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Electromagnetic Fields of New Technologies

Status Report by the German Commission on Radiological Protection

Adopted at the 262th meeting of the Commission on Radiological Protection on 11/12 July 2013

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Elektromagnetische Felder neuer Technologien

Statusbericht der Strahlenschutzkommission

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1 Introduction

The range of ways in which technical devices and systems produce electromagnetic fields (EMF) continues to grow, and the available frequency spectrum is being used more and more completely. Ever-greater amounts of the high-frequency range of the spectrum are being allocated to wireless communication, and ever-higher frequencies, extending even into the infrared range, are being used. In the energy supply and drive technology areas, the application of direct currents and of new frequencies in addition to the conventional frequencies 50 Hz and 16 2/3 Hz is gaining in importance. Even shortwave-range frequencies are becoming important. These trends are affecting the levels of the electric and magnetic fields encountered in everyday life. As new technical applications continue to emerge and spread rapidly, the resulting changes in the exposure situation for human beings need to be determined. This must include a comprehensive assessment of the simultaneous exposure to a variety of different electromagnetic fields affecting humans.

To this end the present report describes the current exposure situation and expected future trends, thereby identifying research areas which must be considered for future investigation. Notable aspects are for example broadband fields and simultaneous exposure to fields from multiple sources.

The assessments presented in this report are made on the basis of the reference levels defined in the EU Council Recommendation 1999/519/EC (EU 1999). The health-risk assessment of the technical developments described is beyond the scope of this report.

From the perspective of the the German Commission on Radiological Protection (Strahlenschutzkommission SSK), with regard to the increases in electromagnetic and magnetic fields the following two aspects need to be considered in particular:

Firstly, the need to determine the background levels of electromagnetic fields by taking account especially of immissions throughout the entire frequency range. Because existing frequency ranges are being used more and more intensively, and new frequency ranges continue to be developed, environmental levels of electromagnetic fields can be expected to increase. These background levels need to be determined by adequate measurements and analyses. To this end, further improvements of measurement methods are needed.

Secondly, exposure conditions change because more and more people use a larger number of devices simultaneously and in more and more versatile ways. In light of the wide range of frequencies and modulations involved as well as the continuing growth in the spectrum of immissions, the currently used "peak summation" method for exposure assessment needs to be improved, and amended, on an expanded scientific basis.

In the past, the Commission on Radiological Protection (SSK) has repeatedly emphasized that devices should be designed with a view to minimizing emissions and user exposure, especially in cases in which technically and economically viable alternatives are available (SSK 2001, SSK 2003). Therefore, the present report does not reiterate discussions on technological options for minimizing total exposure.

2 Additions/changes to the 2003 status report, as a result of new technological developments

In its 2003 status report "Electromagnetic Fields of New Technologies" ("Elektromagnetische Felder neuer Technologien") (SSK 2003), and in a related recommendation, the Commission on Radiological Protection (SSK) requested that the technical development in this area be regularly analysed and critically monitored. The present status report has been produced in keeping with this call.

To that end, the SSK produced overview tables of related new technologies. For purposes of comparison, and to highlight the dynamic development involved, overview tables from the year 2003 have been appended to the present report (Annex 1).

With regard to exposure to EMF, the SSK identifies relevant technological innovations in the following areas[1]:

2.1 Telecommunications

2.1.1 Long Term Evolution (LTE) / Digital Dividend

LTE is an evolution of the UMTS standards for mobile telecommunication networks. The advantages of LTE, compared to UMTS, include higher data rates, a simpler network architecture and lower latency. In Germany, LTE is currently being provided as "LTE-800", in the frequency range 790 MHz to 862 MHz (the "digital dividend"), and as "LTE-1800" in the frequency range around 1.8 GHz. In principle, LTE could also be operated in other frequency ranges (from 700 MHz to 2700 MHz), however, because current frequency tendering procedures are not imposing technological restrictions.

LTE installation is currently deployed on a large scale in Germany. As part of this effort, LTE-800 will also become available in cities as soon as service levels in rural areas are adequate.

A typical LTE base station, like GSM and UMTS base stations, consists of three sector antennas, each with 120° azimuth coverage. Because the transmission power and configurations used with LTE are comparable to those used with GSM and UMTS, which are seen as "established wireless communications technologies", LTE can be expected to produce comparable immissions for the general population (not exceeding the single-digit percent range with regard to the applicable power-density restrictions (EU 1999), and often within or below the per-mill range). Relevant measurements are currently being carried out (Bornkessel et al. 2013).

In rural regions, LTE is used primarily for providing wireless Internet access to areas that still lack DSL service (via land lines) (so-called "white spots"). An LTE base station, like any other mobile-network base station, is a "shared" resource; i. e. all active users connected to it will share its capacity. Services that require extremely wide bandwidth, such as video on demand, can be provided by an LTE base station only when small numbers of users are connected to it. However

[1] In the present report, a technology is termed "new" if, at the time of the report, it is being widely introduced, or will soon be widely introduced, and it was not mentioned in the last status report (2003).

such low-capacity use cannot be expected to be the norm, however. Such data transmissions will thus have to continue to rely on fibre-optic lines ("fibre to the home").

2.1.2 Digital radio network for public safety authorities / emergency services (TETRA-BOS)

Over the past few years a process has been initiated to phase in a digital radio system, conforming to the TETRA standard for the nonpublic communications of emergency and rescue services (Behörden und Organisationen mit Sicherheitsaufgaben – BOS). The system is designed to replace these services' existing analog radio systems. The TETRA system offers a number of advantages over analog systems, including encryption capabilities, more effective use of radio bandwidth, greater capacity, data transmission capabilities, greater voice quality, better radio coverage, interoperability between user groups, and special modes such as group calling/ prioritisation. The network is currently being installed, but the current status of this process in Germany varies widely from Land (federal state) to Land.

In choosing the sites for the system's base stations, existing locations of mobile-network base stations that can meet special security requirements are being preferred. On the basis of the transmission power levels and site configurations used for the system, the resulting immissions can be estimated to be of the same order of magnitude as those from mobile network systems for the general public, i. e. not exceeding the single-digit percent range with regard to the applicable power-density restrictions, and often within or below the per-mill range.

2.1.3 Ultra-wideband (UWB)

Ultra-wideband (UWB) systems, i. e. applications with increased bandwidth of > 500 MHz or > 20 % of the centre frequency, are used for high-bitrate communication between home/office electronic devices, for wireless connection of sensor networks and for UWB sensors (such as radar sensors and chemical sensors for substance analyses). UWB systems' immissions for the general population were studied extensively in a project of the German Mobile Telecommunication Research Programme (Deutsches Mobilfunk-Forschungsprogramm – DMF) (Schmid et al. 2008). Because the systems' transmission power levels are extremely low, due to applicable regulations, it was concluded that UWB technology is of minor relevance with regard to exposure for the general population.

Future trends with regard to adoption of UWB systems are difficult to forecast, especially since initial expectations for the technology have not been confirmed to date with regard to the range and diversity of devices that would use it, and to its market penetration,.

This report does not consider the issue of occupational exposure to UWB systems (as it could occur in connection with e. g. minesweeping devices).

2.1.4 Femtocells

Femtocells are low-power cellular base stations designed to improve the coverage provided by mobile-network base stations. To set them apart from conventional base stations ("Node B" stations), they are also referred to as "Home Node B" stations. In some configurations, a femtocell can be an integral part of a WLAN or DSL router. Some of the models now available already support HSPA, and femtocells for LTE are planned. A femtocell is a base station in its own right that is connected to the user's mobile-service provider via the user's local Internet connection (DSL). It is configured by the network.

At present, very little technical information is available about femtocells. The dates at which femtocells are to be introduced, and the applicable business models and market opportunities, vary greatly from mobile-network operator to mobile-network operator. Due to the paucity of relevant data available, no reliable forecasts can be made at present regarding the future spread of such systems, and of their immissions.

2.1.5 WLAN

The term "WLAN" usually refers to any local wireless networks that conform to one of the many IEEE 802.11 standards. All common systems operate in the two ISM frequency ranges of 2.4 GHz to 2.4835 GHz and 5.15 GHz to 5.725 GHz. Continual improvements in WLAN technologies, and ongoing growth in the numbers of systems in place, are being driven by two key factors: firstly, by a demand for ever-greater bandwidth, which creates a need for increasingly complex modulation methods; secondly, by offering independent providers a highly attractive way of providing low-cost network access that is not subject to licensing requirements, and yet still supporting an ever-increasing array of applications.

A number of studies carried out in recent years have focused on the immissions of WLAN access points and terminal devices – for example, studies in the framework of the German Mobile Telecommunication Research Programme (DMF), and studies carried out under commission to the Swiss Federal Office of Public Health (FOPH). A recent survey conducted by the British Health Protection Agency (HPA) (Peyman et al. 2011) carried out extensive measurements of immissions at 13 access points, and 15 laptop computers, as part of a major study of WLAN-related issues at schools. The study concluded that the laptops' maximum transmission power ranged from 1 mW to 17 mW, while that of the access points varied from 3 mW to 29 mW (for comparison: mobile phones' maximum rms transmission power levels range from 125 mW to 250mW, while their maximum pulse output powers range from 1 W to 2 W). The transmission power outputs of laptops are not distributed evenly in all directions; they tend to be lowest in the direction to the user. In distance measurements of immissions from laptop computers, a maximum of 0.2 % of the applicable power density restriction level was reached at a distance of 0.5 m. At a distance of 1 m, the corresponding figures were less than 0.05 %. Exemplary SAR calculations using a model of a 10-year-old child showed that exposure in connection with laptop use (2.4 GHz) is less than 1 % of that for a typical mobile-phone scenario.

Such considerations, in connection with results of other studies, reveal that the immissions levels occurring at typical exposure sites around access points tend to be less than 0.01 % of the power density reference levels. At a distance of 50 cm, terminal devices reach maximum levels of 0.2 % of the power density reference level. In the case of direct contact with a terminal device, the local exposure (SAR averaged over 10 g tissue) can reach up to 22 % of the basic restriction. All immissions values are highly device-dependent. As a result, the individual exposure in any case will depend primarily on the terminal device in question, and not on the access point. Furthermore, for all results, it must be remembered that the "real" exposure, which depends on momentary data-transmission levels, will be considerably lower than the "maximum" exposure listed.

Finally, it should also be noted that the possibility of allocating additional frequency ranges for short-range wireless communications – for example, in scenarios equivalent or similar to those occurring with femtocells or WLAN applications – is currently being discussed. Such allocation of additional frequencies would likely lead to a great increase in use of such mobile services in the future. One example of such discussion is the consultation process initiated in December 2012 by the Federal Communications Commission (FCC; the U.S. regulatory authority) and entitled "Enabling Innovative Small Cell Use in 3.5 GHz Band NPRM & Order".

2.1.6 Digital radio and digital TV

DVB-T2 is a television broadcast standard that requires modulation methods that are more complex than those used with the DVB-T standard. In principle, it also offers greater transmission bandwidth. Since DVB-T2 is to be used for transmission of high-definition television (HDTV), it requires a greater frequency bandwidth and, thus, a greater transmitter density and/or higher transmission power. The decision on upgrading from the existing DVB-T system to DVB-T2 has not yet been made, partly for the reason that such a move would require consumers to purchase new devices. Without additional frequencies, the transition would have to be "hard", i. e. it would involve shutting off the old system and switching the new one on, at a fixed point in time. To date, no plans for such a transition have been announced in Germany.

DAB+, a new digital radio broadcast standard, is currently being installed alongside the existing analog VHF radio network. It thus requires a new network of transmitters that operates at other frequencies. In most cases, the former channel 5c, at 178 MHz and available via the "digital dividend", is used for this purpose. Some 50 installations, with maximum individual transmission power levels of 10 kW, are currently in place in Germany. Coverage is by no means complete, however, and negotiations on further expansion – especially along autobahns – continue.

Presumably, DVB-H, a special television broadcast standard for mobile applications, will fail to be widely adopted, due to a lack of interest of mobile-phone manufacturers.

2.1.7 Smart home

Wireless technologies for "smart-home" applications are currently playing only a minor role, since most consumer homes are equipped with standard "twisted pair", i. e. line-based, connections. Applications are referred to only in terms of a communications protocol such as TCP-IP or the European Installation Bus (EIB, or KNX, its successor); the pertinent hardware is not specified. The practical implementations shown in relevant publications are almost always wired networks, and not wireless networks. The latter only come into play if consumers ask for remote-monitoring / remote-control functionalities via their mobile phones.

It was not possible to determine the level of market penetration for WLANs in private homes. The great difficulty encountered in such determination is that most routers support both WLAN-based and wired network connections. Each user decides, on location, whether he wishes to use his router's wireless interface or not (just as a laptop user decides whether to connect wirelessly or not, on a case-by-case basis).

2.1.8 Wireless applications in aircraft

In aircraft, on-board systems keep the transmission power levels of mobile phones to a minimum (1 mW). Wireless connections on board of an aircraft are made at 1.8 GHz (GSM). In other mobile frequency ranges, the systems emit noise signals, so that mobile phones will not keep searching for other frequencies when they are switched on. Use of mobile phones is permitted only at elevations of at least 3,000 m (EC 2008).

2.1.9 Changes in the use of mobile services

Current patterns in use of communications systems are changing exposure situations. While the first mobile phones were used solely for making phone calls, modern phones have an enormous range of functionalities and have little in common with those early models. Accordingly the use of such devices has shifted from making calls to the sending and receiving of text messages (via SMS, the short message service), the sending and receiving of photos and video clips (via MMS, the multimedia messaging service) and Internet use (e. g. social networks, music downloads). In a survey taken in 2009 (TNS Infratest 2009), 81 % of all respondents said they use their mobile phone to send and receive text messages, 69 % said they use it for making calls and 32 % said they use it to send and receive multimedia messages (multiple responses were permitted).

The features and performance of modern devices (smartphones, tablet PCs and notebooks with integrated or external wireless interfaces) have greatly expanded the range of potential applications. From 2008 to 2012, sales of conventional mobile phones, as a percentage of sales of all digital devices, decreased by about 60 % worldwide, while sales of smartphones tripled (Bitkom 2012) and sales of tablet PCs boomed as well.

2.1.10 New use of frequency ranges, resulting in changes in immissions

For purposes of radiation protection, it is important to monitor how any new use of frequency ranges previously occupied by other wireless systems (digital dividends 1 and 2) will change the exposure situation. This applies, for example, to any transition from DVB-T to LTE. Past examples of such reallocation include the transition from analog medium-wave transmitters to DRM (Digital Radio Mondiale) and the transition from analog terrestrial TV broadcast systems to DVB-T. Currently, some frequency ranges that used to be occupied by digital TV broadcasters are being reallocated to "wireless network access for provision of telecommunications services", such as wireless Internet via LTE. This applies to both the "digital dividend 1" (790 MHz – 862 MHz) and the "digital dividend 2" (694 MHz – 790 MHz).

With regard to changes in immissions, the network concept chosen, and the installed transmission power before and after the reallocation are ultimately the decisive factors. In connection with the digital dividend, for example, immissions will increase primarily in areas without coverage by former DVB-T transmitters in the 790 MHz – 862 MHz range where a "complete-coverage" LTE-800 network is now being installed. On the other hand, DVB-T immissions in a DVB-T transmitter's "portable indoor" area[2] may be expected to be higher than immissions from an LTE-800 transmitter at a distance of several kilometers. Measurements are currently being carried out in order to obtain reliable data (Bornkessel et al. 2013).

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[2] DVB-T broadcasts can be received in "indoor" environments on portable devices equipped with small rod antennas.

In general, the change in a "mean immission" can be estimated by comparing the transmission power levels in area of interest[3]. Use of this approach indicates that, assuming maximum transmission power levels, the mean immission for a complete-coverage LTE network would be about 5 to 10 times as high as it would be for a DVB-T broadcast system for the same area. However, in a real-world comparison of the two systems, the difference will partly disappear as a result of the transmission power control used with LTE. With LTE transmission power control, any resources that are not being used to transmit data can be temporarily switched off (blanked), which reduces the effective transmission power. The degree of transmission power reduction that occurs in any given case will depend on the relevant base station's traffic load and system configuration.

In this context, it is important to note that frequency-spectrum utilization is going to intensify in the future – for example, as a result of dynamic frequency allocation for wireless transmission systems ("software defined radio").

2.2 Transport sector

2.2.1 Vehicular Communication Systems

Anti-collision systems using radar sensing systems are already available for serial production and are being installed in more and more vehicles. The HF transmission power levels typically used by such systems lie in the range 5 mW to 20 mW, while their frequencies fall into the 76 GHz to 77 GHz or 24 GHz ranges. Such systems are now being installed, on a large scale, as standard equipment in mid-sized cars as of the 2012 model year.

The wireless communications technology foreseen for inter-vehicle communications (Car2Car) conforms to the IEEE 802.11p standard, implementation of which has not yet been completed. For communications between vehicles and stationary systems (Car2Infrastructure, Car2I), a number of different systems and standards are being considered (such as IEEE802.11a,b,g, GSM/UMTS/HSPA/LTE, WiMAX, DVB). In a typical case of use, a vehicle would send out one pulse every 100 ms. Often, a main antenna will be mounted in a roof fin; additional antennas might be installed at other positions on the vehicle. Efforts are being made to design systems that radiate isotropically, in the horizontal plane.

It needs to be considered, that the system functions planned for Car2Car and Car2I systems will only function properly if adequate numbers of vehicles are equipped with such systems. The minimum figure usually cited is about 15 %.

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[3] For example, the typical coverage radius for a DVB-T transmitter is about 50 km (coverage area of 7,850 km²), assuming a transmission power of 50 kW to 100 kW (ERP) and a gain of 14.5 dBd, i. e. an antenna input power of about 2 kW to 4 kW. For a rural LTE-800 base station, the cell radius is about 5 km (coverage area of 78.5 km²), and the antenna input power levels are typically about 240 W for an array of 3 sectors with 2 antennas each (MIMO), with each antenna having a transmission power level of 40 W. To achieve the same coverage area as seen with the DVB-T system, therefore, 100 LTE transmitters would be needed, a number that would translate into a total antenna input power of 24 kW.

For reasons of cost, the stationary systems designed for transport-sector communications (roadside units) will not be installed in a complete-coverage arrangement; they will be placed only at certain strategic locations, such as railway crossings, traffic lights or schools.

Another area of technological development in the automotive sector concerns driverless vehicles (autonomous cars). Initial efforts in this area are underway in Germany (such as the "AutoNOMOS Labs" project of the Federal Ministry of Education and Research (BMBF)). In driverless vehicles, a computer controls the brakes, gas pedal and steering, via a drive-by-wire system. Other cars, and pedestrians, are detected by laser-scanning, radar and video-camera systems. Because the interiors of such vehicles are shielded, the high-frequency radiation (such as radar radiation) emitted by such systems is primarily relevant for other drivers and for pedestrians. At present, data on the transmission power levels involved are not yet available. For the time being, they may be assumed to be of the same order as those found in vehicles' radar-sensing systems.

The wireless networks installed within vehicles are usually either WLAN- or Bluetooth- based. In most cases, standard industry solutions are used, comprising highly integrated modules (i. e. WLAN pursuant to the IEEE802.11b or g standard, with EIRP of 10 mW to 100 mW, and Bluetooth pursuant to IEEE802.15.1, with 2 mW, and with all systems using frequencies of 2.4 GHz to 2.5 GHz).

2.2.2 Electric and hybrid vehicles

Over the past few years, alternative drive concepts for vehicles have been generating greater and greater public interest. The leading concepts at present include electric-hybrid drive systems and all-electric drive systems. A number of car manufacturers are already producing such systems in series. Cars with such drive systems have powerful electrical and electronic components (electric motors, batteries, inverters and supply lines), of necessity installed in close proximity to their passenger compartments. The metal body of the car will shield against the electric fields produced by such components. The magnetic fields produced by such components, on the other hand, remain of relevance to the passengers' exposure situation, an issue that also concerns the safety of medical implants.

Schmid et al. (2009) measured the magnetic field immissions in selected vehicles with hybrid or electric drive systems and assessed them from a standpoint of radiation protection. The vehicles studied included hybrid cars, all-electric cars, commercial vehicles with hybrid drives and a city bus with a hybrid drive system. The study found that the relevant spectral components were limited to the frequency range below about 80 kHz.

In the hybrid cars studied, the locally occurring maximum immissions ranged from 29 % to 35 % of the reference levels given by EU Council Recommendation 1999/519/EC. In the electric cars studied, the corresponding values ranged from 3 % to 25 %. In most cases, the maximum values concerned were highly locally confined, and they occurred at the driver's and passengers' seats, normally at foot / lower-leg level, and primarily during braking and acceleration. When the vehicles were stopped or nearly at a standstill, the immissions levels were often considerably lower than the maximum values cited. In the city bus studied, up to 19 % of the reference level given by EU Council Recommendation 1999/519/EC was reached at the passenger seat with the highest exposure.

The maximum values found were of the same order as the immissions seen in passenger areas of trains. The exposure situations in this area should continue to be monitored as the relevant technologies develop, since the numbers of vehicles with electric drive systems can be expected to increase sharply, and since the electrical operating parameters of such systems can be expected to change.

2.3 Energy transmission

2.3.1 Wireless energy transmission

Wireless energy transmission makes it possible to charge non-stationary electrical devices without wire connections, i. e. without direct contact. The possible applications of this technology include the charging of consumer-electronics devices (such as mobile phones, smartphones, tablets and cameras) and vehicles (charging electric cars). Wireless charging technology and transformers share the same operating principle which is based on magnetic induction: an alternating current flowing in a sending coil (transmitter) produces a time-varying magnetic field that induces an alternating voltage in a receiver coil (receiver). In most cases, the coils involved are planar coils fixed in a parallel arrangement, at a given distance from each other ("air gap"). The efficiency of this form of energy transmission depends primarily on the coil sizes, their distance from each other and the frequency used. In general, it is poorer than that obtained with conventional transformers, since the need for operational convenience – i. e. the need to provide for simple overlaying or placement of the two coils – creates the need for the air gap, in contrast to transformers, which have closed magnetic circuits. Furthermore, the presence of the air gap enhances the magnetic stray field, which can be of basic relevance with regard to exposure. The following section describes two applications that are in the process of becoming established in the market. It is followed by a mention of relevant foreseeable technological trends. That section, in turn, is followed by a discussion of the relevant consequences for exposure assessment.

The Wireless Power Consortium (WPC) has approved a common specification, dubbed "Qi", for wireless charging of mobile electrical devices. This specification, an open standard, permits energy transmissions of up to 5 W, using coils of about 40 x 40 mm^2 in size. An expansion to 35 W is currently being defined. The transmission frequency varies from 110 kHz to 205 kHz, depending on the power required. The devices to be charged are placed on a special charging pad that automatically recognizes the devices and initiates charging. Via "foreign object detection" functionality, the charging pad detects metal parts and terminates the charging process when a preprogrammed loss threshold is reached, to prevent from overheating of metal parts via induced eddy currents. At present, the Qi standard is the most widely adopted standard for wireless charging.

For wireless charging of electric cars, an interest group, consisting of OEMs, suppliers and various institutes, has developed a user rule (VDE 2011) that defines pertinent technical parameters and safety objectives. The system frequency is 140 kHz (-20 kHz, +50 kHz), while the maximum input power is 3.68 kW. In combination with an efficiency target of more than 90 %, this means that vehicles could receive power transfers at levels of more than 3.3 kW. The sending coil, a "stationary field plate", is placed directly underneath the vehicle, i. e. it is embedded in the ground, flush with the street surface, or it is fixed onto the ground surface. In comparison to the corresponding figure set forth in the Qi specification, the planned coil surface of 1000 x 1000 mm² is very large; this makes it possible to keep the magnetic flux density small. In addition, the user rule defines safety objectives for the protection of persons in magnetic fields: in the "public area" (the areas next to, in front of and behind the vehicle), and in the interior of the vehicle, the magnetic flux density must not exceed the ICNIRP 1998 reference level for the general population (i. e. 6.25 µT at 140 kHz, for example). Where that reference level is exceeded, proof of compliance with the applicable basic restrictions must be provided.

Due to a lack of pertinent data, these two applications cannot be fully assessed at present with regard to possible exposure scenarios. In general, however, it may be concluded that the reference field levels for exposure of human beings, at the various operational frequencies concerned, could be exceeded in the actual transmission area, i. e. in the air gap between the two coils. As a result, the air gap's stray field around the coil array is of basic relevance with regard to exposure. The issue thus arises of the accessibility of the relevant areas – i. e. at least with regard to the possible partial body exposure that could occur in practice. Furthermore, little is known at present about the real safety levels of complete systems. While manufacturers' available technical specifications set forth pertinent detection and safety measures, virtually no exposure data, determined by independent agencies, are available for conceivable "worst cases scenarios".

On the other hand, such systems are expected to offer consumers considerable convenience, and thus are thought to have considerable economic success and market-penetration potential: not only will charging cables become obsolete, these systems will also completely eliminate the problem of ensuring compatibility between connectors (the envisioned long-term goal: any smartphone or tablet can be placed on any charging pad; charging pads will become as ubiquitous as electrical outlets are today; every parking area would offer inductive charging stations for electric cars).

Hence for some years a number of other consortia have been working to standardize, and thus bring to the mass market, the process of inductive – wireless – charging of rechargeable batteries in portable electronic devices, especially mobile phones, smartphones and laptops (cf. for example, Heise 2012). In contrast to the aforementioned Qi standard, higher frequencies, in the 6.78 MHz and 13.56 MHz ranges, and larger air gaps, as large as several mm, are to be used. The latter of these two plans would further aggravate stray-field issues.

Stray-field issues in connection with charging of electric cars, in the above-described configuration, have led to further developments. One such system, for which market introduction is pending, uses a coil array with a smaller area and a smaller air gap. The vehicle's coil is installed in the front section of the vehicle. For charging, the vehicle has to be driven very close to a wall with a corresponding sending coil.

Therefore, developments in the area of inductive charging technologies will have to be followed critically with regard to the issue of human exposure.

2.3.2 High voltage direct current (HVDC) transmission

The governmentally encouraged usage of renewable energy sources, and long distances between electricity-generation systems and electricity consumers, are creating needs for new long-distance energy transmission systems. The systems in question include high voltage direct current transmission lines (HVDC overhead power lines), to be operated with nominal voltages greater than 500 kV. HVDC power lines experience a problem that also occurs with high voltage alternating current lines (HVAC power lines): the strong electric fields prevailing around the lines lead to microdischarges (corona discharges) that ionise the surrounding air. However, in contrast to HVAC lines, however, the polarity of HVDC lines does not periodically change, and thus space charge clouds of charged particles can form around HVDC conductors. As a result, HVDC transmission lines tend to produce stronger electrical fields at ground level than HVAC lines. In addition, the charge clouds can be moved and transported by wind, and this can considerably enlarge the areas exposed to electrical fields. The strength of constant magnetic fields produced by HVDC transmission lines depends on the operating mode (monopolar or bipolar) and the configuration of the line conductors. Because of the poorer compensation effects involved, magnetic immissions and their ranges are greater with HVDC transmission lines than they are with HVAC lines. On the other hand, the flux densities with HVDC lie within the variation range of the earth's natural magnetic field. This field exhibits considerable local variations due to distortions caused by ferromagnetic objects (such as transport systems, concrete reinforcements and other objects of everyday use).

2.4 Health-care sector

2.4.1 Wireless applications in health care

Mobile phones can cause interferences when used in close proximity to electromedical equipment. The standard DIN EN 60601-1-2 (Electromagnetic Compatibility of Medical Electrical Equipment) sets forth a range of safety distances, depending on transmission power. The distance specified for mobile phones is in the order of 2 m. Medical devices of critical relevance are found in particular in operation theaters and in intensive-care units.

The applications recently introduced in hospitals include wireless transmission of "bedside monitoring" data (real-time physiological data, including such parameters as blood pressure, pulse and EEG readings).

2.4.2 Medical applications

Use of strong electromagnetic fields has been increasing in the areas of medical diagnostics and therapy. For both patients and the involved medical and technical personnel, this trend is leading to higher levels of exposure to electromagnetic fields. This applies especially to use of magnetic resonance imaging (MRI), in which devices producing 7 T static magnetic fields and 298 MHz excitation fields are now being used routinely in hospitals. Devices producing static magnetic fields of up to 12 T and 511 MHz RF fields can be expected in the foreseeable future.

In the area of medical monitoring, use of telemedical applications is increasing. In such applications, patients wear sensors that receive electrophysiological signals or detect relevant biochemical changes and are linked with wireless communications systems. The transmission power levels of such systems are comparable to those of mobile phones. Such systems communicate with their gateways / base stations several times per day or, during monitoring and alerting in connection with threatening events, continually.

2.5 Other information

2.5.1 Terahertz

The THz frequency range, from 100 GHz + to the far infrared (FIR) at 10 THz, is currently a focus of intense technological development. This applies especially to existing radiation sources – in a trend similar to that seen, for example, in connection with lower-frequency automobile radar systems in recent years.

The technical applications that have the potential to increase exposure for the public include the "body scanners" used for security inspections of persons at airports, courts, etc.. Applications would also include the ultra-high-bandwidth (over 100 Mbps) wireless communications systems, intended to be used over distances of less than 10 m, that would be needed for wireless transmission of HDTV video in homes.

The University of Wuppertal recently produced a report on the immissions that would be generated by systems operating at terahertz frequencies (Clemens et al. 2011). In addition, a recent survey review published in IEEE Spectrum (Armstrong 2012) also reports on the development of THz technology. Overall, it is important to note that, in spite of the progress being made with this technology, no THz sources with power outputs exceeding 10 mW will become available as mass-market products for the aforementioned applications in the next few years. The products available now have outputs considerably below 1 mW. In the coming years, the only products with relevant exposure levels for human beings are likely to be second-generation body scanners for security inspections of people at airports.

2.5.2 LEDs and compact fluorescent lightbulbs

As a result of the adoption, in 2008, of the Energy-related Products Act (Energieverbrauchs-relevante-Produkte-Gesetz – EVPG 2008), and of phasing in of prohibitions on the sale of conventional lightbulbs, more and more new types of light sources have been appearing on the market. The leading types are compact fluorescent lightbulbs (CFLs; often also referred to as "energy-saving lamps") and light-emitting diodes (LED). Unlike conventional lightbulbs, CFLs and white LEDs have discontinuous spectra, usually with a blue shift. LEDs normally use direct current, while CFLs use high-frequency alternating voltage. In CFL lamps, the necessary voltage is produced by a ballast integrated within the lamp. Operation of CFLs thus produces high-frequency electric and magnetic fields in the range 10 kHz – 100 kHz. At the distances occurring in normal use, the strengths of such fields do not exceed the applicable reference levels, however. The SSK has published a detailed statement on this subject (SSK 2010).

2.5.3 Functional clothing

Wearing of functional clothing with integrated electronics leads to extensive bodily contact with current-carrying wires and/or electronic circuits designed as flexible nanostructures. The range of applications seen in this area includes integrated surface antennas of mobile phones, which increase the body's local exposure to high-frequency electromagnetic fields. Sensor clothing is used for detection and recording of electrical and biochemical biosignals, for purposes of medical diagnostics and therapy. Various types of sports and work garments also have integrated sensors for monitoring and recording of body parameters (such as temperature), for purposes of active regulation (warming or cooling) in the interest of comfort.

In other "smart textile" applications, discrete electronic components such as light-emitting diodes (LEDs) integrated in clothing, or textiles with integrated flexible and washable nanostructures are used for optical illumination effects – for purposes of visibility, safety or even fashion. In spite of the low currents used in such applications, body-surface exposures in the mT range can occur as a result of the systems' close proximity to the wearer's body.

2.5.4 Radio Frequency Identification (RFID)

The appearance of wireless systems for identifying products, objects and persons (RFID) has led to wide use of RFID gate control systems. Such systems, which can be either visibly or invisibly installed, expose members of the general population to magnetic and electromagnetic fields with the approved frequencies (low and high frequencies) for the relevant purposes. The maximum emissions of the various systems sold on the market vary by several orders of magnitude. The systems can produce immissions that considerably exceed the relevant ICNIRP reference level. While no values in excess of the basic restriction have been reported, the systems are known to be able to interfere with electronic implants. The range of recent developments in this area includes near-field communication (NFC) devices that can read out RFID chips at close distances. Such devices are used, for example, in connection with implanted RFID chips or laminated RFID nanogrids, or in connection with payment processes using mobile phones / smartphones or RFID cards.

Electronic merchandise protection systems (for theft protection) can also be designed around RFID chips. At present, such systems normally use security tags with resonant circuits that trigger an alarm when the tags are passed through a pair of detection coils. The frequency most commonly used with such systems is 8.2 MHz. Such security tags are deactivated at the point of sale via application of a high-frequency field that irreversibly changes the resonant circuit's capacitor.

3 Summary

In the use of electric, magnetic and electromagnetic fields, for a wide range of applications, developments have occurred in recent years that can/could affect the exposure situation, to varying degrees. The assessments for various specific areas (such as the electromagnetic emissions of modern light sources) that the SSK has already published need to be supplemented by the following considerations.

The use of electromagnetic fields for communications purposes has increased continually in recent years and will continue to increase. This growth is not only due to growing demands (for higher transmission speeds, resulting from the need to handle ever-larger data quantities) of end users accompanied by price drops and the availability of flat rates, but also due to technical development in the area of terminal devices (such as smartphones, tablets). The availability of the necessary infrastructure has practically become unlimited – one can now be connected to the "web" almost anywhere, at almost any time.

Immissions from base stations are going to increase, especially as a result of introduction of the new LTE standard. It is not yet possible to say, with sufficient precision, how large the additional immissions will be, however, since such forecasting must take many uncertain factors into account (such as developments in power control, and in dynamic frequency allocation). Terminal devices will continue to be the most important EMF sources, far and away. At the same time, it is important to note that user behavior has been changing markedly in this area (for example, users have been making fewer calls with their mobiles placed in direct contact with their heads – they have increasingly been using devices for hands-free calling, and they have increasingly been opting to text instead (send SMS messages)).

Similar trends can be expected with regard to the growth in installation of access points (WLAN) in homes and in public areas, although, significantly, the transmission power levels involved with such systems tend to be lower overall. In this area as well, terminal devices are still the most important immissions sources. Access points such as WLAN stations are expected to become part of mobile networks (as femtocells) in future. Use of additional frequency ranges can be expected in this area in the short term.

A different situation presents itself in the area of Radio Frequency Identification (RFID). RFID technology was developed with a view to wireless identification of objects, products and persons. The electromagnetic and magnetic fields that can occur when RFID devices are scanned or pass through control gates considerably exceed the ICNIRP reference levels, although exposure to such excessive levels, for the general population, occurs only transiently. Considerably higher immissions levels may be seen in future, however, because the reference levels in the intermediate frequency range used for RFID have been increased more than 100-fold (ICNIRP 2010).

In the view of the SSK, the largest changes in emissions and immissions are to be expected in the transport and energy transmission sectors. The necessary standards for communications between vehicles (Car2Car) and from vehicles to stationary infrastructure (Car2I) are now in place, and use of such systems, along with radar-based anti-collision systems (many of which are already in service), is going to increase in the near future. These trends can be expected to increase the exposure levels for pedestrians in particular, although exposure levels in excess of basic restrictions are not likely, and should remain so even if such systems become widely used.

The electric motors and supply lines found in electric and hybrid vehicles (cars, buses) generate magnetic fields that, in certain areas of vehicles (such as footwells), can already reach 35% of the level set forth in the relevant EU Council recommendation. This area should continue to be monitored, by measurements, as the technology develops, and measures should be taken to minimise exposure. Similar needs apply to the wireless charging of such vehicles through induction coils; the coils used in such applications operate in the frequency range 20 kHz – 140 kHz and attain power outputs of over 3 kW. In peripheral areas of transmission coils, and when vehicles are not optimally positioned, the potential exposure levels with such systems, for exposed body parts, can be significant and can even exceed the reference levels. In this area as well, therefore, measurements-based monitoring needs to continue, as the technology develops, and measures need to be taken to reduce exposure levels and control access areas.

From the perspective of the SSK (Strahlenschutzkommission – Commission on Radiological Protection), two aspects will become more and more important in connection with the increases in electromagnetic and magnetic field levels.

Firstly, the "background levels" of electromagnetic fields must be determined, taking account especially of immissions throughout the entire frequency range. Because existing frequency ranges are being used more and more intensively, and new frequency ranges continue to be developed, everyday levels of electromagnetic fields can be expected to increase. Such levels, i. e. the "background level" values, need to be determined, via suitable measurements and analyses. To this end, continuing improvements of measurement methods are needed.

Secondly, the exposure conditions change as more and more people use multiple devices simultaneously, in more and more different ways. In light of the great range of frequencies and modulations involved, and of continuing growth in broadband immissions, the existing "peak summation" method used to determine exposure needs to be improved, and amplified, on an expanded scientific basis.

In the past, the Commission on Radiological Protection (SSK) has repeatedly emphasised that devices should be designed with a view to minimizing emissions and user exposure, especially in cases in which technically and economically equivalent alternatives are available (SSK 2001, SSK 2003). For this reason, the present report does not include the current discussion on technological options for minimising total exposure.

Tab. 1. Overview of relevant telecommunications systems – new systems and systems under development – and of systems for wireless energy transmission (wireless applications) [4]

Wireless application Users	Frequency range	Modulation / coding	Output	Transmitter coverage or range	Distance to persons	Safety distance	Number of units / coverage area
Car2Car Vehicle	Frequency range around 5.9 GHz	Depends on the wireless system used	Max. of 2 W (EIRP) in pulses; power control in steps of 0.5 dB	Requirement for range of 1000 m (more is possible)	Not close to bodies[5] (pedestrians) Close to bodies[6] (passengers)	Several decimeters	Plans call for inclusion, as standard equipment, in vehicles as of 2015; in the long term, to be included in all vehicles.

4 For abbreviations, see the list of abbreviations at the end of the report.

5 Not close to bodies: This refers to HF sources that are operated at distances, from human bodies, at which far-field approximations may be used for calculation of the fields affecting human bodies; examples include mobile-network base stations and radio/TV broadcast systems.

6 Close to bodies: This refers to HF sources that are typically operated at distances, from human bodies, ranging from several centimeters to several decimeters; examples include wirelessly interfacing notebook computers used on desks, WLAN routers operated on or under desks and base stations for DECT cordless phones, when placed within easy reach.

Wireless application Users	Frequency range	Modulation / coding	Output	Transmitter coverage or range	Distance to persons	Safety distance	Number of units / coverage area
Car2I Roadside unit (hotspots (strategic locations) such as railway crossings, stoplights and schools, but not installed universally, for complete coverage)	Frequency range around 5.9 GHz	Depends on the wireless system used	Max. of 2 W (EIRP) in pulses; power control in steps of 0.5 dB	Requirement for range of 1000 m (more is possible)	As a rule, not close to bodies	Several decimeters	As of 2015, at all hotspots.

Wireless application Users	Frequency range	Modulation / coding	Output	Transmitter coverage or range	Distance to persons	Safety distance	Number of units / coverage area
Mobile communications /LTE Transmitters, operators of public networks	791 – 821 MHz (LTE-800) 1,805 MHz – 1,825 MHz (LTE-1800) 1,853.1 MHz – 1,875.5 MHz (LTE 1800) Other frequencies at 2 GHz and 2.6 GHz	QPSK, 16-QAM, 64-QAM / OFDMA	With outdoor systems, 20 W to 50 W per channel, power control	Cell radii: Rural, 5 km; city, a few hundred m, nationwide	Not close to bodies	Several meters, depending on the site certification	> 10,000 / entire territory of Germany
Mobile communications /LTE Transmitters, operators of public networks, in connection with indoor applications (indoor coverage and femtocells)	791 MHz – 821 MHz (LTE-800) 1,805 MHz – 1,825 MHz (LTE-1800) 1,853.1 MHz – 1,875.5 MHz (LTE 1800) Other frequencies at 2 GHz and 2.6 GHz	QPSK, 16-QAM, 64-QAM / OFDMA	Heterogeneous at present	Cell radii: several tens of m	Not close to bodies (with ceiling and wall mounting)	Several centimeters; the need for a site certification is currently being discussed	100,000 (5-year period)

Wireless application **Users**	**Frequency range**	**Modulation / coding**	**Output**	**Transmitter coverage or range**	**Distance to persons**	**Safety distance**	**Number of units / coverage area**
Mobile communications / LTE handset; "everyone"	832 MHz – 862 MHz (LTE-800) 1,710 MHz – 1,730 MHz (LTE-1800) 1,758.1 MHz – 1,780.5 MHz (LTE-1800) Other frequencies at 2 GHz and 2.6 GHz	QPSK, 16-QAM, 64-QAM / SC-FDMA	Max. of 200 mW: power control	Up to 5 km	With surfsticks and smartphones, bodily contact (arms, ears, chest, hip region); with routers, close to bodies	Mobile phone: none Other devices: in keeping with user instructions (to several centimeters)	1-10 million (5-year period)
Mobile communications / TETRA BOS Transmitter (base station)	390 MHz – 395 MHz	π/4-DQPSK / TDMA	Up to 40 W per channel, 1 to 8 channels; no channel-based power control	Cell radii: Rural: 10 km – 40 km, city centres: 1 km – 5 km, nationwide	Not close to bodies	Several meters, depending on the site certification	4,300-4,500 Entire territory of Germany

Wireless application Users	Frequency range	Modulation / coding	Output	Transmitter coverage or range	Distance to persons	Safety distance	Number of units / coverage area
Mobile communications / TETRA BOS Handset	380 MHz – 385 MHz	π/4-DQPSK / TDMA	Max. of 250 mW (when 1 of 4 time slots are active); max. of 1 W when all 4 time slots are active; power control	Cell radii: Rural: 10 km-40 km, city centres: 1 km – 5 km	Body contact with handset (head, belt area, stomach area), Close to bodies (vehicle-based handset)	With typical use (1 of 4 time slots active), no safety distance required	500,000 (the network is designed for that number of subscribers)
UWB	Allocations of frequencies from 1.6 GHz to <10.6 GHz by Federal Network Agency Frequency range currently being used: 3.1 GHz to 10.6 GHz	Impulse radio, direct sequence UWB, multiband-OFDM UWB	Maximum of 1 mW; additional Spectrum mask for individual frequency sub-ranges	Range of several m	Close to bodies	Not required	Difficult to estimate The originally predicted boom has not yet occurred.
Femtocells	Depending on the mobile communications system in question – for example, UMTS/HSPA	Depending on the mobile communications system in question – for example, UMTS/HSPA	No reliable data	Several meters to several tens of meters	Not close to bodies to close to bodies	Not required with typical mounting locations	No reliable data

Wireless application **Users**	**Frequency range**	**Modulation / coding**	**Output**	**Transmitter coverage or range**	**Distance to persons**	**Safety distance**	**Number of units / coverage area**
Electric / hybrid vehicles	From constant fields into the kHz range	Not applicable	Not applicable	Not applicable	Close to bodies	Not required	About 4,500 electric cars and 48,000 hybrid cars(Q1 2012); rapid growth predicted
WLAN	5 GHz – 6 GHz 2.4 GHz – 2.5 GHz	OFDM Spread spectrum, hybrid direct sequence and frequency hopping	1 mW-1 W	Up to 100 m	Close to bodies	Not required	> 1 million, either small-area coverage and nationwide networks are possible
Wireless energy transmission	110 kHz – 205 kHz (Qi), 140 kHz (automotive),	Load modulation	5 W (Qi), 3.3 kW (automotive)	A few centimeters	Close to bodies to not close to bodies	Not required with Qi; remains to be determined for automotive applications	Complete coverage

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List of abbreviations

Bluetooth	Open standard for powerful wireless communications technologies at 2.4 GHz
BOS	Emergency services and rescue services (Behörden und Organisationen mit Sicherheitsaufgaben)
BPSK	Binary Phase Shift Keying
Car2Car	Communication from vehicle to vehicle
Car2I	Communication from vehicles to infrastructure
CDMA	Code Division Multiple Access
COFDM	Coded Orthogonal Frequency Division Multiplexing
DAB	Digital Audio Broadcasting
DAB+	Upgraded version of DAB
dBd	Antenna gain with respect to $\lambda/2$ dipole
DECT	Digital Cordless European Telephone
DQPSK	Differential Quadrature Phase Shift Keying
DRM	Digital Radio Mondiale
DSL	Digital Subscriber Line
DVB	Digital Video Broadcasting
DVB-H	DVB- Handhelds
DVB-T	DVB- Terrestrial
DVB-T2	DVB-T version 2 (Successor standard to DVB-T)
EEG	Electroencephalography
EIB	European Installation Bus
EIRP	Equivalent Isotropically Radiated Power
ERP	Effective Radiated Power
FCC	Federal Communications Commission (in the USA)
FDMA	Frequency Division Multiple Access
GSM	Global System for Mobile Communications
HDTV	High Definition Television
HVDC	High Voltage Direct Current transmission
HSPA	High Speed Packet Access
HVAC	High Voltage Alternating Current
KNX	Konnex (standard for home and building control systems)
IEEE	Institute of Electrical and Electronics Engineers
ISM	Industrial, Scientific and Medical

LED	Light-Emitting Diode
LTE	Long-Term Evolution
MIMO	Multiple Input Multiple Output
MMS	Multimedia Messaging Service
MRI	Magnetic Resonance Imaging
OEM	Original Equipment Manufacturer
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RFID	Radio Frequency Identification
SAR	Specific Absorption Rate
SMS	Short Message Service
StOB	Site certification (Standortbescheinigung)
TCP-IP	Transmission Control Protocol-Internet Protocol
TDMA	Time Division Multiple Access
TETRA	Terrestrial Trunked Radio
UMTS	Universal Mobile Telecommunications Service
UWB	Ultra Wideband
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

Annex 1 Excerpt from the SSK 2003 status report

SSK 2003

Examples of relevant telecommunications systems – new systems and systems under development (wireless applications)

Wireless application, users	Frequency range	Modulation / coding	Output	Transmitter coverage or range	Distance to persons	Safety distance[1]	Number of units / coverage area
Mobile communications / UMTS transmitters, operators of public networks	2,110 - 2,170 MHz, downlink	W-CDMA	15 - 30 W	500 m - 10 km, nationwide	Not close to bodies	< 5 m, in keeping with site certification	> 10,000 per network / entire territory of Germany
Mobile communications / UMTS handset; "everyone"	1,920 - 1,980 MHz, uplink	W-CDMA	0.125 - 0.25 W	Up to 10 km	Body contact	Not required	1 - 10 million (5-year period)
Satellite radio; UMTS mobile phones	28 GHz	BPSK / QPSK	2 W		Body contact	Not required	Small number of subscribers overall, due to the good coverage provided by terr. mobile communications
Satellite radio; operators of public networks / company networks, closed user groups	4/6 GHz or 11/12 - 4 GHz or 20/30 GHz	QPSK and 8-PSK; with large antennas, QAM also	For large earth stations, up to about 10 kW (EIRP) in the main radiation direction	Europe	Not close to bodies	< 3,500 m in keeping with site certification	A few
			Back channels via stationary systems, up to 4W (SSPAs)	Communications with satellites	Not close to bodies	Not required	About 100,000 VSAT in Europe

[1] The safety distances given are oriented to typical transmission power levels; they may differ in individual cases.

SSK 2003

Wireless application, users	**Frequency range**	**Modulation / coding**	**Output**	**Transmitter coverage or range**	**Distance to persons**	**Safety distance**	**Number of units / coverage area**
Mobile communications / TETRA transmitters in professional applications: Company networks / special clients (such as police, fire departments, airports, local public transport, public trunked radio)	390 – 400 MHz 420 – 430 (380 – 400) 440 – 450 460 – 470 870 – 876 915 – 921	DQPSK	Up to 100 W ERP	Site-dependent; about 10 km With BOS, nationwide	Not close to bodies	< 10 m, in keeping with site certification	< 20,000 in Europe / regional and national networks
Mobile communications / prof. TETRA Handset Professional use for some individuals; some devices installed in automobiles	380 – 390 MHz 410 – 420 440 – 450 450 – 460 870 – 876 915 – 921	DQPSK up to 200 kbps	In vehicles, up to 6 W ERP	In future, ranges up to 120 km – 200 km (Release 2)	Close to bodies	<1 m	> 10,000 in Germany
			In handhelds, up to 2.5 W ERP	> 10 km	Body contact	Not required	< 5 million in Europe
Digital radio – DAB	Band III, L-Band 1,452 – 1,492 MHz	COFDM	Up to 1 kW	> 60 km; nationwide	Not close to bodies	< 30 m, in keeping with site certification	> 100
Digital radio – MW/KW/LW DRM	< 30 MHz	COFDM	50 kW/120 kW/ 200 kW	> 100 km; nationwide	Not close to bodies	< 300 m, in keeping with site certification	A few

SSK 2003

Wireless application, users	Frequency range	Modulation / coding	Output	Transmitter coverage or range	Distance to persons	Safety distance	Number of units / coverage area
Digital TV – DVB	Terr.: VHF-/UHF broadcast areas Sat.: 10.7 – 12.75 Hz	Terr.: COFDM Cable: QAM Sat.: QPSK	Terr. transmitters, up to 10 kW/ area	Cells have diameters up to 60 km and up to 45 channels à 15 Mbps	Not close to bodies	< 100 m, in keeping with site certification	A few
			Back channels, up to 4 W (SSPAs)	Communications with satellites	Not close to bodies	Not required	> 1000
Local mobile communications (WLAN, Bluetooth)	5 GHz – 6 GHz 2.4 GHz – 2.5 GHz	OFDM Spread spectrum, hybrid direct sequence and frequency hopping	1 mW – 1 W	Up to 100 m	Close to bodies	Not required	> 1 million, either small-area coverage and nationwide networks are possible
Radio relay / WLL Only stationary transmitters Operators of public networks	Europe: 1.88 – 1.9 GHz DECT-WLL 2.5 – 2.67 PMP 3.41 – 3.6 PMP 24.549 – 26.061 PMP	TDMA, CDMA and nearly all common modulation modes	2 – 8 W	Cell diameters from 2 – 5 km	Not close to bodies	< 10 m, in keeping with site certification	At present, still very small / in individual applications, as replacement for cable
Short-range devices	9 kHz – 25 MHz 25 MHz – 1 GHz 1 GHz – 40 GHz	Increasingly, variable-fre-quency trans-mitters, in all modulation modes	Normally, up to 100 mW; higher, in some few cases – up to 2 W	< 100 m	Close to bodies	< 10 cm	Strong market growth, especially for RFID and data/telematics applications