International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Report ITU-R SM.2449-0

(06/2019)

Technical characteristics and impact analyses of non-beam inductive wireless power transmission for mobile and portable deviceson radiocommunication services

SM Series

Spectrum management

International Telecommunication Union

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

Electronic Publication
Geneva, 2019

REPORT ITU-R SM.2449-0

Technical characteristics and impact analyses of non-beam inductive wireless power transmission for mobile and portable devices on radiocommunication services

(Question ITU-R 210-3/1)

(2019)

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1 Introduction[1]

With the increased demand for wireless devices and global mobility, wireless power transmission (WPT) technologies for powering these devices has evolved and are now readily accessible worldwide for consumers. ITU-R conducted preliminary assessments of non-beam inductive WPT applications, including the various use cases, overarching technical characteristics and the corresponding regulatory conditions in several countries. This work was completed in response to Question ITU-R 210-3/1 and can be found in Report ITU-R SM.2303 – Wireless power transmission using technologies other than radio frequency beam, and parts of Recommendation ITU-R SM.2110.

This Report intends to expand on the existing work conducted on inductive non-beam WPT, specifically for mobile and portable device applications in the 100-148.5 kHz frequency range using power transfers of up to 15 Watts. Due to the different operational characteristics, frequency ranges and information availability, higher power non-beam WPT applications such as electric vehicle charging and home appliances are outside the scope of this Report. The conclusions of this Report intend to answer Question ITU-R 210-3/1 *decides* 2 on the steps to be taken to minimize the impact to incumbent radiocommunication services and demonstrate these devices operate in accordance with No. **15.12** of the Radio Regulations.

2 Existing applications for inductive mobile and portable device charging operating in the 100-148.5 kHz frequency range

Based on Report ITU-R SM.2303-1, inductive WPT technology is applied to mobile and portable devices such as smartphones, tablets and laptop computers. After this Report was published, inductive WPT technology is utilized for wearable devices such as smart watches and fitness tracking devices. Non-beam inductive WPT applications are currently available and authorized in several countries operating in the 100-148.5 kHz frequency range.

Non-beam inductive charging generally requires direct contact between the charging device and the power source. When direct contact is made and charging begins, the emission power is assumed to be below 15 watts. Once the contact is broken the device stops charging; however the device may emit some energy for device detection purposes only. Section 4 of this Report outlines the operations and technical characteristics of non-beam induction WPT applications operating in the 100-148.5 kHz frequency range in further detail.

3 International standards for non-beam inductive wireless power transmission application in the 100-148.5 kHz frequency range

The available international standards for non-beam inductive WPT applications are contained in section 4 of Report ITU-R SM.2303-1.

WPT applications may be considered industrial, scientific and medical (ISM) (see RR Nos. **1.15** and **15.13**), generally, if there is no data communication between the charger and charging device. However, many administrations within their national spectrum regulations authorize WPT applications under rules associated with short range devices or as license-exempt applications as they are classified as intentional radiators.

[1] Two of the scenarios in the studies in this Report make use of building entry loss. Information from the responsible group in ITU-R was received that this has limited applicability.

4 Technical and operational characteristics of non-beam inductive WPT applications in the 100-148.5 kHz frequency range

4.1 Operational characteristics

Inductive non-beam WPT applications used for charging mobile and portable devices are used primarily indoors, such as in offices spaces and homes.

Most charging activity only occurs when direct contact is made between the charging device and power source. This activity usually only occurs for short durations until the battery of the charging device is full. Once the battery is completely charged, or if direct contact is broken, emissions drop significantly.

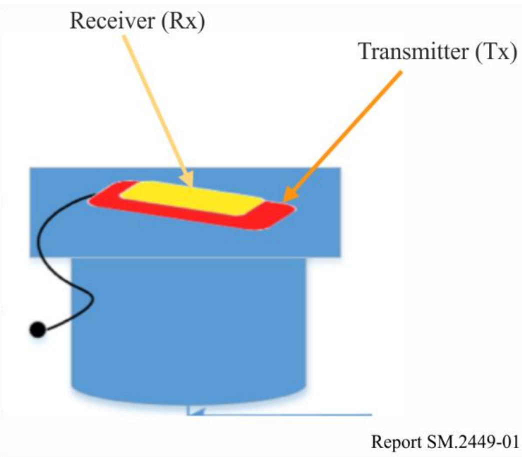
The applications included in this Report are available on the market and are certified under FCC license-exempt rules[2] as they are considered intentional radiators for the use and sale in the United States of America.

4.1.1 Charging scenarios

The testing was performed using both single-entry charging device (Fig. 1) and aggregate using five charging devices (Fig. 2).

FIGURE 1

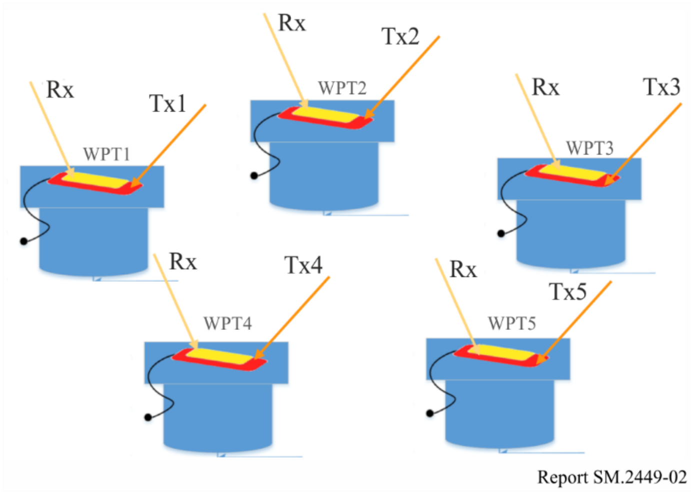
Depiction of single-entry deployment representative of a home environment



[2] 47 C.F.R. §§ 15 and 18 (2017).

FIGURE 2

Depiction of aggregate deployment representative of an office environment



4.2 Technical characteristics

TABLE 1

Operating mode

Bandwidth	417 Hz			
Power levels	Fundamental = −15 dBμV/m @ 300 m			
Field Strength	Fundamental = −15 dBμV/m @ 300 m			
Harmonic Content	**HD3**	**HD5**	**HD7**	**HD9**
	−24 dBμV/m @ 300 m	8.9 dBμV/m @ 30 m	6 dBμV/m @ 30 m	4 dBμV/m @ 30 m

5 Impact analyses with radiocommunication services

In accordance with RR Article **5**, the existing radiocommunication services allocated on a primary basis in the 100-148.5 kHz frequency range are the fixed, radionavigation (including aeronautical), maritime mobile, and maritime radionavigation services. In addition, the amateur service is allocated on a secondary basis in all three regions within the 135.7-137.8 kHz frequency band. The broadcasting service is allocated on a primary basis in Region 1 starting at the 148.5-255 kHz frequency band.

5.1 AM Broadcasting Study 1

The broadcasting service operates in the following frequency ranges:

– Region 1: 148.5-283.5 kHz and 526.5-1 606.5 kHz[3]

– Region 2: 525-1 625 kHz (subject to No. **5.89**)[4]

– Region 3: 526.5-1 606.5 kHz[3]

The testing conducted used non-beam induction WPT applications that operate in the 100-148.5 kHz frequency range. The testing was conducted using the 810 kHz channel, which is the 7th harmonic of the WPT applications. The 810 kHz channel is the closest channel that met the minimum signal strength requirements for AM broadcasting in the United States of America.

5.1.1 Test set-up

This study utilizes data collected through testing in a secured 3 m test chamber. Eight commercially available induction mobile device chargers were tested for interference into two commercially available AM radio receivers. The aggregate scenario used five of the eight mobile charging devices charging devices simultaneously.

The field strength was tested using a shielded loop antenna. Both the aggregate case and single device cases were measured against the two AM radios. The single-entry set-up is shown in Fig. 3 below.

FIGURE 3

Laboratory set-up for the single-entry case

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3 The broadcasting service is subject to the Plan established by the Geneva 1975 regional agreement 148.5-283.5 kHz Region 1 526.5-1 606.5 kHz Region 1 & 3 (Geneva, 1975).

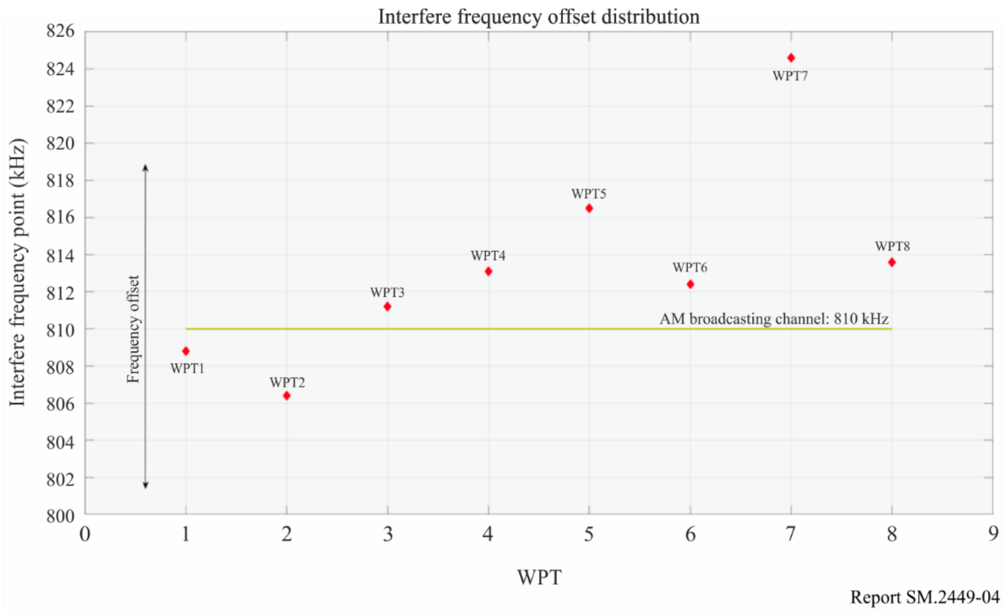
4 No. **5.89**: In Region 2, the use of the band 1 605-1 705 kHz by stations of the broadcasting service is subject to the Plan established by the Regional Administrative Radio Conference (Rio de Janeiro, 1988).

5.1.2 Subjective audible testing (single-entry and aggregate)

The section shows the data and results of the subjective audible testing. Figure 4 shows that all the 7th harmonics of the wireless chargers inside frequency offset range −4 kHz ~ +14.6 kHz. For the aggregate scenario, the wireless chargers are placed approximately 0.6 m apart from each other surrounding the AM receiver.

FIGURE 4

7th harmonic frequency distribution from wireless chargers



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The tested impact to both broadcasting receivers (AM1 and AM2) from each wireless charger is summarized in the following Figures and Tables. The Figures use three impact levels (see Table 2) to assess the level of audible noise each wireless charger caused to the AM receivers to plot the best and worst audible interference, level 1 being intolerable and level 3 being inaudible. The impact level decreases as the distances increases between the wireless charger and the AM receiver.

FIGURE 5

Receiver AM1 subjective audible test summary

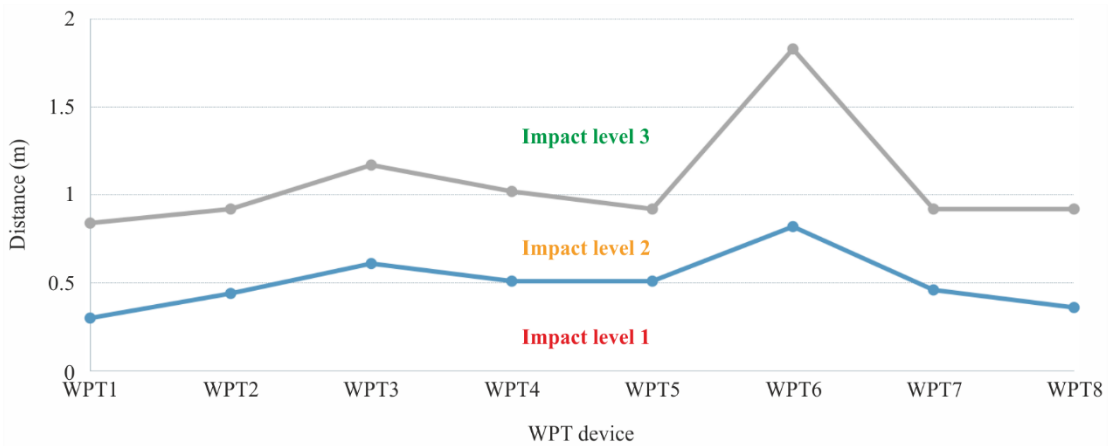

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FIGURE 6

Receiver AM2 subjective audible test summary

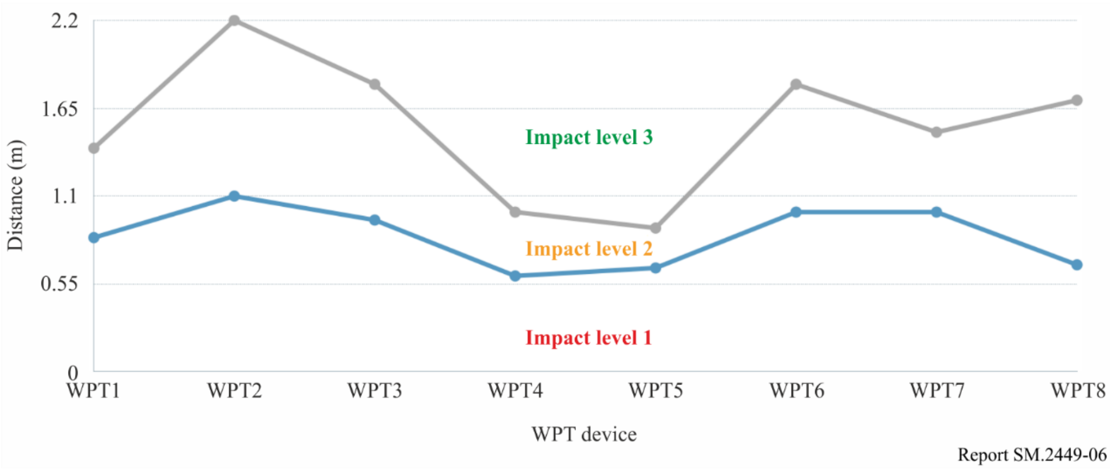


TABLE 2

Description of impact levels

Impact level	Definition
1	Noise intolerable
2	Noise audible, but tolerated
3	Noise non-audible

Tables 3 and 4 summarize the data results for the single-entry case with AM receivers AM1 and AM2. The two far right columns show the distances that correspond to Figs 5 and 6 above. For AM1, if the wireless charger is placed at a distance greater than 1.83 m there is no audible interference. As for AM2, placing the wireless charger at a distance of greater than 1.8 m eliminates audible interference.

TABLE 3

Subjective audible testing AM1 receiver single-entry summary

Wireless charger type	7th Harmonic field strength (dBµA/m) @ 3 m	7th harmonic field strength (dBµA/m) @ 10 m	AM radio signal strength (dBµV/m) (810 kHz channel)	Boundary between level 1 and level 2 (m)	Boundary between level 2 and level 3 (m)
WPT1	−22.06	**−53.36**	54.35	0.3	0.84
WPT2	−27.11	**−58.41**	54.35	0.44	0.92
WPT3	−12.65	**−43.95**	54.35	0.61	1.17
WPT4	−29.74	**−61.04**	54.35	0.51	1.02
WPT5	−16.02	**−47.32**	54.35	0.51	0.92
WPT6	−28.8	**−60.1**	54.35	0.82	1.83
WPT7	−7.04	**−38.34**	54.35	0.46	0.92
WPT8	−29.88	**−61.18**	54.35	0.36	0.92

TABLE 4

Subjective audible testing AM2 receiver single-entry summary

Wireless charger type	7th Harmonic field strength (dBμA/m) @ 3 m	7th harmonic field strength (dBμA/m) @ 10 m	AM radio signal strength (dBμV/m) (810 kHz channel)	Boundary between level 1 and level 2 (m)	Boundary between level 2 and level 3 (m)
WPT1	−22.06	**−53.36**	54.16	0.84	1.4
WPT2	−27.11	**−58.41**	54.16	1.1	2.2
WPT3	−12.65	**−43.95**	54.16	0.95	1.8
WPT4	−29.74	**−61.04**	54.16	0.6	1
WPT5	−16.02	**−47.32**	54.16	0.65	0.9
WPT6	−28.8	**−60.1**	54.16	1	1.8
WPT7	−7.04	**−38.34**	54.16	1	1.5
WPT8	−29.88	**−61.18**	54.16	0.67	1.7

Tables 5 and 6 show the results of the aggregate testing. The five wireless chargers used in this test were placed approximately 0.6 m from each other surrounding the AM receiver. Aggregate results for AM1 show that placing the five wireless chargers at a distance greater than 2.2 m prevents audible interference. For AM2, the five wireless chargers placed farther than 2.3 m will prevent audible interference to the receiver.

TABLE 5

Subjective audible testing AM1 receiver aggregate summary

<table>
<tr><th>Wireless charger type</th><th>7th Harmonic field strength (dBμA/m) @ 3 m</th><th>7th harmonic field strength (dBμA/m) @ 10 m</th><th>AM radio signal strength (dBμV/m) (810 kHz channel)</th><th>Boundary between level 1 and level 2 (m)</th><th>Boundary between level 2 and level 3 (m)</th></tr>
<tr><td>WPT1</td><td>−12.65</td><td>−43.95</td><td>54.16</td><td rowspan="5">1.2</td><td rowspan="5">2.2</td></tr>
<tr><td>WPT2</td><td>−29.74</td><td>−61.04</td><td>54.16</td></tr>
<tr><td>WPT3</td><td>−28.8</td><td>−60.1</td><td>54.16</td></tr>
<tr><td>WPT4</td><td>−7.04</td><td>−38.34</td><td>54.16</td></tr>
<tr><td>WPT5</td><td>−29.88</td><td>−61.18</td><td>54.16</td></tr>
</table>

TABLE 6

Subjective audible testing AM2 receiver aggregate summary

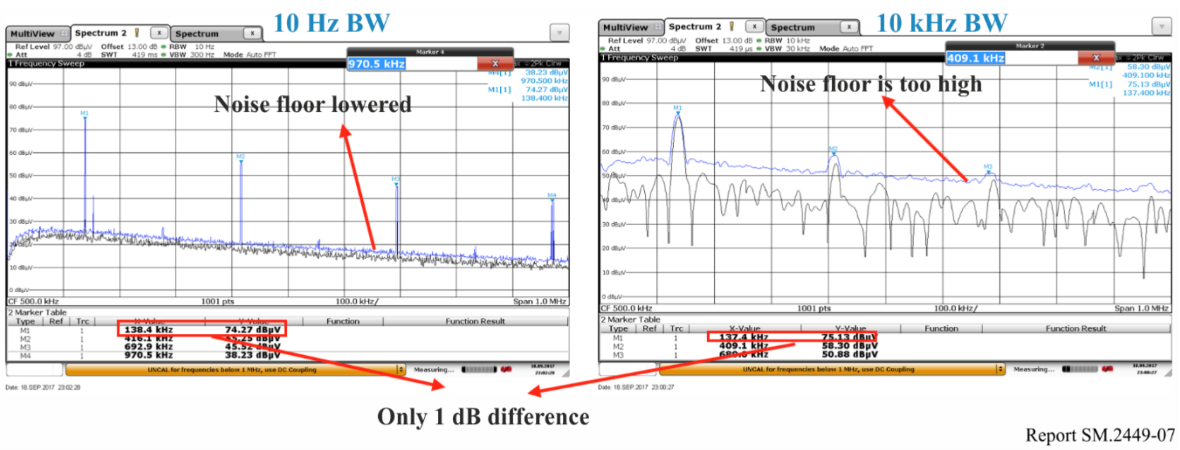
Wireless charger type	7th Harmonic field strength (dBµA/m) @ 3 m	7th harmonic field strength (dBµA/m) @ 10 m	AM radio signal strength (dBµV/m) (810 kHz channel)	Boundary between level 1 and level 2 (m)	Boundary between level 2 and level 3 (m)
WPT1	−12.65	**−43.95**	54.16	**1.1**	**2.3**
WPT2	−29.74	**−61.04**	54.16		
WPT3	−28.8	**−60.1**	54.16		
WPT4	−7.04	**−38.34**	54.16		
WPT5	−29.88	**−61.18**	54.16		

5.1.3 Open field strength quantification for WPT applications and AM receivers

Figure 7 shows the bandwidth setting for the WPT harmonic measurements and the visual justification for using 10 Hz. As shown in the Figure, the difference between 10 Hz bandwidth and 10 kHz bandwidth is only 1 dB, but drastically reduces the noise floor. In addition, the use of 10 Hz is more in alignment with the characteristics of the WPT signal. The WPT signal is similar to a sine wave and therefore has little to do with bandwidth. The change to 10 Hz also enabled a better understanding of what was needed for the measurements.

FIGURE 7

Bandwidth justification



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The AM receiver signal bandwidth setting is shown in Fig. 8. Based on the 1 dB difference, 10 Hz was also used for the AM receivers.

FIGURE 8

AM receiver bandwidth setting

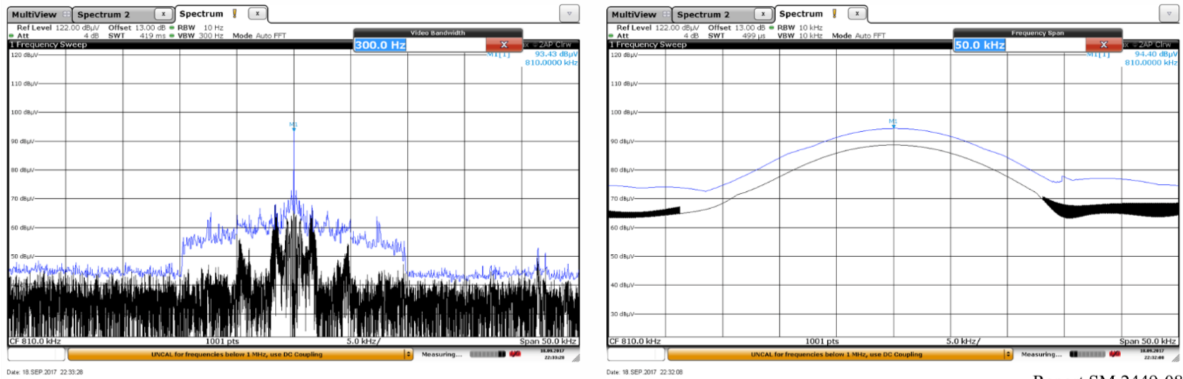

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FIGURE 9

7th harmonic field strength measurement at 3m

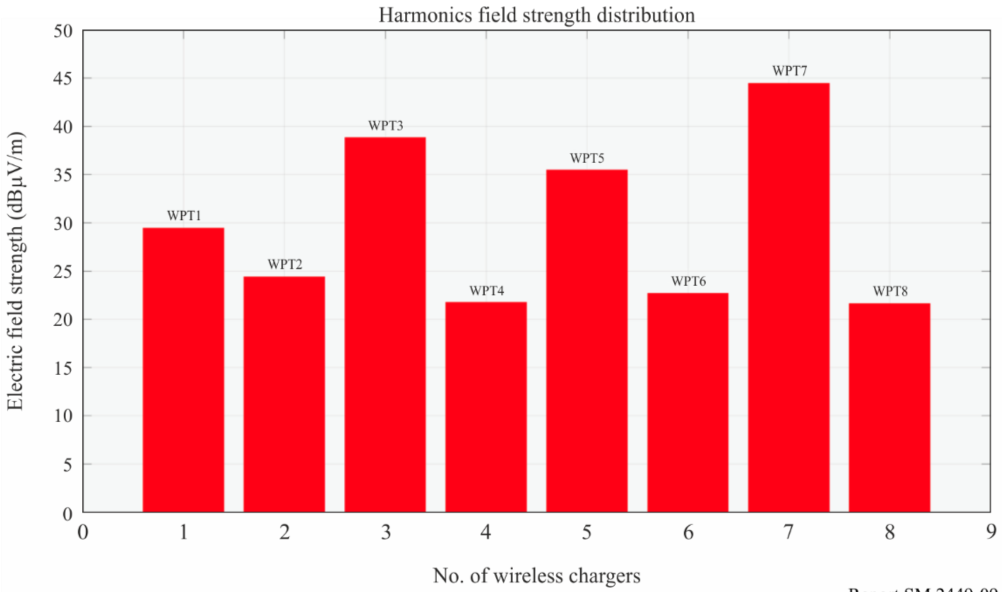

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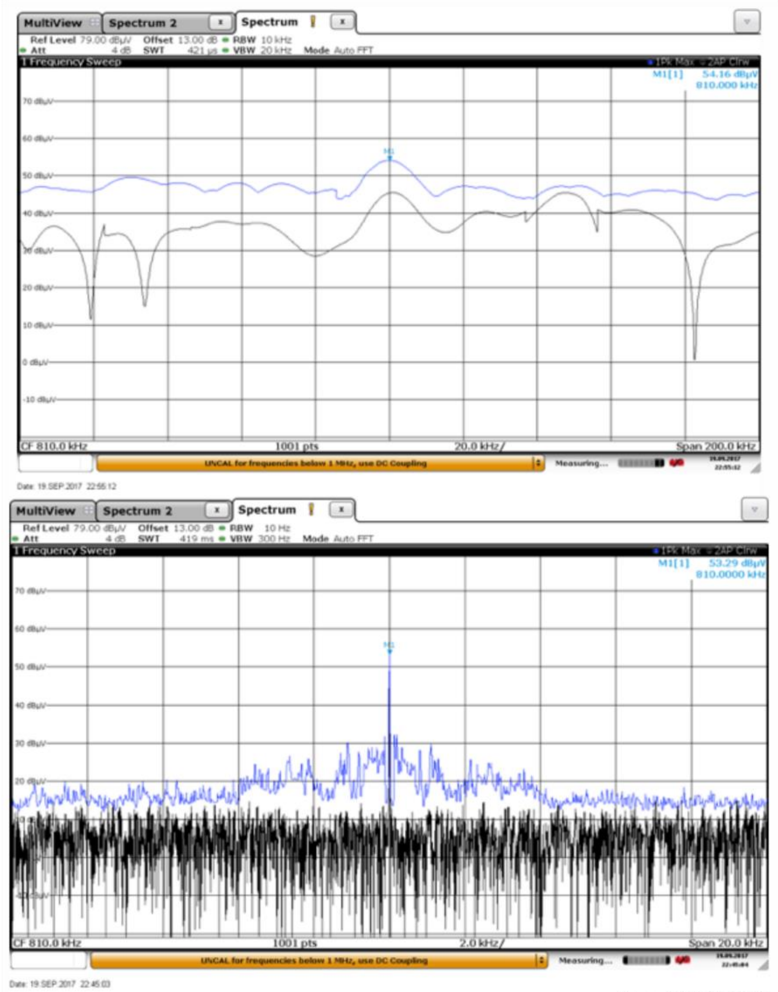
FIGURE 10

AM radio signal strength, 54.16 dBμV/m (0.5 mV/m = 54 dBμV/m)



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5.1.4 Summary of the test results

The laboratory testing results show 2.3 m as the minimum separation distance required to prevent audible interference to AM broadcasting receivers of the 7th harmonic of the induction charging devices testing. Given that this is a mobile device typically used in offices and homes, this distance is achievable and therefore the impact to the broadcasting service is considered by the study as negligible.

TABLE 7

Experiment Summary

AM Radio Receivers	**AM Radio Single Strength(dBμV/m) (Target: 500 μV/m, 54 dBμV/m)**	**Single Impact @ worst, 8 pcs wireless chargers separately tested**	**Aggregate Impact @ worst, 5pcs WPT devices working simultaneously, 0.6 m interval to each other**
AM1	54.35	<0.82 m, Noise intolerable >1.83 m, Noise inaudible	<1.2 m, Noise intolerable >2.2 m, Noise inaudible
AM2	54.16	<1.1 m, Noise intolerable >2.2 m, Noise inaudible	<1.1 m, Noise intolerable >2.3 m, Noise inaudible

5.2 AM Broadcasting Study 2

5.2.1 General observations

A few predominantly subjective tests were carried out using a completely anonymous phone charger, a mobile phone simulator as a dummy load and a smartphone.

From the outset it was clear that repeatability was going to be a major issue. Also it was quite difficult to explain what was seen. What came out of the charger was critically dependent on the exact positioning of the load (or phone) on the charger, its exact location relative to the receiver and its orientation. Not only did the operating frequency change but also the nature of the interference as these parameters were changed. In general the 'output' appeared to be a pulsed and filtered, (seemingly) square wave at a frequency that varied even when the load was held firmly in one place relative to the charger. Even when there was no harmonic within the 'channel' to which the receiver was tuned[5] significant switching transients (at the repetition rate of the pulsing) could sometimes[6] be heard right across the MF band. As well as being somewhat dependent on the exact position of the charger relative to the receiver, the overall effect was markedly dependent on the (assumed) relative polarisation of the charger; the effect of the interference could be more or less eliminated by careful alignment. While the effects of location and polarisation were as might be expected, this was not always the case and in such instances was difficult to explain. The general variability and instability of the whole set up suggested that meaningful measurements might be difficult to make.

The performance of the charger when charging a phone was quite different from that with the dummy load. To what extent variations might be dependent on the state of charge of the phone's battery was not clear. The phone happened to be very nearly fully charged.

With no phone on the charger, effectively an 'off load' condition it would intermittently and fairly frequently emit a pulse of radiation – as sort of "are you there" request to any mobile phone that might be on or near the charger to initiate the charging sequence. Even with no phone being charged, these bursts were clearly audible on a nearby receiver.

A subjective assessment suggested that with the coil load combination and an artificially generated[7], wanted incoming signal of +18.5 dBμA/m (equivalent to 70 dBμV/m – 10 dB above the minimum receiver sensitivity prescribed in Recommendation ITU-R BS.703) the effect of the interferer at 2 m separation could be made to be anything between more or less inaudible and extremely annoying by changing the orientation and/or precise position of the charger. This is markedly at variance with the results in Tables 3 and 4 of this Report, which suggest that for all the chargers tested the effect was inaudible when the separation had reached 2 m (sometimes much less than this) and the incoming (wanted) signal was 16 dB lower.

5.2.2 Test arrangements

The tests were performed in a screened room slightly less than 4 m in length. This imposed certain limitations on the tests that were possible; significantly that 2 m was the maximum possible separation between the receiver and the charger. The physical arrangement is shown in Figs 11 and 12.

---

[5] Very small changes in the position of the load relative to the charger could cause the harmonic to jump into an adjacent channel or even further.

[6] Again dependent on the position of the load and the orientation.

[7] The tests were carried out in a screened room.

FIGURE 11

Test set up (diagrammatic)

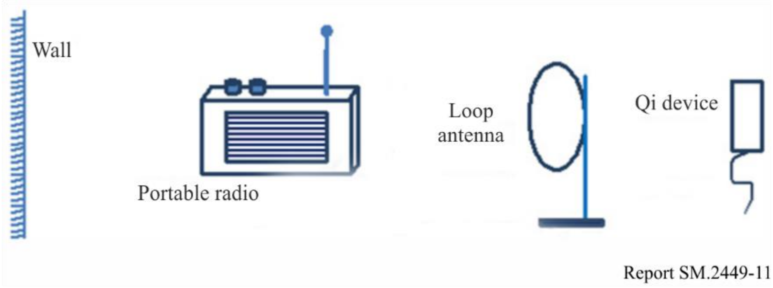
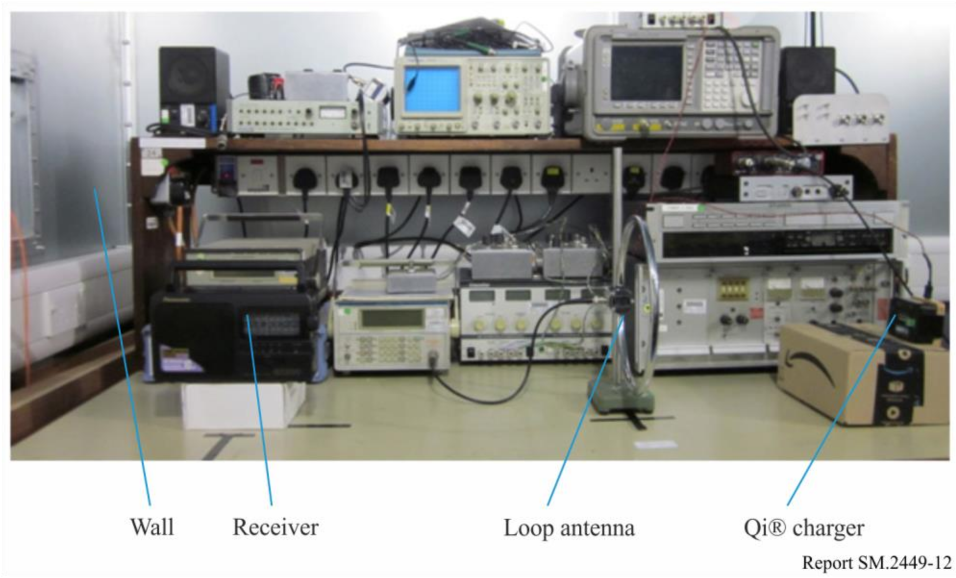


FIGURE 12

Test set up (photographic)



The ferrite antenna in the receiver and the charger were arranged to be on the perpendicular axis of the loop antenna. For the tests the receiver was 0.5 m from the wall, the loop antenna 1.0 m and the charger 1.2 m.

The loop antenna was used to generate a simulated broadcast signal. Simulating the broadcast signal in this way offered advantages over an off air signal.

The signal level at the receiver could be precisely controlled:

The frequency of operation could be precisely controlled; not only did this allow the receiver tuning frequency to be matched to the charger but also meant that different harmonics of the charger which would affect different carrier frequencies (different broadcast channels) could be investigated.

NOTE – The receiver could be / was 'tuned' to the charger and not the other way round.

The same audio samples (speech and music) could be used for all the tests thereby eliminating a potential source of uncertainty.

The ability to control the signal level at the receiver also meant that the effect of moving the charger closer to and further from the receiver could be simulated without actually moving it physically. As already explained, the dimensions of the screened room placed a severe limitation on the actual separation achievable. The effect of wall reflections was considered and taken into account where necessary (see § 3.6.1). Given the inverse cube law relationship between field strength and distance, an increase in the level of the wanted (broadcast) signal by 18 dB would have the effect of doubling the separation distance between the receiver and the charger. Clearly the receiver would be operating with a signal that was 18 dB stronger and so to retain the correct receiver signal to noise ratio an extra 18 dB of RF noise had to be injected into the receiver. This was easily achieved by adding noise to the wanted signal in the loop antenna[8]. In this way, the effective distance between the receiver and the charger could be set to any desired value[9] and the reduction in the effect of the interference with separation distance could be measured.

The angle of the charger was adjusted to have the maximum (worst case) effect on the receiver and give the maximum coupling to the search coils. Minimum coupling of the charger into the receiver – with the interference virtually inaudible in many instances – occurred with the charger, load combination tilted to about 10° from horizontal with the load away from the receiver. The geometry of the situation would suggest that minimum coupling would occur with the charger coil horizontal because the interfering field would coincide with the minimum sensitivity of the ferrite antenna (be at right angles to the maximum sensitivity). In practice, the orientation for minimum sensitivity depended on the exact positioning of the load on the charger. Obviously, it also depended on the vertical and lateral offset of the charger from the axis of the ferrite antenna. Minimum sensitivity was sharp and pronounced while maximum sensitivity was less well defined. The 'cos θ' polar response of the charging coil would give rise to a sharp null at the minimum and a broader plateau at the maximum.

5.2.3 Receiver performance measurements

The 'characteristics of AM sound broadcasting reference receivers for planning purposes' are laid down in Recommendation ITU-R BS.703. The relevant parameters are:

– Audio modulation (frequency) response −3 dB at 2 kHz; −24 dB at 5 kHz

– Audio *S*/*N* with 60 dB dBµV/m field strength 26 dB unweighted ref 30% modulation.

Two portable receivers, Receiver 1 and Receiver 2 were on hand, and were measured to determine how closely they conformed to the reference receiver. Receiver 1 was from the 1980s with push-button tuning and a wooden case. Receiver 2 was more modern; not expensive but with reasonable performance. The results are presented in Figs 13 and 14 – note the effect of the tone controls.

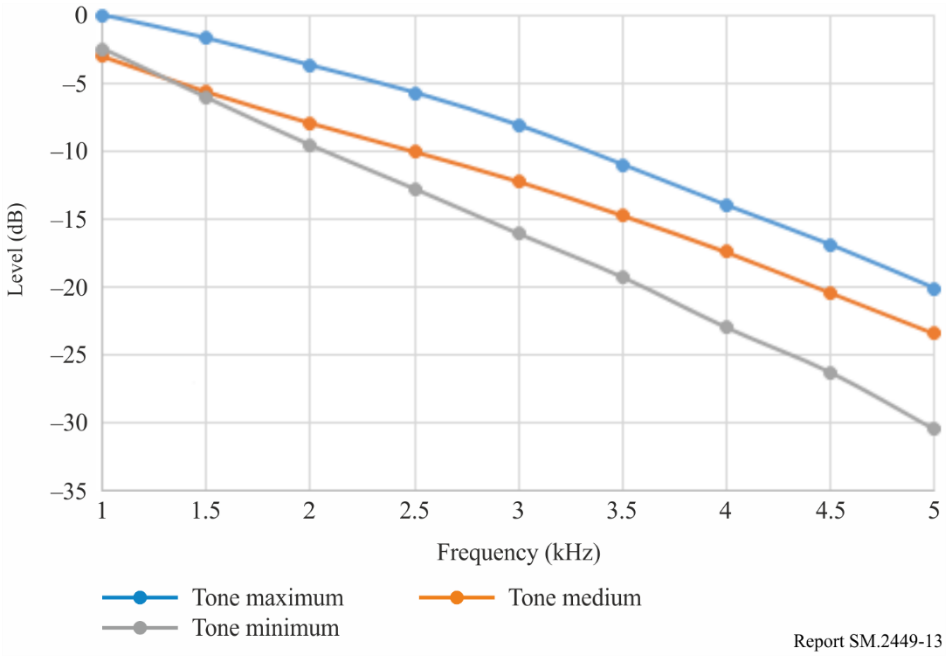
---

8 In practice, pseudo-random noise was generated and added to the audio signal in the PC.

9 Up to the point where the RF front end in the receiver was overloaded by excessive signal strength.

FIGURE 13

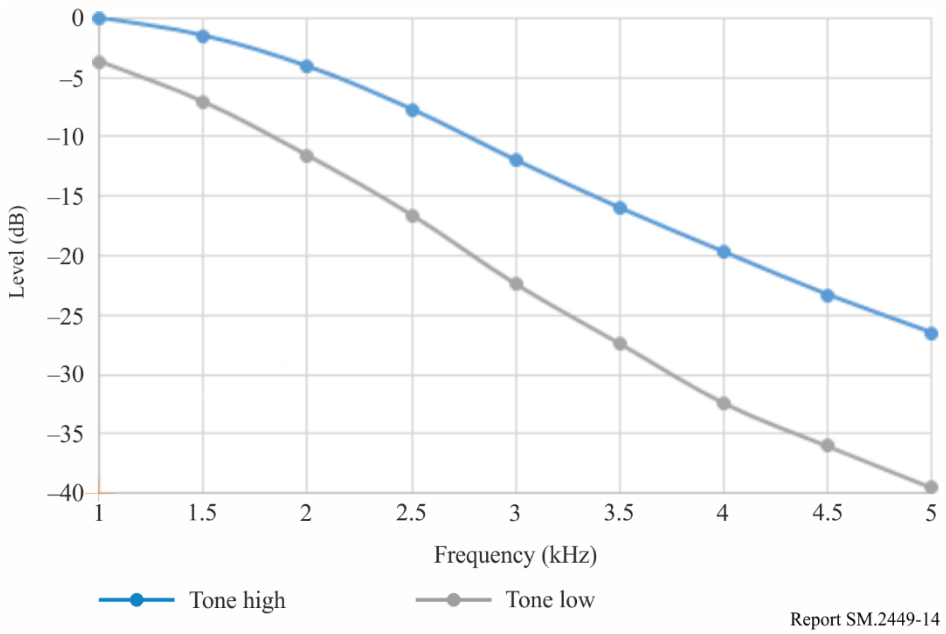
Modulation response of Receiver 1



The behaviour of the Receiver 1 tone control is rather strange; it seems to have more of an effect on the overall level than on the treble response, which is (presumably) largely determined by the IF filters. For the purpose of the interference tests, the control should be set to maximum, to keep the response about right at 2 kHz. The response at 5 kHz is less important, since the interferer would be deliberately placed at about 2 kHz offset from the wanted carrier to represent the worst case.

FIGURE 14

Modulation response of Receiver 2



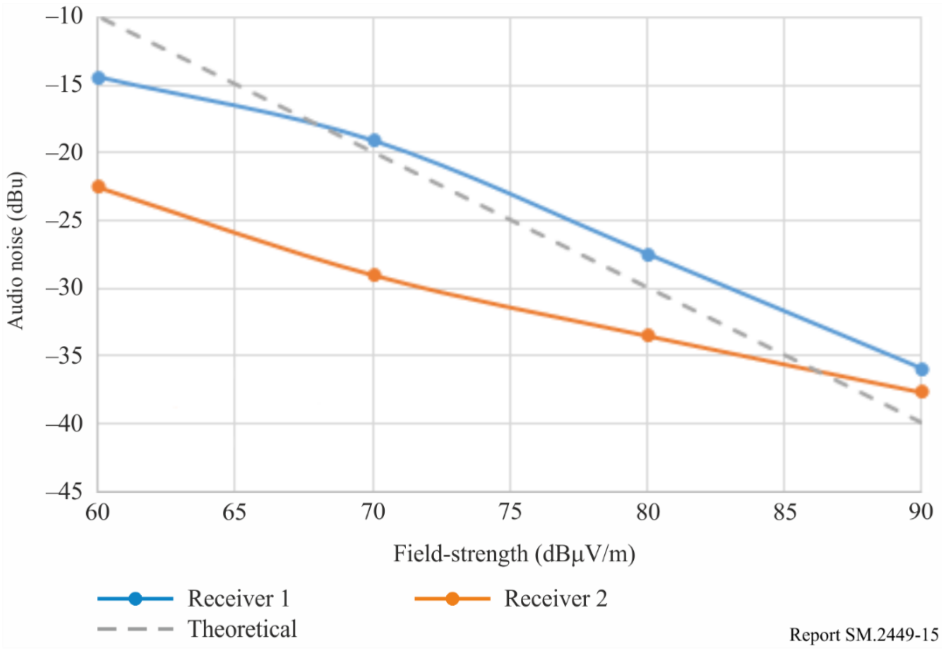
The action of the tone control (switch) is drastic indeed. It is clear that any testing should be carried out with the switch in the 'High' position – there is nothing intermediate between 'High' and

'Low' – where the modulation response is a good match to that of the Recommendation ITU-R BS.703 reference receiver.

Audio noise levels were measured as a function of field-strength and are plotted in Fig. 15.

FIGURE 15

Audio noise levels for both receivers



The noise levels are plotted relative to 30% AM modulation depth, as required by Recommendation ITU-R BS.703. (–30 dB 'audio noise' corresponds to 30 dB *S*/*N*). In theory, the *S*/*N* would be expected to increase dB-for-dB with the wanted signal, as per the dashed line. In practice, 'backstop' noise (in the later stages of the receiver) gives an upper limit, while at low signal levels the AGC runs out of range. At 60 dBµV/m signal strength, the Receiver 1 performance appears to be better than expected. However, this is misleading because the level of the wanted signal has decreased along with the noise.

Receiver 2 seems therefore to be the better receiver to use for tests as it more closely conforms to the Recommendation ITU-R BS.703 reference. It falls about 5 dB short on audio *S*/*N*, but that is not a significant problem because large distances are not practicable when assessing the effects of interference. Smaller separation distances and higher reference field-strengths were used as explained in § 3.2.

Note that the carrier frequency chosen for the tests was a 'standard' 999 kHz. If another frequency is used, the sensitivity of the receiver is likely to be different.

5.2.4 Emission levels from the charger

The emission levels from the charger were measured. The results are broadly in line with those given in Tables 3 to 6 of this Report.

A 'home made' detector was used. This comprised ten turns of wire wound on a short section of drainpipe; the coil diameter was 68 mm. The detector coil was followed by a (nominally) 30 dB low-noise amplifier.

FIGURE 16

Home-made detector (left) and Qi® charger (with load)

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At a distance of 1 m, the level measured on the spectrum analyser was –34 dBm. Since the gain of the preamplifier was 29 dB (measured), the output of the coil was –63 dBm. 0 dBm is equivalent to 224 mV, and so –63 dBm is equivalent to 0.159 mV.[10]

A magnetic field H passing through a coil of area A and number of turns N gives rise to an EMF E of $\mu_0\, H\, A\, N\, \omega$, where μ_0 is the permeability of free space (defined as $4\pi \times 10^{-7}$) and ω is the angular frequency. Rearranging this gives:

$$H = E \,/\, \mu_0\, A\, N\, \omega \qquad (1)$$

Putting in figures: $H = 0.159 \times 10^{-3} \,/\, \{ (4\pi \times 10^{-7}) \times (\pi \times 0.034^2) \times 10 \times (2\pi \times 115 \times 10^3) \}$

Hence $H = 0.0048$ A/m, at a distance of 1 metre.

This is equivalent to 73.6 dBμA/m (or 125.1 dBμV/m for the equivalent electric field in free space). At 300 m, this would reduce by 60 log 300 dB, or 148.6 dB, to give –23.5 dBμV/m. Section 5.1 gives a figure of –15 dBμV/m. This is reasonable agreement given the various uncertainties.

5.2.5 Harmonic emission levels from the charger

Also of interest are the relative harmonic levels; it is the harmonics that will upset LF and MF radio reception.

To measure the harmonics, a four-turn search-coil was placed alongside the charger device at a distance of 200 mm. The geometry of the coil was the same as that used for the earlier measurements (previous section) however it had fewer turns and no amplifier. The output of the coil was connected directly to the spectrum analyser – the same one as before. Doing this introduced a 6 dB loss, since the coil included a 50 Ω termination resistor.

The earlier measurement gave a level of 0.034 A/m for the fundamental at a distance of 1 m. The actual level measured here was –45 dBm. Recalling equation (1) above:

$$\mathrm{H} = \mathrm{E} \,/\, \mu_0\, \mathrm{A}\, \mathrm{N}\, \omega$$

Putting in figures: $H = 1.26 \times 2 \times 10^{-3} \,/\, \{(4\pi \times 10^{-7}) \times (\pi \times 0.034^2) \times 4 \times (2\pi \times 115 \times 10^3)\}$

where 1.26×10^{-3} is –45 dBm in volts and the highlighted 2 is to compensate for the termination loss.

$$H = 0.19 \text{ A/m}$$

---

[10] Strictly, dBm is the units of power in a constant-impedance system. In this instance the coil actually delivers a voltage into a high impedance.

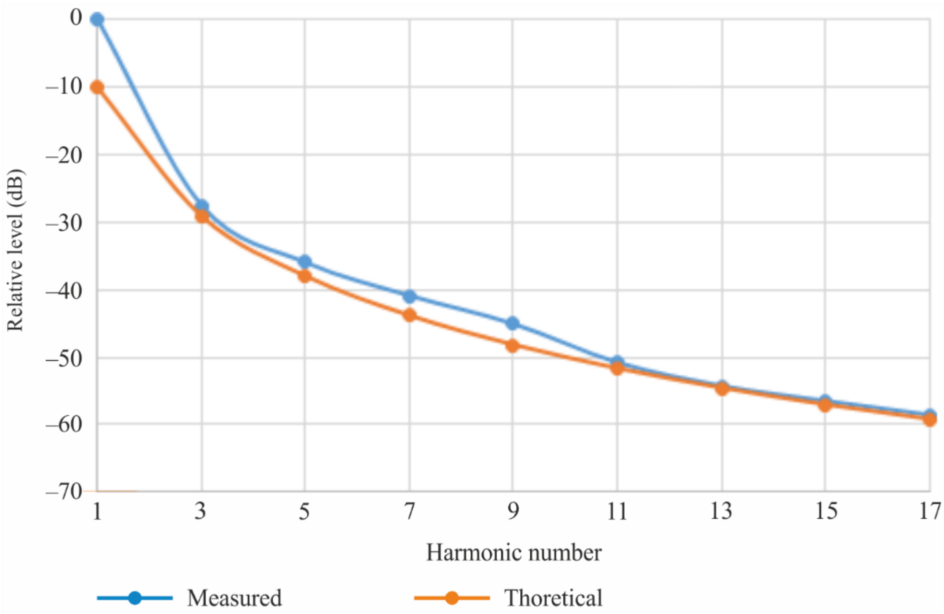
Since the measurement was made at 0.2 m rather than at 1.0 m separation, the inverse cube law dictates that this figure should be divided by 125 for comparison:

$$H = 0.0015 \text{ A/m}$$

The field at a point perpendicular to a dipole is half that at a point at the same distance but in line with the dipole. So this is in reasonable agreement with the earlier result.

FIGURE 17

Relative harmonic levels of the charger



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A plot of the relative harmonic levels is shown in Fig. 17. Normalisation has been carried out as follows:

– The fundamental component has been set to 0 dB.

– The remaining components have had $20 \times \log n$ subtracted, where n is the harmonic number. This is to compensate for the proportional-to-frequency characteristic of the coil.

The 'theoretical' curve assumes a 40 dB per decade law ($1/n^2$): 20 dB per decade from the inductance of the transmit coil (taken to be driven from a voltage source), and 20 dB per decade from the harmonic level of a square-wave (taken to be the waveform driving the coil). This looks to be a reasonable model. (It will obviously not be valid at the fundamental, since the coil will be resonant at that frequency.)

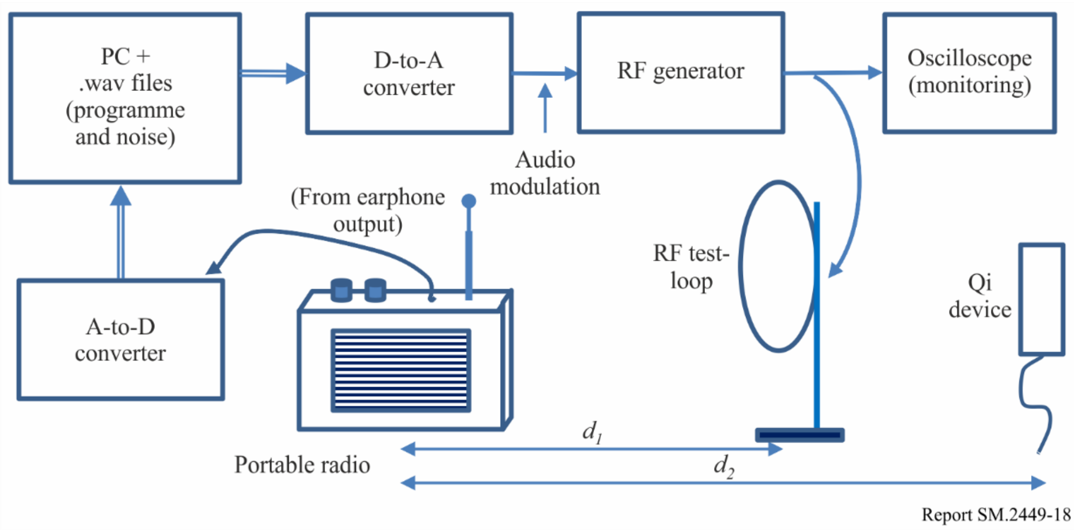
Taking the 7th harmonic as an example, the level is 41 dB below that of the fundamental. Assuming H to be 0.00482 A/m for the fundamental, this equals 32.7 dBμA/m, or an equivalent E-field of about 84.2 dBμV/m at 1 m separation.

5.2.6 Assessment of Interference levels

The effects of interference generated by the charger / load combination were measured both objectively and subjectively on the audio output of the receiver, using the set-up shown in Fig. 18.

FIGURE 18

Set-up for assessment of Qi® interference



The sketch is mostly self-explanatory. The programme material is stored on the PC as .wav files, and is the same as used for the earlier WPT tests[11]. (It was provided by the BBC's Radio 5 studios, and compressed as it would be for transmission.) It is played out through a high-quality 'Benchmark' DAC, and used to modulate an RF generator. The RF generator then drives a test-loop antenna. By convention, the loop is placed 600 mm from the item under test (the radio), in which case the equivalent electric field in V/m is numerically equal to 1/10 of the generator source EMF in V.[12] Finally, the output of the radio, complete with interference, is converted into digital form and stored on the PC as .wav files.

In addition, pseudo-random noise was added to the programme material by the PC's *Audacity* program. This was helpful in allowing the audio S/N out of the receiver to be set to the reference value of 26 dB ref. 30% AM modulation depth, irrespective of the actual field-strength.[13] When carrying out subjective tests on interference, the masking effect of any background noise is obviously an important factor.

Finally, a sanity-check on the calibration of the system. The generator was set to –3 dBm, for a source EMF of 317 mV and a nominal field-strength of 31.7 mV/m (90 dBµV/m). The magnetic field-strength should then be 31.7 / 377 mA/m, or 38.5 dBµA/m. The 4-turn search-coil was again used to measure the actual field-strength and gave a reading of –92 dBm on the spectrum analyser.

Recalling equation (1) above:

$$\mathrm{H = E / \mu_0\, A\, N\, \omega}$$

Putting in figures $H = (5.63 \times 2 \times 10^{-6}) / \{ (4\pi \times 10^{-7}) \times (\pi \times 0.034^2) \times 4 \times (2\pi \times 999 \times 10^3)\}$

where 5.63×10^{-6} is –92 dBm in Volts and the highlighted 2 the termination

$$H = 9.818 \times 10^{-5} \text{ A/m, or } 39.8 \text{ dB}\mu\text{A/m}$$

Which is in reasonable agreement with the nominal field-strength.

[11] For example as described in BBC White Paper WHP 322.

[12] There is no implication that the loop actually generates an electric field – indeed, the loop is screened to prevent it from doing so. The equivalent electric field is calculated using the standard far-field relationship E/H = 377 Ω.

[13] Assuming that the field-strength is sufficient for the reference audio *S*/*N* to be exceeded.

5.2.6.1 Distance multiplication and the effect of the screened room

As mentioned earlier, increased levels of 'wanted' signal at the victim receiver could be useful for assessing the interference caused by a device at distances greater than available in the screened room. Supposing that the reference receiver is working at 60 dBμV/m, and that the interfering charger is 2 metres away. From the inverse-cube law, the interference would increase by 18 dB if the distance were halved to 1 metre. It follows that the effect on the output of the receiver would be exactly the same if the wanted signal were also to be increased by 18 dB. There are two provisos: first, any noise generated elsewhere within the system needs to be kept at the same level (–26 dBu, reference 30% AM); second, the automatic gain control within the receiver needs to hold the (wanted) output level sensibly constant.

Table 8 shows the signal generator levels appropriate for multiplication factors 1-4. It is assumed that a loop antenna is being used, and that the victim receiver is 600 mm from it.

TABLE 8

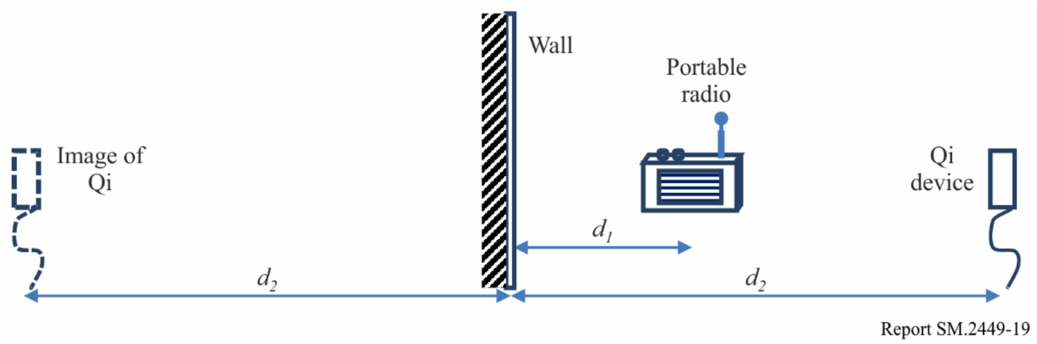
Generator levels for particular multiplication factors

Generator level (dBm)	–33	–15	–4.4	+3	A factor of 4 means that an interferer placed at 600 mm has the same effect as one at 2.4 m
Multiplication factor	1	2	3	4	

The practicable distances available in the screened room are more restricted than might be expected. This is because the room is made of metal, and the metal behaves as a near-perfect reflector. Despite being nearly 4 metres long, the interferer needs to be kept within about 1.2 metres of the receiver. The situation is as shown in Fig. 19.

FIGURE 19

The effect of a reflection



As measured at the radio, the normalised field-strengths for the Qi® device and its reflection are $1 / (d_2 – d_1)^3$ and $1 / (d_2 + d_1)^3$, respectively. To obtain the resultant field-strength, the reflected signal needs to be subtracted from the direct signal:[14]

Resultant field-strength $1 / (d_2 – d_1)^3 – 1 / (d_2 + d_1)^3$

Ratio of resultant to direct field-strengths $\{1 / (d_2 – d_1)^3 – 1 / (d_2 + d_1)^3\} / 1 / (d_2 – d_1)^3$

$= 1 – \{(d_2 – d_1) / (d_2 + d_1) \}^3$

[14] Alternatively, it might be easier to think in terms of electric charges. The voltage needs to be zero at the wall (which is earthed). This can only be achieved if the real and imaginary charges are equal and opposite, and equidistant from the wall.

Putting in actual distances (d_1 = 0.5 m, and d_2 = 1.2 m) gives a ratio of 0.93 – an error of 0.6 dB. In this case, the effect is too small to be serious, and can be corrected by reducing d_2 slightly. However, the error increases rapidly as d_2 becomes greater.

5.2.6.2 Audio Samples

Some preliminary recordings were made, with 30 seconds of speech and 30 seconds of music being 'transmitted' to the portable radio. This was the same material as used previously, for earlier WPT tests, and was taken from the 'Jerusalem' clip provided by Radio 5. It had been processed for distribution to the Radio 5 MF transmitting stations.

The recordings made so far, with some comments, are as follows. In all cases, the 7th harmonic of the interferer was selected. The frequency was typically around 1 MHz, but did vary.

TABLE 9

The recordings made so far

Identifier	Brief Description	Comments
as_clean	Speech, with no impairment apart from the system noise at –26 dBu	The background hiss is audible but not objectionable
bs_wp0_l2_2-4_onc	As above, plus on-channel interference from the unbranded charging pad	The interference at an effective 2.4 metres is very obtrusive
cs_wp0_l2_2-4_offc	As above, but with the interference off-channel	The interference probably would not normally be noticeable
ds_wp0_l2_2-4_idle	As above, but with the load removed from the charging pad	Again, the interference probably would not normally be noticeable
em_clean	Music, with no impairment apart from the system noise at –26 dBu	The background hiss is audible but not objectionable
fm_wp0_l2_2-4_onc	As above, plus on-channel interference from the unbranded charging pad	The interference at an effective 2.4 metres is very obtrusive
gm_wp0_l2_2-4_offc	As above, but with the interference off-channel	The interference probably would not normally be noticeable
hm_wp0_l2_2-4_idle	As above, but with the load removed from the charging pad	Again, the interference probably would not normally be noticeable
is_wp7_s7_2-4_onc	A smartphone generating on-channel interference on 'speech'	Much the same results as for the unbranded charging pad
jm_wp7_s7_2-4_onc	As above, with 'music' programme	As above

It was difficult to obtain consistent results, as the interferer was liable to jump to a different channel without warning. Even whilst stable, it would switch between two fixed frequencies, only one of which the radio would be tuned to. The switching rate was about one per second, giving rise to an easily identified audible 'signature'. The off-channel interference was normally almost inaudible, but that would depend on how off-channel it was.

The lack of subtlety of these effects mean that the usual ITU 5-point impairment scale is hardly necessary: either the interference is overwhelming, or it is inaudible.

5.3 Impact study of non-beam inductive WPT applications to Amateur service

5.3.1 Parameters used for simulation

Within the United States § 47 CFR Part 15.31 (2) governs the measurement requirements for radio frequency devices operating in the near-field. After applying the FCC required extrapolation factor of 40 dB per decade to the –15 dBµV/m @ 300 m, the limit on the non-beam WPT devices is 44.08 @ 10 m. Modelling was used for near field propagation.

The parameters for the amateur service receivers came from Recommendation ITU-R M.1732 and are shown in Table 10. This Recommendation does not contain interference protection criteria for amateur operations in this frequency range. A protection criteria of I/N –6 dB is assumed for the purposes of this study.

TABLE 10

Parameters assumed for the Amateur service receiver

Parameters	Value
Centre frequency (kHz)	136.75
Bandwidth (kHz)	0.4
Antenna pattern	Omni-directional
Minimum noise level (dBµV/m)	31.6
Protection criteria (I/N) (dB)	−6
Permissible interference level (dBµV/m)	25.6

5.3.2 Simulation analysis and results

5.3.2.1 Single-entry scenarios

The single-entry scenarios place a single WPT device inside a building with the amateur receiver located away from the building outdoors. The first simulation uses 3 dB building entry loss and the second uses 10 dB building entry loss to account for different building materials.

FIGURE 20

Single entry scenario

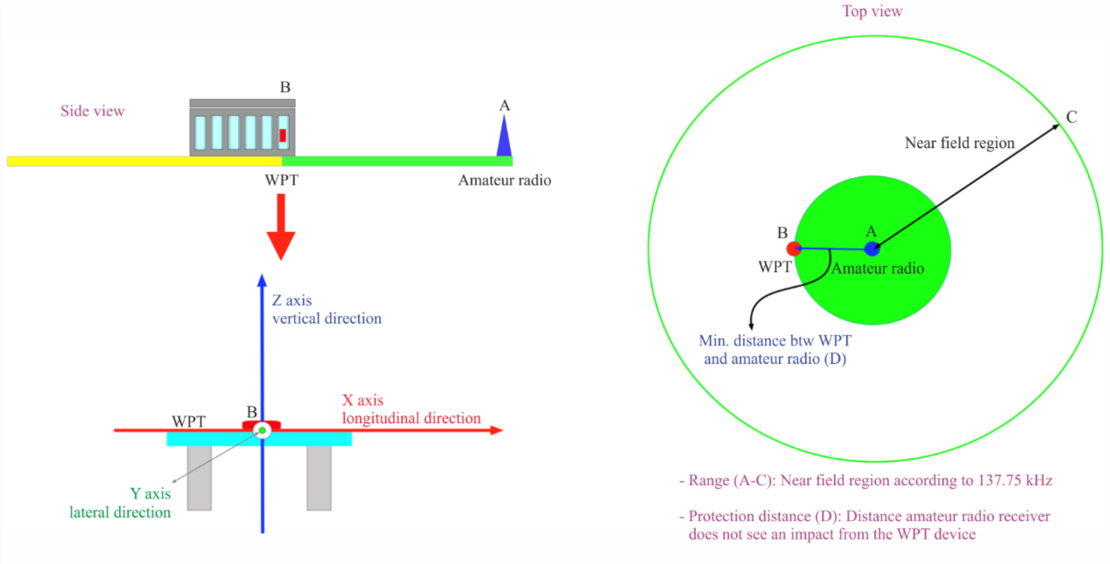


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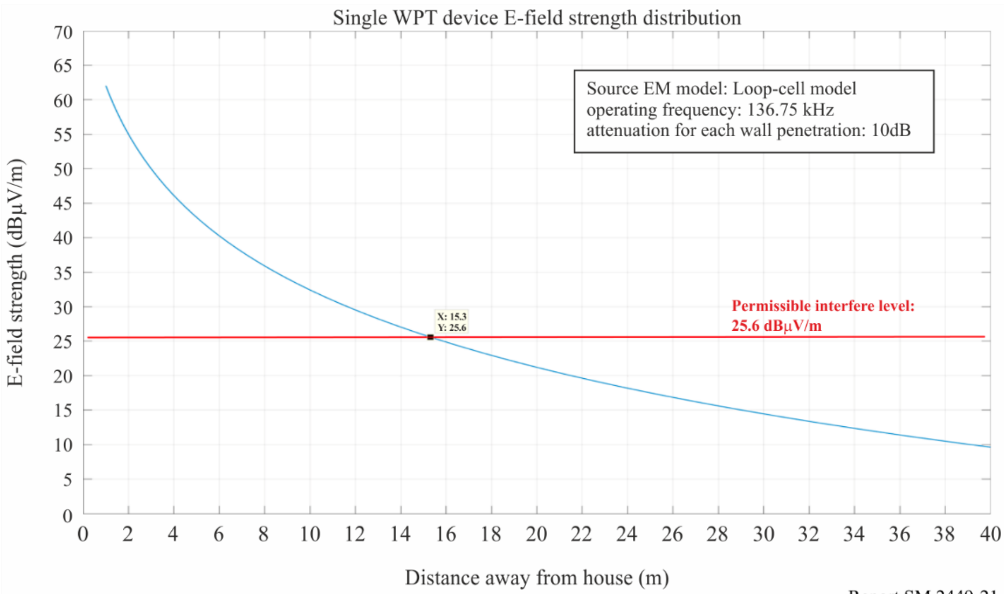
FIGURE 21

Single-entry distribution for scenario 1



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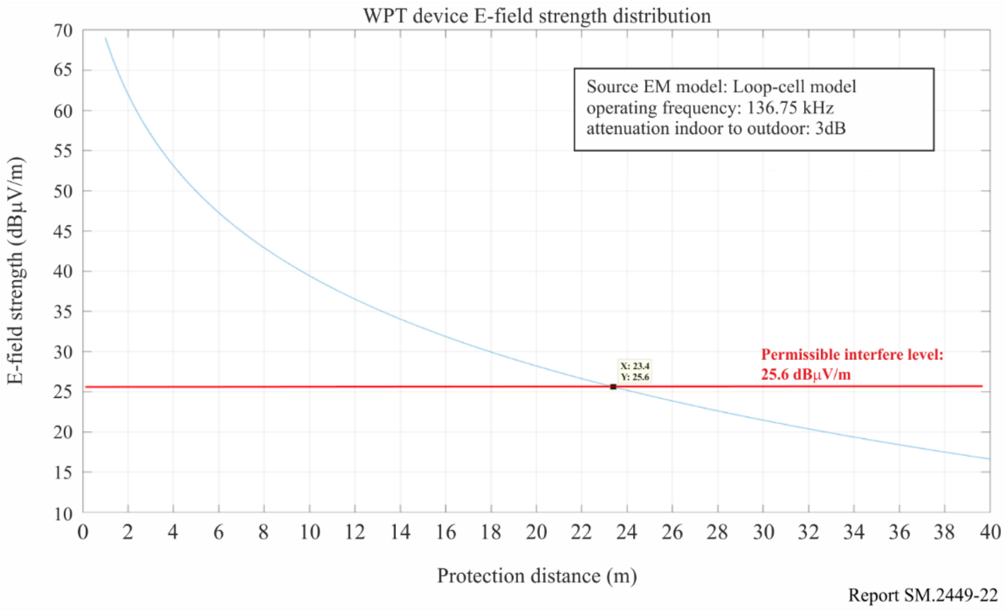
Conclusions for single-entry scenario 1

The results for single-entry scenario 1 using a 10 dB attention to simulate concrete building construction show the WPT device should be placed more than 15.3 m from the amateur radio receiver.

FIGURE 22

Single-entry distribution for scenario 2



Conclusions for single-entry scenario 2

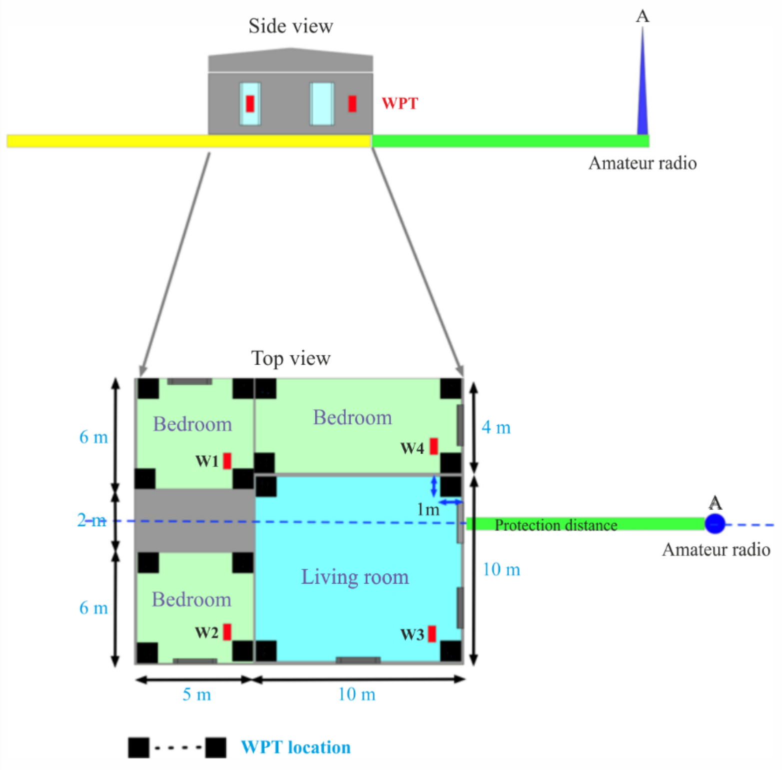
The results for single-entry scenario 2 using a 3 dB attention to simulate wooden building construction show the WPT device should be placed more than 23.4 m from the amateur radio receiver.

5.3.2.2 Aggregate scenarios

The aggregate scenarios use four WPT devices located inside a house. Each of the WPT devices is positioned 1 m from the wall and then is randomly distributed in various corners of the rooms. The first scenario uses 10 dB building entry loss to simulate the effects of concrete or brick walls and the second scenario uses 3 dB for wooden construction.

FIGURE 23

Depiction of Model #1 aggregate scenario



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To simulate different building materials, the building entry loss for both wooden and concrete walls were assessed to determine the protection distance. The values are included in Table 11.

TABLE 11

Values used for building entry loss

Parameter	Number of walls	Wooden wall building entry loss (dB)	Concrete wall building entry loss (dB)
WPT1	2	6	20
WPT2	2	6	20
WPT3	1	3	10
WPT4	1	3	10

FIGURE 24

Results of simulation with 10 dB building entry loss

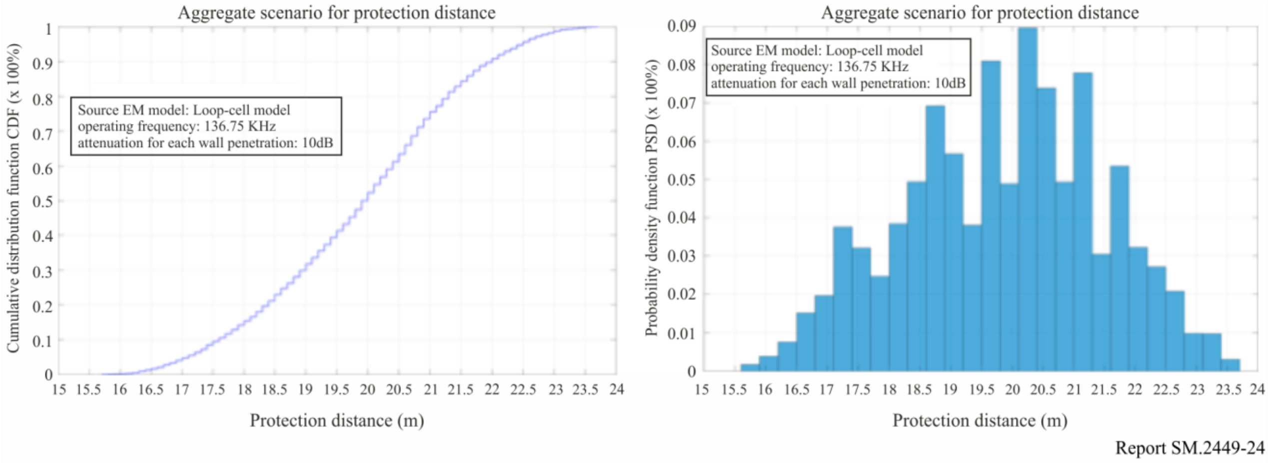

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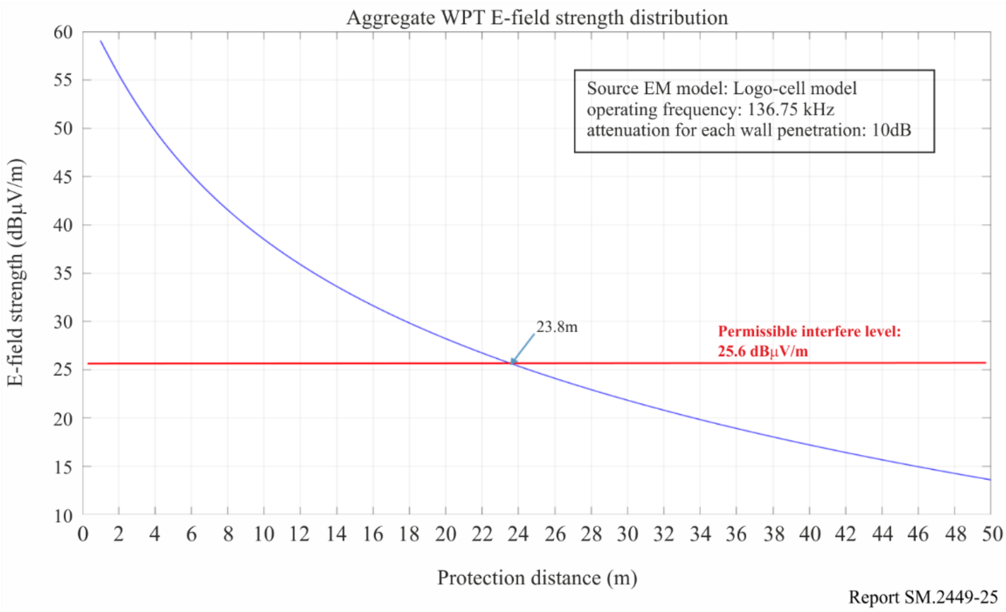
FIGURE 25

Aggregate WPT E-field strength with 10 dB building entry loss



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Conclusions for aggregate simulation 1

The minimum protection distance is 15.5 m and the maximum distance is 23.8 m based on 10 dB building entry loss from concrete walls. The range of values is a result of WPT device placement near windows. The 23.8 m maximum distance is when the WPT device is placed within close proximity to a window and the minimum distance of 15.5 m is when the WPT device is placed near an interior wall.

FIGURE 26

Results of simulation with 3 dB building entry loss

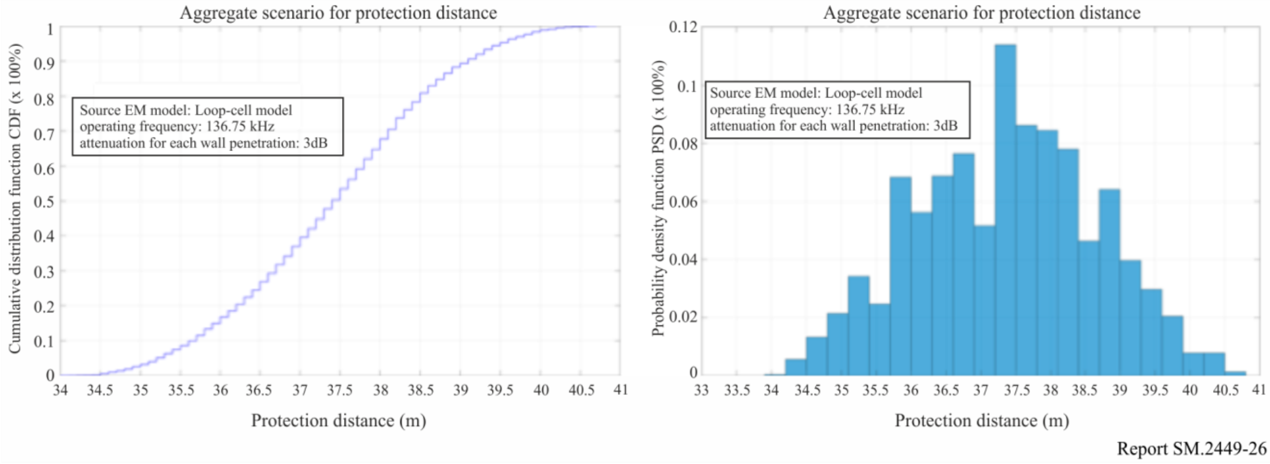

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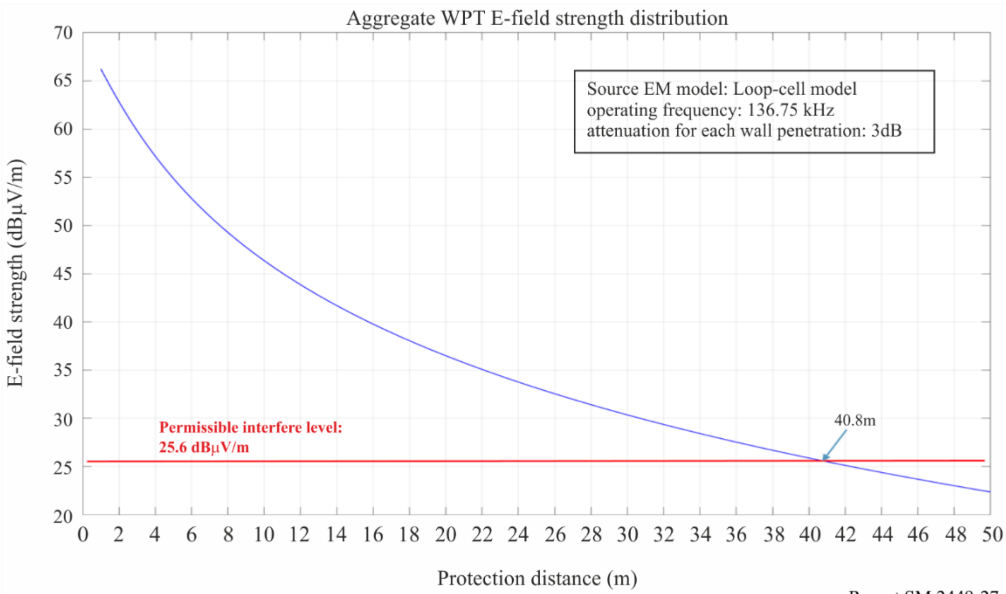
FIGURE 27

Aggregate WPT E-field strength with 3 dB building entry loss



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Conclusions for aggregate scenario 2

The minimum protection distance is 33.8 m and the maximum distance is 40.8 m based on 3 dB building entry loss from wooden walls. The range of values is a result of WPT device placement near windows. The 40.8 m maximum distance is when the WPT device is placed within close proximity to a window and the minimum distance of 33.8 m is when the WPT device is placed near an interior wall.

5.3.3 Summary of results

Table 12 below summarizes the results of the simulations. Based on the simulation results, it can be concluded that non-beam WPT mobile charging devices do not impact amateur service receivers when the devices are placed more than 40.8 m from the receiver.

TABLE 12

Summary of results

Scenario	Permissible interference level (dBμV/m)	Separation distance (m)
Single-entry scenario 1	25.6	15.3
Single-entry scenario 2	25.6	23.4
Aggregate scenario 1	25.6	23.8
Aggregate scenario 2	25.6	40.8

5.4 Impact study of non-beam inductive WPT applications to radionavigation service

Loran-C receiver is considered as an incumbent victim system, which is operating at 90-110 kHz, 20 kHz bandwidth. The characteristics of the Loran-C system are from Recommendation ITU-R M.583 as provided by WP 5B.

Generally, Loran-C system station is built in non-residential area. Figure 28 shows examples for reference. Loran-C receiver is on the ship.

FIGURE 28

Loran-C Stations in non-residential area

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5.4.1 Parameters for simulation

Tables 13 and 14 are parameters used during the simulation for interferer and victim respectively.

Within the United States § 47 CFR Part 15.31 (2) governs the measurement requirements for radio frequency devices operating in the near-field. After applying the FCC required extrapolation factor of 40 dB per decade to the –15 dBμV/m at 300 m, the limit on these devices is 44.08 dBμV/m at 10 m.

The propagation model used for near-field and far field is contained in Report ITU-R SM.2028.

The interference scenarios simulated had the WPT device placed on a table inside a building 50 m from the shoreline in between the transmitter and the receiver located on-board a ship off-shore. The Loran-C transmitter is located 5 km inland from the shoreline.

TABLE 13

Assumption of parameters for WPT interferer impacting Loran-C receiver

Parameters	Details
Device type	WPT mobile device
Operating frequency (kHz)	100-148.5 kHz
Radiated E-field strength (dBμV/m at 10 m)	44.08
Antenna type	Omni-directional
Height (m)	0.7
Min Distance from shore (m)	50
Building entry loss (dB)	10
Propagation model	Near field and free space propagation model

TABLE 14

Assumption of parameters for Victim – Loran-C receiver

Parameters	Details
Victim system	Loran-C receiver
Operating frequency (kHz)	100
Bandwidth (kHz)	20
Antenna pattern	Rod antenna
Loran-C station transmitter output power (kW)	40
Protected minimum Loran-C signal field strength (dBμV/m)	45
Protection criteria (I/S)	−20 dB

The protection criteria used is contained in Fig. 1 from Recommendation ITU-R M.589. According to this reference, the protection criteria from the in-band and out-of-band interference should follow the curve in Fig. 29. Worst curve (near-synch) is used to estimate interference risk.

The worst case is assumed to be –20 dB from near-synchronous at 100 kHz (0 kHz offset from 100 kHz); therefore, 25 dBμV/m is acceptable for noise at Loran-C receiver. Additionally, the worst case is assumed to be –13 dB from near-synchronous at 110 kHz; therefore, 32 dBμV/m is an acceptable noise level at Loran-C receiver. Based on these assumptions, 25 dBμV/m at 100 kHz is used as the max acceptable noise level at Loran-C receiver in this assessment. Figure 29 below depicts the interference protection criteria from Recommendation ITU-R M.589 and Table 15 below summarizes the interference parameters used below.

FIGURE 29

Loran-C/CWI protection criteria

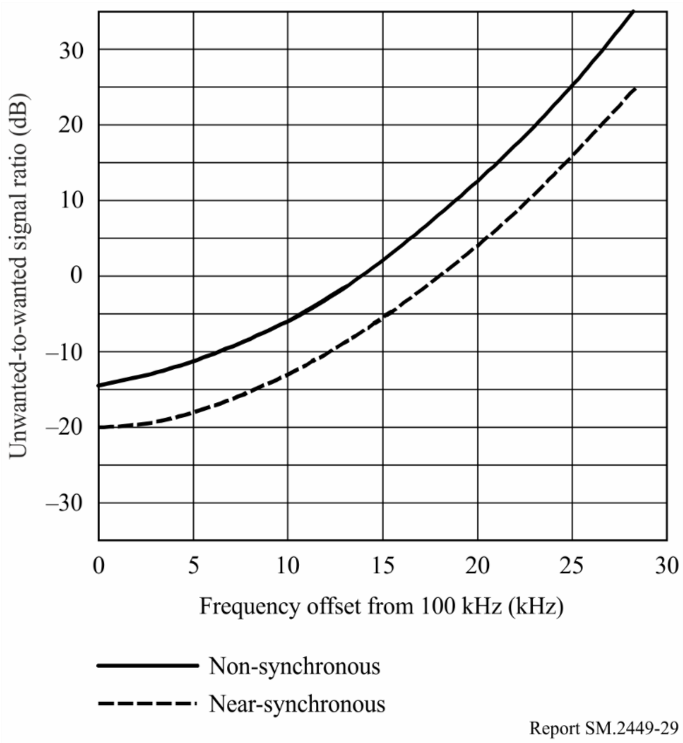


TABLE 15

Assumption of parameters for Victim – Loran-C

Interferer frequency	Min wanted signal field strength	Loran-C/CWI criteria (near-sync)	Acceptable noise @ Loran-C receiver (dBμV/m)
100 kHz	45	−20	25
110 kHz	45	−13	32

TABLE 16

E/H ratio is used to calculate the near field E-Field strengthfrom the WPT device

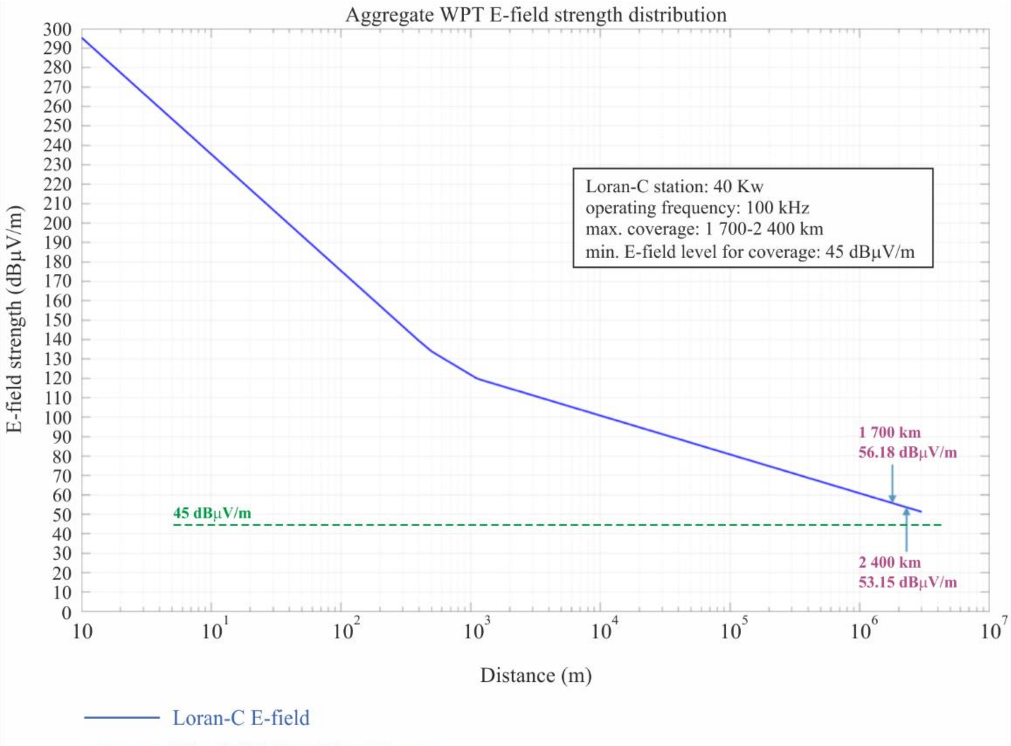
Distance (m)	E/H ratio (dB-ohms)
10	17.95
100	38.32
1 000	53.26
2 000	52.01
5 000	51.61
10 000	51.55

Loran-C signal strength distribution

Based on the 40 kW from Loran-C station, Fig. 30 depicts the Loran-C E-field Distribution along the distance. Inside the 1 700-2 400 km targeted coverage, Loran-C signal strength is much stronger than the minimum required signal level.

FIGURE 30

Typical Loran-C E-field distribution



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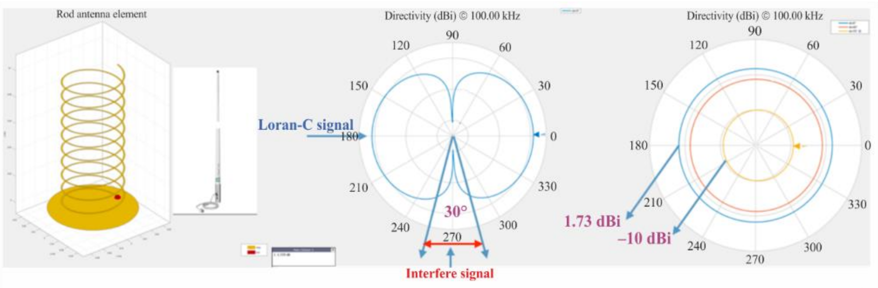
Antenna Model for Loran-C Receiver

In this assessment, a Rod antenna is considered as Loran-C receiver's antenna installed on top of the ship. According to the simulation result in Fig. 31, the delta gain between unwanted to wanted gain ratio is –11.73 dB.

FIGURE 31

Loran-C receiver antenna gain



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5.4.2 Simulation scenarios and results

5.4.2.1 Simulation Model #1

Model #1 considers the WPT device in a building or close to a building, which is 50 m onshore. Loran-C receiver is the victim, which is installed on the ship.

FIGURE 32

Model #1 for Loran-C receiver impact study

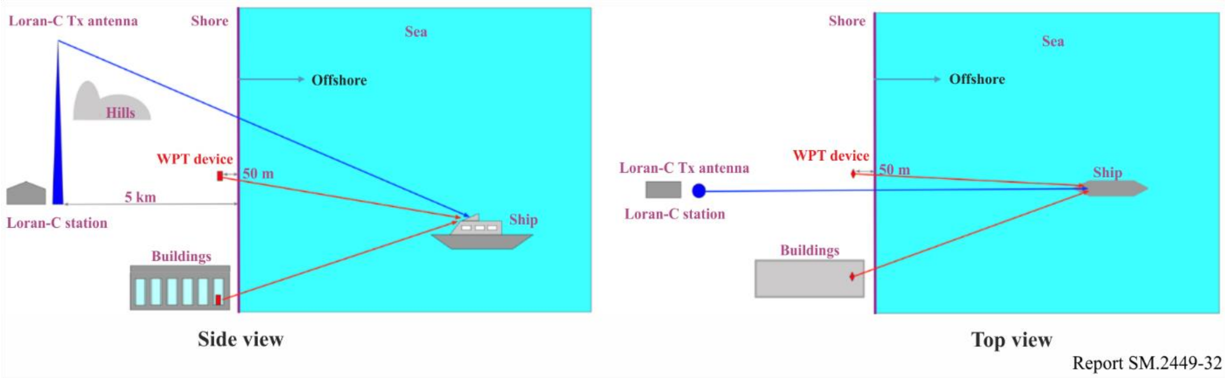

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Figure 33 is the consolidated data results for the Model #1 – single entry scenario. When WPT device is working at 100 kHz, there is an 80 dB margin between the signal to be protected (26.21 dBµV/m) and the E-field strength of the Loran-C transmitter, which is greater than 110 dBµV/m at the shore.

TABLE 17

Model #1 for Loran-C receiver – single entry

Parameters	Value
WPT E-Field strength @ 300 m (dBµV/m)	−15
WPT E-Field strength @ 10 m (dBµV/m)	44.08
WPT E-field strength @ 50 m (dBµV/m) (away from shore)	16.12
Bulding entry loss (dB)	10
Protection ratio (dB)	20
Signal level to be protected (dBµV/m) 50 m protection distance base	26.12
Loran-C signal strength (dBµV/m) @ Shore	>110
Margin (dB)	>80

FIGURE 33

Model #1 for Loran-C receiver – single entry scenario

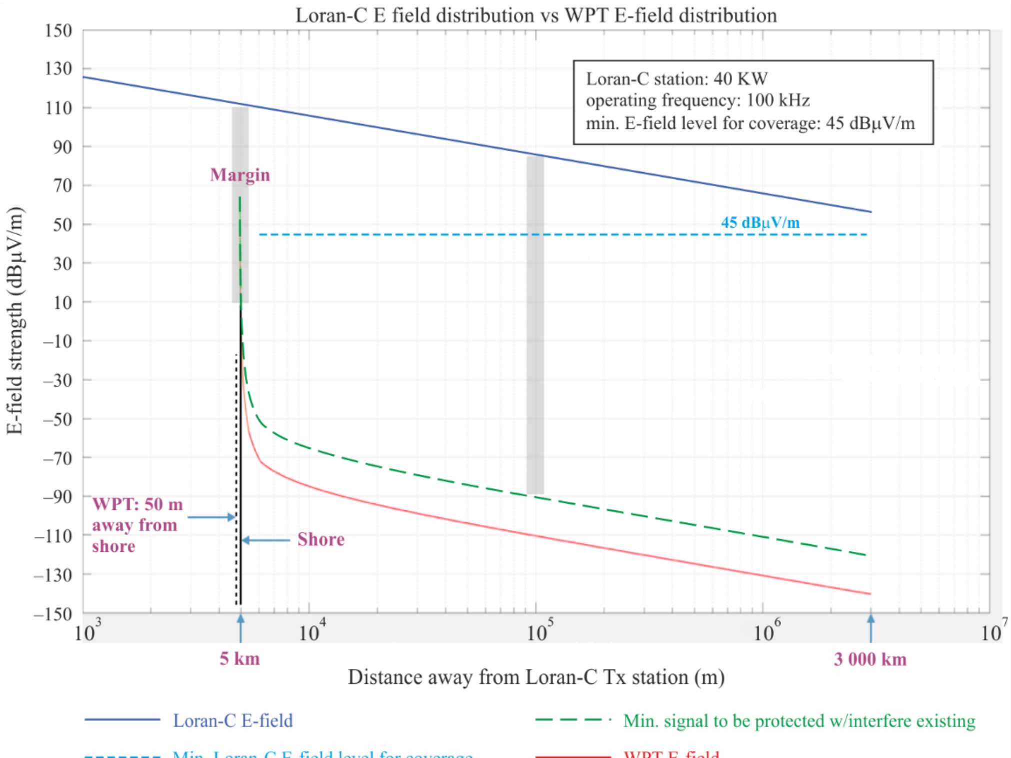

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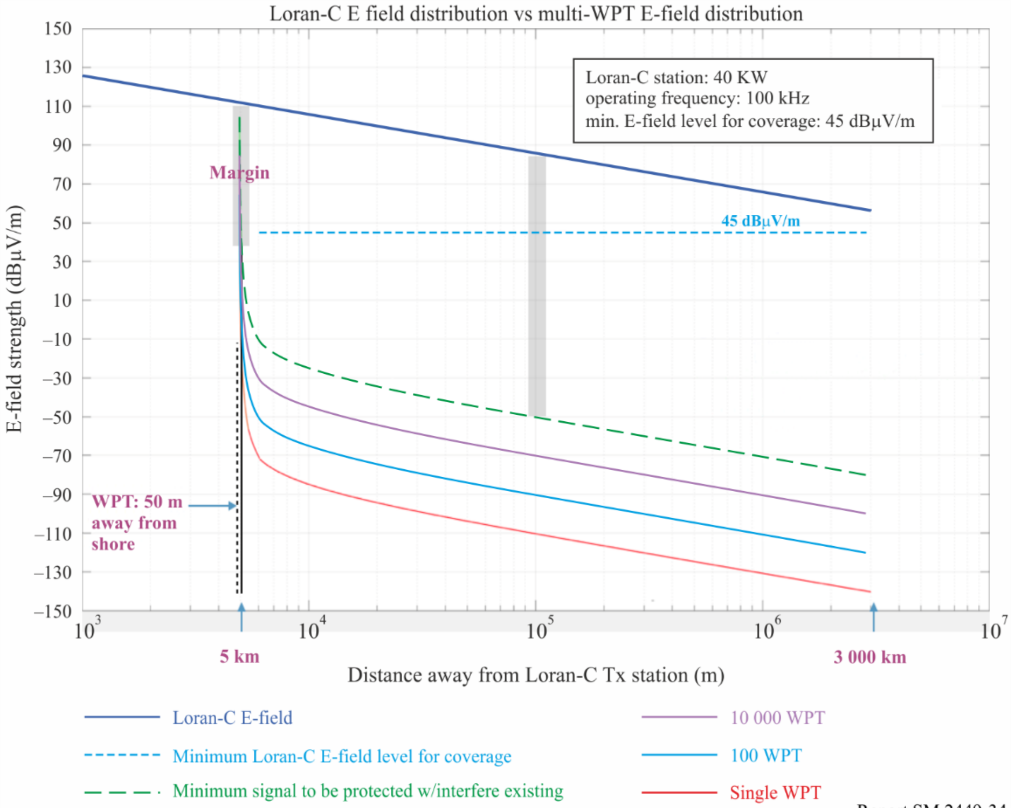
Figure 34 is the consolidated data for different aggregate cases. The Figure depicts the E-field signal levels of 100 and 10 000 active WPT devices operating simultaneously. When 10 000 active WPT devices are operating at 100 kHz simultaneously, there is a 3.88 dB margin between the signal to be protected (66 dBµV/m for 100 devices and 106.12 dBµV/m for 10 000 devices) and the E-field strength of the Loran-C transmitter, which is greater than 110 dBµV/m at the shore.

FIGURE 34

Model #1 for Loran-C receiver – aggregate scenario



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5.4.2.2 Simulation Model #2

The second Model #2 considers the Loran-C transmitter onshore located 5 km from the shoreline, with WPT mobile device is below the deck of the ship, and the Loran-C receiver antenna on the top of the ship. Considering 10 dB building entry loss and 17.95 dB E/H ratio from Table 16, the allowed interference E-Field at 10 m would be 34.08 dBμV/m. As listed in Table 14, -20 dB I/S ratio is required. The max acceptable interference signal level would be 42.35 dBμV/m according to the below equation, when a WPT mobile device is operating at 10 m away from Loran-C receiver antenna.

Maximum acceptable noise at Loran-C receiver equation:

Interfere level – delta gain + protection level = 34.08 – 11.73 +20= 42.35 dBμV/m

Model #2 – single entry scenario

Table 18 contains the input parameters and simulation results for the Model #2 single entry scenario. The simulation results show that a the WPT device with an E-field level of 34.08 dBμV/m should be placed at a distance greater than 5.37 m from the Loran-C receiver antenna in order to maintain the minimum signal level at the maximum 2 400 km coverage distance.

TABLE 18

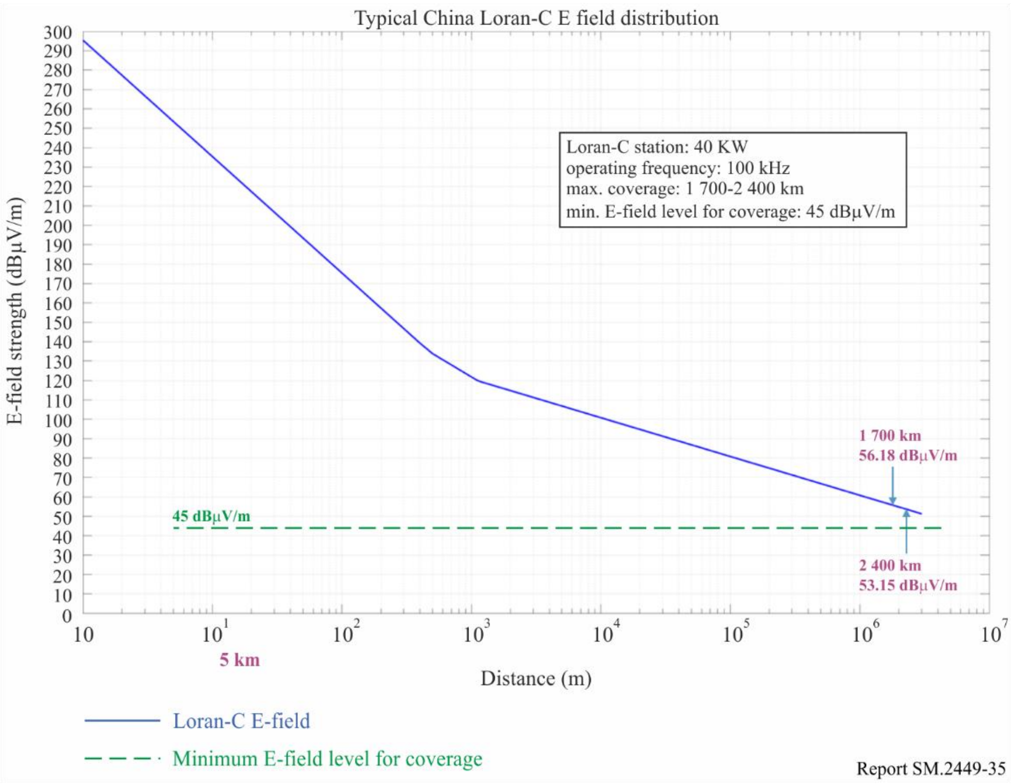
Model #2 for Loran-C receiver – single entry

Parameters	Value
WPT E-Field Strength @ 300 m (dBµV/m)	−15
WPT E-Field Strength @ 10 m (dBµV/m)	44.08
Building entry loss (dB)	10
WPT E-field strength @ 10 m (dBµV/m) with building entry loss	34.08
Antenna Gain delta for wanted signal and WPT interfere (dB)	−11.73
Protection Ratio (dB)	20
Signal level to be protected (dBµV/m) – 10 m protection distance base	42.35
Coverage for signal level protected (km) – 10 m protection distance base	8355
Protection distance (m) – based on 1 700 km	4.51
Protection distance (m) – based on 2 400 km	5.37

Figure 35 is the consolidated data for the Model #2 single entry scenario. The Figure depicts the protection distance results contained in Table 18.

FIGURE 35

Model #2 for Loran-C receiver impact study – Single entry



Model #2 – aggregate scenario

In this scenario, five WPT mobile devices are assumed working at the same time below the deck of the ship with a separation of 3 m between each device, as shown in Fig. 36. The input parameters for the aggregate scenario are contained in Table 19.

FIGURE 36

Model #2 for Loran-C receiver – aggregate scenario

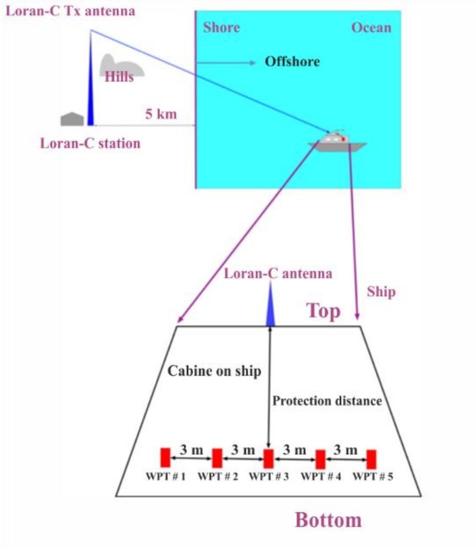


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TABLE 19

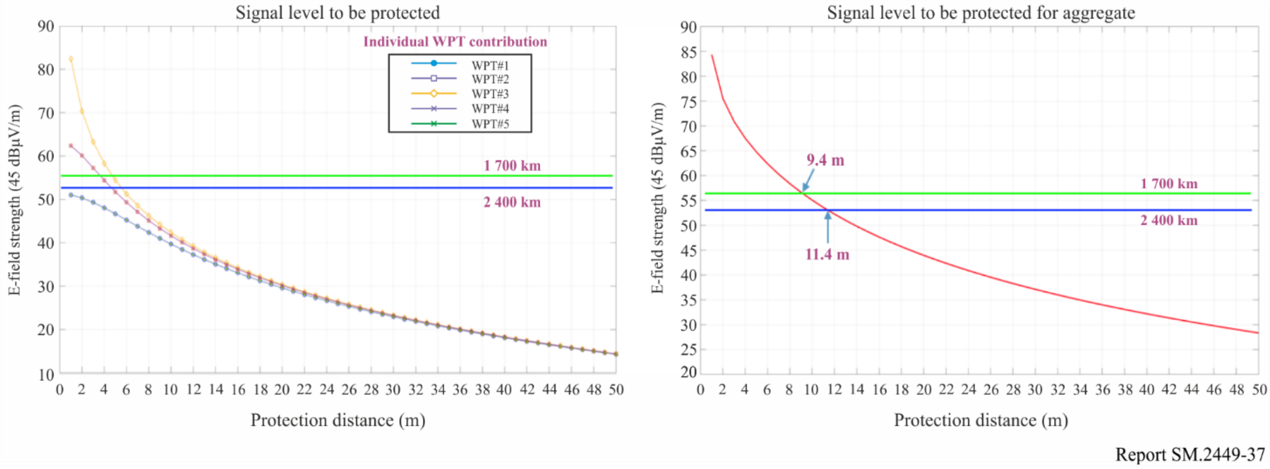
Model #2 for Loran-C receiver – aggregate scenario

Parameters	Value
Number of active WPT devices	5
WPT E-Field Strength @ 300 m (dBμV/m)	−15
WPT E-Field Strength @ 10 m (dBμV/m)	44.08
Building entry loss (dB)	10
WPT E-field strength @ 10 m (dBμV/m) with building entry loss	34.08
Antenna Gain delta for wanted signal and WPT interfere (dB)	−11.73
Protection ratio (dB)	20
Coverage for signal level protected (km) – 10m protection distance base	8355
Signal level to be protected at 1 700 km (dBμV/m)	56.18
Protection distance required for 1 700 km coverage (m)	9.4
Signal level to be protected at 2 400 km (dBμV/m)	53.13
Protection distance required for 2 400 km coverage (m)	11.4

Figure 37 is the consolidated data for Model #2 aggregate scenario. In order not to impact the Loran-C receiver at the max coverage 2 400 km, the closest WPT devices from the Loran-C receiver antenna should be kept 11.4 m away.

FIGURE 37

Model #2 for Loran-C receiver impact study – Aggregated signal level



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5.4.3 Summary of results

The Loran-C receiver is not impacted in Model #1 scenario when WPT mobile charging devices are onshore.

For the Model #2 single-entry scenario, the Loran-C receiver is not impacted by the on-board WPT mobile device charger when the device is located 4.51 m away from the Loran-C receiver antenna at its maximum coverage range of 1 700 km and 5.37 m away when the desired maximum coverage distance is 2 400 km.

In the Model #2 – aggregate scenario, the Loran-C receiver is not impacted by the on-board WPT mobile devices when the closest WPT device is 9.4 m away from the Loran-C receiver antenna at its maximum coverage range of 1 700 km and 11.4 m away when the desired maximum coverage distance is 2 400 km.

5.5 Impact study of non-beam inductive WPT applications on aeronautical radionavigation service

5.5.1 Parameters for simulation

Within the United States § 47 CFR Part 15.31 (2) governs the measurement requirements for radio frequency devices operating in the near-field. After applying the FCC required extrapolation factor of 40 dB per decade to the −15 dBμV/m @ 300 m, the limit on the non-beam WPT devices is 44.08 @ 10 m. Modelling was used for near field propagation.

The responsible group within in ITU-R provided the basis to analyze the impact as provided in Table 20 below.

TABLE 20

Automatic direction finding (ADF)/Non-directional Beacon (NDB) permissible interference limit

Services	Frequency range (kHz)	ADF/NDB receiver bandwidth (kHz)	Permissible Interference limit (dBμV/m)
Aeronautical Radionavigation	130-535	2.7	21.9

5.5.2 Simulation scenarios and results

5.5.2.1 Single Entry scenario

The single-entry scenarios place a single WPT device inside a building with the aircraft placed directly above the building outdoors.

FIGURE 38

Single entry scenario

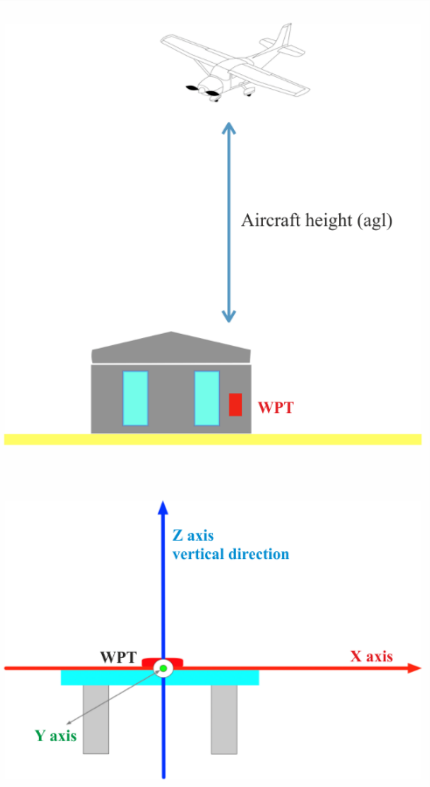

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FIGURE 39

Single-entry E-field vs. height agl (m)

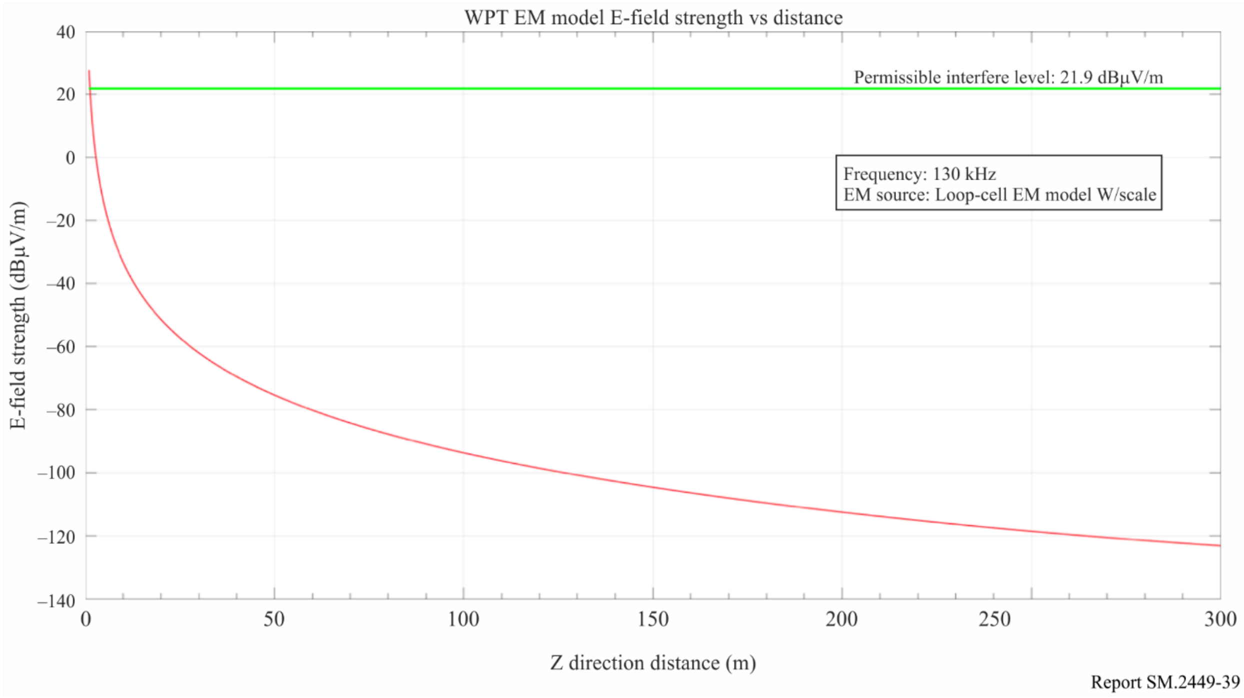
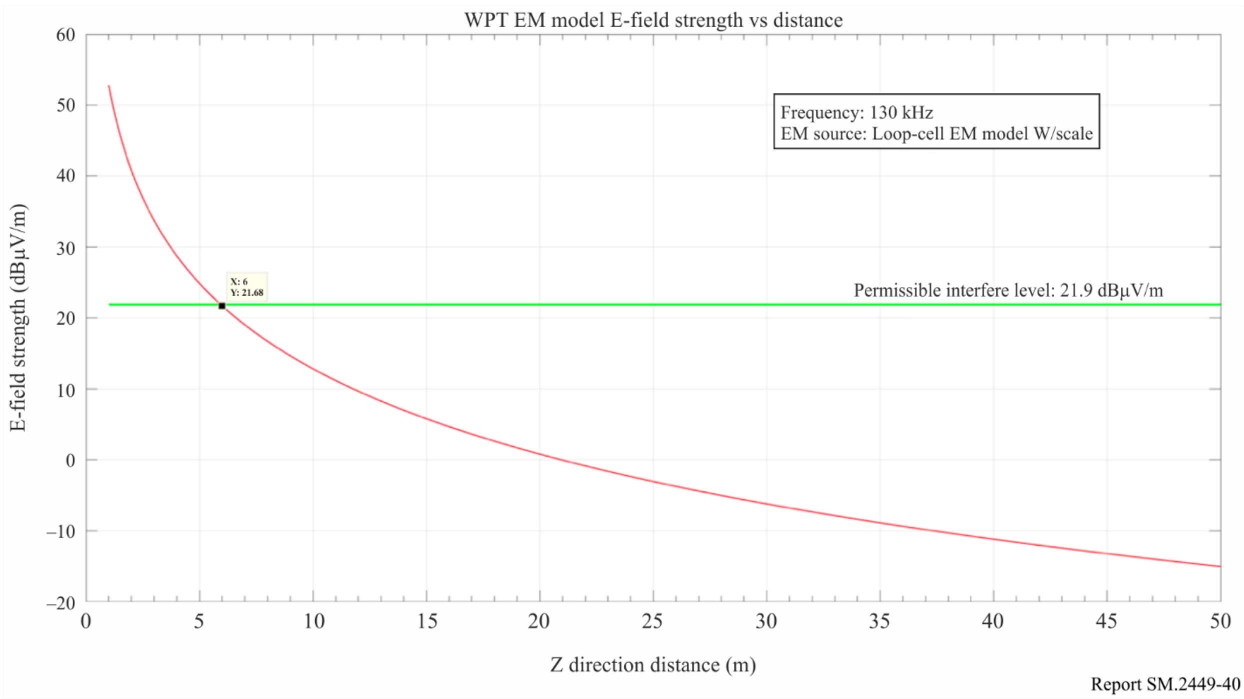


FIGURE 40

Single-entry E-field vs. height agl (m) (zoom in)



Conclusions for single-entry scenario

The results for single-entry scenario show that the impact to the ADF receiver is below the threshold for a distance less than 6 m. Roof or floor penetration losses were not included in the calculation. The inclusion of these loses would further reduce the interference impact of WPT devices to the ADF receiver.

5.5.2.2 Aggregate scenario

The aggregate scenario considers WPT devices separated by 3 m within a 150 m × 150 m square. This represents an array of 50 × 50 WPT devices. Different activity levels are simulated. Two aircraft altitudes were simulated at 100 m and 300 m. As a reference, the minimum safe altitudes in the US are 500 feet (≈150 m) above open water or sparsely populated areas, and 1 000 feet (≈300 m) above urban areas, respectively. The aircraft ADF receiver antenna is located over the center of the square. The radiated fields are aggregated using vector aggregation.

FIGURE 41

Depiction of aggregate scenario

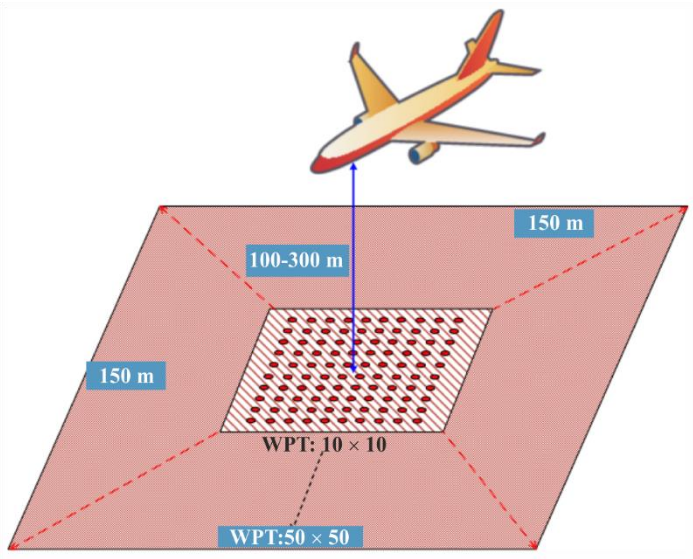


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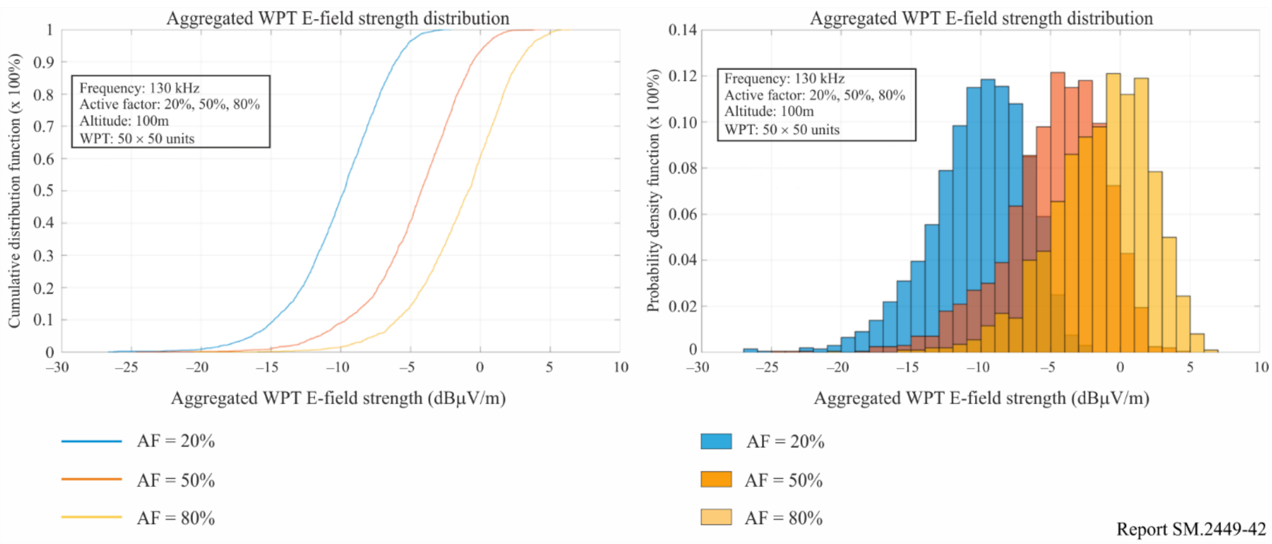
Figure 42 shows the results for an aircraft altitude of 100 m.

FIGURE 42

Aggregate WPT radiated E-field distribution (100m aircraft height)



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Activity Factor	Emax (dBμV/m)	Avg. (dBμV/m)	Std	Max. Permissible Interfere (dBμV/m)	Margin/Gap (dB)
20%	−2.1	−10.2	3.4	21.9	24.0
50%	4.4	−4.7	3.6	21.9	17.5
80%	6.5	−1.3	3.5	21.9	15.4

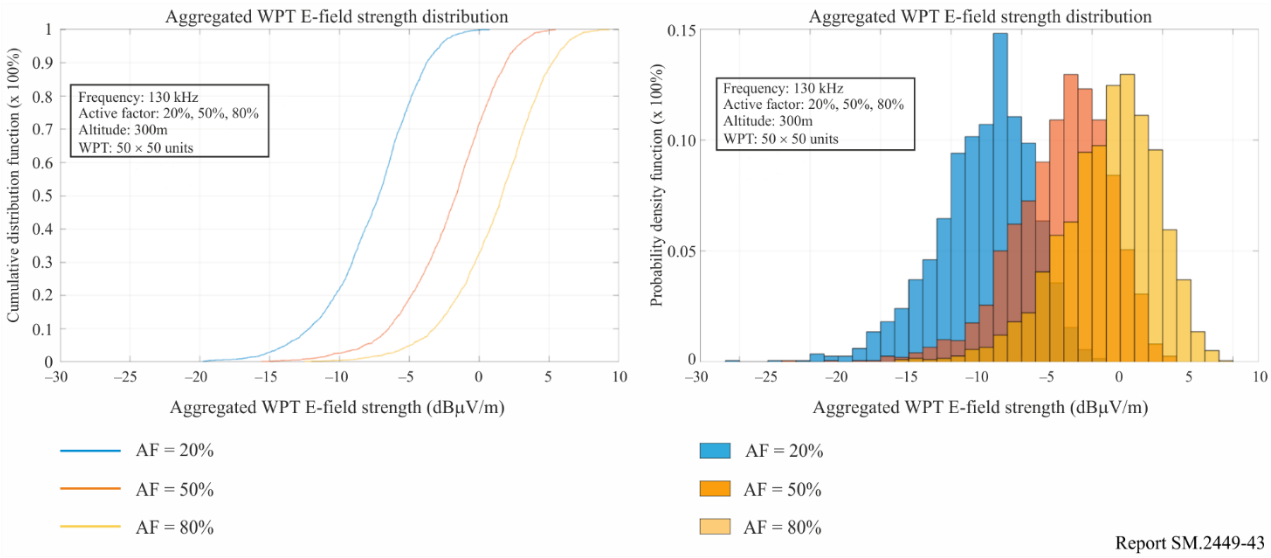
Conclusions for aircraft altitude of 100 m

The simulation has shown that the maximum calculated field strength even at 80% activity factor is less than the maximum permissible interference by 15.4 dB. Roof or floor penetration loss were not included in the simulation, but would further reduce the interference impact from WPT devices to ADF.

Figure 43 shows the results for an aircraft altitude of 100 m.

FIGURE 43

Aggregate WPT radiated E-field distribution (300m aircraft height)



Activity Factor	Emax (dBμV/m)	Avg. (dBμV/m)	Std	Max. Permissible Interfere (dBμV/m)	Margin/Gap (dB)
20%	−24.3	–32.7	3.4	21.9	46.2
50%	−19.5	–27.1	3.4	21.9	41.4
80%	−15.7	–23.8	3.5	21.9	37.6

Conclusions for aircraft altitude of 300 m

The simulation has shown that the maximum calculated field strength even at 80% activity factor is less than the maximum permissible interference by 37.6 dB. Roof or floor penetration losses were not included in the simulation, but would further reduce the interference impact from WPT devices to ADF.

5.5.3 Summary of the results

The simulations have shown that the E-field of WPT chargers for mobile and portable devices do not impact the reception of ADF/NDB signals. Roof or floor penetration loss were not included in the calculation/simulation, but would further reduce the interference impact from WPT devices to ADF.

6 Conclusion

Emissions modelling and measurements were used to analyze the impact from WPT for mobile and portable devices on radiocommunications services. The report analyzed the interference impact on AM Broadcasting, Amateur Radio and Aeronautical Radionavigation (ADF/NDB). WPT devices for charging mobile and portable devices operating in the 100-148.5 kHz frequency range require adequate separation distance from radiocommunication service receivers in order not to cause interference. For AM broadcasting one study found that the required separation distance was 2.3 m while the other study indicated that the required separation distance may be larger. For the Amateur Radio service this distance was between 15.3 m and 40.8 m depending on the scenario. The studies for aeronautical radionavigation (ADF/NDB) found that the required separation distances were much less than the minimum safe flying altitudes (referred to in § 5.5.2.2).

Annex 1

References

ITU-R Document and number	ITU-R Document title
GE75 Regional Plan Agreement	
Recommendation ITU-R P.368-7	Ground-wave propagation curves for frequencies between 10 kHz and 30 MHz
Recommendation ITU-R P.372	Radio noise
Recommendation ITU-R BS.468	Measurement of audio-frequency noise voltage level in sound broadcasting
Recommendation ITU-R BS.498	Ionospheric cross-modulation in the LF and MF broadcasting bands
Recommendation ITU-R P.532	Ionospheric effects and operational considerations associated with artificial modification of the ionosphere and the radio-wave channel
Recommendation ITU-R BS.559	Objective measurement of radio-frequency protection ratios in LF, MF and HF broadcasting
Recommendation ITU-R BS.560	Radio-frequency protection ratios in LF, MF and HF broadcasting
Recommendation ITU-R BS.561	Definitions of radiation in LF, MF and HF broadcasting bands
Recommendation ITU-R M.589	Technical characteristics of methods of data transmission and interference protection for radionavigation services in the frequency bands between 70 and 130 kHz
Recommendation ITU-R BS.638	Terms and definitions used in frequency planning for sound broadcasting
Recommendation ITU-R BS.639	Necessary bandwidth of emission in LF, MF and HF broadcasting
Recommendation ITU-R BS.703	Characteristics of AM sound broadcasting reference receivers for planning purposes
Recommendation ITU-R M.823	Technical characteristics of differential transmissions for global navigation satellite systems from maritime radio beacons in the frequency band 283.5-315 kHz in Region 1 and 285-325 kHz in Regions 2 and 3
Recommendation ITU-R SM.1056	Limitation of radiation from industrial, scientific and medical (ISM) equipment
Recommendation ITU-R P.1147	Prediction of sky-wave field strength at frequencies between about 150 and 1 700 kHz

ITU-R Document and number	ITU-R Document title
Recommendation ITU-R P.1321	Propagation factors affecting systems using digital modulation techniques at LF and MF
Recommendation ITU-R BS.1348	Service requirements for digital sound broadcasting at frequencies below 30 MHz
Recommendation ITU-R BS.1386	LF and MF transmitting antennas characteristics and diagrams
Recommendation ITU-R BS.1387	Method for objective measurements of perceived audio quality
Recommendation ITU-R BS.1514	System for digital sound broadcasting in the broadcasting bands below 30 MHz
Recommendation ITU-R M.1732-2	Characteristics of systems operating in the amateur and amateur-satellite services for use in sharing studies
Recommendation ITU-R BS.1895	Protection criteria for terrestrial broadcasting systems
Recommendation ITU-R SM.1896	Frequency ranges for global or regional harmonization of short-range devices (SRDs)
Recommendation ITU-R SM.2028	Protection distance calculation between inductive systems and radiocommunication services using frequencies below 30 MHz
Recommendation ITU-R SM.2103	Global harmonization of SRD categories
Recommendation ITU-R SM.2110	Frequency ranges for operation of non-beam Wireless Power Transmission (WPT) systems
Report ITU-R BS.401	Transmitting Antennas in LF, MF, and HF broadcasting
Report ITU-R BS.458	Characteristics of systems in LF, MF, and HF broadcasting
Report ITU-R SM.2057	Studies related to the impact of devices using ultra-wideband technology on radiocommunication services
Report ITU-R SM.2153	Technical and operating parameters and spectrum requirements for short-range devices
Report ITU-R SM.2154	Short-range radiocommunication devices spectrum occupancy measurement techniques
Report ITU-R SM.2179	Short-range radiocommunication devices measurements
Report ITU-R SM.2180	Impact of industrial, scientific and medical (ISM) equipment on radiocommunication services
Report ITU-R SM.2210	Impact of emissions from short-range devices on radiocommunication services
Report ITU-R SM.2303	Wireless power transmission using technologies other than radio frequency beam

Annex 2

Abbreviations

Term	Explanation
ADC	Analogue digital converter
ADF	Automatic direction finder
AM	Amplitude modulation
BBC	British Broadcasting Corporation

BW	Bandwidth
FCC	Federal Communications Commission
NDB	Non-directional beacon
EV	Electric vehicle
ISM	Industrial, scientific, and medical (applications)
LF	Low frequency
WPT	Wireless power transmission