CEPT ECC
Electronic Communications Committee

ECC Report 289

Wireless Power Transmission (WPT) systems for electrical vehicles (EV) operating within 79-90 kHz band

approved 25 January 2019

0 EXECUTIVE SUMMARY

The impact of Wireless Power Transmission for Electric Vehicles (WPT-EV) in 79-90 kHz on radiocommunication services operating below 30 MHz is considered in this Report. The effect on services operating in adjacent frequencies as well as the impact of unwanted emissions from WPT-EV was studied. Inputs have been made for some radiocommunication services (i.e. standard frequency and time signal service, broadcasting service, amateur service, radionavigation service and fixed and mobile service) and a radio application (EAS) about the potential impact, and these are set out in this Report.

An important issue identified in 79-90 kHz was compatibility of wanted WPT-EV emissions with the Standard Frequency and Time Signal Service (DCF77) in the frequency range 79-85 kHz. The proposed limit for the magnetic (H-field) field strength in this frequency range is a maximum of 42 dBµA/m at 10m.

There were no compatibility issues identified within the band 85-90 kHz. Therefore, the request in ETSI TR 103 409 for an increase in the magnetic field strength limit is proposed for a maximum of 82 dBµA/m at 10 m in the frequency range 85-90 kHz.

In the spurious domain of WPT-EV, the following radiocommunication services and radio applications have been considered in this Report:

- Broadcasting;
- Amateur service;
- Radionavigation;
- Fixed and mobile service;
- Electronic Article Surveillance (EAS).

The WPT-EV manufacturers have confirmed that systems have been designed to meet the emission limits for inductive SRDs in ERC Recommendation 74-01 [12]. The study in this Report shows that these limits fall well short of providing adequate protection for the services studied within this Report.

For the broadcasting service, the proposed figures for the spurious/harmonic emission limits of a WPT-EV system (if WPT-EV is not operating on the broadcasting channel raster at 81 kHz or 90 kHz) are:

- Band 5 (148.5-283.5 kHz): -67.0 dBµA/m (@10m from the WPT-EV);
- Band 6 (526.5-1606.5 kHz): -74.0 dBµA/m (@10m from the WPT-EV).

The proposed figures for the spurious/harmonic emission limits of a WPT-EV spurious/harmonics (if WPT-EV is on the broadcasting channel raster at 81 kHz or 90 kHz) are:

- Band 5 (148.5-283.5 kHz): -37.0 dBµA/m (@10m from the WPT-EV);
- Band 6 (526.5-1606.5 kHz): -44.0 dBµA/m (@10m from the WPT-EV).

For the amateur service, given the planned density of WPT-EV systems, it is calculated that there will be a widespread and serious impact on its operation in the vicinity of WPT systems should spurious emissions, measured at 10 m be at the current limits of ERC Recommendation 74-01 . An appropriate limit at 10 m would be: -46 dBµA/m at 300 kHz reducing by 7 dB per frequency decade to -60.0 dBµA/m at 30 MHz. This can be relaxed by 20dB if all WPT systems adopt a single common frequency of operation.

For the aeronautical radionavigation service operating in the band 255-526,5 kHz, the maximum permissible interference value at the receiver of 21.9 dBµV/m applies to maintain proper operation of the NDB/ADF system.

For the fixed and mobile service operating between 1.5 and 30 MHz, it is shown that the limits for amateur service are relevant.

For Electronic Article Surveillance (EAS), if a WPT-EV system, with spurious emissions at CISPR 11 levels (similar to ERC Recommendation 74-01 levels at these frequencies), operates in the vicinity of an EAS

system it may degrade the effectiveness of the latter. No shielding effect was taken into account in making this assessment.

It should be noted that the spurious emission levels proposed in this Report for radiocommunication services above 150 kHz are significantly lower than the current inductive spurious emission levels of ERC Recommendation 74-01 [12].

It is to be noted that WPT-EV manufacturers indicate that the proposed spurious emission levels above are not achievable at LF/MF broadcasting frequencies. At higher frequencies (approximately higher than 2 MHz), it could be technically possible to approach the proposed protection levels.

WPT-EV is an emerging and evolving technology. To ensure a low probability of harmful interference to radiocommunication services, further study is required, including evaluation of real equipment, mitigation techniques and other measures to improve WPT-EV systems, to achieve a level of spurious emissions sufficiently below ERC Recommendation 74-01 for WPT-EV.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
AC	Alternating Current
ADF	Automatic Direction Finder
ADSL	Asymmetric Digital Subscriber Line
AM	Amplitude Modulation
BPL	Broadband over power line
BW	Bandwidth
CDF	Cumulative Distribution Function
CENELEC	European Committee for Electrotechnical Standardisation
CEPT	European Conference of Postal and Telecommunications Administrations
CISPR	International Special Committee on Radio Interference
C/I	Carrier to interferer ratio
CW	Continuous Wave
DC	Direct Current
DCF77	Standard time and frequency signal of 77.5 kHz transmitted from Mainflingen (Germany)
DGPS	Differential GPS
DME	Distance measuring equipment
DSL	Digital Subscriber Line
DUT	Device Under Test
EAS	Electronic Article Surveillance
EBU	European Broadcasting Union
ECA	European Common Allocation
ECC	Electronic Communications Committee
eLORAN	Enhanced LORAN
EMC	Electromagnetic Compatibility
EMF	Electromagnetic Field
EMI	Electromagnetic interference
EMRP	Effective Monopole Radiated Power
ERC	European Radiocommunication Committee
ETSI	European Telecommunications Standard Institute
EU	European Union
EV	Electrical Vehicle

FFT	Fast Fourier transform
GPS	Global Positioning System
HF	High Frequency
HBG	Swiss transmitter frequency designation for time signal transmission
IALA	International Association of Lighthouse Authorities
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ID	Identifier
ILS	Instrument Landing System
ISM	Industrial, Scientific and Medical
ITU	International Telecommunication Union
LED	Light emitting diode
LF	Low Frequency
LNA	Low noise amplifier
LORAN (C)	Long range navigation
MIFR	Master International Frequency Register
MF	Medium Frequency
MSF	UK transmitter frequency designation for time signal transmissions
NATO	North Atlantic Treaty Organisation
NDB	Non directional beacon
NM	Nautical Miles
OATS	Open Area Test Site
OBW	Operation Bandwidth
Ofcom	Office of Communications
PLC	Power Line Communications
PLT	Power Line Telecommunications
PHEV	Plug in Hybrid Electric Vehicle
PR	Protection Ratio
PV	Photovoltaic
RAS	Radio Astronomy Service
RBU	Russian transmitter frequency designation for time signal transmissions
RF	Radio Frequency
RFID	Radio Frequency Identification Device
Rms	Root mean square
RNS-E (A,D)	Russian transmitter frequency designation for time signal transmissions
RNS-V (A)	Russian transmitter frequency designation for time signal transmissions
SAC	Semi-anechoic chamber
S/N	Signal to noise ratio

SRD	Short Range Device
SRdoc	System Reference document
TCAM	Telecommunication Conformity Assessment and Market Surveillance Committee
VHF	Very High Frequency
VOR	VHF Omnidirectional Range
VSRD	Very short range device
WPT	Wireless power transmission
WPT-EV	Wireless power transmission (WPT) systems for electrical vehicle charging

1 INTRODUCTION

Wireless Power Transmission for Electric Vehicles (WPT-EV) is an emerging high-power technology that can recharge an electric car or other vehicle. The preferred frequencies for WPT-EV are generally relatively low, but they may involve power levels of many kilowatts. In this Report, the form of WPT-EV considered is essentially an inductive power transfer system via a pad under the vehicle. There may be additional lower power signals for exchanging charging status/control and positioning information, these signals can use the same frequency as WPT-EV or a different one.

Both CISPR and ETSI are currently working on standards for WPT-EV: CISPR 11 [24] and ETSI 303 417 [3]. The former assumes that WPT-EV could be seen as an Industrial, Scientific and Medical (ISM) application while the latter assumes that WPT-EV could be covered by the Short Range Device (SRD) regulatory framework.

ETSI TR 103 409 (see clause 9.2. therein [11]) states that the current radiated emission limits for inductive applications in Annex 9 of ERC Recommendation 70-03 in the range 79-90 kHz are not sufficient to implement practical WPT-EV systems and requests a relaxation of 14 dB, resulting in a radiated emission limit of 82 dBµA/m (at 10m) at 79 kHz, descending with 3 dB/oct.

The ECC discussed whether WPT could be covered by the existing inductive SRD regulations. However, further study was required due to the differences assumed between inductive SRD and WPT such as deployment density and activity factor.

This Report only considers WPT for electrical vehicles (WPT-EV) in the range 79-90 kHz, and it is based on the ETSI TR 103 409 characteristics. Other WPT use cases and WPT-EV in frequency ranges other than 79-90 kHz are to be addressed in a separate ECC Report.

2 EXISTING REGULATION FOR INDUCTIVE APPLICATIONS

Annex 9 to ERC Recommendation 70-03 [1] provides regulatory parameters for inductive applications in the frequency range 9-5000 kHz as follows:

Table 1: Existing regulatory parameters for inductive applications in the frequency range 9-5000 kHz - Annex 9 to ERC Recommendation 70-03 [1]

Frequency Band (kHz)		Power / Magnetic Field	Spectrum access and mitigation requirements	Modulation / maximum occupied bandwidth	ECC / ERC Deliver-able	Notes
a1	9-90	72 dBµA/m at 10m - The limit is reduced according to Table 2	No requirement	Not specified		In case of external antennas only loop coil antennas may be employed. Field strength level descending 3 dB/oct at 30 kHz
a2	90-119	42 dBµA/m at 10m	No requirement	Not specified		In case of external antennas only loop coil antennas may be employed
a3	119-135	66 dBµA/m at 10m - The limit is reduced according to Table 2	No requirement	See note 1		In case of external antennas only loop coil antennas may be employed. Field strength level descending 3 dB/oct at 119 kHz
B	135-140	42 dBµA/m at 10m	No requirement	Not specified		In case of external antennas only loop coil antennas may be employed
C	140-148.5	37.7 dBµA/m at 10m	No requirement	Not specified		In case of external antennas only loop coil antennas may be employed
k1	148.5-5000	-15 dBµA/m at 10 m	No requirement	Not specified		In case of external antennas only loop coil antennas may be employed. The maximum field strength is specified in a bandwidth of 10 kHz. The maximum allowed total field strength is -5 dBµA/m at 10 m for systems operating at bandwidths larger than 10 kHz whilst keeping the density limit (-15 dBµA/m in a bandwidth of 10 kHz)

Note 1: Sub-band a3): RFIDs operating in the frequency sub-band 119-135 kHz shall meet the spectrum mask given in ETSI EN 300 330. This will permit a simultaneous use of the various sub-bands within the range 90-148.5 kHz.

The limits in Table 2 are based on the study published in ECC Report 135 [2] to protect standard frequency and time signal systems.

Table 2: Standard frequency and time signals to be protected

Stations	Frequency	Protected Bandwidth	Maximum Field Strength at 10m	Location
MSF	60 kHz	+/-250 Hz	42 dBµA/m	United Kingdom
RBU	66.6 kHz	+/-750 Hz	42 dBµA/m	Russian Federation
HBG	75 kHz	+/-250 Hz	42 dBµA/m	Switzerland
DCF77	77.5 kHz	+/-250 Hz	42 dBµA/m	Germany
DCF49	129.1 kHz	+/-500 Hz	42 dBµA/m	Germany

It has to be noted that France has an additional time signal system operating at 162 kHz with a protected bandwidth of +/-125 Hz. This system was not studied in ECC Report 135.

Figure 1 below illustrates the existing ERC Recommendation 70-03 and ERC Recommendation 74-01 limits for inductive applications and the limits for dedicated frequency ranges for WPT systems (all kinds of use cases) which are covered by ETSI EN 303 417 [3]. These ranges are: 19-21 kHz, 59-61 kHz, 79-90 kHz, 100-300 kHz and 6765-6795 kHz.

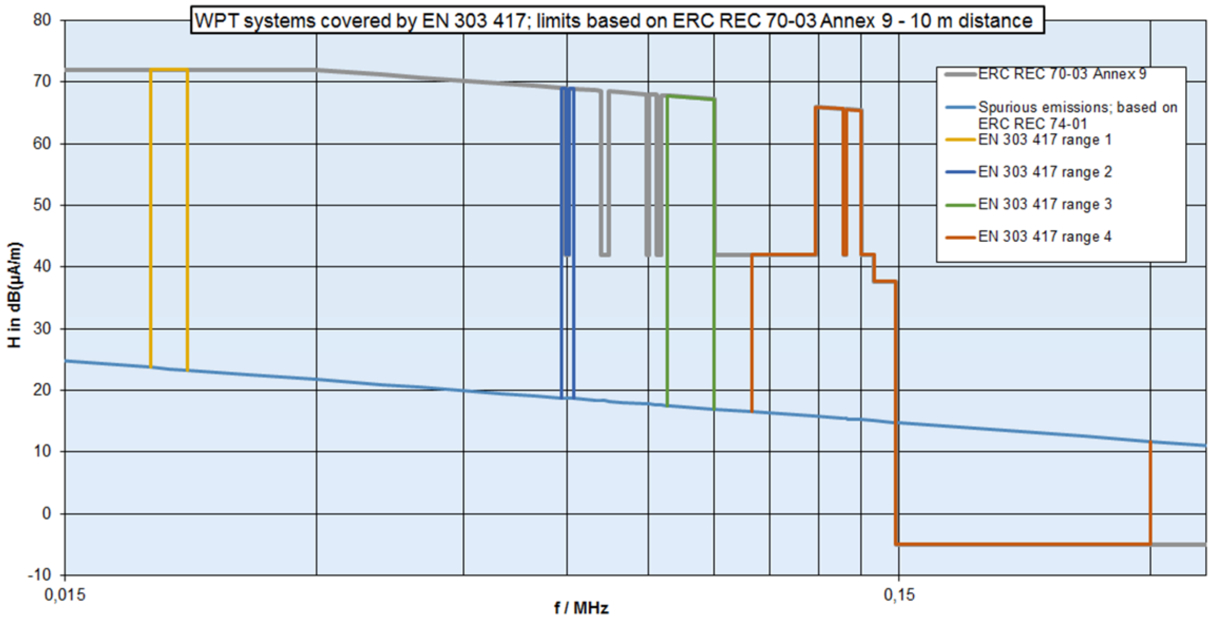


Figure 1: Overview of the existing limits in the frequency range 9-400 kHz

ECC Report 135 [2] considered a relaxation of the magnetic field strength limits required for inductive short range applications (Annex 9 of ERC Recommendation 70-03 [1]) operating in the frequency range from 70 to 90 kHz. After considering the impact on other services, the limits given in Table 1 were expected to protect radio services from harmful interference under the assumption that current long wave radio receivers were not used in a radius of about 100 m around the proposed inductive devices. In addition, the stations listed in Table 2 should be protected by applying a limit of 42 dBµA/m at 10m.

It should be noted that as WPT-EV systems are now projected to be located in significant numbers in urban/suburban residential areas, the separation distance of 100 m to a radio receiver does not reflect the likely "real-world" situation.

In addition, ERC Report 44 [4] considered the frequency range 135-148.5 kHz and indicated that in order to protect the Fixed Service and the Amateur Service, a limit of 42 dBµA/m @ 10m in the band 135-140 kHz and 37.7 dBµA/m @ 10m in the band 140-148.5 kHz would be adequate.

ERC Report 44 allowed the higher field strength level in the following bands:

- Band 1: 9-70 kHz;
- Band 2: 119-135 kHz.

with notches to protect other systems at 60 kHz.

2.1 OVERVIEW OF THE SYSTEMS/SERVICES OPERATING IN THE FREQUENCY RANGE 20-255 KHZ

Table 3 provides the list of European Common Allocations and Applications operating in the frequency range 20-255 kHz.

Table 3: Excerpt from ERC Report 25 [43] for the frequency range 20-255 kHz

Frequency band, RR footnotes applicable to CEPT, ECA footnotes	European Common Allocations and footnotes	Applications
20.05 kHz - 70 kHz (5.56) (ECA36)	FIXED MARITIME MOBILE (5.57)	Land military systems Inductive applications Active medical implants Maritime military systems
70 kHz - 72 kHz (ECA36)	RADIONAVIGATION (5.60)	Active medical implants Inductive applications
72 kHz - 84 kHz (5.56) (ECA36)	FIXED MARITIME MOBILE (5.57) RADIONAVIGATION (5.60)	Standard frequency and time signal Inductive applications Land military systems Active medical implants Maritime military systems
84 kHz - 86 kHz (ECA36)	RADIONAVIGATION (5.60)	Active medical implants Land military systems Inductive applications Maritime military systems
86 kHz - 90 kHz (5.56) (ECA36)	FIXED MARITIME MOBILE (5.57) RADIONAVIGATION	Maritime military systems Inductive applications Land military systems Active medical implants
90 kHz - 110 kHz (5.64) (ECA36)	RADIONAVIGATION (5.62) Fixed	Active medical implants Land military systems Inductive applications Maritime military systems
110 kHz - 112 kHz (5.64) (ECA36)	FIXED MARITIME MOBILE RADIONAVIGATION	Maritime military systems Inductive applications Land military systems Active medical implants
112 kHz - 115 kHz (ECA36)	RADIONAVIGATION (5.60)	Active medical implants Land military systems

		Maritime military systems Inductive applications
115 kHz - 117.6 kHz (5.64) (ECA36)	RADIONAVIGATION (5.60) Fixed Maritime Mobile	Inductive applications Maritime military systems Land military systems Active medical implants
117.6 kHz - 126 kHz (5.64) (ECA36)	FIXED MARITIME MOBILE RADIONAVIGATION (5.60)	Active medical implants Land military systems Maritime military systems Inductive applications
126 kHz - 129 kHz (ECA36)	RADIONAVIGATION (5.60)	Inductive applications Maritime military systems Land military systems Active medical implants
129 kHz - 130 kHz (5.64) (ECA36)	FIXED MARITIME MOBILE RADIONAVIGATION (5.60)	Active medical implants Land military systems Maritime military systems Inductive applications
130 kHz - 135.7 kHz (5.64) (ECA36)	FIXED MARITIME MOBILE	Inductive applications Maritime military systems Land military systems Active medical implants
135.7 kHz - 137.8 kHz (5.67B) (ECA36)	Amateur (5.67A) FIXED MARITIME MOBILE	Active medical implants Amateur Land military systems Maritime military systems Inductive applications
137.8 kHz - 148.5 kHz (5.64) (ECA36)	FIXED MARITIME MOBILE	Inductive applications Land military systems Maritime military systems Active medical implants
148.5 kHz - 255 kHz	BROADCASTING	Active medical implants Broadcasting Inductive applications

More details of the European Allocation is available is available in the ECA table [43].

2.2 EXISTING STUDIES ON INDUCTIVE APPLICATIONS BELOW 30 MHZ

2.2.1 ECC REPORT 135

ECC Report 135 [2] on inductive limits in the frequency range 9-148.5 kHz was published in 2009, and it considered a possible relaxation of the limits for the magnetic field strength for inductive applications operating in the frequency range 70-90 kHz from 42 dBµA/m to approximately 68 dBµA/m. It was concluded that with reduced limits in a few bands (see Figure 1 and Table 2), harmful interference would not appear outside a radius of about 100 m around the proposed inductive devices. As a consequence of this Report, EC Decision 2013/752/EU [5], ERC Recommendation 70-03 [1] and also ETSI EN 300 330-1 [6] were modified to fit that revised limit of approximately 68 dBµA/m (at 79 kHz descending with 3 dB/octave).

2.2.2 ECC REPORT 67

ECC Report 67 [7], published in 2005, covers generic limits in the frequency range 148.5 kHz - 30 MHz, but it makes a number of side-notes on the protection of radiocommunication services.

Conclusion of ECC Report 67:

“ECC/SRD-MG had proposed to establish a new generic limit of -5 dBµA/m @ 10 m to fulfil the existing and future market needs.

That report considered this proposal and compatibility studies were conducted to assess the impact of this proposal. Based on the results of these studies the following generic limit was proposed for the frequency range 148.5-30 MHz:

- a maximum field strength of -15 dBµA/m @ 10m in a bandwidth of 10 kHz allowing;
- a total field strength up to -5 dBµA/m @ 10m for systems with an operating bandwidth larger than 10 kHz whilst keeping the density limit above.

However, it should be noted that this generic limit may not provide adequate protection to some of existing services.

In particular, in the band 3 MHz-30 MHz, this generic limit does not guarantee adequate protection to the broadcast services and additional measures such as more stringent limits (e.g. -25 dBµA/m) may be needed on a national basis.

Additional measures may also be needed in military bands on a national basis.

Such measures may be implemented by including specific limits in Appendix 3 of ERC Recommendation 70-03 [1].

For the radio astronomy (RAS) case, since there are a limited number of radio astronomy sites operating in the 13 MHz and 25 MHz bands any site specific scenario can be handled by the administrations concerned.”

2.2.3 ECC REPORT 1

ECC Report 1 [8], published in 2002, covers the compatibility between inductive LF and HF RFID transponder and other radio communications systems in the frequency ranges 135-148.5 kHz, 4.78-8.78 MHz and 11.56-15.56 MHz.

This Report is only about very low emission level transponders and not about the associated interrogators.

Conclusion of ECC Report 1:

"There are several aspects to be considered for interference to primary users:

- The magnitude of the emission levels of the transponder return signals is in the order or below the atmospheric and/or the environmental noise. The presence of transponder signals will not impair reception quality of primary services;
- There are a few hundred million transponders with valid type approvals in the field. The type approval has been granted in a number of ERC countries as the test of transponders has been done in conjunction with the readers and no particular emissions of transponder signals were detected;
- Considering the ERC Report 74 “Compatibility Between Radio Frequency Identification Devices(RFID) and The Radio Astronomy Service At 13 MHz”, the measurement results show that under realistic conditions, even the interference from RFID reader systems which emit about 70-80 dB higher signals as the transponders, do not cause interference in astronomy sites. Relating this to the considerably lower transponder emission levels, interference is unlikely to occur;

- Concluding, the proposed signal levels of -40 dBµA/m at d = 10 metre can be justified".

2.2.4 ERC REPORT 69

ERC Report 69 [10] studied the propagation model and interference range calculation for inductive systems between 10 kHz-30 MHz.

2.2.5 ERC REPORT 44

ERC Report 44 [4], published in 1997, describes the sharing between inductive systems and radiocommunication services in the band 9-135 kHz.

Conclusion of the ERC Report 44:

"The frequency band 9-135 kHz is useful, because of the unique propagation phenomena. Primary services use these frequencies under far field conditions (wide coverage area), inductive applications under near-field conditions (high close-in field strength with a negligible propagating wave).

The number of inductive systems is increasing rapidly. At the same time the number of primary radio services using this band is generally decreasing, with the exception of Germany, as the services are moving towards higher frequencies.

The units of power/field strength limits are usually expressed in Watts or dBµV/m in ITU and CEPT regulations. These limits should also be expressed in dBµA/m, at least on the lower frequencies, to take into account the measurement methods and the characteristics of inductive equipment.

Although the interference probability from inductive systems to primary radio services is low, interference may occur, when systems operate co-channel within 100 m distance. There is also a risk of interference between inductive systems operating co-channel with different field strength levels within 100 m distance. Such problems are normally solved by site engineering or different system techniques, for example special modulation schemes, TDMA, synchronisation, special antenna design and/or shielding.

SE24 proposed to divide the frequency band 9-135 kHz into sub-bands in order to minimise the risk of interference and to ensure enough suitable frequencies for both services (see note below); the higher field strength level would be allowed in the bands:

- 9-70 kHz;
- 119-135 kHz.

To be able to carry out this proposal, the measuring receiver bandwidth for inductive equipment in ETSI EN 300 330 is proposed to be changed from the current value of 9 kHz at 30-135 kHz to 200 Hz in the whole band of 9-135 kHz.

A division into sub-bands would not change the status of the primary radio services: inductive applications operate on a non-protected and non-interference basis. To avoid interference all suitable site-engineering means should be used by all parties involved.

It is to be noted that In Germany the higher limit would only be allowed in the bands:

- 57-67 kHz;
- 119-127 kHz."

2.2.6 Related ITU Deliverables

The following ITU deliverables were taken for the evaluation:

- Recommandation ITU-R P.368-7 [13] on propagation model;
- Report ITU-R SM.2303-2 (06/2017) [42]: Wireless power transmission using technologies other than radio frequency beam;

- Report ITU-R SM.2153-6 [31], Technical and operating parameters and spectrum use for short range radiocommunication devices;
  - This Report provides information about the regulation for inductive short range devices within the frequency range 9-135 kHz worldwide; in addition see Recommendation ITU-R SM.1896 [47];
  - Some examples for use cases (similar to ERC Recommendation 70-03 Annex 9): Inductive applications include for example car immobilizers, car access systems or car detectors, animal identification, alarm systems, item management and logistic systems, cable detection, waste management, personal identification, wireless voice links, access control, proximity sensors, anti-theft systems including RF anti-theft induction systems, data transfer to handheld devices, automatic article identification, wireless control systems and automatic road tolling.

3 NEW REQUIREMENTS FOR WPT SYSTEMS FOR ELECTRICAL VEHICLES IN THE FREQUENCY RANGE 79-90 KHZ

ETSI TR 103 409 [11], "Wireless Power Transmission (WPT) systems for Electric Vehicles (EV) operating in the frequency band 79-90 kHz", provides information on the spectrum requirements for WPT-EV Systems. Some details are provided in the following sections.

3.1 TECHNICAL REQUIREMENTS

In response to a request to satisfy the above requirements for WPT-EV systems, it was proposed in ETSI TR 103 409 to review ERC Recommendation 70-03 Annex 9 and change the limits in the frequency range 79-90 kHz to 82 dBµA/m (at 79 kHz, descending with 3 dB/oct = 10 dB/dec).

Figure 2 and Figure 3 below illustrate the ETSI TR 103 409 request indicated above.

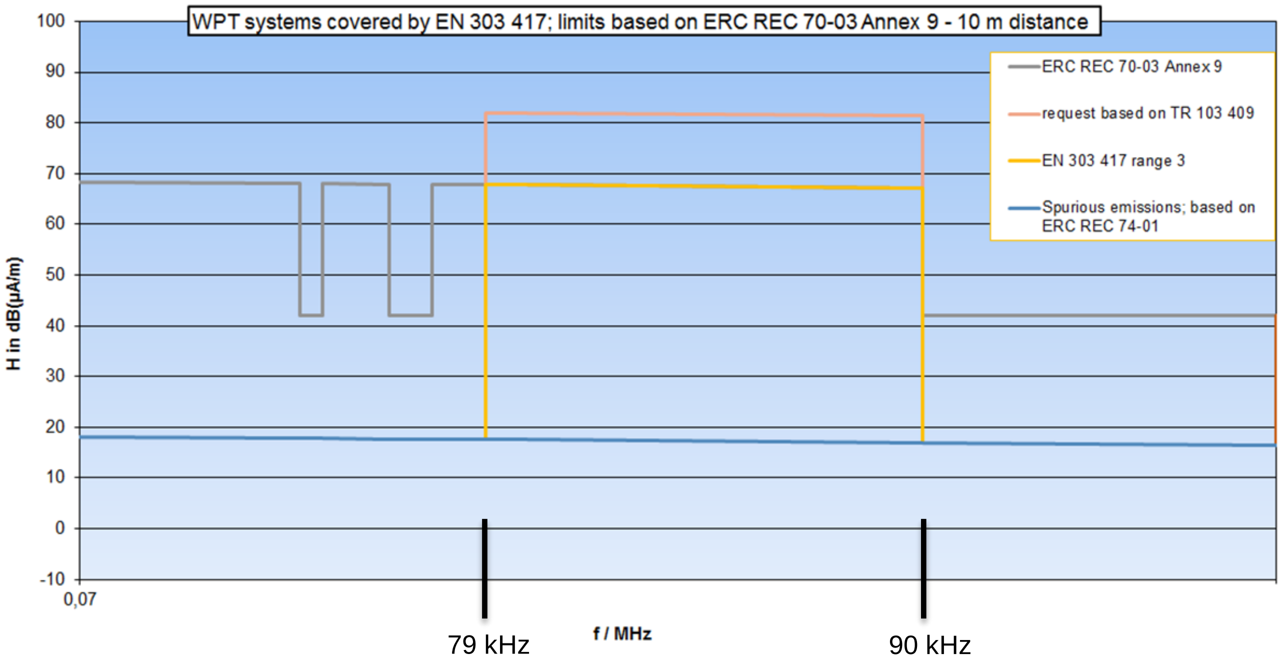


Figure 2: Comparison of ERC Recommendation 70-03 Annex 9 [1], ERC Recommendation 74-01 [12], ETSI EN 303 417 [3] and request in ETSI TR 103 409 [11])

Figure 3 shows a possible theoretical example for spectral mask for such WPT-EV-system.

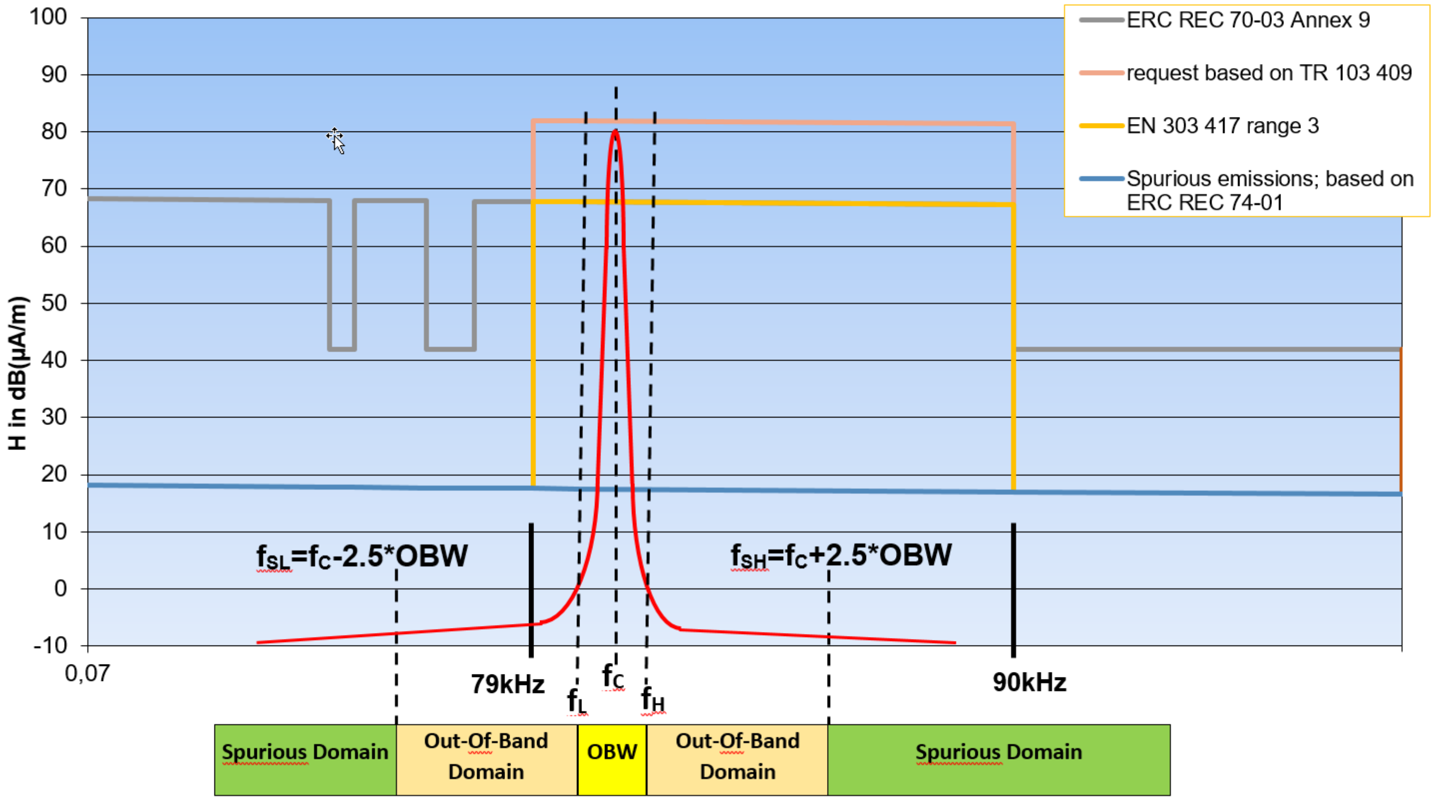


Figure 3: Example of a theoretical spectral mask for WPT-EV-system within 79-90 kHz

For the studies the maximum emission limits in Table 4 were taken into account:

Table 4: Maximum emission limits

Frequency Range (kHz)	Max limit	Kind of situation
79 kHz < fc < 90 kHz	82 dBµA/m @ 10m	with a max OBW of WPT-EV system: 0.5 kHz (99% of the energy)
For the Out-Of-Band Domain fSL < f < fL and fH < f < fSH	42 dBµA/m@10m	Out-of-band / adjacent band situation Worst Case assumption for the out-of-band domain (permitted range): fc @ 79.25 kHz or fc @ 89.75 kHz with a max OBW of WPT-EV system: 0.5 kHz (99% of the energy)
Spurious Domain f < fSL and f > fSH	spurious emission limits based on ERC Recommendation 74-01 [12]	Spurious domain

For interoperability between different WPT-EV systems and the variation of the alignment and air gaps within the WPT-EV system (between charging station and vehicle), a tuning possibility of the WPT-EV centre frequency (fc) could be necessary. Once the fc is adjusted, then the frequency is stable within maximum 50 Hz

It shall be noted that:

- the power level (see Table 5) is not directly related to the radiated emissions of the WPT-EV (fundamental and harmonics). For example, a misaligned 3 kW system could have higher radiated emissions at the harmonics and fundamental than an 11 kW system;
- the H-field levels of the harmonics are not directly related to the emission level at the fundamental frequency of the WPT-EV-system. These emissions can be controlled independently by the manufacturer through system design. For example, a badly engineered WPT-EV system which emits a field strength of 68 dBµA/m at the fundamental can very well have (significantly) higher emissions at the harmonics than a well-engineered WPT-EV-system which emits a field strength of 82 dBµA/m at the fundamental.

Table 5: Characteristics of WPT-EV systems

Parameter/input	WPT- EV
Application area	Electric vehicle
Power levels	1-22 kW
Typical power level	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.
Harmonic emission sources	Mainly from: ▪ Power electronics; ▪ Power cables; A minority is from: ▪ Ferrite antennas of the charging pad; ▪ Currently, it is not clear whether the harmonics of the WPT-EV are emitted by the "coils", which would be a TX spurious emission scenario, or if the harmonics are radiated by the cables and electronic parts, which would lead to an EMC scenario. Since the emissions will be at the same time, it is difficult to separate them during an emission measurement. As examples, see Figure 4, Figure 5and Figure 6.
Coupling mechanism	Inductive resonant
Coupling situation (air gap between vehicle and charging pad)	Near field: 0.1-0.4 meters
Efficiency of the system	85% (min)- 95%

3.2 INFORMATION FOR MARKET AND USE CASE

The information on the characteristics and market penetration of WPT-EV-systems are compiled from information that is publicly available and/or from dedicated feedback from some stakeholders.

Table 6: Use cases of WPT-EV systems

Parameter/input	WPT for EV
Application area	Electric vehicle
Use cases	Parking spot: ▪ At home; ▪ At the office; ▪ In public locations (e.g. next to a motorway, restaurant). Garage: ▪ At home; ▪ Public garage.
Charging direction	Unidirectional
Expected density for WPT-EV charging pads	Parking residential area ▪ in 2025: 17.1/km^2 ▪ in 2030: 64.2//km^2
Charging time (example scenario)	Typical battery capacity: 20 kWh – 40 kWh Assumption for a 11 kW WPT-EV: Therefore. 1hr 50min (20 kWh) to 3hr 40min (40 kWh) is necessary to charge a battery completely (0-100%). Assumption for a 3.6 kW WPT-EV: Therefore. 5hr 32min (20 kWh) to 11hr 4min (40 kWh) is necessary to charge a battery completely (0-100%).
Typical charging time (example scenario)	Typical car usage 55km/day on average everyday use (lower in urban areas) Assume <20kWh/100km electric vehicle efficiency Typical charging time 11 kW WPT-EV system: 1 hour Typical charging time 3.6 kW WPT-EV system: 3 hours
Note: An example for a statistical analysis of an average charging time/per charging station of 1hr/day is given in ANNEX 5:. The scenarios and derived charging times in this table are statistical averages that are not necessarily meaningful in a future aggregate study. They also do not take into account, amongst other factors, the actual battery charge at the time of charging, the aging of batteries and seasonal temperature changes influencing charging time.	

The estimated deployment for electric vehicles equipped with WPT-EV is shown in Table 7:

- In the beginning, WPT-EV will be an optional equipment for electric vehicles;

Table 7: Estimated deployment of electric vehicles equipped with WPT-EV

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 vehicles with take rate (million)
Number of vehicles in 2020	4	0.71%	0,03
Increase 2021 -> 2025	24	1.72%	0,4

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 vehicles with take rate (million)
Increase 2026 -> 2030	43	2.83%	1,2
Total Number of vehicles in 2030	71	2.33%	1,7

It should be noted that ERC Report 44 [4], whilst making some projections about interference to primary radio services, makes clear that "In addition to co-channel operation, the interference from inductive loop systems to primary radio services depends on many probability factors, for example time-co-incidence, location criticality, typical average field strength level, average field directivity, local EMI noise factor, fringe area factor (ratio of country-average to the minimum primary service signal amplitude), etc."

This supports the position that probability issues were originally taken into account in setting current limits for emissions. It should be noted that some of these probability factors may not be valid for WPT-EV. As of March 2018, Germany (and the rest of Europe is similar) had less than 0.1% EVs (i.e. ratio of EVs (34.000) to total number of vehicles (43 million)). The government wanted this rate to go up to approximately 2% in 2020, but this target will not be reached. Optimistic projections now expect 1% earliest in 2025. So even if half of all EVs will be charged wirelessly (which again is very optimistic, considering the early adopters' cost of such systems), maybe 0.5% of all households would have a WPT-EV system by 2025. So in a typical suburban domestic environment, one out of 200 houses might have a WPT-EV system. Furthermore, the power levels involved in WPT-EV and the high activity factor may devalue the relevance of previous studies and recommendations on spurious emissions.

ERC Report 44 [4] continues: "All the reports prove that the theoretical attenuation of 60 dB/decade correlates well with the practical measurements. However, it was perceived that for certain installations, free space conditions may not apply, for example near metal doors or metal window frames. Then the field attenuation is subject to the antenna design and the proximity of the antenna to the metalwork. It was also noted that free space conditions may not apply, when mains or telephone cables run close to the antenna. Inductive loop antennas can induce into metal constructions a current which can be carried over a significant distance and cause a much reduced rate of attenuation. On the other hand, the proximity of metal construction can also cause shielding".

Although it is not mentioned in ERC Report 44, it should also be noted that at higher frequencies (e.g. where harmonics of low frequency WPT-EV systems exist), the attenuation rate of the emissions reverts to the "far field" figure of 20 dB/decade relatively close to the WPT installation. This has the effect of extending the area affected by spurious emissions.

3.3 RADIATED EMISSION MEASUREMENTS OF REAL WPT-EV SYSTEMS

3.3.1 System 1 (11 kW)

3.3.1.1 System overview and introduction

In this section, some practical example measurements for the H leakage field from a prototype WPT-EV system are provided. It operates at 85 kHz centre frequency and can transfer 11 kW charging power from the charging station to the EV. The operating frequency of this system is basically adjustable to any given value between 81.38-90 kHz. For this WPT3 study, 85 kHz was chosen randomly, although it is understood that other values (e.g. 85.5 kHz or 90 kHz) would be more suitable to avoid issues with AM broadcasting interference, due to the WPT system sitting on a 9 kHz (or 4.5 kHz) raster. However, the characteristics of the H leakage field (especially the harmonics) would be no different when using those other frequencies.

Figure 4 shows the system which was used for this Report.

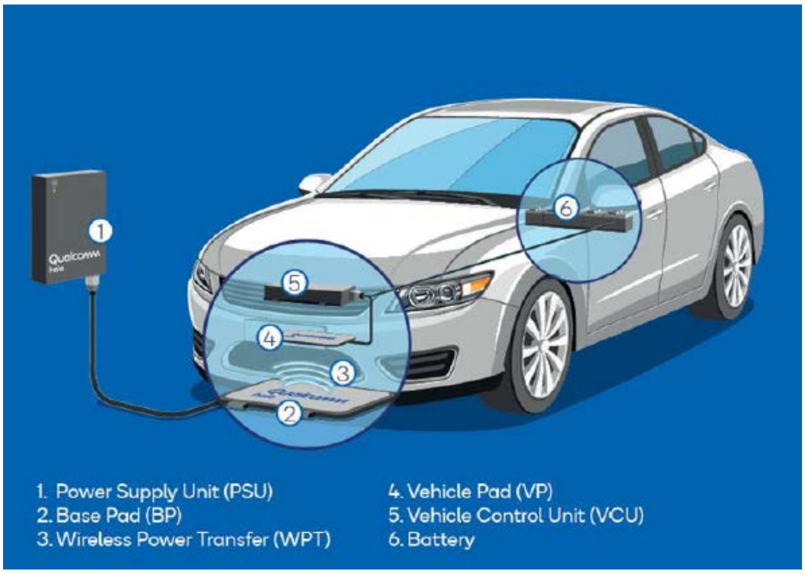


Figure 4: WPT-EV system which was used for this study

First and foremost, it is important to understand which kind of emissions is generated by a typical WPT-EV system. Figure 5 shows the terminology which will be used in the following. The electrical power is transmitted across the air gap to the vehicle pad located under the vehicle. The vehicle control unit converts the 85 kHz AC and delivers DC power as requested to the vehicle's battery management system.

At the fundamental frequency (e.g. f = 85 kHz, red colour in Figure 5), the dominant emission source is the WPT-EV coil system, specifically the base pad due to its typically larger coil size. A mitigation is very difficult (virtually impossible) because the magnetic field is required for wireless power transfer. It is a wanted phenomenon.

Within the unwanted domain (out-of-band/spurious; approximately f < 1 MHz, orange colour in Figure 5), the dominant emission source still is the WPT-EV coil system (primary and secondary coils). Mitigation is possible, but it is relatively difficult due to the relatively high coil currents and due to the low frequencies which would require relatively large and heavy filters. A common approach is to avoid the generation of the harmonics, e.g. by smart design of power electronics devices.

At higher frequencies (EMC, approximately f > 1 MHz, green colour in Figure 5), a mitigation is possible and relatively easy (e.g. by using shielding and applying filtering).

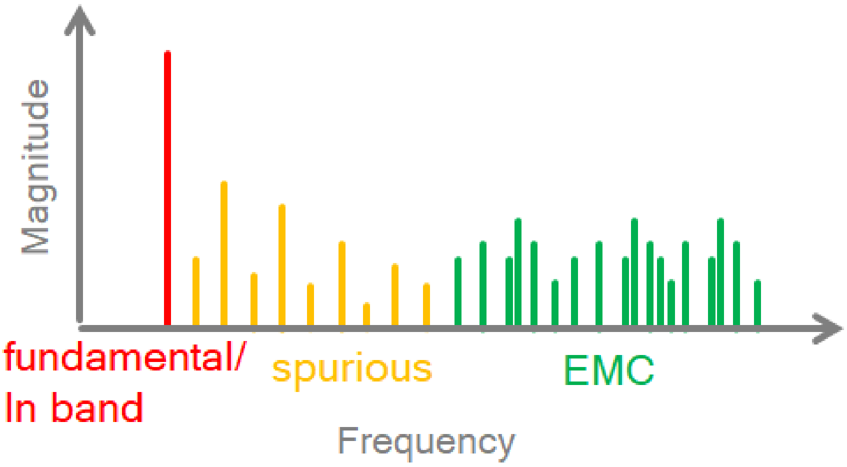


Figure 5: Distinction between "fundamental", "spurious (incl. harmonics)" and "EMC"

The system 1 used for this study operates at a very narrow bandwidth and at a very stable (fixed) frequency. Figure 6 is a screenshot from an oscilloscope, showing the 22nd harmonic. The blue trace shows the actual real-time signal, the yellow trace is that same signal as max-hold over 5 minutes. The green-diamond marker "1" is set at 84.99 kHz x 22 = 1.869703 MHz. The x-axis is set to 5 Hz/div. Thus, it can be seen that the whole occupied bandwidth at this 22nd harmonic is less than 15 Hz over 5 minutes. Any frequency variation is just the result of typical oscillation quartz tolerances. No wider frequency band is used for operation of this system.

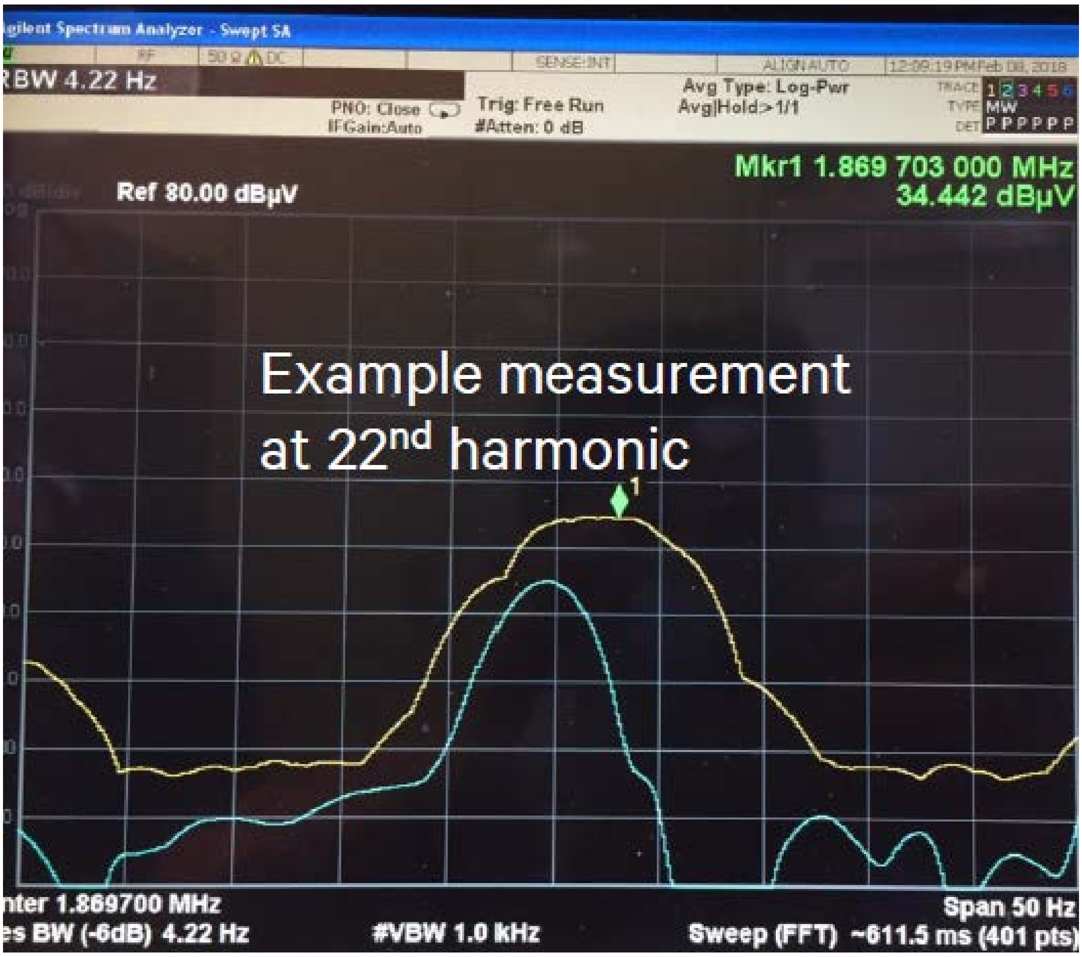


Figure 6: Example screenshot at 22nd harmonic

3.3.1.2 Measurement results from an Open Area Test Site

This section shows some example measurement results which were obtained on an Open Area Test Site (OATS). Figure 7 shows a picture of the OATS (which is actually a large free parking place in Eastern Munich), and the test setups which were used for vehicle testing and test bench testing.

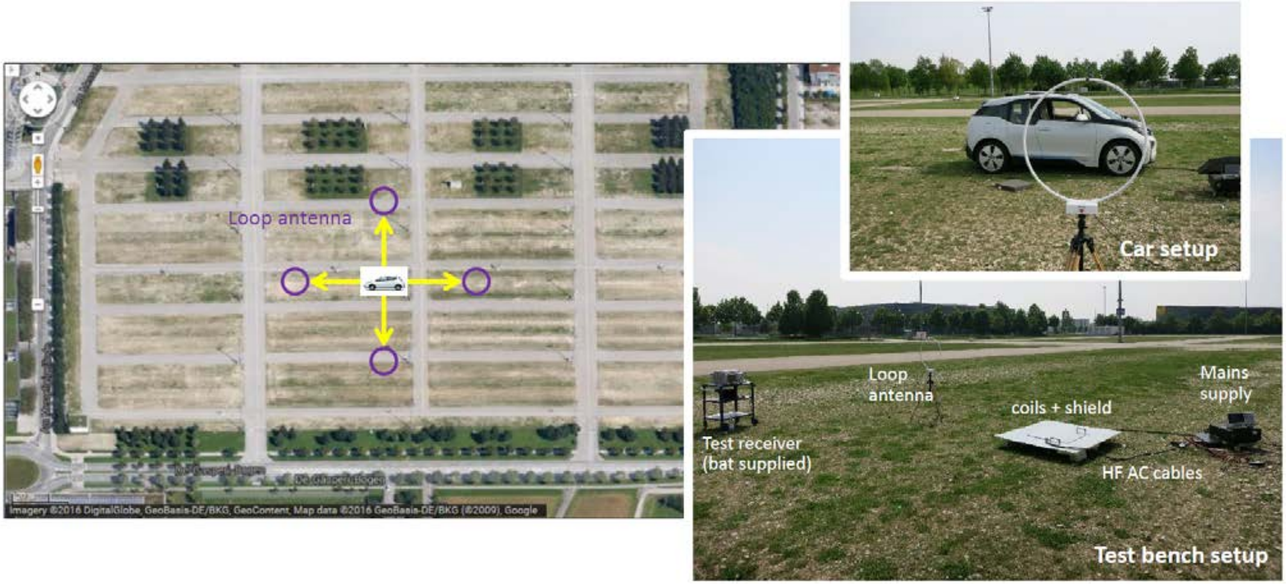


Figure 7: Test site layout (left), vehicle under test (top right), test bench setup (bottom right)

Figure 8 shows the measured H-fields for these two setups, separated by x, y and z components. The measurements distance was 10 m.

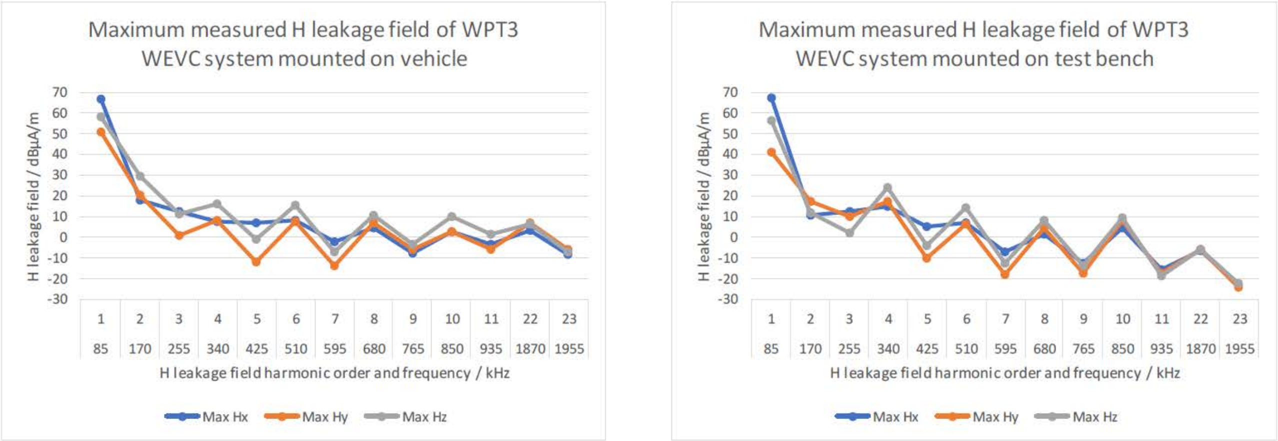


Figure 8: Measured H-fields for vehicle setup (left) and test bench setup (right)

3.3.1.3 Measurement results from a semi-anechoic chamber

The same measurements with the same system were also performed on a second test site, namely in a semi-anechoic chamber (SAC). Figure 9 shows the test bench in the SAC. More info about the SAC (which is the "EMV-Labor Regensburg" of TDK/EPCOS) can be found in [46].

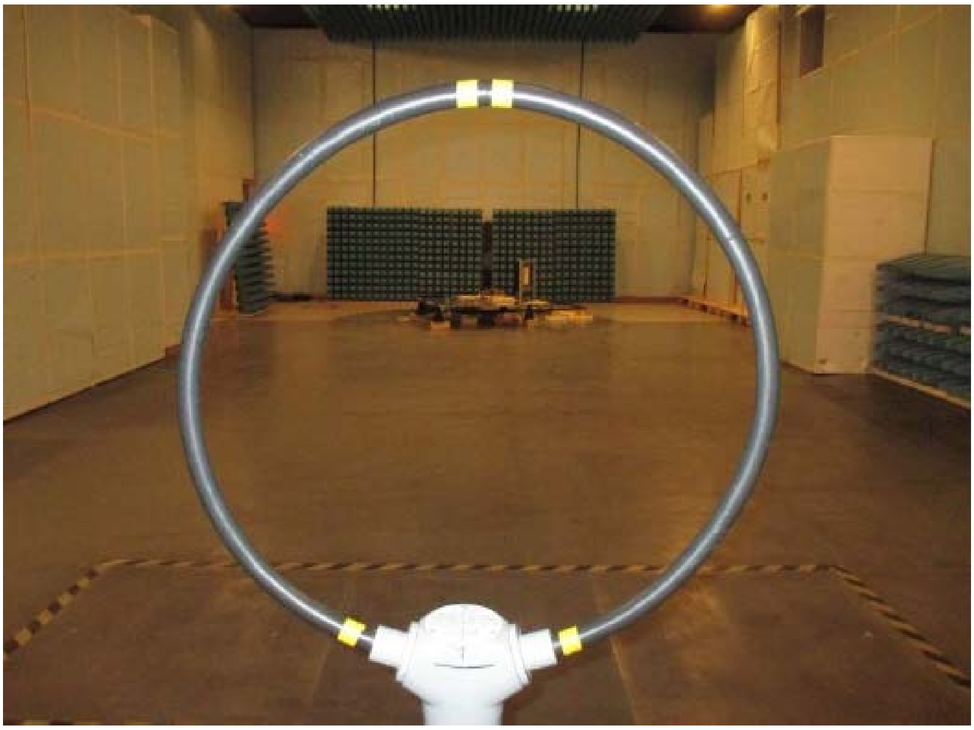


Figure 9: Test bench setup in semi-anechoic chamber (SAC)

Figure 10, Figure 11 and Figure 12 show the measured x, y and z components. Again, the measurement distance was 10 m.

Informal Note to Figure 10 - Figure 12: It needs to be understood that the primary focus for these figures is to show “real” emissions for the fundamental emissions (at 85 kHz) and the first 10 harmonics (spikes indicated by numbers). But as shown in Figure 5, those are the emissions which are clearly generated by the WPT-part of system itself, i.e. by the inductive coil system and the associated power electronics. Any higher frequency emissions – for example, especially the emissions above 10 MHz, which exceed the proposed green limit line in Figure 10 - Figure 12 are not representative for a final WPT-EV system. Those emissions occur primarily due to the prototype character of the WPT system, which consisted of special components such as unshielded laboratory supplies, prototype housings, etc.

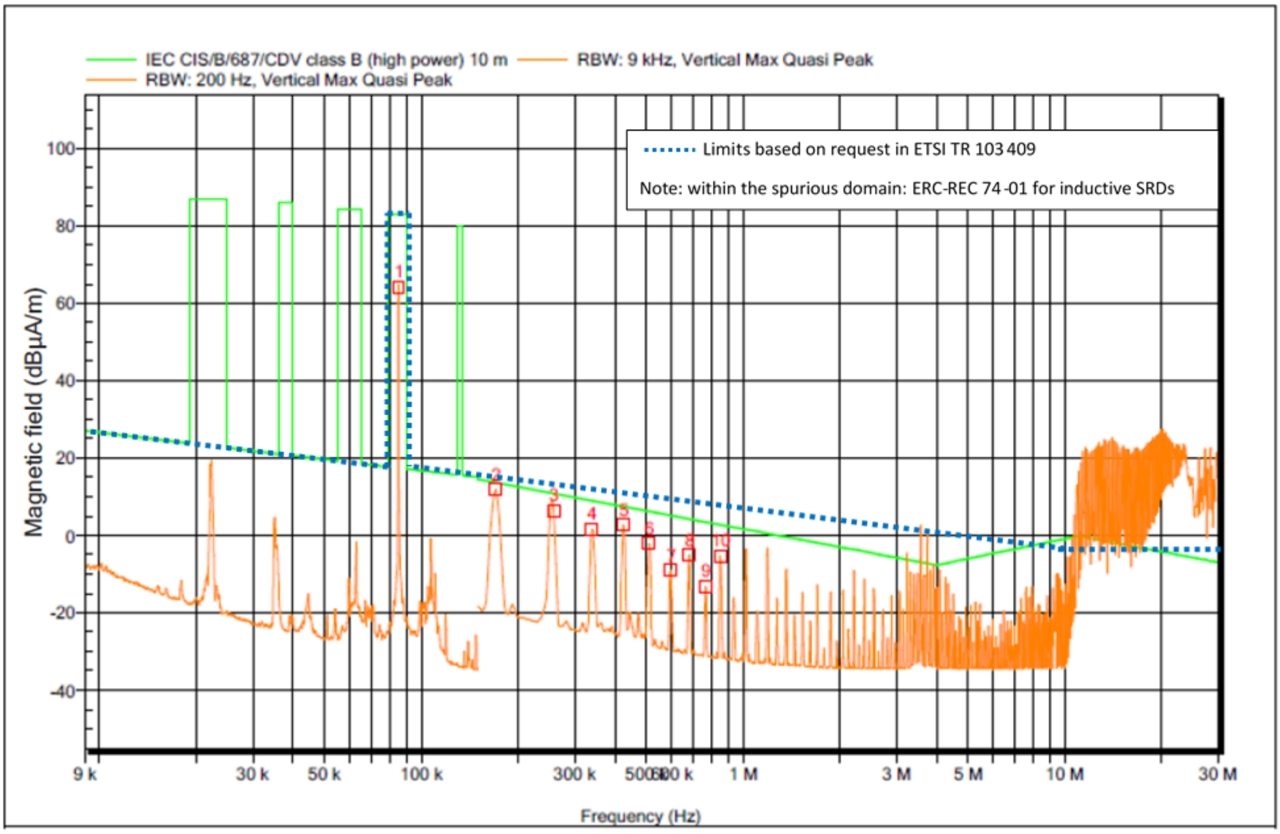


Figure 10: Measured H-field in semi-anechoic chamber (SAC) (x-component)

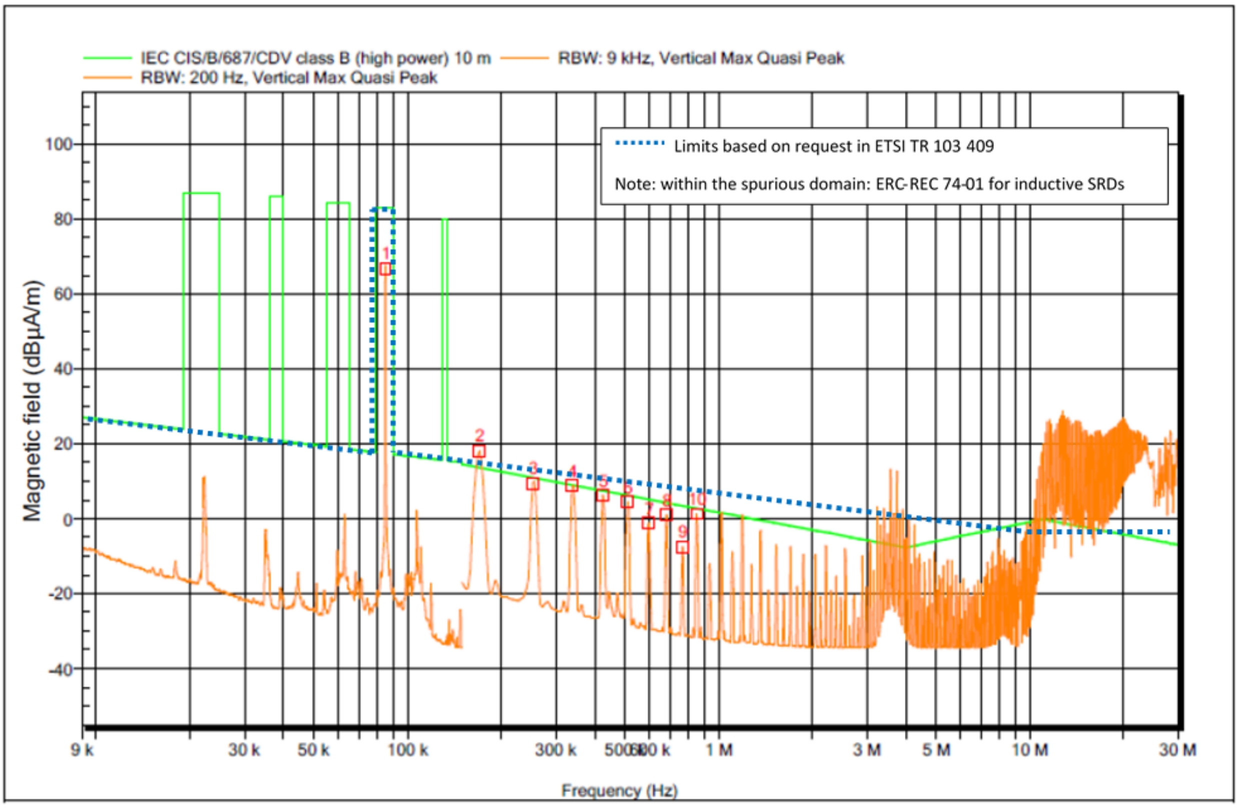


Figure 11: Measured H-field in semi-anechoic chamber (SAC)(y-component)

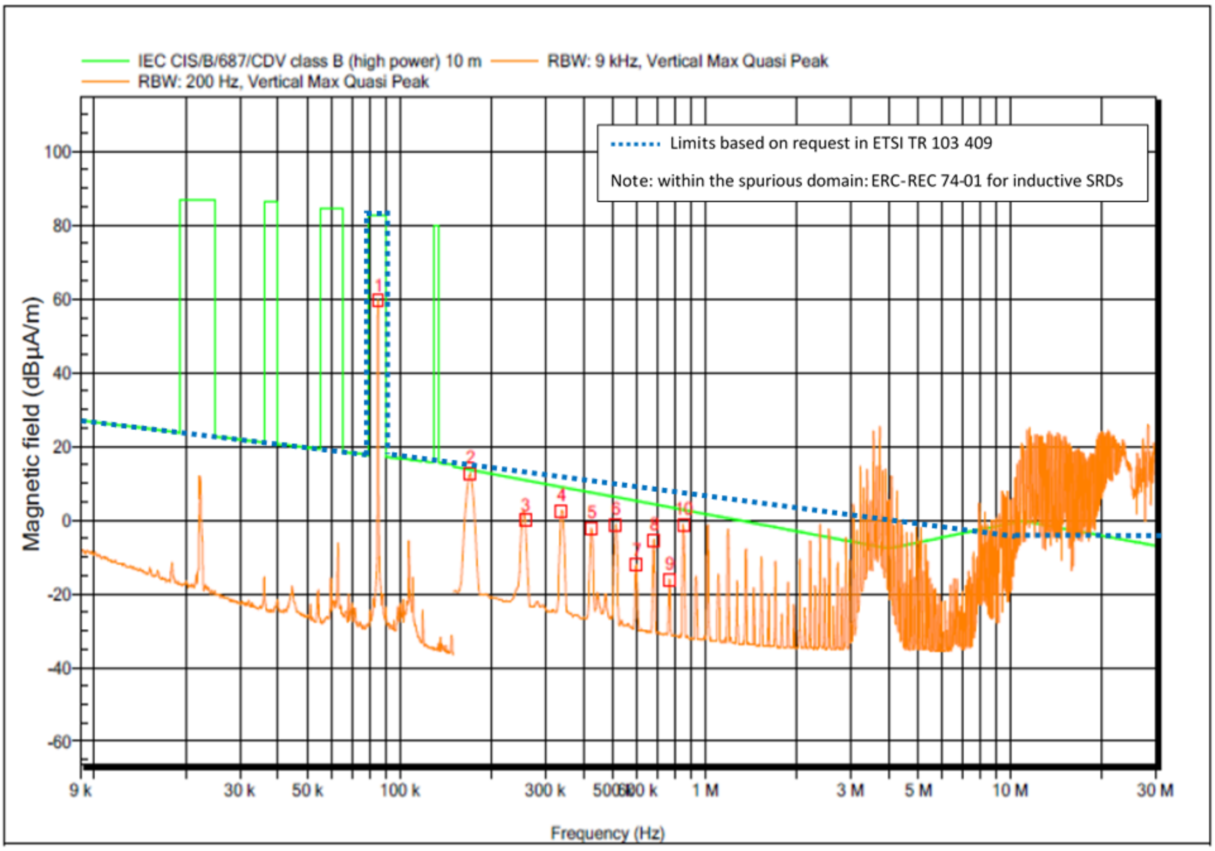


Figure 12: Measured H-field in semi-anechoic chamber (SAC) (z-component)

3.3.2 System 2 - Parking Lot Test Site

3.3.2.1 Introduction and system desciption

This section describes measurements performed in Germany on a wireless power transmission system (WPT) for the charging of electric vehicles (EV).

The aim was to assess the values of unwanted emissions in the frequency range below 30 MHz especially on harmonic frequencies.

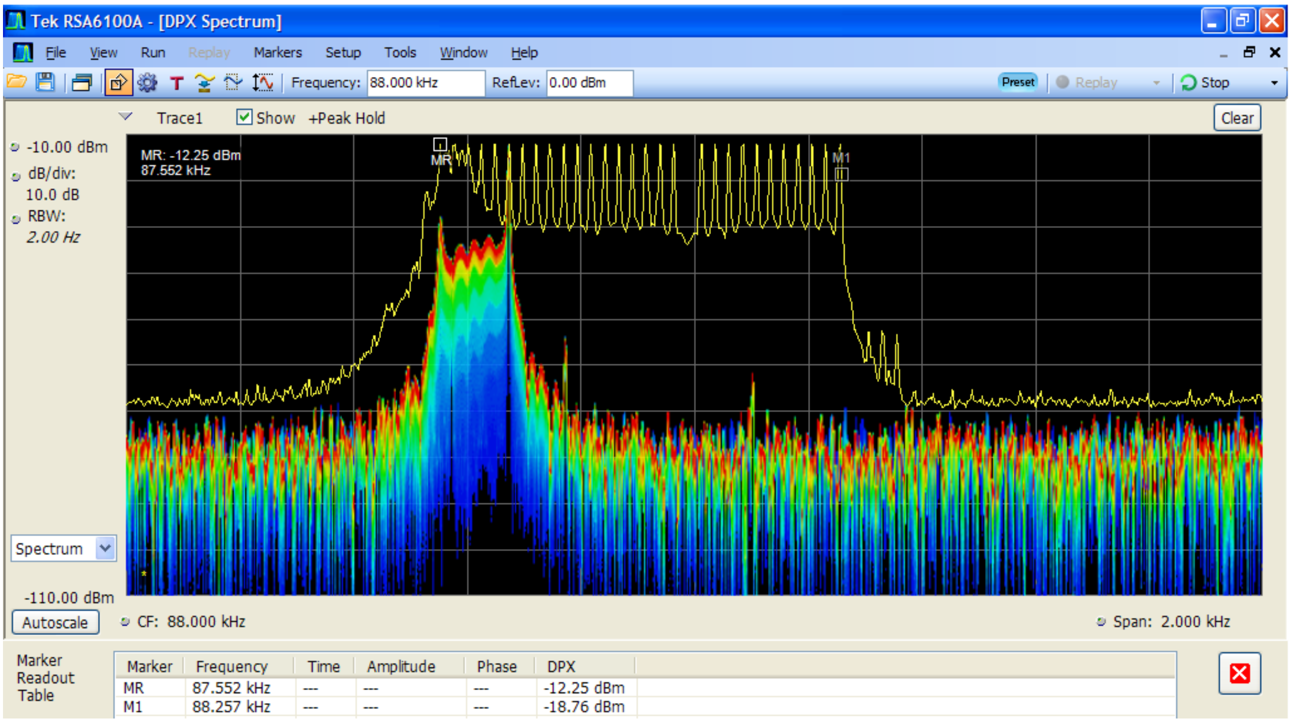
The measurements were performed on a parking lot in a city environment.

The coil of the charging station was placed on the ground of the parking lot. After authentication, the measured system provides a charging power of 3.2 kW. The dimensions of the charging station unit are about 80 x 92 cm. The WPT receiving device was installed underneath an electric passenger car. When approaching the charging coil, the display of the on-board navigation system changes to a graphic that shows the current offset between car and charging coil. This enables exact positioning of the car in a relatively easy way. The tested system is already in production.

The air gap between base station and car unit was only 80 mm. The charging unit is placed on the ground and has as such a height of 60 mm which reduces the distance between transmitting and receiving coil.

The (operational) frequency of the base station was around 88 kHz. However, this frequency was not constant. It hopped in arbitrary multiples of 25 Hz in a frequency range between about 87.6 kHz and 88.3 kHz. A change was initiated every few seconds during the charging process.

The following figure shows the spectrum of the WPT fundamental frequency range.



Frequency: 88.000 kHz

RefLev: 0.00 dBm

-10.00 dBm

dB/div: 10.0 dB

RBW: 2.00 Hz

MR: -12.25 dBm
87.552 kHz

-110.00 dBm

CF: 88.000 kHz

Span: 2.000 kHz

Marker Readout Table

Marker	Frequency	Time	Amplitude	Phase	DPX
MR	87.552 kHz	---	---	---	-12.25 dBm
M1	88.257 kHz	---	---	---	-18.76 dBm

Figure 13: Wanted WPT spectrum (yellow trace = MaxHold)

3.3.2.2 Measurement Setup

The measurement of the unwanted emissions was done with a real time analyser (Tektronix RSA6100A). The analyser was set up to record the incoming signal for 1 second. The spectrum was calculated using FFT with a resolution of 8000 points per record. The analyser was placed inside a measurement vehicle and supplied by external mains power. The main analyser settings were:

- Resolution bandwidth: 1 kHz
- Detector: rms

A calibrated magnetic loop antenna R&S HFH2-Z2 was used as measurement antenna. It was mounted on a tripod in 1.5 m height above ground that enabled positioning in all three polarisation planes (X-, Y- and Z-axes). The measurement antenna was placed in a distance of 10 m from the centre of the charging coil in four different directions (front, back, left and right of the charged car). The following Figure 14 shows the measurement of the front radiation.

Figure 14: Measurement setup

The following Figure 15 shows the block diagram of the measurement setup.

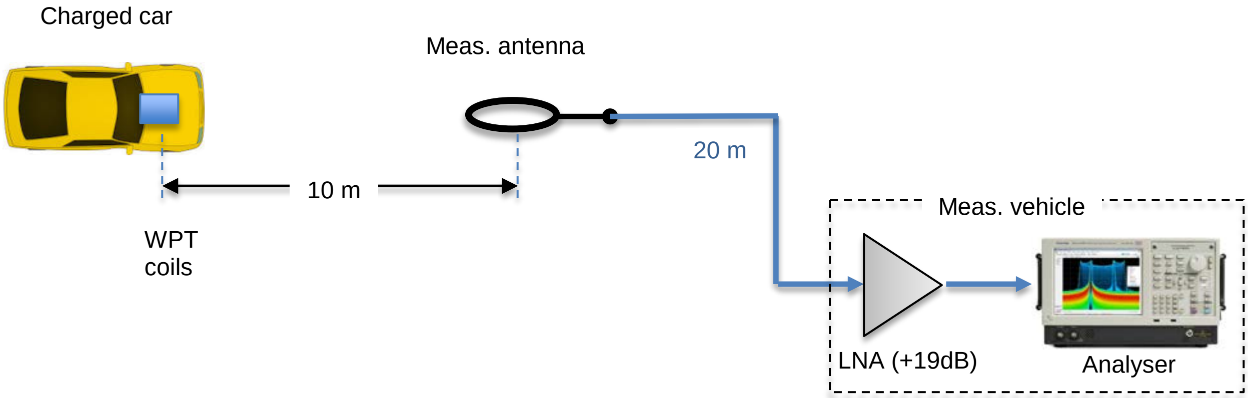


Figure 15: Block diagram

First, at each antenna position and with the vehicle charging switched off, three recordings (x-, y- and z-plane) were taken as a reference to establish the emissions from the various other sources.

Directly after this, the WPT was switched on and set to maximum charging. The same frequency range as before was then recorded (also in all three polarisation planes). All traces were stored to disk for later evaluation.

To enable the required frequency resolution, the whole frequency range up to 30 MHz was divided into four sub-ranges. The maximum range of one recording was 8 MHz which, at 8000 FFT points and an RBW of 1 kHz, resulted in an overall frequency resolution of 1 kHz.

3.3.2.3 *Evaluation of results*

a) First, the trace levels without WPT (reference measurement) and with active WPT were compared. Only those frequencies were further processed where the level with active WPT was higher than the level of the reference measurement. This ensures that emissions from other devices that were switched off during the measurement with active WPT are not influencing the result;

b) Next, the remaining levels of the reference measurement were subtracted from the levels with active WPT in linear units. This cancels out all emissions from other sources that were present during both measurements from the result;

c) All remaining measured levels were converted to magnetic field strengths using the antenna factor of 20 dB (from dBµV to dBµV/m), the conversion of 51.5 dB (from dBµV/m to dBµA/m), and the amplification of the LNA (19 dB);

d) The previous evaluation steps were done with the traces from each polarisation plane separately. Next, the field strengths of all three polarisation planes (x, y and z) were added to get the total field strength using the following formula;

e) $H_{tot} = \sqrt{H_x^2 + H_y^2 + H_z^2}$ where all H are entered in linear units (µA/m);

f) For the final evaluation, only those frequency ranges were filtered that fall inside the calculated ranges of harmonics from the WPT fundamental frequency. Although the WPT system may also produce unwanted emissions outside these harmonic ranges, there may have been emissions from other sources that were switched on between reference and active WPT measurements by coincidence. It can therefore not be guaranteed that these emissions actually originated from the WPT system.

As already stated before, the fundamental WPT frequency was changing over time. Therefore, the exact harmonic frequencies cannot be predicted. Their possible frequency range widens with increasing frequency. The following figure shows the possible harmonic frequency ranges of the tested system up to 10 MHz.

Figure 16: Harmonic ranges

It can be seen that the harmonic ranges even overlap above about 9 MHz which means that a harmonic emission can appear on any frequency.

Because the unwanted WPT emissions at the harmonics can be assumed as being (nearly) Continuous Wave (CW) in nature, their correct level and field strength is independent of the detector and measurement bandwidth. Therefore, the measurement results for the harmonics can directly be compared with the limits of ERC Recommendation 74-01, which are specified as quasi peak magnetic field strength in 10 m distance.

3.3.2.4 Result presentation

The following figures show the main results of the measurements. The green dots are the resulting WPT field strengths at all frequencies evaluated after (b) in Section 6, the black dots are only those occurring around the calculated harmonic frequencies (+/- 0.5 kHz). Because of the widening of these harmonic ranges with increasing frequency, the proof that an emission actually originates from the WPT system becomes more and more questionable. Therefore, the results are only presented up to 3 MHz. It was, however, ensured that all WPT harmonic emissions above 3 MHz were below the limit from ERC Recommendation 74-01 [12].

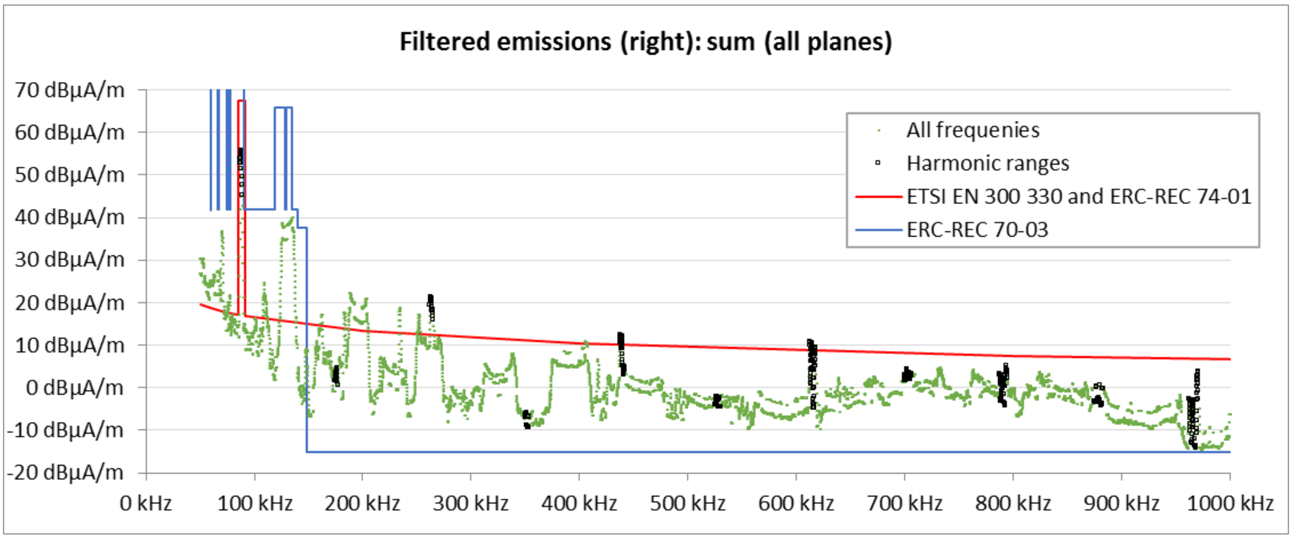


Figure 17: WPT emissions below 1 MHz to the right

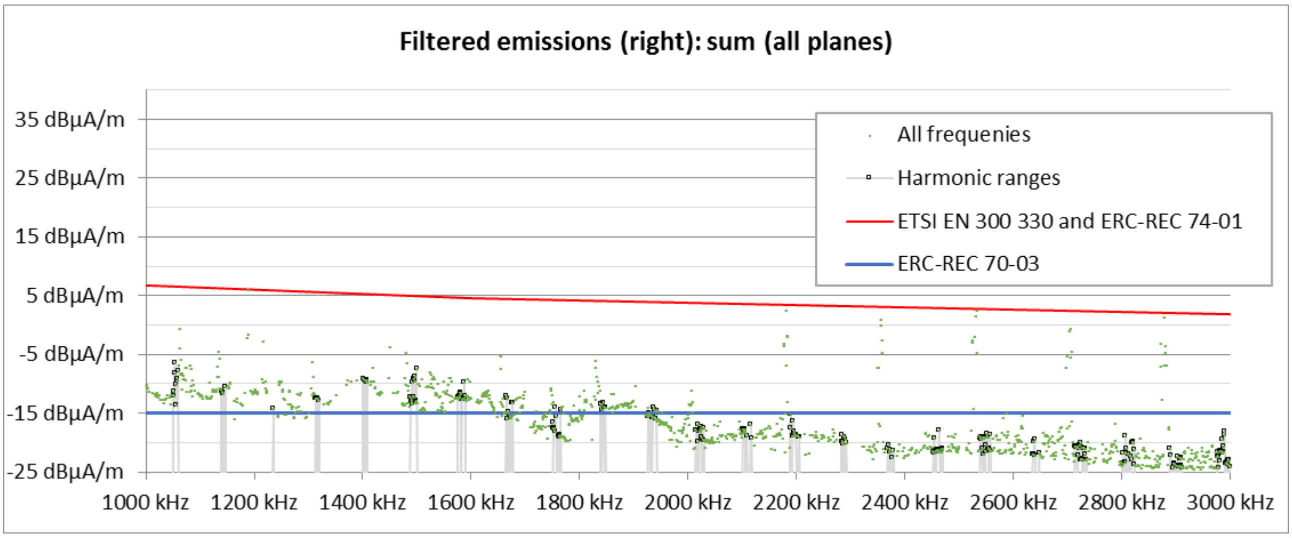


Figure 18: WPT emissions above 1 MHz to the right

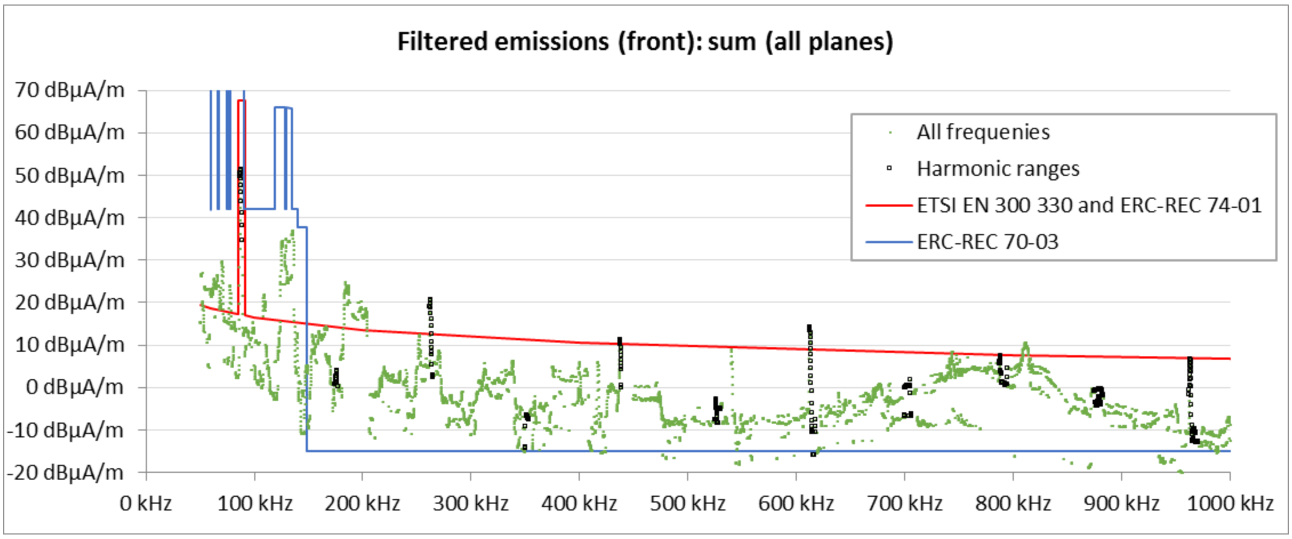


Figure 19: WPT emissions below 1 MHz to the front

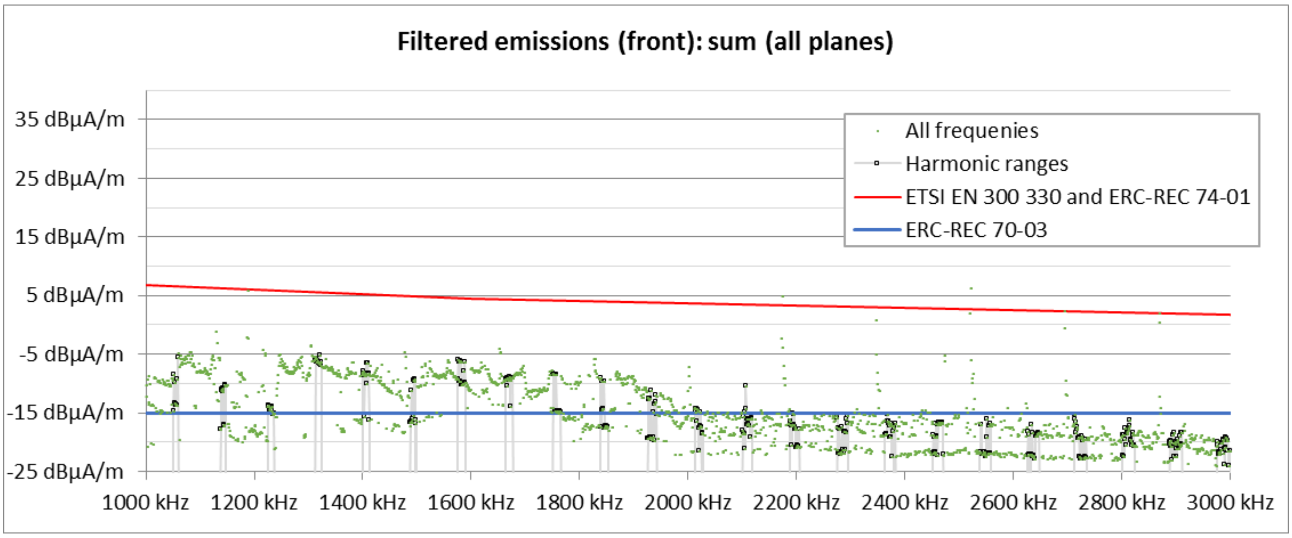


Figure 20: WPT emissions above 1 MHz to the front

3.3.2.5 Conclusion of the tests

The measurements allow the following conclusions:

- The level of the measured WPT system at the fundamental frequency of 56 dBµA/m in 10 m distance is far below the maximum level defined in ERC Recommendation 74-01 and ERC Recommendation70-03;
- The levels of most harmonic emissions meet the limits of ERC Recommendation74-01. Exceptions are the 3rd harmonic (around 264 kHz) with a maximum measured level of 21 dBµA/m to the front which exceeds the limit by 8 dB, and the 7th harmonic (around 616 kHz) with a maximum measured level of 14 dBµA/m to the front which exceeds the limit by 5 dB (see Figure 19). Exceeding the limits by other harmonics fall inside the measurement uncertainty;
- The measured noise level varied between -15 and -25 dBµA/m. Any interferences below this level cannot be allocated to a specific radio system; that includes WPT for EV;
- Due to the frequency hopping of the fundamental frequency, the exact frequencies of the harmonic emissions cannot be predicted. Above about 9 MHz, these emissions can appear on any frequency. Therefore, a possible relaxation of the general limit for emissions on harmonic frequencies could not be used to protect radio services in the HF frequency range.

4 EVALUATION INCLUDING STUDIES WITHIN 79-90 KHZ

4.1 HUMAN EXPOSURE

The subject of human exposure was raised during the preparation of this report, and the question was if 82dBµA/m @ 10 m would lead to the ICNIRP human exposure limits (reference levels) at distances close to the car being exceeded.

The issue Human Exposure is out of the scope of this Report, and each manufacturer has to take care of Human Exposure e.g. based on Safety Directive in EC.

Some information on human exposure can be found in [42], Annex 1 and in current work of IEC TC106 WG9.

4.2 FINDINGS IN FORMER REPORTS

Based on ECC Report 135 [2],an increase of the power in the near-field of the WPT-EV-system to 82 dBµA/m @ 10 m would lead to an increase of the ground wave effect distance from 211 m to around 370 m, see Figure 21 (increase is reflected with the red line in Figure 21).

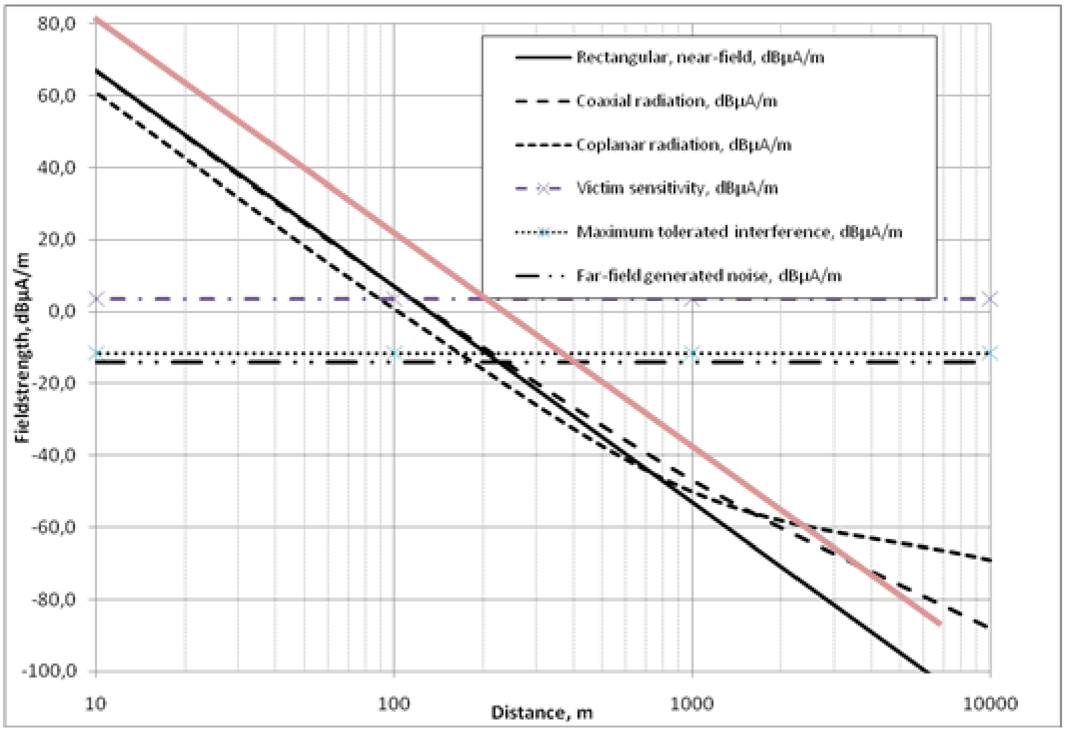


Figure 21: Ground wave effect distance

A dedicated calculation at the frequency of 80 kHz resulted in a ground wave effect distance of 400 m (see Figure 22)

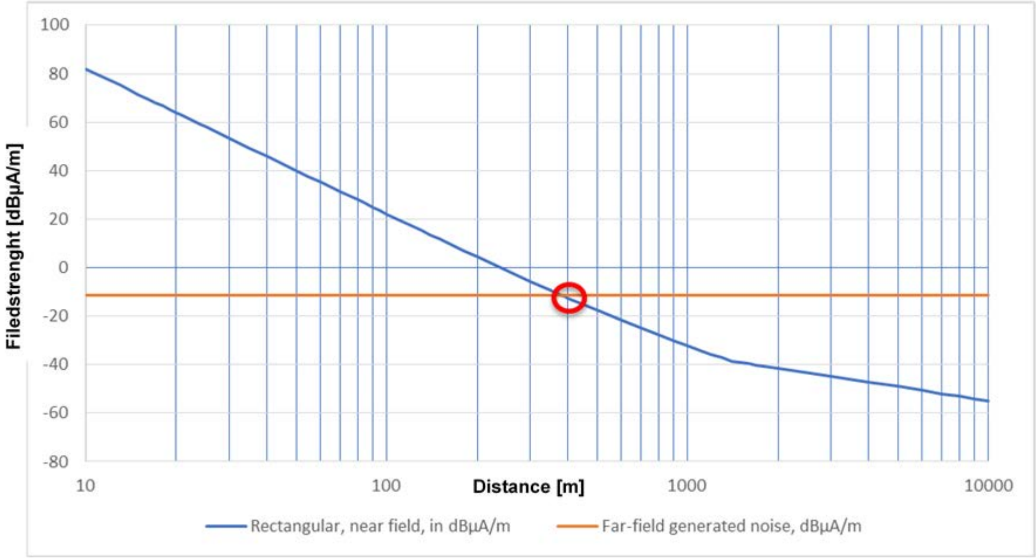


Figure 22: Ground wave effect distance (m) at 80 kHz (based on ECC Report 135 [2])

Excerpt from ECC Report 135 [2]:

"According to ERC Report 69 [10], it is necessary to consider if any ground wave effect is to be added by using Recommendation ITU-R P.368-7 [13].The calculation is made by a software programme, CILIR110, which is available as part of ERC Report 69."

Some additional calculations are available in Table 8.

Table 8: Additional calculations of the ground wave effect distance

Frequency (kHz)	Near field (dBµA/m) @ 10m	Ground wave effect interference distance (m)
85	82	362
85	62	168
85	42	78
150	-5	13
150	-15	9
150	-25	6
150	-35	4
200	-5	7
200	-15	5
200	-25	3
200	-35	2

4.3 NATO

The range 14-148.5 kHz is a NATO harmonised band and essential to NATO, and it is in military use for naval communications and tactical non-directional beacons. In this report no studies were carried out on NATO military systems.

5 STUDIES WITHIN THE ADJACENT FREQUENCY RANGE

5.1 EVALUATION OF THE WORST CASES FOR THE OUT-OF-BAND DOMAIN STUDIES

Based on Figure 3, the evaluation for the out-of-band/adjacent band situation leads to the following two situations which need to be considered.

It can be noted that if the WPT-EV emissions, including out-of-band emissions, are completely within the 79-90 kHz band, then the study is covered by the in-band studies in section 4.

If WPT-EV frequency is at one edge of the requested operation frequency range (79 or 90 kHz), the following worst-case assumptions for the out-of-band domain could be considered:

- fLmin @ 79 kHz or
- fHmax @ 90 kHz

with a max OBW of WPT-EV-system:1 kHz (99% of the energy).

1 WPT-EV frequency at the lower edge @ 79 kHz

- With fC=79.5 kHz it leads to fSL= 77 kHz and fSH=82 kHz;
- With the related power limits for the studies of the out-of-band domain (see ETSI TR 103 409 [11]):
  - 77 kHz < f < 79 kHz: 42 dBµA/m ;
  - f < 77kHz: spurious emissions for generic inductive devices SRD;
  - It can be noted that the out-of-band emissions inside 79-90 kHz (above fSH@82 kHz) are not relevant in this case, because the limit of 42 dBµA/m @ 10 m is smaller than the requested wanted emission of 82 dBµA/m @ 10 m.

2 WPT-EV frequency at the upper edge @ 90 kHz

- With fC= 89.5 kHz it leads to fSL= 87 kHz and fSH= 92 kHz
- With the related power limits for the studies:
  - 92 kHz > f > 90 kHz: 42 dBµA/m;
  - f < 77 kHz: spurious emissions for generic inductive SRD devices.
  - It can be noted that the out-of-band emissions of any WPT-EV system operating inside 79-90 kHz (below fSL@87 kHz) are not relevant in this case, because the limit of 42 dBµA/m @ 10 m is more stringent than the requested wanted emission of 82 dBµA/m @ 10 m.

5.2 FINDINGS IN FORMER REPORTS

The most relevant Reports are: ECC Report 135 [2] and ERC Report 44 [4].

Editorially amended conclusion ERC Report 135:

The limits given in table 1 of that ECC Report 135 at 10 m for inductive SRD for the frequency range of 9-148.5 kHz will not produce harmful interference to radio services under the assumption that current long-wave radio receivers are not used in an area of about 100 m around the proposed inductive devices.

Based on the worst cases assumption in clause 5.1, the standard frequencies and other frequencies to be protected with a limit of 42 dBµA/m at 10 m, which could fall inside the adjacent ranges, are given in Table 9.

Table 9: Radio Services in the adjacent frequencies

Station	Frequency	Protection bandwidth	Location
DCF77 (note 1 and note 2)	77.5 kHz	+/-250 Hz	Germany
LORAN C / eLORAN	90-110 kHz	Over the entire band	World-wide
Note 1: This band is already protected by the existing regulation via a notch in the limit. Note 2: Standard frequencies and time signals are defined by Recommendation ITU-R TF.768 [14]			

5.3 UPDATED INFORMATION ON DCF77

Receivers for DCF77 reception are fairly simple on the RF hardware side, consisting of a simple tuned circuit and signal processing hardware. As Engeler [37] indicates, most performance improvement can be achieved on the data processing. Udo Klein developed a noise tolerant decoder [38] in 2013. Further improvement, however, is expected to be marginal. Harmonised standards on receiver specifications for DCF77 receivers do not exist but also do not add much value since the basics are known and are unlikely to change much in the future. WPT-EV systems are only one of several possible reasons for interference to time synchronization at DCF77 clocks.

5.3.1 Measurements

The subject of these measurements was to investigate whether the main charging signal, e.g. at 85 kHz, at a WPT station for charging electric vehicles may block the reception of radio controlled clocks at 77.5 kHz in the vicinity of the WPT station. The aim was to determine the tolerable interfering field strengths from WPT stations and to estimate the minimum required distance to DCF77 receivers.

Therefore, the DCF77 signal was produced by a signal generator and the unwanted WPT signal was emulated by an unmodulated carrier from a signal generator and transmitted by a “Helmholtz coil”.

For the majority of the measurements, the field strength of the DCF77 signal at the location of the devices under test (DUTs) was adjusted to -1.5 dBµA/m. This corresponds to the minimum outdoor field strength of the real DCF77 transmitter at 1000 km distance. To get indications on the nature of the interfering effect, additional measurements were made with a wanted field strength of 18.5 dBµA/m.

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 synchronise was determined for each DUT until failure.

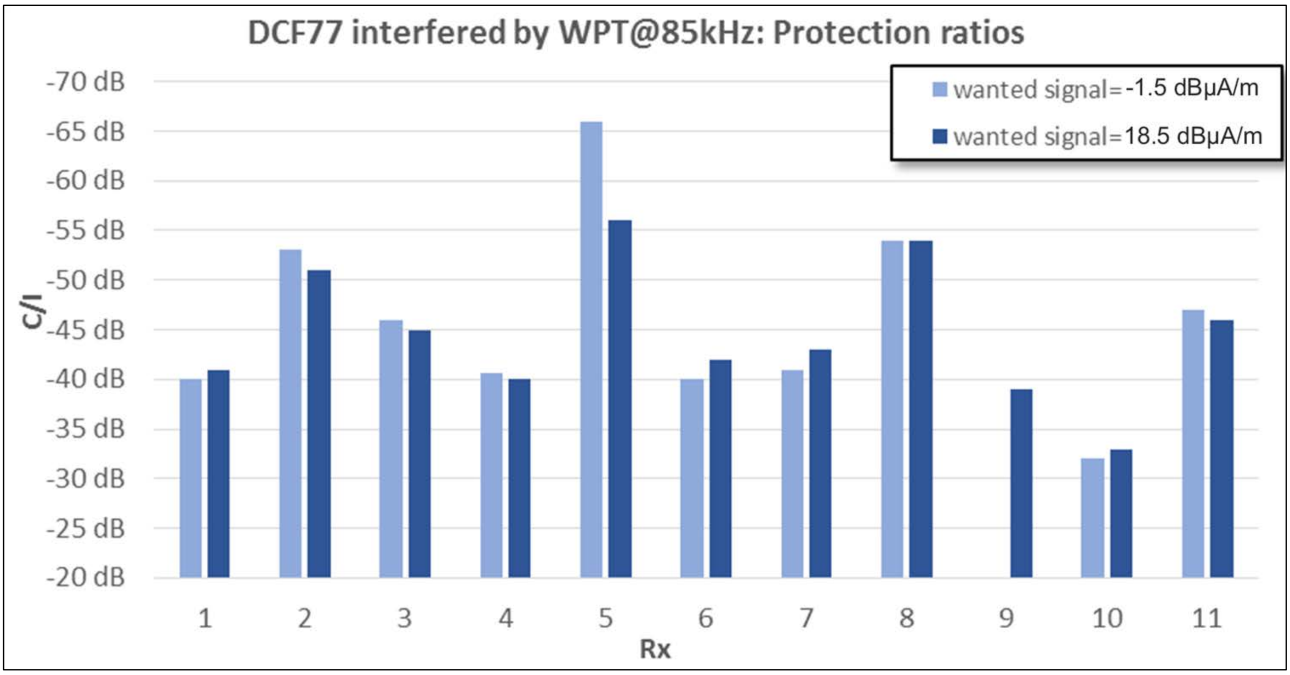


Figure 23: Measured C/I for different wanted field strengths

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

5.3.2 Evaluation of the measurement results

For the underlying calculations, the following assumptions were made.

All C/I values are taken from the results under optimum antenna alignments. It should be noted that C/I is a function of frequency offset (larger C/I close to the DCF77 signal frequency).

Compatibility distances can be derived for different WPT field strengths using the formula below. This compatibility distance is the minimum distance at which a given percentage of DCF77 receivers will work properly.

The WPT field strength in the near-field (for the H-field) is assumed to follow a 60 dB/decade drop with distance.

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

The resulting compatibility distance then is calculated according to following formula:

$$d\left(H_{WPT}, H_{DCF}, \frac{C}{I}\right) = 10^{\left(\frac{H_{WPT}-H_{DCF}+\frac{C}{I}}{60\frac{dB}{dec}}+1\right)}$$

Where:

- H_{WPT} is the magnetic field strength of a WPT system at 10 m (e.g. 68.5 dBµA/m at 10 m);
- H_{DCF} is the magnetic field strength of the DCF77 signal (e.g. -1.5 dBµA/m at 1000 km from transmitter);

- $\frac{C}{I}$ is the minimum ratio between DCF77 and WPT signal ensuring that a given percentage of DCF77 receivers are protected. C/I is a function of frequency offset and percentage of receivers being protected. Values measured vary from -61 dB to -20 dB.

Figure 24, Figure 25 and Figure 26 show the influence of the signal strength of the wanted DCF77 signal on the compatibility distance.

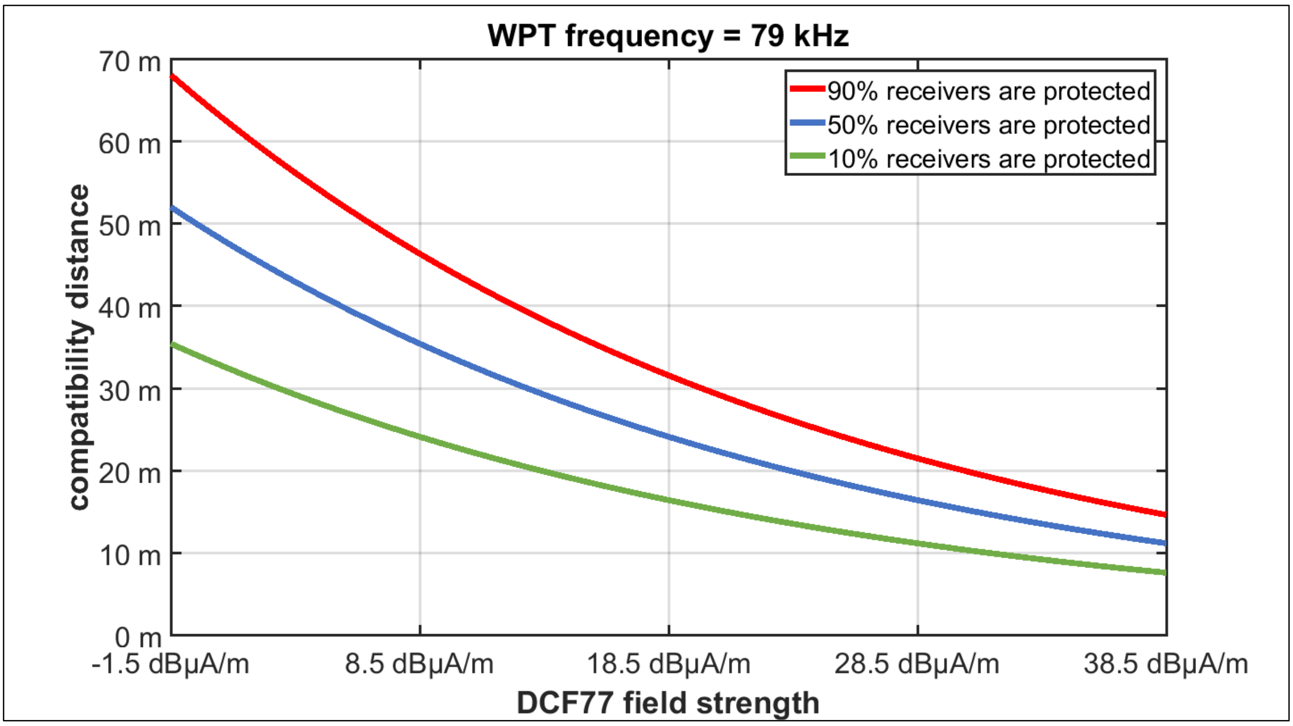


Figure 24: Compatibility distances at different wanted DCF77 field strengths for a WPT frequency of 79 kHz and a WPT signal strength of 68.5 dBµA/m @ 10 m

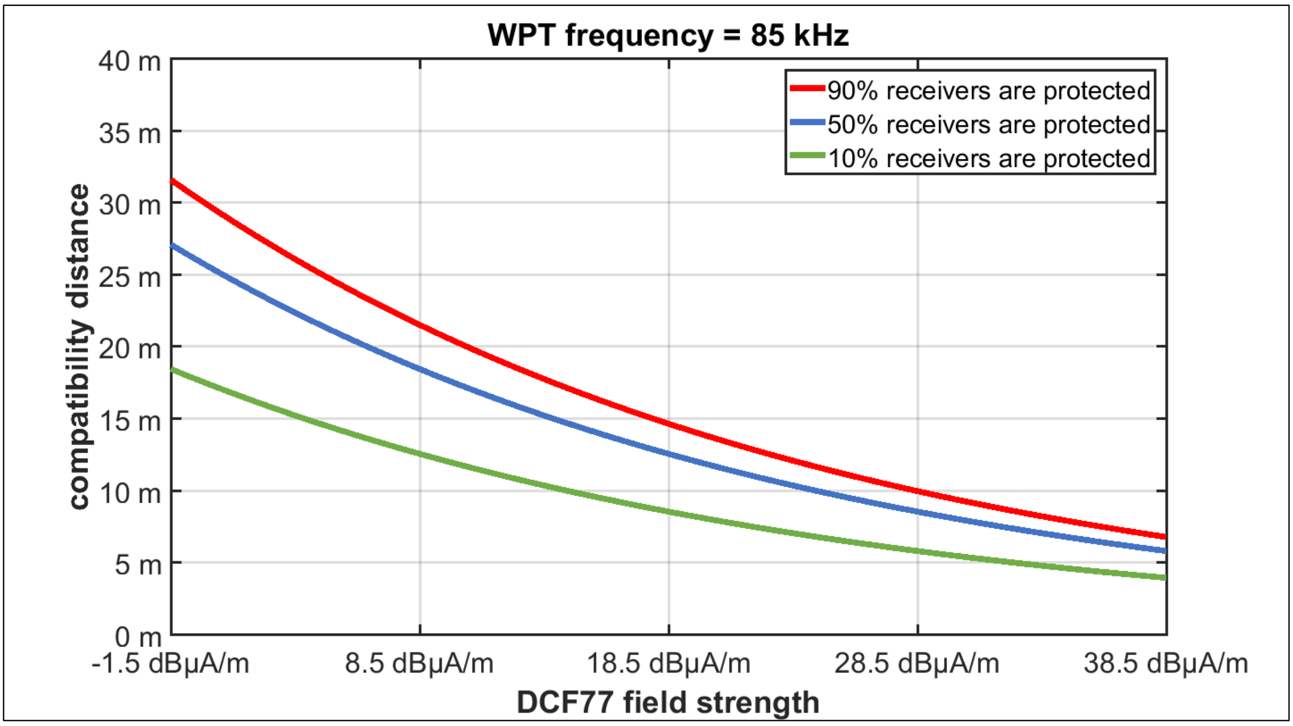


Figure 25: Compatibility distances at different wanted DCF77 field strengths for a WPT frequency of 85 kHz and a WPT signal strength of 68.5 dBµA/m @ 10 m

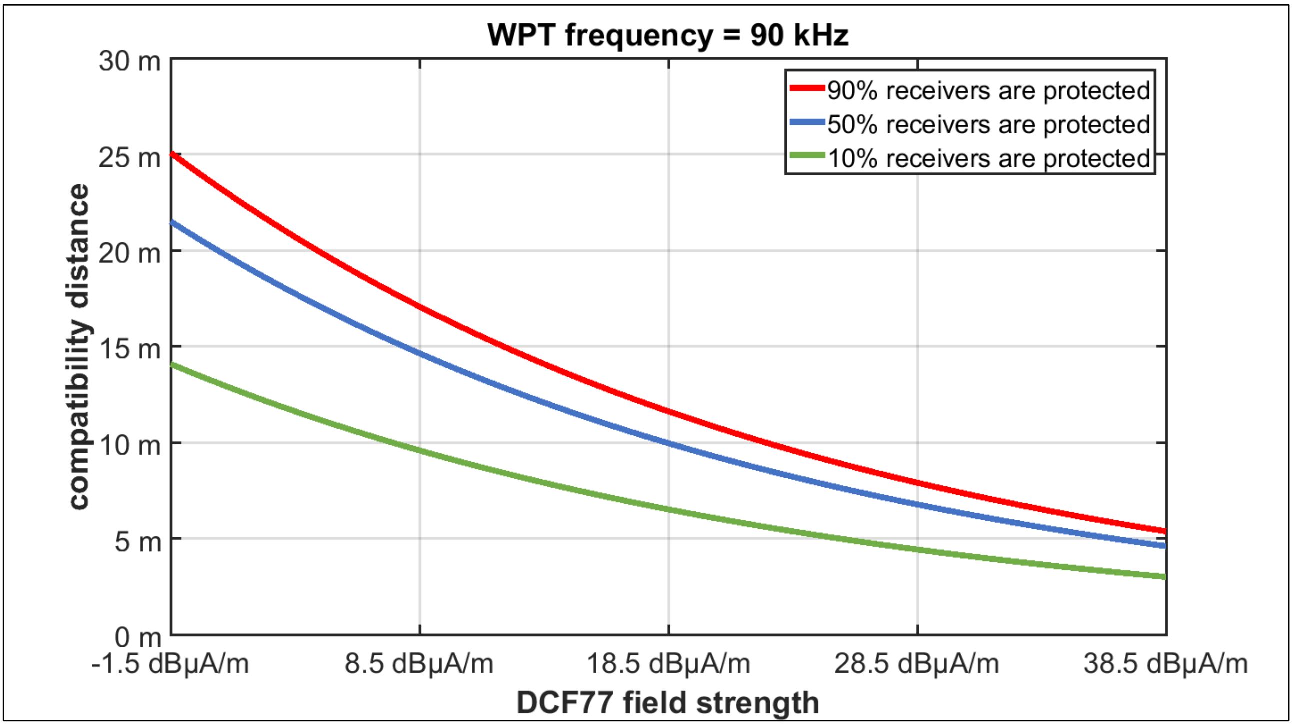


Figure 26: Compatibility distances at different wanted DCF77 field strengths for a WPT frequency of 90 kHz and a WPT signal strength of 68.5 dBµA/m @ 10 m

Figure 27 and Figure 28 show the influence of the frequency offset between DCF77 and WPT signals on the compatibility distance.

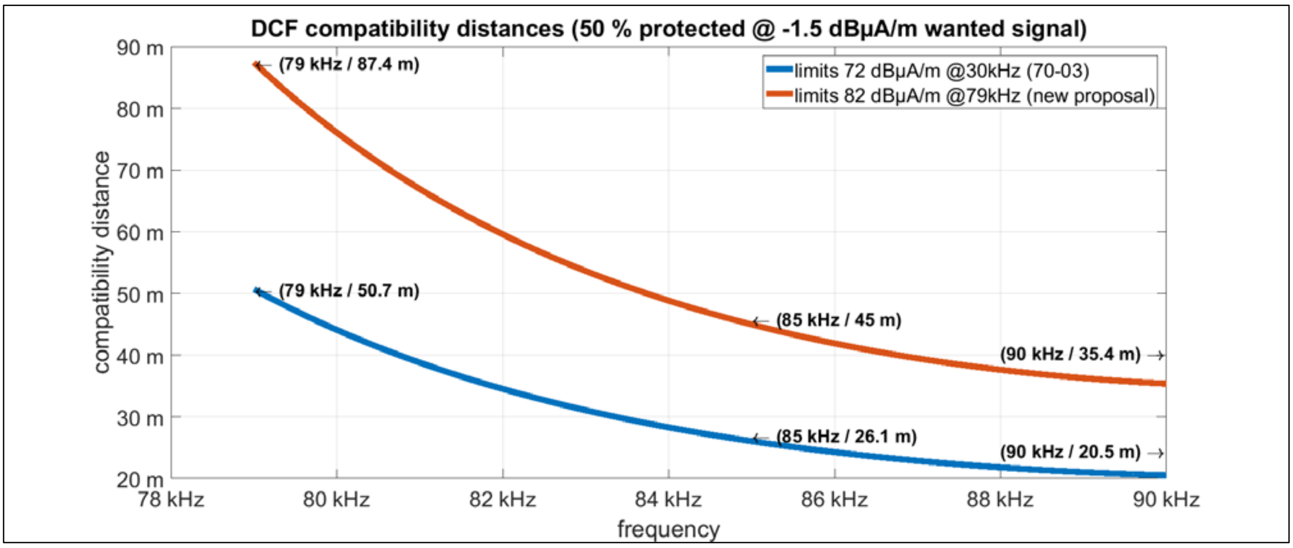


Figure 27: Compatibility distances at different frequencies protecting 50 % of DCF77 receivers receiving a minimum wanted signal of -1.5 dBµA/m at 10 m

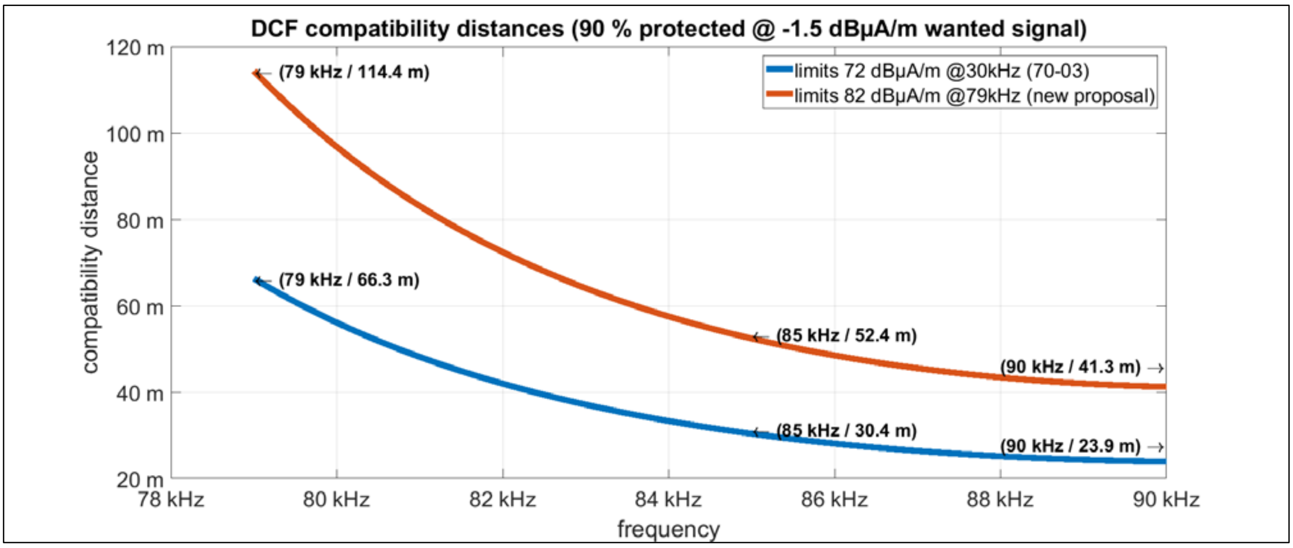


Figure 28: Compatibility distances at different frequencies protecting 90 % of DCF77 receivers receiving a minimum wanted signal of -1.5 dBµA/m at 10 m

5.3.3 Conclusion on DCF measurements

Even if the current limit for inductive SRD given in ERC Recommendation 70-03 Annex 9 of 68.5 dBµA/m for the main WPT emission is met, none of the tested DCF devices work at 10 m distance when receiving only the minimum required wanted field strength of -1.5 dBµA/m.

The actual protection distance depends on the 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 8.5 dBµA/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.

Additionally decreasing the wanted signal to -1.5 dBµA/m which corresponds under ideal propagation conditions to a signal radius of 1000 km would lead to compatibility distances of 45 m. It has to be noted that DCF77 receivers are deployed throughout Europe and should work up to 2000 km away from the DCF77 transmitter.

Summarised it can be derived that:

- Increasing the limits for WPT to 82 dBµA/m @ 79 kHz would increase the compatibility distances for today's limits by nearly a constant 72 %;

  (For example, at 79 kHz the compatibility distance increases from 50.7 m to 87.4 m for the proposed new limits and protection of 50 % of DCF77 devices @ -1.5 dBµA/m at 10 m wanted signal)
- Compatibility distances can be reduced by using the higher frequency areas greater than or equal to 85 kHz. Up to 85 kHz the compatibility distances decrease very rapidly, whereas in the area of 85 kHz to 90 kHz they do not change significantly;

  (For example, the above mentioned 87.4 m at 79 kHz could be reduced to 45 m if the frequency of 85 kHz would be used under the proposed new limits and protection of 50 % of DCF77 devices @ -1.5 dBµA/m at 10 m wanted signal);
- The compatibility distances depend strongly on the wanted signal strength. With increasing distance to the DCF77 transmitter the compatibility distances will also increase. This appears also in close areas when DCF77 receivers suffer poor reception environments.

A distinction should be made between critical DCF77-Receivers and non-critical DCF77-Receivers.

Mobile non-critical DCF77-receivers (e.g. wristwatches) should be able to synchronise in general. For fixed non-critical DCF77-receivers (e.g. personal clocks) it can be assumed that one single WPT charging station within the compatibility distance would not cause harmful interference, because charging should not last for 24 h. So the DCF77 device should be able to synchronise several times a day. An aggregation of several chargers would reduce the possibility of synchronisation.

For critical DCF77-receivers (e.g. traffic control, time related tariffs and military), a conclusion depends on the systems description. The switch to/from summer time is one possible important event which should be paid attention. Filters might be already embedded in those devices.

Mitigation measures for DCF77 might include a minimum separation distance between WPT-EV charging stations (for unsynchronized charging). Because this distance depends on the wanted DCF77 signal strength and therefore depends on the distance to the DCF77 transmitter, different values might be introduced by each administration, as IEC61980-3 norm [48] mandates as the specified behaviour of a WPT-EV charging station; synchronised interruption of WPT-EV charging stations to allow synchronization of time signal receivers.

This measure would further need to be studied because it is not clear if DCF77 receivers will automatically start synchronisation in the period of synchronized interruption of WPT-EV charging stations. However, allowing harmful interference may go against principles of spectrum management.

In the past, it was common to also use DCF77 disciplined frequency references [38], but these are likely replaced with GPS disciplined versions. If any of these are still in use specific measures for these, small number, of devices may be needed.

It should be noted that no harmonised technical documentation for DCF77-receivers was found. An additional possible future mitigation could be better receiver characteristics enforced by standardisation.

6 STUDIES WITHIN THE SPURIOUS DOMAIN

Based on the assumption of a maximum operating BW of WPT-EV of 0.5 kHz, the following radio systems need to be considered within the spurious domain of the WPT-EV-system (see Table 10).

Table 10: Radio systems within the spurious domain of WPT-EV

Station	Frequency	Protection bandwidth	Location
MSF (Note 1)	60 kHz	+/-250 Hz	United Kingdom
RBU (Note 1)	66.6 kHz	+/-750 Hz	Russian Federation
Amateur	73 kHz		Nationally allocated but cross band communication possible depending on regulation
HBG (Note 1)	75 kHz	+/-250 Hz	Switzerland
LORAN C (Note 2)	90-110 kHz	Over the entire band	World-wide
RNS-E(A) RNS-E(D) RNS-V(A)	100 kHz	+/-250 Hz	Russian Federation
SRD for car keyless entry system (Note 3)	125 kHz	+/- 4 kHz	World-wide
DCF49	129.1 kHz	+/-500 Hz	Germany
Broadcasting service	148.5-255 kHz 526.5-1606.5 kHz 525-1705 kHz		Region 1 Regions 1 and 3 Region 2
Amateur	135.7-137.8 kHz	Over the entire band	CEPT allocation
Amateur	160-190 kHz	Over the entire band	Nationally allocated but cross band communication possible depending on regulation
Allouis time signal	162 kHz	+/-125 Hz	France
NDB (aeronautical)	200-415 kHz	Over the entire band	Non Directional Beacons (NDBs) are deployed world-wide
Radiolocation (DGPS)	283.5-325 kHz	Over the entire band	World-wide
Amateur	472-479 kHz	Over the entire band	World-wide allocation

Note 1: Standard frequency and time signals are defined by Recommendation ITU-R TF.768 [14]

Note 2: This band/system was studied within the out-of-band domain (see chapter 5). Based on that, the spurious emission limit is more stringent than the out-of-band domain limit of 42 dBµA/m. This study is not relevant.

Note 3: Whilst not in the scope of this Report, it was noted that studies show a significant impact to keyless entry systems from nearby WPT-EV charging stations (< 6 m), see [31].

6.1 FINDINGS IN FORMER REPORTS

The findings in former ECC deliverables are:

- ECC Report 67 [7]

Assumption: Very Short Range Devices (VSRD) were approximately 40 million units (excerpt Annex 2, ECC Report 67).

- ERC Recommendation 74-01 [12]

The discounting which took place in assessing the limits in this Report allowed the limit for spurious emissions to be set at a relatively high level. This discounting took account of the likelihood of incidence of time, frequency and location of emitter and victim receiver (this is also mentioned in ERC Report 44 [4]). These assumptions might no longer be valid for widespread deployment of WPT-EV technology in the urban/suburban residential environments and so new limits might need to be established to provide adequate protection to authorised radio services operating in these environments.

The present Report provides updated information on:

- Broadcasting service, see clause 6.2;
- Amateur Service, see clause 6.3;
- Radiolocation Service, see clause 6.4.

For the other services in Table 10, it can be noted that frequencies/radio services operating below 30 MHz are considered in this Report. Based on the review of the results of former studies in the relevant ECC Reports and considering the fact that there was no contribution to this Report from some existing radio services below 30 MHz, it can be assumed for these services that the current SRD limits (ERC Recommendation 74-01 are relevant.

6.2 UPDATED INFORMATION ON THE IMPACT ON THE BROADCASTING SERVICE

6.2.1 Impact on the broadcasting service

6.2.1.1 Background

Inductive power transfer charging stations, operating at powers up to tens of kilowatts, for electric vehicles are projected to become widely accessible from public roadways and on driveways and garages of residential properties. Many of these are expected to operate or produce harmonics in the LF Broadcasting band 148.5-283.5 kHz and the MF Broadcasting band 526.5-1606.5 kHz. Charging systems with the emissions shown in clause 3.3.1.3 (which are compliant with CISPR 11 [[24])used in close proximity to home and mobile users of these bands pose, 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 Annex A2.1, A2.2, A2.3, and A2.4.

Importantly SRD and by implication WPT-EV chargers must not cause harmful interference to radio services. This principle is enshrined in Articles **15.12** and **15.13** of the Radio Regulations and (among other places) in [1], [17], [25] and [31]and is discussed in Annex A2.8.

Quite clearly and not unreasonably, radio services which have allocations in the Radio Regulations, are licensed and which are usually carefully regulated should not suffer harmful interference from SRD. The design and operation of SRD should respect this principle.

6.2.1.2 Factors affecting the impact of interference

Before considering the ways in which interference might be caused by SRD 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 have an audible impact especially in fringe (low signal strength) reception areas. The extent to which such interference is ‘harmful’ depends on a number of psycho-acoustic factors 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.

Any SRD is likely to generate some stray field with the potential to interfere with radio services. This can be at or close to the frequency(s) of operation of the SRD or at some other, quite likely harmonic frequency; the latter is styled ‘spurious’ radiation. 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 harmful. The major influences, some of which are included for completeness as much as relevance to WPT, are:

- Power Output of the SRD;
- Separation Distance;
- Intermittency;
- Antenna Directionality;
- Building Penetration Loss and;
- Polarisation Alignment.

A brief explanation of each of these is given in Annex A2.5.

6.2.1.3 Commentary and application to WPT systems and broadcast receivers

Looking at the specific case of an AM broadcast receiver (LF, MF or possibly even HF) suffering interference from a WPT-EV charger, the relevant factors are the strength of the stray fields at the operating frequency of the receiver (fundamental or spurious/harmonic) and the physical separation between the receiver and the WPT-EV system.

A WPT-EV system will operate continuously during the active charging time (see clause 3.2).

During the charging process, LF/MF receivers in close proximity to the WPT-EV system could be adversely affected should the WPT-EV system be operating with spurious emissions at or near the limits of ERC Recommendation 74-01 [12].

The operating range for WPT-EV system is 79-90 kHz which is not co-incident with any broadcasting band and so emissions at the operating frequency are unlikely themselves to cause harmful interference to broadcasting services. However, it is possible that spurious emissions, and in particular harmonic emissions, could lie within the LF (148.5-283.5 kHz) MF (526.5-606.5 kHz) or HF (various bands between 3.2-26.1 MHz) broadcasting bands.

6.2.1.4 Tolerable field strength limits

Absolute maximum levels for magnetic fields from inductive devices are given in (among other places) CEPT ERC Recommendation 70-03 [1] and ERC Recommendation 74-01 [12]. For broadcasting systems operating at frequencies above the proposed WPT-EV frequencies the latter (ERC Recommendation 74-01) is significant. These limits are specified in Annex 2, Table 2.1, rows 2.1.3 and 2.1.4 of Recommendation 74-01 [12]. Nowhere in either of the Recommendations does it state or even imply that these limits are adequate to protect radio services in any situation. Indeed, they are demonstrably inadequate and the fact that instances of harmful interference from SRD are rare depends on the mitigating effect of the factors listed above; in particular it is likely that even if the SRD generates fields that are close to the limit, intermittency and separation restrict the harmfulness of the interference. For example, as stated previously in Section 2 of the present Report and here recalled, after considering the impact on other services, the limits given in Table 1 (itself extracted from ERC Recommendation 70-03 [1]) are expected to protect radio services from harmful interference under the assumption that current long wave radio receivers are not used within an radius of about 100 m around the proposed inductive devices.

At the receiver

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 in a low field strength or fringe reception area, the maximum tolerable level of any interfering magnetic field is[1]:

- Band 5 (LF): -44.0 dBµA/m;
- Band 6 (MF): -51.0 dBµA/m.

A detailed description of how these figures are derived from Recommendation ITU-R BS.703 [15] and Recommendation ITU-R BS.560 [16] is given in Annex A2.6 along with an alternative derivation based on Recommendation ITU-R BS.1895 [17].

Noise Masking

Further studies carried out by the BBC and detailed in Annex A2.9 reveal that system noise - a combination of environmental (natural and man-made) noise and receiver noise - can mask the effect of a sinusoidal interferer. For a receiver with the same performance as that predicated in ITU-R Recommendation BS.703 [15] the masking effect of system noise would raise the tolerable level of any interfering magnetic field by 8 dB. These figures become:

- Band 5 (LF): -36.0 dBµA/m;
- Band 6 (MF): -43.0 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. The graph in Figure 21 (section 4.2) shows that the interfering field strength varies considerably with the distance away from the source. By convention, the magnetic field, strength from SRD is specified at 10 metres reference distance, but it cannot be expected that the separation between a broadcast receiver and a WPT-EV charger will actually be 10 metres. In practice, the realistic separation distance could be no more than 3 metres in a worst-case scenario. A justification for this figure is given in Annex A2.7.

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), from Figure 21 above, will be smaller by around 31 dB calculated with the appropriate attenuation per decade.

The figures for a WPT-EV at 10 metres:

- Band 5 (LF): –75.0 dBµA/m.
- Band 6 (MF): –82.0 dBµA/m.

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

- Band 5 (LF): –67.0 dBµA/m;
- Band 6 (MF): –74.0 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 Figure 21.

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[1] Recommendation ITU-R BS.703 assumes an rms modulation depth for AM radio of 30%. Work carried out more recently suggests that a more realistic figure for current usage (more speech based) is 20%. Using the 30% figure from the Recommendation would increase these field strengths by 3.5 dB.

Geographical location

It must be stressed that all of these figures are calculated for a receiver operating in a fringe reception area at the limit of coverage. Wherever possible, broadcasters plan their services such that population centres get a stronger signal. Conversely, however, services are planned such that fringe reception areas tend to be in places that are 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 WPT-EV system will be suitable for use in any location and so will have to respect the protection criteria.

6.2.1.5 Mitigation techniques

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 [18] and in Region 2 the Rio de Janeiro 1981 Frequency Plan [19]. 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 BS.560 cited above. Importantly, the regional assignment plans set the transmitter operating frequencies on a grid or raster; under [18] Plan each (carrier) frequency is a multiple of 9 kHz and under [19] Plan a multiple of 10 kHz; the bands are channelised[2]. 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 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 Figure 1 of Recommendation ITU-R BS.560 [16] (reproduced in Annex A2.6), 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-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. Subjective tests carried out by the BBC and described in [20] indicate that if the WPT operating frequency and its harmonics[3] 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 Recommendation ITU-R BS.703 [15] and Recommendation ITU-R BS.560 still apply. The relevant graph from the BBC report is reproduced here.

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[2] For Regions 1 and 3, 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.

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

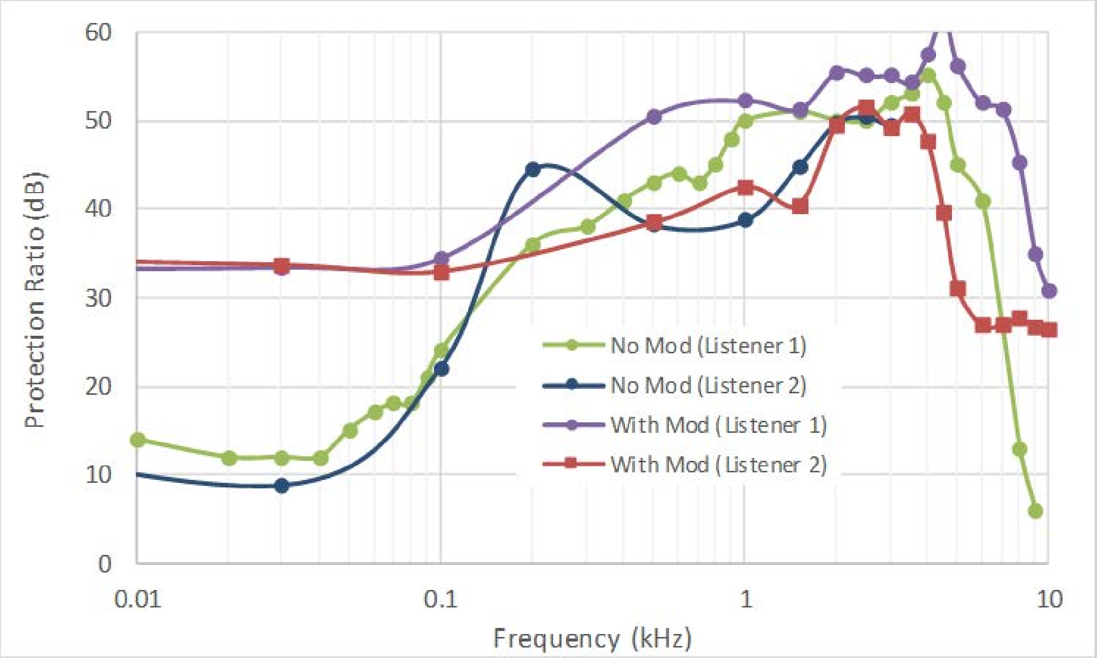

Figure 29: Required protection ratios with modulated and unmodulated interferers

It has to be noted that the subjective tests covered considerably more than two listeners – see [20]. To benefit from the additional 38 dB, the frequency has to be very tightly controlled. The offset between every significant harmonic and the corresponding raster frequency has to be less than about +/- 50Hz. 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. 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 in the 79 kHz to 90 kHz range. 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[4], 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 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.

6.2.1.6 Summary

Around the world, there is increasing interest in WPT devices for various applications including charging of vehicles.

Within CEPT, WPT-EV systems are considered as Short Range Devices (SRD). Guiding principles for the deployment of SRD are given ERC Recommendation 70-03 [1] which states;

“The term "Short Range Device" (SRD) is intended to cover the radio transmitters which provide either unidirectional or bi-directional communication which have low capability of causing interference to other radio

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

equipment. SRDs use either integral, dedicated or external antennas and all modes of modulation can be permitted subject to relevant standards. SRDs are not considered a "Radio Service" under the ITU Radio Regulations (Article 1)."

ERC Recommendation 70-03 [1] and ERC Recommendation 74-01 [12] specify absolute maximum levels for the electric and magnetic field strengths associated with SRD. It is nowhere stated either explicitly or implicitly that, or how, adherence to these field strength limits will actually offer protection to radio services. Indeed, these inductive SRD limits are tens of dB higher than those needed adequately to protect a broadcast radio receiver in close proximity to the SRD (see ECC Report 067 [7])Taking as an example a broadcast receiver operating at 900 kHz in the MF band in a fringe (low received signal strength) area, the EBU has shown that the maximum acceptable interfering magnetic field strength at the receiver is -51.0 dBµA/m. ERC Recommendation 74-01 allows a magnetic field strength at this frequency of 7.0 dBµA/m at 10 m distance from the device; so 58.0 dB higher. For a SRD device emitting this level of spurious emissions not to interfere with the broadcast receiver, the separation distance would have to be approximately 90 m.

The emission limits defined in ERC Recommendation 70-03 and ERC Recommendation 74-01 has never been seen as problematic in the past. Additional considerations such as intermittency, antenna characteristics, as well as location have meant that the probability of interference is very low. WPT-EV systems, however, are likely to operate at high powers, continuously (potentially for hours at a time, see Table 7) and in domestic environments where they are close to broadcast receivers. This Report suggests that 3 m is a reasonable expectation for the minimum separation between a WPT-EV system and a broadcast receiver (see Section 6.2.1.4 and Annex A2.7). By convention, the strength of magnetic fields is expressed at 10 m distance from the source, so correction factors would have to be applied to ensure 'no interference' in different scenarios. In the circumstances under consideration, the magnetic field strength varies with the cube of the distance.

In [20], it was demonstrated that the actual propensity for interference depends critically on the operating frequency of the WPT system and, importantly, its significant harmonics. If the interfering WPT harmonic is within about +/-50 Hz of the wanted broadcast carrier frequency, the protection field strength of -51.0 dBµA/m (for MF) at the receiver (or at 3 m from the WPT charger) can be relaxed to -13.0 dBµA/m; a significant relaxation of 38 dB.

In practice, nearly all LF and MF transmissions operate on a fixed frequency raster. In ITU Regions 1 and 3 all channels are centred on (have their carrier frequency at) a multiple of 9 kHz and in Region 2 each carrier is a multiple of 10 kHz. This is done to minimise harmful interference between the radio stations themselves and to make the process of network planning easier. It does, however, knock on to the choice of WPT operating frequency. The choice of 90 kHz, for example, as the WPT operating frequency would automatically ensure that all harmonics would be aligned with the Region 1, 2 and 3 broadcast carrier frequencies.

To recap, in order to avoid harmful interference from WPT-EV systems to LF and MF broadcast transmissions, WPT-EV systems must be engineered with care and to high technical quality. The keys to this are thoughtful choice of operating frequencies, accurate control of both frequency and stability and maintaining spurious / harmonic radiation at the lowest possible levels.

The figures for the spurious/harmonics emissions of the WPT-EV system (if WPT-EV is not operating on the broadcasting channel raster/ 81 kHz or 90 kHz) are:

- Band 5 (148.5-283.5 kHz): -75.0 dBµA/m (@10m from the WPT-EV);
- Band 6 (526.5-1606.5 kHz): -82.0 dBµA/m (@10m from the WPT-EV).

The figures for the spurious/harmonics emissions of the WPT-EV system (if WPT-EV is operating on the broadcasting channel raster/ 81 kHz or 90 kHz) are:

- Band 5 (148.5-283.5 kHz): -37.0 dBµA/m (@10m from the WPT-EV);
- Band 6 (526.5-1606.5 kHz): -44.0 dBµA/m (@10m from the WPT-EV).

A study carried out by the BBC in June 2018 using an 'off the shelf, commercial receiver' and reported in Annex A2.9.3 suggests that system noise – the combination of environmental and receiver noise - has the effect of masking a single tone interferer. The psycho-acoustic effect of this masking relaxes these figures by 8 dB.

The figures for the spurious/harmonics emissions of the WPT-EV system (if WPT-EV is not operating on the broadcasting channel raster/ 81 kHz or 90 kHz) are:

- Band 5 (148.5-283.5 kHz): -67.0 dBµA/m (@10m from the WPT-EV);
- Band 6 (526.5-1606.5 kHz): -74.0 dBµA/m (@10m from the WPT-EV).

The figures the emissions of the WPT-EV spurious/harmonics (if WPT-EV is on the broadcasting channel raster/ 81 kHz or 90 kHz) remain as:

- Band 5 (148.5-283.5 kHz): -37.0 dBµA/m (@10m from the WPT-EV);
- Band 6 (526.5-1606.5 kHz): -44.0 dBµA/m (@10m from the WPT-EV).

6.3 THE AMATEUR SERVICE

6.3.1 Introduction

An analysis of the impact of WPT-EV systems on radio communications in the Amateur Service is provided. 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.

6.3.2 Background

The Amateur Service is a radio service defined in the ITU Radio Regulations (RR **1.56**). There are around 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 11 provides a general overview of current allocations up to 1 GHz. There are also numerous allocations above 1 GHz.

Table 11: Global allocations to the Amateur Service below 30 MHz in the ITU Radio Regulations

Frequency range	Allocation status
135.7-137.8 kHz	Secondary allocation
472.0-479.0 kHz	Secondary allocation
1800-2000 kHz	Part primary, part secondary
3500-4000 kHz	Primary allocation
5351.5-5366.5 kHz	Secondary allocation
7000-7300 kHz	Primary allocation
10100-10150 kHz	Secondary allocation
14000-14350 kHz	Primary allocation
18068-18168 kHz	Primary allocation
21000-21450 kHz	Primary allocation
24890-24990 kHz	Primary allocation
28.0-29.7 MHz	Primary allocation

The characteristics of stations operating in the Amateur Service are set out in Recommendation ITU-R M.1732 [21]. The Amateur Service is essentially a low-power service which relies on having a low background noise level for its effective 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[5] 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 30 below shows the distribution of A1A signal to noise ratios in the Amateur Service drawn from 528280 data points.

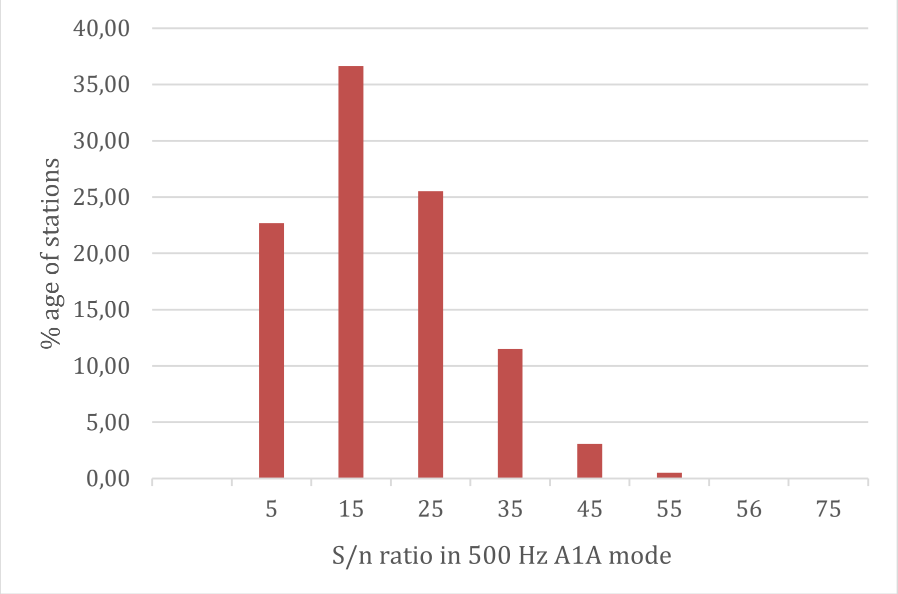

Figure 30: Distribution of typical S/N ratio in Amateur Service communications

This chart shows convincingly that any significant increase 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.

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 [22] are relevant as a reference point. Although there has been some increase above these levels in the "city" noise, recent reports submitted to ITU have suggested that the residential and rural levels are still representative of the real world. In terms of quiet rural, there is some evidence that the levels have risen somewhat, 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 [23].

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.

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[5] http://www.reversebeacon.net/

Precedents have been set to recognise the need for protection of Amateur Service frequencies in standards and limits relating to Power Line Telecommunications [26], DSL services [28] and Gfast [29]. 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 in this Report.

6.3.3 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 31 represents a schematic representation of a typical WPT-EV domestic installation co-sited with an installation in the Amateur Service located in a typical series of semi-detached dwelling houses in the UK. Figure 32 a and b show typical such developments. It will be noted that it is entirely feasible (indeed likely in many cases) that the antenna for the Amateur Service installation is within 10 m of the WPT installation.

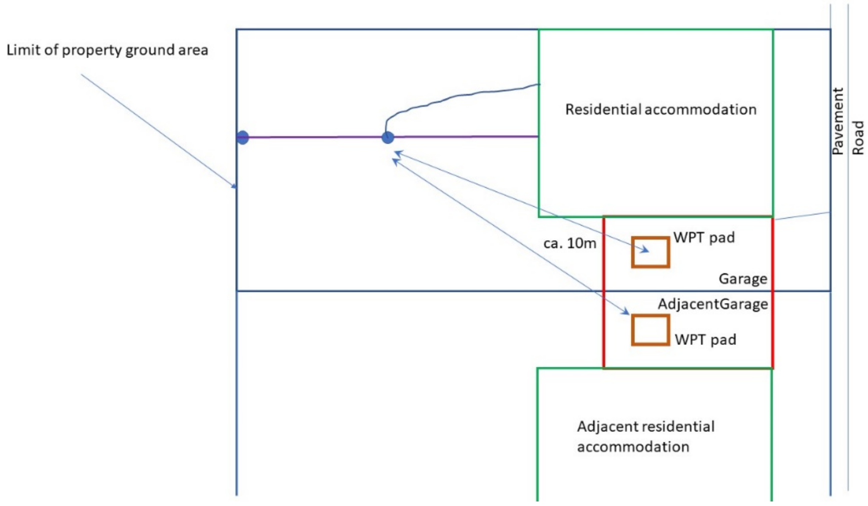

Figure 31: Schematic of a typical dwelling house location in the United Kingdom

(a) (b)

Figure 32a and b – Typical London suburban development showing adjacent garages as modelled in Figure 31

6.3.4 Levels of emissions in the spurious domain

Limits for emissions from electronic systems are governed by EMC standards and also documented in CEPT and ITU Recommendations/Reports in terms of the radio emissions. The relevant limits are in Recommendation ITU-R SM.329-12 [23], ERC Recommendation 74-01 [12] and CISPR 11 [24]. A draft under development in CISPR for WPT-EV is CISPR 687CDV (but not publicly available at the time of writing). All three limits are relatively close in emission levels and for the purpose of this study are grouped together as “the limits”. 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, should these be at these limits.

Figure 33 shows the levels from Recommendation ITU-R SM.329-13 [23], ERC Recommendation 74-01[12] and derived CISPR 11 [24] Class B (the limits) and Recommendation ITU-R P.372-13 [22] over the frequency range from 300 kHz to 30 MHz. It will be seen that there is a very significant gap between the limits and the noise levels in Recommendation ITU-R P.372-13. Spurious emissions at the level of the limits will exceed the noise level by 40-50 dB. This would have a very harmful effect on radio services operating in the vicinity. The basis for the data in this graph is set out in ANNEX 4.

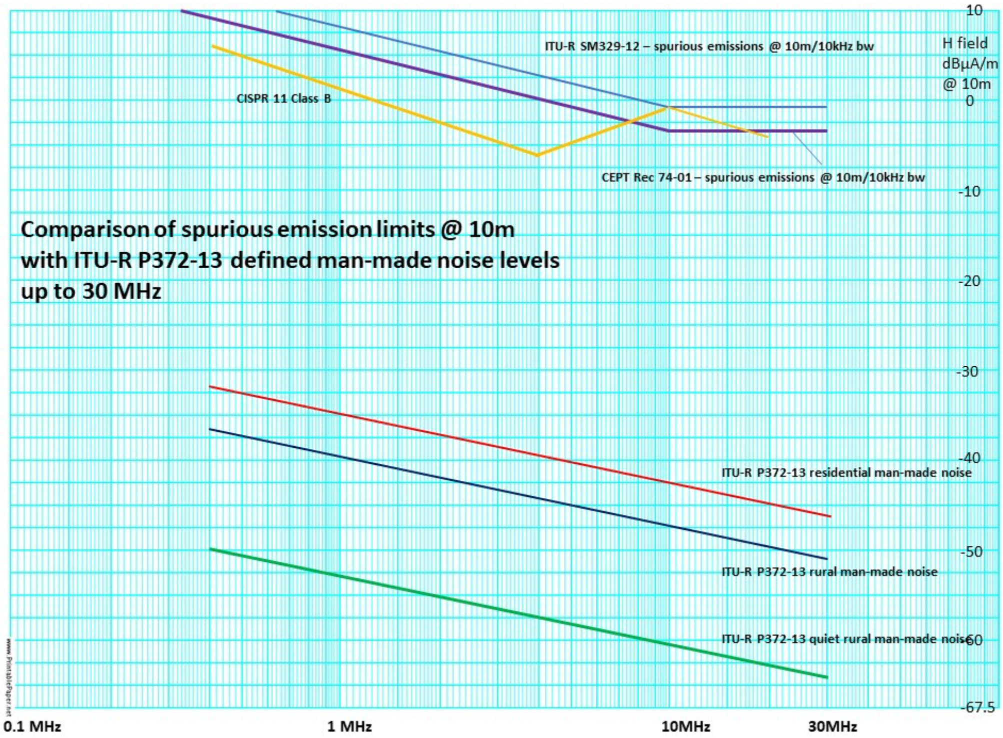

Figure 33: Graphical representation of emissions limits compared with background noise levels in Recommendation ITU-R P.372-13 [22]

Furthermore, effects of far field and near field emissions and the transition from near-field to far-field have been studied in the development of the ETSI EN 300 330 [6]. Although previous modelling of WPT systems has often assumed a “near-field” decay rate of 60 dB/distance decade, the ETSI document clearly shows that decay rates of the emissions depend on frequency, with the far-field decay rate of 20 dB per distance decade starting relatively close to the WPT installation at higher order harmonics. This data allows an assessment to be made of the emissions from WPT-EV systems which have with emissions (measured at 10 m) at the limits.

Using this data, the plots on the next page (Figure 34 and Figure 35) show the projected emission field at 5 MHz and 10 MHz arising from harmonics of the WPT system which are for instance at the Recommendation ITU-R SM.329 [23] limit when measured at 10 m. It will be seen that at 5 MHz, the emissions exceed the rural background noise at distances of up to 1.5 km from the WPT installation and at 10 MHz this distance increases to 2.0 km. This gives added weight to the argument that spurious emissions measured at 10 m need to be very significantly below the current limits to prevent harmful interference to radio services.

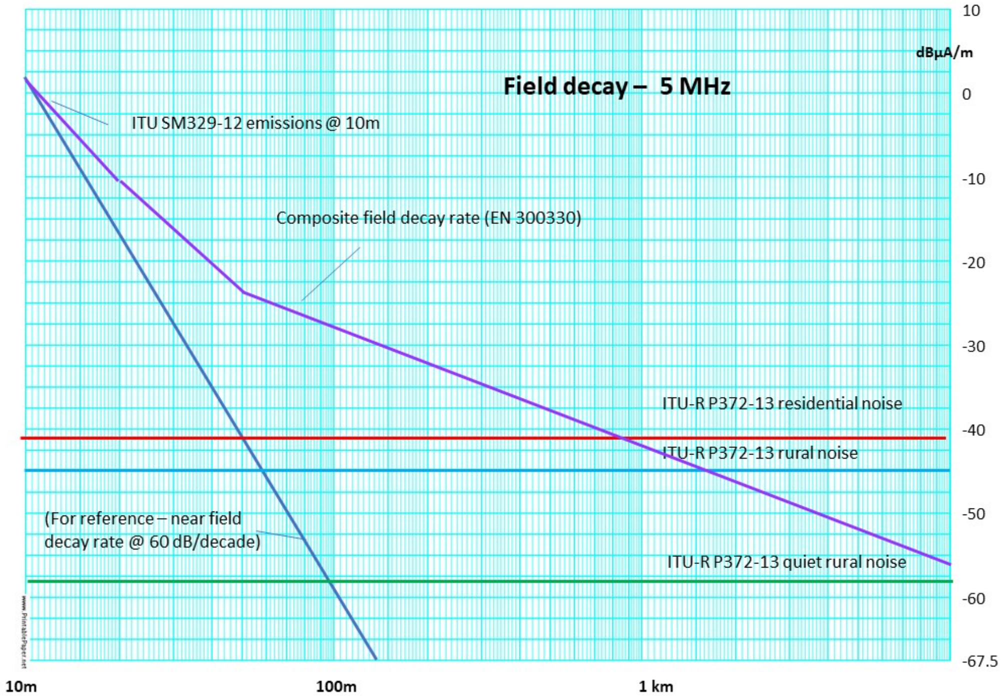

Figure 34: Emission decay at 5 MHz

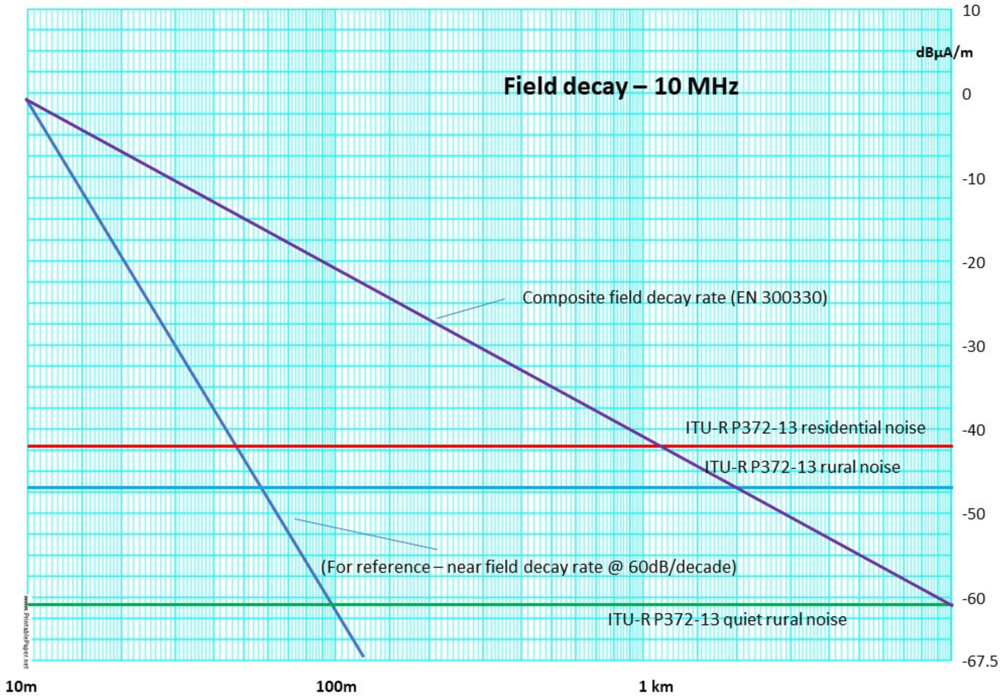

Figure 35: Emission decay at 10 MHz

Given the planned density of WPT-EV systems, the amateur service calculates that there will be a widespread and serious impact on its operation in the vicinity of WPT systems should spurious emissions, measured at 10 m be at the current limits of ERC Recommendation 74-01 [12].

6.3.5 An appropriate level of protection

For small-signal services, there are established precedents for limiting the increase of background noise to 0.5 dB [40]. This provides a reasonable level of protection.

Recommendation ITU-R SM.329-12 [23] currently sets the limits for spurious emissions as follows.

Short range devices operating below 30 MHz:
- 29 – 10 log(f (kHz)/9) dB(µA/m) at 10 m for 9 kHz < f < 10 MHz;
- –1 dB(µA/m) at 10 m for 10 MHz < f < 30 MHz;
- –36 dBm for 30 MHz ≤ f (except frequencies below) < 1 GHz;
- –54 dBm for f within the bands 47-74 MHz, 87.5-118 MHz, 174-230 MHz, 470-862 MHz;
- –30 dBm for 1 GHz ≤ f < (see recommends 2.5).

It might be reasonable to set the level of protection with reference to the Recommendation ITU-R P.372-13 [22] quiet rural noise level, as WPT systems will be deployed universally. This would represent a very harsh target for WPT installations, however, with the emissions at 10 MHz needing to be --72 dBµA/m. So, as a planning basis, it is proposed to take the reference point as the residential line of Recommendation ITU-R P.372-13 [13], and to assume that WPT-EV emissions are unstable in frequency or are not all exactly on a common frequency and/or with low levels of phase or sideband broadband noise. This then gives a maximum permissible spurious emission of approximately:
- -46 dBµA/m at 300 kHz reducing by 7 dB per frequency decade to -60.0 dBµA/m at 30 MHz.

All measurements are in 10 kHz bandwidth and at 10 m distance.

This would have the effect of increasing the residential noise by 0.5 dB, the rural noise by 2.4 dB and quiet rural by 8 dB.

Similar degrees of improvement in emission limits are also needed at f > 30 MHz.

If WPT-EV is a highly stable pure sinusoidal signal, 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. In such a case, the harmonics of the pure sinusoid could reasonably be permitted to exceed the above level by some 20 dB as this would constrain harmful interference to spot frequencies across the radio spectrum.

6.3.6 Measuring existing systems

A study of some of the data submitted on measurements of prototype 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.

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.

6.3.7 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**[6] and **15.13**[7] of the Radio Regulations [1]. Given the planned density of WPT-EV systems, the amateur service calculates that there will be a widespread and serious impact on its operation in the vicinity of WPT-EV systems, should spurious emissions, measured at 10 m be at the current limits of ERC Recommendation 74-01 [12].

The WPT-EV manufacturers have confirmed that systems have been designed to meet the emission limits ERC Recommendation 74-01 which was the best available information at the time. The study in this Report shows that these limits fall well short of providing adequate protection.

6.4 THE RADIONAVIGATION SERVICE

The frequency band 255415 kHz is allocated to the radionavigation service in the RR. A number of applications are in use.

6.4.1 Non directional beacons / Automatic Direction Finder

These are aeronautical applications consisting of CW modulated beacons on the ground and an automated direction finder in the aircraft. The beacon only transmits the (3 letter) ID of the beacon in Morse code. The coverage of a typical beacon received in an aircraft is about 25 nautical miles (NM) usable distance. For large airliners the non-directional beacon (NDB) is largely replaced with a combination of VHF Omnidirectional Range (VOR) and GPS but for smaller aircraft NDB systems are still in use, for example at oil drilling rigs at sea to aid helicopters.

A specific type of NDB is the locator, these are placed at a typical distance of 10 NM from the beginning of the landing strip at an airport, these beacons have a lower transmitter power than the normal NDBs and have a range of 15 NM. The send their ID in 2 letter Morse code.

In Europe, the frequency band 255-526.5 kHz (except 495-505 kHz) is allocated to the radionavigation service, dedicated to NDF/ADF.

These include aeronautical applications consisting of CW modulated (A1 or A2) beacons on the ground and an automated direction finder in the aircraft. The beacon transmits a 2 or 3 letter ID in Morse code. The coverage of a typical beacon received in an aircraft is about 50 nautical miles (NM) usable distance. It has to be noted that some NDBs can have a designated operational coverage up to 250 NM. On a global basis, the use of NDB beacons is expected to continue in the medium subject to Regional or sub-Regional requirements.

These bands support NDBs for short- and medium-range navigation. NDBs transmit non-directional signals in the low and medium frequency (LF/MF) bands. With appropriate ADF equipment on board an aircraft, the pilot can determine the bearing of the station or can "home" on the station. The ADF receiver can be tuned in all the operational NBD frequency band.

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[6] 15.12 § 8 Administrations shall take all practicable and necessary steps to ensure that the operation of electrical apparatus or installations of any kind, including power and telecommunication distribution networks, but excluding equipment used for industrial, scientific and medical applications, does not cause harmful interference to a radiocommunication service and, in particular, to a radionavigation or any other safety service operating in accordance with the provisions of these Regulations.

[7] 15.13 § 9 Administrations shall take all practicable and necessary steps to ensure that radiation from equipment used for industrial, scientific and medical applications is minimal and that, outside the bands designated for use by this equipment, radiation from such equipment is at a level that does not cause harmful interference to a radiocommunication service and, in particular, to a radionavigation or any other safety service operating in accordance with the provisions of these Regulations

NDBs are mainly used as a non-precision instrument approach aid, either in conjunction with an instrument landing system (ILS) (then designated as a "locator") or to define air routes/airways. NDBs are extensively deployed at aerodromes for general aviation. NDBs are comparatively inexpensive navigation aids and relatively simple to install and maintain. NDBs are assigned frequencies on the basis of daytime propagation conditions.

Aeronautical NDBs at coastal locations are also used by the maritime service, and in the reverse sense, beacons provided for maritime purposes are potentially usable by aviation. Any interference signal, transmitting in the band would jeopardise the reliability reception of the NDB.

General aviation use of NDBs is expected for at least the medium term (2035) Recent developments include the need to retain NDB systems on a larger scale to provide back-up for GNSS failures in areas where alternative back-up systems such as VOR/DME or DME-DME navigation is technically or economically not practicable.

NDB/ADF receiver characteristics on board the aircraft are depicted in section 3.2.1.4 of ECC Report 67, and they are shown in Table 12 below:

Table 12: NDB/ADF Receiver characteristics according to ECC Report 067 [7]

Service	**Frequency range**	**NDB/ADF receiver BW**	**Electric field 1 kW at 1 km land**	**Permissible Interference**
	MHz	kHz	dBµV/m	dBµV/m
Aeronautical Radionavigation	0.225-0.495	2.7	147	21.9

The maximum permissible interference value at the receiver should be respected in order to maintain the proper operation of the couple NDB/ADF. Separation distances could be derived from the table above.

6.4.2 Differential GPS beacons

A chain of Differential GPS (DGPS) beacons is deployed worldwide mainly for use at sea in the band 283.5-325 kHz. The International Association of Lighthouse Authorities (IALA) is responsible for the organisation of the chain of beacons but the beacons themselves are nationally maintained. Ad hoc beacons for specific applications are also allowed in this frequency range. Depending on the distance, sub cm accuracy can be obtained.

6.5 FIXED AND MOBILE SERVICE BETWEEN 1.5-30 MHZ

During the last years, the HF radio medium experienced renewed interests at global level for the fixed and mobile services from the tactical, maritime and aeronautical domain. The frequency allotment for these different HF services is distributed over all the 1.5-30 MHz frequency bandwidth.

The fixed and mobile stations are also used in urban, residential or rural environments for reception and/or emission, particularly for governmental usages. The maritime mobile stations can also be used near an urban environment or residential environment, when the ships docked in ports.

Considering the expected density of WPT-EV systems (1.7 million units in 2030), their locations and the emission power targeted, and the possible proximity with the HF mobile and fixed stations used in their operational use context, it is necessary to set the unwanted emissions of WPT-EV to levels bringing no significant additional interferences to the HF receiving stations in order to limit their impact on the reception quality, thus on the HF radio coverage.

6.5.1 HF current man-made interferences

The radio frequency noise picked up by the receiver antennas has a significant impact on the quality reception and thus on the radio links performances as the radio coverage. In the HF frequency band (1.5-30 MHz), the most powerful constantly present noise picked by the receiver is the man-made noise.

This noise is defined in the Recommendation ITU-R P.372-13[22] and corresponds to the aggregated unintended radiations from electrical machinery, electrical and electronic equipment, power transmission lines, or from internal combustion engine ignition. This noise is higher than the HF receive chains self-noise and constitutes a background noise.

In this Recommendation, the median man-made noise is described by a noise factor for different environments. The noise in city environment is the most powerful man-made noise and this encountered in quiet rural environment is the lowest.

The relation between the noise factor and the electrical field is given in this recommendation. Assuming the well-known relation between electrical field and magnetic field verified ($\frac{E}{H} = 377\,\Omega$), the level of magnetic field corresponding to the median man-made noise is obtained.

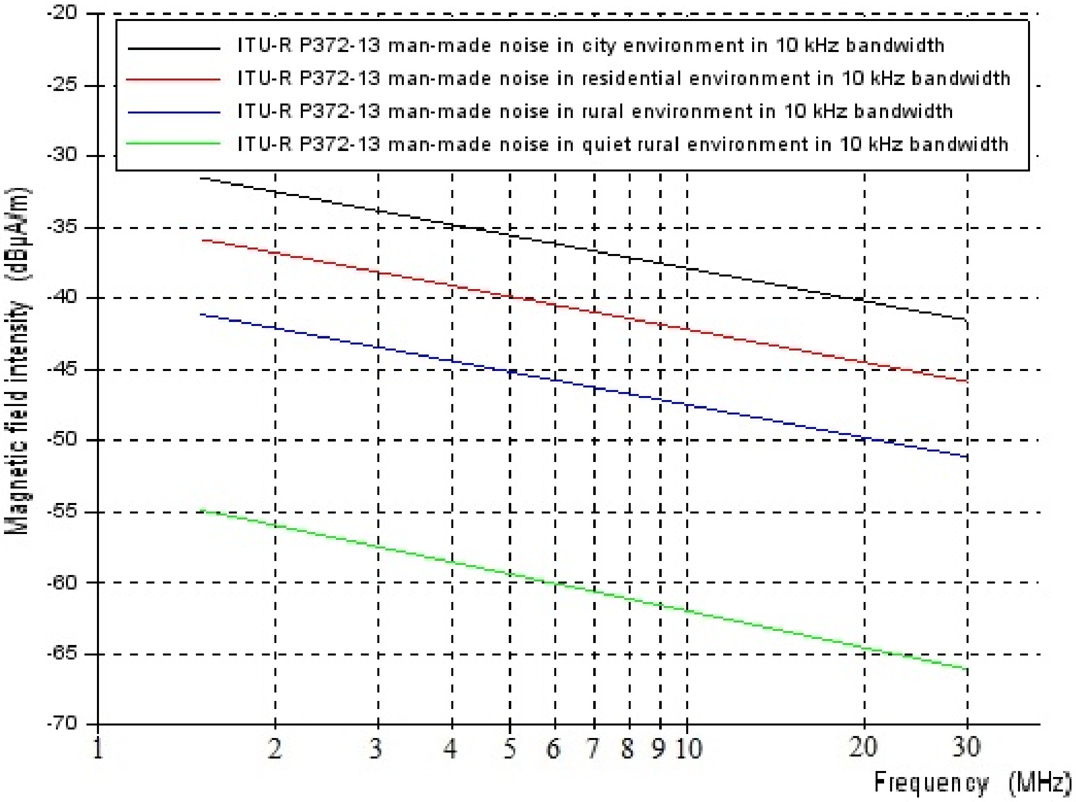


Figure 36: Magnetic field corresponding to Recommendation ITU-R P.372-13 median man-made noises in 10 kHz receive bandwidth versus frequency

ANNEX 3: of this Report supports with measurements and references that Recommendation ITU-R P.372-13 man-made noise levels still represent “real life” for urban, rural and quiet rural environments. The HF mobile and fixed stations are used in these different environments in operational use contexts where the reception is strongly impacted by this noise.

These curves are median values. There are variations of the curve according to the location of the station and the time characterised in this Recommendation for city, residential and rural environments. Deviation values are not given for a quiet rural environment.

Table 13: Values of decile deviations of man-made noise,
from the Recommendation ITU-P.372-13

Category	Decile	Variation with time (dB)	Variation with location (dB)
City	Upper Lower	11.0 6.7	8.4 8.4
Residential	Upper Lower	10.6 5.3	5.8 5.8
Rural	Upper Lower	9.2 4.6	6.8 6.8

6.5.2 Comparison between spurious emission limits based on ERC Recommendation 74-01 and Recommendation ITU-R P.372-13 median man-made noise

For the unwanted emissions in the 1.5-30 MHz, WPT-EV spurious emission limits are based on ERC Recommendation 74-01, the following comparison depicted in Figure 37 stands with Recommendation ITU-R P.372-13 median man-made.

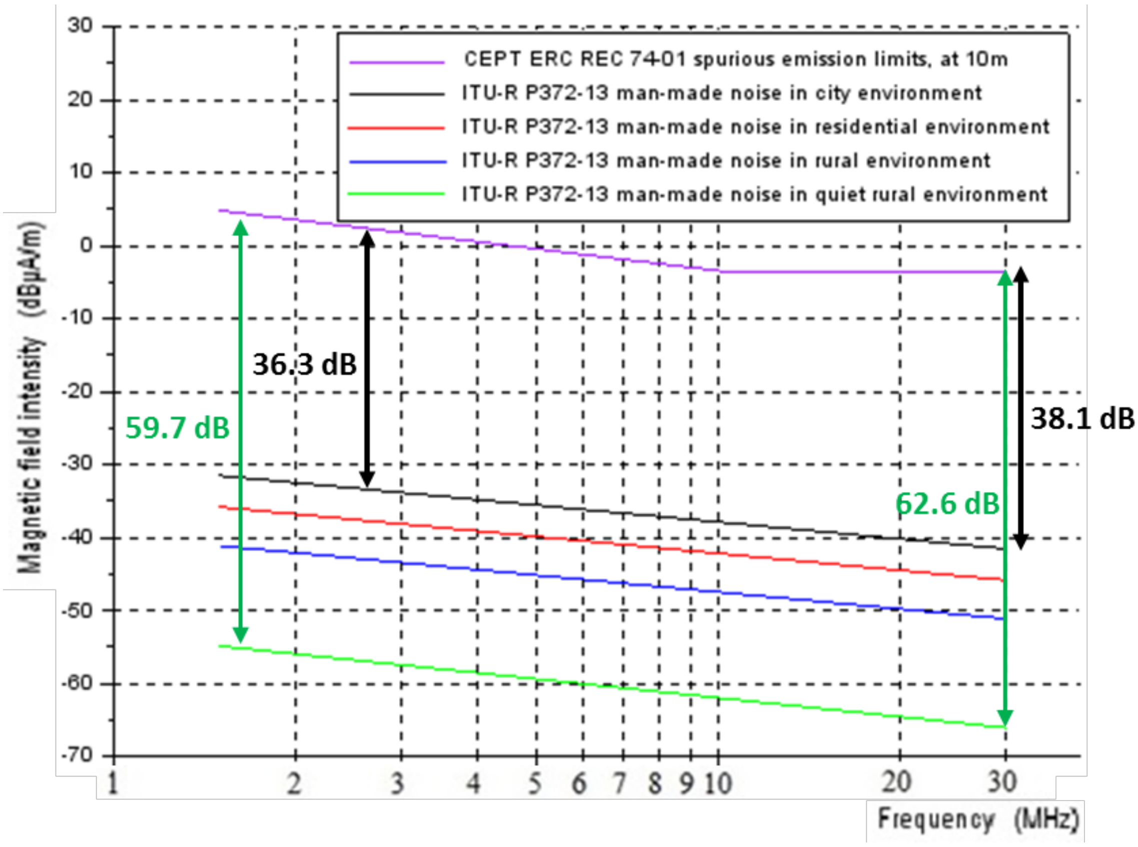


Figure 37: ERC Recommendation 74-01 spurious emission limits at 10 m in 10 kHz bandwidth compared to Recommendation ITU-R P.372-13 median man-made noise curves in 10 kHz bandwidth

The city, residential and rural man-made noise curves decrease from 10 to 15 dB if the lower variations with time and location are taken into account, increasing the gap with ERC Recommendation 74-01 spurious emission limits for these environments.

HF mobile stations are used on operational contexts in cities, residential, rural and calm environments. They can be mounted on vehicles or carried by people. HF fixed stations are also used as receivers in these environments. An increase in the man-made noise perturbations picked-up by the HF mobile and fixed stations involve a decrease on reception quality, thus on radio coverage for a given HF link.

In order to avoid sharp losses in HF mobile and fixed services links performances, it is necessary to avoid significant rise in interferences picked up by antennas of HF mobile and fixed stations used in their operational use contexts. Thus, it is to limit WPT-EV spurious emissions to avoid a significant increase in the man-made noise perturbations picked-up by these stations. WPT-EV stations locations in parking lots and garages will be considered in this section.

6.5.2.1 HF mobile and fixed stations in city and residential environments

In city and residential environments:

- HF mobile stations move on the roads (vehicles) and the walkways (e.g. man-pack), near domestic garages or parking lots, at distances inferior to 10 meters,
- HF fixed stations are neighbour to on-site parking lots in the same area, indoors or outdoors parking lots or neighbour to houses with interior domestic garage.

The following distances are retained in order to evaluate the HF spurious emissions at ERC Recommendation 74-01 limits for city and residential operational use conditions, between a HF station and a WPT-EV station in a parking lot or a domestic garage:

- for a mobile station: a 5 m minimum distance in city environment and a 10 m minimum distance in residential environment;
- for a fixed station: a 10 m minimum distance in city and residential environments.

With regards to free-space losses, the ERC Recommendation 74-01 limits would increase by 6 dB at 5 m (higher values could be considered depending on the near-field attenuation versus distance assumption).

Thus, considering the Recommendation ITU-R P.372-13 median man-made noise values as the current perturbations picked-up by these HF mobile or fixed stations and only one WPT-EV station, the WPT-EV emissions would increase the man-made noise by:

- 42.3 dB in city environment, at 5 m;
- 36.3 dB in city environment, at 10 m;
- 40.6 dB in residential environment, at 10 m.

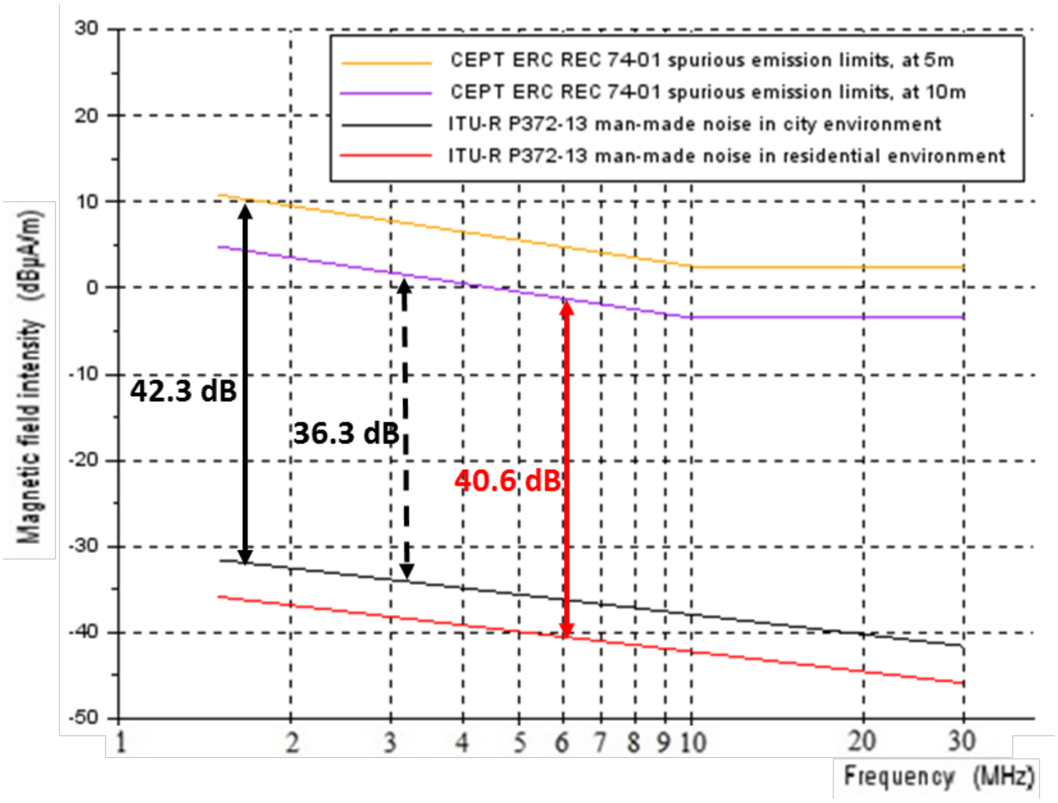


Figure 38: ERC Recommendation 74-01 spurious emission limits estimated at 5 and 10 metres in 10 kHz bandwidths compared to Recommendation ITU-R P.372-13 median man-made noise curves in 10 kHz bandwidths

6.5.2.2 HF and fixed stations in rural and calm rural environments

In rural and quiet rural environments:

- HF mobile stations move on the roads or the fields, at higher distances from these domestic garages and parking lots than 10 m;
- HF fixed stations have few neighbours at distances superior to 10 m. However, on-site parking lots are present in the same area.

The following distances are retained in order to evaluate the HF spurious emissions at ERC Recommendation 74-01 limits for rural or quiet rural operational use conditions, between a HF station and a WPT-EV station in a parking lot or a domestic garage:

- a 30 m minimum distance in rural environment;
- a 50 m minimum distance in quiet rural environment.

For free-space losses, the ERC Recommendation 74-01 limits would decrease by:

- 9.5 dB at 30 m;
- 14 dB at 50 m.

Thus, considering the Recommendation ITU-R P.372-13 median man-made noise values as the current perturbations picked-up by these HF mobile or fixed stations and only one WPT-EV station, the WPT-EV emissions would increase the man-made noise by:

- 36.4 dB in rural environment at 30 m;
- 45.7 dB in quiet rural environment at 50 m.

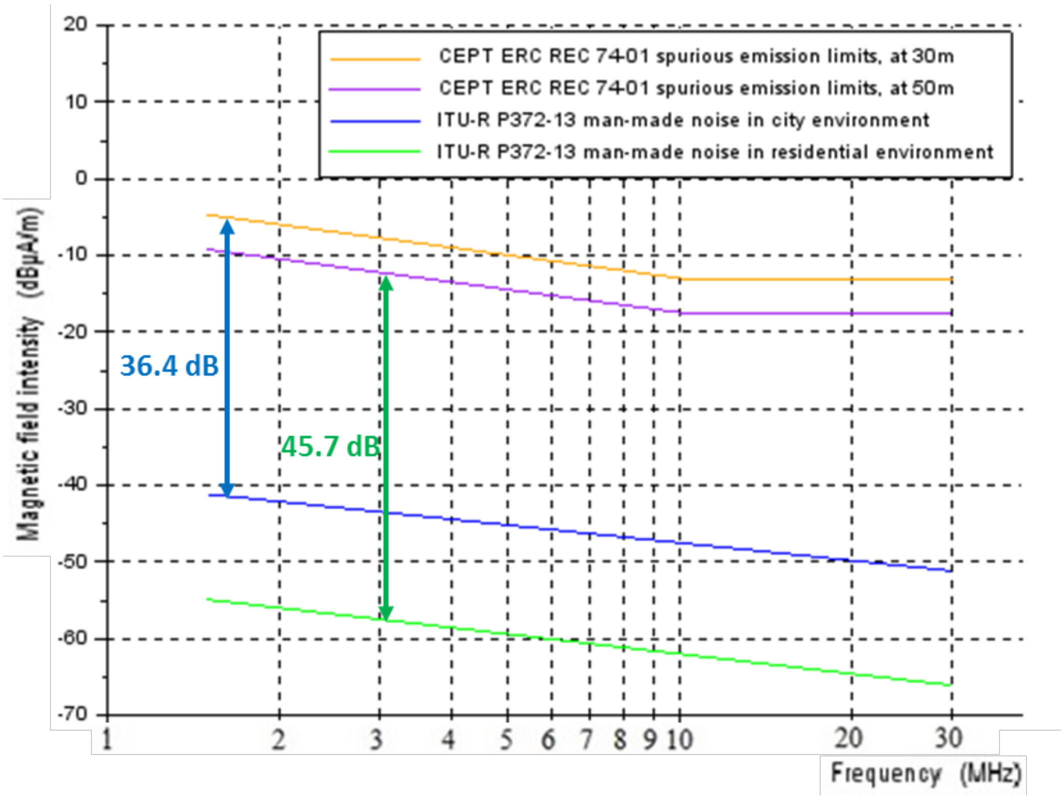


Figure 39: ERC Recommendation 74-01 spurious emission limits estimated at 30 and 50 metres in 10 kHz bandwidth compared to Recommendation ITU-R P.372-13 median man-made noise curves in 10 kHz bandwidth

6.5.3 Conclusion for the fixed and mobile service between 1.5 and 30 MHz

This compatibility analysis highlights the incompatibility of ERC Recommendation 74-01 spurious emission limits with HF mobile and fixed stations used in their operational use contexts with spurious emission limits values of 36 dB or higher than average HF man-made noise picked-up in these operational use contexts, in the 1.5 MHz to 30 MHz range.

Moreover, in this study, the Recommendation ITU-R P.372-13 median man-made noise was considered but the man-made noise lower variations with time and location, or more than one WPT-EV station emitting near the stations to consider the future WPT-EV stations density were not taken into account. These factors would increase the gap estimated between the current perturbations picked-up by the fixed and mobile stations and the perturbations caused by the WPT-EV stations emitting at the ERC Recommendation 74-01 spurious emission limits.

The spurious emission limits proposed in section 6.3.5 seems to also to cover the protection requirement for the mobile and fixed services between 1.5 and 30 MHz: “-46 dBµA/m at 300 kHz reducing by 7 dB per frequency decade to -60.0 dBµA/m at 30 MHz”.

6.6 ELECTRONIC ARTICLE SURVEILLANCE (EAS) SYSTEM

Harmonics of WPT-EV systems operating in 79-90 kHz, with spurious emissions at CISPR 11 levels, may have impact on EAS systems operating in 7400-8800 kHz. EAS stands for Electronic Article Surveillance and consist of a security tag attached to an identified item and inductive antennas using a swept frequency or a pulse-listen technique to detect the tag between the antennas giving need for a broad frequency band. The detection distance is about 1 m with transmitted power of 9 dBµA/m at 10 m. The tag is a passive circuit and contains a resonant circuit, consisting of an air coiled loop and a capacitor. If the tag enters the alternating magnetic field of the transmitting antenna, an electric voltage is generated in the winding.

If the frequency of the alternating magnetic field corresponds to the resonant frequency of the tag, the induced voltage will cause an alternating current in the series connection of the coil and the capacitor. The resonance circuit current in the tag then generates its own, secondary, alternating magnetic field (90° shifted), that induces a voltage in the receiver antenna and the system detects this tag signal in a phase sensitive manner in a swept frequency system. In a pulse-listen system the transmitter sends short excitation burst and immediately after the Tx burst the Rx listens to the typical exponential decaying amplitude envelope of the excitated resonance circuit.

From this, it should be clear that the transmitter and receiver need to be on the resonance frequency of the tag.

The labels are manufactured with a typical resonance frequency of about 8200 kHz +/-5%. Europe allows a frequency band 7400-8800 kHz.

At the point of sales, the labels are removed or destroyed by means of a deactivator. The deactivation system scans over the band 7400-8800 MHz and once it discovers a tag within range it produces a burst with a much higher field strength (>1A/m) at the resonance frequency of the tag and the tag is destroyed by capacitor dielectric breakdown so it cannot be detected by the gates anymore.

The receiver sensitivity is based on the necessary S/N ratio above the ambient noise level. The necessary S/N ratio for EAS systems is 8 dB to obtain error free operation. The noise value is for the ambient noise in a commercial environment. The value used for the frequency range 7.4−8.8 MHz is −13 dBµA/m which comes from ERC Report 44. If CISPR 11 Class A Group 2 spurious emission limits are applied the interference distance is 356 m. The spurious limits for CISPR 11 Class A Group 2 at 8.2 MHz is 8.5 dBµA/m at 30 m. According to CISPR 11, the roll off at this frequency is almost linear. (8.5 dBµA/m at 30 m and 18.5 dBµA/m at 10 m results in 20 log 30/10 = 9.5 dB) 8.5 – (-13) = 20 log d/30 results in d= 356 m.

If CISPR 11 Class B Group 2 spurious emission limits are applied, the interference distance is 60 m. The spurious limits for CISPR 11 Class B Group 2 at 8.2 MHz is 13 dBµA/m at 3 m. As mentioned above, according to CISPR 11 the roll off at this frequency is almost linear. 13 – (-13) = 20 log d/33 results in d= 60 m. Taking into account conducting along metal (i.e. reinforced concrete) these figures can increase considerably. If the CISPR 11 Class A Group 2 spurious emission limits are applied, there is a high probability that a WPT system will disturb an EAS system. This can also be the case when the Class B limits are applied.

From the above it may be concluded that if a fully functioning WPT-EV system, with spurious emissions at CISPR 11 levels, is mounted on a parking spot near a shop equipped with an EAS system or in a parking building above this shop it may degrade the effectiveness of the EAS system.

7 CONCLUSIONS

The impact of Wireless Power Transmission for Electric Vehicles (WPT-EV) in 79-90 kHz on radiocommunication services operating below 30 MHz is considered in this Report. The effect on services operating in adjacent frequencies, as well as the impact of unwanted emissions from WPT-EV was studied. Inputs have been made for some radiocommunication services (i.e. standard frequency and time signal service, broadcasting service, amateur service, radionavigation service and fixed and mobile service) and a radio application (EAS) about the potential impact, and these are set out in this Report.

An important issue identified in 79-90 kHz was compatibility of wanted WPT-EV emissions with the Standard Frequency and Time Signal Service (DCF77) in the frequency range 79-85 kHz. The proposed limit for the magnetic (H-field) field strength in this frequency range is a maximum of 42 dBµA/m at 10m.

There were no compatibility issues identified within the band 85-90 kHz. Therefore, the request in ETSI TR 103 409 for an increase in the magnetic field strength limit is proposed for a maximum of 82 dBµA/m at 10 m in the frequency range 85-90 kHz.

In the spurious domain of WPT-EV the following radiocommunication services and radio applications have been considered in this Report

- Broadcasting
- Amateur service
- Radionavigation
- Fixed and mobile service
- EAS

The WPT-EV manufacturers have confirmed that systems have been designed to meet the emission limits for inductive SRDs in ERC Recommendation 74-01 [12]. The study in this Report shows that these limits fall well short of providing adequate protection for the services studied within this Report.

For the broadcasting service, the proposed figures for the spurious/harmonic emission limits of a WPT-EV system (if WPT-EV is not operating on the broadcasting channel raster at 81 kHz or 90 kHz) are:

- Band 5 (148.5-283.5 kHz): -67.0 dBµA/m (@10m from the WPT-EV);
- Band 6 (526.5-1606.5 kHz): -74.0 dBµA/m (@10m from the WPT-EV).

The proposed figures for the spurious/harmonic emission limits of a WPT-EV spurious/harmonics (if WPT-EV is on the broadcasting channel raster at 81 kHz or 90 kHz) remain are:

- Band 5 (148.5-283.5 kHz): --37.0 dBµA/m (@10m from the WPT-EV);
- Band 6 (526.5-1606.5 kHz): -44.0 dBµA/m (@10m from the WPT-EV).

For the amateur service, given the planned density of WPT-EV systems, it is calculated that there will be a widespread and serious impact on its operation in the vicinity of WPT systems should spurious emissions, measured at 10 m be at the current limits of ERC Recommendation 74-01 . An appropriate limit at 10 m would be: -46 dBµA/m at 300 kHz reducing by 7 dB per frequency decade to -60.0 dBµA/m at 30 MHz. This can be relaxed by 20dB if all WPT systems adopt a single common frequency of operation.

For the aeronautical radionavigation service operating in the band 255-526,5 kHz, the maximum permissible interference value at the receiver of 21.9 dBµV/m applies to maintain proper operation of the NDB/ADF system.

For the fixed and mobile service operating between 1.5 and 30 MHz, it is shown that the limits for amateur service are relevant.

For Electronic Article Surveillance (EAS), if a WPT-EV system, with spurious emissions at CISPR 11 levels (similar to ERC Recommendation 74-01 levels at these frequencies), operates in the vicinity of an EAS system it may degrade the effectiveness of the latter. No shielding effect was taken into account in making this assessment.

It should be noted that the spurious emission levels proposed in this Report for radiocommunication services above 150 kHz are significantly lower than the current inductive spurious emission levels of ERC Recommendation 74-01 [12].

It is to be noted that WPT-EV manufacturers indicate that the proposed spurious emission levels above are not achievable at LF/MF broadcasting frequencies. At higher frequencies (approximately higher than 2 MHz), it could be technically possible to approach the proposed protection levels.

WPT-EV is an emerging and evolving technology. To ensure a low probability of harmful interference to radiocommunication services, further study is required, including evaluation of real equipment, mitigation techniques and other measures to improve WPT-EV systems, to achieve a level of spurious emissions sufficiently below ERC Recommendation 74-01 for WPT-EV.

ANNEX 1: MEASUREMENT ON DCF77

A1.1 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 (see Figure 40). 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 40: 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 meters and traffic lights are synchronised 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” [48].

The current version of ERC Recommendation 70-03 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 (ETSI EN 303 417 [3]) 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 (see Figure 41) 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.

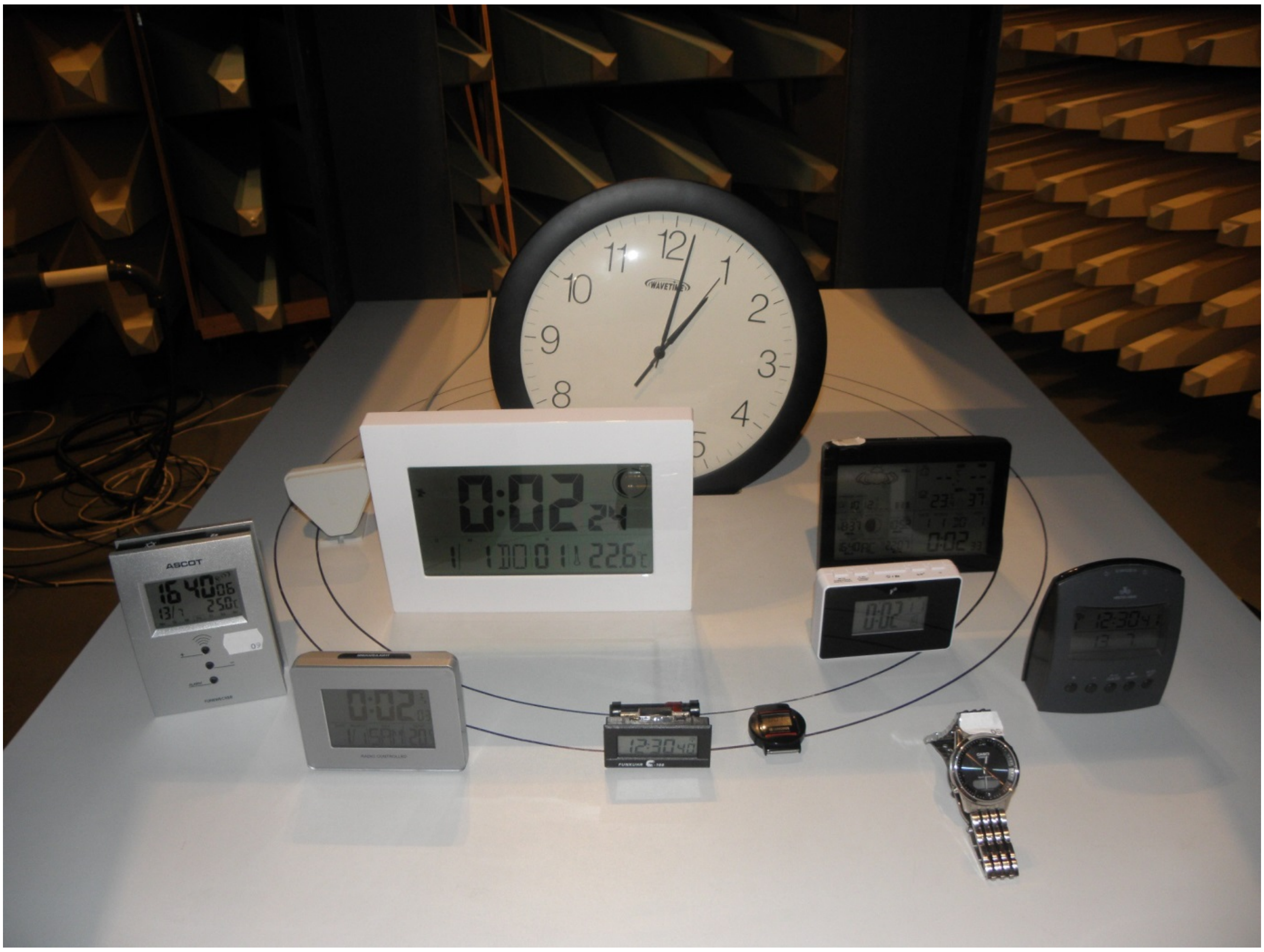


Figure 41: DUTs

A1.2 DCF77 (WANTED) SIGNAL

The DCF77 signal was produced by a signal generator (R&S SMU200). A programmed 10 minutes 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 -1.5 dBµA/m. This corresponds to the minimum outdoor field strength of the real DCF77 transmitter in 1000 km distance.

To get indications on the nature of the interfering effect, additional measurements were made with a wanted field strength of 18.5 dBµA/m.

A sensitivity measurement has proven that except for Rx9, all clocks were able to synchronise at a minimum wanted field strength of -1.5 dBµA/m which was selected for the following interference measurements. Rx9 was excluded from following measurements because it could not synchronise at the wanted field strength.

A1.3 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” (see Figure 42). 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).

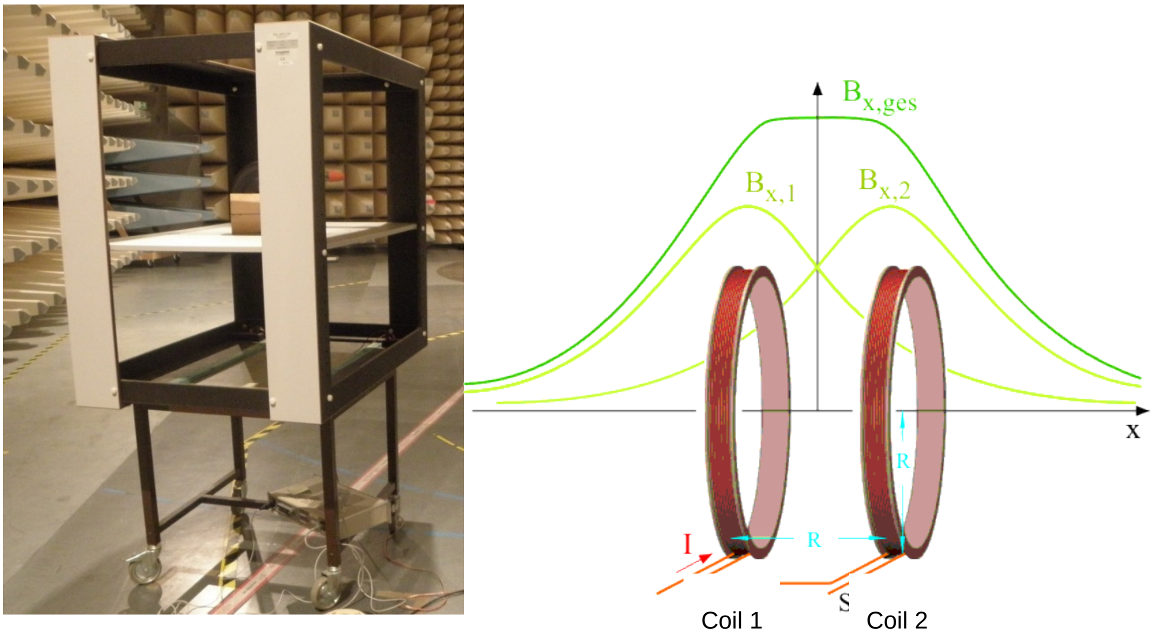


Figure 42: Helmholtz coil with principle

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

A1.4 FAILURE CRITERION

Without interferer, all clocks finished the synchronisation process within 3 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 synchronise 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.

A1.5 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 43: Measurement setup. Front: Wanted DCF77 signal generation Background: Helmholtz coil with DUT

A1.6 INTERFERENCE MEASUREMENTS

The wanted DCF77 level was adjusted to -1.5 dBµA/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 synchronise was determined for each DUT until failure.

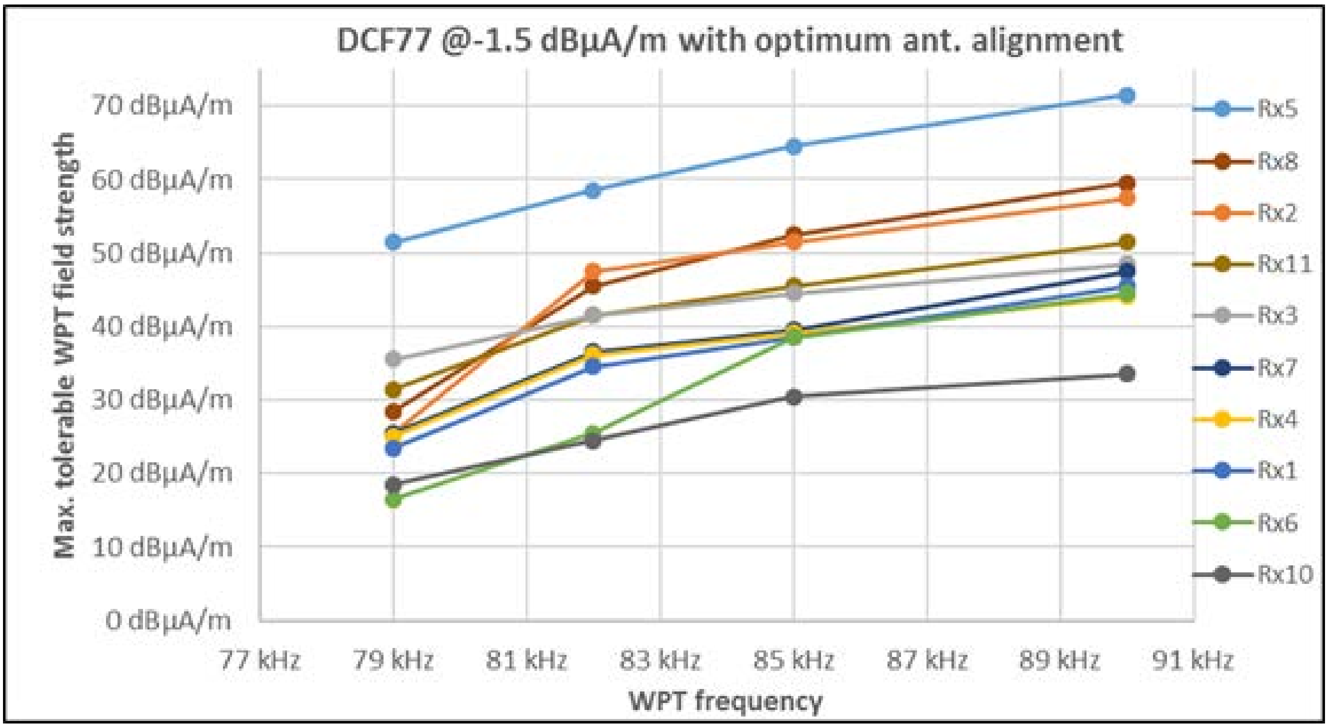


Figure 44: Measurement results for 50 dBµ/m wanted field strength and optimum antenna alignment

The results (see Figure 44) 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 18.5 dBµA/m.

A1.7 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 synchronise at -1.5 dBµA/m wanted field strength (without interferer), but all receivers could synchronise at 18.5 dBµA/m.

Figure 45 compares the two measurements: The one with optimum antenna alignment is labelled “optimum”, the one with cross-alignment from this section is called “worst”.

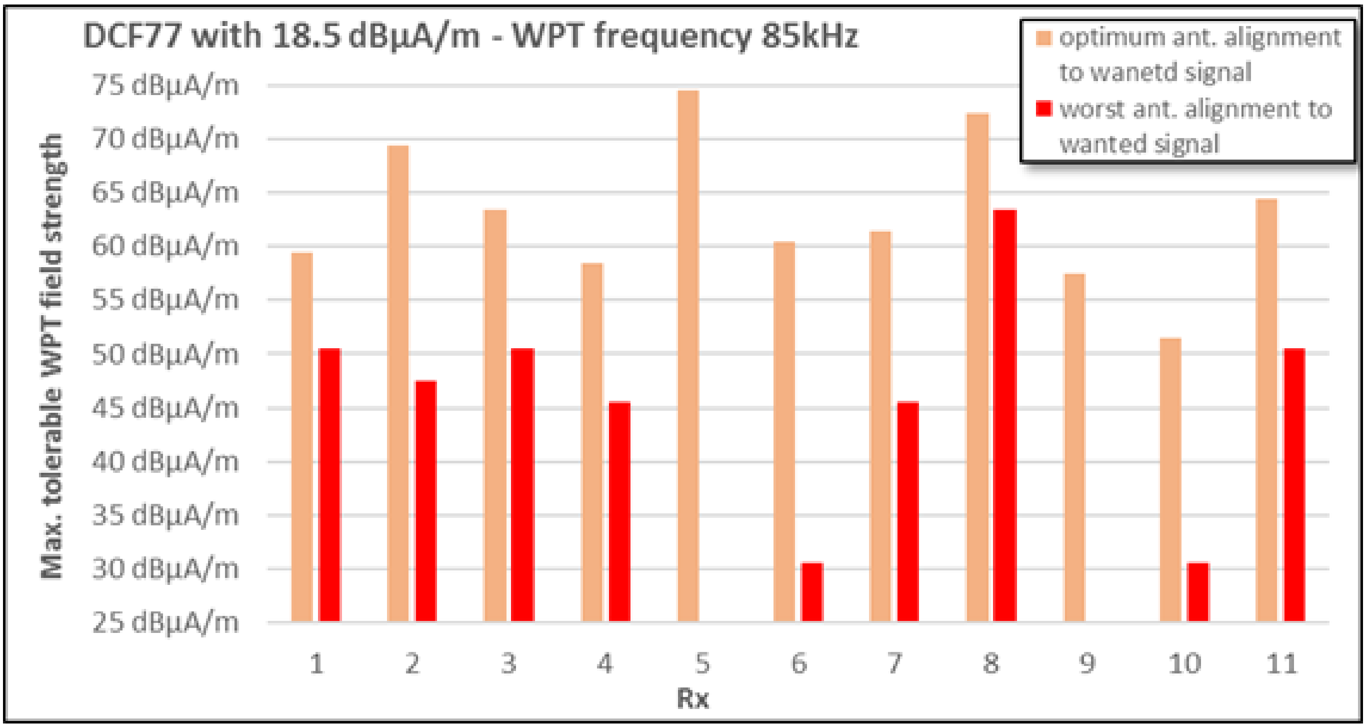


Figure 45: Comparison of results with different antenna alignment for high wanted field strength

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 realised for all DUTs.

A1.8 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:

1. All C/I values are taken from the results under optimum antenna alignments.
2. The maximum WPT field strength on the main frequency from ERC/REC 70-03 is 68.5 dBµA/m in 10 m distance.
3. The WPT field strength in the near-field is assumed to follow a 60 dB/decade drop with distance.
4. 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:

$$d\left(H_{DCF}, \frac{C}{I}\right) = 10^{\left(\frac{68.5\frac{dB\mu A}{m} - H_{DCF} + \frac{C}{I}}{60\ dB/dec} + 1\right)}$$

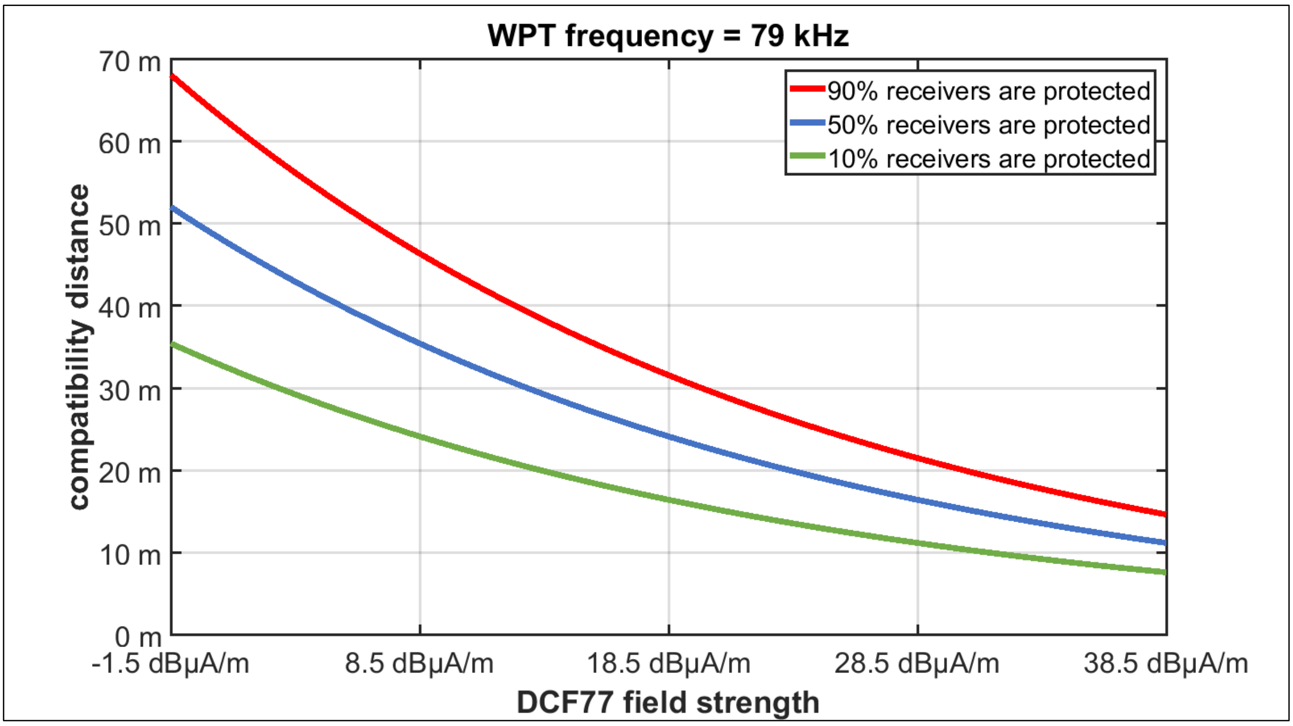


Figure 46: Protection distances at different wanted DCF77 field strength for a WPT frequency of 79 kHz and a WPT signal strength of 68.5 dBμA/m @ 10 m

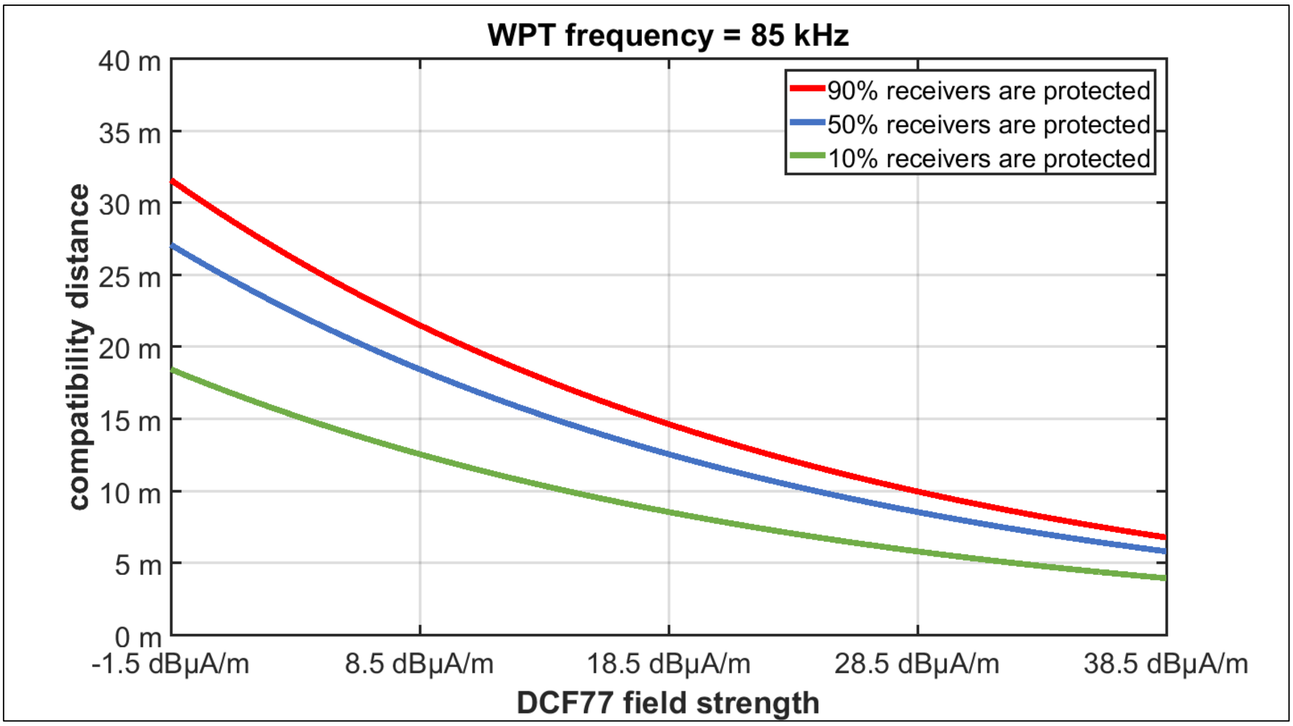


Figure 47: Protection distances at different wanted DCF77 field strength for a WPT frequency of 85 kHz and a WPT signal strength of 68.5 dBμA/m @ 10 m

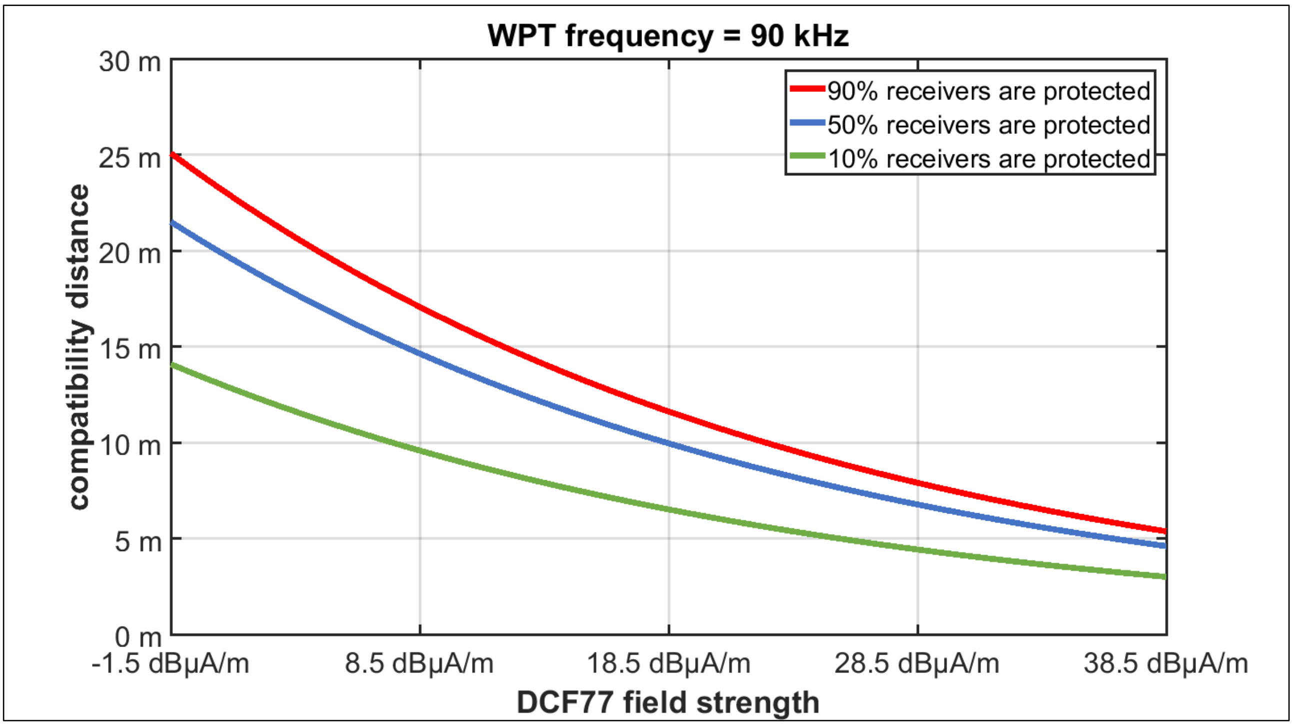


Figure 48: Protection distances at different wanted DCF77 field strength for a WPT frequency of 90 kHz and a WPT signal strength of 68.5 dBµA/m @ 10 m

A1.9 CONCLUSION

Even if the current limit for WPT devices (inductive SRD) given in ERC Recommendation 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 -1.5 dBµA/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 8.5 dBµA/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.

ANNEX 2: INFORMATION RELATED TO THE PROTECTION OF THE BROADCASTING SERVICE IN THE LF AND MF BANDS

A2.1 INTRODUCTION

This Annex 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.

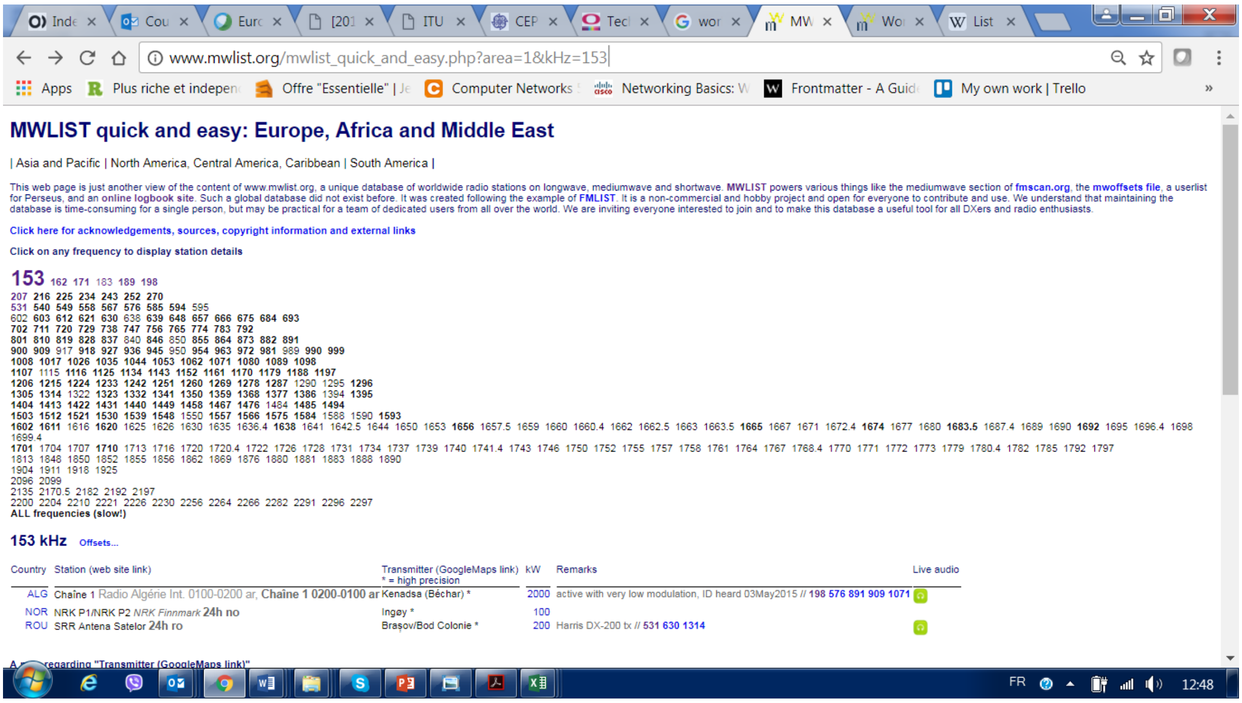
A2.2 MIFR (TERRESTRIAL SERVICES) ON-LINE QUERY (BETA RELEASE)

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 Master International Frequency Register (MIFR) can be done as appropriate.

A2.3 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



MWLIST quick and easy: Europe, Africa and Middle East

| Asia and Pacific | North America, Central America, Caribbean | South America |

This web page is just another view of the content of www.mwlist.org, a unique database of worldwide radio stations on longwave, mediumwave and shortwave. MWLIST powers various things like the mediumwave section of fmscan.org, the mwoffsets file, a userlist for Perseus, and an online logbook site. Such a global database did not exist before. It was created following the example of FMLIST. It is a non-commercial and hobby project and open for everyone to contribute and use. We understand that maintaining the database is time-consuming for a single person, but may be practical for a team of dedicated users from all over the world. We are inviting everyone interested to join and to make this database a useful tool for all DXers and radio enthusiasts.

Click here for acknowledgements, sources, copyright information and external links

Click on any frequency to display station details

153 162 171 183 189 198
207 216 225 234 243 252 270
531 540 549 558 567 576 585 594 595
602 603 612 621 630 638 639 648 657 666 675 684 693
702 711 720 729 738 747 756 765 774 783 792
801 810 819 828 837 840 846 850 855 864 873 882 891
900 909 917 918 927 936 945 950 954 963 972 981 989 990 999
1008 1017 1026 1035 1044 1053 1062 1071 1080 1089 1098
1107 1115 1116 1125 1134 1143 1152 1161 1170 1179 1188 1197
1206 1215 1224 1233 1242 1251 1260 1269 1278 1287 1290 1295 1296
1305 1314 1322 1323 1332 1341 1350 1359 1368 1377 1386 1394 1395
1404 1413 1422 1431 1440 1449 1458 1467 1476 1484 1485 1494
1503 1512 1521 1530 1539 1548 1550 1557 1566 1575 1584 1588 1590 1593
1602 1611 1616 1620 1625 1626 1630 1635 1636.4 1638 1641 1642.5 1644 1650 1653 1656 1657.5 1659 1660 1660.4 1662 1662.5 1663 1663.5 1665 1667 1671 1672.4 1674 1677 1680 1683.5 1687.4 1689 1690 1692 1695 1696.4 1698 1699.4
1701 1704 1707 1710 1713 1716 1720 1720.4 1722 1726 1728 1731 1734 1737 1739 1740 1741.4 1743 1746 1750 1752 1755 1757 1758 1761 1764 1767 1768.4 1770 1771 1772 1773 1779 1780.4 1782 1785 1792 1797
1813 1848 1850 1852 1855 1856 1862 1869 1876 1880 1881 1883 1888 1890
1904 1911 1918 1925
2096 2099
2135 2170.5 2182 2192 2197
2200 2204 2210 2221 2226 2230 2256 2264 2266 2282 2291 2296 2297
ALL frequencies (slow!)

153 kHz Offsets...

Country	Station (web site link)	Transmitter (GoogleMaps link) * = high precision	kW	Remarks	Live audio
ALG	Chaîne 1 Radio Algérie Int. 0100-0200 ar, **Chaîne 1 0200-0100 ar**	Kenadsa (Béchar) *	2000	active with very low modulation, ID heard 03May2015 // 198 576 891 909 1071	🎧
NOR	NRK P1/NRK P2 *NRK Finnmark* **24h no**	Ingøy *	100		
ROU	SRR Antena Satelor **24h ro**	Brașov/Bod Colonie *	200	Harris DX-200 tx // 531 630 1314	🎧

A regarding "Transmitter (GoogleMaps link)"

Figure 49: 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 14 shows the LF transmitters in Europe, Africa and Middle-East as provided in www.mwlist.org, data extracted in September 2017.

Table 14: 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) *	2000
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 *	1100
171	MRC	Médi 1	Nador (LW) *	1600
183	D	Europe 1	Felsberg/Zum Sender (Sauberg) *	1500
189	ISL	RÚV Rás 1/RÚV Rás 2	Gufuskálar (Hellissandur) *	300
198	ALG	Chaîne 1	Berkaoui (Ouargla) *	2000
198	G	BBC Radio 4	Droitwich/Mast A-B *	500
198	G	BBC Radio 4	Westerglen *	50
198	G	BBC Radio 4	Burghead *	50
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 *	1400/700
225	POL	Polskie Radio Jedynka	Solec Kujawski/Kabat *	1000
234	LUX	RTL	Beidweiler *	1500
243	DNK	DR Langbølge	Kalundborg/Radiovej *	50
252	ALG	Chaîne 3	Tipaza *	1500/750
252	IRL	RTÉ Radio 1	Clarkestown/Summerhill *	150/60
270	CZE	ČRo Radiožurnál	Topolná *	50

Figure 50 and Figure 51 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.

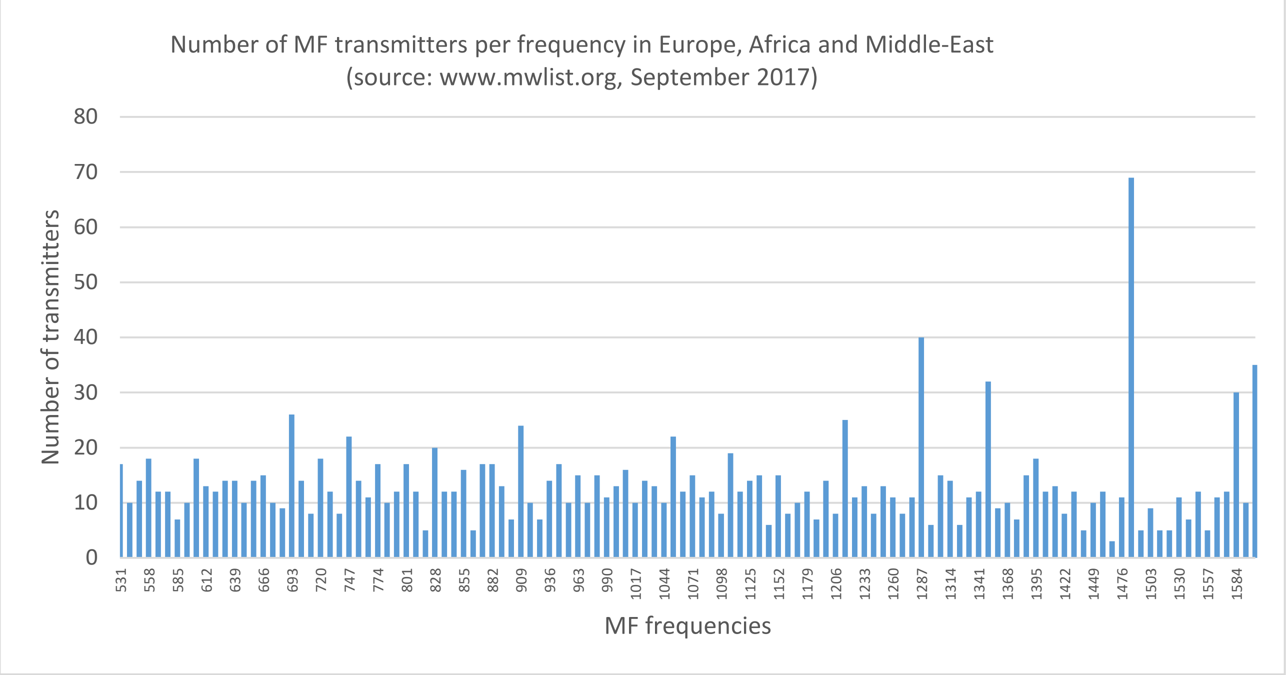


Figure 50: Number of MF transmitters per frequency in Europe, Africa and Middle-East (source: www.mwlist.org, September 2017)

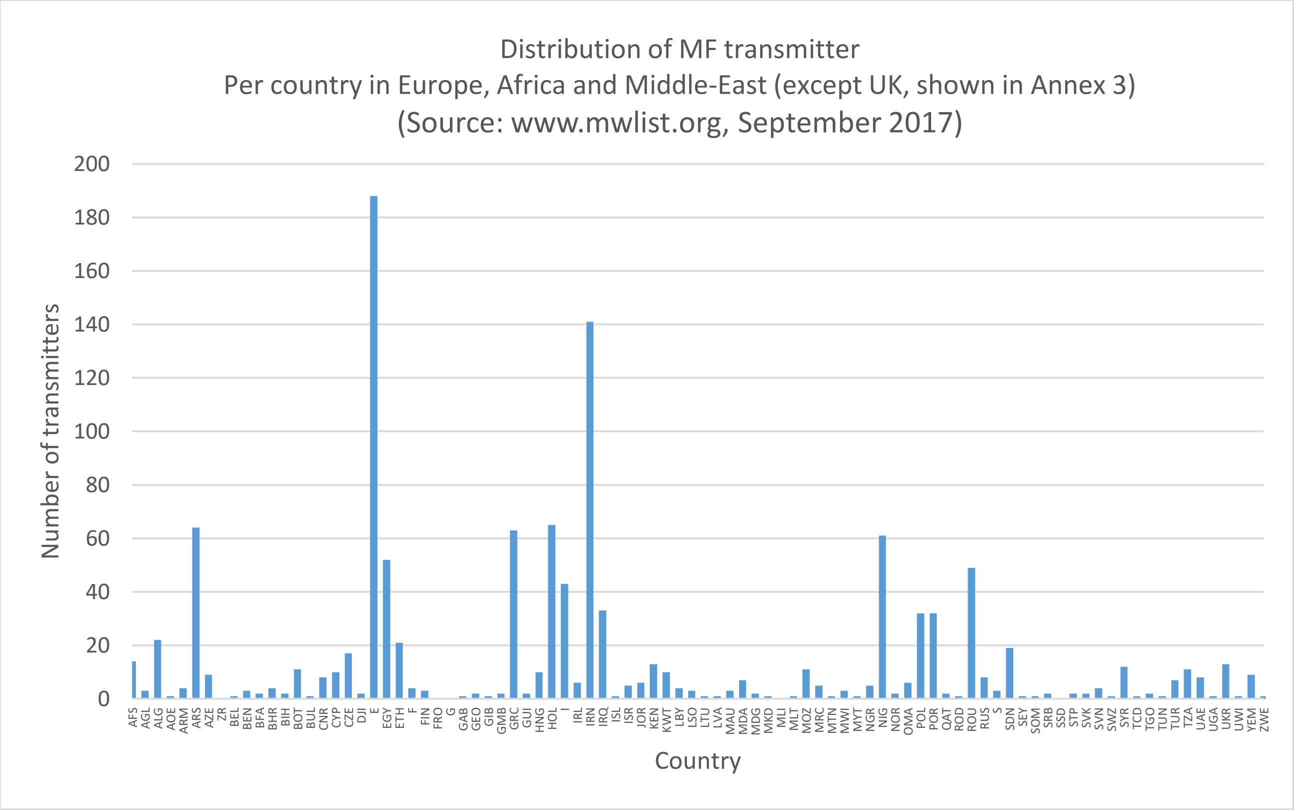


Figure 51: Distribution of MF transmitter per country in Europe, Africa and Middle-East (except UK, shown inA2.4) (Source: www.mwlist.org, September 2017)

A2.4 MEDIUM WAVE (MF) TRANSMITTERS IN THE UK (COMPLEMENT TO THE INFORMATION IN PARAGRAPH A2.3)

Technical parameters for broadcast radio transmitters:

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

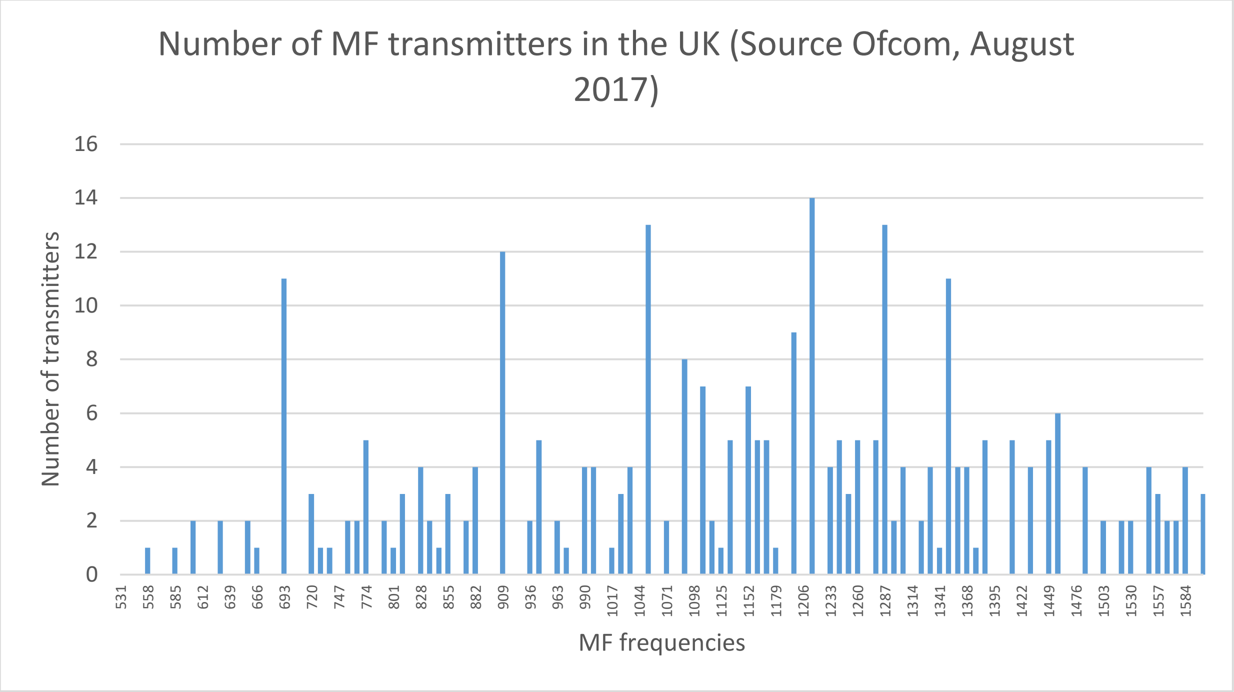


Figure 52: Number of MF transmitters in the UK (Source Ofcom, August 2017)

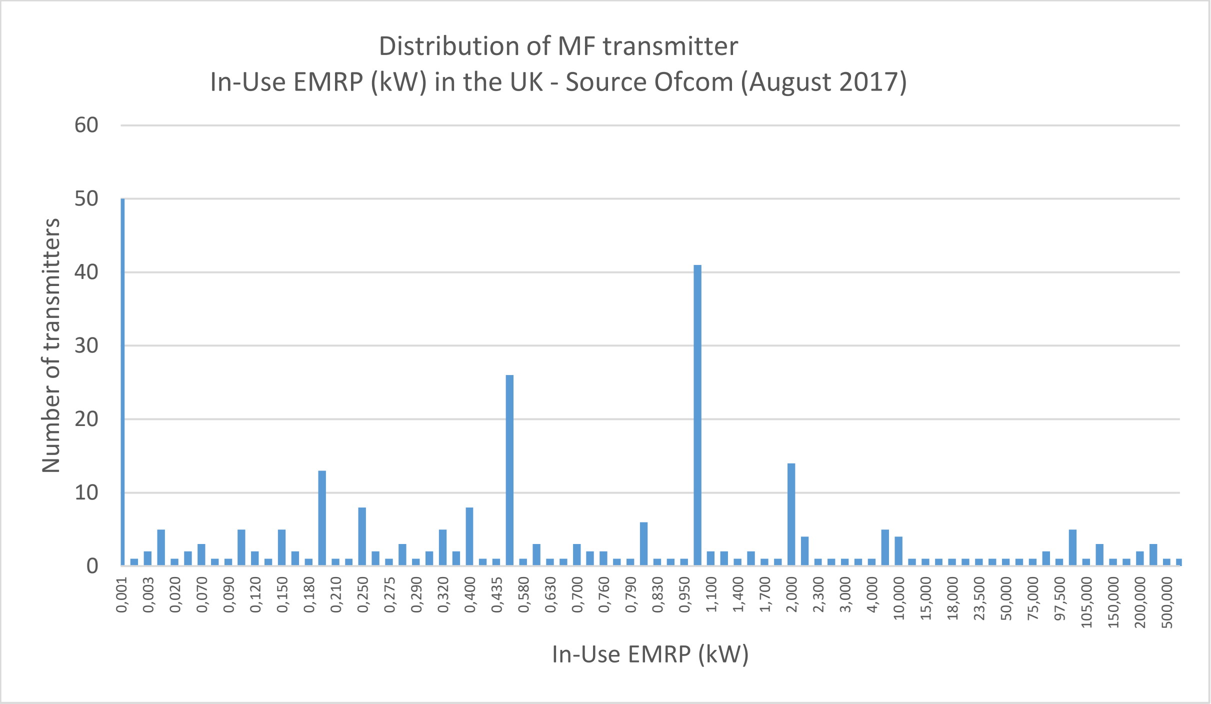


Figure 53: Distribution of MF transmitter In-Use Effective Monopole Radiated Power (EMRP - kW) in the UK (Source Ofcom UK (August 2017))

Note related to Figure 52 and Figure 53: The Ofcom UK on-line database suggests that in the UK there are 294 MF transmitters in use on 75 different frequencies. These range in Effective Monopole Radiated Power (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.

A2.5 FACTORS AFFECTING THE IMPACT OF INTERFERENCE

Power output of the SRD: Obviously this will have a significant impact on the propensity of the SRD to cause harmful interference. The higher the power output, the greater the potential is for interference. Spurious (harmonic) radiation from the SRD must also be considered. The mechanisms for generating spurious radiation can be many and varied and there is no guarantee that the levels of spurious interference are directly related to the level of the wanted output from the SRD.

Separation distance: As shown in the graph in Section 4.2 (itself Figure 4 in Section 6 of Reference [4]), in the near field the 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, limits on radiated emissions from an SRD 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 the SRD and the victim receiver; the stray field has to be specified somewhere.

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 negligible psycho acoustic effect.

Antenna directionality: This is probably only relevant in specific cases; if all the SRD radiation is, for example, directed vertically upward and all the potential victim receivers are spread horizontally around the SRD 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 SRD will always, or even often, be in the direction of minimum sensitivity.

Building penetration loss: It has been argued that where a WPT-EV system is operating outside a building, the building penetration loss will help alleviate harmful interference to radio receivers located inside the building. However, where receivers and their antennas are located inside buildings and the associated transmitter is outside the building, the wanted signal will suffer from some building penetration loss. Generically, an SRD could be operated inside the building where the receiver is located and so the interference would not be subject to building penetration loss and would be more likely to cause harmful interference. If the SRD is operated outside the building, the penetration loss for both wanted and unwanted radiation is likely to be the same.

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 an SRD 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 SRD 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 SRD might itself not be related to the intended polarisation of the ‘antenna’, it must be assumed that worst case conditions apply and that the interference is maximised.

A2.6 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” [15] 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.

Recommendation ITU-R BS.560 “Radio-frequency protection ratios in LF, MF and HF broadcasting” [16] outlines applicable protection ratios for interference between AM broadcast signals. Although WPT 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.

Starting from the planning considerations and protection criteria given in Recommendation ITU-R BS.703 and Recommendation 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 emission limits from WPT 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:

$$H_{dB(\frac{\mu A}{M})} = E_{dB(\frac{\mu V}{m})} - 51.5\ dB$$

So the receiver sensitivities at LF and MF (above) can also be expressed as 14.5 and 8.5 dBµA/m respectively.

Recommendation ITU-R BS.560 is formulated for the protection of one AM radio service from another similar AM radio service[8]. 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.

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[8] 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.

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.

Recommendation ITU-R BS.560 calls for a co-channel protection ratio between the wanted and interfering signal (carrier levels) of 40 dB. The GE 75 Regional Planning agreement [18] 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 GE 75 plan does not foresee there being any such offsets.

b) The additional relative 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; 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 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 has 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 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 [20] that if the interfering carrier/WPT is un-modulated and within a few tens of Hz (onset of hearing) a higher level of interference can be tolerated (See 6.2.1.5 on Mitigation Techniques).

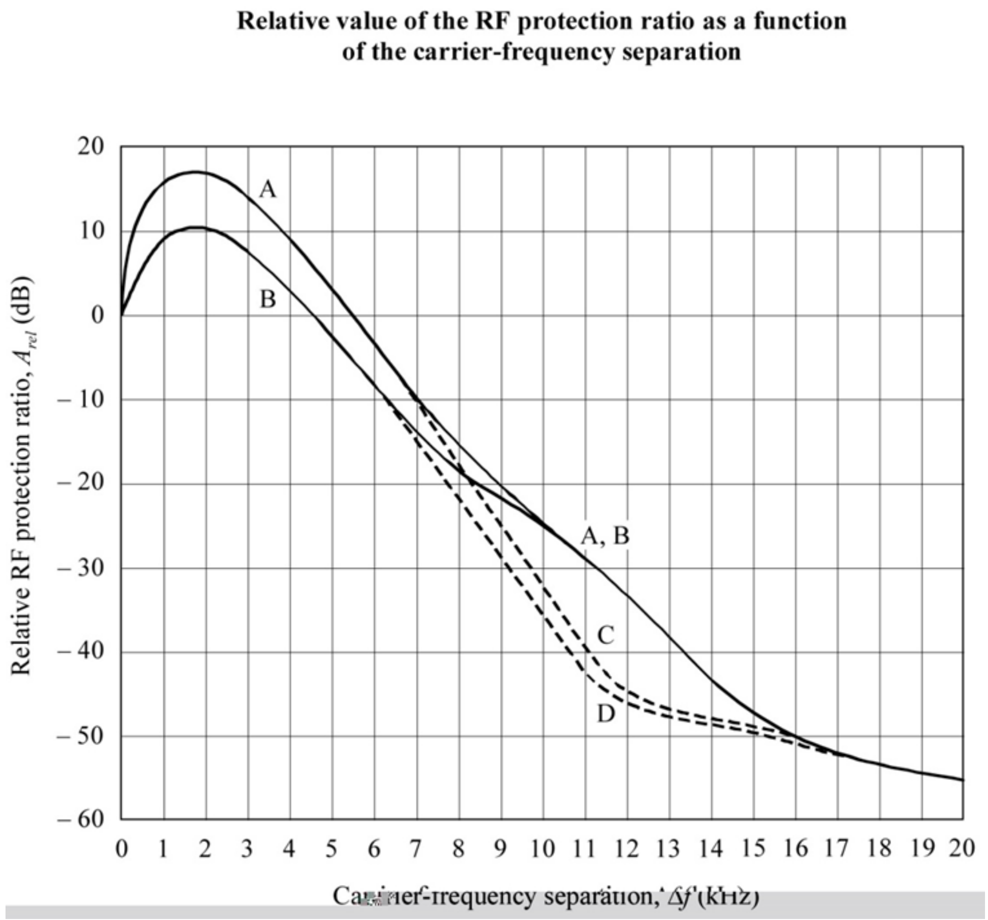

Figure 54: From Recommendation ITU-R BS.560 [16] showing the variation with offset frequency of the relative protection ratio (PR)

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 transmission 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 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 frequency to be uncontrolled, it may be assumed that the worst case occurs. Figure 1 of Recommendation ITU-R BS.560 (reproduced above) 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 interference to AM broadcasting of (40 + 16) = 56 dB.

It therefore follows that the maximum acceptable WPT field strength, at the broadcast receiver location, is given by subtracting this PR from the receiver sensitivity. The maximum acceptable WPT 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

Historically, the minimum field strengths quoted in Recommendation ITU-R BS.703 [15] 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 BS.560:

- Band 5 (LF): (41.5 - 3.5) = –45.0 dBµA/m;
- Band 6 (MF): (47.5 - 3.5) = –51.0 dBµA/m.

An alternative method for calculating the tolerable level of interference is based on Recommendation ITU-R BS.1895 [17].

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 is no longer usable. 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 and 60 dBµV/m for MF. In both 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[9]. This means that the wanted sideband 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.

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.

which 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.

A2.7 ASSESSMENT OF SEPARATION DISTANCE BETWEEN A WPT-EV CHARGER AND AM BROADCAST RECEIVER

In the case of a WPT 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 author either lived there himself or knows someone who does; they are not exceptional in any way.

Typical inner city housing in the city of Derby (Figure 55): - It is suggested that WPT 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.

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[9] 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 considers potentially intelligible programme material from another broadcaster which is more 'psycho-acoustically' intrusive than random noise.

Figure 55: Typical inner city housing in the city of Derby (UK)

Outer suburban housing in South London (Figure 56): A WPT 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 56: Outer suburban housing in South London

Rural Cottages about 70 km South East of London (Figure 57): 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 chargers could again be deployed in the garage(s) or the parking spaces bedside or in front of the houses.

Figure 57: Rural Cottages about 70km South East of London

Apartment building in East London (Figure 58) - A multi storey building with garages allocated on the ground floor. It is considered most likely that any WPT charger would be located inside the garage. Some of the apartments do not have garages and rely on non-allocated on street parking.

Figure 58: Apartment building in East London

Looking at the examples in the photographs it is suggested that in every case a more realistic distance from the nearest radio receiver to a WPT 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 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.

A2.8 PROTECTION OF RADIO SERVICES FROM INTERFERENCE CAUSED BY SHORT RANGE DEVICES

In the European context, setting standards for such high power inductive power transfer units under a regime designed for SRD is at variance with the EU Commission Decision 9 November 2006 (revised in 2017) on harmonisation of the radio spectrum for use by short-range devices (see [25]).

For the purpose of this Decision, Article 2 states that:

":

1. " ´short-range device’ means radio transmitters which provide either unidirectional or bidirectional communication and which transmit over a short distance at low power";

2. " ´non-interference and non-protected basis’ means that no harmful interference may be caused to any radio communications service and that no claim may be made for protection of these devices against harmful interference originating from radio communications services".

This requirement for SRD is reflected in ERC Recommendation 70-03 [1], which similarly defines SRD thus:

“The term ‘Short Range Device’ (SRD) is intended to cover the radio transmitters which provide either uni-directional or bi-directional communication which have low capability of causing interference to other radio equipment. SRDs use either integral, dedicated or external antennas and all modes of modulation can be permitted subject to relevant standards. SRDs are not considered a ‘Radio Service’ under the ITU Radio Regulations (Article 1).”

ITU-R texts on SRD are also based on the assumption that they do not cause interference to radio services. Report ITU-R SM.2153-6 [31] "Technical and operating parameters and spectrum use for short-range radiocommunication devices" (October 2017) states as part of the definition of a Short Range Device that:

“ ..... the term short-range radio device, is intended to cover radio transmitters which provide either unidirectional or bidirectional communication and which have low capability of causing interference to other radio equipment.

Such devices are permitted to operate on a non-interference and non-protected basis.”

It also states in the introduction:

“SRDs operate on a variety of frequencies. They must share these frequencies with other radio applications and are generally prohibited from causing harmful interference to or claiming protection from those radio applications. If an SRD does cause interference to authorized radiocommunications, even if the device complies with all of the technical standards and equipment authorization requirements in the national rules, then its operator will be required to cease operation, at least until the interference problem is solved.”

Recommendation ITU-R BS.1895 “Protection criteria for terrestrial broadcasting systems” (05/2011) [17] recommends:

1. that the values in *recommends 2 and 3* be used as guidelines, above which compatibility studies on the effect of radiations and emissions from other applications and services into the broadcasting service should be undertaken;

2. 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;

3. that the total interference at the receiver arising from all sources of radio-frequency emissions from radiocommunication services with a corresponding co-primary frequency allocation should not exceed 10% of the total receiving system noise power.

While this Recommendation is specific to the (sound) Broadcasting Service, similar Recommendations exist for other services.

In the EU, the EMC Directive [34] is the legal instrument that provides protection to the radio spectrum and specifically to licensed radio services. The "essential requirements" of the EMC Directive require equipment to 'operate as intended' in its radio environment and to 'not prevent other devices from operating as intended' in this environment. These requirements are achieved through the application of standards that carry presumption of conformity with the Directive. Appropriate standards are under preparation in ETSI and CISPR and CISPR 11 in common with most CISPR publications will be an international standard that can be called up by any country or region (e.g. the EU) to provide protection to the radio spectrum.

A2.9 PERFORMANCE OF MF AM SOUND BROADCASTING RECEIVERS IN THE PRESENCE OF INTERFERENCE FROM WPT

A2.9.1 Introduction and background

This Annex describes studies carried out by the BBC which seek to define acceptable field-strength limits for interference from Wireless Power Transfer (WPT) devices. This work supplements an earlier study which is described in BBC White Paper WHP 332, published in November 2017 [20]. This further study uses a real, 'off the shelf', portable receiver with the wanted an 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 [15] 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 [16] used when planning the LF and MF broadcast bands and used to set acceptable interference limits for WPT systems[10];
- to repeat some of the earlier measurements with a difference test arrangement.

The work for WHP 332 [20] 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 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.

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[10] 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.

A2.9.2 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;
- Sony ICF-700W.

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 EN 303 345 [45], ‘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 below (Figure 59). About two-thirds of the radios were more sensitive than the proposed ETSI requirement of 66 dBµV/m.

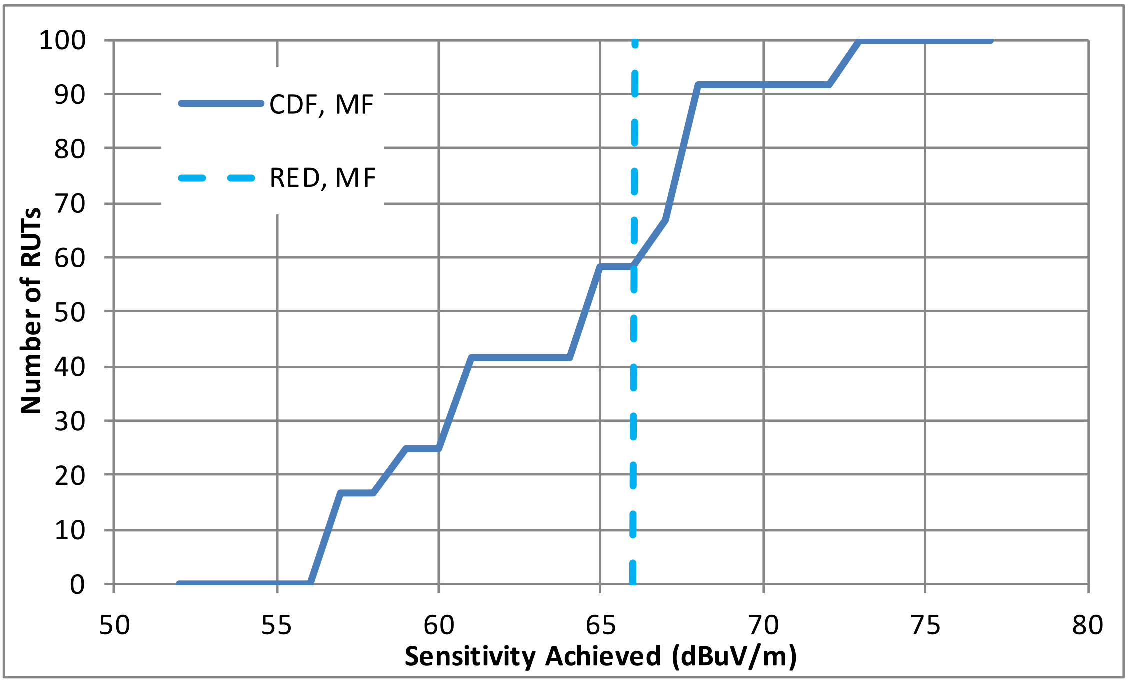

Figure 59: CDF of the sensitivities of a batch of typical portable radios

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 ETSI 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. A plot is shown in 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, and improves the measured sensitivity (although not the audio fidelity).

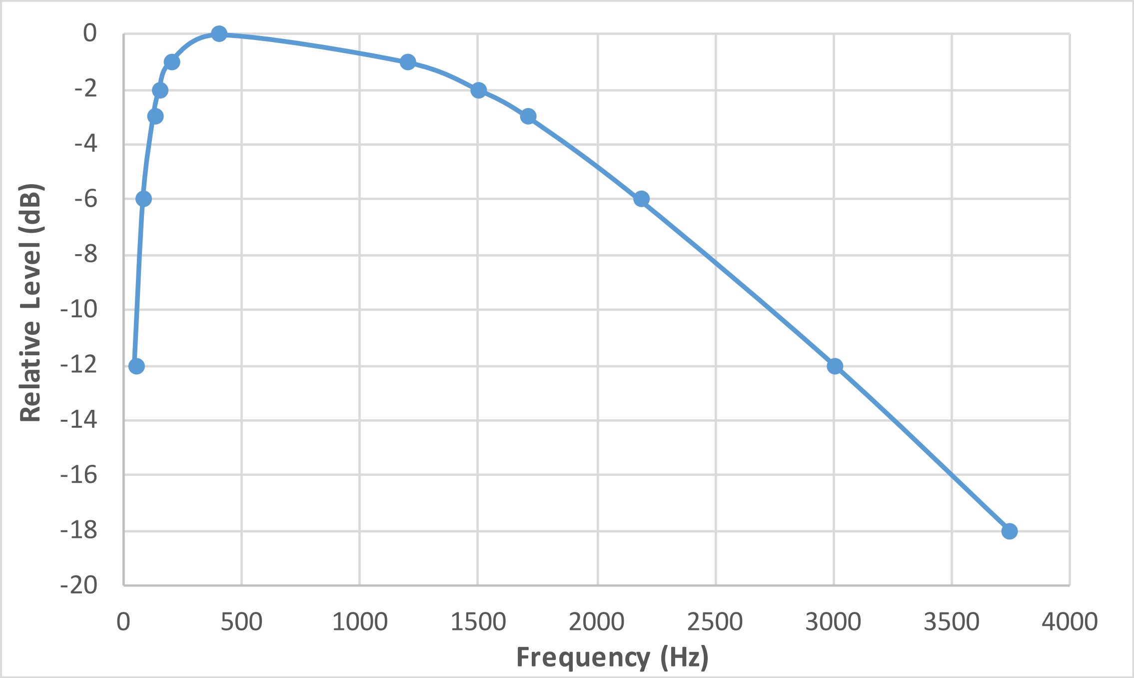

Figure 60: Modulation response of chosen portable radio

A2.9.3 The test set-up

The test set-up was essentially similar to that described in WHP 332 [20], with two RF signal generators: one set to 999 kHz and used to provide the wanted transmission; the second set to 1001 kHz and providing the (un-modulated) interferer with a 2 kHz offset. 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.

A picture of the test set-up is shown in Figure 61.

Figure 61: The test set-up in the BBC R&D screened room

In the Figure 61, 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 (see A2.9.4 below) 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.

Block diagrams of the original (Figure 62) and present test arrangements (Figure 63) are given here.

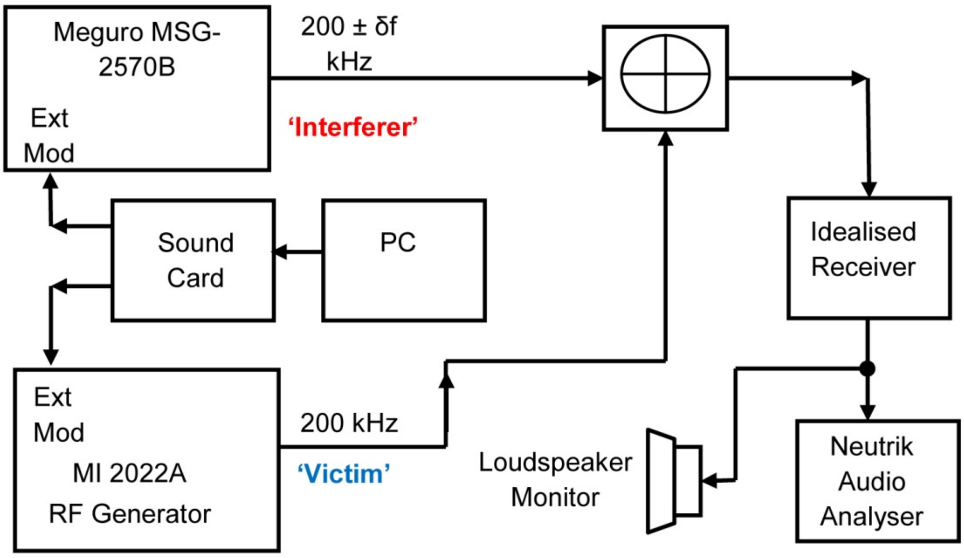

Figure 62: The test set-up as originally used for WHP 332

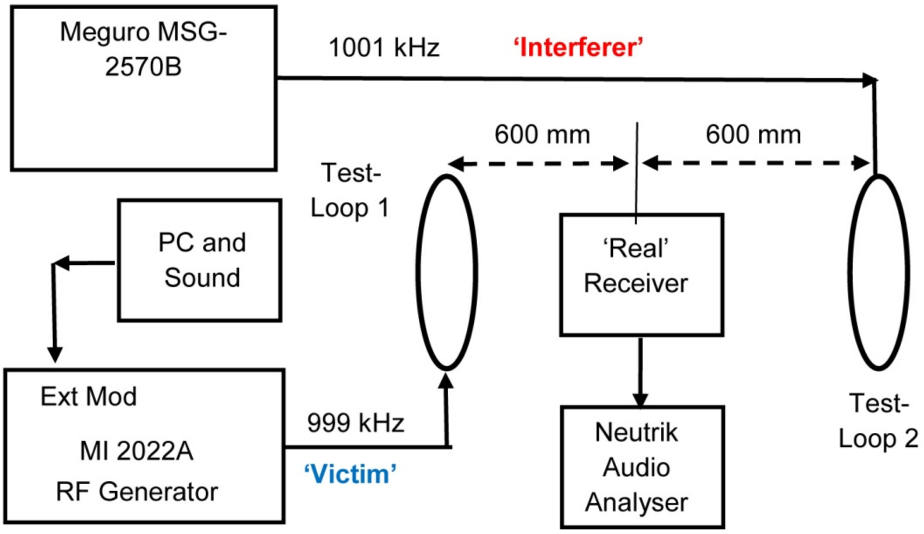

Figure 63: Modified set-up as used for the present work

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.

A2.9.4 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 dBµA/m at the receiver, a figure which was verified with the field-strength meter. The calculation of field-strength is carried out as follows:

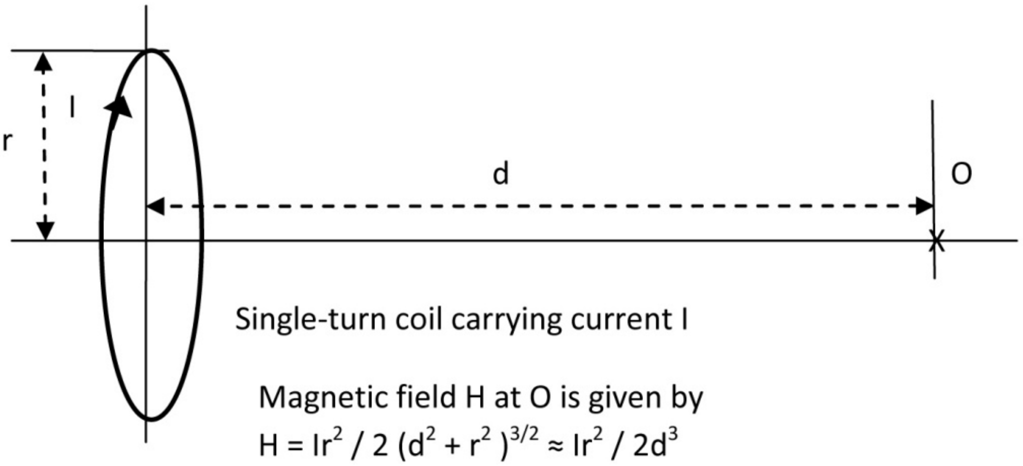

Figure 64: Magnetic field generated by a current-carrying loop

Figure 64 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.

$$I = H\,.\,(2d^3/r^2)$$

For the field strength to be $8.5\ dB\mu A/m$

$$H = \ 10^{(\frac{8.5}{20})}\ \ \mu A/m$$

$$= 2.66\ \mu A/m$$

The necessary current is therefore:

$$I = 2.66\ \mu A/m\ \ .\ (2\,.\,0.6^3/\ 0.125^2)$$

$$= 73.54\ \mu A$$

The necessary generator EMF is therefore:

$$V = 73.54\ \mu A\,.\,136\ \Omega$$

$$= 10\ mV$$

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.

A2.9.5 Performance of the receiver used for the present tests

To ensure that the tests carried out with the portable radio are ‘fair’, it has to be checked check how the sensitivity compares with that of the reference receiver in Recommendation ITU-R BS.703 [15]. The measured results are best summarised in the form of Table 15.

Table 15: 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 15 shows that the noise performance of the Panasonic receiver is 2.5 dB worse than the Recommendation ITU-R BS.703 reference receiver, but exceeds the ETSI requirement of 66 dBµV/m 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 ETSI EN 303 345 [45], 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 Recommendation ITU-R BS.703 and ETSI EN 303 345 hence seem reasonable.

A2.9.6 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 interferers suggested in WHP 332 [20]. 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.

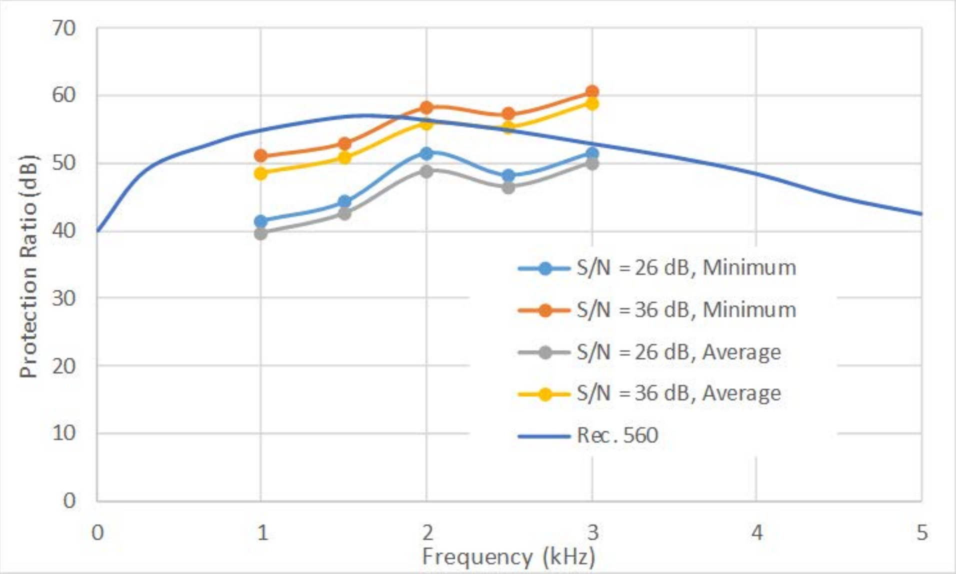

Figure 65: Single tone interference thresholds with a 'real world' receiver "Frequency" is the frequency offset from the AM carrier

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 Figure 65, 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 Figure 3.1 of WHP 332. 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[11].

A further test was carried out in an attempt to quantify the psycho-acoustic difference between random (white) noise and a single tone interferer. The reference receiver proposed in Recommendation ITU-R BS.703 assumes an audio signal to random, system noise ratio of 26 dB, reference 30% AM modulation depth, at the limit of sensitivity. 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.

At the limit of sensitivity, the total system noise would be

$$-28\,\frac{dB\mu A}{m} = 8.5\,\frac{dB\mu A}{m} - \;10.5\;dB - 26\;dB$$

Where

$$8.5\,\frac{dB\mu A}{m}\;is\;the\;magnetic\;sensitivity\;limit\;(from\;Rec\;BS.703\;[15])$$

$$-10.5\;dB\;is\;the\;ratio\;of\;the\;audio\;modulation\;(30\%\;modulation)\;to\;the\;carrier^{12}$$

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[11] This applies to single tone interferers at frequencies away from the broadcast carrier and does not affect the conclusions of[20].

[12] This includes a correction for the correlation between the upper and lower modulation sidebands.

$$-26\ dB\ is\ the\ specified\ audio\ signal\ to\ random\ noise\ ratio$$

Note:

$$8.5\frac{dB\mu A}{m}\ is\ the\ level\ of\ the\ carrier$$

A single tone interferer was injected at the same level as the total system noise[13], 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. These levels correspond to -36 dBµA/m and -38 dBµA/m respectively for the Recommendation ITU-R BS.703 reference receiver. These results correlate well with the 8 dB masking effect of the system noise reported above. In higher noise environments, the absolute 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.

A2.9.7 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 Recommendations ITU-R BS.703 [15] and ITU-R BS.560 [16] are basically correct. However, a number of things did come out of the tests.

A2.9.7.1 Validity of 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 good 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 peak modulation depth of 30% (21.2% rms) and a modulation to random (system) noise of 26 dB. The total system noise is, therefore 60 dBµV/m (minimum carrier level from Rec. ITU-R BS.703) minus 13.5 dB (level of modulation below carrier) minus 26 dB (wanted signal to noise ratio) which equals 20.5 dBµV/m or –31 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 –34 dBµA/m; a figure that will increase by 3 dB when they are added together. It can be seen from figure 66 that this lies between the anticipated environmental noise levels for rural and residential environments.

A2.9.7.2 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

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[13] For this test an idealised receiver was used with random noise deliberately injected at the equivalent of -31 dBµA/m to simulate the performance of the Rec. ITU-R BS.703 reference receiver.

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.

A2.9.7.3 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 [22], 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.

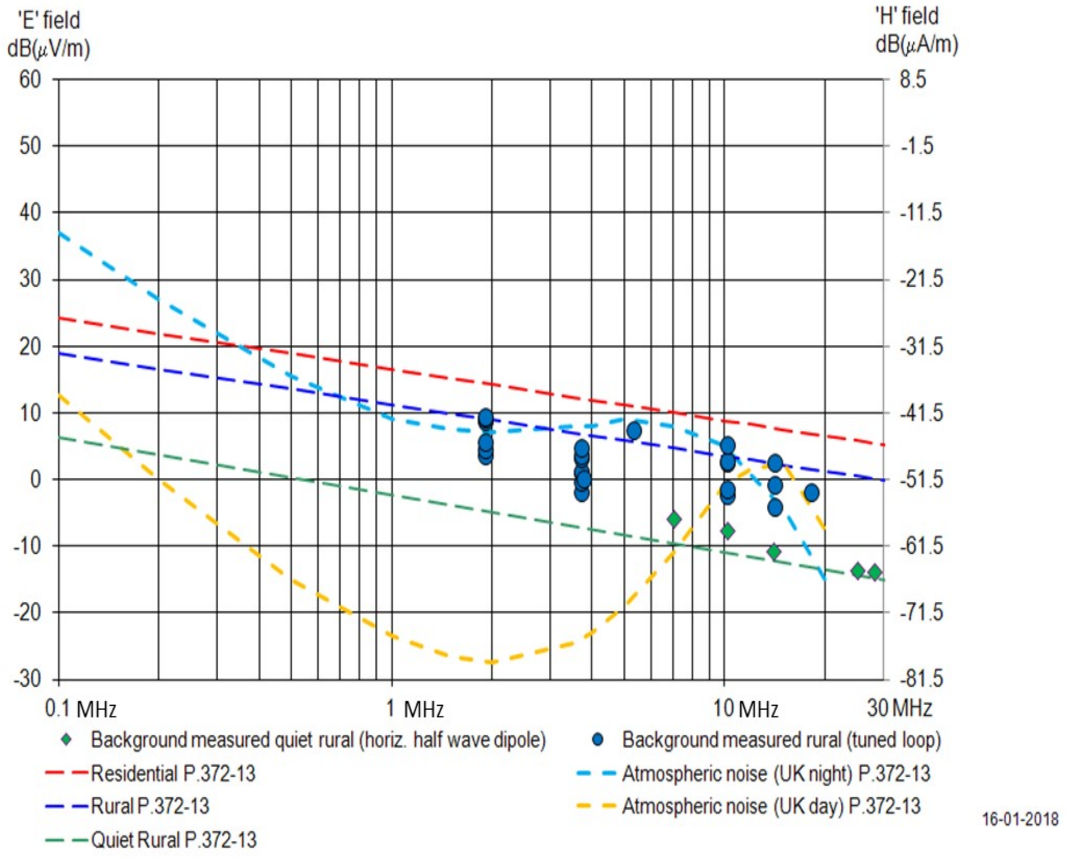
ANNEX 3: MAN-MADE NOISE LEVELS TODAY COMPARED TO RECOMMENDATION ITU-R P.372-13

A3.1 MAN-MADE NOISE LEVELS TODAY COMPARED TO RECOMMENDATION RECOMMENDATION ITU-R P.372-13

During the course of discussions on WPT-EV emissions, comments have been made that the Recommendation ITU-R P.372-13 [22] levels are no longer representative of the real-life situation today. Whilst it is true that in the city environment, these levels are hard to replicate, nonetheless in urban, suburban and rural environments, recent measurements support the argument that the levels still represent “real life”. Figure 66 shows the results of recent measurements conducted in the UK.

Other papers have been submitted to ITU suggesting that noise levels are still reasonably close to the Recommendation ITU-R P.372 levels. A recent German paper of measurements at sea suggests a rise in background noise level of around 10 dB in mid-ocean (comparable to a quiet rural environment). It therefore would seem that the rural and residential lines still represent the real-life situation in most cases.

A measurement in the Netherlands in 2009 at a specific quiet location shows that the ITU curves are indeed still valid for frequencies between 3 and 30 MHz. However some practical cases show that noise has increased significantly above ITU and acceptable levels at particular urban locations.



16-01-2018

Figure 66: Actual measurements of background noise levels compared with Recommendation ITU-R P.372-13 [22]

ANNEX 4: DATA SOURCES FOR FIGURE 33, FIGURE 34 AND FIGURE 35

Recommendation ITU-R SM.329-12 [23] "Unwanted Emissions in the Spurious Domain" and in ERC/REC 74-01 [12], table 2.1 following requirements are given for the spurious domain for inductive SRD.

Table 16: Excerpt from ERC Recommendation 74-01 [12] table 2.1

Spurious domain emission limits for the land mobile service and maritime mobile service (VHF)		
Reference number	**Type of equipment**	**Limits** mean power or, when applicable, average power during bursts duration in the reference bandwidth
2.1.3	Short range inductive devices operating below 30 MHz (in transmit mode)	27 dBμA/m, for (at 9 kHz then decaying by 10 dB/decade) (Note 1) 9 kHz ≤ f ≤ 10 MHz
		-3.5 dBμA/m, for 10 MHz < f ≤ 30 MHz (Note 1)
		-54 dBm , for f within the bands : 47–74 MHz, 87.5–118 MHz, 174–230 MHz, 470–862 MHz
		-36 dBm , for 30 MHz < f ≤ 1 GHz (except above frequency bands)
		-30 dBm , for 1GHz < f ≤ F_{UPPER} (see *recommend 3*)
Notes : - *f* is the frequency of the spurious domain emission for systems that use digital modulation and narrow-band high power (≥1 Watt) analogue modulated systems, the reference bandwidth is specified in section 2 of this annex, while for any other analogue modulation the reference bandwidth specified in *recommend 4* is applicable. Note 1: Levels are H-field limit at 10 m distance, measured by shielded loop antenna as specified by CISPR.		

This computes to:

Table 17: Computation of limits based on ERC Recommendation 74-01 [12]

Frequency (kHz)	Limit based on ERC Recommendation REC 74-01 (dBµA/m)
100	18.5
1000	8.5
10000	-1.5

Background noise is computed from Recommendation ITU-R P.372-13 [22].

For a vertical monopole:

En = Fa + 20 log f_{MHz} + B – 95.5 dBµV/m

or

$E_n = F_a + 20 \log f_{MHz} + B – 95.5 - 51.5$ dBµA/m[14]

Reference bandwidth (b) = 10 kHz and where B=10 log(bHz)

This computes to:

Table 18: Computation of the noise level based on Recommendation ITU-R P.372-13 [22]

	Frequency	Fa*	Noise level
	MHz		dBµA/m
Residential	0.3	86	-31.5
	30	31	-46.5
Rural	0.3	82	-35.5
	30	26	-51.5
Quiet rural	0.3	68	-49.5
	30	13	-64.5
* from P.372-13 Figure 10			

Finally, the rate of decay of the field of spurious emissions has been computed from the ETSI EN 300 330 [6]. This standard defines the correction factors to be used when measurement of emissions from inductive “short range devices” is done at a distance other than that specified in standards. This allows the calculation of a decay rate for any specific frequency. The higher the frequency and/or the further from the source, the more the decay rate approaches the “far-field” decay rate of 20 dB/decade.

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[14] Converted at the impedance of free space.

ANNEX 5: "STILLE" PROJECT – FORECAST OF EU MARKET DEVELOPMENT OF INDUCTIVE CHARGING SYSTEMS UNTIL 2025

The German project STILLE has researched the prognoses of WPT devices on the streets for the next years. The research is based on the media research of STILLE members made in October 2018

The first time horizon of the project was 2025, because the public information available doesn't allow further prognoses with enough quality. In order to be aligned with this ECC Report time horizon, STILLE members have extrapolated the available data until 2030.

A5.1 BACKGROUND

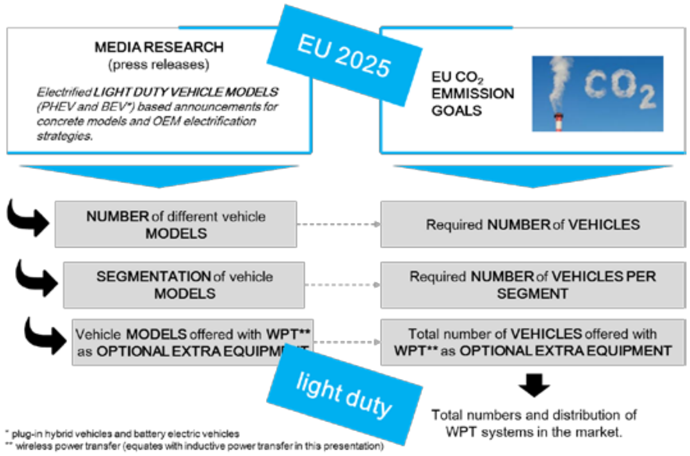
Since the current limit discussions in different groups are partly based on the distribution of inductive charging systems, project STILLE was asked to provide calculations.

- Project STILLE is funded by the German government and is one of the technical backbones for the international standardization of inductive charging systems.
- The main goal of the project is to technically validate and enable the interoperability of inductive charging systems. The gained experiences serve to support the international standardization activities.
- In addition to the technical scope, one work package of the project is investigating the market potentials/ penetration of inductive charging systems. The investigations shown in this Annex are based on the calculations done by STILLE members.

A5.2 INDUCTIVE CHARGING OF ELECTRIC VEHICLES, WHAT ACTUALLY IS

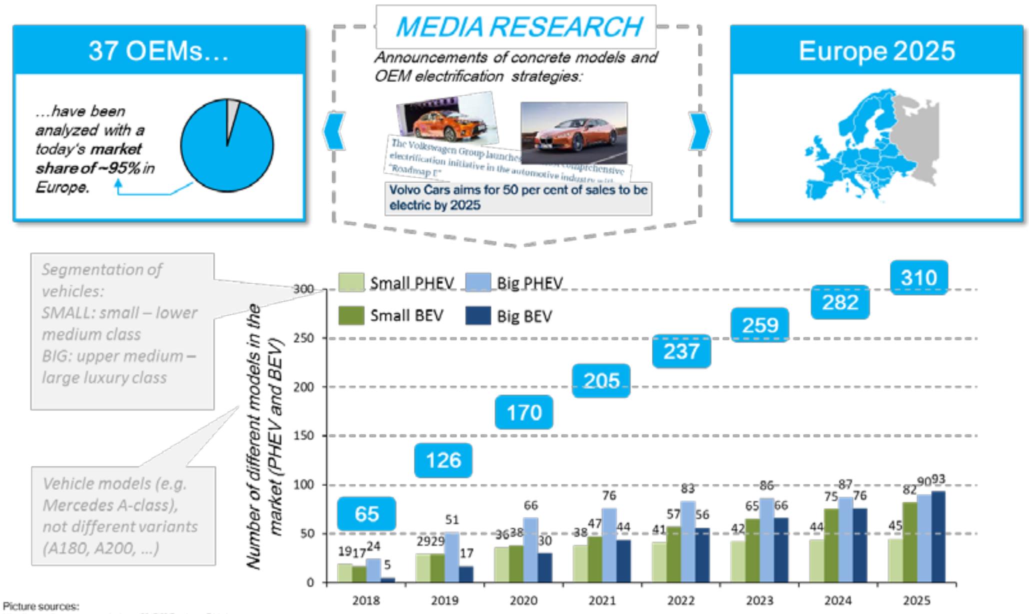
- Inductive charging mainly serves as a convenient alternative to conductive charging (by cable). Alternative is thereby not understood as a complete switch to inductive charging. The more costly technology will (probably always) be available as optional extra equipment;
- At least in the mid-term, the charging power for light duty vehicles will probably not exceed 11 kW;
- Inductive charging (as an automated charging solution) is strongly related to automated parking. Also other automated charging solutions (e.g. automated plugging) are under development, the status however, is less advanced compared to WPT and standardization activities have not been started, yet;
- The success of inductive charging of EVs is quite hard to be estimated today. However, the technology has the potential to become one essential piece in the puzzle of driving electric mobility.

A5.3 FINDINGS



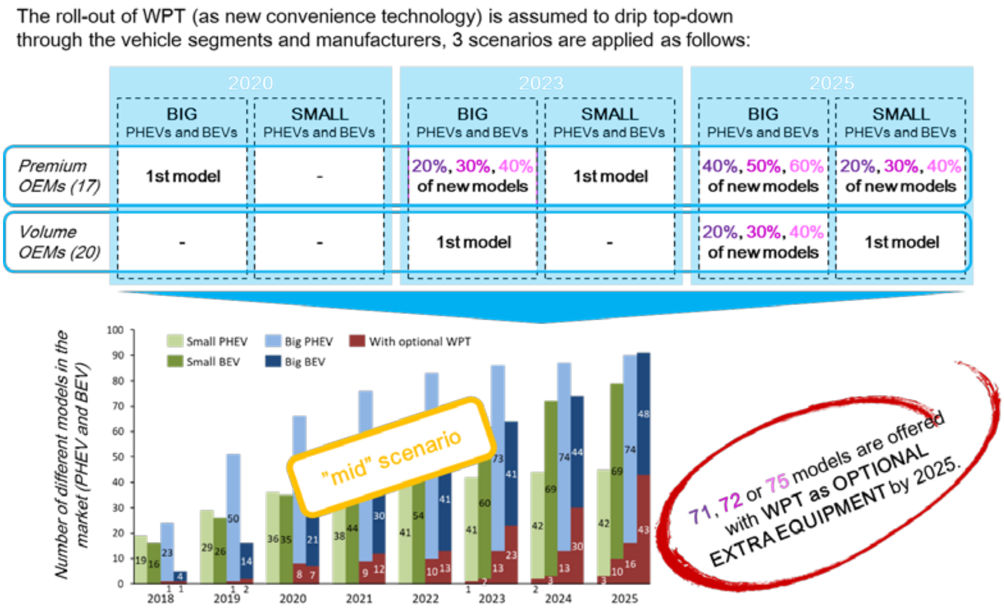
* plug-in hybrid vehicles and battery electric vehicles
** wireless power transfer (equates with inductive power transfer in this presentation)

Figure 67: The calculation of the EU market penetration is generally based on the CO2 emission goals of the EU



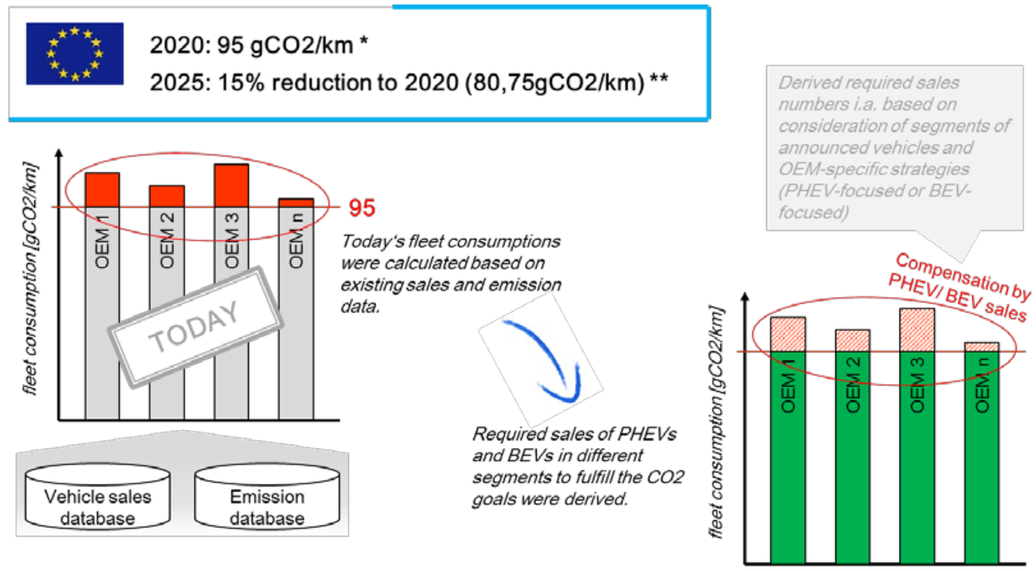
Picture sources:
https://www.volkswagenag.com/en/news/2017/09/Roadmap_E.html
https://www.media.volvocars.com/global/en-gb/media/pressreleases/227602/volvo-cars-aims-for-50-per-cent-of-sales-to-be-electric-by-2025
https://www.focus.de/auto/elektroauto/auto-insider-bmw-i4-i5-abgas-null-ihr-naechster-bmw-koennte-so-aussehen_id_8390331.html
http://www.automotorblog.com/toyota-plans-corolla-levin-phevs-versions-china-2018-90496.html

Figure 68: According to the research there will be 310 different electrified vehicle models available in the European market by 2025


The roll-out of WPT (as new convenience technology) is assumed to drip top-down through the vehicle segments and manufacturers, 3 scenarios are applied as follows:

	2020		2023		2025	
	BIG PHEVs and BEVs	SMALL PHEVs and BEVs	BIG PHEVs and BEVs	SMALL PHEVs and BEVs	BIG PHEVs and BEVs	SMALL PHEVs and BEVs
Premium OEMs (17)	1st model	-	20%, 30%, 40% of new models	1st model	40%, 50%, 60% of new models	20%, 30%, 40% of new models
Volume OEMs (20)	-	-	1st model	-	20%, 30%, 40% of new models	1st model

Figure 69: Cascading WPT through the vehicle segments, 71 – 75 models are available with WPT as optional extra equipment by 2025



* Average for all OEMs, OEM-specific numbers depend on weight of fleet. 15% is the intermediate goal on the way to 30% in 2030.
** 17,5% currently under discussion

Figure 70: The absolute number of vehicles in the market was derived from the CO2 emission goals of the EU

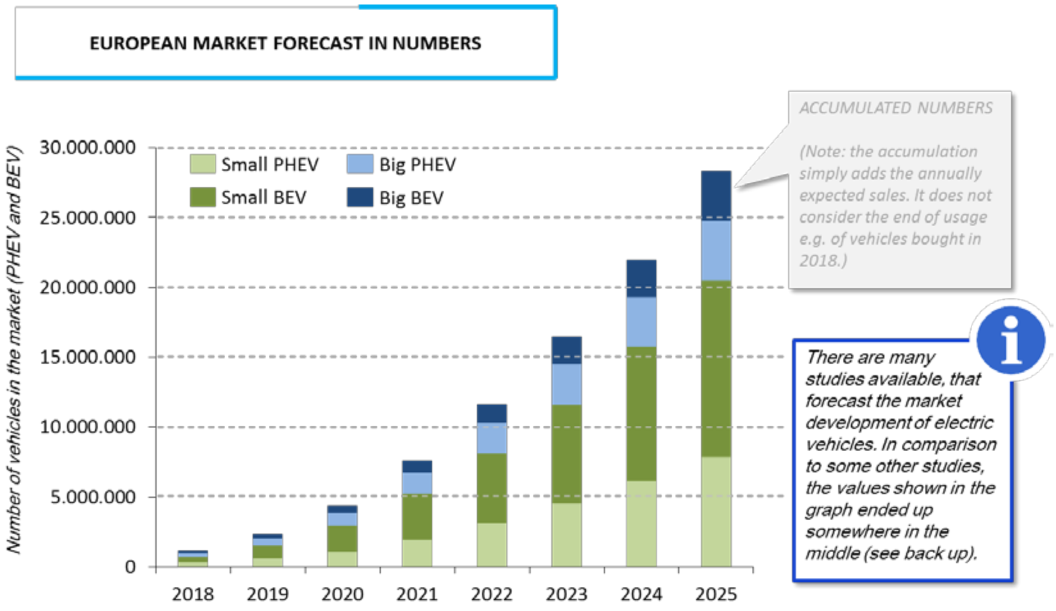


Figure 71: Based on these assumptions, there will be about 28 millions of electrified vehicles on European roads in 2025

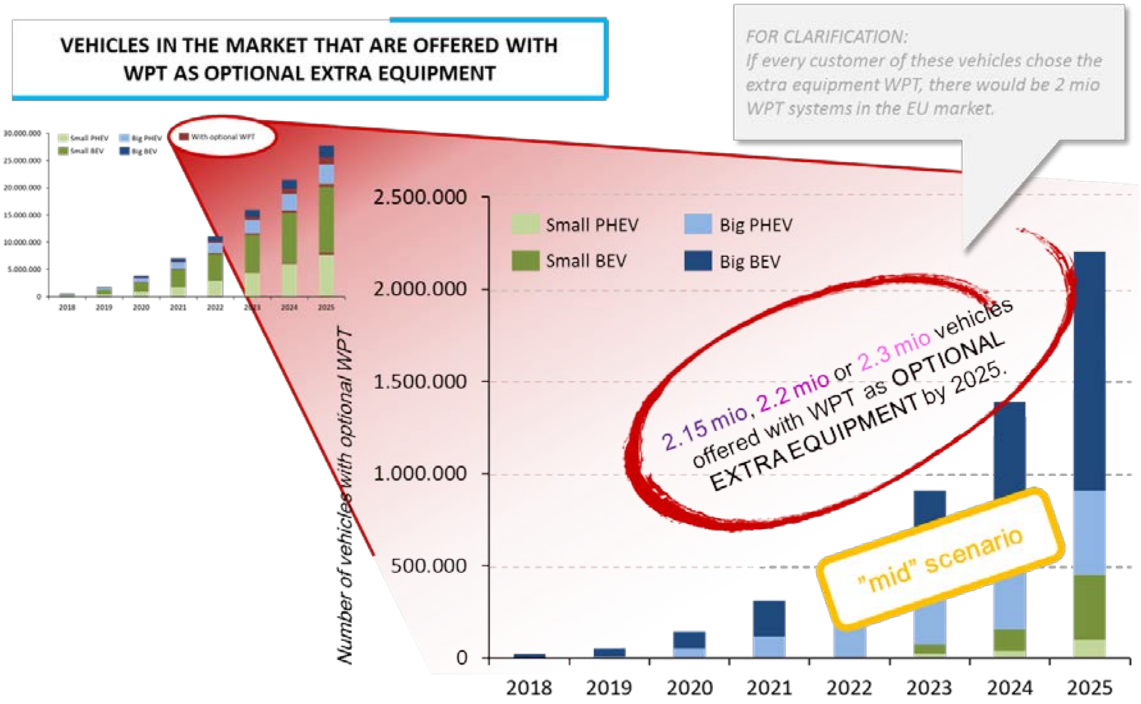
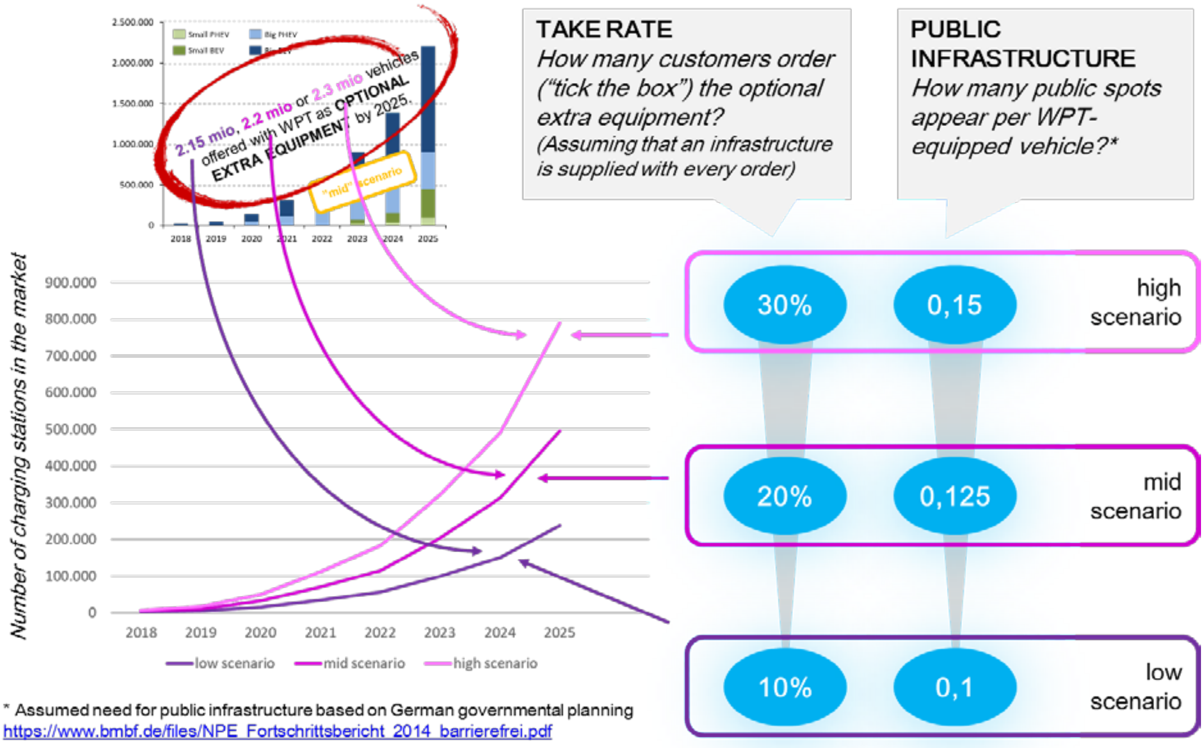
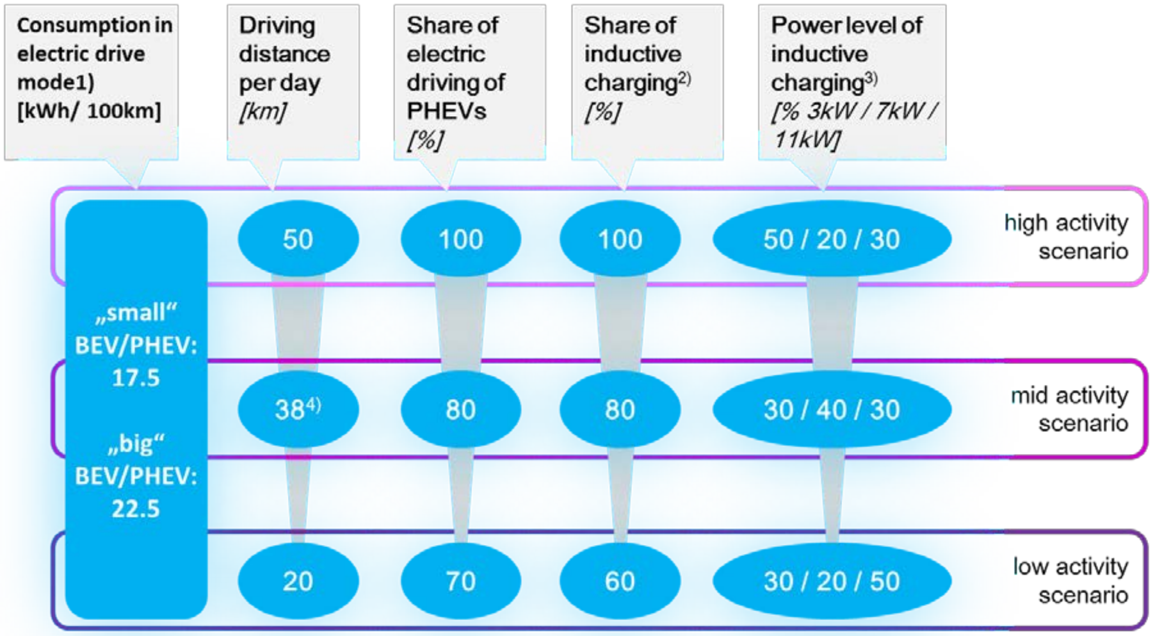


Figure 72: Combining the model and sales numbers, about 2.2 millions of the vehicles in the market are optionally equipped with WPT



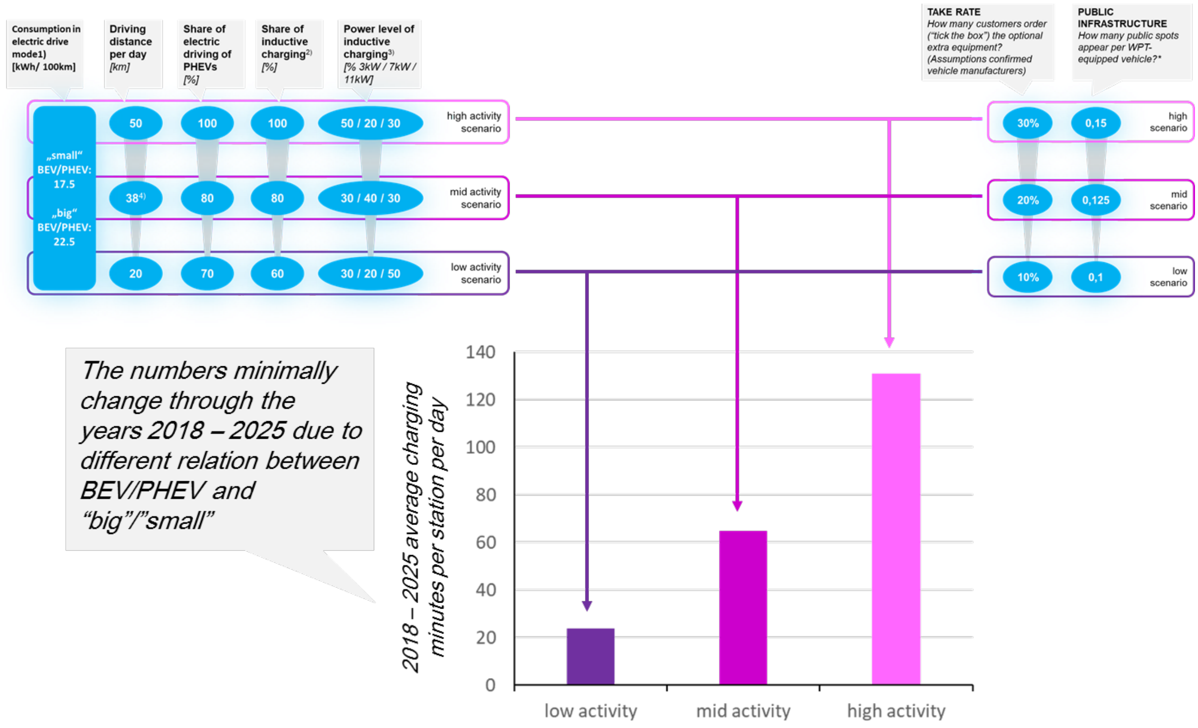
* Assumed need for public infrastructure based on German governmental planning
https://www.bmbf.de/files/NPE_Fortschrittsbericht_2014_barrierefrei.pdf

Figure 73: Applying different take rates for WPT systems and including public infrastructure ends up in max 800000 stations



[1] Assumptions based on current real driving testing https://www.adac.de/rund-ums-fahrzeug/e-mobilitaet/stromverbrauch-elektroautos-adac-test/
[2] Since WPT is an extra equipment, this factor is applied to catch the relation between inductive and conductive charging of a vehicle.
[3] The charging power determines the charging time. The factor describes the distribution of the usage of different power levels.
[4] Based on average driving distance in Germany https://www.kba.de/DE/Statistik/Kraftverkehr/VerkehrKilometer/verkehr_in_kilometern_node.html

Figure 74: Several influencing factors were identified and modeled to derive the daily activity of WPT charging stations



The numbers minimally change through the years 2018 – 2025 due to different relation between BEV/PHEV and "big"/"small"

Figure 75: Combining the assumptions results in a max average daily activity of about2 hours per station

It is necessary to note, that for the best guest (mid activity) prognoses, the daily average charging time per station is one hour.

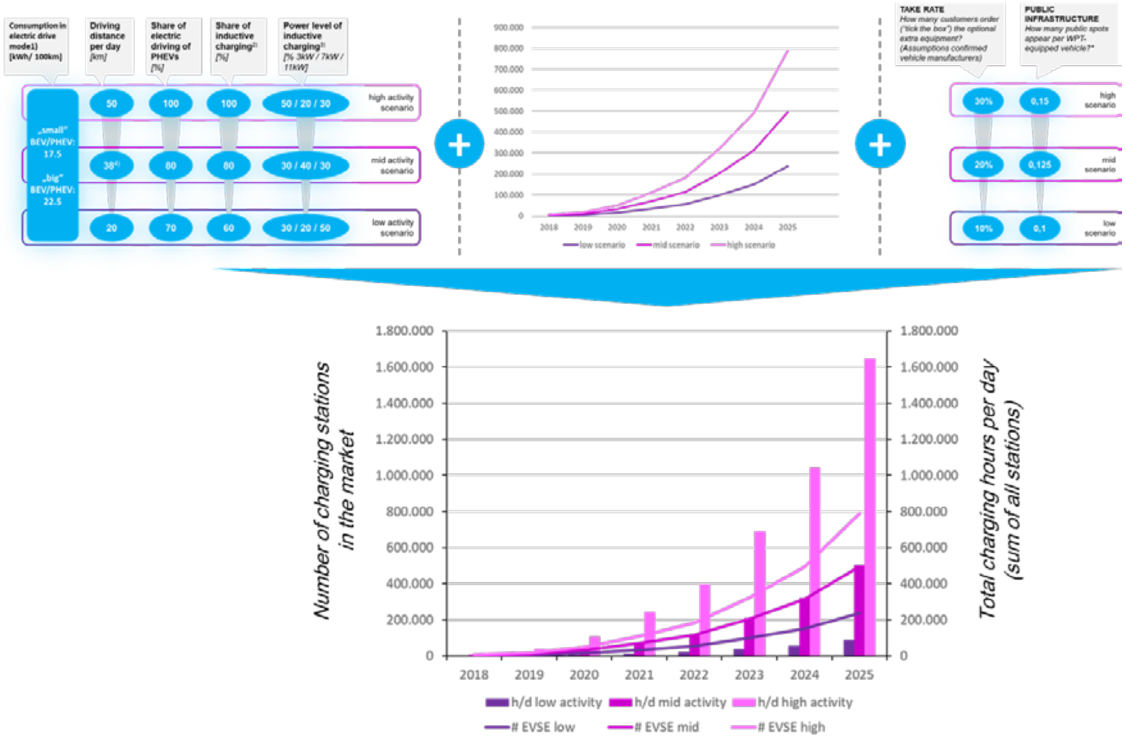
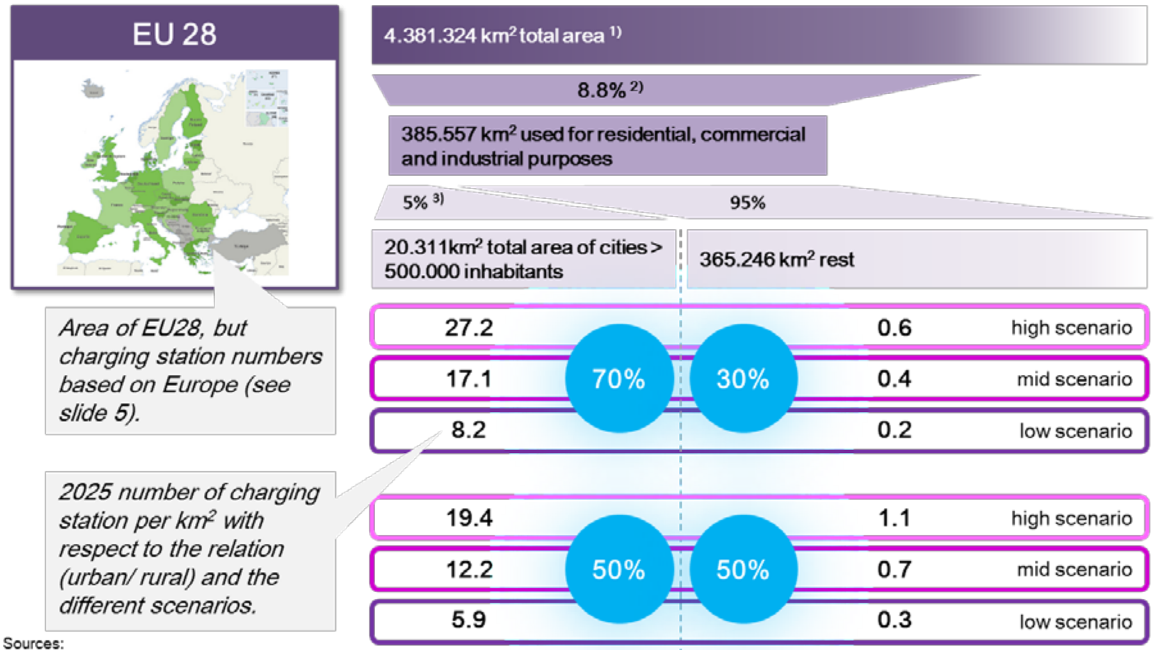


Figure 76: Considering Europe 2025 in the "high" scenarios, ~800000 charging stations are running ~1.6 millions hours in total per day



EU 28

4.381.324 km² total area ¹⁾

8.8% ²⁾

385.557 km² used for residential, commercial and industrial purposes

5% ³⁾

95%

20.311km² total area of cities > 500.000 inhabitants

365.246 km² rest

27.2	70%	30%	0.6	high scenario
17.1			0.4	mid scenario
8.2			0.2	low scenario

19.4	50%	50%	1.1	high scenario
12.2			0.7	mid scenario
5.9			0.3	low scenario

Area of EU28, but charging station numbers based on Europe (see slide 5).

2025 number of charging station per km² with respect to the relation (urban/ rural) and the different scenarios.

Sources:
Picture: https://ec.europa.eu/taxation_customs/facts-figures/28-eu-member-states-links-national-customs-websites_de
¹⁾ Total area EU: https://de.wikipedia.org/wiki/Europ%C3%A4ische_Union
²⁾ Usage of area: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Woodland_as_share_of_land_cover,_by_NUTS_2_regions,_2009.PNG
³⁾ Area of biggest cities: https://de.wikipedia.org/wiki/Liste_der_gr%C3%B6%C3%9Ften_St%C3%A4dte_der_Europ%C3%A4ischen_Union

Figure 77: Based on the land utilization in EU28, the maximum density of charging stations ends up at ~27 stations per km^2 in big cities

A5.4 EXTRAPOLATION RESULTS UNTIL 2030.

The above information represents the presentation made from the project STILLE. Because it was only possible to research the data until 2025, the result until 2030 was still missing. Some STILLE members have extrapolated the data until 2030 and the more relevant information is show below.

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 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 charging station. It is interesting to notice, that this value remains stable with the years. The reason is that the suspected amount of cars increases every year, on the other hand, the drive profile remains and the WPT charge stations increase in the same ratio.

Taking into account all the data of the project STILLE, is possible to extrapolate the given data and calculate the total amount of vehicles that will have the optional WPT system mounted in the year 2030.

Table 19: Extrapolation of the total amount of vehicles with optional WPT 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 vehicles 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

ANNEX 6: LIST OF REFERENCES

[1] ERC/REC 70-03: "Relating to the use of Short Range Devices (SRD)"

[2] ECC Report 135: "Inductive limits in the frequency range 9 kHz to 148.5 kHz"

[3] ETSI Harmonised European Standard EN 303 417 (V1.1.1): "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

[4] ERC Report 44: "Sharing between inductive systems and radiocommunication systems in the band 9 - 135 kHz"

[5] EC Decision 2013/752/EU, Commission Implementing Decision - Harmonisation of the radio spectrum for use by short-range devices

[6] ETSI Harmonised European Standard EN 300 330 (V2.1.1): "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 Directive 2014/53/EU"

[7] ECC Report 67: "Compatibility study for generic limits for the emission levels of inductive SRDs below 30MHz"

[8] ECC Report 1: "Compatibility between inductive LF and HF RFID transponder and other radio communications systems in the frequency ranges 135-148.5 kHz, 4.78-8.78 MHz and 11.56-15.56 MHz"

[9] ERC Report 74: "Compatibility between radio frequency identification devices (RFID) and the radio astronomy service at 13 MHz"

[10] ERC Report 69: "Propagation model and interference range calculation for inductive systems 10 kHz - 30 MHz"

[11] ETSI TR 103 409 (V1.1.1): "System Reference document (SRdoc); Wireless Power Transmission (WPT) systems for Electric Vehicles (EV) operating in the frequency band 79 - 90 kHz"

[12] ERC/REC 74-01: "Unwanted Emissions in the Spurious Domain"

[13] Recommendation ITU-R P.368-7: "Ground-wave propagation curves for frequencies between 10 kHz and 30 MHz"

[14] Recommendation ITU-R TF.768: "Standard frequencies and time signals"

[15] Recommendation ITU-R BS.703, Characteristics of AM sound broadcasting reference receivers for planning purposes

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

[17] Recommendation ITU-R BS.1895, Protection criteria for terrestrial broadcasting systems

[18] Final Acts of the Regional Administrative LF/MF Broadcasting Conference (Regions 1 and 3) Geneva, 1975

[19] Final Acts of the Regional Administrative Broadcasting Conference (Region 2) (Rio de Janeiro, 1981)

[20] BBC Research and Development White Paper WHP322 (2017) – Wireless Power Transfer: Plain Carrier Interference to AM Reception; http://www.bbc.co.uk/rd/publications/wireless-power-transfer-plain-carrier-interference-to-am-reception

[21] Recommendation ITU-R M.1732-2, Characteristics of systems operating in the amateur and amateur-satellite services for use in sharing studies

[22] Recommendation ITU-R P.372-13: "Radio Noise"

[23] Recommendation ITU-R SM.329-12: "Unwanted emissions in the spurious domain"

[24] CISPR 11, Industrial, scientific and medical equipment - Radio-frequency disturbance characteristics - Limits and methods of measurement

[25] EC Decision (EU) 2017/1483: "Amendment to Decision 2006/771/EC on harmonisation of the radio spectrum for use by short-range devices and repealing Decision 2006/804/EC (notified under document C(2017) 5464)"

[26] Report ITU-R SM.2158: "Impact of power line telecommunication systems on radiocommunication systems operating below 80 MHz"

[27] EN 50561-1:2013: "Power line communication apparatus used in low-voltage installations. Radio disturbance characteristics. Limits and methods of measurement. Apparatus for in-home use"

[28] 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)"

[29] Recommendation ITU-T G.9700 Amendment 2 (06/2017): "Fast access to subscriber terminals (G.fast) - Power spectral density specification (Section 6.5 Notching of specific frequency bands)"

[30] International Electrotechnical Commission CISPR SC-H Radio Services Database www.iec.ch/emc/database/

[31] ITU-R Document 1A/220-E (also Document 1B/202-E) - Liaison statement to ITU-R Working Parties 1A and 1B regarding WRC-19 agenda item 9.1 issue 9.1.6 - From Working Party 6A 25th October 2017 on the subject of AM modulation depth
[32] Report ITU-R SM.2153-6: "Technical and operating parameters and spectrum use for short-range radiocommunication devices" (June 2017)
[33] ITU-R Recommendation BS.1895 Protection criteria for terrestrial broadcasting systems, (05/2011)
[34] Directive 2014/30/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to electromagnetic compatibility.
[35] EN 55016-1-4:2010+A1:2012:"Specification for radio disturbance and immunity measuring apparatus and methods. Part 1-4: Radio disturbance and immunity measuring apparatus — Antennas and test sites for radiated disturbance measurements"
[36] EN 50561-1:2013 "Power line communication apparatus used in low-voltage installations. Radio disturbance characteristics. Limits and methods of measurement. Apparatus for in-home use"
[37] Engeler: "Performance Analysis and Receiver Architectures of DCF77 Radio-Controlled Clocks"
[38] https://blog.blinkenlight.net/experiments/dcf77/dcf77-receiver-modules
[39] Friedrich Krug: "A receiver for the VLF time and frequency standard transmissions from DCF-77,UKW Berichte 2/1984"
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[46] https://de.tdk.eu/download/192906/aabebbb7879ca81b90346561fd57b16e/emc-labor-pp--de.pdf]
[47] [Recommendation ITU-R SM.1896: "Frequency ranges for global or regional harmonization of short-range devices (SRDs)"
[48] Andreas Bauch, Peter Hetzel and Dirk Piester: "Time and Frequency Dissemination with DCF77: From 1959 to 2009 and beyond"
[49] IEC 61980 (parts 1 to 3): "Electric vehicle wireless power transfer (WPT) systems"