International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Report ITU-R SM.2303-2

(06/2017)

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

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REPORT ITU-R SM.2303-2

Wireless power transmission using technologies other than radio frequency beam

(2014-2015-2017)

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Acronyms and abbreviations

A4WP	Alliance for Wireless Power
AFA	AirFuel Alliance
AGV	Automated Guided Vehicle
AHG	Ad-Hoc Group
APT	Asia-Pacific Telecommunity
ARIB	Association of Radio Industries and Businesses (Japan)
ATS	Automatic Train Stop Systems
AWG	APT Wireless Group
BBC	British Broadcasting Corporation
BWF	Broadband Wireless Forum (Japan)
CATR	China Academy of Telecommunication Research
CCSA	China Communications Standards Association
CE	Consumer Electronics
CENELEC	European Committee for Electrotechnical Standardization/ Comité Européen de Normalisation Electrotechnique
CEPT	European Conference of Postal and Telecommunications Administrations/ Conférence européenne des administrations des postes et des télécommunications
CISPR	Comité International Spécial des Perturbations Radioélectriques
CJK	China-Japan-Korea
CTA	Consumer Technology Association
DGPS	Differential Global Positioning System
DoC	Declaration of Conformity
DRM	Digital Radio Mondial
EBU	European Broadcasting Union
ECC	European Consumer Centres
EDM	Electrical Discharge Machining
EMC	Electromagnetic Compatibility
EMF	Electromagnetic Fields
EMI	Electromagnetic Interference
ENAP	EN approval procedure
ERC	European Radiocommunications Committee
ETSI	European Telecommunications Standards Institute
ETSI TC ERM	ETSI Technical Committee (TC) EMC and Radio Spectrum Matters (ERM)
EV	Electric Vehicle
FCC	Federal Communications Commission (USA)

ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IS	International Standard
ISM	Industrial, Scientific, and Medical
ISO	International Organization for Standardization
ITRS	Inductive Train Radio Systems
ITU-R	ITU Radiocommunication Sector
ITU-T	ITU Telecommunication Standardization Sector
JARI	Japan Automobile Research Institute
JTC	Joint Technical Committee
KAIST	Korea Advanced Institute of Science and Technology
KATS	Korean Agency for Technology and Standards
KWPF	Korea Wireless Power Forum
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LF	Low Frequency
LORAN	Long-Range Navigation
MF	Medium Frequency
MF-WPT	Magnetic Field Wireless Power Transmission
MIC	Ministry of Internal Affairs and Communications (Japan)
MIIT	Ministry of Industry and Information Technology (China)
MSIP	Ministry of Science, ICT and future Planning (Korea)
NAVDAT	Navigational Data
NAVTEX	Navigation Telex
OLEV	OnLine Electric Vehicle
OOB	Out-of-band
PAS	Publicly Available Specification
PHEV	Plug-in Hybrid Electric Vehicle
PMA	Power Matters Alliance
PR	Protection Ratio
RED	Radio Equipment Directive
RF	Radio Frequency
RFI	Radio Frequency Interference
RR	Radio Regulations
RRA	National Radio Research Agency (Korea)

SAC	China National Standardization Administration Commission
SAE	Society of Automotive Engineers
SAR	Specific Absorption Rate
SCRD	Standard Clock Radio Device
SDO	Standards Development Organization
SMFIR	Shaped Magnetic Field In Resonance
SRD	Short Range Device
TC	Technical Committee
TCAM	Telecommunications Conformity Assessment and Market Surveillance Committee
TELEC	Telecom Engineering Center (Japan)
TG	Task Group
TIR	Technical Information Report
TTA	Telecommunications Technology Association (Korea)
WD	Working Document
WG	Working Group
WHO	World Health Organization
WPC	Wireless Power Consortium
WPS	Wireless Power Supply
WPT	Wireless Power Transmission
WPT-WG	Wireless Power Transmission Working Group
WRC	World Radiocommunication Conference

1 Introduction

This Report refers to 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, Asia-Pacific Telecommunity (APT) Survey Report on WPT [1] and APT Report on WPT [9] provide 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.

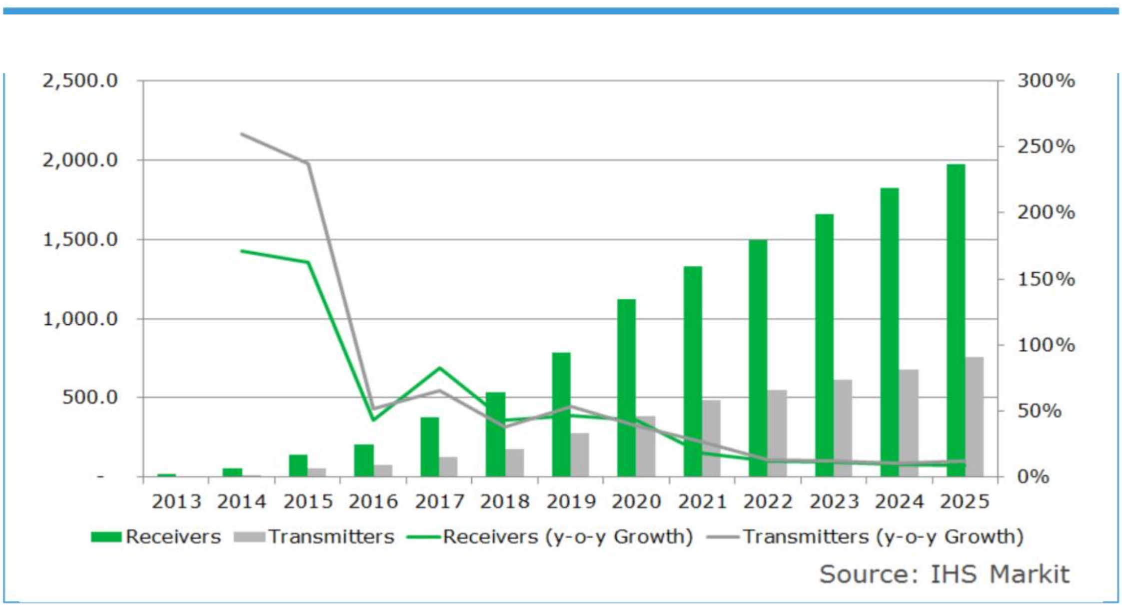
2 Applications developed for use of WPT technologies

2.1 Market situation

The number of devices enabled with wireless charging will exceed 300 million units a year for the first time in 2017, according to the latest IHS Market forecast. Driven by shipments in mobile phones, laptops and wearables, this represents a 75 percent increase over 2016 levels as more consumers experience wireless charging for the first time and new applications adopt the technology. Meanwhile, consumer survey results show that consumer demand for wireless charging is growing each year, as the volume of enabled devices continues to rise.

FIGURE 1

Wireless Power Market Forecast



2.2 Portable and mobile devices

Portable and mobile devices form by far the largest volume of WPT devices currently being used. An IHS consumer survey indicates that 35% of consumers in the USA use wireless power charging for their mobile devices (primarily smartphones). The Wireless Power Consortium website indicates that about 150 million WPT transmitters for smartphone charging are in use as of mid-2017.

2.2.1 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.

2.2.2 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.

2.3 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, system performance and related factors.

2.4 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. The transferred power at car will be used for driving, powering supplemental car devices such as air-conditioning, and other car-necessities. WPT technologies and applications both while parking and while driving are taken into consideration.

WPT Systems for EV is a nascent technology that shows great promise in accelerating the adoption of electric vehicles and reducing the adverse impact of vehicle emissions on the environment. They are under development and it is anticipated that the commercialization of this technology will happen by 2020.

In parallel, public charging stations for such EVs are needed in advance to meet such a timeline. Standardization of such WPT-systems is therefore necessary a few years before this (e.g. 2018) to ensure compatibility of such a public charging infrastructure with the systems installed in EVs and to ensure interoperability between different system types. In Europe, European Commission published the directive on the deployment of alternative fuels infrastructure (2014/94/EU) in October of 2014, Then having regard to that directive, European Commission published the commission implementing decision on a standardization request (M/533) addressed to the European standardization organizations to draft European standards for alternative fuels infrastructure in March of 2015. Almost 20 items including the standardization for electricity supply, hydrogen supply and natural gas supply are listed in this document. The standardization on WPT system for EV is listed at the top of these items. In that document, CENELEC is requested to publish a European standard containing technical specifications with a single solution for wireless recharging for passenger cars and light duty vehicles, and that is interoperable with the specification in IEC 61980-3, by 31/12/2019.

Charging power may depend on the requirement of the users.

In most use cases for passenger vehicles of the personal use, 3.3 kW, 7.7 kW or 11 kW. However, some users for the public use want to charge quickly or their car for specific use purpose may need much bigger power. 22 kW or higher power range is also taken in consideration for passenger vehicles today.

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.

Projects for standardization of WPT systems started already some years ago. IEC/TC69/WG7 is developing IEC 61980 series which covers the requirements for the supply side equipment and ISO/TC22/SC37/JPT19363 is developing ISO 19363 which covers the requirements for EV side, with close cooperation. The timelines of the development is shown in the Table below.

Number	Title	(Estimated) Publication Date	Estimated Revision/ Trans-formation Date
IEC 61980-1	Electric vehicle wireless power transfer (WPT) systems – Part 1: General requirements	2015/7 (IS 1st Ed.)	2019/6 (IS 2nd Ed.)
IEC 61980-2	Electric vehicle wireless power transfer (WPT) systems – Part 2: Specific requirements for communication between electric road vehicle (EV) and infrastructure with respect to wireless power transfer(WPT) systems	2017/12 (TS)	2019/6 (IS 1st Ed.)
IEC 61980-3	Electric vehicle wireless power transfer (WPT) systems – Part 3: Specific requirements for the magnetic field wireless power transfer systems	2017/12 (TS)	2019/6 (IS 1st Ed.)
ISO 19363	Electrically propelled road vehicles – Magnetic field wireless power transfer	2017/1 (PAS)	2018/12 (IS 1st Ed.)

Concerning the WPT system frequency for passenger cars and light duty vehicles, several potential frequency bands were evaluated by considering parameters such as difficulty of meeting EMC and EMF requirements, packaging on vehicle, mass and volume, comparative cost of power electronics, etc. As the result, the industry concluded that 79-90 kHz (so-called 85 kHz band) is the most appropriate selection for those applications

In IEC 61980-3 and ISO 19363, which specifically cover the magnetic field wireless power transfer (MF-WPT) systems, the 85 kHz band is specified as the system frequency band for the MF-WPT up to 11.1 kW.

3 Technologies employed in or incidental to WPT applications

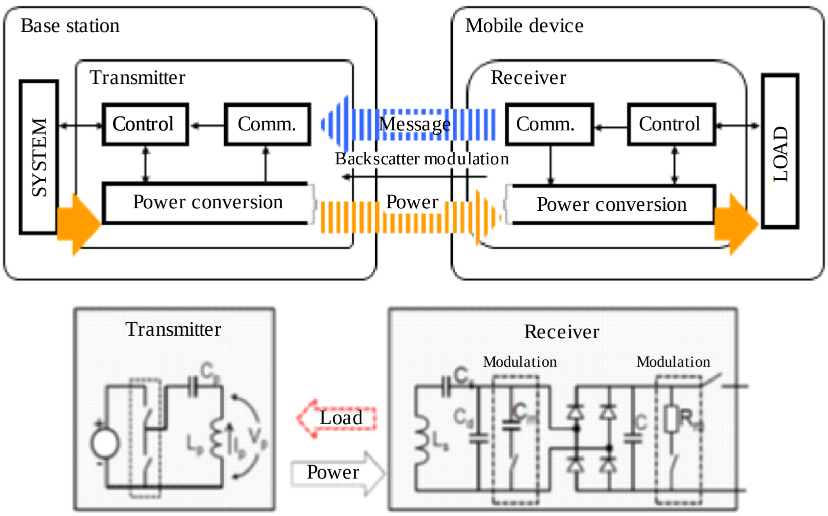
3.1 For portable and mobile devices

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 2

Example magnetic induction WPT system block diagram



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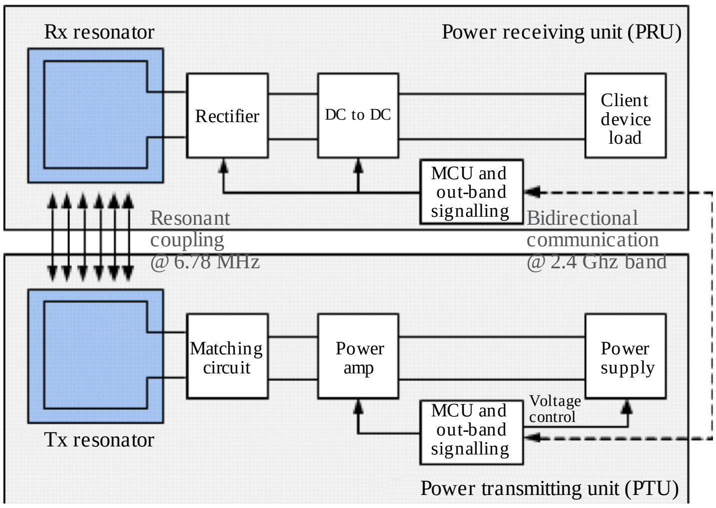
3.1.2 Magnetic resonance WPT technology

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

Example magnetic resonance WPT system block diagram



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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 4 and 5 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 4

Capacitive coupling WPT system block diagram

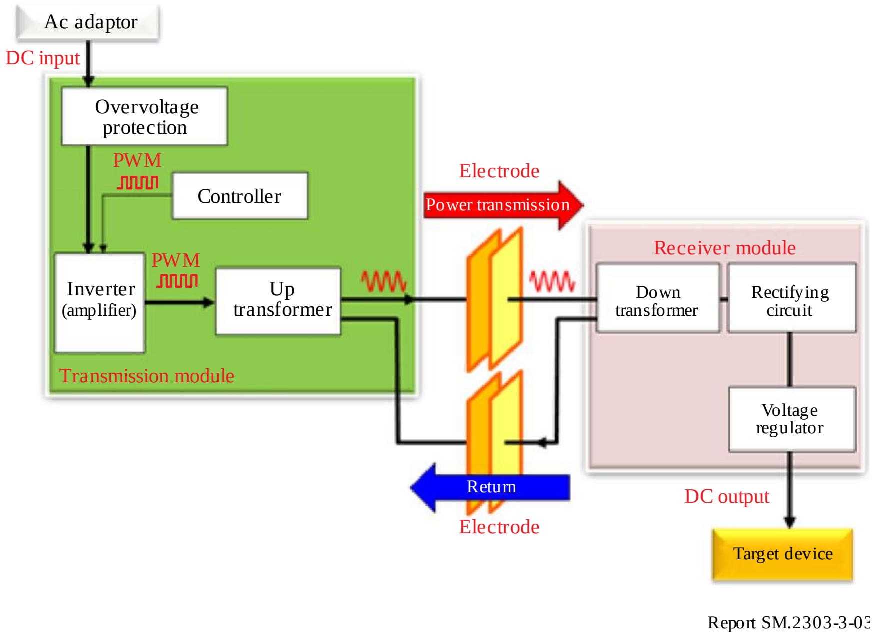
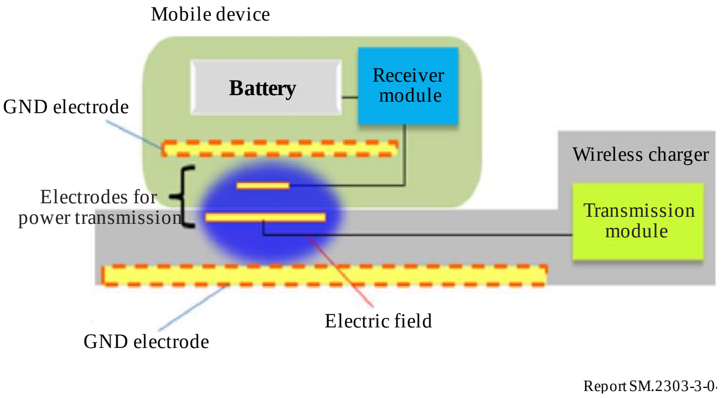


FIGURE 5

Typical structure of the capacitive coupling system



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.

And high reliable devices such as IGBTs are usually used and these devices are working in 10-100 kHz frequency range.

The product applied in the kitchen must meet the safety and electromagnetic field (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 6

Wireless power kitchen appliances

Tightly coupled mixer Tightly coupled rice cooke

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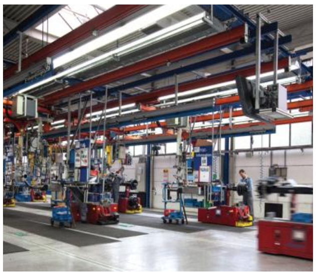
WPT systems are already integrated in the product lines of Semiconductor and LCD panel, the following pictures show examples.

FIGURE 7

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)

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3.3 For electrical vehicles

Magnetic Field Wireless Power Transmission (MF-WPT) is one of the focus points in standardization groups such as IEC TC69/WG7 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 Fig. 8.

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.

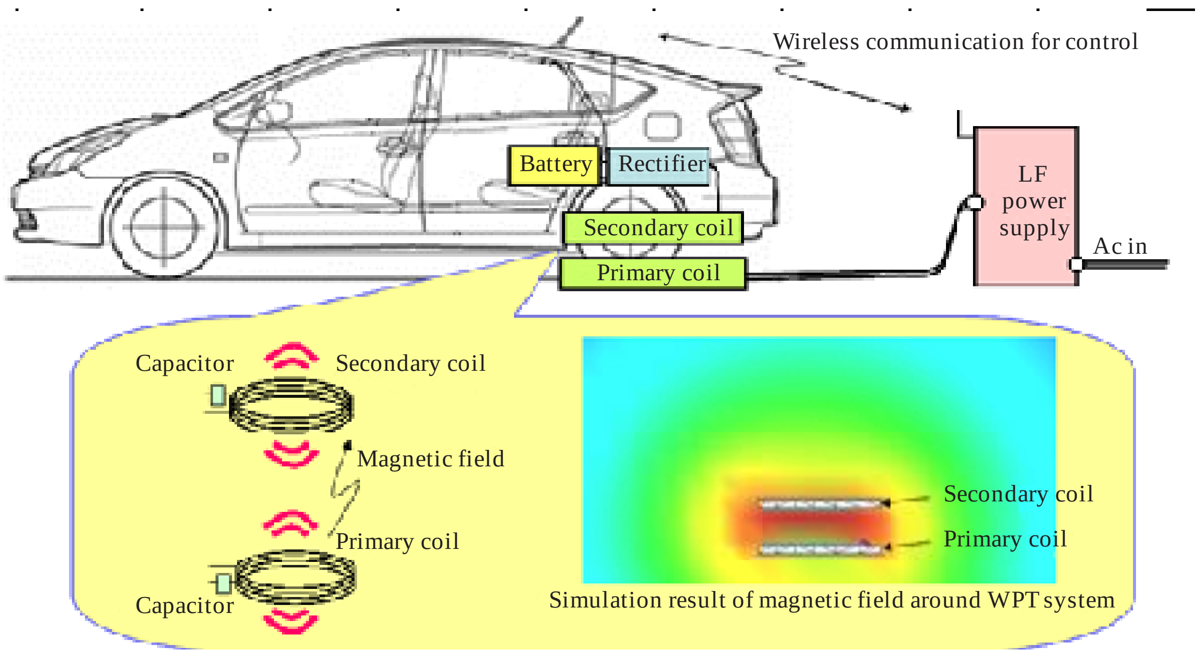
7) Air gap between primary and secondary coils: Less than 30 cm.

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 8

Example of a WPT system for EV/PHEV



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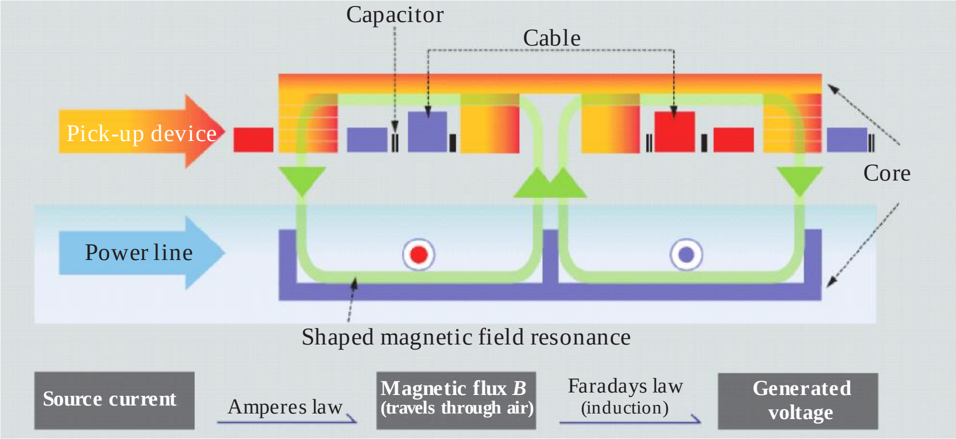
In order to run heavy duty vehicles such as an electrical bus, the infrastructure of the system is to embed electric strips in roadbeds that magnetically transmit energy to battery-powered vehicles above. The bus can move along the electrical strips without any stopping for charging its power, known 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 9

Technical characteristics of an online electric vehicle



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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 10

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. Technical and safety requirements standards have been approved.

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 suite of draft standards developed by BWF are sent to ARIB for approval. BWF performed in-depth technical study for WPT spectrum for all the applications and technologies. In 2015, the following WPT technologies were approved by ARIB as Japanese standards:

ARIB STD-T113 V1.1 "*Wireless Power Transmission Systems*"

Part 1 *"400 kHz Capacitive Coupling Wireless Power Transmission System"*

Part 2 "*6.78 MHz Magnetic Coupling Wireless Power Transmission System for Mobile Devices*"

Part 3 "*Microwave Electromagnetic Field Surface Coupling Wireless Power Transmission System for Mobile Devices*"

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 an aim of the Ministry of Internal Affairs and Communications (MIC) 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. Given the outcomes from the WG, the Report for WPT rulemaking was approved by the Information and Communications Council of MIC and was published in 2015. Further information is provided in Chapter 6. ARIB STD-T113 refers to the new rules for its compliance.

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 1.

TABLE 1

Standardization activities 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 and regional organizations

Some international and regional organizations dealing with WPT standardization and their relevant activities are summarized in Table 2.

TABLE 2

WPT related international and regional organizations

Name of Organization	Activities
APT (Asia Pacific Telecommunity)	APT Wireless Group (AWG) began a study towards an APT Recommendation on frequency ranges for non-beam WPT for mobile devices in February 2016. The AWG has initiated a development of APT Report on Frequency Ranges used for Non-Beam WPT for Electric Vehicles which is planned to complete in September 2017 and the initial framework was agreed at its 20th meeting (September 2016). Furthermore, the AWG is going to carry out studies providing information and necessary supports to APT members on their preparation for WRC-19 A.I. 9.1, issue 9.1.6. In addition to the above activities, the working document "APT new Report on "services and applications of "Wireless Power Transmission (WPT)" Technology" was completed in 2017, by adding broad range of information and study results.
ITU-T SG 13	ITU-T Q1/13 is developing Y.Supplement WPT, Wireless Power Transfer application services, with the scope: – Definition of the concept of WPT application service – Service model of WPT application service – Use case of WPT application service The ITU-T Y.WPT describes various use cases on how to provide service using WPT technology to construct a service framework that includes user/device authentication, service management, accounting, service security, etc. The main objective is to define service framework to providing WPT service.
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 D (electric/electronic equipment on vehicles), F (household appliances, lighting equipment, etc.) and I (information technology equipment, multimedia equipment and receivers) are also considering WPT. SC-B formed a Task Force (presently AHG 4) in June 2014 intended for specification development. Amendment to CISPR 11 for including the emission requirements in the frequency range 9 kHz to 150 kHz for power electronic WPT including EV is expected to be published by not later than 2019. It must be noted that the scope of CISPR 11 is for ISM, currently there is no ISM band in the RR for 9-150 kHz.
IEC TC 100	IEC TC100/TA 15 develops international publications related to wireless power transfer (WPT) for multimedia systems and equipment, and interoperability between the WPT transmitting and the WPT receiving functions. IEC published one standard for Wireless Power Transfer (IEC PAS 63095 Ed1) and anticipates the imminent publication of a second standard (IEC 63028 Ed 1). IEC PAS 63095 specifies the use of frequencies in the range 87-205 kHz, and the IEC 63028 specifies the use of 6.78 MHz. IEC TC100/TA 15 recommends that ITU support a suitable harmonized frequency range for WPT that fully supports these two IEC standards.

TABLE 2 (*continued*)

Name of Organization	Activities
IEC TC 106	– New working groups WG 8 “Addressing methods for assessment of contact current related to human exposures to electric, magnetic and electromagnetic fields” and WG 9 were established in relation to the WPT. – Addressing methods for assessment of Wireless Power Transfer (WPT) related to human exposures to electric, magnetic and electromagnetic fields”.
IEC 61980 (IEC TC 69 / WG7)	IEC TC 69 (Electric road vehicles and electric industrial trucks) WG7, together with ISO TC22 (Road Vehicles), discusses WPT for a vehicle. – IEC 61980-1: General Requirements (Published in July, 2015) – IEC 61980-2: Communication (Under development) – IEC 61980-3: Magnetic Field Power Transfer (Under development) 85 kHz band (81.39-90 kHz) will be specified as the system frequency for passenger cars and light duty vehicles in IEC 61980-3. Publications of TSs (Technical Specifications) of the IEC 61980-3 and IEC 61980-2 are planned to be by the end of 2017. Also, the publication of the 2nd edition of IEC 61980-1 is expected by the end of 2018
ISO 19363 (ISO (TC22/SC37 /JPT19363))	ISO 19363: Magnetic field wireless power transfer – Safety and interoperability requirements – The JPT19363 was established in early 2014 – Target is to develop a standard which specifies requirements for the vehicle-side parts – A close synchronization with IEC 61980 and SAE J2954 85 kHz band (81.39 – 90 kHz) is specified as the system frequency for passenger cars and light duty vehicles. PAS (Publicly Available Specification) was published in January of 2017, followed by the upgrading to IS (International Standard) by the end of 2018.
ISO/IEC JTC 1 SC 6	ISO/IEC JTC 1 SC 6 is developing In-band PHY and MAC Layer Protocol of WPT – Working Item was approved in Jan. 2012. – On Circulation with WD (Working Document)
ETSI TC ERM	– ETSI TC ERM has recently published a technical report (TR 103 409) titled “System reference document (SRdoc); “Wireless Power Transmission (WPT) systems for Electric Vehicles (EV) operating in the frequency band 79-90 kHz”. This SRdoc must now be considered by CEPT who will consider WPT-EV systems and look at co-existence with radiocommunication systems. – ETSI TC ERM approved a final draft version of a new Harmonised Standard (EN 303 417*) for the ETSI EN approval procedure (ENAP), which covers all kinds of WPT systems (instead of EN 300 330 – Non-specific short range devices, which was used for WPT systems in the past, but is no longer applicable to WPT equipment). EN 303 417 specifies technical characteristics and methods of measurements for wireless power transmission (WPT) systems using technologies other than radio frequency beam in the 19 – 21 kHz, 59 – 61 kHz, 79 – 90 kHz, 100 – 300 kHz, 6 765 – 6 795 kHz ranges. Publication of the new standard is forecast for the second half of 2017. In addition, a new systems reference document

* This standard was still “draft ETSI EN 303 417” when the revision 2 of this Report (i.e. ITU-R SM.2303-2) was approved on 21 June 2017.

TABLE 2 (*continued*)

Name of Organization	Activities
	(TR 103 493) is now under consideration within TC ERM to cover the technical specifications and characteristics of WPT systems other than EV-WPT, operating below 30 MHz, which in time will be considered by CEPT/ECC/WG SE for co-existence studies.
CTA (Consumer Technology Association)	CTA R6-WG22 (Wireless Power Transfer) This working group develops standards, recommended practices, and related documentation related to wireless power transfer. It developed ANSI/CTA-2042.1-B Wireless Power Glossary of Terms. It is currently developing CTA-2042.3, Methods of Measurement for Efficiency and Standby Power of Wireless Power Systems.
SAE (Society of Automotive Engineers)	The SAE International J2954™ Task Force for Wireless Power Transfer for Electric and Plug-in electric vehicles was established in 2010. The SAE International published "SAE TIR J2954 Wireless Power Transfer for Light-Duty Plug-In/ Electric Vehicles and Alignment Methodology" in May 2016, which establishes 85 kHz band (81.39 – 90 kHz) as a common frequency band for wireless power transfer for all light duty vehicle systems up to 22kW. The TIR (Technical Information Report) specifies two power classes (3.7 kW and 7.7 kW). Two more classes of higher power levels up to 22 kW are given for future revisions. SAE International is a global association uniting over 128,000 engineers and technical experts in the aerospace, automotive and commercial-vehicle industries. See http://www.sae.org/news/3415/ and http://standards.sae.org/j2954_201605/.
AirFuel Alliance	A global, nonprofit consortium formed by the merger of A4WP and PMA in 2015. AirFuel Alliance (AFA) continues and extends all activities which were proceeding in A4WP and PMA. The specifications released from A4WP and PMA were directly adopted as AirFuel Alliance specifications. AFA has been working on the WPT standardizations in the areas as follows: – Inductive (Magnetic induction WPT) – Resonant (Magnetic resonance WPT) – Uncoupled – Infrastructure The Wireless Power Transfer – AirFuel Resonant Baseline System Specification (BSS) specification is expected to be published as IEC 63028 Ed 1 in July 2017
A4WP	A4WP developed a WPT specification using 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 The specification specifies operation at 6.78MHz. A4WP was merged with PMA to form AirFuel Alliance in 2015.

TABLE 2 (*end*)

Name of Organization	Activities
PMA	Power Matters Alliance (PMA) is a global, not-for-profit, industry organization cooperated in wireless power technology, including charging for battery equipped devices. Since being founded in 2012, the PMA has grown rapidly across a diverse set of industries including telecommunication, consumer devices, automotive, retail, furniture, surfaces and more. Our growth and success is attributed to a unique approach of making wireless power ubiquitous in the places that consumers need it most as well as the hard work and dedication of our members. PMA was merged with A4WP to form AirFuel Alliance in 2015.
WPC	Founded in 2008, the Wireless Power Consortium has been leading the way in wireless charging with an open standard for all. Its work focuses on tightly coupled inductive coupling solutions across a range of power levels, from 5-15W for mobile wireless power transfer to 1KW for kitchen appliances. Its website lists 219 members and 668 certified products including accessories, chargers and devices. – Released technical specification (Qi ver.1) in July 2010 The Qi Specification has been published as IEC PAS 63095 Ed1 The Qi Wireless Power Transfer System Power Class 0 Specification defines the interface between a Power Transmitter and a Power Receiver, i.e. Power Class 0 Base Stations and Mobile Devices. Power Class 0 is the WPC designation for flat-surface devices, such as chargers, mobile phones, tablets, cameras, and battery packs, in the Baseline Power Profile (≤ 5 W) and Extended Power Profile (≤ 15 W). It specifies operation at frequencies in the 87-205 kHz range.
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 – Released CJK WPT Technical Report 2 in Spring 2014 – Released CJK WPT Technical Report 3 in May 2015

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 (fundamental), 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 WPT and for use of CISPR EMC emission standards in regional and/or national regulation is found in Table 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 (electric 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. In order to avoid the duplication of the works, the scope of each standard is coordinated as follows:

Classification of Target Areas	Detailed classifications (Scope of related CIPR Standards)		Related CISPR Standards	Responsible Sub-Committee	Status of works on WPT
ISM applications(*)	Industrial equipment		CISPR 11	B	–
	Scientific equipment				–
	Medical equipment				–
	Domestic equipment	Equipment not covered by other CISPR standards			Already covered
		Household appliances and electric tools	CISPR 14-1	F	CD was circulated in June 2017
		Electrical lighting equipment	CISPR 15		Revisions will be included in Edition 9 (2018)
		ITE, Multimedia and receiver	CISPR 32	I	CD will be circulated in 2017
	Similar purposes	Power electronics WPT (including EV charger)	CISPR 11	B	CDV will be circulated in 2017
Vehicles, boats and internal combustion engines			CISPR 12 CISPR 36	D	(To be started)

(*) The ISM applications are classified in accordance with the definition of the Article **1.15** of the Radio Regulations.

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.

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 11 Ed. 6.0 (2015-06). It covers:

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. These requirements were introduced in the Edition 3.0 (1997) of CISPR 11 and since then have been used for protection to the radio services from the ISM equipment and also used for common EMC requirements. 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 3).

TABLE 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 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 Radio Equipment Directive (RED), as long as it can be shown that the WPT appliance in question meets the essential requirements of the Directive. This may be through application of a relevant Harmonised Standards cited in the Official Journal of the European Union[1].

[1] https://ec.europa.eu/growth/single-market/european-standards/harmonised-standards/rtte_en

TABLE 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 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 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">RED</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 for a specific harmonized standard (EN 303 417) for all kinds of WPT systems with a communication functionality. This harmonized standard could also be used to specify/test the radiations outside the WPT system which are based on the power transmission.</td></tr>
</table>

TABLE 4 (*end*)

Case	**Relevant regulation**	**Other specifications also used by regulators**	**Applicable essential requirements/standards**		
			EMF	**EMC**	**Radio**
3 WPT systems with data transfer or communication function at different frequency to energy transfer	EMC Directive	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 apply			
	RED (radio communi-cations	None	EMF standards for radio appliances	EMC standards for radio appliances	Functional standards for radio appliances
		9 kHz < band < 30 MHz	EN 62311 (EN 62479)	EN 301 489-1/3	EN 300 330
		30 MHz < band < 1 GHz			EN 300 220
		1 GHz < band < 40 GHz			EN 300 440
	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 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.				

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.

AHG 4 (former Task Force WPT in CISPR/B/WG 1 is working on an Amendment to CISPR 11 (Ed.6.0) to include new emission requirements and methods of measurements for power electronic WPT with close relationship with IEC/TC69/WG7, SAE/J2954TF and ETSI/ERM/TG28. The 1st Committee Draft (CISPR/B/663/CD) was circulated in June 2016 and submitted comments from the 18 National Committees (NC) were discussed in the AHG 4 meeting in November 2016. Concerning the proposal from four NCs to relax the radiated disturbance limits on the fundamental frequency for WPT for EV in the frequency range 79-90 kHz from 67.8 dBμA/m to 82.8 dBμA/m at 10m distance. The value 67.8 dBμA/m is nearly identical to the transmitter output level of the European SRD Standard and the confirmed levels by means of a study of impacts in Japan. The basis of relaxation proposal was necessary to leave room for future development of technology, but they did not show specific evidences 15 dB basis and any results of study of impact to the radiocommunications. The meeting could not agree on the specific limits, it was decided that the values in Table for Class B limits frequency range 9 kHz to 150 kHz from CISPR/B/663/CD should be removed temporarily such that the agreed comments of the 663/CD could be implemented into the 2nd CD (CISPR/B/678/CD) for WPT systems, with a view to reinserting an agreed set of values at a later date.

It was also agreed to circulate a DC (CISPR/B/673/DC) in inviting opinions from the National Committees on the limit value for Class B, frequency range 9 kHz to 150 kHz. Two documents were circulated in January 2017 and were received from 15 NCs and two international organizations including EBU and IARU. A liaison statement from IEC/TC 69/WG 7 and ISO/TC 22/SC 37/JPT 19363 was also received as an input.

The AHG 4 meeting was held in Daejeon, Korea in 15 to 18 May 2017. AHG 4 recognized the draft power classes of WPT charger for EV that TC 69/WG 7, ISO/JPT 19363 and SAE J2954 are considering in order to realize interoperability of power classes internationally. The above product committees wish is as follows: Input power classes MF-WPT1, 2 and 3 are expected to be connected to a low voltage power supply network and installed in a mixed state in the residential environment and may require interoperability among the classes.

TABLE 1 (quoted from IEC document 69/485/CD(2017-02))

MF-WPT input power classes

Class	**MF-WPT1**	**MF-WPT2**	**MF-WPT3**	**MF-WPT4**	**MF-WPT5**
Power [kW]	$P \leq 3.7$	$3.7 < P \leq 7.7$	$7.7 < P \leq 11.1$	$11.1 < P \leq 22$	$P > 22$

Most of the NCs comments on CISPR/B/678/CD were not controversial and mostly accepted.

But the NCs opinions on the limits table for Class B equipment (CISPR/B/673/DC) in the frequency range 79-90 kHz were divided and it was difficult to decide either. As shown in the annexes of document CISPR/B/673/DC, the original proposed limit value in CISPR/B/663/CD does not exceed the H-field regulatory level for SRD in CEPT ERC Recommendation 70-03 and also confirmed by impact study in Japan below 7.7 kW power class. CISPR is discussing relaxing limits by 15 dB based on the ETSI System Reference document (SRdoc) TR 103 409 v1.1.1 (2016-10): "Wireless Power Transmission (WPT) systems for Electric Vehicles (EV) operating in the frequency band 79-90 kHz".

Finally a compromised draft was accepted to propose to CISPR B to go for a CDV (Committee Draft for Voting) with revisions accepted by the meeting of AHG 4. The decision for a CDV takes into account the following considerations:

- NCs are forced to evaluate and assess the Class B limit compromise and the general WPT issues
- NCs are forced to express a vote and can still submit technical comments
- A positive VOTE would give guidance for future (and to other parties as TC 9, TC 69, other CISPR SCs, etc.)
- A negative VOTE would clearly show the deficiencies and would give a direction what needs to be changed

The main items which will be contained in draft CDV is as follows:

Table 5 shows the CISPR proposed list of candidate frequency ranges for WPT.

TABLE 5

CISPR Candidate frequency bands also used for wireless power transmission (WPT) below 150 kHz
[* subject to change in the future]

Frequency range kHz	Typical WPT use	Emission limits for type tests according to this standard
19 to 25	Local WPT via an air gap in cm range, throughput power up to 200 kW – automated in-plant transportation systems, trams and electric buses	See clause 6.3 of CISPR 11
36 to 40	Local WPT via an air gap in cm range, throughput power up to 200 kW – automated in-plant transportation systems, trams and electric buses	
55 to 65 [a]	Local WPT via an air gap in cm range, throughput power up to 200 kW – automated in-plant transportation systems, trams and electric buses	
79 to 90 [b]	Local WPT via an air gap in cm range, throughput power in the range up to 22 kW – electric personal passenger vehicles (e.g. automobile), automated in-plant transportation systems	
130 to 135	automated in-plant transportation systems	

a It should be noted that 60 kHz is being used as a standard frequency and time signal service.

b CISPR Candidate WPT frequency range for global harmonization. The frequency range of 79 kHz to 90 kHz is being considered for Electric Vehicles.

NOTE 1 – The power for WPT systems is given for information only and is not related to any limits.

NOTE 2 – The candidate frequency ranges listed in this table will be aligned with future ITU-R Recommendations and WRC Decisions in a similar way as in Table 1.

The frequency band of 79-90 kHz was agreed in CISPR as a candidate frequency band for WPT charger for passenger vehicles for worldwide use.

The frequency bands of 19-25 kHz, 36-40 kHz and 55-65 kHz are accepted in CISPR to be listed for high power WPT, e.g., automated in-plant transportation systems, trams and electric buses including heavy duty EV, and also 130-135 kHz is added for automated in-plant transportation systems only, because some of such application systems have been used in some countries.

It should be noted that the frequency bands described in this table should be consistent with the provisions of the Radio Regulations or Recommendations made by the ITU-R in future.

The radiated emission requirements are not yet completed and the present status are summarized as follows:

1) In radiation measurement, 10m should be the reference distance below 1 000 MHz.

2) Considering that almost power electronic WPT use fundamental frequency below 150 kHz, and limited frequency ranges should be identified for WPT operation, the graphical representation of limits show chimney shape.

3) Class B[2] limits in the range of 9-150 kHz are divided into three sub-classes by rated power below 1 kW, 1kW to 7.7 kW, and above 7.7 kW. Table 6 shows the current proposed limits.

4) Class B limits in the range of above 150 kHz shall be kept the existing established requirements.

5) Class A[3] limits in the range of 9-150 kHz are divided into two sub-classes by rated power below or above 22 kW. In case of below 22 kW, the limits will be 10 dB higher from SRD requirements, in above 22 kW, 20 dB higher limits are considered.

6) Considering that WPT is in the development stage, the harmonic frequencies up to 5th should be relaxed 10 dB because WPT cannot efficiently operate if the relaxation is not allowed especially for the lower harmonics.

TABLE 6

Electromagnetic radiation disturbance limits for class B WPT equipment for EVs measured on a test site

Frequency range (kHz)	Limits for a measuring distance D in m					
	Low power (≤ 1 kW)[a]		Medium power (> 1 kW to ≤ 7,7 kW)[a]		High power (> 7,7 kW)[a]	
	D = 10 m	D = 3 m	D = 10 m	D = 3 m	D = 10 m	D = 3 m
	Magnetic Field Quasi-Peak [dB(μA/m)]	Magnetic Field Quasi-Peak [dB(μA/m)]	Magnetic Field Quasi-Peak [dB(μA/m)]	Magnetic Field Quasi-Peak [dB(μA/m)]	Magnetic Field Quasi-Peak [dB(μA/m)]	Magnetic Field Quasi-Peak [dB(μA/m)]
9-19	27-23.8	51.5-48.3	27-23.8	51.5-48.3	27-23.8	51.5-48.3
19-25	57	81.5	72	96.5	87	111.5
25-36	22.6-21	47.1-45.5	22.6-21	47.1-45.5	22.6-21	47.1-45.5
36-40	56.2	80.7	71.2	95.7	86.2	110.7
40-55	20.6-19.3	45.1-43.8	20.6-19.3	45.1-43.8	20.6-19.3	45.1-43.8
55-65	54.4	78.9	69.4	93.9	84.4	108.9
65-79	18.5-17.7	43-42.2	18.5-17.7	43-42.2	18.5-17.7	43-42.2
79-90	52.8	77.3	67.8[b]	92.3[b]	82.8[c]	107.3[c]
90-130	17.2-15.6	41.7-40.1	17.2-15.6	41.7-40.1	17.2-15.6	41.7-40.1

2 The following classification is specified in CISPR 11.

Class B equipment is equipment suitable for use in locations in residential environments and in establishments directly connected to a low voltage power supply network which supplies buildings used for domestic purposes.

3 The following classification is specified in CISPR 11.

Class A equipment is equipment suitable for use in all locations other than those allocated in residential environments and those directly connected to a low voltage power supply network which supplies buildings used for domestic purposes.

TABLE 6 (*end*)

Frequency range (kHz)	Limits for a measuring distance D in m					
	Low power (≤ 1 kW)[a]		Medium power (> 1 kW to ≤ 7,7 kW)[a]		High power (> 7,7 kW)[a]	
	D = 10 m	D = 3 m	D = 10 m	D = 3 m	D = 10 m	D = 3 m
	Magnetic Field Quasi-Peak [dB(μA/m)]	Magnetic Field Quasi-Peak [dB(μA/m)]	Magnetic Field Quasi-Peak [dB(μA/m)]	Magnetic Field Quasi-Peak [dB(μA/m)]	Magnetic Field Quasi-Peak [dB(μA/m)]	Magnetic Field Quasi-Peak [dB(μA/m)]
130-135	50	75	65	90	80	104.5
135-150	15.4-15	39.9-39.5	15.4-15	39.9-39.5	15.4-15	39.9-39.5

On a test site, class B equipment can be measured at a nominal distance of 3 m or 10 m. A measuring distance less than 10 m is allowed only for equipment which complies with the definition given in 3.17 (small size equipment).

At the transition frequency, the more stringent limit shall apply.

Where the limit varies with the frequency, it decreases linearly with the logarithm of the increasing frequency.

National authorities may request additional suppression of emissions within specific frequency bands used by sensitive radio services at designated installations, for example by imposing the limits in Table E.2 (Examples for limits for electromagnetic radiation disturbances for in situ measurements to protect specific sensitive radio services in particular areas, valid if listed in Annex G: See CISPR/B/678/CD).

a Selection of the appropriate set of limits shall be based on the rated a.c. power stated by the manufacturer.

b for WPT system > 3.6 kW the limits may be relaxed by 15 dB when no sensitive equipment is used within a distance of 10 m (to be documented in the manual)

c limits reduced by 15 dB shall be applied for installations where sensitive equipment in public space is used within a distance of 10 m.

4.2.2 Information from ICNIRP

International Commission on Non-Ionizing Radiation Protection (ICNIRP) offers guidelines and recommendations on exposure levels to protect people worldwide. This material refers to the relevant frequency bands of WPT. Additional material is found at chapter 8.

ICNIRP has published guidelines on human exposure to electromagnetic fields. Two publications of ICNIRP guidelines of 1998 [7] and 2010 [8] are relevant to the frequency ranges proposed for 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. For practical exposure assessment purposes, the ICNIRP guidelines provide reference levels of exposure.

The ICNIRP reference level guidelines on electric and magnetic fields exposure are used in many countries to help establish national limits, and countries’ threshold are compared to the ICNIRP reference levels.

Operators of WPT equipment should consider 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 in the vicinity of WPT equipment are encouraged.

5 Status of spectrum

5.1 WPT, distinction between industrial, scientific and medical and short range device bands

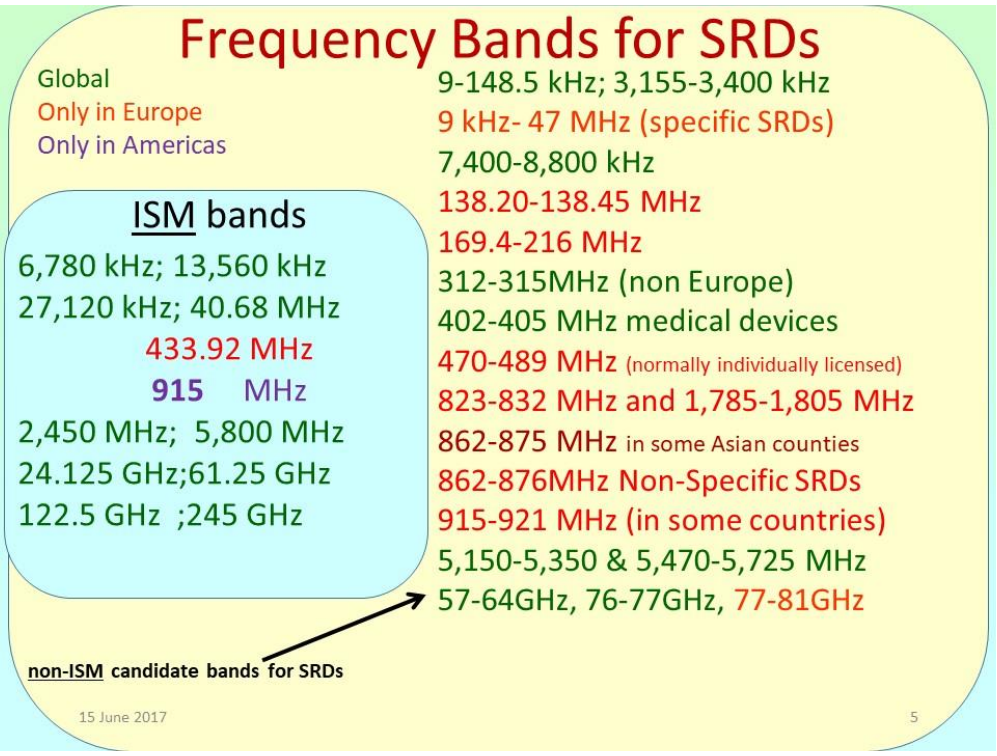
RR provisions of No. **1.15** – industrial, scientific and medical (ISM) applications (of radio frequency energy): operation of equipment or appliances designed to generate and use locally radio frequency energy for industrial, scientific, medical, domestic or similar purposes, excluding applications in the field of telecommunications. The ISM RF bands are primarily for use by those non-telecommunication applications. Therefore, WPT is SRD only if there are telecommunications (for the data communication), such as Bluetooth or ZigBee. WPT is an intentional radiator.

The WPT energy transfer function is ISM: Industrial, Scientific, Medical; the data transfer is Short Range Device. CISPR already suggested treating the WPT function separately to the telecommunications function which could be SRD; see section 4.2 of Report ITU-R SM.2303. Depending on national regulations, SRDs usually operate as un-licensed and un-protected ruling.

ITU Radio Regulations provisions Nos. **5.138** and **5.150** define the ISM RF bands. Candidate Short Range Device (SRD) band is different than ISM band. Following Recommendation ITU-R SM.1896 ‘Frequency ranges for global or regional harmonization of short-range devices (SRDs)’ Annexes 1 and 2, practically ISM band is sufficient condition but not obligatory for harmonized SRD operation. All the ISM bands serve short range and electronic devices. However, SRDs operate also at non-ISM bands. The ISM bands may serve WPT for the energy transfer; the SRD bands may potentially serve as preferred RF for national, regional or global WPT use. The following figure depicts the ISM bands in the different ITU Regions and non-ISM candidate bands for SRDs in different Regions. SRDs operate at all ISM RF bands; but also at other RF bands.

FIGURE 11

ISM and non-ISM candidate frequency bands for SRDs*



*_Source_: Mazar, 2016 [12]

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

42-48 kHz

52-58 kHz

79-90 kHz

100-205 kHz

425-524 kHz

The frequency bands assigned or designated under study and key parameters for these applications are summarized in Tables 7 and 8. Concerned incumbent systems for which coexistence is required are also provided in these Tables.

Compatibility with all incumbent systems, especially those operating in safety allocations such as Aeronautical Radio Navigation Service, would need to be studied and fully considered before completing ITU Reports and Recommendations on WPT in these frequency bands: 9-21/59-61 kHz, 79-90 kHz, and 100/110-300 kHz.

i) Magnetic induction

Many products based on magnetic induction technologies have already been introduced in many countries today. The Wireless Power Consortium website indicates that about 150 million transmitters for smartphone charging, following the IEC PAS 63095 Ed1 specification that uses this frequency range at low power (5 W – 15 W), have been sold world-wide as of mid-2017. In addition power tool battery charging by WPT (50 W – 100 W) and kitchen appliances powered by WPT (1 kW – 2 kW), both using magnetic induction technologies, have also been introduced in many countries over the last few years.

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 was examined and demonstrated 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).

WPT for EV while parked has been considered by BWF, IEC, SAE and JARI. It was commonly agreed that the frequency range 20-200 kHz has advantages to achieve high energy transmission efficiency in high power circuit design.

In Japan, 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. Intensive survey of the current spectrum usage in the world was carried out to narrow down candidate spectrums so that possible interference to the existing applications can be minimized. As of May 2015, 79-90 kHz range has been chosen for wireless EV charging. Similarly, SAE International J2954 Task Force agreed on 81.38-90.00 kHz for light duty vehicle WPT.

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.

5.3 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. New rules on the “type specification”, which exempt permission of individual equipment installation application for WPT equipment, allowing transmission power greater than 50 W, came into effect in 2016.

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 7

Frequency ranges assigned or designated, or 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 devices, tablets, note-PCs	Mobile 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: 20.05-38 kHz, 42-58 kHz, 62-100 kHz	
Frequency ranges assigned or designated nationally	Korea: 100-205 kHz	Korea: 6 765-6 795 kHz Japan: 6 765-6 795 kHz		Japan: 425-471 kHz; 480-489 kHz; 491-494 kHz; 506-517 kHz; 519-524 kHz
Power range		Japan: Several W – up to 100 W	Japan: Several W – 1.5 kW	Japan: Up to 100 W

TABLE 7 (*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 (AirFuel Alliance) [4]		
Concerned incumbents for spectrum sharing		Japan: mobile/fixed radio systems Korea: ISM band	Japan: Standard clockradios (40 kHz, 60 kHz) railway safety 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 8

Frequency ranges assigned or designated 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 8 (*end*)

	Magnetic resonance and/or induction for electric passenger vehicles	**Magnetic induction for heavy duty vehicles**
Frequency Range assigned or designated nationally	79-90 kHz	19-21 kHz, 59-61 kHz
Power Range	Up to 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 Global / regional harmonization effort in progress	– 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) ISO PAS 19363 (TC22/SC37) SAE J2954	
Concerned incumbents for spectrum sharing		Korea: 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].

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 3 m. 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 9.

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

TABLE 9

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 10

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)

ii) In Japan

a) Frequency ranges and emission limits

In March 2016, new rules on the "type specification" for WPT mobile devices using 6.78 MHz and those using 400 kHz and those using 79-90 kHz for EVs, with intention transmitting power greater than 50W, became effective. The new rules provide specifications to allow equipment installation without permission. The systems that conform to the "type specification", can be used everywhere. Referenced standards and additional conditions are summarized in Table 11. Emission limits are shown in Tables 12, 13 and 14 in accordance with frequency ranges designated.

In 2015, the Information and Communications Council of MIC completed studies on the impact of every proposed WPT system to incumbent radiocommunications systems. Spectrum use survey was performed first in domestic and global viewpoint. Once candidate frequency ranges has been determined, emission limits not causing harmful interference were derived through WPT performance simulation and measurement executed from Q4 2013 to Q3 2015. In order forWPT performance survey and to provide regulatory compliance requirements, emission measurement models and measurement methodologies were also studied and provided. See Annexes 3 and 4 for details.

In specifying conductive and radiated emission limits, CISPR standards were referenced in light of international regulatory harmonization as shown in Table 11. For some specific use cases against the incumbent spectrum use, additional domestic coexistence conditions were proposed and agreed.

In Japan's regulation, any devices with transmission power not exceeding 50 W do not require a permission by the administrator for operation. The WPT technologies for mobile devices using 6.78 MHz and those using 400 kHz band have been assumed such use cases not exceeding 50 W of transmission power so far. The new rules enable such WPT technologies to increase transmission power greater than 50 W.

TABLE 11

Referenced standards and conditions for specifying emission limits in Japan

Proposed technology	**Conductive emission**		**Radiated emission**			
	9-150 kHz	**150 kHz - 30 MHz**	**9-150 kHz**	**150 kHz - 30 MHz**	**30 MHz – 1 GHz**	**1-6 GHz**
(a) WPT for EVs (3 kW class and 7 kW class)	Not specified for the near term (*1)	CISPR 11 Group 2 (Ed. 5.1)	WG coexistence condition (*1)	CISPR 11 Group 2 (Ed. 5.1) (*4) WG coexistence condition	CISPR 11 Group 2 (Ed. 5.1)	Not specified
(b) WPT for mobile devices using 6.78 MHz (< 100 W)	Not specified as the range does not meet the frequency bands concerned	CISPR 11 Group 2 (Ed. 5.1) (*2) CISPR 32 (Ed. 1.0)	Not specified	CISPR 11 Group 2 (Ed. 5.1) (*2), (*3), (*4) WG coexistence conditions	CISPR 11 Group 2 (Ed. 5.1) (*2) CISPR 32 (Ed. 1.0) WG coexistence conditions	CISPR 32 (Ed. 1.0)
(c) WPT for home/office equipment (< 1.5 kW)	CISPR 14-1 Annex B (Ed. 5.2)	CISPR 11 Group 2 (Ed. 5.1) CISPR 14-1 Annex B (Ed. 5.2)	CISPR 14-1 Annex B (Ed. 5.2) WG coexistence conditions	CISPR 11 Group 2 (Ed. 5.1) (*2), (*3), (*4) CISPR 14-1 Annex B (Ed. 5.2) WG coexistence conditions	CISPR 11 Group 2 (Ed. 5.1) (*2) CISPR 14-1 (Ed. 5.2)	Not specified
(d) WPT for mobile devices 2 (capacitive coupling) (< 100 W)	Not specified as the range does not meet the frequency bands concerned	CISPR 11 Group 2 (Ed. 5.1) (*2) CISPR 32 (Ed. 1.0)	Not specified	CISPR 11 Group 2 (Ed. 5.1) (*2), (*3), (*4) WG coexistence conditions	CISPR 11 Group 2 (Ed. 5.1) (*2) CISPR 32 (Ed. 1.0)	CISPR 32 (Ed. 1.0)

NOTES:

(*1) When specified in CISPR 11 in future, discuss for specification again.

(*2) In case the WPT function device works without the host device, CISPR 11 shall be applied as primary; then the others as secondary.

(*3) Unless otherwise specified on the specific frequency for the use, CISPR 11 shall be applied as primary; then the others as secondary.

(*4) For CISPR 11 Group-2 Class-B, emission limits at 10 m distance is specified based on the emission limit at 3 m distance.

(*5) Class A/B classification is compliant with the CISPR definition.

(*6) For the cases specified as CISPR 32 in (b) and (d), CISPR 32 is applied when necessary as CISPR 32 is appropriate.

TABLE 12

Emission limits for WPT mobile devices using 6.78 MHz (magnetic coupling) in Japan

WPT target application	Conductive emission limits		Radiated emission limits of fundamental wave	Radiated emission limits in other bands			
	9-150 kHz	150 kHz - 30 MHz	6.765-6.795 MHz	9-150 kHz	150 kHz - 30 MHz	30 MHz - 1 GHz	1-6 GHz
(b) WPT for mobile devices using 6.78 MHz	Not specified	0.15-0.50 MHz: Quasi-peak 66-56 dBuV (linearly decreasing with log(f) Average 56-46 dBuV (linearly decreasing with log(f) 0.50-5 MHz: Quasi-peak 56 dBuV, Average 46 dBuV 5-30 MHz: Quasi-peak 60 dBuV, Average 50 dBuV, except ISM bands	6.765-6.776 MHz: 44.0 dBuA/m at 10 m (quasi-peak); 6.776-6.795 MHz: 64.0 dBuA/m at 10 m (quasi-peak)	Not specified	Taking basis on CISPR 11 Ed. 5.1, converting to values at 10 m distance, emission limit linearly decreases with log(f) from 39 dBuA/m at 0.15 MHz to 3 dBuA/m at 30 MHz. Exception-1: 20.295-20.385 MHz: 4.0 dBuA/m at 10 m (quasi-peak). Exception-2: 526.5-1 606.5 kHz: –2.0 dBuA/m at 10 m (quasi-peak)	Taking basis on CISPR 11 Ed. 5.1, the following is applied:30-80.872 MHz: 30 dBuV/m; 80.872-81.88 MHz: 50 dBuV/m; 81.88-134.786 MHz: 30 dBuV/m; 134.786-136.414 MHz: 50 dBuV/m; 136.414-230 MHz: 30 dBuV/m; 230-1 000 MHz: 37 dBuV/m In the case CISPR 32 (Ed. 1.0) should be applied, the limits at 3 m in Table A.5 is applied. Exception: 33.825-33.975 MHz: 49.5 dBuV/m at 10 m (quasi-peak)	In the case CISPR 32 (Ed. 1.0) (1) should be applied, the limits at 3 m in Table A.5 of (1) is applied

TABLE 13

Emission limits for WPT mobile devices using 400 kHz band (capacitive coupling) in Japan

WPT target application	**Conductive emission limits**		**Radiated emission limits of fundamental wave**	**Radiated emission limits in other bands**			
	9-150 kHz	**150 kHz - 30 MHz**	**425-471 kHz; 480-489 kHz; 491-494 kHz; 506-517 kHz; 519-524 kHz**	**9-150 kHz**	**150 kHz - 30 MHz**	**30 MHz - 1 GHz**	**1-6 GHz**
(d) WPT for mobile devices using 400 kHz band (capacitiv e coupling)	Not specified	0.15-0.50 MHz: Quasi-peak 66-56 dBuV (linearly decreasing with log(f) Average 56-46 dBuV (linearly decreasing with log(f) 0.50 5 MHz: Quasi-peak 56 dBuV, Average 46 dBuV 5-30 MHz: Quasi-peak 60 dBuV, Average 50 dBuV, except ISM bands	Taking basis on CISPR 11 Ed. 5.1, converting to values at 10 m distance, emission limit linearly decreases with log(f) from 39 dBuA/m at 0.15 MHz to 3 dBuA/m 30 MHz	Not specifie d	Taking basis on CISPR 11 Ed. 5.1, converting to values at 10 m distance, emission limit linearly decreases with log(f) from 39 dBuA/m at 0.15 MHz to 3 dBuA/m at 30 MHz. Exception: 526.5 kHz – 1 606.5 kHz: –2.0 dBuA/m at 10 m (quasi-peak) is applied	Taking basis on CISPR 11 Ed. 5.1, the following is applied: 30-80.872 MHz: 30 dBuV/m; 80.872-81.88 MHz: 50 dBuV/m; 81.88-134.786 MHz: 30 dBuV/m; 134.786-136.414 MHz: 50 dBuV/m; 136.414-230 MHz: 30 dBuV/m; 230-1 000 MHz: 37 dBuV/m In the case CISPR 32 (Ed. 1.0) should be applied, the limits at 3 m in Table A.5 is applied	In the case CISPR 32 (Ed. 1.0) (1) should be applied, the limits at 3 m in Table A.5 of (1) is applied

TABLE 14

Emission limits for WPT for EV applications in Japan

WPT target application	**Conductive emission limits**		**Radiated emission limits of fundamental wave**	**Radiated emission limits in other bands**			
	9-150 kHz	**150 kHz - 30 MHz**	**79-90 kHz**	**9-150 kHz**	**150 kHz - 30 MHz**	**30 MHz - 1 GHz**	**1-6 GHz**
WPT for EV charging	Not specified	0.15-0.50 MHz: Quasi-peak 66-56 dBuV (linearly decreasing with log(f) Average 56-46 dBuV (linearly decreasing with log(f), 0.50-5 MHz: Quasi-peak 56 dBuV, Average 46 dBuV 5-30 MHz: Quasi-peak 60 dBuV, Average 50 dBuV, except ISM bands	68.4 dBuA/m at 10 m. (quasi-peak)	23.1 dBuA/m at 10 m. (quasi-peak), except 79-90 kHz	Taking basis on CISPR 11 Ed. 5.1, converting to values at 10 m distance, linearly decreasing with log(f) from 39 dBuA/m at 0.15 MHz to 3 dBuA/m at 30 MHz (1). Exception-1: For 158-180 kHz, 237-270 kHz, 316-360 kHz, and 3 965-450 kHz, emission limits is higher than (1) above by 10 dB. Exception-2: For 526.5-1 606.5 kHz, –2.0 dBuA/m (quasi-peak)	Taking basis on CISPR 11 Ed. 5.1, the following is applied: 30-80.872 MHz: 30 dBuV/m; 80.872-81.88 MHz: 50 dBuV/m; 81.88-134.786 MHz: 30 dBuV/m; 134.786-136.414 MHz: 50 dBuV/m; 136.414-230 MHz: 30 dBuV/m; 230-1 000 MHz: 37 dBuV/m	Not specified

b) RF exposure assessment

In Japan, the Radio-Radiation Protection Guidelines (RRPG) is applied to conformity assessment on RF exposure to human bodies from the WPT systems. The RRPG provides recommended guidelines used when a person uses radio waves and whose body is exposed to an electromagnetic field (in a frequency range of 10 kHz through 300 GHz) to ensure that the electromagnetic field is safe without producing an unnecessary biological effect on the human body. These guidelines consist of numeric values related to electromagnetic strength, the method of evaluating the electromagnetic field, and the protection method to reduce electromagnetic field irradiation.

The guideline-values applied to the WPT systems are of the administrative guidelines in the RRPG of the general environment in a state when electromagnetic field exposure to the human body cannot be recognized, appropriate control cannot be expected, and uncertain factors exist. For example, the state where residents are exposed to the electromagnetic field in general residential environment falls under this case.

However, in the case a human body is located within 20 cm from the WPT system operating in the frequency range of 10 kHz to 100 kHz, for which the partial body absorption guidelines cannot be applied, the basic guidelines in the RRPG is applied.

The basic guidelines do not discriminate the general environment and the professional environment; therefore, in case of applying the general guidelines, the values counting safety factor of 1/5 ($1/\sqrt{5}$ in electromagnetic field strength and electric current density) which is applied in the administrative guidelines.

Assessment methodology provides the assessment Patterns to perform conformity assessment to the RRPG which provides the guideline values and the guidelines. An assessment Pattern is defined by the combination of the following parameters. Each target WPT technology (e.g. WPT using 6.78 MHz WPT for mobile, WPT for EVs) has independent assessment Patterns.

1) Possibility of human body located < 20 cm from the WPT system or located between the transmitting and receiving coils.
2) Contact hazard protection.
3) Ungrounded condition,
4) Whole body average SAR.
5) Partial body SAR.
6) Induced current density.
7) Contact current.
8) Outer electric field, and
9) Outer magnetic field.

The simplest assessment Pattern of all the target WPT technologies consists of 8) and 9) above, which is the minimum number combination of the parameters. In the evaluation, this simplest pattern is assumed to derive the worst (maximum) radio wave energy absorption to the human body. In other words, much larger excess RF exposure than actual exposure value to the human body is estimated; and then the assessment would result in much lower allowable emission power from the WPT system.

The other Patterns consist of more number of the parameters. As the number of the adopted parameters increases, assessment methodology requires more detailed evaluation, which results in more accurate RF exposure estimation. Some patterns prepared for detailed assessment apply a coupling factor which is multiplied with the measured maximum magnetic field strength to confirm that RF exposure is less than the guideline values. Derivation of a coupling factor is also provided.

If one demonstrated conformity of a system using one of the target WPT technologies to the guideline values is defined in any one of the patterns, the system is deemed conforming to the RRPG.

If a new assessment methodology which is intended for an assessment is qualified by appropriate engineering approaches in the future or it can prove an improvement in the applicable assessment methodologies as appropriate, it can be applied for this purpose.

Noting at the end of this section, for the RRPG, ICNIRP 2010 guideline has been agreed for adoption for low frequency ranges. Hence, human exposure should be qualified for exposure quantities to prevent nerve stimulation in addition to prevent tissue heating on SAR for in 100 kHz to 10 MHz frequency range.

iii) In China

This section provides classification and regulation analysis on WPT device in current Chinese radio regulation system with regard to WPT device and WPT wireless communication part according to the definition, frequency range and restriction of different radio devices.

a) Classification and regulation analysis on WPT device

China does not have official WPT regulations. Currently, only the SRD regulation covers all the WPT frequency bands. Therefore, in order to protect the incumbent radio communication systems, WPT device has to go through a market entrance test which is the same as SRD market entrance test. However, it is not appropriate to regulate WPT devices as SRD in the long term. Hence, the classification and regulation research of WPT is done as follows. As the research is in the early phase, different regulation and classification methods are not excluded.

a-1) ISM device

a-1-1) Analysis from frequency range and definition perspectives

In Chinese radio regulation system, ISM device is defined as: the equipment or apparatus using RF energy for industrial, scientific, medical, household and similar purpose, which does not include the equipment used in telecommunication, information technology and other national standards. WPT device is the equipment used in household or industrial field to using RF energy. Therefore, WPT device can be put under ISM device.

According to Chinese ISM regulations [10], ISM devices are divided into two groups based on their applications: (1) all the ISM devices which produce and/or use conductively coupled RF energy intentionally for playing its own function; (2) all the ISM devices, including EDM and arc welding equipment, which produce or use electromagnetic RF energy intentionally to treat material. In addition, each group is divided into two categories according to their application scenarios: (A) the ISM devices which are not used in house or are not directly connected to residential low-voltage power facilities; (B) the ISM devices which are used in house or are directly connected to residential low-voltage power facilities.

According to Chinese ISM regulations [10], which is equivalent to CISPR 11:2003, whether the WPT frequency range, 6.675-6.795 MHz, belongs to the scope of ISM frequency range or not needs a special permission from Chinese radio regulatory agency. Nevertheless, the other WPT frequency ranges do not belong to the scope of ISM frequency range.

Hence, based on the analysis above, if the permission is available, the WPT device working in 6.675-6.795 MHz band belongs to the B category of group 2 ISM device.

a-1-2) Analysis from restriction perspective

According to Chinese ISM regulations [10], the in band transmission power restriction of ISM device working in 6.675-6.795 MHz band is under consideration. Furthermore, its spurious radiation needs to satisfy the electromagnetic radiation disturbance restriction shown in Table 15.

TABLE 15

The electromagnetic radiation disturbance restriction of the B category of group 2 ISM device

Frequency range/MHz	Disturbance restriction of the B category of the group 2 ISM device/dB(µV/m) (measured at 10 m)
0.15-30	–
30-80.872	30
80.872-81.848	50
81.848-134.768	30
134.768-136.414	50
136.414-230	30
230-1 000	37

(China’s ISM standard, GB 4824-2004, is equivalent to CISPR 11:2003. Group 1 is for ISM equipment that generated and/or used conductively coupled radio-frequency energy. Group 2 is ISM equipment in which radio-frequency energy is intentionally generated and/or used in the form of electromagnetic radiation)

Based on the analysis above, if the permission is available, the WPT devices working in 6.675-6.795 MHz band can be administered in accordance with the B category of group 2 ISM device in China. Moreover, the WPT working in other frequency bands cannot be administered in accordance with ISM equipment according to current Chinese radio regulation.

a-2) Short Range Device (SRD)

a-2-1) Analysis from frequency range and definition perspectives

In Chinese radio regulation system [11], SRD has 7 categories from the A category to the G category. Among them, the working frequency bands of the categories from A to D are below 30 MHz. The frequency band of the A category is 9-190 kHz. The frequency bands of the B category and WPT working frequency bands do not overlap. The frequency bands of the C category include 6.675-6.795 MHz. The D category, whose working frequency band is 315 kHz – 30 MHz, includes all the SRD except the A category, the B category and the C category. Hence, all the WPT working frequency bands except 190-205 kHz band belong to the frequency range of SRD. Furthermore, the frequency band of the first generation WPC’s WPT device is partial beyond the scope of the category A SRD’s frequency band. Therefore, in frequency standpoint, all the WPT devices are in the scope of SRD except the WPT device working in 190-205 kHz band.

There is no definition of SRD in existing Chinese radio regulation system. Nonetheless, the existing administration regulation [11] was established for general micro-power (short range) radio transmitting equipment. The power transfer of WPT device does not belong to the category of radio emission. The vast majority of power is transmitted to receiver through coupling, induction and other technologies, rather than radiating energy to the wireless space. Therefore, in definition perspective, WPT device does not belong to the scope of SRD.

In terms of the impact of wireless signal on environment, WPT device can be administrated temporally in accordance with SRD regulation method. This administration method can make sure that the impact of WPT device on wireless environment does not exceed the impact of SRD in corresponding frequency band. But in the long term, it is not suitable to administrate WPT device in accordance with SRD.

a-2-2) Analysis from restriction perspective

According to the regulation [6], SRD only has to satisfy the magnetic field strength limit. The magnetic field strength limit of the category A SRD, the category C SRD and the category D SRD are shown in Table 16.

TABLE 16

The magnetic field strength limit of the category A SRD, the category C SRD and the category D SRD

Category	Corresponding frequency band of WPT devices	Magnetic field strength restriction (10 m)
The category A SRD	9-190 kHz The frequency band of the first generation WPC's WPT device is partial beyond the scope of the category A SRD's frequency band	72 dBµA/m
The category C SRD	6 765-6 795 kHz	42 dBµA /m
The category D SRD	425-524 kHz	–5 dBµA /m

a-3) The result of analysis on WPT device classification and administration regulation

In conclusion, if the permission is available, the WPT devices working in 6.675-6.795 MHz band can be administered in accordance with the B category of group 2 ISM device, and the WPT devices working in other band can be administered in accordance with SRD temporally. In the long term, it is necessary to allocate WPT frequency band as soon as possible and formulate the EMC technical specifications of WPT device.

b) Analysis on wireless communication part of WPT device

Before power transfer, in order to make sure the secondary WPT device exist, the primary WPT device needs to realize the handshake process through wireless communication. This communication process has short range, short time and micro power characteristics, which are in accordance with the characteristic of SRD communication. Hence, if the working frequency band of the wireless communication part of WPT device is in the scope of SRD, it is regulated as SRD.

7 Status of impact studies between WPT and radiocommunication services, including the radio astronomy service

7.1 Study results and ongoing activities in some administrations

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 designation or assignment of frequencies for WPT.

Figures 12 and 13 show the WPT spectrum designated or 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. Table 17 shows spectrum use of incumbent wireless systems below 1.6 MHz, which should be considered in impact studies for WPT systems for EVs.

TABLE 17

Spectrum use of incumbent wireless systems

<table>
<tr><th colspan="2">Radio systems</th><th>Frequency bands</th><th>Communication technologies</th><th>Remarks</th></tr>
<tr><td colspan="2">Standard frequency and time signal service</td><td>19.95 kHz – 20.05 kHz (20 kHz, Global)
39 kHz – 41 kHz (40 kHz, Japan)
49.25 kHz – 50.75 kHz (50 kHz, Russia)
59 kHz – 61 kHz (60 kHz, UK, US and Japan)
65.85 kHz – 67.35 kHz (66.6 kHz, Russia)
68.25 kHz – 68.75 kHz (68.5 kHz, China)
74.75 kHz – 75.25 kHz (75 kHz, Switzerland)
77.25 kHz – 77.75 kHz (77.5 kHz, Germany)
99.75 kHz – 102.5 kHz (100 kHz, China)
128.6 kHz – 129.6 kHz (129.1 kHz, Germany)
157.5 kHz – 166.5 kHz (162 kHz, France)</td><td>Amplitude modulation (BCD)</td><td>The clocks and watches that periodically receive digital signals of the standard time transmitted from the standard-time-signal transmitting stations to synchronize and adjust own time.</td></tr>
<tr><td colspan="2">Ripple Control Service</td><td>128.6 kHz – 129.6 kHz
(129.1 kHz, Europe)
138.5 kHz – 139.5 kHz (139 kHz, Europe)</td><td>–</td><td>Load/demand management system for power plants and their electric power network</td></tr>
<tr><td rowspan="4">Train radio systems</td><td rowspan="2">Automatic Train Stop Systems (ATS) Systems</td><td>10 kHz – 250 kHz (Japan)</td><td rowspan="2">–</td><td rowspan="2">Telecommunication system that applying electric current to coils installed along with railroad track and detects electric current carried through coils which are installed on train vehicles on the rail to control trains.</td></tr>
<tr><td>425 kHz – 524 kHz (Japan)</td></tr>
<tr><td rowspan="2">Inductive Train Radio Systems (ITRS)</td><td>100 kHz – 250 kHz (Japan)</td><td rowspan="2">–</td><td rowspan="2">Signal transmission system which uses inductive coupling between transmission line which is installed along with the railroad track and so forth and antenna that is installed on train vehicles.</td></tr>
<tr><td>80 kHz, 92 kHz (Japan, only one station)</td></tr>
</table>

TABLE 17 (*end*)

Radio systems	Frequency bands	Communication technologies	Remarks
Amateur radio	135.7 kHz – 137.8 kHz	Amplitude modulation, frequency modulation, SSB etc.	Radio service with transmitter and receiver devices used for technology research and training of amateur radio operators.
	472 kHz – 479 kHz		
Maritime radio	90 kHz – 110 kHz (LORAN)	Pulse, FSK etc.	Radio system that secures safety of vessel operation which is used at port and harbor or on the sea.
	424 kHz, 490 kHz, 518 kHz (NAVTEX)		
	495 kHz – 505 kHz (NAVDAT)		
Sound broadcast	148.5 kHz – 283.5 kHz (Region 1) 525 kHz – 526.5 kHz (Region 2) 526.5 kHz – 1606.5 kHz (Global) 1605.5 kHz – 1705 kHz (Region 2)	Amplitude modulation/DRM	Audio broadcasting service with receiver devices which use medium wave band.

FIGURE 12

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

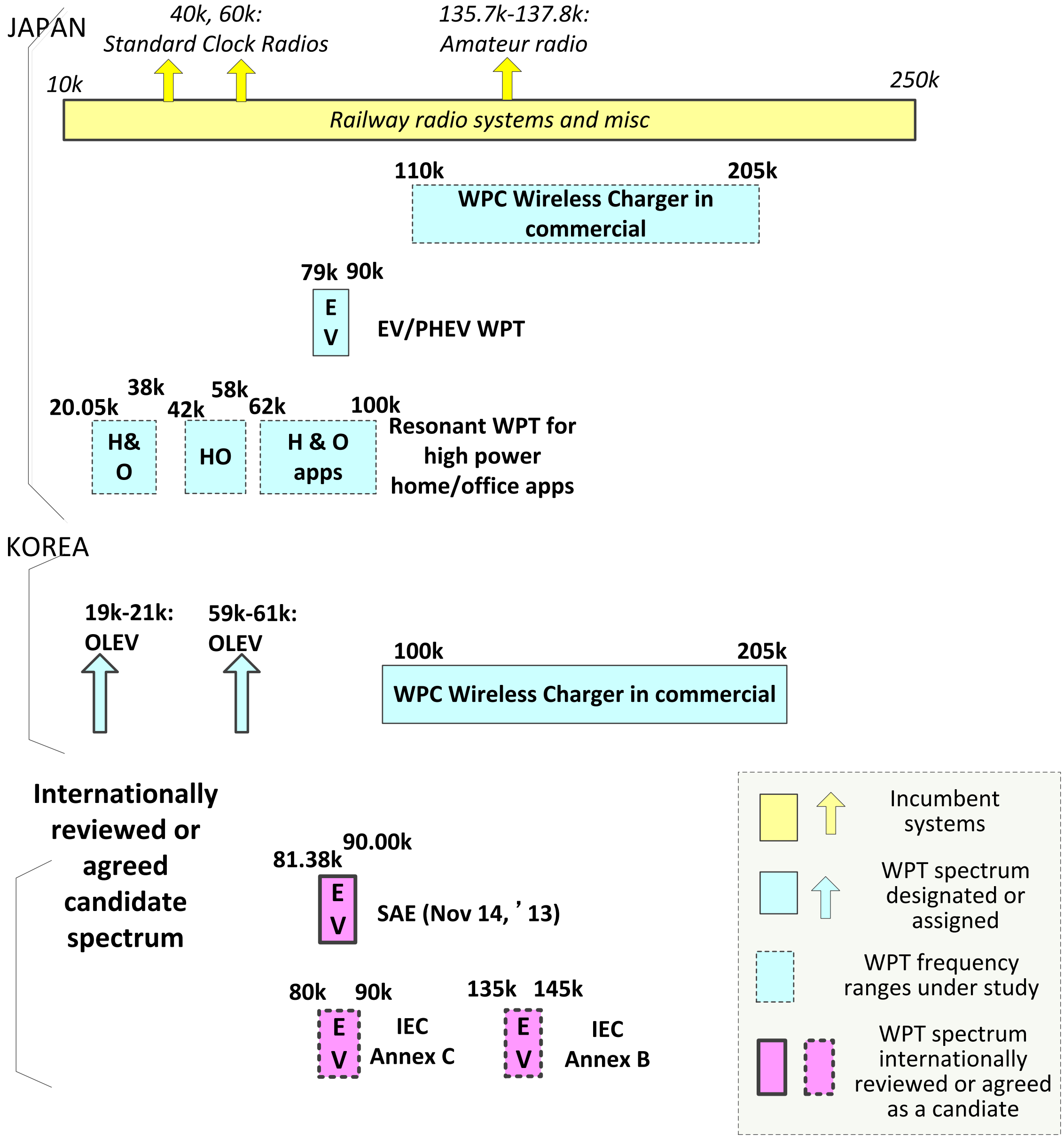
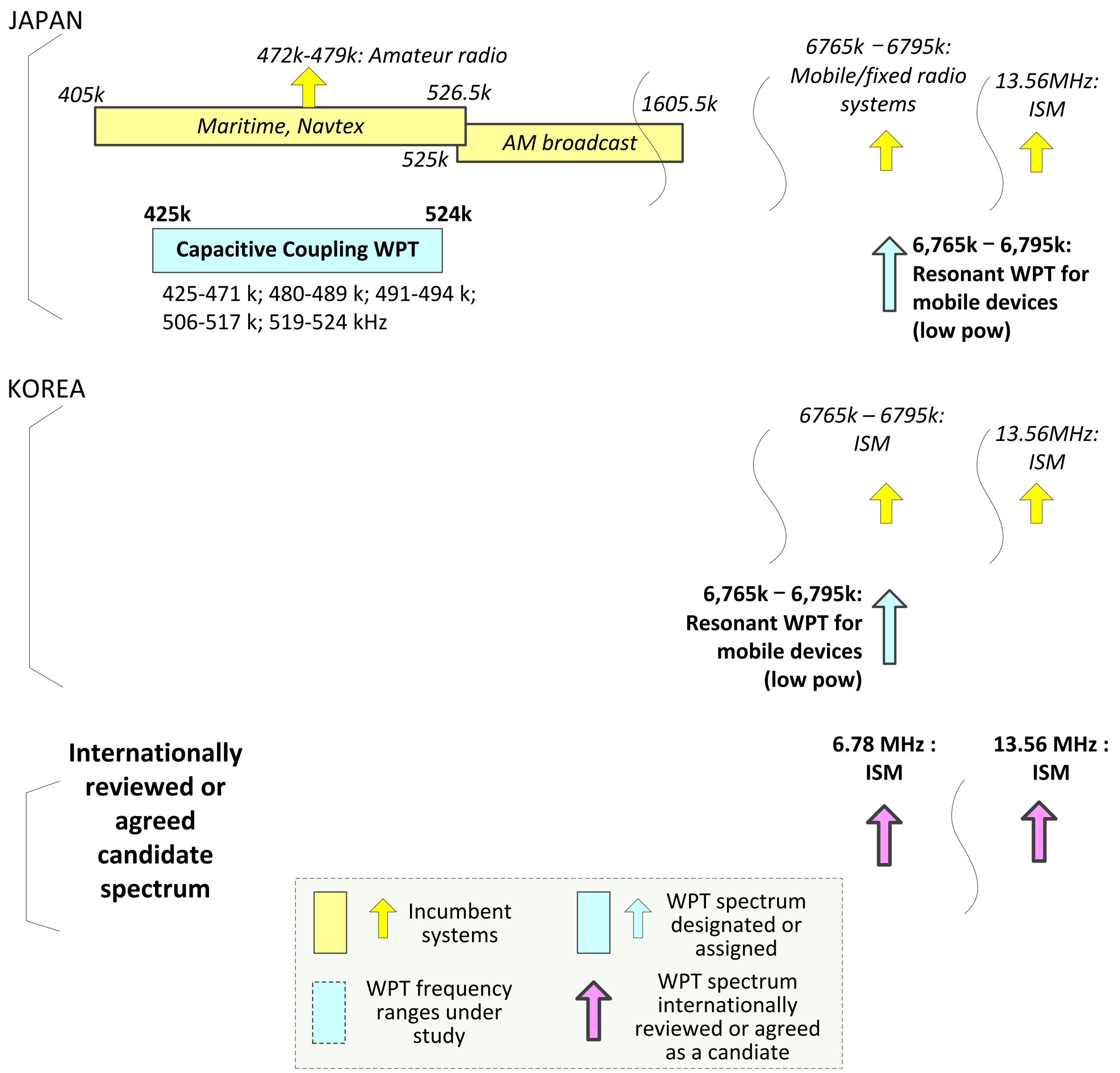


FIGURE 13

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



In China, different kinds of high power WPT devices have been invented, which include WPT for home appliance operating frequency ranges of 47-53 kHz and WPT for light and heavy duty vehicles operating working frequency ranges of 37-43 kHz and 82-87 kHz. Facing the market requirement, sufficient coexistence research before relevant frequency planning is urgent and necessary. Considering current national frequency planning, the wireless communication system which has been put into practice and other wireless communication requirements, the coexistence studies including dedicated frequency band, shared frequency band, separation distance and so on are ongoing. CCSA TC5 WG8 will initiate a new project to study the coexistence issues of WPT with incumbent radio-communication systems in 2015. Partial research results will be completed in 2016.

In Japan, target WPT systems and candidate proposed frequency ranges with fundamental parameters were summarized as shown in Table 18.

TABLE 18

WPT technologies considered in Japan MIC WPT Working Group 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
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.

7.1.1 Japan

For spectrum sharing and coexistence studies, the WPT-Working Group (WG) under MIC's Committee on Electromagnetic Environment for Radio-wave Utilization picked up many possible and practical combinations of the incumbent radio systems and the target WPT systems which might cause a harmful interference event in specific use cases. In such an event, the fundamental WPT radio wave may fall in the same spectrum of the incumbent radio systems when located within the minimum required separation distance from the WPT device or when an appropriate power attenuation measure is not taken. In another case, a WPT harmonic wave might fall into the spectrum of the incumbent radio system to cause degradation of signal quality at the incumbent radio receiver. Seeing varieties of concerned events, the WG defined the worst case conditions to assess the impact of WPT. Usage scenarios have been reviewed; and then, simulations and field experiments have been performed. The coexistence conditions, which gives a criteria of the use of a WPT system together with the incumbent systems, were defined by the WG based on the current receiver sensitivities and actual use cases assumed.

In December 2014, 6.78 MHz magnetic coupling WPT and capacitive coupling WPT demonstrated coexistence in the defined conditions.

6.78 MHz magnetic coupling WPT device coexistence with the public radio systems using small frequency segments in the range of 6.765-6.795 MHz were assessed. The maximum transmission power of 100 W was assumed. Specific emission limits (see Table 12) were derived and specified per a small segment in the range to meet coexistence requirements.

Capacitive coupling WPT device coexistence was assessed by theoretical calculation and field experiments. The results showed much lower magnetic emission strength than the emission limit requirement to coexist with the concerned incumbents. Accordingly, coexistence of a capacitive coupling WPT device with transmission power less than 100 W was proved. It should be noted that, however, frequency ranges used for maritime radio devices and amateur radio devices were excluded from the candidate operation frequency ranges as international spectrum usage is taken into consideration.

Another magnetic coupling WPT technology using kHz range for home appliance has still not demonstrated coexistence for all the defined test cases in the assessment.

WPT for EV applications using 79-90 kHz demonstrated coexistence with standard clock radio devices, AM broadcast devices, and Amateur radios. Those using the other candidate frequency ranges than 79-90 kHz have still not met with the requirements. Thus, candidate frequency ranges for EV have converged to 79-90 kHz.

The WG performed further assessment to prove coexistence with railway wireless systems, namely Automatic Train Stop Systems (ATS) deployed all over the railway networks in Japan and Inductive Train Radio Systems (ITRS) for very specific actual use cases. The WG finally agreed on the technical requirements on coexistence with railway wireless systems.

As a result of coexistence studies, Japan would like to add emphasis to global attention to coexistence study with railway wireless systems in particular ATS. Today, ATS is operated around 100 kHz and is deployed not only in the Japanese railway network but also in many countries and regional railway networks of the globe. In the future, it may happen that many countries deploying ATS face the same issue to prove coexistence with WPT systems to ensure the safety of the passengers. This study should be taken into global consideration, not in a country specific approach. Japan believes that ITU-R is invited to take action on this study in collaboration with CISPR.

Railway wireless systems by electro-magnetic control mechanism are absolutely crucial for secure operation. Robustness of the systems against unwanted radio waves is a critical measure and may have independent characteristics from one by one. Accordingly, coexistence criteria for the systems differs from one country or one region to another. Therefore, emission limits to specify in CISPR should take account of such variety and reliability of the systems.

The WG concluded that WPT systems for EVs in the frequency range of 79-90 kHz for 3 kW and 7.7 kW power classes can be used without causing harmful interference to the selected incumbent systems and services under practical conditions. The new rules of WPT systems for EVs, 6.78 MHz magnetic coupling WPT and capacitive coupling WPT, were published and put into force in March, 2016.

Table 19 (A), (B), (C) and Table 20 summarize results of coexistence studies.

TABLE 19

Summary of WPT for mobile and home appliance coexistence study results in Japan

(A) Coexistence with Standard Clock Radio Devices, Automatic Train Stop Systems and Inductive Train Radio Systems

<table>
<tr><th colspan="2">WPT for mobile and home appliances</th><th colspan="3">Incumbent systems</th></tr>
<tr><th>Technologies</th><th>Candidate frequency ranges</th><th>Standard Clock Radio Devices (SCRD) (*1)
(40 kHz, 60 kHz)</th><th>ATS (*2)
(10-250 kHz)</th><th>ITRS (*3)
(10-250 kHz)</th></tr>
<tr><td>Magnetic coupling (low power for mobile devices)</td><td>6.765-6.795 kHz</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td rowspan="3">Magnetic coupling (low-high power for home appliances)</td><td>20.05-38 kHz</td><td rowspan="3">Meets coexistence conditions with the notes below:
• The 2nd and 3rd harmonics shall not fall in the SCRD operation bands.
• Inviting users’ attention to the possibility of interference to the SCRDs</td><td rowspan="3">Further assessment necessary for coexistence.
• Need to derive required separation distance not to cause harmful interference</td><td>Meets coexistence conditions</td></tr>
<tr><td>42-58 kHz</td><td>Meets coexistence conditions</td></tr>
<tr><td>62-100 kHz</td><td>Further assessment necessary.
• Need to derive required separation distance not to cause harmful interference</td></tr>
<tr><td>Capacitive Coupling (low power for mobile devices)</td><td>425-524 kHz</td><td>N/A</td><td>Meets coexistence conditions by reducing magnetic field strength by 12 dB achieved</td><td>N/A</td></tr>
</table>

Coexistence conditions in assessment:

(*1) Standard clock radio devices: WPT devices shall not cause harmful interference in simulated use cases.

- 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.
- 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.

(*2) (*3) ATS and ITRS: WPT devices shall not cause harmful interference in the actual use cases in operation. The criteria for coexistence are:

- WPT frequency band should not be overlapped with those used for the train signalling communication systems including ATS, or
- The separation distance to the ATS/ITRS devices, in which a WPT device does not cause harmful interference, should be less than the most critical threshold (approx. 1.5 m) specified in the train systems building standards.
- Above shall be met with all types of railways building layout in Japan.

(B) Coexistence study with AM broadcast and Maritime radio devices

<table>
<tr><th colspan="2">WPT for mobile and home appliances</th><th colspan="2">Incumbent systems</th></tr>
<tr><th>Technologies</th><th>Candidate frequency ranges</th><th>AM broadcast (*1)
(526.5-1 606.5 kHz)</th><th>Maritime radio devices (*2)
(405-526.5 kHz)</th></tr>
<tr><td>Magnetic coupling (low power for mobile devices)</td><td>6.765-6.795 kHz</td><td>N/A</td><td>N/A</td></tr>
<tr><td rowspan="3">Magnetic coupling (low-high power for home appliances)</td><td>20.05-38 kHz</td><td rowspan="3">Not meet coexistence conditions as found required separation distance far exceeding 10 m as the target requirement</td><td>N/A</td></tr>
<tr><td>42-58 kHz</td><td>N/A</td></tr>
<tr><td>62-100 kHz</td><td>Meets coexistence conditions with the following
• Avoiding the use of WPT systems emitting power in the LORAN-C frequency range (*3)</td></tr>
<tr><td>Capacitive coupling (low power for mobile devices)</td><td>425-524 kHz</td><td>Meets coexistence conditions with the following notes.
• Inviting users’ attention to the possibility of interference to the AM radio devices.
• If harmful interference observed, WPT devices shall take appropriate measures</td><td>Meets coexistence conditions with the following.
• Avoiding the use of WPT systems emitting power in the frequency ranges of NAVTEX and NAVDAT</td></tr>
</table>

Coexistence conditions in assessment:

(*1) AM Broadcast: A WPT device shall not cause harmful interference to an AM broadcast receiver at least 10 m distance based on the CISPR residential environment. Multiple number of WPT devices and an indoor AM-radio receiver is assumed in the system model. Field tests were performed in agreed worst use case conditions with variables of frequencies, number of WPT devices, separation distances, and high and low background city noise level areas. CISPR 11 Group 2 Class-B was referred as well.

(*2) Maritime radio devices: A WPT device shall not cause harmful interference. Assessment showed that the proposed WPT system 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, the same frequencies have been deleted for the use. (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) LORAN-C, eLORAN (90-100 kHz): Maritime radiocommunication operators commented that this spectrum should not be arranged for the use of WPT.

(C) Coexistence Amateur radio devices and Public radio systems

WPT for mobile and home appliances		Incumbent systems	
Technologies	**Candidate frequency ranges**	**Amateur radio devices (*1) (135.7-137.8 kHz, 472-479 kHz)**	**Public radio systems (*2) (6,765-6,795 kHz)**
Magnetic coupling (low power for mobile devices)	6.765-6.795 kHz	Meets coexistence conditions with the following • Avoiding the use of WPT systems transmitting power in the amateur radio frequency ranges	Meets coexistence conditions with specific emission limits provided
Magnetic coupling (low-high power for home appliances)	20.05-38 kHz		NA
	42-58 kHz		NA
	62-100 kHz		NA
Capacitive coupling (low power for mobile devices)	425-524 kHz		NA

Coexistence conditions in assessment:

(*1) Amateur radio devices: For capacitive coupling, 472-479 kHz band is an in-band case (sharing the same spectrum). For amateur radios, no official interference level requirements or rules from other systems are found. However, an agreement was to exclude this band allocated to Amateur Radios in the WPT operation frequency range and to set appropriate frequency offset.

(*2) Public radio systems: 6 765-6 795 kHz is not designated as an ISM band in Japan. However, the regulations' provisions allow the use for WPT applications in the band. New emission limits for WPT products in this band have been agreed, which may allow coexistence with the incumbent systems and higher transmission power in this band.

TABLE 20

Summary of WPT for EV coexistence study results in Japan

<table>
<tr><th>WPT for EV</th><th colspan="5">Incumbent systems</th></tr>
<tr><th>Candidate frequency ranges</th><th>SCRD (*1) (40 kHz, 60 kHz)</th><th>ATS (*2) (10-250 kHz)</th><th>ITRS (*3) (10-250 kHz)</th><th>AM broadcast (*4) (526.5-1 606.5 kHz)</th><th>Amateur radio devices (*5) (135.7-137.8 kHz)</th></tr>
<tr><td>42-48 kHz</td><td>Not meet coexistence conditions</td><td>Not assessed since another condition did not meet</td><td>Meets coexistence conditions</td><td rowspan="4">Meets coexistence conditions with the following notes.
• Inviting user's attention to the possibility of interference to AM broadcast radio receivers.
• If harmful interference observed, WPT devices shall take appropriate measures</td><td rowspan="4">Meets coexistence conditions with the following note.
• Avoiding the use of WPT systems transmitting power in the amateur radio frequency ranges</td></tr>
<tr><td>52-58 kHz</td><td>Not meet coexistence conditions</td><td>Not assessed since another condition did not meet</td><td>Meets coexistence conditions</td></tr>
<tr><td>79–90 kHz</td><td rowspan="2">Meets coexistence conditions with the following note.
• Inviting user's attention to the possibility of interference to Standard Clock radio devices</td><td>Meets coexistence conditions with the following requirement.
• Minimum separation distance from the rail of 4.8 m shall be kept</td><td>Meets coexistence conditions with the following requirement.
• Minimum separation distance from the rail of 45 m shall be kept.
• Only one rail track operation uses 80 kHz and 92 kHz where this technical requirement shall be applied</td></tr>
<tr><td>140.91-148.5 kHz</td><td>Not assessed since another condition did not meet</td><td>Not meet coexistence conditions</td></tr>
</table>

TABLE 20

Notes to Table 20:

Coexistence conditions in assessment

(*1) Standard clock radio devices: WPT devices shall not cause harmful interference defined by *C*/*I* ratio derived from the minimum receiver sensitivity of the Standard clock radio devices in agreed use cases. Separation distance of 10 m was used as a coexistence criterion. Additional measures on operation time non-overlapping between WPT and Standard clock radio, radio propagation direction variation, and possible performance improvement were taken into consideration.

(*2) (*3) ATS and ITRS: WPT devices shall not cause harmful interference in the actual use cases in operation. The criteria for coexistence is: (i) WPT frequency band should not be overlapped with those used for the train signaling communication systems including ATS, or (ii) The separation distance to the ATS/ITRS devices, in which a WPT device does not cause harmful interference, should be less than the most critical threshold (approx. 1.5 m) specified in the train systems building standards. These (i) and (ii) shall be met with all types of railways building layout in Japan.

(*4) AM Broadcast: A WPT device shall not cause harmful interference to an AM broadcast receiver at least 10 m distance based on the CISPR residential environment. Field test by WPT transmitter and receiver on a mock wagon was performed in agreed worst use case conditions in which WPT's 7th harmonics of *Fc* = 85.106 kHz falls into 594 kHz AM broadcasting service channel covering wide area of Kanto-region of Japan. Hearing assessment was performed as well.

(*5) Amateur radio devices: This is an out-band case (not sharing the same spectrum). Candidate frequency ranges for WPT for EVs have 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. 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 radio devices.

7.1.2 Korea

In Korea, it uses 19-21 kHz and 59-61 kHz for heavy-duty vehicle WPT system since 2009. The power level is around 100 kW for charging wirelessly electric buses. From 2011, Korea supplies expansion to variable regional cities such as Seoul (Seoul Grand Park shuttle bus), Daejeon (KAIST shuttle bus), Sejong (New administrative intra-city bus) and Gumi city (Industrial complex intra-city bus) and so on. In addition, Korea government has distributed the frequency band (19-21 kHz and 59-61 kHz) to frequency application equipment included WPT (Wireless Power Transfer) technology in May, 2011 and has supported the relevant impact study to protect preexistence frequency resource and/or frequency services of adjacent band.

The test result based on the already proposed measurement method under real operating sites is shown in Annex 4. This result of Annex 4 indicates the *in-situ* test output under every 10 m, 30 m, 50 m and 100 m from the fixed bus-charging station (around 100 kW).

In addition, Impact Study for Japan's 60 kHz Radio clock and EBU LF band (148.5-283.5 kHz) is also reported to same condition under real commercial sites.

In conclusion, it is so hard to detect direct correlation interferences between the fixed heavy-duty WPT system and Japanese radio clock, EBU LF band in the case of far-away 100 m distance. This 100 m means a traditional measurement technic of electric field and it also refers the Radio law to protect any other frequency services. Therefore, it must adhere strictly to the separation distance if it uses the fixed high power WPT system.

In Annex 5, Korean mobile WPT devices in the frequency range100-300 kHz are specified as one of weak electromagnetic field strength devices according to the Radio Waves Act. To launch WPT devices using 100-300 kHz into the Korean market, products have to comply with the corresponding regulatory requirements to prevent any harmful interference with other systems. Essentially, any WPT frequency including 100-300 kHz will be allowed as long as it meets the regulatory requirements as a weak electromagnetic filed strength device except for some specific prohibited frequencies.

Annex 5 provides the measured data of electromagnetic radiation disturbance from the WPT system for mobile devices using magnetic induction technology and its compliance to the European standards and CISPR 11 requirements as well as Korea regulations.

7.1.3 Germany

Germany performed measurements on a WPT system for the charging of cars in an anechoic chamber and provided the results in January 2016. The field strength of the WPT system operated at 85 kHz was measured in the range 20 kHz up to about 1.5 MHz and compared with the limits in ETSI EN 300 330-1 for inductive SRDs.

The measurements done in different polarization planes, only the plane with maximum emissions is considered. To allow direct comparison with the limits in ETSI EN 300 330, only the measurement results for 10 m distance are taken into account, because this is the normative distance defined in that standard.

The measurement results at 10 m distance show the following:

– In general, the spurious emissions are slightly higher when the vehicle is not positioned exactly over the centre of the charging coil (max offset). The difference, however, is less than the difference when considering different measurement directions (front/back/left/right).
– Spurious emission levels are generally higher to the front and back than sideways.
– The field strength (carrier power) inside the used channel is around 71 dBuA/m (no offset) to 75 dBuA/m (max offset). This exceeds the limits of ETSI EN 300 330-1 by 4 and 8 dB respectively. But a new harmonized standard EN 303 417 specifically for WPT systems is currently under development within ETSI.
– The spurious emission levels in the frequency range of the standard time signals (below 85 kHz) are well below the limit from ETSI EN 300 330-1, typically by 20 dB.
– The spurious emission levels at the harmonic frequencies below 1.5 MHz exceed the limit of ETSI EN 300 330-1 by as much as 20 dB. It should be noted that the WPT system tested was a prototype setup which is still under development and may therefore not represent the final production design.

7.2 Ongoing WPT studies and results on the impact to broadcasting services

The broadcasting service has the following Primary allocations in the LF and MF bands:

148.5-283.5 kHz in Region 1

526.5-1 606.5 kHz in Regions 1 and 3

525-1 705 kHz in Region 2

Both allocations are used for AM sound broadcasting and/or for DRM (Digital Radio Mondial).

For co-existence between WPT systems and broadcasting services, the impact to broadcasting services should be discussed in any radio environments, such as rural, residence and urban areas.

Subsection 7.2.1 contains a study based on an analytical approach using the protection criteria of broadcasting service from ITU-R Recommendations and reports. It derives the maximum tolerable magnetic field from WPT at the broadcasting receiver in the LF and MF bands. The derived maximum tolerable magnetic field strengths are almost at same level as the environment noise level in quiet rural areas as described in Recommendation ITU-R P.372-13.

Subsection 7.2.2 describes a study on the impact in urban and suburban areas conducted by a committee of the administration of Japan. Basic requirement for co-existence between WPT systems and broadcasting services in this study is that the emission level at broadcasting receivers from WPT is lower than environmental noise in "city" environment described in Recommendation ITU-R P.372-13. The radiated emission limits for the MF broadcasting band at 10 meters from WPT receivers are determined by a different approach from the analytical study above. The approach includes emission measurements and audibility tests of interferences to broadcasting service in an emission test site.

7.2.1 Analysis of the impact of WPT systems to broadcasting services

7.2.1.1 Protection criteria and acceptable interference

Recommendation ITU-R BS.703 – Characteristics of AM sound broadcasting reference receivers for planning purposes, sets the minimum sensitivity of an AM sound broadcasting sound receiver for planning purposes as:

– Band 5 (LF): 66 dBμV/m

– Band 6 (MF): 60 dBμV/m

Recommendation ITU-R BS.560 – Radio-frequency protection ratios in LF, MF and HF broadcasting, outlines applicable protection ratios for interference between AM broadcast signals. Although WPT is not a broadcast signal, it may take the form of a (mostly) unmodulated carrier and to that extent is actually very similar to a broadcast AM signal, during a pause or quiet passage as presented to the receiver. The protection ratios of Recommendation ITU-R BS.560 can therefore be considered to be a good basis for deriving radiated emission limits from WPT.

7.2.1.2 Derivation of the maximum tolerable H field at the broadcasting receiver from WPT installations

Part of any emission limit is the specification of the distance from the interfering source at which a particular field strength limit should apply. This issue can be dealt with completely separately from the question of what the limit should be:

– The first step in the derivation is to consider the wanted and interfering field strengths at the broadcasting receiver, whatever the distance this happens to be from the interfering source. Where distances are mentioned, we do so only in order to establish the field strength that was present.

– The second step is to consider what assumptions are necessary about the separation distance and the factors affecting the propagation between the interference source and the broadcasting receiver, as well as the scenarios for WPT use cases (from low power chargers for mobile phones etc. up to high power chargers for Heavy Electric Vehicles).

The limits may then be derived in the first step above for WPT interference falling in the band of an AM signal.

Importantly, radiated disturbances caused by WPT equipment can occur on:

– harmonics of a fundamental WPT frequency; for example a WPT EV charger using a frequency in the 79 to 90 kHz band can generate harmonics falling in the LF broadcasting band (148.5 to 283.5 – second harmonic) and in the MF broadcasting bands (526.5 to 1 606.5 kHz and 525 to 1 705 kHz – sixth harmonic and above) or,

– the fundamental of the WPT itself; for example a WPT mobile phone charger using a frequency in the LF Broadcasting Band in Region 1 (148.5 to 283.5 kHz).

Starting from the recommended planning considerations and protection criteria given in Recommendations ITU-R BS.703 and ITU-R BS.560 and noting that broadcast receivers used in the home commonly use ferrite-rod antennas that respond to the magnetic-field component H of the wave, it is convenient to use the corresponding H-field strengths when considering emission limits on WPT equipment. Assuming far-field free-space conditions (which will apply to the received broadcast signal at the receiver antenna) the relationship between the electric and magnetic fields (from Maxwell's equations) is:

$$\frac{E}{H} = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\ \Omega$$

Where μ_0 is the permeability of free space and ε_0 it the permittivity of free space.

This means that the following conversion factors apply:

$$H_{(\frac{\mu A}{m})} = E_{(\frac{\mu V}{m})} \cdot \frac{1}{377}$$

which may be expressed as:

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

So the receiver sensitivities at LF and MF (in § 7.2.1.1) can also be expressed as 14.5 and 8.5 dBµA/m respectively.

The protection ratios for AM broadcasting comprise two components:

– the "co-channel" protection ratio (PR) needed when the interferer and wanted signal carrier are on essentially the same frequency (so any beat between them is of a frequency below the audible range; in this case the modulation of the interferer is the dominant cause of audible disturbance);

– the additional "relative PR" that must be added when the wanted and interfering signals have a frequency difference, which then gives rise to a continual audible beat tone; this correction depends on the frequency offset, primarily because the frequency response of the human ear is far from 'flat'.

Unless WPT device frequencies are carefully aligned with the broadcast frequency raster, the additional relative PR for non-co-channel operation will need to be added. Assuming the WPT frequency to be uncontrolled, we may assume that the worst case occurs. Figure 1 of Recommendation ITU-R BS.560 shows that the greatest relative PR is approximately 16 dB, which corresponds to frequency offsets of around 2 kHz.

For the worst case, this relative PR must be added to the co-channel PR of 40 dB to give an overall PR for WPT interference to AM broadcasting of (40 + 16) = 56 dB.

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

The maximum acceptable WPT H field at the broadcast receiver location is therefore:

– Band 5 (LF): (14.5 – 56) = –41.5 dBµA/m

– Band 6 (MF): (8.5 – 56) = –47.5 dBµA/m.

It will be seen that these values are smaller than:

– the man-made and external-noises at LF; see Recommendation ITU-R P.372 radio-noise; and

– the –15 dBµA/m at 10 m, in a 10 kHz bandwidth, recommended for SRDs operating in the range 148.5 kHz – 5 MHz in ERC Rec 70-03 Annex 9.

However, there are good reasons for this:

– the beat-tone caused when the carrier of an interferer lies at a frequency offset from that of the broadcast signal being received is more disturbing than the same level of noise; this is clear in comparing the recommended protection ratios quoted above with the carrier-to-noise ratios considered acceptable for AM broadcasting (see Note below);

– these same protection ratios are applicable to other potentially-interfering broadcast signals in broadcast planning (see Annex 6) – it would not be acceptable to apply less-stringent conditions to non-broadcast (non-licensed) interferers than to broadcasts which have primary allocation in this frequency range in Region 1;

– noise levels at LF vary widely with location on the globe, seasons and time of day, so Recommendation ITU-R P.372 needs very careful interpretation; LF broadcasting is used in those parts of the world where the noise levels are acceptable (e.g. use of LF broadcasting does not occur in the Tropics);

– the limits for SRDs in ERC Rec. 70-03 (relevant to Europe) would have been derived under assumptions as to the separation from broadcast receivers which would be expected for the SRD types then considered, together with the likely intermittency of their use; these assumptions need revision for ubiquitous household devices used in the home for significant periods.

NOTE – The signal strength of an AM radio transmission is defined as the strength of the carrier. Recommendation ITU-R BS.703 effectively sets the minimum carrier level which can be considered as providing a service and therefore defines boundary of the service area. Indeed, broadcasters and frequency planners use this figure to make this definition. It is based on a wanted audio signal to random noise ratio of 26 dB. The modulation gives rise to only a small amount of additional energy in (information carrying) sidebands. If and rms modulation depth of 0.2 (20%) is assumed[4] the power in the carrier is around 14 dB greater than the modulation power in the sidebands. By comparison with the carrier, the sideband power is negligible adding less than 4% overall. Taking this typical sidenband to carrier relationship into account, Recommendation ITU-R BS.560 specifies the protection ratio that a given service should have from an interferer as 40 dB. If the carriers are on the same frequency and it is assumed that the modulation depth of the two programmes is the same, this in turn defines the wanted audio signal to unwanted audio signal (from the interfering station) ratio as 40 dB. Clearly this is somewhat higher than the wanted signal to random noise ratio, the reasons being that an unwanted audio signal represents a greater intrusion into the wanted audio and that the signals in the upper and lower sidebands are correlated; whereas random noise is not.

This in turn means that at the fringe of the service area, as defined by the minimum sensitivity requirement for planning purposes, the unwanted signal should be 40 dB lower. In the MF case this is therefore 60 dBμV/m (from § 7.2.1.1 above – expressed as a voltage) minus 40 dBμV/m = 20 dBμV/m. If there is an offset between the carriers, the carrier component itself becomes a much more pernicious interferer as it is 14 dB stronger than the modulation and is much more audibly intrusive. As stated above, any modulation becomes negligible in this situation and can be ignored. Recommendation ITU-R BS.560 recognizes this requires up to an additional 16 dB of protection from a single sine wave. For all practical purposes, single tone interference from WPT equipment will appear to the receiver to be the same as another interfering carrier, potentially offset in frequency, and should be treated as such. The fact that it is not modulated is irrelevant as it would be for another radio service.

See also Document 6/229(Rev.1) (2 November 2005) for an explanation of AM Radio protection.

[4] Work carried out by the BBC in about 2007 revealed that the rms modulation depth on AM transmissions varied from around 20% for speech to around 40% for heavily compressed ‘pop’ music. AM radio is used primarily for speech and so this must be considered as the ‘worst case’.

7.2.1.3 Consideration of distance and propagation related factors

A categorization of WPT chargers is needed in terms of:

– Use (ranging from low power chargers for mobile phones etc. up to high power chargers for heavy duty Electric Vehicles)
– Indoor versus outdoor use
– Power output
– Coupling mechanism
– Residential versus non-residential use.

This would help in defining the most appropriate assumptions about minimum separation distance and propagation related factors.

For example, low power domestic mobile phone chargers and LF/MF broadcast receivers are both intended to be used in domestic environments, foreseeably within the same room. Therefore large separation distances cannot be achieved. It is therefore proposed that the H field limits given above should apply at a distance from the WPT device of 1 m. As another example, a separation distance of 10 m would be a more reasonable assumption between a WPT bus charger and a domestic broadcast receiver, noting however that in a large bus terminus there are likely to be several (many) charging systems operating at the same time, each contributing to the underlying noise environment; the cumulative effect needs to be considered as well.

The image shows the lower floors of an apartment block in South East London. It can be seen that the ground floor is given over to garages with apartments immediately above. The height of the garage ceilings is about 2.3 metres. It could reasonably be assumed that a radio receiver being operated in one of the lowest level apartments might be no more than 3 metres above the floor of the garage and hence no more than 3 metres away from at least one WPT charger which was intended for charging cars in the garages. There could be three chargers within 3 metres and several more within 10 metres. Other scenarios can be envisaged where a car could be being charged and the distance between the charger and a receiver in a neighbour's apartment of house might be no more than 3 metres. Magnetic field reduces with the inverse cube of the distance from the source and conversely increases with proximity to the source. The ratio of H fields at 3m and 10m is therefore $(10/3)^3 = 37.0$. In dBuA/m terms this is a difference of 20.log10(37) = 31dB. So to give an equivalent field strength at 10 metres, a correction factor of 31 dB would have to be applied. In the case of a charger intended for a car. The tolerable magnetic field strength at 10 metres from the charger would have to be 31dB smaller than the value calculated to protect the receiver. Other distances and other correction factors would have to be used for other scenarios.

Brief experiments (reported in August 2015) have confirmed interference from WPT devices to reception of broadcasting does occur, even with WPT of lower power.

7.2.1.4 Mitigation Strategies

Very clearly there is a wide disparity between the levels of interference that a broadcast receiver can tolerate and the levels allowed for ISM devices. This is not usually a problem because such devices are operated under controlled conditions and physically separated from broadcast receivers (or any other radio receiver) that might be affected. Steps can be taken to ensure that licensed radio services are no affected. In the case of WPT chargers for vehicles, controlled use is more difficult to guarantee. It seems unlikely that stray radiation from a WPT device can be brought down to the levels necessary to protect the broadcasting service and so an alternative strategy needs to be found.

As a starting point, the receiver protection levels can be relaxed by 16 dB (the relative protection ratio) if the source of interference, including all the relevant harmonics, can be arranged to sit on the carrier frequencies of the MF transmissions. In ITU Regions 1 and 3 LF and MF transmission carrier frequencies lie on a fixed raster with each frequency being a multiple of 9 kHz. In Region 2, MF transmission carrier frequencies lie on a fixed raster with each frequency being a multiple of 10 kHz. If, therefore the charging frequencies are themselves made to be multiples of 9 kHz or 10 kHz respectively, they and all of their harmonics will automatically lie on the broadcast frequency raster.

While this may be sufficient on its own in some cases, it will probably not be enough to narrow the gap between the requirements of the broadcast receiver and, for example, a vehicle charger in a domestic environment. This can again be addressed by careful choice of the operating frequency of the WPT device but now, as well as placing this frequency and (importantly) its harmonics on the broadcast raster, these must also be set such that they are well separated (spectrally) from the frequencies used by broadcast services in the area where the WPT device is operating. In effect the frequencies used for the WPT devices would have to be ‘planned’ on the same basis as broadcast transmissions which would otherwise interfere with each other. It is important to note that this strategy is very much simplified if the WPT frequencies follow the same raster as the broadcast frequencies. A description of the broadcast transmission planning process is given in Annex 6.

7.2.1.5 Further Work

The mitigation techniques described in the previous section form the basis of a ‘toolbox’. This ‘toolbox’ would need to be developed with a lot more detail which has yet to be finalized. Areas that would need to be covered include:

Frequency Accuracy and Stability – Ideally, the frequency of the WPT device would be precisely and consistently on the 9 kHz or 10 kHz raster as appropriate to ensure that it and its harmonics were accurately aligned with the frequencies of the broadcast stations. In practice it is likely that a small amount of static and dynamic variation could be tolerated but exactly what the tolerances are would need to be established. There are two factors involved here. Fist, ist is essential that any frequency offset did not give rise to ‘beat tones’ that were within the audible range. A ‘beat would occur at the difference frequency between the WPT and the broadcast station and the bottom end of the audible range would be partly determined by the audio filtering in the receiver. In practice it is possible that there will be some variation in the operating frequency of the WPT device because it has to optimize itself to cope with inaccurate physical alignment between the charger and the item being charged.

Modulation of the Charging ‘Field’ – This follows on from the previous point. It is suggested that the WPT charger could be used to transfer data to the item being charged by modulating the charging (magnetic) ‘field’ in some way. Communication in the other direction would need a separate system. Any attempt to modulate the charging ‘field’ would manifest itself as sidebands. Limits would need to be placed on this sideband energy because it would have the potential to interfere with broadcast services even if the basic frequency was accurately on the raster. It is necessary to look at the modulation schemes envisaged. In the case of a high power charger it would be logical to imagine that there are easier ways to communicate over very small distances than to modulate the high power charging 'field'.

Database of Available Frequencies – In any one geographical location, the range of LF and MF broadcasts that can be received will be different from another geographical location. For this reason the range of available (non-interfering) frequencies for the WPT charger will be different in different locations. The charger will therefore have to know where it is (geographically) and have access to a database of usable frequencies. It will, of course, also require a degree of frequency agility.

Use of 'Off-Raster' Frequencies – Given a knowledge of its location and the LF or MF broadcasting environment, it might be possible to use frequencies that are not on the broadcast raster provided that the drawbacks of doing this are recognized and the field power is kept within appropriate limits. Of particular interest might be the frequencies at the mid-point between the frequencies on the broadcast raster. Even harmonics would all lie on the raster and odd harmonics would lie on the boundary between adjacent broadcast channels; a point at which the receiver filtering might well reduce the audible impact.

Control of Harmonics – In the MF band, certainly at the higher frequency end, it is likely that only the higher order harmonics of the charging frequency will generate interference. The better the energy in these higher order harmonics is controlled, the easier it will be to find a suitable operating frequency for the WPT device.

7.2.2 Japan's study on the impact to and compatibility with broadcasting services in urban and suburban areas

While § 7.1.1 provides outlines of spectrum sharing and coexistence studies taken in Japan's new rule making process, this section describes details of the methodology taken in the study on the impact of WPT for EVs to the broadcasting services and assessment results. The study was performed by the WG and approved by MIC's Committee (see § 7.1.1).

7.2.2.1 Japan's points of view for impact study

Japan's approach taken in the impact study emphasizes the following points:

1) *WPT system compatibility with the incumbent radiocommunication services in urban areas may be a priority concern.*

WPT systems for EVs will be commercialized mainly from urban areas. Therefore, radio environment and usage models in urban areas should carefully be considered to demonstrate ability to coexist without causing problems. The radiated emission limits in Japan's new regulation on WPT were determined by the results of the impact study focusing on urban areas.

For the impact study to protect broadcasting services, the radiated emission limits from WPT systems should be lower than the environment noise level as described in Recommendation ITU-R P.372-13, where different environment categories are defined, "City", "Residential", "Rural", and "Quiet rural". It is assumed that the separation distance in suburban and rural areas is larger than in urban areas while man-made-noise level in suburban and rural areas goes lower.

Detailed conditions for assessment were assumed, which include:

– Required separation distance for assessment between WPT systems and the closest AM broadcast receiver: 10 m (referring to CISPR Standards, others).
– Propagation loss due to house/building walls:10 dB (from Japanese study results).
– Self-interference (the WPT system interferes to owner's wireless devices): not considered.

2) Radiated emission limits for WPT systems in the broadcasting service frequency range consistent to the existing living regulations

Since inductive cooking heaters conforming to international standards such as CISPR 11, Group 2, Class B, and/or CISPR 14-1 have been already commercialized and are widely spread, any harmful disturbances and troubles to other wireless systems from inductive cooking heaters have not been reported. This situation is same in many countries and regions. To prevent generating harmful interference in the frequency range of AM broadcasting services from WPT equipment, the target radiated emission limits in the range were determined by referring to the existing emission limits. The emission limits were agreed among broadcast representatives and WPT proponents to be specified in the regulation.

3) Assessment in suburban and rural areas and protection of incumbent radio systems through regulations

Due to various physical constraints for measurements in the study, the WG has not come to a conclusion that the impact to medium-wave broadcast receivers is acceptable to coexist when the receivers are used in wooden houses located in medium and low environmental noise areas. However, even in those situations, the above mentioned does not mean that the WPT system causes harmful interference at every WPT operation time and at consistent basis to the receivers located nearby when taking account of the following statistics: average time for operation of the WPT systems for EV (e.g. less than one hour), relatively high proportion of users who prefer short-time charging (e.g. several tens of minutes) after returning home, and the WPT frequency to be determined within a certain band based on the environment and installation condition.

Given the considerations above, it is deemed that substantial problems to the reception of broadcasting service may not be probable even when the required condition for coexistence cannot be achieved in some cases. A cautionary statement such as "This equipment may cause harmful interference to medium wave broadcast receivers" attached to the WPT system user instruction and/or the product can remind the users of possible harmful interference to the receivers.

WPT industries should continuously take appropriate interference mitigation measure to reduce the interference to lower than the allowable level in order to avoid harmful disturbance to broadcasting services in suburban and rural areas.

If the WPT system should cause unacceptable interference to the receivers, radio administrations shall provide necessary regulatory measures/orders to stop WPT system operation causing harmful interference to the other incumbent radio systems.

7.2.2.2 Power transmission specifications for measurement

Specifications of WPT systems for EVs were determined as follows:

– WPT technology: Magnetic coupling (resonant magnetic coupling)

– Application: Electric passenger vehicle charging while parking (Static)

– Frequency range: 79-90 kHz (so-called 85 kHz band)

– 79-90 kHz range was selected as the primary frequency range by referring to Japan domestic impact study results and IEC and SAE discussion results in the view of global harmonization.

– Transfer power range: 3 kW-class and 7.7 kW-class; Classes are assumed for passenger vehicles

7.2.2.3 Emission limits for assessment

The target emission limits in the power transmission frequency ranges for the studies of WPT systems was assumed by referring to the emission limits of FCC Part 18. The target emission limits out of the power transmission frequency range were assumed by referring to one of Japan's radio regulations for inductive cooking heaters. As to the frequency range over 150 kHz, CISPR 11 Group 2 Class B was referred to. The assumed target emission limits of magnetic field are described below:

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

68.4 dBμA/m@10m for 3 kW Tx Power

72.5 dBμA/m@10m for 7.7 kW Tx Power

b) Frequency range from 526.5-1 606.5 kHz (AM broadcasting frequency range):

-2.0 dBμA/m@10m

c) Frequency range except for the above frequency range:

23.1 dBμA/m@10m

The above target emission limits were settled firstly, in the frequency ranges both under 526.5 kHz and over 1 606.5 kHz. However, in later stages the Committee concluded to adopt the limits of CISPR 11 Group 2 Class B in the frequency range over 150 kHz except for AM broadcasting frequency ranges.

7.2.2.4 Analytical study, measurement results and audibility testWPT systems for EVs shall not cause harmful interference to an AM broadcasting receiver located at least within 10 meters distance from the systems based on the target radiated emission limits. Emission measurements using a WPT transmitter and WPT receivers on a mock wagon were performed under the agreed worst use case conditions, where the rotation angle of AM broadcasting receivers was selected and set to null direction to receive broadcasting signal considering antenna directive patterns. In addition, the AM receivers were located on the axis at which the strongest WPT unwanted emission waveform arrives considering WPT coil emission patterns. WPT's 7th harmonic of *Fc* = 85.106 kHz falls into 594 kHz AM broadcasting channel, which covers a wide area of Kanto-region of Japan. Hearing (audibility) assessment was performed as well. A criterion for satisfactory mitigation of the impact of WPT for EVs to AM broadcasting was confirmed.

Details are described below:

a) Basic conditions of the impact study

At first, the WPT-WG of MIC clarified the following conditions and use cases for the impact study.

– Acceptable maximum emission (the target emission limit) is –2.0 dBμA/m@10m which follows the existing emission limit for inductive cooking heaters in the 526.5-1 606.5 kHz range (AM broadcasting frequency range)
– Self-interference is out of scope of this impact study. Self-interference means that an owner's WPT system interferes to the same owner's AM broadcasting receiver.
– AM broadcasting receivers are located inside houses or buildings. On the other hand, a WPT system for EVs is located outside of the houses or buildings. Propagation loss due to house walls should be considered.
– Separation distance between a WPT system and an AM broadcasting receiver is 10 m, under assumption that the nearest neighborhood house is located more than 10 m apart from the WPT owner's house.
– Receivers are assumed to be located in a high-field strength area (receiving electric field strength is more than 80 dBμV/m), and a medium-field strength area (66 dBμV/m). The protection for the broadcast reception users in a low–field strength area (48 dBμV/m) is also important. However, the impact study in the WG focused on high-field strength and medium-field strength areas, because WPT systems are expected to gain in popularity in urban areas in the initial stage and then spread over other areas.

b) Analytical study

In the next step, the impact of WPT for EVs on AM broadcasting was studied by an analytical approach. In this step, the following criteria were agreed and taken.

– Acceptable radiated emission limits should be lower than environmental noise level in a particular area. An emission limit of 26.0 dBμV/m at 594 kHz is adopted by referring to the environmental noise of “City” described in Recommendation ITU-R P.372-13. This electric field strength (26.0 dBμV/m) is converted to magnetic field strength (–25.5 dBμA/m) as the acceptable maximum unwanted emission at the receiver.

– Propagation loss due to walls of houses and buildings between a WPT system and an AM broadcasting receiver is assumed to be 10 dB by referring to the reported results of MIC’s round-table conference concerning MF broadcasting pre-emphasis (Dec. 1983).

This analysis intended to assess the impact to the AM receiver in terms of magnetic-field emission by calculation when a measured unwanted emission strength was given and applied. For that purpose, the system model simulated the condition in (a) and other conditions were agreed; and then, unwanted emission strength at the receiver location was calculated. It was assumed that a WPT system for EV was located 10 m apart from the nearest neighbourhood house in which the receiver was located. Furthermore, an AM broadcasting receiver was located at 50 cm inside from windows of the house. The WPT parameters such as radiated emission strength (i.e., –15.6 dBμA/m) and necessary conditions were the same as the WPT system shown as “Test Equipment B” for EVs described in Annex 3.

The following points were suggested in this analytical study:

– Calculated emission strength derived with the measured emission strength satisfies the acceptable unwanted emission strength.

– The measured emission strength used for calculation is lower than the target emission limit of –2.0 dBμA/m by more than 10 dB, which shows substantial clearance for emission to the limit. This number was supported because industries sensibly and commonly take account of uncertainty budget by 10 dB or more for their emission performance margin in their design and test stages.

– In practical condition, unwanted emission strength from WPT systems reaches to –25.6 dBμA/m (= –15.6 dBμA/m – 10 dB), which is nearly or less than the acceptable unwanted emission strength, –25.5 dBμA/m.

The above consideration was accepted by the WPT-WG of MIC. Thereafter, the agreed target emission limit of –2.0 dBμA/m in the AM broadcasting frequency range in Japan was confirmed to be the acceptable number and then approved as a new regulation concerning WPT.

c) Magnetic field emission measurement

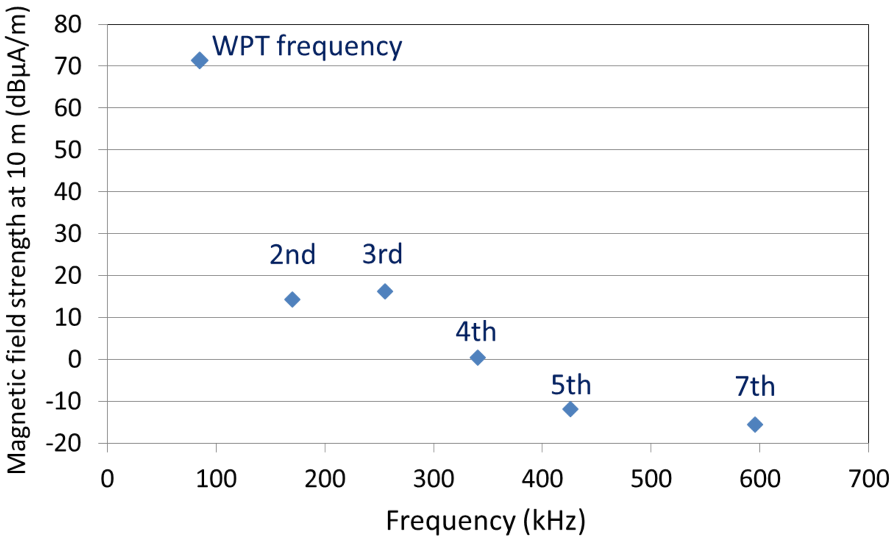
In order to confirm the result of the analytical study above, emission measurement using WPT test equipment and AM broadcasting receivers was performed. Conditions and methods were as follows:

i) Measurement set up

As mentioned above, the “Test Equipment B” for EVs, described in Annex 3, was used in this experimental test. The WPT frequency of the Test Equipment was 85.106 kHz. The transfer power was 3 kW at the input port of the transmission coil. The 7th harmonic of this WPT equipment was 595.742 kHz. Measured radiated emission levels of the WPT frequency and harmonics of “Test Equipment B” are plotted in Fig. 14.

FIGURE 14

Measured magnetic field strength of "Test Equipment B" (Quasi-peak value)



Note: The 6th harmonic is not plotted as can be plotted below the bottom of the y-axis scale.

d) Audibility test

i) AM broadcasting receiver selection

Several types of AM broadcasting receivers, including high-end type and portable type were prepared for this experimental test.

ii) Date and place

Date of this experimental test is from 1st July to 2nd July, 2014. Open area test site of Telecom Engineering Center (TELEC) Matsudo Laboratory was used for this experimental test. TELEC Matsudo Laboratory is located in a general residential suburb area nearby Tokyo.

iii) Broadcasting service channel and frequency

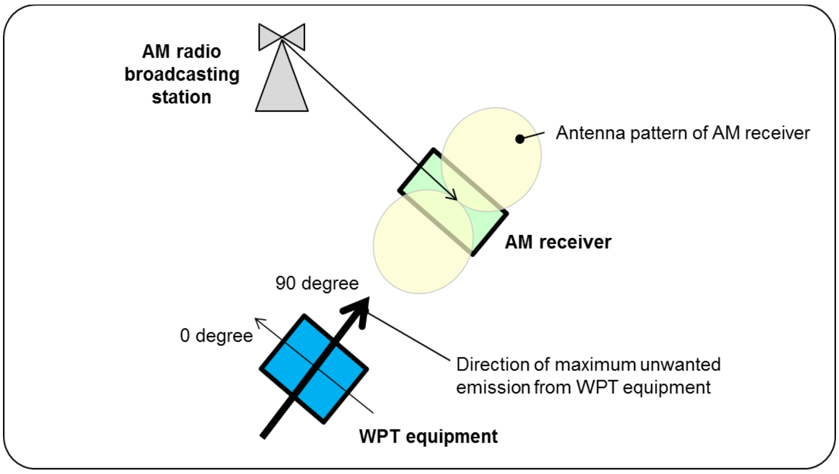
In the Tokyo area, there is an AM broadcasting channel of NHK Radio 1 at 594 kHz. The frequency difference between NHK Radio 1 and the 7th harmonic of "Test Equipment B" is about 1.7 kHz. If the 7th harmonic of "Test Equipment B" is larger than environmental noise, we can hear noise of 1.7 kHz.

Test procedure was as follows:

- At first, received field strength of AM broadcasting, radiated emission strength of harmonics of WPT equipment and environmental noise level were measured by using a spectrum analyzer. In the measurement, the receiving antenna received vertical and horizontal directions of H-field. The WPT equipment was placed at the 90 degrees rotated direction which maximizes the received unwanted emission strength. From these checking operations which consider the polarization and the radiated emission directivity from the WPT equipment, the maximum unwanted emission strength can be realized. Figure 15 shows the condition of the worst case which demonstrates the maximum impact to broadcasting receivers from the WPT equipment in this experimental study. This Figure illustrates the location of the AM radio broadcasting station, AM radio receivers and the WPT equipment, and also describes the relationship between the antenna pattern of radio receivers and the direction of the maximum emission from the WPT equipment.

FIGURE 15

Measurement condition of audibility test



- Next, an audibility test was performed by the participants listening to the broadcasting programs at several different locations separated by different distances including 10 m and 3 m from the WPT equipment. In this audibility test, the separation distance of 10 m matches the required conditions for this impact study. The test of 3 m separation distance was done only as reference. In this test, the face direction and the rotation angle of broadcasting receivers were selected at the worst condition for broadcasting reception considering antenna directive patterns and polarizations of those receivers. At the same time, the face direction and the rotation angle of broadcasting receivers were also adjusted to maximize the interference emission from the WPT equipment.

iv) Test results

The measurement results of received electric field strength are shown in Fig. 16. The field strength of AM broadcasting was about 100 dBμV/m and the environmental noise level was about 60 dBμV/m, which are much higher than the assumption described in (a). In this Figure, electric field strengths where the WPT equipment is ON and OFF are described. The difference between the WPT equipment of ON and OFF conditions is not clearly found in this Figure, because the environmental noise level is slightly higher than the 7th order harmonic from the WPT equipment.

The results of this audibility test were as follows:

- AM broadcasting receivers located at 10 m from WPT equipment

  The tone noise could be recognized as a very small sound only in very silent broadcasting programs but never in normal audio programs. In general, the tone noise under this test condition deems not to disturb general broadcasting listeners listening radio programs.

- AM broadcasting receivers located at 3 m from WPT equipment

  The tone noise can be easily caught when broadcasting programs are relatively silent, such as news programs. On the other hand, when broadcasting programs are busy, such as music programs, the tone noise cannot be easily caught.

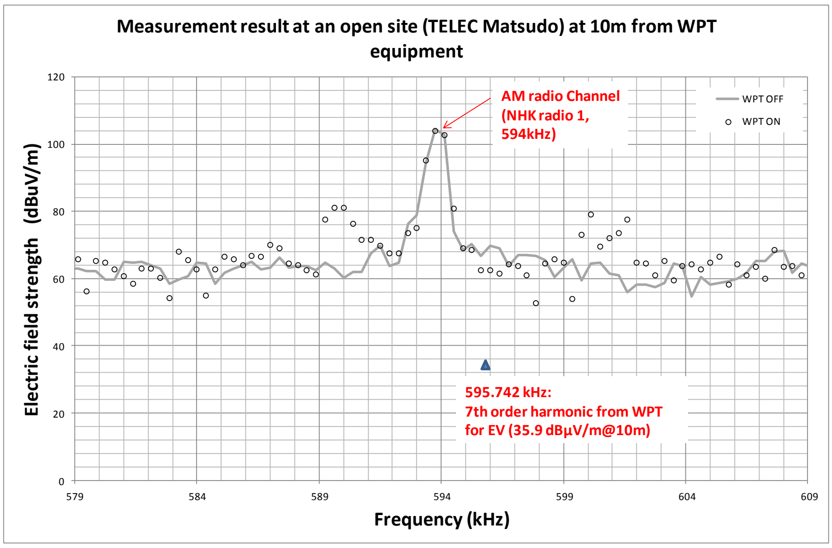
7.2.2.5 Assessment of study results

Under agreed test conditions and use cases assumed in urban area, magnetic field emission strength derived by analytical study and also that measured by a WPT-EV test equipment in a field measurement site showed acceptable (= non-harmful) level of emission received while settling the emission limit –2.0 dBμA/m in the AM broadcasting frequency range. In audibility assessment, It was confirmed that the tone generated by the WPT 7th harmonic falling in an AM broadcast channel in MF band was indistinct while listening to radio programs or obscurely audible during very quiet programs. It demonstrated little impact and no harmful interference to the AM broadcasting service. From this result, Japan's new regulations for WPT systems adopted this limit in the frequency range of AM broadcasting service.

This methodology for measurement and assessment must be useful for radio regulators who intend new rule making for WPT for EVs in urban area where Environment Category "City" in Recommendation ITU-R P.372-13 can be applied.

FIGURE 16

Measured electric field strength of an AM broadcasting channel when WPT is ON and OFF



7.3 Considerations in the frequency ranges 100/110-300 kHz for WPT

The LF and VLF ranges are being promoted for WPT use by Standards Developing Organizations (SDOs) industry alliances and manufacturer; the frequency range 100/110-300 kHz is also under consideration in the present studies in Working Parties 1A and 1B. A liaison statement (August 2015) to Working Party 1A, Working Party 6A noted its concerns on the use of LF frequencies adjacent to or overlapping the Region 1 LF broadcasting band, 148.5-255 kHz. Other Working Parties have also expressed concerns about adverse impact on radiocommunication and radionavigation services making use of the LF bands.

7.4 Considerations in the frequency range 6 765-6 795 kHz for WPT

There have been concerns expressed by other working parties about the possibility of unwanted RF energy that is harmonically-related to WPT systems operating in this and other bands. Working Parties 7D and 6A in particular have expressed concern about the second harmonic of WPT energy in this ISM band (6 765-6 795 kHz × 2 = 13 530-13 590 kHz) which overlaps with the HF broadcasting band 13 570-13 870 kHz and falls close to the band 13 360-13 410 kHz, which is allocated to the radio astronomy service on a primary basis.

According to experts involved in studying WPT issues, the energy in this band would generally be line spectra (and therefore would have narrow bandwidths). However, there is some possibility of unwanted energy sidebands on both sides of the primary emission. The level of these sidebands should be much lower, but may depend on a number of factors, including: the design of the WPT equipment, characteristics of the load being supplied, filtering/shielding of the source and load, the degree of coupling to the load and possibly other factors.

Considering that the 6 765-6 795 kHz band is one that is designated for ISM use under RR No. **5.138** (subject to Administration approval), and also noting the interference protections provided to radiocommunications services under RR No. **15.13**, more study is needed to ensure that unwanted RF energy (including harmonic energy) from WPT operations is at a level that does not cause harmful interference to a radiocommunication service operating in other spectrum bands.

7.5 Considerations of the impact to the standard frequency and time signal services

Working Party 7A provided information for consideration on frequency ranges that over the years World Radiocommunication Conferences allocated the frequency bands 19.95-20.05 kHz, 2 495-2 505 kHz (2 498-2 502 kHz in Region 1), 4 995-5 005 kHz, 9 995-10 005 kHz, 14 990-15 010 kHz, 19 990-20 010 kHz and 24 990-25 010 kHz, to the standard-frequency and time-signal service. In addition the following frequency bands for use by the standard-frequency and time-signal satellite service were allocated:

400.05-400.15 MHz,

4 200-4 204 MHz (space-to-Earth),

6 425-6 429 MHz (Earth-to-space),

13.4-14 GHz (Earth-to-space),

20.2-21.2 GHz (space-to-Earth),

25.25-27 GHz (Earth-to-space),

30-31.3 GHz (space-to-Earth).

Additional standard frequencies and time signals are emitted in other frequency bands, e.g. 14-19.95 kHz and 20.05-70 kHz and in Region 1 also in the bands 72-84 kHz and 86-90 kHz, which have been designated by other conferences (see No. **5.56** of the Radio Regulations).

The ERC Recommendation 70-03 on the use in Europe specifies frequency ranges, their maximum field strength, and locations as shown in Table 21:

TABLE 21

Standard frequency and time signals to be protected within 9-90 kHz and 119-135 kHz (ERC Recommendation 70-03)

Stations	Frequency	Protection bandwidth	Maximum field strength at 10 m	Location
MSF	60 kHz	+/–250 Hz	42 dBuA/m	United Kingdom
RBU	66.6 kHz	+/–750 Hz	42 dBµA/m	Russian Federation
HBG	75 kHz	+/–250 Hz	42 dBµA/m	Switzerland
DCF77	77.5 kHz	+/–250 Hz	42 dBµA/m	Germany
DCF49	129.1 kHz	+/–500 Hz	42 dBµA/m	Germany

NOTE 1 – The limit is reduced to 42 dBµA/m at 10 m.

Section 7.1 and Table 18 in this Report provide practical case studies in Japan on the impact to the standard frequency and time signal services.

7.6 CEPT experiences till now with the protection of services from the emissions of inductive SRD applications

In 2009 the inductive SRD limits were discussed to accommodate higher power SRD applications and WPT applications. A study was performed and the results published in ECC Report 135 "Inductive limits in the frequency range 9 kHz to 148.5 kHz".

It was found that a protection was needed for the time signal transmitters operating in the CEPT countries. Notches with a maximum emitted power level of 42 dBuA/m at 10 m were specified to protect these transmitters. It needs to be noted that the frequency range studied does not include frequencies above 148.5 kHz, it also does not discuss harmonics far outside the range 9-148.5 kHz.

This means that for example 350 kHz DGPS beacons and 198 kHz broadcasting and time signal transmitters are not studied, it is likely that these need more stringent protection limits due to the higher frequency.

These limits and notches were later included in the EC commission decision on SRD's and later reflected in ETSI standard EN 300 330.

In 2014 European industry requested wider spectrum masks and higher power for 13.6 MHz inductive devises such as RFID and contactless smartcards. A study was performed and the results published in ECC Report 208 "Impact of RFID devices on radio services in the band 13.56 MHz".

The services considered where the broadcasting and radio astronomy service.

It was concluded that a solution could be found in two different spectrum masks accommodating both high power narrowband and low power wideband emissions. An emission level of -3,5 dBuA/m at 10 m was found to be an absolute maximum for the mentioned services.

It needs to be noted that only interference to the broadcasting service was actually tested. Other services such as the radio amateur service are not adequately protected but based on the relatively low deployment of devices, this was considered acceptable at that time.

For the higher deployment of WPT and its associated spurious emissions these limits need to be seriously reconsidered.

Supporting CEPT documents for further studies are:

ERC Report 69: "Propagation model and interference range calculation for inductive systems 10 kHz – 30 MHz".

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

ECC Reports 67: "Compatibility study for generic limits for the emission levels of inductive SRD's below 30 MHz"

The inductive approach of actively notching out sensitive frequencies could be used as a spectrum management solution to accommodate WPT devices in regions or area's where specific services are active while the 13MHz approach of setting a maximum OOB limit in combination with a stringent spectrum mask provides a generic out of band limit for the global protection of radiocommunication services.

8 WPT human hazards

Human exposure to electromagnetic fields (EMF) is addressed by a number of regulatory agencies as well as international expert organizations such as the World Health Organization (WHO), the Institute of Electrical and Electronics Engineers (IEEE), and the International Commission on Non Ionizing Radiation Protection (ICNIRP). The determination of EMF safety limits are addressed by these groups and are not in the scope of ITU-R's work. There are a number of different guidelines on human exposure to EMF that have been published by these organizations, across several frequency ranges. These guidelines include: ICNIRP guidelines of 1998 and 2010 and IEEE Std. C95.1-2005. Many Administrations have or may at some point adopt these guidelines, or modified/updated guidelines based on their own experts' studies. System designers, manufacturers and operators of WPT equipment should consider steps to adequately protect the public from the hazardous effects of EMF and should consider these limits in their planning and deployment of WPT systems. Some additional references to guidelines can be found in Annex 1.

9 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 are being studied with candidate frequency ranges converging to around 85 kHz. That for Electric heavy duty vehicles is being studied with candidate frequency ranges of 19-21 kHz and 59-61 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.

10 References

[1] APT/AWG/REP-48 "APT Survey Report on "Wireless Power Transmission", March 2014. http://www.aptsec.org/AWG-RECS-REPS

[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] (reserved)

[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/

[9] APT/AWG/REP-62(Rev.1) “APT Report on "Wireless Power Transmission (WPT)", March 2015. http://www.aptsec.org/AWG-RECS-REPS

[10] The State Standard of People’s Republic of China, “Industrial, scientific and medical (ISM) radio-frequency equipment Electromagnetic disturbance characteristics Limits and methods of measurement”, GB 4824-2004.

[11] National Radio Administration Bureau of MIIT No 423, “Micro Power (short) Radio Equipment Technology Requirements”.

[12] Mazar (Madjar) H. 2016 ‘Radio Spectrum Management: Policies, Regulations and Techniques’, John Wiley & Sons

[13] Report on “Technical Requirements for Wireless Power Transmission Systems for Electric Vehicles (in Japanese)”, Document 22-5, the 22nd meeting of Subcommittee on Electromagnetic Environment for Radio-wave Utilization, Information and Communications Council (ICC), Ministry of Internal Affairs and Communications (MIC), Japan, http://www.soumu.go.jp/main_content/000367149.pdf, (6th July, 2015)

Annex 1

Guidance on RF exposure assessment in various organizations and administrations

The following information provides some guidance on RF exposure that are provided by various organizations and also information from some administrations. This should be considered as a reference toward understanding the issues surrounding human hazards. Readers are urged to consult the latest information from ICNIRP, IEEE, regulatory administrations and other expert bodies for the latest information:

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 most cases based on compliance with ICNIRP98). ICNIRP98 does not include a discussion of WPT devices and suitable measurement methods specific to WPT yet.

TABLE A1-1

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
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 – The detailed human exposure assessment methodologies for Wireless Power Transmission Systems for EV (79-90 kHz) and for mobile applications (400 kHz and 6.78 MHz) can be found in the partial Reports of Information and Communications Council (ICC) of MIC in January and July 2015.	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. Specification for three types of WPT systems is regulated in 2016 in Japan

TABLE A1-1 (*end*)

		– Incident H field level can exceed the reference levels while induced E field/SAR is much lower than basic restrictions – Using coupling factor in compliance relaxes limit of input power for WPT systems – Measurement of contact current is also required Ministry of Internal Affairs and Communications (MIC) received from the Information and Communications Council (ICC), as a consultative body of the Minister of MIC, a partial reports on the "technical requirements on the Wireless Power Transmission Systems" in January 2015 (for mobile WPT) and July 2015 (for EV WPT). The reports specify technical requirements with the aim of making new rules on the "type specification", which exempt permission of individual equipment installation application for WPT technologies. It provides overall WPT rulemaking status including coexistence conditions, emission limits, and RF human exposure assessment methodologies.
Republic of Korea	– The current EMF regulation is referenced by ICNIRP guideline	– Plans to introduce assessment methods specified for WPT during 2015

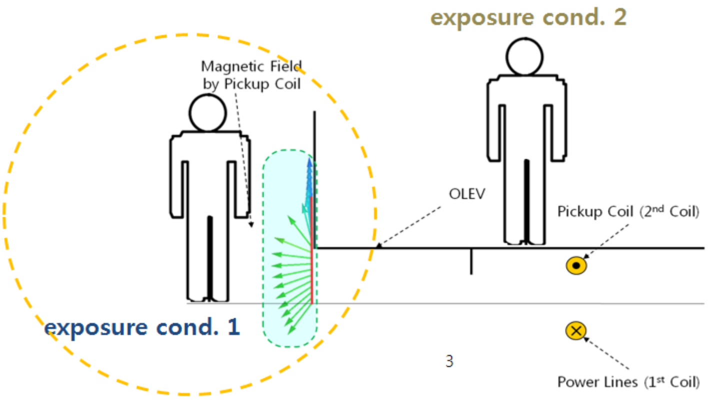
Evaluation of EMF human exposure from Electric Vehicle in Korea

The Republic of Korea studied the evaluation method of magnetic fields generated by on-line electric vehicle (OLEV) using the wireless power transfer technology in 2013, which is operated in area accessible to the public. The electric power lines in roadbeds (1st coil) and 5 pickup coil segments under the OLEV (2nd coil) is considered as a field source, in which resonance frequency is of 20 kHz and output power 75 kW.

Figure A1-1 shows the EMF human exposure condition from the power lines and pickup coils of OLEV system.

FIGURE A1-1

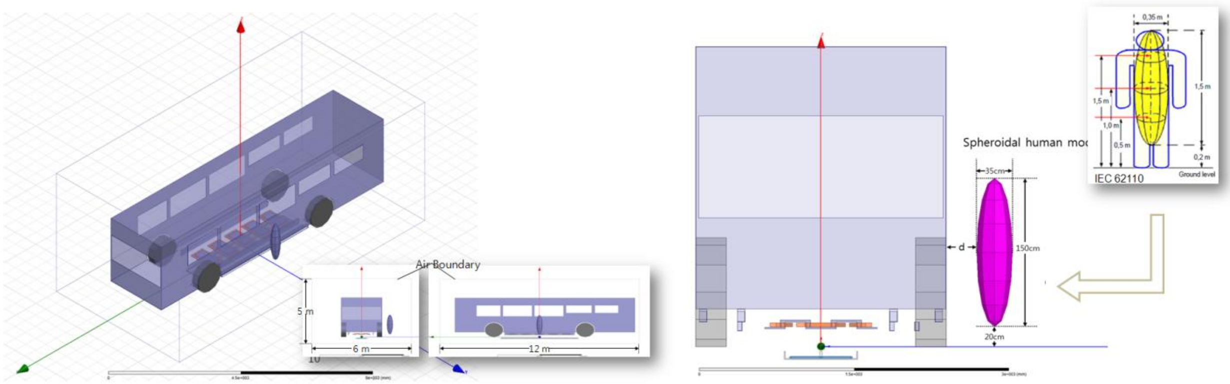
EMF human exposure condition of OLEV system



Where the field at exposure condition 1 of OLEV is considered to be non-uniform that is similar to AC power system (IEC 62110), the field level at the position of interest is calculated and measured at the three heights, 0.5 m, 1.0 m, and 1.5 m above the ground.

FIGURE A1-2

The model in the field generated by OLEV

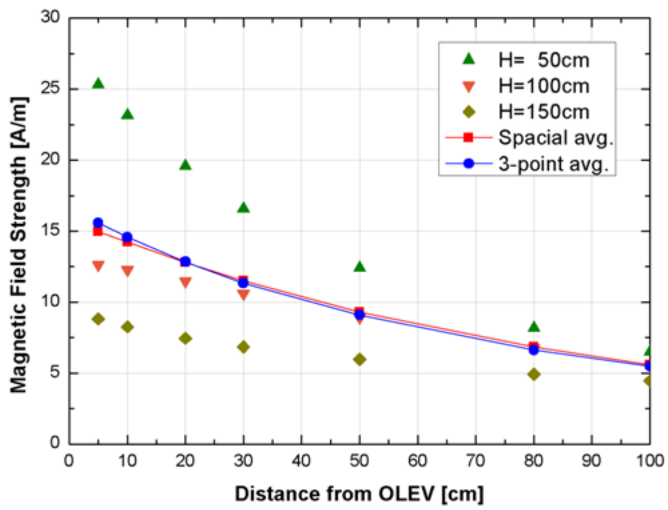


The average exposure level is calculated using the spheroidal human model whose vertical and horizontal axes are 1.5 m and 0.35 m, located 0.2 m above ground.

The deviation is 4% at distance of 5 cm from OLEV, and –2% at distance of 100 cm accessible to the public. Figure A1-3 shows that the vertical distribution of magnetic fields is uniform. We can know that the three-point average exposure level almost corresponds to the average exposure level for the exposure condition 1 of the electric vehicle (OLEV).

FIGURE A1-3

The calculated magnetic field distributions at each distances from OLEV



From the numerical analysis, the three-point (at the three heights, 0.5 m, 1.0 m, and 1.5 m above the ground) average exposure level represents the average exposure level over the entire human body, which is evaluated as 2.1 A/m, 40% less than the technical criteria of RF exposure.

The magnetic field strength at exposure condition 2 of each seat inside OLEV is assessed and the evaluation values are represented as in Fig. A1-4.

FIGURE A1-4

The calculated magnetic field distributions at each distances from OLEV

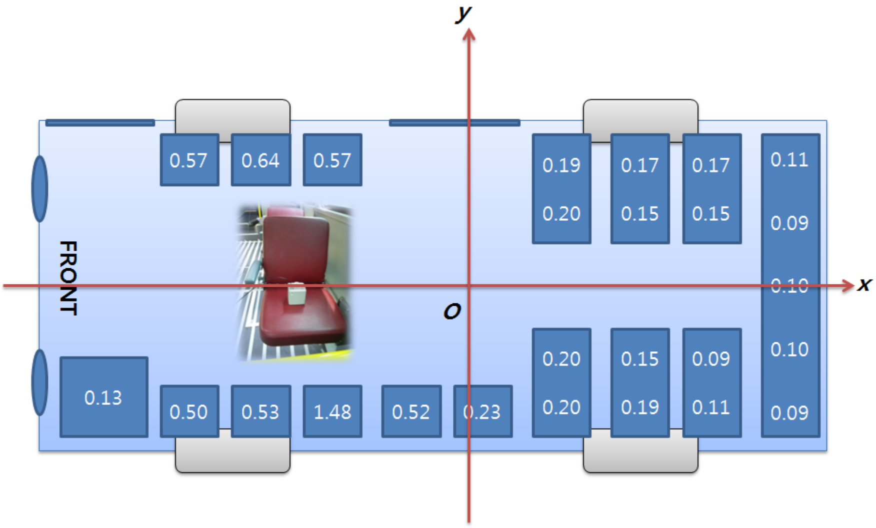


FIGURE A1-5

The calculated magnetic field distributions at each distances from OLEV

< Simulated Data(S.D.: 72 cm) >

Measuring points	Measured values	Adopted values
P1	1.07	
P2	1.93	
P3	3.96	X
P4	2.12	X
P5	3.99	X

< Measured Data(S.D.: 60 cm) >

Measuring points	Measured values[A/m]	Adopted values
P1	3.82	X
P2	3.41	X
P3	1.96	X
P4	0.90	
P5	1.08	

From the numerical analysis using 5-point average method, the 3.36 A/m is resulted, but 3.06 A/m is measured in the same condition. However, if using 3-point average method, simulated data and measured data are acquired as 0.53 A/m and 0.57 A/m, respectively. Considering the complex exposure conditions such as internal shielding architecture, the difference of altitude, and positions, the 5-point average method is more optimal than 3-point average method in measuring the worst case of RF exposure.

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;

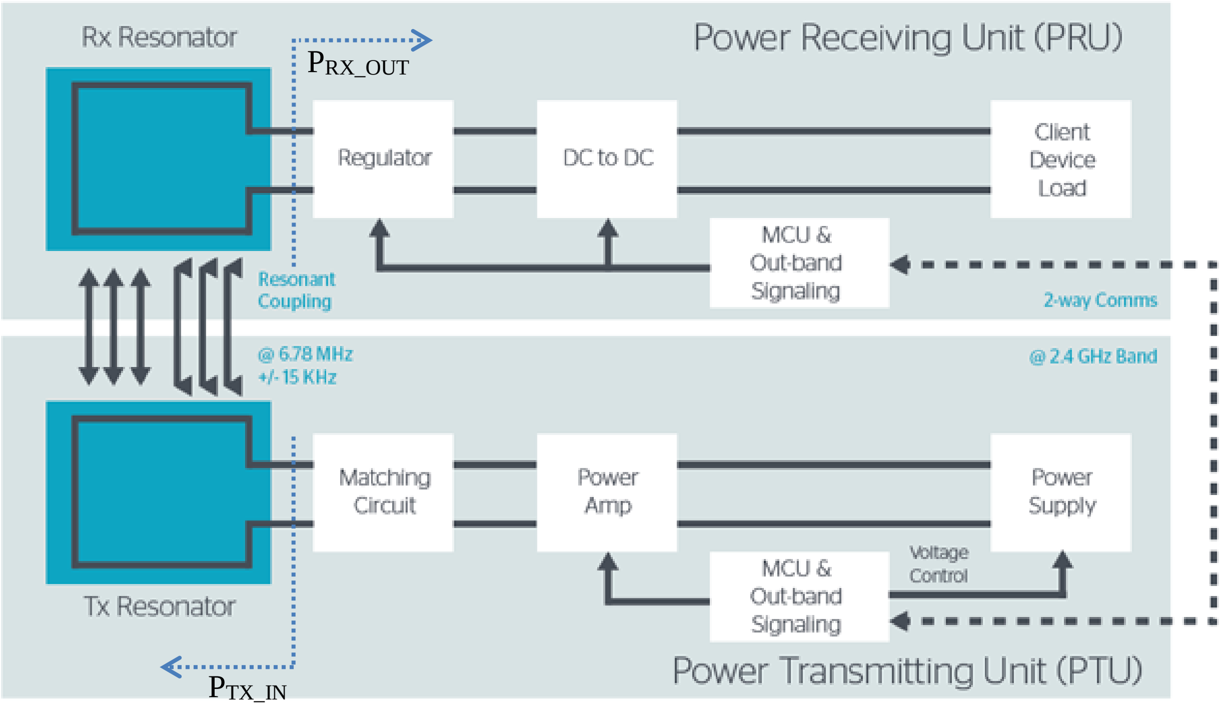
– miniaturization;

– 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^{TM} 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

TABLE OF CONTENTS

Page

1 Introduction

This Annex 3 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 16.

(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:

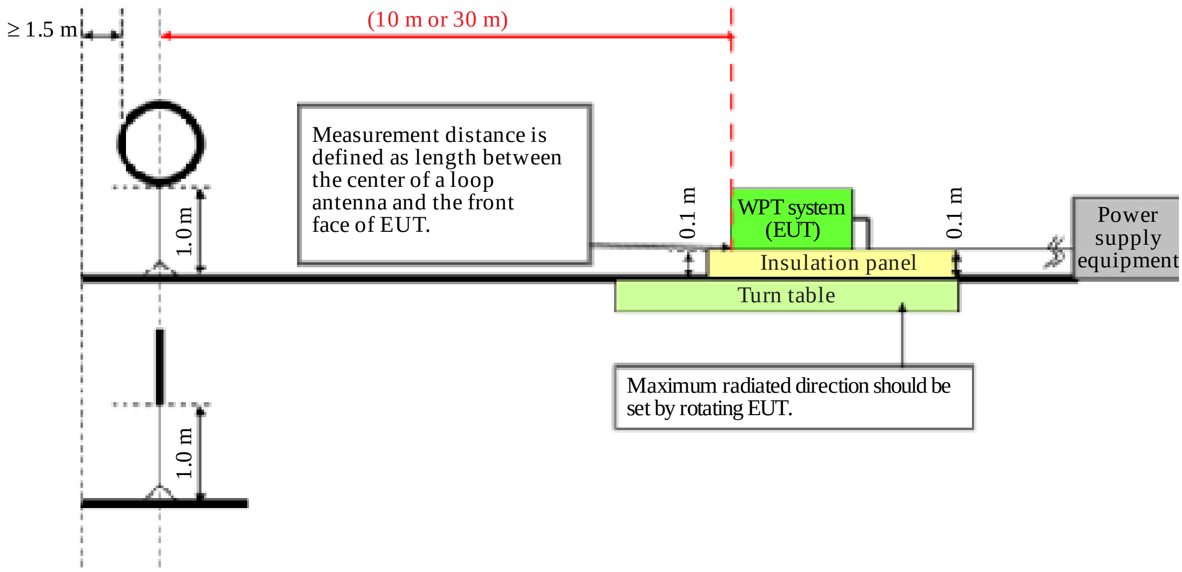
Conductive noise radiated from power supply lines is measured. In this measurement, EUT (Equipment under Test) should be connected to AMN (Artificial Mains Network).

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-A3-0

FIGURE A3-2

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

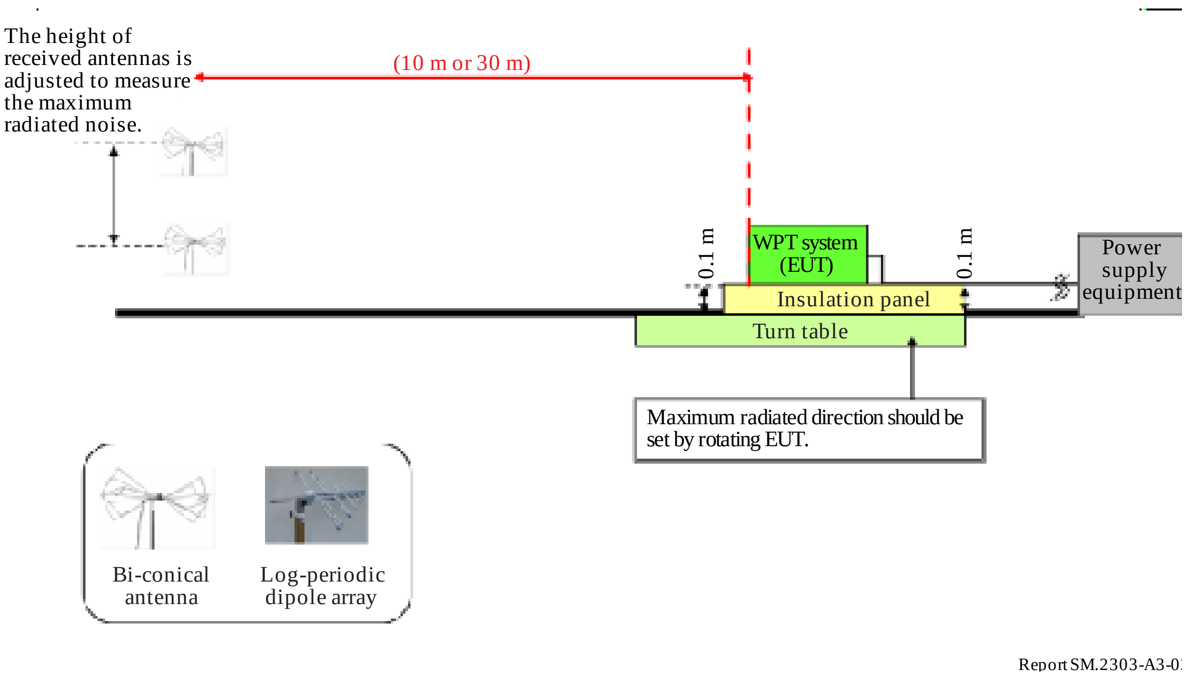


FIGURE A3-3

Top view of EUT and its arrangement for radiated noise measurement

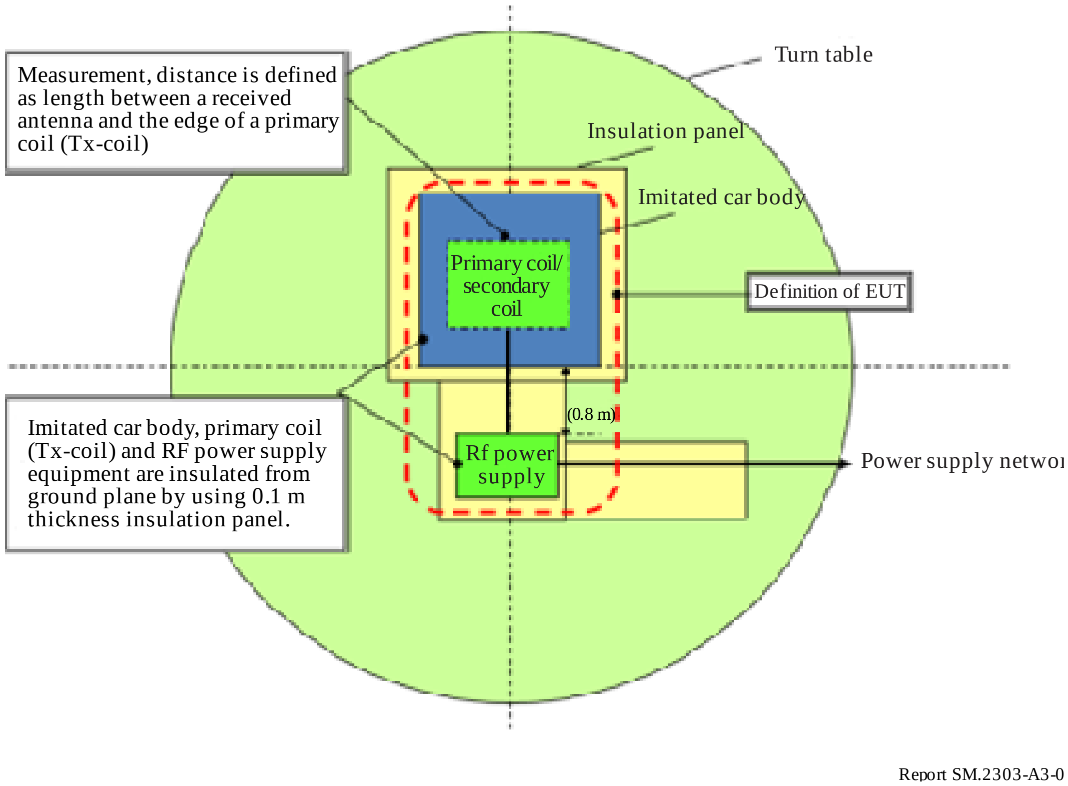


FIGURE A3-4

Configuration of the imitated car body

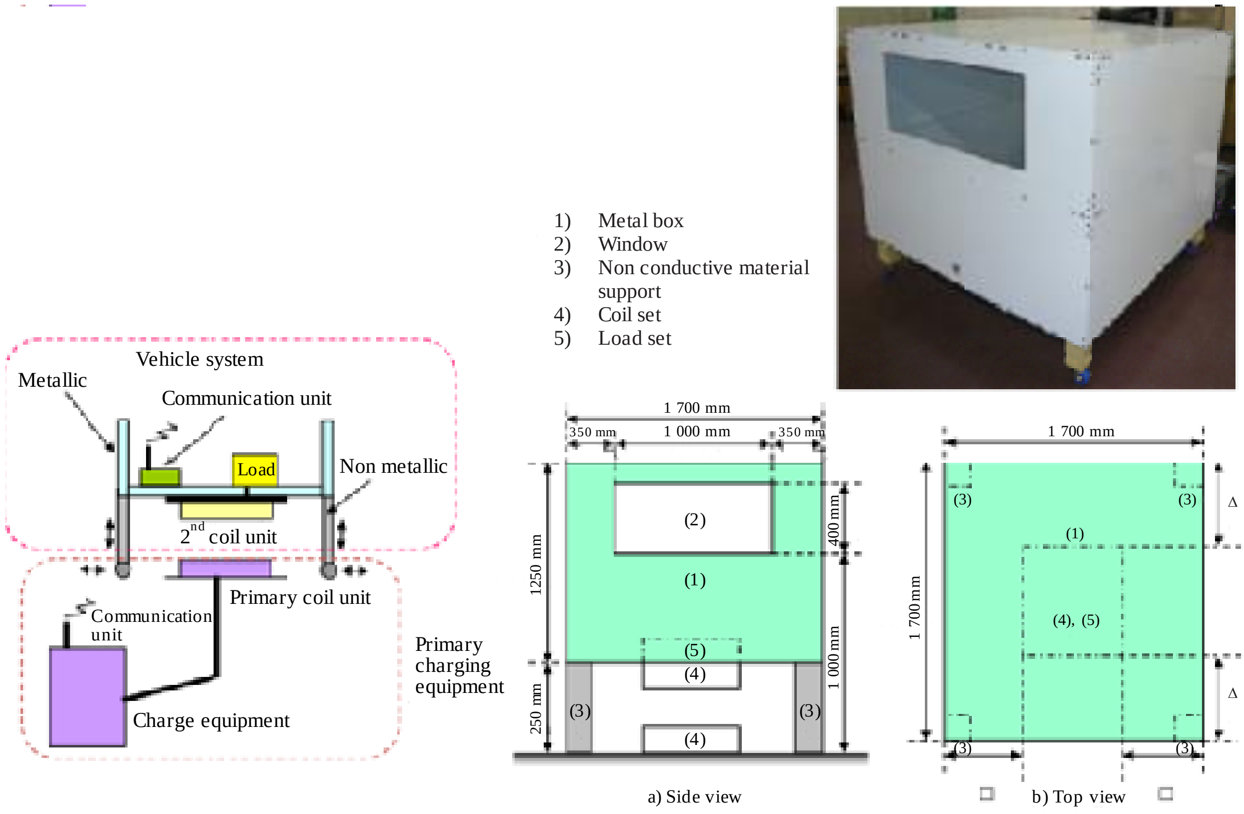


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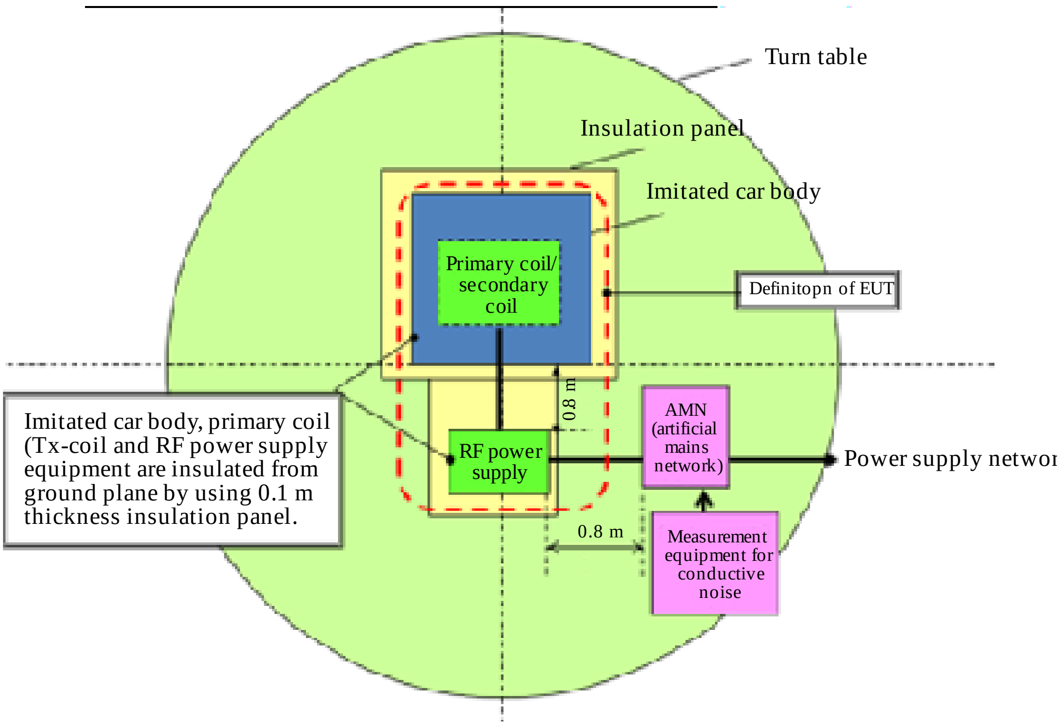
FIGURE A3-5

Top view of EUT and its arrangement for conductive noise measurement



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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

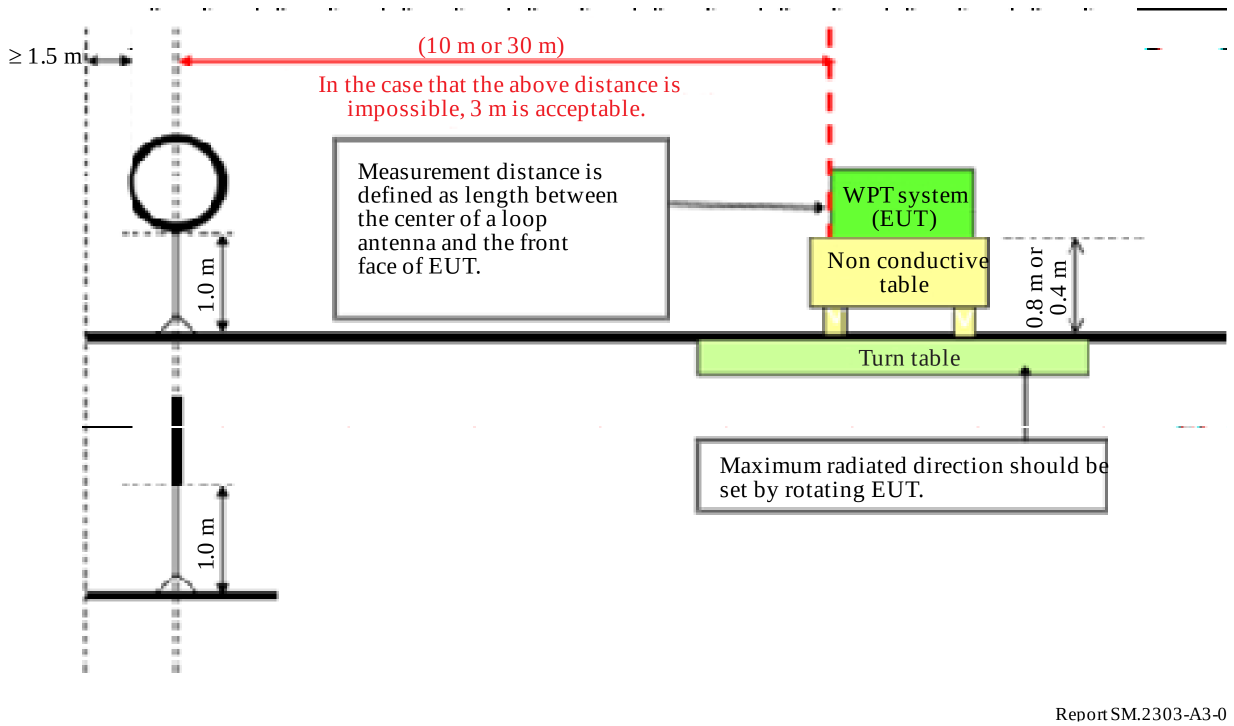

FIGURE A3-7

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

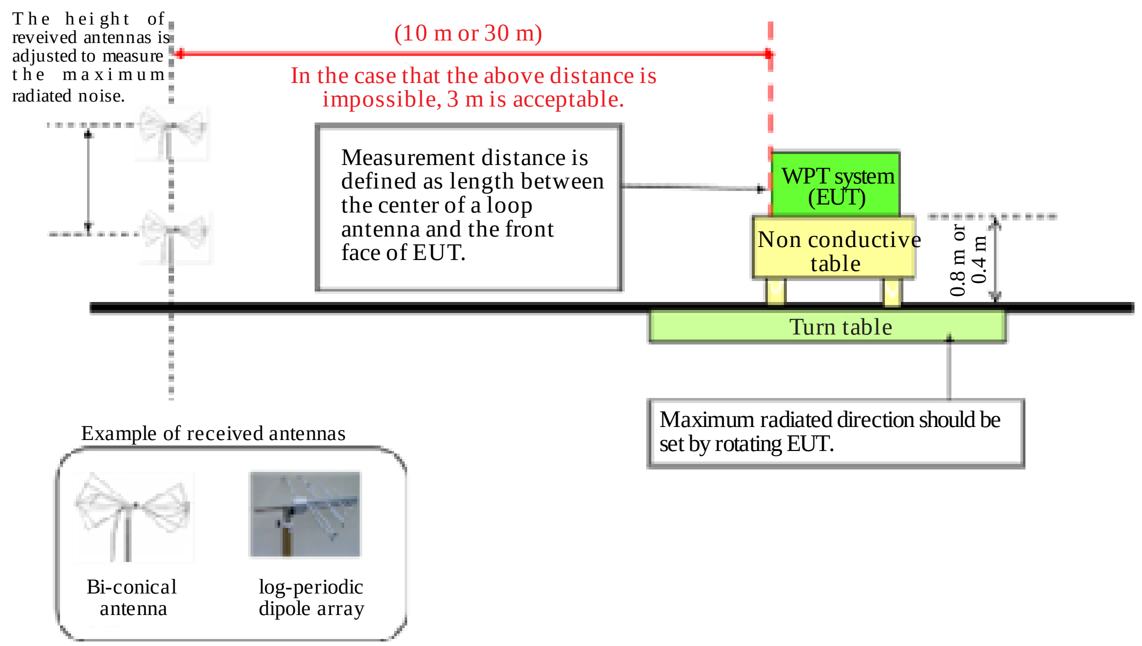

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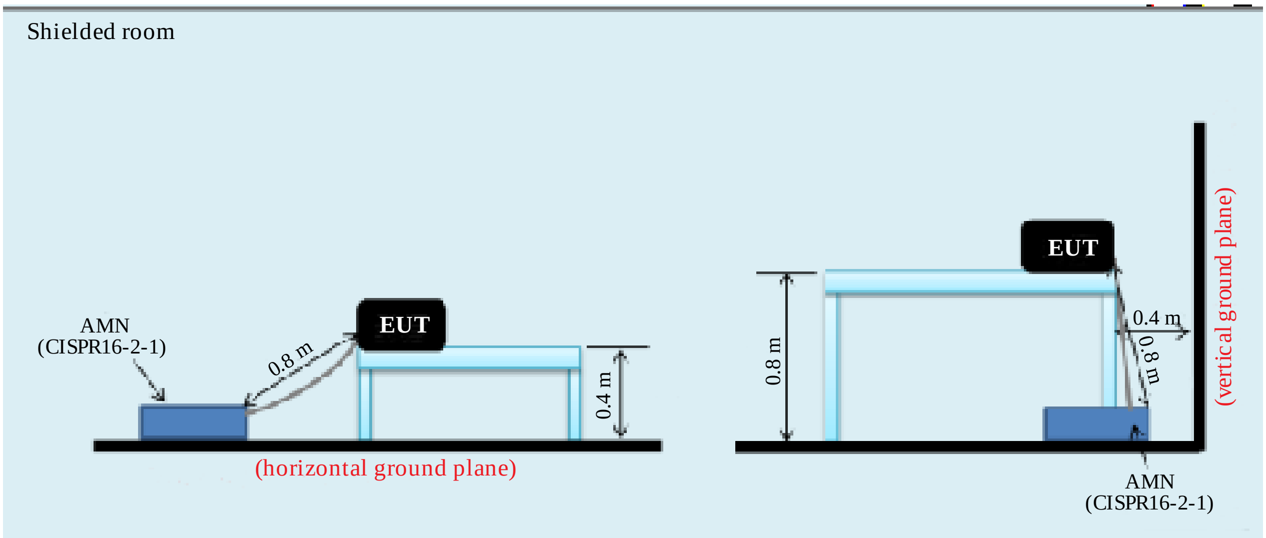
FIGURE A3-8

Measurement methods for conductive noise measurement



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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 526.5-1 606.5 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

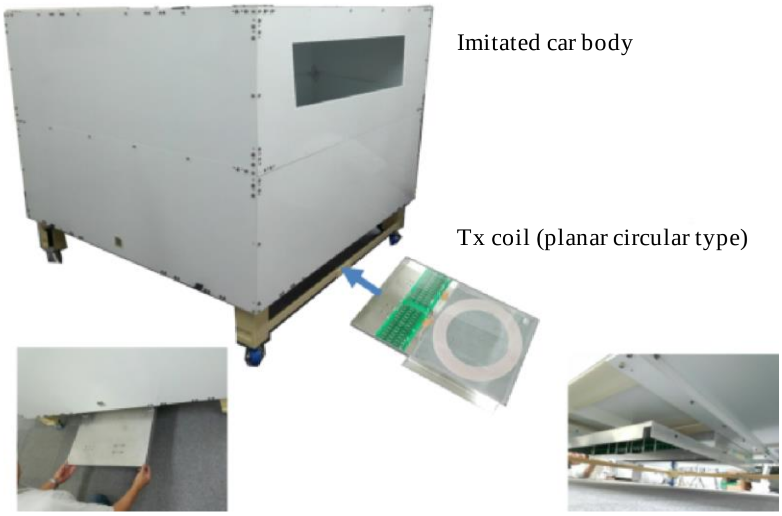

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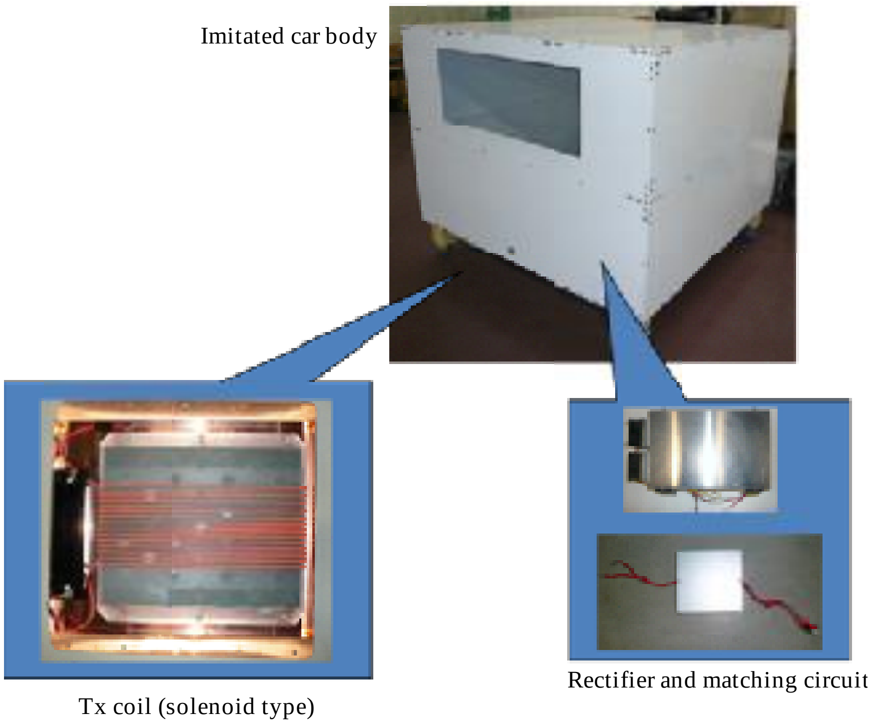
FIGURE A3-10

Test equipment B



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(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)

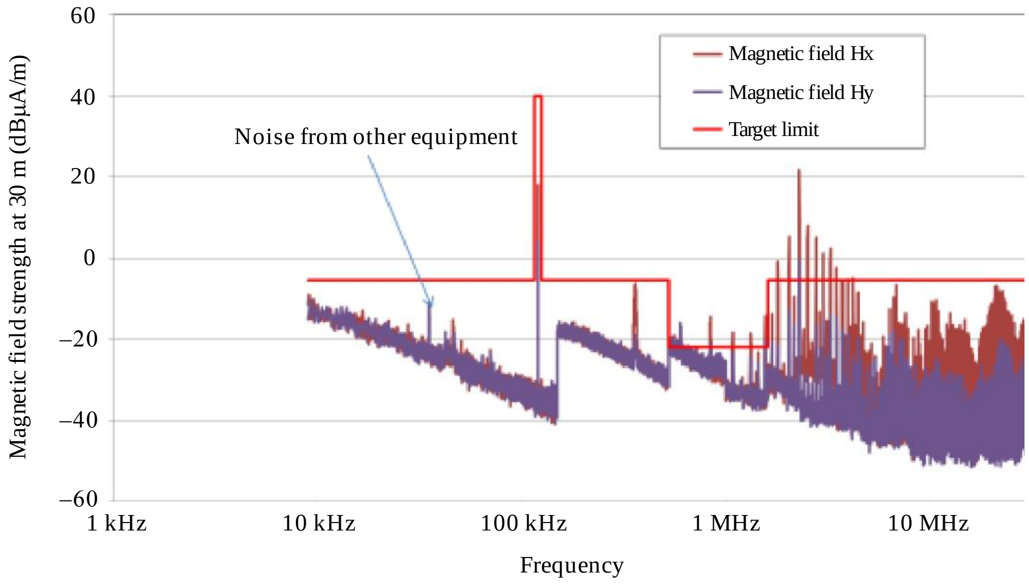

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FIGURE A3-12

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

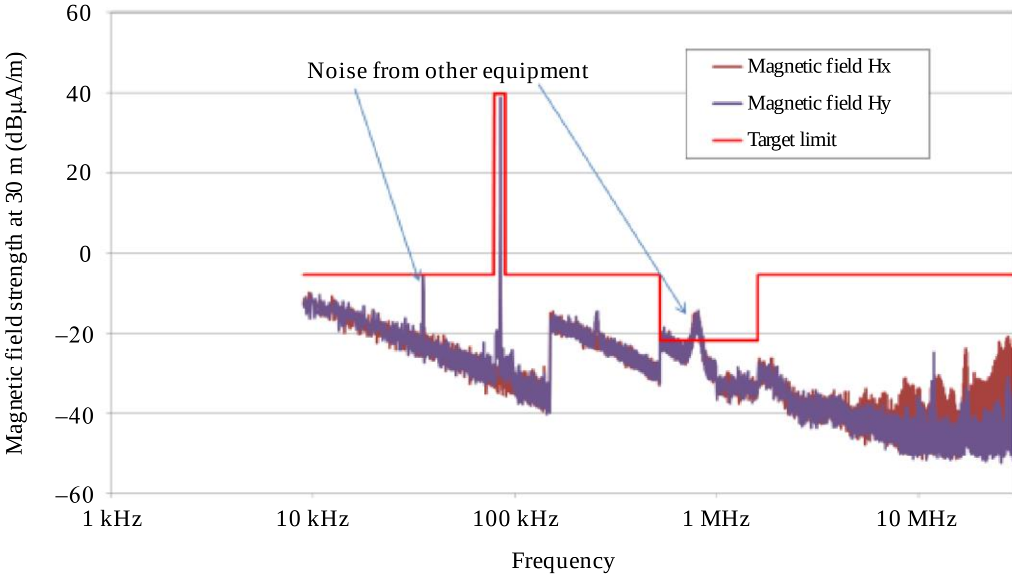

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FIGURE A3-13

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

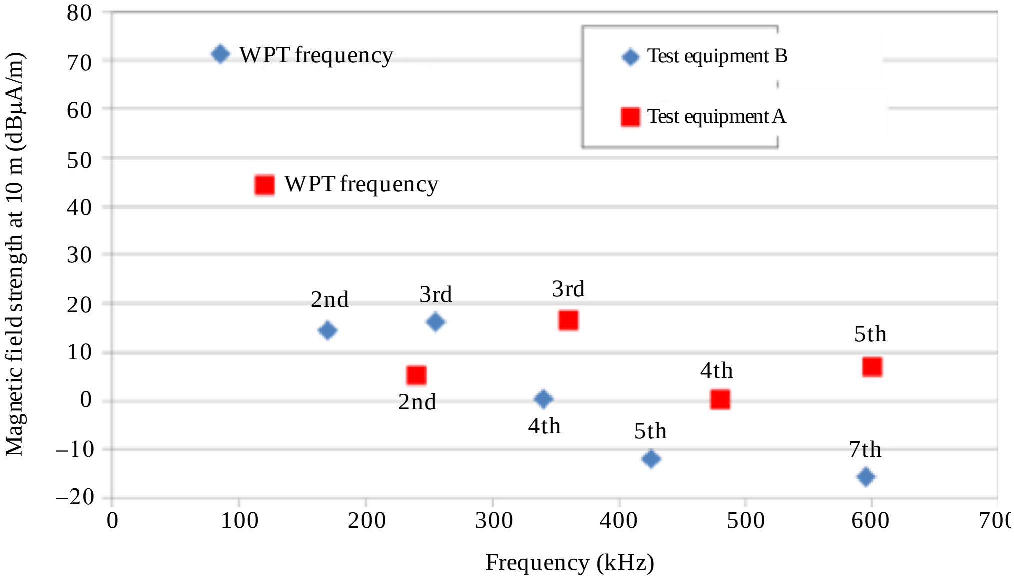

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FIGURE A3-14

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

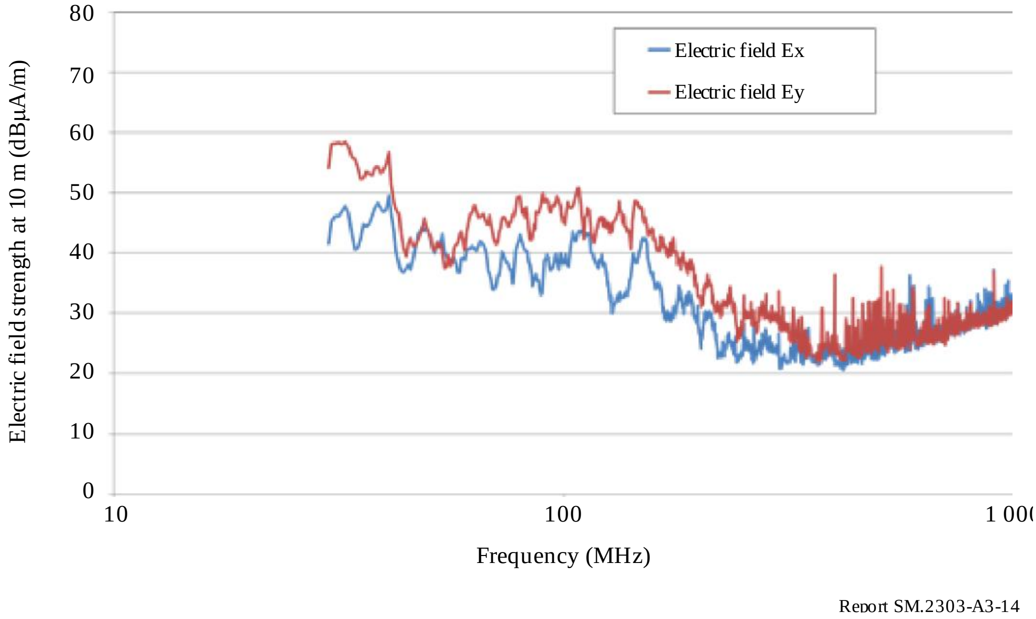
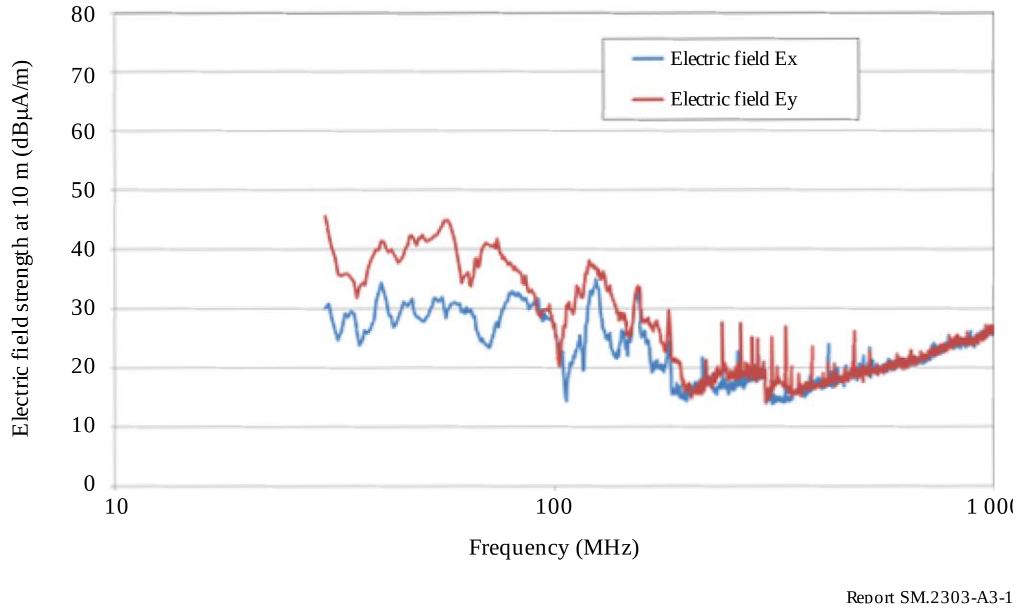


FIGURE A3-15

Radiated noise of test equipment B (30 MHz – 1 GHz, 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 Figs A3-16 and A3-17.

FIGURE A3-16

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

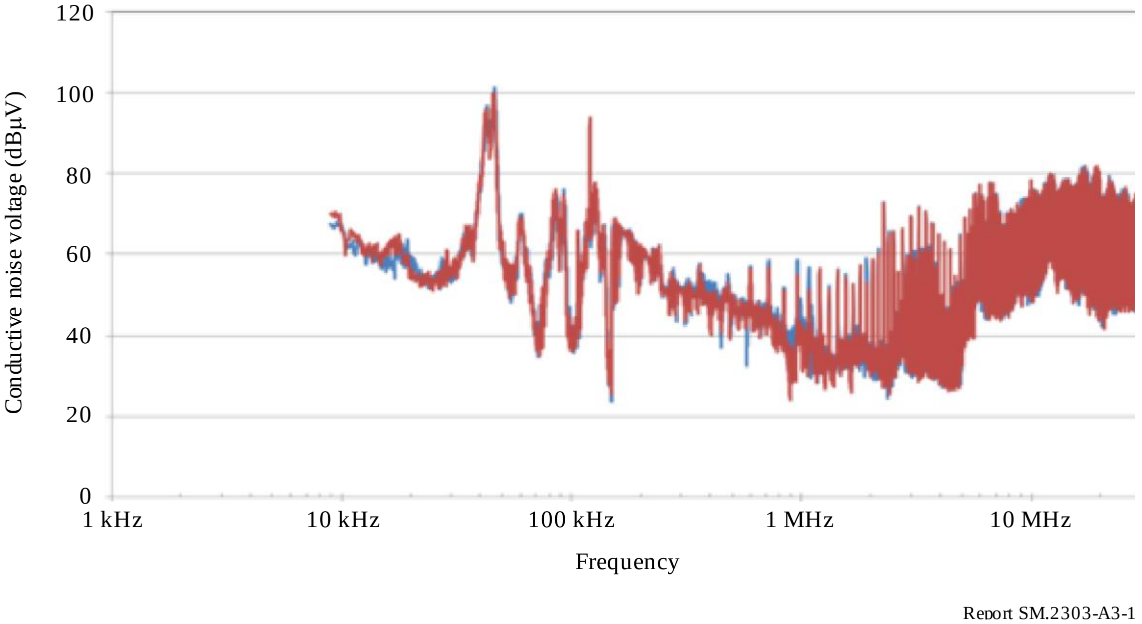
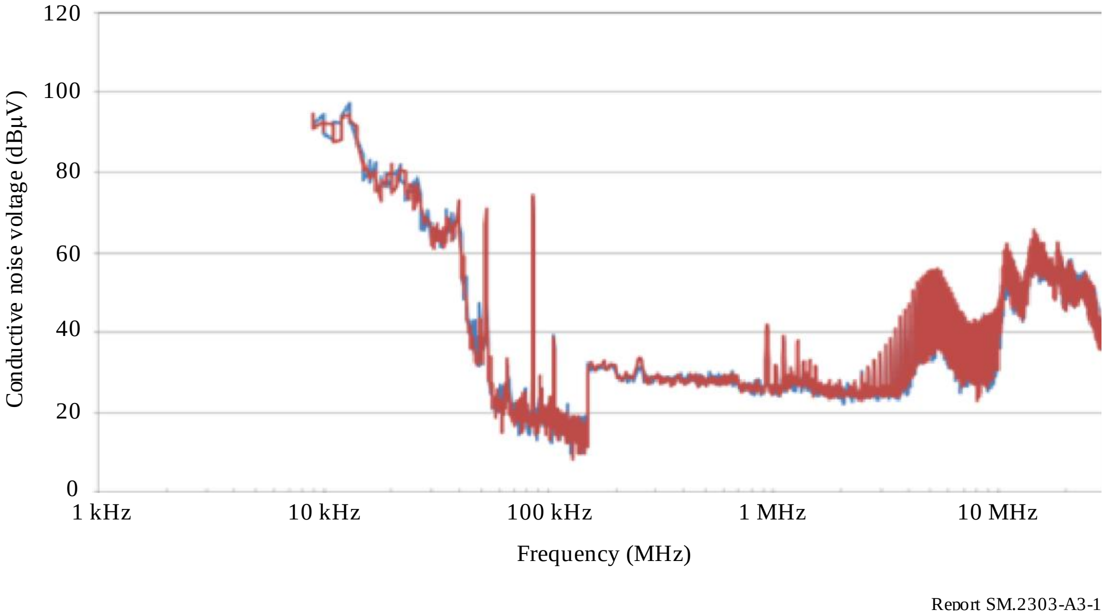


FIGURE A3-17

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



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.

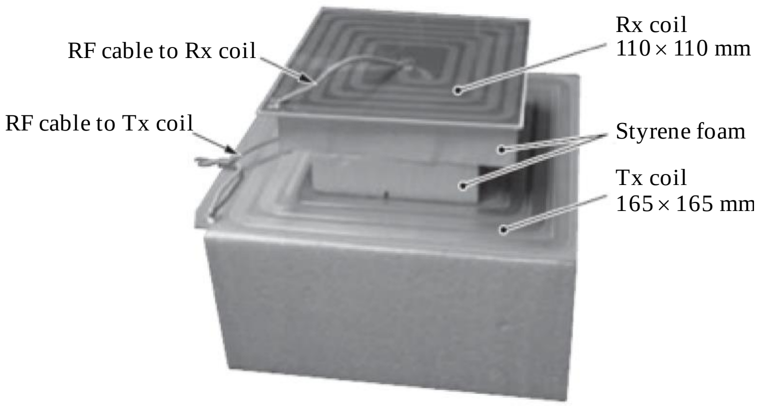
TABLE A3-2

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 centimetres

FIGURE A3-18

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



(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)

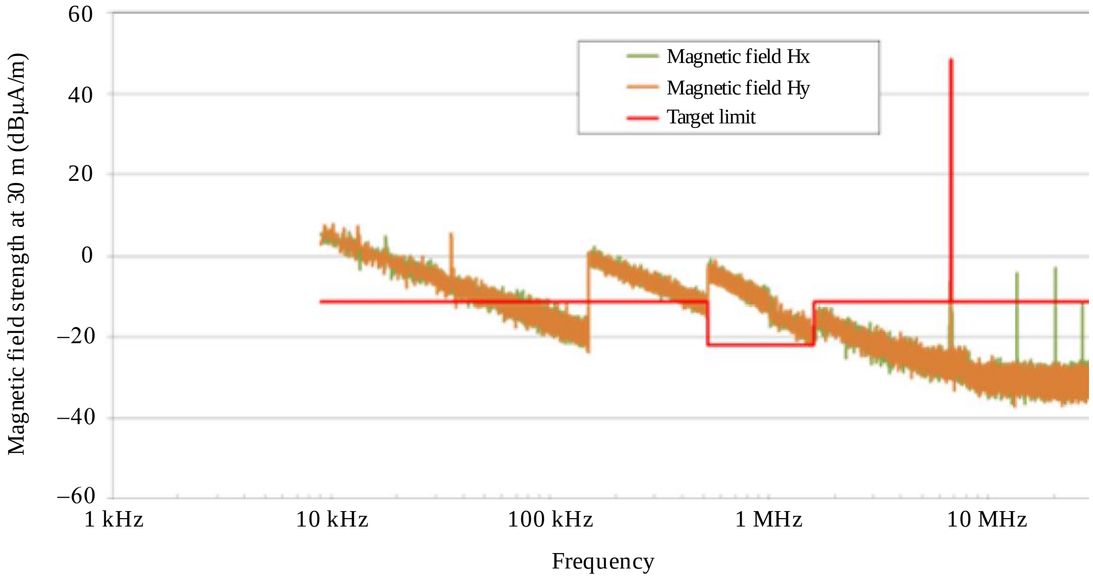


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FIGURE A3-20

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

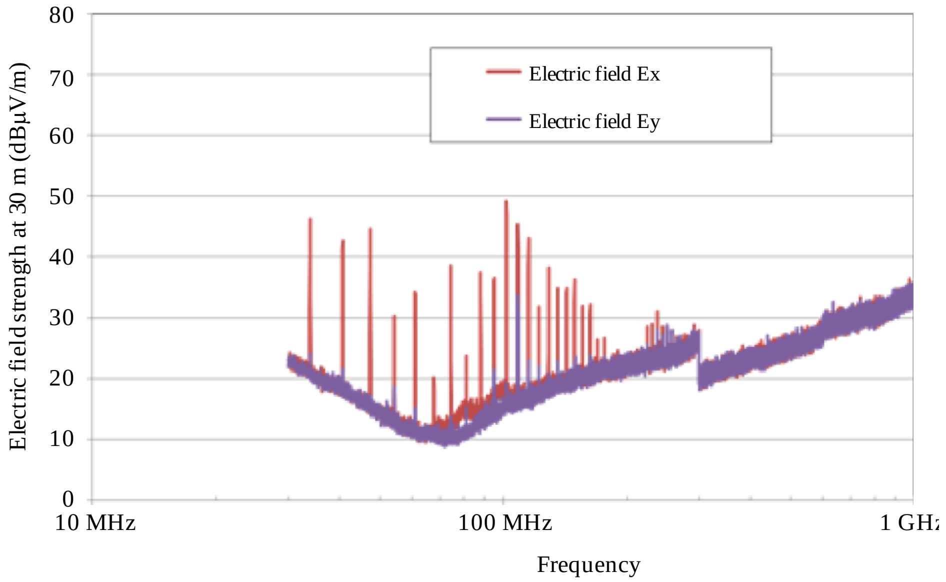

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FIGURE A3-21

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

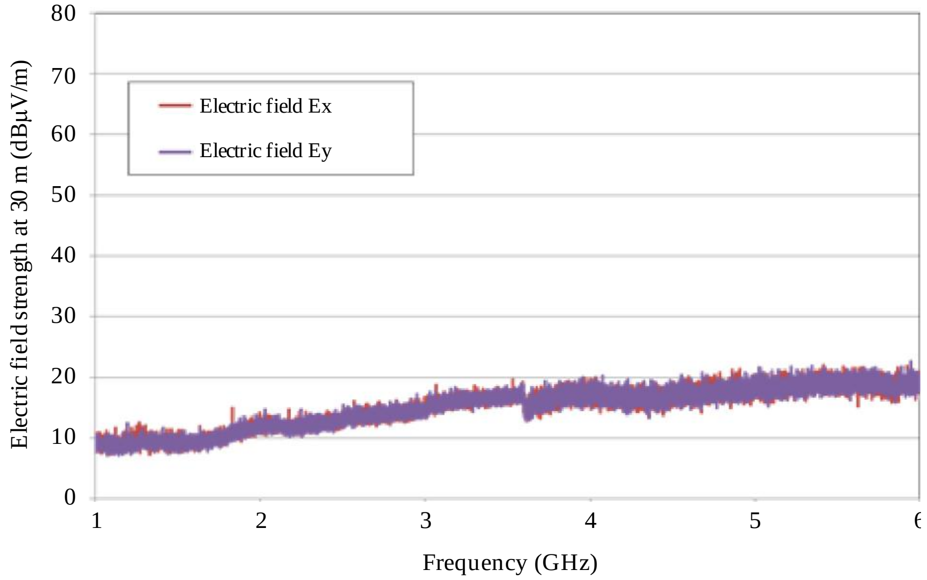

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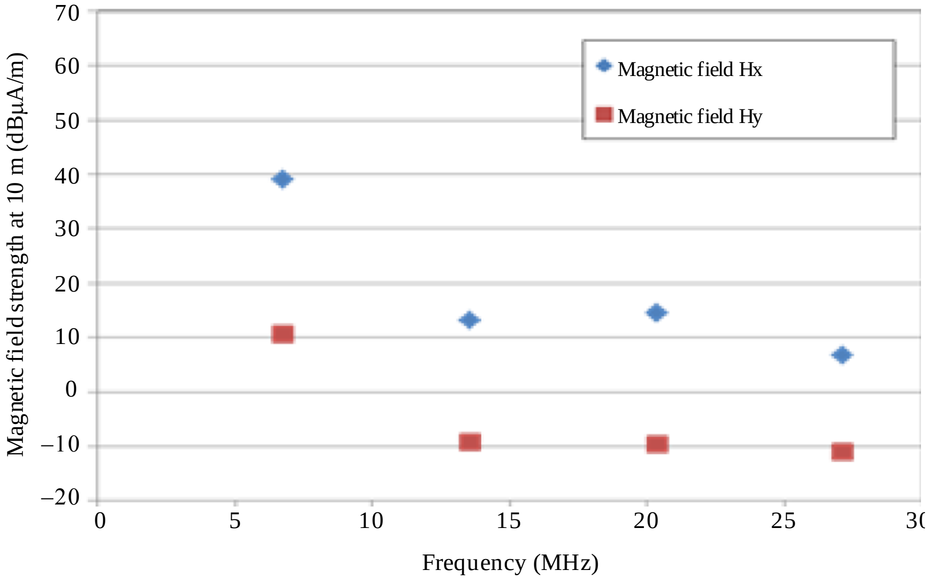
FIGURE A3-22

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



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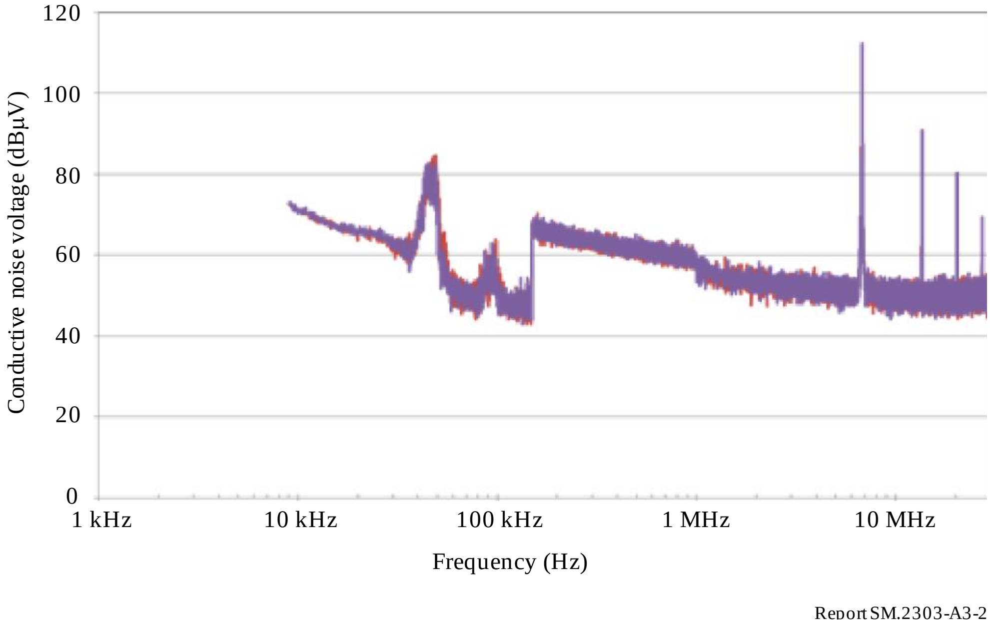
(3) Measurement results of conductive noise

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

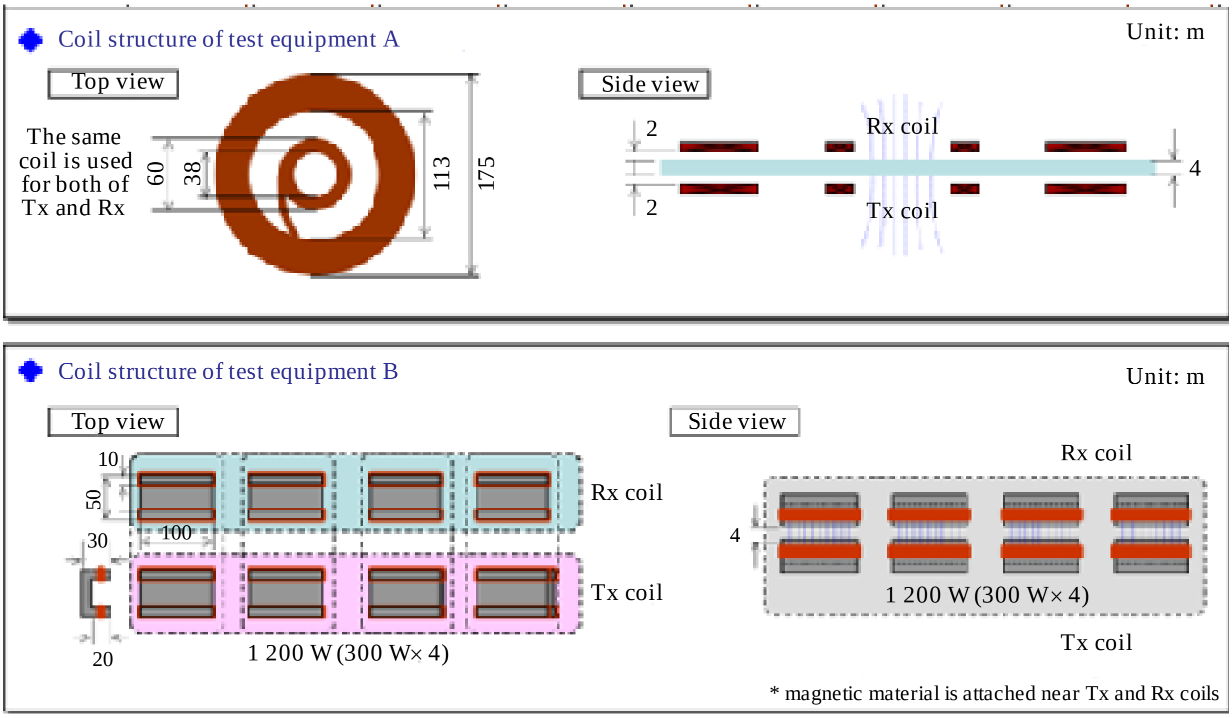
TABLE A3-3

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



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(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)

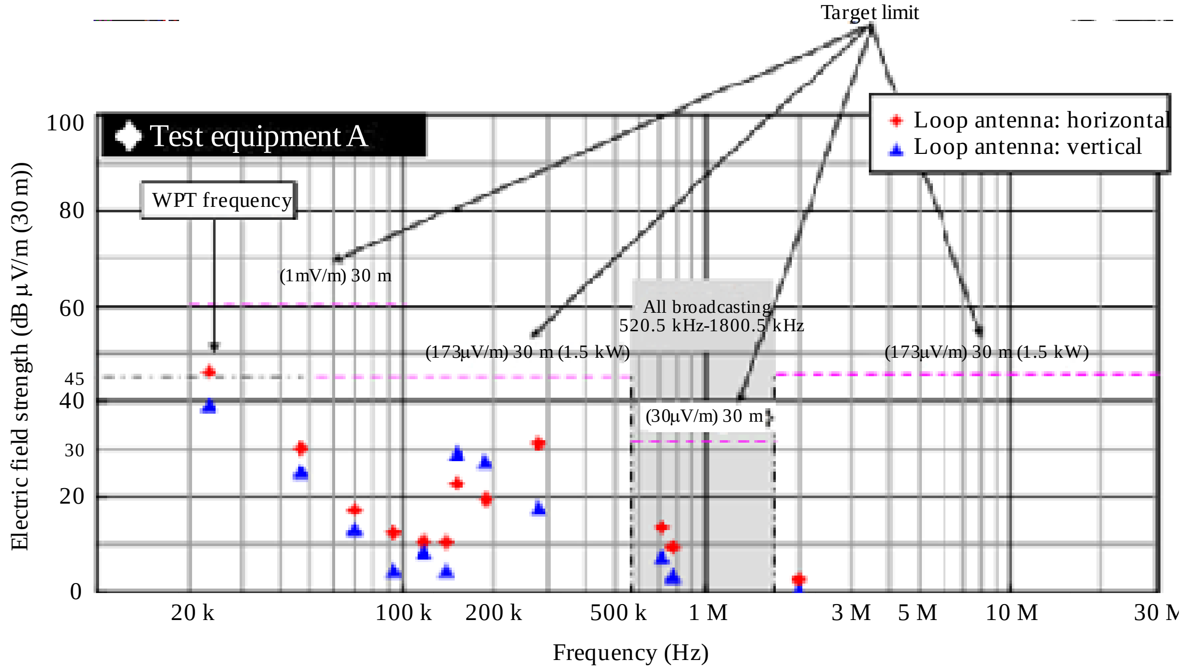

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FIGURE A3-26

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

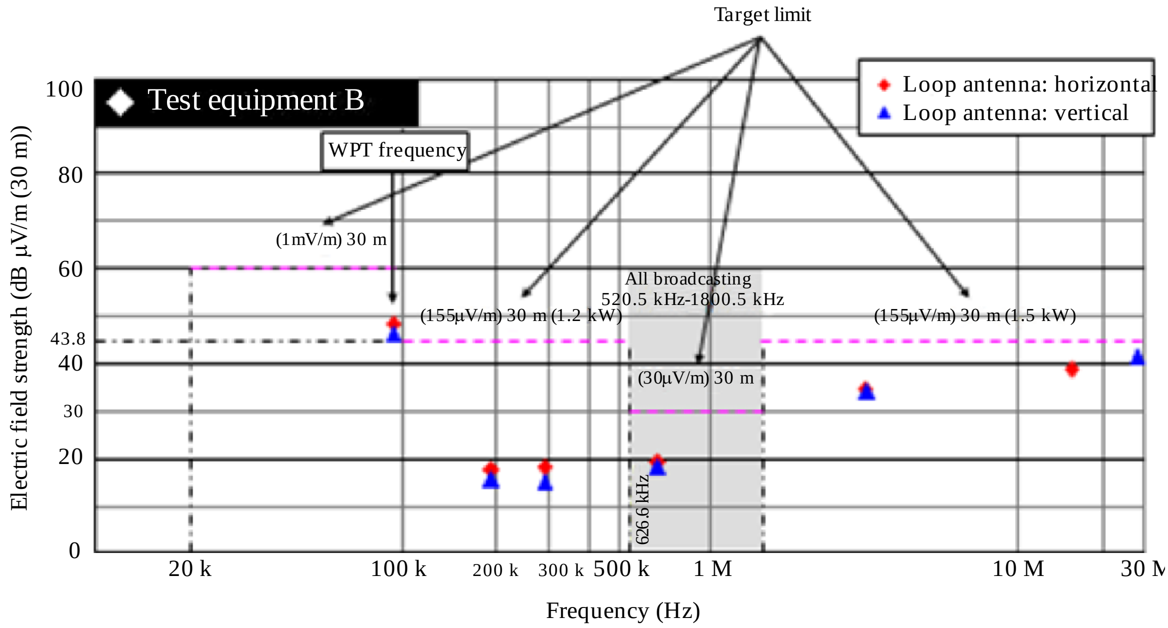

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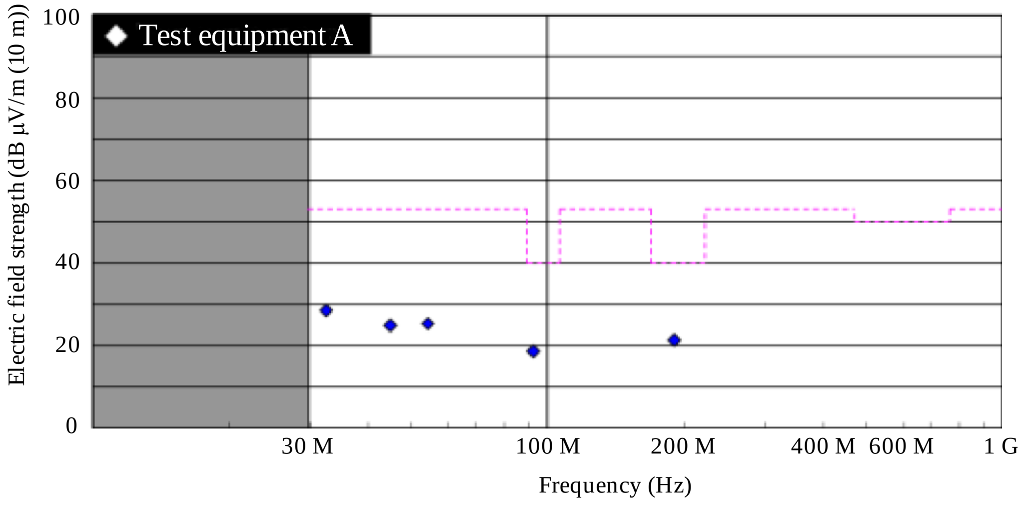
FIGURE A3-27

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



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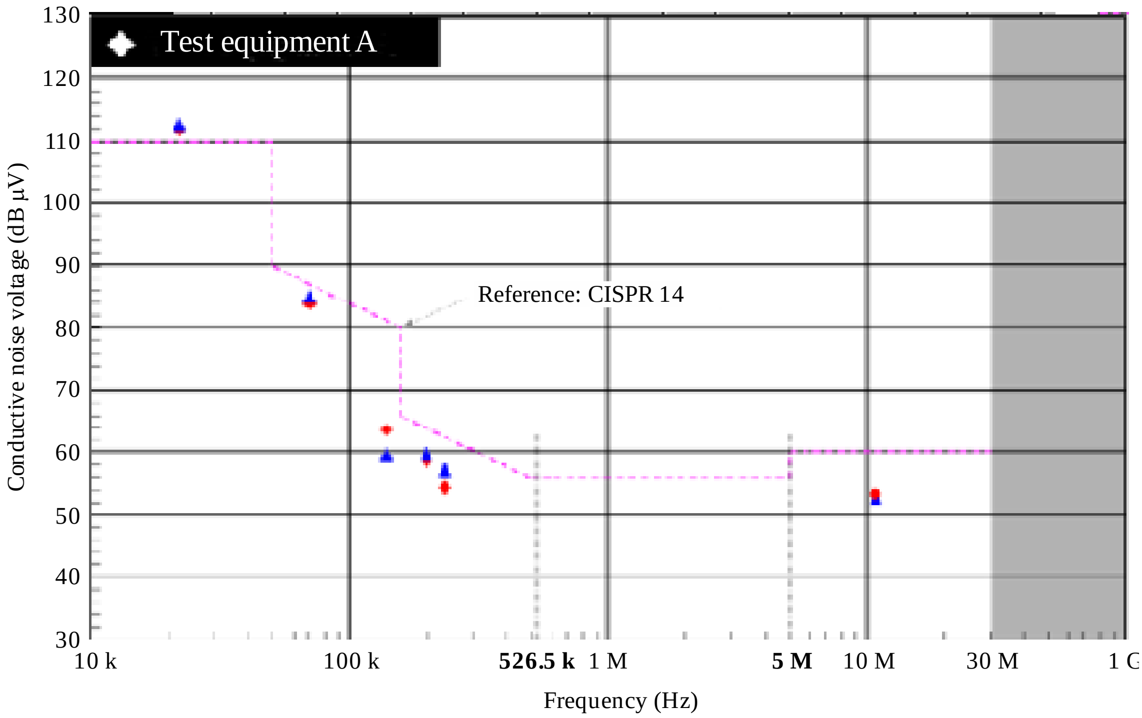
(3) Measurement results of conductive noise

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

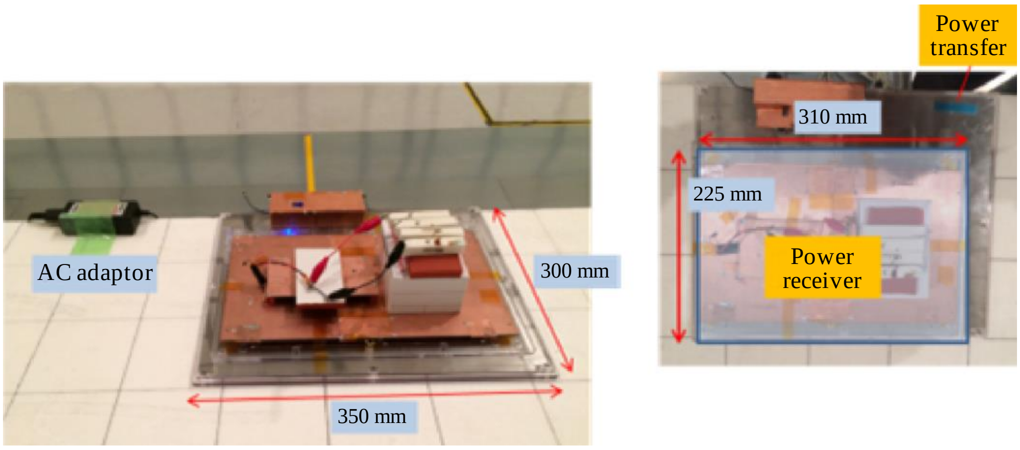

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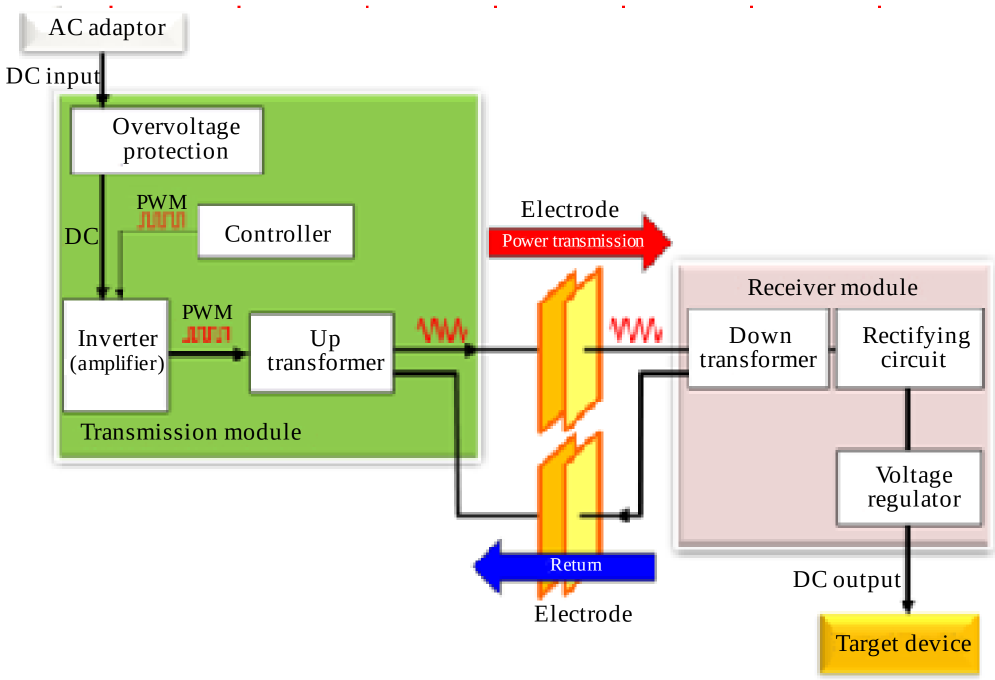
FIGURE A3-30

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)

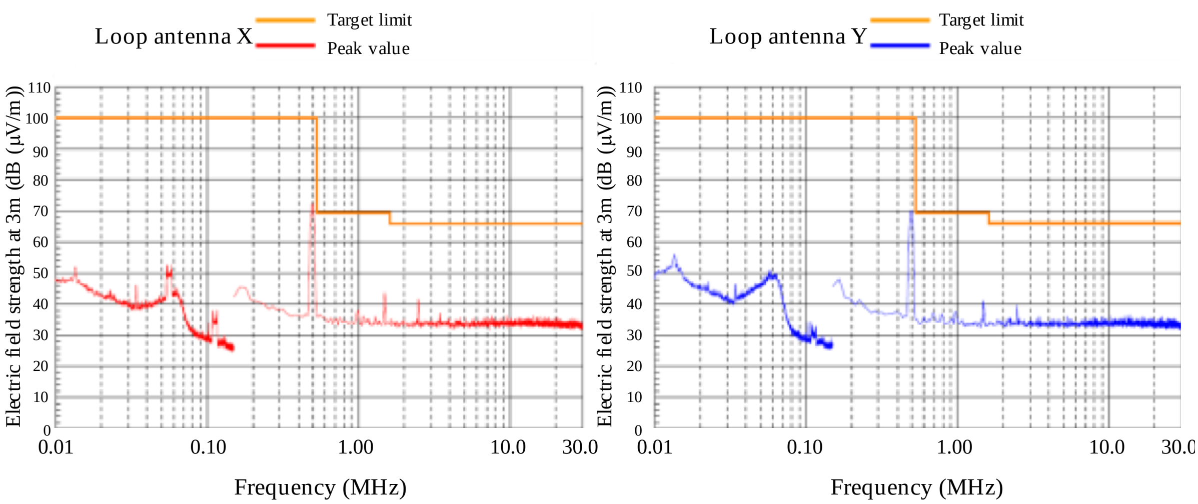

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FIGURE A3-32

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

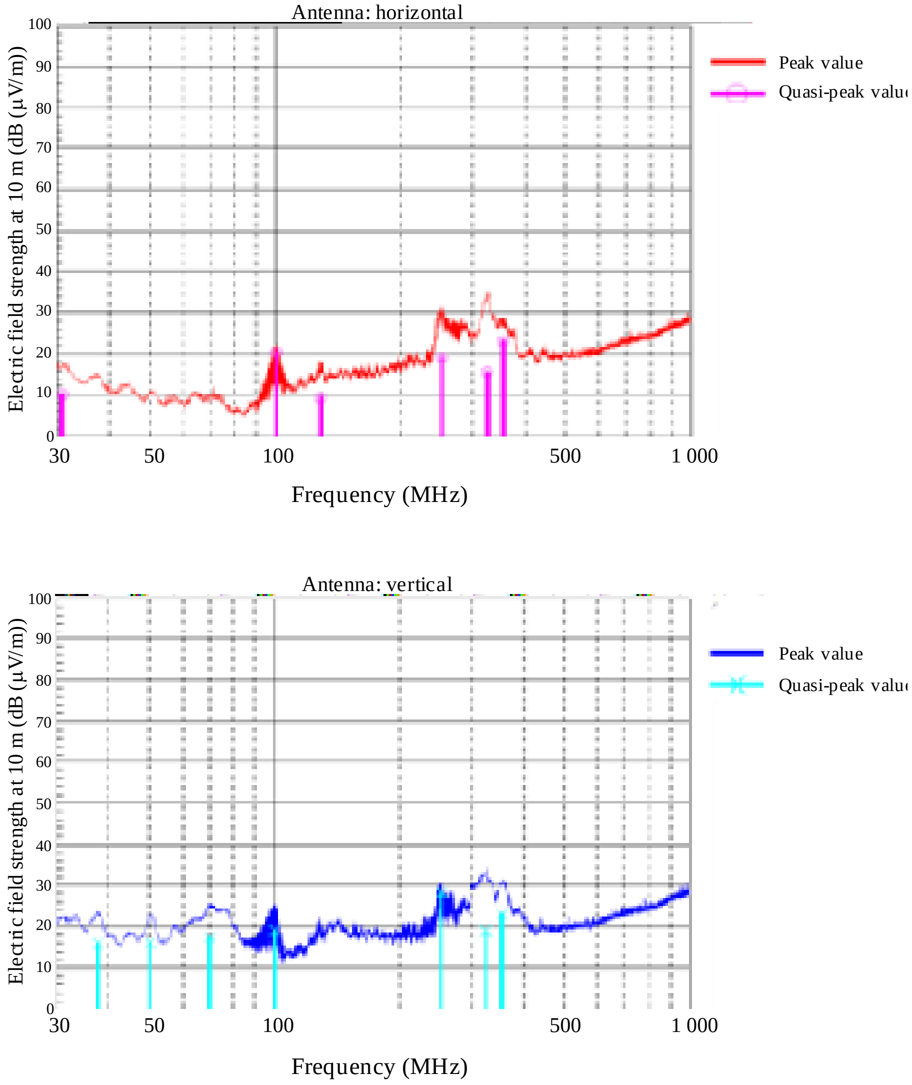

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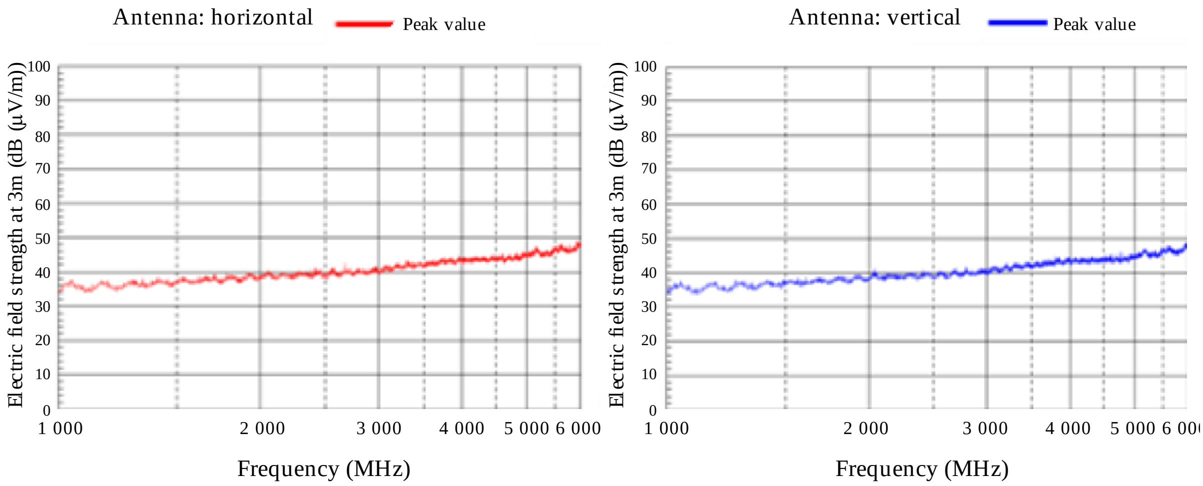
FIGURE A3-33

Radiated noise (1-6 GHz, peak value)



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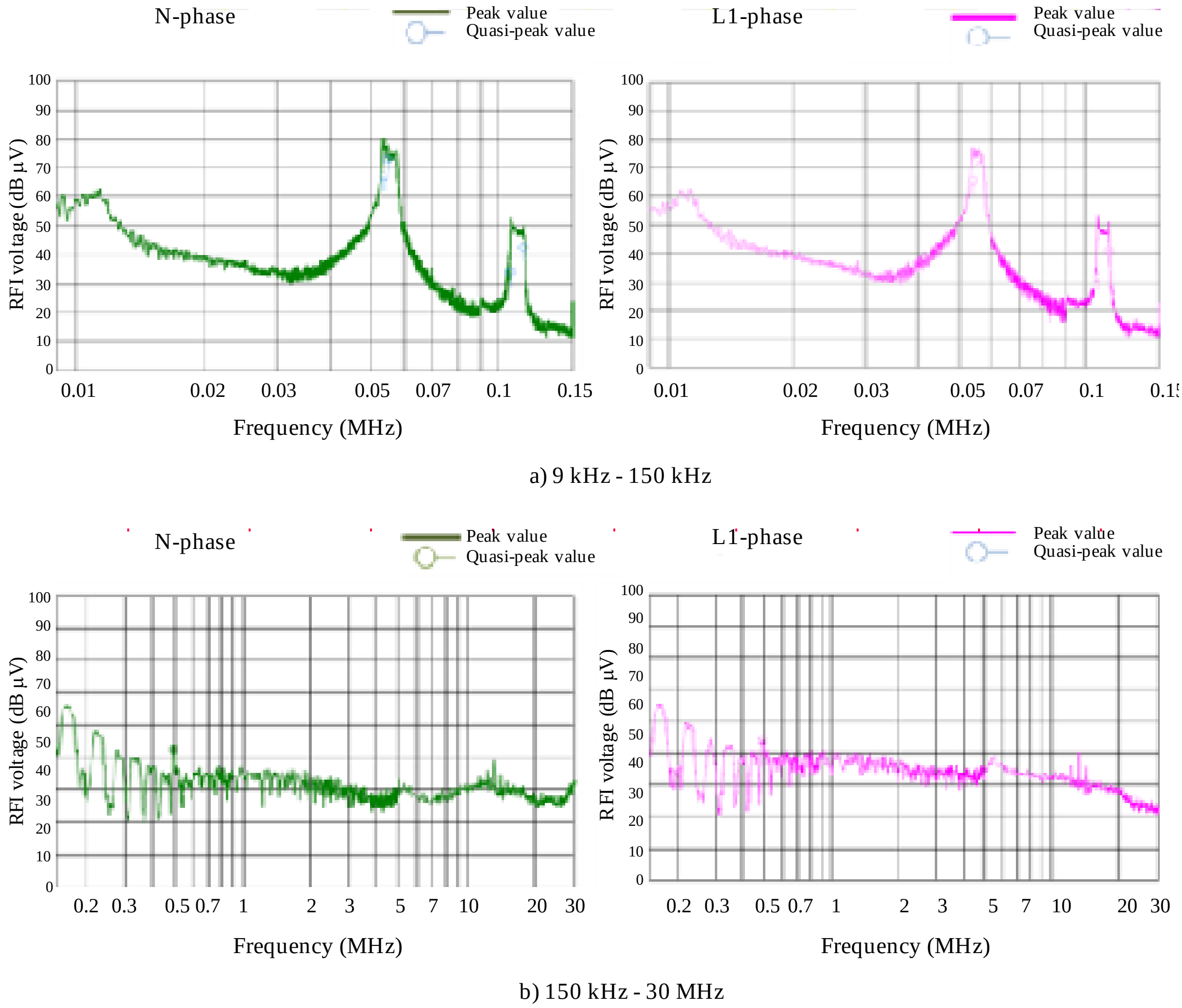
(3) Measurement results of conductive noise

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

FIGURE A3-34

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



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Annex 4

Measurements of WPT EV systems for the heavy-duty vehicle taken in Korea

Test results of electromagnetic disturbance of heavy-duty WPT EV systems

1 Test conditions

1.1 Circumstance of test site

Test environment of the heavy-duty WPT EV with the power inverter and power lines is shown in Fig. A4-1. Figure A4-2 shows four different measurement distances required for testing.

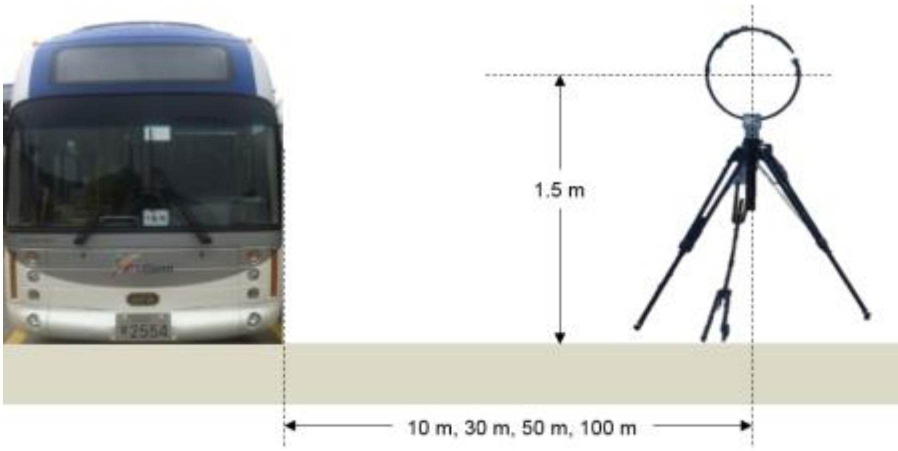
FIGURE A4-1

Surroundings of test site (in Gumi City)

H field intensities are measured with a loop antenna at four different distances from a WPT bus based on a fixed 1.5 m antenna height as shown in Fig. A4-2.

FIGURE A4-2

Measurement setup at four different distances adopted in our test



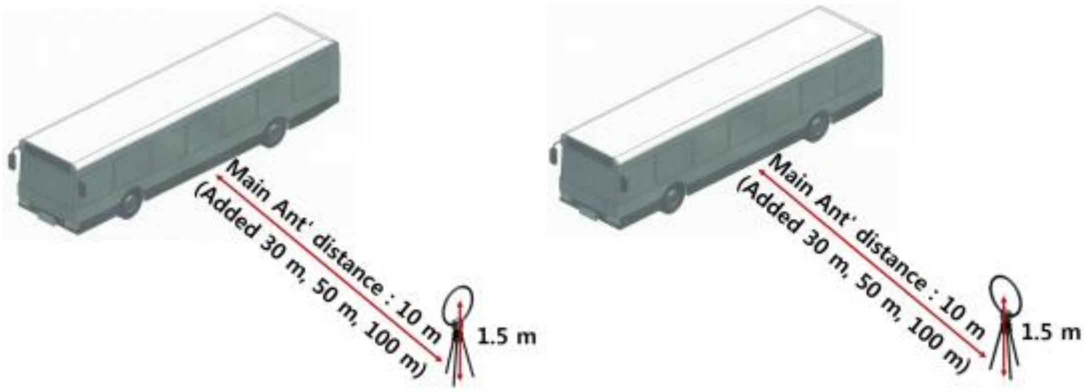
10 m is a reference distance provided by the test measurement method. However, the test was done at 30 m, 50 m and 100 m for checking the impact test conditions.

The reference is IEC 62236-2:2008, Railway applications -Electromagnetic Compatibility – Part 2.

The loop Antenna has frequency range 9 kHz to 30 MHz and additionally the antenna position can be a vertical x-axis and vertical y-axis (90o to the x-axis) as shown in Fig. A4-3.

FIGURE A4-3

Antenna positions for vertical x-axis and y-axis

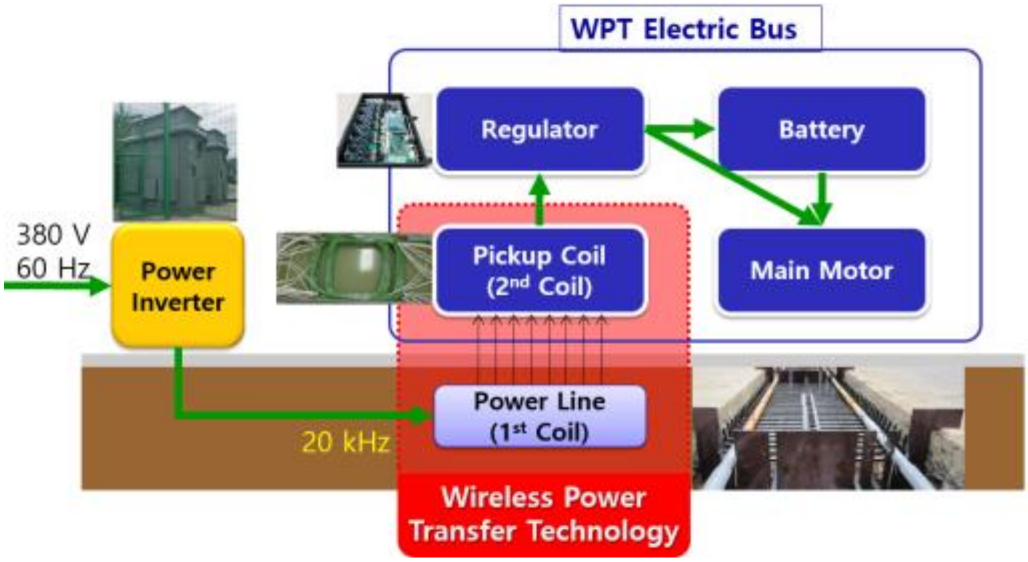


1.2 Configuration of heavy-duty WPT EV system

The power inverter in the yellow coloured block in Fig. A4-4 generates 20 kHz signals from 380 Vac@60 Hz and the signals are supplied to power line (1st Coil). The pickup coil (2nd Coil) is capturing the strong magnetic fields. Then the induced currents are changed to DC current from 20 kHz currents by its built-in rectifier. The changed DC current feeds to a regulator to charge the batteries or runs the main motors.

FIGURE A4-4

Block-diagram of WPT bus charging system for test



1.3 Operating conditions

Figure A4-5 shows the real charging site and on-charging heavy-duty WPT EV.

FIGURE A4-5

WPT bus and charging area (right hand side)

This test is carried out under the conditions of 125 A and 680 V (85 kW charging power), 99.26 kW main power, 85.6 % charging efficiency and 20 kHz.

FIGURE A4-6

Power inverters (left hand side) and meter indicating the main power of the inverter when a series of measurements have been carried out

1.4 Testing conditions

Measurement Devices are as follows:

① Antenna: Rhode & Schwarz, HFH2-Z2, Loop Antenna (calibrated in 8th Mar, 2017)

② Receiver: Agilent E4440A, Spectrum Analyzer (Calibrated in 15th Apr, 2016)

The weather conditions for testing are as follows;

① Test period: April 13 to April 14, 2017

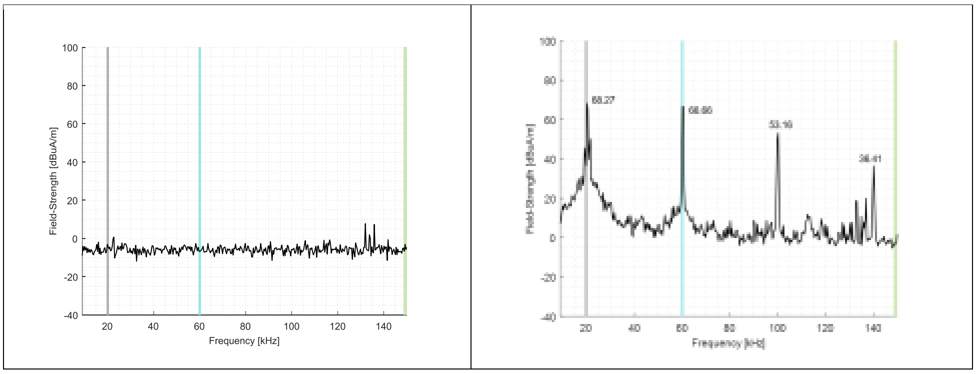
② Temperature: 12 ℃ ~ 25 ℃ (10:00 AM to 5:00 PM)

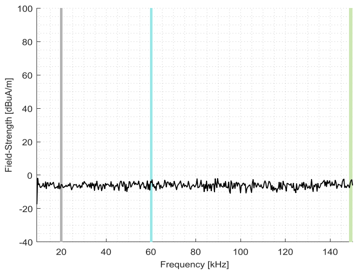
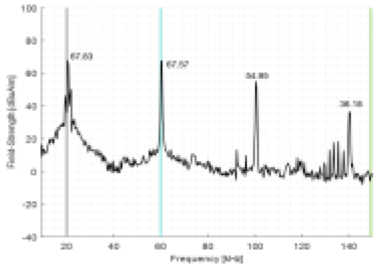
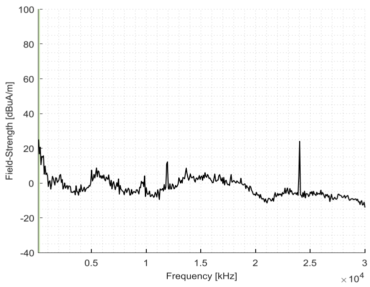
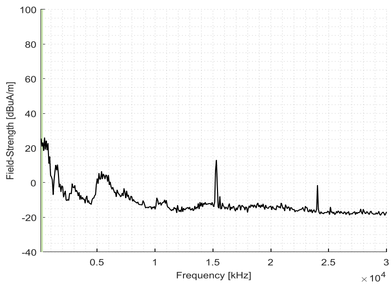
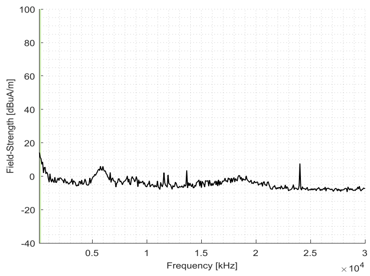
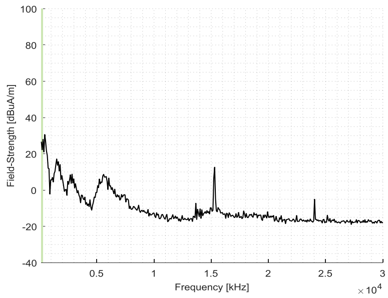
③ Humidity: 45 %R.H. (Rainfall probability: 16%)

④ Wind speed: 4 m/s

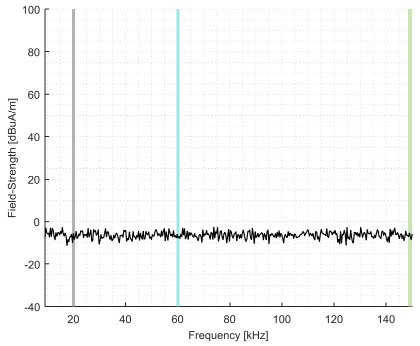
2 Test results at different distances

2.1 10 m

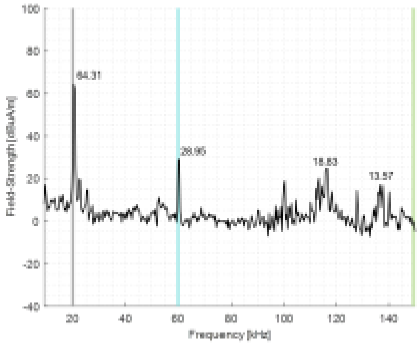


<table>
<tr><td>Vertical X-axis 9 ㎑~ 150 ㎑
(Ambient)</td><td>Vertical X-axis 9 ㎑~ 150 ㎑
(Charging)</td></tr>
<tr><td>
</td><td></td></tr>
<tr><td>Vertical Y-axis 9 ㎑~ 150 ㎑
(Ambient)</td><td>Vertical Y-axis 9 ㎑~ 150 ㎑
(Charging)</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Vertical X-axis 150 ㎑~ 30 ㎒
(Ambient)</td><td>Vertical X-axis 150 ㎑~ 30 ㎒
(Charging)</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Vertical Y-axis 150 ㎑~ 30 ㎒
(Ambient)</td><td>Vertical Y-axis 150 ㎑~ 30 ㎒
(Charging)</td></tr>
</table>

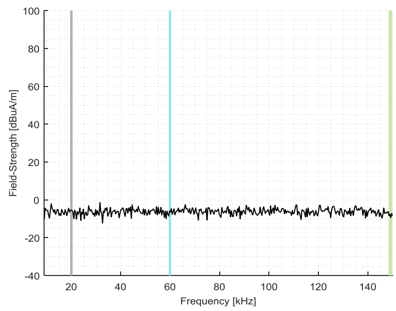
2.2 30 m



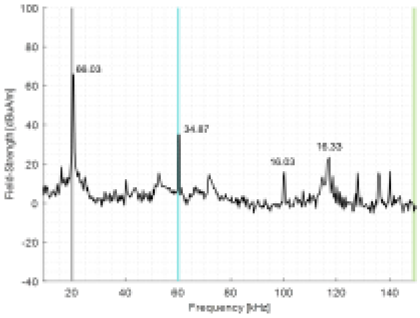
Vertical X-axis 9 ㎑~ 150㎑(Ambient)



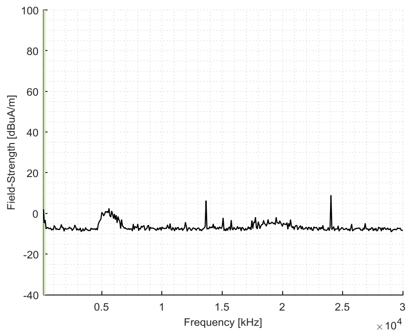
Vertical X-axis 9㎑~ 150㎑(Charging)



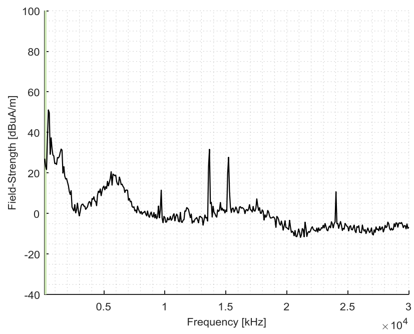
Vertical Y-axis 9㎑~ 150㎑(Ambient)



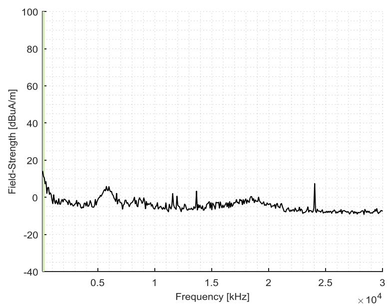
Vertical Y-axis 9㎑~ 150㎑(Charging)



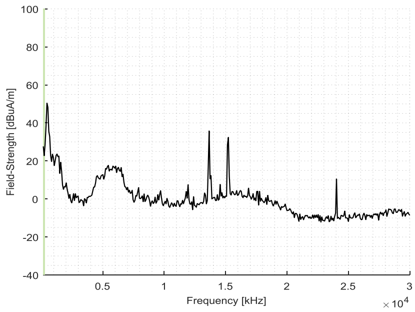
Vertical X-axis 150㎑~ 30㎒(Ambient)



Vertical X-axis 150㎑~ 30㎒(Charging)

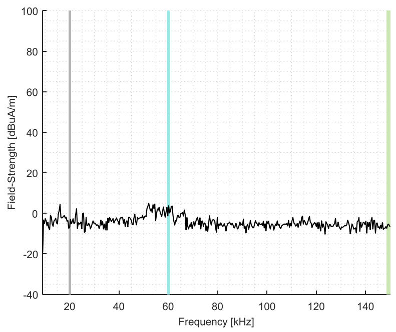


Vertical Y-axis 150㎑~ 30㎒(Ambient)

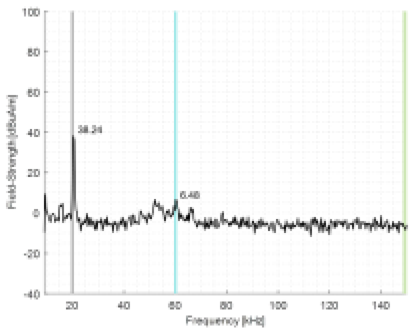


Vertical Y-axis 150㎑~ 30㎒(Charging)

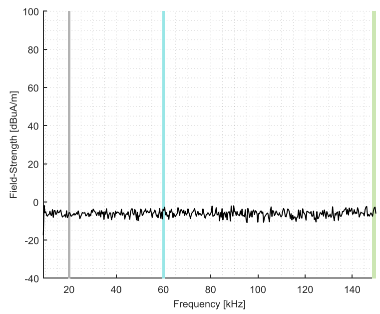
2.3 50 m



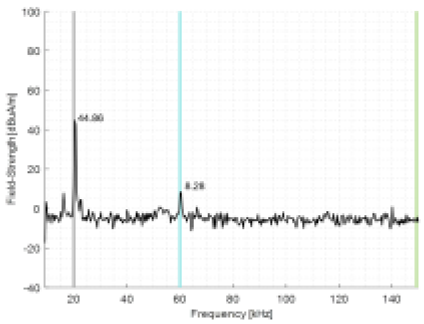
Vertical X-axis 9㎑~ 150㎑(Ambient)



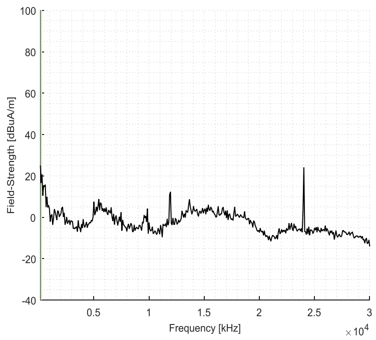
Vertical X-axis 9㎑~ 150㎑(Charging)



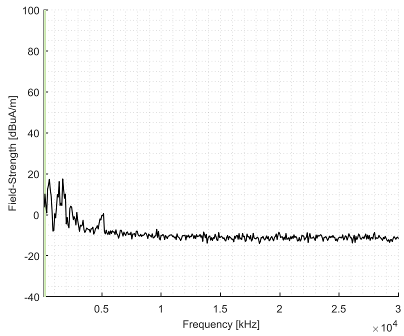
Vertical Y-axis 9㎑~ 150㎑(Ambient)



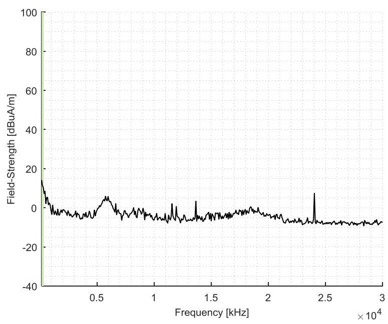
Vertical Y-axis 9㎑~ 150㎑(Charging)



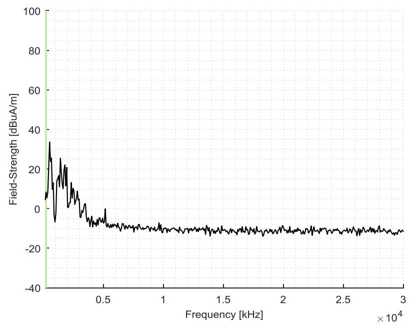
Vertical X-axis 150㎑~ 30㎒(Ambient)



Vertical X-axis 150㎑~ 30㎒(Charging)

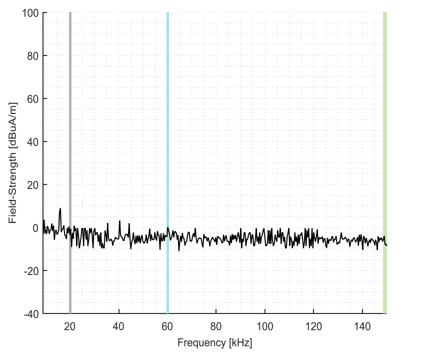


Vertical Y-axis 150㎑~ 30㎒(Ambient)

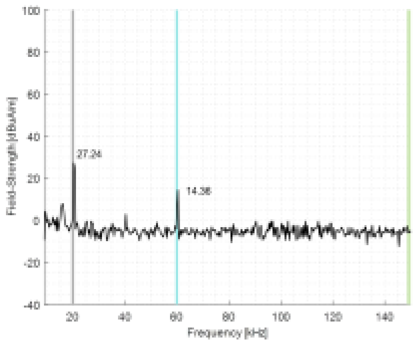


Vertical Y-axis 150㎑~ 30㎒(Charging)

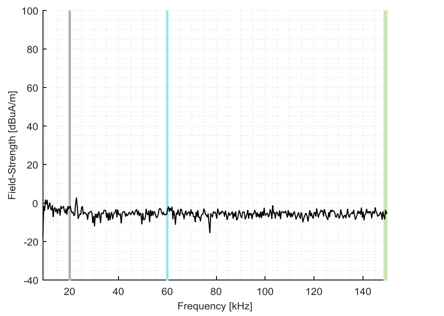
2.4 100 m



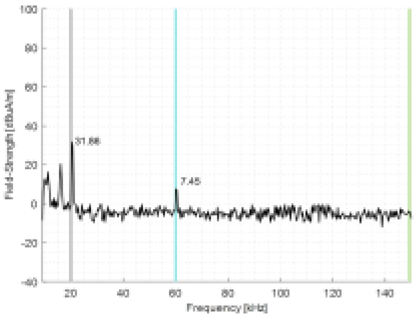
Vertical X-axis 9㎑~ 150㎑(Ambient)



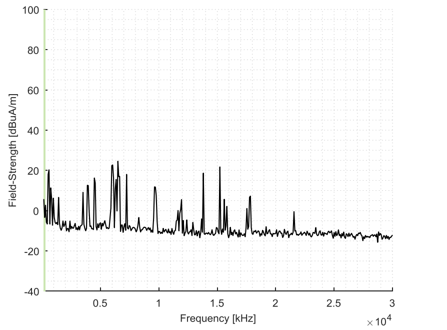
Vertical X-axis 9㎑~ 150㎑(Charging)



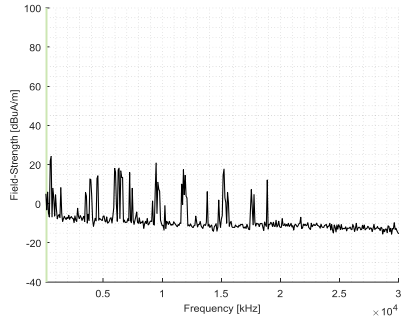
Vertical Y-axis 9㎑~ 150㎑(Ambient)



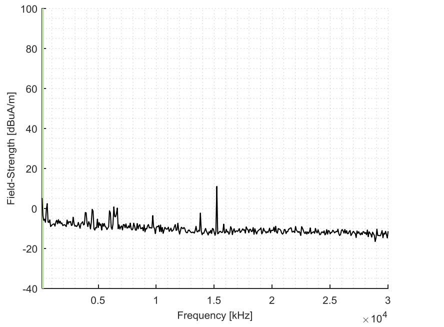
Vertical Y-axis 9㎑~ 150㎑(Charging)



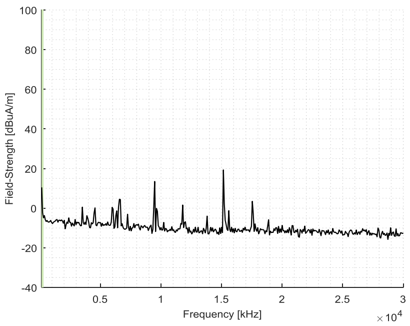
Vertical X-axis 150㎑~ 30㎒(Ambient)



Vertical X-axis 150㎑~ 30㎒(Charging)



Vertical Y-axis 150㎑~ 30㎒(Ambient)

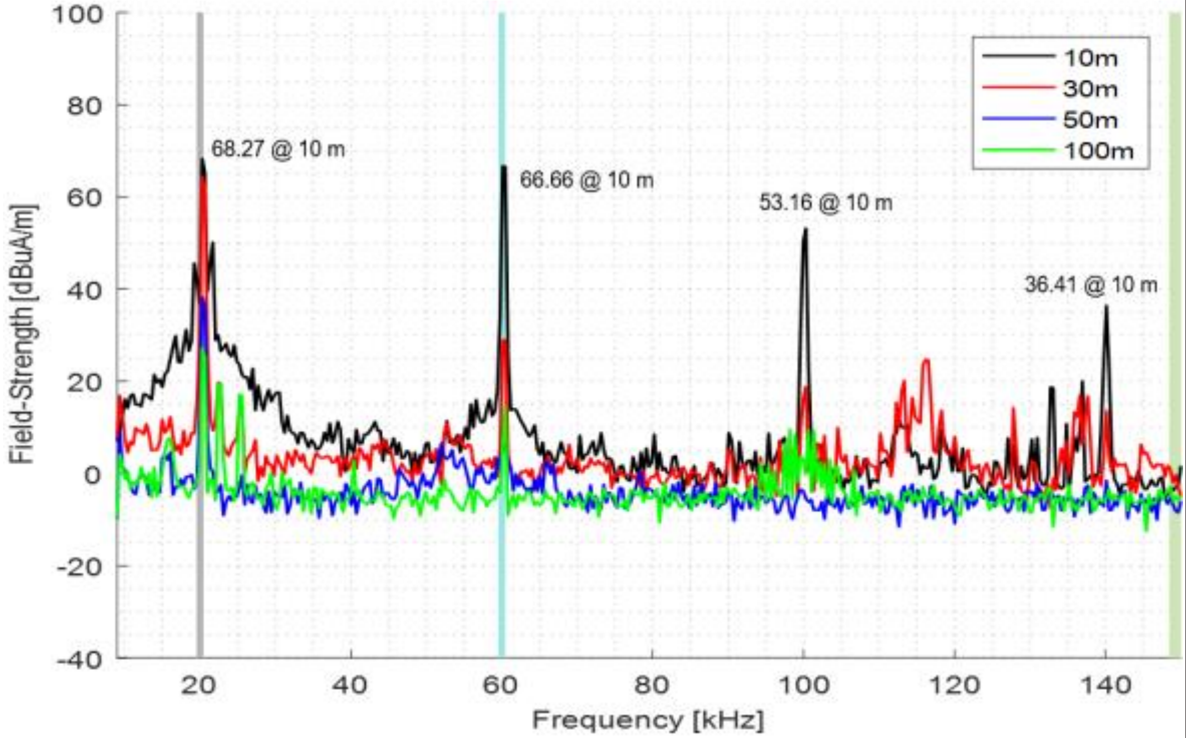


Vertical Y-axis 150㎑~ 30㎒(Charging)

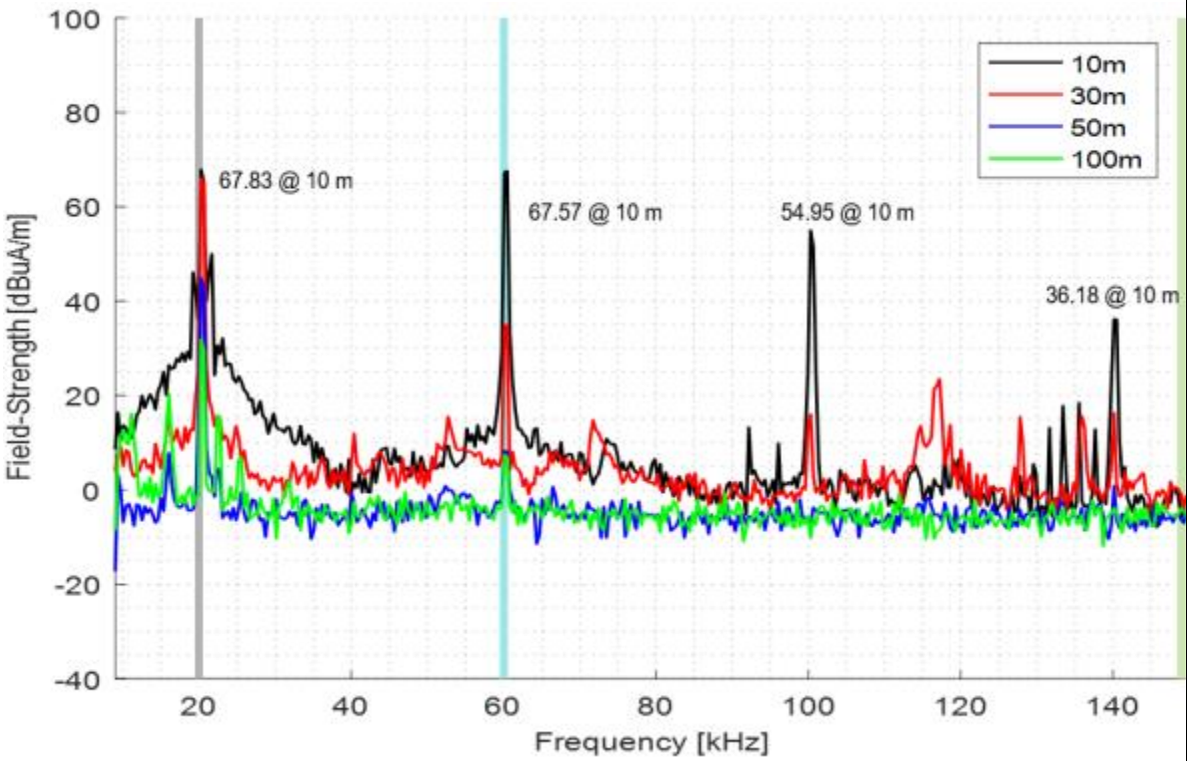
2.5 Compared data I (9 kHz ~ 150 kHz)

FIGURE A4-7

Comparison of H field characteristics at each distance for 9 ㎑ ~ 150 ㎑



Vertical X-axis 9 ㎑~ 150 ㎑

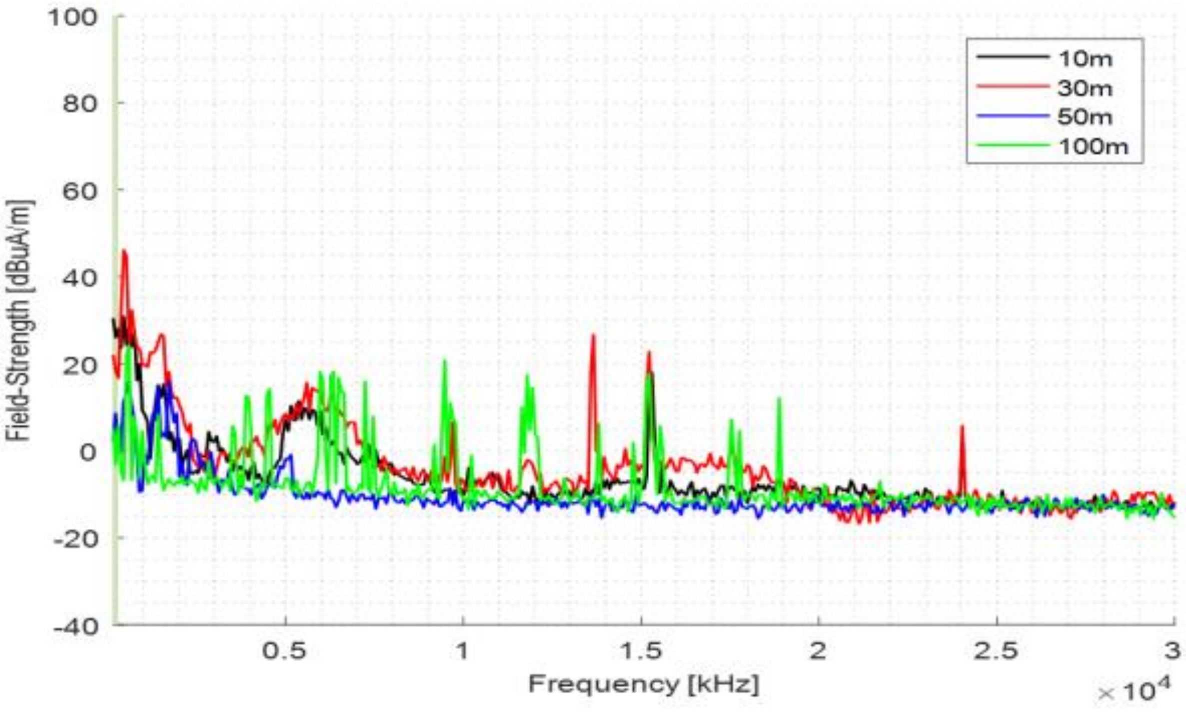


Vertical Y-axis 9 ㎑~ 150 ㎑

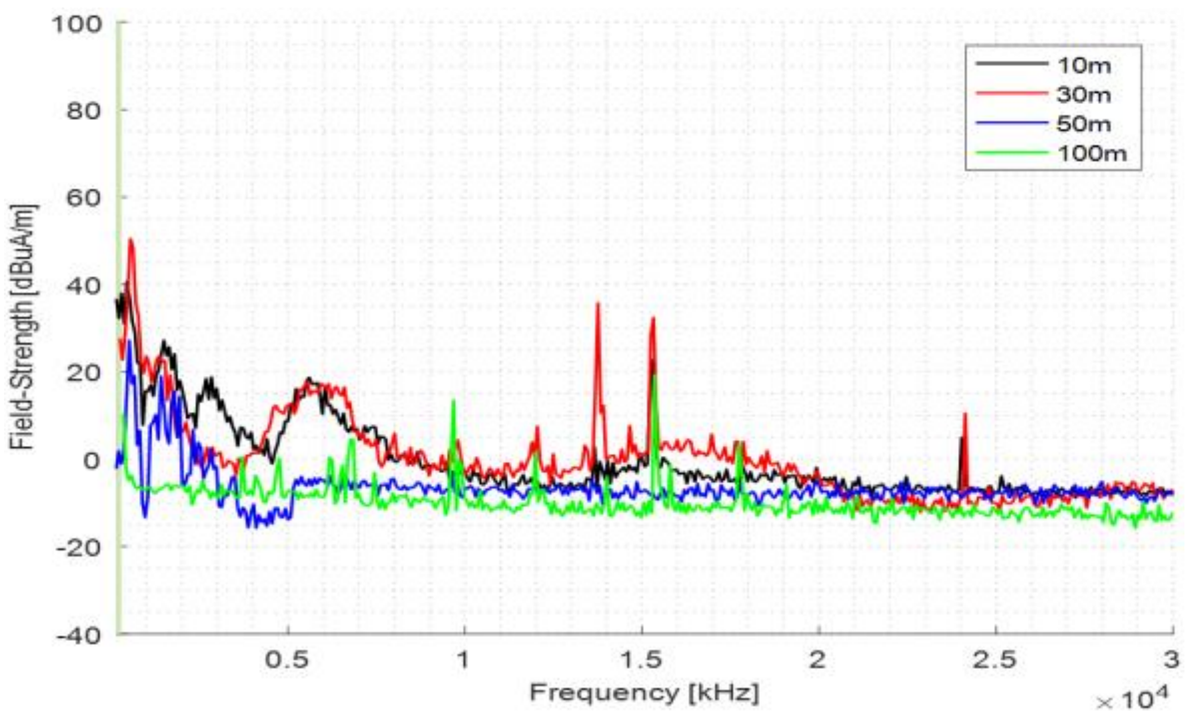
2.6 Compared data II (150 kHz ~ 30 MHz)

FIGURE A4-8

Comparison of H field characteristics at each distance for 150 ㎑ ~ 30 MHz



Vertical X-axis 150 ㎑~ 30 ㎒



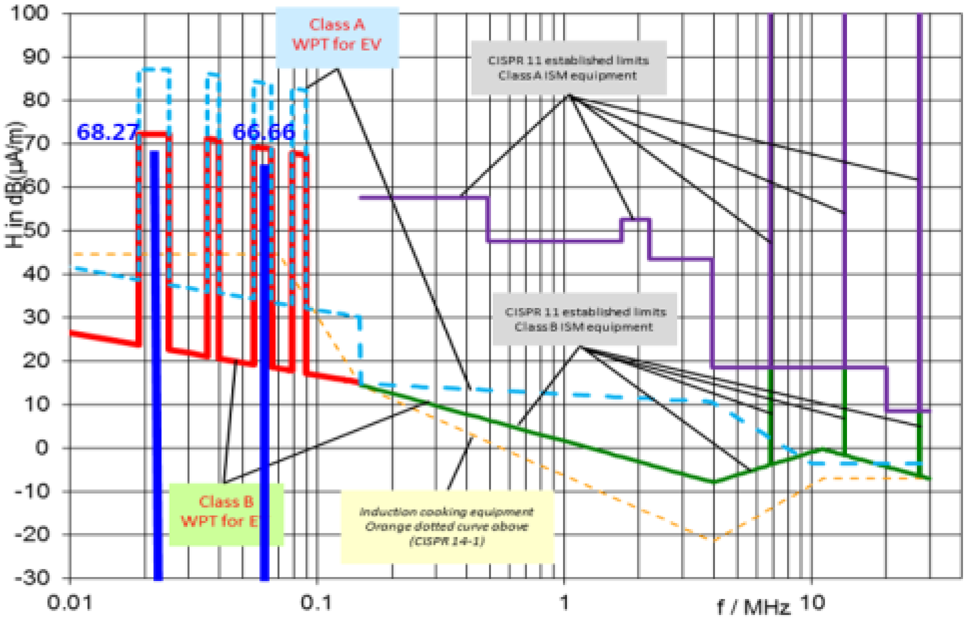
Vertical Y-axis 150 ㎑~ 30 ㎒

3 Conclusions

The test result at 10 m shows the maximum 68.27 dBμA/m@20 kHz and 66.66 dBμA/m@60 kHz under the condition of WPT EV being charged by the power line. The measurement value meets the H-field limitation proposed by CISPR B (not only "Class A" but "Class B" WPT for Electric Vehicle).

FIGURE A4-9

H-Field limits adopted in the CISPR B/TF-WPT meeting



4 Impact study in Korea

4.1 Introduction

Since Japan suggested an impact study for an interference between WPT EV frequencies and Japan Radio Standard time signal (60 kHz) in 2015, Korea has tried various impact case studies for many times.

The study items are as follows:

– 60 kHz interference from Japan NICT

– Harmonic frequencies interference for EBU (European Broadcasting Union) LF (148.5 ~ 283.5 kHz)

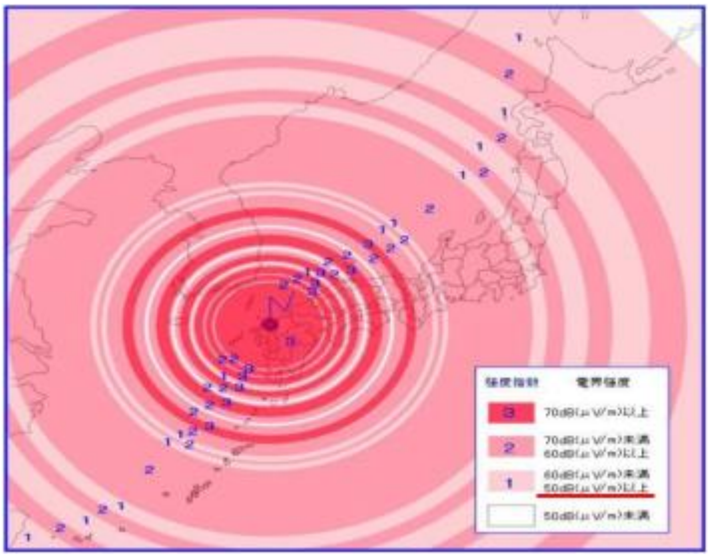
4.2 The impact study for 60 kHz standard time signal from Japan (NICT)

Japan reported to ITU-R SG1 WP1A the co-existence study internally between WPT EV and other electronic devices in Nov 2014 written in Japanese language. It included also EMI and EMF issues.

Since ITU-R SG1 WP1A meeting in June 2015, Japan delegation of ITU-R SG1 introduced that NICT(Japan) uses 60 kHz as standard time signal from the Hagane-transmitting station located in Kitakyushu. Japan requested the interference and/or impact study between Korean heavy-duty WPT EV and Japanese standard time signal.

FIGURE A4-10

Electric field strength of 60 kHz standard time signal (source: NICT Homepage)



According to electric field strength table of the 60 kHz (source: NICT homepage), the lowest level is 50 dBμV/m. In this reason, the limitation of 60 kHz standard time signal is 50 dBμV/m.

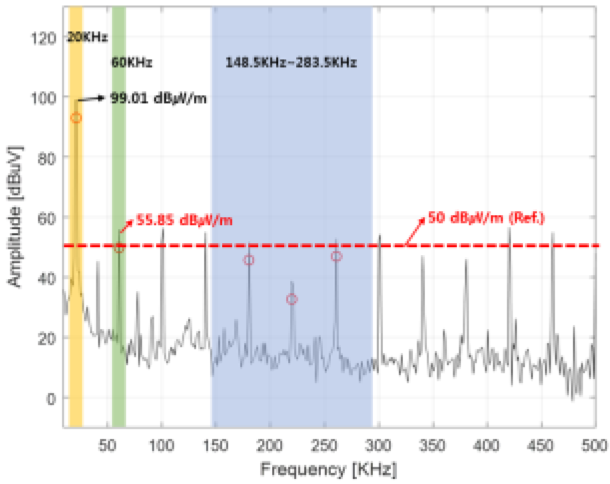
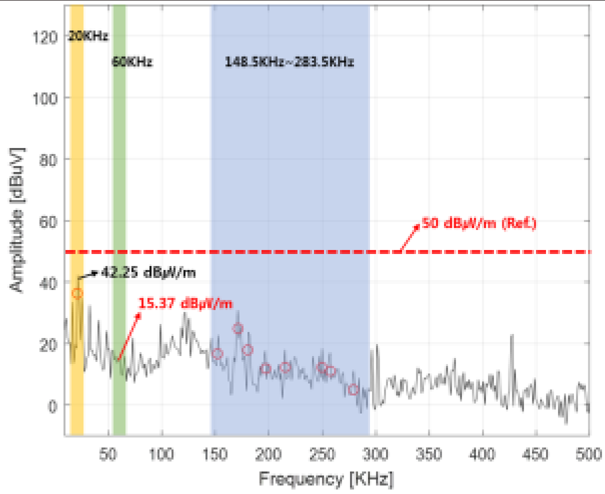
The real clocks used 60 kHz time signal is shown in Fig. A4-11 and the test result is shown in Fig. A4-12.

FIGURE A4-11

Real clocks used 60 kHz standard time signal

FIGURE A4-12

Test result at 10 m and 100 m based on 60 kHz standard time signal

10 m (charging)	100 m (charging)
	

At 10 m, the amplitude of 60 kHz is 55.85 dBuV/m and the value is greater than the limitation with 5.85 dB . At 100 m, the amplitude of 60 kHz is 15.37 dBuV/m and the limitation had a margin of 34.63 dB.

In a result, 100 m of separation distance is enough to protect the 60 kHz time signal clock from a heavy-duty WPT EV charging station. In practice, 50 m distance is acceptable to meet the 40 dBuV/m limitation.

4.3 Impact study for broadcasting LF (148.5 ~ 283.5 kHz)

Since ITU-R SG1 WP1A meeting in 2015, EBU (European Broadcasting Union) indicated that European countries are using the broadcasting radio signal for special emergency. The LF frequency range is 148.5 kHz ~ 283.5 kHz.

Therefore, EBU proposed that it needs to take an impact study or harmonizing interference study for WPT EV frequency band not only 20/60 kHz but also 85 kHz.

According to the liaison letter of ITU-R WP6A in the 4th of August 2015, the maximum acceptable interference level from receiver is summarized in Table A3-5.

TABLE A3-5

The limitation level of receiver at LF and MF

SG6 Liaison letter (WP1A/86-1B/70, 4th Aug 2015)	Receiver Level	
	LF	MF
Frequency	148.5~283.5 kHz	-
Sensitivity	66 dBμV/m (14.5 dBμA/m)	60 dBμV/m (8.5 dBμA/m)
Co-channel Protection Ratio	40 dB	40 dB
Non-co-channel Protection Ratio	16 dB	16 dB
Overall Protection Ratio	56 dB	56 dB
Maximum acceptable Interference Level	10 dBμV/m (-41.5 dBμA/m)	4 dBμV/m (-47.5 dBμA/m)

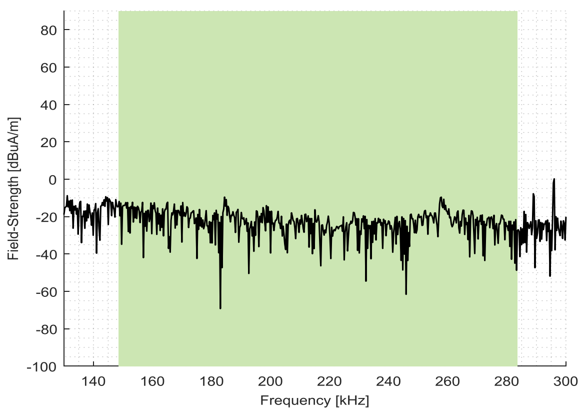
Test results are summarized in Fig. A4-13.

FIGURE A4-13

Test results

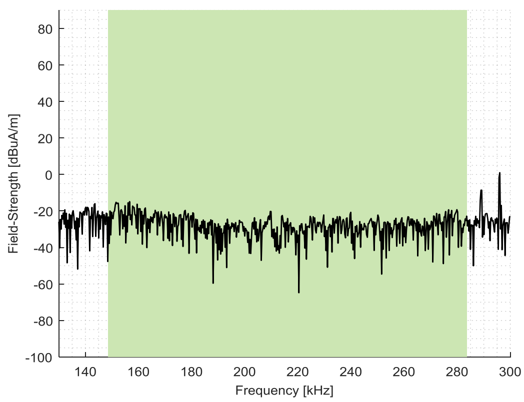
– Under ambient condition

130 kHz to 300 kHz @ 10 m (Ambient)



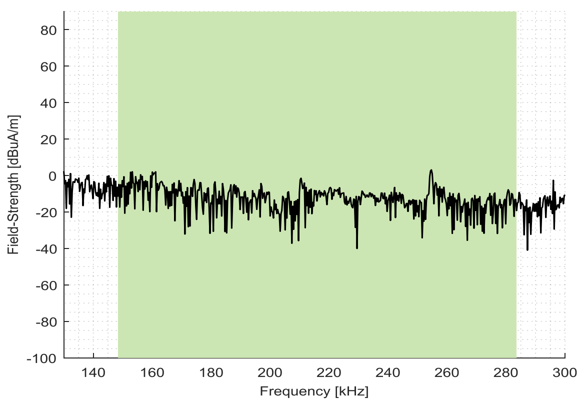
Peak: -9.58 dBμV/m @ 184.4 kHz

130 kHz to 300 kHz @ 30 m (Ambient)



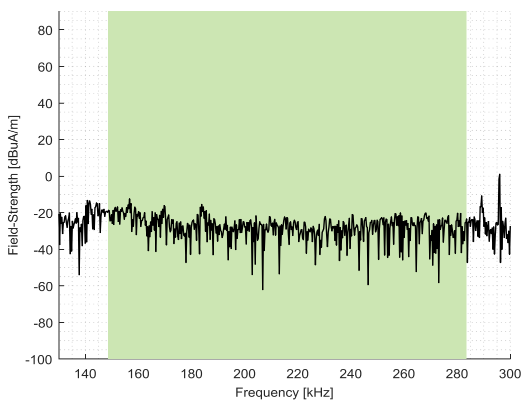
Peak: -15.23 dBμV/m @ 151.5 kHz

130 kHz to 300 kHz @ 50 m (Ambient)



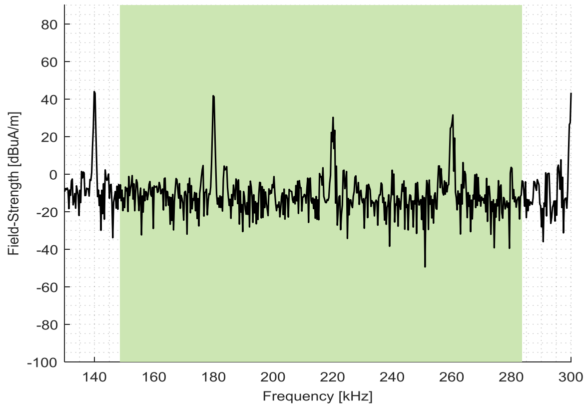
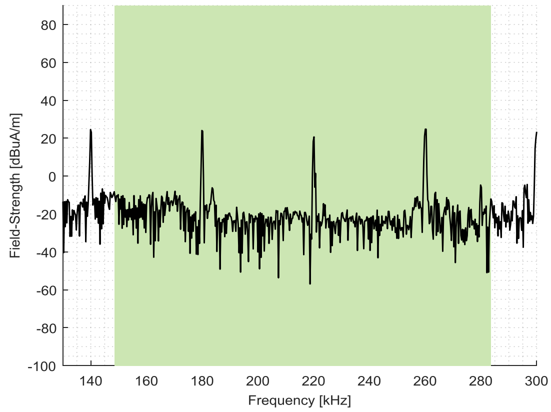
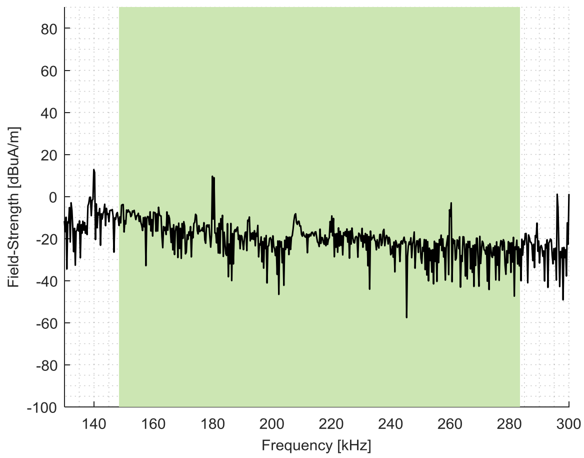
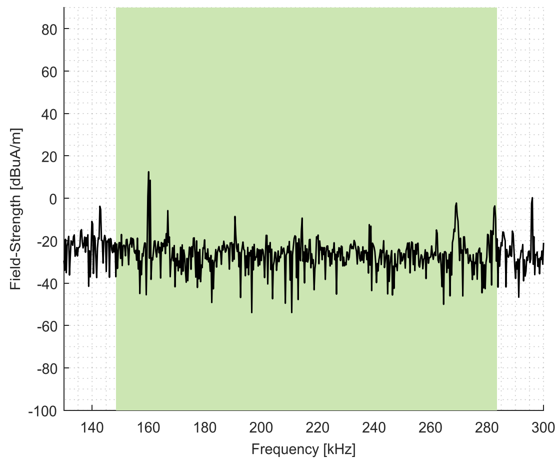
Peak: 3.1 dBμV/m @ 254.7 kHz

130 kHz to 300 kHz @ 100 m (Ambient)

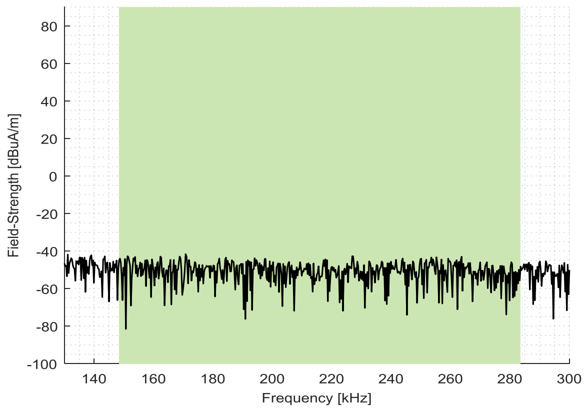
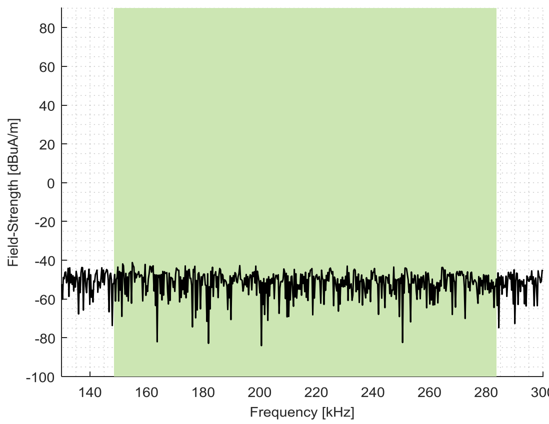


Peak: -12.48 dBμV/m @ 156.6 kHz

– Under charging condition

130 kHz to 300 kHz @ 10 m (Charging)	**130 kHz to 300 kHz @ 30 m (Charging)**
 Peak: 41.78 dBµA/m @ 179.9 kHz	 Peak: 24.77 dBµA/m @ 260.1 kHz
130 kHz to 300 kHz @ 50 m (Charging)	**130 kHz to 300 kHz @ 100 m (Charging)**
 Peak: 9.63 dBµA/m @ 179.9 kHz	 Peak: 12.51 dBµA/m @ 160.0 kHz

– Without any antenna cable

150 kHz to 300 kHz @ 10 m (without Ant')	**130 kHz to 300 kHz @ 100 m (without Ant')**
 Peak: -40.99 dBµA/m @ 170.8 kHz	 Peak: -40.66 dBµA/m @ 154.93 kHz

Under the ambient condition, there is no charging on the heavy-duty WPT EV because the maximum value is already more than 3.1 dBuA/m @ 254.7 kHz at 50 m and the minimum value is –15.23 dBuA/m @ 151.5 kHz at 30 m. It means that any value never meets the given limitation from EBU.

At charging mode, the maximum value is 41.78 dBuA/m @ 179.9 kHz at 10 m and the minimum value is 9.63 dBuA/m @ 179.9 kHz at 50 m. Needless to say, it exceeds significantly the limitation more than 80 dB.

In conclusion, Korea reports to the impact study for EBU LF Band 148.5 – 283.5 kHz as two results.

1) It is impossible to meet the given EBU limitation under any urban circumstance regardless of WPT charging condition or not such as Figure 17 (Test result).

   Because the limitation, 10 dB㎶/m (= – 41.4 dB㎂/m), of Table A3-5 is very tight, itself noise level of equipment (the receiver, Agilent E4440A) system without any antenna connecting is already exceeded the limitation.

2) It needs to approach other compromise with a more realistic view from EBU.

   As it investigated the table of EBU LF audio broadcasting, two broadcasting frequencies are linked to 19 – 21 kHz. One is 173 kHz broadcasting station. The 9th harmonics of 173 kHz is 19.2 kHz. The other is 182 kHz broadcasting station. The 9th harmonics of 182 kHz is 20.2 kHz. If Korea not uses two pin point frequencies, 19.2 kHz and 20.2 kHz, it may not affect the inference between EBU LF band and heavy-duty WPT system. Korea is willing to avoid those pin point frequencies when EBU accepts this condition. It will use more another frequencies under the same 20 kHz band (19 – 21 kHz).

Annex 5

Test results of electromagnetic disturbance of WPT for mobile devices in Korea

1 Introduction

This Annex provides the measured data of electromagnetic disturbance from the WPT systems for mobile devices using magnetic induction technology under the consideration of Korean regulation (KN 17).

* KN17: Measurement method of WPT electromagnetic interference for WPT home appliance below 10W in Korea

2 General measurement layout and conditions

Measurement methods of electromagnetic disturbance for WPT systems are regulated as KN 17:2013-06 in Korea. A magnetic loop antenna with diameter of 0.6 meter is used for the frequency domain of 30 MHz or less. See EN 16-1-4 for details.

Figures A5-1 and A5-2 describe measurement methods for electromagnetic disturbance of WPT systems for mobile devices, respectively. Figure A5-1 shows test site layout in the frequency range from 9 kHz to 30 MHz. Within the frequency range 9 kHz ~ 30 MHz, the properties of a test site may be determined by confirming that the ambient noise level is at least 6 dB lower than the allowable limits specified in Chapter 3.

FIGURE A5-1

Test site layout for electromagnetic noise of WPT systems for mobile devices in the frequency range from 9 kHz to 30 MHz

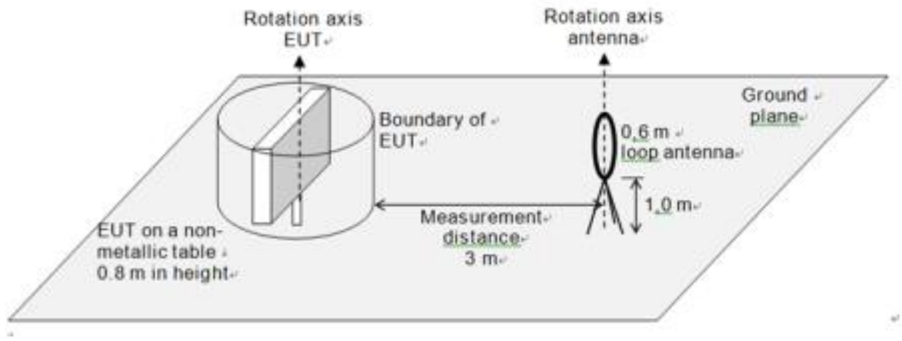
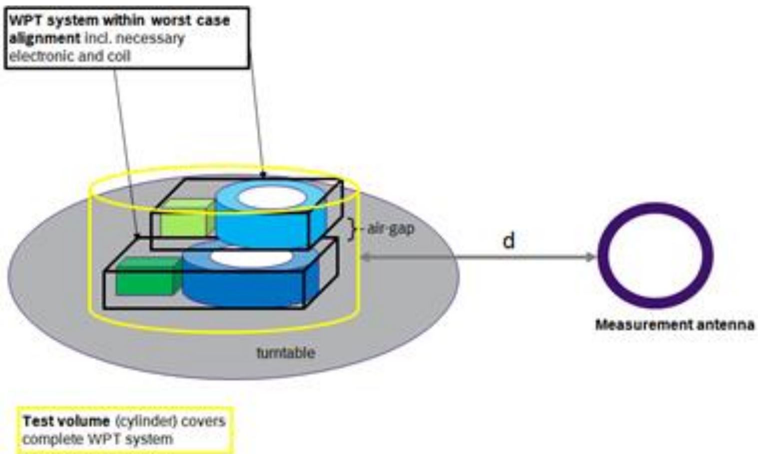


FIGURE A5-2

Setup for power transmission arrangement (Tx Horizon, Antenna Horizon)



3 Emission limit

The KN 17 is applied to the emission limit in Korea. The Equipment Under Test (EUT) must satisfy the Table A5-1 limits. According to the EN 300 330-1 Annex F, the conversion of the H-field limits at 10 m to a 3 m measurement distance is determined by the following equation:

$$H_{3m} = H_{10m} + \text{about } 31(\text{from } 0.1 \text{ MHz to } 2 \text{ MHz})$$

TABLE A5-1

Interference permissible level for WPT home appliance below 30 MHz

<table>
<tr><th>Frequency range (MHz)</th><th>Quasi-peak limits (dBμV/m)</th><th>Measuring distance (m)</th></tr>
<tr><td>0.009 ~ 0.45</td><td>47-20 log f</td><td rowspan="2">3</td></tr>
<tr><td>0.45 ~ 30</td><td>54</td></tr>
<tr><td colspan="3">f is in [MHz]
2. Margin of Harmonics:
3rdharmonic(+20dB),5thharmonic(+10dB),7/9thharmonics(+5dB)
3. Far E-field to H-field conversion constant: 51.5
dBμA/m = dBμV/m – 51.5
4. H-field Measurement Conversion factor: H_{3m} = H_{10m} + 31(below 2 MHz)(see EN 300 330-1)</td></tr>
</table>

4 Measurement results of electromagnetic disturbance

Measurement results of eletromagnetic disturbance of WPT system for mobile devices are described. The test equipment of the WPT system for mobile devices is on the market.

4.1 Measurement results for mobile devices using magnetic induction technology

4.1.1 Overview of test equipment

Table A5-2 shows the overview of the EUT for mobile devices using magnetic induction technology. WPT frequency is 144.6 kHz. Figure A5-3 shows the transmitter and receiver of the EUT.

TABLE A5-2

Overview of EUT for mobile devices using magnetic induction technology

EUT	Transmitter: SAMSUNG WIRELESS CHARGER EP-PG9201 Receiver: SAMSUNG Galaxy S7
WPT technology	Magnetic induction
WPT frequency	144.6 kHz
Condition for WPT	Typical transfer power: 5 W (WPT efficiency: above 75%) Power transfer distance: 1 centimeter below

FIGURE A5-3

Overview of EUT for mobile devices using magnetic induction technology

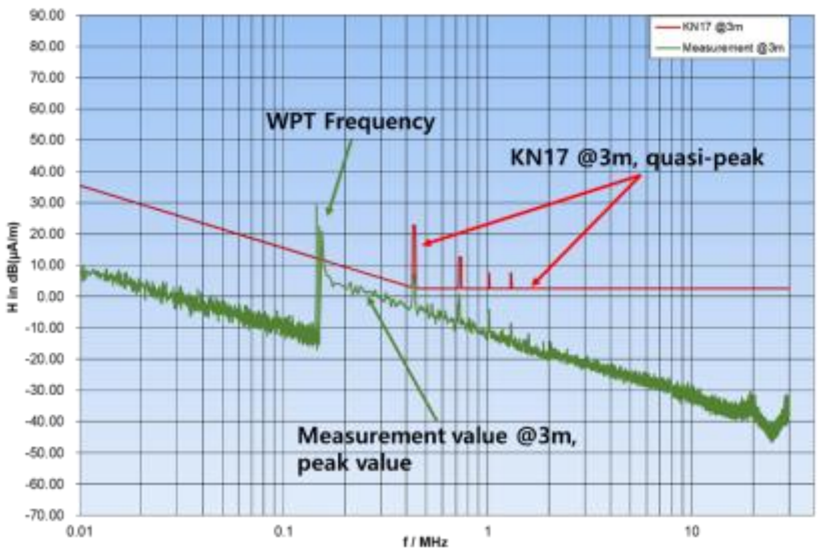
4.1.2 Measurement results of electromagnetic emissions

Emissions from EUT were measured in a typical 3 m semi anechoic chamber with a conductive ground plane. Measurement results in the frequency range from 9 kHz to 30 MHz are shown in Figure A5-4. The result meets KN17 of Korean regulation where the red line is KN 17 @ 3m, and the dark green line is a peak measurement value at 3 m. The WPT frequency level is 29.27 dBμA/m@144.6 kHz, 3rd harmonic value is –0.71 dBμA/m@434 kHz, 5th harmonic value is 0.61 dBμA/m@726 kHz, 7th harmonic is –4.07 dBμA/m@1 018 kHz, and 9th harmonic is -8.76 dBμA/m@1 306 kHz.

The main carrier, WPT frequency, is regulated by the Weak Electromagnetic Field Strength Device Limits and the harmonics are regulated by the KN 17 under the Korean Radio Waves Act. The permissible limit at the WPT frequency is 94.8 dBμV/m according to the Korean technical regulation and EN 303 417 limit is 89.2 dBμV/m at the frequency. The measurement value at the WPT frequency 144.6 kHz is 80.77 dBμV/m. The WPT main carrier emission passes the Korean and European technical regulation, and the harmonics meet the KN 17 EMC limits.

FIGURE A5-4

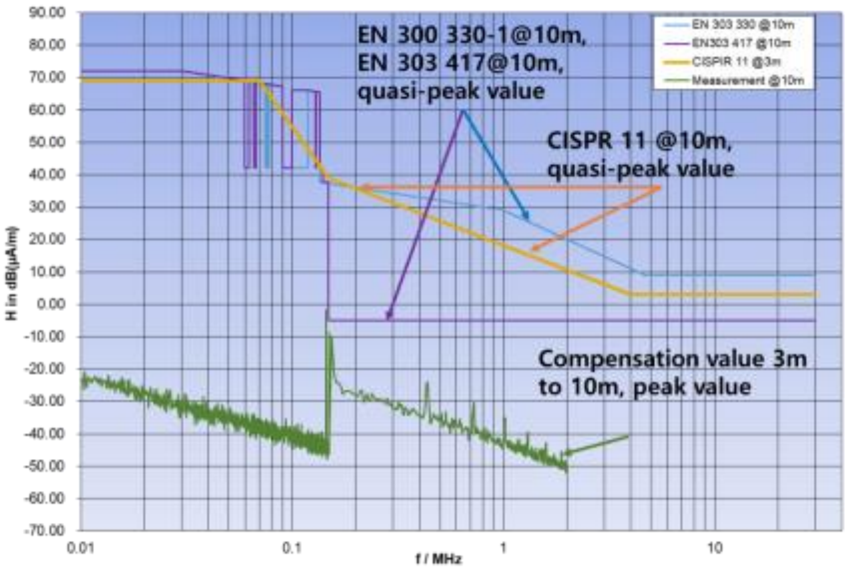
Tx horizon, antenna horizon (9 kHz – 30 MHz, measurement value@ 3m)



In Fig. A5-5, the compensated values which are converted from the peak measurement data at 3 m to the data at 10 m with the conversion factor of 31 according to the EN 300 330-1 Annex F between 100 kHz and 2 MHz meet the European standards and CISPR 11 requirements sufficiently.

FIGURE A5-5

Tx horizon, antenna horizon (9 kHz – 30 MHz, compensation value 3m to 10m)



Consequently, because the compensated value meets the international standards EN 303 417 and CISPR 11 as in Fig. A5-5, it is supposed to meet the international requirements in case of measuring electromagnetic emissions of the EUT for mobile devices at 10 m.

Annex 6

Broadcast Planning

Broadcast transmitters can and do interfere with each other and the choice of operating frequency for each transmitter is therefore critical. As a general principle, Broadcasting Services are planned on an interference-limited basis. The service area of a particular transmitter is the area within a contour outside which the service becomes unusable because of interference. Exactly what counts as 'unusable' might be different for different types of programme material or for different users, but certain assumptions are made in defining the planning criteria.

Also, variability in propagation conditions means that there is a statistical element to this which is similarly accounted for in the planning criteria. A particular signal is deemed to be unusable when it is overtaken either by interference from natural sources, from internal noise within the receiver or from other broadcast services.

The LF/MF Regional Frequency Assignment Plans of Geneva 75 (GE75) and Rio de Janeiro 1981 (RJ81) show how ITU has implemented such considerations in practice.

Where two transmitters are needed to cover the same geographical area with different programmes, they must have different frequencies and the frequency separation must be such that a receiver can isolate one from the other. The ability of the receiver to do this is called selectivity and is defined by the quality of the filtering in the radio frequency (RF) part of the receiver. Modern receivers tend to be better in this respect than older ones but as there are a large number of older receivers operating in the world, the planning criteria specified by the ITU tend to be conservative. The broadcast bands are not wide enough to allow every station throughout the world to have a unique frequency of its own which is well separated from all of the others. This means that the frequencies have to be re-used. The key to re-use of frequencies without causing interference is geographical separation. Where two transmitters are operating on the same frequency, the geographical separation must be large enough to ensure that each does not cause harmful interference to the other within its defined service area. Taking a very simple (hypothetical) case with only two transmitters, both on the same frequency and with the same power, there will be a point roughly half way between them where the signal strength from each one is the same. Clearly, neither will be usable at this point; it is necessary to move closer to one of them to find a point where it is dominant and the interference from the other can be neglected. In many cases, it is this phenomenon that defines the limit of the service area of one or other of the transmitters.

In the real world, there are a large number of different transmitters operating over a two dimensional geographic space. Each will have its own frequency, power output and antenna characteristics. Broadcast transmitting antennas are often directional and so, even with two transmitters of equal power, their signal strengths might not be equal at the geographical mid-point between them. While not strictly necessary, to simplify the planning process (and the understanding of it) the broadcast bands are typically channelized. In the case of MF and LF transmissions in the GE75 plan the channels are usually 9 kHz wide and the carrier frequencies are organised on a 9 kHz raster[5]. The channels therefore are contiguous in frequency (with no ‘guard band’ between them) but do not overlap. While the radio frequency filtering in the receiver attempts to isolate a single 9 kHz channel with a carrier at its centre), older receivers in particular, with lumped tuned circuit filtering as opposed to solid state surface wave filtering, are less than perfect at doing this. Recognising that AM radio is not a ‘HiFi’ medium, the RF filters in many receivers are narrower than 9 kHz. What this means in practice is that two transmitters on adjacent channels cannot cover the same geographic area because each will ‘leak’ interference into the channel filter of the other. Transmitters on adjacent channels can, however, operate with a smaller geographic separation between them, because the filter will reduce the level of interference. Clearly the situation gets easier with greater frequency separation; a transmitter on the second adjacent channel can operate at a closer distance and one on the third adjacent channel closer still, until no geographic separation at all is needed. In most places several broadcast services are available in the same band; they do not interfere with each other because there is sufficient frequency separation between them.

All of these principles, including assumptions about typical receiver selectivity, are incorporated in the planning guidelines laid down by the ITU such as the GE75 and RJ81 Plans. Radio frequency propagation has no respect for international frontiers and so planning has to be done at an international level. Nearly all Administrations have agreed broadcast frequency allocations which are published in the BRIFIC from the ITU. Allocations are tied to particular geographic locations and specify the transmitter power and the antenna directivity in an agreed plan. While most of these allocations are static, changes can be, and are, made to accommodate the changing service aspirations of different broadcasters. The ITU has computer programmes which simulate the effect of changes to the agreed plan to see if they can be accommodated or how they might be adapted to be acceptable.

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[5] While nearly all channels under the GE75 Plan are 9 kHz wide there are a very small number with a wider allocation. It is also possible to accommodate carrier frequencies that are not on the 9 kHz raster. The channelling arrangements for the RJ81 plan are a little more complicated and based on a 10 kHz raster.

Based on the above, the choice of frequency and raster defining the channelling arrangements used for planning are therefore important factors in guiding SDOs on how to ensure that standards for WPT equipment will naturally minimize the risk of interference, by using parameters appropriate to the area of intended use.

In a given area, an operating frequency could be set for the WPT device, and perhaps more importantly its relevant harmonics, which is well separated from the broadcast services planned for that area. The choice of frequency for the WPT device is made easier if the same broadcast planning raster is used.

It is also important to consider the radiation characteristics of the WPT devices across the area that is likely to be affected (frequency stability, harmonic content, and, importantly, field strength). In effect, this type of mitigation solution assumes that the spectral purity and frequency stability requirements set through ITU-R instruments and equipment standards will be as rigorous as for ISM applications.