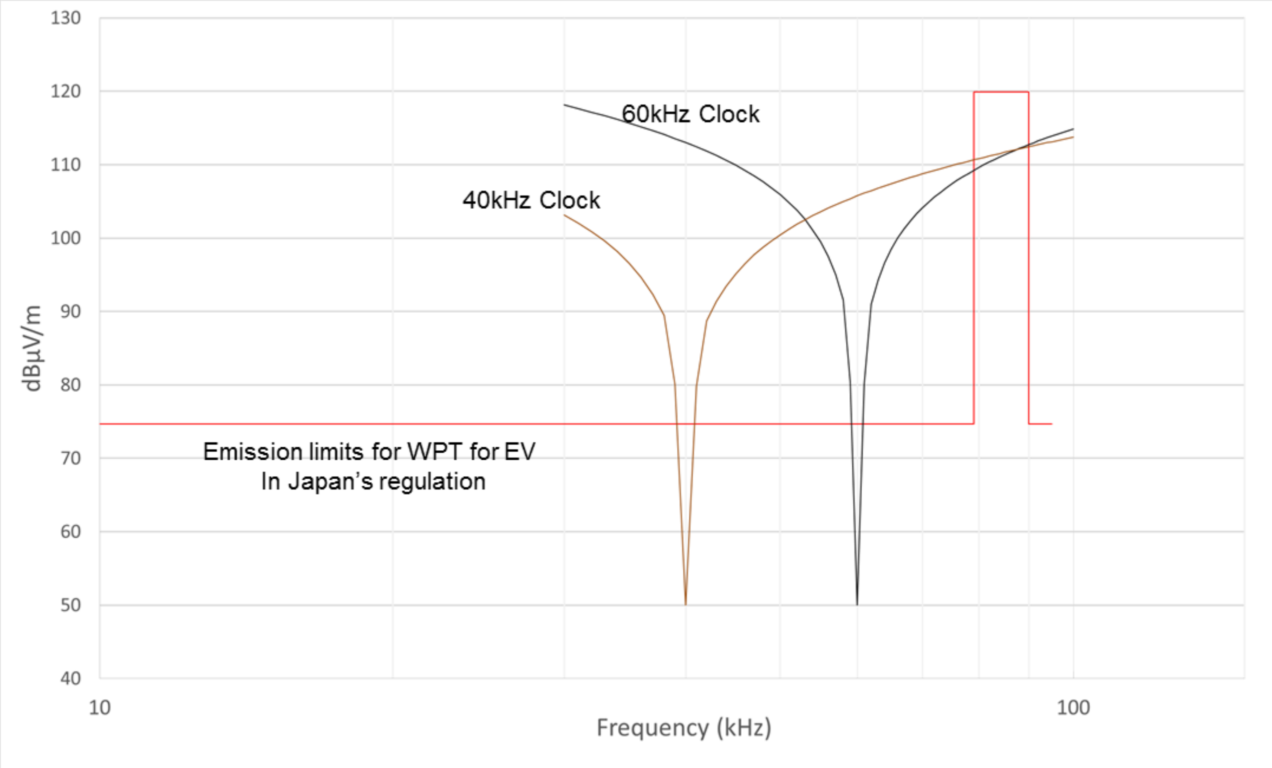


b) Interference from WPT systems to radio clock/watch devices receiving SFTS

Figure A7-3 plots emission limit of WPT for EVs and allowable interference field strength of SFTS receiver in the interested frequency range. Here, the receiver is assumed to receive SFTS at field strength 50 dBuV/m (i.e. minimum receiver sensitivity) when the receiver performance is derived from measurement results of commercial radio clock/watch devices receiving the 40/60 kHz transmitted SFTS waveforms. From this Figure, it is expected that SFTS waveforms at 40/60 kHz received less than 50 dBuV/m might be blocked by emission of WPT for EVs in 79-90 kHz received at higher field strength than 110 dBuV/m. Some types of widely used commercial radio-controlled clock/watch devices might come up against a problem caused by low interference immunity and poor frequency selectivity of receivers.

FIGURE A7-3

Emission limit for WPT for EVs and allowable interference field strength of SFTS receiver



c) SFTS receiving timing distribution for time adjustment

Radio-controlled clock/watch devices receive SFTS data automatically to keep own time adjusted to the reference time. Table A7-5 shows scheduled time distribution for automatic time adjustment of several commercial products. To receive data certainly every day, all companies' watches/clocks receive data during 2:00am – 5:00am.

TABLE A7-5

Scheduled timing distribution for automatic time adjustment

		Time to start receiving time data signal																							
		12	13	14	15	16	17	18	19	20	21	22	23	0	1	2	3	4	5	6	7	8	9	10	11
Watch 1	Company A															○	△	△							
Watch 2																○		△							
Watch 3																○	△								
Watch 4	Company B															○	△	△							
Watch 5																○		△							
Watch 6	Company C													○	△	△	△	△	△						
Watch 7																○	△	△							
Watch 8															○	○	△	△	△						
Clock 9	Company D	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Clock 10			○	○	○	○	○	○	○	○	○	○			○	○	○	○	○	○	○	○	○	○	
Clock 11				○				○				○				○	○			○				○	
Clock 12	Company E			○			○			○			○			○			○			○			○
Clock 13																○	△	△	△	△					
Clock 14		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Clock 15		Every 3 hours																							
Clock 16	Company F	△	△	△												○	△	△							
Clock 17		○		○		○		○		○		○		○		○		○		○		○		○	
Clock 18			○	○	○	○									○	○	○	○							

Note: "circle" means "primary scheduled adjustment timing" "triangle" means "secondary adjustment timing for backup".

d) Considerations on the impact of WPT for EVs to SFTS services

Potential impact to SFTS receiver performance and mitigation measure

Receiver performance of radio-controlled watch/clock devices receiving SFTS might be degraded by receiver blocking caused by WPT emission in its operating frequency range due to insufficient sensitivities of SFTS receiving devices. It should be noted that the event can be observed only when planned SFTS receiving timing falls into wireless EV charging period. Thus, harmful interference event may not continue beyond the overlapped period. WPT charging time alignment programs must thrive on timing adjustment to solve SFTS receiver blocking issues.

Compatibility framework agreed between WPT for EVs and radio-controlled watch/clock devices

In the WG (see § A7.1), leaders from WPT for EVs proponents and representatives from the radio-controlled watch/clock device industry reached a consensus on compatibility framework on the two technologies. The baseline was that WPT for EVs with the proposed limits of 68.4 dBuA/m @ 85 kHz band (79-90 kHz) can be used while the radio-controlled watch/clock devices for 40/60 kHz are in use practically throughout Japan. The following points were carefully considered and agreed.

– Minimum received field strength 50 dBuV/m may be relaxed by about 10 dB,
– Wireless EV charging period is not always overlapped with the SFTS reception timing of radio-controlled watch/clock devices,
– SFTS arriving direction having maximum field strength at the receiver device may not always be same to the main direction of the WPT device,
– In the WPT device manual or on the WPT product, the following instruction or equivalent should be indicated as: “Possible harmful electro-magnetic interference to the radio-controlled watch/clock devices receiving SFTS.”

A7.4.4 Impact to amateur radio services

The frequency range for WPT for EVs, 79-90 kHz, does not overlap with and has enough separation in frequency from the intended frequency range for amateur radio services. Therefore, receiver sensitivity suppression (out-of-band) by interference is not taken into consideration. Radiated emission strength of harmonics (spurious emission) from WPT might need to be counted in the case they fall into the frequency ranges for amateur radio services. The assumptions of WPT systems for EVs in the candidate frequency range show acceptable system parameters and performance to demonstrate possible non-harmful interference to amateur radio. Details of the impact study are described in § 7.1.1 of Report ITU-R SM.2303.

A7.4.5 Impact to railways control radios

In the studies on the impact to train radio systems, harmful interference in the actual use cases in operation was considered and discussed by simulation and measurements. The conditions for discussion were as follows:

– Frequency range for WPT should not overlap with those used for the train radio systems including Automatic Train Stop Systems (ATS) Systems and Inductive Train Radio Systems (ITRS).
– The separation distance to the ATS/ITRS devices, in which a WPT system does not cause harmful interference, should be less than the most critical threshold (approximatly1.5 m) specified in the train systems building standards.

As the results of this impact study, the separation distance required to meet the condition was more than 5 m for ATS, and more than 45 m for ITRS, respectively. However, ITRS which uses the same frequency band as WPT for EVs is in operation in the very specific and locally limited areas. The impact to ITRS can be mitigated by cooperation between WPT industries and a railway operator.

Therefore, the WG for WPT rule-making in MIC has decided that the above – mentioned separation distance should not be applied to Japan's new regulations concerning WPT. As a result of discussions, a condition, that WPT systems for EVs should be located more than 5 m apart from train tracks, has been clearly described in the Japan's regulations concerning WPT. Details of the impact study are described in § 7.1.1 of Report ITU-R SM.2303.

Annex 8

Analysis of the impact of WPT systems to broadcasting services

A8.1 Background

Inductive power transfer charging points, operating at powers up to tens or hundreds of kilowatts, are projected to become widely accessible. Many of these are expected to operate or produce harmonics in the LF Broadcasting band 148.5 to 283.5 kHz, the MF Broadcasting band 526.5 to 1 606.5 kHz and the HF Broadcasting band 2.3 to 26.1 MHz. Charging at these powers in close proximity to home and mobile users of these bands poses a significant potential threat to the reception of LF and MF broadcasting. Information on LF and MF broadcast transmitters in Europe, Africa and Middle East can be found in Attachment 1 to Annex 8. Information on MF Broadcasting across Portions of Region 2 can be found in Attachment 2 to Annex 8.

Importantly, WPT systems must not cause harmful interference to radio services operating in their allocated bands. This principle is enshrined in Articles **15.12** and **15.13** of the Radio Regulations.

Quite clearly and not unreasonably, radio services operating according to the Radio Regulations in their allocated bands, are subject to licensing, and are usually carefully regulated; as such, they should not suffer harmful interference from WPT devices operating without any specific regulatory status. The design and operation of WPT systems should respect this principle.

A8.2 Factors affecting the impact of interference

Before considering the ways in which interference might be caused by WPT devices, and eventually controlled, it is worth briefly examining what might constitute 'harmful interference'. Analogue AM, for example, is not well defended and quite small levels of interference can degrade audibility to intolerable levels. The extent to which such interference is 'harmful' depends on a number of psycho-acoustic factors as well as received signal strength and will vary from one listener to another. However, work carried out in the ITU has established limits for tolerable levels of interference. Some other radio services will, and in many instances are designed to, operate in hostile propagation conditions. Such systems are typically well defended against, at least, certain types of interference.

Some of the RF energy generated by any WPT device is likely to escape and result in the radiation of stray electromagnetic (EM) fields with the potential to interfere with radio services. The interfering radiated EM fields can be at or close to the magnetic resonance frequency(s) of operation of the WPT device or at some other frequency, quite likely harmonically related. Ignoring the ability of the system or receiver to defend itself against interference there are a number of factors which will dictate whether or not the interference is severe enough to be considered as harmful. The major influences, some of which are included for completeness as much as relevance to WPT, are:

– power Output of the WPT device;

– separation distance;

– intermittency;
– antenna Directionality;
– building entry Loss and;
– polarisation Alignment.

A brief explanation of each of these is given in Attachment 3 to Annex 8.

A8.3 Commentary and application to WPT systems and broadcast receivers.

Looking at the specific case of an AM broadcast receiver (LF, MF or HF) suffering interference from a WPT device, the relevant factors are the strength of the stray EM fields within the operating frequency band of the receiver (typically comprising a combination of radiation on the nominal WPT operating frequency, plus harmonics thereof, and possibly noise-like radiation as well) and the physical separation between the receiver and the WPT-EV system.

In the case of WPT equipment designed for electric vehicle charging (WPT-EV) operational use will typically last for long periods at a time; interference should therefore be regarded as continuous and so there can be no relaxation of the protection requirement based on intermittency[11]. It is unlikely that directivity of the radiation from WPT-EV systems (especially on frequencies other than the fundamental) can be controlled, even less directed away from the location of any nearby broadcast receiver so no relaxation is possible here. Equally, it is unlikely that the polarisation of radiation from WPT-EV systems (and again particularly the harmonics) can be controlled and so these must also be considered as ‘worst case'.

Most of the operating ranges for WPT systems are not co-incident with any broadcasting band[12] and so radiation at these operating frequencies are unlikely themselves to cause harmful interference to broadcasting services. However, it is possible that radiation on harmonically related frequencies could lie within the LF (148.5 kHz to 283.5 kHz) MF (526.5 to 1 606.5 kHz) or HF (several between 3.2 MHz and 26.1 MHz) broadcasting bands.

A8.4 Tolerable field strength limits

Suggested limits on magnetic fields from low power inductive devices operating over short ranges given in various places (e.g. ERC REC 70-03 for in-band emission limits and ERC REC 74-01 for emission limits in the spurious domain, CISPR11, etc.). None of these suggested limits appear to protect radio services in all circumstances. Indeed, they are demonstrably inadequate since instances of harmful interference are known to occur. The fact that these instances are rare is a result of the various mitigating factors such as intermittency of use, density of deployment and separation distances between sources and victims of interference being effective so far in limiting the extent and severity of interference to ‘tolerable’ levels. There is no evidence to support the contention that adapting the limits developed for low power, intermittent use inductive applications will be adequate for high power inductive power transfer applications such as WPT-EV.

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[11] BBC news bulletins are frequently of no more than two minutes duration and a general interest programme is typically half an hour long. A listener’s tolerance of a continuous background whistle is likely to be no more than a few seconds, after which the reaction will be to re-tune to another (competing) station.

[12] Unless harmonics of the operating frequency play a role in the energy transfer process.

Derivation of maximum tolerable level of interference at the AM receiver

It is therefore necessary to derive appropriate limits from first principles of electromagnetic compatibility. The first step in the derivation of tolerable field strength limits is to consider the wanted and interfering field strengths at the broadcasting receiver, whatever the distance this happens to be from the interfering source.

For an AM broadcast receiver to continue operating as intended at the levels set to maintain a satisfactory level of signal quality and audibility over the planned service area for, the maximum tolerable level of any interfering magnetic field can be calculated from Recommendations ITU-R BS.703 and ITU-R BS.560 as:

– Band 5 (LF) (148.5 – 283.5 kHz): –45.0 dBμA/m

– Band 6 (MF) (526.5 – 1606.5 kHz): –51.0 dBμA/m (A)

– Band 7 (HF) (3.2 – 26.1 MHz)[13]: –71.0 dBμA/m

Details of the calculation are given in Attachment 4 to Annex 8.

Noise masking

Further studies carried out by the BBC and detailed in Attachment 7 to Annex 8 reveal that system noise – a combination of environmental (natural and man made) noise and receiver noise – can mask the effect of a stable sinusoidal interferer. For a receiver with the same performance as that predicated in Recommendation ITU-R BS.703 [15] the masking effect of system noise would raise the tolerable level of any interfering magnetic field by 8 dB. These figures (A) become:

– Band 5 (LF): –37.0 dBμA/m

– Band 6 (MF): –43.0 dBμA/m

– Band 7 (HF)[3]: –63.0 dBμA/m

Separation between the receiver and the source of interference

The next step in the process of determining whether co-existence is feasible is to consider what assumptions are necessary about the separation distance used for defining an emission limit and the range of separation distances likely to be encountered in practice, together with the factors affecting the propagation between the interference source and the broadcasting receiver. These will depend on the scenarios for WPT-EV use.

By these means acceptable field strength limits at the location of the receiver can be assessed against the proposed emission limits at the reference distance from the interfering source. Electromagnetic theory dictates that the interfering field strength will vary with the cube of the distance from the source. A ten fold increase in the distance will result in a 60 dB reduction in the field strength. By convention the magnetic field strength from inductive devices is specified at a 10 metres reference or measurement distance, but it cannot be expected that the separation between a broadcast receiver and a WPT device will actually be 10 metres. In the case of a domestic electric vehicle charger, for example, a more realistic separation distance for assessing compatibility is 3 metres and could well be less. A justification for this figure is given in Attachment 5 to Annex 8.

[13] The HF broadcasting band (Band 7) is divided into 14 sub-bands: 2.30-2.495, 3.20-3.40, 3.90-4.00, 4.75-5.06, 5.80-6.20, 7.20-7.45, 9.40-9.90, 11.60-12.10, 13.57-13.87, 15.10-15.83, 17.48-17.90, 18.90-19.02, 21.45-21.85 and 25.60-26.10 (all in MHz).

It is essential therefore that the limits derived earlier for the maximum tolerable interfering magnetic field strength at the receiver should prevail at 3 metres distance from the WPT-EV system. Normalising this to the reference measurement distance of 10 metres from the charger (i.e. a further 7 metres from the receiver on the opposite side from the charger) will, be smaller by around 31 dB because at these distances the magnetic field strength decreases with the cube of the distance (60 dB per decade).

Subtracting 31 dB from the figures in (A), gives implies a limit on radiation from a WPT-EV installation measured at 10 metres distance of:

–	Band 5 (LF): (−45.0 – 31.0)	= –76.0 dBµA/m	
–	Band 6 (MF): (−51.0 – 31.0	= –82.0 dBµA/m	(B)
–	Band 7 (HF): (−71.0 – 31.0)	= −102.0 dBµA/m	

Or, if the 8 dB relaxation due to noise masking is taken into account

–	Band 5 (LF):	−68.0 dBµA/m	
–	Band 6 (MF):	−74.0 dBµA/m	(B bis)
–	Band 7 (HF):	−94.0 dBµA/m	

Clearly it would be ‘challenging’ to measure field strengths of this magnitude directly and so they must be measured at a closer distance and ‘corrected’ again using the 60 dB per decade (distance) rule.

Geographical location

The operation of AM broadcast transmitters is regulated by the ITU. In Regions 1 and 3 the relevant instrument is the Geneva 1975 Frequency Plan (GE75) and in Region 2 the Rio de Janeiro 1981 Frequency Plan (RJ81). It must be stressed that all of the above figures are calculated for a receiver operating anywhere in the planned service area which is protected under these agreements. Wherever it is possible, broadcasters plan their services such that population centres get a signal stronger than the minimum planning figure. Conversely, however, it may also be possible to combine this objective with having the lowest field strengths, at the edge of the planned service area, in rather more sparsely populated rural areas which are typically quieter in terms of radiated noise. Further, in any one location there might be a mix of strong signals from transmitters that are relatively close by and weaker signals from transmitters that are further away. It is assumed that a WPT system, particularly for WPT-EV use, will be suitable for use in any location and so will have to respect the protection criteria for the weakest useable signals.

Further studies and mitigation techniques

The GE75 and RJ81 Plan agreements allot operating frequencies to LF and MF transmitters such that they do not cause interference to each other based on factors such as geographical separation, transmitter power and antenna characteristics. The underlying basis for these Plans is Recommendations ITU-R BS.703 and ITU-R BS.560 cited above. Importantly, the regional assignment plans set the transmitter operating frequencies on a grid or raster; under the GE75 Plan each (carrier) frequency is a multiple of 9 kHz and under the RJ81 Plan a multiple of 10 kHz; the bands are channelised[14]. This means that any interference suffered by one transmitter from another will always be on the same carrier frequency or separated by at least (a multiple of) 9 kHz or 10 kHz. The re-use of frequencies is also organised with geographic separation in mind so that the signal from

[14] The ‘bottom’ channel in the LF band has a carrier frequency of 153 kHz and extends from 148.5 kHz to 157.5 kHz. The next channel has a carrier frequency of 162 kHz and extends from157.5 kHz to 166.5 kHz. etc.

a co-channel or adjacent channel interferer will be attenuated by distance from the service area of the wanted signal.

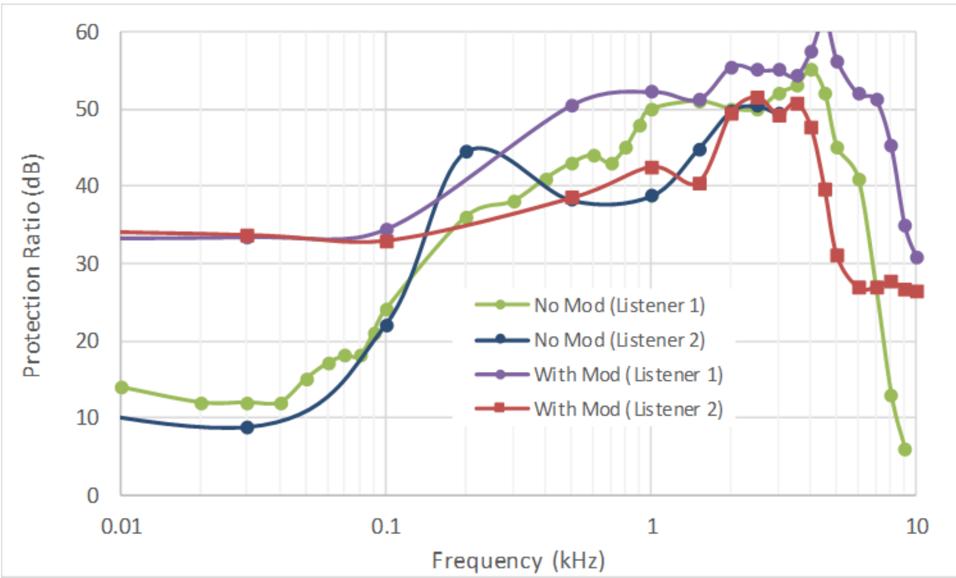
A significant benefit of having all the carriers on a common raster is that when there is co-channel interference it is up to 16 dB less intrusive than if the frequencies were chosen randomly. From Fig. 1 of Recommendation ITU-R BS.560[15] it can be seen that the relative protection ratio between the different stations will always be zero or better; the effect of the interference will be less pernicious.

The same principle can be applied to a WPT system if its operating frequency can be chosen and fixed to be a multiple of 9 kHz or 10 kHz. If the operating frequency is chosen in this way any harmonics will also (automatically) lie on the broadcast frequency raster. Subjective tests to investigate the subjective effects of interference from an unmodulated carrier situated on or off the raster were carried out by the BBC in November 2017. These tests are described in BBC Research and Development White Paper WHP 332, November 2017 – Wireless Power Transfer: Plain Carrier Interference to AM Reception which is reproduced as Attachment 6 to Annex 8.

The relevant graph from the BBC report is reproduced here as Fig. A8-1.

FIGURE A8-1

Required protection ratios with modulated and unmodulated interferers



Apart from supporting the earlier calculations of tolerable field strength the study shows that if the WPT operating frequency and its harmonics[16] are plain sinusoids (are un-modulated) and close to the broadcast raster frequencies they can be 22 dB stronger (over and above the 16 dB from Recommendation ITU-R BS.560 i.e. 38 dB stronger in total) without having an audibly detrimental effect on the demodulated audio from the receiver. However, if the interferer is not sufficiently close to the raster frequency the provisions of Recommendations ITU-R BS.703 and ITU-R BS.560 still apply.

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[15] Reproduced in Attachment 4 to Annex 8.

[16] If WPT-EV operating frequencies (vehicle chargers for example) are restricted to the range 79-90 kHz it is only harmonics that will affect the broadcasting service.

The offset between every significant harmonic and the corresponding raster frequency has to be less than about ±50 Hz. If the highest significant harmonic is, for example, the 12th, the frequency of the fundamental will have to be set and controlled to within about 4 Hz. In the case of a medium power WPT device operating in the range 79 kHz to 90 kHz, if all the harmonics are to be multiples of 9 kHz (Region 1 and 3) this limits the choice of the fundamental to either 81 kHz or 90 kHz. Similarly, for the 10 kHz raster (Region 2) the choice is limited to 80 kHz or 90 kHz.

Looking particularly to ITU Regions 1 and 3[17], across the broadcast bands there are 15 LF channels and 120 MF channels. Assuming that the WPT operating frequency is chosen to respect the 9 kHz broadcast planning raster, the only radio stations that will be affected are those where a harmonic of the WPT-EV system is co-incident with the carrier of a receivable broadcast station. Looking at harmonics of the WPT-EV system up to the 19th (the 18th harmonic of 90 kHz and the 20th harmonic of 81 kHz fall outside and above the MF broadcast band) 4 (of 15) LF channels will be affected along with 25 (of 120) MF channels. If stray radiation at the higher order harmonics can be controlled, it may be that considerably fewer MF channels are affected. In some situations, where it is known that there is a particularly weak but receivable incoming signal from a particular station it may be possible to choose the WPT-EV operating frequency to avoid a conflict. Note however, that the 10th harmonic of 81 kHz and the 9th harmonic of 90 kHz are coincident on the 810 kHz broadcast channel. Similar considerations are employed when planning broadcast networks such that transmitters do not interfere with each other.

Starting with equations (A) above, revised figures for tolerable levels of radiation from WPT-EV systems at the receiver (or at the minimum anticipated separation distance) when operating on the broadcasting channel raster are:

–	Band 5 (LF): (−45.0 + 38.0)	−7.0 dBµA/m	
–	Band 6 (MF): (−51.0 + 38.0)	−13.0 dBµA/m	(C)
–	Band 7 (HF): (−71.0 + 38.0)	−33.0 dBµA/m	

Or, considering equations (B), at a measurement distance of 10 metres;

–	Band 5 (LF): (−76.0 + 38.0)	−38.0 dBµA/m	
–	Band 6 (MF): (−82.0 + 38.0)	−44.0 dBµA/m	(D)
–	Band 7 (HF): (−102.0 + 38.0)	−64.0 dBµA/m	

Studies using a commercially available receiver

A further study was carried out by the BBC in June 2018 using an "off the shelf, commercial receiver". This study is described in Attachment 7 to Annex 8:

A significant conclusion from this Report is that system noise – the combination of environmental and receiver noise – could have the effect of masking a single tone interferer. The psycho-acoustic effect of this masking relaxes the figures listed in (A) and (B) above by 8 dB.

At the receiver:

–	Band 5 (LF):	−37.0 dBµA/m	
–	Band 6 (MF):	−43.0 dBµA/m	(A *bis*)
–	Band 7 (HF);	−63.0 dBµA/m	

[17] A similar assessment can be made for Region 2 but is omitted here for brevity.

At 10 metres measurement distance:

– Band 5 (LF): −68.0 dBµA/m
– Band 6 (MF): −74.0 dBµA/m (B *bis*)
– Band 7 (HF): −94.0 dBµA/m

These Figures are presented in tabular form in Table A8-1.

TABLE A8-1

Limits on WPT-EV radiated emissions to protect radiocommunication services operating below 30 MHz where the WPT-EV system is not locked to the broadcasting raster[(1)]

Service	**Band**	**WPT-EV power[(2)]**	**Protection requirements/limits of WPT-EV harmonics (at minimum separation distance or at the receiver antenna)**			**Corrected to 10 m measurement distance[(3)]**
			1 m	**3 m**	**10 m**	
Broadcasting	LF 148.5-283.5 kHz	Low/Small	−37 dBµA/m			**−97 dBµA/m**
		Medium		−37 dBµA/m		**−68 dBµA/m**
		High			−37 dBµA/m	**−37 dBµA/m**
	MF 526.5-1 606.5 kHz	Low/Small	−43 dBµA/m			**−103 dBµA/m**
		Medium		−43 dBµA/m		**−74 dBµA/m**
		High			−43 dBµA/m	**−43 dBµA/m**
	HF 2.30-26.10 MHz[(4)]	Low/Small	−63 dBµA/m			**−123 dBµA/m**
		Medium		−63 dBµA/m		**−94 dBµA/m**
		High			−63 dBµA/m	**−63 dBµA/m**

(1) When the WPT-EV harmonics ARE aligned with the broadcast frequency raster a relaxation of 30 dB in these figures can be tolerated – Table A8-2.

(2) WPT-EV Power classes: High Power WPT-EV is more than 22 kW; Medium Power WPT-EV is between 3.3 kW and 22 kW; Low Power WPT-EV is between 50 W and 3.3 kW; Small Power WPT-EV is less than 50 W.

(3) See Attachment 5 to Annex 8.

(4) The HF broadcasting band (Band 7) is divided into 14 sub-bands: 2.30-2.495, 3.20-3.40, 3.90-4.00, 4.75-5.06, 5.80-6.20, 7.20-7.45, 9.40-9.90, 11.60-12.10, 13.57-13.87, 15.10-15.83, 17.48-17.90, 18.90-19.02, 21.45-21.85 and 25.60-26.10 (all in MHz).

TABLE A8-2

Limits of WPT-EV radiated emissions to protect the broadcasting services operating below 30 MHz where the WPT-EV system is locked to the broadcasting raster

Service	Band	WPT-EV Power(1)	Protection requirements/limits of WPT-EV harmonics (at minimum separation distance or at the receiver antenna)			Corrected to 10 m measurement distance(2)
			1 m	**3 m**	**10 m**	
Broadcasting	LF 148.5-283.5 kHz	Low/Small	−7 dBμA/m			**−67 dBμA/m**
		Medium		−7 dBμA/m		**−38 dBμA/m**
		High			−7 dBμA/m	**−7 dBμA/m**
	MF 526.5-1 606.5 kHz	Low/Small	−13 dBμA/m			**−73 dBμA/m**
		Medium		−13 dBμA/m		**−44 dBμA/m**
		High			−13 dBμA/m	**−13 dBμA/m**
	HF 2.30-26.10 MHz(3)	Low/Small	−33 dBμA/m			**−93 dBμA/m**
		Medium		−33 dBμA/m		**−64 dBμA/m**
		High			−33 dBμA/m	**−33 dBμA/m**

(1) WPT-EV Power classes: High Power WPT is more than 22 kW; Medium Power WPT-EV is between 3.3 kW and 22 kW; Low Power WPT-EV is between 50 W and 3.3 kW; Small Power WPT-EV is less than 50 W.

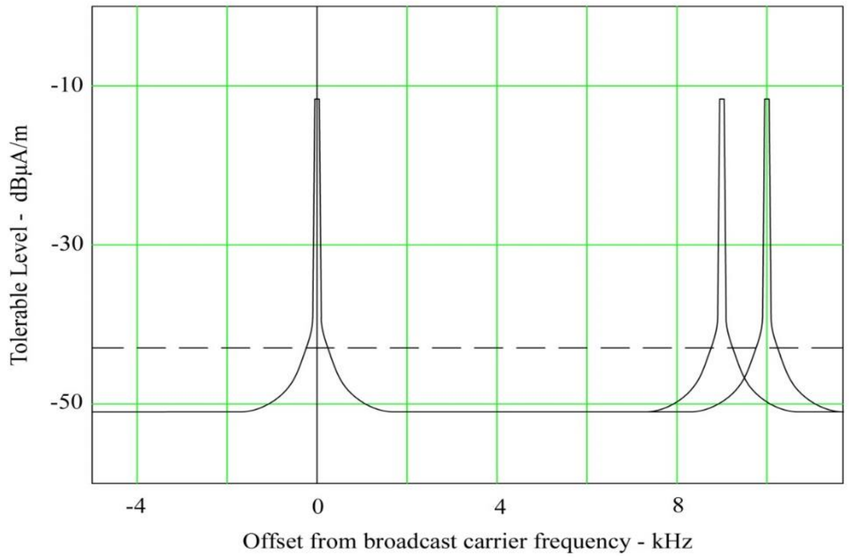
(2) See Attachment 5 to Annex 8.

(3) The HF broadcasting band (Band 7) is divided into 14 sub-bands: 2.30-2.495, 3.20-3.40, 3.90-4.00, 4.75-5.06, 5.80-6.20, 7.20-7.45, 9.40-9.90, 11.60-12.10, 13.57-13.87, 15.10-15.83, 17.48-17.90, 18.90-19.02, 21.45-21.85 and 25.60-26.10 (all in MHz).

Figure A8-2 below shows the effect of ‘on raster’ operation.

FIGURE A8-2

Spectrum mask representing the limits of WPT-EV radiated emissions as a function of the offset from AM broadcast carrier frequency



In Fig. A8-2, the solid line shows the tolerable level of interference from an un-modulated sine wave interferer in the absence of noise masking while the broken line shows the effect of noise masking at the limit of reception. The mask is applicable only to a single sine wave interferer.

Attachment 1
to Annex 8

Information on LF and MF broadcast systems subject to impact from WPT-EV

A8-A1.1 Introduction

This Attachment provides a list of sources of information along with an overview about existing LF and MF transmitters in Europe, Africa and Middle East. These transmitters are used for national and international broadcasting services and mostly analogue, although digital services are being introduced.

A8-A1.2 Available sources of information

The information provided in the sources below correspondent to the indicated dates on the tables and graphics below, and may have changed after that date.

A8-A1.2.1 MIFR (Terrestrial Services) on-line query (BETA release)

Link: https://www.itu.int/ITU-R/terrestrial/eTerraQuery/eQry.aspx

Extraction and statistical analysis of the information related to LF and MF transmitters recorded in the MIFR can be done as appropriate.

A8-A1.2.2 MWLIST – long wave, medium wave, tropical bands and short wave radio database

Link: http://www.mwlist.org/mwlist_quick_and_easy.php?area=1&kHz=530

See Appendix 1 for example of information that could be obtained from this source.

A8-A1.2.3 For Medium Wave (MF) transmitters in the UK (Complement to the information in § 2.2)

Technical parameters for broadcast radio transmitters:

Link: https://www.ofcom.org.uk/__data/assets/excel_doc/0017/91304/TechParams.xlsx

See Appendix 2 for example of information that could be obtained from this source.

A8-A1.2.4 For the DRM implementation in Medium Wave (MF)

Digital Radio Mondiale: http://www.drm.org/

All India Radio DRM Medium Wave:
http://allindiaradio.gov.in/Oppurtunities/Tenders/Documents/DRM%20Medium%20Wave%20update%2004042016.pdf

Supplement 1
to Attachment 1
to Annex 8

Screen shot from "MWLIST – longwave, mediumwave, tropical bands and shortwave radio database": http://www.mwlist.org/mwlist_quick_and_easy.php?area=1&kHz=530

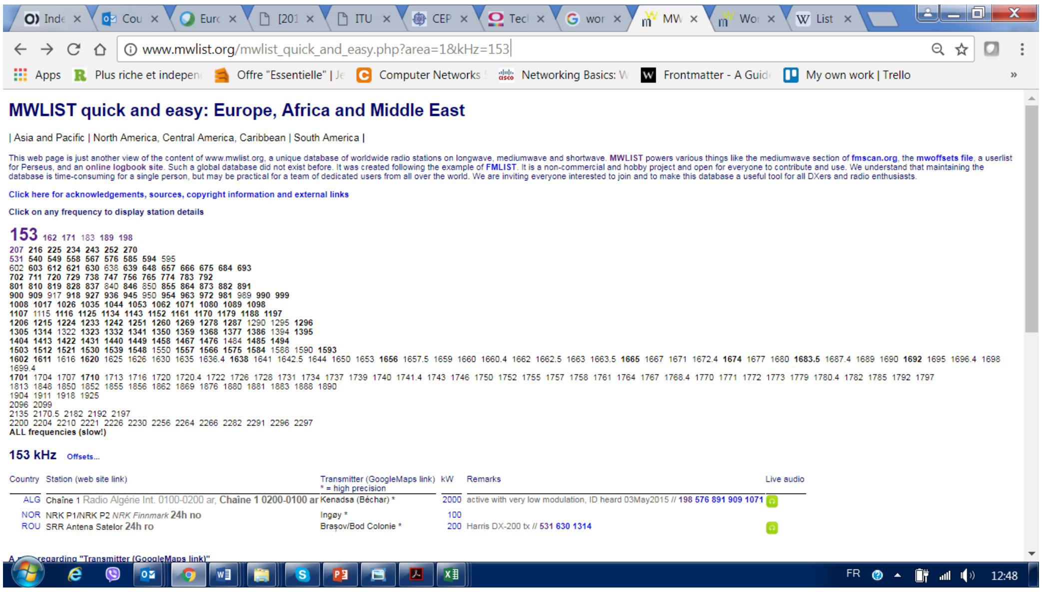


Table A8-3 below shows the LF transmitters in Europe, Africa and Middle-East as provided in www.mwlist.org, data extracted in September 2017.

TABLE A8-3

LF transmitters in Europe, Africa and Middle-East as provided in www.mwlist.org, data extracted in September 2017

Frequency (kHz)	Country	Station	Transmitter	kW
153	ALG	Chaîne 1 Radio Algérie Int.	Kenadsa (Béchar) *	2 000
153	NOR	NRK P1/NRK P2 NRK Finnmark	Ingøy *	100
153	ROU	SRR Antena Satelor	Brașov/Bod Colonie *	200
162	F	TDF time signal	Allouis *	1 100
171	MRC	Médi 1	Nador (LW) *	1 600
183	D	Europe 1	Felsberg/Zum Sender (Sauberg) *	1 500
189	ISL	RÚV Rás 1/RÚV Rás 2	Gufuskálar (Hellissandur) *	300
198	ALG	Chaîne 1	Berkaoui (Ouargla) *	2 000
198	G	BBC Radio 4	Droitwich/Mast A-B *	500
198	G	BBC Radio 4	Westerglen *	50
198	G	BBC Radio 4	Burghead *	50

TABLE A8-3 *(end)*

Frequency (kHz)	**Country**	**Station**	**Transmitter**	**kW**
198	G	BBC Radio 4	Dartford Tunnel *	0.004
207	ISL	RÚV Rás 1/RÚV Rás 2	Eiðar *	100
207	MRC	SNRT Al Idaâ Al-Watania	Azilal Demnate *	400
216	F	RMC Info	Roumoules *	1 400/700
225	POL	Polskie Radio Jedynka	Solec Kujawski/Kabat *	1 000
234	LUX	RTL	Beidweiler *	1 500
243	DNK	DR Langbølge	Kalundborg/Radiovej *	50
252	ALG	Chaîne 3	Tipaza *	1 500/750
252	IRL	RTÉ Radio 1	Clarkestown/Summerhill *	150/60
270	CZE	ČRo Radiožurnál	Topolná *	50

Figures A8-3 and A8-4 below show the distribution of MF transmitters per frequency and per country in Europe, Africa and Middle-East as provided in www.mwlist.org, data extracted in September 2017.

FIGURE A8-3

Number of MF transmitters per frequency in Europe, Africa and Middle-East (source: www.mwlist.org, September 2017)

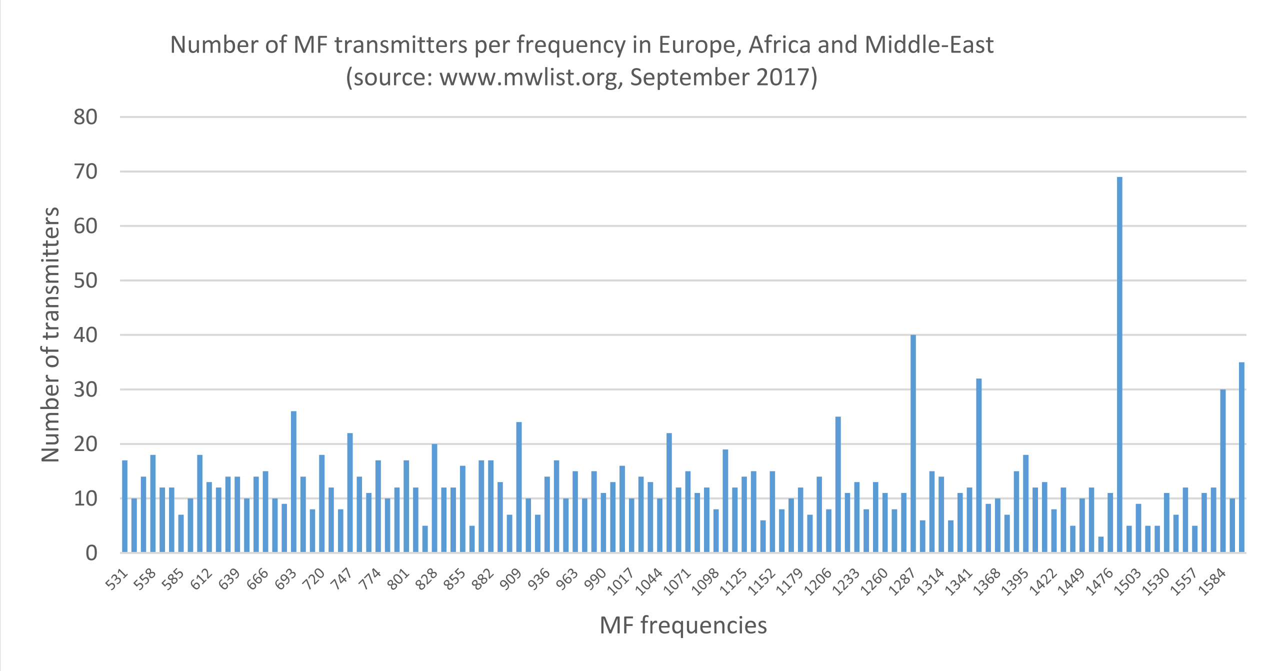
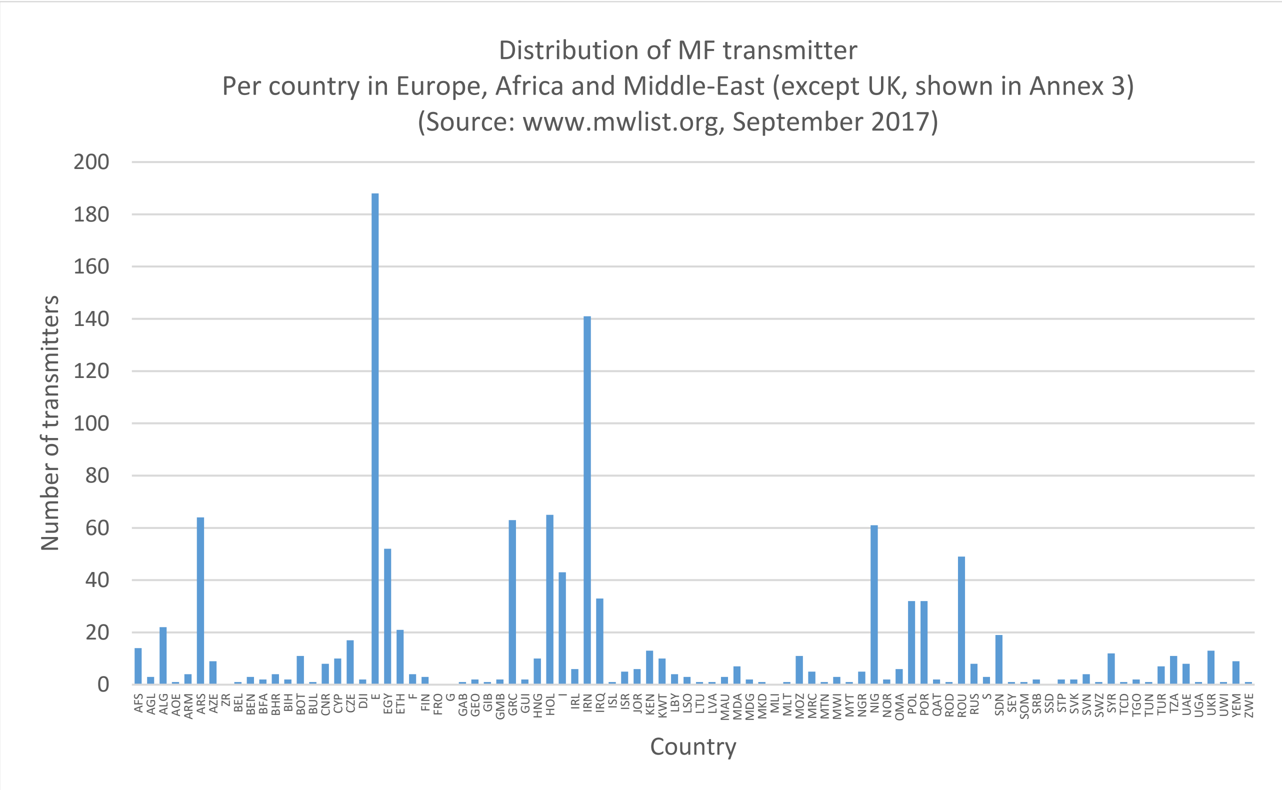


FIGURE A8-4

Distribution of MF transmitter per country in Europe, Africa and Middle-East (except UK, shown in Supplement 2) (Source: www.mwlist.org , September 2017)



Supplement 2
to Attachment 1
to Annex 8

Information from
Technical parameters for broadcast radio transmitters (Ofcom UK)

FIGURE A8-5

Number of MF transmitters in the UK
(Source Ofcom, August 2017)

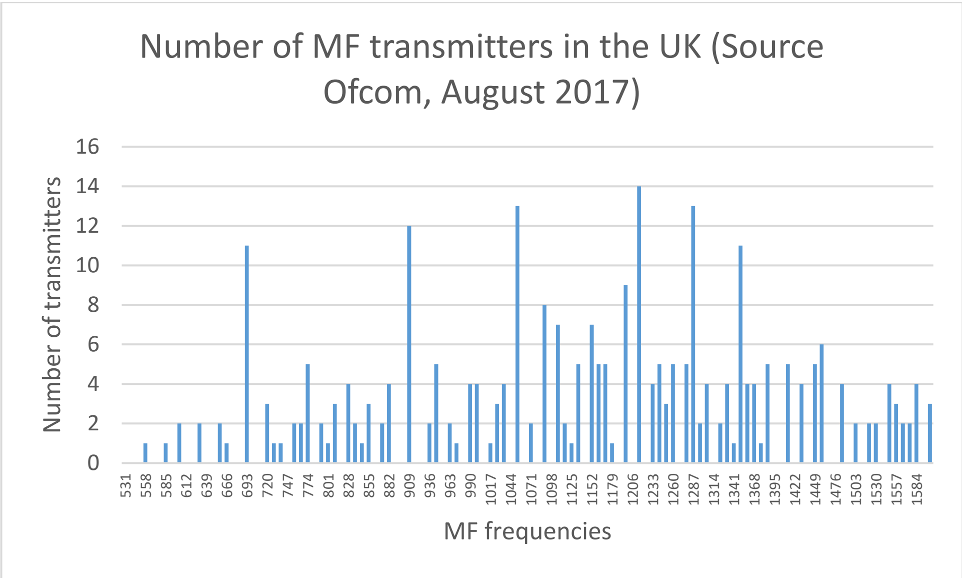
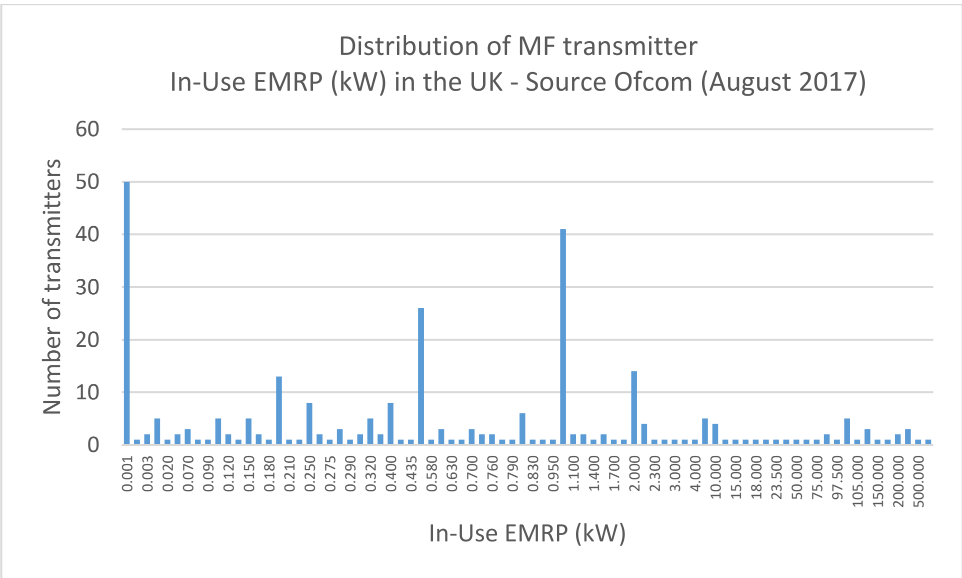


FIGURE A8-6

Distribution of MF transmitter in-use effective monopole radiated power (EMRP – kW) in the UK – Source Ofcom (August 2017)



Note related to Figs A8-5 and A8-6 – The Ofcom on-line database suggests that in the UK there are 294 MF transmitters in use on 75 different frequencies. These range in EMRP from 1 W (for tiny hospital radio, community or campus stations) to several hundred kW for some of the bigger, national, commercial stations. The Ofcom database can be downloaded from the Ofcom website at https://www.ofcom.org.uk/spectrum/information/radio-tech-parameters.

Attachment 2
to Annex 8

Report of MF Broadcasting across Portions of Region 2

A8-A2.1 Executive Overview

Wireless power transfer (WPT-EV) devices represent a significant source of potential interference to MF broadcasting in Region 2. Previous reports and studies have identified reception interference to broadcast stations operating between 540 kHz and 610 kHz from 15 W wireless chargers designed for mobile devices. The potential impact of WPT-EV devices intended for electric vehicles and operating at 3 kW – 11 kW constitutes a larger threat to AM broadcasting.

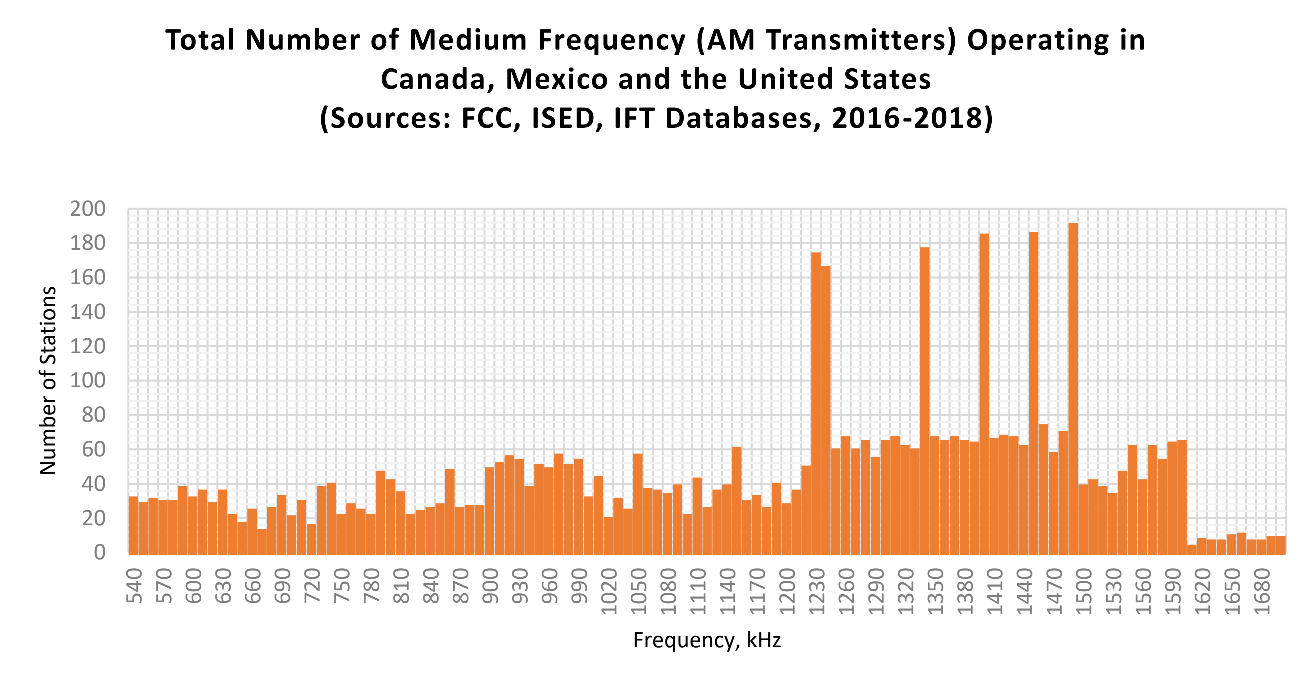
MF broadcasting provides an important communication channel to hundreds of millions of people across Region 2 on a daily basis. This service is especially important during times of emergency and disaster when critical, life-saving information must be rapidly conveyed.

A8-A2.2 Introduction

MF broadcasting is increasingly challenged by man-made noise and interference. Yet, AM radio is relied upon to provide critical local news, weather, traffic, sports, and emergency information.

Listening in the MF band continues to be vibrant across Canada, Mexico, and the United States. Recent analysis of the radio station databases maintained by the FCC (U.S.), IFT (Mexico), and ISED (Canada) identifies over 5 000 MF broadcast transmitters operating across these North American countries and serving a population over 570 million people. With vast geographic areas to cover, medium-frequency transmissions are still the most cost-effective way to fill in areas not otherwise covered by short-range VHF stations.

FIGURE A8-7



A8-A2.3 Market Study

United States of America

In the United States of Amercia alone, over 4 685 MF transmitters are in operation across all 50 states. AM radio listening in the US reaches 64 698 500 listeners age 18+ weekly.[18]

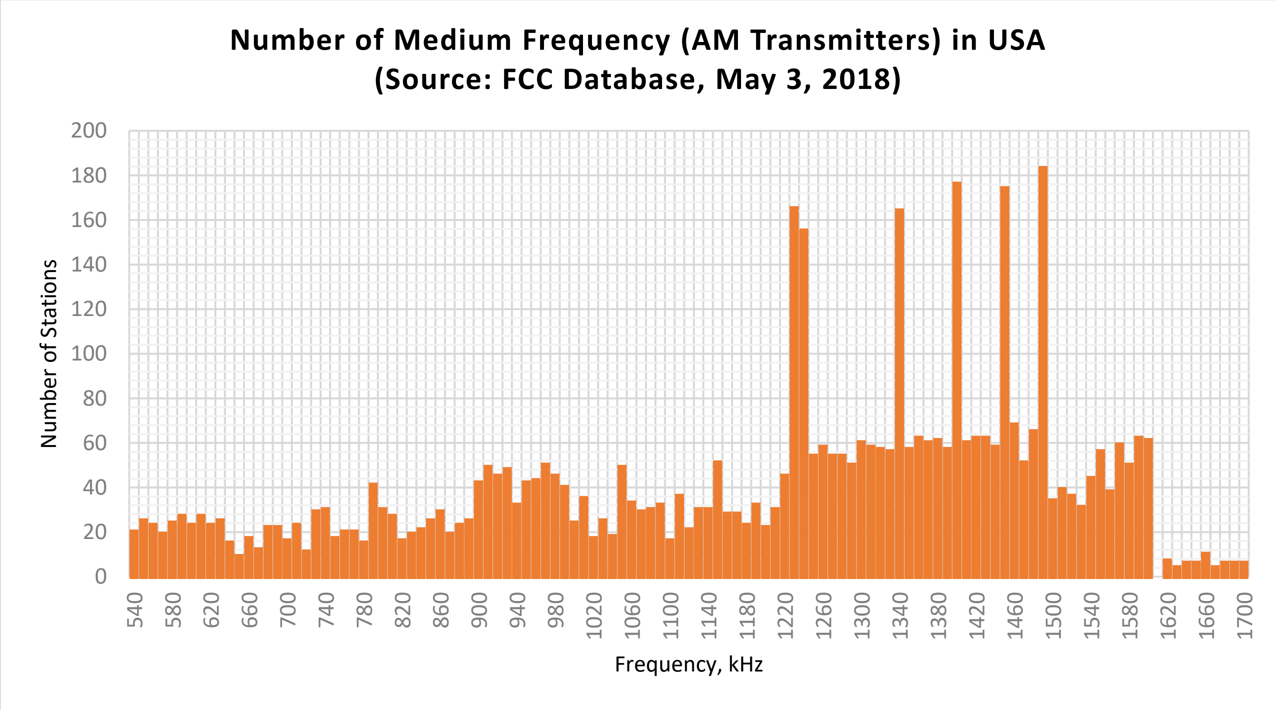
Traditionally, in the U.S., these stations have long been the flagship outlets for news, talk, and sports programming due to their extensive signal coverage capabilities, especially for high-power stations. Of the top 10 highest-billing radio stations in America, five of them are MF broadcasters.

The histogram of Fig. A8-8 shows the distribution with frequency of the 4 685 operating AM stations in the USA.

Total number of stations:	4 685
Maximum power level:	50 kW
Minimum power level:	0.135 kW

[18] Nielsen Fall 2017 Survey period, Total Person 12+, Mon-Sun 6AM-12 Mid.

FIGURE A8-8



Canada

In June of 2017, Edison Research released the first-ever Share of Ear study in Canada. It was commissioned by the radio industry marketing and advocacy group Radio Connects. Results of the study showed that broadcast radio stations account for 61 percent of all Canadian listening. Correspondingly, the U.S. had 50 percent during the same period.

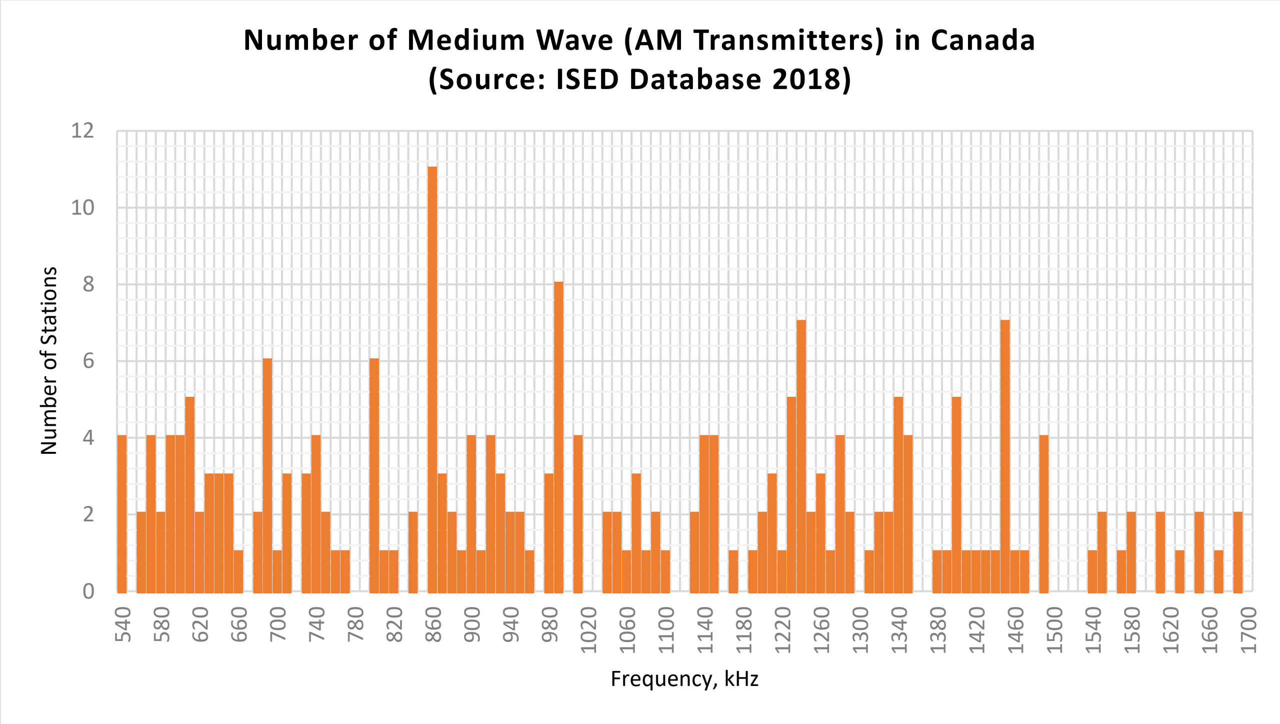
While there has been a steady shift from MF (AM) to VHF (FM) listening where the spectrum allows, a core group of 227 AM radio stations remain across Canada. This number represents 8% of the total number of operating radio stations in Canada. Further to that, Canada has protected allocations for an additional 482 AM frequencies.

The Canadian Prairies, a region in Western Canada, comprising the provinces of Alberta, Saskatchewan, and Manitoba, is the Canadian portion of the North American Great Plains. The First Nations peoples, native to the region, are an important influence on this Prairie culture. Radio is very effective in reaching and serving this large geographic expanse and in targeting the distinct languages of the indigenous peoples. Medium Frequency broadcasting in particular is especially suited to efficiently deliver usable signals over large geographic areas.

The Histogram of Fig. A8-9 represents the 227 operating AM stations in the Canadian market and the frequency distribution for those stations.

Total number of stations:	227
Maximum power level:	50 kW
Minimum power level:	0.1 kW (night-time)

FIGURE A8-9



Mexico

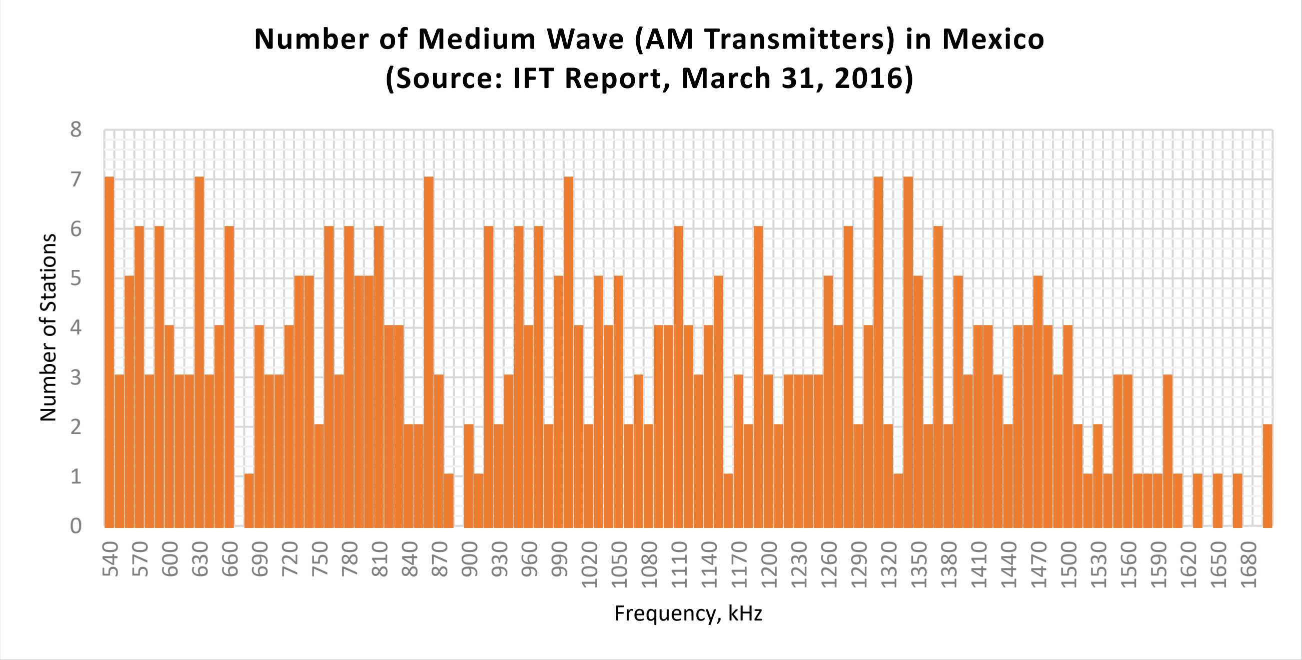
A national media survey published by IFT in 2016 highlights that 15% of the population in Mexico actively listens to MF radio.[19]

The Histogram of Fig. A8-10 represents the 393 operating MF (AM) stations in Mexico and the frequency distribution of those stations.

Total number of stations:	393
Maximum power level:	250 kW
Minimum power level:	0.025 kW (night-time)

[19] IFT: Reporte trimestral de audiencias de radio y televisión con perspectiva de género, abril – junio 2017.

FIGURE A8-10



Attachment 3
to Annex 8

Factors affecting the harmful impact of interference

Power output of the WPT-EV device – Obviously this will have a significant impact on the propensity of the WPT-EV device to cause harmful interference. The higher the power output, the greater the potential for interference. Radiation from WPT-EV devices on harmonically related frequencies must also be considered. The mechanisms for radiating EM fields outside the confines of WPT devices can be many and varied and there can be no assumption that the levels of interference are directly related to the level of the RF energy generated within WPT-EV devices.

Separation distance – Over short distances[20], magnetic field strength falls with the cube of the distance between the source of radiation and the measuring point. The potential for interference therefore increases markedly as the source of interference moves closer to the affected receiver. Conventionally, EMC limits set for 'radiated emissions' from any device are defined at a convenient measurement distance of 10 m from the device. This, of course, in no way implies that 10 m is a representative or expected separation distance between a WPT-EV device and the victim receiver; a reference measurement distance for setting limits on stray fields has to be specified at some suitable distance fit for purpose.

Intermittency – A short burst of radiation, even at quite a high level, with a small mark space ratio is much less likely to cause harmful interference to a radio service than a device which operates continuously. On a broadcast radio channel for example a short burst will be perceived as an occasional short click which will have a minor psycho-acoustic effect.

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[20] Less than $\lambda/2\pi$ where λ is the wavelength at the frequency under consideration.

Antenna directionality – This is probably only relevant in specific cases; if all the stray radiation is, for example, directed vertically upward and all the potential victim receivers are spread horizontally around the WPT-EV device interference is likely to be minimised. The antenna systems in most radio receivers are to some extent directional but it is difficult to ensure that an uncontrolled WPT-EV device will always, or even often, be in the direction of minimum sensitivity.

Building entry loss – At high frequencies (much higher than those envisaged for WPT-EV) a wall or other barrier interposed between the WPT-EV device and the victim receiver might attenuate the effect of the any interference. However, in the case of low frequency WPT-EV systems this will only occur if the wall or barrier is made of a material with high magnetic permeability, is itself a conductor or has conducting elements within it. Most common building materials, brick, wood, etc are neither conducting nor magnetic. Informal tests carried out by the BBC and reported in an Ofcom Report support this. Some buildings have metal (conducting) re-enforcement buried in concrete or plastics and eddy currents in the conducting elements might affect magnetic fields. However, not all, and probably most, buildings are not constructed of such materials. Moreover, there no reason to suppose that a receiver will always be operated inside a building, some way away from a WPT-EV unit.

Polarisation alignment – With most radiocommunication systems an attempt is made to align the polarisation of the receiving antenna with that of the transmitter. For example, an LF or MF portable broadcast receiver typically has a horizontally mounted ferrite rod antenna which is most sensitive to the horizontally polarised magnetic component of the wanted signal. LF and MF broadcast transmitters nearly always generate a vertically polarised electric field component and a horizontally polarised magnetic field component thereby optimising the sensitivity of the receiver. If a WPT-EV device could be designed and operated such that the polarisation of its own stray field was at right angles to that of the receiving antenna a little more interference might be tolerable. In practice this is likely to be very difficult to achieve. If the WPT-EV device and the receiver are in close proximity (less than about a quarter of a wavelength at the operating or interfering harmonic frequency – the reactive field region) the actual polarisation of the magnetic (or electric) field is difficult to control or even ascertain. Adding to this the fact that any harmonic radiation from the WPT-EV device might itself not be related to the intended polarisation of the 'antenna', it must be assumed that worst case conditions apply and that there is no justification for assuming that interference levels will be less that the maximum possible.

Attachment 4
to Annex 8

Derivation of maximum tolerable level of interference at the AM receiver

Recommendation ITU-R BS.703 – Characteristics of AM sound broadcasting reference receivers for planning purposes, sets the minimum sensitivity of an AM sound broadcasting sound receiver for planning purposes as:

– Band 5 (LF): 66 dBμV/m;

– Band 6 (MF): 60 dBμV/m;

– Band 7 (HF): 40 dBμV/m.

Recommendation ITU-R BS.560 – Radio-frequency protection ratios in LF, MF and HF broadcasting, outlines applicable protection ratios for interference between AM broadcast signals. Although WPT-EV is not a broadcast signal, it may take the form of a (mostly) un-modulated carrier and to that extent is actually very similar to a broadcast AM signal, during a pause or quiet passage as presented to the receiver. The protection ratios of Recommendation ITU-R BS.560 can therefore be considered to be a good starting point for deriving *radiated emission* limits from WPT-EV For EMC purposes.

Starting from the planning considerations and protection criteria given in Recommendations ITU-R BS.703 and ITU-R BS.560 and noting that broadcast receivers used in and around the home commonly use ferrite rod antennas that respond to the magnetic-field component -H- of the wave, it is convenient to use the corresponding H-field strengths when considering radiated emission limits from WPT-EV equipment. Assuming far-field free-space conditions (which will apply to the received broadcast signal at the receiver antenna) the relationship between the electric and magnetic fields (from Maxwell's equations) is:

$$\frac{E}{H} = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\ \Omega$$

Where μ_0 is the permeability of free space and ε_0 is the permittivity of free space.

This means that the following conversion factors apply:

$$H_{(\frac{\mu A}{m})} = E_{(\frac{\mu V}{m})} \cdot \frac{1}{377}$$

Which may be expressed as:

$$H_{dB(\frac{\mu A}{M})} = E_{dB(\frac{\mu V}{m})} - 51.5\text{ dB}$$

So the receiver sensitivities at LF, MF and HF (above) can also be expressed as:

– Band 5 (LF): 14.5 dBμA/m;
– Band 6 (MF): 8.5 dBμV/m.
– Band 7 (HF): −11.5 dBμV/m.

Recommendation ITU-R BS.560 is formulated for the protection of one AM radio service from another similar AM radio service[21]. Importantly, this means that both the wanted and interfering signals consist of a high-power carrier and much lower power sidebands which carry the modulation. For a typical speech-based programme with a 20% (rms) modulation depth the sideband/modulation power is 4% of the carrier power.

The protection ratios for AM broadcasting defined in Recommendation ITU-R BS.560 comprise two components:

a) The co-channel protection ratio (PR) needed when the interferer and wanted signal carrier are on essentially the same frequency so any beat between them is of a frequency below the audible range. In this case the modulation of the interferer is the dominant cause of audible disturbance.

   If the interfering signal is another radio station on exactly (or close to) the same carrier frequency as the wanted signal, the carrier component, despite being very large can be ignored. It has an effect on the linearity of the AM detector which is not noticeable while the interfering carrier is 13 dB or more below the wanted carrier. The wanted signal only has to be defended against the sidebands of the unwanted signal. It is assumed that the ratio of the sideband power to the carrier power is comparable for both wanted and unwanted signals and so the ratio of the sideband powers is the same as the ratio of the carrier powers.

[21] It has been assumed that in a frequency band where only AM broadcasting has a primary allocation the principal sources of interference will be other AM broadcastings stations.

Recommendation ITU-R BS.560 calls for a co-channel protection ratio between the wanted and interfering signal (carrier levels) of 40 dB. The Geneva 1975 Frequency Plan for LF and MF radio in some circumstances tolerates a smaller co-channel protection ratio in an attempt to fit more channels into the available spectrum. This relaxation does not extend to any situation where there is an offset between the wanted and unwanted carrier frequencies; the GE75 plan does not foresee there being any such offsets.

b) The additional relative protection ratio (PR) that must be added when the wanted and interfering signals have a frequency difference which will give rise to a continual audible beat tone; the magnitude of this correction depends on the frequency offset, primarily because the frequency response of the human ear is far from ‘flat’. If there is an offset between the carrier frequency of the wanted signal and the carrier frequency of the interferer, the unwanted carrier itself (or the interfering sine wave from the WPT-EV system) starts to become psycho-acoustically dominant and, because the carrier is so large, greater protection is needed. Between zero and about ±5 kHz offset, the protection curve is a similar shape to that for hearing acuity.

Note that Recommendation ITU-R BS.560 does not cover the situation where there is no offset between the wanted and the interfering carrier/WPT-EV when and if the latter are un-modulated. As the frequency offset falls below the onset of hearing (or below the low frequency filtering in the receiver) the perturbation mechanism in the receiver is different (at least psycho acoustically). It has been established by the BBC through subjective tests reported in WHP 332 that if the interfering carrier/WPT-EV is un-modulated and within a few tens of Hz (onset of hearing) a higher level of interference can be tolerated. See § 5.2 on Mitigation Techniques.

Figure 1 from Recommendation ITU-R BS.560 showing the variation with offset frequency of the relative protection ratio (PR) is reproduced in Fig. A5-3.

The relevant curve is A blending into C. Curve B blending into D is relevant for highly compressed audio material with a high modulation depth while curves A and B above about 7 kHz are pertinent to transmissions with a 10 kHz audio bandwidth. A large proportion of AM transmissions are speech based which, even when highly compressed does not result in a high modulation depth. Even though it is, in a few instances, allowed for in the frequency plan, very few AM transmissions have an audio bandwidth greater than 5 kHz. The frequency offset can be positive or negative.

Unless WPT-EV device frequencies and all of their significant harmonics are carefully aligned with the broadcast frequency (channelling) raster, the relative PR for non-co-channel operation will need to be added. Assuming the WPT-EV frequency to be uncontrolled, it may be assumed that the worst case occurs. Figure A5-3 shows that the greatest relative PR is approximately 16 dB, corresponding to a frequency offset of around 2 kHz.

For this worst case, the relative PR must be added to the co-channel PR of 40 dB to give an overall PR for WPT-EV interference to AM broadcasting of (40 + 16) = 56 dB.

It therefore follows that the maximum acceptable WPT-EV field strength, at the broadcast receiver location, is given by subtracting this PR from the receiver sensitivity. The maximum acceptable WPT-EV H field at the broadcast receiver location is therefore:

– Band 5 (LF): (14.5 − 56) = −41.5 dBμA/m

– Band 6 (MF): (8.5 − 56) = −47.5 dBμA/m

– Band 7 (HF): (−11.5 − 56) = −67.5 dBμA/m.

Historically, the minimum field strengths quoted in Recommendation ITU-R BS.703 are based on assumed modulation depth for the AM signal of 30%. Work carried out by the BBC in 2007, the results of which are in the process of being adopted by the ITU-R suggest that a lower assumed modulation depth, 20%, is probably more appropriate. In the period, since Recommendation ITU-R BS.703 was last revised there has been a trend for AM radio to carry a lot more speech and a lot less (popular) music. Speech is characterised by generally lower modulation density and is interspersed with short periods of silence. To reflect the ‘real world’ situation where the most vulnerable AM signals are roundly 3.5 dB quieter than assumed in Recommendation ITU-R BS.703 (20% modulation depth compared with 30%) a further 3.5 dB should be subtracted from the figures derived from Recommendations ITU-R BS.703 and ITU-R BS.560.

– Band 5 (LF): (−41.5 – 3.5) = −45.0 dBμA/m

– Band 6 (MF): (−47.5 – 3.5) = −51.0 dBμA/m

– Band 7 (HF): (−67.5 – 3.5) = −71.0 dBμA/m

An alternative method for calculating the tolerable level of interference is based on Recommendation ITU-R BS.1895.

The edge of the service area for a broadcast transmitter is defined by noise; the service is noise limited. When all the sources of noise and interference exceed a given proportion of the level of the wanted signal, the service no longer meets the quality criteria set by the ITU. The principal sources of noise and interference are: naturally occurring noise, man-made noise, receiver noise and other broadcast stations operating in the allocated band.

On this basis Recommendation ITU-R BS.1895 defines protection criteria for Terrestrial Sound Broadcast Systems. Specifically, it requires that:

> “the total interference at the receiver from all radiations and emissions without a corresponding frequency allocation in the Radio Regulations should not exceed 1% of the total receiving system noise power”

Recommendation ITU-R BS.703 specifies a minimum usable field strength of 66 dBμV/m for LF, 60 dBμV/m for MF and 40 dBμV/m for HF. In all three cases it specifies a modulation depth for the wanted signal of 30% (assumed to be rms) and a wanted audio signal to (random) noise ratio of 26.0 dB[22]. This means that the wanted sideband (modulation) power will be 10.5 dB down from the carrier power and the noise power a further 26.0 dB down; a total of 36.5 dB in each case. This means that the (assumed) receiving system noise is:

– Band 5 (LF): (14.5 – 10.5 – 26.0) = −22.0 dBμA/m

– Band 6 (MF): (8.5 – 10.5 – 26.0) = −28.0 dBμA/m

– Band 7 (HF): (−11.5 – 10.5 – 26.0) = −48.0 dBμA/m

To comply with Recommendation ITU-R BS.1895, the contribution from an interferer without status in the Radio Regulations must be 20 dB below the receiving system noise; this gives the following limits:

– Band 5 (LF): (22.0 – 20.0) = −42.0 dBμA/m

– Band 6 (MF): (28.0 – 20.0) = −48.0 dBμA/m

– Band 7 (HF): (−48.0 – 20.0) = −68.0 dBμA/m

which, it will be seen, are very close to those calculated using Recommendation ITU-R BS.560 (above). Using the more recent figure of 20% (rms) for modulation depth would reduce these figures by a further 3.5 dB.

[22] It will be seen that this is less stringent than the 40 dB called for in Recommendation ITU-R BS.560. This is because Recommendation ITU-R BS.560 is considering potentially intelligible programme material from another broadcaster which is more ‘psycho-acoustically’ intrusive than random noise.

Attachment 5
to Annex 8

Anticipated separation distance between a WPT-EV charger and a domestic AM receiver – Photographic survey

In the case of a WPT-EV charger in a domestic environment it can be assumed that the charger will be either in a garage or a dedicated parking space adjacent to the owner's dwelling. The following four images show residential properties in the UK which might be considered typical. They are chosen on the basis that one of the authors either lived there himself or knows someone who does; they are not exceptional in any way.

FIGURE A8-11

Typical inner city housing in the city of Derby (UK)

It is suggested that WPT-EV charging might be difficult to deploy in this situation and that roadside charging points with a physical connection to the car might be more appropriate.

FIGURE A8-12

Outer suburban housing in South London

A WPT-EV charger might be fitted in the garage (several of the houses in this location have garages alongside them) or in the parking space beside or immediately to the front of the house.

FIGURE A8-13

Rural cottages about 70 km south east of London

This is an isolated group of cottages (they are mainly surrounded by agricultural land) but is in many respects similar to the suburban housing above. WPT-EV chargers could again be deployed in the garage(s) or the parking spaces bedside or in front of the houses.

FIGURE A8-14

Apartment building in east London

A multi storey building with garages allocated on the ground floor. It is considered most likely that any WPT-EV charger would be located inside the garage. Some of the apartments do not have garages and rely on non-allocated on street parking.

Looking at the examples in the photographs it is suggested that in every case a realistic distance from the nearest radio receiver to a WPT-EV charger would be around 3 metres. It is unlikely to be less than this but in the apartment building, for example, it is quite possible that there could be two WPT-EV chargers at about 3 metres from a radio receiver in the bottom floor apartment and even more within 10 metres. A second charger at 3 metres distance would, obviously, increase the interference potential by 3 dB.

Attachment 6
to Annex 8

Performance of an MF sound broadcast receiver in the presence of interference from WPT-EV

Effect of interference from an unmodulated carrier

Introduction and background

This report describes work carried out by the BBC on behalf of the EBU in seeking to define acceptable field strength limits for interference from Wireless Power Transfer (WPT-EV) devices. Although most of the suggested frequencies for use by WPT-EV do not lie within broadcast bands, harmonic levels are likely to be appreciable, with AM radio services being victims to interference. Traditionally, WPT-EV has been used for low-power devices such as toothbrush chargers. However, it is now being considered for recharging electric vehicles, with many kilowatts being involved, and the problem is correspondingly more serious.

In determining the acceptable limits for harmonic levels, work so far has been based on Recommendations ITU-R BS.560 and ITU-R BS.703. Recommendation ITU-R BS.560 states at the beginning that “the RF protection ratio … for co-channel transmissions should be 40 dB…”. Figure 1 of Recommendation ITU-R BS.560 then gives the relative protection ratio (PR) as a function of relative (or offset) interferer frequency. (PR is defined as the ratio of wanted signal to interferer carrier powers required to achieve a given quality criterion, usually an audio signal-to-noise ratio.) BS.703 adds that the minimum field-strengths for satisfactory LF and MF reception are 66 and 60 dBuV/m, respectively.

The assumption made in Recommendation ITU-R BS.560 is that the interferer will be another broadcast signal with similar characteristics to that of the wanted signal. As a WPT-EV interferer is equivalent to a plain carrier without modulation, this report looks into whether BS.560 is still applicable. In particular, it discovers whether a relaxation would be possible if the frequency of the interferer can be tightly controlled.

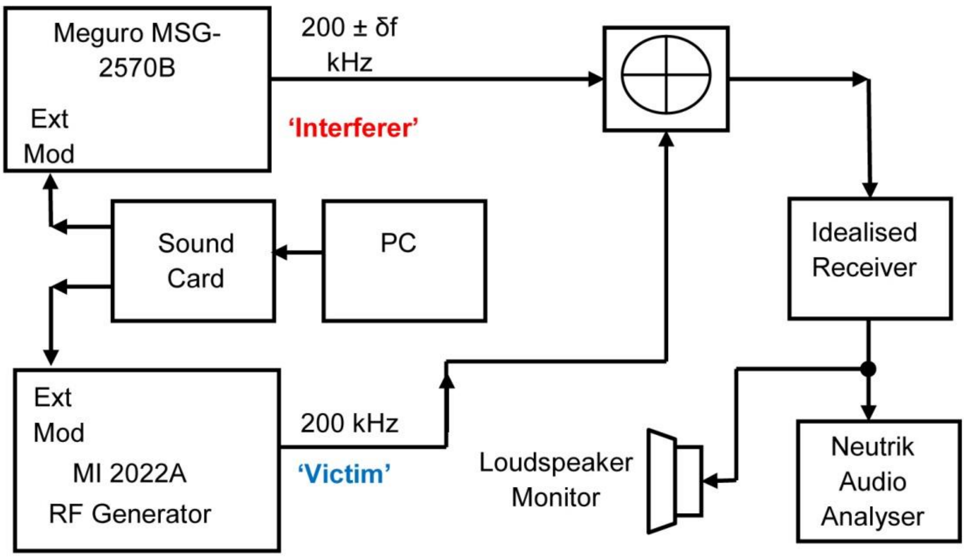
Experimental arrangements

The experimental arrangements are illustrated in Fig. A8-15. In essence, there are two signal generators to provide the wanted, or ‘victim’, transmission and the interferer. Audio modulation can be applied to either or both of these signals by means of a PC equipped with a sound-card. The audio is taken from ‘real’ programme material, recorded at the output of the Radio Five Live studio and passed through an Orban Optimod processor (which would normally be located at the transmitting station).

The combined wanted transmission and interferer are demodulated by an ‘ideal’ receiver especially made for the purpose. It includes AGC, a precision envelope detector and 4.5 kHz low-pass filter. There is no RF selectivity, as this being largely irrelevant for the work in hand. A panel of non-expert listeners was assembled to assess the output of the receiver when played out over a high-quality loudspeaker. The listening environment was a quiet area of a laboratory, and was not specifically designed for listening tests: as AM is not a high-quality medium, the hire of a certified listening room was not felt to be justified.

FIGURE A8-15

Experimental Set-up



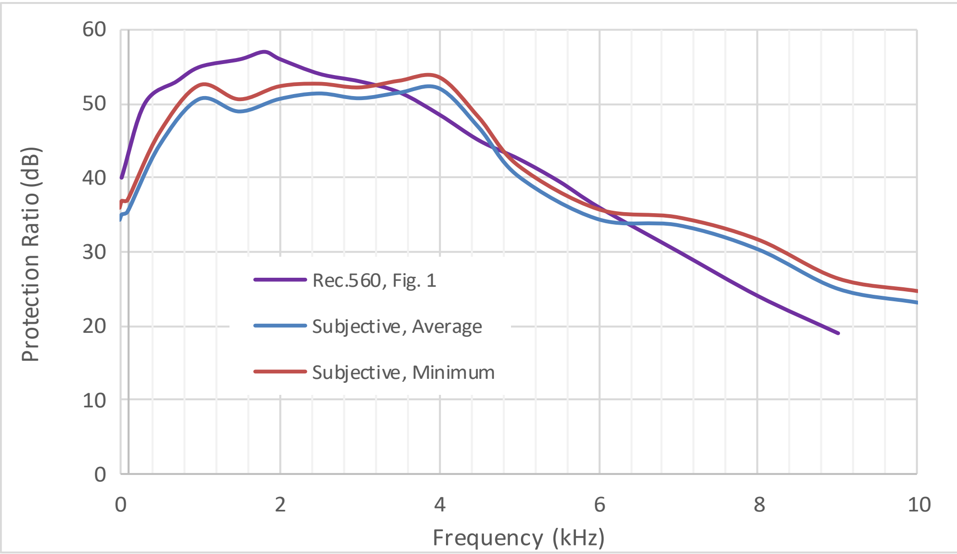
Verification of ITU-R BS.560 and ITU-R BS.703

The experimental set-up was as just described, with the venue being the DCT Screened Room at BBC R&D, Centre House. For the wanted, or ‘victim’, transmission, the programme material was a 27-second clip identified as ‘Jerusalem orchestra’. It comprised a few seconds of male speech, followed by female speech. There was a gap of under a second at the end of the clip to allow the loop-back to the start. The modulation for the interfering carrier was male speech identified as ‘new fighting talk’.

The volunteer was asked to listen to the wanted programme material at the output of the receiver, at a comfortable volume. The interferer was then added at the required offset frequency, and the level increased until the listener said that the interference was audible. Then the level was reduced until he or she claimed that the interference had gone. This procedure took place three times. Only the second and third pairs of results were recorded; the first results were just to enable ‘ballpark’ level settings to be established. The results are plotted below for offset frequencies covering the range 0 Hz to 10 kHz.

FIGURE A8-16

Protection ratios required with modulated interferers



Comment on Fig. A8-16:

– The ‘Subjective, Average’ plot is the average of all 40 figures for the particular frequency (10 listeners, 4 figures each).

– The ‘Subjective, Minimum’ plot is the average of all 20 figures for the point at which the interferer became inaudible as it was being reduced.

– Agreement with Recommendation ITU-R BS.560 is reasonable below 3 kHz, bearing in mind that the listeners were not ‘critical’. With experience, the interferer could certainly be heard at lower carrier levels than suggested by the ‘Subjective, Minimum’ plot.

– The response of the loudspeaker was not known and therefore not taken into account. In an ideal world, the tests would have been repeated with a number of loudspeakers.

– The slightly pessimistic PR figures above 3 kHz could reflect the receiver’s lack of RF selectivity.

– Above 500 Hz, the only audible component was the beat between the two carriers – the modulation on the interferer was completely swamped by this.

Protection required with a plain carrier interferer

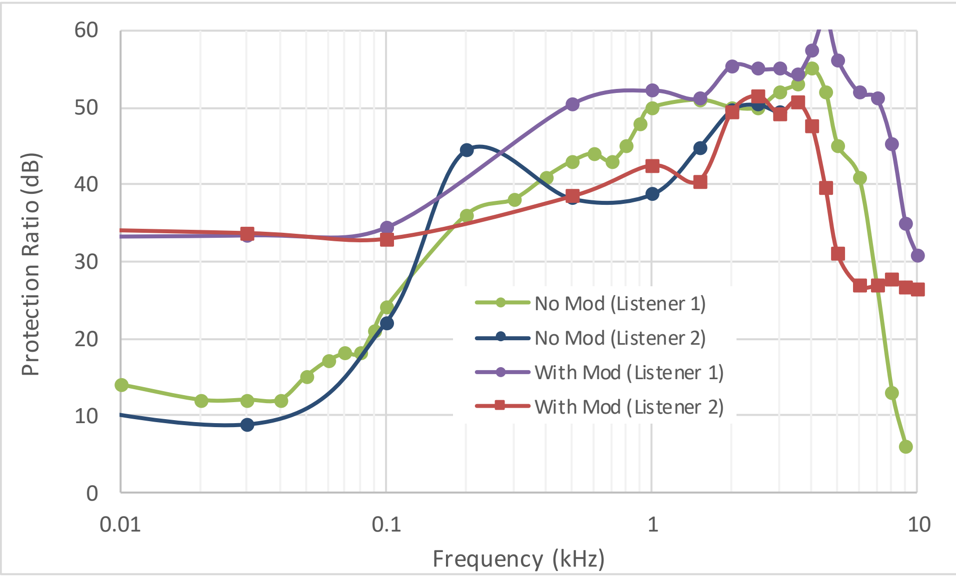
The work just described has established that the requirements laid down in BS.560 accord reasonably with reality – and with the author’s experimental arrangements. The interesting thing that needs to be established is the difference in requirements if the modulation is removed from the interfering carrier.

Further PR measurements were made, in just the same way as before, except for the absence of modulation on the interfering carrier. It would have been ideal to use the same panel of listeners, but that proved not to be possible owing to staff sickness and so forth. Six listeners were members of the original panel, and six new ones were added. Although the listeners varied appreciably in acuity and consistency, all results were used. Measurements were confined to the range 0-1 kHz, since the modulation component was inaudible at greater offsets.

The chart in Fig. A8-17 below contrasts the PR results with and without modulation on the interferer. Those with modulation present are just the same as those plotted in the previous section. To make the results easier to interpret, the horizontal axis has a logarithmic scale covering the two decades from 10 Hz to 1 kHz. As before, the Recommendation ITU-R BS.560 protection requirements are shown, although the data could not be read off Fig. 1 of BS.560 with any accuracy.

FIGURE A8-17

Protection ratios required with modulated and unmodulated interferers



Comments on Fig. A8-17:

– The response of the loudspeaker was not known and therefore not taken into account. In an ideal world, the tests would have been repeated with a number of loudspeakers.

– The 'Subjective, Average' and 'Subjective, Minimum' figures have been plotted in just the same way as before.

– At frequencies above about 300 Hz, where the predominant component of the interference is the carrier beat, the results with and without modulation on the interferer agree well –within a couple of dB. This is encouraging, bearing in mind the different listening panels.

– Below 300 Hz, where the modulation of interferer dominates (if present), the PR plot levels off. Although the Recommendation ITU-R BS.560 requirements seem about 5 dB too strict, they do correspond to the limit of audibility for the most critical listeners, as per the 'error bars' described in the final bullet-point below.

– Below 300 Hz, where the modulation is absent, the PR continues to fall with decreasing frequency. The slope of the plot is close to 6 dB per octave, or 20 dB per decade – in accordance with Recommendation ITU-R BS.468 weighting 3.

– Below 50 Hz, the carrier beat becomes nearly inaudible because of the falling response of the loudspeaker and the human ear. The most important factor is the distortion caused by the cyclical variation in modulation depth.

– ‘Error bars’ of ±4.3 dB have been added to the ‘Modulated, Minimum’ plot. These represent the RMS difference between the acuity of the various listeners. They do not take into account possible systematic errors such as the response of the loudspeaker.

– It is evident that the absence of modulation confers an advantage of some 25 dB over the PR requirement given in Recommendation ITU-R BS.560, provided that the offset frequency can be kept below 50 Hz

Co-channel interferer and audio quality

The previous section provides a good indication that there is an advantage in keeping the frequency of an unmodulated interferer close to that of the wanted carrier – if that can be arranged. To explore this possibility further, a panel of ten listeners was convened, and asked to judge the sound quality of three audio clips described below.

– A female presenter (27 seconds). (The same clip as that used to verify Recommendation BS.560).

– Some music (soprano and string quartet) (31 seconds).

– A male presenter and jingle (45 seconds).

The listeners were invited to score each sample on the ITU-R 5-point impairment scale, 5 being ‘imperceptible’ and 1 being ‘very annoying’. See Recommendation ITU-R BS.1284. Although not sanctioned by BS.1284, a score of zero was allowed for sound that was deemed unusable. Fractional scores of, say, 3.7 were also allowed, so that listeners could differentiate between small changes in sound quality.

Five levels of interferer were tried: –5, –10, –15, –20 and down to –∞ dB. The interferer itself was at either 0 Hz or 30 Hz offset. In the 0 Hz case, the two carriers were not synchronous, and slowly drifted in and out of phase. This was felt to be a more realistic situation than locking the interferer to the wanted carrier. When the carriers were in antiphase, the resultant carrier was overmodulated, causing serious audio distortion. The audio level was also at a maximum, since the receiver AGC acts on the average level of the signal. Conversely, when the carriers were in phase, the modulation depth and audio level were at a minimum, and the distortion disappeared.

FIGURE A8-18

Impairment scores for different levels of unmodulated interferer

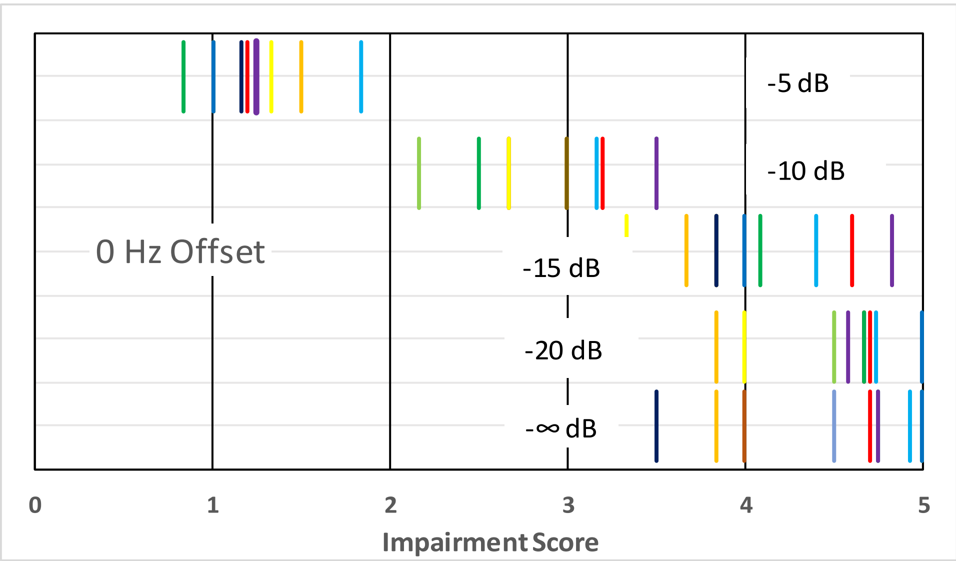
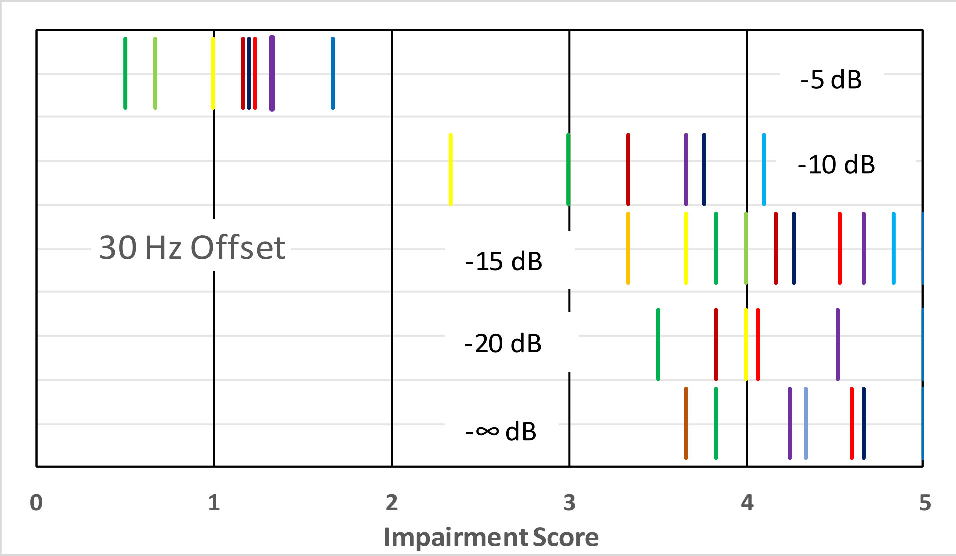


FIGURE A8-19

Impairment scores for different levels of unmodulated interferer

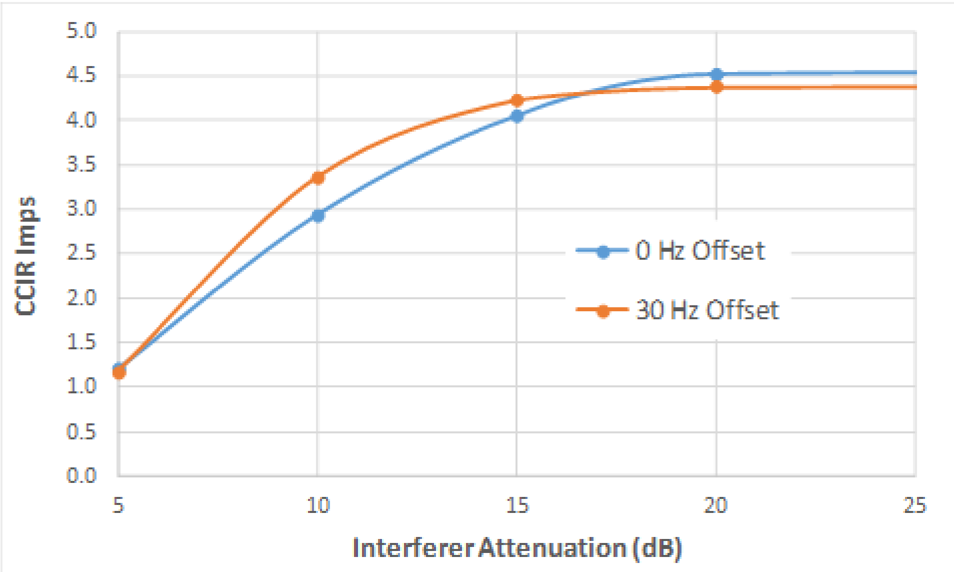


In the plots Figs A8-18 and A8-19, the scores of the individual listeners are shown as short vertical lines, with each listener being allocated an individual colour. These scores are the averages for the three clips. As will be discussed later, the scores for the three clips showed significant differences.

The results averaged over all ten listeners are as below:

FIGURE A8-20

Impairment scores against interferer level



Comments on Fig. A8-20:

– The 30 Hz offset appears to be slightly more benign than 0 Hz, unless the interference is severe. This is possibly because the receiver's AGC is not fully responsive to 30 Hz variations in carrier level, and therefore does not cause such noticeable pumping effects.

– For both offsets, the interferer is inaudible at −20 dB, and just audible at −15 dB.

– As the interferer is increased from −15 dB, its presence rapidly becomes more objectionable. When the interferer is above −10 dB, the audio quality is very poor.

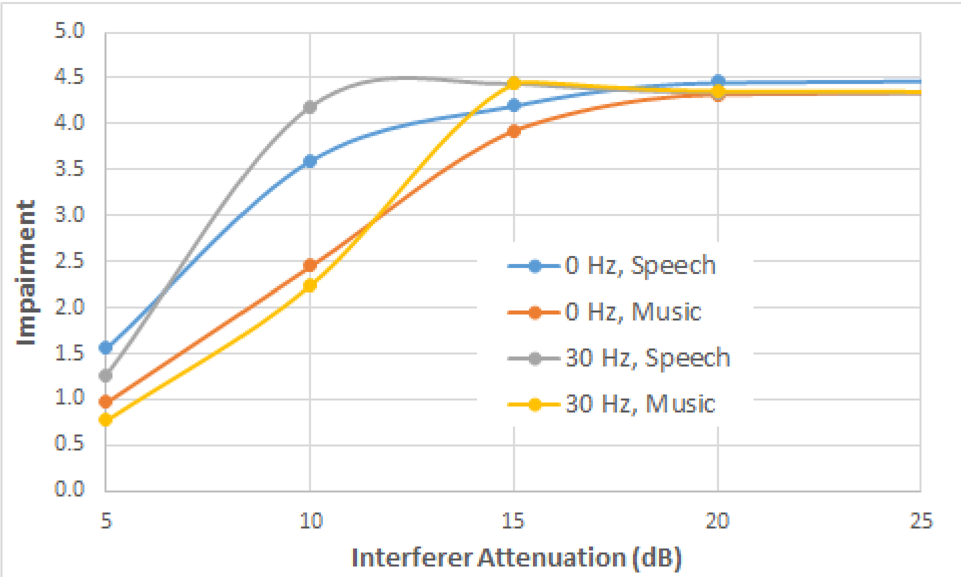
The effect of introducing a small frequency offset is worth looking at further – it appears to be at least mildly beneficial. The chart below shows that the situation is more complicated than that. 'Speech' refers to Clip 1, and 'Music' to Clip 2.

The offset really is beneficial for speech, and allows the interferer to be as great as −10 dB without causing significant distress to the listener. However, the same is not true for music, where, if anything, the offset makes the sound quality worse. During the tests, the different effect the interferer had on speech and music was quite startling: at −10 dB and 30 Hz, the interference was hard to hear on speech, but very unpleasant with music.

It appears that the problem with music is caused by the AGC having some response to the 30 Hz carrier beat, and hence cross-modulating the 30 Hz on to the wanted carrier. A musical tone thus acquires 30 Hz sidebands, and the effect is bad because these are not harmonically related. Speech signals are more complicated and already contain large numbers of spectral components. The result is more akin to noise, and the addition of 30 Hz sidebands makes little difference.

FIGURE A8-21

Comparison of impairment scores for speech and music



Allowable WPT-EV interferer field-strengths

The final task is to relate the PRs shown in Figs A8-20 and A8-21 to actual field-strengths. This can be done simply as follows:

– The minimum field-strength for satisfactory MF reception is given in BS.703 as 60 dBμV/m.

– This is converted to dBμA/m by subtracting 51.5 dB. (The impedance of free space, Z0, is 377 Ω, and 20 log10 377 equals 51.5.) Hence 60 dBμV/m corresponds to a magnetic field-strength of 60 − 51.5 = 8.5 dBμA/m.

– The PR requirement laid down in BS.560 is 40 dB at zero offset frequency. The corresponding field-strength is therefore 8.5 – 40 = –31.5 dBμA/m.

Note that the work just described suggests that a PR of 18 dB is adequate, provided that the interferer is kept within about 50 Hz of the victim's carrier frequency – a relaxation of 22 dB. In other words, a limit of –10 dBμA/m would suffice.

For LF reception, BS.703 gives the minimum field-strength as 66 dBμV/m – 6 dB greater than the MF figure. In that case, the corresponding limit would be –4 dBμA/m.

No consideration has been given in this report, or in [2], about allowable *electric* field-strengths. This seems reasonable, since WPT-EV relies on magnetic fields, and most LF/MF receivers use ferrite rod and frame antennas. To be on the safe side, perhaps standards such as [2] should quote both electric and magnetic field-strengths. A PR of 18 dB corresponds to 48 dBμV/m and 42 dBμV/m for LF and MF respectively.

Conclusion

This Attachment has taken a look at the interference caused by the use of WPT-EV devices to AM radio broadcast services, with the aim of establishing the maximum tolerable magnetic field-strength. The conclusions are as follows:

– Recommendation ITU-R BS.703 quotes a protection ratio requirement of 40 dB for co-channel interference to AM broadcast services, whilst Recommendation ITU-R BS.560 gives the *relative* requirement where the interferer is offset in frequency. The experimental work described in this Report confirms these figures.

– The experimental work also shows that, where the interferer is an unmodulated carrier, a relaxation in the requirement is possible below about 500 Hz. A protection ratio of 18 dB is sufficient for offset frequencies of 50 Hz and below. Note that there is no advantage in a 0 Hz offset, unless the interferer can be locked in phase with the wanted carrier.

– Assuming that minimum field-strengths of the broadcast services are 66 dBμV/m and 60 dBμV/m, the maximum acceptable levels of near co-channel interference by an unmodulated carrier are –4 dBμA/m –10 dBμA/m for LF and MF respectively.

It is emphasised that the experimental arrangements used for these listening tests had their limitations, and the results should be regarded as provisional. In an ideal world, and if time and money permit, the tests should be repeated ‘double-blind’ in a certified listening room, with all parameters fully controlled. However, these provisional results probably provide a good indication of the final outcome.

References for this Attachment

[1] Wikipedia, 2017. Wireless Power Transfer https://en.wikipedia.org/wiki/Wireless_power_transfer

[2] ETSI, 2017. ‘Wireless Power Transmission Systems, Using Technologies Other than Radio Frequency Beam, in the 19–21 kHz, 59–61 kHz, 79–90 kHz, 100–300 kHz, 6 765–6 795 kHz ranges: Harmonised Standard Covering the Essential Requirements of Article 3.2 of Directive 2014/53/EU.’ ETSI EN 303 417 V1.1.1

[3] Recommendation ITU-R BS.560-4 – ‘Radio-Frequency Protection Ratios in LF, MF and HF Broadcasting

[4] Recommendation ITU-R BS.703 – Characteristics of AM Sound Broadcasting Reference Receivers for Planning Purposes

[5] Recommendation ITU-R BS.1284-1 – General Methods for the Subjective Assessment of Sound Quality

Attachment 7 to Annex 8

Further studies using a commercially available receiver

Background and Introduction

This work supplements an earlier study which is described in BBC White Paper WHP 332 (published in November 2017) and reproduced as Attachment 6 to Annex 8. This further study uses a real, ‘off the shelf’, portable receiver with the wanted and unwanted signals injected using magnetic loop antennas to excite the inbuilt ferrite rod antenna in the receiver itself. This approach fulfils three objectives:

– to demonstrate that the reference receiver defined in Recommendation ITU-R BS.703 is comparable with a real receiver;

– to offer a ‘reality check’ on the assumed interplay between Recommendations ITU-R BS.703 and ITU-R BS.560 used when planning the LF and MF broadcast bands and used to set acceptable interference limits for WPT-EV systems[23];

– to repeat some of the earlier measurements with a difference test arrangement.

The work for WHP 332 was carried out with an ‘ideal’ receiver – ‘ideal’ meaning that it did not introduce any noise of its own, and had a ‘flat’ frequency response with a modulation bandwidth of 4.5 kHz at –6 dB. In addition, the wanted signal and a single tone signal, simulating a WPT-EV unit as an interferer, were combined before being fed into the ‘ideal’ receiver. This was a ‘hard wire’ connection, and did not involve an antenna. This ‘purist’ approach was adopted to eliminate as many variables as possible. However, it is argued that a cross check to demonstrate that this approach corresponds with what happens in the ‘real world’ would be beneficial.

The principal conclusion of the earlier study was that for single tone signals, representing a source of interference, separated from the wanted transmission by more than 500 Hz, Recommendations ITU-R BS.560 and ITU-R BS.703 are a suitable basis for defining the required protection against interference levels. (‘Protection’ is defined as the ratio of wanted to unwanted signal levels presented to the receiver.) The ‘by more than 500 Hz’ qualification’ is important, as appreciably higher levels of interferer can be tolerated at lower frequency separations.

The work described here duplicates some of the earlier work, this time using a real but inexpensive radio, receiving signals off-air.

Choice of receiver

At the time when the studies were carried out three representative commercial portable receivers of various ages were available:

– Panasonic GX500;

– Roberts RP26-B; and

– Sony ICF-700W.

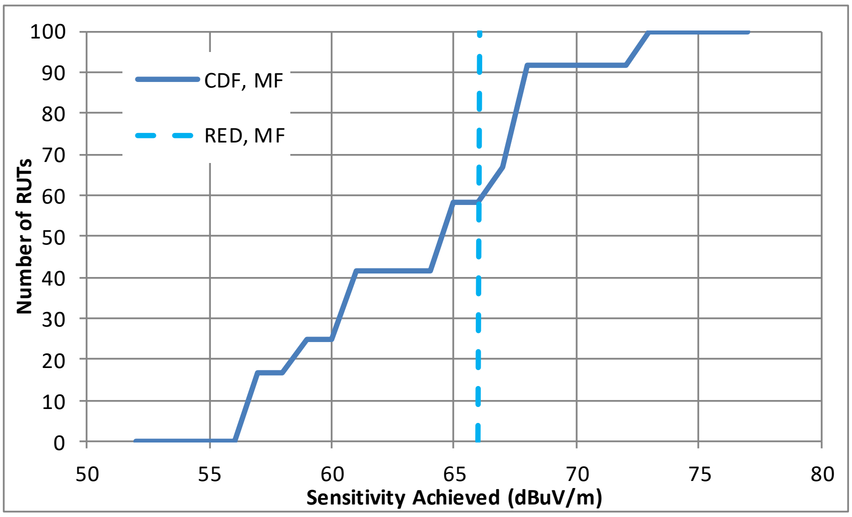
[23] To obtain the maximum allowable interferer level in absolute terms, the protection ratio (PR) as specified in Recommendation ITU-R BS.560 needs to be linked to the field-strength of the wanted signal at the receiver’s antenna. Recommendation ITU-R BS.703 gives the minimum sensitivity requirement for the ‘reference receiver’ as 60 dBµV/m, at which signal level the receiver should be capable of an audio signal-to-noise ratio (S/N) of 26 dB. The reference is 30% AM, with an un-weighted RMS detector being used for the noise measurement.

A subjective assessment demonstrated that the Panasonic receiver had the lowest internal noise and so was chosen for the remainder of the tests. The receiver chosen was representative of the inexpensive end of the market. As the sensitivity and modulation bandwidth have an important bearing on the results, some details are given here.

A number of portable radios had previously been tested in relation to ETSI specification EN 303 345, 'Broadcast Sound Receivers: Harmonised Standard' covering the essential requirements of Article 3.2 of the Radio Equipment Directive (RED) 2014/53/EU'. A cumulative distribution function (CDF) of their sensitivities is shown here. About two-thirds of the radios were more sensitive than the proposed ETSI requirement of 66 dBµV/m.

FIGURE A8-22

CDF of the sensitivities of a batch of typical portable radios



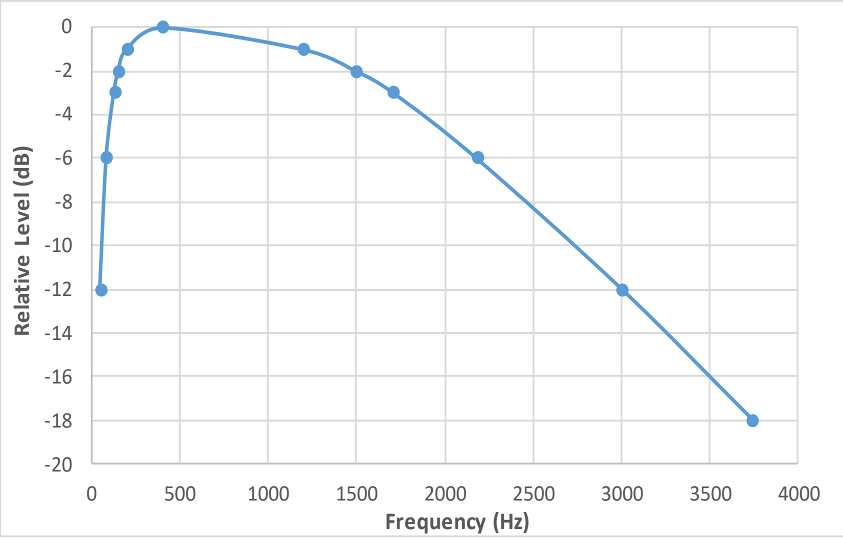
The Panasonic GX500 achieved a sensitivity of 65 dBµV/m on the same scale; so it just met the ETSI requirements. Note that the sensitivity here is not defined in the same way as in Recommendation ITU-R BS.703. This is discussed below but for the moment, the requirements of Recommendation ITU-R BS.703 and EN 303 345 can be taken as approximately equivalent. The important point is that the Panasonic radio is typical and its noise performance is comparable with the ITU reference receiver.

Also important is the modulation frequency response of the receiver, as this will determine both the noise level at the output and the impact of the interfering WPT-EV. A plot is shown in Fig. A8-23 below.

Note that the response falls off sharply beyond 1.5 kHz, whereas that of the earlier 'ideal' receiver was essentially flat to 4 kHz. The narrow bandwidth implies greater tolerance to WPT-EV, and improves the measured sensitivity (although not the audio fidelity).

FIGURE A8-23

Modulation response of chosen portable radio

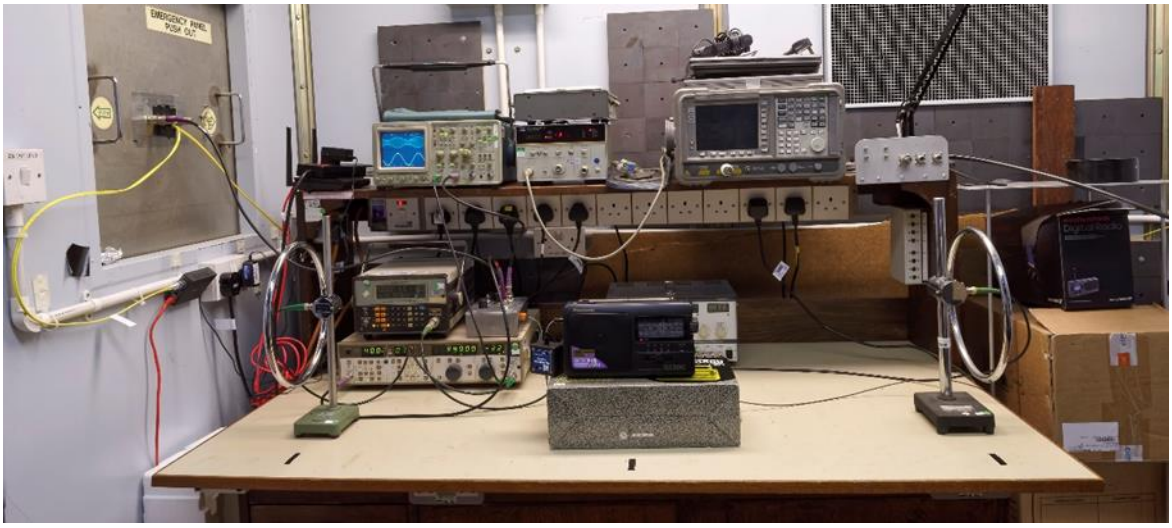


The test set-up

The test set-up was essentially similar to that described in WHP 332, with two RF signal generators: one set to 999 kHz and used to provide the wanted transmission; the second set to 1 001 kHz and providing the (un-modulated) interferer with a 2 kHz offset.

FIGURE A8-24

The test set-up in the BBC R&D screened room



The two signals were ‘transmitted’ from separate calibrated loop antennas. To eliminate other sources of interference, the generators, loops and receiver were placed in an RF screened room, with the PC providing the programme material for listening tests (itself an appreciable source of radio noise) outside the screened test area). The audio analyser was connected to the receiver with a fibre-optic link. All incoming mains supplies were filtered and any un-necessary equipment was turned off.

In Fig. A8-24, the portable radio is centre-stage, supported on a cardboard box to allow its ferrite antenna to be aligned with the axis of the loop antennas. The two loops are shown either side and are spaced from the radio by 600 mm – the magnetic field strength bore a simple relationship with the measured output of the signal generators which made setting up easier and more accurate. Alongside the radio (but not clearly visible) is the transmitter for the fibre-optic link. Out of frame is a measurement meter for double-checking the field-strength generated by the loops. The two RF signal generators are behind the left-hand loop.

FIGURE A8-25

The test set-up as originally used for WHP 332

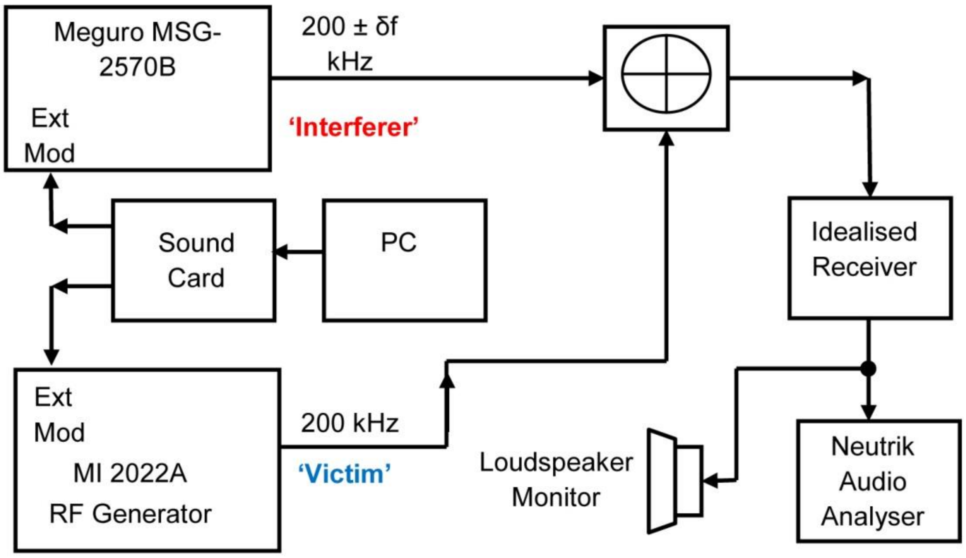
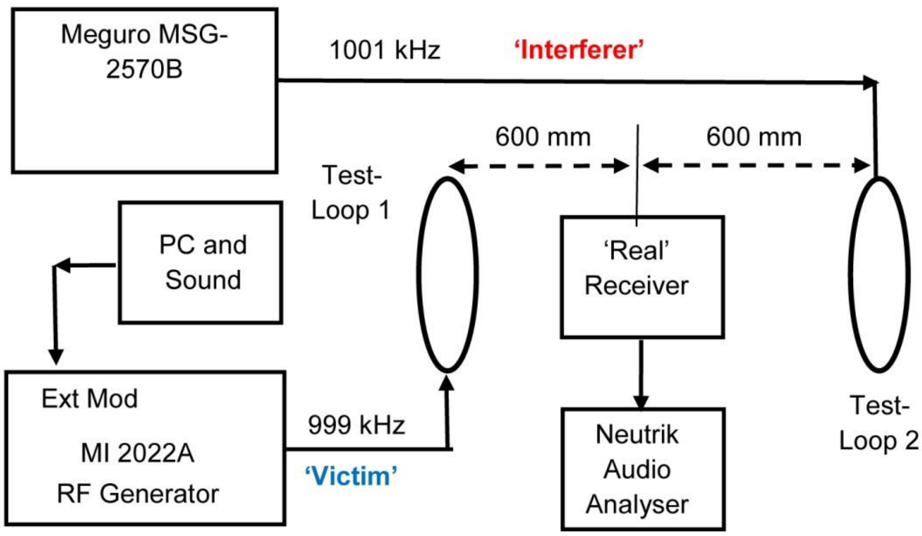


FIGURE A8-26

Modified set-up as used for the present work



Block diagrams of the original (Fig. A8-25) and present test arrangements (Fig. A8-26) are given here.

Essentially, the two set-ups are the same, except that the interferer and the wanted transmission are combined in the ether, rather than electronically. The use of test-loops and an internal loudspeaker mean that the 'real' receiver has no electrical connections to it.

The same audio 'clip' was used for all the relevant tests. This consisted of 16 seconds of speech followed by 2 seconds of silence and 12 seconds of music. It was taken from the BBC's Radio Five

Live MF network and recorded 'downstream' of the transmission processor. A large amount of AM radio is now speech based. Speech is characterised by lower modulation depths and frequent short silences as the speaker comes to the end of a sentence, stops for breath etc. Low levels of interference can be masked by the audio signal but equally can be intrusive during the frequent silences and it is these that tend to dominate from the listener's perspective.

Calibration

Calibration was carefully carried out. A thermal power meter was used to check the output power of the generators at an indicated level of 0 dBm (1 mW into a 50 Ω termination). When set to −33 dBm, the generator should give rise to a signal level of 8.5 dBuA/m at the receiver, a figure which was verified with the field-strength meter. The calculation of field-strength is carried out as follows:

FIGURE A8-27

Magnetic field generated by a current-carrying loop

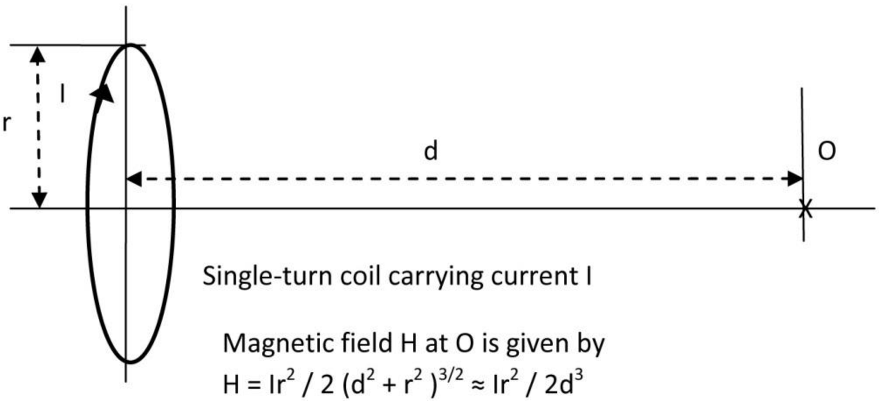


Figure A8-27 gives the magnetic field *H* arising from a current *I* through the coil. The current is defined by the generator EMF *V* and the source resistance *R*, so that *I* = *V/R*. The radius of the coil r is 125 mm and the distance d is 600 mm.

The equation can be re-arranged to find the current necessary to generate a given field at *O*.

$$I = H \cdot (2d^3/r^2)$$

For the field strength to be 8.5 dBμA/m

$$H = 10^{\left(\frac{8.5}{20}\right)} \text{ μA/m}$$
$$= 2.66 \text{ μA/m}$$

The necessary current is therefore:

$$I = 2.66 \text{ μA/m } . (2 . 0.6^3 / 0.125^2)$$
$$= 73.54 \text{ μA}$$

The necessary generator EMF is therefore:

$$V = 73.54 \text{ μA } . 136 \, \Omega$$
$$= 10 \text{ mV}$$

The 136 Ω source resistance includes 50 Ω within the RF generator itself, and 86 Ω forming part of the loop. For H to be 2.66 μA/m (or 8.5 dBμA/m), V must be 10 mV. The generator output (EMF) is calibrated in dBm, 0 dBm corresponding to a generator EMF of 448 mV, and 10 mV is therefore equivalent to 20 log (10/448), or –33 dBm.

The response of the receiver has already been mentioned. A further measurement confirms that the response is −4 dB at 2 kHz (the offset frequency of the interferer) relative to 1 kHz (the line-up tone for the system). Hence, to obtain a true comparison of what can be expected with 'good' receiver having a flat response, the interferer needs to be increased in level by 4 dB.

Performance of the receiver used for the present tests

To ensure that the tests carried out with the portable radio are 'fair', we need to check how the sensitivity compares with that of the reference receiver in Recommendation ITU-R BS.703. The measured results are best summarised in the form of Table A8-4.

TABLE A8-4

Signal-to-noise ratios achieved by portable radio

Field strength	***S/N*, Ref 40% AM**		***S/N*, Ref 30% AM**
dBµV/m	**Unweighted (dB)**	**Weighted (dBq)**	**Unweighted (dB)**
60	26	18	23.5 (26)
65 (66)	30	22	28

Table 1 shows that the noise performance of the Panasonic receiver is 2.5 dB worse than the Recommendation ITU-R BS.703 reference receiver (shaded pink), but exceeds the ETSI requirement of 66 dBµV/m (shaded blue) with 1 dB in hand. For this particular radio, the weighted noise is 8 dB greater than the unweighted noise. There is no 'universal' difference between the weighted and unweighted noise figures, since the bandwidth of the receiver is an important factor. In the work carried out for EN 303 345, the figure was taken as 10 dB: 4 dB to convert between rms and quasi-peak, and 6 dB for the rising response of the weighting filter. With the Panasonic receiver the figure is slightly less because of the poor modulation response.

An important point is that it is possible to make the radio appear to match the performance of the reference receiver by increasing the incoming field-strength by 2.5 dB – where external noise is negligible, S/N increases with signal level pro rata. In other words, the radio will achieve 26 dB S/N reference 30% AM with a field-strength of 11 dBµA/m/62.5 dBµV/m. Of course, when carrying out listening tests etc. it is necessary to increase the interferer by the same amount to keep the relative levels correct.

No comprehensive survey of environmental noise has been carried out, but walking around with the radio indicates that, at least in some locations, reception is limited by the radio's internal noise. The requirements laid down by ITU-R BS.703 and EN 303 345 hence seem reasonable.

Interference thresholds

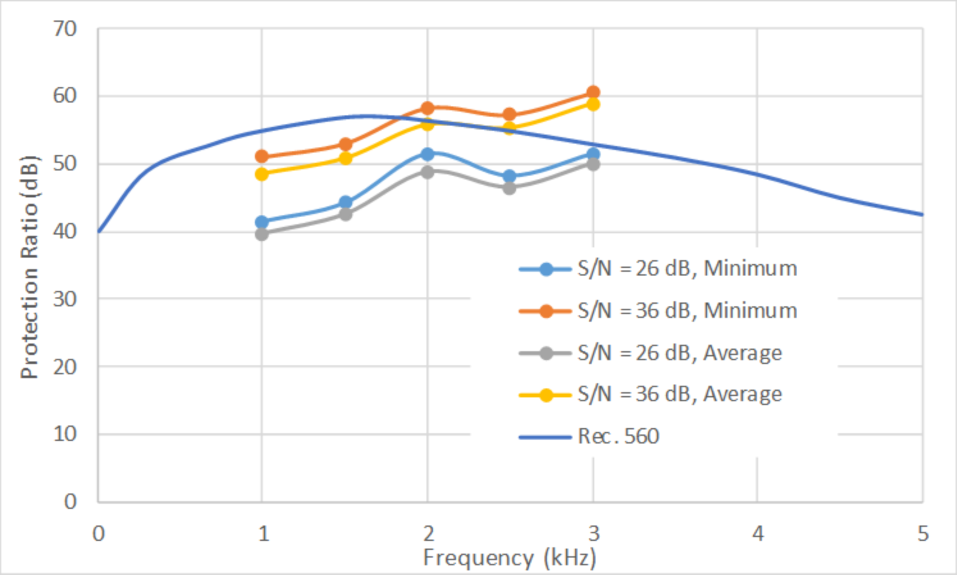
The earlier work on interference thresholds was carried out with a noiseless receiver. It might be expected that the noise present at the output of a 'real world' receiver would have a masking effect. If so, there could be a case for relaxing the limits for WPT-EV interferers suggested in WHP 332. To find out in a rigorous manner would mean repeating the listening tests described in WHP 332. These tests involved playing out samples of programme material on the wanted 'transmitter', and asking a listening panel to determine at what level the interferer became audible. The tests had to be repeated over a wide range of offset frequencies. Although straightforward in principle, such listening tests need organisation, and such an approach was not possible with the resources available.

Rather than repeat all the previous work, a more pragmatic approach was adopted. A single listener judged the point at which the interference became audible at two different wanted signal levels.

Level 1 was chosen to give 26 dB *S*/*N* (ref. 30% AM), to mimic the performance of the reference receiver working at 60 dBµV/m, Level 2 was 20 dB greater, when the noise was 10 dB lower and much less obtrusive. In that way, a small difference could be established, which could then be used to ‘correct’ the original ‘noiseless’ figures. Provided the difference really was small, any experimental uncertainties would have negligible effect.

FIGURE A8-28

Single tone interference thresholds with a ‘real world’ receiver



“Frequency” is the frequency offset from the AM carrier.

For each frequency offset, in the range 1 to 3 kHz, and wanted signal level, the interfering signal level was slowly increased, and the level recorded at which the interference became just audible. A second level was recorded, at which the interference became unnoticeable as it was decreased. The process was repeated four times and averages taken. In Fig. A8-28, the ‘Minimum’ figures correspond to the second level, whilst the ‘Average’ figures are the mean of the first and second levels. This allows a comparison to be made with Fig. A8-20. In plotting the results, allowance was made for the sideband response of the receiver; the curves would fall away at the high-frequency end if that were not done.

It is concluded that the presence of noise masks the interference, and allows the interferer to be about 8 dB greater than would be the case in the absence of noise.

A further test was carried out in an attempt to quantify the psycho-acoustic difference between random (white) noise and a single tone interferer. At the limit, the total system noise will be a mixture of receiver noise and environmental noise. Moving away from the limit of sensitivity into areas where the environmental noise is likely to be higher, the receiver noise will become less significant and the total system noise will be dominated by the environmental noise.

A single tone interferer was injected at the same level as the total system noise[24], as measured at the audio output of the receiver with an RMS detector, and progressively reduced in 2 dB steps until it became inaudible; masked by the system noise. The effect of the interferer had ceased to be objectionable (although it was still audible) when the level had been reduced by 8 dB and had disappeared when it was reduced by 10 dB. In higher noise environments, the absolute noise

[24] For this test an idealised receiver was used with random noise deliberately injected at the equivalent of minus 31 dBµA/m to simulate the performance of the Rec.703 reference receiver.

levels would be higher but the ratio of the interferer to the total system noise would always be the same: –8 dB to 10 dB if audible interference was to be avoided. In environments where the receiver noise itself is insignificant, the interferer would have to be 8 to 10 dB below the environmental noise level to be inaudible.

Conclusions

Measurements made with the Panasonic GX500 receiver were in general agreement with the earlier measurements made with an idealised system to quantify the level of tolerable interference when a single tone interferer is aligned with the broadcast channel raster. The assumptions made when calculating the tolerable field strength from Recommendation ITU-R BS.703 and ITU-R BS.560 are correct. However, a number of things did come out of the tests.

Validity of the Recommendation ITU-R BS.703 reference receiver as a datum

The Panasonic GX500 receiver did not perform as well as the assumed performance of the reference receiver. Its audio frequency response was not flat and the receiver noise was a slightly greater. This is a relatively inexpensive portable receiver and work carried out previously by the BBC indicates that better quality receivers are available. This in turn means that the specification for the reference receiver is, as it should be, representative of a reasonable quality commercial receiver and so earlier studies based on the reference receiver are perfectly valid. Recommendation ITU-R BS.703 effectively specifies the total system noise level at the fringe of reception by assuming a modulation depth of 30% and a modulation to random (system) noise of 26 dB. The total system noise is, therefore 60 dBμV/m (minimum carrier level from Recommendation ITU-R BS.703) minus 10.5 dB (level of modulation below carrier) minus 26 dB (wanted signal to noise ratio) plus 3dB (sideband correlation gain) which equals 26.5 dBμV/m or –25 dBμA/m (magnetic). In practice this will be a combination of internal receiver noise and environmental noise. Assuming both noise sources contribute equally to the system noise each will be –28 dBμA/m; a figure that will increase by 3 dB when they are added together. According to calculations made by Japan from Recommendation ITU-R P.372 this is, unsurprisingly, close to the environmental noise level to be expected in a rural situation.

Masking effect of system noise

When the interference is at a low level, it can be masked by the presence of audio modulation. With the tendency for broadcasters to use AM radio for speech broadcasting, there are frequent gaps and silences in the programme and it is in these gaps that the interference is noticeable or annoying because it is not masked. A single tone interferer is more disturbing than random noise. The earlier, subjective tests described in BBC White paper WHP 332 were performed using an idealised, noise free receiver. The presence of background, random noise in the gaps in speech was found itself to have the effect of masking the interference. A subjective test involving one listener but repeated several times suggests that the masking effect of system noise could offer an 8 dB relaxation in the tolerable noise level at frequencies away from the broadcast carrier. This does not have any effect on the levels suggested in WHP 332.

Level of interferer relative to system noise

Because of the more intrusive psycho-acoustical effect, a single tone interferer must be at least 8 dB below the total system noise in any location to be inaudible. The total system noise itself will be location dependent. In the electrically quietest environments, internal receiver noise will play a large part but in more noisy environments (suburbs and cities perhaps) the environmental noise will dominate. Statistical guidance on anticipated environmental noise levels in various environments can be found in Recommendation ITU-R P.372, however, it must be stressed that these levels are for guidance and should not be used as targets. This does not address the general principle that electrical noise should always be minimised.

References for this Attachment

[1] BBC Research and Development White Paper WHP 332, November 2017 – Wireless Power Transfer: Plain Carrier Interference to AM Reception

[2] Report ITU-R BS.2433-0 – Loudness in Internet delivery of broadcast originated soundtracks (10/2018)

Annex 9

Analysis by EBU to reconcile the results of impact study described in Annex 5 with the required limits of WPT-EV radiated emission for the protection of AM broadcasting in section 4.4

Introduction

Annex 5 "WPT-EV Impact study from China" describes reception studies carried out on MF broadcast transmissions in the Shanghai area. At first sight it appears from the study in Annex 5 that levels of interference considerably greater than those based on Recommendations ITU-R BS.703 and ITU-R BS.560 have no adverse effect on broadcast reception (cf. § 4.4). However, the test conditions used for study are quite different from the reception conditions assumed in the ITU-R Recommendations and so this is perhaps not surprising.

Broadcast network planning in ITU Regions 1 and 3 and hence in Europe is based on Recommendations ITU-R BS.703 and ITU-R BS.560. A study has been conducted in this Annex which compares the results from Shanghai with the situation pertaining in parts of Europe and attempts to reconcile them. By applying appropriate correction factors, it can be seen that there is actually good agreement.

The interference levels measured in the Shanghai tests are, apparently, significantly larger than the tolerable field strength levels which have emerged from studies in § 4.2.2. However, the much higher broadcast signal strength and the potential masking effects of both high background noise and high modulation depth (of the broadcast signal) indicate that the results from Shanghai are broadly in line with the ITU-R based protection criteria. In essence, it appears likely that the combined effects of a higher level of broadcast signal, high environmental noise and high modulation depth have masked the impact of any WPT-EV interference. It is not therefore surprising that in this situation little or no impact from the WPT-EV system was noted.

Taking a global view, it remains necessary, however, to protect lower strength broadcast signals in lower noise environments and the tolerable levels proposed in § 4.4 are there to do this.

A9.1 Summary

Section A5.1.2 shows a study of coexistence between WPT-EV and MF broadcast submitted to ITU by the People's Republic of China. It describes reception studies carried out on MF broadcast transmissions in the Shanghai area. At first sight it appears that levels of interference considerably greater than those based on Recommendations ITU-R BS.703 and ITU-R BS.560 have no adverse effect on broadcast reception. However, the test conditions used for the Chinese study are quite different from the reception conditions assumed in the ITU-R Recommendations and so this is perhaps not surprising.

Broadcast network planning in ITU Regions 1 and 3 and hence in Europe is based on Recommendations ITU-R BS.703 and ITU-R BS.560. A study has been conducted which compares the results from Shanghai with the situation pertaining in parts of Europe and attempts to reconcile them. By applying appropriate correction factors, it can be seen that there is actually good agreement.

The interference levels measured in the Shanghai tests are, apparently, significantly larger than the tolerable field strength levels which have emerged from studies in § A5.1.3. However, the much higher broadcast signal strength and the potential masking effects of both high background noise and high modulation depth (of the broadcast signal) indicate that the results from Shanghai are broadly in line with the ITU-R based protection criteria. In essence, it appears likely that the combined effects of a higher level of broadcast signal, high environmental noise and high modulation depth have masked the impact of any WPT-EV interference. It is not therefore surprising that in this situation little or no impact from the WPT-EV system was noted.

Taking a global view, it remains necessary, however, to protect lower strength broadcast signals in lower noise environments and the tolerable levels proposed in § 4.4 are there to do this.

A number of factors which could have a significant impact on the results have not been quantified in the report of the Shanghai study. Among these are programme genre (of the incoming broadcast signal) receiver audio frequency response and receiver orientation. All these and the potential effects are described here. Conservative estimates of the quantitative effects of these factors have been included in the analysis. Also, there is no explanation of the potentially anomalous nature of the interfering field strength values in Column 9 of Table A5-4 (Annex 1 to this Report). The field strength should vary with the cube of the distance; so 18 dB for a doubling of the distance. The Table shows, for example, the field strength as 6.3 dBuA/m at 10 metres and (only) 14 dBuA/m at 5 metres. It would be expected to be 24.3 dB. Moving even closer, the field strength actually reduces. The values have been taken at face value without any attempt at interpretation.

A9.2 Definitions

A9.2.1 Orientation – Noise, Interference and Masking

AM radio is not a high fidelity medium. Among the reasons for this are the effects of noise and interference. The planning criteria, cited above and based on Recommendations ITU-R BS.703 and ITU-R BS.560, define the basic acceptable quality level.

Perturbations affecting AM radio (LF, MF and HF) fall into three basic categories. In reality, AM reception is usually affected by a combination of all three.

A9.2.2 Random Noise

Environmental noise (natural and man-made) and receiver noise. The minimum acceptable audio signal to random noise ratio proposed by the ITU is 26 dB based on an assumed audio modulation depth of 30%[25].

A9.2.3 Overlapping Audio Sources

Other AM stations. Psycho acoustically, the presence of another interfering, intelligible, audio source is more intrusive than random noise. For this reason, the ITU targets a protection criterion for from another audio source of 40 dB. Traditionally, other sources of audio in the AM bands have been other radio stations and it is this protection ratio which guides the geographical separation between AM

[25] If this is assumed to be 30% 'modulation index' the audio signal power will be 13.5 dB lower than that of the carrier. Because the audio signal is correlated across the upper and lower sidebands of the composite AM signal there is 3 dB correlation gain over any random noise.

stations operating on the same frequency in the planning process. Traditionally there has been far more demand for AM channels than there are channels available and so in certain planning scenarios this is relaxed from 40 dB to 26 dB with an attendant reduction in quality. Such reductions are usually agreed by the affected parties at regional planning conferences: see for example the Geneva 1975 Frequency Plan.

A9.2.4 Single Sinusoids

Given that the Broadcasting service has a primary allocation in the LF and MF broadcasting bands, the expectation has been that the principal source of interference would be another AM broadcasting station. An AM signal consists of a large sinusoidal carrier component with relatively small information carrying sidebands so, as a source of interference, could be regarded as a single sinusoid. A single sinusoid (or the sinusoidal carrier from another broadcast station) is more pernicious as an interferer than even an audio source. Depending on the frequency, Recommendation ITU-R BS.560 calls for the wanted to unwanted ratio to be increased buy up to another 16 dB – from 40 dB to 56 dB. If the unwanted interferer is 2 kHz offset from the wanted carrier the maximum 16 dB of extra protection is required; if there is no offset the 16 dB falls to 0 dB because the effect becomes inaudible. Because of this, regional planning agreements (such as Geneva 1975 Frequency Plan cited above) aim to align all AM broadcasters onto a common frequency raster. For 'off raster' operation, the 16 dB criterion cannot be and is not relaxed anywhere. This is partly because the situation does not arise and partly because a single tone is such an aggressive source of interference. Studies carried out by the BBC and reported in [1] suggest that considerably more interference can be tolerated from an un-modulated sinusoid (such as a harmonic from a WPT-EV system) if it is accurately aligned with a broadcast raster frequency.

In practice, the psycho acoustic effect of any interference will be different depending on the genre of the AM programme material. In the presence of loud, continuous and acoustically dense material such as compressed 'pop' music, the interferer will be masked and a higher level of interference can be tolerated. Much AM broadcasting is, however, speech based. Speech is characterised by lower modulation depth, and frequent silences at the ends of sentences, pauses for breath, changing from one speaker to another, etc. The effect of any interferer and particularly a single sinusoid is most pronounced in the gaps and silences. The ITU criteria are intended to protect audio sources such as speech.

Elevated levels of random background or system noise (environmental and receiver noise) also have the effect of masking a sinusoidal interferer. A study carried out by the BBC [2] suggests that if the background noise is at the upper limit from Recommendation ITU-R BS.703 –26 dB below the wanted audio with 30% modulation depth – the masking effect would raise the tolerable level of sinusoidal interference by 8 dB; the 56 dB cited above would become 48 dB. The same study suggests that background noise at any level will mask a sinusoidal interferer that is 10 dB smaller than the noise. This does not imply that the noise itself is at a tolerable level relative to the audio.

A9.3 Background

The following is the relevant extract from § A5.1.3.4 related to the measurements done in Shanghai:

> **A5.1.3.4 Measurement results and analysis**
>
> There are total 9 AM channels in Shanghai. The signal bandwidth of each channel is 9 kHz. Two MF channels were carefully selected to address the harmonic interference test, which are the channels the harmonics of the testing WPT-EV frequency can fall into. The broadcast radio signal levels and sound quality for the MF channels were measured without any WPT-EV interference as show in Table A5-3.

TABLE A5-3

Field signal levels of MF channels in Shanghai

MF Channel (kHz)	Signal level	Sound quality score
855	Strong (94 dBµV/m)	5
1 197	Strong (86.4 dBµV/m)	4

The H field environment noise measurement result is about –17 ~ –13 dBµA/m/15 Hz around 850 kHz in an urban area in Shanghai. H field strength of environment noise level in 9 kHz is about 10.8 ~ 14.8 dBµA/m. Convert H field strength to E field strength with E/H ratio of 51.5 dBΩ. E field strength of environment noise level in 9 kHz is about 62.3 ~ 66.3 dBµV/m.

Regarding AM broadcast field strength in urban area, it was tested in Shanghai. According to the field test, the AM broadcast field strength should be at least higher than 80 dBµV/m to keep radio sound quality score above 3 in typical urban area. Since the signal level of 855 kHz is measured to be about 94 dBµV/m, SIR of radio receiver in 855 kHz channel in the field with the environment noise is estimated to be around 27.7 dB ~ 31.7 dB.

The WPT-EV signal was measured at 10 metres from the base pad. The waveform is a CW wave with field strength of about 74.4 dBµA/m. The centre frequency was set at 85.5 kHz, 85.68 kHz or 85.2 kHz respectively. The 6 dB signal bandwidth is about 1 Hz, which is restricted by the test equipment resolution. And all harmonics are CW type of very narrow band noise.

Analysis

Where a range is given in the Shanghai study, the centre value from the range is taken. Reference is sometimes made to Table A5-4 in A.9-Supplement 1 from the Shanghai study. This is in shown in Table A5-4 "The field test results summary" in Annex 5. Certain relevant values in the Table are highlighted. Summarising the measured figures in the Shanghai study it can be seen that:

Received Signal Level (Broadcast Carrier) E	+94.0 dBµV/m	(a)
Conversion Factor dBµV/m to dBµA/m	–51.5 dBΩ	(b)
Received Signal Level (Broadcast Carrier) H	+42.5 dBµA/m	(c)
Environmental Noise (15 Hz bandwidth)	–15.0 dBµA/m	(d)
Environmental Noise (9 kHz bandwidth)	+13.0 dBµA/m	(e)
Broadcast Carrier to Noise Ratio (c – e)	+29.5 dB	(f)

Commentary

From Recommendation ITU-R BS.703, the minimum usable MF broadcast signal strength is signal +60 dBµV/m based on a carrier to system noise level of 36.5 dB. The wanted broadcast signal measured in the Shanghai tests is therefore 34.0 dB stronger and the signal to noise ratio 6.5 dB worse. Both these factors will reduce the audible impact of a WPT-EV interferer. However, a quality score of 5 being achieved with such a low carrier to noise ratio suggests that the broadcast programme material at the time of the tests was heavily modulated, heavily processed and quite 'dense'; compressed 'pop' music for example. The genre of the programme material is not stated. Measurements of modulation depth on AM transmissions carried out by the BBC and reported in [Reference 3] demonstrated that the modulation depth of heavily processed 'pop' music could be 6 dB greater than speech; 40% rms as opposed to 20% rms. If this were the case, at least 6 dB more (higher level of) interference could be tolerated; probably more than this because the continuous nature of music with no silences or gaps would mask the effect.

Looking at Table A5-4 – Field Tests Results Summary (see A.9-Appendix 1) – in the report of the Shanghai tests and particularly at Column 9 – Harmful H Field – (highlighted yellow in A.9-Appendix 1) it can be seen that the actual measured values of interfering H field at the receiver location varied between 6.3 dBµA/m and 14.0 dBµA/m at 856.8 kHz (the 10th harmonic of 85.68 kHz: 1.8 kHz off raster) and between 3 dBµA/m and 11.2 dBµA/m at 1 199.52 kHz (the 14^{th} harmonic of 85.68 kHz: 2.52 kHz off raster). Curiously, at 856.8 kHz, the measured field strength reduces as the receiver/measuring point moves closer to the source of interference, which is the opposite of what might be expected. None of the figures reflects the anticipated (theoretical) 60 dB per decade[26] reduction in the magnetic field strength at increased distances from the source. Either of these factors would suggest that there might be a magnetic or possibly measurement anomaly.

Taking the figures at face value and looking at the row 8 (of data) Table A5-4 (highlighted blue in A.9-Appendix 1) which is cited as the 'worst case' the field strength measured at the receiver is 5.3 dBuA/m at a distance of 4.3 m from the source:

Separation 4.3 m	Frequency of harmonic	856.8 kHz	
Wanted signal		+42 dBµA/m	(j)
WPT-EV Level at 4.3 m from source		+5.3 dBµA/m	

Section A5.1.3 in Annex 5 suggests that the minimum separation distance between a WPT-EV charger and a victim receiver should be taken to be 3 m. 4.3 m separation is the smallest separation for which any assessment was made. Ideally, a correction should be made for this, however, extrapolation from the results in column 9 of Table A5-4 (A.9-Appendix 1) would be difficult and anyway, no test results are available.

Reconciliation

As already stated, Recommendation ITU-R BS.703 (which is itself quoted in the study) suggests that the minimum sensitivity of an average MF receiver is 60 dBµV/m; which is equivalent to 8.5 dBµA/m. At 42.5 dBµA/m (c) the wanted broadcast signal level in the Shanghai study is 34.0 dB greater than this. For comparison with the figure proposed in § A5.1.3, which is based on the minimum usable field strength and not the high incoming field strength of the Shanghai study, the figure from the study should be decreased by 34 dB.

+5.3 dBµA/m – 34.0 dB –28.3 dBµA/m (k)

To compensate for the inferred high modulation depth (see Orientation and Commentary above) this should be further decreased by *at least* 6 dB

−28.3 dBµA/m – 6 dB –34.3 dBµA/m (l)

The analysis in § A5.1.3 suggests that the maximum tolerable level should be no more than −43 dBµA/m at the receiver. So there is still an 8.7 dB gap between the levels in the Shanghai study and those from the EBU studies. However, there are a number of other factors which should be taken into account. Without having been measured at the time of the tests it is not possible accurately to quantify these effects but the following is an attempt a realistic estimate.

Receiver audio frequency response

The frequency response of the Tecsun PL-380 receiver used for the tests is unknown and not reported. The EBU analysis assumes that the audio frequency response of the receiver is flat across the audio band – up to about 4 kHz. However, the commercial receiver used for the BBC study in May 2018

[26] In the near field.

[2], a Panasonic GX-500, had an audio frequency response of which was 4 dB down at 1.8 kHz. Assuming the performance of the Tecsun receiver to be similar, the figure calculated in (l) above should be further reduced by (about) 4 dB.

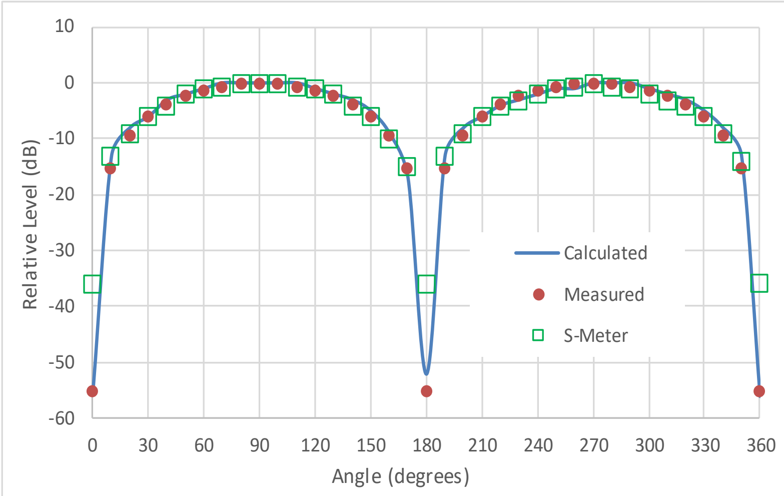
−34.3 dBµA/m – 4.0 dB −38.3 dBµA/m (m)

Receiver orientation

Nearly all commercial analogue MF receivers use a ferrite rod antenna and so the response to incoming signals is not omni-directional. Such antennas have a figure-of-eight response that allows an interfering signal to be nulled by careful orientation of the receiver. However, the attenuation of the interferer drops rapidly if the orientation is changed, as illustrated in the plot below. Tests carried out by the BBC confirm that real antennas behave as predicted, as indicated on the plot.

FIGURE A9-1

Calculated and measured receiver directivity



NOTE:

i) The receiver was equipped with a meter giving a direct reading in dBµA/m. The original idea was to rotate the receiver and take the meter reading at 10° intervals. However, the ‘Measured’ results shown were actually obtained by varying the generator level, so as to keep the meter reading constant (at 70 dBµA/m). This was felt to be more accurate.

ii) As a cross check, the original idea was also pursued. The associated results are shown as ‘S-Meter’. Note that the minimum is not as sharply defined because the noise-floor of the meter is around 32 dBµA/m.

Given the nature of the results of the Shanghai tests it seems unlikely that the receiver was deliberately oriented to maximize the interferer at the expense of the wanted signal. Indeed, the results suggest the opposite and that the orientation was quite likely not actually considered. If a median value of about 3 dB is assumed the figure calculated in (m) above should be reduced by a further 3 dB.

−38.3 dBµA/m – 3 dB −41.3 dBµA/m (n)

Audio Masking

While the BBC studies reported in [2] go some way to quantifying the effects of masking by random background noise, no quantitative assessment has been made of the masking effect of the audio signal itself. It is known (from the subjective tests reported in [1] that the intrusive effect of the interferer was greatest during short silences in speech programme. Clearly, however, louder continuous and denser audio material will have the effect of additionally masking the interference. The genre of the programme material used during the Chinese study is not reported but the fact that such high quality scores were achieved in the presence of high levels of background noise suggests that it was not speech. While difficult to quantify, an estimate, based on the results of studies relating to random noise in [2] suggests that the additional masking effect of continuous 'loud' programme could be at least 4 dB and probably more. Adjusting the figure calculated in (n) by 4 dB would bring it below the EBU figure. The fact that the figures are very close is probably coincidence.

$$-41.3 \text{ dB}\mu\text{A/m} - 4.0 \text{ dB} \qquad -45.3 \text{ dB}\mu\text{A/m} \tag{o}$$

Work carried out by the BBC in May 2018 [2] indicates that if a sinusoidal interferer, such as a WPT-EV harmonic, is more than 10 dB below the prevailing system noise it will; be masked. In this instance, the environmental noise alone[27] is 13 dBµA/m and the interfering WPT-EV harmonic is 5 dBµA/m; already 8 dB lower. Given all of the other factors (receiver frequency response, etc.) that should be taken into account, it is hardly surprising that the interferer is inaudible.

A similar analysis of the results pertaining to the 1 197 kHz broadcast transmission leads to a broadly similar conclusion.

Postcript – Building Penetration Loss

Section A5.1.2 cites: "building penetration loss" as a mitigating factor which will help to reduce the impact of WPT-EV systems on broadcast receivers. It states: "there are usually walls between the underground garages and resident buildings. The wall penetration loss will introduce about additional 17 dB attenuation to WPT-EV signal level. It has been measured and verified by the field test".

This is irrelevant for a number of reasons and so cannot be considered as a mitigation factor, namely:

1) It is not true that there will always be a wall of any kind between the WPT-EV charger and a broadcast receiver. Portable receives are often operated outdoors and a high proportion of AM broadcast listening takes place in cars[28]. Also the vast majority of car users (certainly in Europe) do not have access to underground parking.

2) The figure of 17 dB is derived from a study carried out with formed radio waves at 5.8 GHz. It cannot be assumed without further study that the behavior of radio waves at 6 GHz is in any way comparable to the behavior of magnetic fields at below 30 MHz.

3) Following from 2), at the separation distances envisaged (and quite likely everywhere), the spurious emissions from WPT-EV systems will not be radio waves and so the whole concept of building penetration loss is probably not relevant. What is relevant is the propensity for magnetic fields to penetrate buildings. An informal study carried out by the BBC and reported in Attachment 3 to Annex 8 (building entry loss) demonstrates that most common building materials (brick, wood, plastics, glass) are completely transparent to magnetic fields and so will have no attenuating effect. Exceptions are magnetic materials like steel and conducting materials in which eddy currents might perturb the magnetic field. Of itself, concrete is magnetically transparent however, it is frequently used with metal (conducting) re-enforcement and eddy currents in the re-enforcement could perturb the magnetic field. On a global scale residential buildings made from conducting materials and from steel are uncommon. Residential buildings made from re-enforced concrete are more common but not sufficiently so to make this a factor.

[27] Given the high level of environmental noise it is unlikely that receiver noise will make any significant contribution. If it did it would only add to it.

[28] Figures in the UK from RAJAR (Radio Joint Audience Research) suggests that 22.8% of the radio audience is in cars.

A9.4 References

[1] BBC Research and Development White Paper WHP322 (2017) – Wireless Power Transfer: Plain Carrier Interference to AM Reception
https://www.bbc.co.uk/rd/publications/wireless-power-transfer-plain-carrier-interference-to-am-reception

[2] BBC Research and Development White Paper WHP322 (2017) – Wireless Wireless Power Transfer (WPT) – Further Studies on the Performance of MF Sound Broadcasting Receivers in the Presence of Interference from WPT.

[3] Report ITU-R BS.2433-0, "Assessment of modulation depth for AM sound broadcasting transmissions" (10/2018).

Annex 10

Study on the Impact of WPT-EV operating in the 79-90 kHz range on Radio Communications Systems in the Amateur Service

A10.1 Introduction

This Annex sets out an analysis of the impact of WPT-EV systems on radio communications in the amateur service. Data for the analysis is drawn from published information about the amateur service, WPT-EV systems and from existing reports and studies in CEPT, ITU and CISPR/CENELEC.

A10.2 Background

The amateur service is a radio service defined in the ITU Radio Regulations (RR No. 1.56). There are some 3 million licensed amateur radio operators around the world. ITU Radio Regulations set out the frequencies allocated to the amateur service. Although allocations vary slightly between ITU Regions and in individual countries, Table A10-1 provides a general overview of current allocations up to 1 GHz. There are also numerous allocations above 1 GHz.

TABLE A10-1

Global allocations to the amateur service below 1 GHz in the ITU RR and under RR 4.4

(Note that there are national and regional variations to this Table in some frequency ranges)

Frequency range	Allocation status
135.7-137.8 kHz	Secondary allocation
472.0-479.0 kHz	Secondary allocation
1 800-2 000 kHz	Part primary, part secondary
3 500-4 000 kHz	Primary allocation
5 351.5-5 366.5 kHz	Secondary allocation
7 000-7 300 kHz	Primary allocation
10 100-10 150 kHz	Secondary allocation
14 000-14 350 kHz	Primary allocation
18 068-18 168 kHz	Primary allocation
21 000-21 450 kHz	Primary allocation

Frequency range	Allocation status
24 890-24 990 kHz	Primary allocation
28.0-29.7 MHz	Primary allocation
50.0-54.0 MHz	Part primary, part secondary
70.0-70.5 MHz	Secondary allocation
144-148 MHz	Primary allocation
430-450 MHz	Secondary allocation

The characteristics of stations operating in the amateur service are set out in Recommendation ITU-R M.1732 [1]. Protection issues for the amateur service are drawn from Recommendation ITU-R F.240.

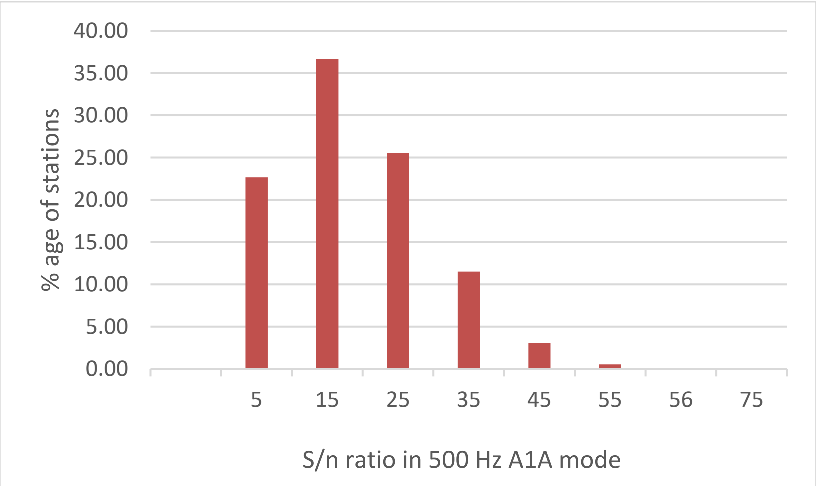
The amateur service is essentially a low-power service which relies on having a low background noise level for its operation.

Because there are no minimum signal levels associated with amateur service communications, then to properly assess the service's susceptibility to harmful interference it is necessary to examine the actual pattern of communication in the service. The amateur service Reverse Beacon Network[29] provides a real-time database of amateur A1A mode signals automatically monitored at several hundred receiving stations around the world and globally aggregated. To arrive at some indication of the typical signal to noise ratio of communication in the amateur service, the data from these monitoring stations over an extended period has been analysed.

Figure A10-1 shows the distribution of A1A signal levels in the amateur service drawn from 528 280 data points.

FIGURE A10-1

Distribution of typical S/N ratio in amateur service communications



Should the above data be presented in the same bandwidth as the Recommendation ITU-R P.372-13 [2] measurements, this would result in a 13 dB worsening of the above signal to noise ratios.

This chart shows convincingly that any significant raising of the background noise level will have a very significant impact on amateur service communications, as the majority of communication is currently relatively close to the noise level.

[29] http://www.reversebeacon.net/

The above signal to noise ratios are relative to the background noise levels and for this purpose, the man-made background noise levels defined in Recommendation ITU-R P.372-13 are relevant as a reference point. Although there has been some increase above these levels in the 'city' noise, recent reports have suggested that the residential and rural levels have risen somewhat – in the order of 10-16 dB. In terms of quiet rural, there is some evidence that the levels have risen a little, believed to be due to the cumulative effect of millions of low power digital devices (e.g. switch-mode power supplies, LED lighting system power units, solar PV systems and PLT/BPL installations) creating broadband emissions propagated by ionospheric reflection.

One aspect of the need for a low noise environment in the amateur service is that users of the amateur services are called upon to provide disaster relief communications – often at low signal levels. In many countries, amateur radio is seen as a valuable back-up service in case of breakdown or overload of normal communications systems. Governments rely on this capability at times of emergency. Amateur service HF and VHF allocations are used for this purpose. The word 'amateur' can be misleading, as stations in the amateur service are also involved in fundamental ionospheric and propagation research. It is self-evident that any significant degradation of the background noise level will adversely impact the service's capability in all these areas.

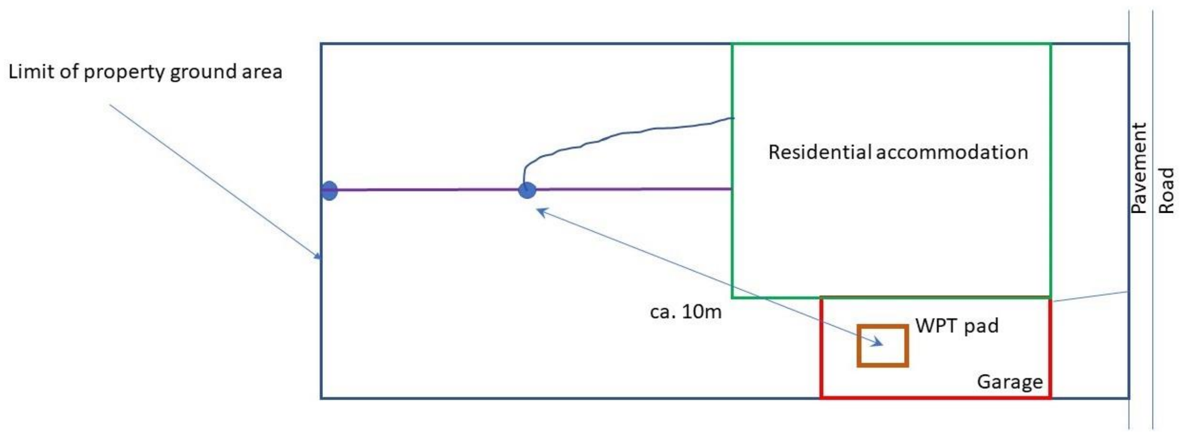
Precedents have been set to recognise the need for protection of amateur service frequencies in standards and limits relating to Power Line Telecommunications [3], DSL services [4] and Gfast [4]. It is worthy of note that the level of additional protection enshrined in, for example, the PLT limits in CISPR are of the same order as are proposed later in the Annex.

A10.3 The location of WPT-EV installations

WPT-EV systems are planned for the home environment, in domestic garages, as well as parking lots and public service areas. Therefore, domestic WPT-EV installations can be expected to be close to living accommodation. Figure A10-2 represents a schematic representation of a typical WPT-EV domestic installation co-sited with an installation in the amateur service. It will be noted that it is entirely feasible (indeed likely in many cases) that the antenna for the amateur service installation is within 10m of the WPT-EV installation.

FIGURE A10-2

Schematic of a typical dwelling house location in the UK



A10.4 Levels of emissions in the spurious domain

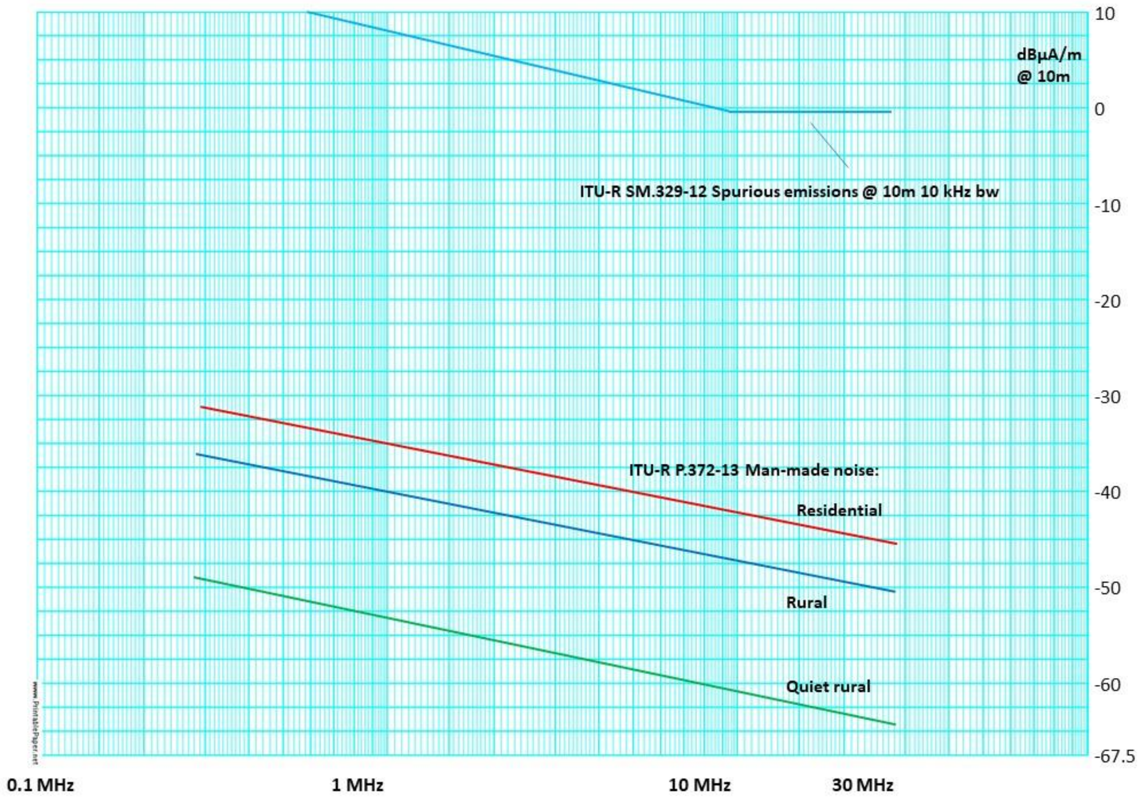
There are currently no agreed limits for harmonic and other radiated emissions from WPT-EV systems. There is limited information available about the actual radiated emissions at harmonic frequencies from such systems operating in the 79-90 kHz range. In some papers, assumptions have been made that limits developed for other purposes (e.g. low power inductive devices) may be appropriate for WPT-EV. These limits do not, of themselves, claim to provide adequate protection from harmful interference, but there is evidence that they are being taken as a planning basis by some developers of WPT-EV systems. Nonetheless, taking these limits as a basis for system performance allows an assessment to be made of the gap between proper protection of stations in the amateur service and WPT-EV emissions.

Figure A10-3 below shows the emission levels set out in Recommendation ITU-R SM.329-13 (these are close to the CISPR11 Class B limits) and the background noise levels in Recommendation ITU-R P.372-12. It will be seen that there is a very significant gap between these levels. Spurious emissions at the limit levels shown will exceed the background noise level by 40-50 dB, which would clearly have a very harmful effect on radio services operating at low signal to noise ratios.

NOTE – The noise levels are derived from Recommendation ITU-R P.372-13. The values in § 1.2.3 of the 'r.m.s noise field strength' are in dB(μV/m). The two following Figures depict dB(μA/m) unit. The conversion assumes the far-field resistance of 377 Ω.

FIGURE A10-3

Graphical representation of Rec. ITU-R SM.329-12 unwanted emissions limits compared with background noise levels in Recommendation ITU-R P.372-13

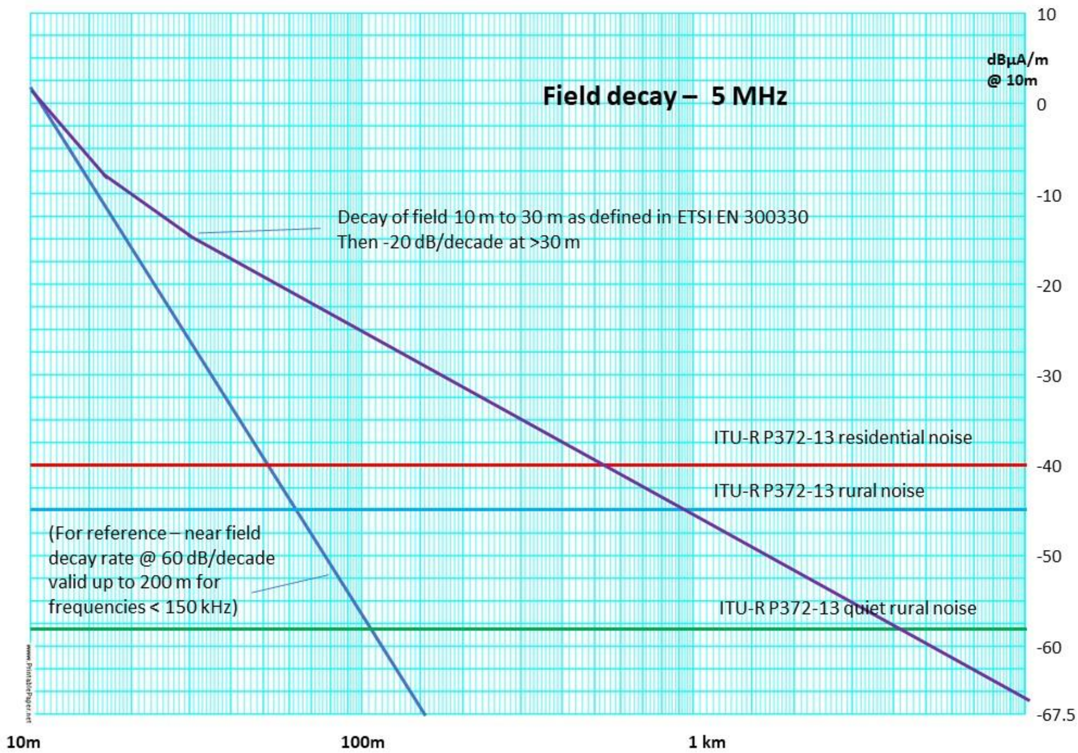


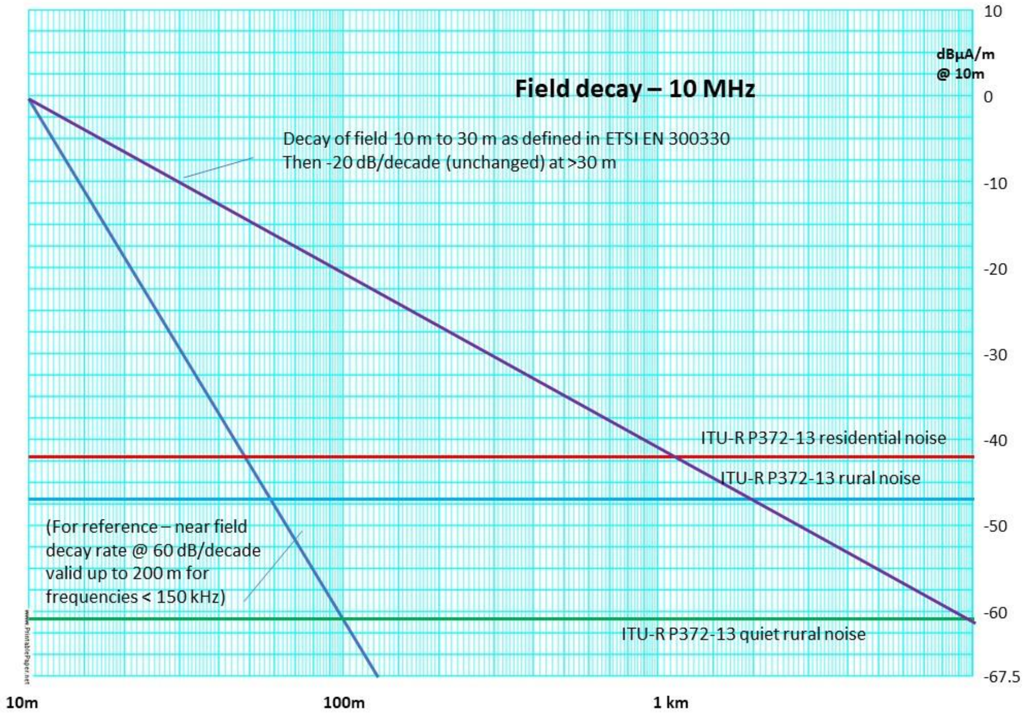
Furthermore, the characteristics of the emissions from inductive devices is defined in, inter alia, the European Harmonised Standard ETSI EN 300330 [5]. Although previous modelling has often assumed a "near-field" decay rate of 60 dB/distance decade, the ETSI document confirms that decay rates of the emissions depend on frequency. Appendix I of EN 300330 sets out the relevant decay rates for adjustments of measuring distance from 10 m to 30 m and combining this with other data on near-field to far-field transition distances allows an assessment to be made of the emissions from a WPT-EV systems with emissions (measured at 10 m) at the short-range device limits of Recommendation ITU-R SM.329.

Using this data, the plots in Fig. A10-4 show the projected harmonic radiated emissions at 5 MHz and 10 MHz arising from harmonics of the WPT-EV system operating at the levels hypothesised. It will be seen that at 5 MHz, the emissions exceed the rural background noise by 10 dB or more at distances of around 250 m from the WPT-EV installation and at 10 MHz this distance increases further. This gives added weight to the argument that spurious radiated emissions measured at 10 m need to be very significantly below the limits understood to be being considered by WPT-EV developers, so as to prevent harmful interference to radio services.

FIGURE A10-4

Emission decay at 5 MHz and 10 MHz based on EN 300330





A10.5 An appropriate level of protection

In the absence of meaningful measurement being provided to ITU of harmonic radiated emissions from 79-90 kHz WPT-EV systems, any assessment of the true size of the performance gap is speculative. It is for this reason that the above analysis has used the limits which have been suggested elsewhere as being considered for WPT-EV.

More meaningful would be a definition of what is required to provide an appropriate level of protection in the amateur service.

Recommendation ITU-R F.240 requires a judgement to be made of the required service level and the mode of communication employed. To arrive at a generic protection requirement for the amateur service, the least demanding of the service levels has been adopted, coupled with the most demanding protection level in terms of the transmission modes most common in the amateur service. For small-signal services, there are established precedents for limiting the increase of background noise to 0.5 dB [3]. This broadly aligns with the least demanding protection levels suggested in Recommendation ITU-R F.240 using the above methodology.

Using the ITU-R P.372-12 levels for rural environments suggests that, assuming that the WPT-EV emissions are unstable in frequency or are not all exactly on a common frequency and/or with levels of phase or sideband broadband noise, then this gives a required protection level of:

−45.5 dBµA/m at 300 kHz reducing by 8 dB per frequency decade to −61.5 dBµA/m at 30 MHz.

For comparison, should the residential noise line be selected as the baseline, then the protection requirement becomes:

−4.5 dBµA/m at 300 kHz reducing by 8 dB per frequency decade to −57.5 dBµA/m at 30 MHz.

It should be noted that this will fall short of necessary protection in rural areas.

All measurements conducted at 10 m distance

If WPT-EV is a highly stable pure sinusoidal signal, using a universally adopted common frequency of operation, with broadband noise no higher than the above, then the amateur service signals are more tolerant to some level of interference from the sinusoidal emission, as harmonic radiation would be confined to a number of "spot" frequencies throughout the spectrum. In such a case then harmonics of the pure sinusoid could reasonably be permitted to exceed the above level by some 20 dB.

A10.6 Measuring existing systems

A study of some of the data submitted on measurements of existing WPT-EV systems shows that measurements of the background noise level in some reports on emissions from WPT-EV systems appear to be seriously technically flawed, as a result of using measuring equipment that simply lacks the sensitivity to measure the true background noise level.

For background noise measurements between 3-30 MHz as a rule of thumb a minimum system sensitivity of −158 dBm/Hz is needed to perform a meaningful measurement. Noise in the measuring system (particularly the active antenna) presents a false impression of the true background noise levels. In particular the studies included in the current ITU-R PDNR for WRC-19 agenda item 9.1.6, present an inaccurate picture of the true noise levels through use of inappropriate measuring equipment.

Great care is therefore needed, when seeking to measure the background noise levels at a test site, to ensure that appropriate antennas and test receivers are used for the levels of emissions anticipated. Tests so far have often failed to properly reflect the full dynamic range of the spectrum in question.

It is very likely that, given the protection requirements necessary to prevent harmful interference to radio services from WPT-EV, new test methods and procedures will be needed to be specified.

A10.7 Summary

Preservation of the utility of the radio spectrum must be a prime objective in the introduction of new technologies; this is enshrined in Articles 15.12 and 15.13 of the Radio Regulations and in relevant EMC standards. WPT-EV for Electric Vehicles will cause significant and widespread damage to the radio spectrum unless appropriate standards and limits are established which are significantly more stringent than those existing for inductive devices for other purposes at present. This study shows that setting radiated emission limits outside the operating frequency of the WPT-EV system which provide proper protection is an essential element of the introduction of WPT–EV technology. Without this, co-existence of radio communications services and WPT-EV systems in the same environment is not viable.

References

[1] Recommendation ITU-R M.1732 – Characteristics of systems operating in the amateur and amateur-satellite services for use in sharing studies

[2] Recommendation ITU-R P.372-13 – Radio Noise

[3] Report ITU-R SM.2158 – Impact of power line telecommunication systems on radiocommunication systems operating below 80 MHz

[4] Recommendation ITU-T G.993.2 Amendment 2 (03/2016) –Very high speed digital subscriber line transceivers 2 (VDSL2), (Section 7.2.1.2 Egress Control)

[5] EN300330 Short Range Devices (SRD) –Radio equipment in the frequency range 9 kHz to 25 MHz and inductive loop systems in the frequency range 9 kHz to 30 MHz; Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU

[6] Recommendation ITU-R F.240 – S/I in the fixed service, below about 30 MHz

Annex 11

Analysis of the impact of WPT-EV systems to T-Coil hearing aid systems

The T-coil has been in use since 1927 and is the only universal world-wide communication systems for the hard of hearing it can be found in many environments from domestic to business and is common or in some Countries mandated in mobile and land line phones.

It will be available where the blue ear symbol is displayed:

It uses a base band audio signal of up to 10 kHz.

Whilst practical testing has taken place with two types of bus WPT-EV systems and < 15 Watt (conducted transfer power devices which show minimal interference the high power EV systems have yet to be considered. Further information is available in Recommendation ITU-R M.1076-1.

A11.1 Operational parameters

Achievable magnetic field strength of an induction loop system over a 'covered area' should be 400 mA RMS per metre.

Frequency range: 50 Hz to 10 kHz

Sensitivity is between −98 dBVrms to −95 dBVrms

A11.2 Interference limits

It is considered that exceeding the field strengths identified below will generate interference to T-Coil receivers

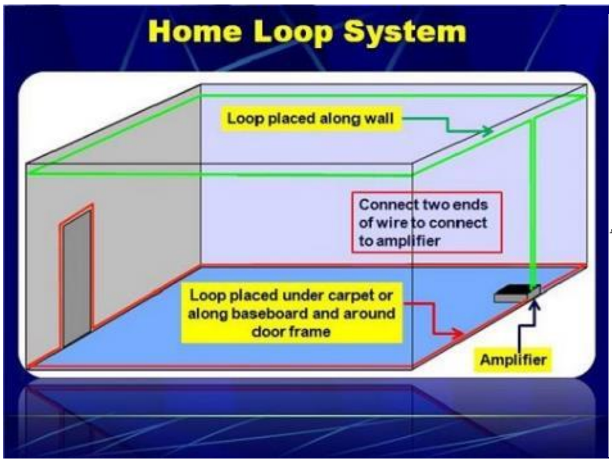
Frequency range	Minimum field strength at 1M to cause interference
50 Hz – 12 kHz	0.3 mA/m
>12 kHz – 100 kHz	300 mA/m

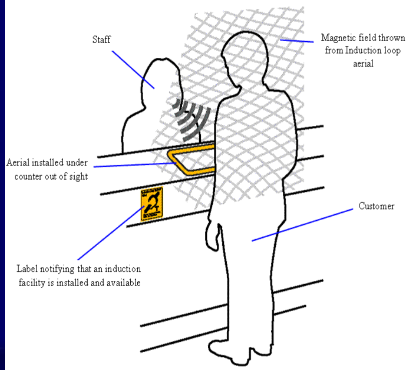
A11.3 T-Coil Transmitters

A hearing loop (sometimes called an audio induction loop) is a special type of sound system for use by people with hearing aids. The hearing loop provides a magnetic, wireless signal that is picked up by the hearing aid when it is set to 'T' (Telecoil) setting.

The hearing loop consists of a microphone to pick up the spoken word; an amplifier which processes the signal which is then sent through the final piece; the loop cable, a wire placed around the perimeter of a specific area i.e. a living or meeting room, a church, a service counter etc to act as an antenna that radiates the magnetic signal to the hearing aid.

Below is a diagram of a hearing loop at a shop counter or bank and a home setup:





A11.4 T-Coil receivers

These come in a variety of types although the majority of modules are made by the same company

Plug in module for Hearing aid

Over ear unit to enhance for phones etc

Neck loop

T-Coil incorporated in Hearing Aid

:

Annex 12

Impact studies on HF amateur radio in United States for WPT-EV

A12.0 Abstract

The impact study reviews the current status of amateur radio regulations and selected allocated HF bands in the United States as of February 2020. A standard pre-production prototype ~11 kW WPT-EV system mounted on a Nissan Leaf is described. Radiated emissions testing was performed with the WPT-EV system in accordance with standardized international practices at an accredited third-party open area test site and the results compared with typical amateur radio equipment used. Calibrated data was collected by the third-party lab, and licensed amateur radio operators performed the amateur radio tests to collect data both with a calibrated spectrum analyser and off-the-shelf amateur radio equipment. The study attempts to identify interference potential caused by the harmonics of standardized WPT-EV systems in a real-world environment.

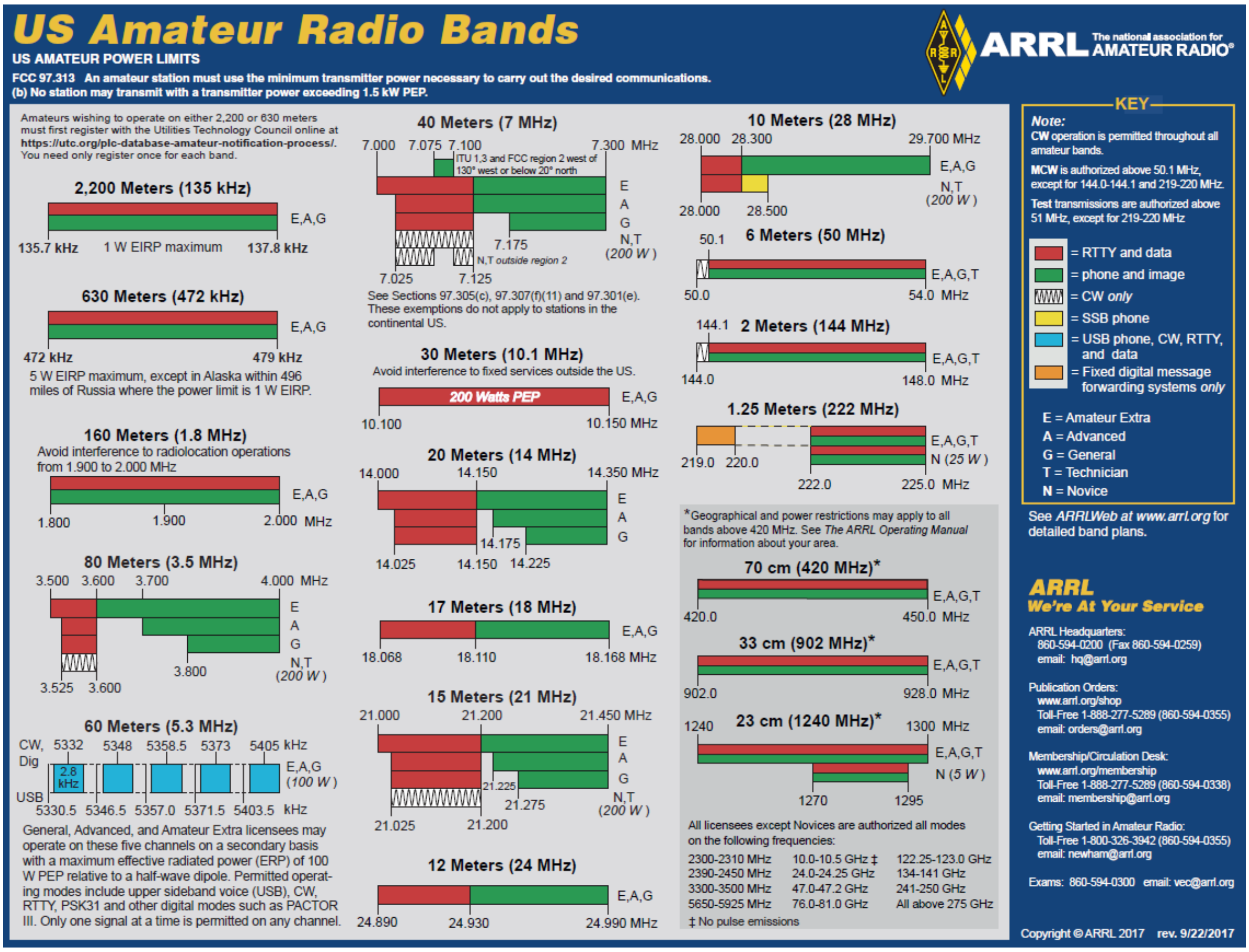
A12.1 Introduction to amateur radio in the United States

In the United States of America, the amateur service is regulated by Title 47 Part 97 of the Federal Code of Regulations. The primary purposes for amateur radio include usage for non-commercial, public, and voluntary emergency communications as well as providing opportunities for the advancement of radio art, skills in communications, and generally enhancing international goodwill. According to the American Radio Relay League (ARRL) and the FCC's Licensing system, as of February 12, 2020, the number of active FCC amateur radio licenses held by individuals in the United States is 765006 with an average annual growth rate of about 1% over the last 5 years. The number of licensees corresponds to approximately 0.23% of the US population and an estimated density in the range from 0.2 to 2 licenses per km^2 in suburban areas. The United States may belong to the top 5 countries with the highest number of issued amateur radio licenses per inhabitant. The states of California and Texas rank as the top 2 states respectively for the number of active amateur radio licenses.

Amateur operators use many different types of analogue and digital communication techniques such as SSB AM (single side-band amplitude modulation), CW (continuous wave), FM (frequency modulation), TV, PACTOR, PSK31, RTTY, and other modes. In the United States, a "Band Plan" is used and published by ARRL to indicate how each portion of the spectrum is to be used effectively by amateur operators. FCC regulations and amateur radio operators typically refer to their available bands of spectrum as indicated by the radio wavelength in free space. An example of the ARRL band plan for the United States is shown below and can be found on ARRL's website [2].

FIGURE A12-1

ARRL band plan for United States of America



Some amateur operators create homemade transceivers; however, most amateur transceivers are purchased from commercial sources known for their amateur radio equipment such as ICOM, YAESU, KENWOOD, or ELECRAFT. A review of mobile and base station transceiver products from these sources indicate all the HF products (including most portable transceivers) can transmit using a number of analog and digital operating modes on bands starting with the 80 m band (3.5 MHz to 4 MHz) and going up in frequency to the 6 m (50 MHz to 54 MHz) or 2 m (144 MHz to 148 MHz) bands. Most base station transceivers also have the capability to go as low in frequency as the 160 m band (1.8 MHz to 2 MHz). The longer wavelengths of the low frequency bands also require much larger antennas for effective radio communication meaning that most portable HF antennas target the 80 m to 6 m bands for operation which isn't fixed to a station location. Most commercial transceivers can transmit at power levels from 50 W to 200 W and require a separate linear power amplifier to operate at higher power levels. FCC's Title 47, Part § 97.313 requires the use of minimum necessary power to carry out the desired communications, but it allows operators to transmit up to 1.5 kW peak envelope power (PEP) for the 80 m, 40 m, and 20 m HF bands; and up to 200 W PEP for the 30 m HF band.

Ionospheric propagation is one of the key modes of propagation used in the HF bands enabling communication over distances of thousands of kilometres in some cases. Amateur operators utilizing the HF bands make extensive use of these "skywave" propagation modes to communicate with other licensed amateur operators in all continents around the globe. The lower frequency bands such as the 80 m and 40 m band are favoured for communication within shorter ranges (e.g. < 1000 km) or even shorter (e.g. < 100 km) using Near Vertical Incidence Skywave (NVIS) modes.

For the qualitative assessment of impact that is part of this impact study, the 80 m and 40 m amateur radio bands were determined to be the most feasible and likely to be impacted from harmonics originating from a WPT-EV system operating in the ITU-R recommended frequency range of 79-90 kHz (~85 kHz nominal). Additional data was also collected for the 30 m (10.10 MHz to 10.15 MHz) and 20 m (14 MHz to 14.35 MHz) bands as well. For practical reasons, the 160 m band was not tested, although the amateur operators doing the testing agreed that data from the 80 m band could reasonably be extrapolated to the 160 m band. The impact study was funded by a SAE J2954 Cooperative Research Program made up of many automakers and several suppliers. All testing was performed by an independent EMC lab at TDK RF Solutions in Cedar Park, Texas using an accredited Open Area Test Site (OATS). One or more licensed amateur radio operators, all of whom were also members or staff of ARRL, or officials within the International Amateur Radio Union were also involved in collecting the qualitative assessment data and selecting the appropriate amateur equipment.

A12.2 Characteristics of standardized WPT-EV systems

For the purposes of this impact study, only WPT-EV systems designed to meet the SAE J2954 and related WPT-EV standards, with specific characteristics outlined in § 3.3.1, were considered.

A12.3 Measurements performed on an open area test site (OATS)

A12.3.1 Characteristics of the WPT-EV equipment under test (EUT)

The WPT-EV system used for this impact study was a prototype pre-production system with the vehicle coil assembly mounted on a Nissan Leaf just behind its front axle at a height providing a ground clearance of 175 mm. The WPT-EV system comprised of a wall box power supply, the ground assembly, and the vehicle assembly together with the vehicle corresponding to a typical garage setting is considered the EUT. The vehicle assembly was operationally connected for charging the vehicle’s traction battery. The power input level to the WPT-EV was ~11.1 kW complying with the WPT3 power class as defined by SAE J2954. For radiated emissions testing, in order to reduce undesirable effects of the ground plane, the vehicle and the ground assembly were raised 15 cm from the OATS metal floor as recommended by several standards bodies (to better emulate real-world conditions and avoid parasitic metal ground plane interaction). The coil of the vehicle assembly was centred on the turn table and worst-case alignment offsets were set by shifting the ground assembly coil accordingly. Standard EMC practices based on international standards for radiated emissions testing were applied.

FIGURE A12-2

WPT-EV system setup for radiated emissions testing on an OATS (side view)

FIGURE A12-3

WPT-EV system setup for radiated emissions testing on an OATS (front view)

The design of the particular WPT-EV study used is based on the criteria and details outlined in SAE J2954, ISO 19363, and IEC 61980. The system operates at a fixed frequency of 85 kHz and utilizes magnetic resonance to transfer its energy at that frequency. Refer to the text and images shown in § 3.3.1 which provide information related to the relative harmonic content expected in the ground assembly coil current. While the magnetic field emanating directly from ground assembly coil is not the only possible source of emissions, it is generally the source of most discussion regarding potential impact of WPT-EV on radio broadcasts and amateur radio reception.

A12.3.2 Characteristics of the OATS

The OATS used for testing is owned by TDK RF Solutions, Incorporated and is located in Cedar Park, Texas near Austin, Texas. All measurements were made at this A2LA accredited calibration lab. A satellite image of the OATS can be seen using Google Maps as shown below.

FIGURE A12-4

Satellite image of TDK RF solutions OATS

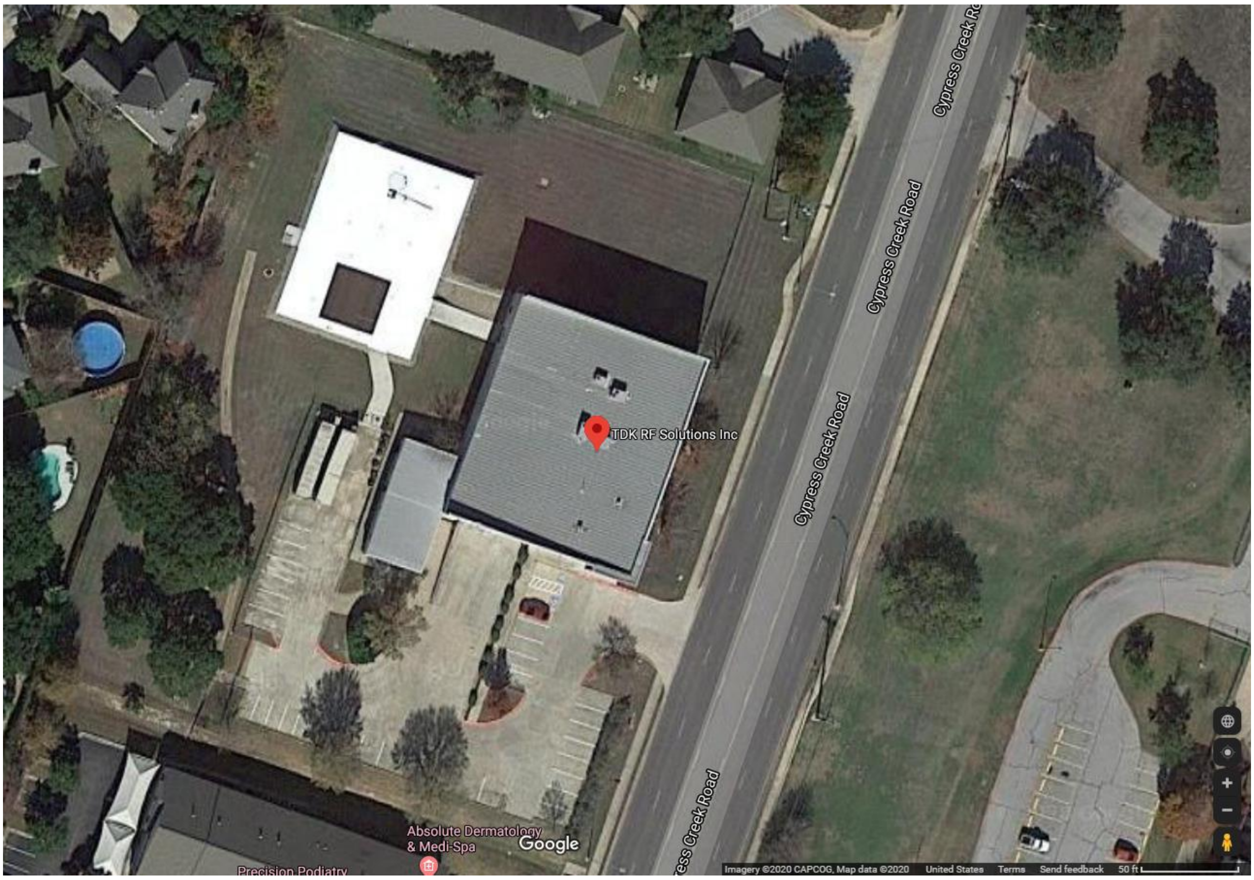
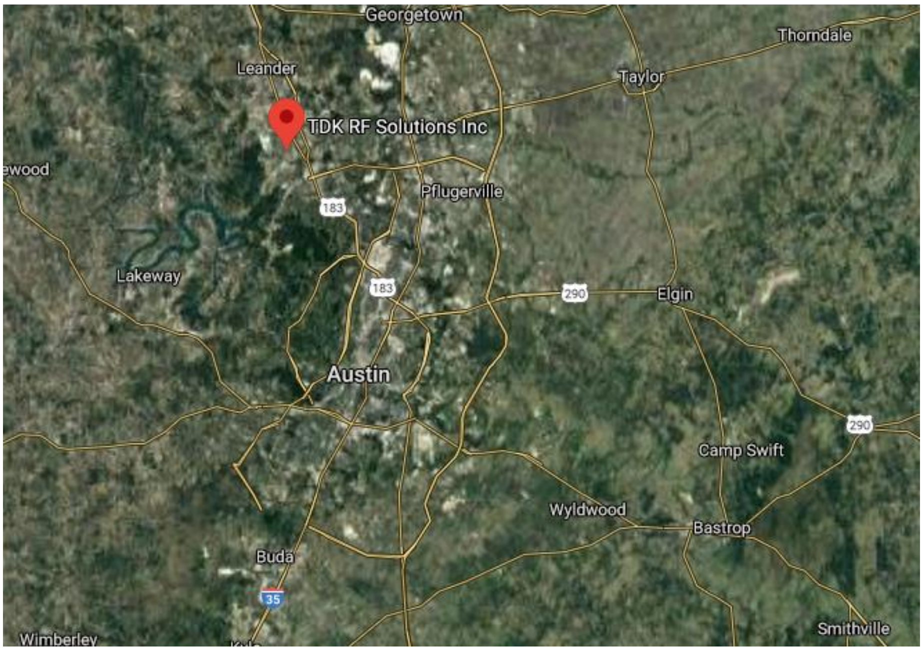


FIGURE A12-5

Overview map of location of TDK RF solutions OATS

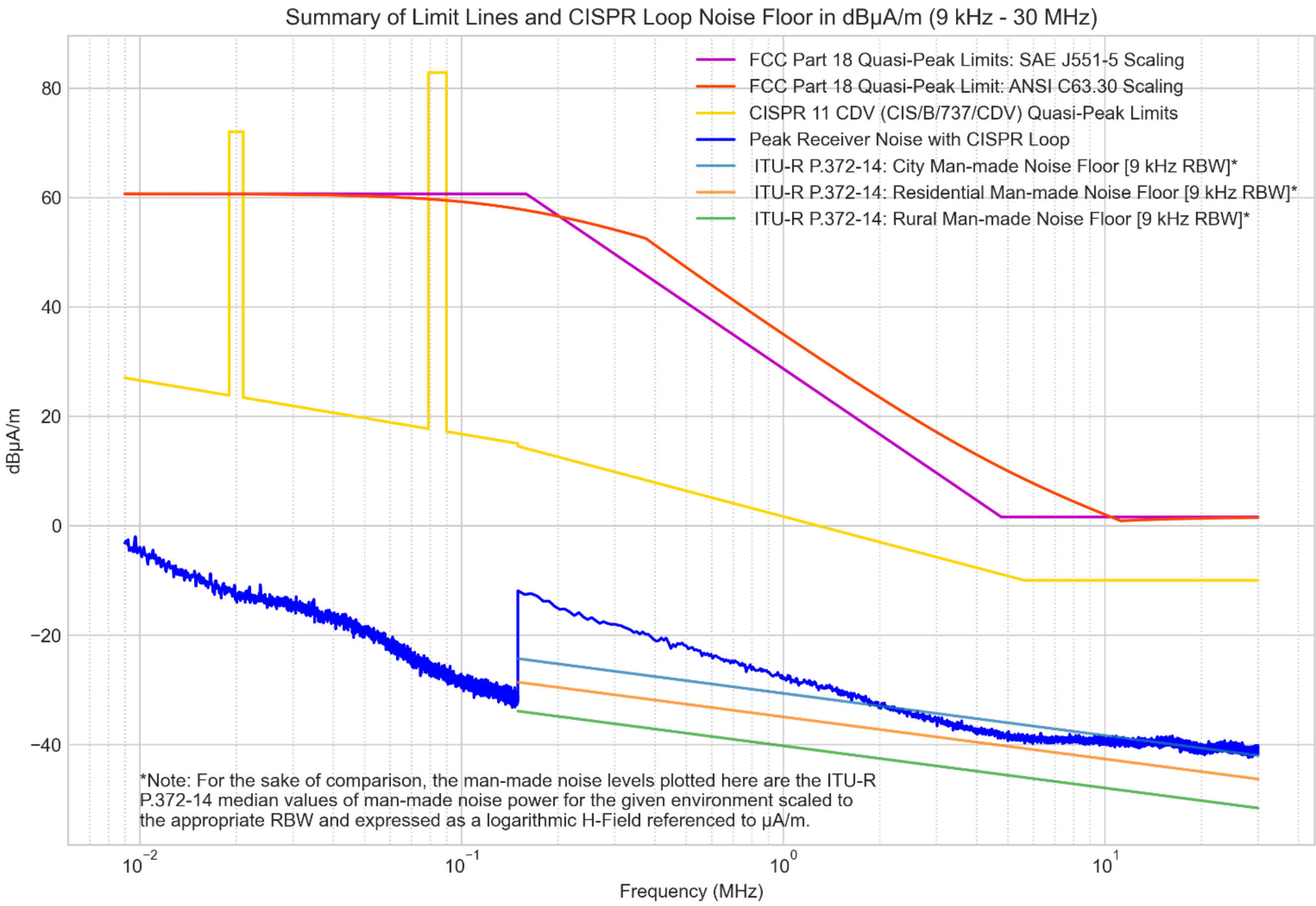


According to the United States Census Bureau, Cedar Park had an estimated population of 76,999 in July of 2018 [4]. Its population density is based on census data in 2010 and was 2,141.9 people per square mile (~5,547.5 people per square kilometre). According to the U.S. FCC's Universal Licensing System, as of February 12, 2020 there are 342 active amateur radio licenses registered in Cedar Park corresponding to 0.44% of the estimated population.

In order to characterize the peak ambient RF conditions at the TDK RF Solution's site, a calibrated loop, as defined in CISPR 16-1-4, was used to record radiated emissions measurements at various times of the day and with various antenna orientations. The results of the ambient emissions with this antenna is shown below combined with standardized and proposed emission limits. The FCC Part 18 limits shown in the plots are based on conversion and scaling from the 300 m limits to magnetic field limits at 10 m based on ANSI C63.30 [20] scaling as proposed by Joseph McNulty of the FCC [19]. Additional scaling has been proposed such as SAE's J551-5 scaling procedures that result in similar scaled limits to 10 m as seen in the comparison chart below. The extrapolations are conservatively based on the principle that field strength decays at a 20 dB/decade rate in the far-field region of a radiating source and decays at a rate of 60 dB/decade within the near-field region. The limits as outlined in the failed CIS/B/737/CDV document are also shown in the charts only for comparison. Standard CISPR settings utilizing a resolution bandwidth (RBW) of 200 Hz from 9 kHz to 150 k Hz, and a RBW of 9 kHz from 150 kHz to 30 MHz was used for EMC assessment and ambient peak correlation to collect the data. It should be noted that the ambient data collected represents peak data as seen at the receiver (using the CISPR peak detector) including local ambient transmission bursts and some time-varying narrow-band signals. The peak ambient data does not represent the man-made radio noise floor as outlined in Recommendation ITU-R P.372 [15], which is based on median values of man-made noise for the given environment. It has been suggested by several more recent studies e.g. carried out by the University of Twente in the Netherlands (IEEE paper [16]) and the Basque University in Spain [17], however, that the man-made noise floor in the MF and HF band has risen in recent years. For a complete comparison of measured data, EMC limits, and noise floor levels, the chart below shows a comprehensive summary including the Recommendation ITU-R P.372-14 median man-made noise factors converted to magnetic field strength (in dBμA/m) assuming a monopole antenna. It also includes the Recommendation ITU-R P.372-14 value updates as suggested in [16], peak ambient conditions, and measured peak system receiver noise.

FIGURE A12-6

Overview of limits and system noise with CISPR loop, as well as converted Recommendation ITU-R P.372-14 man-made noise levels and suggested IEEE paper updates based on different noise measurement procedures as outlined in Recommendation ITU-R SM.1753-2 (i.e. statistical, non-peak measurements)



* For the sake of comparison, the man-made noise levels plotted here are the ITU-R P.372-14 median values of man-made noise power for the given environment scaled to the appropriate RBW and expressed as a logarithmic H-field referenced to µA/m.

NOTE – Recommendation ITU-R P.372-14 and IEEE referenced levels are included for informational purposes; however, it is important to note that the measurement procedures for the peak measurements and the Recommendation ITU-R P.372 man-made noise measurements and procedures are very different as outlined in Recommendation ITU-R SM.1753.

For a direct comparison of only the system receiver noise with the TDK CISPR 60 cm loop antenna used in measurements and other commercially available antennas, the plot below is from a study conducted by CISPR B in CIS/B/736/INF [21] using the same RBW settings (200 Hz RBW from 9 kHz to 150 kHz and 9 kHz RBW from 150 kHz to 30 MHz).

FIGURE A12-7

System noise measurements with various system loops as performed by CISPR B and reported in CIS/B/736/INF

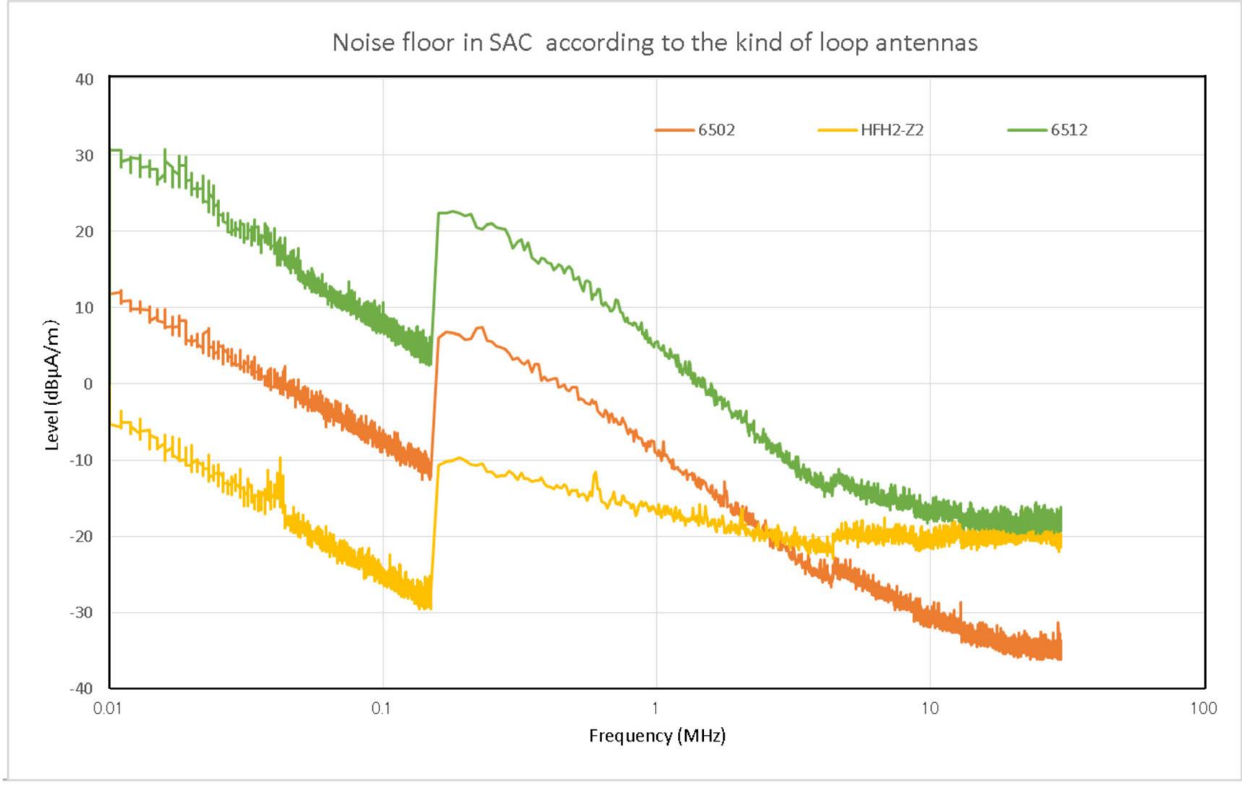
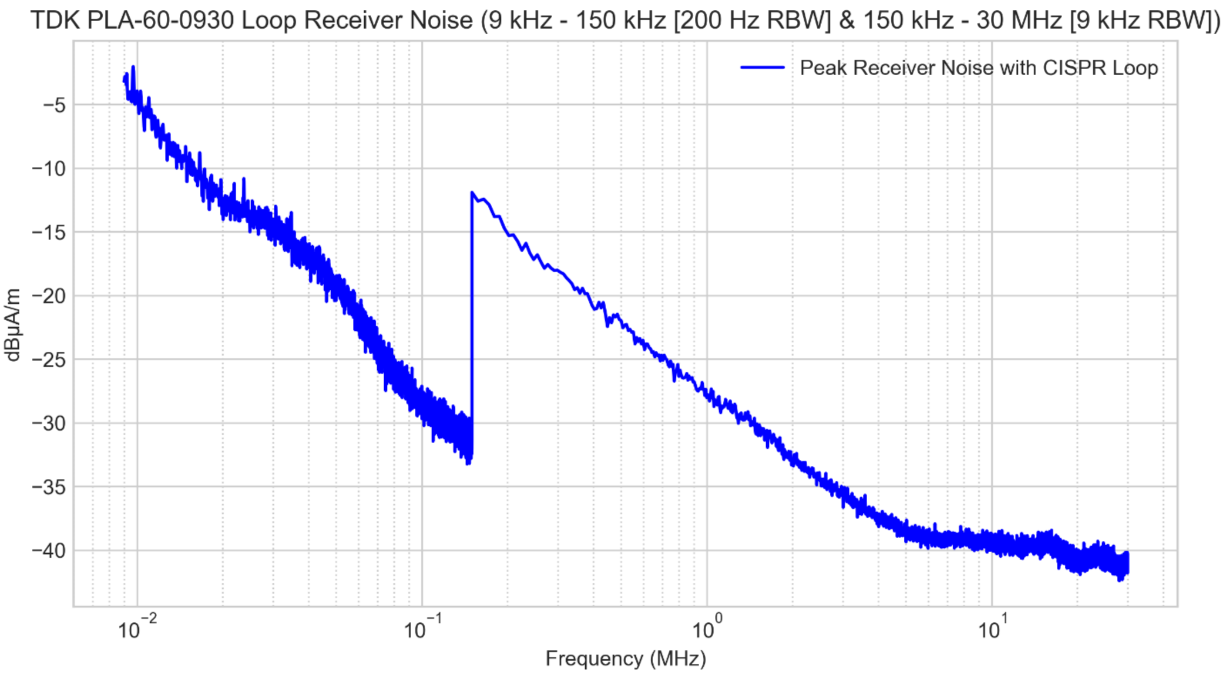


FIGURE A12-8

System noise measurements with the TDK PLA-60-0930 CISPR Loop used for measurements in this impact study



The following plots show peak ambient emissions at the OATS to assist in visually identifying peaks related to the WPT-EV system tested versus ambient peaks present at various times during testing. Plots are given in consideration with orientations in X and Y being coaxial and coplanar respectively to the location of the EUT (i.e. perpendicular from ground plane) as well as the Z orientation with the loop being horizontal (i.e. parallel with ground plane).

FIGURE A12-9

Ambient peak measurements on the OATS with calibrated magnetic loop orthogonal to the ground plane

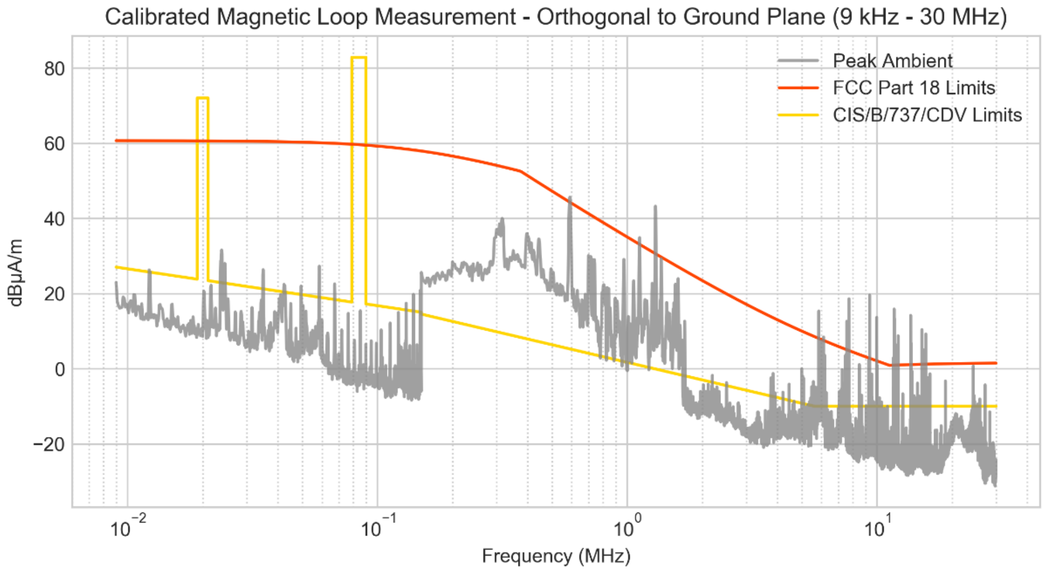
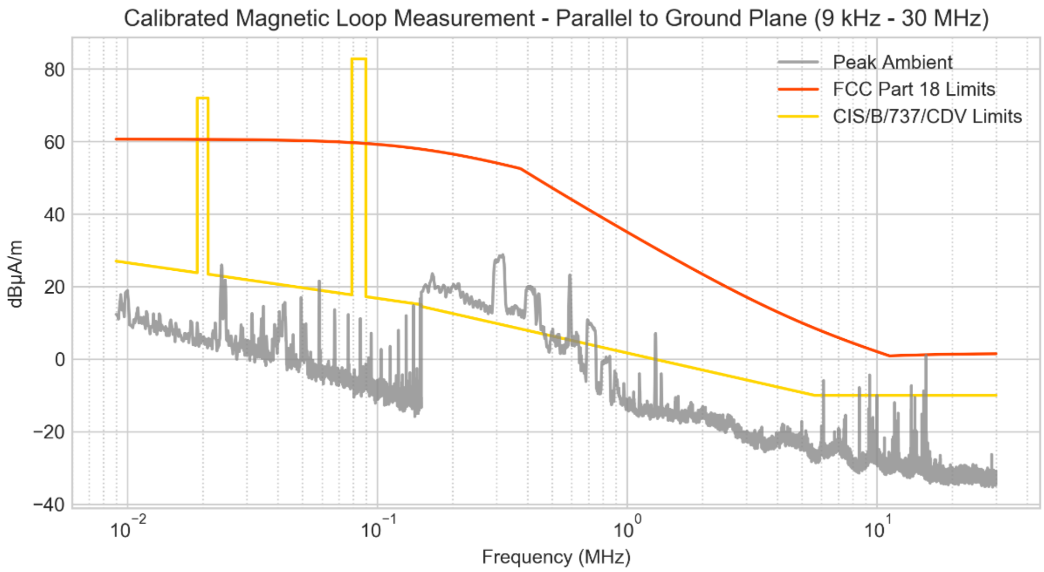


FIGURE A12-10

Ambient peak measurements on the OATS with calibrated magnetic loop parallel to the ground plane



To assess relative ambient conditions using standard amateur radio equipment, a typical portable monopole antenna (quite a bit larger than the calibrated monopole) capable of operating from the 80 m amateur band to the 6 m amateur band was also used (see § A12.3.3 for measurement equipment list). The spectrum analyser trace was set in a max hold mode measuring from 150 kHz to 30 MHz with 9 kHz RBW, 30 kHz VBW, and 40001 points.

In each of the bands, a marker indicates where a projected WPT-EV harmonic could potentially occur (though the WPT-EV system was not operating during the measurements). It is noted that the measurement conditions using a CISPR peak or peak-hold detector for standard EMC limit evaluation are not the same as the measurement conditions used to measure man-made noise floor levels that are indicated in Recommendation ITU-R P.372 which are derived using measurement techniques outlined in Recommendation ITU-R SM.1753. The intent of the ambient measurements made with a typical amateur radio monopole are to assess the relative differences seen at the radio receiver with the WPT-EV system OFF (peak ambient emissions) and ON (peak ambient + WPT-EV system emissions) and to ensure capture of all time varying and rotationally dependent peaks emanating from the WPT-EV system in comparison with ambient emissions otherwise present. It should be noted, however, that peak-hold measurements maintain the maximum peak of time-varying signals or noise that can, in turn, mask noise floor conditions. This is particularly true in a location where any impulse or time-varying noise is present. The OATS location in Cedar Park, Texas abuts a residential neighbourhood to the west and business complexes to the north and south. The location of the OATS could generally be described as a light-business area with offices and small businesses in operation during testing. The site complies with the ANSI C63.7 construction methods for EMC measurements, requiring among other criteria, that the site be located a minimum distance away from obstruction-free areas that could perturb the measurements.

In the chart below and associated charts found within this study, ambient noise consists of both wanted radio service emissions and unwanted ambient emissions present in the environment unrelated to the WPT-EV system under study.

FIGURE A12-11

Peak ambient seen at receiver using the amateur radio monopole antenna

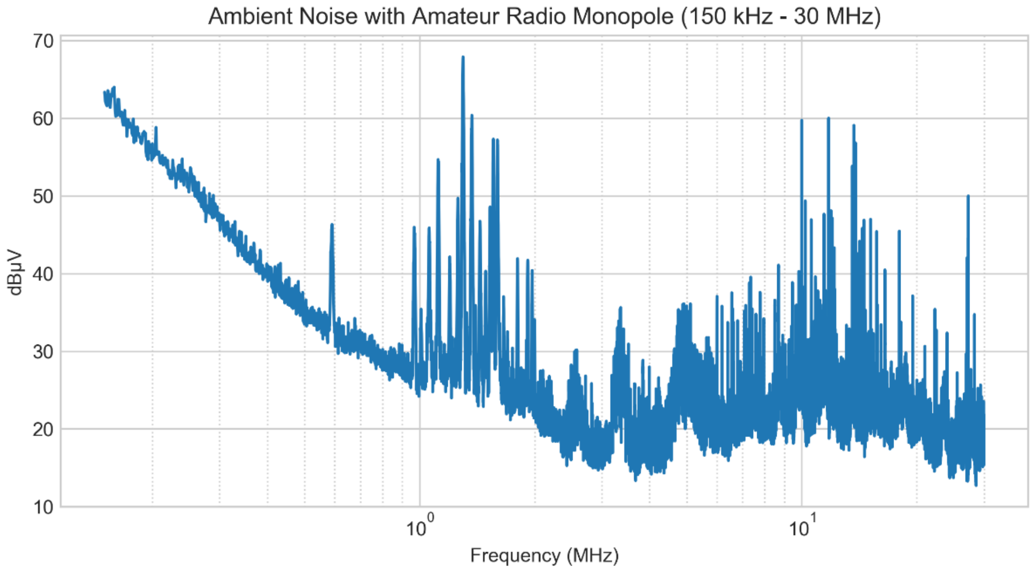


FIGURE A12-12

Peak ambient seen at receiver using the amateur radio monopole antenna (80 m band)

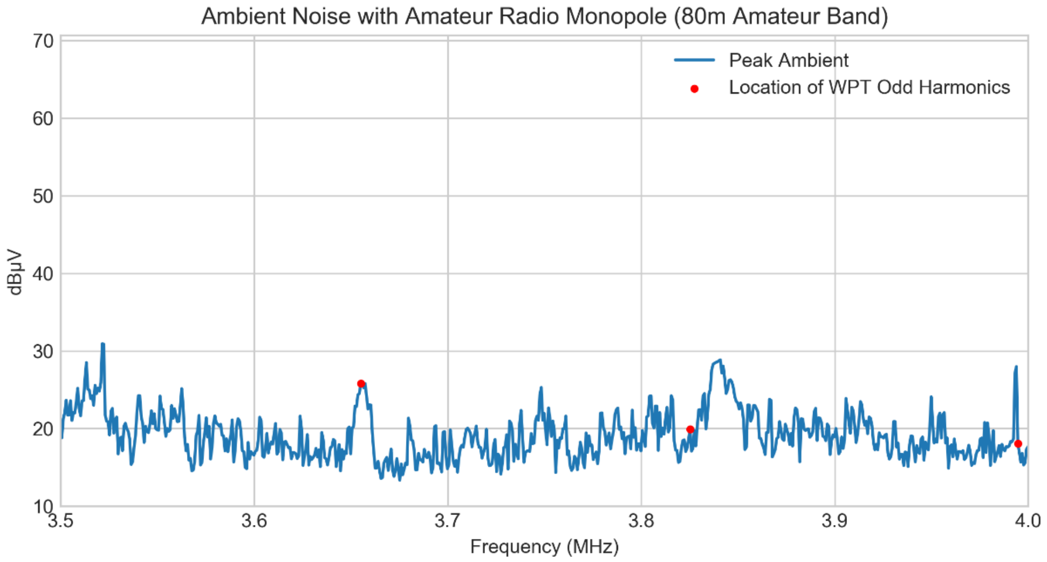


FIGURE A12-13

Peak ambient seen at receiver using the amateur radio monopole antenna (40 m band)

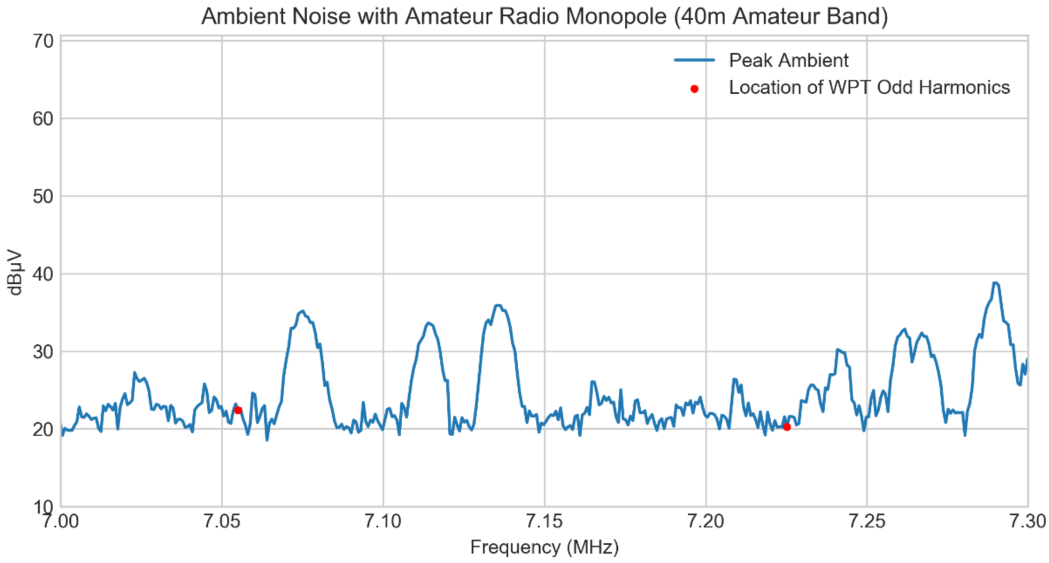


FIGURE A12-14

Peak ambient seen at receiver using the amateur radio monopole antenna (30 m band)

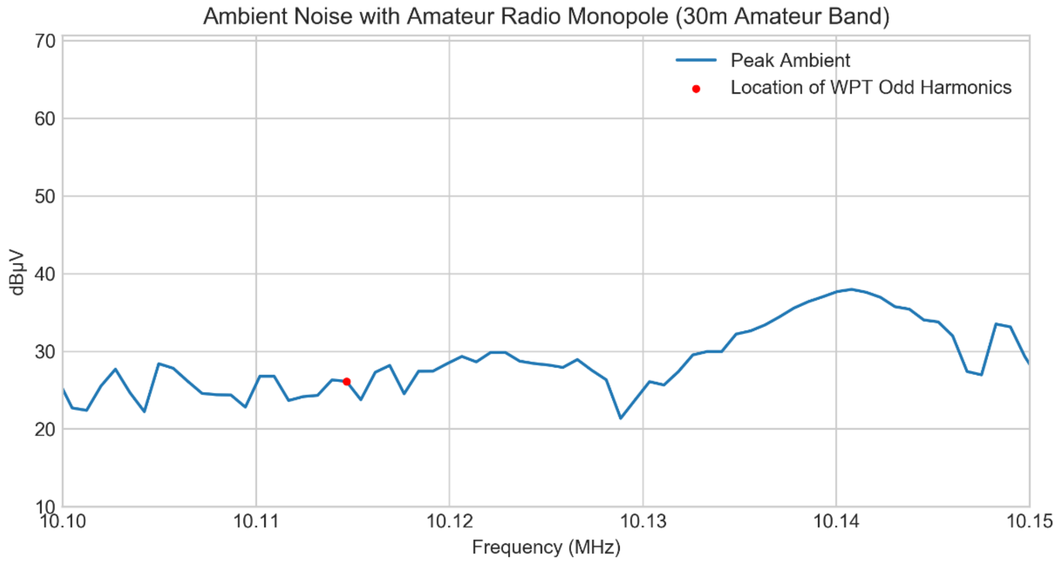
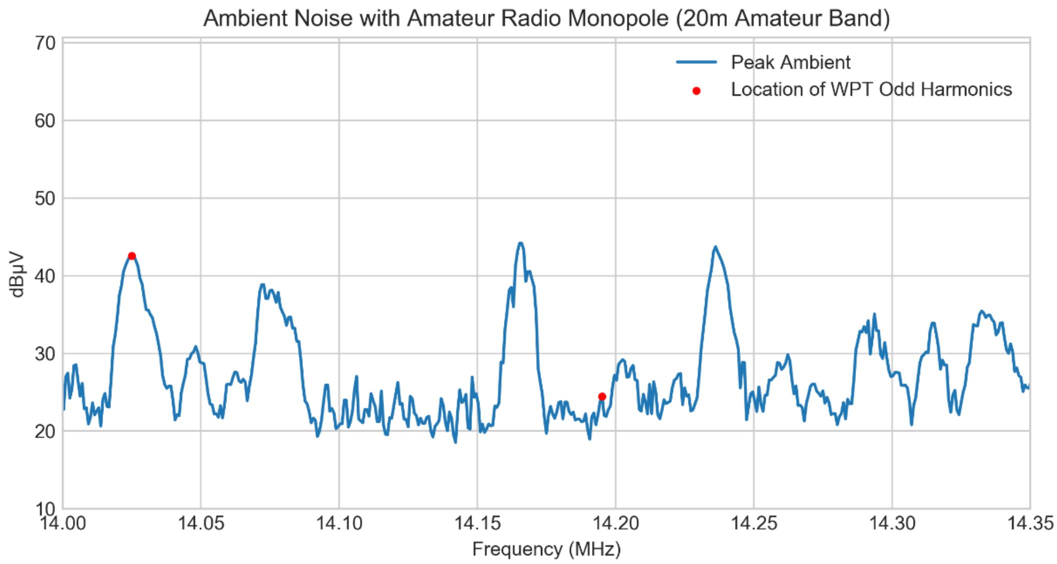


FIGURE A12-15

Peak ambient seen at receiver using the amateur radio monopole antenna (20 m band)



It was noted by a test observer that the ambient conditions of the test site seemed high and therefore additional ambient measurements were taken in a more rural part of the United States in Nibley, Utah to compare relative conditions that an amateur radio operator may experience. Census data from 2010 on Nibley, Utah shows its population density was 87.4 people per square mile (226.4 people per square kilometre). The FCC's ULS database shows 44 amateur operators with active licenses registered in Nibley, Utah as of 12 February 2020. A comparison of relative peak ambient measurements as seen at the receiver (not converted to field levels) using the amateur radio monopole from 150 kHz to 30 MHz is shown below with zoomed conditions in each of the measured amateur radio bands. The duration of the peak hold measurements was in the range of 5 to 15 minutes just before midday. It is however difficult to draw meaningful conclusions of the noise environments at different sites when using long-term peak-hold.

The location of measurement in Nibley, Utah occurred in a local residential field with a local business and school approximately 75 metres north and west of the measurement point. The measurements in Nibley, Utah were performed approximately 10 metres from the office where the measurement equipment resides. At the time of measurement for the Nibley, Utah data, the school and businesses within a 75-metre radius were not operating due to local economy shutdown. Amateur stations could be located in the residential portion of either location, so these tests are representative of what could be found in a range of amateur stations. It must be noted, however, that comparisons between EV harmonics and the two locations being measured can be applied only to the locations with similar ambient noise and signal levels.

FIGURE A12-16

Peak ambient comparison between two locations seen at receiver using amateur radio monopole antenna

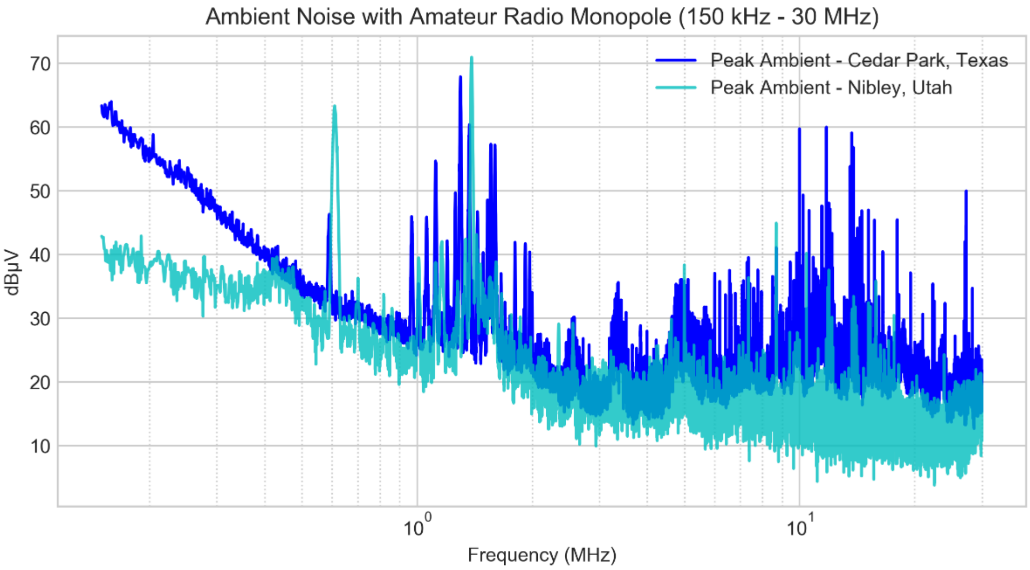


FIGURE A12-17

Peak ambient comparison between two locations seen at receiver using amateur radio monopole antenna (80 m band)

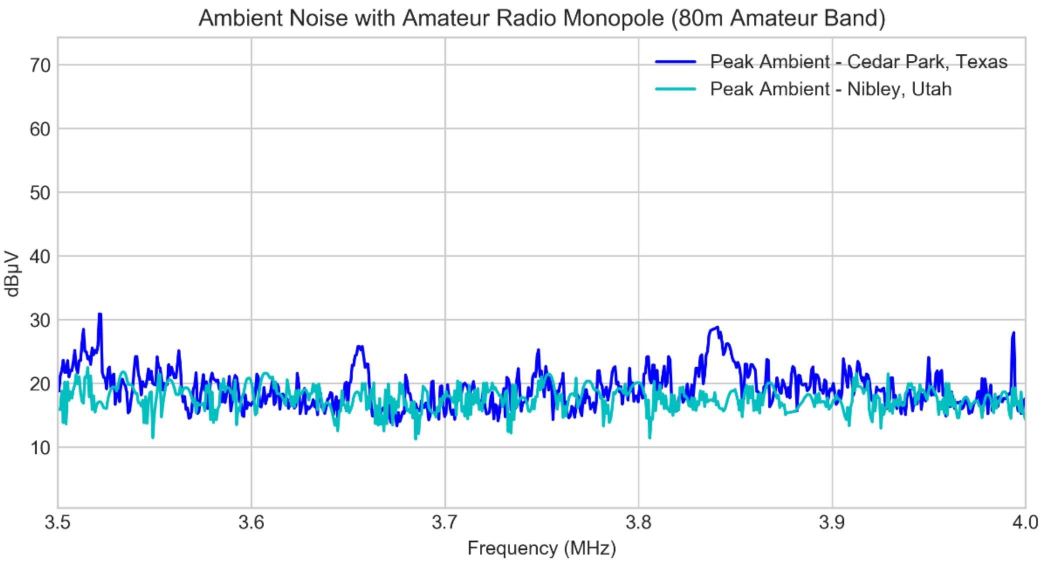


FIGURE A12-18

Peak ambient comparison between two locations seen at receiver using amateur radio monopole antenna (40 m band)

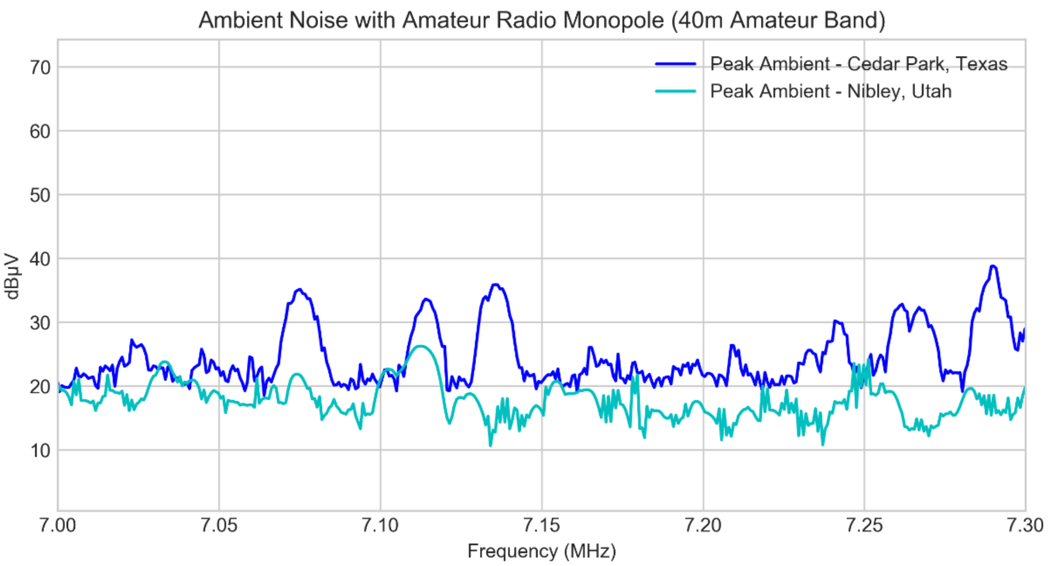


FIGURE A12-19

Peak ambient comparison between two locations seen at receiver using amateur radio monopole antenna (30 m band)

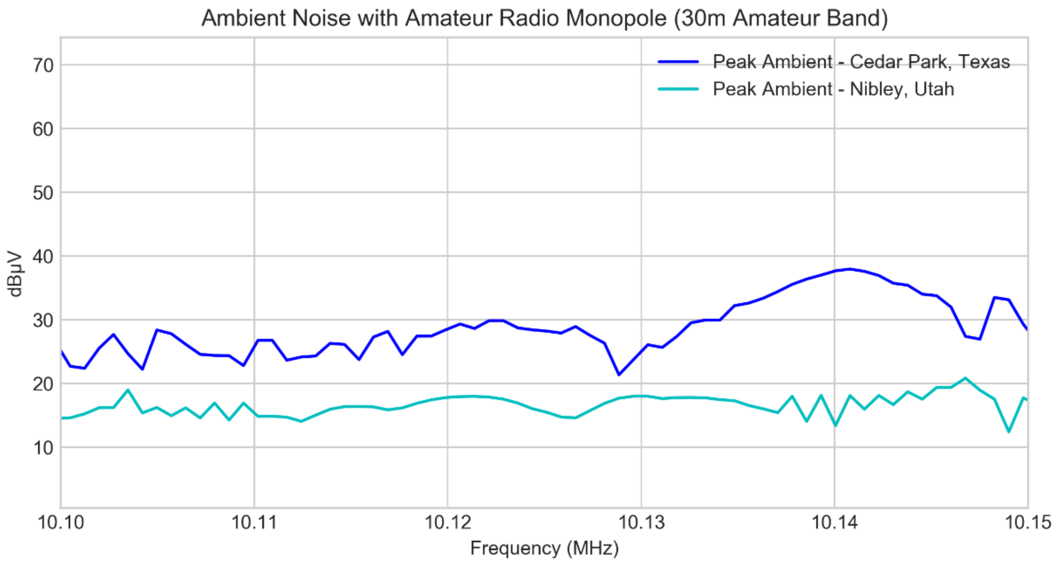
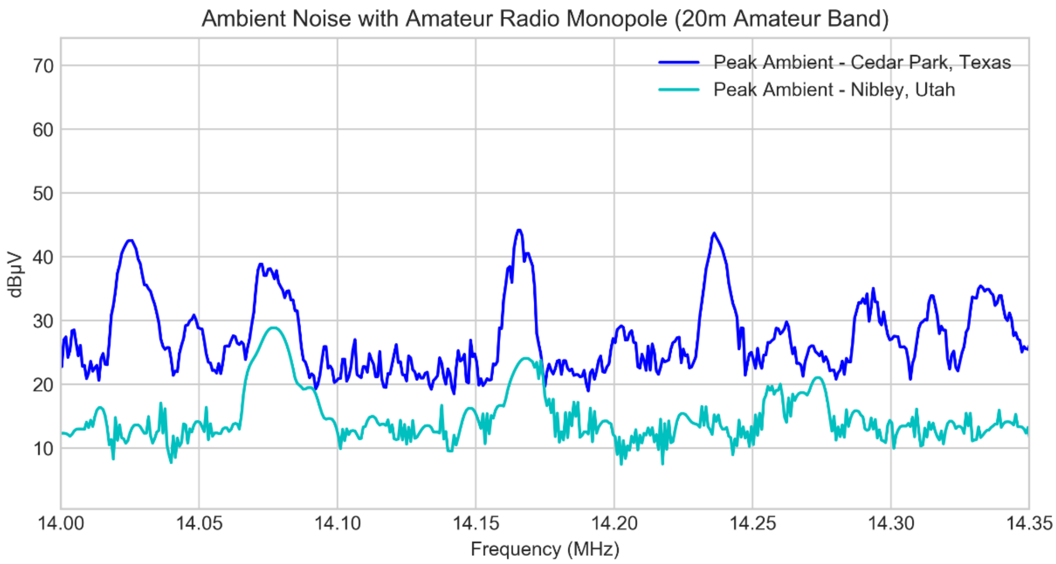


FIGURE A12-20

Peak ambient comparison between two locations seen at receiver using amateur radio monopole antenna (20 m band)



As can be seen, the ambient conditions between these two distant locations (separated by ~1300 miles or ~2100 km), the peak-hold ambient measurements in the 80 m and 40 m bands showed similar characteristics, whereas in the 30 m and 20 m bands, the levels in Nibley, Utah were on average ~10 dB lower than those in Cedar Park, Texas. A satellite image of Nibley, Utah is shown below for comparison.

FIGURE A12-21

Satellite map view of Nibley, Utah

While it is generally expected that ambient conditions would be even lower in un-populated areas of the U.S. (e.g. forests, mountains, fields, etc.) where many amateur radio operators enjoy setting up portable stations for low-noise conditions, it is not expected that WPT-EV systems would be generally located nearby (e.g. much greater than 30 m) in such areas.

After testing, additional questions were raised as to the levels of ambient emissions shown in previous figures and whether the test environment is typical to those in which a WPT-EV system would operate (e.g. residential / commercial). The peak-hold ambient figures shown cannot be compared to the Recommendation ITU-R P.372 man-made noise (MMN) levels because the measurement methods for MMN, containing white-gaussian noise (WGN) and some periodic impulse noise (IN) (with all galactic noise removed), are very different from those used for measuring single-carrier noise (SCN) such as harmonic emissions from WPT-EV. More particularly, there has been suggestion that the background ambient noise plots in Annex 12 might be abnormally higher than typical residential and commercial environments since the apparent noise levels in the plot are higher than the man-made noise (MMN) levels indicated in Recommendation ITU-R ITU-R P.372. Fundamentally this comparison is flawed because levels in Recommendation ITU-R P.372 are based on statistical median measurements of white-gaussian noise (WGN) with some periodic impulse noise (IN) included. All single-carrier noise (SCN) and locally identifiable impulse noise (IN) and galactic noise is removed from the MMN levels as indicated in Recommendation ITU-R SM.1753, which includes the basis for the Recommendation ITU-R P.372 MMN levels. Furthermore, these Recommendation ITU-R P.372 measurements are taken over several seasons and across 24-hour periods to obtain the statistical results. For comparison of understanding, it is important to note that Recommendation ITU-R P.372 MMN has the following distinct characteristics in the spurious bands of interest below 30 MHz:

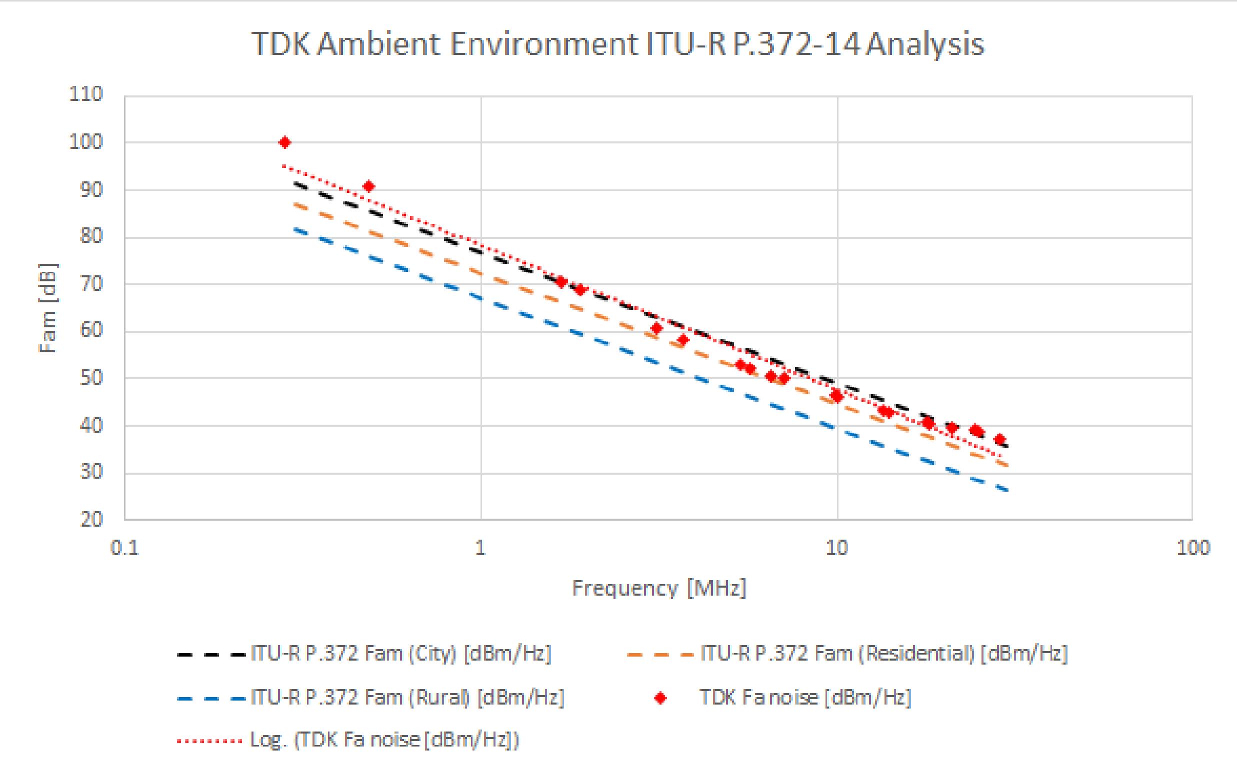
- Recommendation ITU-R P.372 represents ONLY WGN (not SCN) and ITU-R SM.1753 clearly indicates that both SCN and WGN are important. Recommendation ITU-R SM.1753 also clearly states that "it is virtually impossible to find a location that is not at least temporarily dominated by noise or emissions from a single source…" and that "it may be unrealistic to exclude these components from radio noise measurements." Recommendation ITU-R SM.1753 also indicates that "Recommendation ITU-R P.372 … specifically excludes emissions from single, identifiable sources." Recommendation ITU-R SM.1753 reiterates how important both the SCN and WGN are to radio by noting that, “radiocommunications have to cope with all unwanted signals, whether it is noise or interference, to function properly. For practical reasons it may therefore be desirable to measure the sum of both.” Particularly in the HF band, it also notes that, “In the HF frequency band, it is virtually impossible to find a frequency that is free of wanted emissions for the whole 24 h measurement period.”

- Recommendation ITU-R P.372 values that are being referenced are based ONLY on man-made noise (MMN) which specifically removes any natural environmental effects. More particularly, Recommendation ITU-R SM.1753 states that “Even on one frequency the radio noise level, especially when dominated by MMN, varies depending on time and location. In frequency bands below 30 MHz, noise levels mainly change over time due to propagation conditions.”
- Recommendation ITU-R P.372 WGN MMN values below 30 MHz are based on median values of measurements which occurred in at least 10 locations over 24-hour periods and across multiple seasons. Specifically, in Recommendation ITU-R SM.1753, it states that in addition to a standard measurement period of 24 hours, it is important “To take into account variation due to seasons, HF measurements may be repeated a number of times each year.” This is noteworthy considering that HF propagation conditions change frequently.
- Recommendation ITU-R P.372 WGN MMN values are based on RMS measurements – not peak. The Recommendation ITU-R P.372 values do not represent the only source of noise and clearly do not represent the dominant source of noise, which is SCN as also indicated in Recommendation ITU-R SM.1753.

The previous comparisons made were done using peak measurements (using methods described in Recommendation ITU-R SM.329, Annex 2) as seen by the amateur radio receiver; however, some additional measurements were taken by TDK RF Solutions of the ambient environment using similar metrology to that used to measure MMN in Recommendation ITU-R P.372. This is shown below for reference and shows an underlying noise level around 20 dB lower than in the figures taken with peak-hold measurements.

FIGURE A12-22

Additional TDK WGN ambient measurements

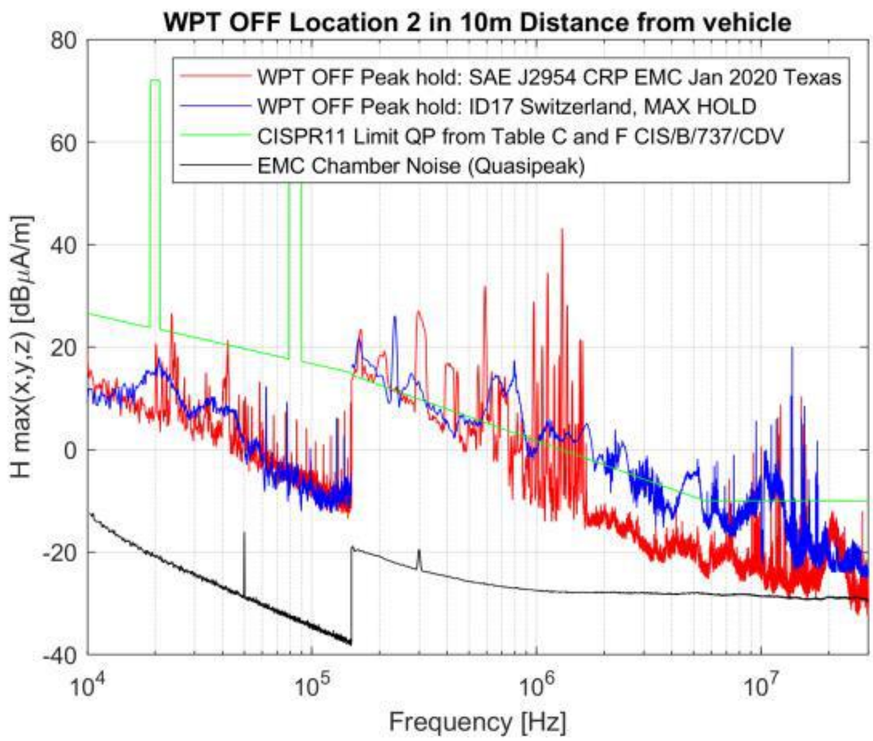


The primary differences in the measurement done by TDK for this plot and the method described in Recommendation ITU-R SM.1753 included the following: 1) these measurements were taken using a standard CISPR loop antenna rather than a monopole antenna, 2) these measurements were taken over a short period of time only (during the day only when the levels are expected to be highest), 3) these measurements were taken in only one season (close to the time period of the original study), 4) these measurements were taken only at the single site and do not include other locations. These additional measurements taken at the accredited OATS are for reference only and are not definitive by themselves. On-going work is being undertaken in the United States of America to provide further characterization in this respect.

The conclusion that the ambient environment noise is typical of a residential environment is further supported by independent data and tests shared with the European CEPT SE 24 group [23]. In a separate study performed entirely independently by Swiss amateur radio experts from USKA and Brusa [24], using a different WPT-EV system operating in a residential Switzerland neighbourhood, ambient environment measurements were also taken and compared with those taken in Cedar Park Texas, U.S.A. These measurements taken in Ersigen, Switzerland next to an amateur radio station in a residential neighbourhood were also taken by BAKOM using the standardized CISPR EMC settings as is typical globally for such measurements (and as described in Annex 2 of Recommendation ITU-R SM.329). In the USKA/Brusa study [25], the independent assessors reference the data from the contributed U.S. study and provide the following peak-hold comparison plot for review. It should be noted, however, that the ambient comparison measurements in peak-hold are entirely unrelated to the man-made noise measurements shown in Recommendation ITU-R P.372 and the measurement procedures indicated in Recommendation ITU-R SM.1753.

FIGURE A12-23

Ambient comparison measurements performed in a separate study by USKA and Brusa



A12.3.3 Measurement equipment, measurement standards, and measurement setup

TDK RF Solutions provided standard calibrated equipment for all radiated emissions and electromagnetic field (EMF) exposure measurements. Attending amateur radio operators provided additional equipment for radiated emission impact testing in the HF amateur radio bands of interest. The same calibrated spectrum analysers used for the standardized EMI testing were also used to measure the spectrum as seen using the different amateur radio antennas as well.

TDK RF Solutions Calibrated Equipment for Radiated Emissions Testing:

- Keysight Technologies (formerly Agilent Technologies) MXE Spectrum Analyzer.
- Rhode and Schwarz ESCI EMI Test Receiver.
- Rhode and Schwarz ZNL3 Vector Network Analyzer (VNA).
- TDK RF Solutions Magnetic Loop Antenna PLA-60-0930.
- A.H. Systems Monopole Antenna SAS-551.
- TDK RF Solutions Accredited Open Area Test Site.

TDK RF Solutions Calibrated Equipment for EMF Testing:

- Narda ELT-400 Field Probe.
- TDK RF Solutions Automated Robotic Positioning System.

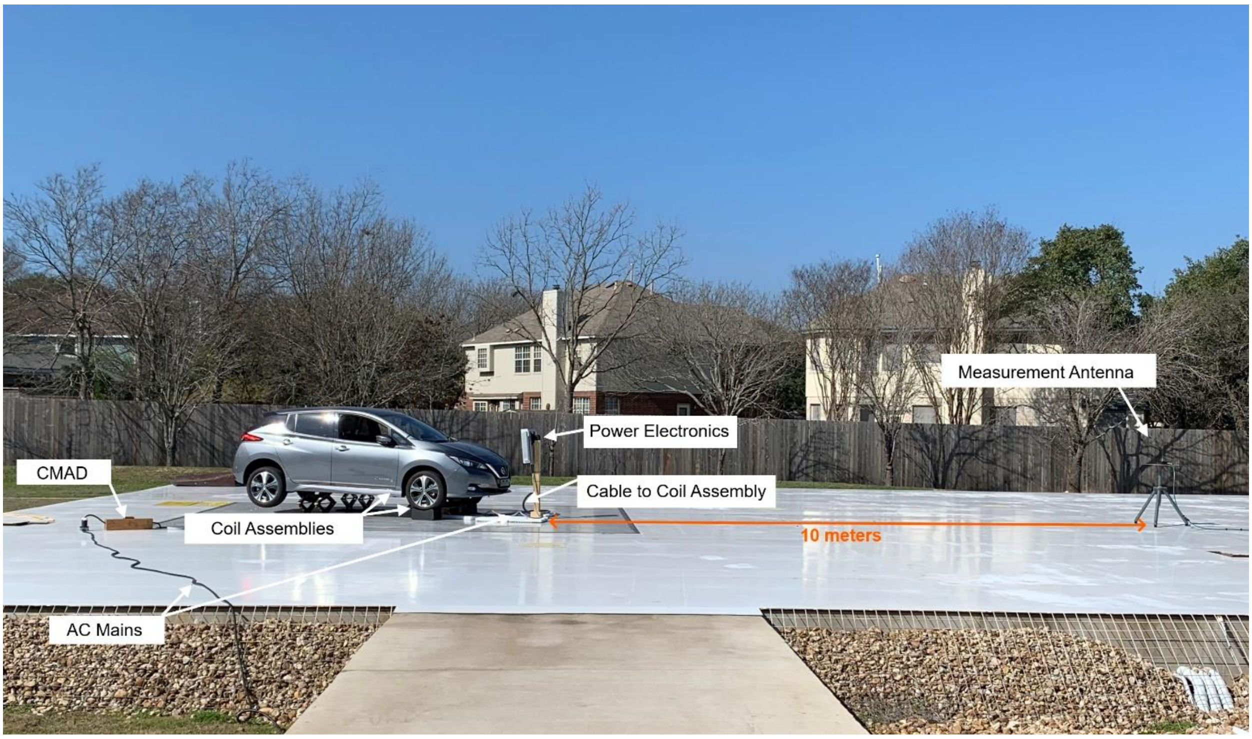
Amateur Radio Equipment for Radiated Emissions Interference Testing:

- Alpha Antenna HD-FMJ 6-80 Meter Portable HF Antenna (~20 feet / ~6 metres tall).
- Chameleon V1 HF 6-80 Meter Vertical Dipole Antenna raised ~20 feet (~6 metres).
- Yaesu 857D HF/VHF/UHF Transceiver.
- Airspy HF+ Discovery Software Defined Radio with SDRSharp Software Interface.

Below is an annotated image of the WPT-EV test setup on the OATS for calibrated radiated emissions testing.

FIGURE A12-24

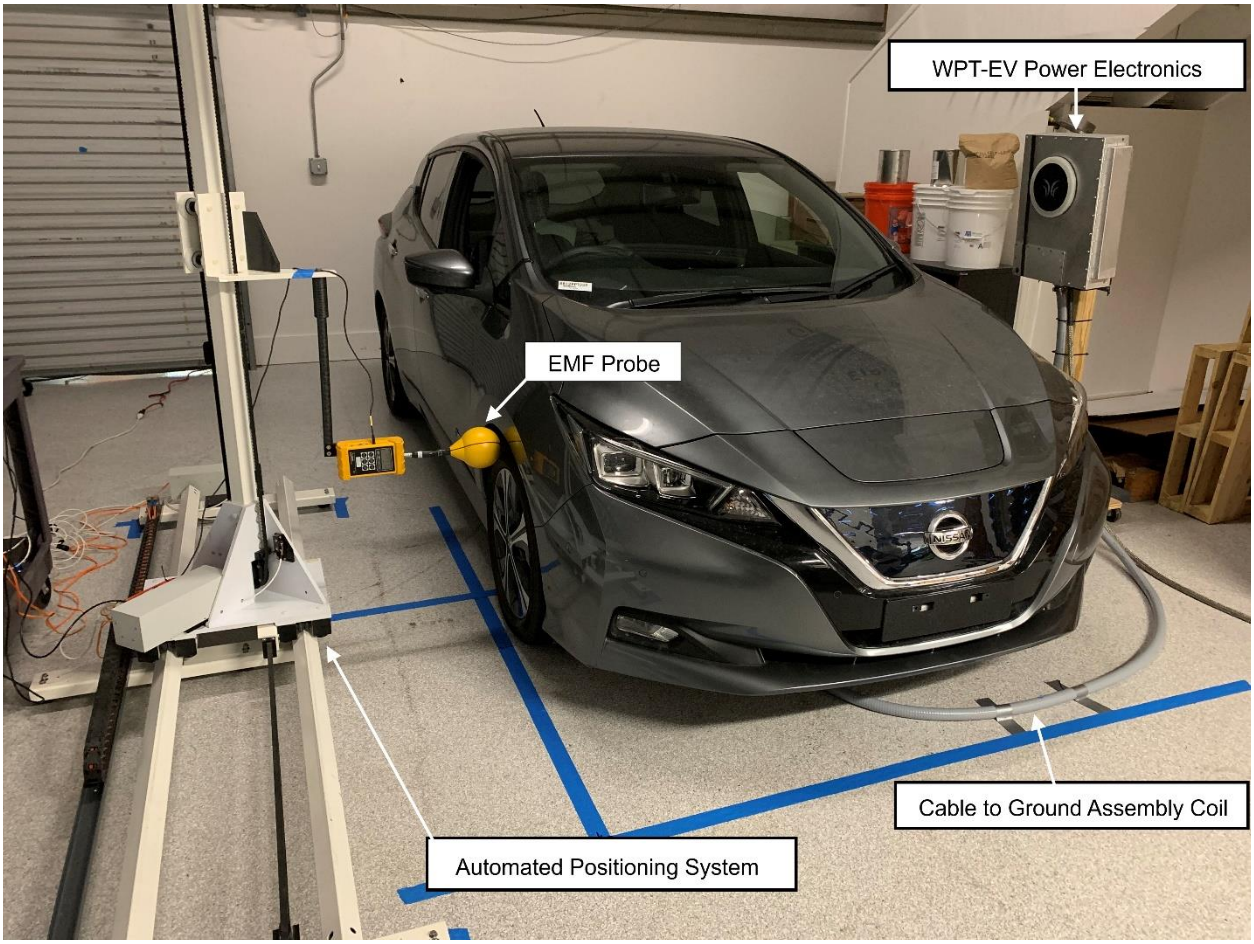
Setup on OATS for calibrated radiated emissions testing



Below is an annotated image of the WPT-EV test setup in a typical garage setting for calibrated EMF exposure testing.

FIGURE A12-25

Setup over in garage with concrete floor for calibrated EMF measurement testing



The amateur radio antennas (Chameleon V1 vertical dipole and HD-FMJ monopole) were setup over real earth at 10 m, 20 m, and 30 m distances from the WPT-EV system on the OATS and turn table. The turn table was rotated to obtain worst-case conditions. While two types of antennas were initially used (both a vertical dipole and monopole), the qualitative results from the two antennas appeared similar and the vertical dipole was determined to be less sensitive so all remaining data was collected using the HD-FMJ monopole which was a much simpler setup for measurement. These two antenna types and the setup conditions for 10 m, 20 m and 30 m distances are shown below.

FIGURE A12-26

Setup of amateur radio vertical dipole antenna at a distance of 10 m from WPT-EV system

FIGURE A12-27

Setup of amateur radio monopole antenna at a distance of 10 m from the WPT-EV system

FIGURE A12-28

Setup of amateur radio monopole antenna at a distance of 20 m from the WPT-EV system

FIGURE A12-29

Setup of amateur radio monopole antenna at a distance of 30 m from the WPT-EV system

The amateur radio monopole antenna has multiple configurations for changing the characteristics of the antenna e.g. by adding a line for NVIS (Near Vertical Incidence Skywave) transmission and reception. Because the amateur radio antennas have not been specifically calibrated for absolute field strength measurements, all measurements shown are relative. The plots below show an S-parameter (S_{11}) characterization of the amateur radio monopole antenna with and without the NVIS line.

FIGURE A12-30

S_{11} measurements of amateur radio monopole antenna

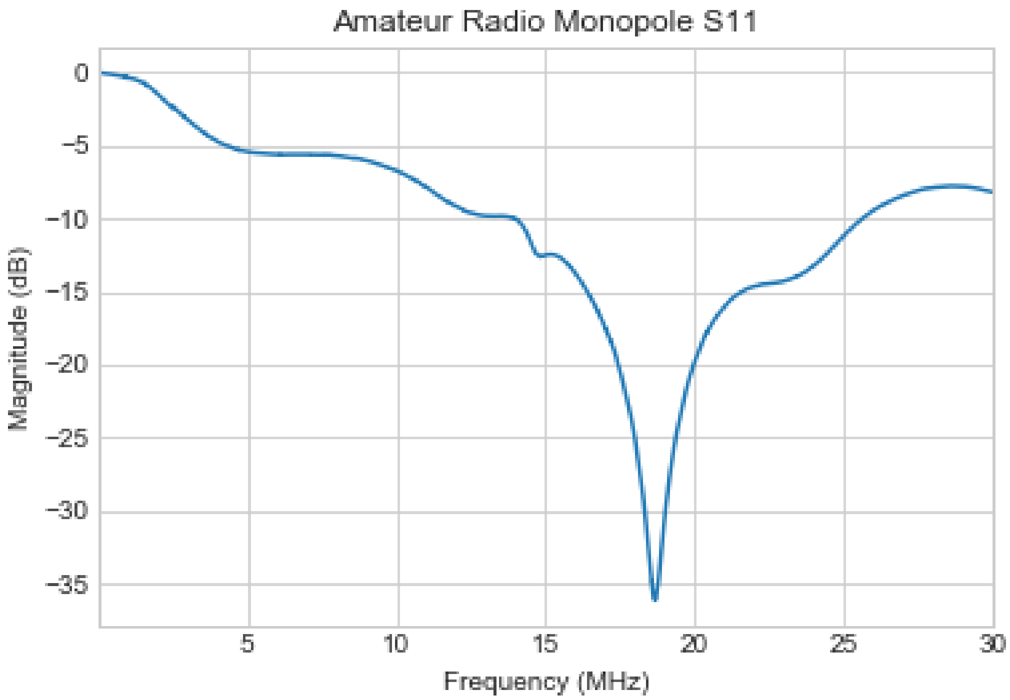


FIGURE A12-31

Smith chart for measurements of amateur radio monopole antenna

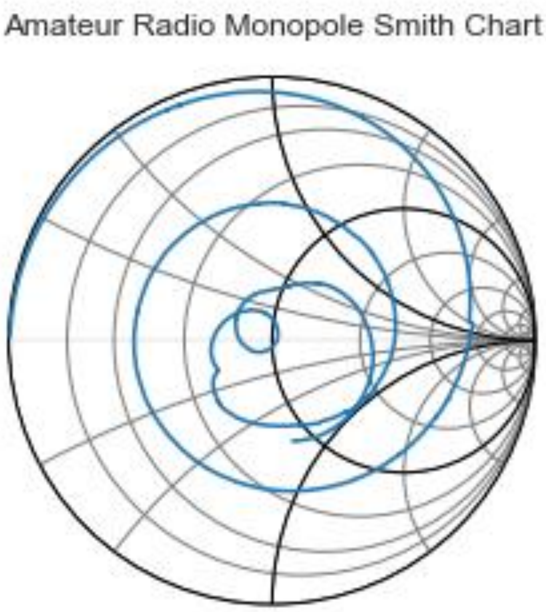


FIGURE A12-32

S_{11} measurements of amateur radio monopole antenna with NVIS line

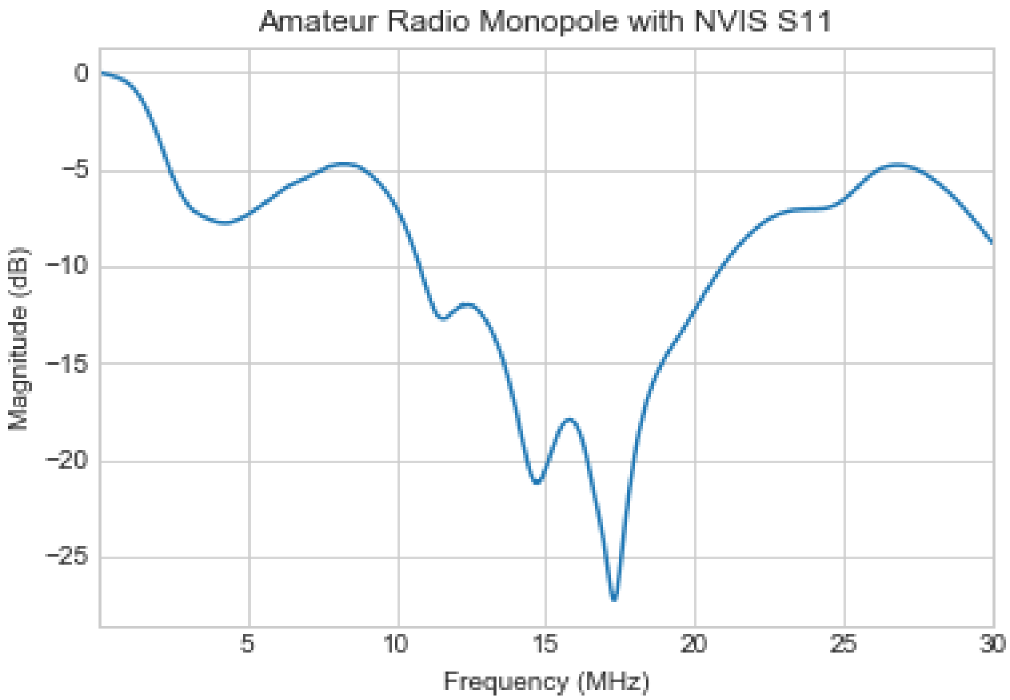
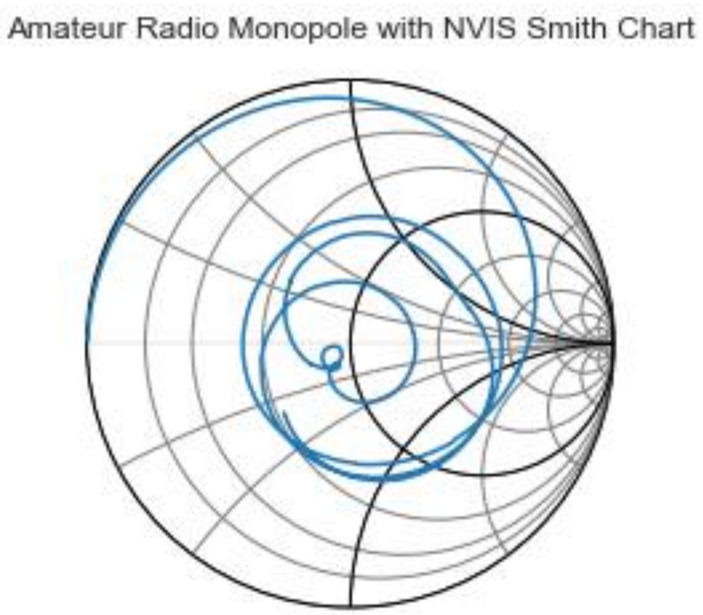


FIGURE A12-33

Smith chart for measurements of amateur radio monopole antenna with NVIS line



A12.3.4 Measurement results

A12.3.4.1 Radiated emissions measurement results

A12.3.4.1.1 Calibrated testing with magnetic loop antenna

A calibrated CISPR-16-1-4 60 cm magnetic loop from TDK RF Solutions was used to perform radiated emission measurements from 9 kHz to 30 MHz on the OATS. The WPT-EV system was turned on to charge the Nissan Leaf with ~11 kW of input power at efficiencies around 90% AC grid input to DC battery output. The state of charge of the Nissan leaf ranged from ~25% to 85% during testing to ensure that the power level was maintained constant, but the battery voltage changed overtime. Within this range, these variations in charge level and battery voltage did not significantly affect emissions for the WPT-EV system evaluated. The Nissan leaf battery capacity was specified at 62 kWh. The WPT-EV alignment between the ground coil and the vehicle coil were put in worst-case offset conditions at the specified 175 mm ground height (referring to the ground-to-vehicle pad distance if the vehicle were to be on the road) to ensure the highest current and the most exposed coil conditions possible. Due to the fact that the WPT-EV system was a pre-production prototype, it was not expected to fully comply with present radiated emission regulatory requirements in all cases; however, this testing is considered generally representative for an SDO conformant WPT3 WPT-EV system.

To capture maximum emission peaks in the spectrum scans, the turn table with the WPT-EV system was rotated in 2-degree increments across the entire 360 degree rotation and for each loop orientation (e.g. x, y, z axis). From 9 kHz to 150 kHz the resolution bandwidth was set to 200 Hz, and from 150 kHz the resolution bandwidth was set to 9 kHz as defined by standardized EMI measurement procedures. To obtain more detailed results for the fundamental and harmonically related peaks in the amateur radio bands, the resolution bandwidth was set to 200 Hz and the turn table rotated in 2-degree increments to find the maximum condition to perform quasi-peak and average measurements as well as obtain a polar radiation plot.

Below are the maximum peak scans with ambient measurements collected separately (and hence not necessarily time-correlated) for relative comparison. The FCC Part 18 limits shown are based on conversion and scaling from the 300 m limits to magnetic field limits at 10 m based on ANSI C63.30 scaling procedures discussed in § A12.3.2. The current draft 3rd amendment of CISPR 11 Ed 6 limits as outlined in CIS/B/737/CDV (Committee Draft for Vote) are also shown in the charts for comparison.

FIGURE A12-34

Calibrated magnetic loop measurements in X-axis (loop coaxial to EUT) with WPT-EV system on and off for comparison

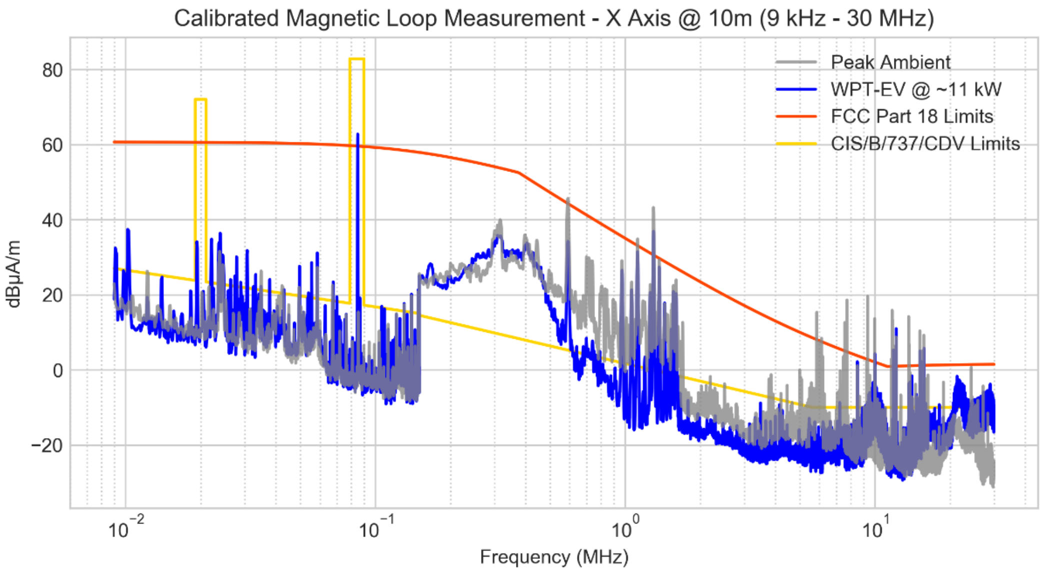
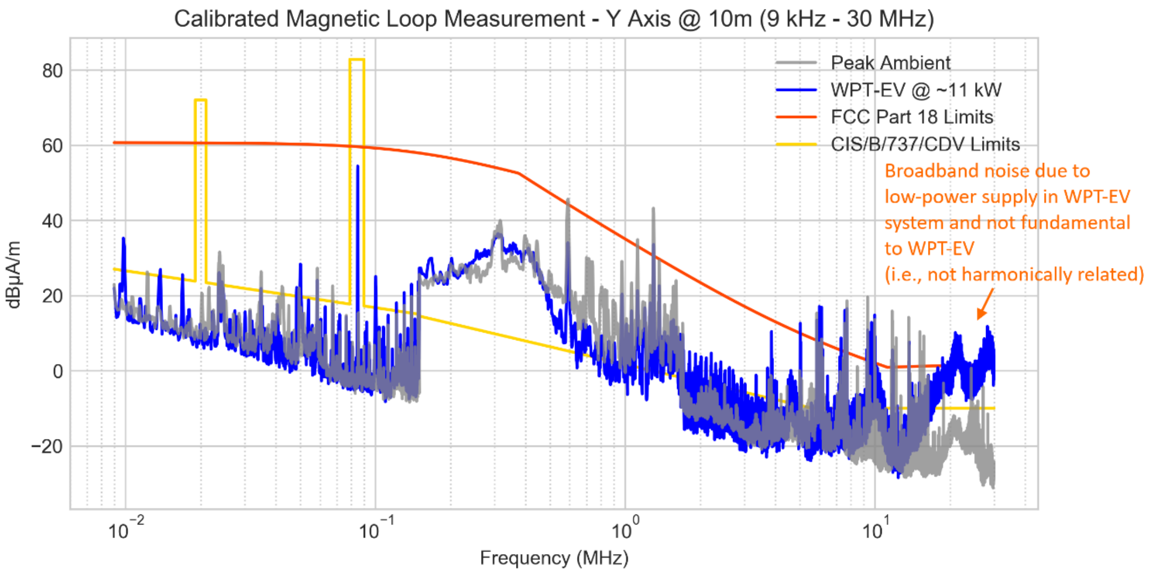


FIGURE A12-35

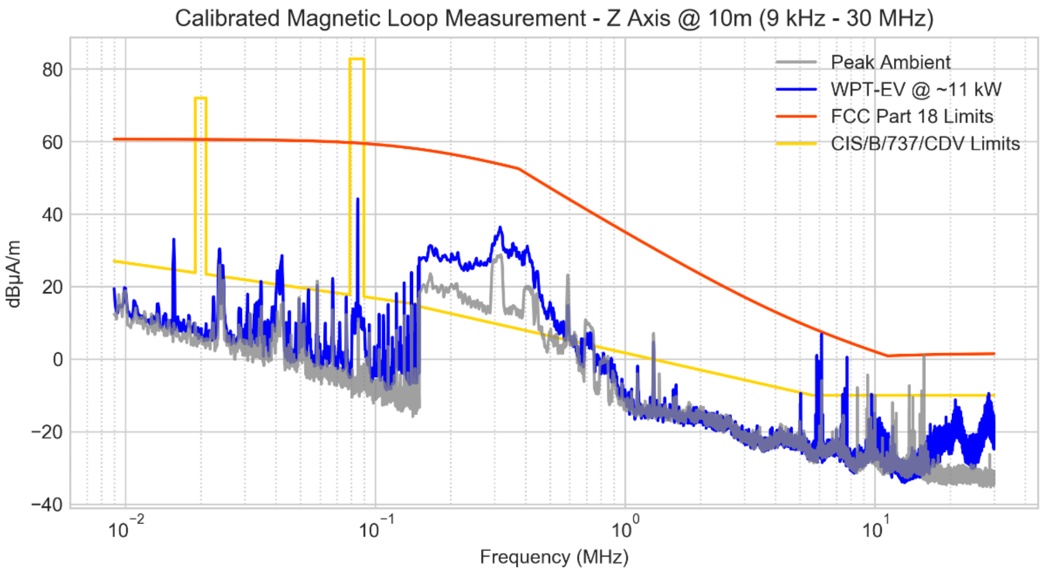
Calibrated magnetic loop measurements in Y-axis (loop coplanar to EUT) with WPT-EV system on and off for comparison



The increased broadband noise level at frequencies above 15 MHz is attributed to an auxiliary low power switched-mode power supply and is not fundamentally related to the WPT-EV core system.

FIGURE A12-36

Calibrated magnetic loop measurements in Z-axis (loop parallel to ground) with WPT-EV system on and off for comparison



A zoomed in view of the 85 kHz fundamental as well as the 80 m, 40 m, 30 m, and 20 m amateur radio bands are shown below along with the measured quasi-peak and average values. It should be noted that the specifically annotated values in the plot were collected with a much lower RBW (i.e. 200 Hz) than the continuous plots which utilized a higher RBW (i.e. 9 kHz) as prescribed by CISPR. Only peaks that appeared to be somewhat discernible at a low-resolution bandwidth were collected though some of the peaks were barely above ambient conditions. Narrowband signals (with respect to the selected CISPR RBW) being essentially continuous wave (CW) signals and displaying sufficient signal to noise ratios will produce essentially the same amplitude response for peak, QP (quasi-peak), or AVG (average) detectors. It is noted that the results of these measurements show that the WPT-EV system has minimal interference potential to stations operating in the noise levels present at the OATS. For quieter locations, additional measurement would be required to ascertain interference potential (at expected distances between a WPT-EV system and receiver) in such environments.

FIGURE A12-37

Detailed worst-case calibrated magnetic loop measurements with WPT-EV system on and off for comparison

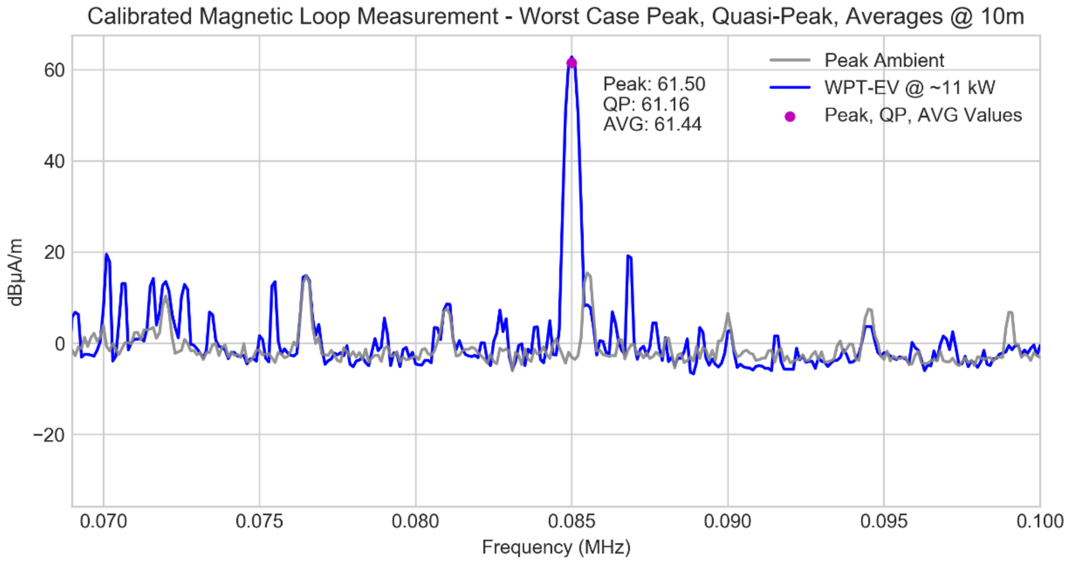


FIGURE A12-38

Detailed worst-case calibrated magnetic loop measurements with WPT-EV system on and off for comparison

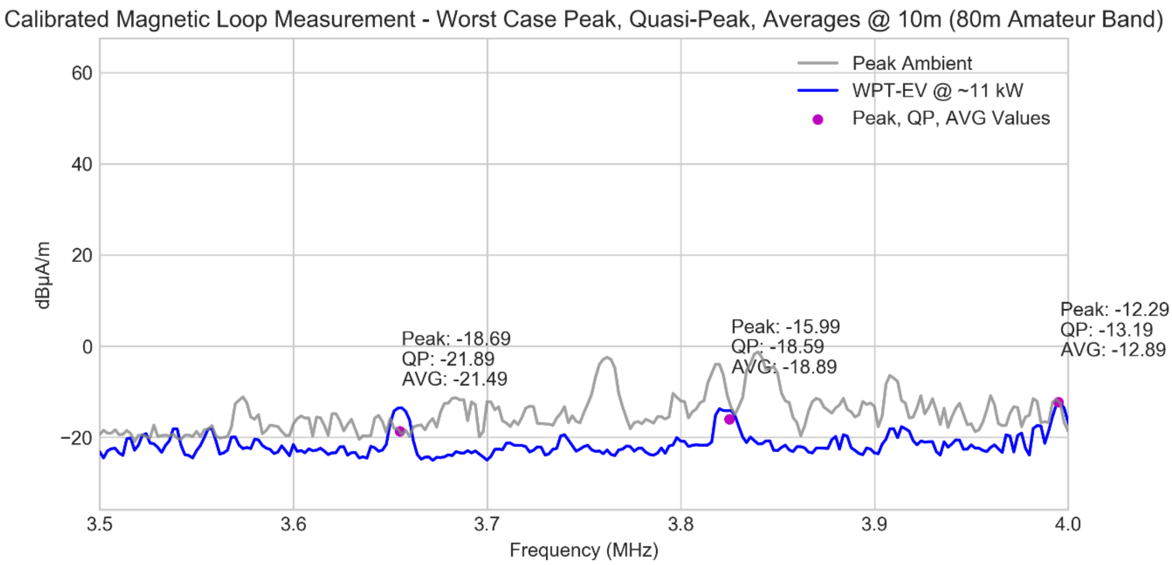


FIGURE A12-39

Detailed worst-case calibrated magnetic loop measurements with WPT-EV system on and off for comparison

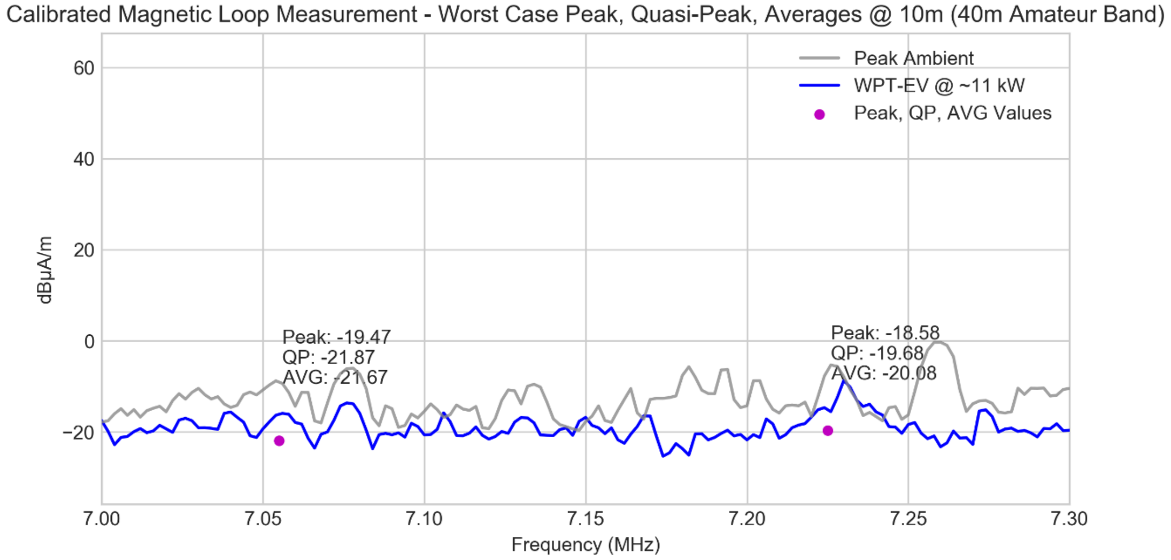


FIGURE A12-40

Detailed worst-case calibrated magnetic loop measurements with WPT-EV system on and off for comparison

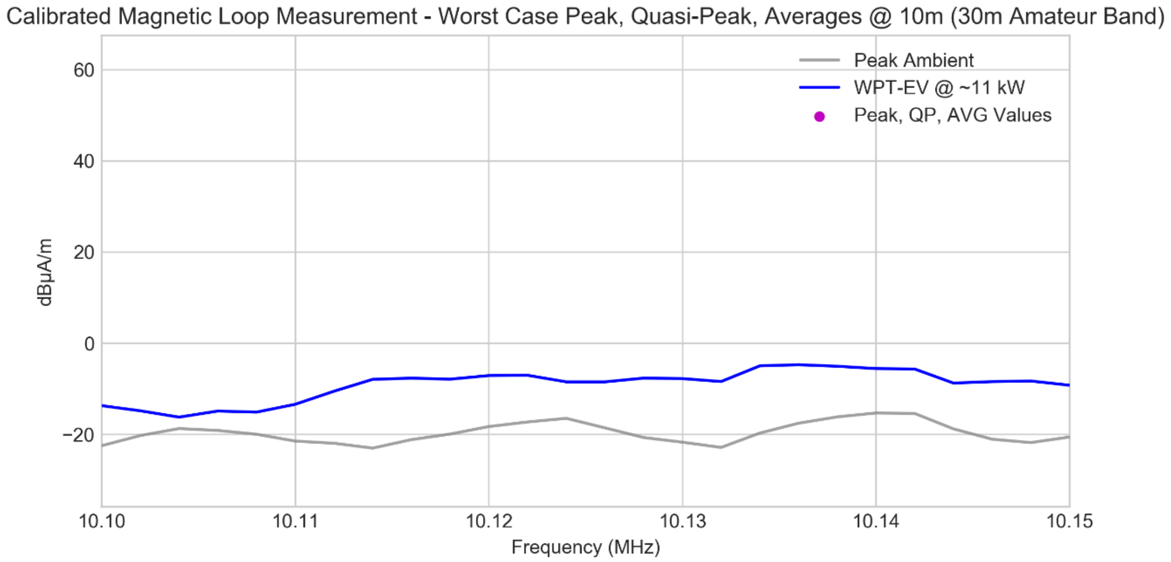
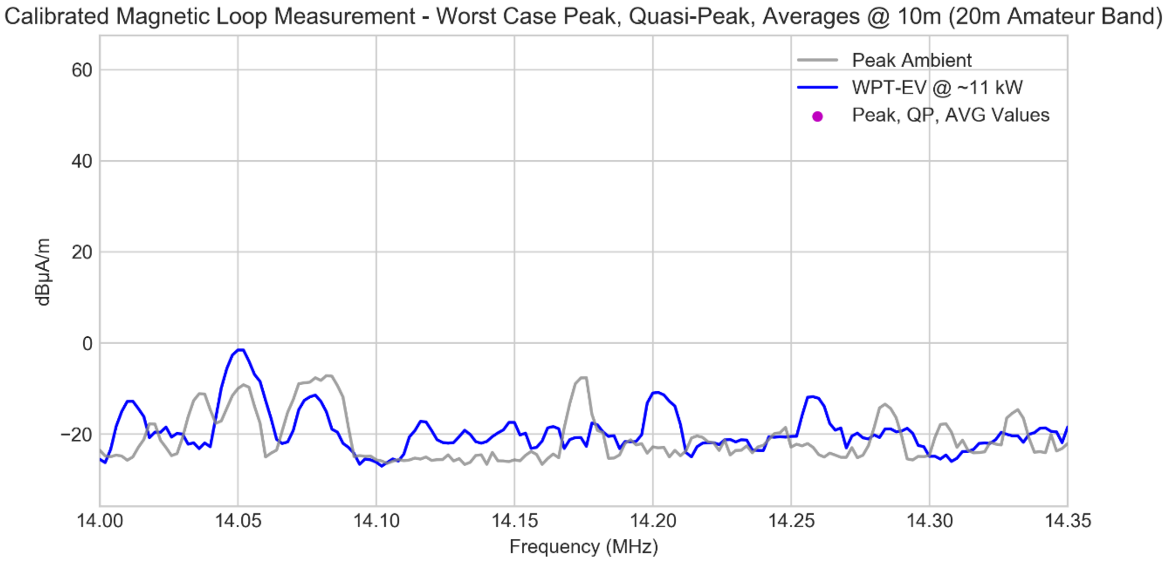


FIGURE A12-41

Detailed worst-case calibrated magnetic loop measurements with WPT-EV system on and off for comparison



For brevity, polar plots of the radiation pattern for several of the harmonics are shown below.

FIGURE A12-42

Polar radiation plot for 85 kHz fundamental of WPT-EV system

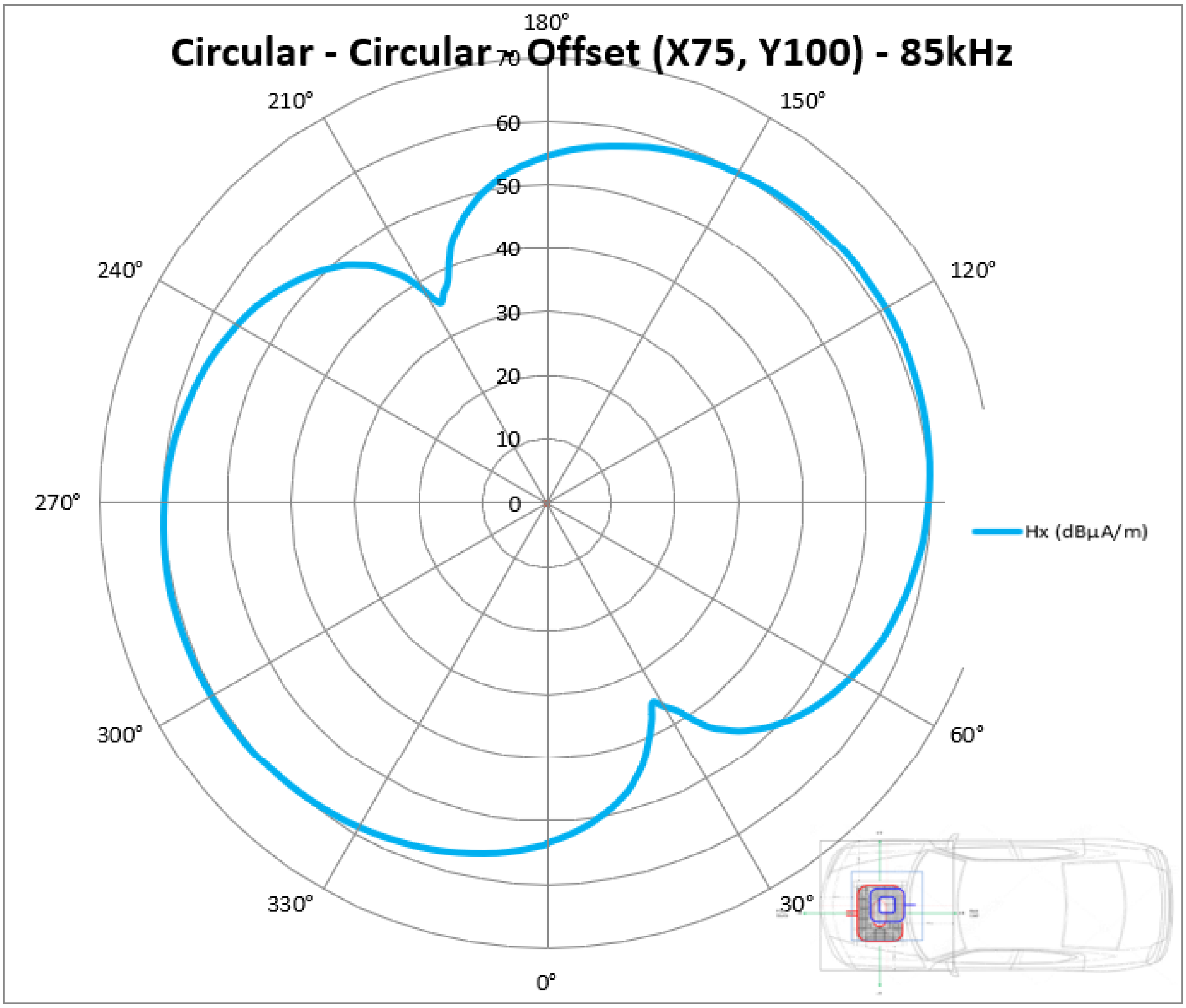


FIGURE A12-43

Polar radiation plot for 3.825 MHz harmonic of WPT-EV system

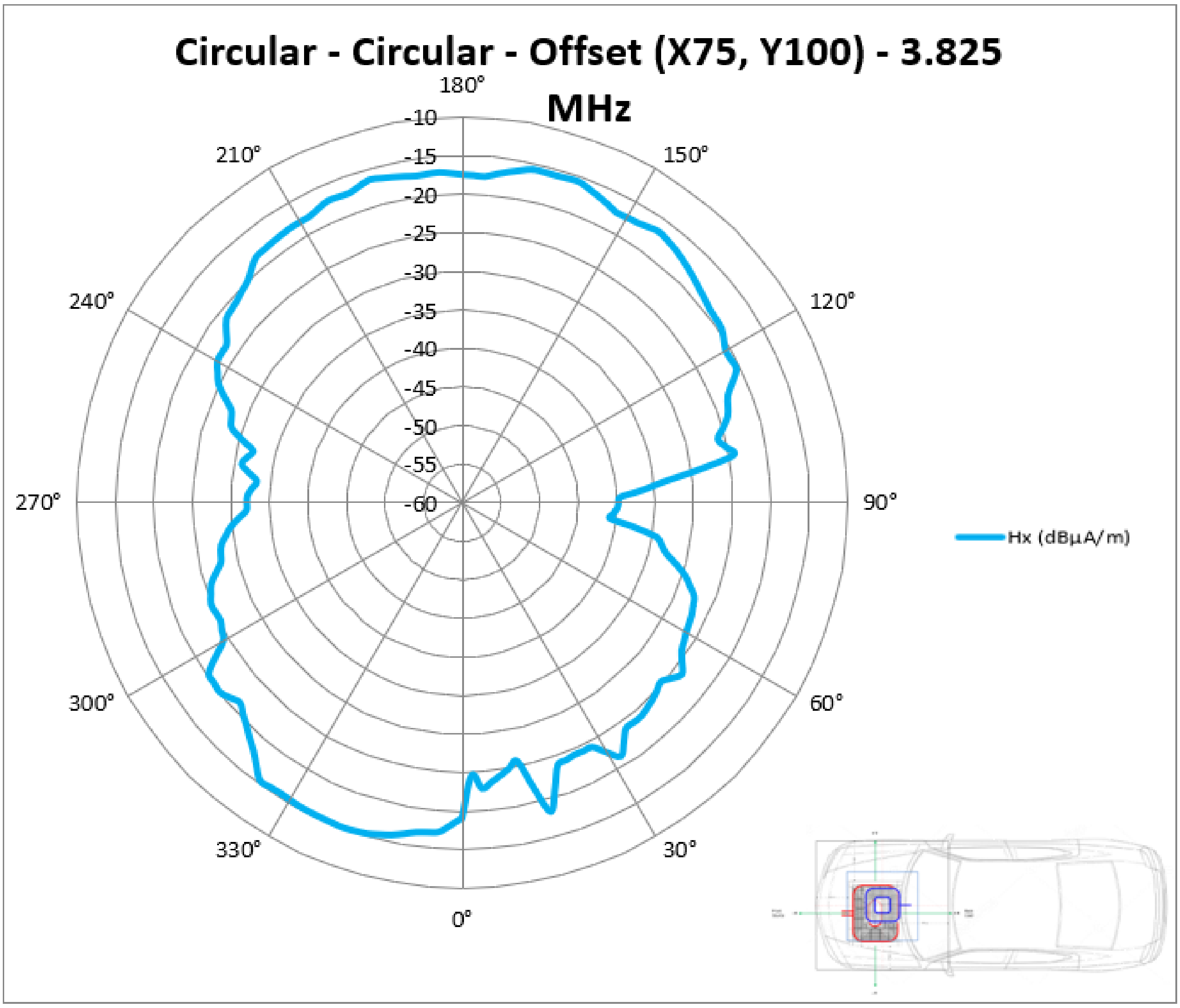


FIGURE A12-44

Polar radiation plot for 3.995 MHz harmonic of WPT-EV system

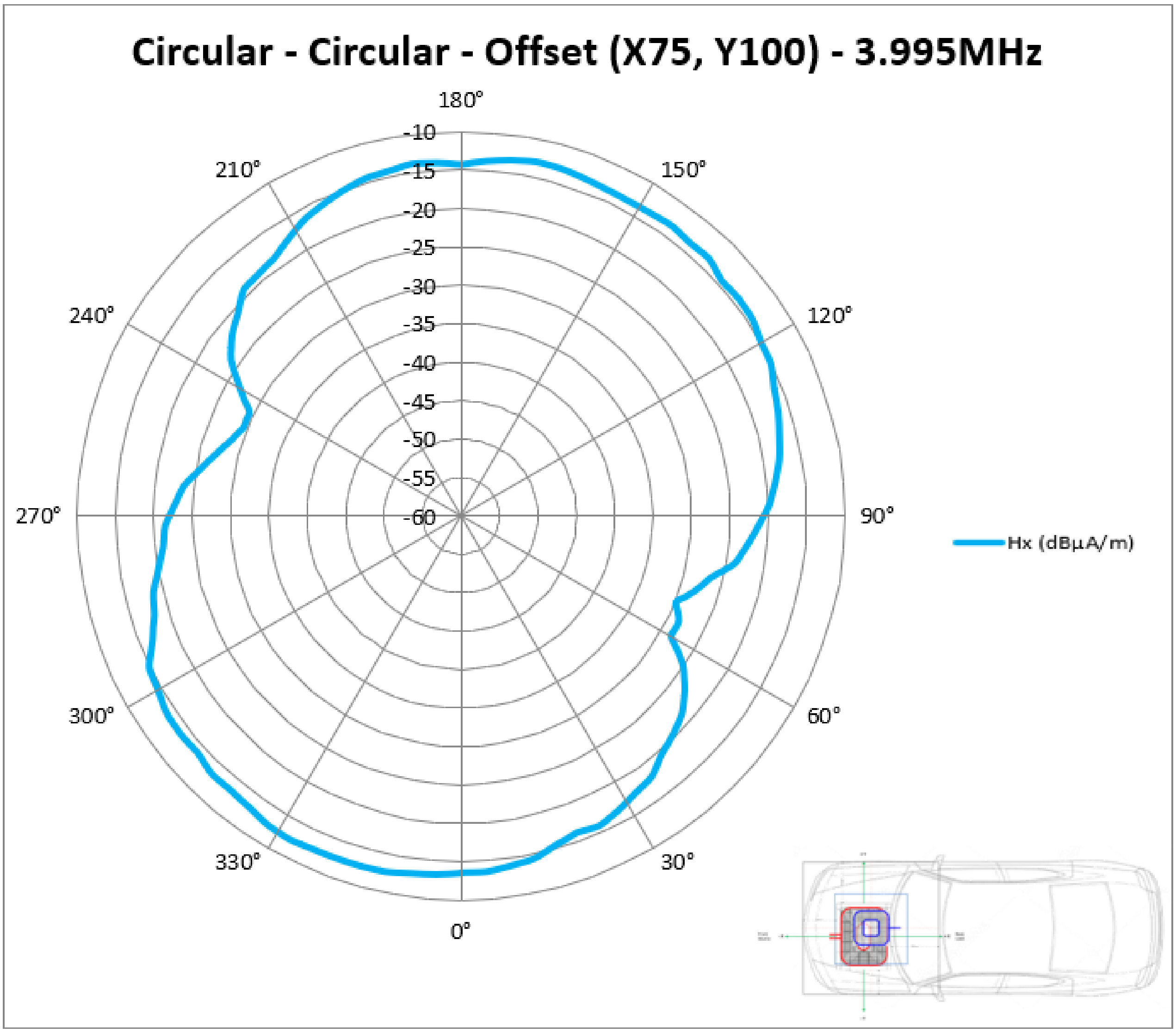
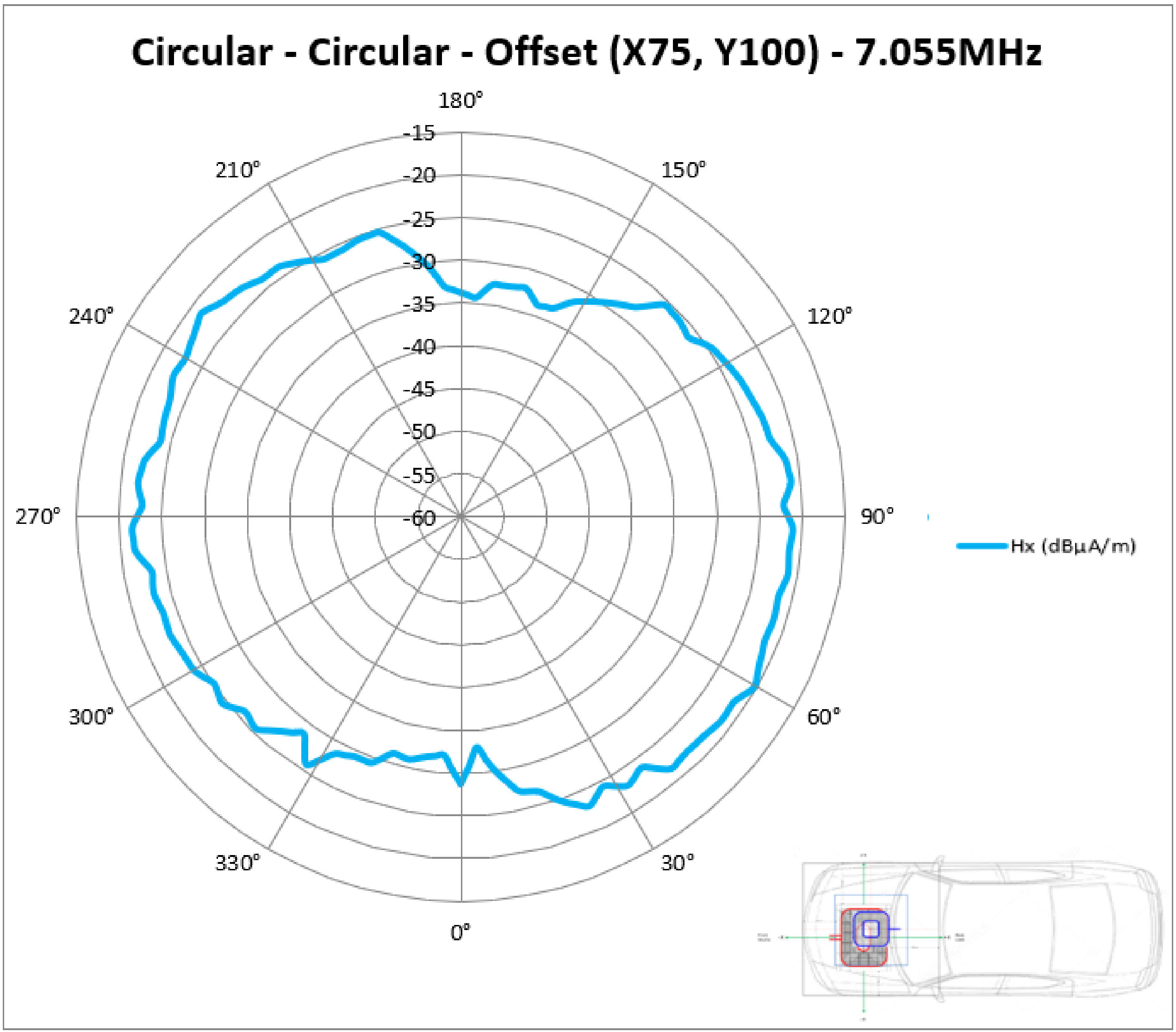


FIGURE A12-45

Polar radiation plot for 7.055 MHz harmonic of WPT-EV system



Additionally, to show relative fall-off correlation, several spectrum analyser measurements were collected at 10 m and 3 m distances for comparison. Since the fundamental was a large signal in comparison, attenuators were added and correlation made to ensure that no non-linear or saturation effects were observed due to high signal strength. The Table below shows the results.

Frequency	10 m	3 m	3 m 40 dB attenuation	3 m 20 dB attenuation	3 m 10 dB attenuation
85 kHz	41.89 dBµA	62.33 dBµA	22.87 dBµA	42.46 dBµA	52.11 dBµA
1.955 MHz	4.84 dBµA	21.45 dBµA			
3.655 MHz	3.34 dBµA	20.9 dBµA			

Electric field measurements were not made with monopole as suggested in CIS/B/737CDV. In general, a monopole is more sensitive to vertically polarized noise and responds to surface-wave noise not typically seen by horizontally polarized antennas such as half-wave dipoles commonly used by amateur radio operators [22]. The same characteristics hold true for EMC measurements. Therefore, additional precautions should be followed when utilizing monopoles on an OATS or in a shielded anechoic chamber in the presence of strong radiators that may compose part of the ambient environment. Given this, if calibrated monopole measurements are to be considered, as recommended for certain WPT-EV conditions in CIS/B/737/CDV, it is important for the EMC lab to apply appropriate metrology measures. The use of narrow-band filtering to improve selectivity, suitable pre-amplifiers for the range of measurement, and an understanding of the ambient environment will all prove useful when performing calibrated measurements using a monopole. Outside the domain of EMC regulatory measurements, radio receivers utilizing a monopole antenna typically require appropriate tuning to improve noise rejection and selectivity in the band of interest. The measurements performed with the amateur radio monopole antenna used for further qualitative testing was supplied with such a matching network for its designated amateur bands of operation (i.e. 80 m to 6 m bands).

A12.3.4.1.2 Amateur Radio Monopole Antenna Testing

A portable HF amateur radio monopole was chosen based on many qualitative reviews about the antenna from the amateur radio community. For example, eHam.net is a website for independent reviews of amateur radio products. The HD-FMJ antenna from Alpha Antennas is about ~20 feet (~6 metres) tall and has excellent reviews. As of 12 February 2020 there were 66 reviews posted resulting in a qualitative rating by amateur radio operators of 4.9 out of 5 on eHam.net [14]. Due to the large effective height (ratio of induced voltage to incident field) of this antenna compared to smaller antennas typically used for commercial radio broadcasting reception, it was expected and verified that this particular antenna was slightly more sensitive in the HF amateur radio bands. An overview of spectrum from 150 kHz to 15 MHz at 10 m, 20 m, and 30 m distances from the WPT-EV system are shown below. The results are based on a max-hold plot with the WPT-EV system rotated slowly on the turn-table to ensure maximum peaks were obtained. The resolution bandwidth was set to 9 kHz. Ambient results with the same antenna configuration were collected separately with the WPT-EV system OFF for comparison with the WPT-EV system ON.

FIGURE A12-46

Peak measurements at a distance of 10 m using amateur radio monopole with WPT-EV system on and off for comparison

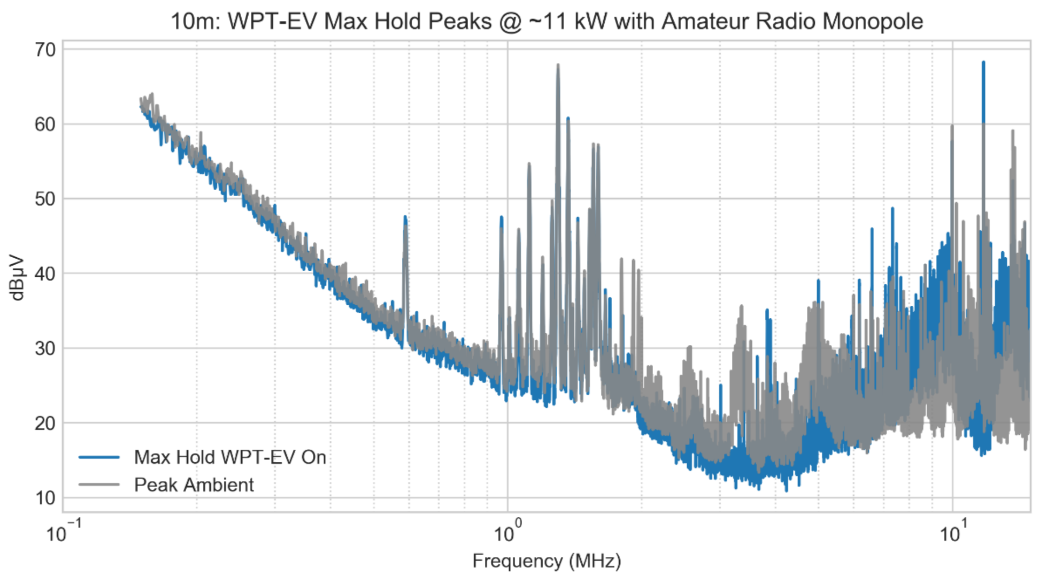


FIGURE A12-47

Peak measurements at a distance of 20 m using amateur radio monopole with WPT-EV system on and off for comparison

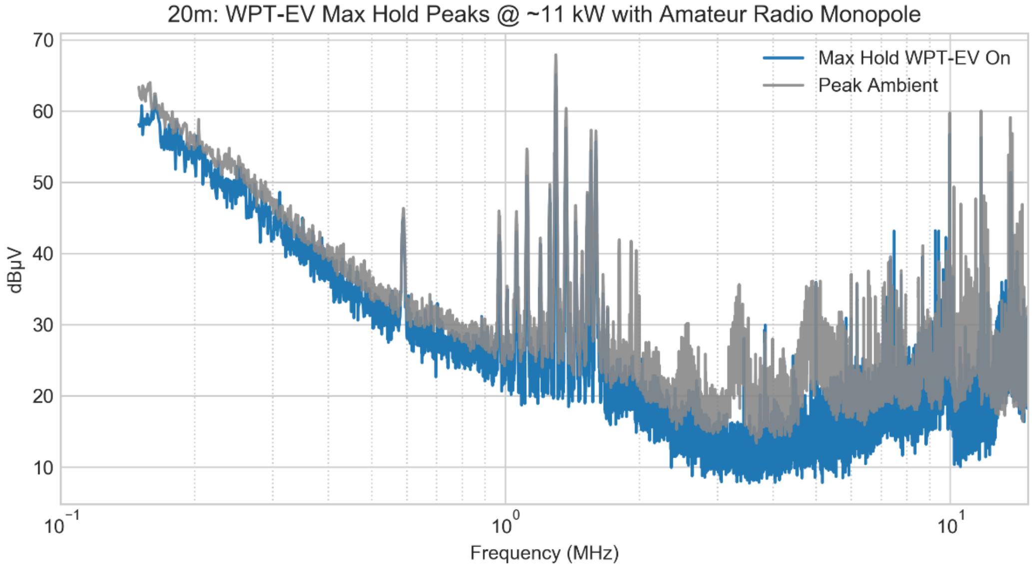
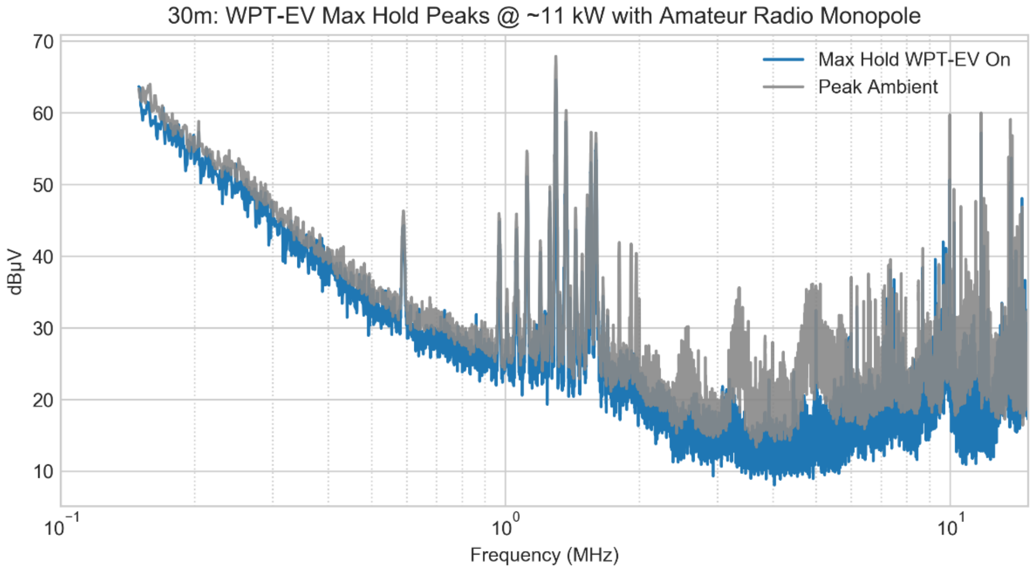


FIGURE A12-48

Peak measurements at a distance of 30 m using amateur radio monopole with WPT-EV system on and off for comparison



For better qualitative comparison, plots in each of the 80 m, 40 m, 30 m and 20 m amateur radio bands are shown taken at distances of 10 m, 20 m and 30 m from the WPT-EV system. The 80 m amateur band at the various distances is shown below along with the marked expected locations of the WPT-EV odd harmonics.

FIGURE A12-49

Peak measurements at a distance of 10 m using amateur radio monopole with WPT-EV system on and off for comparison

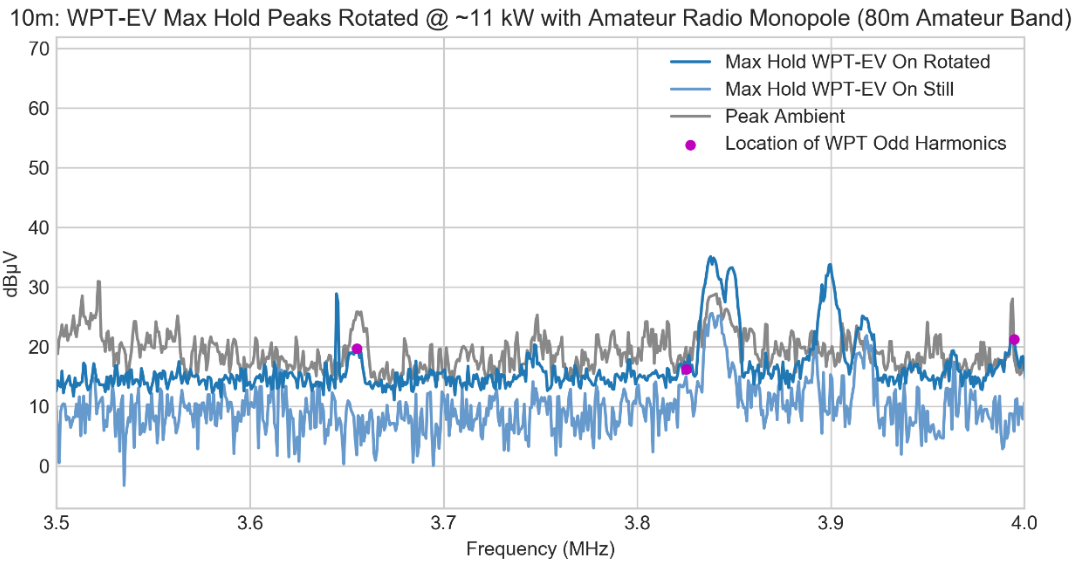


FIGURE A12-50

Peak measurements at a distance of 20 m using amateur radio monopole with WPT-EV system on and off for comparison

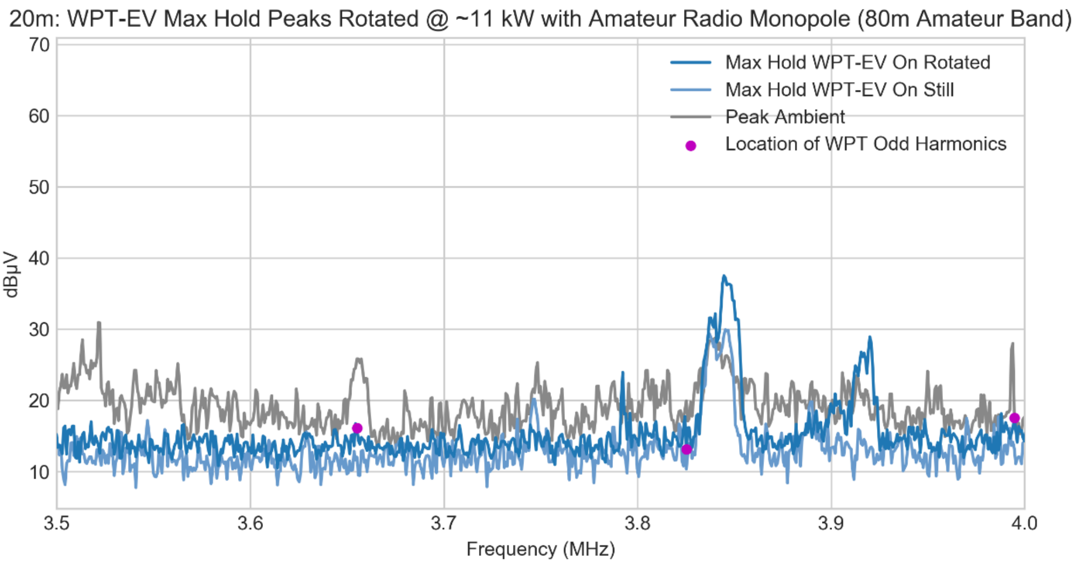
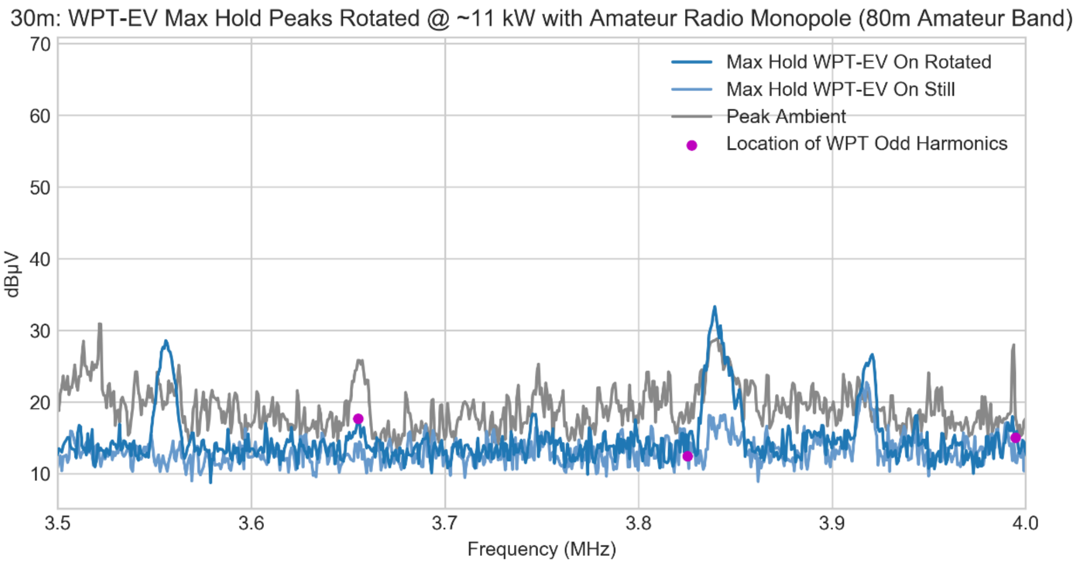


FIGURE A12-51

Peak measurements at a distance of 30 m using amateur radio monopole with WPT-EV system on and off for comparison



The 40 m amateur band at the various distances is shown below.

FIGURE A12-52

Peak measurements at a distance of 10 m using amateur radio monopole with WPT-EV system on and off for comparison

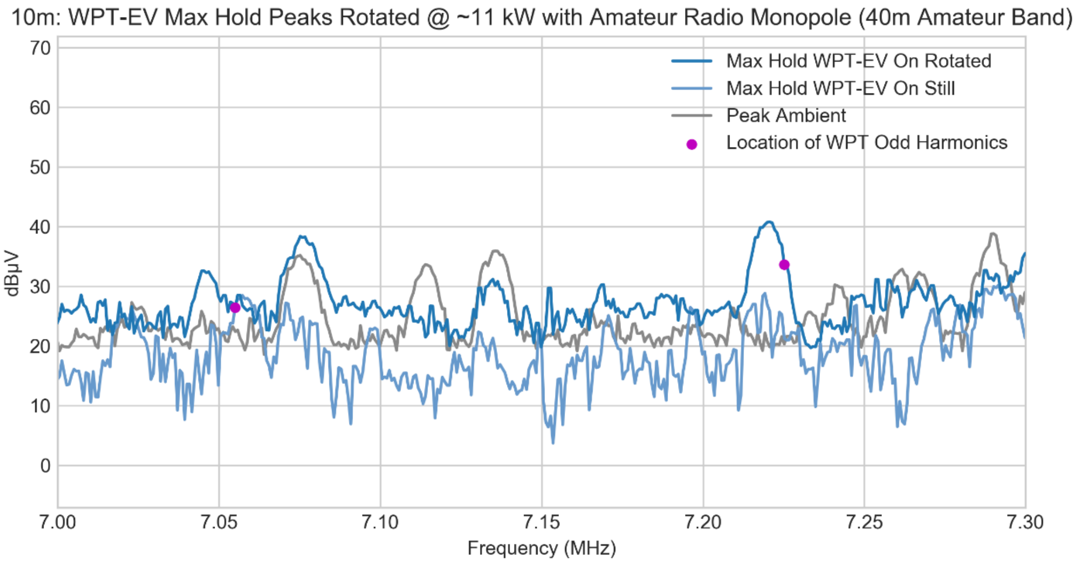


FIGURE A12-53

Peak measurements at a distance of 20 m using amateur radio monopole with WPT-EV system on and off for comparison

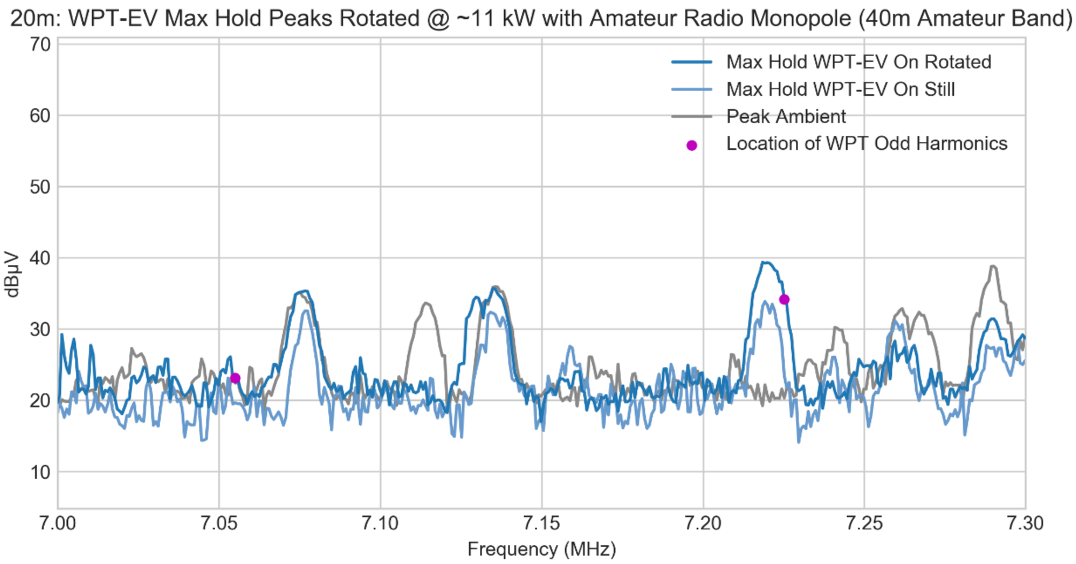
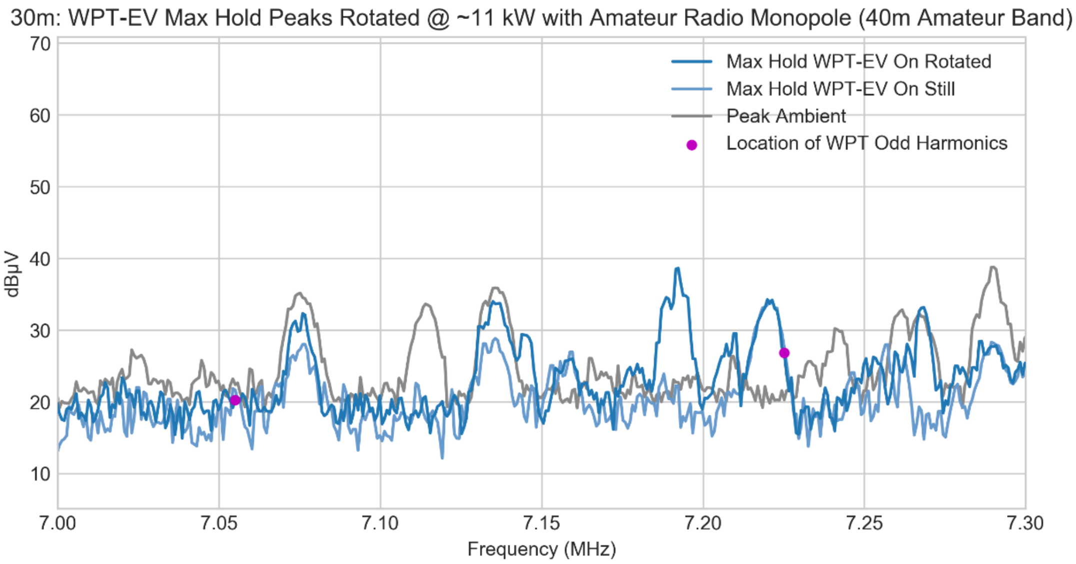


FIGURE A12-54

Peak measurements at a distance of 30 m using amateur radio monopole with WPT-EV system on and off for comparison



The plots for the 30 m amateur band at the various distances are shown below.

FIGURE A12-55

Peak measurements at a distance of 10 m using amateur radio monopole with WPT-EV system on and off for comparison

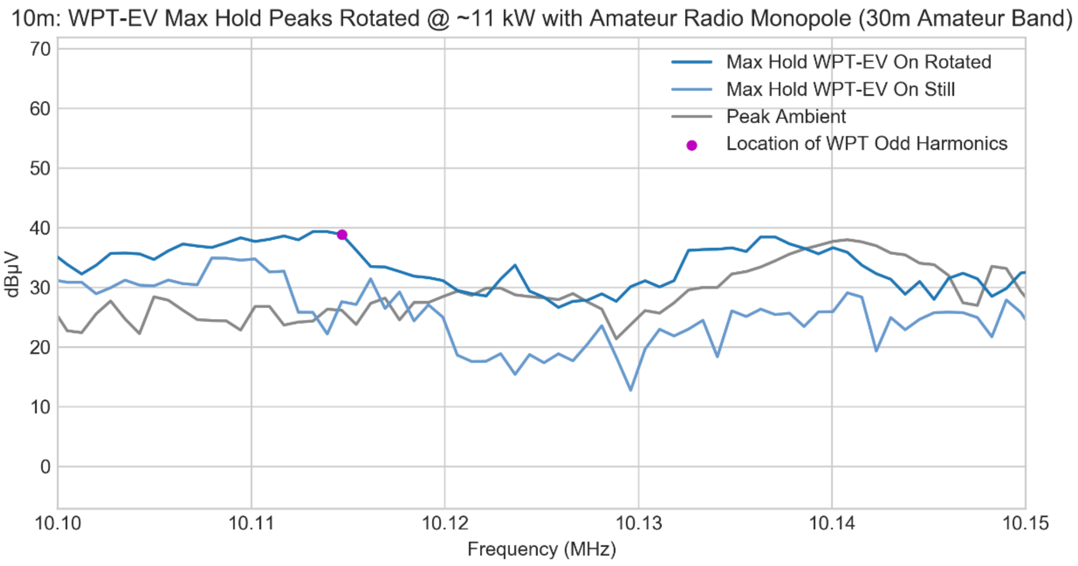


FIGURE A12-56

Peak measurements at a distance of 20 m using amateur radio monopole with WPT-EV system on and off for comparison

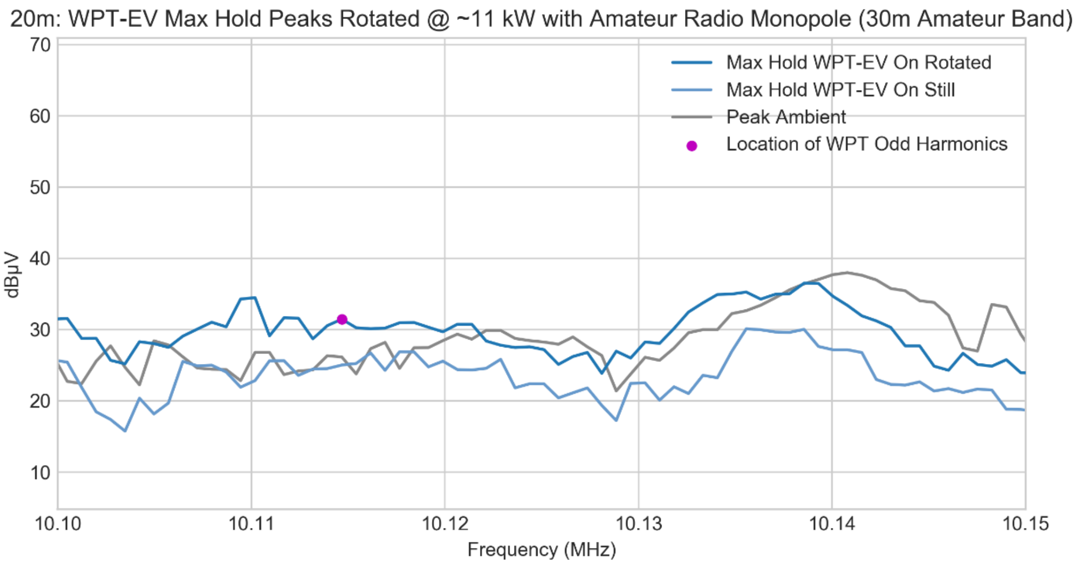
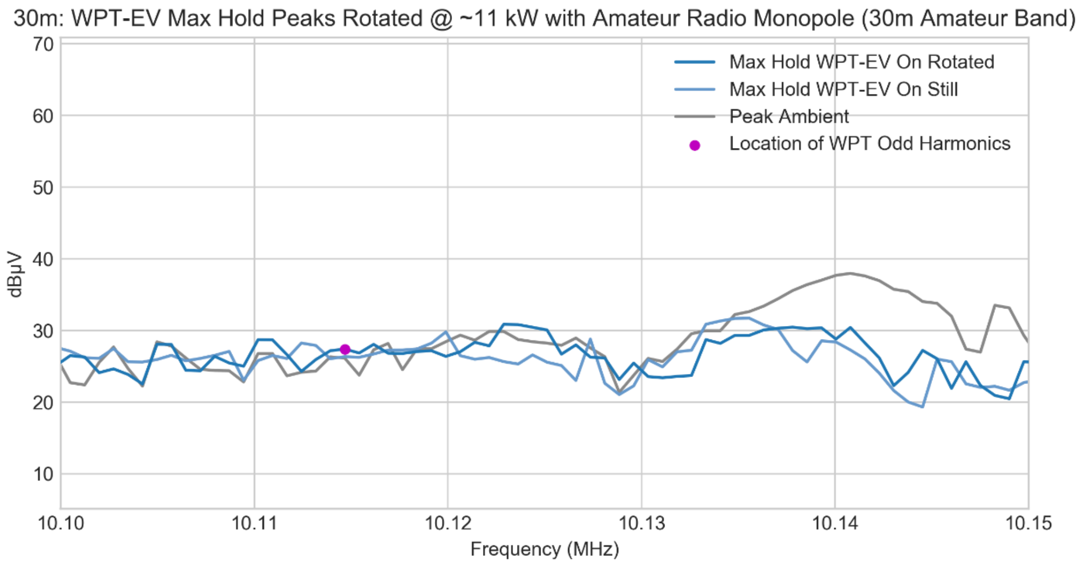


FIGURE A12-57

Peak measurements at a distance of 30 m using amateur radio monopole with WPT-EV system on and off for comparison



The plots for the 20 m amateur band at the various distances are shown below.

FIGURE A12-58

Peak measurements at a distance of 10 m using amateur radio monopole with WPT-EV system on and off for comparison

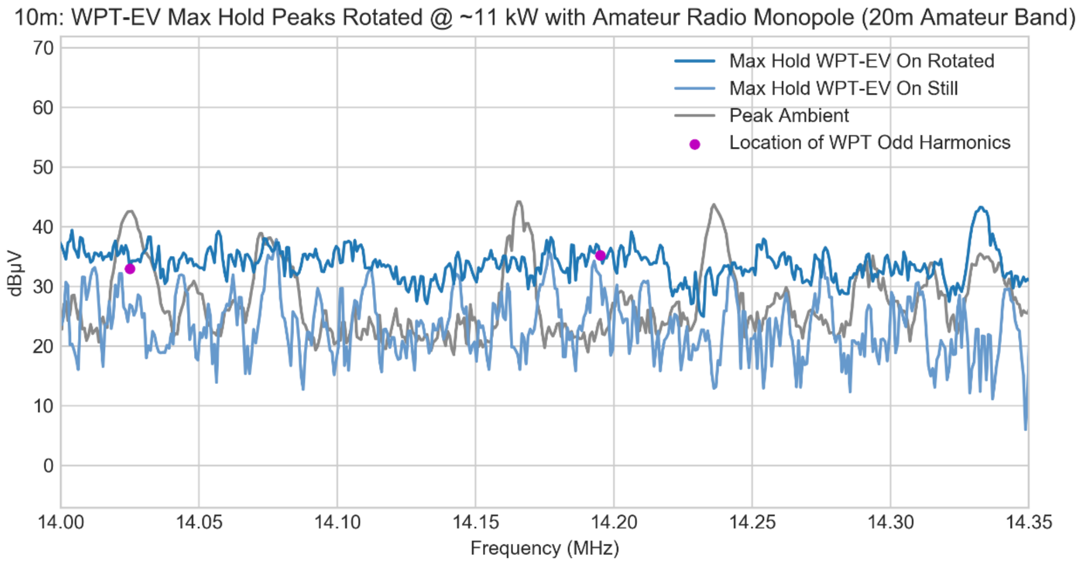


FIGURE A12-59

Peak measurements at a distance of 20 m using amateur radio monopole with WPT-EV system on and off for comparison

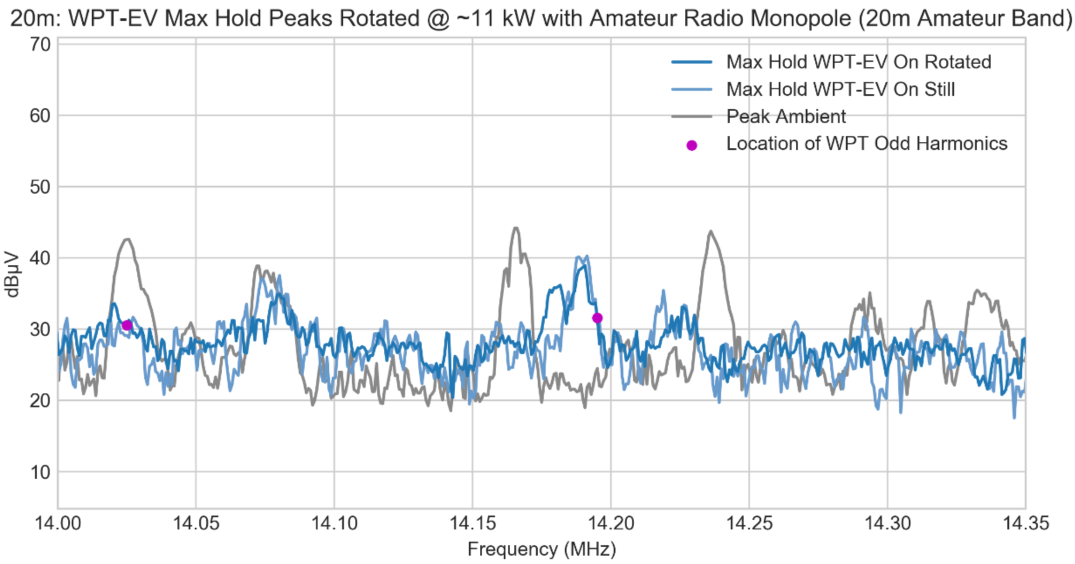
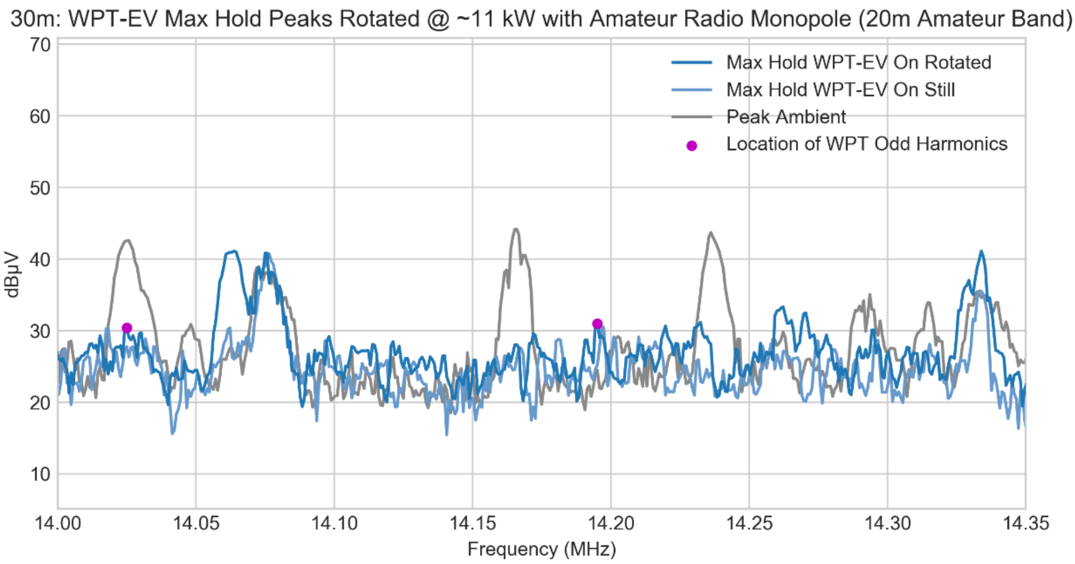


FIGURE A12-60

Peak measurements at a distance of 30 m using amateur radio monopole with WPT-EV system on and off for comparison



In addition to the various plots collected from the calibrated spectrum analyser, the amateur radio transceiver and receiver were used to assess qualitative audio impact of the WPT-EV system on communications. In general, at the various distances, no visual or audio impact in the tested amateur radio bands (80 m, 40 m, 30 m, 20 m) was detected above the ambient environment levels present at this site whenever the vehicle was reasonably aligned and rotated on the turn table. However, in one specific worst-case condition where the ground assembly coil and vehicle assembly coil were misaligned to maximum offset, the turn table was set to a specific angle relative to the amateur monopole antenna, and the antenna had an NVIS line attached to increase near-field sensitivity at a distance of 10 m from the WPT-EV system, audio characteristics from the WPT-EV were detectable as a faint “whistle”. In this same condition, a soft SSB voice transmission was also recorded directly over top of the interference signal at 3.825 MHz.

Despite the faintly heard WPT-EV interference, this voice transmission was clearly audible and intelligible. A before and after image of the recorded transmission using the Airspy HF+ Discovery receiver and SDRSharp radio software are shown below along with an overlay.

The interference signal from the WPT-EV system at 3.825 MHz using the SDRSharp software is shown below.

FIGURE A12-61

SDR# Software snapshot of WPT-EV interference signal at 3.825 MHz in worst-case condition

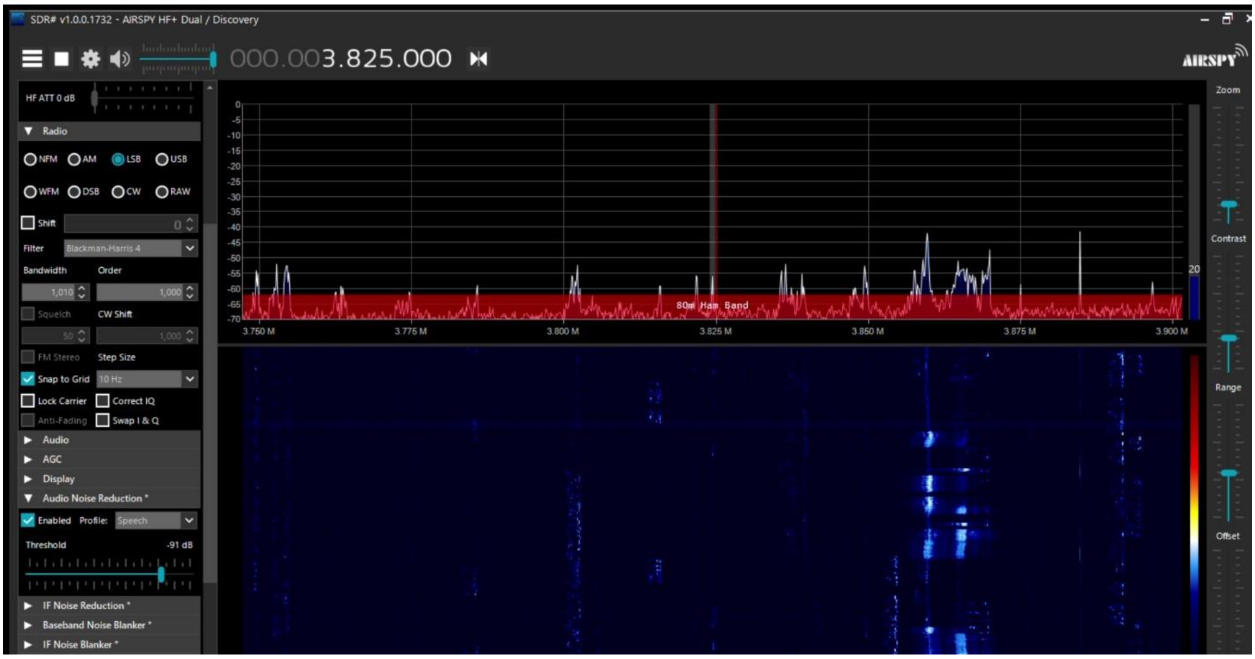
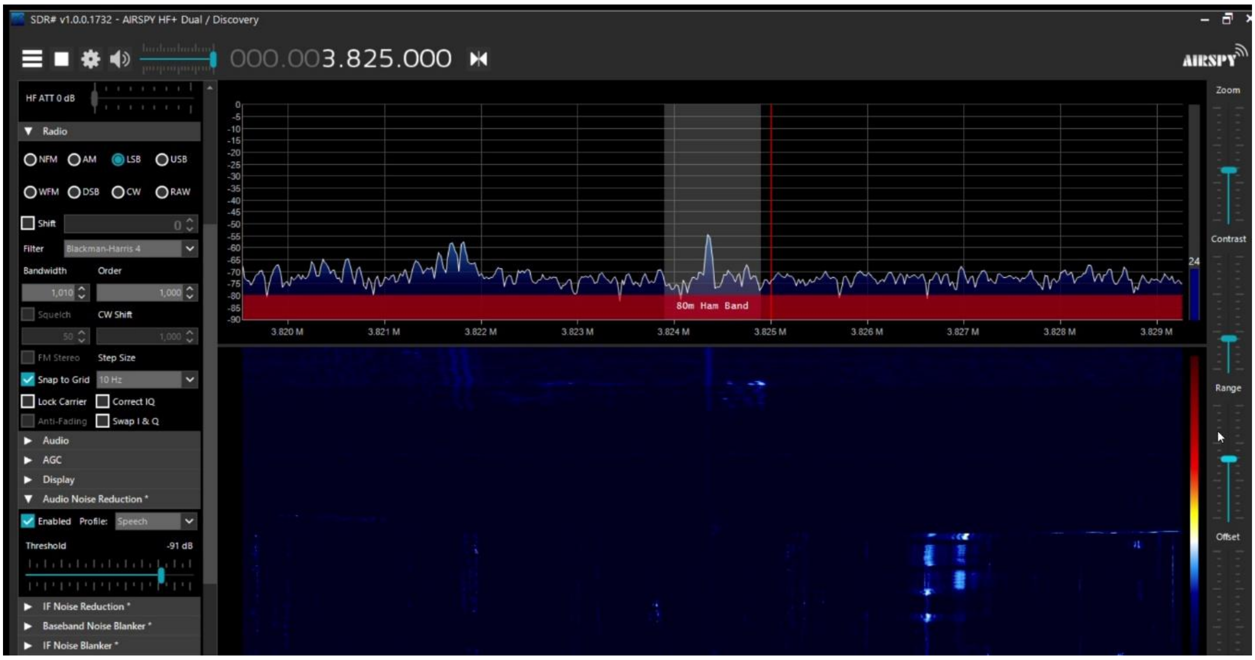


FIGURE A12-62

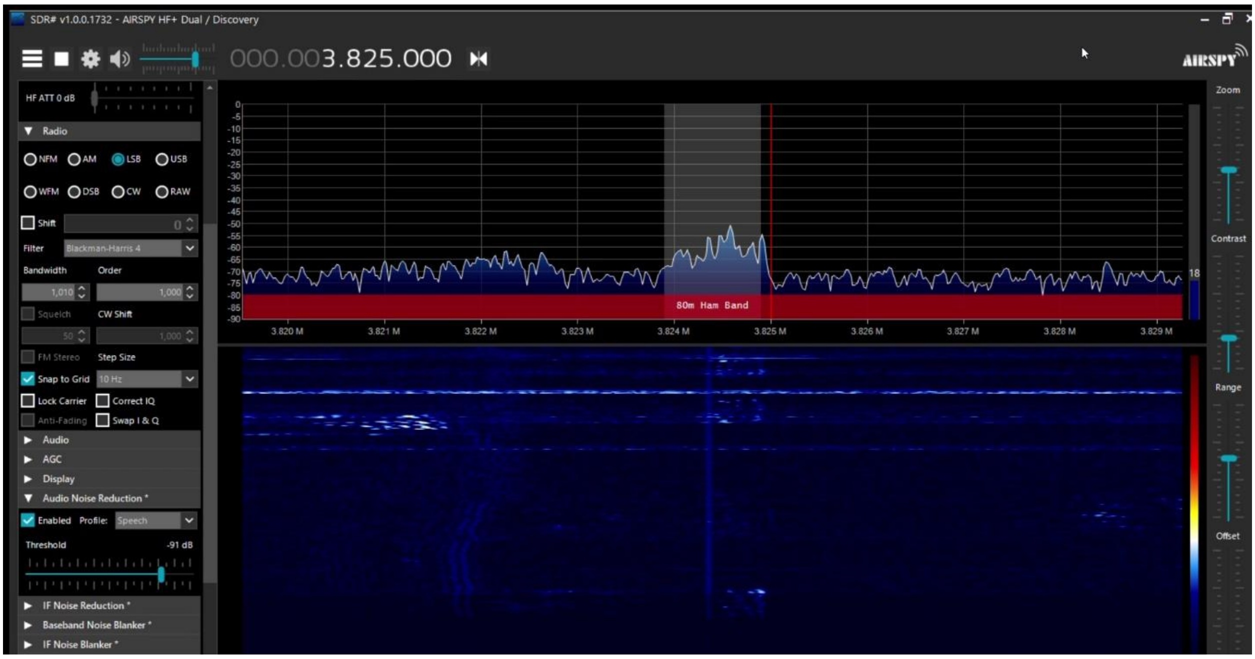
SDR# Software zoomed snapshot of WPT-EV interference signal at 3.825 MHz in worst-case condition



A distant amateur radio voice transmission occurred at the same frequency as the WPT-EV harmonic interference captured and is shown below.

FIGURE A12-63

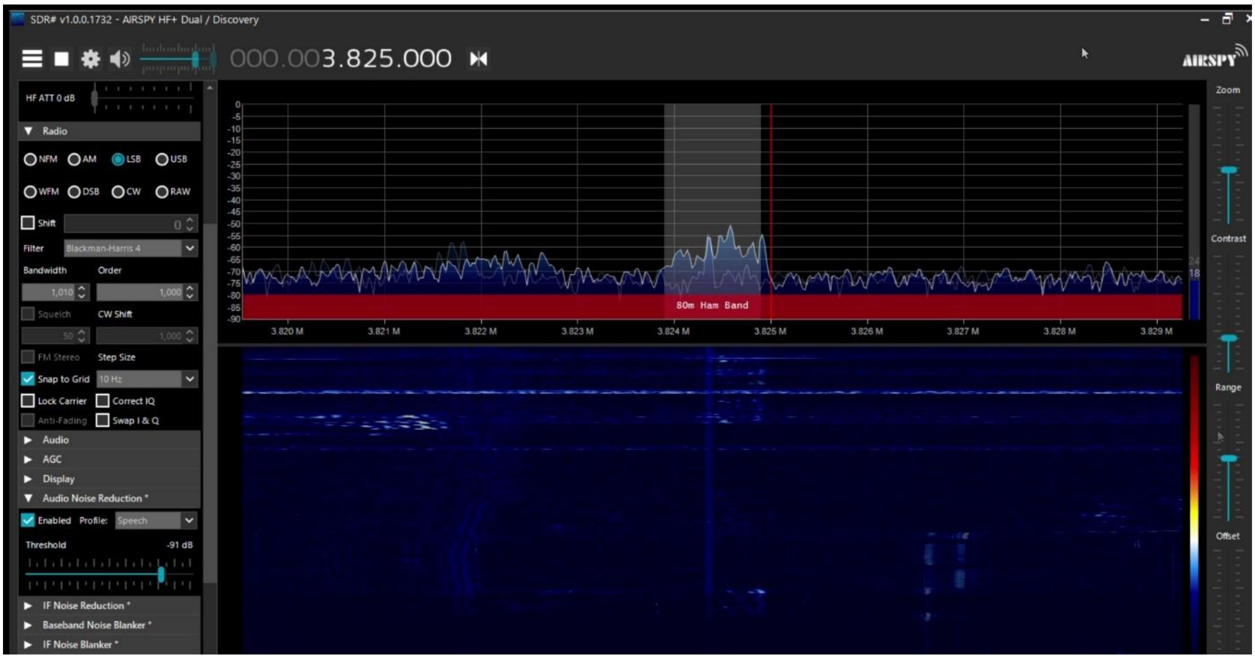
SDR# Software zoomed snapshot of distant amateur radio verbal audio broadcast at 3.825 MHz



An overlay of the interference and the SSB AM transmission together and shown below.

FIGURE A12-64

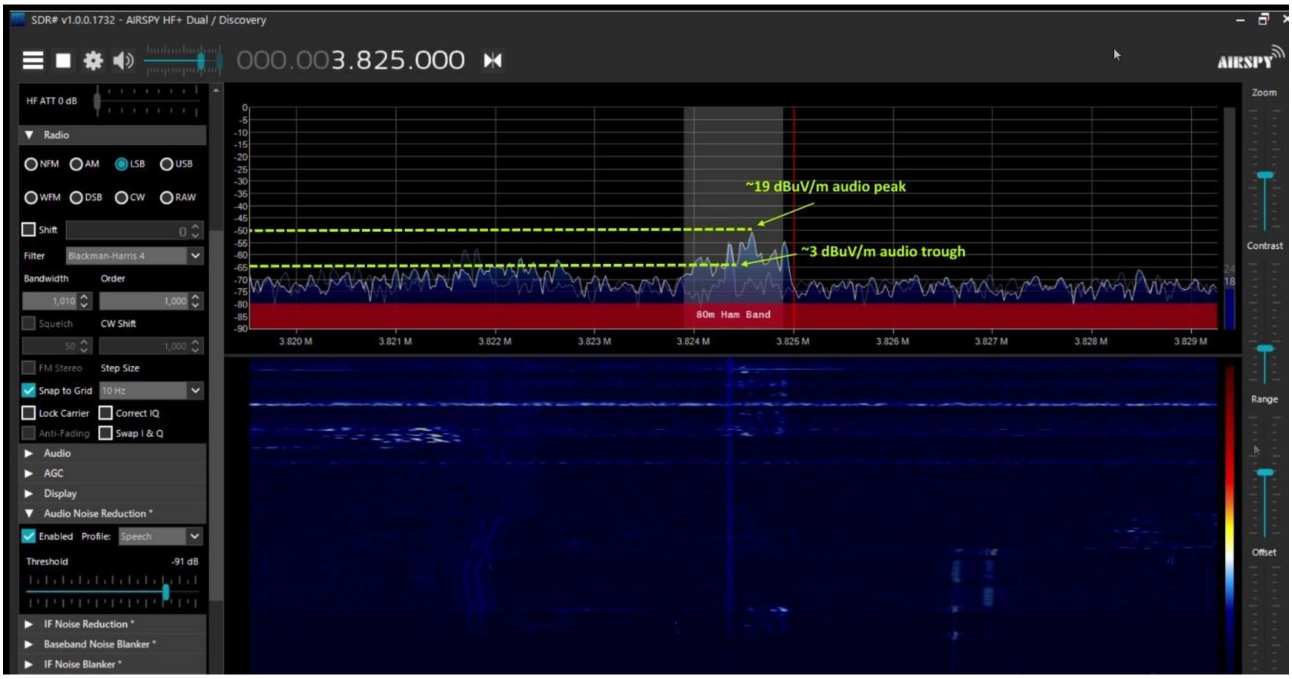
SDR# Software zoomed snapshot of distant amateur radio verbal audio broadcast at 3.825 MHz with WPT-EV interference signal underlay



Following the qualitative testing, additional characterization of the amateur radio monopole and the software-defined receiver (SDR) were performed to convert the signal strengths from the levels shown in the software to vertically polarized electric-field levels. The result of this conversion is shown in the Figure below. Note: Care should be exercised when viewing the noise trace in these figures because of limitations in some SDRs.

FIGURE A12-65

SDR# Software zoomed snapshot of distant amateur radio verbal audio broadcast at 3.825 MHz with WPT-EV interference signal underlay and E-Field levels



A12.4 Summary of Results

A WPT-EV system as defined by the referenced SDOs operating at ~11 kW input power and ~90% efficiency AC grid input to DC battery output mounted on a Nissan Leaf with a 62 kWh battery was measured on a third-party accredited Open Area Test Site (OATS). The characteristics of the ambient environment were collected for comparison of emissions with the WPT-EV system transferring power and turned off. Ambient characteristics measured using a recommended HF amateur radio monopole antenna for the designated operating bands were collected at the OATS and compared directly with the same measurement performed in a rural area separated by ~1300 miles or ~2100 km. In the 80 m and 40 m bands, the ambient measurements showed similar characteristics, whereas in the 30 m and 20 m bands, the levels in Nibley, Utah were typically up to ~10 dB lower than those in Cedar Park, Texas. Other ambient environment comparisons were also made, including one in Erigen, Switzerland. These additional comparisons indicate that the ambient conditions of the study are at least similar to another residential location in a different part of the world. The ambient environment comparison, however, can be applied to other locations and amateur installations only if the environment and ambient conditions are similar to what they are in the specific locations measured. Additionally, these measurements were made using EMC measurement techniques, so they do not represent the median man-made noise (MMN) values indicated in Recommendation ITU-R P.372.

The WPT-EV system was setup to operate continuously at full-power transfer and in worst-case misaligned conditions. Radiated emission data in the 9 kHz to 30 MHz range was collected by a third-part accredited lab using calibrated equipment used to perform certification measurements required by local administrations. Measurements were performed with a standard calibrated CISPR 60 cm loop antenna at a distance of 10 m. The magnetic loop antenna showed the WPT-EV operating fundamental as well as some other emissions above the ambient conditions present at the OATS. Detailed quasi-peak and average measurements were also taken with the magnetic loop antenna on discernible WPT-EV odd harmonics seen above ambient conditions in the 80 m to 20 m amateur radio bands. Radiation patterns were obtained for the fundamental as well as the measured harmonics.

For direct comparison and correlation with the calibrated measurements taken, additional data was collected by licensed amateur radio operators using a monopole antenna with a large effective antenna height. The amateur radio antenna was placed at distances of 10 m, 20 m, and 30 m over real earth from the WPT-EV system that was located on the OATS (and rotated for maximum interference potential). In several unique cases, very narrow-band harmonics were discernible with the amateur radio monopole antenna but their amplitude was no higher than the typical ambient peaks seen without the WPT-EV system operating.

Qualitative listening tests were also conducted in the presence of WPT emissions. One amateur service signal operating in the far-field with an average E-Field strength of ~16 dBµV/m (-35 dBµA/m) was heard at a frequency coinciding with a WPT harmonic and resulted in an intelligible and audible voice transmission yielding non-harmful interference. In this case, the approximate amateur signal-to-ambient-noise-peak ratio was about 13 dB with the ambient noise peaks occurring at an average of ~−2 dBµV/m (−53.5 dBµA/m). In the near-field, where the WPT-EV system is located at a 10 m distance, the calibrated H-Field EMC measurements cannot be converted to E-Field using far-field approximations. Further work is encouraged to examine the full impact of the measured levels of WPT emissions on general communications in the amateur service in multiple environments.

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Annex 13

Measured signals in the amateur bands

A13.1 Introduction

This Annex provides further information signals measured with a software-defined radio (SDR) in the amateur bands drawn from off-air measurements, and overlays as reference points the spurious emission limits defined in Recommendation ITU-R SM.329-12 (Short Range Devices below 30 MHz), the spurious emission levels suggested in the now rejected CIS/B/737/CDV and the WPT harmonic emission levels measured in the United States of America by SAE and set out in Annex 12.

The data presented provides a picture of the relationship between signal levels commonly present in the amateur service and WPT-EV emission limits.

A13.2 The methodology

The measurements set out to determine:

– The general level of signals in the amateur service. There are no minimum service levels defined in the amateur service and it is a "low signal" service. The off-air measurements conducted, provide detail on the actual levels of signal in everyday communication.

– The background noise level at the rural test site[30]

Equipment used comprised the following:

– A wideband calibrated SDR receiver RSP1A: https://www.sdrplay.com/docs/RSP1Adatasheetv1.9.pdf

– SDR software giving access to FFT length data to allow accurate conversion of measurements to other bandwidths: https://www.sdrplay.com/docs/SDRplay_SDRuno_User_Manual.pdf

– A calibrated signal source Elecraft XG3: https://elecraft.com/products/xg3

– A vertical monopole – Titanex V160HD (feed point at ground level)

– A vertical monopole for 10 MHz (feed point at 1 m above ground level)

– A three-element Yagi antenna (SteppIR 3-element yagi) at 12 m above ground

– A screened 50Ω termination resistor.

Three sets of measurements were taken:

– The noise level with the input to the receiver terminated with 50 Ω

[30] 52.480301 N, 2.856970 W – England.

– The noise level with the antenna connected
– The spectrum of signals with the antenna connected.

In carrying out these tests, it became evident that measurements of background noise levels using an SDR are not straightforward, and that care is needed to understand how the relevant SDR software conducts an analysis of the FFT bins in the receiver. Initial tests with two types of SDR software (SDR# and SDR Console) yielded inaccurate results. These software packages did not allow access to the FFT data and so misleading noise bandwidth data was measured. A third software package and SDR (RSP1A) gave full information on the FFT length and resulting measurement bandwidth which was validated as accurate to within the measurement accuracy of the system.

Measurements are only presented for the 1.8-14 MHz amateur bands as the maximum impact of WPT harmonic emissions is expected in this part of the spectrum.

A13.3 Measurement methodology

A13.3.1 Calibration

A calibrated 50 Ω signal source was injected into the receiver on each frequency band measured at various levels. The levels were compared with the dBµV scale on the receiver. The tracking from 0 dBuV to +74 dBuV was seen to be well within ±1 dB.

A13.3.2 50 Ω termination

The system noise was measured to confirm that the receiver noise factor would not influence the overall measurement integrity. The results show:

Band (MHz)	Noise in 3 kHz with 50 Ω (dBm)	Margin below off-air noise (dB)
1.8	−118	26.0
3.5	−118	20.4
7	−122	15.1
10.1	−125	18.2
14	−126	14.9

These measurements confirm a suitably low level of receiver noise to conduct valid measurements, with inherent noise being at least some 15 dB or more below off-air background noise.

A13.3.3 Off-air measurements

Vertical monopoles were generally used for the off-air measurements (but a 3-element yagi antenna 7.4 dBi forward gain for 14 MHz). They had antenna factors as shown in Table A13-1 below. The Table also notes the off-air background noise at the test site:

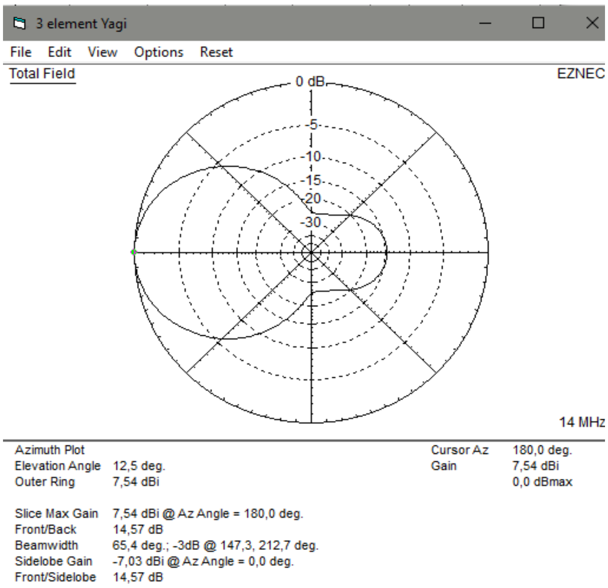
TABLE A13-1

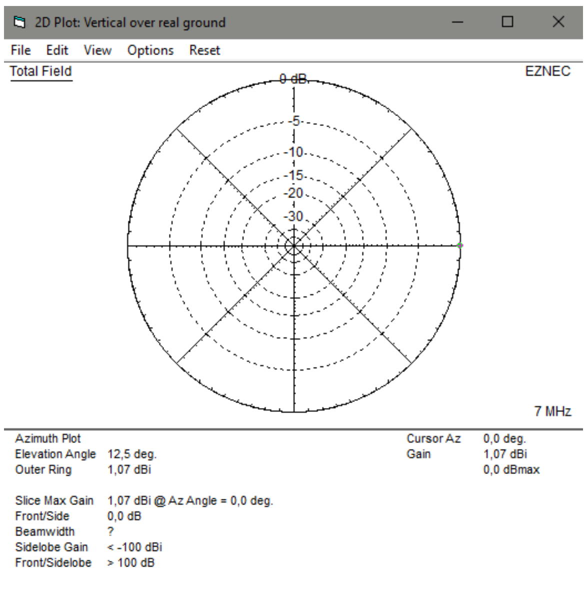
Antenna factors of the antennas used in the tests

Frequency (MHz)	Antenna	Gain (dBi)	Gain (G) multiple	Antenna factor*	Background noise (dBuA/m)
1.8	Vertical monopole	0	1.00	−24.7	−56.1
3.5	Vertical monopole	0	1.00	−18.9	−56.0
7	Vertical monopole	1.2	1.32	−14.1	−58.3
10	Vertical monopole	0	1.00	−9.8	−56.1
14	3 element Yagi	7.4	5.5	−14.3	−60.6

* Antenna factor is derived from 20 log (9.73/λ*√(*G*)) Gain measured at 12.5-degree elevation. Overall error from change of gain with elevation assessed at less than 1.5 dB for relevant elevations.

Antenna factors were software-calculated using method of moments (NEC-2 engine EZNEC v 6.0). Representative examples of the software plots are shown below.





Spectrum plots were then taken of amateur service traffic, together with a note of the background RMS noise level. Measurements were taken late afternoon with the exception of 1 800 kHz where the measurements were taken in the evening to ensure presence of radiocommunications traffic. However, checks were taken at other times of the day to ensure that the data presented is suitably representative. There are times of day when signal levels are significantly lower than shown.

A13.4 Results

Spectrum scans for the 1.8, 3.5, 7, 10.1 and 14 MHz amateur bands are included below. For the purpose of comparison, lines have been added showing the emission levels which would have applied under the CIS/B/737/CDV draft standard (subsequently rejected) and Recommendation ITU-R SM.329 at 10 m from the WPT. Data at 20 m has also been added in the case of the CISPR proposal.

Conversion of all data has been carried out to ensure that a consistent RBW is used for all data – noise, signals, emission limit lines. The calculator used to make these conversions is included as an embedded file at the end of this document. The steps taken in the conversion process are as follows:

a) All measurements are with an SDR RBW of 3 kHz.

b) Noise level in that RBW is shown (top left) on each chart.

c) The FFT BIN length is shown bottom right on each chart.

d) We then convert the relevant limit to align with the LH dBm scale as follows:

- Limit (dBuA/m) converted to FFT BIN length RBW (= 10*log(FFT BIN/standard RBW) dB adjustment)
- Then converted to dBuV/m (= +51.5 dB)
- Then converted to dBuV (= −AF)
- Then converted to dBm (= −107) thus allowing it to be plotted on the spectrum scan.

e) To convert the indicated noise to other (e.g. standards) RBW for comparison purposes, we proceed as follows:

- Convert indicated noise in dBm to dBuV (= +107)
- Convert to dBuV/m (= +AF)
- Convert to dBuA/m (= −51.5)
- Convert to standards RBW (= 10*log(standards bandwidth/FFT BIN RBW)).

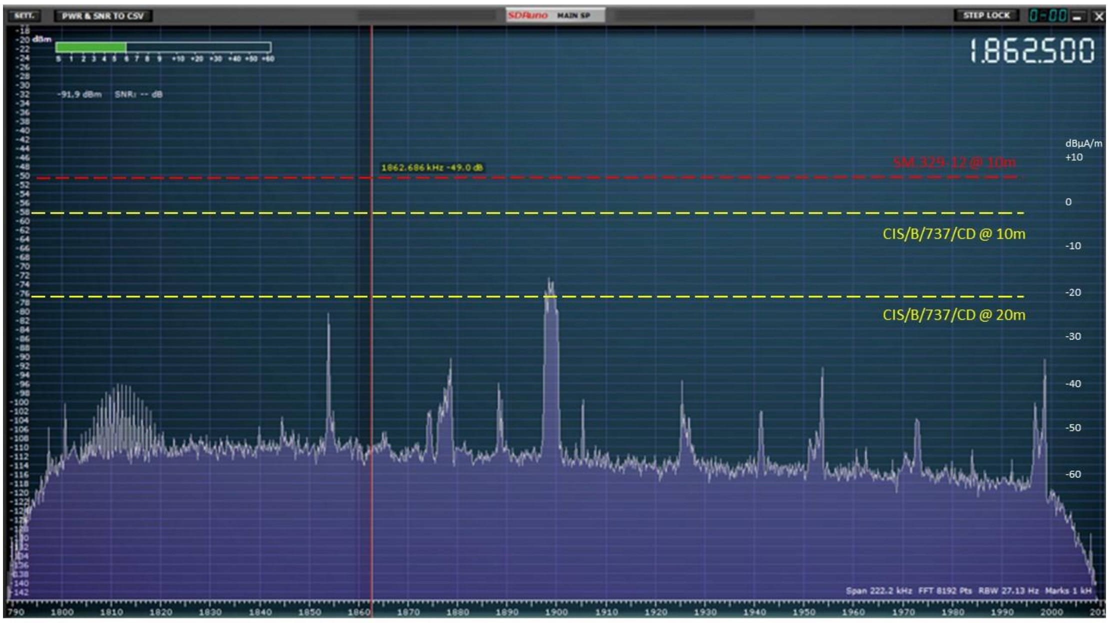
f) A scale in dBuA/m was also added to each plot on the above basis.

All measurements were taken with an SDR RBW of 3 000 Hz. FFT BIN length varies by spectrum slice.

It will be noted that the general level of signals and signal/noise ratio is broadly consistent with that shown in Fig. A10-1 of Report ITU-R SM.2451, which suggests mean level of signals in the amateur service of 15-20 dB above noise level.

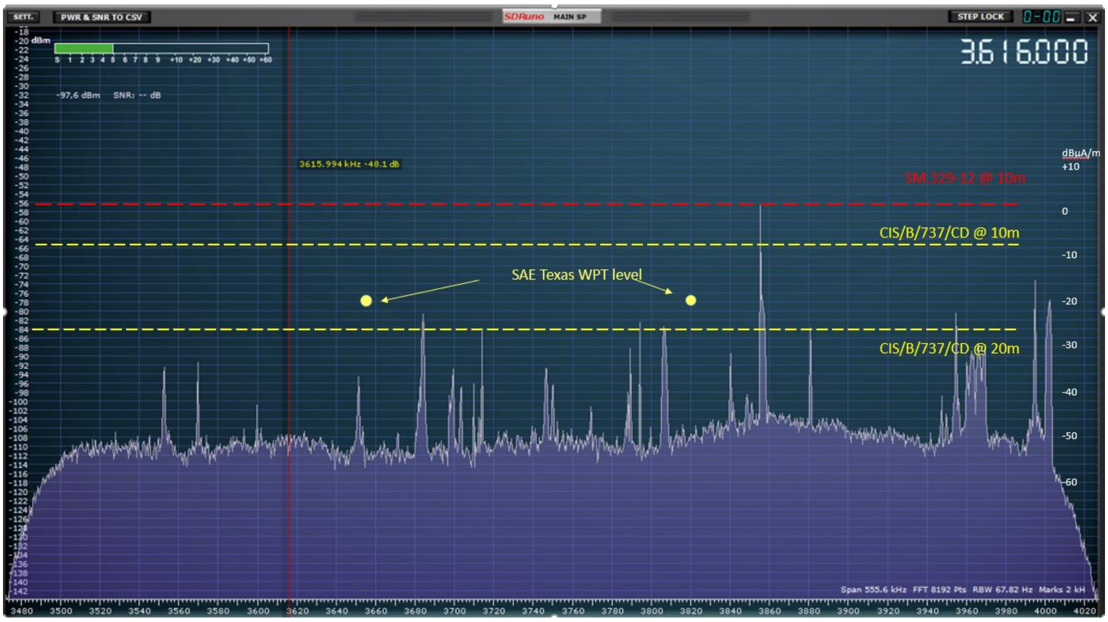
For the purpose of this study, the modelling has been done assuming that the receiving antenna is a magnetic loop, although the signal levels measurements have been undertaken using E-field antennas and converted to H-field units.

A13.4.1 1,800 kHz spectrum – evening – March 2021



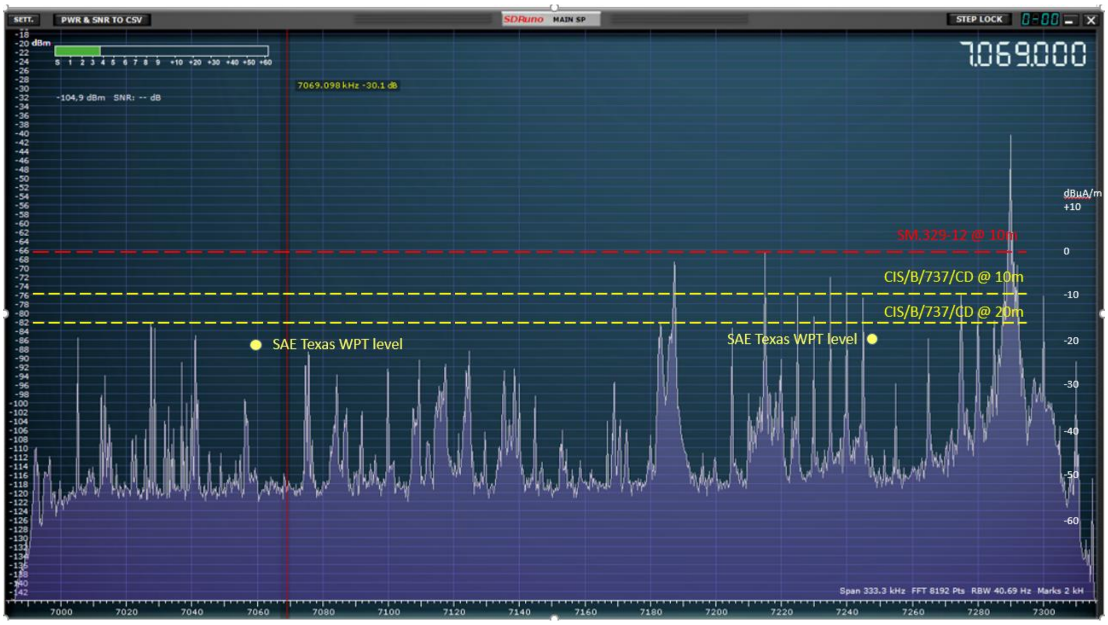
Measurement bandwidth = 3 kHz. FFT BIN = 27.13 Hz. Noise in SDR RBW = −91.9 dBm
Outputs from calculation**:**
SM.329-12: −50.5 dBm scale
CIS/B/737/CDV level: −58.0 dBm scale
Noise level in 9.5 kHz (compromise between SM.329-12 and CIS/B/737/CDV RBWs): −56.1 dBμA/m

A13.4.2 3.5 MHz spectrum – late afternoon – March 2021



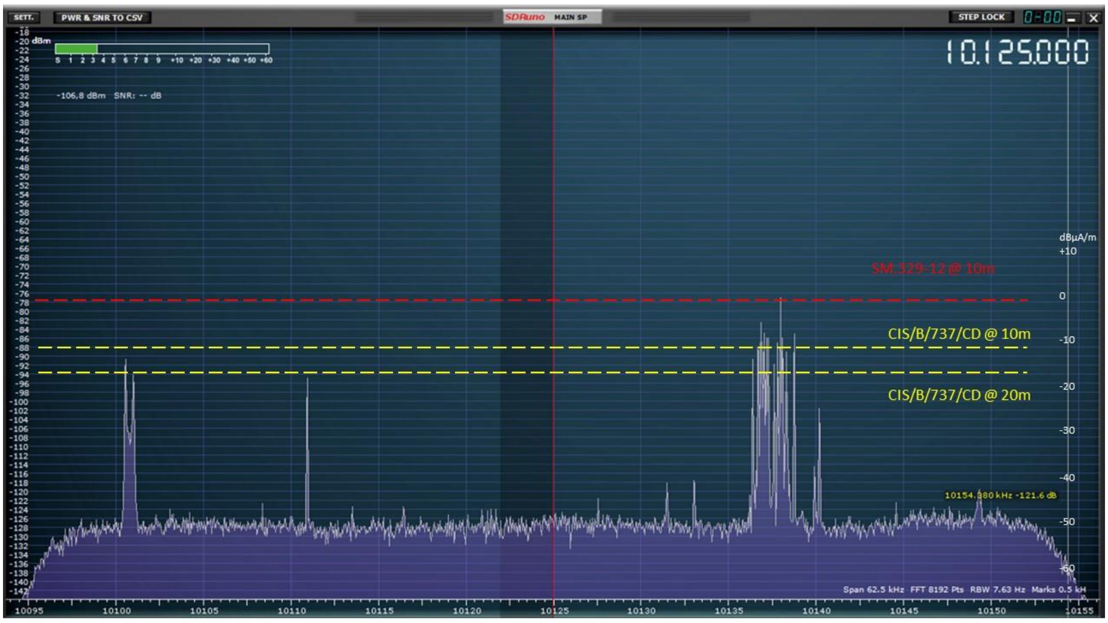
Measurement bandwidth = 3 kHz. FFT BIN = 67.82 Hz. Noise in SDR RBW = −97.6 dBm
Outputs from calculation**:**
SM.329-12 level @10 m: −53.5 dBm scale
CIS/B/737/CDV level @10 m: −64.8 dBm scale
Noise level in 9.5 kHz (compromise between SM.329-12 and CIS/B/737/CDV RBWs): −56.1 dBμA/m

A13.4.3 7 MHz spectrum – late afternoon March 2021



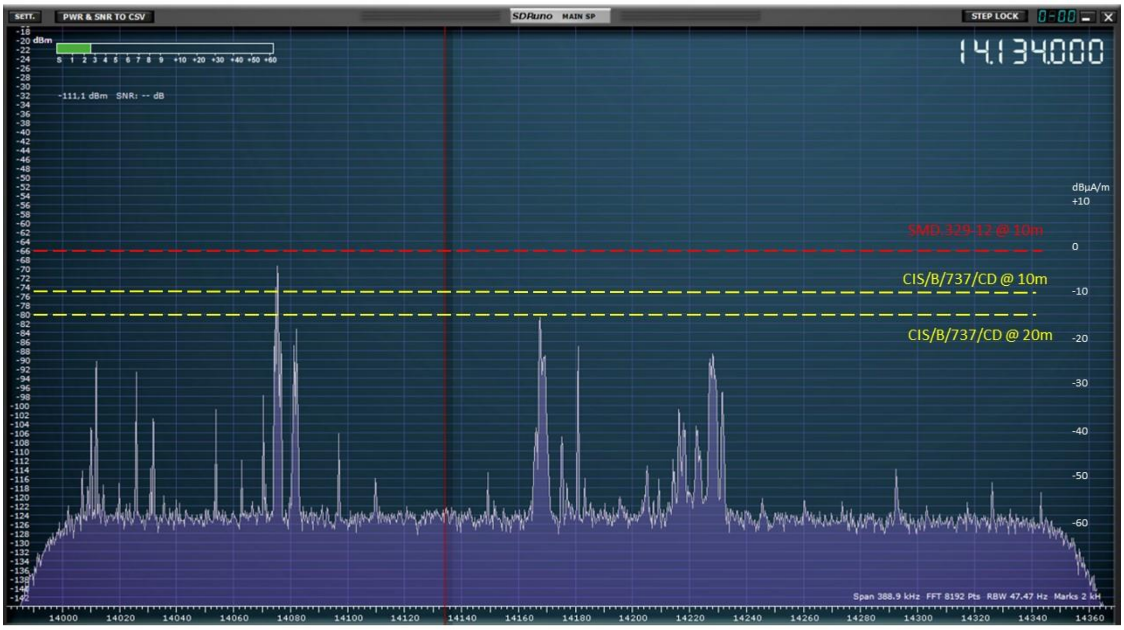
Measurement bandwidth = 3 kHz. FFT BIN = 40.69 Hz. Noise in SDR RBW = −104.9 dBm
Outputs from calculation**:**
SM.329-12: −65.9 dBm scale
CIS/B/737/CDV level: −75.7 dBm scale
Noise level in 9.5 kHz (compromise between SM.329-12 and CIS/B/737/CDV RBWs): −57.9 dBµA/m

A13.4.4 10 MHz spectrum – late afternoon – March 2021



Measurement bandwidth = 3 kHz. FFT BIN = 7.63 Hz. Noise in SDR RBW = −106.8 dBm
Outputs from calculation**:**
SM.329-12 level: −77.9 dBm scale
CIS/B/737/CDV level: −86.7 dBm scale
Noise level in 9.5 kHz (compromise between SM.329-12 and CIS/B/737/CDV RBWs): −56.1 dBµA/m

A13.4.5 14 MHz spectrum – late afternoon March 2021



Measurement bandwidth = 3 kHz. FFT BIN = 61.04 Hz. Noise in SDR RBW = −91.9 dBm
Outputs from calculation**:**
SM.329-12: −65.5 dBm scale
CIS/B/737/CDV level: −74.3 dBm scale
Noise level in 9.5 kHz (compromise between SM.329-12 and CIS/B RBWs): −60.6 dBµA/m

A13.5 Summary

This study has measured the typical levels of signals in the amateur service bands between 1.8 and 14 MHz. It shows a broadly consistent result, from which it will be seen that:

a) The measured level of signals in one rural location in the amateur bands indicated have *S*/*N* of some 10-30 dB at the receiver with a median of some 20 dB.

b) According to measurements from a software defined radio (SDR) at one location, the emission limits under Recommendation ITU-R SM.329-12 and the rejected limits from CIS/B/737/CDV at a measurement distance of 10m could exceed the levels of amateur service signals by 10 to 30 dB or more when using a magnetic loop antenna. When using an E-field antenna, the comparative levels cannot be stated for sure, but for 7, 10 and 14 MHz at least, 10 m spacing places the antenna in the far field and so emissions are likely to be close to the H-field levels converted in the conventional way using the impedance of free space.

c) According to measurements from the SDR at one location, the WPT single-carrier harmonic levels measured in Texas by SAE could be above the median amateur signal levels on the two frequency bands where calibrated SAE measurements were taken.

d) No qualitative data was collected to compare the impact of a WPT-EV system; however, data collected with an SDR at one location shows that if the single-carrier harmonic were present at the same frequency used by an amateur operator, it is possible that the WPT harmonic levels measured from the WPT-EV system in Texas could impact analogue transmission modes in the amateur service. The impact on digital transmission modes needs further study, but is also likely to be significant.

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