International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Report ITU-R SM.2303-0
(06/2014)

Wireless power transmission using technologies other than radio frequency beam

SM Series

Spectrum management

International Telecommunication Union

Foreword

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

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

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ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Annex 1 of Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from http://www.itu.int/ITU-R/go/patents/en where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

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REPORT ITU-R SM.2303-0

Wireless power transmission using technologies other than radio frequency beam

1 Introduction

This Report contains proposed frequency ranges and associated potential levels for out-of-band emissions which have not been agreed within the ITU-R, and require further study to ascertain if they provide protection to radiocommunication services on co-channel, adjacent channel and adjacent band criteria. The Report gives an overview of current research and development and work being undertaken in some Regions.

Technologies to transmit electric power wirelessly have been developed since the 19th century, beginning from induction technology. Since the Massachusetts Institute of Technology innovation on Non-Beam wireless power technology in 2006, technologies of wireless power transmission (WPT) under development vary widely; e.g. transmission via radio-frequency beam, magnetic field induction, resonant transmission, etc. WPT applications are expanding to mobile and portable devices, home appliances and office equipment, and electric vehicles. New features such as freedom of charging device placement are added. Some technology claims simultaneous multiple device charging. Inductive WPT technologies are widely commercially available today. Nowadays, resonant WPT technologies are coming out to consumer market. Automotive industry looks at WPT for electric vehicle (EV) applications in the upcoming future.

Suitable frequencies for WPT to attain required transmission power level and power efficiency, applicable physical dimensions of coil/antenna are mostly specified. However, WPT coexistence study with the incumbent radio systems are now carefully examined and is pointed out with many issues which should be resolved in a timely manner. Some countries and international radio-related organizations are discussing radio regulations necessary to introduce WPT technologies. Some discussion results and ongoing discussions are now publicly available to share. For example, APT Survey Report on WPT [1] provides the latest information on regulatory discussions in Asia-Pacific Telecommunity (APT) member countries on WPT to consider introduction.

This Report provides information about WPT using technologies other than radio frequency beam, as partial answers to Question ITU-R 210-3/1.

This Report includes information about national regulations but this information has no international regulatory effect.

2 Applications developed for use of WPT technologies

2.1 Portable and mobile devices

2.1.1 Inductive WPT for mobile devices such as cellular phones and portable multimedia devices

Inductive WPT uses inductive technologies and is applied to the following applications:

– Mobile and portable devices: cellular phones, smartphones, tablets, note-PCs.
– Audio-visual equipment: digital still cameras.
– Business equipment: handy-digital-tools, table-order-systems.
– Others: lighting equipment (e.g. LED), robots, toys, car-mounted devices, medical equipment, healthcare devices, etc.

Some technologies of this type may require exact device positioning on the power source. In general, the device to be charged should be contacted with the power source such as the power tray. Operational emission power is assumed in the range from several watts to 10 s of watts.

2.1.2 Resonant WPT for mobile devices such as cellular phones and portable multimedia devices such as smartphones, tablets, portable multimedia devices

Resonant WPT uses resonant technologies, have more spatial freedom than inductive technology. The technology is applied to the following applications for any orientation (x-y and z) with no alignment techniques:

– cellular phones, smartphones, tablets, note-PCs, wearable devices
– digital still cameras, digital video cameras music-players, portable TVs
– handy-digital-tools, table-order-systems, lighting equipment (e.g. LED), robots, toys, car-mounted devices, medical equipment, healthcare devices, etc.

Annex 2 describes an example of this type of WPT technology.

2.2 Home appliance and logistics applications

This application may require similar features and aspects to WPT for portable and multimedia devices. However, in general they use higher power than those. Therefore, it may require additional regulatory compliance in some countries.

As operation power of CE appliances such TV with big video screen increases, WPT for these products require higher charging power above 100 W which may not obtain certification in the current regulatory categories and radio policies in some countries.

Magnetic induction and magnetic resonance methods can be applied according to the type of Home and logistics applications of WPT. The applications are as follows:

– Home appliance applications: Household electrical appliances, furniture, cooker, mixer, television, small robot, audio-visual equipment, lighting equipment, healthcare devices, etc.
– Logistics applications: stocker at logistics warehouse, medical equipment, Overhead Transfer at LCD and Semiconductor product lines, Automated Guided Vehicle (AGV) system etc.

The operation power is expected to be from several hundreds of watts to several kW range due to the consumption power of application devices. Suitable frequency band is under 6 780 kHz in considering the RF emission, exposure, and system performance.

2.3 Electric vehicle

A concept of WPT for EV including plug-in hybrid electric vehicle (PHEV) is to charge the car without a power-cable wherever WPT is available.

Charging power may depend on the requirement of the users. In most use cases for passenger vehicles at their home garage, 3.3 kW or equivalent charring power could be accepted. However, some users want to charge quickly or their car for specific use purpose may need much bigger power. 20 kW or higher power range are also taken in consideration today.

Charging power may depend on the requirement of the heavy duty vehicles. In use cases for heavy duty vehicles, the initial 75 kW equivalent charging power may be required. The 100 kW or higher power range are also taken into consideration.

Were WPT for EV to become a ubiquitous power source, it may lead to a reduction of EV battery size and unlimited drive.

Charged power at car will be used for driving, powering supplemental car devices, air-conditioning, and other car-necessities.

WPT technologies and applications both while parking and while driving are taken into consideration.

3 Technologies employed in or incidental to WPT applications

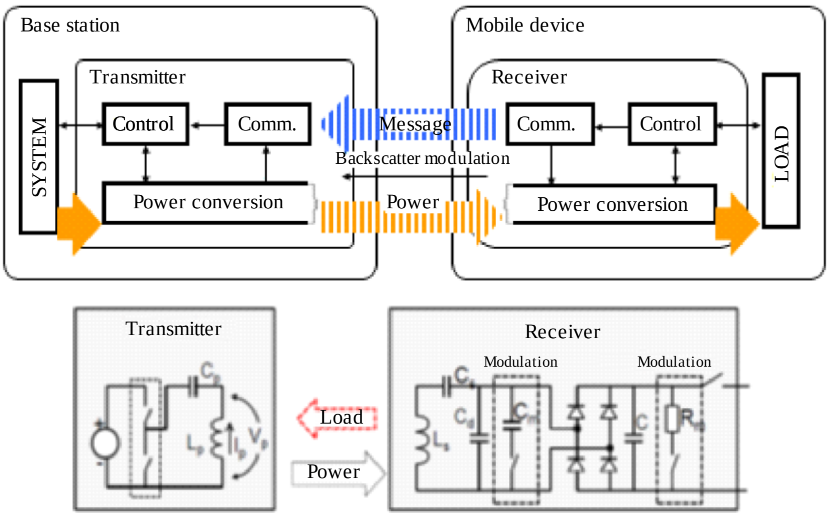
3.1 For portable and mobile devices

3.1.1 Magnetic induction WPT technology

The WPT by magnetic inductance is a well-known technology, applied for a very long time in transformers where primary and secondary coils are inductively coupled, e.g. by the use of a shared magnetic permeable core. Inductive power transmission through the air with primary and secondary coils physically separated is also a known technology for more than a century, also known as Tightly Coupled WPT. A feature of this technology is that the efficiency of the power transmission drops if the distance through the air is larger than the coil diameter and if the coils are not aligned within the offset distance. The efficiency of the power transmission depends on the coupling factor (k) between the inductors and their quality (Q). This technology can achieve higher efficiency than magnetic resonance method. This technology has been commercialized for charging of smart phones. With a coil array, this technology also offers flexibility in the receiver coil location of the transmitter.

FIGURE 3.1

Example magnetic induction WPT system block diagram



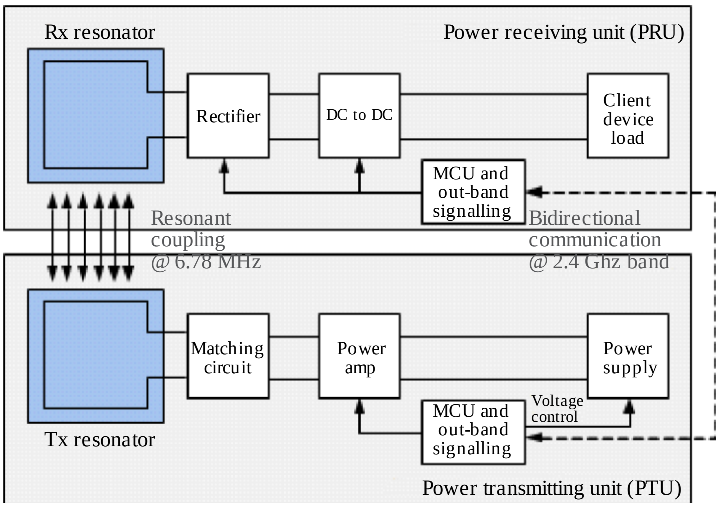
Report SM.2303-3-01

3.1.2 Magnetic resonance WPT technology

The WPT by magnetic resonance is also known as Loosely Coupled WPT. The theoretical basis of this magnetic resonance method was first developed in 2005 by Massachusetts Institute of Technology, and their theories were validated experimentally in 2007 [3]. The method uses a coil and capacitor as a resonator, transmitting electric power through the electromagnetic resonance between transmitter coil and receiver coil (magnetic resonant coupling). By matching the resonance frequency of both coils with high Q factor, electric power can be transmitted over a long distance where magnetic coupling between two coils is low. The magnetic resonance WPT can transmit electric power over a range of up to several meters. This technology also offers flexibility in the receiver coil location of the transmission coil. Practical technical details can be found in many technical papers, for example, those in [3] and [4].

FIGURE 3.2

Example magnetic resonance WPT system block diagram



Report SM.2303-3-02

3.1.3 Capacitive coupling WPT

The capacitive coupling WPT system has two sets of electrodes, and does not use coils as magnetic type of WPT systems. Power is transmitted via an induction field generated by coupling the two sets of electrodes. The capacitive coupling system has some merits as follows. Figures 3.3 and 3.4 show system block diagram and typical structure, respectively.

1) Capacitive coupling system provides horizontal position freedom with an easy-to-use charging system for end customers.

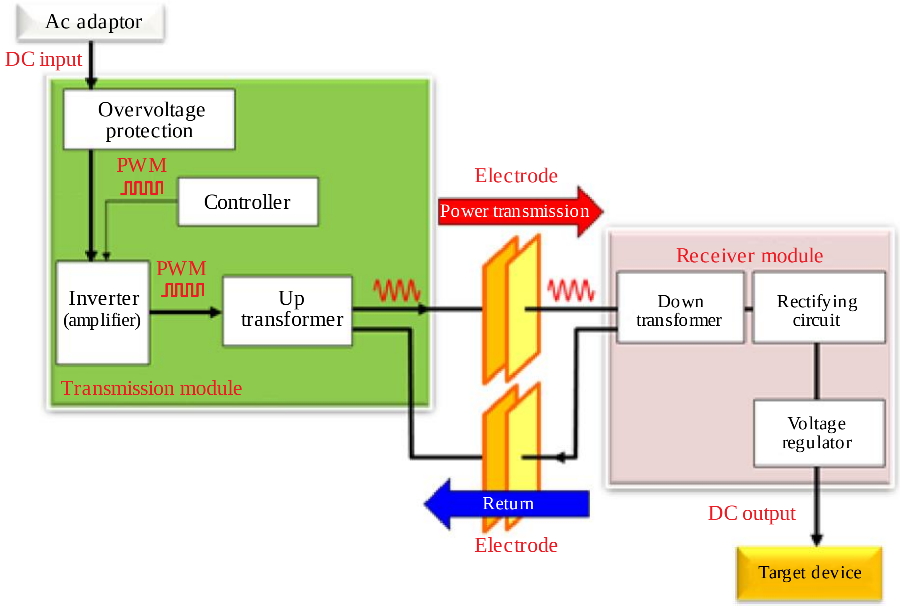
2) Very thin (less than 0.2 mm) electrode can be used between transmitter and receiver in the system, and hence suitable for integration into slim mobile devices.

3) No heat generation in the wireless power transmission area. This means the temperature does not rise in the wireless power transmission area, which protects the battery from heating even when the unit is placed nearby.

4) The emission level of the electric field is low because of the structure of its coupling system. The electric field is emitted from electrodes for power transmission.

FIGURE 3.3

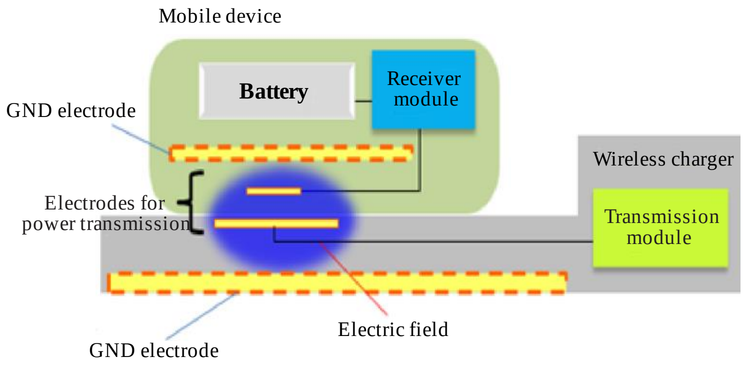
Capacitive coupling WPT system block diagram



Report SM.2303-3-03

FIGURE 3.4

Typical structure of the capacitive coupling system



Report SM.2303-3-04

3.2 For home appliances

Inductive power sources (transmitters) may stand alone or be integrated in the kitchen counter tops or dining tables. These transmitters could combine the WPT to an appliance with conventional inductive heating.

For the home appliance application, the power level is usually up to several kilowatts, and the load maybe motor-driven or heating type. Future products will support more than 2 kW power and some new design proposal for cordless kitchen appliances is being investigated.

Considering the high power usage in home, frequencies in the order of tens of kHz are preferred to restrict electromagnetic exposure to human bodies. And high reliable devices such as IGBTs are usually used and these devices are working in 10 kHz-100 kHz frequency range.

The product applied in the kitchen must meet the safety and EMF requirements. And it is a key issue that transmitter should be light and small size to fit the kitchen in addition to being low cost. The distance between the transmitter and the receiver is intended to be less than 10 cm.

The following pictures show examples of wireless power kitchen appliances that will come to the market soon.

FIGURE 3.5

Wireless power kitchen appliances

Tightly coupled mixer Tightly coupled rice cooke

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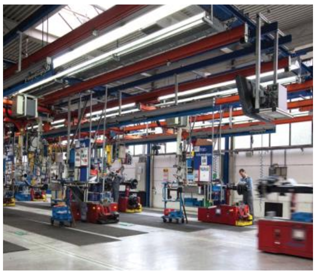
WPT systems are already integrated in the product lines of Semiconductor and LCD panel, the following pictures show examples.

FIGURE 3.6

Use cases of the LCD and semiconductor product lines and kitchen WPT systems

(WPT overhead shutter of LCD product line)



(WPT overhead transmission of Semiconductor product line)

(WPT kitchen island of apartment)

Report SM.2303-3-06

3.3 For electrical vehicles

Magnetic Field Wireless Power Transmission (MF-WPT) is one of the focus points in standardization discussion such as IEC PT61980 and SAE J2954TF regarding WPT for EV including PHEV though there are several types of WPT methods. MF-WPT for EV and PHEV contains both inductive type and magnetic resonance type. Electric power can be transmitted from the primary coil to the secondary coil efficiently via magnetic field by using resonance between the coil and the capacitor.

Expected passenger vehicle applications assume the following aspects:

1) WPT application: Electric power transmission from electric outlet at a residence and/or public electric service to EVs and PHEVs.

2) WPT usage scene: at residential, apartment, public parking, etc.

3) Electricity use in vehicles: All electric systems such as charging batteries, computers, air conditioners, etc.

4) Examples of WPT usage scene. An example for passenger vehicles is shown in the following figure.

5) WPT method: AWPT system for EV/PHEV has at least two coils. One is in the primary device and the other is in the secondary device. The electric power will be transmitted from primary device to secondary device through magnetic flux/field.

6) Device location (Coil location):

a) Primary device: On ground or/and in ground.

b) Secondary device: Lower surface of vehicle.

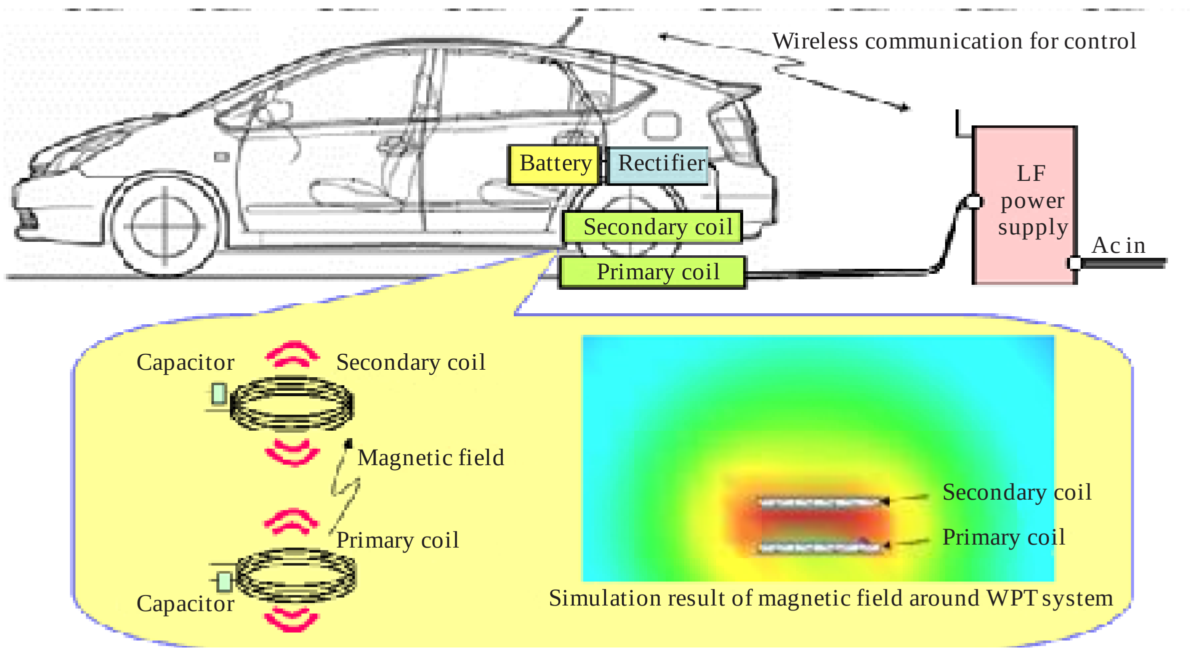
7) Air gap between primary and secondary coils: Less than 30 cm.

8) Transmission power class example: 3 kW, 6 kW, and, 20 kW.

9) Safety: Primary device can start power transmission only if secondary device is located in the proper area for WPT. Primary device needs to stop transmission if it is difficult to maintain safe transmission.

FIGURE 3.7

Example of a WPT system for EV/PHEV



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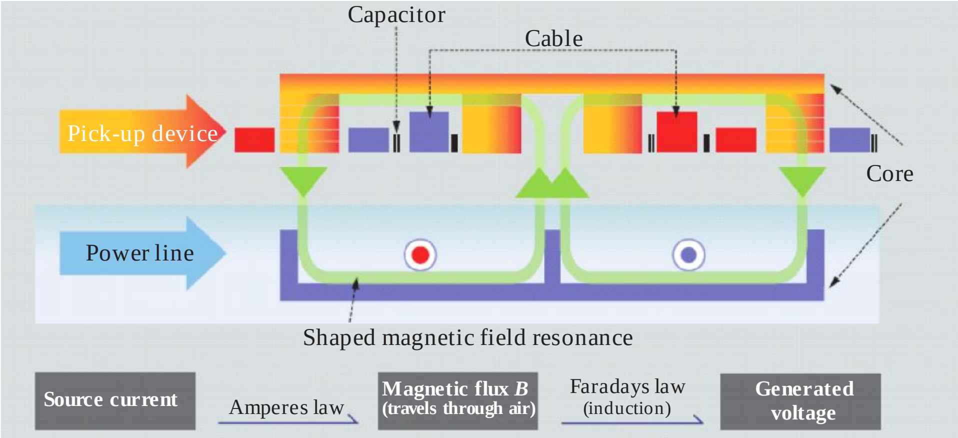
In order to run heavy duty vehicles such as an electrical bus, the infrastructure of the system is to embed electric strips in roadbeds that magnetically transmit energy to battery-powered vehicles above. The bus can move along the electrical strips without any stopping for charging its power, known as on-line electric vehicle (OLEV). Furthermore the bus can be charged a stopping condition in bus stop or bus garage. The online bus at an amusement park or at the city is the first system operated in the form of EV for heavy duty vehicles in the world.

FIGURE 3.8

Technical characteristics of an online electric vehicle



Report SM.2303-3-08

The design of magnetic field from transmitting coil to receiving coil is the key in WPT system design for maximum power and efficiency.

First, the magnetic field should be in resonance by using resonant transmitting and receiving coils to have high power and efficiency.

Second, the magnetic field shape should be controlled, by using magnetic material such as ferrite-core, to have minimum magnetic resistance in the path of the magnetic field, for lower leakage magnetic field and higher transmission power.

It is called as SMFIR (Shaped Magnetic Field in Resonance).

FIGURE 3.9

Example of an online electric vehicle

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4 WPT's standardization situation in the world

4.1 National standards development organizations

4.1.1 China

In China, CCSA (China Communication Standard Association) has been creating WPT standards for portable devices, such as Mobile Stations. In 2009, CCSA TC9 set up one new research report project "Research on Near-field Wireless Power Supply Technology". This project was finished in March, 2012 and developed the report on the wireless power supply technology research. In 2011, CCSA TC9 created two standard projects: (1) Electromagnetic field (EMF) Evaluation Methods for Wireless Power Supply (WPS); (2) Electromagnetic compatibility (EMC) Limits and Measurement Methods for WPS. These two standards will be published soon.

Now, there are three new standards related to the technical requirements and test methods (Part 1: General; Part 2: Tightly Coupled; Part 3: Resonance wireless power) and the development of safety requirements have been in the final draft status. More and more standard projects related to wireless power transmission will be created. The target products are audio, video and multimedia devices, information technology equipment, and telecommunication devices.

These standards focus on performance, radio spectrum, and interface. It is planned that this standard will not involve intellectual property rights. Generally, the possibility for these standards to become mandatory is low.

The standards may define new logos to identify which Part of standard (Parts 2/3) the product belongs to.

China National Standardization Administration Commission (SAC) is planning to set up a National Standardization Technical Committee (TC) on WPS. China Academy of Telecommunication Research (CATR) of MIIT has been promoting it. This TC is responsible for creating national standards on WPS for mobile phones, information technology equipment, audio, video and multimedia devices.

Considering the plan and/or timeline of standard/guideline/regulation development at CCSA, EMC and EMF standards will be published soon. Part 1 of the Technical requirements standards has been approved, and Part 2, Part 3 and safety requirements standards will be completed in 2014.

In China, a national SDO oriented to wireless-powered home appliance was set up in November 2013 and it has a plan to make the national standards. Moreover, other issues such as safety and performances are also discussed there.

4.1.2 Japan

The WPT-Working Group of BWF (Broadband Wireless Forum, Japan) is taking responsibility for drafting WPT technical standards utilizing the ARIB (Association of Radio Industries and Businesses) drafting protocols. A draft standard developed by BWF will be sent to ARIB for approval. BWF is now performing in-depth technical study for WPT spectrum for all the applications and technologies. Currently, the following WPT technologies are put in pipeline with timelines for standardization. The first three with less than 50 W transmission power are intended for approvals in 2014. The others with higher power (> 50 W) are expected in 2015.

– Capacitive coupling WPT,
– WPT using microwave two-dimensional waveguide sheet,
– Magnetic resonant WPT using 6 765-6 795 kHz for mobile/portable devices,
– Magnetic resonant WPT for home appliances and office equipment,
– WPT for EV/PHEV.

In addition to developing and evaluating power-transmission radio wave specifications, control-signalling-transmission mechanisms are taken into account. Global harmonization on spectrum is carefully considered for those intended for global market.

In June 2013, with MIC's aim of directing new regulation for WPT, the Wireless Power Transmission Working Group (WPT-WG) was formed under MIC's Subcommittee on Electromagnetic Environment for Radio-wave Utilization. Studies on WPT frequency bands and coexistence with the incumbents are the main subjects of the WPT-WG. Further information is provided in Chapter 6. Referring to the recent study results at BWF, new rulemaking works are in progress. The results will be reflected to the WPT standard development.

4.1.3 Korea

MSIP (Ministry of Science, ICT and future Planning) and its RRA (National Radio Research Agency) are government agencies in charge of WPT Regulations in Korea. And the main standardization organizations developing the standards for WPT are shown in Table 4.1.

TABLE 4.1

Standardization activities status in Korea

Name	URL	Status
KATS	http://www.kats.go.kr/en_kats/	On-going – Multi-device charging management
KWPF	http://www.kwpf.org	On-going – spectrum related to WPT – regulatory related to WPT – WPT based on magnetic resonance – WPT based on magnetic induction Completed – Use Case – Service Scenario – Functional Requirement – In-band communication for WPT – Control for management of WPT
TTA	http://www.tta.or.kr/English/index.jsp	Completed – Use Case – Service Scenario – Efficiency – Evaluation – In-band communication for WPT – Control for management of WPT On-going – WPT based on magnetic resonance – WPT based on magnetic induction

4.2 International organizations

Some international organizations dealing with WPT standardization and their relevant activities are summarized in Table 4.2.

TABLE 4.2

WPT related international organizations

Name of Organization	Activities
CISPR (Comité International Spécial des Perturbations Radioélectriques)	WPT is taken by CISPR SC-B (Interference relating to ISM radio frequency apparatus, and to overhead power lines, etc.) for discussion. The other SCs are considering WPT if they take.
IEC TC 100	Survey for Technical Reports regarding WPT – IEC TC 100 Stage 0 Project – Survey Completed: July. 2012 – Under Drafting Technical Reports
IEC TC 69	IEC TC 69 (Electric road vehicles and electric industrial trucks) WG4, together with ISO TC22 (Road Vehicles), discusses WPT for automotive.
ISO/IEC JTC 1 SC 6	In-band PHY and MAC Layer Protocol of WPT – ISO/IEC JTC 1 SC 6 – Working Item was approved in Jan. 2012. – On Circulation with WD (Working Document)
ITU-R SG1 WP1A	Recommendation/Report of regulatory and spectrum aspect on WPT – Question ITU-R 210-3/1 – Question Updated in Nov. 2012. – CG-WPT was established in June 2013 for Report/Recommendation developments.
CEA (Consumer Electronics Association)	CEA R6-TG1 (Wireless Charging Task Group) discusses WPT and related issues.
SAE (Society of Automotive Engineers)	WPT standardization has been getting active since 2010. Proposed specifications by OEMs are reviewed. Standardization is to complete in 2013-2014 as IEC plans. Currently specific frequency bands selection is under consideration for future decision.
A4WP	Non-radiative near- and mid-range magnetic resonant coupling (highly resonant coupling) (loosely-coupled WPT). – Baseline Technical Specification completed 2012 – Released its technical specification (ver.1) in January 2013
WPC	Tightly coupled inductive coupling solutions across a range of power levels. Website lists more than 120 members and 80 certified products including accessories, chargers and devices – Released technical specification (ver.1) in July 2010
CJK WPT WG	The working group on WPT of the CJK Information Technology Meeting. Shares information in the region to study and survey on low power and high power WPT – Released CJK WPT Technical Report 1 in April 2013 – To release CJK WPT Technical Report 2 in Spring 2014

4.2.1 IEC CISPR

From a regulatory point of view IEC CISPR can distinguish WPT applications into:

a) WPT applications offering wireless power transmission at a particular operating frequency without additional data transmission;

b) WPT applications also using the WPT frequency (band) for additional data transmission or communications with the secondary device;

c) WPT applications using other frequencies than those used for WPT for additional data transmission or communications with the secondary device.

From CISPR perspective (protection of radio reception) there is however no need to distinguish into WPT applications a) or b). In both cases, the radio frequency interference (RFI) potential of such WPT applications will be dominated by their primary function only, i.e. by the wireless power transmission at the given frequency (or within the given frequency band). Since CISPR standards offer already complete sets of limits and measurement methods for control of wanted, unwanted and spurious emissions from WPT applications according to item a) or b) we are convinced that it suffices just to continue in applying these standards. Clearly these standards might be employed in regulations concerning general EMC for electric and electronic products, as e.g. for ISM applications.

For WPT applications according to item c) above, existing regulations concerning general EMC should continue in application to the primary WPT function (inclusive of additional data transmission, if any, according to item b) above. Independently, further radio regulations may apply to any radio data transmission or communications at frequencies different from the WPT frequency. In this case, other EMC and functional standards for radio equipment may have to be taken into account too. An assessment of the total RFI potential of WPT applications according to item c) above in respect of the protection of radio reception in general and in respect of compatibility/coexistence with other radio appliances or services should always be done. This assessment should be comprised of the application of the respective CISPR standard and EMC and functional standard(s) for the radio communications components or modules of the WPT system.

The normal way to apply these standards will be to use them for type testing. Dependent on national or regional regulation, the results of such type test may be used then as basis for an approval of the type by a type approval authority, or for other kinds of conformity assessment and declaration.

A proposal of CISPR for classification of power electronic equipment offering wireless power transmission (WPT) and for use of CISPR EMC emission standards in regional and/or national regulation is found in Table 4.3. The proposal is also valid for WPT applications within the scopes of CISPR 14-1 (household appliances, electric tools and similar apparatus), CISPR 15 (lighting equipment) and CISPR 32 (multimedia and broadcast receiver equipment). For them, reference to CISPR 11 (ISM equipment) is to be replaced by reference to these relevant CISPR standards.

CISPR is about to extend applicability of the requirements for power electronic WPT equipment in the scope of CISPR 11, with appropriate adjustments at some point in the future, to WPT applications in the scopes of CISPR 14-1, CISPR 15 and CISPR 32. For the time being, only CISPR 11 offers a complete set of emission requirements for type tests on WPT applications, in the range 150 kHz up to 1 GHz, or up to 18 GHz, respectively.

CISPR is aware in a common gap in its CISPR standards, in control of conducted and radiated disturbances from WPT equipment in the range 9 kHz to 150 kHz. Controlling these emissions is an essential issue if the WPT equipment in question actually uses fundamental or operation frequencies allocated in this frequency range.

Just for information: CISPR/B agreed to clarify the group 2 classification in CISPR 11 to cover WPT equipment as follows:

Group 2 equipment: group 2 contains all ISM RF equipment in which radio-frequency energy in the frequency range 9 kHz to 400 GHz is intentionally generated and used or only used, in the form of electromagnetic radiation, inductive and/or capacitive coupling, for the treatment of material, for inspection/analysis purposes, or for transmission of electromagnetic energy.

This modified definition is found in CISPR/B/598/CDV which was approved, during the National Voting in 2014. It covers the project General Maintenance (GM) for CISPR 11 Ed. 5.1 (2010) and will provide CISPR 11 Ed. 6.0. If finally approved, this 6th Edition of CISPR 11 will be published in summer 2015. It will cover:

a) the extended and accomplished definition for group 2 equipment also comprising any type of power electronic WPT product,

b) the set of essential emission limits and measurement methods agreed so far for performance of type tests on power electronic WPT products.

Please note that CISPR standards consist of the combination of suitable methods of measurement and appropriate limits for permissible conducted and/or radiated disturbances in the applicable radio frequency range. For group 2 equipment CISPR 11 presently specifies such requirements in the range 150 kHz to 18 GHz. They also apply to all types of power electronic WPT equipment, for the time being by default.

CISPR urgently recommends recognition of type test reports verifying compliance with these CISPR emission requirements as Type Approval, for WPT applications with or without additional data transmission or communications at the same WPT frequency (see also Cases 1 and 2 in Table 4.3).

TABLE 4.3

Recommendation of CISPR for classification of power electronic equipment offering wireless power transmission (WPT) and for use of CISPR EMC emission standards in regional and/or national regulation

<table>
<tr><th rowspan="2">Case</th><th rowspan="2">Relevant regulation</th><th rowspan="2">Other specifications also used by regulators</th><th colspan="3">Applicable essential requirements / standards</th></tr>
<tr><th>EMF</th><th>EMC</th><th>Radio</th></tr>
<tr><td>1
WPT systems without data transfer or communication function</td><td>EMC
ITU-R RR for ISM appliances</td><td>Rec. ITU-R SM.1056-1</td><td>IEC 62311
(IEC 62479)</td><td>IEC/CISPR 11 Group 2
(or more specific IEC product standard, if available)</td><td>N/A</td></tr>
<tr><td>2
WPT systems with data transfer or communication function at same frequency as energy transfer</td><td>EMC
ITU-R RR for ISM appliances</td><td>Rec. ITU-R SM.1056-1</td><td>IEC 62311
(IEC 62479)</td><td>IEC/CISPR 11 Group 2
(or more specific IEC product standard, if available)</td><td>Application not necessary</td></tr>
<tr><td rowspan="2">3
WPT systems with data transfer or communication function at different frequency to energy transfer</td><td>EMC
ITU-R RR for ISM appliances</td><td colspan="4">For final assessment of the RFI potential of the WPT function of the power electronic WPT system, application of the rules for Case 1 resp. Case 2 is recommended.</td></tr>
<tr><td>Efficient use of the RF spectrum
ITU-R RR for radio appliances</td><td colspan="4">For final assessment of the (radio-based) signal/control and/or communication function of the power electronic WPT system, national and/or regional regulation (such as licensing and/or conformity assessment) in respect of an efficient use of the radio frequency (RF) spectrum may apply in addition. For type testing, adequate national or regional standards for radio equipment, as e.g. according to Rep. ITU-R SM.2153-1 (short-range radiocommunication devices), may be used.</td></tr>
</table>

Case 3: If the WPT equipment operates with accompanying data transmission or communications utilizing a frequency different from the frequency used for WPT, then:

a) compliance of the WPT function with the EMC emission requirements specified in the relevant CISPR product standard should be deemed to establish presumption of conformity with existing national and/or regional regulation on EMC according to Recommendation ITU-R SM.1056-1, in respect of any wanted, unwanted and spurious emissions resulting from WPT in the radio frequency range,

b) compliance of the data transmission and/or communication function with the EMC and functional requirements for radio equipment specified in national and/or regional specifications and standards for control of the efficient use of the radio frequency spectrum should be deemed to establish presumption of conformity with existing national and/or regional regulation for radio devices or modules being part of the WPT system under test, in respect of any wanted, unwanted and spurious emissions which can be attributed to the radio data transmission and/or communications function.

In Case 3, the WPT system under test is regarded as multifunction equipment. An Approval of the Type should be granted if it had been demonstrated that the respective type of WPT equipment complies with the essential EMC emission (and immunity) requirements specified in the relevant CISPR (or other IEC) standard(s), for its WPT function, see indent a). Another precondition for granting the Type Approval should be that it had been demonstrated that the radio device or module being integral part of the WPT systems complies with the essential EMC and functional requirements for radio equipment specified in respective national or regional specifications and standards for radio equipment.

For the time being CISPR observed ambivalent approaches of national and/or regional regulatory authorities to the type approval, conformity assessment and licensing business in conjunction with permission of operation and use of WPT applications in the field.

While European authorities could obviously imagine sole application of the European regulatory framework for Short Range radio Devices (SRD) for Case 2, the Federal Communications Commission (FCC) in the United States of America indicated that WPT devices operating at frequencies above 9 kHz are to be regarded as intentional radiators and hence are subject to either Part 15 and/or Part 18 of the FCC rules. The specific applicable rule part depends on how the device operates, and if there is communication between the charger and the device being charged.

Table 4.4 contains an overview about present regulation in Europe. It should be noted that TCAM, the Telecommunications Conformity Assessment and Market Surveillance Committee of the European Commission approved these proposals offered by the European SDOs CENELEC and ETSI, at its meeting in February 2013. In doing so TCAM indicated that current European regulation applies to all present and upcoming types of WPT appliances.

For Case 2, Declarations of Conformity (DoCs) with sole reference to the EMC Directive will be accepted for a type of power electronic WPT appliance with or without additional data transmission at the WPT frequency, and with any rated throughput power, as long as it can be shown that the WPT appliance meets the emission requirements for group 2 equipment specified in EN 55011 (see Case 2a). In addition Case 2b opens the possibility for a DoC solely referring the R&TTE Directive, as long as it can be shown that the WPT appliance in question meets the requirements of respective harmonized EMC and functional standards of ETSI for radio communications equipment.

TABLE 4.4

European regulation concerning EMC and efficient use of the radio frequency (RF) spectrum (TCAM, CEPT/ERC, SDOs ETSI and CENELEC)

<table>
<tr><th rowspan="2">Case</th><th rowspan="2">Relevant Directive</th><th rowspan="2">Other specifications also used by regulators</th><th colspan="3">Applicable essential requirements / standards</th></tr>
<tr><th>EMF</th><th>EMC</th><th>Radio</th></tr>
<tr><td>1
WPT systems
without data transfer or communication function</td><td>EMC Directive</td><td>None</td><td>EN 62311
(EN 62479)
or other applicable standards from the OJEU
listed under the Low Voltage Directive</td><td>EN 55011
Group 2
(or more specific CENELEC standard,
if available)</td><td>N/A</td></tr>
<tr><td rowspan="2">2a
WPT systems
with data transfer or communication function at same frequency as energy transfer
(Any power transfer rate)</td><td>EMC Directive</td><td>None</td><td>See above</td><td>See above</td><td>Application not necessary</td></tr>
<tr><td colspan="5">NOTE For the time being, type tests on power electronic WPT equipment with or without additional data transfer or communications at one and the same frequency in the radio frequency range can be performed based on EN 55011. There is no constraint in the rated throughput power, as long as it can be shown that the product type in question meets the emission requirements specified in EN 55011.
It is expected that CENELEC starts closing the gap in the limits in EN 55011 for conducted and radiated emissions in the range 9 kHz to 150 kHz, in particular for power electronic WPT equipment using fundamental operation frequencies allocated in that frequency range. It is also expected that CENELEC starts adapting emission limits for WPT appliances in the other EMC product standards too.</td></tr>
<tr><td rowspan="5">2b
WPT systems
with data transfer or communication function at same frequency as energy transfer
(Limited power transfer rate)</td><td rowspan="4">R&TTE Directive</td><td>None</td><td>EMF standards for radio appliances</td><td>EMC standards for radio appliances</td><td>Functional standards for radio appliances</td></tr>
<tr><td>9 kHz < band < 30 MHz</td><td rowspan="3">EN 62311
(EN 62479)</td><td rowspan="3">EN 301 489-1/3</td><td>EN 300 330</td></tr>
<tr><td>30 MHz < band < 1 GHz</td><td>EN 300 220</td></tr>
<tr><td>1 GHz < band < 40 GHz</td><td>EN 300 440</td></tr>
<tr><td colspan="5">NOTE Where possible, the combination of the ETSI standards EN 301 489-1/3 and a respective ETSI functional radio standard can be used for type tests on short range radio devices (SRD) which provide both, WPT and radio data transfer or radio communications at one and the same radio frequency.
Presently, possibility of type testing of SRDs with WPT functionality is still limited to rather low rated power throughput levels. Work is on the way in ETSI to adapt EN 300 330 for application in type testing of SRDs with WPT functionality and power throughput rates in the range of up to a couple of tens of Watt.</td></tr>
<tr><td rowspan="6">3
WPT systems
with data transfer or communication function at different frequency to energy transfer</td><td>EMC Directive</td><td colspan="4">For final assessment of the RFI potential of the WPT function without or with data transfer at the same frequency, the rules of Case 1, or of Case 2a resp. Case 2b apply.</td></tr>
<tr><td rowspan="4">R&TTE Directive
(radio communications function)</td><td>None</td><td>EMF standards for radio appliances</td><td>EMC standards for radio appliances</td><td>Functional standards for radio appliances</td></tr>
<tr><td>9 kHz < band < 30 MHz</td><td rowspan="3">EN 62311
(EN 62479)</td><td rowspan="3">EN 301 489-1/3</td><td>EN 300 330</td></tr>
<tr><td>30 MHz < band < 1 GHz</td><td>EN 300 220</td></tr>
<tr><td>1 GHz < band < 40 GHz</td><td>EN 300 440</td></tr>
<tr><td colspan="5">NOTE The combination of the ETSI standards EN 301 489-1/3 is just an example and shall be used for type tests on SRD modules providing the data transfer and/or communications function for the WPT product subject to the type test.
In principle any other kind of radio application fitting the purpose of local data transfer and/or radio communications in between the devices forming the local wireless power transmission (WPT) system can be used. In this case, other combinations of harmonized functional and EMC standards of ETSI apply, e.g. Bluetooth -> EN 300 328 & EN 301 489-1/17, dependent on the communication technology.</td></tr>
</table>

The CISPR, being interested in a harmonized way of worldwide proceedings with additional regional or national regulation for WPT applications, recommends to adapting the approach proposed in Cases 1, 2 and 3.

As noted above there is a gap in the essential emission requirements in CISPR 11, in the frequency range 9-150 kHz. However, for the time being, the obvious gap was only confirmed for WPT power electronic appliances in the scope of CISPR 11 which uses operation (or fundamental) frequencies in the range below 150 kHz. Hence, if the limits are determined in the frequency range, they will preferably apply to such WPT power electronic equipment only.

CISPR/B recommends application of the existing group 2 limits to any WPT power electronic appliances. In proceeding this way CISPR/B does not identify any need to consult with ITU-R about possible allocation of further ISM frequency bands.

4.2.2 ICNIRP

International Commission on Non-Ionizing Radiation Protection (ICNIRP) levels are the reference accepted worldwide, and countries' threshold are compared to the ICNIRP exposure level. This material refers to the relevant frequency bands of WPT.

ICNIRP has published guidelines on human exposure to electromagnetic fields. Two publications of ICNIRP guidelines of 1998 [7] and 2010 [8] are applicable to WPT. Those guidelines describe basic restrictions and reference levels. Limitations of exposure that are based on the physical quantities directly related to the established health effects are termed basic restrictions. In the ICNIRP guidelines, the physical quantity used to specify the basic restrictions on exposure to EMF is the internal electric field strength, as it is the electric field that affects nerve cells and other electrically sensitive cells. However, the internal electric field strength is difficult to assess. Therefore, for practical exposure assessment purposes, reference levels of exposure are provided.

Compliance with the reference level will ensure compliance with the relevant basic restriction. If the measured or calculated value exceeds the reference level, it does not necessarily follow that the basic restriction will be exceeded. However, whenever a reference level is exceeded it is necessary to test compliance with the relevant basic restriction and to determine whether additional protective measures are necessary. The ICNIRP reference levels on electric and magnetic fields exposure are accepted worldwide, and countries' threshold are compared to the ICNIRP reference levels.

Operators of WPT may take steps to adequately protect the public from EMF effects.

Recent measurements of WPT H-field emissions related to RF exposure from Japan appear at Annex 3. Additional measurements on field strengths nearby WPT are encouraged.

5 Status of spectrum

5.1 Non-ISM bands used on a national basis for WPT

42-48 kHz

52-58 kHz

79-90 kHz

100 kHz to 205 kHz

425 kHz to 524 kHz

The frequency bands under study and key parameters for these applications are summarized in Table 5.1. Concerned incumbent systems for which coexistence is required are also provided in this table.

(i) Magnetic induction

The frequency range anticipated for magnetic induction applications is 100-205 kHz. Given the current use cases and technical conditions, WPT operation are expected to conform to domestic and international rules and guidelines for radiated emission limits and RF exposure limits.

Some products based on the magnetic induction technologies are already introduced in some countries.

(ii) High power magnetic induction

The frequency range is similar to those for EV applications (see below).

There are many incumbent devices and systems including standard clock radios and railway radio systems operating on similar frequencies to high power magnetic induction applications and hence coexistence studies will be necessary.

(iii) Capacitive coupling

The capacitive coupling WPT systems are originally designed for the use of frequency range 425-524 kHz. Transmission power level is less than 100 W. Several reasons of the frequency selection are provided as follows.

The first reason is to balance efficiency and equipment size. There are many parts designed for the use in this band for example; inverters, rectifiers, etc., which lead to broader variety of components with low loss performance that optimizes WPT equipment design. The transformers are key parts of capacitive coupling WPT system. The transformer performance depends on the Q-value of ferrite material, which can be optimized in this frequency range. Consequently, total efficiency of capacitive coupling system is about 70% to 85%.

The second reason is capability to suppress unwanted emission in the electric field in order to co-exist with the incumbents in the adjacent frequency bands such as AM broadcast. The spectrum mask of capacitive coupling WPT systems in the frequency range 425-524 kHz is now being examined to meet the coexistence conditions with AM broadcast and other services.

(iv) Electric Passenger Vehicles

In this Chapter, the word “EVs” means Electric Vehicles and Plug-in Hybrid Electric Vehicles (PHEV).

In Japan, WPT for EV while parked has been considered by BWF, IEC, SAE and JARI. It was decided that the frequency range 20-200 kHz has advantages to achieve high energy transmission efficiency in high power circuit design. The sub-bands; 42-48 kHz, 52-58 kHz, 79-90 kHz, 140.91-148.5 kHz were the focus of spectrum sharing studies and coexistence talks related to incumbent applications including clock radios and railway radio systems. Currently, the 79-90 kHz range is the most likely candidate for WPT because currently the studies in BWF, IEC, SAE and JARI indicate that use of this band is the least likely to cause interference to other services.

(v) Heavy duty electric vehicles

In May 2011, the Korean government allocated the frequencies for OnLine EV (OLEV) to 20 kHz (19-21 kHz) and 60 kHz (59-61 kHz). These frequencies can be used for any type of vehicle whether it is heavy duty or passenger vehicle in Korea. Now, OLEV system is in trial and licensed at one site.

5.2 ISM bands used on a national basis for WPT

6 765-6 795 kHz

13.56 MHz

(i) Magnetic resonance

6 765-6 795 kHz supports magnetic resonant WPT of low power in some countries. 6 765-6 795 kHz is designated as an ISM band in No. **5.138** of the Radio Regulations.

In Japan, ISM equipment up to a transmitted RF power limit of 50 W can use this band without permission. A new type-approval rule for WPT equipment is being considered, which may allow transmission power greater than 50 W.

The reasons why 6 765-6 795 kHz may be favoured for magnetic resonance WPT technology are summarized as follows:

– ISM band.

– Several standardization development organizations are developing WPT standards for use in 6 765-6 795 kHz.

– Small physical dimensions are possible for WPT components for example; power transmitter coils and receiver coils.

In Korea, the 13.56 MHz band is used for WPT charged 3D glasses to watch 3D TV.

TABLE 5.1

Frequency ranges under study, key parameters, incumbent systems on WPT systems for mobile/portable devices and home/office equipment

	Magnetic induction (low power)	**Magnetic resonant coupling**	**Magnetic induction (high power)**	**Capacitive coupling**
Application types	Mobile/portable devices, tablets, note-PCs	Mobile/portable devices, tablets, note-PCs	Home appliances, office equipment (incl. higher power applications)	Portable devices, Tablets, note-PCs
Technology principle	Resonant magnetic induction	High resonance		WPT via electric field
Names of countries considering	Commercially available in Japan, Korea	Japan, Korea	Japan	Japan
Frequency ranges under consideration	Japan: 110-205 kHz	Japan,: 6 765-6 795 kHz	Japan: 20.05-38 kHz, 42-58 kHz, 62-100 kHz	Japan: 425-524 kHz
Frequency ranges assigned nationally	Korea: 100-205 kHz	Korea: 6 765-6 795 kHz		
Power range under consideration		Japan: Several W – up to 100 W	Japan: Several W – 1.5 kW	Japan: Up to 100 W

TABLE 5.1 (*end*)

	Magnetic induction (low power)	**Magnetic resonant coupling**	**Magnetic induction (high power)**	**Capacitive coupling**
Advantage	Global harmonized spectrum Higher power transmission efficiency	– Global spectrum availability possible – Flexibility for placement and distance of receiving end – Transmitter can supply power for several receivers within a wide range contemporary.	– Increased power – Flexibility for placement and distance of receiving end – Transmitter can supply power for several receivers within a wide range contemporary.	High efficiency (70-85%) – No heat generation at the electrode – Low emission level – horizontal position freedom
Application Areas	Portable devices, CE, Industrial Fields, Specific Areas	Portable devices, tablets, note-PCs, home appliances (low power)	Home appliance (high power), office equipment	Portable devices, tablets, note-PCs, home and office equipment
Related Alliances / international standards	Wireless Power Consortium (WPC)[6]	A4WP [4]		
Concerned incumbents for spectrum sharing		Japan: mobile/fixed radio systems Korea: ISM band	Japan: Standard clock radios (40 kHz, 60 kHz) railway radio systems (10-250 kHz)	Japan: AM Broadcast (525-1 606.5 kHz), maritime/ NAVTEX (405-526.5 kHz), and amateur radio (472-479 kHz).

TABLE 5.2

Frequency ranges under study, key parameters, and incumbents systems on WPT systems for EV applications

	Magnetic resonance and/or induction for electric passenger vehicles	**Magnetic induction for heavy duty vehicles**
Application types	EV charging in parking (Static)	On-Line Electric Vehicle (OLEV) (EV charging while in motion including stopping/parking)
Technology Principle	magnetic resonance and/or induction	magnetic induction
Countries under consideration	Japan	Korea

TABLE 5.2 (*end*)

	Magnetic resonance and/or induction for electric passenger vehicles	**Magnetic induction for heavy duty vehicles**
Frequency Range	42-48 kHz, 52-58 kHz, 79-90 kHz, and 140.91-148.5 kHz are in study.	19-21 kHz, 59-61 kHz
Power Range	3.3 kW and 7.7 kW; Classes are assumed for passenger vehicle	– Minimum power: 75 kW – Normal power: 100 kW – Maximum power: On developing – Air gap: 20 cm – Time and cost saving
Advantage	Higher power transmission efficiency	– Increased power transmission efficiency – Maximized air gap – Reduced audible noise – Effective shield design – Time and cost saving
Related Alliance / international standards	IEC 61980-1 (TC69)	
concerned incumbents for spectrum sharing	Standard clock radios (40 kHz, 60 kHz) Railway radio systems (10-250 kHz) Amateur radio (135.7-137.8 kHz)	Fixed maritime mobile (20.05-70 kHz) → Ship station for radio-telegraphy Restricted to hyperbolic curve radio-navigation (DECCA) (84-86 kHz)

6 Status of national regulation

For China, Japan, and Korea, country specific rules and conditions which can be applied to WPT frequency and ongoing rulemaking topics are introduced in [1] and [5].

i) In Korea

All radio communications equipment including WPT devices should comply with three regulations under Radio Waves Act, 1) Technical regulation, 2) EMC Regulation, 3) EMF Regulation. The followings are the further explanation regarding technical regulations in Korea.

WPT equipment is regulated as ISM equipment and equipment over 50 W needs a license for operation. For the equipment under 50 W, compliance with weak electric field strength and EMC testing technical regulation is required. Recently, the government revised the compliance requirements and the operating characteristics as follows, where all WPT devices are treated as ISM equipment.

– In the range of 100-205 kHz, the electric field strength of the WPT devices are less than or equal to 500 uV/m at 3m. This value should be obtained by the measurement guideline referred to CISPR/I/417/PAS.

– In the range of 6 765-6 795 kHz, the electric field strength of the spurious emission should be satisfied in accordance with Table 6.1.

– In the range 19-21 kHz, 59-61 kHz, the electric field strength is less than or equal to 100 uV/m at 100m.

TABLE 6.1

Applied field strength limits for WPT in Korea

Frequency range	**Field strength limit (Quasi-peak)**	**Measurement bandwidth**	**Measuring distance**
9-150 kHz	78.5-10 log(*f* in kHz/9) dBμV/m	200 Hz	10 m
150-10 MHz		9 kHz	
10-30 MHz	48 dBμV/m		
30-230 MHz	30 dBμV/m	120 kHz	
230-1 000 MHz	37dBμV/m		

TABLE 6.2

Applied regulations to WPT in Korea

Power level	**Name of application**	**Applied technical regulations**	**Concerned WPT technology**
Low power (≤ 50 W)	ISM Equipment – WPT device using the frequency range of 100-205 kHz	Weak Electric Field Strength	– Commercial products using inductive technology
	ISM Equipment – WPT device using the frequency range of 6 765-6 795 kHz	ISM	– Considering products using resonant technology
High power (≥ 50 W)	ISM Equipment using the frequency range 19-21 kHz, 59-61 kHz	ISM	– Installed in a specific area – SMFIR (Shaped Magnetic Field In Resonance)

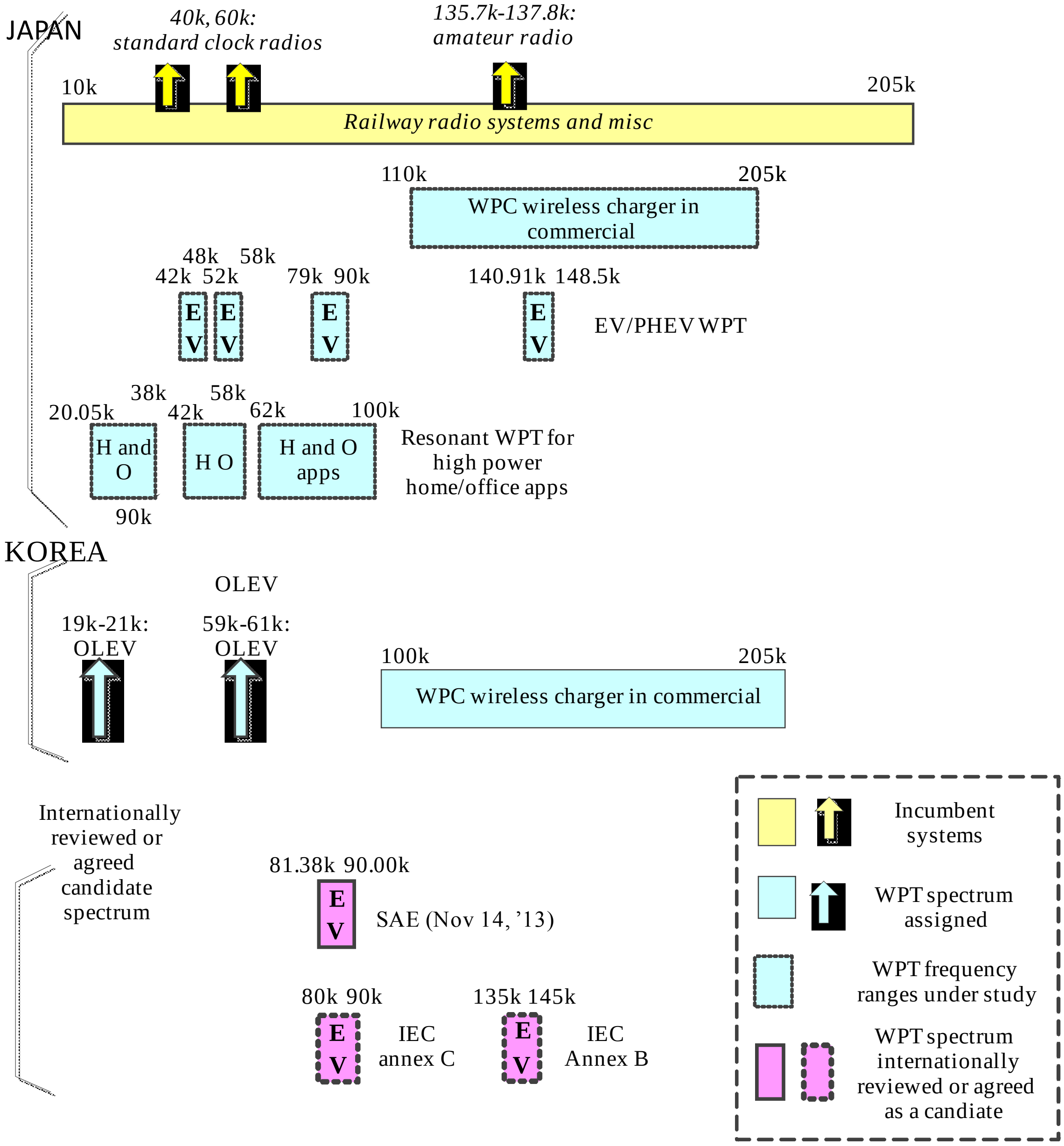
7 Status of co-existence studies between WPT and radiocommunication services, including the radio astronomy service

In light of the high field strengths that can be produced by WPT systems, there is the potential for interference to communications signals operating in nearby bands. A determination of the required characteristics of WPT RF signals must be based on studies of potential interference from WPT to other services. Such studies and the resultant determination of characteristics must be completed prior to the assignment of frequencies for WPT.

Figures 7.1 and 7.2 show the WPT spectrum under considerations in Japan and assigned in Korea [1]. Spectrum sharing studies should be performed between the concerned systems with WPT systems to clarify the availability of coexistence. Some WPT equipment are classified into ISM equipment which shall not cause harmful nor claim protection from other stations.

FIGURE 7.1

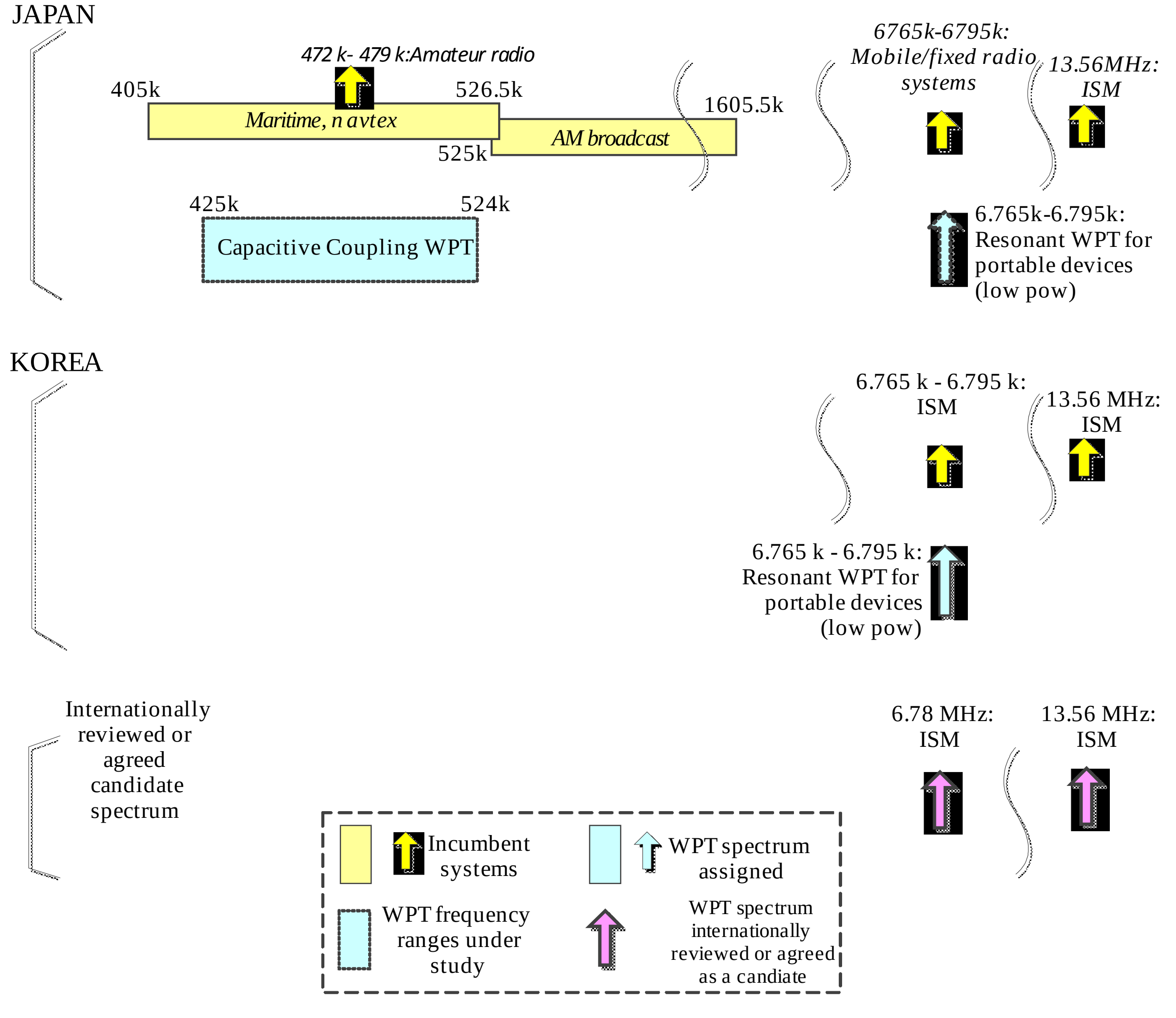
WPT spectrum considered and incumbent systems (10-300 kHz)



Report SM.2303-7-01

FIGURE 7.2

WPT spectrum considered and incumbent systems (400 kHz-13.56 MHz)



Report SM.2303-3-02

Japan is discussing WPT technologies shown in Table 7.1. Candidate frequency ranges under consideration and the target WPT systems with fundamental parameters are summarized.

TABLE 7.1

WPT technologies under Japan MIC WPT WG discussion

Target WPT applications	**(a) WPT for EVs**	**(b) WPT for mobile and portable devices (1)**	**(c) WPT for home appliances and office equipment**	**(d) WPT for mobile and portable devices (2)**
WPT technology	Magnetic field power transmission (inductive, resonance)			Capacitive coupling

TABLE 7.1 (*end*)

Target WPT applications	**(a) WPT for EVs**	**(b) WPT for mobile and portable devices (1)**	**(c) WPT for home appliances and office equipment**	**(d) WPT for mobile and portable devices (2)**
Transmission power	Up to approx.3 kW (max 7.7 kW)	Several W – approx.100 W	Several W – 1.5 kW	Approx.100 W
Candidate WPT frequency ranges	42-48 kHz (45 kHz band), 52-58 kHz (55 kHz band), 79-90 kHz (85 kHz band), 140.91-148.5 kHz (145 kHz band)	6 765-6 795 kHz	20.05-38 kHz, 42-58 kHz, 62-100 kHz	425-524 kHz
Transmission distance	0 – approx. 30 cm	0 – approx. 30 cm	0 – approx. 10 cm	0 – approx. 1 cm

The information in this Table may be changed by the domestic and global standardization trend of WPT.

Japan

In Japanese regulations, any devices with transmission power not exceeding 50 W do not require permission by the administrator for operation in general. Currently, the proposed technologies of (b), (c), and (d) in Table 7.1 intend operation with power not exceeding 50 W in each spectrum. These technologies are expected to increase transmission power greater than 50 W in the future upon completion of successful coexistence studies with the relevant incumbent radiocommunication services.

Those who are interested in Japanese regulatory aspects relating to WPT may refer to the "Guidelines for the use of Wireless Power Transmission Technologies, Edition 2.0" in April 2013 [2]. http://bwf-yrp.net/english/update/2013/10/guidelines-for-the-use-of-wireless-power-transmission-technologies.html

Japan has already identified the domestic incumbent systems that might suffer from WPT emission in/out of the operating frequency bands. MIC's WPT WG has directed the concerned parties to investigate possible unwanted effects (e.g. system performance degradation) by WPT emission. In addition, the WG suggested necessary talks to find appropriate conditions to coexist. There found many incumbent systems in/around WPT spectrum under considerations. Typical ones are listed in Tables 5.1 and 5.2. Those include standard clock radios, amateur radios, railway radio systems, maritime/NAVTEX, and AM broadcast services, which are also illustrated in Figs 7.1 and 7.2. Some results as of April 2014 and ongoing considerations are summarized in Table 7.2.

In addition, the WG performed emission measurement on radiated noise and conductive noise from the WPT systems shown in Table 7.1 to discuss emission limits and coexistence conditions with the incumbent systems. Measured data is summarized in Annex 3.

TABLE 7.2

Summary of the coexistence studies and ongoing considerations in Japan

Target WPT applications	**Candidate frequency ranges**	**Incumbent systems in/around WPT bands**	**Coexistence study results and ongoing discussions (NOTE – "separation distance" in this column is calculated in the worst case scenario of the assessment models)**
WPT for home/office equipment (2) (resonant, high power)	20.05-38 kHz, 42-58 kHz, and 62-100 kHz (NOTE – Power transmission frequency is selected from the ranges above. Spectrum within ±30% of the fundamental wave frequency is used.)	1) Standard clock radios (40 kHz, 60 kHz) 2) Railway systems (10-250 kHz) 3) LORAN-C, eLORAN (9-100 kHz) 4) AM Broadcast (525.6-1 606.5 kHz	1) Standard clock radios: Separation distance of 10 m was used as a coexistence criterion. In addition to the fundamental wave characteristics, integer harmonics was examined as well when they fall into the Standard clock radios operation bands. Assessment by April 2014 showed the following results and ongoing considerations. • The maximum separation distance required is 12.9 m at 62 kHz outside the Standard radio clock operation bands. • The maximum separation distance required is 24.6 m at 60 kHz inside the Standard radio clock bands. • Additional measure on operation time condition is considered since WPT operation of home/office equipment is not expected or observed less frequently in midnight when Standard clock radios receive their signals frequently. Advertisement of radio hazard from WPT for home appliances may lead to less interference to share the same spectrum as utilization time is not overlapped entirely. • WPT harmonics generated fundamental waves of 20.05 kHz and 30 kHz fall into the Standard clock radios operation spectrum. This is critical to ensure non-harmful interference. The candidate frequency ranges and the WPT operation conditions need to be re-considered. 2) Railway systems: • The criteria for coexistence with the ATS (Automatic Train Stop) and ITRS (Inductive Train Radio Systems) are (a) WPT frequency band should not be overlapped with those used for the train signaling systems including ATS. Or (b) the separation distance should be less than the threshold (1.9 m) specified in the train systems building standards. • ATS (Automatic Train Stop): Separation distance required for coexistence between WPT for home/office equipment and ATS have been derived referring to the existing ATS test regulation. The models without radio-blocking object such as building walls between WPT and ATS were assumed as the worst case. Assessment showed that WPT would not generate harmful interference to ATS when horizontal separation distance is not less than 1.8 m.

TABLE 7.2 (*cont.*)

Target WPT applications	**Candidate frequency ranges**	**Incumbent systems in/around WPT bands**	**Coexistence study results and ongoing discussions (NOTE – "separation distance" in this column is calculated in the worst case scenario of the assessment models)**
			• Inductive Train Radio Systems: – 20.05-38 kHz and 42-58 kHz: These ranges are not in use for Railway systems using space propagation medium; available for WPT to coexist. – 62-100 kHz: This frequency range includes a band used for ITRS (sent from the ground system to a train). Separation distance required is 11 m as calculated. On this service segment using this frequency range, the inductive line and the on-board antenna are aligned on the center line of the railway track. Then, the separation distance to be secured would be around 1.9 m which is derived from the threshold specified in the train systems building standards. To meet this criterion, 25 dB reduction of the WPT emission strength should be required at the minimum separation distance. Given these considerations and assumption of 3 kHz guard band for the ITRS bands, possible WPT frequency ranges of 62-77 kHz, 83-89 kHz, and 95-100 kHz could meet the coexistence conditions with ITRS. 3) LORAN-C, eLORAN (90-100 kHz) • Maritime radiocommunication operators commented that this spectrum should not be arranged for the use of WPT. 4) AM Broadcast: Coexistence conditions and requirements have not been agreed yet and are still under discussion. Separation distance calculation models and methodologies are also under discussion. In the next step, the necessary conditions shown above should be agreed; and interference mitigation measures including definition of interference model, radiated electric field emission strength from WPT, wall attenuation for calculation, cumulative interferences from WPT devices, interference experiments, and background noise effect should be taken into consideration. Field experiments are expected.
WPT for EVs (NOTE – Not only domestic frequency availability but also global frequency harmonization is counted. Taking the updated SAE and IEC discussions	42-48 kHz		1) Standard clock radios: Separation distance of 10 m was used as a coexistence criterion. Assessment by April 2014 showed that separation distance required is 41.9 m. Deemed difficult to meet the coexistence requirements even if additional interference mitigation measures are taken. 2) Railway systems: • The criteria for coexistence with the ATS (Automatic Train Stop) and ITRS (Inductive Train Radio Systems) are (a) WPT frequency band should not be overlapped with those used for the train signaling systems including ATS. Or (b) the separation distance should be less than the threshold (1.9 m) specified in the train systems building standards.

TABLE 7.2 (*cont.*)

Target WPT applications	Candidate frequency ranges	Incumbent systems in/around WPT bands	Coexistence study results and ongoing discussions (NOTE – "separation distance" in this column is calculated in the worst case scenario of the assessment models)
into consideration, 85 kHz is assumed to be the primary frequency. In the Inductive Train Radio System discussion, 140.91-148.5 kHz are examined mainly as spectrum is overlapped or neighboured.			• ATS: For the case of WPT installed at a home garage (nominal 3 kW), separation distance required is 2.2 m or longer. The target WPT emission strength assumed in the study should be reduced to meet the threshold specified in the train systems building standards. For the case of WPT at a public parking intended for a higher power charging (nominal 7.7 kW), separation distance required is 2.6 m or longer. The target WPT emission strength assumed in the study should be reduced to meet the threshold specified in the train systems building standards. • ITRS: This frequency range is not in use for the Railway systems using space propagation medium; available for WPT to coexist with ITRS. 3) LORAN-C, eLORAN: N/A 4) AM Broadcast: See the part of 79-90 kHz.
	52-58 kHz		1) Standard clock radios: Separation distance of 10 m was used as a coexistence criterion. Assessment by April 2014 showed that separation distance required is 28.9 m. Deemed difficult to meet the coexistence requirements even if additional interference mitigation measures are taken. 2) Railway systems: • The criteria for coexistence with the ATS (Automatic Train Stop) and ITRS (Inductive Train Radio Systems) are shown in (a) and (b) in the case of 42-48 kHz. • ATS: For the case of WPT installed at a home garage (nominal 3 kW), separation distance required is 2.2 m or longer. The target WPT emission strength assumed in the study should be reduced to meet the threshold specified in the train systems building standards. For the case of WPT at a public parking intended for a higher power charging (nominal 7.7 kW), separation distance required is 2.6 m or longer. The target WPT emission strength assumed in the study should be reduced to meet the threshold specified in the train systems building standards. • ITRS: This frequency range is not in use for Railway systems using space propagation medium; available for WPT to coexist with ITRS. 3) LORAN-C, eLORAN: N/A 4) AM Broadcast: See the part of 79-90 kHz.

TABLE 7.2 (*cont*)

Target WPT applications	Candidate frequency ranges	Incumbent systems in/around WPT bands	Coexistence study results and ongoing discussions (NOTE – "separation distance" in this column is calculated in the worst case scenario of the assessment models)
	79-90 kHz		1) Standard clock radios: Separation distance of 10 m was used as a coexistence criterion. Assessment by April 2014 showed that separation distance required is 20.4 m. Some technical interference mitigation measures have been introduced and are taken into consideration. Having them, a latest assessment shows 11-13 m separation distance available which could be acceptable conditionally. 2) Railway systems: • The criteria for coexistence with the ATS (Automatic Train Stop) and ITRS (Inductive Train Radio Systems) are shown in (a) and (b) in the case of 42-48 kHz. • ATS: For the case of WPT installed at a home garage (nominal 3 kW), separation distance required is 3.7 m or longer. The target WPT emission strength assumed in the study should be reduced to meet the threshold specified in the train systems building standards. For the case of WPT at a public parking intended for a higher power charging (nominal 7.7 kW), separation distance required is 4.3 m or longer. The target emission WPT strength assumed in the study should be reduced to meet the threshold specified in the train systems building standards. • ITRS: 79-90 kHz frequency range includes frequency bands used for the ITRS (sent from the ground to a train) in one railway service segment in Japan. The separation distance required derived from calculation is approx. 45 m from the on-board antenna mounted on a car. On this service segment using this frequency range, the inductive line and the on-board antenna are aligned on the center line of the railway track. Then, the separation distance to be secured would be around 1.9 m which is derived from the threshold specified in the train systems building standards. • Having this separation distance condition, the emitted magnetic field strength should be reduced by 80 dB or more. However, it seems difficult to achieve such attenuation by the effect of a car body, structural objects, and other practical measures. Therefore, the WPT for EVs cannot meet the coexistence conditions in the ITRS operating bands. To be specific, 80-83 kHz and 89-90 kHz should be taken into consideration for ensuring non-harmful interference from WPT.

TABLE 7.2 (*cont*)

Target WPT applications	**Candidate frequency ranges**	**Incumbent systems in/around WPT bands**	**Coexistence study results and ongoing discussions (NOTE – "separation distance" in this column is calculated in the worst case scenario of the assessment models)**
			• Considering such specific inductive radio system operation bands to exclude from the WPT operation frequency range, at least the frequency range of 83-89 kHz seems feasible for WPT for EVs to coexist with the Inductive radio systems. If required guard band is 1 kHz ensuring the requirements sufficiently, there might be coexistence possibility in the frequency range of 81-90 kHz with the Inductive radio systems. It turned out that the number of the actual service operation case using 79-90 kHz frequency range is very few in Japan. If additional frequency coordination for the Inductive radio system operation is available in the future, WPT coexistence could be easier. 3) LORAN-C, eLORAN: N/A 4) AM Broadcast: Coexistence conditions and requirements have not been agreed yet and are still under discussion. Separation distance calculation models and methodologies are also under discussion. In the next step, the necessary conditions shown above should be agreed; and interference mitigation measures including definition of interference model, radiated electric field emission strength from WPT, wall attenuation for calculation, cumulative interferences from WPT devices, interference experiments, and background noise effect should be taken into consideration. Field experiments are expected.
	140.91-148.5 kHz	1) Standard clock radios (40 kHz, 60 kHz) 2) Railway systems (10-250 kHz) 3) Amateur radio (135.7-137.8 kHz) 4) AM Broadcast (525.6-1 606.5 kHz)	1) Standard clock radios: Separation distance of 10 m was used as a coexistence criterion. Assessment by April 2014 shows that separation distance required is 17.8 m. Some technical interference mitigation measures have been introduced and are taken into consideration. Having them, a latest assessment shows approx. 10 m separation distance available which could be acceptable conditionally. 2) Railway systems: • The criteria for coexistence with the ATS (Automatic Train Stop) and ITRS (Inductive Train Radio Systems) are shown in (a) and (b) in the case of 42-48 kHz. • ATS: For the case of WPT installed at a home garage (nominal 3 kW), separation distance required is 4.1 m or longer. The target WPT emission strength assumed in the study should be reduced to meet the threshold specified in the train systems building standards. For the case of WPT at a public parking intended for a higher power charging (nominal 7.7 kW), separation distance required is 4.9 m or longer. The target emission WPT strength assumed in the study should be reduced to meet the threshold specified in the train systems building standards.

TABLE 7.2 (*cont*)

Target WPT applications	Candidate frequency ranges	Incumbent systems in/around WPT bands	Coexistence study results and ongoing discussions (NOTE – "separation distance" in this column is calculated in the worst case scenario of the assessment models)
			• ITRS: 100-250 kHz range includes many frequency bands for the ITRS which are widely used for many railway segments. The separation distance required derived from calculation is approx. 28 m from the inductive line and approx. 76 m from the on-board antenna mounted on a car. On this service segment using this frequency range, the inductive line and the on-board antenna are aligned on the center line of the railway track. Then, the separation distance to be secured would be around 1.9 m from the threshold specified in the train systems building standards. • Having this separation distance condition, the emitted magnetic field strength should be reduced by 88 dB or more. However, it seems difficult to achieve such attenuation by the effect of a car body, structural objects, and other practical measures. Hence, an assessment shows that WPT in the 140 kHz band deems difficult to coexist with. 3) Amateur radio: This is an out-band case (not sharing the same spectrum). Candidate frequency ranges for WPT for EVs has appropriate offset frequencies (guard band) to detune in the Amateur radio bands. Therefore, receiver sensitivity suppression (out-of-band) by interference is not taken but radiated emission levels of harmonics (spurious emissions) from WPT devices are counted in the case they fall into the Amateur Radio bands. Note that this band is a neighboring band to the Amateur Radios. Referring to the emission level regulations in the Japan Radio Law and other related rules as the criteria, currently the assumptions of WPT systems for EVs show acceptable system parameters to demonstrate possible non-harmful interference to the Amateur Radios. 4) AM Broadcast: See the part of 79-90 kHz.

TABLE 7.2 (*end*)

Target WPT applications	**Candidate frequency ranges**	**Incumbent systems in/around WPT bands**	**Coexistence study results and ongoing discussions (NOTE – "separation distance" in this column is calculated in the worst case scenario of the assessment models)**
WPT for mobile devices (2) (Capacitive coupling)	425-524 kHz Candidate frequency range has recently been extended from 480-524 kHz to seek for non-harmful frequency band(s) for Maritime radio services. Total 50-80 kHz spectrum in this range is intended for WPT operation.	1) AM Broadcast (525.6-1 606.5 kHz) 2) Maritime, (405-526.5 kHz) 3) Amateur radio (472-479 kHz)	1) AM Broadcast: Coexistence conditions and requirements have not been agreed yet and are still under discussion. Separation distance calculation models and methodologies are also under discussion. In the next step, the necessary conditions shown above should be agreed; and interference mitigation measures including definition of interference model, radiated electric field emission strength from WPT, wall attenuation for calculation, cumulative interferences from WPT devices, interference experiments, and background noise effect should be taken into consideration. Field experiments are expected. 2) Maritime: Assessment showed that the proposed target emission limit does not meet the coexistence conditions now assumed but meet those taken from actual commercial models. Therefore we conclude that the proposed WPT here has possibility substantially to coexist with the maritime radio systems. However, it is worth noting that the following frequencies in the frequency range in this study are used for secure marine navigation safety. Therefore, non-use of the same frequencies should be directed. (i) NAVTEX: 518 kHz (424 kHz, 490 kHz) (ii) NAVDAT: 495-505 kHz. In addition, harmonics should not fall into the Marine VHF radio band (156-162 MHz) used internationally. 3) Amateur radio: This is an in-band case (sharing the same spectrum). WPT for mobile and portable devices (2) (capacitive coupling) assumes the same frequency segment sharing with Amateur Radios in 475 kHz band. For Amateur Radios, no official interference level requirements or rules from other systems are found. Further evaluation should be necessary between WPT proponents and Amateur radios. One possible solution discussed is to exclude 472-479 kHz allocated to Amateur Radios in the WPT operation frequency range and to set appropriate offset frequency bands.
WPT for mobile devices (1) (resonant, low power)	6 765-6 795 kHz	1) Mobile/fixed radio systems (6 765-6 795 kHz)	1) 6 765-6 795 kHz is not designated as an ISM band in Japan. There exists a transmitted RF power limit such as not exceeding 50W for operation without administrator's permission. However, the regulations' provisions allow the use for WPT applications in the band. A new type-approval rule for WPT products in this band is now considered, which may allow coexistence with the incumbent systems and higher transmission power in this band.

8 Summary

This Report contains proposed frequency ranges and associated potential levels for out of band emissions which have not been agreed within the ITU-R, and require further study to ascertain if they provide protection to radiocommunication services on co-channel, adjacent channel and adjacent band criteria. The Report gives an overview of current research and development and work being undertaken in some Regions.

Portable and mobile devices, home appliance, and EV are candidate applications to use WPT technologies. Magnetic induction and Magnetic resonant and capacitive coupling technologies are being studied and developed. Co-existence studies are ongoing and are done in some countries.

Magnetic induction WPT technologies typically utilize the frequency ranges 100-205 kHz with powers ranging from several Watts to 1.5 kW. This frequency range is also under study for home appliances and office equipment incorporating WPT technologies.

Magnetic induction WPT technologies for Electric passenger vehicles and heavy duty vehicles are being studied with candidate frequency ranges of 19-21 kHz, 42-48 kHz, 52-58 kHz, 59-61 kHz, 79-90 kHz, 140.91-148.5 kHz. Typical powers for electric passenger vehicles are 3.3 kW and 7.7 kW. Typical powers for Heavy Duty vehicles range from 75-100 kW.

Magnetic resonance WPT technologies typically utilize the 6 765-6 795 kHz ISM band with typical powers of several watts to 100 W.

Capacitive coupling WPT technology utilizes the frequency range 425-524 kHz and typical powers can be up to 100 W.

9 References

[1] Document 1A/133, liaison statement to ITU-R Working Party 1A from the Asia Pacific Telecommunity.

[2] BWF "Guidelines for the use of Wireless Power Transmission/Technologies, Edition 2.0" in April 2013. http://bwf-yrp.net/english/update/docs/guidelines.pdf

[3] http://www.mit.edu/~soljacic/wireless_power.html

[4] http://www.rezence.com/

[5] Document 1A/135, response from TTA to the liaison statement to external organizations sent out by working party 1A regarding question ITU-R 210-3/1 "Wireless power transmission" from TTA.

[6] http://www.wirelesspowerconsortium.com/

[7] ICNIRP 1998 Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz), http://www.icnirp.de/documents/emfgdl.pdf

[8] ICNIRP 2010 Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz), http://www.emfs.info/Related+Issues/limits/specific/icnirp2010/

Annex 1

RF exposure assessment methodologies

The BWF WPT-WG released BWF "Guidelines for the use of wireless power transmission technologies, Edition 2.0" [2] in April 2013. English version is available to download from the following BWF website.

http://bwf-yrp.net/english/update/2013/10/guidelines-for-the-use-of-wireless-power-transmission-technologies.html

The following aspects on RF exposure assessment methodologies are provided with detailed excerptions from the regulations and guidelines.

"Considerations for the radio-radiation protection guidelines" in [2] provides guidelines in detail in accordance with the usage scenes defined by the BWF WPT-WG and biological and technical aspects such as WPT frequency ranges to apply. Stimulating effect, heating effect, contact current, and induced current to / in human body tissue are described. In addition, recommended flowcharts for selecting an evaluation methodology and a measurement methodology are also provided since the traditional measurement methodologies may not meet the RF exposure assessment for WPT devices.

Annexes A to G in [2] excerpt domestic and international regulations and guidelines related to RF exposure and safety issues and also explain how to read and use them. In these annexes, Japanese regulations, ICNIRP Guidelines, and IEEE Guidelines are introduced. In addition, some papers recently published in the field of simulation-based SAR assessment are introduced as references.

In addition to the document above, "APT Survey Report on WPT" [1] provides information on this topic in APT member countries.

RF exposure

Each country has own guideline or regulation on RF exposure in compliance with ICNIRP98, which does not include WPT devices and suitable measurement method yet.

TABLE [3.10]

Regulatory status on RF exposure

Country	RF exposure	RF assessment
Australia	– The ACMA is responsible for the management of the mandatory *Radiocommunications (Electromagnetic Radiation – Human Exposure) Standard 2003* (incorporating amendments to Radiocommunications (Electromagnetic Radiation - Human Exposure) Amendment Standard 2011 (No. 2)), • specifying the RF exposure limits for most mobile and portable radiocommunication transmitters with integral antenna operating 100 kHz ~ 300 GHz – Radiation Protection Standard for Maximum Exposure Levels to Radiofrequency Fields – 3 kHz to 300 GHz (RPS3) • set by ARPANSA (Australian Radiation Protection and Nuclear Safety Agency)	Such devices are required to show compliance using test methods such as EN 62209-2 (Human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices – Human models, instrumentation, and procedures – Part 2: Procedure to determine the specific absorption rate (SAR) for wireless communication devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz) http://infostore.saiglobal.com/store/details.aspx?ProductID=1465960. The ACMA mandates the limits for RF and EMR exposure set by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). The primary source of RF exposure limit information is ARPANSA's *Radiation Protection Standard for Maximum Exposure Levels to Radiofrequency Fields - 3 kHz to 300 GHz* (RPS3) – http://www.arpansa.gov.au/Publications/codes/rps3.cfm

TABLE [3.10] (*end*)

Country	RF exposure	RF assessment
Japan	– BWF's guideline on RF exposure http://bwf-yrp.net/english/ : compliance requirements – Referring to Radio Radiation Protection Guidelines and ICNIRP guidelines • RF exposure limit	BWF of Japan considers the following approaches in RF exposure assessment. Assume specific worst cases, such a case that a part of the human body is contiguous to Tx or located between Tx and Rx. Additional safety measures to take into account if safety cannot be declared. Magnetic fields by the WPT products are non-uniform and RF exposure is expected to be local. Therefore ICNIRP guidelines can be safer references. Simulation assessment methodologies such as radiation dosimetry are suggested to consider if dosimetry experts can participate. Assessment method should not take longer time unnecessarily and not intend to search for exact RF exposure. It should be a reasonable one which could be useful for certification procedures and acceptance tests.
Republic of Korea	– Plans to revise current EMF regulation to include WPT device for application during 2013	– Plans to introduce assessment methods specified for WPT during 2013

Annex 2

Implementation example of the use of the 6 765-6 795 kHz ISM band for wireless charging of mobile devices

A wireless power transmission technology and specification based on the principles of magnetic resonance using the 6 765-6 795 kHz ISM band for wireless charging of mobile devices has been developed. This technology brings a number of unique benefits to the wireless charging ecosystem.

SUPERIOR CHARGING RANGE

A superior charging range allowing for a true drop and go charging experience, through most surfaces and materials commonly encountered in the home, office and commercial environments.

MULTI-DEVICE CHARGING

Ability to charge multiple devices with different power requirements at the same time, such as smartphones, tablets, laptops and Bluetooth® headsets.

READY FOR THE REAL WORLD

Charging surfaces will operate in the presence of metallic objects such as keys, coins, and utensils, making it an ideal choice for home, office, automotive, retail, and dining and hospitality applications.

BLUETOOTH COMMUNICATION

Uses existing Bluetooth Smart technology, minimizing the manufacturer's hardware requirements, as well as opening the door for future Smart Charging Zones.

Technical specification

The objective of the specification is to deliver a convenient, safe and exceptional user experience in real-world charging situations, while defining the technical basis for industry to build compliant products. The technology is an interface specification for the wireless power transmitter and receiver, mutual coupling, and mutual inductance - leaving most options open to implementers.

To pair wireless power with real-world conditions, spatial freedom allows for higher variability in coupling coefficient, device size, load conditions and separation between the power transmitter and receiver. This offers wireless power product designers greater latitude in implementing charging systems, and results in a superior consumer experience.

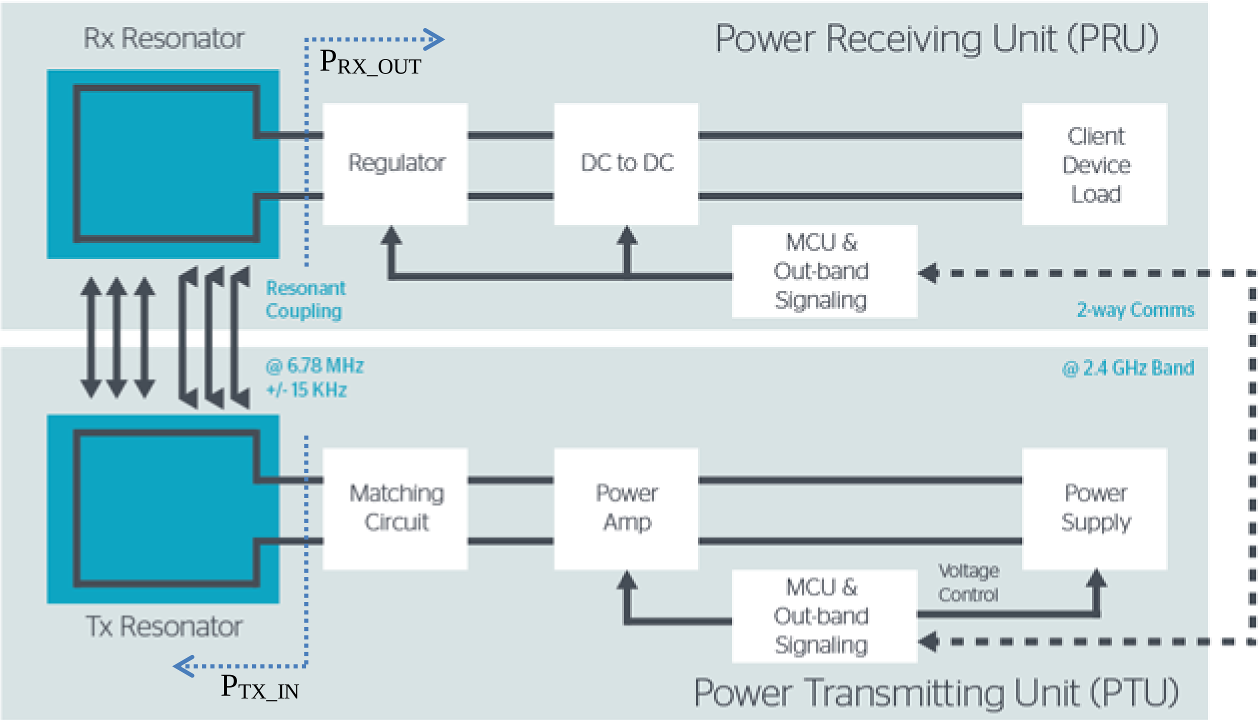
Electronic products intended for this technology integration should address several factors:

- Power dissipation and layout;
- Integration of resonator to device;
- Miniaturization;
- Integration of communication link to on-board radio.

Designers may specify and source their own implementation of the required out-of-band radios, power amplifiers, DC-to-DC converters, rectifiers, microprocessors – discrete or integrated – and assemble them as they require.

As long as the components conform to the specification, they can utilize any topology. The specification reserves only the interfaces and model of transmitter resonator to be used in the system.

The below figure illustrates the basic wireless power transmission system configuration between a Power Transmitting Unit (PTU) and a Power Receiving Unit (PRU). The PTU can be expanded to serve multiple independent PRUs. The PTU comprises three main functional units which are a resonator and matching unit, a power conversion unit, and a signalling and control unit (MCU). The PRU also comprises three main functional units like the PTU.



As shown in the above figure, the Transmitting Resonator (Tx Resonator) uses 6 780 kHz (±15 kHz) to transmit power from the PTU to the PRU. Bluetooth Smart™ at 2.4 GHz band is used for 2-way communication in a channel outside of the frequencies used to transmit power and provides a reliable communication channel between the wireless power receivers and the charging surfaces.

The specification provides for many categories of PRU and classes of PTU based on the power delivered using the 6 780 kHz band, they range from a low power charging unit for small device that can require only a few watts to larger devices that require many watts. Shown in the below tables are PTU classes and PRU categories based on a draft Baseline System Specification, new categories/classification are being developed.

PRU Categories

PRU	$P_{RX\_OUT\_MAX'}$	Example applications
Category 1	TBD	BT Headset
Category 2	3.5 W	Feature Phone
Category 3	6.5 W	Smart Phone
Category 4	13 W	Tablet, Phablet
Category 5	25 W	Small Form Factor Laptop
Category 6	37.5 W	Regular Laptop
Category 7	50 W	Performance Laptop

$P_{RX\_OUT\_MAX'}$ is the maximum value of P_{RX_OUT} (Output power of the Rx Resonator).

PTU Classes

	$P_{TX\_IN\_MAX'}$	Minimum category support requirements	Minimum value for max number of devices supported
Class 1	2 W	1 × Category 1	1 × Category 1
Class 2	10 W	1 × Category 3	2 × Category 2
Class 3	16 W	1 × Category 4	2 × Category 3
Class 4	33 W	1 × Category 5	3 × Category 3
Class 5	50 W	1 × Category 6	4 × Category 3
Class 6	70 W	1 × Category 7	5 × Category 3

$P_{TX\_IN\_MAX'}$ is the maximum value of P_{TX_IN} (Input power to the Tx Resonator).

The Bluetooth operations will transmit between −6 dBm to +8.5 dBm measured at the antenna connector.

The specification for PTUs and PRUs enables products to be built in compliance with regulatory requirements for the country they are sold. For example, in the USA, the operation in 6 785 kHz will be in compliance with FCC Part 18 requirements and 2-way operation in 2.4 GHz will be in compliance with FCC Part 15 requirements.

Annex 3

Measurement data of radiated noise and conductive noise from WPT systems

Contents

1 Introduction

This Annex provides measured data of radiated noise and conductive noise from the WPT systems under the consideration of the new rulemaking in Japan. The systems are listed as follows and fundamental parameters are shown in Table 7.1. Detailed information on the coexistence studies of the systems are introduced in Doc 1A/152:

(1) WPT system for passenger EV (Electric Vehicle) charging,

(2) WPT system for mobile and portable devices using magnetic resonance technology,

(3) WPT system for home appliances and office equipment using magnetic inductive technology, and

(4) WPT system for mobile and portable devices using capacitive coupling technology.

2 Measurement models and measurement methods

Measurement models and measurement methods for radiated noise and conductive noise from WPT systems were discussed and determined by WPT-WG under the Subcommittee on Electromagnetic Environment for Radio-wave Utilization of the Ministry of Internal Affairs and Communications (MIC). The following measurements were conducted.

(1) Radiated noise in the frequency range from 9 kHz to 30 MHz.

Magnetic field strength is measured by using loop antennas. Electric field strength is obtained by simple translation using the characteristic impedance of plane wave, 377 ohm.

(2) Radiated noise in the frequency range from 30 MHz to 1 GHz.

Electric field strength is measured by using bi-conical antennas or log-periodic dipole arrays. In the case of portable devices applications, the measured frequency range is expanded to 6 GHz.

(3) Conductive noise in the frequency range from 9 kHz to 30 MHz.

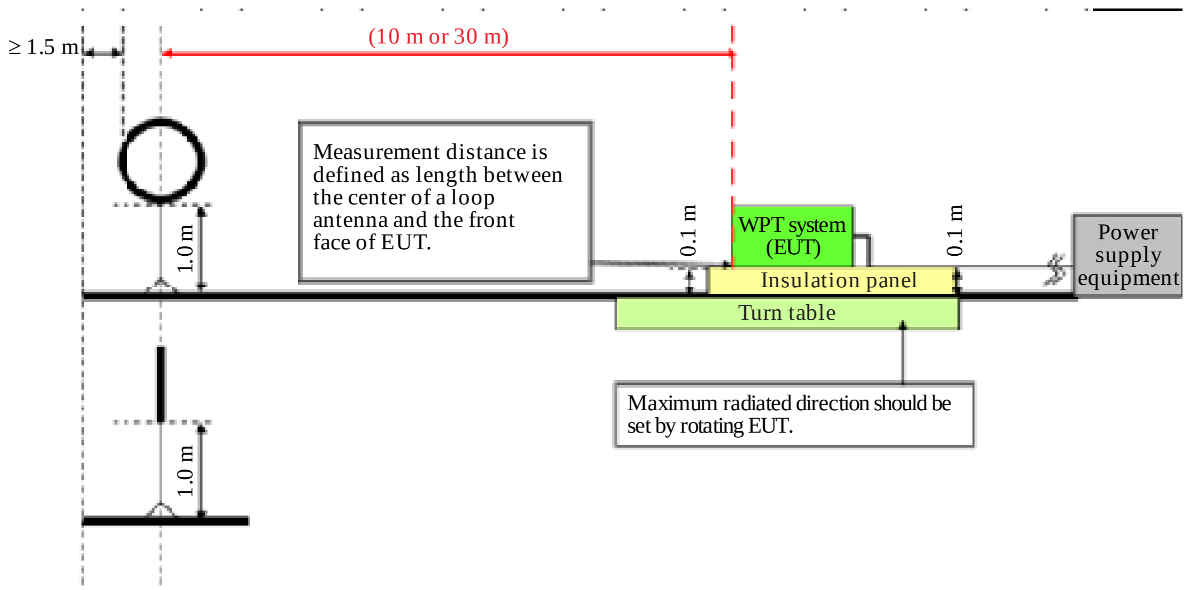
Conductive noise radiated from power supply lines is measured. In this measurement, EUT (Equipment under Test) should be connected to AMN (Artificial Mains Network).

2.1 Measurement model and measurement method for WPT system for EV charging

Figures A3-1 and A3-2 describe measurement methods for radiated noise from WPT systems for EV charging. Figure A3-1 is in the frequency range from 9 kHz to 30 MHz. Figure A3-2 is in the frequency range from 30 MHz to 1 GHz. Figure A3-3 describes the top view of EUT and its arrangement for radiated noise measurement. In this measurement method, CISPR 16-2-3 "Radiated disturbance measurements" is referred. Figure A3-4 describes an imitated car body used in this measurement. This imitated car model was proposed to IEC TC 69 / PT 61980, in which an international standard regarding WPT systems for EV charging. Figure A3-5 describes the top view of EUT and its arrangement for conductive noise measurement. In these measurements, the transmission power is defined as power level measured at the input port of RF power supply equipment or the primary coil.

FIGURE A3-1

Measurement methods for radiated noise from WPT systems for EV charging, in the frequency range from 9 kHz to 30 MHz



Report SM.2303-A3-01

FIGURE A3-2

Measurement methods for radiated noise from WPT systems for EV charging, in the frequency range from 30 MHz to 1 GHz

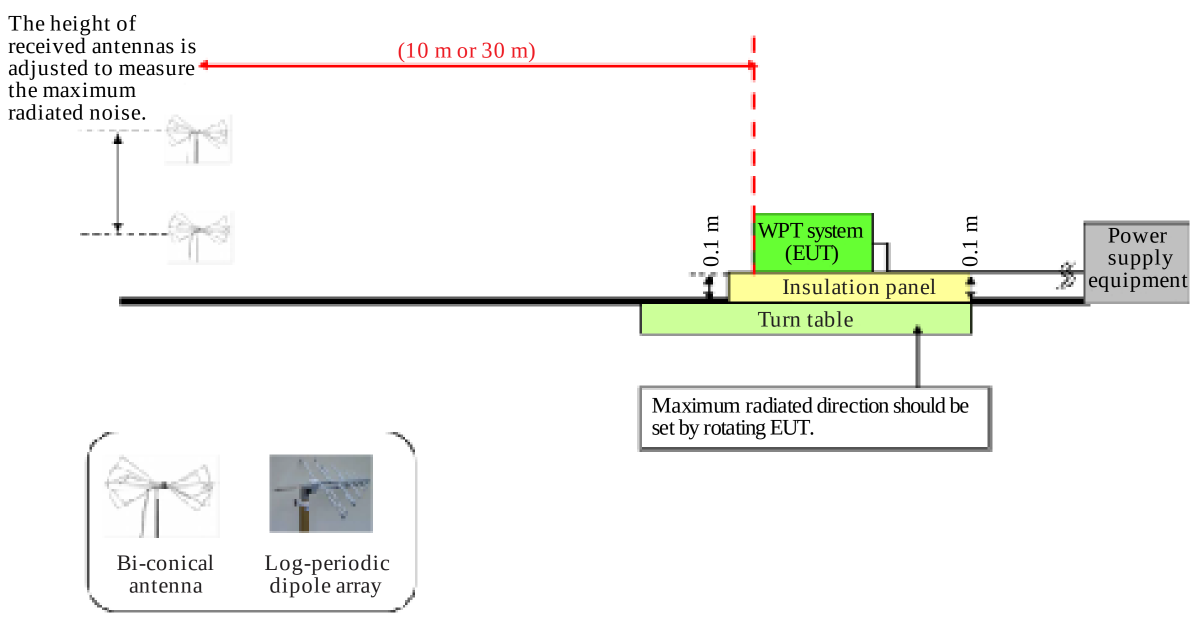


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FIGURE A3-3

Top view of EUT and its arrangement for radiated noise measurement

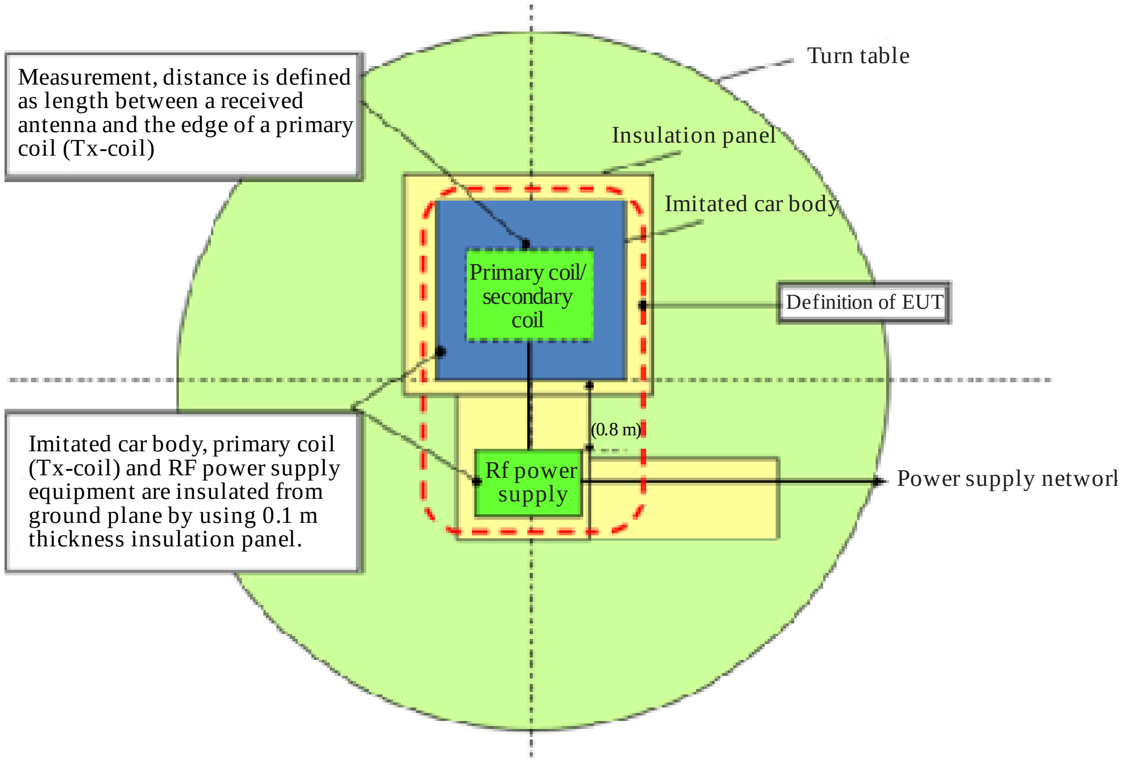

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FIGURE A3-4

Configuration of the imitated car body

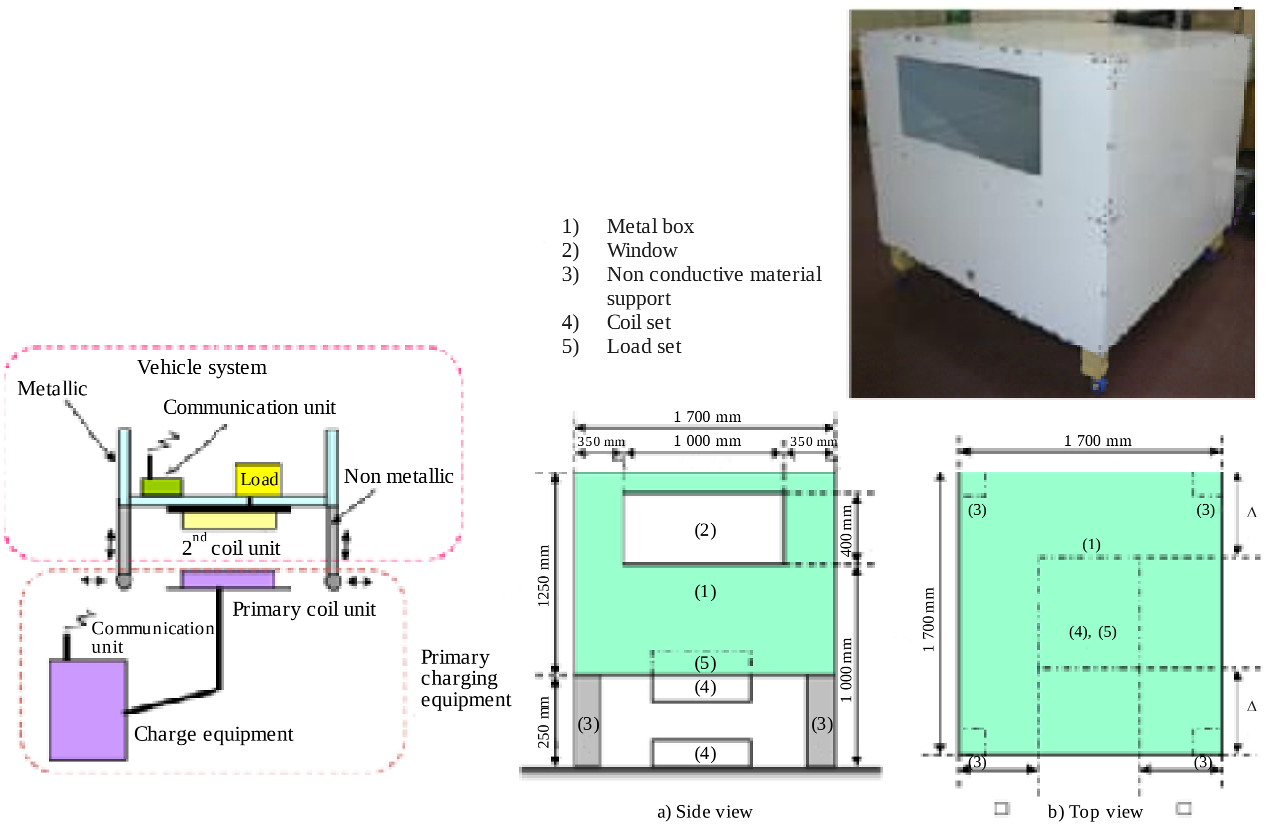

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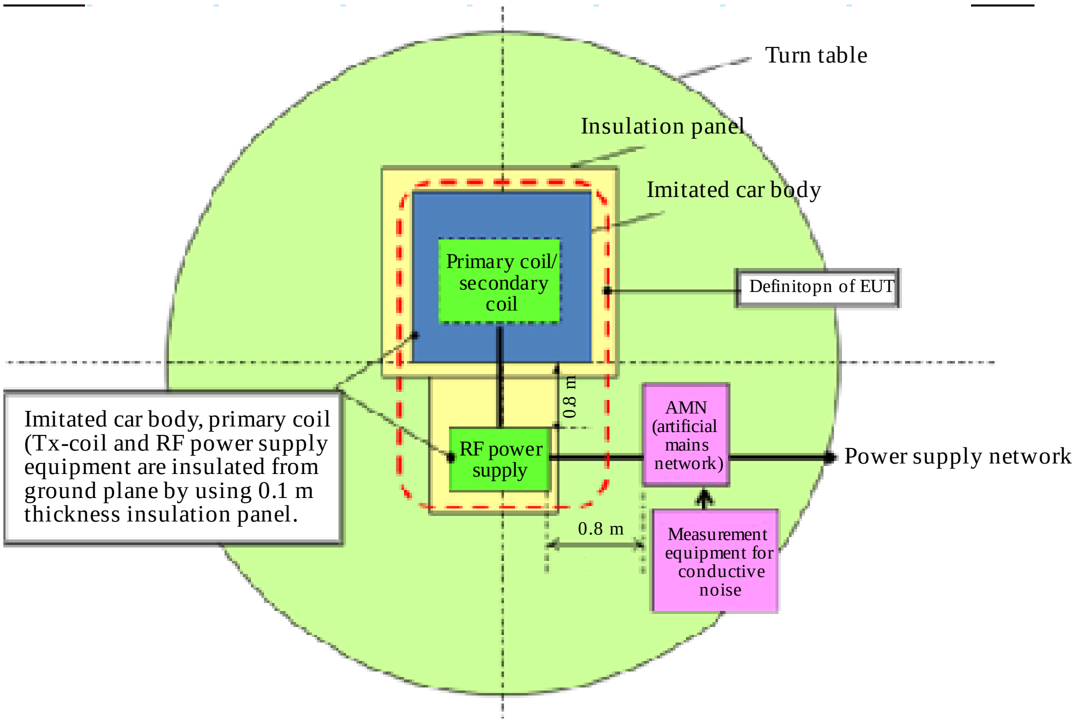
FIGURE A3-5

Top view of EUT and its arrangement for conductive noise measurement



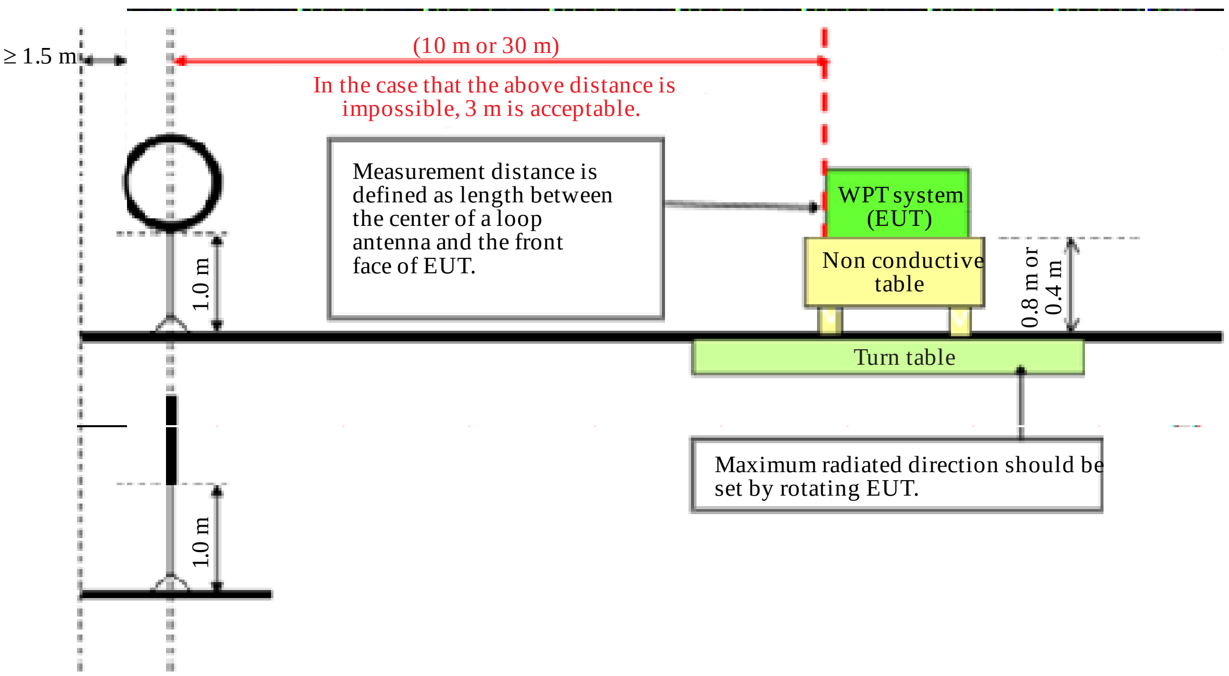
Report SM.2303-A3-05

2.2 Measurement model and measurement method for mobile devices, portable devices, and home appliances

Figures A3-6 and A3-7 describe measurement methods for radiated noise from WPT systems for mobile and portable devices and home appliances. Figure A3-6 is in the frequency range from 9 kHz to 30 MHz. Figure A3-7 is in the frequency range from 30 MHz to 6 GHz. It is noticed that the frequency range is expanded to 6 GHz only in case of mobile and portable devices. For home appliances, the upper limit of measured frequency range is 1 GHz. Those are because CISPR 14-1 is referred to a measurement method for home appliances, and CISPR 22 for mobile and portable devices. Figure A3-8 describes measurement methods for conductive noise measurement. Two measurement methods are considered here.

FIGURE A3-6

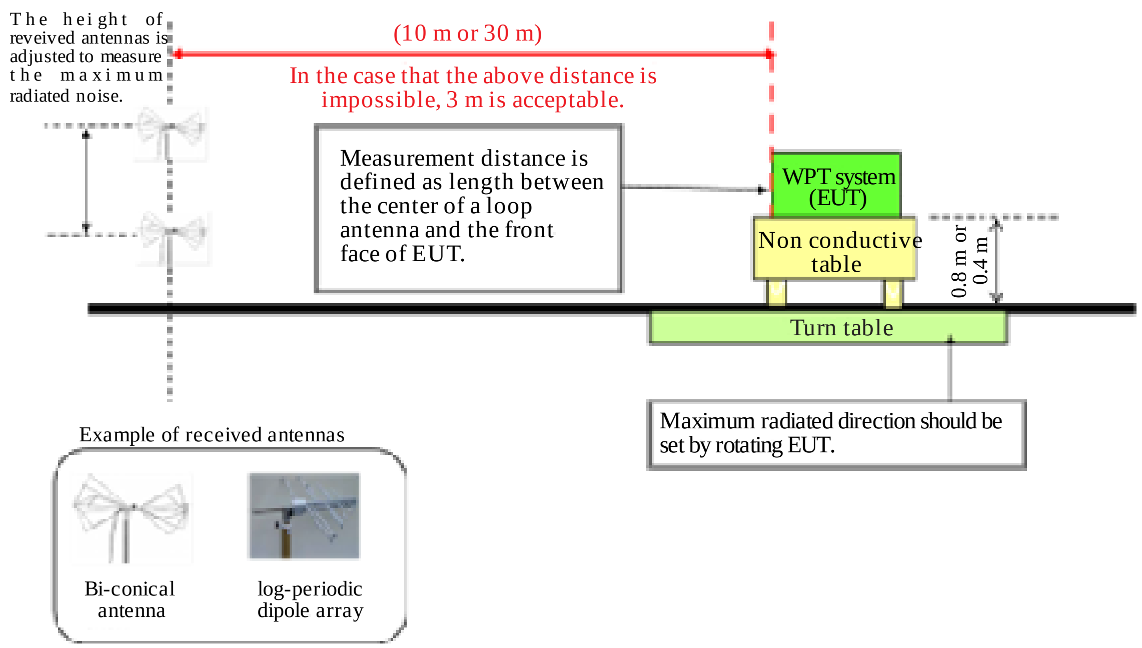
Measurement methods for radiated noise from WPT systems for mobile and portable devices and home appliances, in the frequency range from 9 kHz to 30 MHz



Report SM.2303-A3-06

FIGURE A3-7

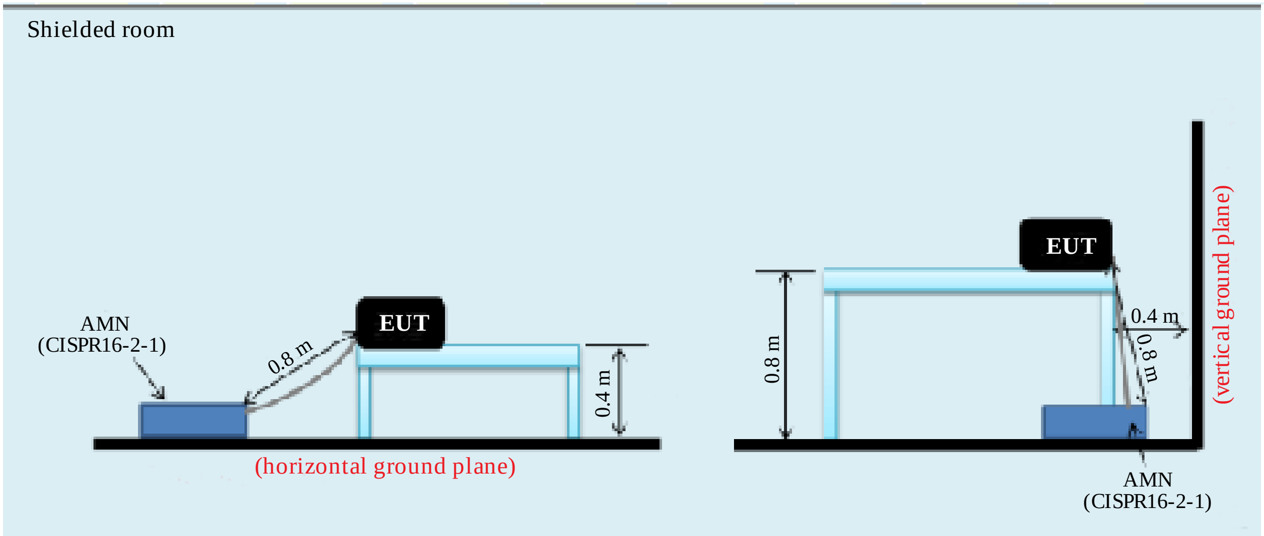
Measurement methods for radiated noise from WPT systems for mobile and portable devices and home appliances, in the frequency range from 30 MHz to 6 GHz



Report SM.2303-A3-07

FIGURE A3-8

Measurement methods for conductive noise measurement



Report SM.2303-A3-07

3 Target radiation emission limit set by BWF

The radiation emission limit for a new Japanese regulation is under discussion in WPT-WG, MIC. But, Broadband Wireless Forum (BWF), Japan, has already set the target radiation emission limit as tentative values to discuss co-existing conditions for other wireless systems. The fundamental viewpoints for the target radiation emission limits are as follows;

(1) Target radiated noise limits are set only in the frequency range from 9 kHz to 30 MHz. Both of electric field strength limits and magnetic field strength limits are described here.

(2) Target radiated noise limits of electric field strength are firstly considered, because BWF refers to the current Japanese national radio regulation and its radiated noise limits are basically determined by electric field strength. Translation of electric field strength to magnetic field strength is done by calculation using the characteristic impedance of TEM wave (plane wave), 377 ohm.

(3) BWF does not set the target limits of radiated noise over 30 MHz and conductive noise.

Next, the target radiation emission limits for each WPT system are described. It should be noted that these are tentative and are under discussion.

3.1 Target radiation emission limit for WPT system for EV charging

Tentative target radiated noise limit for WPT frequency range was proposed by reference to FCC Part 18 Subpart C as an international rule and by measurement results of developed WPT systems. Tentative target radiated noise limit for the other frequency range was proposed on the basis of the Japanese radio regulation applied to inductive cooking equipment as a commonly used magnetic inductive application.

(1) Tentative target limit of radiated electric field noise

(a) WPT frequency range (frequency range used for power transmission)

3 kW – Tx Power : 36.7 mV/m@30m (91.3 dBμV/m@30m)

7.7 kW – Tx Power : 58.9 mV/m@30m (95.4 dBμV/m@30m)

(b) Frequency range from 526.5-1606.5 kHz

: 30 μV/m@30m (29.5 dBμV/m@30m)

(c) Frequency range expect for the above frequency range

: 200 μV/m@30m (46.0 dBμV/m@30m)

(2) Tentative target limit of radiated magnetic field noise

(a) WPT frequency range (frequency range used for power transmission)

3 kW – Tx Power : 97.5 μA/m@30m (39.8 dBμA/m@30m)

7.7 kW – Tx Power : 156 μA/m@30m (43.9 dBμA/m@30m)

(b) Frequency range from 526.5-1606.5 kHz

: 0.0796 μA/m@30m (−22.0 dBμA/m@30m)

(c) Frequency range expect for the above frequency range

: 0.531 μA/m@30m (−5.51 dBμA/m@30m)

3.2 Target radiation emission limit for mobile and portable devices using magnetic resonance technology

Tentative target radiated noise limit for WPT frequency range was proposed on the basis of measurement results of developed WPT systems. Tentative target radiated noise limit for the other frequency range was proposed on the basis of the Japanese radio regulation applied to inductive cooking equipment as a commonly used magnetic inductive application.

(1) Tentative target limit of radiated electric field noise

(a) WPT frequency range (frequency range used for power transmission)

: 100 mV/m@30m (100 dBμV/m@30m)

(b) Frequency range from 526.5-1 606.5 kHz

: 30 μV/m@30m (29.5 dBμV/m@30m)

(c) Frequency range expect for the above frequency range

: 100 μV/m@30m (40.0 dBμV/m@30m)

(2) Tentative target limit of radiated magnetic field noise

(a) WPT frequency range (frequency range used for power transmission)

: 265.3 μA/m@30m (48.5dB μA/m@30m)

(b) Frequency range from 526.5-1 606.5 kHz

: 0.0796 μA/m@30m (−22.0 dBμA/m@30m)

(c) Frequency range expect for the above frequency range

: 0.265 μA/m@30m (−11.5dB μA/m@30m)

3.3 Target radiation emission limit for home appliances using magnetic inductive technology

Tentative target radiated noise limit for WPT frequency range was proposed on the basis of measurement results of developed WPT systems. Tentative target radiated noise limit for the other frequency range was proposed on the basis of the Japanese radio regulation applied to inductive cooking equipment as a commonly used magnetic inductive application.

(1) Tentative target limit of radiated electric field noise

(a) WPT frequency range (frequency range used for power transmission)

: 1 mV/m@30m (60 dBμV/m@30m)

(b) Frequency range from 526.5-1 606.5 kHz

: 30 μV/m@30m (29.5 dBμV/m@30m)

(c) Frequency range expect for the above frequency range

: 173 μV/m@30m (44.8 dBμV/m@30m)

(2) Tentative target limit of radiated magnetic field noise

(a) WPT frequency range (frequency range used for power transmission)

: 2.66 μA/m@30m (8.5 dBμA/m@30m)

(b) Frequency range from 526.5-1 606.5 kHz

: 0.0796 μA/m@30m (−22.0 dBμA/m@30m)

(c) Frequency range expect for the above frequency range

: 0.459 μA/m@30m (−6.7 dBμA/m@30m)

3.4 Target radiation emission limit for mobile and portable devices using capacitive coupling technology

The tentative target radiated noise limit for WPT frequency range was proposed on the basis of measurement results of developed WPT systems. The tentative target radiated noise limit for the other frequency range was proposed on the basis of the Japanese radio regulation applied to inductive cooking equipment as a commonly used magnetic inductive application.

(1) Tentative target limit of radiated electric field noise

(a) WPT frequency range (frequency range used for power transmission)

: 100 μV/m@30m (40 dB μV/m@30m)

(b) Frequency range from 526.5-1 606.5 kHz

: 30 μV/m@30m (29.5 dBμV/m@30m)

(c) Frequency range expect for the above frequency range

: 100 μV/m@30m (40 dB μV/m@30m)

(2) Tentative target limit of radiated magnetic field noise

(a) WPT frequency range (frequency range used for power transmission)

: 0.265 μA/m@30m (−11.5 dB μA/m@30m)

(b) Frequency range from 526.5-1606.5 kHz

: 0.0796 μA/m@30m (−22.0 dBμA/m@30m)

(c) Frequency range expect for the above frequency range

: 0.265 μA/m@30m (−11.5 dB μA/m@30m)

4 Measurement results of radiated noise and conductive noise

Measurement results of radiated noise, conductive noise and related measurements for each WPT system are described. WPT systems measured here are equipment for test and under development.

4.1 Measurement results for WPT system for EV charging

(1) Overview of test equipment

Two pieces of test equipment were prepared for this measurement as shown in Table A3-1. In test equipment A, WPT frequency is 120 kHz and planer circular Tx and Rx coils are used. In test equipment B, WPT frequency is 85 kHz and solenoid type coils are used for both of Tx and Rx.

Also, test equipment B includes devices to suppress higher order harmonics of WPT frequency. Photographs of each test equipment are described in Figs A3-9 and A3-10, respectively.

TABLE A3-1

Overview of test equipment for EV charging

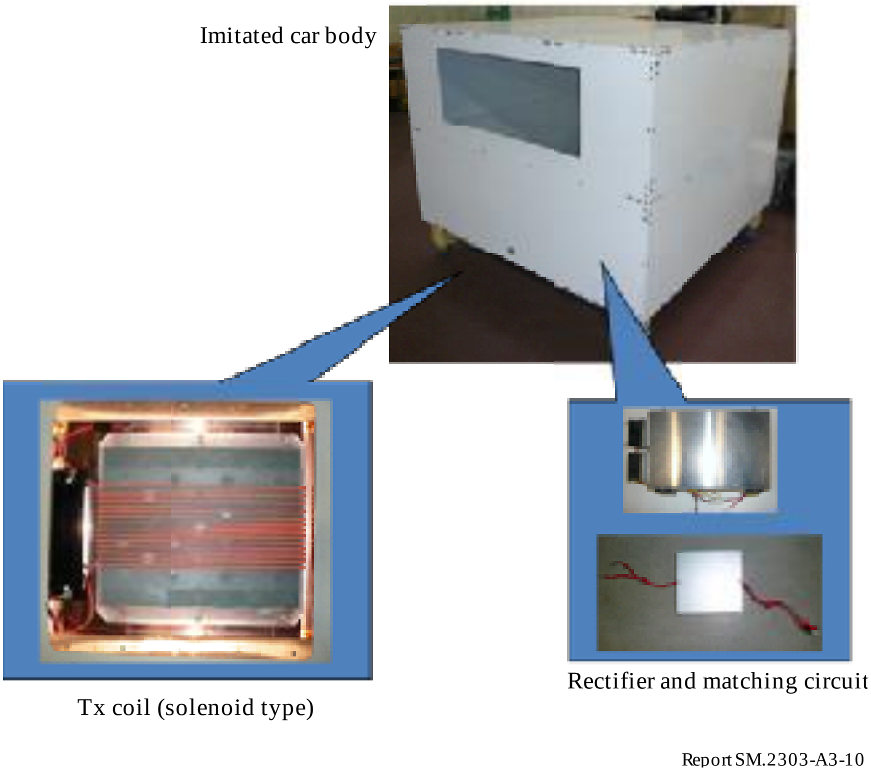
WPT system	EV charging
WPT technology	Magnetic resonance
WPT frequency	Test equipment A: 120 kHz Test equipment B: 85 kHz
Condition for WPT	Transfer power: 3 kW Power transfer distance: 150 mm

FIGURE A3-9

Test equipment A

FIGURE A3-10

Test equipment B



(2) Measurement results of radiated noise

Radiated noise from each test equipment was measured in shielded anechoic chamber. Measured distance is 10 m. When field strength at 30 m is described, the field strength is obtained by the following translation rule which is published in Japanese radio regulation.

[Attenuation factor due to measurement distance from 10 m to 30 m]

Lower frequency than 526.5 kHz:	1/27
From 526.5-1 606.5 kHz:	1/10
Over 1 606.5 kHz to 30 MHz:	1/6

Measurement results in the frequency range from 9 kHz to 30 MHz are shown in Figs A3-11 and A3-12. Figure A3-13 describes measurement result of higher order harmonics of each test equipment. The results of these measurements show that test equipment B clears the tentative target limit of radiated noise. Test equipment A clears the tentative target limit for WPT frequency, and does not clear the tentative target limit of the other frequency range. But, by including the suitable devices to suppress high frequency noise, it is thought that the tentative target limit can be cleared.

Measurement results in the frequency range from 30 MHz to 1 GHz are shown in Figs A3-14 and A3-15.

FIGURE A3-11

Radiated noise of test equipment A (9 kHz – 30 MHz, peak value)

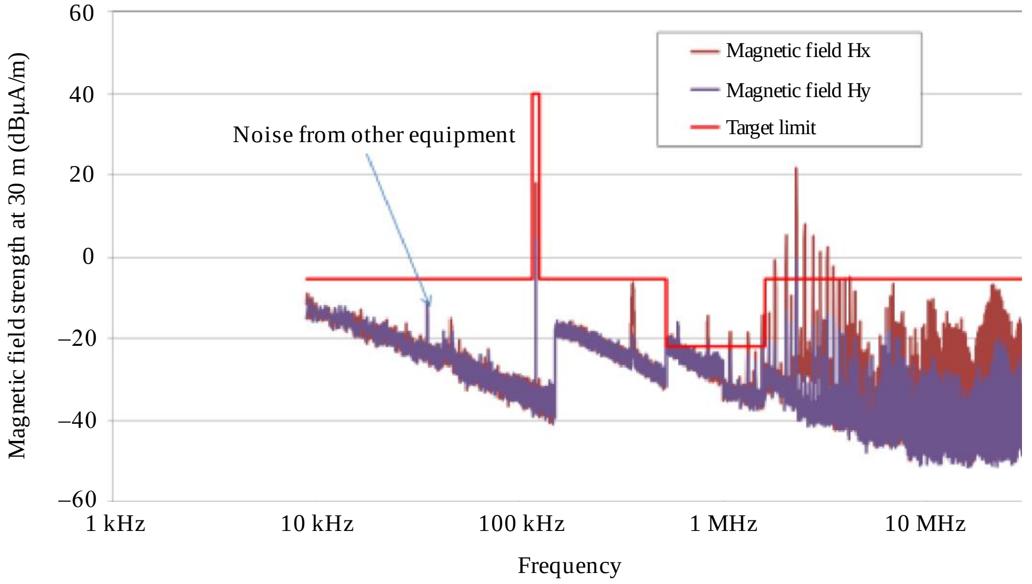


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FIGURE A3-12

Radiated noise of test equipment B (9 kHz – 30 MHz, peak value)

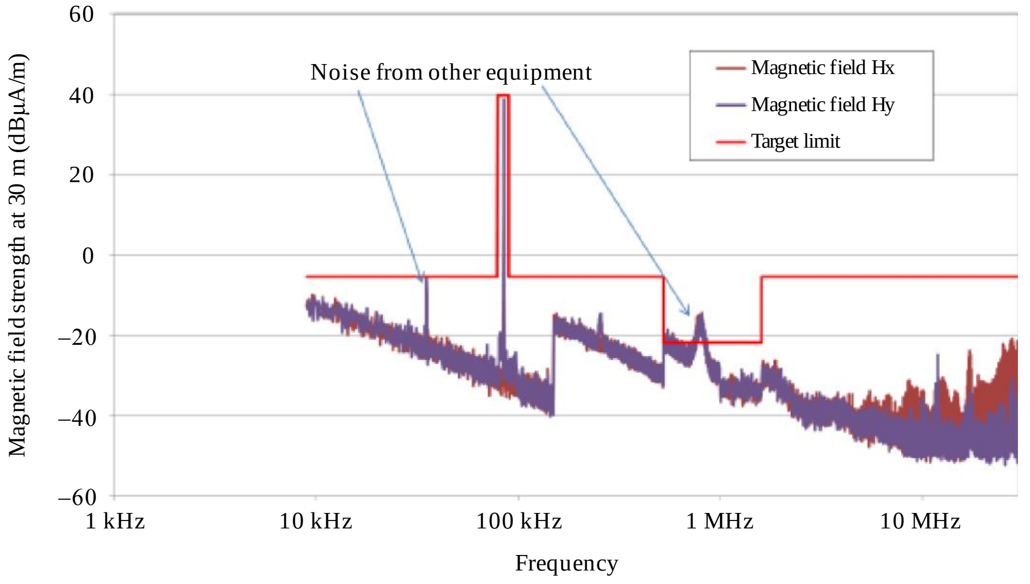

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FIGURE A3-13

Measurement results of higher order harmonics (Quasi-peak value)

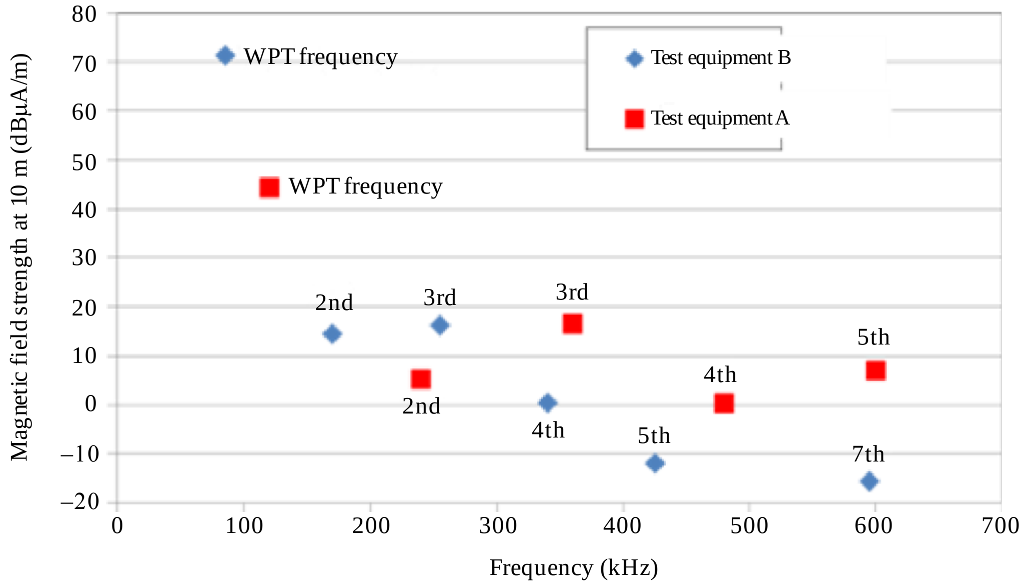

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FIGURE A3-14

Radiated noise of test equipment A (30 MHz – 1 GHz, peak value)

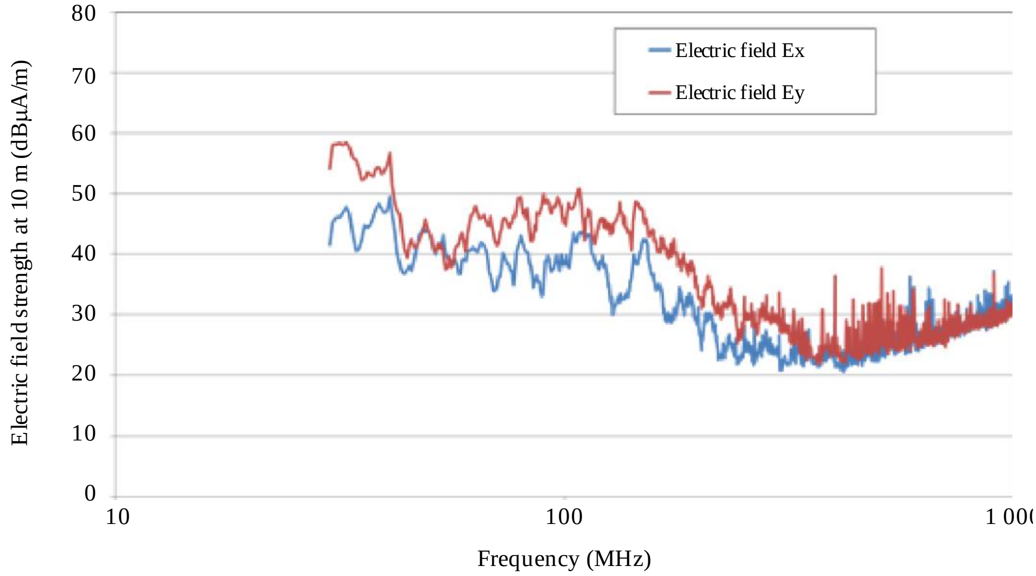

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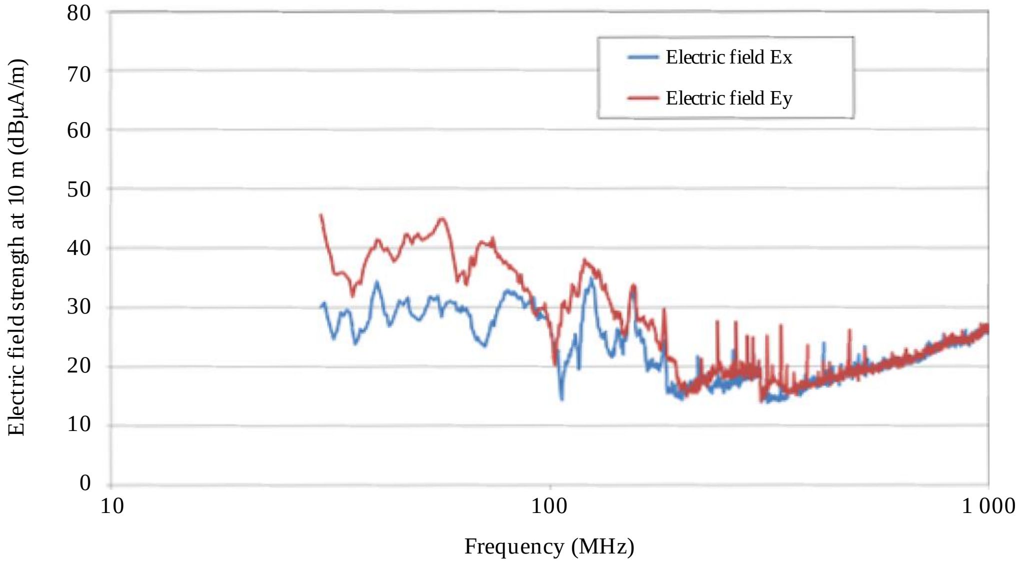
FIGURE A3-15

Radiated noise of test equipment B (30 MHz – 1 GHz, peak value)



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(3) Measurement results of conductive noise

Measurement results of conductive noise in the frequency range from 30 MHz to 1 GHz are shown in Figs A3-16 and A3-17.

FIGURE A3-16

Conductive noise of test equipment A (9 kHz – 30 MHz, peak value)

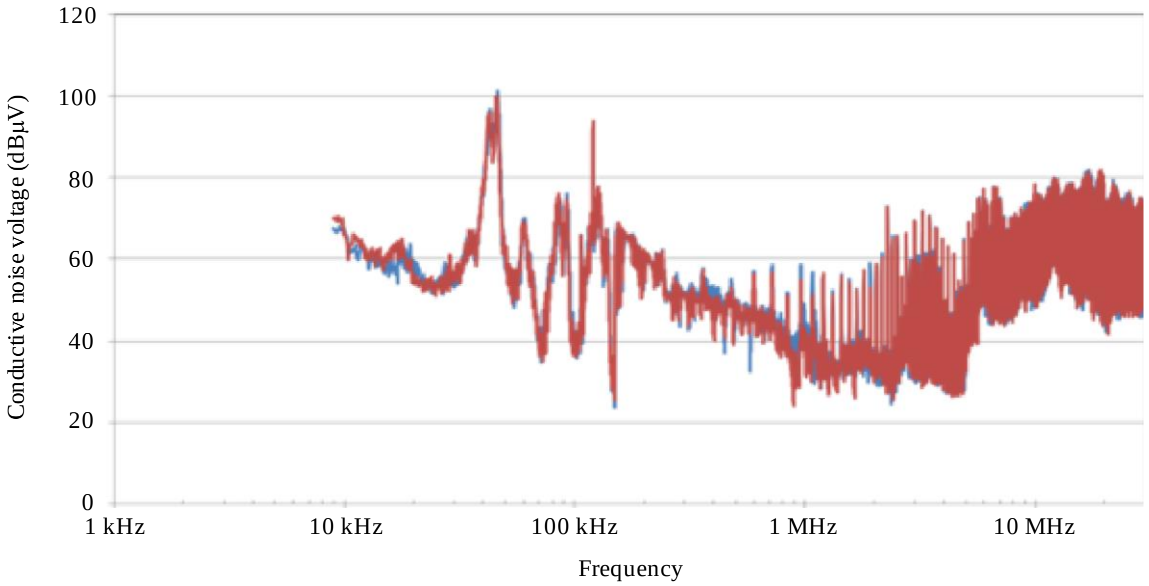

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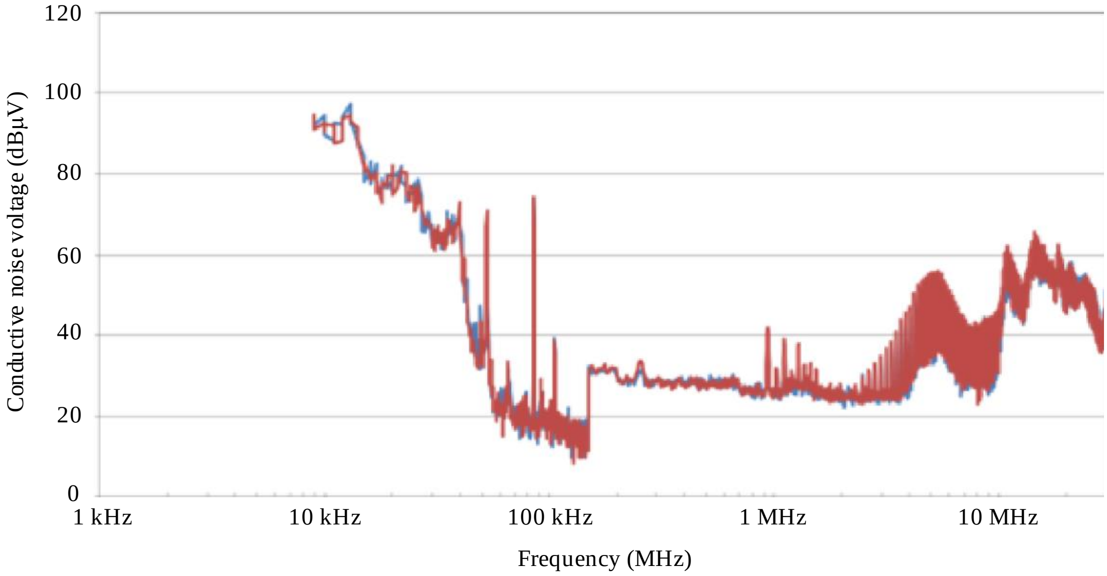
FIGURE A3-17

Conductive noise of test equipment B (9 kHz – 30 MHz, peak value)



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4.2 Measurement results for mobile and portable devices using magnetic resonance technology

(1) Overview of test equipment

Table A3-2 shows the overview of the test equipment for mobile and portable devices using magnetic resonance technology. WPT frequency is 6.78 MHz. Figure A3-18 describes a typical coil structure for this test equipment. The portable device measured here includes this coil structure inside. Transmission power of this test equipment is 16.8 W. In measurement results shown next, the transmission power is converted to 100 W, and measurement distance is translated to 30 m using the translation factor mentioned in § 4.1(2). It is noted that test equipment includes no devices to suppress higher order harmonics of WPT frequency.

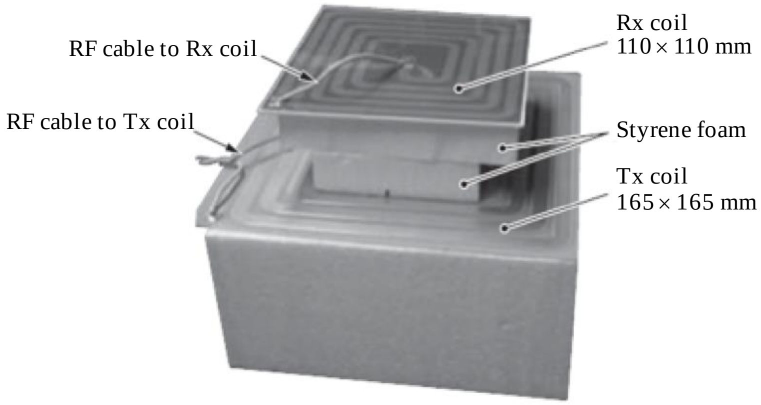
TABLE A3-2

Overview of test equipment for mobile and portable devices using magnetic resonance

WPT system	Mobile and IT devices
WPT technology	Magnetic resonance
WPT frequency	6.78 MHz
Condition for WPT	Transfer power: 16.8 W Power transfer distance: several centimeters

FIGURE A3-18

Typical coil structure for test equipment for mobile and portable devices using magnetic resonance



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(2) Measurement results of radiated noise

Radiated noise from test equipment was measured in shielded anechoic chamber. Measurement results in the frequency range from 9 kHz to 30 MHz, from 30 MHz to 1 GHz, and from 1 GHz to 6 GHz are shown in Figs A3-19, A-20 and A3-21, respectively. Also, Fig. A3-22 describes measurement result of higher order harmonics of this test equipment. As results of these measurements, it is found that this test equipment clears the tentative target limit of radiated noise for WPT frequency. And also, it is recognized that there is no emission noise over 1 GHz.

FIGURE A3-19

Radiated noise of test equipment (9 kHz – 30 MHz, peak value)

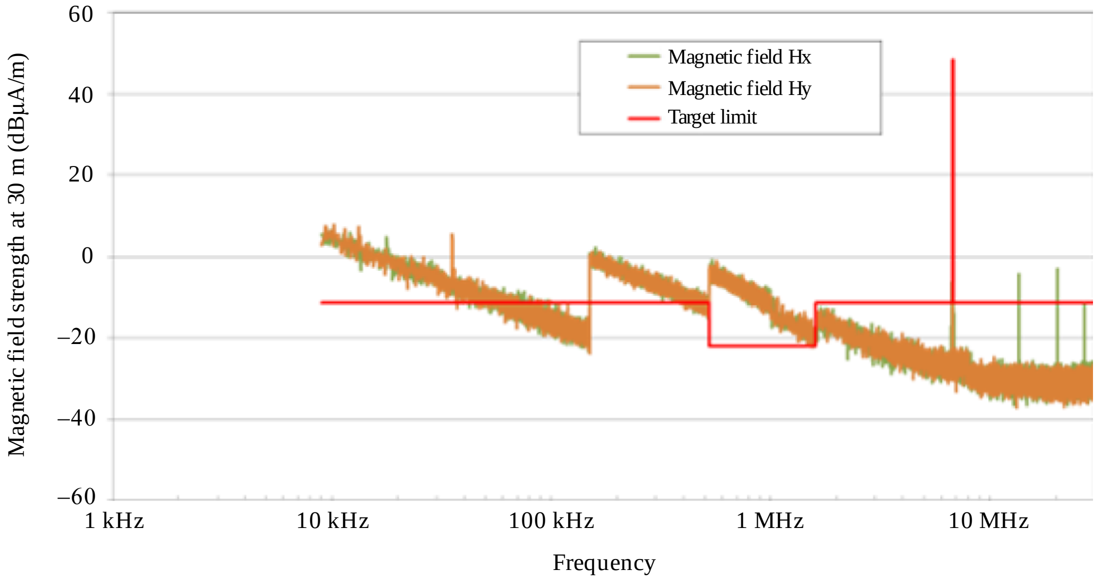

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FIGURE A3-20

Radiated noise of test equipment (30 MHz – 1 GHz, peak value)

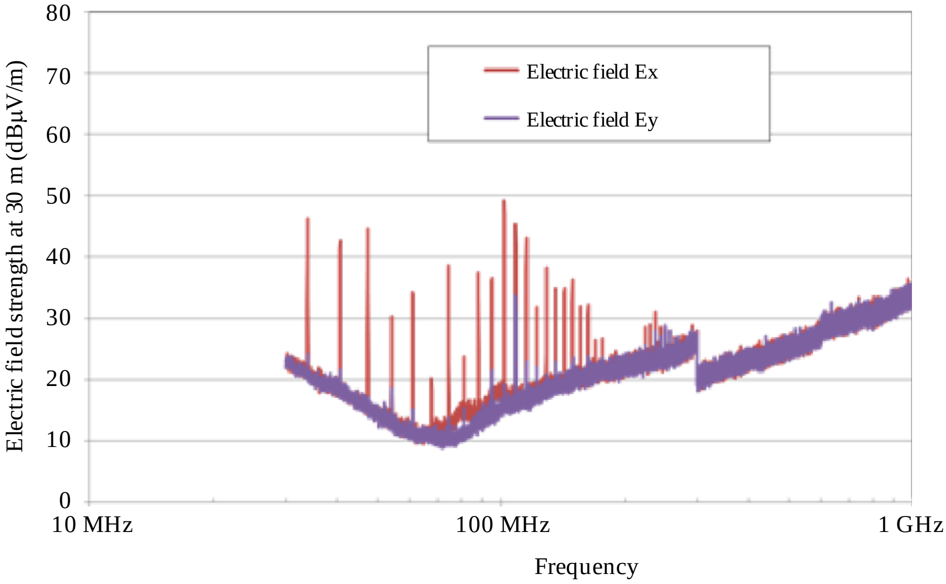

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FIGURE A3-21

Radiated noise of test equipment (1 GHz – 6 GHz, peak value)

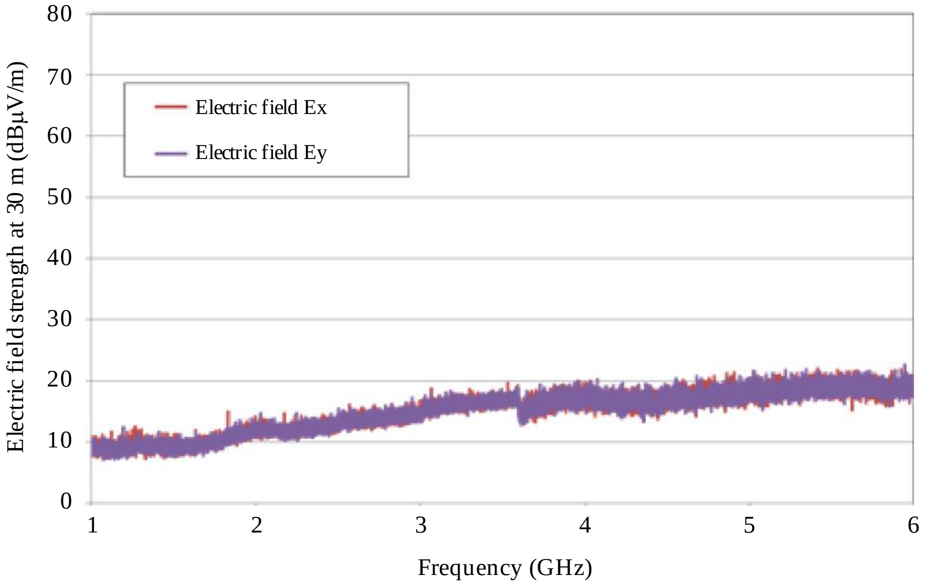

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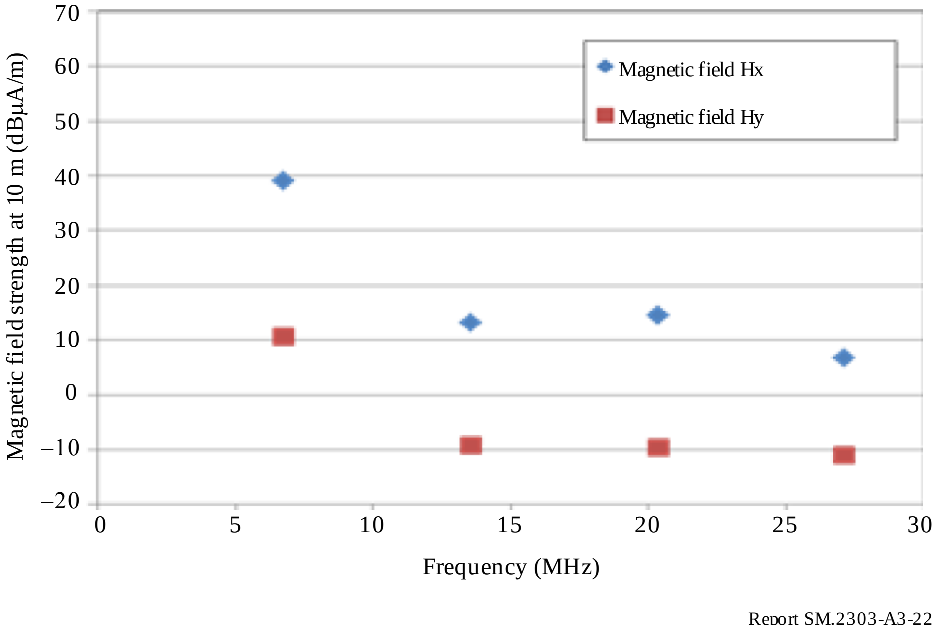
FIGURE A3-22

Measurement results of higher order harmonics (Quasi-peak value)

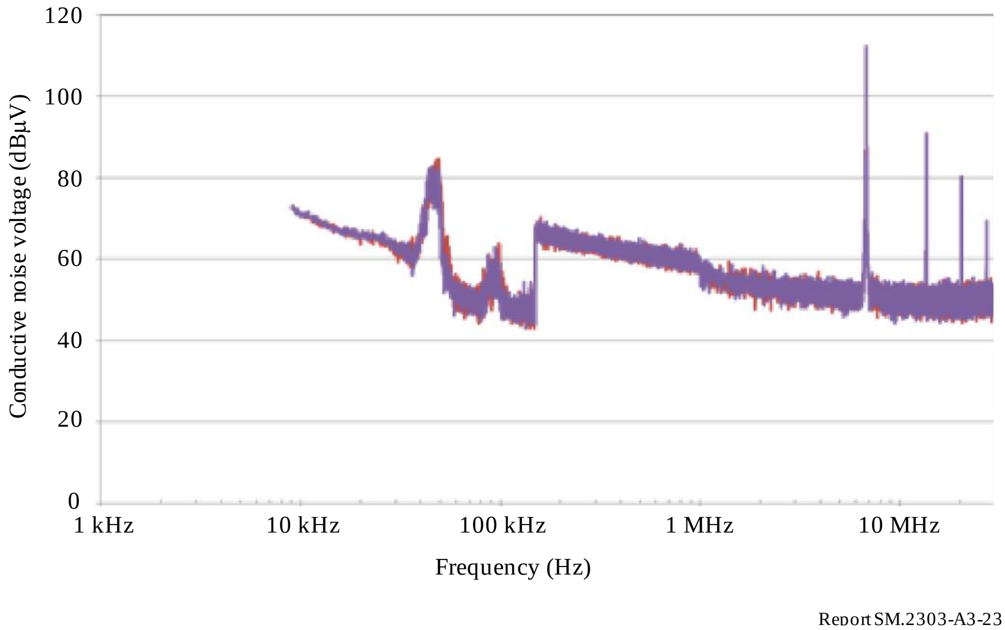


(3) Measurement results of conductive noise

Measurement results of conductive noise in the frequency range from 30 MHz to 1 GHz are shown in Fig. A3-23.

FIGURE A3-23

Conductive noise of test equipment (9 kHz – 30 MHz, peak value)



4.3 Measurement results for home appliances using magnetic inductive technology

(1) Overview of test equipment

Table A3-3 shows the overview of the test equipment for home appliances using magnetic inductive technology. There are two coil structures for this WPT system as shown in Fig. A3-24. WPT frequency is 23.4 kHz and 94 kHz. Transmission powers are 1.5 kW for test equipment A, and

1.2 kW for test equipment, respectively. Measurement distance is translated to 30 m using the translation factor mentioned in § 4.1(2). It is noted that the two pieces of test equipment include devices to suppress higher order harmonics of WPT frequency.

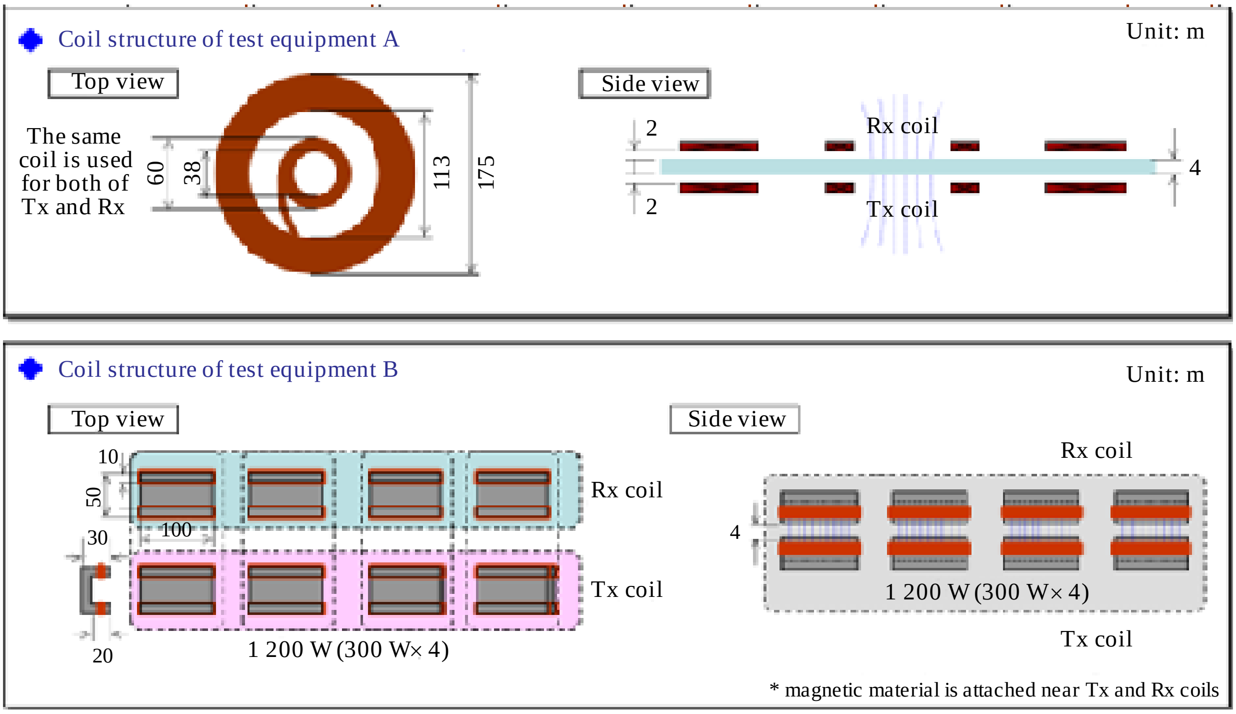
TABLE A3-3

Overview of test equipment for home appliances using magnetic induction

WPT system	Home appliances
WPT technology	Magnetic inductive technology
WPT frequency	Test equipment A: 23.4 kHz Test equipment B: 95 kHz
Condition for WPT	Transfer power (Test equipment A): 1.5 kW Transfer power (Test equipment B): 1.2 kW Power transfer distance: less than 1 cm

FIGURE A3-24

Typical coil structures for test equipment for home appliances using magnetic inductive technology



Report SM.2303-A3-24

(2) Measurement results of radiated noise

Radiated noise from each test equipment was measured in shielded anechoic chamber. Measurement results in the frequency range from 9 kHz to 30 MHz are shown in Figs A3-25 and A3-26 for each test equipment. Measurement in the frequency range from 30 MHz to 1 GHz was done only for test equipment A. That result is shown in Fig. A3-27. As results of these measurements, it is found that these two pieces of test equipment clear the tentative target limit of radiated noise for WPT frequency and higher frequencies.

FIGURE A3-25

Radiated noise of test equipment A (9 kHz – 30 MHz, Quasi-peak value)

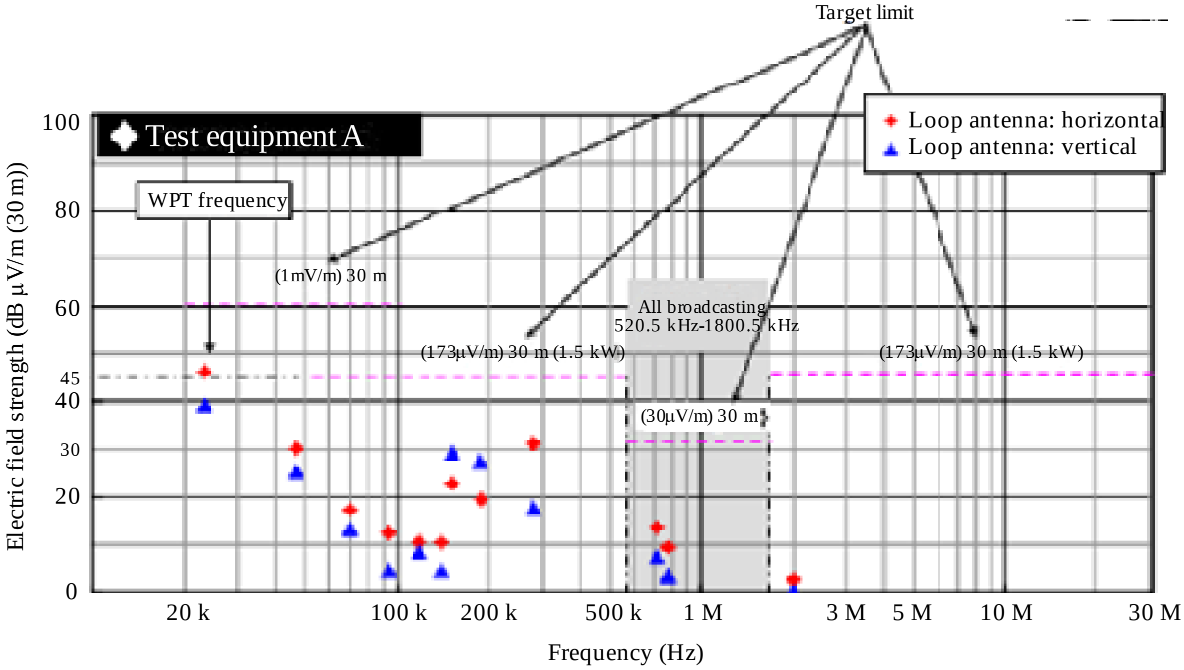


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FIGURE A3-26

Radiated noise of test equipment B (9 kHz – 30 MHz, Quasi-peak value)

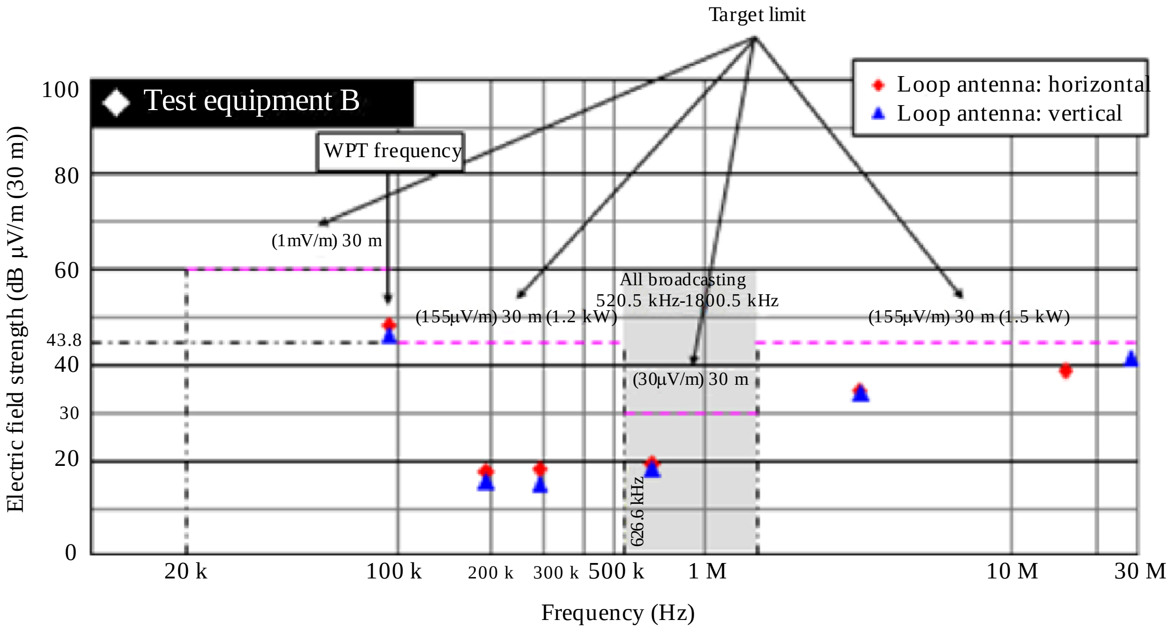

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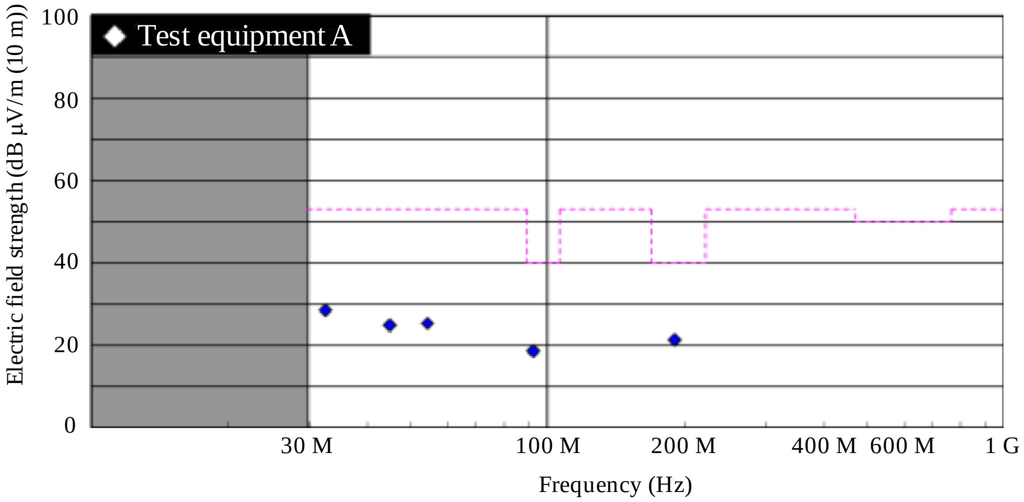
FIGURE A3-27

Radiated noise of test equipment A (30 MHz – 1 GHz, Quasi-peak value)



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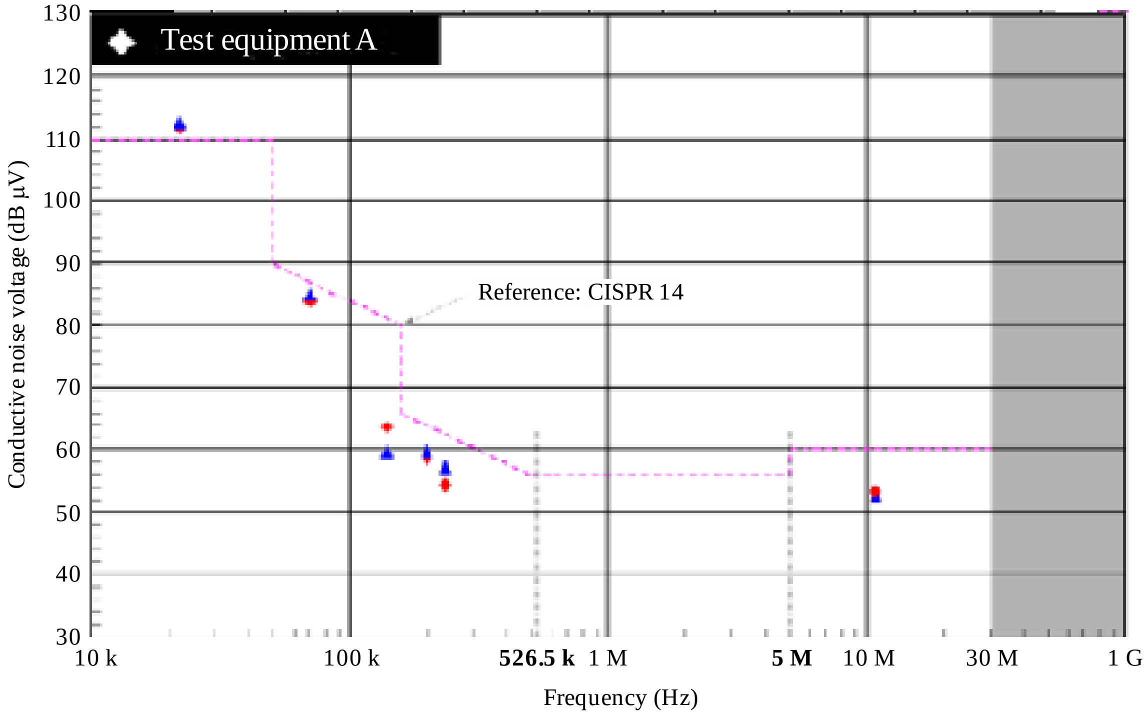
(3) Measurement results of conductive noise

Measurement results of conductive noise in the frequency range from 9 kHz to 30 MHz are shown in Fig. A3-28.

FIGURE A3-28

Conductive noise of test equipment A (9 kHz – 30 MHz, Quasi-peak value)



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4.4 Measurement results for mobile and portable devices using capacitive coupling technology

(1) Overview of Test equipment

Table A3-4 shows the overview of the test equipment for mobile and portable devices using capacitive coupling technology. Figures A3-29 and A3-30 show the test equipment for this measurement and the block diagram of the WPT system, respectively. WPT frequency is 493 kHz. Transmission power is 40 W in maximum. It is noted that this test equipment adopts as many commercial product requirements as possible including shield design to suppress radiation emission and higher order harmonics.

TABLE A3-4

Overview of test equipment for mobile and portable devices using capacitive coupling technology

WPT system	Mobile and IT devices
WPT technology	Electric field coupling
WPT frequency	493 kHz
Condition for WPT	Transfer power: 40 W max Power transfer distance: 2 mm

FIGURE A3-29

Test equipment for mobile and portable devices using capacitive coupling technology

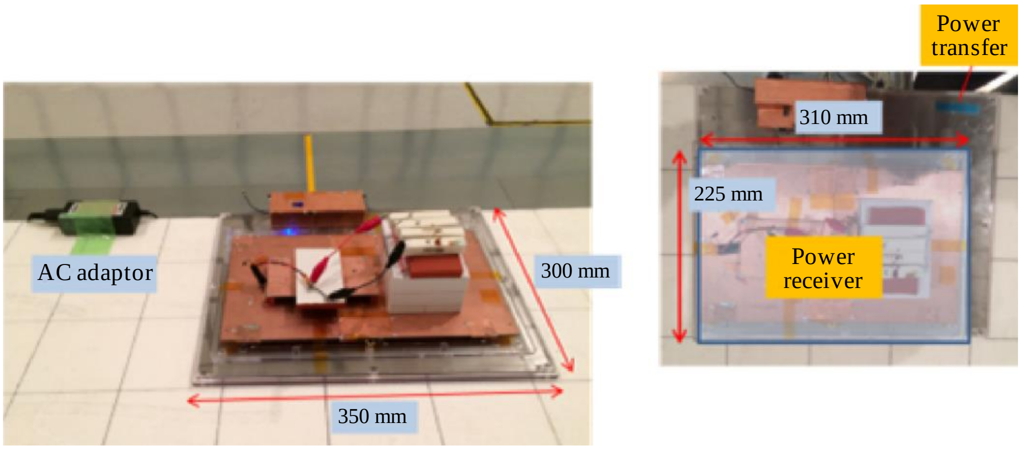

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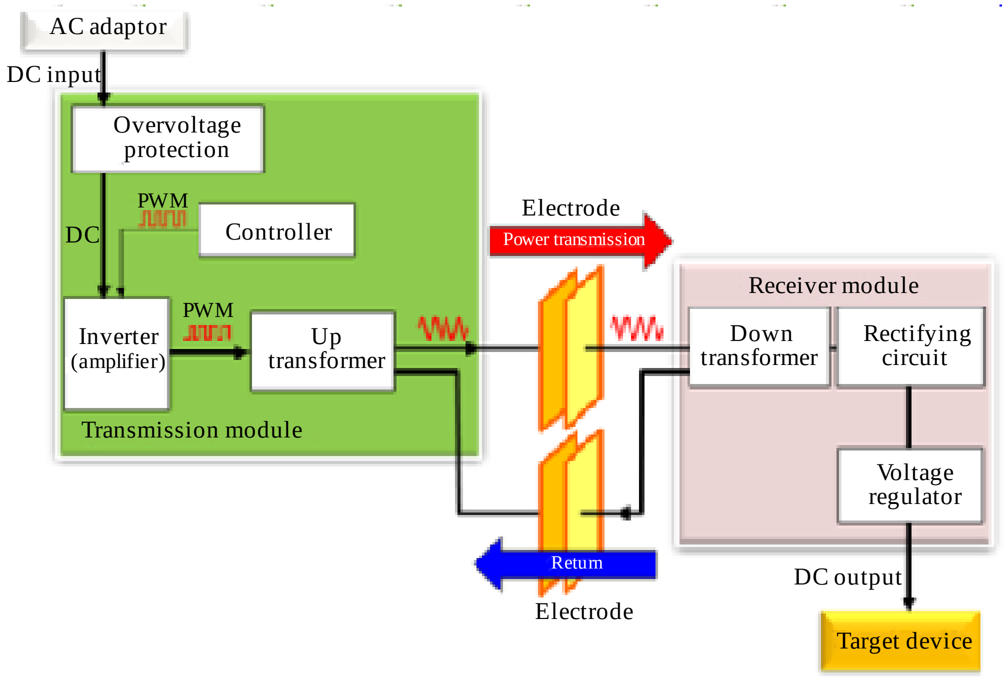
FIGURE A3-30

Block diagram of WPT system for mobile and portable devices using capacitive coupling technology



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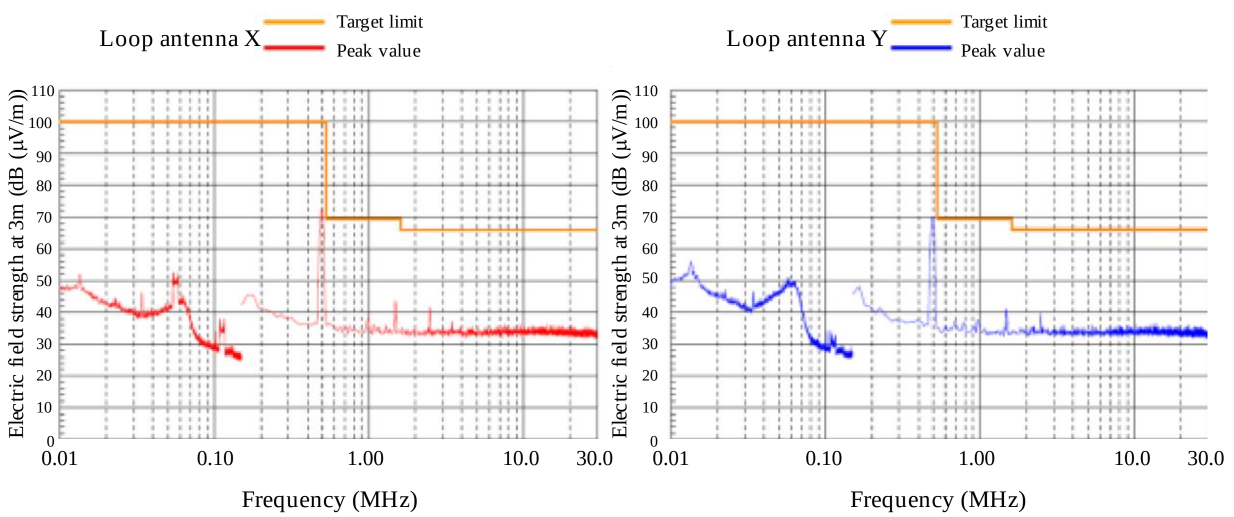
(2) Measurement results of radiated noise

Radiated noise from this test equipment was measured in shielded anechoic chamber. Measurement results in the frequency range from 9 kHz to 30 MHz, from 30 MHz to 1 GHz, and 1 GHz to 6 GHz are shown in Figs A3-31, A3-32, and A3-33, respectively. The results of the measurements in Fig. A3-31 show that the radiated noise is less than the tentative target limit, which may be due to the means to suppress radiation and emission.

FIGURE A3-31

Radiated noise (9 kHz – 30 MHz, peak value)



Report SM.2303-A3-31

FIGURE A3-32

Radiated noise (30 MHz – 1 GHz, peak and Quasi-peak value)

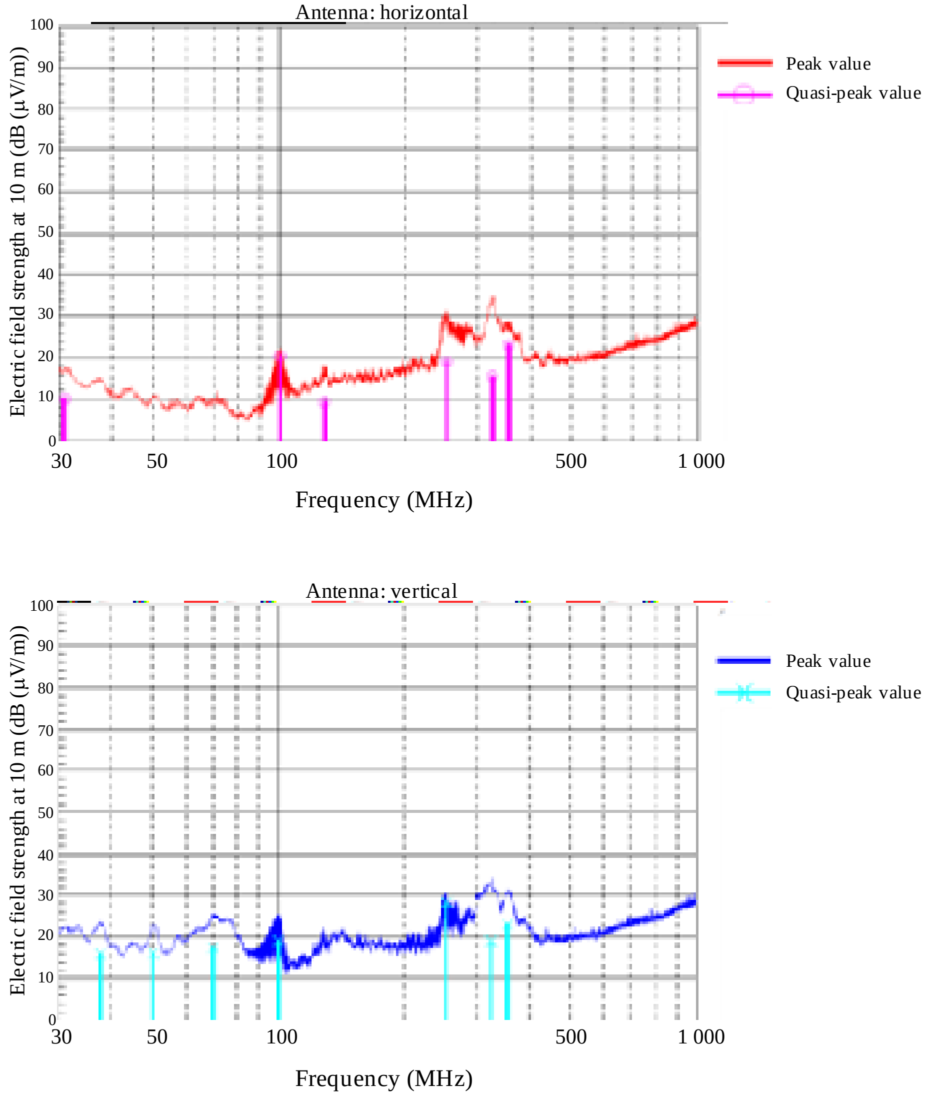


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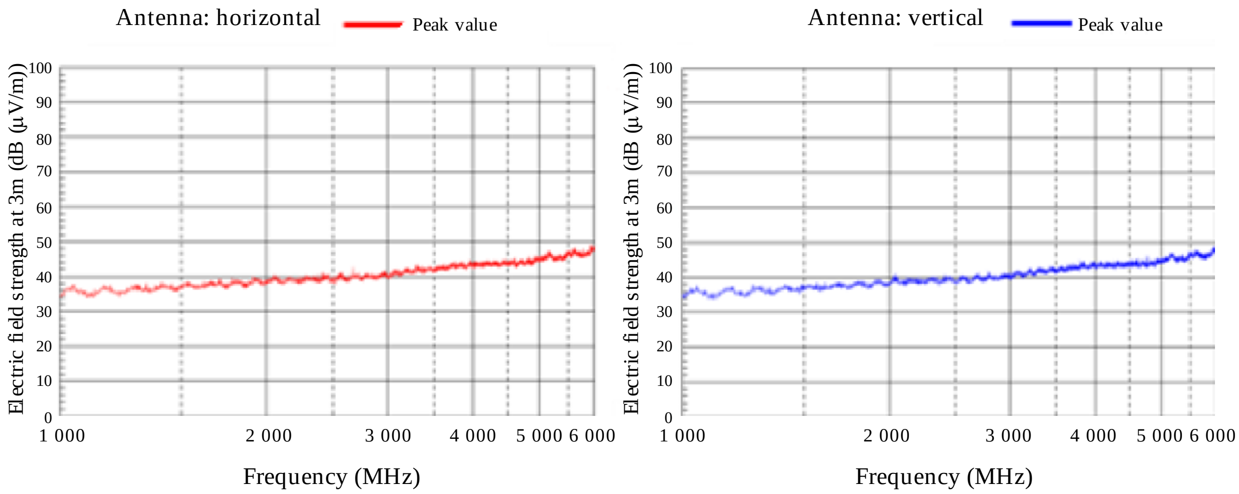
FIGURE A3-33

Radiated noise (1-6 GHz, peak value)



Report SM.2303-A3-33

(3) Measurement results of conductive noise

Measurement results of conductive noise in the frequency range from 9 kHz to 30 MHz are shown in Fig. A3-34.

FIGURE A3-34

Conductive noise of test equipment (9 kHz – 30 MHz, peak and Quasi-peak value)