UNWANTED EMISSIONS IN THE SPURIOUS DOMAIN FROM WIRELESS POWER TRANSFER FOR ELECTRIC VEHICLES ON FREQUENCIES ALLOCATED TO THE AMATEUR SERVICE

1 Introduction

This document sets out an analysis of the impact of WPT-EV systems on radio communications in the amateur service. Data for the analysis is drawn from published information about the amateur service, WPT(EV) systems and from existing reports and studies in CEPT, ITU and CISPR/CENELEC.

2 Background

The amateur service is a radio service defined in the ITU Radio Regulations (RR 1.56). There are some 3 million licensed amateur radio operators around the world. ITU Radio Regulations set out the frequencies allocated to the amateur service. Although allocations vary slightly between ITU Regions and in individual countries, the following table provides a general overview of current allocations up to 1GHz. There are also numerous allocations above 1 GHz.

Frequency range	Allocation status
135.7 - 137.8 kHz	Secondary allocation
472.0 - 479.0 kHz	Secondary allocation
1,800 -2,000 kHz	Part primary, part secondary
3,500-4,000 kHz	Primary allocation
5,351.5-5,366.5 kHz	Secondary allocation
7,000 -7,300 kHz	Primary allocation
10,100 – 10,150 kHz	Secondary allocation
14,000 -14,350 kHz	Primary allocation
18,068-18,168 kHz	Primary allocation
21,000 – 21,450 kHz	Primary allocation
24,890 – 24,990 kHz	Primary allocation
28.0 – 29.7 MHz	Primary allocation
50.0 – 54.0 MHz	Part primary, part secondary
70.0 - 70.5 MHz	Secondary allocation
144 - 148 MHz	Primary allocation
430 - 450 MHz	Secondary allocation

TABLE 1: GLOBAL ALLOCATIONS TO THE AMATEUR SERVICE BELOW 1GHZ IN THE ITU RADIO REGULATIONS AND UNDER RR 4.4. NOTE THAT THERE ARE A NUMBER OF NATIONAL AND REGIONAL VARIATIONS TO THIS TABLE IN SOME FREQUENCY RANGES.

The characteristics of stations operating in the amateur service are set out in ITU-R M.1732 [1] – "Characteristics of systems operating in the amateur and amateur-satellite services for use in sharing studies". 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 [1] 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.

The chart below shows the distribution of A1A signal levels in the amateur service drawn from 528,280 data points.

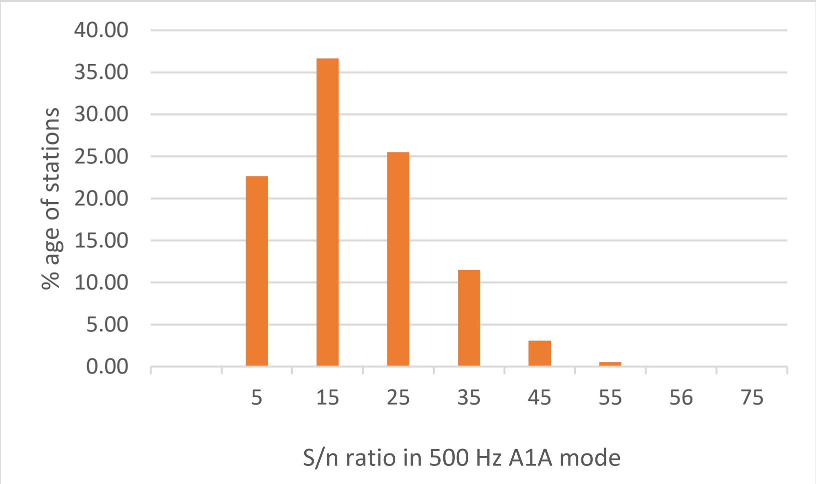


FIGURE 1: DISTRIBUTION OF TYPICAL S/N RATIO IN AMATEUR SERVICE COMMUNICATIONS

Should the above data be presented in the same bandwidth as the ITU-R P.372-13 [2] measurements, this would result in a 13 dB worsening of the above signal to noise ratios.

This chart shows convincingly that any significant raising of the background noise level will have a very significant impact on amateur service communications, as the majority of communication is currently relatively close to the noise level.

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 ITU-R P.372-13 are relevant as a reference point. Although there has been some increase above these levels in the "city" noise, recent reports submitted to ITU (eg [3]) 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 (eg switch-mode power supplies, LED lighting system power units, solar PV systems and PLT/BPL installations) creating broadband emissions propagated by ionospheric reflection [4]

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

One aspect of the need for a low noise environment in the amateur service is that users of the amateur services are called upon to provide disaster relief communications – often at low signal levels. In many countries, amateur radio is seen as a valuable back-up service in case of breakdown or overload of normal communications systems. Governments rely on this capability at times of emergency. Amateur service HF and VHF allocations are used for this purpose. The word “amateur” can be misleading, as stations in the amateur service are also involved in fundamental ionospheric and propagation research. It is self-evident that any significant degradation of the background noise level will adversely impact the service’s capability in all these areas.

Precedents have been set to recognise the need for protection of amateur service frequencies in standards and limits relating to Power Line Telecommunications [6], DSL services [7] and Gfast [8]. 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 paper.

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 2 represents a schematic representation of a typical WPT-EV domestic installation co-sited with an installation in the amateur service. It will be noted that it is entirely feasible (indeed likely in many cases) that the antenna for the amateur service installation is within 10m of the WPT installation.

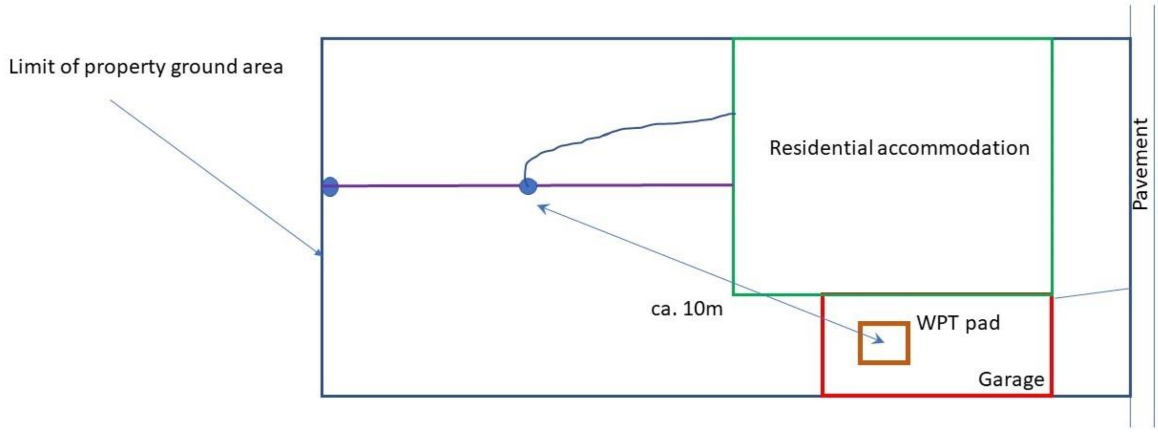


Figure 2 – schematic of a typical dwelling house location in the UK

4 Levels of emissions in the spurious domain

The present ITU limits for emissions in the spurious domain from short range devices are defined in ITU-R SM.329-12 [5]. These limits do not, of themselves, claim to provide adequate protection from harmful interference, but there is evidence that they are being taken as a planning basis by some developers of WPT systems. Nonetheless, taking these limits as a basis for system performance allows an assessment to be made of the gap between proper protection of stations in the amateur service and WPT-EV emissions, should these be at the limit set out in SM.329-12.

Figure 3 below shows the levels from SM.329-13 and P.372-12. It will be seen that there is a very significant gap between these levels. **Spurious emissions at the SM.329-12 level will exceed the noise level by 40-50 dB, which would clearly have a very harmful effect on radio services operating at low signal to noise ratios**. The basis for the data in this graph is set out in Annex 2.

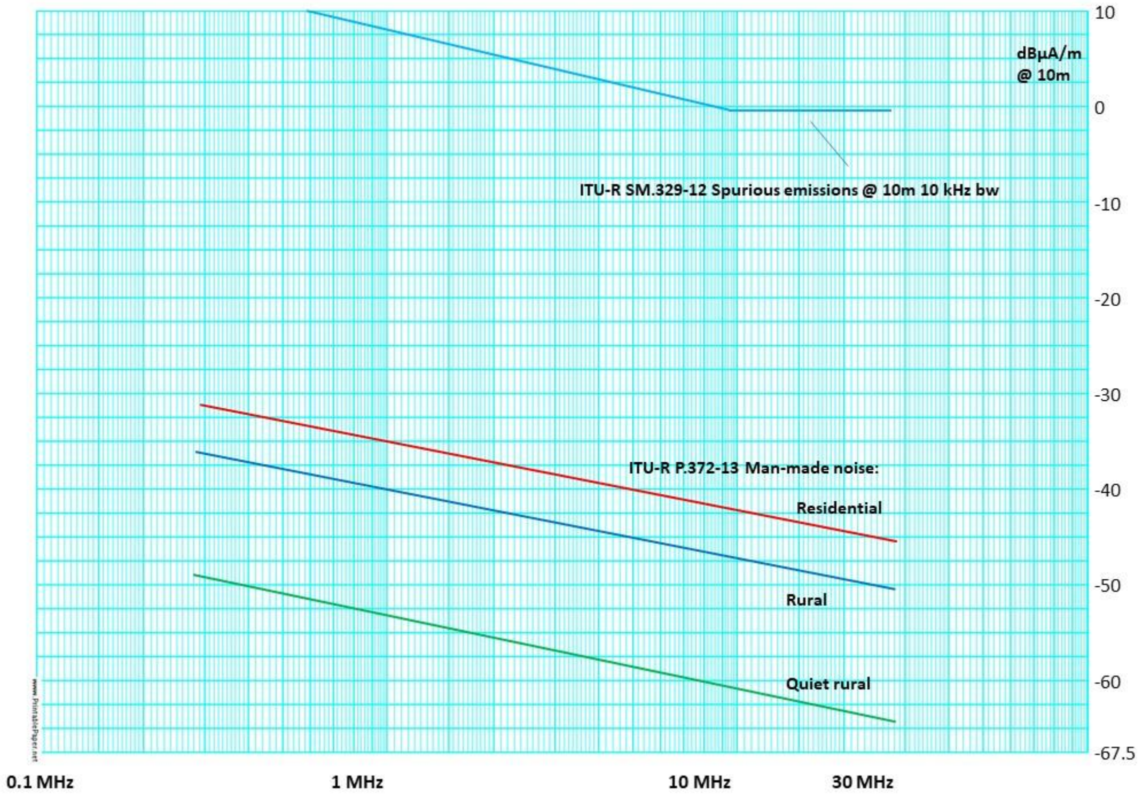


Figure 3: Graphical representation of ITU_R SM.329-12 emissions limits compared with background noise levels in ITU-R P.372-13

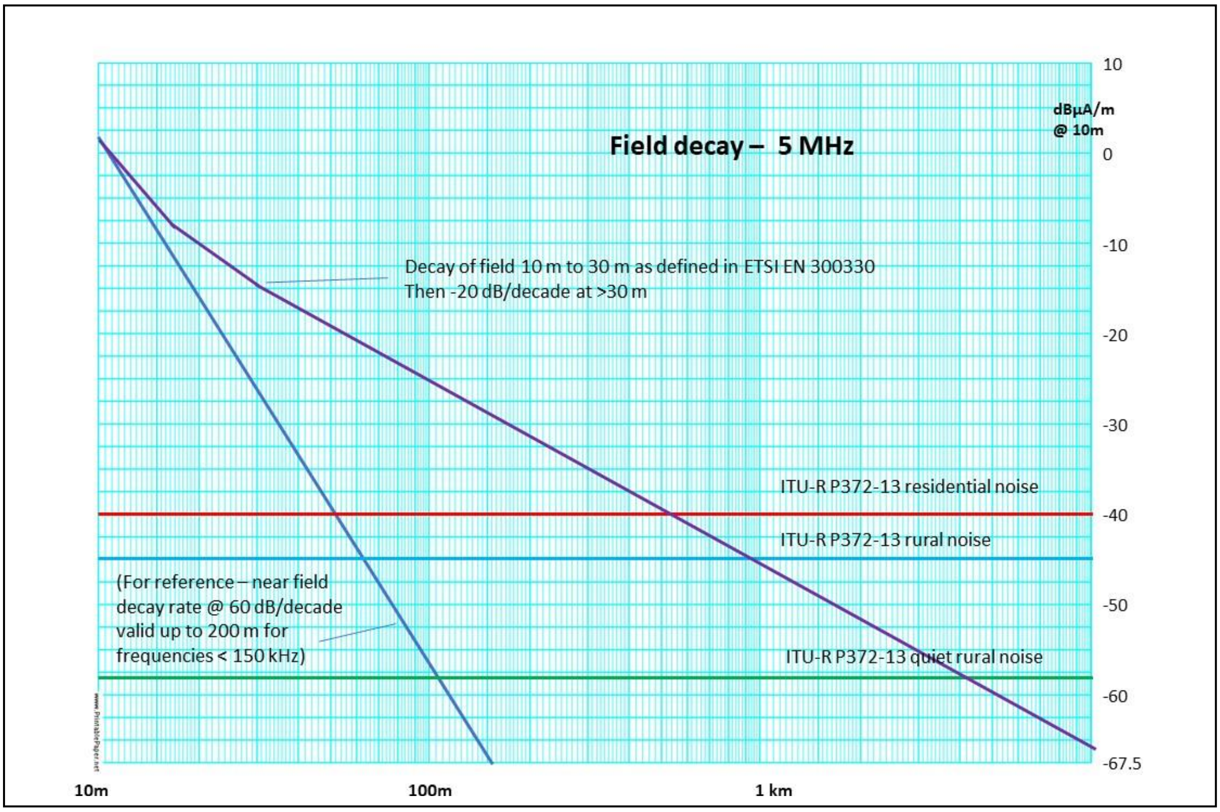
Furthermore, the characteristics of the emissions from inductive devices is being defined in, inter alia, the draft Harmonised Standard ETSI SM 300330 [11]. Although previous modelling has often assumed a “near-field” decay rate of 60 dB/distance decade, the ETSI document shows that decay rates of the emissions depend on frequency. Appendix I of EN 300330 sets out the relevant decay rates for adjustments of measuring distance from 10m to 30m and combining this with other data on near-field to far-field transition distances allows an assessment to be made of the emissions from a WPT-Electric Vehicle systems with emissions (measured at 10m) at the limit of ITU-R SM-329.

Using this data, the plots on the next page (figures 4a and 4b) show the projected emission field at

5 MHz and 10MHz arising from harmonics of the WPT system which are at the SM-329 limit when measured at 10m.

It will be seen that at 5MHz, the emissions exceed the rural background noise at distances of up to 250m from the WPT installation and at 10 MHz this distance increases to 1.5 km. This gives added weight to the argument that spurious emissions measured at 10m need to be very significantly below the limits in ITU-R SM 329-12 to prevent harmful interference to radio services.

Given the planned density of WPT-Electric Vehicle systems, there will be a widespread and serious impact on radio communications operating in the vicinity should spurious emissions, measured at 10m be at the limits set in ITU-R SM329-12 (which broadly corresponds to the limits of CEPT ERC Rec 74-01).



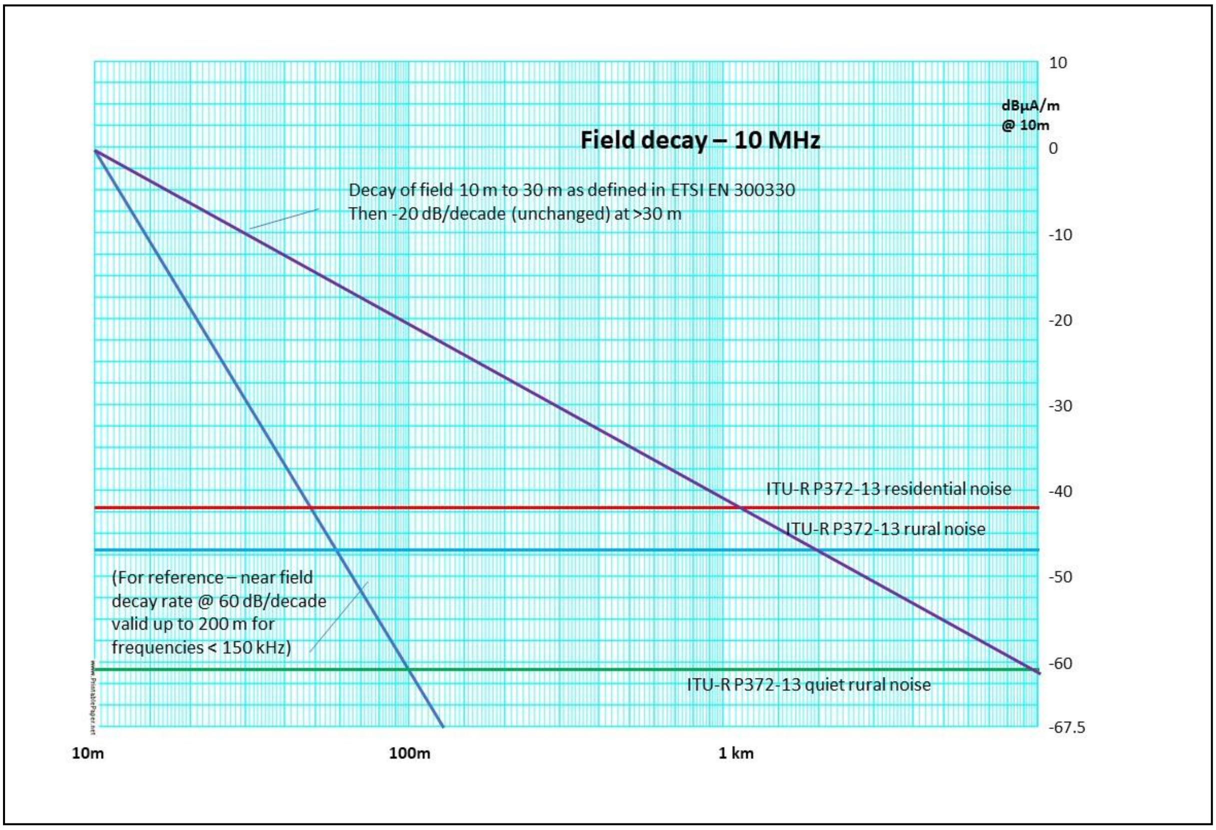


Fig 4a and 4b – emission decay at 5 MHz and 10MHz based on EN 300330

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 [9]. This provides a reasonable level of protection.

ITU-R SM.329-12 currently sets the limits for spurious emissions as:

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 ≤ 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)

Taking this with reference to the residential and rural lines of ITU-R P.372-13, and assuming that WPT(EV) emissions are unstable in frequency or are ***not*** all exactly on a common frequency and/or with levels of phase or sideband broadband noise, then this gives a maximum permissible spurious emission of approximately:

-21.5 -10 log(f (kHz)/9) dBμA/m for 9kHz < f < 10MHz and

-52 dBμA/m for 10MHz < f < 30MHz

- when measured in 10kHz bandwidth and at 10m distance.

Similar degrees of improvement 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 then harmonics of the pure sinusoid could reasonably be permitted to exceed the above level by some 20 dB.

6 Measuring existing systems

A study of some of the data submitted on measurements of existing WPT 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 -158dBm/Hz is needed to perform a meaningful measurement. Noise in the measuring system (particularly the active antenna) presents a false impression of the true background noise levels. In particular the studies included in the current ITU-R PDNR for WRC Agenda Item 9.1.6, present an inaccurate picture of the true noise levels through use of inappropriate measuring equipment Annex 3 seeks to summarise these issues.

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, new test methods and procedures will be needed to be specified

6 Summary

Preservation of the utility of the radio spectrum must be a prime objective in the introduction of new technologies; this is enshrined in Articles 15.12 and 15.13 of the Radio Regulations [10]. WPT for Electric Vehicles will cause significant and widespread damage to the radio spectrum unless appropriate standards and limits are established which are significantly more stringent than those existing at present. **This study shows that existing limits fail to provide adequate protection and that a tightening of these limits is an essential element of the introduction of WPT (EV) technology. Without this, co-existence of radio communications services and WPT-Electric Vehicle systems in the same environment is not viable.**

ANNEX 1: LIST OF REFERENCES

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

[2] ITU-R P.372-13 – Radio Noise (09/2016)

[3] ITU-R R12-WP3L-0094: Study on the present condition of man-made noise derived from the SG 3 radio noise databank (27 August 2014)

[4] ITU-R R15-WP5B-C-0411 Working document towards A Preliminary Draft New Report ITU-R M.[HF NOISE AT SEA]

[5] ITU-R SM.329-12 Unwanted emissions in the spurious domain (09/2012)

[6] 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

[7] 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); https://www.itu.int/rec/T-REC-G.993.2

[8] 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) https://www.itu.int/rec/T-REC-G.9700-201706-I!Amd2/en

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

[10] Radio Regulations:

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.

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.

[11] EN300330 Short Range Devices (SRD); Radio equipment in the frequency range 9 kHz to 25 MHz and inductive loop systems in the frequency range 9 kHz to 30 MHz; Harmonised Standard (draft) covering the essential requirements of article 3.2 of the Directive 2014/53/EU

Annex 2 – data sources for Figure 3 and 4a/4b

(a) ITU-R SM.329-12 Unwanted Emissions in the Spurious Domain

Table 3 – Short range devices – limits stated as:

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 ≤ except frequencies below < 1 GHz
–54 dBm for 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)
All in 10 kHz bandwidth, measured at 10m distance

This computes to:

Freq	**Limit per Table 3**
kHz	**dbµA/m**
100	18.5
1,000	8.5
10,000	-1.5

(b) ITU-R P.372-13 – Radio Noise

Background Noise

For a vertical monopole: $E_n = F_a + 20 \log f_{MHz} + B - 95.5$ dBµV/m

or $E_n = F_a + 20 \log f_{MHz} + B - 95.5 - 51.5$ dBµA/m*

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

** Converted at the impedance of free space*

This computes to:

	Freq	*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*

(c) Emissions decay rate – EN 300330

The rate of decay of the field of spurious emissions has been computed from the draft EN 300330 European Harmonised Standard. 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. The graphs in Appendix I of the document can be used to arrive at a decay rate for any specific frequency. The higher the frequency the more the decay rate approaches the “far-field” decay rate of 20 dB/decade.

The relevant graph below is an indication of the adjustments to be made when computing decay rates.

I.1 Limits for measurements at 30 m distance

The H-field limit at 30 m, H_{30m}, is determined by the following equation:

$$H_{30m} = H_{10m} + C_{30} \qquad (I.1)$$

where:

H_{10m} is the H-field limit in dBµA/m at 10 m distance according to the present document; and

C_{30} is a conversion factor in dB which is determined from figure I.1.

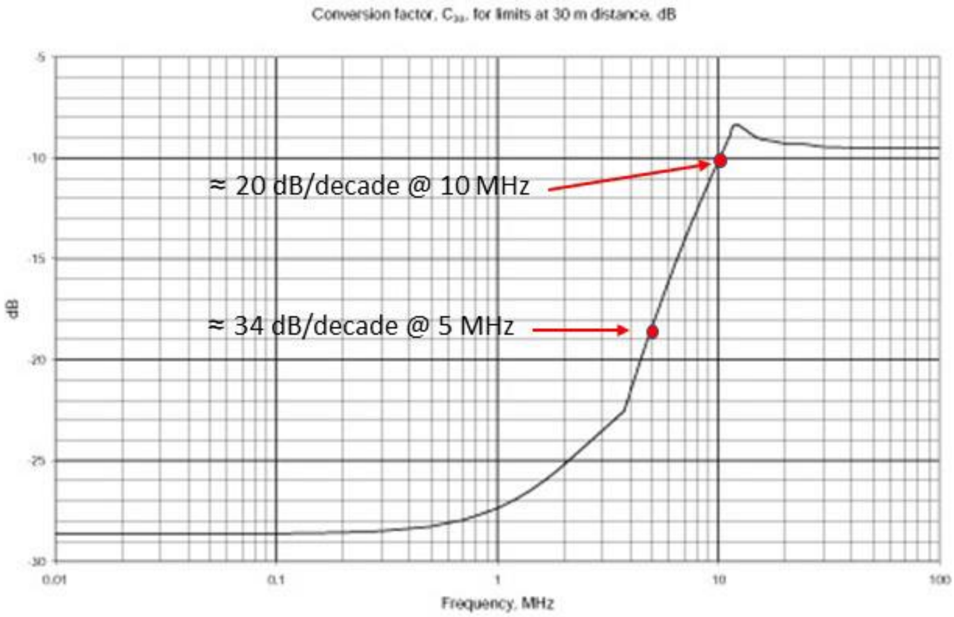


Figure I.1: Conversion factor C_{30} versus frequency

Figure A2.1 – Extract from ETSI EN 300330 Appendix I

Annex 3

Measurement methodologies for emissions from WPT(EV) systems

H-field radiated emissions may be measured using an active measuring loop antenna according to EN55016, sections 4.3.2 and 4.4.2 (see Ref. 1).

It should be noted that for an untuned electrically-screened active loop antenna, the measuring system noise floor will generally be determined by the noise of the pre-amplifier in the active antenna. This measuring system noise is generally substantially higher than the man-made noise or natural atmospheric noise at all ITU-R P.372-13 environmental categories, i.e. City, Residential, Rural and Quiet Rural.

A note in EN55016 Section 4.4.2 states that tuned electrically balanced loop antennas may be used to make measurements of magnetic field strengths lower than with untuned electrically-screened loop antennas where the noise level is approximately 25 dB higher.

The use of a measuring system with a relatively high measuring system noise floor has two consequences:

- The measuring system is not representative of some radio communication systems that are to be protected by EMC standards.
- The true background man-made or atmospheric noise level cannot be measured as it is substantially lower than the measuring system noise floor.

The measuring system noise floor for various measuring antennas compared with

ITU-R .P372-13 median man-made noise levels is shown in Figure 3 below. All field strengths are either average or RMS in 9 kHz bandwidth.

Curve 'A' shows the smallest detectable field strength (average) for a Rohde and Schwarz HFH2-Z2 active loop antenna. This is derived from the typical values given on the manufacturer's data sheet.

Curve 'B' shows the smallest detectable field strength (RMS) for a Schaffner-Chase HLA6120 active loop antenna. This is derived from measurements made in a shielded enclosure.

Curve 'C' shows the noise floor (RMS) of a custom version of the Schaffner-Chase HLA6120 that is 30 cm diameter instead of the standard 60 cm diameter type. This antenna was used by Ofcom for WPT tests and its use results in a measuring system noise floor that is 8 - 9 dB higher than the standard 60 cm antenna.

Curve 'D' shows the field strength sensitivity for 0 dB SNR for the Rohde and Schwarz HM525 loop. This antenna has five switched ranges A - F. It is designed for laboratory use and would require a suitable non-conductive cover for outdoor use. The curve is derived from the typical values given on the manufacturer's data sheet, using the most sensitive range at each frequency.

Curve 'E' shows the measured noise floor (average) of a set of tuned loops type AY3920. These allow a measuring system noise floor, equivalent to 0 dB(μV/m) or lower, to be achieved from 1 MHz to 30 MHz.

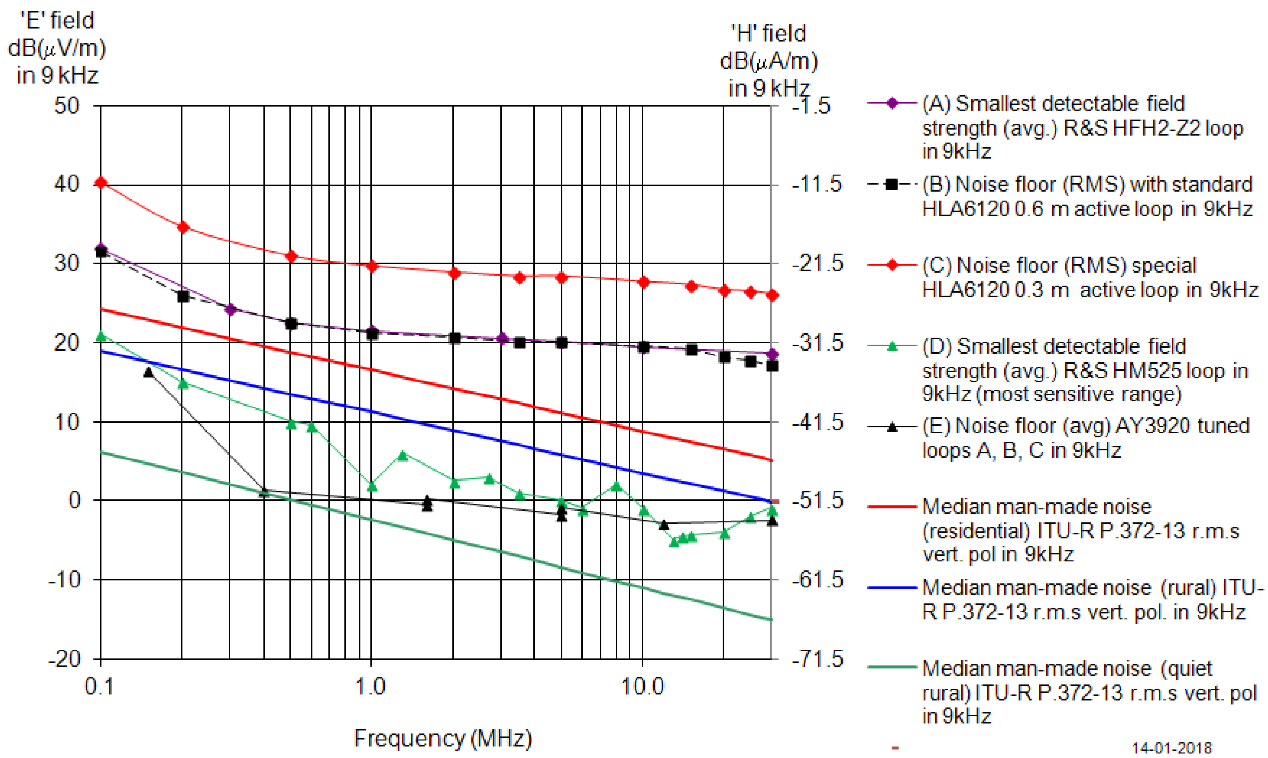


Figure 3: Measuring system noise floor for various measuring antennas compared with ITU-R P.372-13 noise levels

References

[1] 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