UNWANTED EMISSIONS IN THE SPURIOUS DOMAIN FROM WIRELESS POWER TRANSFER SYSTEMS

1 Introduction

This document sets out an analysis of the impact of WPT systems on radio communications in the amateur service. Prime consideration is given to systems operating in the 100-148.5 kHz range. A separate report has been submitted to the studies now completed on WPT-EV. Data for the analysis is drawn from published information about the amateur service, WPT 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.

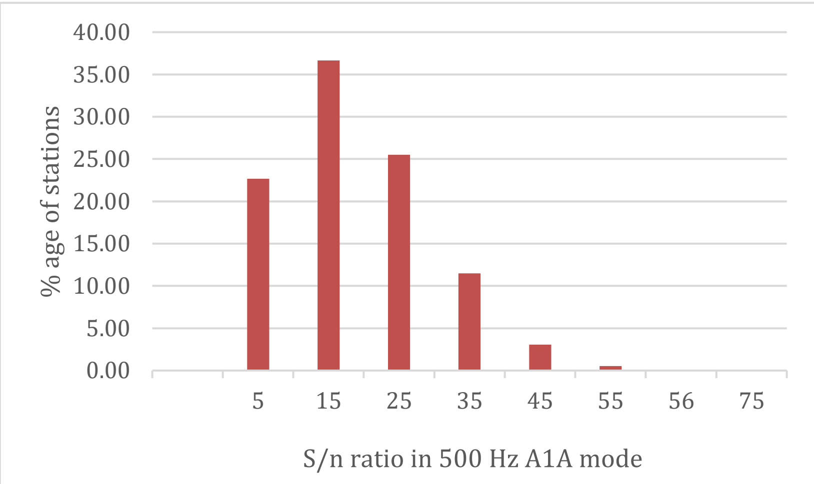


Figure 1: Distribution of typical S/N ratio in amateur service communications

This chart confirms that any significant raising of the background noise level will have a significant impact on amateur service communications, as the majority of communication is currently 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. 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.

Precedents have been set to recognise the need for protection of amateur service frequencies in standards and limits relating to Power Line Telecommunications [5], DSL services [6] and Gfast [7]. It is worthy of note that the level of additional protection enshrined in, for example, the PLT limits in CISPR are of the same order as are proposed later in this document.

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

4 Levels of emissions in the spurious domain

The present ITU limits for emissions in the spurious domain from short range devices are currently defined in ITU-R SM.329-12 [3]. The equivalent CEPT limits are in ERC Rec 74-01 [4]. These limits (hereafter called "*the current spurious emission limits*") appear to have been taken as a representative emission limit for design of WPT systems, so 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 current spurious emission limits.

Figure 2 below shows the current spurious emission and P.372-12. It will be seen that there is a very significant gap between these levels. Spurious emissions at the current spurious emission limits 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.

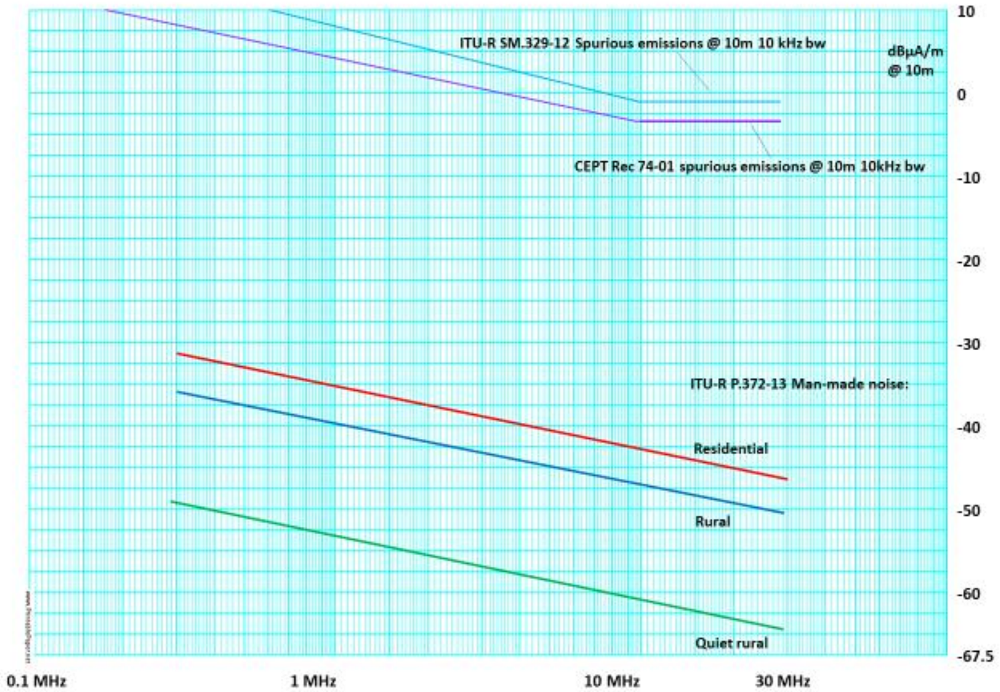


Figure 2: Graphical representation of the current spurious emission limits compared with background noise levels in ITU-R P.372-13

Decay rates of emissions from a WPT unit in the near field are 60 dB/distance decade. When transition takes place to the far field (at a distance of some $\lambda / 2\pi$) the rate decreases to 20dB/distance decade. This is shown in Annex I of EN 300330 [10].

Using this data, the plots on the following page (figures 3a and 3b) show the projected emission field at 5 MHz and 10MHz at increasing distance from the WPT system, arising from harmonics of the WPT system operating at the current spurious emission limits.

It will be seen that at 5MHz, the emissions exceed the rural background noise at distances of up to 800m from the WPT installation and at 10 MHz this distance increases to 1.5 km+.

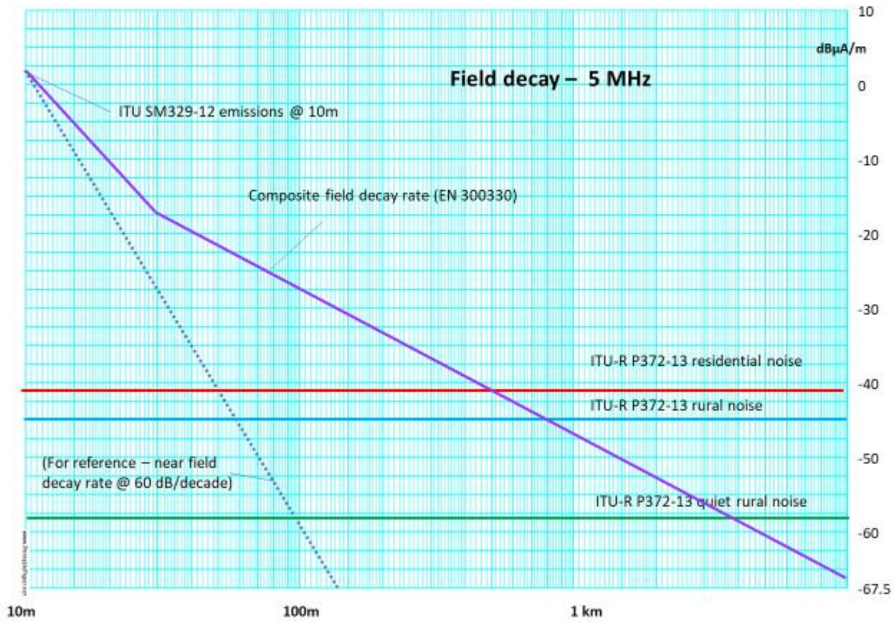


Figure 3a: Decay rate of emissions with distance at 5MHz

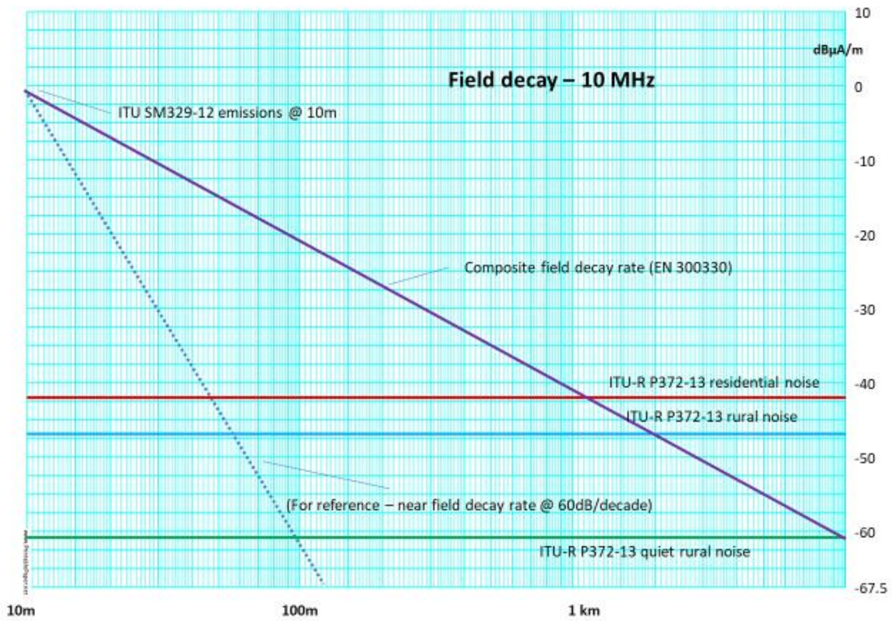


Figure 3b: Decay rate of emissions with distance at 10 MHz

The above graphs assume a WPT device which operates at the current spurious emission limits of ITU SM.329, but in effect this is almost identical to ERC 74-01). Should there be adequate protection distance between the WPT device and the radio receiver, this may not be a problem. However, modelling of the projected installed density provided by WPT manufacturers (Section 5 below) allows the real-life maximum protection distance to be determined. This then leads to an understanding of the minimum expected level of interferer if the WPT devices operate at the existing spurious / harmonic emission limit.

5 Probability of Impact

The data provided by WPT developers can be used to help model the likely levels of interference if WPT devices operate at the current spurious emission limits.

A working document submitted to SE24 in conjunction with WPT developers sets out a summary of the current limits which are assumed to apply to generic SRD inductive WPT devices, together with use data and projected deployment density. From that data, Table 2 below summarises a few examples of devices that are expected to be deployed, with power levels and installation density.

Device type	Frequency range	Power	Operating duration (hrs/day)	Installed density (units / km²)
Mobile phone charger	90 kHz – 13.567 MHz	1W<P ≤ 5W	8	5,000
Tablets/notebooks etc	90 kHz – 13.567 MHz	5W < P < 31.5W	8	5,000
Power tools	90 – 205 kHz	P < 200W	8	Up to 6,700
Kitchen appliances	20-79 kHz	P < 2.4kW	2.5	1/household

Table 2 Projected installed densities of various non-EV inductive SRD WPT devices

All the above devices are stated as currently being subject to the current spurious emission limits.

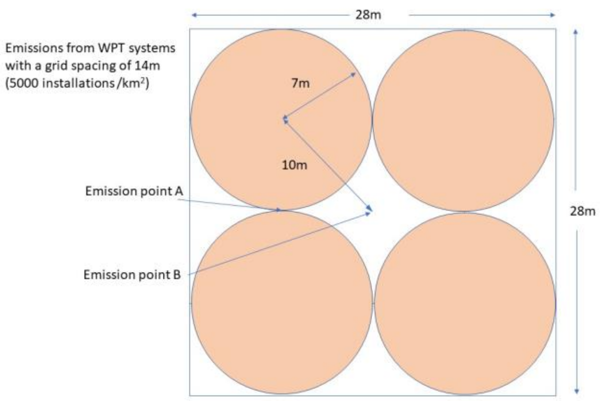
To translate this to a physical installed density a linear distribution of these units on a grid. This gives a grid of 14m spacing. These grid spacings can then be developed to ascertain distances from each point source for assessing emission levels.

There are two distances for consideration:

a) The half-way point between two point sources (Emission point A). Self evidently this is 7m. At this point, the victim receiver is subject to emissions of equal strength from two WPT systems (and lower emissions from others).

b) The furthest distance that a victim receiver can statistically be located – which is 10m – is simply determined through Pythagoras ($7 \times \sqrt{2}$) - Emission point B. At these points the victim receiver is subject to emissions at equal strength from the four nearest systems. This is the maximum distance a receiver can be located from a WPT device in this deployment density. See figure 4

Figure 4: Average installation density of generic WPT systems



This coincidentally results in each radio receiver in the surrounding area being subjected to emissions at the 10m distance at the current spurious emission limits. For 78.5% of them, which are within the 7m radius, the emissions are 9.3 dB above that level (60 x $\log_{10}$ (10/7))

This confirms that spurious emissions measured at 10m need to be very significantly below the current spurious emission limits to prevent harmful interference to radio services.

6 The location and nature of WPT installations

WPT systems (operating in the 100-148.5 kHz range) are planned for the home environment and typical use scenarios have these devices located in any living room in residential premises.

Antennas in use in the amateur service can be expected to be 10m away from the device in most cases and so it is helpful to consider the emissions limits at the standard measurement distance of 10m.

WPT emissions are of long duration (hours) and can vary in frequency within the range set aside for such systems. They therefore differ from the typical short-term emissions of many SRD devices, which is how CEPT classifies WPT devices. Density projections for WPT systems (CEPT ECC Report 289 – Annex 5) suggest that low power devices could exceed 5,000 units per km^2. Section 5 above has modelled the impact of this on the *minimum* expected levels of spurious emissions at a receiving antenna for a WPT device operating at the current emission limits

7 The impact of the spurious emissions

Radiocommunications services protection ratios are set out in ITU-R F.240 (Signal-to-interference protection ratios for various classes of emission in the fixed service below about 30 MHz). Most HF radiocommunication services rely on operating with a relatively modest signal-to-noise ratio, implying that the received signal is as little as 10-15 dB above the background noise for effective communication. Figure 5 below shows the wide gap between the current spurious emission limits and the background noise level. It will be seen, for example, at 5 MHz, the limits are some 35-40 dB above the residential background noise level and, self-evidently significantly above the signal level in typical point-to-point radiocommunications services.

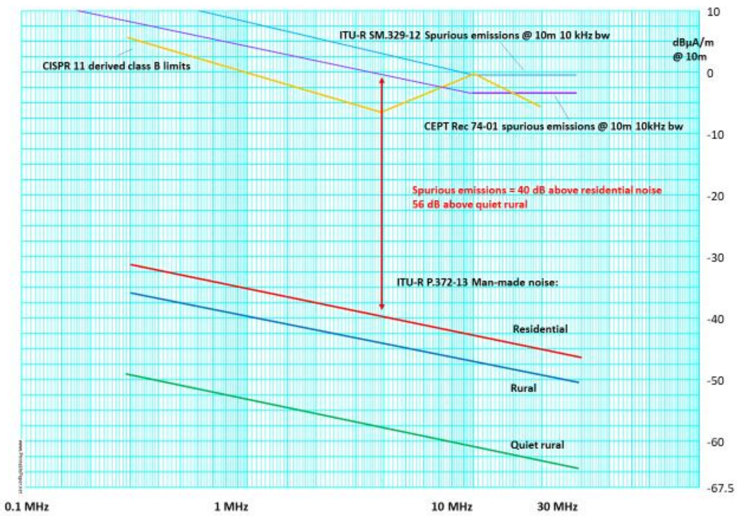


Fig 5 ERC 74-01, ITU-R SM.329-12 and CISPR 11 compared to ITU-R P.372-13 noise levels

The data earlier in this document has been developed on the basis that WPT devices use the full scope offered by the current spurious emission limits. A number of factors make the nature of spurious emissions from WPT systems particularly harmful to radiocommunications services. These are:

- WPT systems are **high duty cycle**, meaning the interference from such systems cannot be treated as “transient” or short term.

- As shown in section 5, generic WPT systems are projected for **high density deployment,** meaning that proximity to radio receivers is assured

- A number of WPT systems adjust their operating frequency to achieve optimum coupling to the device being charged. WPT-EV systems are planned to use a relatively low operating frequency. The higher order harmonics of the operating frequency can lie anywhere in the HF spectrum. Table 3 below shows the occurrence of harmonics at around 2 MHz from WPT systems operating within the full projected range (100-148.5 kHz).

Reception MHz ->	**frequency**	1.8	1.81	1.82	1.83	1.84	1.85	1.86	1.87	1.88	1.89	1.9	2
Interferer	**Harmonic**												
100-148.5 kHz	n=18	100 kHz										111.1 kHz	
	n=17	105.8 kHz										117.6 kHz	
	n=16	112.5 kHz										125.0 kHz	
	n=15	120 kHz										133.3 kHz	
	n=14	128.5 kHz										142.8 kHz	

Table 3: Impact of WPT harmonics in the 2 MHz region.

It will be seen that, taking each harmonic in turn shows spurious emission sin the 1.8 – 2 MHz range based on a different fundamental frequency of the WPT. Often there is overlap between the n^{th} harmonic and the $n+1^{th}$ etc, meaning that **no frequency is immune to spurious emissions**. This pattern continues at higher frequencies in the radio spectrum. It can only be avoided if WPT adopts a single tightly controlled operating frequency. Under circumstances where the operating frequency is not mandated in that way, a calculation of the probability of frequency coincidence (ie the wanted signal being on the same frequency channel as the interferer) shows that this ranges from 30% to 40% for the broadcast service and slightly lower for the amateur service.

The above sections of this study show that the necessary protection distance between WPT installations and sensitive HF spectrum receivers can be in the order of hundreds of metres where the WPT systems operate at the current spurious emission limits.

Data has been submitted to both CEPT and ITU which suggests that emissions from generic low power WPT systems are below the SM.329 levels. This suggests that there is scope to define a more stringent emission limit, so that future products will not be developed which exploit the full current limit with the inevitable resulting impact on radiocommunications services.

8 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)

So based on the inevitable proximity of WPT systems to radio receivers/antennas, and 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*

9 Measuring existing systems

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.

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.

Nonetheless, measurements taken of a number of representative low power WPT devices (up to 15 W) paint a hopeful picture of the emission levels. Annex 1 (file embedded in this document) summarises the results of a series of tests conducted on a sample of devices. Despite the concerns expressed above about the potential for harmful interference to radiocommunication services, measurements taken of a sample of WPT systems suggest that their performance is relatively close to this required emission limit set out above.

No measurements have been conducted on the intermediate power range systems (> 15W) and so no conclusions can be drawn about typical system performance of these systems.

6 Summary

This study shows that the current spurious emission limits fail to provide adequate protection at representative separation distances between WPT devices and radio antennas. The necessary separation distances to ensure adequate protection are impractical. This therefore points to a need to tighten the current spurious emission limits. Without this, co-existence of radio communications services and WPT systems in the same environment is not viable without protection distances which are operationally impractical. It is therefore clear that, given the planned density of these WPT systems, there will be a widespread and serious impact on radio communications operating in the vicinity should spurious emissions, measured at 10m remain at the current spurious emission limits.

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 [9]. Those low power WPT systems which have been tested, however, appear to offer spurious and harmonic emission levels which may allow satisfactory coexistence with radiocommunication services subject to all products meeting matching the performance of the sample tested.

In the interests of preventing other products entering the market with substantially worse performance, an emission level for WPT systems should be defined which ensures that spurious / harmonic emissions continue to be at levels which allow radiocommunications services to operate as intended.

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 SM.329-12 Unwanted emissions in the spurious domain (09/2012)
[4] CEPT ERC Rec 74-01 Unwanted emissions in the spurious domain
[5] 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
[6] 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
[7] 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
[8] ITU-R SM.2158 Impact of power line telecommunication systems on radiocommunication systems operating below 80 MHz
[9] 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.
[10] 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: $En = Fa + 20 \log fMHz + B - 95.5\ dB\mu V/m$

or $En = Fa + 20 \log fMHz + B - 95.5 - 51.5\ dB\mu A/m$*

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.

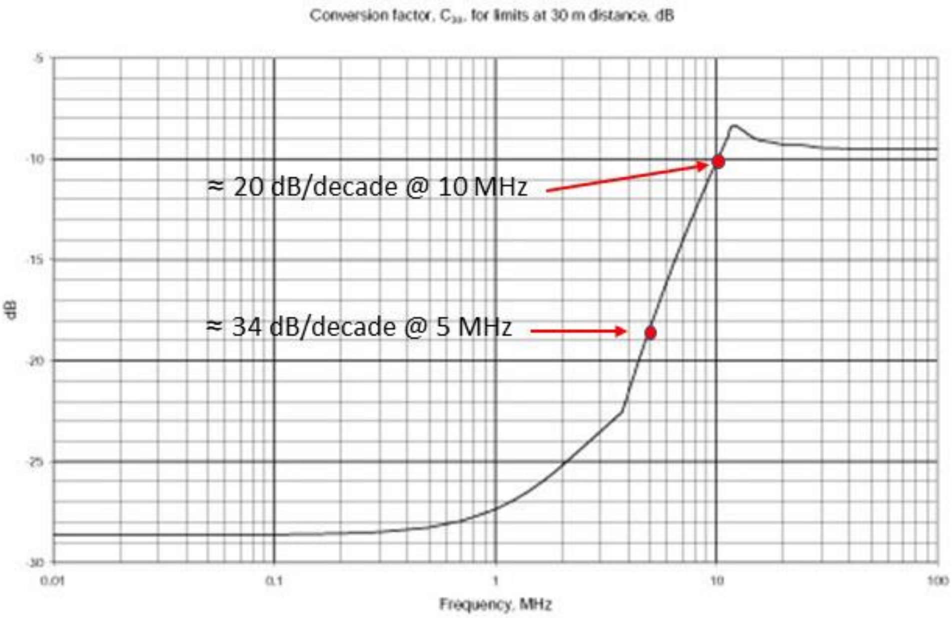


Figure I.1: Conversion factor C_{30} versus frequency

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