Report ITU-R SM.2303-4

(06/2023)

SM Series: Spectrum management

Wireless power transmission using technologies other than radio frequency beam

Foreword

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

Electronic Publication
Geneva, 2023

REPORT ITU-R SM.2303-4

Wireless power transmission using technologies other than radio frequency beam

(Question ITU-R 210-4/1)

(2014-2015-2017-2021-2023)

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Abbreviations/Glossary

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
DRL	Dosimetric Reference Limit
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
ERL	Exposure reference level
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
LCC	Inductor(L) Capacitor(C) Capacitor(C) matching topology
LCD	Liquid crystal display
LDC	Low voltage DC/DC converter
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)
MSIT	Ministry of Science and ICT (Korea)
NAVDAT	Navigational data
NAVTEX	Navigation telex
OLEV	OnLine electric vehicle
OOB	Out-of-band
PAS	Publicly available specification
PFC	Power factor correction
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
SMPS	Switched-mode power supply
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 provides information about wireless power transmission (WPT) using technologies other than radio frequency beam, as partial answers to Question ITU-R 210-4/1.

This Report includes information about national regulations, but this information has no international regulatory effect, and provides experiences by the countries mentioned and merely reflect the views of those countries.

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.

Most significant information on non-beam WPT is found in:

- Recommendation ITU-R SM.2110 – Guidance on frequency ranges for operation of non-beam wireless power transmission for electric vehicles;
- Recommendation ITU-R SM.2129 – Guidance on frequency ranges for operation of non-beam wireless power transmission systems for mobile and portable devices;
- Report ITU-R SM.2449 – Technical characteristics and impact analyses of non-beam inductive wireless power transmission for mobile and portable devices on radiocommunication services;
- Report ITU-R SM.2451 – Assessment of impact of wireless power transmission for electric vehicle charging on radiocommunication services.

2 Applications developed for use of WPT technologies

2.1 Portable and mobile devices

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

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

– mobile and portable devices: cellular phones, smartphones, tablets, note-PCs;

– audio-visual equipment: digital still cameras;

– business equipment: handy-digital-tools, table-order-systems;

– others: lighting equipment (e.g. LED), robots, toys, car-mounted devices, medical equipment, healthcare devices, etc.

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

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

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

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

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

2.2 Home appliance and logistics applications

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

As operation power of Consumer Electronics (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.

2.2.1 Home appliances

Wireless power home appliances are being developed as an alternative for induction heaters in the kitchen appliances, and some external standardization organizations plan to release standards (e.g. Ki v1.0 by Wireless Power Consortium[1]) for wireless power kitchen appliances. Some companies have showcased prototype products at trade shows, but commercial products are not yet available. As home appliances applying WPT becomes more diverse, CISPR and other Standard Development Organizations (SDOs) are discussing measurement methods for EMC and EMF evaluation. Figure 1 shows a sample of kitchen appliances equipped with wireless power transmission equipment. It has a food processor, a blender and a rice cooker, etc. Figure 1 is an exhibition scene at Mini CES held at Exhibit Concepts Inc. headquarters, Vandalia, Ohio May 9-11, 2022.

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[1] The Wireless Power Consortium (WPC) is described in § 4.2, Table 2.

FIGURE 1

Exhibition of WPC's kitchen appliances prototype

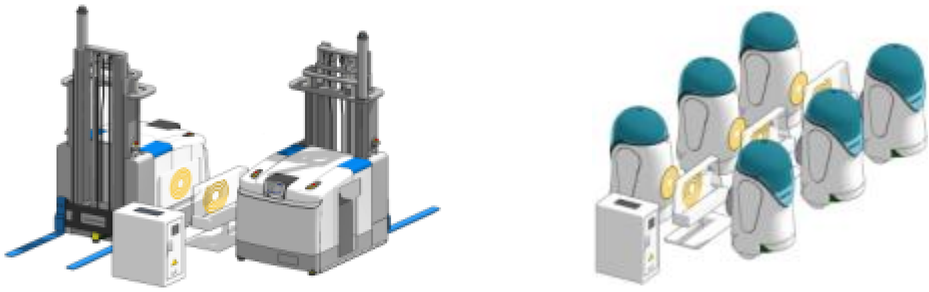
2.2.2 Logistics applications

Robots and AGVs are actively used in logistics, and large logistics warehouses use a large number of robots/AGVs. In order to charge them, autonomous charging and wireless charging are typically used since it is not possible for humans to manually charge them one by one.

The charging power for small robots is about 200 W to 600 W, while large factory robots and AGVs require 1 kW to 4 kW. The typical charging method involves placing a transmitter on the floor, but in places like factories or logistics warehouses, where there is a concern for foreign substances getting in the way, horizontal charging is usually used. Figure 2 is a conceptual diagram of a dual-side and six-cluster robot/AGV wireless charger applicable to a smart factory.

FIGURE 2

Dual-side and 6-cluster wireless charging configuration



2.3 Electric vehicle

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

Number	Title	Publication status	Publication date
IEC 61980-1	Electric vehicle wireless power transfer (WPT) systems – Part 1: General requirements	IS 2nd Ed.	2020-11-19
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	FDIS 1st Ed.	Estimated 2022/2023 (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	FDIS 1st Ed.	Estimated 2022/2023 (IS 1st Ed.)
ISO 19363	Electrically propelled road vehicles – Magnetic field wireless power transfer	IS 1st Ed.	2020–04

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

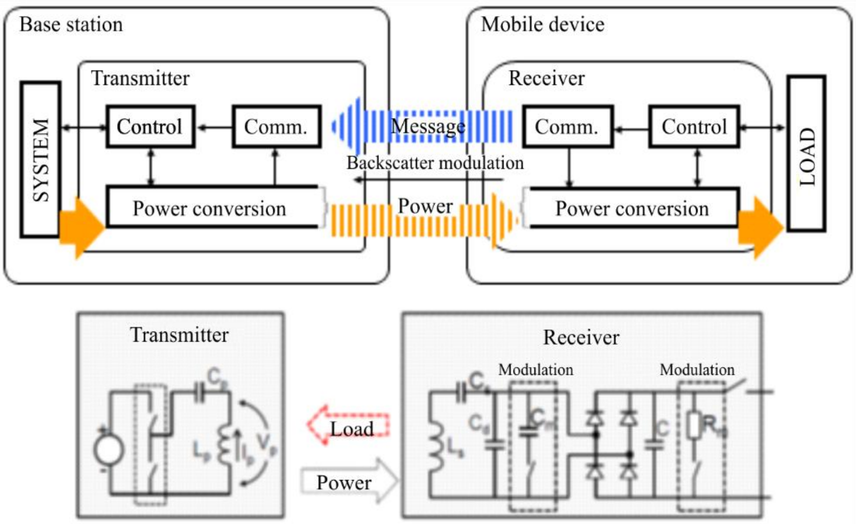
3.1 For portable and mobile devices

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 3

Example magnetic induction WPT system block diagram



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3.1.1.1 Qi system

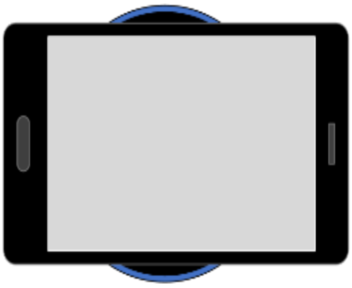
The power transfer is based on near field magnetic induction between coils. Devices operate typically over less than a 2 mm range. These applications generate high magnetic field strengths close to the transmitter coil to achieve high power transfer efficiency > 90%. Since applications are not designed to produce an intentional radiating electric field, Qi transmitter coils are extremely inefficient transmitters of electric fields, with a typical effective radiated power of 2.9 µW.

A simple control system is used to initiate, manage and terminate power transfer. Foreign object detection is included as a safety feature.

A power receiver (PRx) is contained within the mobile device when it is placed on top of a power transmitter (PTx), as shown in Fig. 4.

FIGURE 4

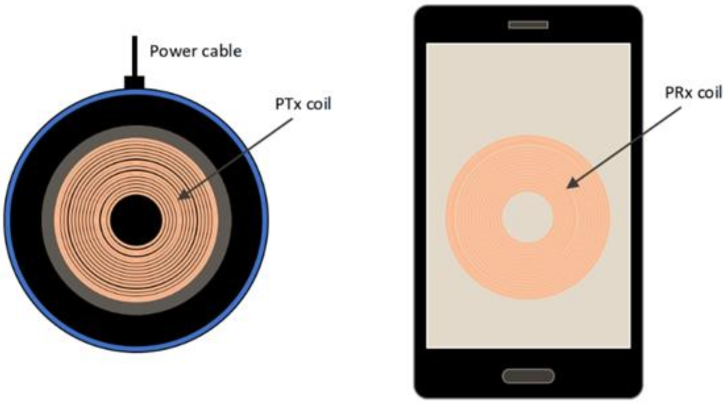
A wireless smartphone on a charging pad



Both the PTx and PRx contain coils, as shown in the conceptual diagram in Fig. 5 as well as circuitry that handles the communication and power transfer between them.

FIGURE 5

Coils in charger and smartphone

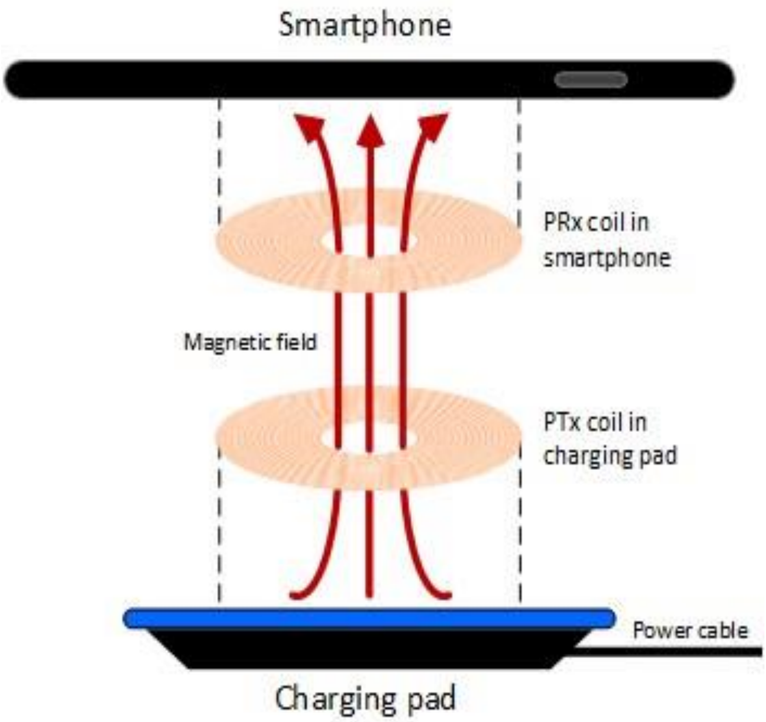


In the system, illustrated in Fig. 5, power is transferred from the PTx contained in the charging pad to a PRx contained in the smartphone. Before charging begins, the PRx and PTx communicate with each other to establish that the mobile device is compatible and capable of being charged, whether it needs to be charged, how much power is required, etc. In short, the communication ensures an appropriate power transfer from the power transmitter to the power receiver.

When charging begins, the power transmitter runs an alternating electrical current through its coil, which generates an alternating magnetic field in accordance with Faraday's law (see Fig. 6). This magnetic field is in turn picked up by the coil inside the power receiver and transformed by a power converter back into an alternating electrical current that after rectification, can be used to charge the battery.

FIGURE 6

Qi wireless power transmission using magnetic induction



3.1.2 Magnetic resonance WPT technology

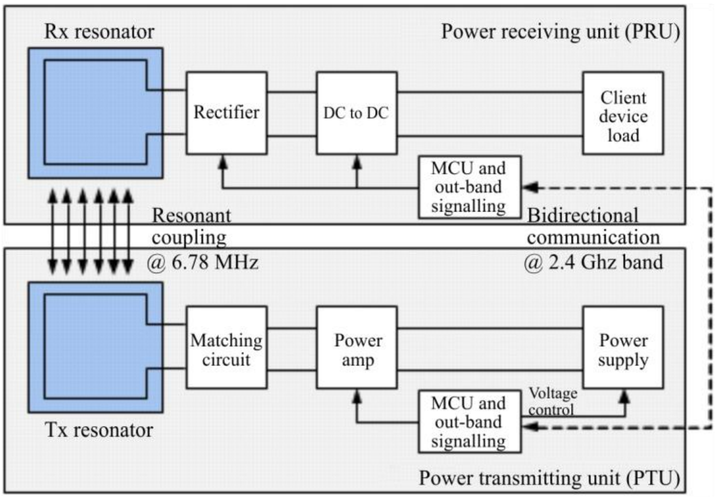
The WPT by magnetic resonance is also known as Loosely Coupled WPT. The theoretical basis of this magnetic resonance method was first developed in 2005 by Massachusetts Institute of Technology, and their theories were validated experimentally in 2007[2]. The method uses a coil and capacitor as a resonator, 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 metres.

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 http://www.mit.edu/~soljacic/wireless_power.html and http://www.rezence.com/.

2 http://www.mit.edu/~soljacic/wireless_power.html

FIGURE 7

Example magnetic resonance WPT system block diagram



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3.1.2.1 Portable and Mobile WPT devices in 13.553-13.567 MHz

Smart glasses are one kind of smart wearable devices, which are usually configured with independent operating systems and smart audio function. In addition, smart glasses can be charged with wireless charging technology. One kind of the smart glasses[3] is shown in Fig. 8. It has used 13.56 MHz wireless charging technology that leverages the NFC communication link to control the power transfer. As shown in Fig. 9, Wireless charging is performed on smart glasses with glasses case, where the glasses case serves as a transmitter and the smart glasses serve as a receiver of the NFC wireless charging. The transmitting coil is located on the side of the glasses case, and the receiving coil is located inside the glasses leg. When the glasses are placed in the case, two coils are closed to each other and magnetic coupling is established. Transmitter emits the alternating magnetic field with a frequency of 13.56 MHz. The flux of the magnetic field induces alternating voltage on the receiving coil, which can be used to drive the battery in glasses arms after rectification. The total charging power of glasses legs is less than 1 W and devices can operate over less than a 1 cm range.

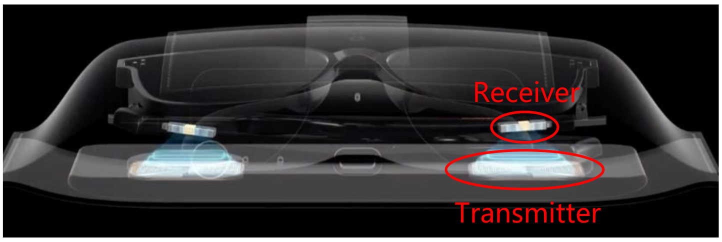
FIGURE 8

One kind of smart glasses

[3] Specific information of this smart glasses can be seen in the following link: https://www.vmall.com/product/10086622420520.html

FIGURE 9

Transmitter and receiver of smart glasses



By using magnetic fields in NFC communication to transmit energy, without introducing extra electromagnetic radiation, 13.56 MHz wireless charging technology enables NFC devices to support high frequency wireless charging with minor modification.

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 10 and 11 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 10

Capacitive coupling WPT system block diagram

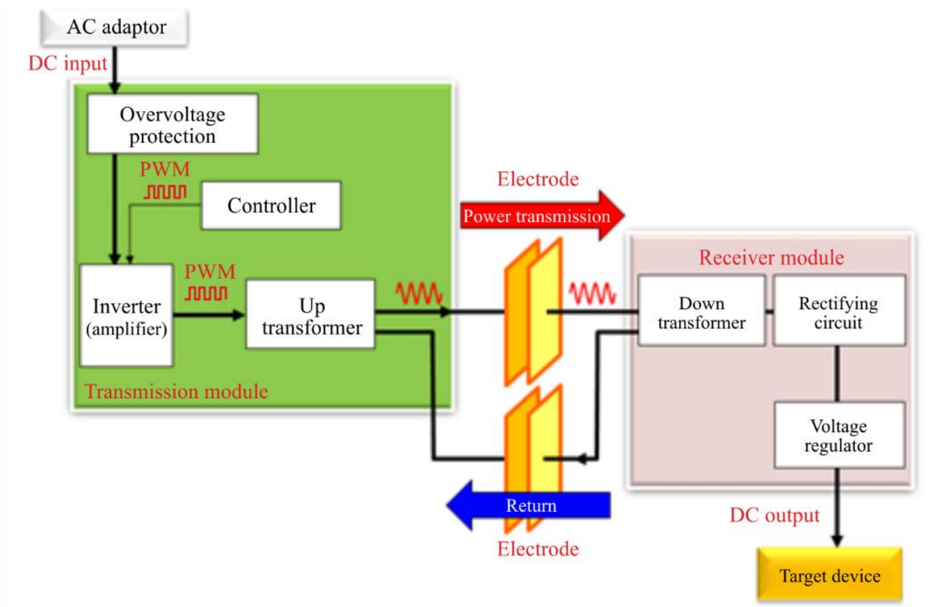


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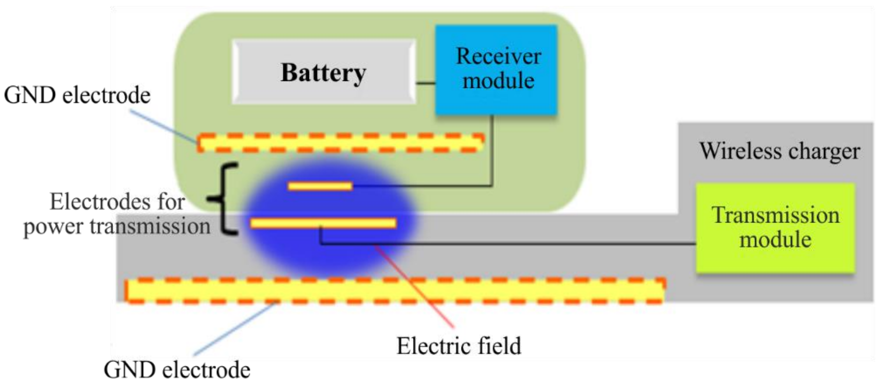
FIGURE 11

Typical structure of the capacitive coupling system



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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 insulated gate bipolar transistors (IGBTs) are usually used and these devices are working in 10 to 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.

Figures 12 and 13 show examples of wireless power kitchen appliances that will come to the market soon.

FIGURE 12

Wireless power kitchen appliances

Tightly coupled mixer

Tightly coupled rice cooker

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

FIGURE 13

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

(WPT overhead shutter of LCD product line)

(WPT overhead transmission of Semiconductor product line)

(WPT kitchen island of apartment)

Report SM.2303-07

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. 14.

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.

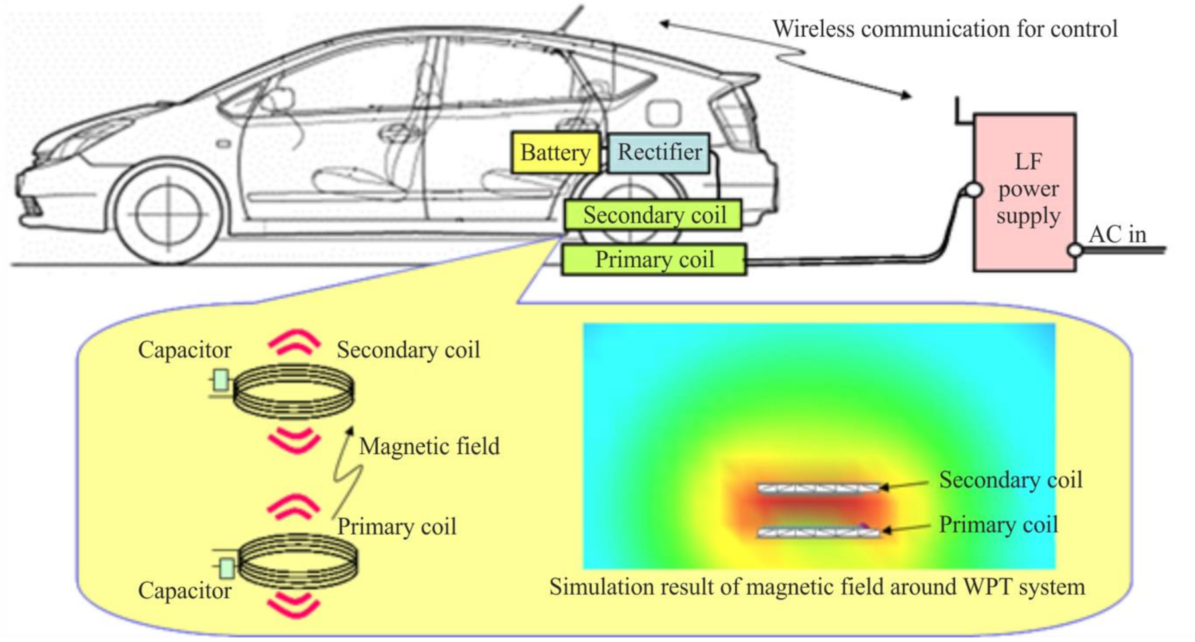
7) Air gap between primary and secondary coils: Less than 30 cm.

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 14

Example of a WPT system for EV/PHEV

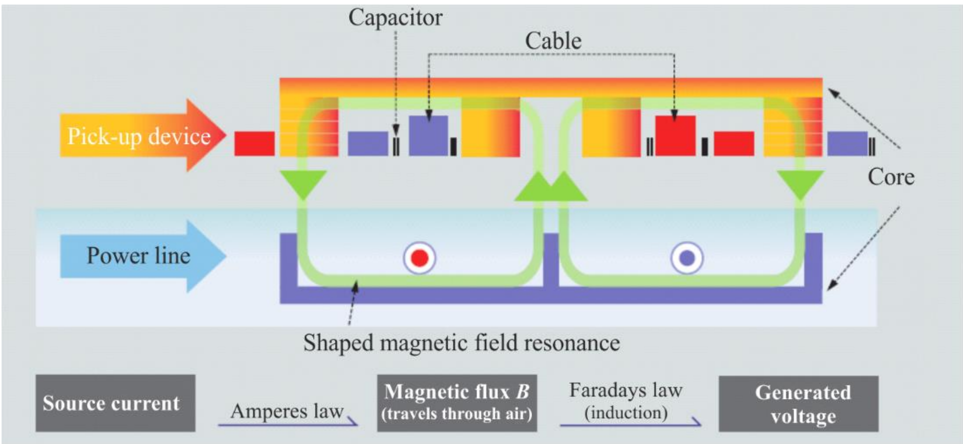


Report SM.2303-08

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 15

Technical characteristics of an online electric vehicle



Report SM.2303-09

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 ferritecore, 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 16

Example of an online electric vehicle

Report SM.2303-10

3.4 For Robot and AGVs

3.4.1 3.3 kW Single-side wireless charging transceiver coil technology

In the 3.3 kW class transmission environment for robot wireless charging, a multi-layered transmission/reception coil such as that shown in Fig. 17 is designed considering the size of the mountable coil and the distance between the transmission/reception coils. In addition, loss and heat generation of the coil can be minimized through the structural design of the grounding conductor.

FIGURE 17

Example of a two-layer structure transmit/receive coil

A coil topology for cluster wireless charging for six receivers has been studied. At this time, a structure without ferrite is used in the transmitting coil so that wireless charging is possible simultaneously in both directions of one transmitting coil. In addition, a receiving coil and a ferrite structure capable of increasing the directivity of a magnetic field are designed to reduce the influence of adjacent receiving coils. As a result, in order to wirelessly charge six devices at the same time, three transmitting coils and six receiving coils are used.

3.4.2 3.3 kW class single-side wireless charging transceiver module technology

In order to optimize and obtain maximum efficiency of the 3.3 kW class wireless charging transmission/reception module, stable power through a DC power supply unit (e.g. Switched-Mode Power Supply (SMPS)) with a built-in circuit protection function was used. To this end, a 4 kW class SMPS with Totem-Pole Bridgeless PFC (Power Factor Correction) topology, which can secure maximum efficiency by minimizing loss of internal elements (inductor, diode, etc.) in the existing structure, was used. A natural heat dissipation structure may be desirable to reduce the overall system size and simplify the heat dissipation structure.

In the 79-90 kHz band, by the use of a 3.3 kW class transmission module, efficiency of power transmission is maximized, and heat generation is minimized by using a low-loss LCC (Inductor-Capacitor-Capacitor) matching structure and Dual-MOSFET. In addition, it has a built-in transmission power control function using Wi-Fi communication with the receiving module.

The receiving module for charging a 100 V class battery was used with a rectifier circuit using a 400 V class diode and a MOSFET switch for automatic on/off charging control. Low-loss LCC matching was also applied to the receiving module for constant current charging.

A high-efficiency LDC (Low voltage DC/DC Converter) that converts the battery voltage (100 V class) into a suitable power source (DC 25 V) for the transportation robot is expected to be manufactured.

The frequency band for WPT-EV (79-90 kHz) was used to charge the prototype robots. Electronics and Telecommunications Research Institute (ETRI), Republic of Korea, has developed a 1 kW wireless charging robot in 2022, which demonstrated over 90% DC/DC transmission efficiency while satisfying both EMC/EMF Korean standards at a spacing of 7 cm between transmitter and receiver. ETRI is developing a 3.3 kW multi-wireless charger for robots and AGVs from 2022. The goal of technology development is a dual-side charger for AGV that can simultaneously charge two receivers with 1.75 kW each with one transmitting coil, and a cluster wireless charger that can simultaneously charge six robots with 600 watts of receiving power. Each charger targets an AC/DC efficiency of over 86% at a spacing of 5 cm between transmitter and receiver.

4 WPT's standardization situation in the world

4.1 National standards development organizations

The following sections provide for information only experiences and merely reflect the views of the countries mentioned therein.

4.1.1 China

In China, CCSA (China Communication Standard Association) has been studying WPT standards for portable devices Some other reports had been carried out by CCSA, such as "Research on issues of low power wireless charging system", "Research on wireless charging frequency and management - low frequency low power mobile devices", and "Research on RF specification and relevant regulations applicable to mobile and portable WPT devices".

In 2015, the national SDO of automobile industry was established and formulated three national standards, led by China Automotive Technology and Research Center (CATARC). And since 2017, the national SDO of energy industry led by China Electricity Council (CEC) has formulated relevant national standards for WPT-EV. Some national standard related to WPT-EV are listed in the table below.

Number	Title	Publication date
GB/T 37132	General requirements and test methods of electromagnetic compatibility for wireless power transmission equipment	2018/12/28

4.1.2 Japan

The WPT-Working Group of Broadband Wireless Forum (BWF), Japan, is taking responsibility for drafting WPT technical standards utilizing the Association of Radio Industries and Businesses (ARIB) 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

Ministry of Science and ICT (MSIT) and National Radio Research Agency (RRA) are government agencies in charge of WPT regulations in Korea. The main standardization organizations developing the standards for WPT are shown in Table 1.

In 2022, two standards have been developed: TTAK.KO-06.0578, “Requirements and reference model for visual-assisted foreign material and biometric detection for wireless power transmission in robots and AGVs”, which is a foreign material detection standard applied to robots and AGVs, and TTAK.KO-06.0579, “Technical specifications for wireless power transmission transceiver for mobile devices up to several hundred watts – Part 1: Electric bicycles”, which is an electric bicycle standard. A measurement method standard for electronic wave human exposure standards, KS C 3380, “Measurement method for the amount of human exposure to low-frequency magnetic fields generated in electric vehicles and charging systems”, is also being developed.

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 for information.

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-F considered the application of non-beam WPT technology to kitchen appliances and/or battery-powered tools and determined that in these applications, the technology of power transmission devices is common to induction cooking appliances. Therefore, SC-F has decided to combine WPT for household appliances with inductive cooking appliances under the broader concept of “inductive power transfer (IPT) equipment”. The emission limit values of IPT equipment are inherited from those of inductive cooking appliances. The CISPR 14-1 Edition 7.0 was published in 2020.

TABLE 2 (*continued*)

Name of Organization	Activities
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.
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 January of 2012. – On Circulation with WD (Working Document)

TABLE 2 (*continued*)

Name of Organization	Activities
ETSI TC ERM	ETSI TC ERM has 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 has been considered by CEPT ECC, and ECC Report 289 "Wireless Power Transmission (WPT) systems for electrical vehicles (EV) operating within 79-90 kHz" has been published. An addition / supplement to the ECC Report 289 on "the impact of unwanted emissions from WPT-EV on the radio services" is in preparation. In September of 2017, ETSI TC ERM published the new Harmonised Standard (EN 303 417), 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. ETSI (TR 103 493), published in 2017, covers the technical specifications and characteristics of WPT systems other than EV-WPT, operating below 30 MHz. It is being used by CEPT/ECC/WG SE in coexistence 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 the SAE J2954 Standard, "Wireless Power Transfer for Light-Duty Plug-In/ Electric Vehicles and Alignment Methodology" in October 2020, which establishes the 85 kHz band (79-90 kHz) as a common frequency band for wireless power transfer for all light duty vehicle systems up to 11.1 kW (with future considerations up to 60 kW). The Standard specifies three power classes (up to 3.7 kW, up to 7.7 kW, and up to 11.1 kW). Two more classes of higher power levels up to 60 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 https://www.sae.org/standards/content/j2954_202010/.

TABLE 2 (*continued*)

Name of Organization	Activities
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 6.78 MHz. A4WP was merged with PMA to form AirFuel Alliance in 2015.
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.

TABLE 2 (*end*)

Name of Organization	Activities
WPC	Established in 2008, the Wireless Power Consortium is an open, collaborative standards development group of more than 400 member companies from around the globe. WPC's member companies are large and small competitors and ecosystem partners representing brands from all parts of the industry and all parts of the globe. Its work focuses on tightly coupled inductive coupling solutions across a range of power levels, from 5 W for mobile wireless power transfer to > 1 KW for kitchen appliances and industrial applications. WPC has more than 5 000 different Qi Certified wireless charging products in the market. In 2017 WPC started to develop the Ki Cordless Kitchen standard, for delivering power to cordless appliances and enabling seamless integration of cooking hobs into countertops and other surfaces. The Ki standard builds on the success of the Qi and enables the development of safer, smarter and more convenient kitchen appliances. This will ensure interoperability and safety. This standard defines transmitters and versatile cooktops that wirelessly deliver up to 2200 W of power to smart cordless kitchen appliances. The new Ki Cordless Kitchen wireless power standard is currently under development. The consortium released a technical specification (Qi ver.1) in July 2010 and released ver.1.3 in August 2021. The Qi specification is also published as IEC PAS 63095 series. Currently investigations are ongoing to transform these PASs into full International Standards (IS). In addition to Qi and Ki, WPC is active in developing new standards in the following areas: i) The Light Electric Vehicle (LEV) standard for e-bikes and e-scooters: The growing number of e-bikes, electric scooters, and other Light Electric Vehicles (LEVs) drive the demand for flexible, fast, and relatively low-cost urban transportation. A LEV standard is also under development. ii) The industry standard for wireless power transmission to charge robots, auto-guided vehicles (AGVs) and other industrial automation machinery in the industrial sector: WPC is working also on standards for unmanned robotic equipment in industrial and logistics settings around the world. This includes robotic arms used in heavy manufacturing, drones used to monitor gas pipelines and electric towers, massive use of AGVs in logistics with power levels up to several kW.
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 Not Used

4.2.2 Information on human exposure to EMF

Human exposure to electromagnetic fields (EMF) is addressed by administrations for their own countries. Administrations can seek guidance for human exposure to EMF from other international organizations such as the World Health Organization (WHO), the International Commission on Non Ionizing Radiation Protection (ICNIRP) and the Institute of Electrical and Electronics Engineers

(IEEE). The determination of EMF safety limits is addressed by these organization and is not in the scope of ITU-R's work.

The most recent and relevant guidelines on human exposure to EMF, that have been published by these organizations for WPT operating frequencies up to 100 kHz, can be found in ICNIRP 2010 Guidelines [5] and IEEE C95.1-2019 [7]. Relevant guidelines for human EMF exposure for WPT operating frequencies above 100 kHz can be found in ICNIRP 2020 Guidelines [6] and IEEE C95.1-2019 [7]. Furthermore, IEC TC 106 WG 9 provides documentation on methods of EMF measurement in order to satisfy the safety requirements (see Table 2).

Many administrations have adopted 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.

Detailed information on monitoring EMF is available in the Report ITU-R SM.2452 – Electromagnetic field measurements to assess human exposure.

Guidelines for human exposure to EMF describe basic restrictions for ICNIRP or equivalently dosimetric reference limits (DRLs) for IEEE and reference levels for ICNIRP, or equivalently exposure reference levels (ERLs) for IEEE. Limitations of exposure, that are based on the physical quantities directly related to the established health effects, are termed basic restrictions (or DRLs). For simple exposure assessment purposes, the ICNIRP guidelines and IEEE C95.1 provide reference levels (or ERLs) of exposure.

The ICNIRP guidelines and IEEE C95.1 on electric and magnetic fields exposure are used in many countries to help establish national limits, and countries' threshold.

Operators of WPT equipment should consider steps to adequately protect the public from EMF effects.

Measurements before 2017 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. Enclosed EMF Measurement Results in the USA.

4.2.3 EMF measurement results

Measurements were taken of the standardized WPT-EV WPT3 system operating at about 11 kW in worst-case conditions for EMF exposure considerations including maximum offset and full power. As a reference consideration for EMF Exposure, ICNIRP 2010 guidelines set a reference level of 27 µT[4] RMS for 85 kHz. Additionally, ISO 14117 for consideration of CIEDs (Cardiac Implantable Electronic Devices) sets induced lead-loop induced voltage requirements in a 225 cm^2 loop which results in a magnetic field level restriction of 15 µT RMS. The images below show the measurement planes and the resultant magnetic flux density values measured with an EMF probe containing three orthogonal 100 cm^2 loops and automatically calculating the root mean square sum of all of the axes together. A coarse scan with a resolution of 7.5 cm spacing was taken to determine the hot-spot location. Once the region of the largest field was identified, a finer resolution scan with 3.75 cm spacing was used. As a result of the fine measurements, the largest field level measured was found to be 4.226 µT RMS in the XZ plane (on the side of the vehicle). Measurements in the YZ plane (at the front of the vehicle) were approximately four times lower than the XZ plane and so are not shown for brevity.

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4 Magnetic flux density is expressed in tesla (T). One gauss (deprecated unit) equals 10^{-4} T.

FIGURE 18

Maximum offset conditions for worst-case emission of WPT-EV system used for both EMF and radiated emissions testing

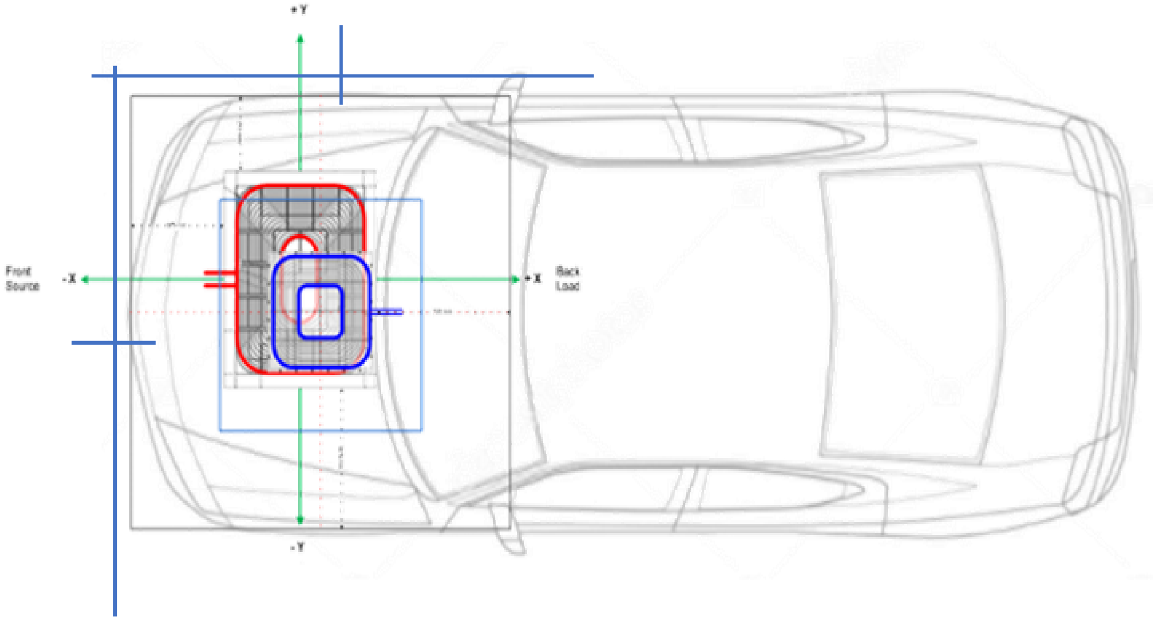


FIGURE 19

EMF measurements taken on a course grid with resolution of 7.5 cm

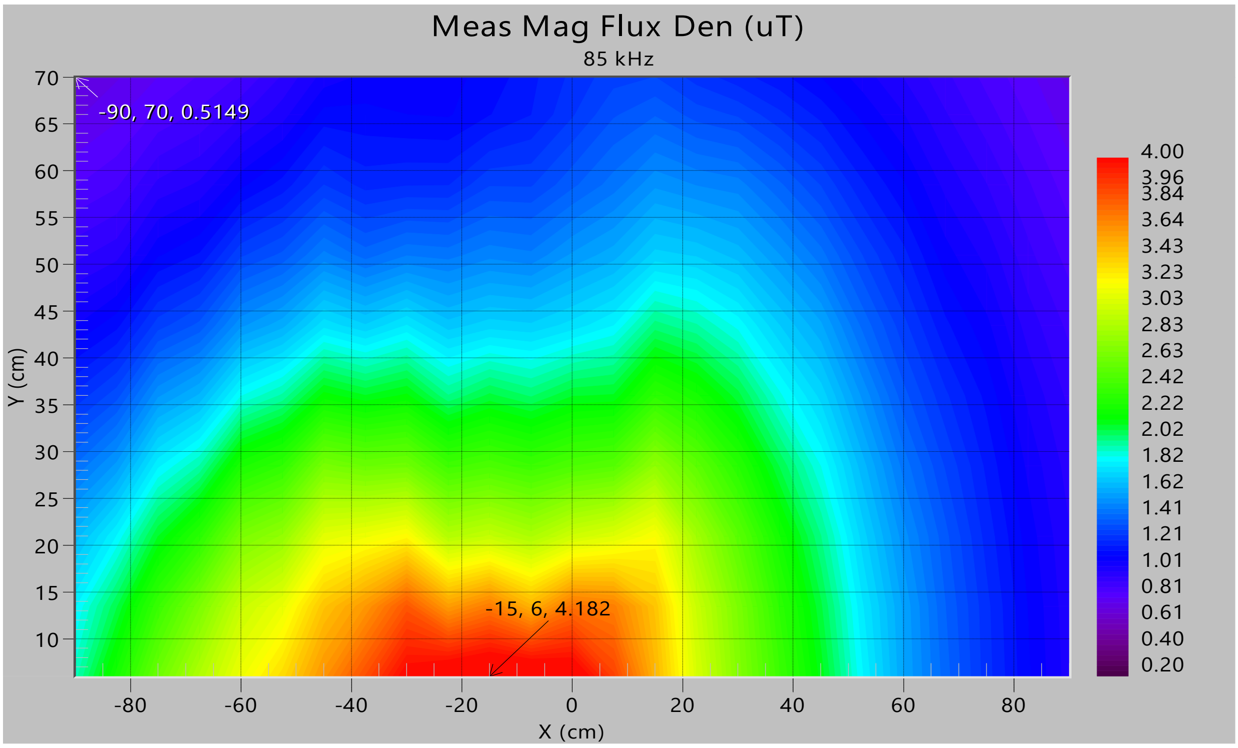
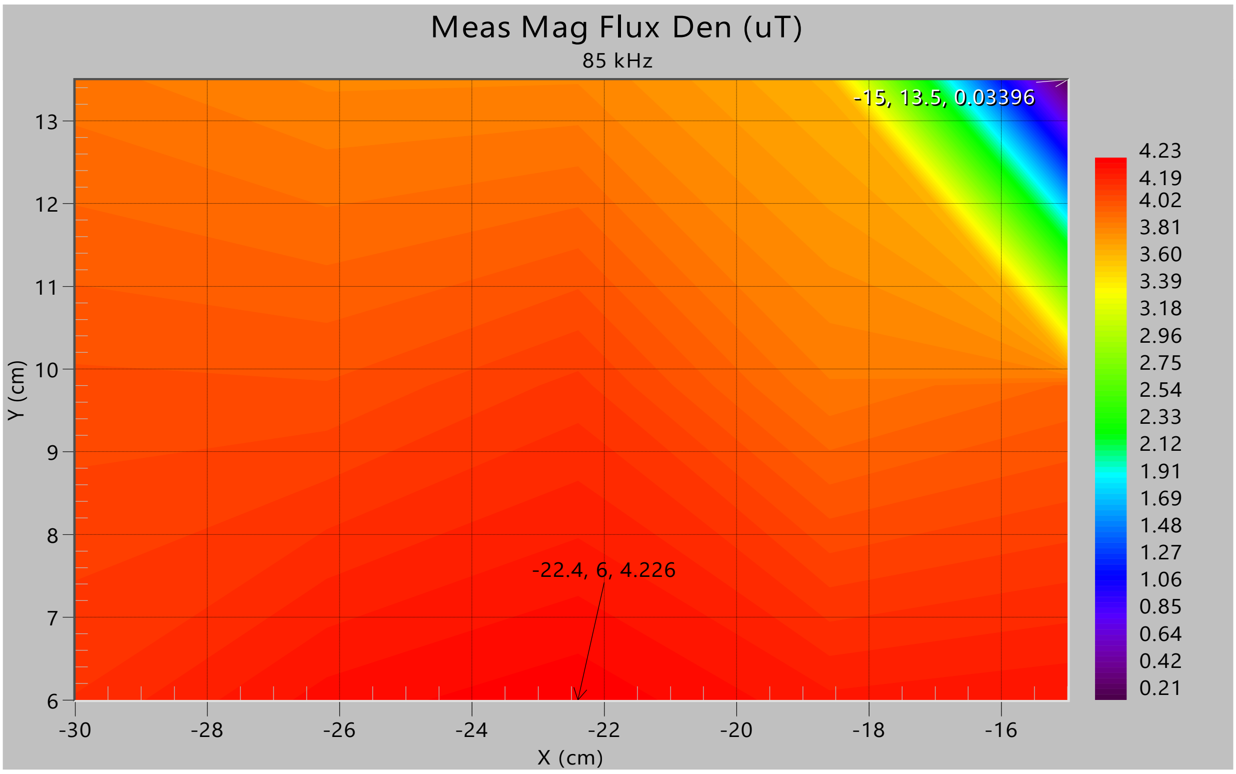


FIGURE 20

EMF measurements taken on a fine grid in the area of maximum EMF with resolution of 3.75 cm



5 Status of spectrum

5.1 WPT, distinction between ISM and short range device RF bands

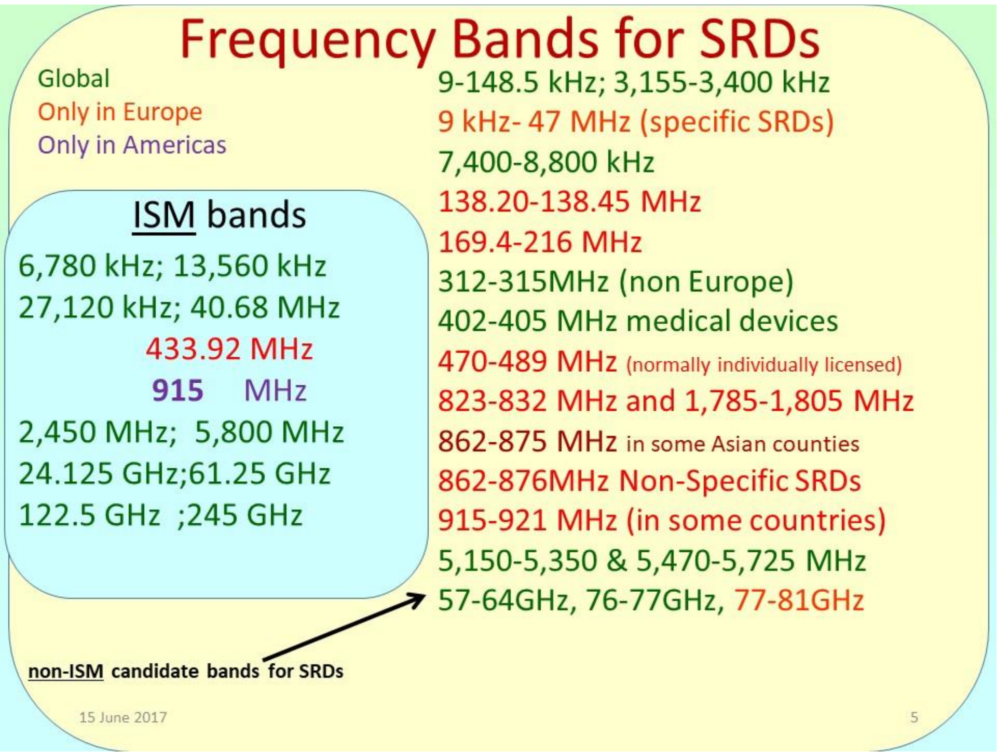
RR provisions of No. **1.15** – industrial, scientific and medical (ISM) applications (of radio frequency energy): operation of equipment or appliances designed to generate and use locally radio frequency energy for industrial, scientific, medical, domestic or similar purposes, excluding applications 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 § 4.2 of this Report. 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. 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. Figure 21 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 21

ISM and non-ISM frequency bands for SRDs*



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.

5.2.1 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.

5.2.2 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.

5.2.3 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 coexist 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.

5.2.4 Electric passenger vehicles

In this section, 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 79-90.00 kHz for light duty vehicle WPT.

5.2.5 Heavy duty electric vehicles

In May 2011, the Korean government allocated the frequencies for OnLine EV (OLEV) to 20 kHz (1921 kHz) and 60 kHz (5961 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

5.3.1 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 3

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
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

TABLE 3 (*end*)

	Magnetic induction (low power)	**Magnetic resonant coupling**	**Magnetic induction (high power)**	**Capacitive coupling**
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) [3]	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 4

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
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

TABLE 4 (*end*)

	Magnetic resonance and/or induction for electric passenger vehicles	**Magnetic induction for heavy duty vehicles**
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 Examples of national regulations

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].

Asia-Pacific Telecommunity (APT) Survey Report on WPT [1] and APT Report on WPT [8] provide the latest information on regulatory discussions in Asia-Pacific Telecommunity (APT) member countries on WPT to consider introduction.

The following examples of national regulations are provided for information.

6.1 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.

– For WPT equipment operating in the range of 100-205 kHz, the electric field strength is less than or equal to 500 μV/m at 3 m. A compensation factor of 6π/λ is required to be applied to the measurement value (where λ is the wavelength of the measurement frequency).
– For WPT equipment operating in the range of 6 765-6 795 kHz, the electric field strength of the spurious emission should be satisfied in accordance with Table 5.
– For WPT equipment operating in the ranges 19-21 kHz and 59-61 kHz, the electric field strength is less than or equal to 100 μV/m at 100 m.
– For WPT equipment operating in the range of 79-90 kHz, the magnetic and electric field strengths should be satisfied in accordance with Table 6.

TABLE 5

Field strength limits for WPT equipment operating in the ranges of 6 765-6 795 kHz 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
0.15-10 MHz		9 kHz	
10-30 MHz	48 dBµV/m		
30-230 MHz	30 dBµV/m	120 kHz	
230-1 000 MHz	37 dBµV/m		

TABLE 6

Field strength limits for WPT equipment operating in the ranges of 79-90 kHz in Korea

Frequency range	Field strength limit (Quasi-peak)	Measurement bandwidth	Measuring distance
9-150 kHz	27-15 dBµA/m	200 Hz	10 m
0.15-4 MHz	14.5- –7.7 dBµA/m	9 kHz	
4-11 MHz	–7.7 - –0.2 dBµA/m		
11-30 MHz	–0.2 - –7 dBµA/m		
30-80.872 MHz	30 dBµV/m	120 kHz	
80.872-81.848 MHz	50 dBµV/m		
81.848-134.786 MHz	30 dBµV/m		
134.786-136.414 MHz	50 dBµV/m		
136.414-230 MHz	30 dBµV/m		
230-1 000 MHz	37 dBµV/m		

6.2 In Japan

6.2.1 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 50 W, 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 7. Emission limits are shown in Tables 8, 9 and 10 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 for WPT 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 7. 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 7

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 to Table 7:

(*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 8

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 dBμV (linearly decreasing with log(f) Average 56-46 dBμV (linearly decreasing with log(f) 0.50-5 MHz: Quasi-peak 56 dBμV, Average 46 dBμV 5-30 MHz: Quasi-peak 60 dBμV, Average 50 dBμV, except ISM bands	6.765-6.776 MHz: 44.0 dBμA/m at 10 m (quasi-peak); 6.776-6.795 MHz: 64.0 dBμA/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 dBμA/m at 0.15 MHz to 3 dBμA/m at 30 MHz. Exception-1: 20.295-20.385 MHz: 4.0 dBμA/m at 10 m (quasi-peak). Exception-2: 526.5-1 606.5 kHz: –2.0 dBμA/m at 10 m (quasi-peak)	Taking basis on CISPR 11 Ed. 5.1, the following is applied: 30-80.872 MHz: 30 dBμV/m; 80.872-81.88 MHz: 50 dBμV/m; 81.88-134.786 MHz: 30 dBμV/m; 134.786-136.414 MHz: 50 dBμV/m; 136.414-230 MHz: 30 dBμV/m; 230-1 000 MHz: 37 dBμV/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 dBμV/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 9

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 (capacitive coupling)	Not specified	0.15-0.50 MHz: Quasi-peak 66-56 dBµV (linearly decreasing with log(f) Average 56-46 dBµV (linearly decreasing with log(f) 0.50-5 MHz: Quasi-peak 56 dBµV, Average 46 dBµV 5-30 MHz: Quasi-peak 60 dBµV, Average 50 dBµV, 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 dBµA/m at 0.15 MHz to 3 dBµA/m 30 MHz	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 dBµA/m at 0.15 MHz to 3 dBµA/m at 30 MHz. Exception: 526.5-1 606.5 kHz: –2.0 dBµA/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 dBµV/m; 80.872-81.88 MHz: 50 dBµV/m; 81.88-134.786 MHz: 30 dBµV/m; 134.786-136.414 MHz: 50 dBµV/m; 136.414-230 MHz: 30 dBµV/m; 230-1 000 MHz: 37 dBµV/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 10

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 dBμV (linearly decreasing with log(f) Average 56-46 dBμV (linearly decreasing with log(f), 0.50-5 MHz: Quasi-peak 56 dBμV, Average 46 dBμV 5-30 MHz: Quasi-peak 60 dBμV, Average 50 dBμV, except ISM bands	68.4 dBμA/m at 10 m. (quasi-peak)	23.1 dBμA/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 dBμA/m at 0.15 MHz to 3 dBμA/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 dBμA/m (quasi-peak)	Taking basis on CISPR 11 Ed. 5.1, the following is applied: 30-80.872 MHz: 30 dBμV/m; 80.872-81.88 MHz: 50 dBμV/m; 81.88-134.786 MHz: 30 dBμV/m; 134.786-136.414 MHz: 50 dBμV/m; 136.414-230 MHz: 30 dBμV/m; 230-1 000 MHz: 37 dBμV/m	Not specified

6.2.2 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 are 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 a greater 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 it is demonstrated that the 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.

6.3 In China

The national regulation of WPT in China is under study.

7 Impact studies between WPT and radiocommunication services

This section details the status of impact studies between WPT and radiocommunication services, including the radio astronomy service[5].

Some of the studies in this section apply to WPT emissions from mobile and portable devices which is also covered by Report ITU-R SM.2449 such as the studies in § 7.2 and in Annex 3. However, since those are general in nature they also apply in the context of portable and mobile devices.

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 22 and 23 show the WPT spectrum designated in Japan and assigned in Korea [1] together with those for non-beam WPT systems agreed by international organizations. Additional spectrum may also be used for WPT, pursuant to Recommendations ITU-R SM.2110 'Guidance on frequency ranges for operation of non-beam wireless power transmission for electric vehicles' and ITU-R SM.2129 'Guidance on frequency ranges for operation of non-beam wireless power transmission systems for mobile and portable devices'. 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 interference nor claim protection from other stations. Table 11 shows spectrum use of incumbent wireless systems below 1.6 MHz, which should be considered in impact studies for WPT systems for EVs.

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[5] This section may be reviewed in the future within the context of ongoing revisions to Reports ITU-R SM.2449 and SM.2451.

TABLE 11

Spectrum use of incumbent wireless systems

Radio systems		Frequency bands	Communication technologies	Remarks
Standard frequency and time signal service		19.95-20.05 kHz (20 kHz, Global) 39-41 kHz (40 kHz, Japan) 49.25-50.75 kHz (50 kHz, Russia) 59-61 kHz (60 kHz, UK, US and Japan) 65.850-67.35 kHz (66.6 kHz, Russia) 68.25-68.75 kHz (68.5 kHz, China) 74.75-75.25 kHz (75 kHz, Switzerland) 77.25-77.75 kHz (77.5 kHz, Germany) 99.75-102.5 kHz (100 kHz, China) 128.6-129.6 kHz (129.1 kHz, Germany) 157.5-166.5 kHz (162 kHz, France)	Amplitude modulation, Binary Coded Decimal (BCD)	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.
Ripple Control Service		128.6-129.6 kHz (129.1 kHz, Europe) 138.5-139.5 kHz (139 kHz, Europe)	–	Load/demand management system for power plants and their electric power network
Train radio systems	Automatic Train Stop Systems (ATS)	10-250 kHz (Japan)	–	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.
		425-524 kHz (Japan)		
	Inductive Train Radio Systems (ITRS)	100-250 kHz (Japan)	–	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.
		80 kHz, 92 kHz (Japan, only one station)		
Amateur radio		135.7-137.8 kHz	Amplitude modulation, frequency modulation, SSB, etc.	Radio service with transmitter and receiver devices used for technology research and training of amateur radio operators.
		472-479 kHz		

TABLE 11 (*end*)

Radio systems	**Frequency bands**	**Communication technologies**	**Remarks**
Maritime radio	90-110 kHz (LORAN) 424 kHz, 490 kHz, 518 kHz (NAVTEX) 495-505 kHz (NAVDAT)	Pulse, FSK etc.	Radio system that secures safety of vessel operation which is used at port and harbour or on the sea.
Sound broadcast	148.5-283.5 kHz (Region 1) 525-526.5 kHz (Region 2) 526.5-1606.5 kHz (Global) 1605.5-1705 kHz (Region 2)	Amplitude modulation/DRM	Audio broadcasting service with receiver devices which use medium wave band.

FIGURE 22

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

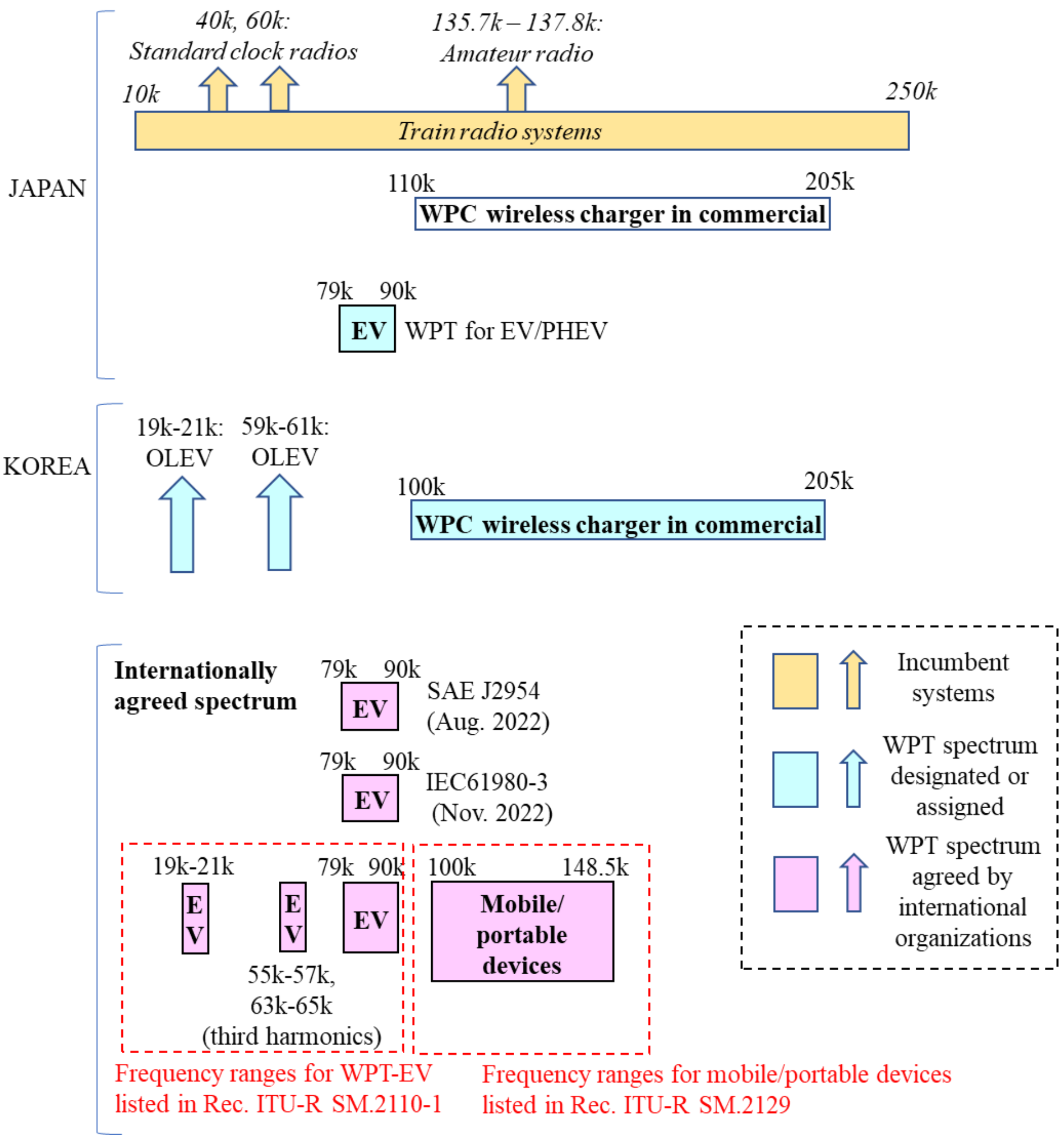
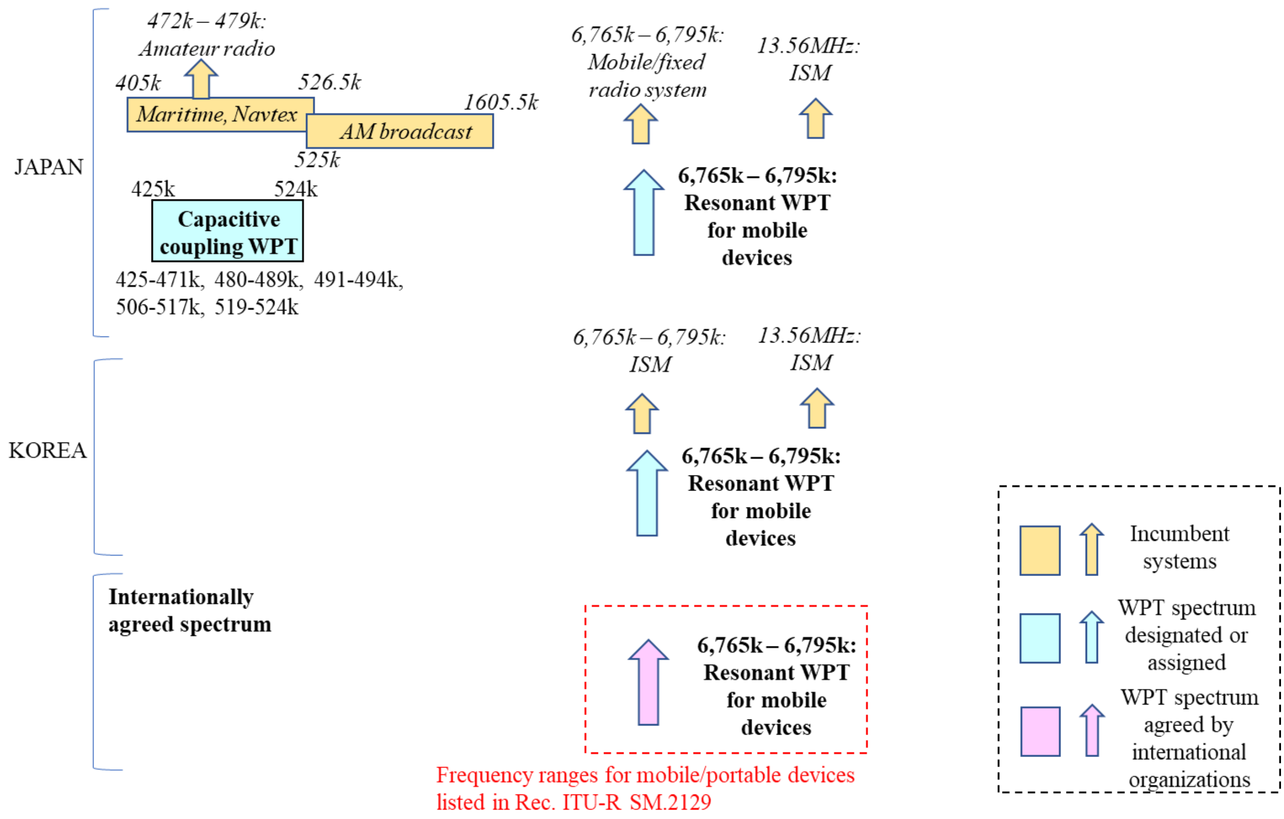


FIGURE 23

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



In Japan, target WPT systems and candidate proposed frequency ranges with fundamental parameters are summarized as shown in Table 12.

TABLE 12

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 criterion 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 8) 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 appliances 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 candidate frequency ranges other 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 13 (A), (B), (C) and Table 14 summarize results of coexistence studies.

TABLE 13

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

WPT for mobile and home appliances		Incumbent systems	
Technologies	Candidate frequency ranges	AM broadcast (1) (526.5-1 606.5 kHz)	Maritime radio devices (2) (405-526.5 kHz)
Magnetic coupling (low power for mobile devices)	6.765-6.795 kHz	N/A	N/A
Magnetic coupling (low-high power for home appliances)	20.05-38 kHz	Not meet coexistence conditions as found required separation distance far exceeding 10 m as the target requirement	N/A
	42-58 kHz		N/A
	62-100 kHz		Meets coexistence conditions with the following • Avoiding the use of WPT systems emitting power in the LORAN-C frequency range (3)
Capacitive coupling (low power for mobile devices)	425-524 kHz	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	Meets coexistence conditions with the following. • Avoiding the use of WPT systems emitting power in the frequency ranges of NAVTEX and NAVDAT

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		N/A
	42-58 kHz		N/A
	62-100 kHz		N/A
Capacitive coupling (low power for mobile devices)	425-524 kHz		N/A

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 14

Summary of WPT for EV coexistence study results in Japan

WPT for EV	**Incumbent systems**				
Candidate frequency ranges	**SCRD (1) (40 kHz, 60 kHz)**	**ATS (2) (10-250 kHz)**	**ITRS (3) (10-250 kHz)**	**AM broadcast (4) (526.5-1 606.5 kHz)**	**Amateur radio devices (5) (135.7-137.8 kHz)**
42-48 kHz	Not meet coexistence conditions	Not assessed since another condition did not meet	Meets coexistence conditions	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	Meets coexistence conditions with the following note. • Avoiding the use of WPT systems transmitting power in the amateur radio frequency ranges
52-58 kHz	Not meet coexistence conditions	Not assessed since another condition did not meet	Meets coexistence conditions		
79-90 kHz	Meets coexistence conditions with the following note. • Inviting user's attention to the possibility of interference to Standard Clock radio devices	Meets coexistence conditions with the following requirement. • Minimum separation distance from the rail of 4.8 m shall be kept	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		
140.91-148.5 kHz		Not assessed since another condition did not meet	Not meet coexistence conditions		

Notes to Table 14:

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 criterion for coexistence is: (i) WPT frequency band should not be overlapped with those used for the train signalling 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 were taken in different polarization planes, with only the results from the plane with maximum emissions 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 tested channel is around 71 dBμA/m (no offset) to 75 dBμA/m (max offset). This exceeds the limits of ETSI EN 300 330-1 by 4 and 8 dB respectively. ETSI has published EN 303 417 "Wireless power transmission 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; Harmonised Standard covering the essential requirements of Article 3.2 of Directive 2014/53/EU".
– 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 Generic 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 Mondiale).

However, the analysis below focuses on AM sound broadcasting only.

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

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. 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. These protection ratios 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 from:

– 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 kHz – 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; from a WPT charger using a frequency in a Broadcasting Band.

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 is 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 Recommendation 70-03 [3] 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 Recommendation 70-03 [3] (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 an rms modulation depth of 0.2 (20%) is assumed[6] 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 sideband 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.

6 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 EVs)
– 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.

FIGURE 24

London apartment block

Figure 24 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 3 m and 10 m is therefore $(10/3)^3 = 37.0$. In dBμA/m terms this is a difference of 20.log10(37) = 31 dB. 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 31 dB 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 not 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. First, it 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, 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 at 10 m for 3 kW Tx Power

72.5 dBμA/m at 10 m for 7.7 kW Tx Power

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

−2.0 dBμA/m at 10 m

c) Frequency range except for the above frequency range:

23.1 dBμA/m at 10 m

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 test WPT systems for EVs shall not cause harmful interference to an AM broadcasting receiver located at least within 10 metres 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 7^{th} 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 at 10 m 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 neighbourhood 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. 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

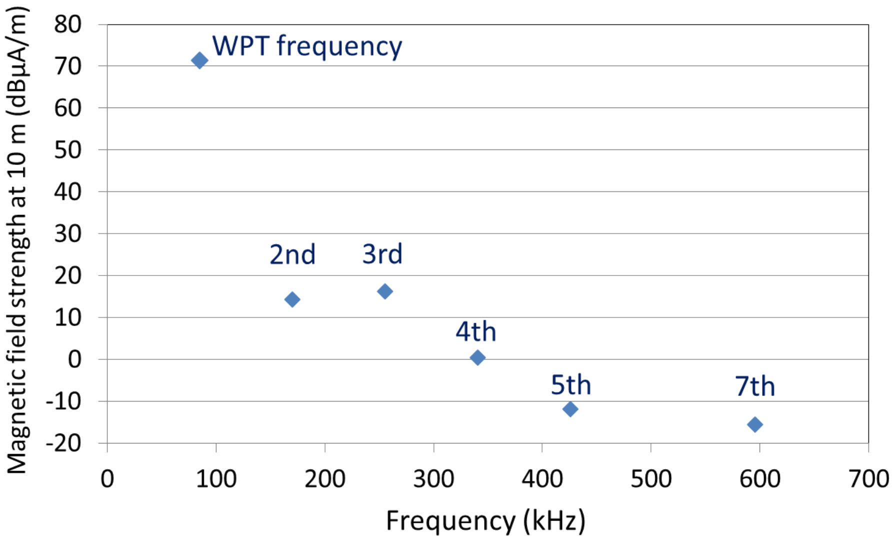
In order to confirm the result of the analytical study above, emission measurement using WPT test equipment and AM broadcasting receivers was performed. Conditions and methods were as follows:

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. 25.

FIGURE 25

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 was from 1 July to 2 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

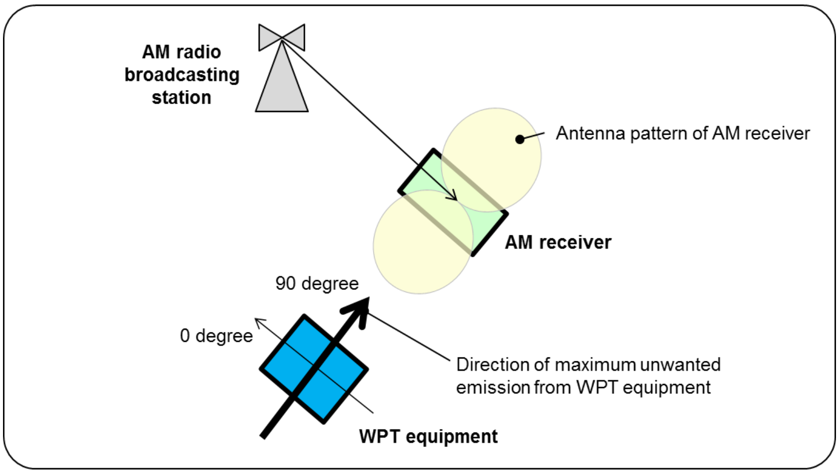
In the Tokyo area, there is an AM broadcasting channel of NHK Radio 1 at 594 kHz. The frequency difference between NHK Radio 1 and the 7th harmonic of "Test Equipment B" is about 1.7 kHz. If the 7th harmonic of "Test Equipment B" is larger than environmental noise, we can hear noise of 1.7 kHz.

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 analyser. 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 26 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 26

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. 27. 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 7^{th} 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.

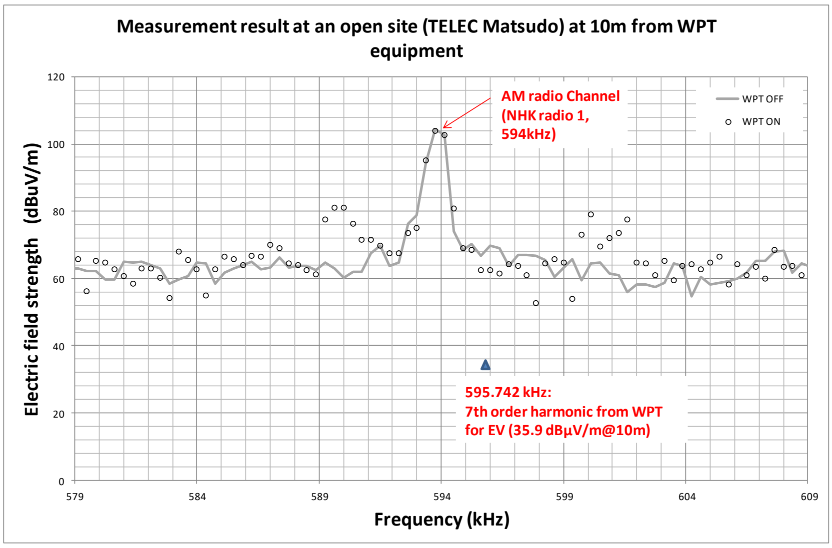
7.2.2.5 Assessment of study results

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 can be applied.

FIGURE 27

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



7.3 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 manufacturers; the frequency range 100/110-300 kHz is also under consideration in the present studies. There are concerns on:

– The use of LF frequencies adjacent to or overlapping the Region 1 LF broadcasting band, 148.5-255 kHz; and

– Adverse impact on radiocommunication and radionavigation services making use of the LF bands.

7.4 Frequency range 300-405 kHz for WPT for mobile and portable devices

Further studies pursuant to Recommendation ITU-R SM.2129 'Guidance on frequency ranges for operation of non-beam wireless power transmission systems for mobile and portable devices' can be found in Report ITU-R SM.2449.

7.5 Frequency range 1 700-1 800 kHz for WPT for mobile and portable devices

Further studies pursuant to Recommendation ITU-R SM.2129 'Guidance on frequency ranges for operation of non-beam wireless power transmission systems for mobile and portable devices' can be found in Report ITU-R SM.2449.

7.6 Frequency range 2 000-2 170 kHz for WPT for mobile and portable devices

Further studies pursuant to Recommendation ITU-R SM.2129 'Guidance on frequency ranges for operation of non-beam wireless power transmission systems for mobile and portable devices' can be found in Report ITU-R SM.2449.

7.7 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.

7.8 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 RR No. **5.56**).

The ERC Recommendation 70-03 [3] on the use in Europe specifies frequency ranges, their maximum field strength, and locations as shown in Table 15.

TABLE 15

Standard frequency and time signals to be protected within 9-90 kHz and 119-135 kHz (ERC Recommendation 70-03) [3]

Stations	Frequency	Protection bandwidth	Maximum field strength at 10 m	Location
MSF	60 kHz	±250 Hz	42 dBμA/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 12 in this Report provide practical case studies in Japan on the impact to the standard frequency and time signal services.

7.9 CEPT experiences to protect services from the emissions of inductive SRDs

This section details the 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 dBμA/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 were 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 dBμA/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 13 MHz 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 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 the frequency band 79-90 kHz. That for Electric heavy duty vehicles are being studied with frequency bands of 19-21 kHz and 59-61 kHz. Typical powers for electric passenger vehicles are 3.3 kW, 7.7 kW, 11 kW and 22 kW. Typical powers for Heavy Duty vehicles range from 75-100 kW.

Magnetic resonance WPT technologies typically utilize the 6 765-6 795 kHz and 13 553-13 567 kHz ISM bands with typical power of several watts to 50 W.

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

9 References

[1] APT/AWG/REP-48 "APT Survey Report on "Wireless Power Transmission", March 2014. https://www.apt.int/AWG-REPTS

[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] The ERC Recommendation 70-03, Relating to the use of Short Range Devices (SRD)

[4] 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

[5] 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/

[6] ICNIRP (2020): Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz)

[7] IEEE C95.1 (2019) IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz

[8] APT/AWG/REP-62(Rev.1) "APT Report on Wireless Power Transmission (WPT)", March 2015. https://www.apt.int/AWG-REPTS

[9] 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.

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

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

[12] 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); see AS/NZS. 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) see arpansa
Japan	– BWF's guideline on RF exposure: 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*)

Country	RF exposure	RF assessment
		– 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

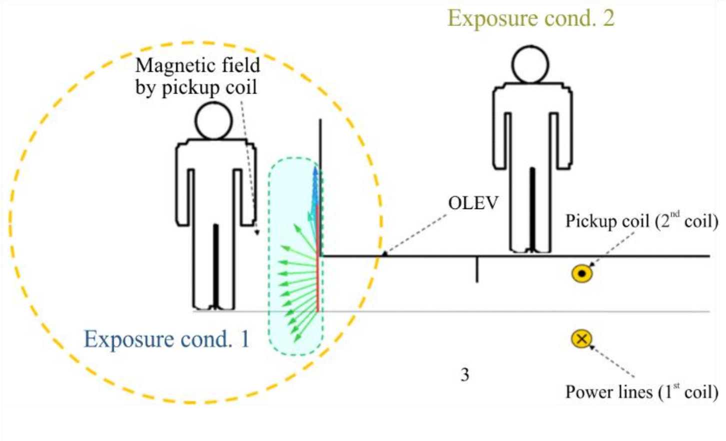
Evaluation of EMF human exposure from Electric Vehicle in Korea

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 (1^{st} coil) and 5 pickup coil segments under the OLEV (2^{nd} 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 2^{nd} condition from the power lines and pickup coils of OLEV system.

FIGURE A1-1

EMF human exposure condition of OLEV system

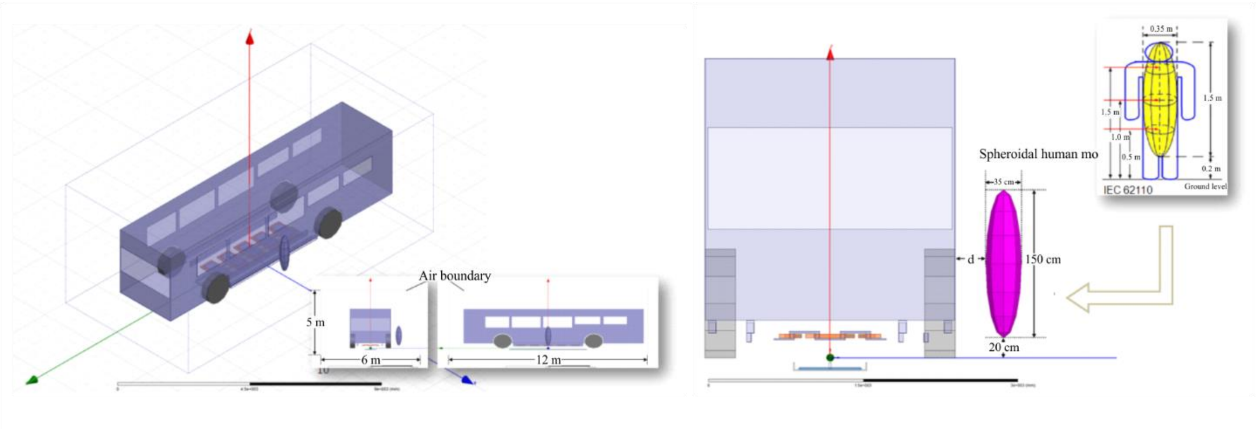


Report SM.2303-A1-01

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



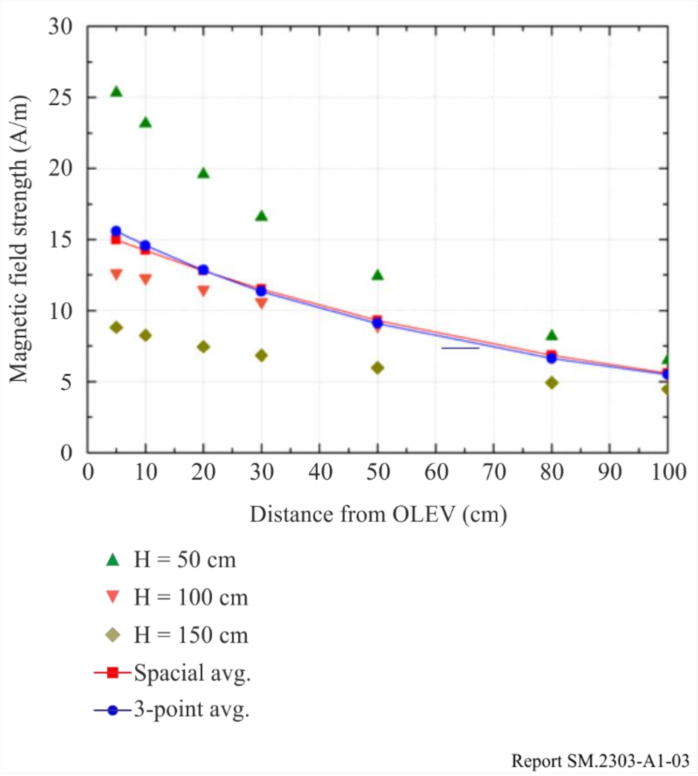
Report SM.2303-A1-02

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. It can be known 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 distance 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

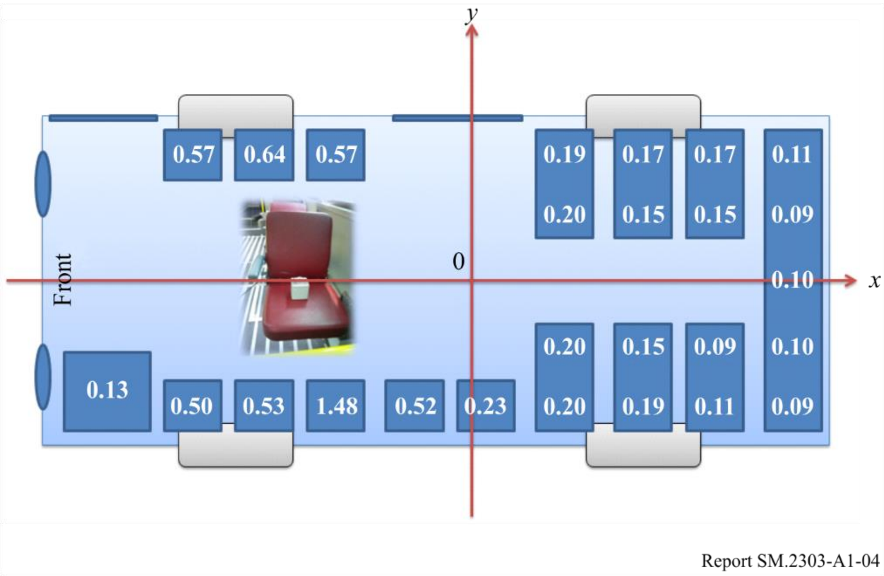


FIGURE A1-5

The calculated magnetic field distributions at each distance from OLEV

Simulated data (S.D.: 72 cm)

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

Measured data (S.D.: 60 cm)

Measuring points	Measuring values (A/m)	Adopted values
P1	3.82	×
P2	3.41	×
P3	1.96	×
P4	0.90	
P5	1.08	

Report SM.2303-A1-05

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

Example of the use of the 6 765-6 795 kHz ISM band to charge mobile devices

This Annex provides an 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 to wireless power product designers greater latitude in implementing charging systems, and results in a superior consumer experience.

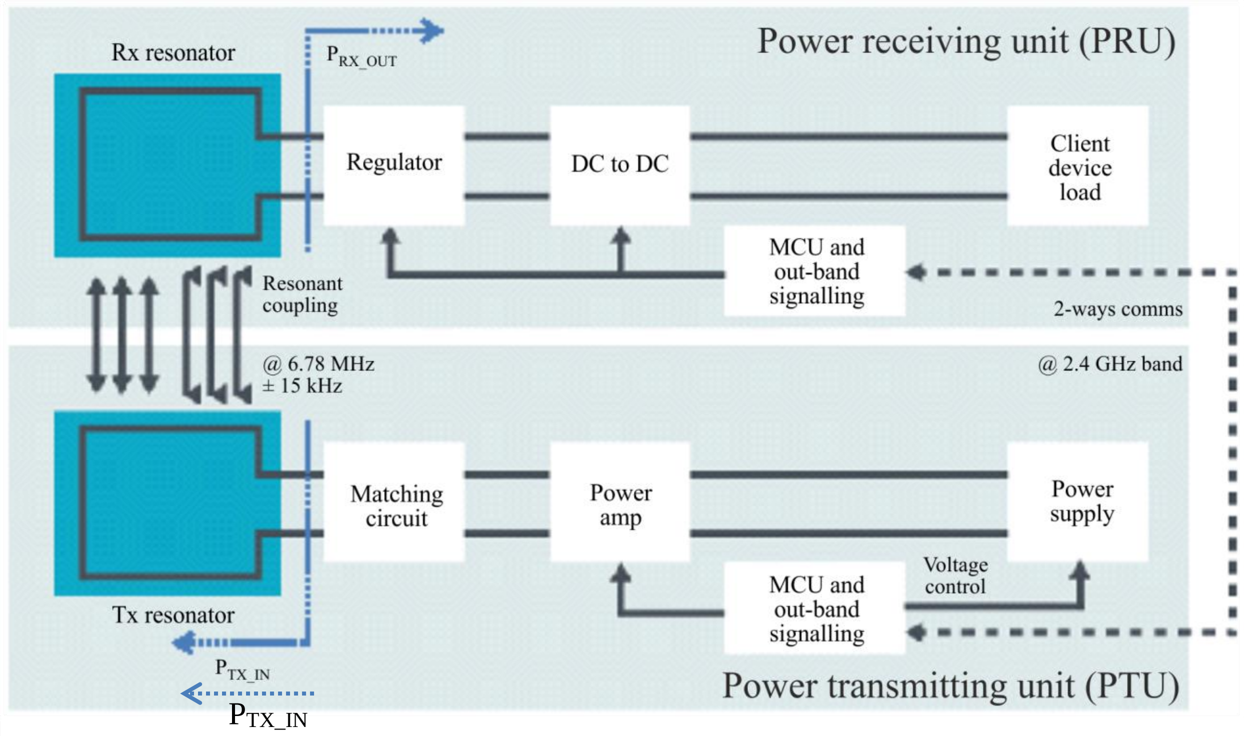
Electronic products intended for this technology integration should address several factors:

– 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.



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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 two-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 two-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

1 Introduction

This Annex 3 provides measured data in Japan 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.

(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 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

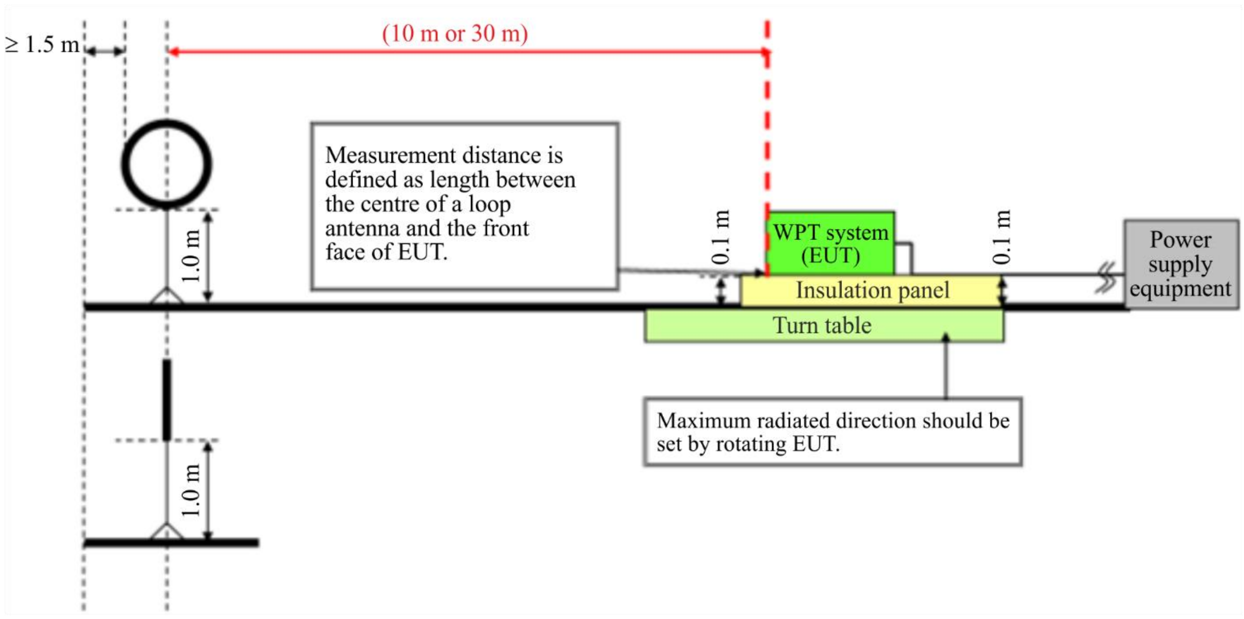

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FIGURE A3-2

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

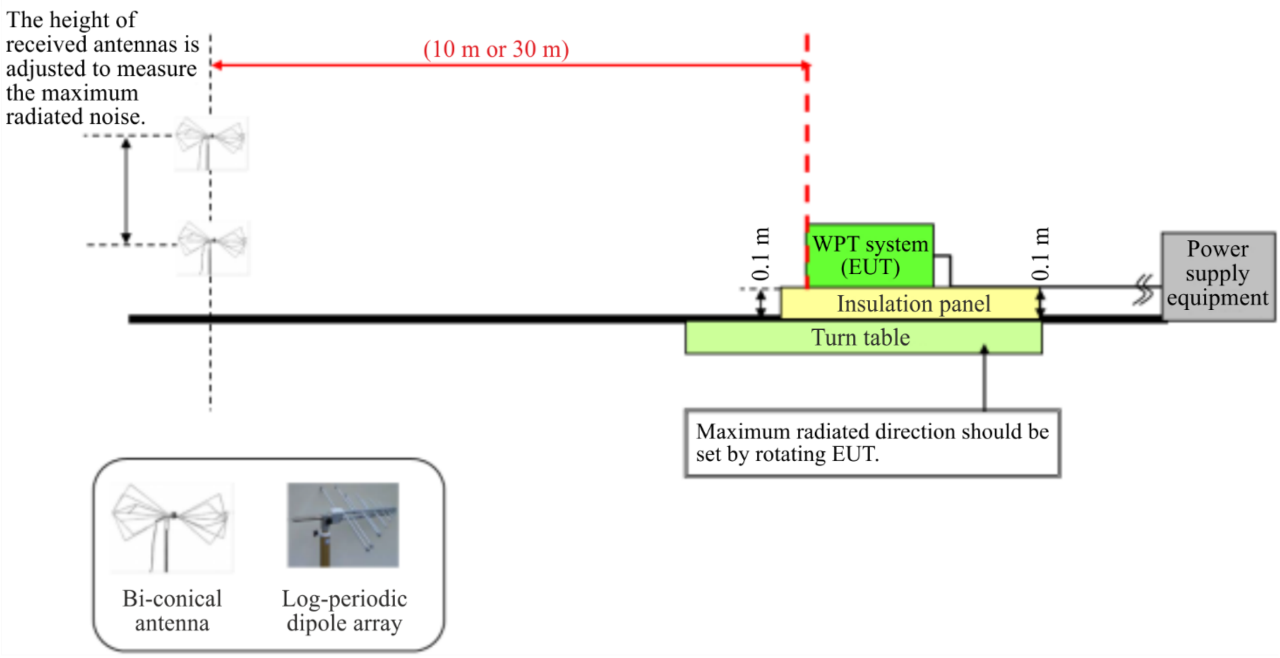

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FIGURE A3-3

Top view of EUT and its arrangement for radiated noise measurement

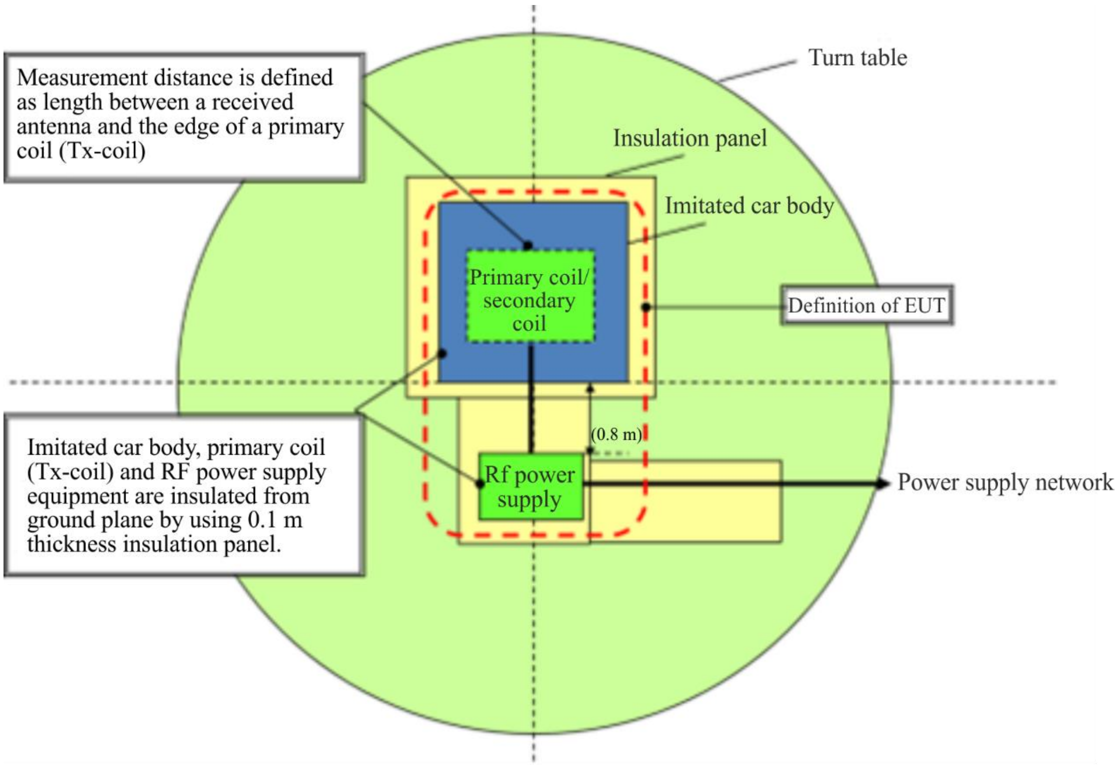

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FIGURE A3-4

Configuration of the imitated car body

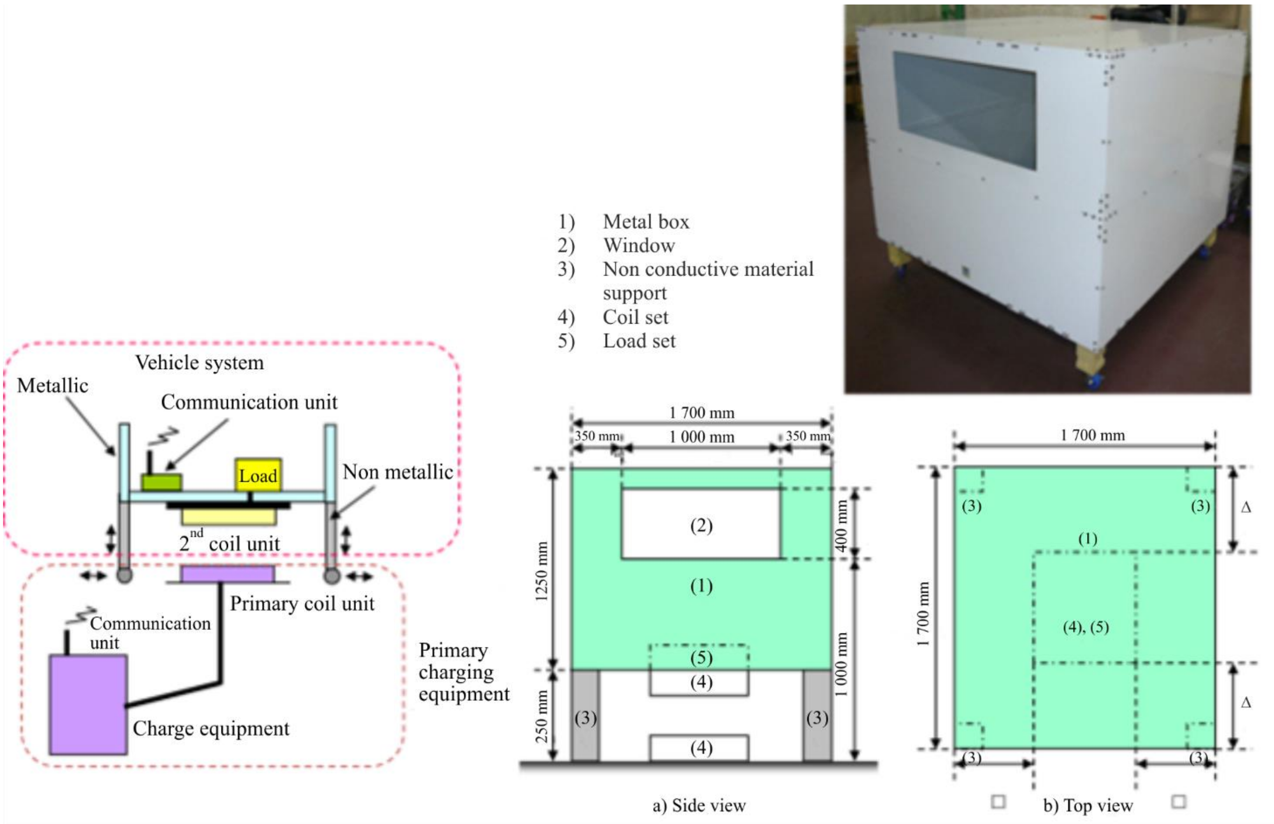

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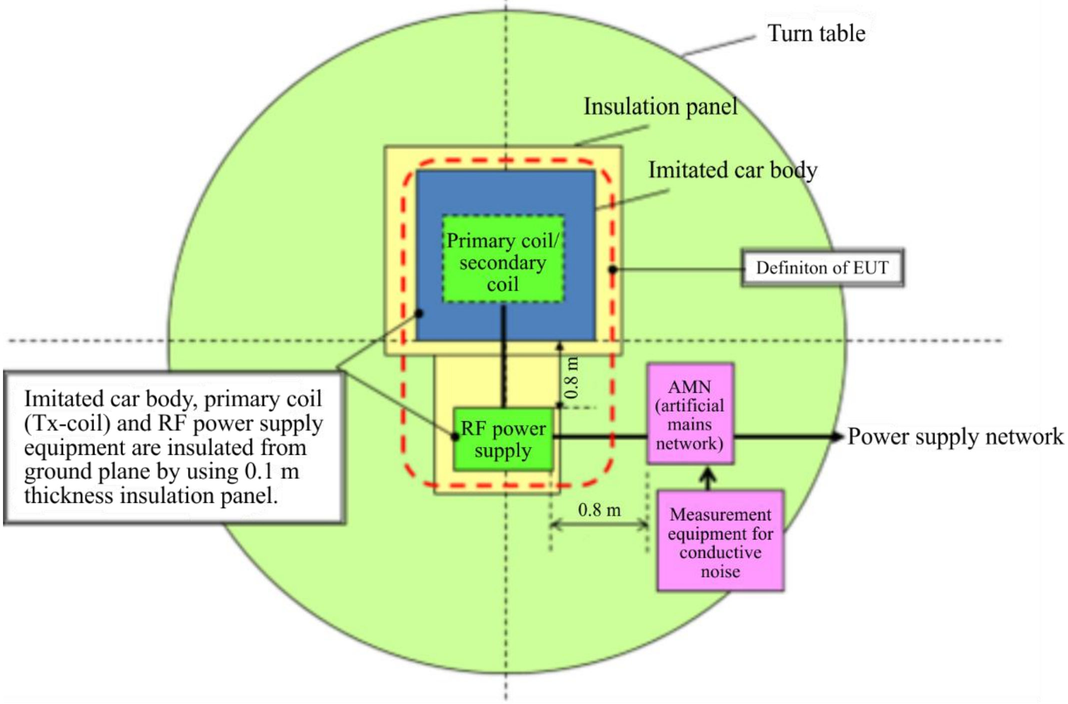
FIGURE A3-5

Top view of EUT and its arrangement for conductive noise measurement



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2.2 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

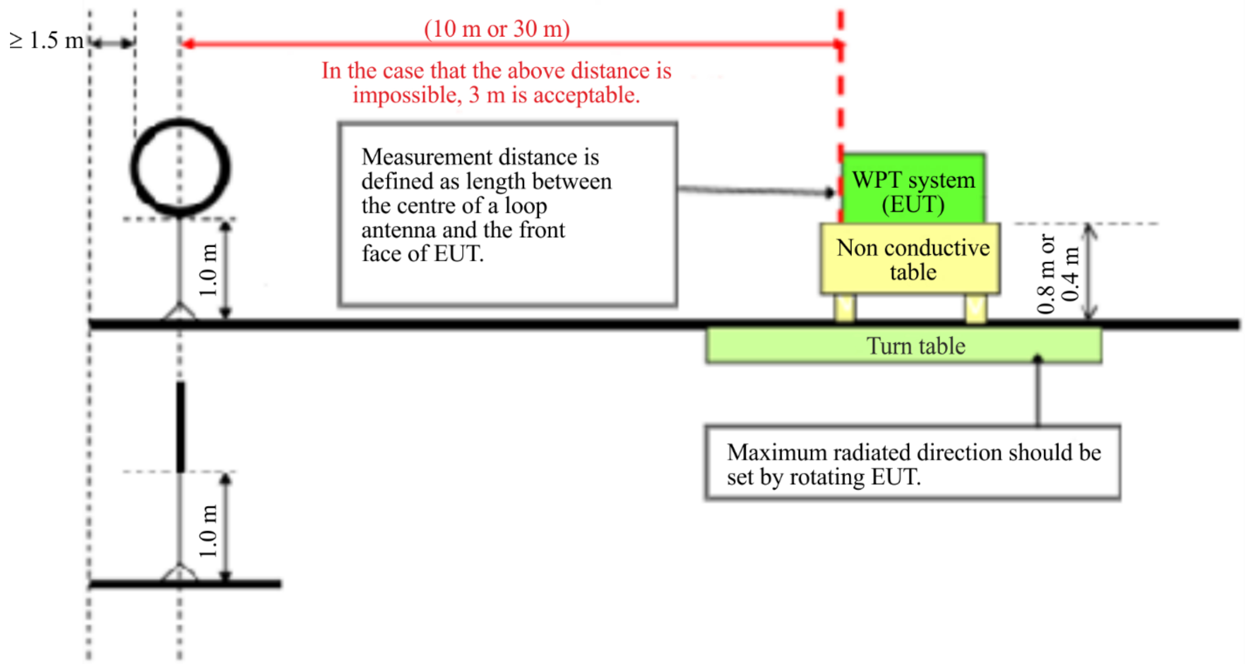

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FIGURE A3-7

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

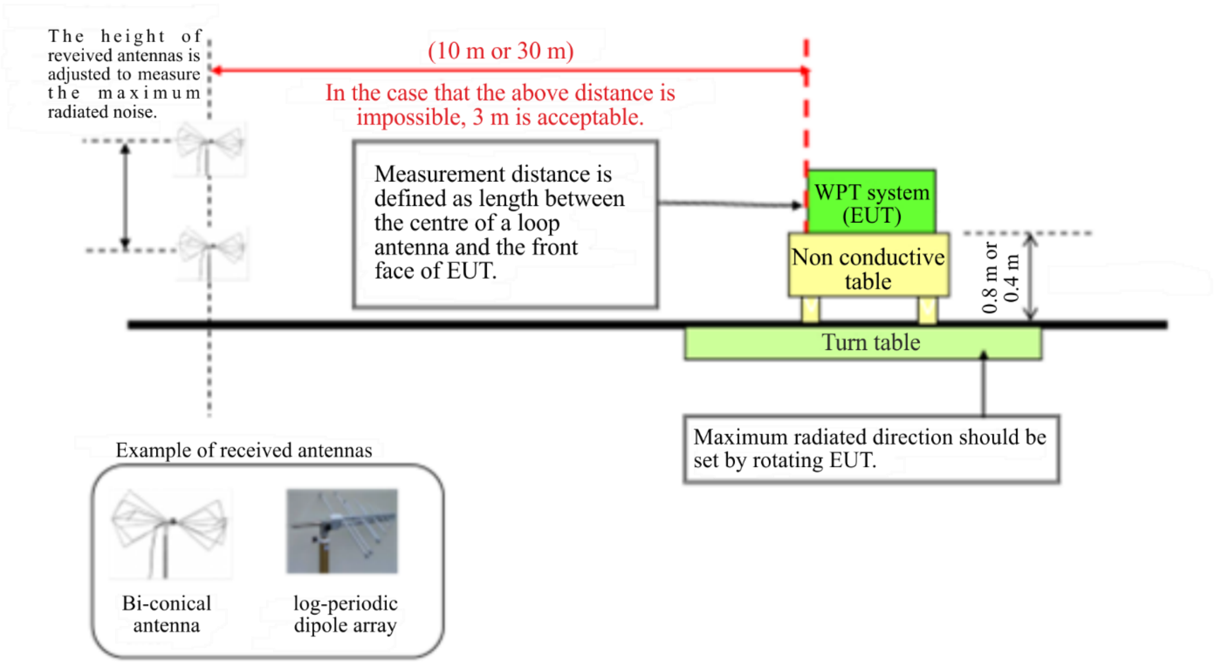

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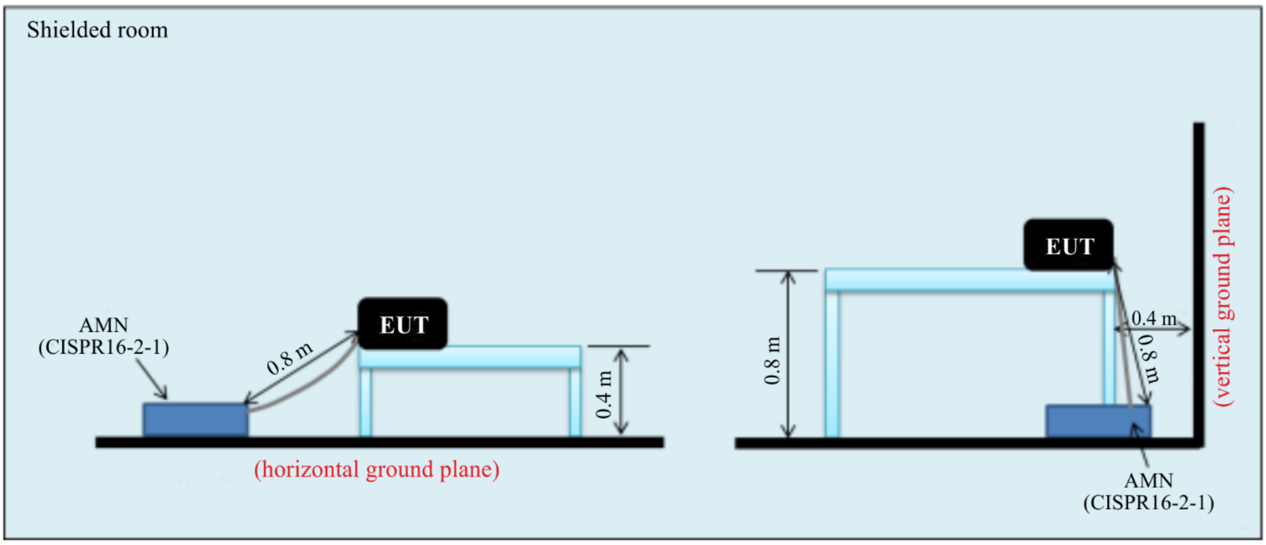
FIGURE A3-8

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 ohms.

(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 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 at 30 m (91.3 dBμV/m at 30 m)

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

(b) Frequency range from 526.5-1 606.5 kHz

30 μV/m at 30 m (29.5 dBμV/m at 30 m)

(c) Frequency range expect for the above frequency range

200 μV/m at 30 m (46.0 dBμV/m at 30 m)

(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 at 30 m (39.8 dBμA/m at 30 m)

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

(b) Frequency range from 526.5-1606.5 kHz

0.0796 μA/m at 30 m (−22.0 dBμA/m at 30 m)

(c) Frequency range expect for the above frequency range

0.531 μA/m at 30 m (−5.51 dBμA/m at 30 m)

3.2 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 at 30 m (100 dBμV/m at 30 m)

(b) Frequency range from 526.5-1 606.5 kHz

30 μV/m at 30 m (29.5 dBμV/m at 30 m)

(c) Frequency range expect for the above frequency range

100 μV/m at 30 m (40.0 dBμV/m at 30 m)

(2) Tentative target limit of radiated magnetic field noise

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

265.3 μA/m at 30 m (48.5 dBμA/m at 30 m)

(b) Frequency range from 526.5-1 606.5 kHz

0.0796 μA/m at 30 m (−22.0 dBμA/m at 30 m)

(c) Frequency range expect for the above frequency range

0.265 μA/m at 30 m (−11.5 dB μA/m at 30 m)

3.3 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 at 30 m (60 dBμV/m at 30 m)

(b) Frequency range from 526.5-1 606.5 kHz

30 μV/m at 30 m (29.5 dBμV/m at 30 m)

(c) Frequency range expect for the above frequency range

173 μV/m at 30 m (44.8 dBμV/m at 30 m)

(2) Tentative target limit of radiated magnetic field noise

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

2.66 μA/m at 30 m (8.5 dBμA/m at 30 m)

(b) Frequency range from 526.5-1 606.5 kHz

0.0796 μA/m at 30 m (−22.0 dBμA/m at 30 m)

(c) Frequency range expect for the above frequency range

0.459 μA/m at 30 m (−6.7 dBμA/m at 30 m)

3.4 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 at 30 m (40 dB μV/m at 30 m)

(b) Frequency range from 526.5-1 606.5 kHz

30 μV/m at 30 m (29.5 dBμV/m at 30 m)

(c) Frequency range expect for the above frequency range
100 µV/m at 30 m (40 dB µV/m at 30 m)

(2) Tentative target limit of radiated magnetic field noise

(a) WPT frequency range (frequency range used for power transmission)
0.265 µA/m at 30 m (−11.5 dB µA/m at 30 m)

(b) Frequency range from 526.5-1606.5 kHz
0.0796 µA/m at 30 m (−22.0 dBµA/m at 30 m)

(c) Frequency range expect for the above frequency range
0.265 µA/m at 30 m (−11.5 dB µA/m at 30 m)

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 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

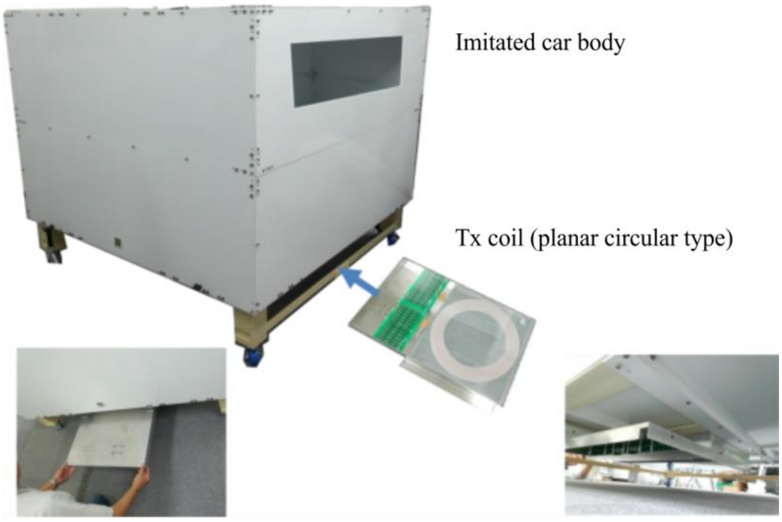

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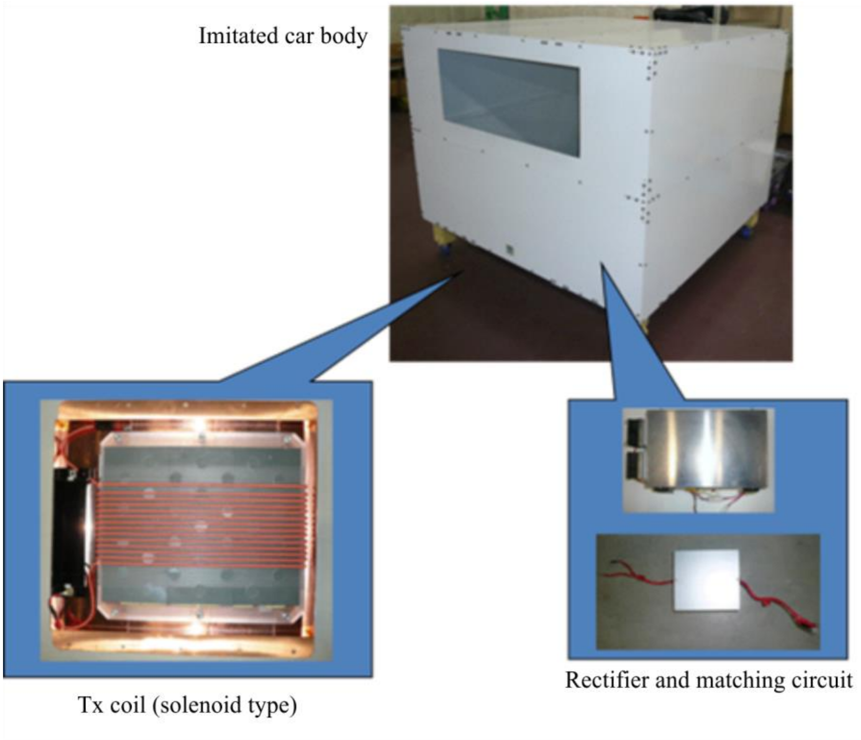
FIGURE A3-10

Test equipment B



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(2) Radiated noise

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

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

Lower frequency than 526.5 kHz: 1/27

From 526.5-1 606.5 kHz: 1/10

Over 1 606.5 kHz to 30 MHz: 1/6

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

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

FIGURE A3-11

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

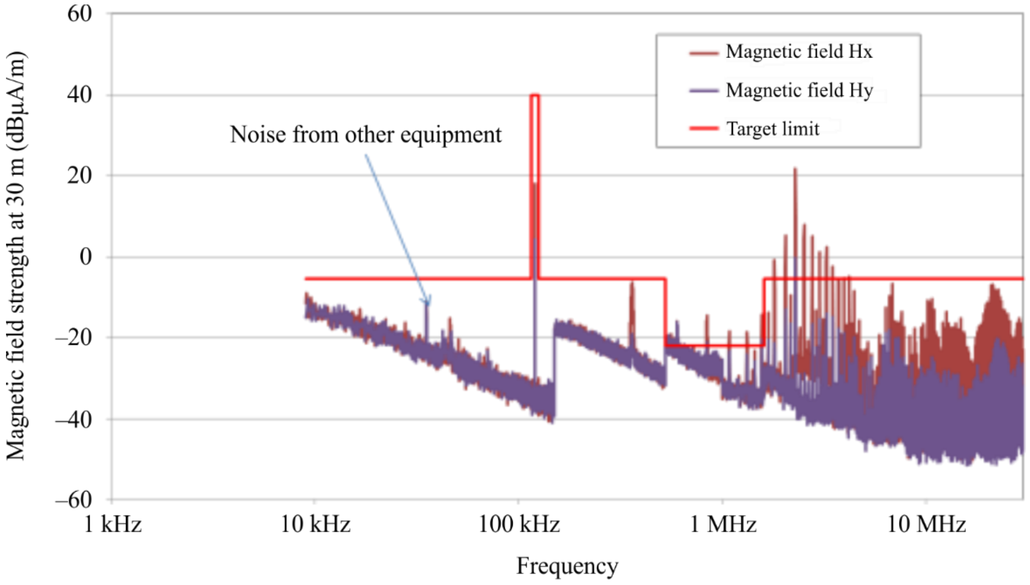

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FIGURE A3-12

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

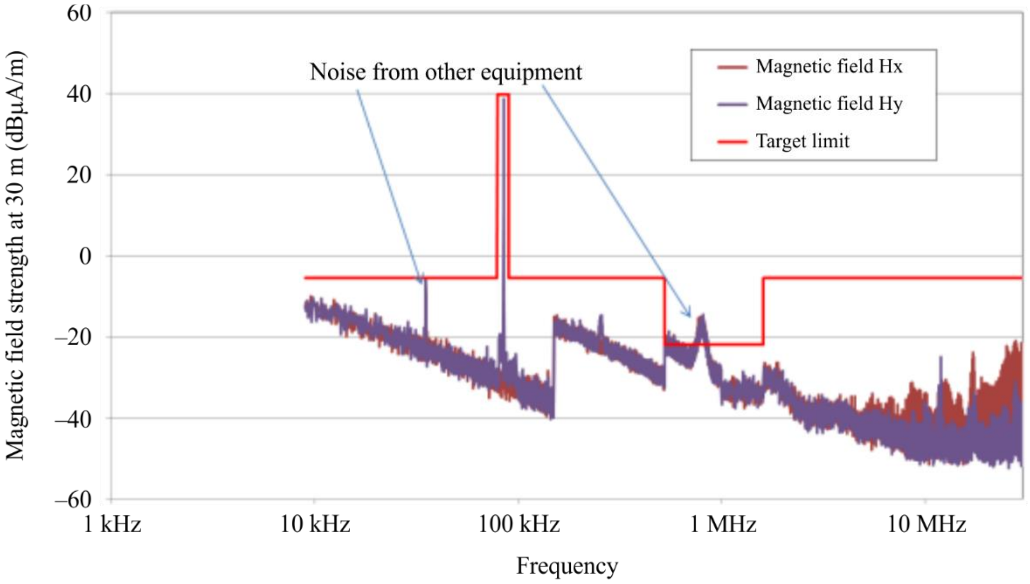

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FIGURE A3-13

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

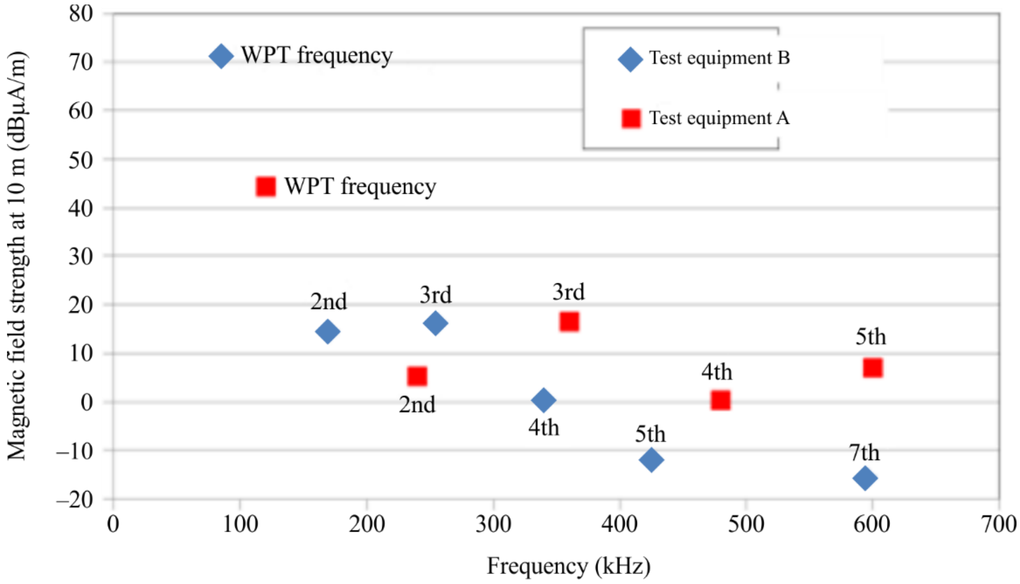

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FIGURE A3-14

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

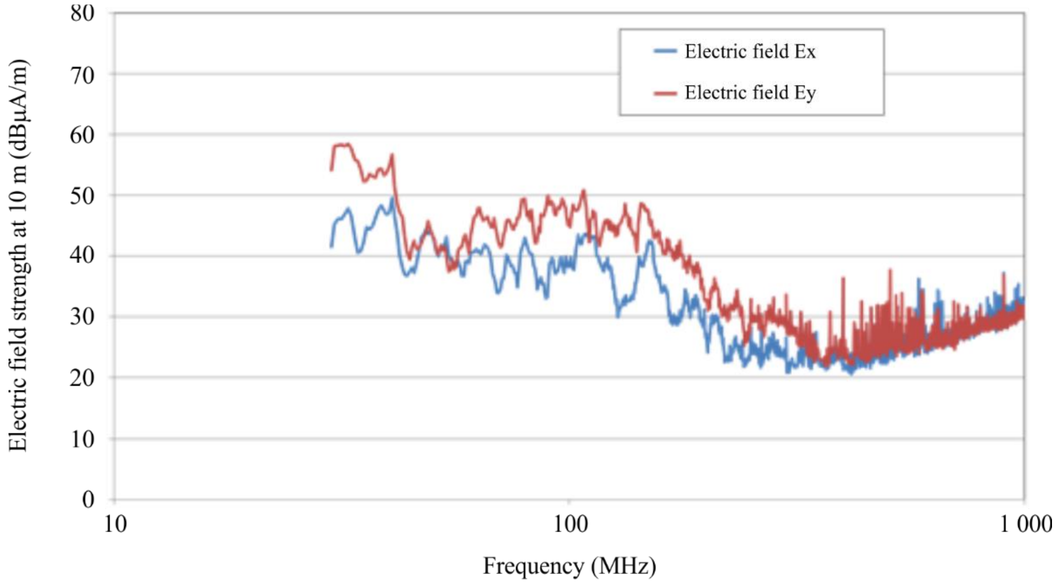

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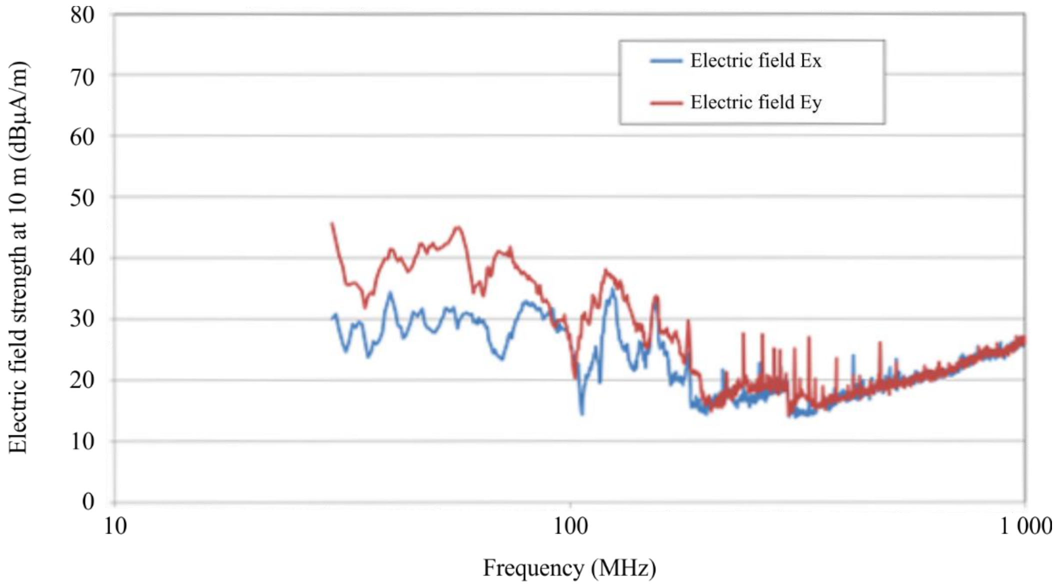
FIGURE A3-15

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



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(3) Conductive noise

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

FIGURE A3-16

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

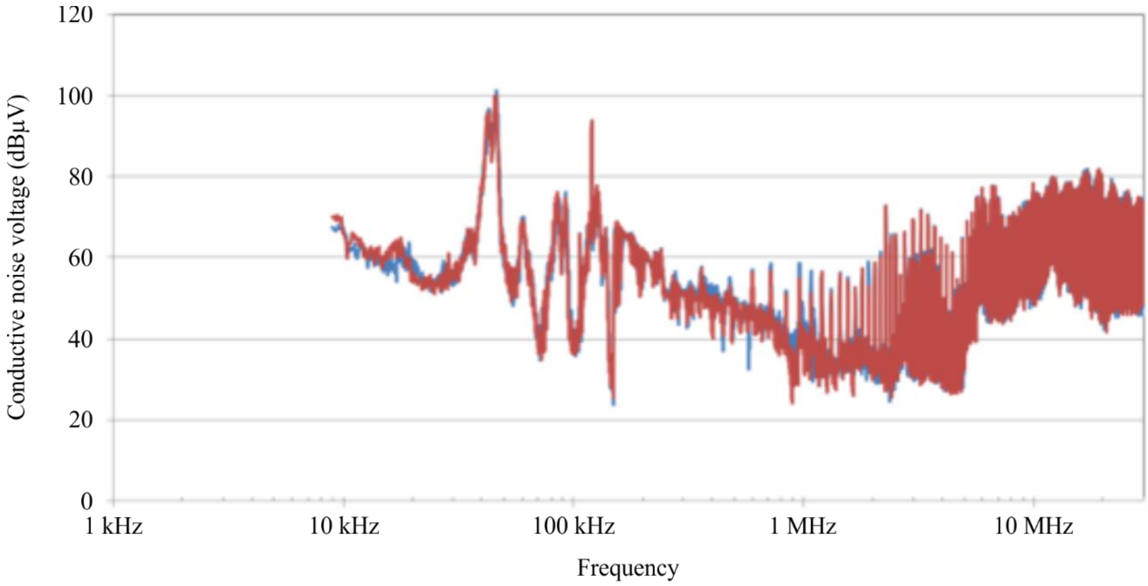

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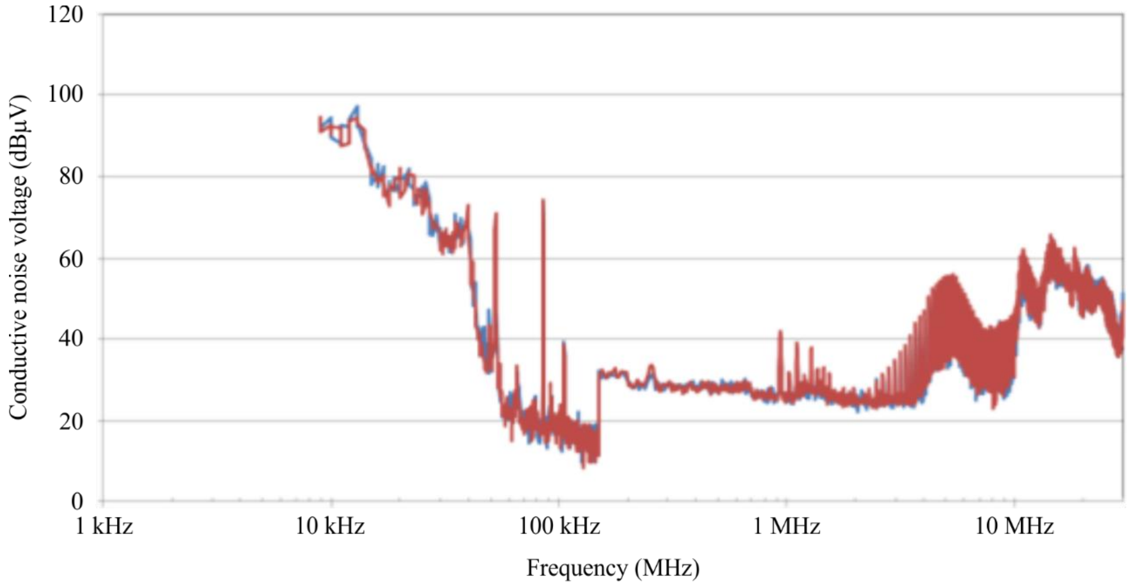
FIGURE A3-17

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



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4.2 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.

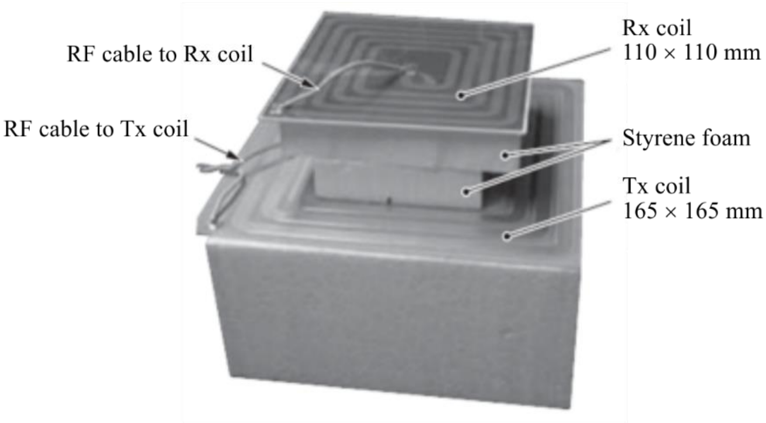
TABLE A3-2

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



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(2) 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, A3-20 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)

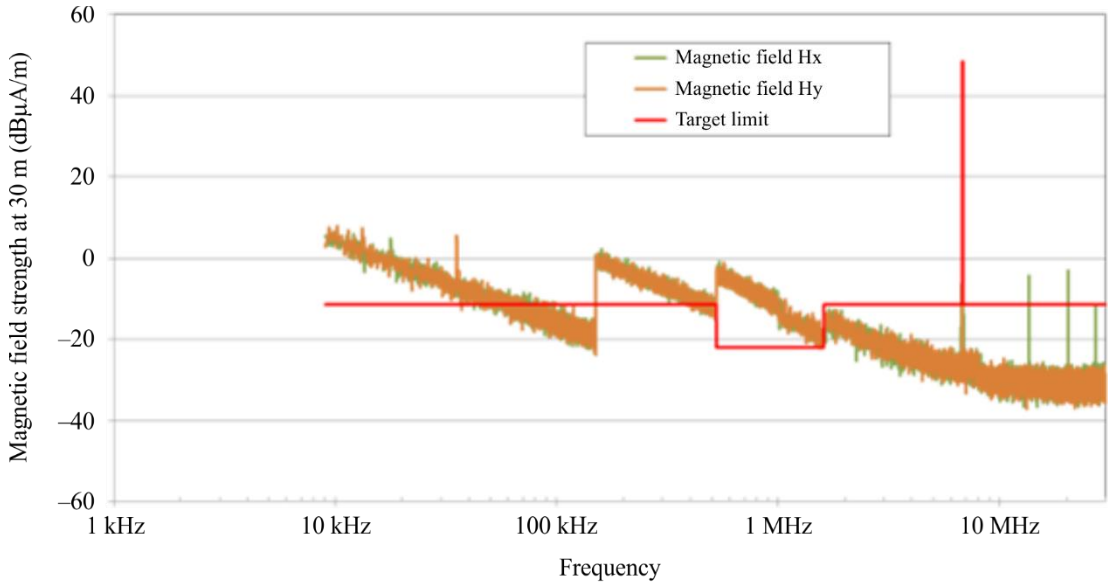

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FIGURE A3-20

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

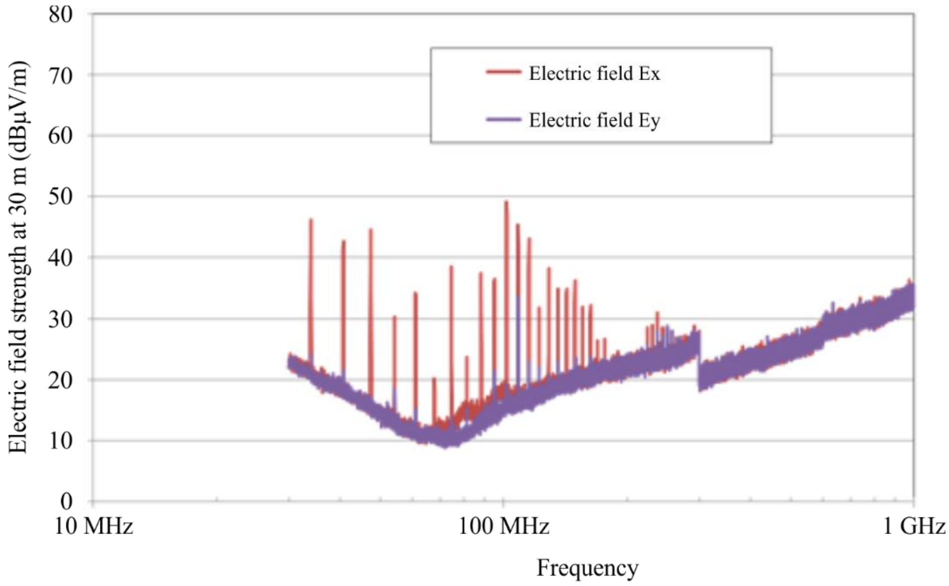

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FIGURE A3-21

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

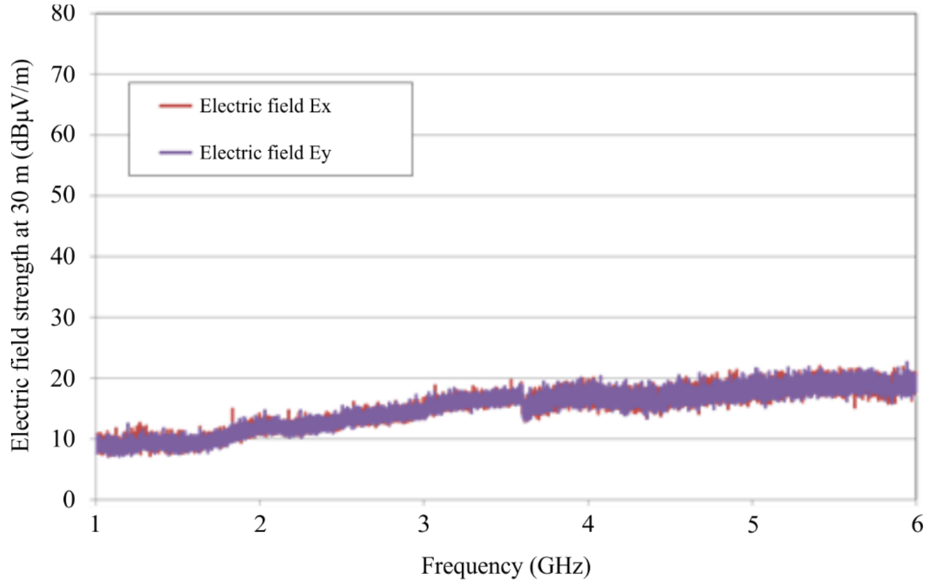

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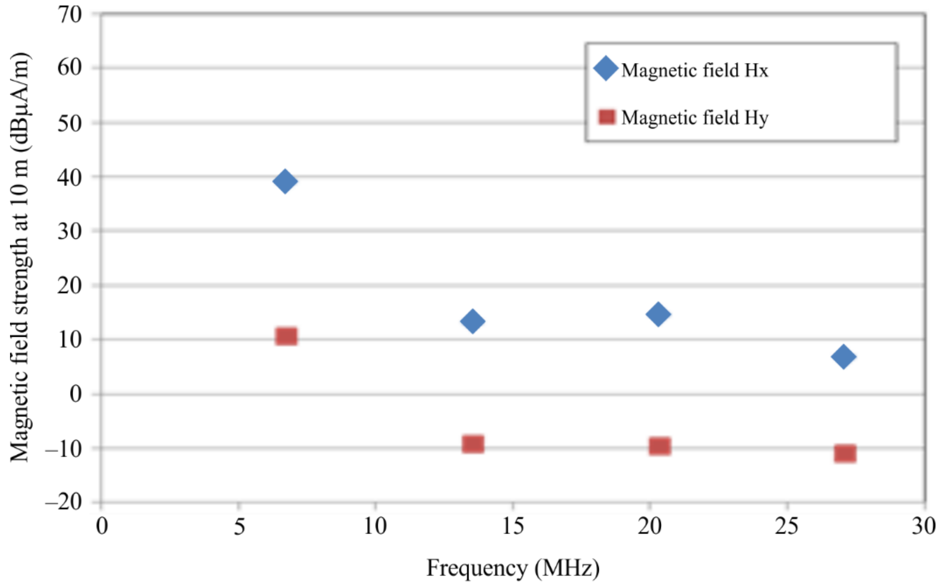
FIGURE A3-22

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



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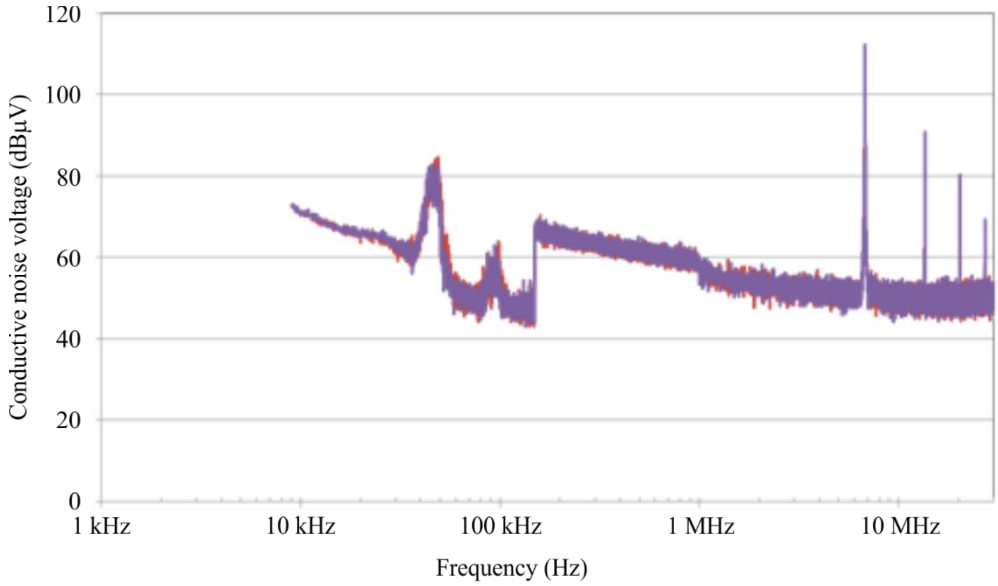
(3) Conductive noise

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)



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4.3 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.

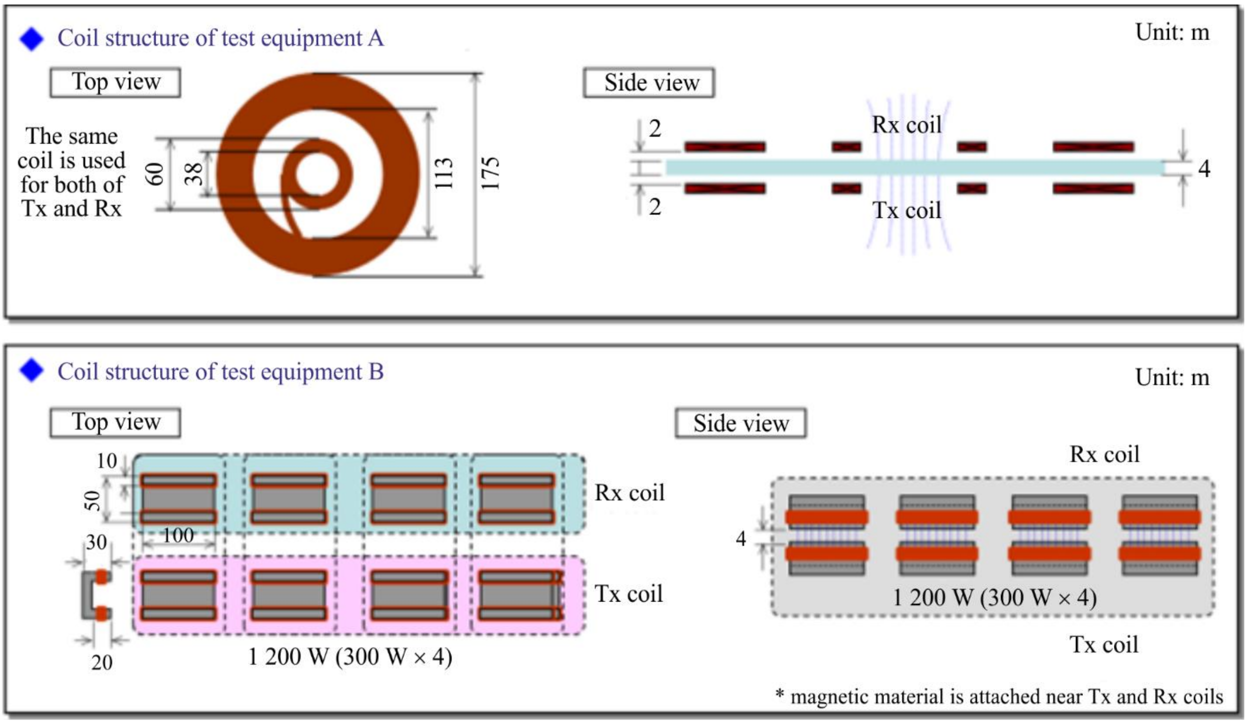
TABLE A3-3

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) 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)

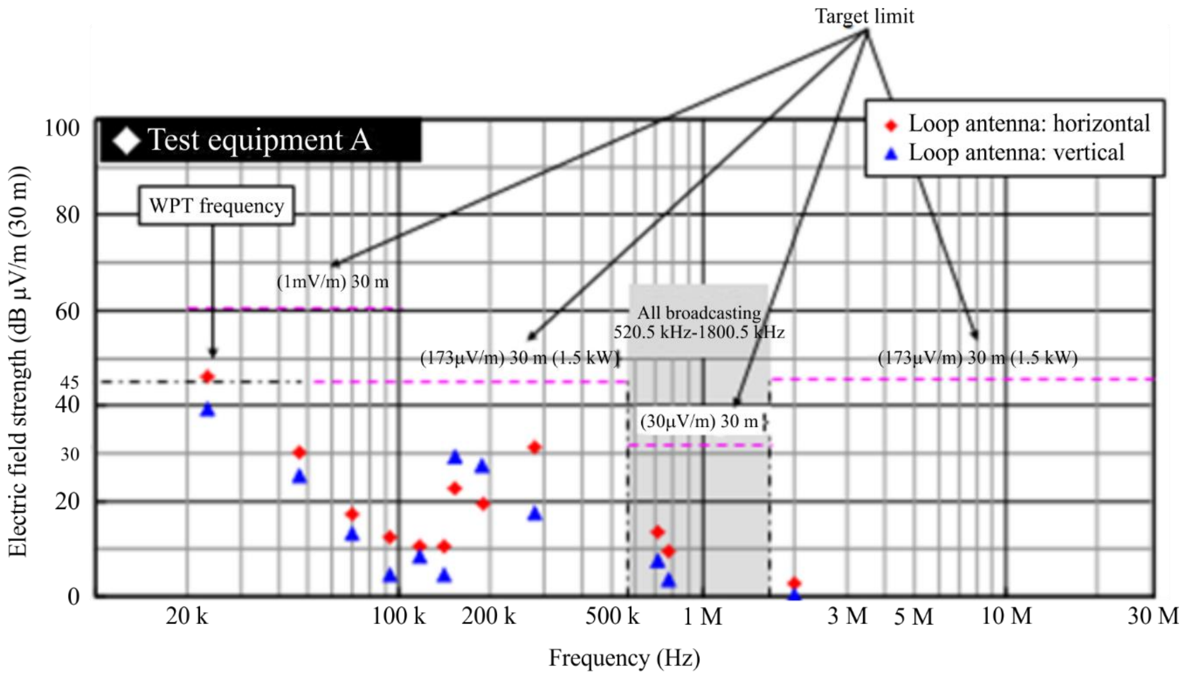

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FIGURE A3-26

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

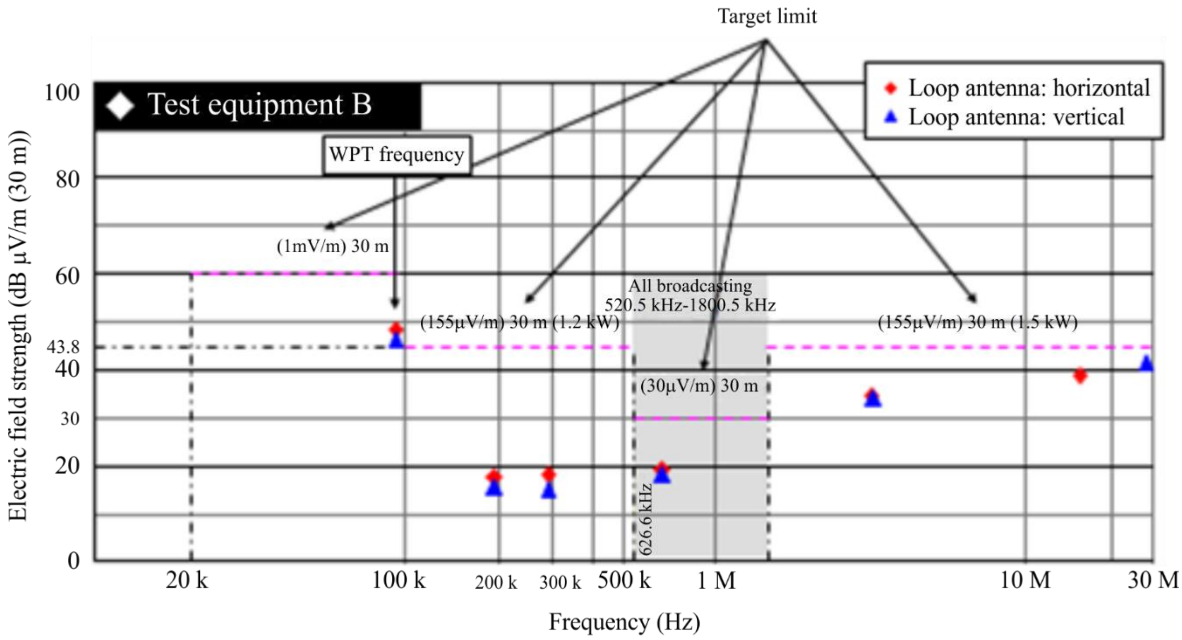

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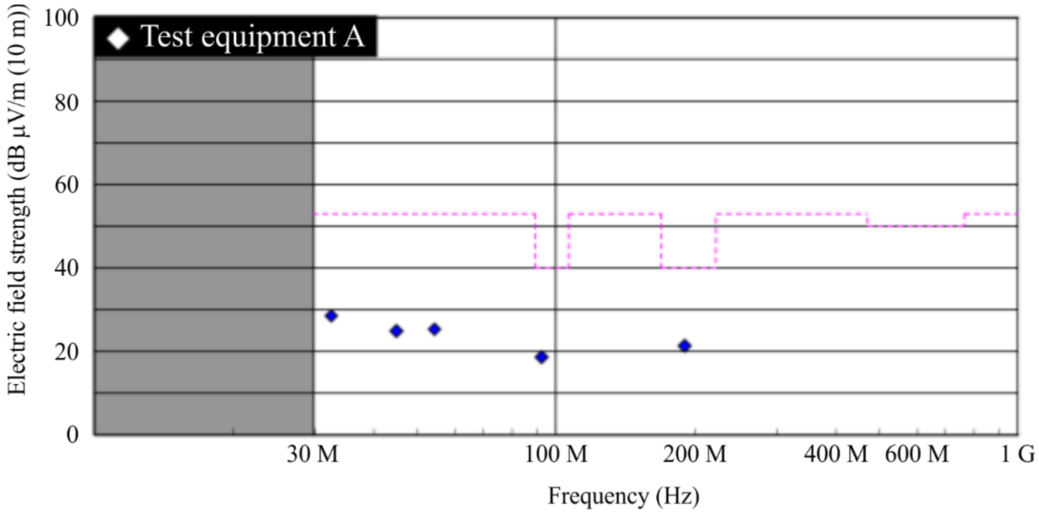
FIGURE A3-27

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



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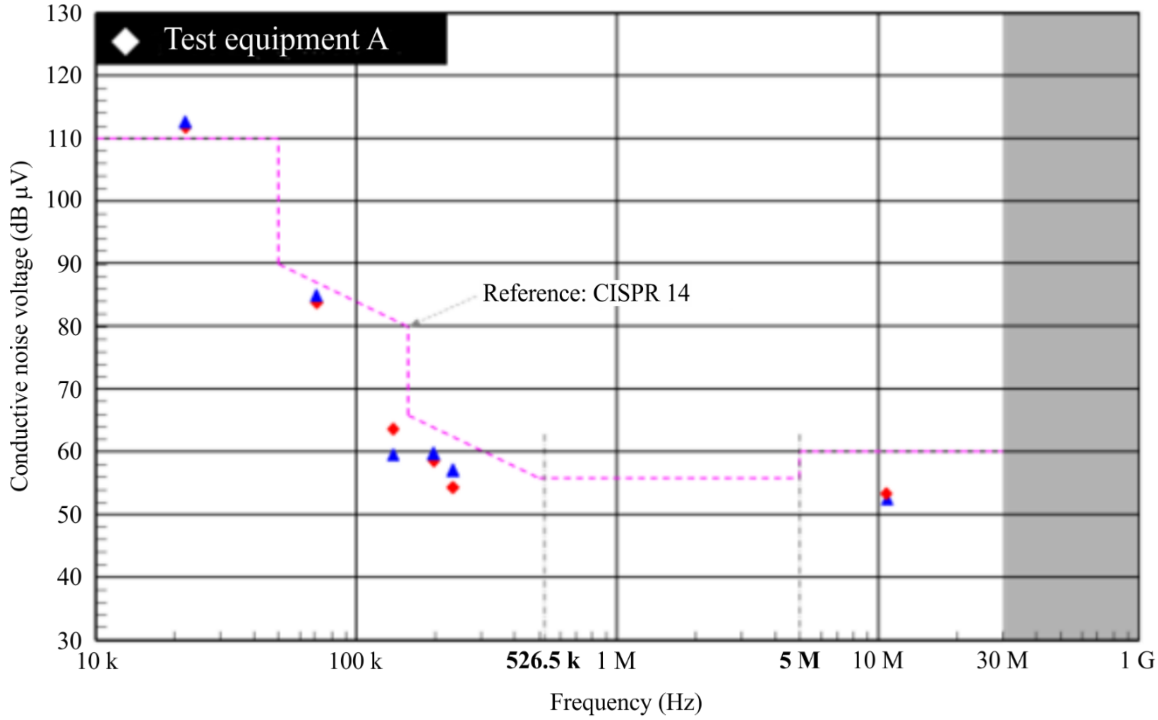
(3) Conductive noise

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 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

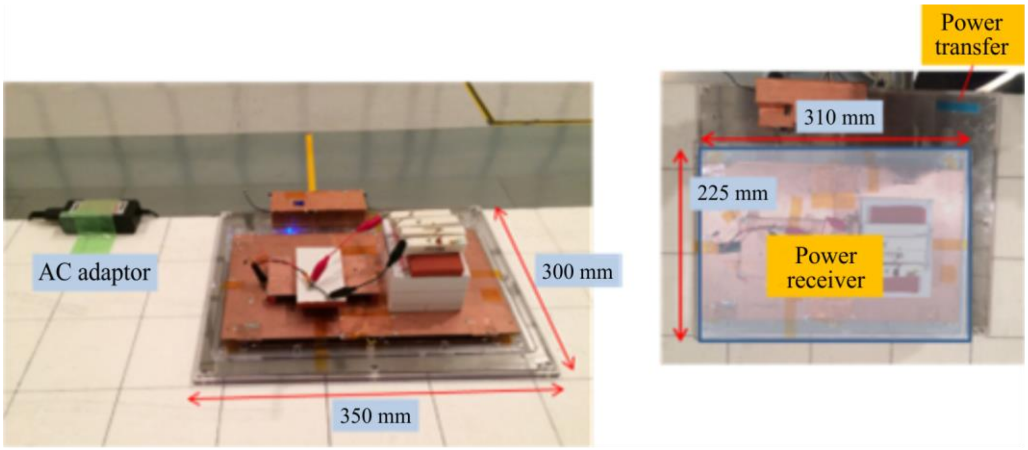

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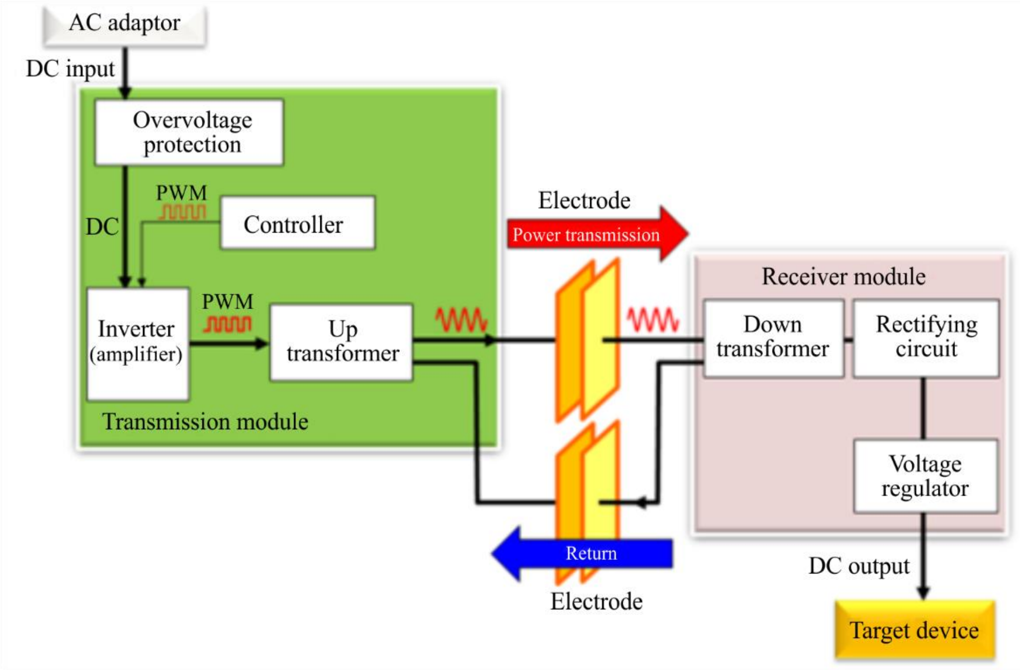
FIGURE A3-30

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



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(2) 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)

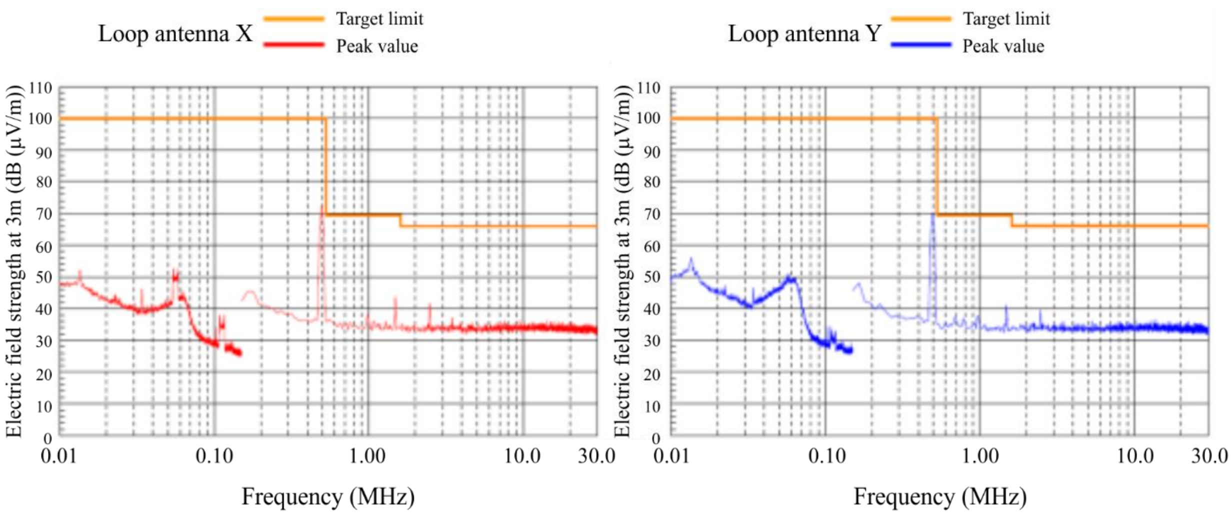

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FIGURE A3-32

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

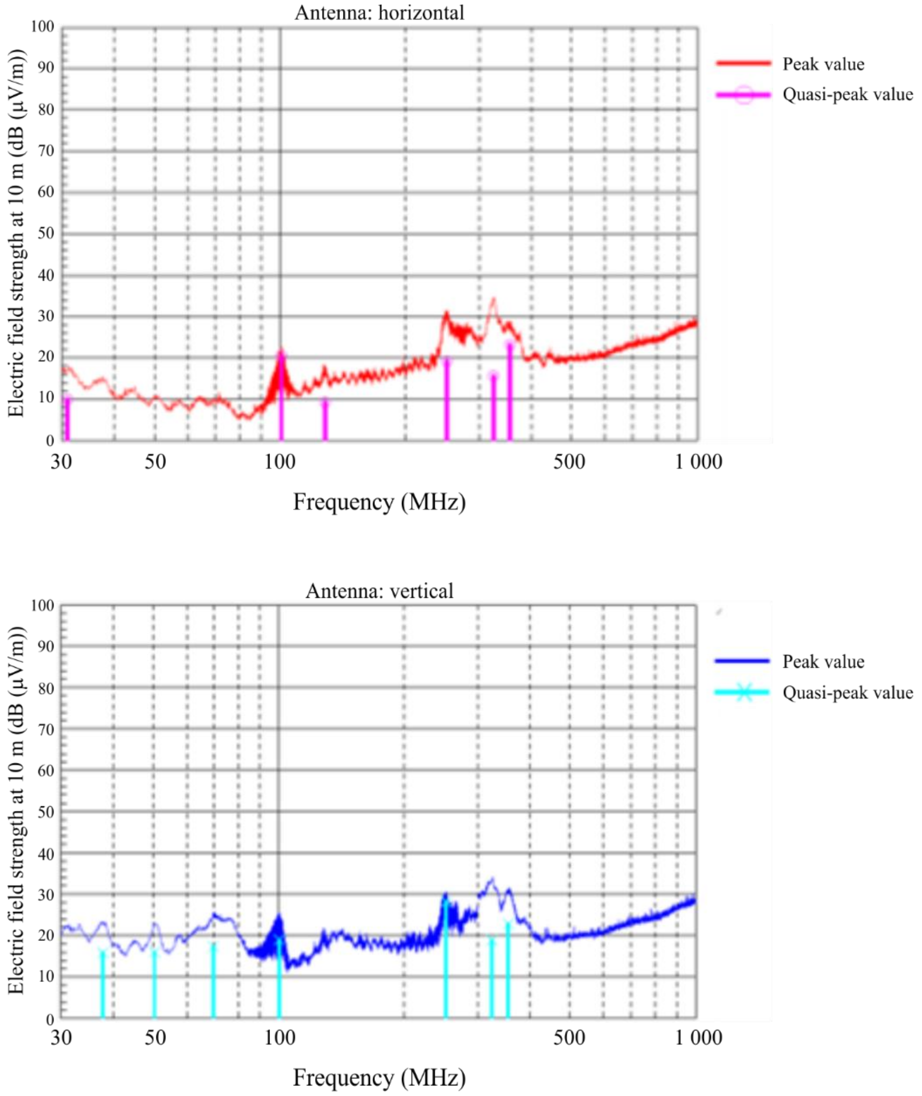

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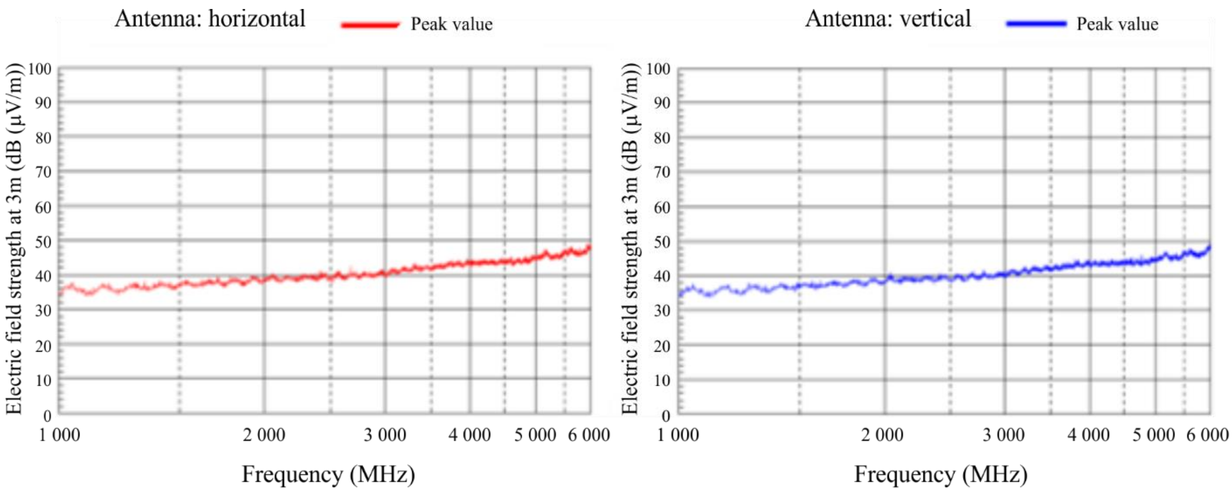
FIGURE A3-33

Radiated noise (1-6 GHz, peak value)



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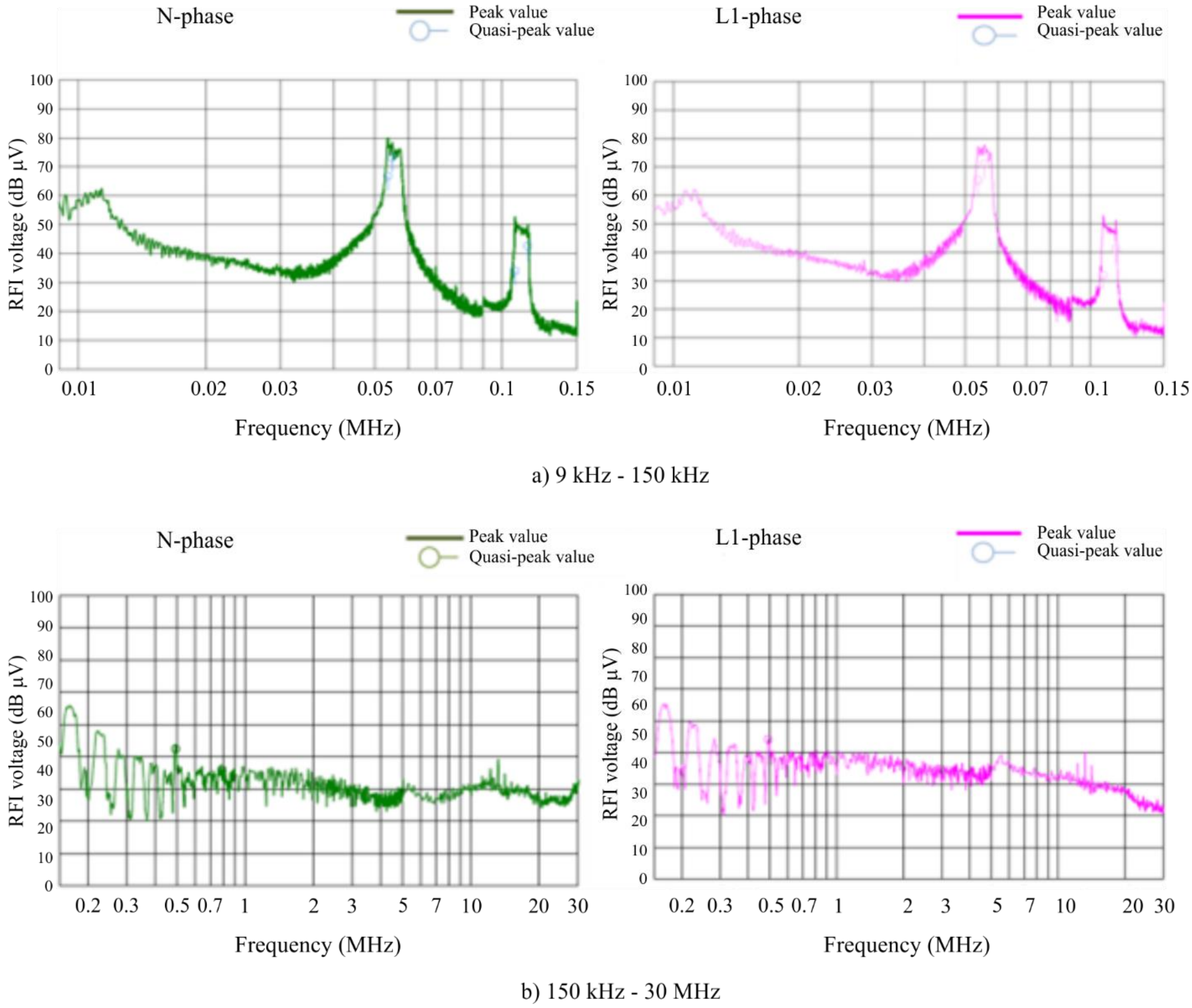
(3) Conductive noise

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

Not used

(Note: Information previously included in Annex 4 has been incorporated into Annex 6.3 of Report ITU-R SM.2451.)

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