FOUNDATION

Foundation for Research on Information Technologies in Society

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Final Report

Development of Procedures for the Assessment of Human Exposure to EMF from Wireless Devices in Home and Office Environments

Submitted To:
Swiss Federal Office of Public Health
Dr. Mirjana Moser
Contract #: 03.001524

Submitted By:
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Zurich, January 29, 2005

Executive Summary

The Foundation for Research on Information Technologies in Society (IT'IS) was mandated by the Swiss Federal Office of Public Health (BAG) to perform a study on the exposure from indoor mobile communications. The aim of this study is to provide classifications of RF exposures from wireless devices other than mobile phones used in home and office environments (e.g., DECT, Bluetooth, WLAN, and other technologies).

Objectives of the Study

The following subjects are treated in detail:

- Overview of current and future wireless data transmission technologies for indoor applications and classification of currently used short-range emitters
- Overview of current procedures for assessing electromagnetic exposure from short-range emitters in real-life situations (home/office)
- Evaluation of procedures for the characterization of equipment (and software) used for exposure assessment
- Assessment of short-range wireless RF device exposure under normal and worst-case operating conditions.

Technologies, Standards and Classification of Devices

A review of the most commonly employed standards used for indoor data transmission are given. This includes CT standards, DECT, Bluetooth and WLAN as well as potentially upcoming technologies such as HyperLAN and UWB. Since this project is focused on the exposure assessment of short-range indoor wireless technologies, we particularly concentrate on physical and compliance relevant parameters such as frequency, emitted peak power, average power, pulse modulation and associated low frequency components. The most common wireless transmission technologies were selected for further investigation: DECT, Bluetooth, WLAN (IEEE802.11b). In addition, information on devices whose transmission technology is not standardized was collected. From this and a survey of the availability and the degree of pervasiveness of these devices, five device classes were chosen for experimental exposure determination. In the class of standardized technologies we assessed DECT telephones, WLAN access points, as well as several Bluetooth devices. In the field of devices using proprietary communication standards we assessed wireless peripherals for personal computers (PCs) and baby surveillance devices.

A number of commercial products were selected in order to obtain firm indications about the expected exposure levels for each of the different short-range wireless communication devices. An overview is given in Table I.

Exposure Assessment

The first draft of IEC 62209 Part II [1] defining guidelines for the exposure assessment of devices operating within 200 mm of the human body, was submitted for national consultation this January. The dosimetric evaluations in this study were conducted according to these guidelines wherever appropriate. It must be noted that the standard only applies to transmitters designed to be operated within 200 mm of the body. This is not the case for all devices included in this

	E Field (in Air)		**Dosimetry**
	far-field	**near-field**	
DECT:			
Siemens Gigaset 2000c			Handset
Siemens Gigaset 3015	Base Station	Base Station	Handset
Binatone	Base Station	Base Station	
Hitel, Moai 414	Base Station	Base Station	
Ascom Avana 265			Handset
Swisscom R106			Handset
Bluetooth:			
Headset: Nokia HDW-2 (Class III)			X
Headset: Sony Ericsson (Class III)			X
Acer dongle (Class II)	X	X	X
Mitsumi dongle WML-C51APR (Class I)	X	X	X
WLAN:			
SMC 2804WBR 11b/g	X	X	X
Apple Air Port Extreme	X	X	X
Apple Air Port Express			X
Babyphone:			
Philips SBC 363 91U		X	
Vivanco BM 900	X	X	X
Vivanco BM 800	X	X	X
Wireless Mouse:			
Gyration Ultra GT optical		X	
MS Intellimouse optical	X	X	X
Wireless Keyboard:			
Logitech Wireless Desktop	X	X	X

Table I: Overview of the short-range wireless devices selected for experimental exposure evaluations

study. Nevertheless, the same procedure was applied to all devices. The evaluations were conducted with the latest version of DASY4 (Version 4.4) of Schmid & Partner Engineering AG, Zurich. For DECT devices the tests were performed according to IEC 62209 Part I [2] and IEEE 1528 [3].

Little progress has been made in the last decade regarding guidelines for the evaluation of incident *in situ* exposures in indoor situations. The only document available to the knowledge of the authors comprises the guidelines issued by BUWAL for testing the compliance of base stations with NISV [4]. However, this approach is not suitable for the task of this study since generic information about indoor transmitters shall be collected. Hence the exposure has been determined as a function of distance. The evaluations were conducted as follows:

- All measurements were conducted in a semi-anechoic environment.
- First the main beam was determined by measuring the E-field in the azimuth and elevation around the device.
- Along the determined direction of the main beam a radial scan was then conducted from very close to increasingly farther distances.

- In the near-field we used SPEAG high precision probes which provide high spatial resolution of less than 5 mm^3. The data were acquired with DAEasy4 via EASY4.
- At larger distances the measurements were conducted using the PCD 8250 antenna of ARCS and evaluated with a spectrum analyzer.
- When the operational mode could not be predefined, it was determined based on knowledge of the system and the signal received in the time domain. In all cases the measured field strength was then extrapolated to worst-case exposure conditions.

Technically it would be necessary to evaluate the E-field as well as the H-field to demonstrate compliance in the near-field of transmitters. However, H-field evaluations were not conducted since the exposures in the near-field were compared to the primary SAR limits; for larger distances the measurements were done in a semi-anechoic environment, i.e., in a non-reflective environment.

The results of the worst-case spatial peak SAR evaluations are summarized in Table II. WLAN and Bluetooth (class 1) devices can lead to exposure levels similar to those of mobile phones, i.e., in the range of 0.1 - 1 W/kg. These evaluations reflect extreme exposure scenarios in terms of signal transmission and proximity to the body. Under normal operational circumstances these devices are operated at lower output power than applied in this study. Additionally, the devices are in general not operated as close to the body as during assessment of the SAR.

Exposures from DECT handsets are rather low, i.e., below 0.1 W/kg. Surprisingly high are the exposures incurred in the close vicinity of baby phones; their SAR values are similar to those of DECT phones. As expected, the SAR exposure from computer peripherals operating at 27 MHz is low. In summary, all tested devices satisfy the spatial peak SAR limit of 2 W/kg under all circumstances when evaluated following the guidelines of IEC 62209 Part II [1]. This is also true when considering the multiplication factors currently discussed for consideration of the increased absorption occurring in skin/fat layers below 800 MHz.

The results of the incident exposure evaluations are summarized in Table II for distances of 200 mm and 1 m. The incident exposure posed by the investigated devices is below the ICNIRP limits for all distances, even when taking into account a reflective environment. It is also evident from Table II that the cumulated worst-case exposures from indoor wireless communication devices can be significantly larger than exposure limits from base stations and broadcasting transmitters.

Based on the review and the results obtained, we can identify the following open issues for a systematic evaluation of exposure from short-range communication devices typically used in office and home environments:

- Extension or adaption of IEC 62209 Part II for general short-range wireless communication devices. We suggest that the Swiss National Committee propose a corresponding recommendation to the IEC.
- The discrepancy between the safety limits defined for fixed and mobile transmitters becomes more evident when evaluating exposures posed by indoor wireless communication devices. The incident fields of indoor devices are in the same range as those from base stations. Whereas the base stations must comply with the limits defined by NISV [4], the limits for wireless indoor devices are 10 times higher. A dialog between the agencies and other competence centers should be initiated in order to prevent confusion during communication with the public. For example, it might be worth considering that indoor wireless

Device Class	**Frequency Range** [MHz]	**worst-case 10g SAR** [W/kg]	**worst-case E-field** [V/m] (200 mm)	**worst-case E-field** [V/m] (1000 mm)	**ICNIRP limit** [V/m]	**NISV limit**[1] [V/m]
Baby Surveillance	40 - 863	0.077	8.5	3.2	29	4
DECT[2]	1880 - 1900	0.055	11.5	2.9	60	6
WLAN	2400 - 2484	0.81	3.9	1.1	61	6
Bluetooth	2402 - 2480	0.49	3.1	1.0	61	6
PC Peripherals	27 - 40	≤0.005	≤1.5	≤1.5	28	4

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[1] NISV limits for fixed transmitters with ERP of ≥ 6 W

[2] Extrapolated maximum for asymmetric transmission mode

Table II: Worst-case E-field and spatial peak SAR of the investigated devices. (An absolute worst-case for all commercially available products cannot be estimated based on this data)

communications not be evaluated *in situ* as base stations but characterized in exposure classes based on dosimetric evaluations and usage considerations.

- Development of a classification system including corresponding evaluation guidelines.
- Dissemination of results to standardization committees.

Contents

1 Introduction

In the last few years, many new wireless connectivity standards/technologies have emerged. These technologies enable users to connect a wide range of computing and telecommunications devices easily and simply, without the need to buy, carry, or connect cables. They deliver opportunities for rapid ad hoc and automatic connections.

The ever increasing use of these new technologies will result in more and more RF exposure in home and work situations. In order to protect the population from adverse health hazards, safety guidelines are already implemented and being harmonized in most countries. These guidelines are considered to reliably protect the general population against thermal effects. The standardization commissions had considered the data regarding non-thermal effects to be insufficient to serve as a basis for safety guidelines. On the other hand, the results of recent studies seem to confirm the hypothesis of athermal effects, which appear to be amplitude-modulation dependent [5]. As in the case of GSM, the use of new technologies such as DECT, Bluetooth and WLAN will result in exposures with significant ELF components from the pulse modulation spectrum. The spectrum will depend on the technology utilized as well as on the implementation.

Techniques for assessing the exposures of transmitters at large distances from the body (e.g. EN50392 and IEC61983 [6]) as well as for devices operating at the ear of the users are well established (e.g., EN50360 [7] and EN50361 [7], IEEE1528 [3], IEC 62209 [2]). The guidelines for determining the exposure of body-mounted devices (operated within a distance of less than 200 mm from the body) are close to submission (IEC 62209 Part II [1]). However, none of these standards are really applicable for testing compliance within apartments and offices. Only BUWAL has issued guidelines for testing compliance within buildings [8] with respect to the Ordinance on Protection from Non-Ionising Radiation (NISV) [4].

The aim of this project is to provide scientific support for the assessment procedures to analyze RF exposures from wireless technology used in home and office environments (DECT, Bluetooth, WLAN). This includes (1) a review and classification of different technologies of short-range wireless transmitters and (2) assessment of their exposure under normal and worst-case operating conditions

In Chapter 2 the main aspects of current and future technologies are reviewed and the background for the relevant measures for exposure assessment, such as power classes and the main modulation components, are identified. Exposure assessment methods are critically reviewed in Chapter 3. Studies reporting the exposure assessment of short range wireless transmitters are presented and summarized in Chapter 4, and the results of our own experimental SAR testing of a representative selection of short-range transmitters are reported in Chapter 5 . The results are summarized and discussed in Chapter 5.7.

2 Current Technologies

2.1 CT Technologies

It is evident that analog and the first generation digital cordless telephones (CT standards) are rapidly being replaced by DECT phones. Nevertheless, CT standards are reviewed for reasons of completeness.

2.1.1 CT1 Technology

CT1 (cordless telephone 1) was the first generation of analog cordless telephones which were introduced in the 1980's on the European market, working in the frequency range of 914-915 MHz (uplink) and 959-960 MHz (downlink) and with a 40-channel capacity. The mean average power was 10 mW. After establishment of the first GSM 900 networks, CT1 equipment disappeared from the market (1).

2.1.2 CT1+ Technology

CT1+ (cordless telephone 1+) devices are an extension of CT1 devices with a 80-channel capacity and are operated in the frequency range of 885-887 MHz (uplink) and 930-932 MHz (downlink) with analog modulation. The mean average power is 10 mW as in the case of CT1 devices. On the Swiss market, only telephones of the CT1+ type are currently offered. Although in rare cases still available and advertised as an alternative to digital cordless telephones, CT1+ systems will not have any practical relevance in the future.

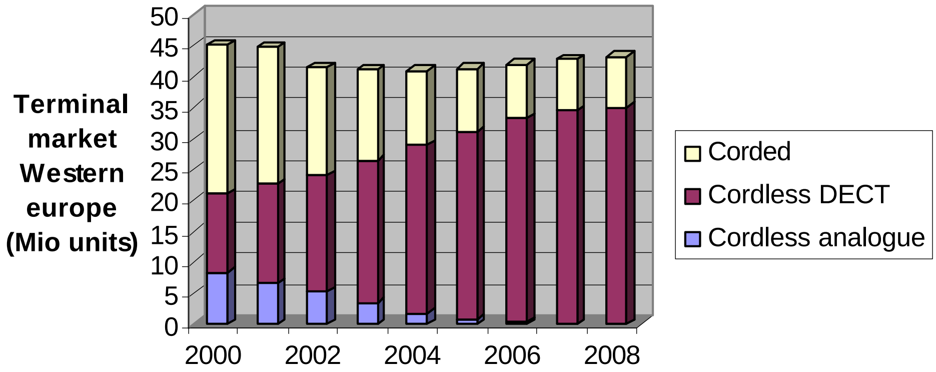
2.1.3 CT2 Technology

CT2 (cordless telephone 2) was the 1st generation among cordless telephones with digital modulation and new frequencies (864.1-868.1 MHz). It uses Gaussian Frequency Shift Keying (GFSK) modulation and a Time Domain Multiplex (TDM) system for separation of the uplink and downlink. The maximum power of CT2 is 10 mW. Almost no devices remain available on the market since CT2 was unable to compete with DECT type cordless telephones.

The CT1+ and CT2 frequency ranges will continue to be reserved for this technology until 31 December 2005 at the latest. After this date it will still be possible to use the equipment, subject to the condition that it does not cause interference to other systems. However, it will no longer enjoy protection from interference.

2.2 Digital Enhanced Cordless Telecommunications (DECT)

DECT stands for “Digital Enhanced Cordless Telecommunications” and denotes a radio technology suited for voice data and networking applications with range requirements up to a few 100 m. DECT is a mass market technology operating on a protected unlicensed spectrum and has already been adopted in more than 110 countries in the world. More than 100 companies are involved in DECT product development; the introduction of the first DECT devices occurred in 1992, and the market share of DECT technology is still growing. DECT products are increasingly replacing other telecommunication terminals, e.g., the development of cordless telephones as displayed in Figure 1.



Source: DECT Forum, 01.2004

Figure 1: DECT terminal evolution

DECT	
frequency (MHz)	1880-1900
no. of RF channels	10
channel bandwidth (MHz)	1.728
bit rate (Mbps)	1.152
transmission technique	TDMA, TDD
basic frame duration (ms)	10
time slot (ms)	0.417
modulation	GFSK
typ. data rate (kbps)	24-552
range (m)	100
max. power (mW)	250
power control	no

Table III: Summary of the basic features of the DECT standard

2.2.1 DECT Technology

The DECT standard provides a general radio access technology for wireless telecommunications, operating in the preferred 1880 to 1900 MHz band using GFSK modulation. A DECT system comprises a Fixed Part (FP), or base station, and one or more Portable Parts (PP's). Basic DECT frequency allocation uses 10 carrier frequencies (MC) in the 1880 to 1900 MHz range. These frequency channels can be used simultaneously by one base station. The time spectrum for DECT is subdivided into time frames, whereby the basic frame repeats every 10 ms. 16 frames form a multi frame (160 ms), 25 multi frames form a hyper frame (4 s). The frame structure is depicted in Figure 2. The basic frame consists of 24 time slots, each individually accessible (TDMA), that may be used for either transmission or reception (Figure 3). A time slot is defined by a length of 0.417 ms or 480 bits. For the basic DECT speech service the 10 ms time frame is split in two halves (Time Division Duplex (TDD)); the first 12 time slots are used for FP transmissions (downlink), and the other 12 are used for PP transmissions (uplink). During a time slot, normally a burst of 424 bits is transmitted (Figure 2, bottom), whereby a fraction of this burst contains the user data, yielding a maximum data throughput of 24 kbit/s per channel (at maximum forward error correction). Utilizing both frequency and time dimensions a total spectrum of 120 duplex channels is available to a DECT device.

The protocol layers of DECT offer better protection against eavesdropping and tapping into foreign telephone circuits than the analog cordless telephone predecessor systems. DECT requires the mobile units (PP) to be registered with the fixed part. This one-time registration prevents foreign users from entering a DECT network or to accidentally listen or connect to a neighbor's DECT. Furthermore, DECT also supports advanced features for voice telephony such as caller ID (displaying the number of the calling station).

Further information about the DECT standard is explained in documents on the web platform of the DECT Forum (http://www.dect.org) and on the web site of The European Telecommunications Standard Institute (ETSI, http://www.etsi.org).

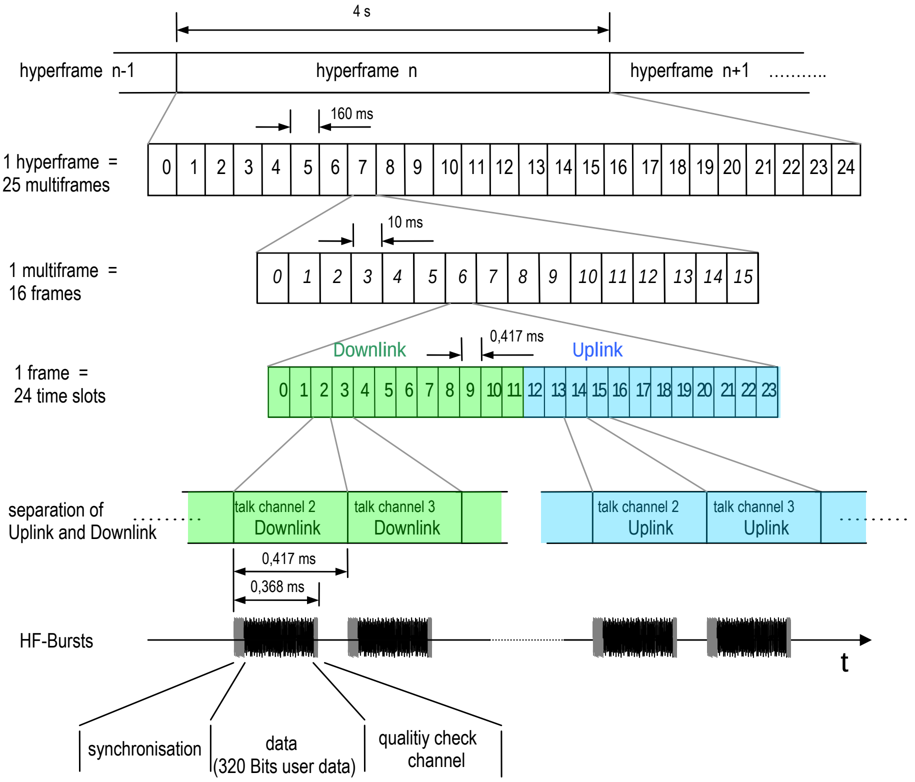


Figure 2: Scheme of DECT frames and timing structure

2.2.2 Applications of DECT

The main application areas of the DECT technology comprise residential and business telephony, combined voice and data applications, personal area applications, telemetry, control and supervision applications, and public applications (e.g., bridging the last mile to the fixed net, the so-called Wireless Local Loop). According to the DECT Forum, DECT will continue to be the dominant unlicensed enterprise voice mobility technology for several years. 2.4 GHz ISM

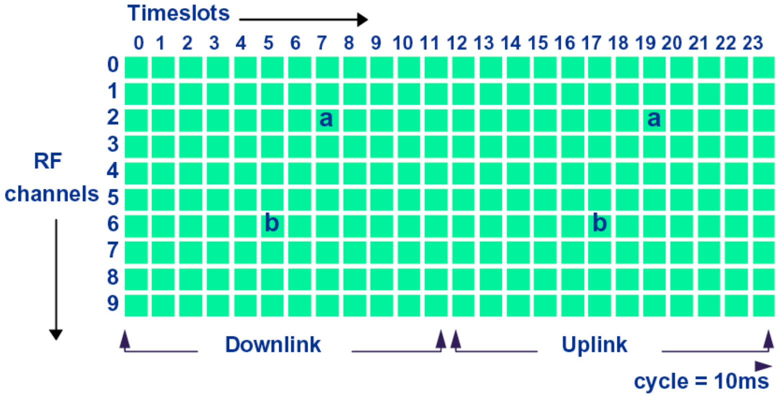


Figure 3: The DECT frequency/time spectrum

(industrial, scientific and medical) band technologies such as Bluetooth and WLAN are not suitable for voice mobility applications and are not real alternatives to DECT.

Since DECT is an access technology, it can front-end practically any network. Current implementations can be found in domestic and small office/home office environments in the form of a base station wired to a normal telephone line (either ISDN or analogue), containing all functions to support multiple DECT handsets. Since DECT is a scalable technology, a system can be expanded to cover a larger area and support a higher traffic load; situations that can be found in a business environment. Users can make and receive calls when in range of a base station (up to about 50 m indoors). A DECT system can be the front-end of a private branch exchange. Even the public domain is a possible application area for DECT. Due to its use of high frequencies, dynamic channel selection and short range, it is ideally suited for noisy radio environments with high traffic loads as modern cities are today.

DECT Products: The majority of DECT products is intended for cordless home and office telephony (Figure 4). Many manufacturers offer a variety of different models, whereby most models allow only 6 PP's at maximum.

Apart from devices for home use there have been solutions and components for professional use for several years (mobile parts, base stations, repeaters, external antennas). Here, the diversity of manufacturers and products is significantly lower; however, the capability of the devices is higher accordingly.

2.2.3 Exposure Relevant Questions

Power: The normal transmit power (NTP) of a DECT device indicates the emitted power averaged over a physical packet; a physical packet consists of a certain number of bits, smaller than 480 bits, transmitted during one time slot with the bit rate of DECT. **According to the DECT standard the maximum NTP is 250 mW**. It should be noted that the basic DECT standard has two permitted output power levels, the standard level of 250 mW and a low power mode in which the peak power is 2.5 mW. The basic standard allows manufacturers to choose their own power levels up to the peak levels mentioned. However, the interoperability standard for voice systems requires that the standard transmit power is at least 80 mW. Most DECT equipment currently available uses close to 250 mW peak power to maximize the communication range. Therefore the following calculations are based on 250 mW peak power. There is no

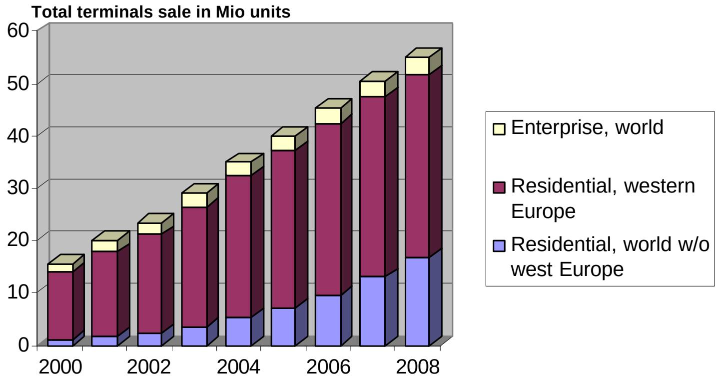


Figure 4: DECT terminal evolution. It is evident from the graphics that most of the DECT terminals are currently for residential use.

power control for DECT devices. Thus in most devices the burst power always corresponds to the maximum power, i.e., 250 mW. A summary of the maximum and minimum time-averaged power of DECT devices is given in Table IV.

- **DECT base station:** Since normally not more than 6 simultaneous full slot bearer transmissions are used in residential applications (telephone), the maximum time-averaged power is typically no more than 55 mW (250 mW*(6*0.368 ms/10 ms)).

  Assuming an extreme case in which the DECT base station is operated in asymmetric data transmission with double slot bursts (every second transmission gap is filled with data) and with up to 23 time slots as the downlink, a maximum time-averaged power of 225 mW is emitted (250 mW*(23*0.368 ms+11*0.049 ms)/10 ms).

  A DECT base station continuously transmits on - at least - one channel, thus providing a beacon function for DECT portables to lock onto. The transmission can be part of an active communication link with a portable or a dummy bearer transmission. In the case of one speech connection (basic physical packet: 424 bits and 0.368 ms), the base station radiates continuously with a minimum time-averaged power of ca. 10 mW (424bits/11520bits*250 mW, i.e., one active time slot). In the case of standby mode (short physical packet: 96 bits), the base station works in active idle mode (dummy bearer transmission) with ca 2 mW (96bits/11520bits*250 mW, i.e., one active time slot with reduced bit length).

  It should be noted that the continuous transmission of the base station is a unique property of the DECT system (CT devices did not continuously radiate) which potentially makes DECT the dominant RF source in homes and offices.

- **DECT portable part:** The initiative to set up radio links in basic DECT applications is always taken by the portable part. The PP only radiates if a connection is to be activated from its own location or if it has to respond to a connection call from the base station. A standard voice connection requires one single time slot; thus a cordless handset phone exhibits a maximum average power of 10 mW (speech and low rate messaging). From a literature search on SAR values for DECT portable parts, only the Ericsson DT590 10g SAR value of 0.06 mW/g is available. Other manufacturers (e.g., Siemens) only affirm compliance by means of EN50360 and the ICNIRP guidelines. However, for most available DECT phones no statements on their compliance testing could be found.

Power (mW)	**FP**	**PP**
peak	250	250
max. (time-averaged)	225	10
normal (time-averaged)	10-55	10
min. (time-averaged)	2	0

Table IV: Transmit power of DECT devices. FP (fixed part or base station), PP (portable part, e.g., cordless phone). Minimum power is defined as "without active connection" and "off-sate" for the FP and PP, respectively

Low-Frequency Content: In addition to the carrier frequency around 1900 MHz, the pulsed nature of DECT signals involves low frequency components in the electromagnetic spectrum. From the basic frame of 10 ms a frequency of 100 Hz is present. From the time slotting (slot length 0.417 ms) other low frequency components between 0.1-2.4 kHz can appear, depending on the slot allocation and user traffic. The low frequency components are summarized in Table V.

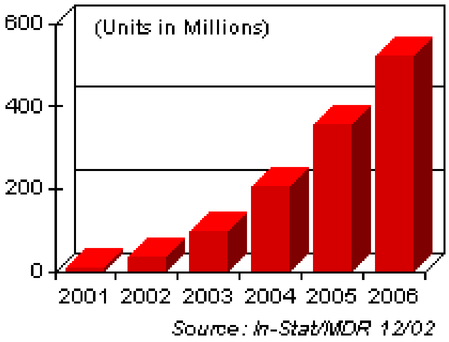
LF spectral component (Hz)	**period (ms)**	**caused by**
0.25	4000	hyper frame
6.25	160	multi frame
100	10	basic frame
100-2400	0.417-10	TDMA data transmission

Table V: Low frequency spectral components of DECT technology

2.3 Bluetooth

Bluetooth is a Radio Frequency (RF) specification for short-range, point-to-point and point-to-multi-point voice and data transfer. It enables users to connect to a wide range of computing and telecommunications devices without the need for proprietary cables that often fall short in terms of ease-of-use. Bluetooth technology was developed by the Bluetooth Special Interest Group (SIG), a trade association comprised of leaders in the telecommunications, computing, automotive, industrial automation and network industries. The Bluetooth standard is planned to be adopted by the IEEE working group 802.15.

Bluetooth is a high-speed, low-power wireless link technology, typically used to connect phones, laptops, organizers, printers, cameras, beamers and other portable equipment together with little or no work by the user. Numerous new applications for Bluetooth are continuously found. In addition to wireless substitution for all cable connections between different devices, systems for home and industry automation, wireless personal area networks (WPAN) and internet access or vehicle equipments are developing rapidly. The Bluetooth chipset forecast (Figure 5) illustrates a more than linearly growing market, predicting future development quite well according to recent figures: IMS Research reports that Bluetooth technology shipment figures now exceed three million units per week (September 2004). This news comes just three months after the technology met the two million units per week milestone, showing that the Bluetooth market is experiencing a continued period of significant growth.



Source: In-Stat/MDR 12/02

Figure 5: Bluetooth Chipset Forecast. The forecast from Dec 2002 (200 Mio chips in 2004) is reasonably supported by the latest news of Sep 2004 (3 Mio chips per week).

2.3.1 Bluetooth Technology

Bluetooth operates in the 2.4 GHz range referred to as the Industrial, Scientific, and Medical (ISM) band. This band provides license-free operation in the United States, Europe, Japan, and most industrialized nations worldwide.

Bluetooth	
frequency (MHz)	2402-2480
no. of RF channels	79
channel bandwidth (MHz)	1
bit rate (Mbps)	1
transmission technique	TDD, FHSS
basic frame duration (ms)	-
time slot (ms)	0.625
modulation	GFSK
typ. data rate (kbps)	434-723
range (m)	10-100
max. power (mW)	1-100
power control	yes (and optional)

Table VI: Summary of the basic features of the Bluetooth standard

Bluetooth uses a frequency hopping spread spectrum (FHSS) technique. Spectrum spreading is accomplished by frequency hopping up to 1600 hops per second on 79 channels between 2.402 GHz and 2.480 GHz. The basic features of the Bluetooth standard are summarized in Table VI. Bluetooth radio modules avoid interference from other signals by hopping to a new frequency after transmitting or receiving a data packet. The sophisticated mode of transmission adopted in the Bluetooth specification ensures protection from interference and seeks to ensure the security of the data. The modulation Bluetooth uses is GFSK. A bit is encoded by a change of the carrier frequency by ±200 kHz. Thereby a gross data rate of 1 Mbps is achievable. The protocol splits that bandwidth to support both voice and data communication. Bluetooth can support an asynchronous data channel, up to three simultaneous synchronous voice channels, or a channel which simultaneously supports asynchronous data and synchronous voice. Each voice channel supports a 64 Kbps synchronous (voice) link. The asynchronous data channel can support an asymmetric link of up to 723 Kbps in either direction, while permitting 57.6 Kbps in the return direction or a symmetric link up to 434 Kbps. The channel is divided into time slots, each 0.625 ms in length. The time slots are numbered according to the Bluetooth clock of the piconet master. In the time slots, transmitter and receiver can transmit packets. A time-division duplex (TDD) scheme is used where master and slave alternatively transmit (see below: Bluetooth networks). The master shall start its transmission in even-numbered time slots only, and the slave shall start its transmission in odd-numbered time slots only. The packet start shall be aligned with the slot start. Packets transmitted by the master or the slave may extend over up to five time slots. The RF hop frequency shall remain fixed for the duration of the packet. A simplified scheme of Bluetooth communication is illustrated in Figure 6.

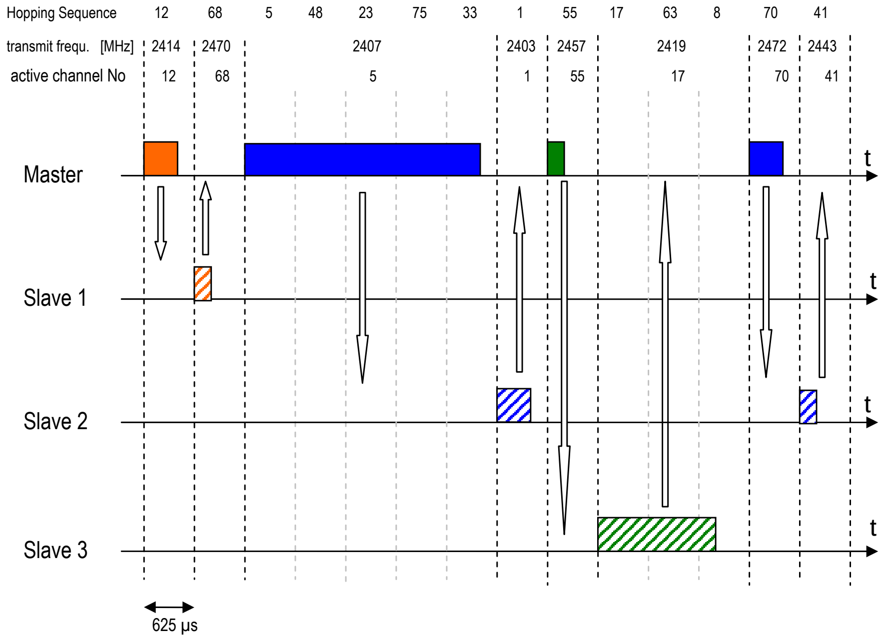


Figure 6: Scheme of Bluetooth communication between a master and three slaves showing variable package length and multi slot packages

Bluetooth Networks: The Bluetooth system provides a point-to-point connection (only two Bluetooth units involved), or a point-to-multipoint connection. In the point-to-multipoint connection, the channel is shared among several Bluetooth units. Two or more units sharing the same channel form a piconet. One Bluetooth unit acts as the master of the piconet, whereas the other unit(s) act as slave(s). The communication is organized such that the data is always exchanged alternately from a master to a slave and consecutively from a slave to a master (TDD, see also Figure 6). Up to seven slaves can be active in the piconet. In addition, many more slaves can remain associated to the master in a so-called parked state. These parked slaves cannot be active on the channel, but remain synchronized to the master. Both for active and parked slaves, the channel access is controlled by the master. There are several operation modi of Bluetooth devices, explained in the following:

- Standby: Devices not connected in a piconet are in standby mode. In this mode, they listen for messages every 1.28 s over 32 hop frequencies.

- Page/Inquiry: If a device wishes to make a connection with another device, it sends out a page message, if the address is known, or an inquiry followed by a page message, if it is unknown. The master unit sends out 16 identical page messages on 16 hop frequencies to the slave unit. If there is no response, the master retransmits on the other 16 hop frequencies. The inquiry method requires an extra response from the slave unit, since the media access control (MAC) address is unknown to the master unit.
- Active: Data transmission occurs.
- Hold: When either the master or slave wishes, a hold mode can be established, during which no data is transmitted. The purpose of this is to conserve power. Otherwise, there is a constant data exchange. A typical reason for going into hold mode is the connection of several piconets.
- Sniff: The sniff mode, applicable only to slave units, is for power conservation, though not at as reduced a level as hold. During this mode, the slave does not take an active role in the piconet, but listens at a reduced level. This is usually a programmable setting.
- Park: Park mode is a more reduced level of activity than the hold mode. During park mode, the slave is synchronized to the piconet, thus not requiring full reactivation, but is not part of the traffic. In this state, active Bluetooth addresses are not maintained, only synchronization with the master to check for broadcast messages.

2.3.2 Applications of Bluetooth

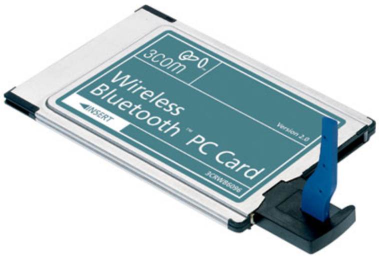


Figure 7: Typical Bluetooth device: PC card for computers

Before Bluetooth wireless technology, the only ways to connect two devices were either cable or infrared, each of which had limitations. Bluetooth now allows devices to work together within a range of 10-100 meters. Users no longer have to keep their computer and cell phone aligned to maintain a connection using the infrared port. Bluetooth allows users to leave their cell phone in a briefcase and still connect to the office or to the internet. Designed to be a low cost technology, other peripherals are likely to contain Bluetooth, such as fax machines, cameras, alarm systems and virtually any other electronic device (examples are given in Figure 7 and Figure 8). Unlike other technologies available today, Bluetooth is designed to be a bubble of connectivity that moves with the user. Bluetooth wireless technology is also included in less obvious, peripheral applications, e.g., it serves as a trusted wireless connection in critical medical devices such as Nonin Medical's pulse oximetry system (http://www.nonin.com). Bluetooth technology is used to scan bar codes with the Baracoda Pencil (http://www.akron.it) and keep UPS logistics running smoothly across the globe.

Figure 8: Typical widespread application of Bluetooth technology: Use of a mobile phone with headset

2.3.3 Exposure Issues

Power: In the Bluetooth specification there are three classes of radios, which are characterized by their output power (Table VII). Class 1 is specified to have a maximum transmit power of +20 dBm (100 mW). Class 2 has a maximum transit power of +4 dBm (2.5 mW). Class 3 has a maximum transmit power of 0 dBm (1 mW). The Bluetooth specification limits the radio output power exactly to that actually required. For instance, if the receiving radio indicates that it is only a few meters away, the transmitter immediately modifies its signal strength to suit the exact range. This feature dramatically reduces the radio power consumption as well as radio interference. Furthermore, the radio chip automatically shifts to a low-power mode as soon as traffic volumes become low or stop. The low-power mode is only interrupted by very short signals with the purpose of verifying the established connection.

A power control is required for power class 1 equipment. The power control step size lies between minimal 2 and maximal 8 dB. Class 1 equipment with a maximum transmit power of 20 dBm must be able to control its transmit power down to 4 dBm or less. Equipment with power control capability optimizes the output power in a link with commands coming from the link controller. By considering the Bluetooth receiver sensitivity of about -70 dBm, for which a raw bit error rate (BER) of 0.1 % is met, the communication range is typically about 100 meters for class 1 equipment and about 10 meters for class 3 equipment.

device class	**max. power (mW)**	**max. time-averaged power (mW)**
I	100	76
II	2.5	1.9
III	1	0.8

Table VII: Power classes of Bluetooth devices

The actual time-averaged power radiated by a device depends on one hand on the operating conditions on the other hand on the length of the data packages and is usually lower than the maximum power. **The ratio of actual transmitted time-averaged power to the maximum power for Bluetooth devices is maximal 0.76**, when asymmetric transmission is enabled with 5-slot packages (see Figure 6, third package). A device is then active for 2.87 ms over the duration of 5 slots. The following slot is empty for listening (one slot duration is 0.625 ms). However, this mode is unlikely to be active over longer periods of time; therefore the ratio of actual transmitted time-averaged power to the maximum power is usually lower.

Low-Frequency Content: Beside the carrier frequency around 2450 MHz the pulsed nature of Bluetooth signals involves low frequency (LF) components in the electromagnetic spectrum. From the repeat of the fixed sequence of the hopping frequency within a piconet a 20 Hz component arises (1/(79 x 0.625 ms)). From the frequency hopping every 0.625 ms a frequency of 1600 Hz is present. The variable length of the data packages (1-slot, 3-slot and 5-slot master signal packages are possible) can introduce spectral components in the range of 267 Hz - 800 Hz, depending on the operating modus and traffic. Some operating modi like the standby mode imply signals every 1.28 s, which generates a frequency component of 0.78 Hz. However, the most prominent LF component is the 1600 Hz component; the others depend on the operating mode and traffic.

LF spectral component (Hz)	**period (ms)**	**caused by**
0.78	1280	standby mode
20	79 x 0.625	fixed sequence of hopping frequency
267-800	2 x 0.625 - 6 x 0.625	multi-slot data transmission
1600	0.625	TDD data transmission

Table VIII: Low frequency spectral components of Bluetooth technology

2.3.4 Products

In general many of the Bluetooth products available are devices of power classes II or III, especially body-worn devices or devices that are commonly used in proximity to the human body with integrated Bluetooth transmitters. Currently, power class I devices are available as optional extensions or as a substitute of WLAN devices with a low data rate. An overview of several Bluetooth devices in relation to the typical exposure type of the particular device is given in Table IX.

2.4 Wireless Local Area Network

A Wireless Local Area Network (WLAN) is a flexible data communications system which provides short to medium range network connectivity to a range of devices including both mobile and fixed computers, typically implemented as either an extension to, or as an alternative for, a conventional wired LAN. WLAN's can provide a high data rate (1-54 Mbps) and a typical access distance of 10-100 m. WLAN devices have begun emerging in office and home environments in recent years, representing a powerful and flexible alternative to wired LANs. A strong development of WLAN infrastructures can be observed, for example in conference rooms, hotel lobbies, universities and in airport lounges.

Typical exposure	**Device type**	**Power class**
near-field	Logitech Cordless Presenter	3
	Motorola HDT 600 Handheld	3
	Avant 4000 Pulse-Meter	3
	Sony Ericsson HBH 35 Headset	≥2
	Nokia HDW 2 Headset	≥2
	Huges 320 Headset	2
	COM1 Bluelight Compact Flash	2
	Sonorix Audio Player / Headphone	2
	Socket Cordless Hand Scanner	1
far-field	D-Link DBT-120	2
	PSI Bluetooth 56K Modem	1
	EXP PCMCIA Bluetooth Adaptor	1
	X-Micro Bluetooth USB Dongle	1

Table IX: Exposure relevant overview of Bluetooth products

2.4.1 WLAN Technology

Until five years ago, the speed of WLAN was limited to 2 Mbps. However, with the introduction of new standards, WLAN's can support up to 54 Mbps both in the 2.45 GHz ISM band (Standard IEEE 802.11g) and in the 5.2 GHz band (IEEE 802.11a or HiperLan/2). Additional modifications and enhancements are still being developed for IEEE 802.11. Currently, the available and planned WLAN systems operate in the ISM bands at 2.4 GHz and 5.2 GHz. The different frequency ranges are given in Table X. Products which are predominant on the European market function mainly according to IEEE 802.11b and IEEE 802.11g, both in the 2.45 GHz band. We therefore focus in this report only on these two standards. The basic features of these standard are summarized in Table XI.

Property	*IEEE 802.11*	IEEE *802.11a*	**IEEE 802.11b**	**IEEE 802.11g**	*HiperLAN Type 1*	*HiperLAN Type 2*
frequency bands (GHz)	2.4-2.4835	5.15-5.35, 5.47-5.725	2.4-2.4835	2.4-2.4835	5.15-5.35	5.15-5.35, 5.47-5.725
max. transmit power EIRP (dBm)	20	16, 23, 29 with 6 dBi	20	20	10,20,30	23, 30
max. data rate (Mbps)	2	54	11	54	20	54
devices available	no	rare	yes	yes	no	no

Table X: Frequency bands and maximum transmit power for wireless LAN described in different standards (EIRP: Equivalent Isotropically Radiated Power)

IEEE 802.11b: 802.11b (also referred to as 802.11 High Rate or 802.11HR) is an extension to 802.11 that applies to wireless LAN's and provides 11 Mbps transmission (with a fallback to 5.5, 2 and 1 Mbps) in the 2.4 GHz band (2.4-2.4835 MHz). 802.11b uses only direct sequence spread spectrum technology (DSSS) as the transmission technology. Here, the signal spectrum is spread from 1 MHz to 22 MHz to enhance the robustness of the transmission. For the different data rates different modulation schemes are used (DBPSK and DQPSK). The range of IEEE802.11b is up to a distance of 100m; however the data rate decreases with distance. A full data rate of 11 Mbps is normally achieved up to a distance of 50 m for an undisturbed propagation path. Beyond this distance the data rate decreases to 1-2 Mbps (Figure 9).

WLAN	**802.11b**	**802.11g**
frequency (MHz)	2400-2483.5	2400-2483.5
no. of RF channels	3	3 or 4
channel bandwidth (MHz)	22	16.6 or 22
bit rate (Mbps)	11	54
transmission technique	DSSS+CCK	OFDM or (DSSS+CCK)
basic frame duration (ms)	-	-
time slot (ms)	-	-
modulation	PSK and QAM	PSK and QAM
typ. data rate (kbps)	<11	<54
range (m)	100	100
max. power (mW)	100	100
power control	no	no

Table XI: Basic characteristics of the mostly used WLAN standards 802.11b/g

IEEE 802.11g The 802.11g standard (ratified in June 2003) provides data rates of up to 54 Mbps. It operates in the 2.4 GHz band and uses orthogonal frequency division multiplexing (OFDM) modulation for data rates above 20 Mbps and direct-sequence spread spectrum (DSSS) with complementary code keying (CCK) for data rates below 20 Mbps. The devices are compatible with the IEEE 802.11b standard. The range of IEEE802.11g is up to 100 m; however the data rate decreases with distance. A full data rate of 54 Mbps is normally achieved only at a distance range of 25 m. Beyond this distance the data rate decreases to a value of 1-2 Mbps (Figure 9).

Wi-Fi: Wi-Fi is not a standard of its own. However, it is a certification which assures tested and proved interoperability among wireless computer equipment. Wi-Fi is short for “Wireless Fidelity”, and it is the popular name for 802.11-based technologies that have passed Wi-Fi certification testing. This includes IEEE 802.11a, 802.11b, 802.11g and upcoming 802.11 technologies.

Networks: WLAN’s typically operate in one of two modes. One is the so-called “Ad-Hoc Mode”, in which two terminals establish a peer-to-peer connection with no assistance from other infrastructure. The second is the “Infrastructure Mode”, whereby an Access-Point (AP) is used to connect many terminals to a LAN, which may be an extension of a wired LAN. Infrastructure based WLAN’s can range in complexity and size from a single AP in an office to deployments with many overlapping cells to give blanket coverage over an entire site. This is similar to a small-scale cellular radio system using an always-on packet switching interface with the access points acting as base stations. A number of WLAN systems have been standardized or are in the process of standardization by various organizations.

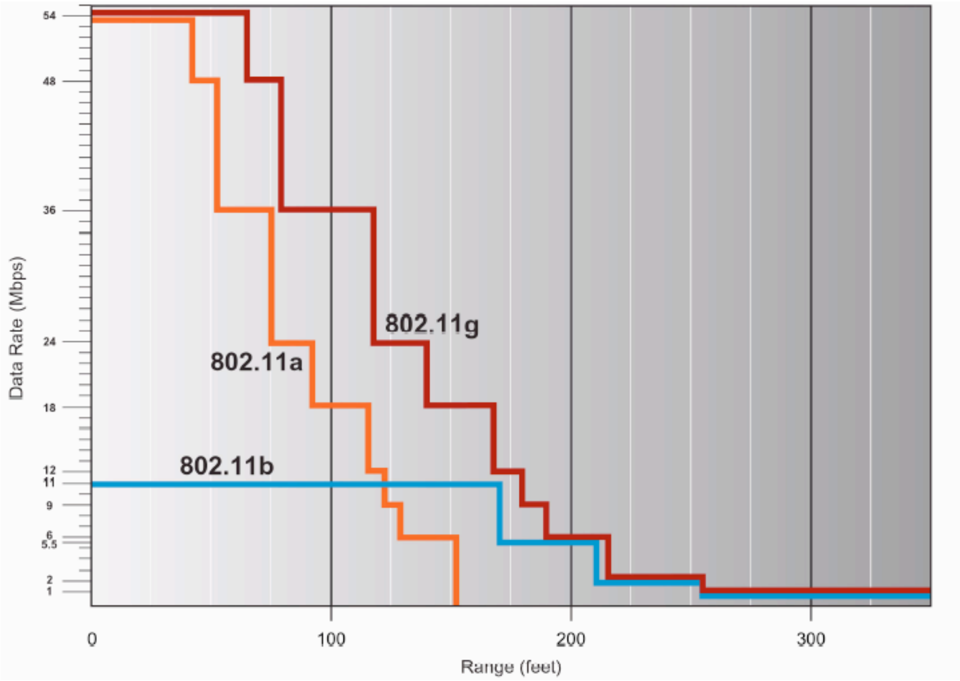


Figure 9: Variation of data rate of different WLAN standards over distance (Source: White Paper, Broadcom Corporation; Irvine CA)

Regulation: The regulation situation in Switzerland for WLAN systems is the following: other than WLAN in the 2.45 GHz ISM band, currently only the 5.15-5.25 GHz band is available for indoor operated wireless LANs and only with a maximum power of 60 mW.

Opening of the bands 5.25-5.35 GHz / 200 mW EIRP and 5.47-5.725 GHz / 1000mW EIRP for HIPERLAN/2 (and IEEE802.11a meeting the same requirements) both with mandatory TPC (Transmitter Power Control) and DFS (Dynamic Frequency Selection) for sharing is under investigation.

2.4.2 Exposure Issues

An overview of the different WLAN technologies and respective maximum transmit power is given in Table X. The maximum power (EIRP) of a WLAN device operated in Switzerland is 100 mW for IEEE802.11b/g and 60 mW for IEEE802.11a. The time-averaged transmitted power of a WLAN device cannot be assessed as a fixed number but depends on the actual data traffic and can vary between 0 (sleep mode over a long time) and almost maximum power (for high data rates during long time periods). Exploiting the full capacity of a WLAN device means a time-average transmit power of almost 100 mW. It is approximately 2% less since after transmission of a data package a receipt message has to be awaited (Table XII). The minimum time-averaged transmit power of an active device is defined by the periodic transmission of the beacon signal (usually every 0.1 s for 0.5 ms), yielding a value of 0.5 mW.

Since the standards 802.11b/g do not use the TDMA technique, several WLAN networks can be operated spatially overlapping at the same time. The available frequency band in 802.11b/g allows the simultaneous operation of three or four networks (each with 16 or 22 MHz bandwidth). This implies that the exposure of a person can be the sum of the radiation of several access points

Power	(mW)
peak	100
max. (time-averaged)	98
min. (time-averaged)	0.5

Table XII: Transmit power of WLAN devices of standards 802.11b/g. Note that the time-averaged transmit power under normal operating conditions depends strongly on the momentary data traffic. Here, the upper and lower limits are shown.

which are simultaneously active. Another important issue is that the carrier frequencies (2.45 and 5.5 GHz) for WLANs are rather unexplored frequencies, from a dosimetric and biological viewpoint.

2.4.3 Products

Products based on 802.11b gained mainstream acceptance as the first wireless networking products with acceptable speeds, affordable prices, and universal compatibility as certified by the Wi-Fi Alliance. More than 95% of today's WLAN infrastructure includes 802.11b products. 802.11g technology satisfies the bandwidth needs of the market globally and economically, while remaining compatible with the installed base of mainstream products. Products have only been available for a short time, such as PC cards, modules for the connection of computer periphery (printer, scanner, etc.) or access point modules (Figure 10), but will conquer the market rapidly.

Figure 10: Typical range of WLAN products, from Cisco Aironet series 340

2.4.4 Market Forecast

The market watcher Forrester Research has forecast in the report "WLAN and Bluetooth update: Beyond the hype" from June 2003, that by 2008 there will be 286.5 million Bluetooth enabled phones, PDAs and notebooks in Europe alone - not to mention all the wireless headsets, keyboards, mice and webcams that will use Bluetooth as well (Figure 11). Around 77% of phones, 60% of PDAs and 67% of notebooks will have this technology built in. Chip prices are falling, making technology integration into new products cheaper, and the arrival of Bluetooth-WLAN combo chips - leveraging the fact that they both use the 2.4 GHz band - in 2005 will further greatly facilitate Bluetooth incorporation, the research company believes.

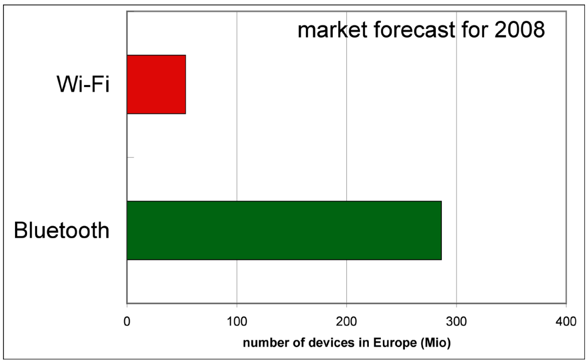


Figure 11: WLAN and Bluetooth devices in Europe in 2008. Source: Forrester Research

Wi-Fi devices will number 53.4 million. While 80% of notebooks that ship in 2008 will feature Wi-Fi, only 34% of PDAs will, and just 2% of cellphones. Of course, many devices will support both technologies: 27% of PDAs and 65% of notebooks - just 1% of notebooks will offer Bluetooth alone, while 33% of PDAs will and so will 75% of cellphones. The forecast numbers do not mean that Bluetooth technology will have the lead over Wi-Fi. Looking at Forrester's figures, Bluetooth's lead in 2008 will come about solely because of its inclusion in phones.

2.5 Unstandardized Wireless Devices

A variety of commercially available wireless devices rely on unstandardized communication protocols. Most of these devices operate in the ISM radio frequency bands. Other than the operating frequency range of the devices hardly any further technical information is given. Thus in most cases no information about the time domain signal shape and transmitted power is available. Therefore, in order to be able to make statements about the exposure from these devices, the signal type and the transmitted power has to be analyzed and evaluated.

In the following a selection of different commonly used non-standard wireless devices is analyzed.

2.5.1 Baby surveillance devices

Within the range of so-called *baby phones* there are numerous devices on the market. Most operate without a specific communication standard. Hence the ISM radio frequency bands are often used for transmission. Additionally, in Europe a specific band for *baby phone* communication is defined at 864 MHz. Some devices use the Private Mobile Radio band at 446 MHz. Others are based on DECT technology.

A collection of several *baby phone* devices is given in Table XIII, showing the occupied frequency band together with the transmitting power and the distance coverage. In many cases no information on the transmitted power and the modulation scheme or the signal type of the particular devices is available. It is interesting that many devices are able to cover a relatively large range of reception. Furthermore, devices are available that not only provide acoustic but also visual information (e.g., Philips SBCSC490). These devices are likely to transmit at higher power levels. To reduce the electromagnetic exposure in stationary applications, some devices provide the capability to adjust the transmitting power manually. Furthermore, *baby phone* devices must be voice controlled, suppressing the carrier in idle mode.

***Babyphone* Type**	**f [MHz]**	**P (peak) [mW]**	**distance range [m]**
H&H MBF1010	27		400
Philips SC 363	40		150
Hama Baby-Control BC-433 Mobil	433		400
Vivanco BM 1000	446	100	1000
Vivanco BM 800	864	10	400
Philips SC477 DECT	1900	10	300
Philips SBCSC490	2400		300

Table XIII: *Babyphone* device overview.

2.5.2 Wireless PC Peripherals

Currently, Bluetooth is an upcoming technology in the fields of wireless PC peripherals. Further, there is a large variety of devices using proprietary wireless communication standards of which a selection is presented in Table XIV. None of the peripheral devices using proprietary standards provides a statement on the actual transmitting power in the data sheets. Hence it is evident that the communication signal has to be analyzed experimentally in order to be able to make statements about exposure caused by these devices.

Device Type	**f [MHz]**	**distance range [m]**
Wireless IntelliMouse Explorer	27	2
Logitech Cordless Desktop Pro	Mouse: 27.045 Keyboard: 27.145	2
Interlink Remote Point RF	433	30
Logitech Cordless Rumblepad 2	2400	5

Table XIV: PC wireless device overview

2.6 Future Technologies

2.6.1 HyperLAN/2

The HyperLAN/1 standard was introduced in 1998. However, technology operated according to the HyperLAN/1 standard could not establish any relevant market presence, therefore products are hardly to be found on the market. The HyperLAN/2 standard, introduced in 2000, offers several significant advantages compared to the standard IEEE802.11a, which uses the same frequency range (QoS, connection potential to Ethernet, UMTS, ATM, power save, security). HyperLAN/2 constitutes an attractive alternative to 802.11a, still it is not yet clear whether it will successfully compete with IEEE802.11a on a worldwide basis. A brief overview of the standard details of HyperLAN/2 is given in Table XV. However, HyperLAN/2 products are not yet available on the market. Moreover, in Switzerland there is still discussion over opening the bands 5.15-5.35 GHz / 200 mW EIRP and 5.47-5.725 GHz / 1000 mW EIRP for HyperLAN/2 (only 5.15-5.35 GHz in Switzerland).

2.6.2 Ultrawideband Technologies

Ultrawideband (UWB) is a future concept for wireless communications that is being developed now but is still far from completion. Unlike most standards of data transmission, which are

HyperLAN/2		
frequency (MHz)	5150-5350	5470-5725
no. of RF channels	8	11
channel bandwidth (MHz)	16.6	16.6
transmission technique	OFDM	OFDM
basic frame duration (ms)	2	2
modulation	PSK and QAM	PSK and QAM
typ. data rate (kbps)	<54	<54
max. power (mW)	200	1000
power control	yes	yes

Table XV: Characteristics of HyperLAN/2

narrow band, UWB uses bandwidth in the 100's of MHz. There are two radically different approaches to UWB currently adbocated by different standards groups:

a) an impulse based radio transmission, backed mainly by Freescale Semiconductor (ex-Motorola Semiconductors), and

b) a multiband-OFDM (Orthogonal Frequency Domain Multiple Accesss) based transmission format, backed by the MBOA (Multiband OFDM Alliance).

Both of these proposed standards work in the 3.1 to 10.1 GHz frequency range, in which the US FCC (United States Federal Communications Commission) has allowed wide-band transmissions to overlay existing narrow-band services as long as the as the energy transmitted by such an UWB device stays below -41 dBm/MHz. An impulse UWB transmitter emits short pulses of a special form which distributes all the energy of the pulse within the given, quite wide, spectral range (approximately from 3 GHz to 10 GHz). In impulse radio, data usually is encoded using pulse position modulation where the information bits are encoded into a specific time of the pulses relative to the reference clock. As a result, according to the FCC regulation, such a signal has a very low transmitted power of max. -10 dBm/GHz. Thus the maximum allowed transmit power is always lower than 1 mW. Below 3.1 GHz the signal almost disappears, i.e., its level is lower than -60 dBm. In Europe work towards a regulation is ongoing by the CEPT (European Conference of Postal and Telecommunications Administrations). From the exposure point of view, such impulse signals are very different from all classical radio transmission, especially due to the pulsed nature low frequency components have to be expected.

The second proposal for UWB radio is much more closely linked with the already existing format OFDM that is also used in the IEEE802.11a/g/h Wireless LAN standards. The proposal of the MBOA calls for dividing the spectrum between 3.1 and 10.1 GHz into several 500 MHz wide sub-bands. At any given instance in time, one of these sub-bands is used for transmitting a 500 MHz wide OFDM coded signal. To comply with FCC regulations, and to avoid interference by existing users, a multiband OFDM transmitter jumps from one band to the next for consecutive symbols. Therefore such a signal also contains properties of frequency hopping. The first implementation will use three bands between 3.1 and 4,7 GHz [MBOA website]. The maximum power allowed is of course the same as with impulse radio, i.e., about -14 dBm for a 500 MHz wide OFDM signal.

3 Exposure Assessment

The use of mobile and portable transmitting equipment continues to grow exponentially. In order to protect workers and the general public from exposure to radio-frequency (RF) electromagnetic radiation (EMR), most countries have regulations that limit personal exposure to RF fields. The regulations relevant for Switzerland are issued by the Swiss Federal Office of Public Health (BAG), which has adopted the regulations from the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [9]. Fixed stations are regulated under environmental law as defined in the Ordinance on Protection from Non-Ionising Radiation (NISV) [4]. This causes a very special situation, since fixed transmitters are differently regulated than portable and mobile transmitters. The tolerable incident field strengths are set 20 dB lower than for fixed transmitters. This is especially relevant for exposure from base stations versus indoor transmitters.

Devices used very close to the body are evaluated against the primary limits, namely limits defined in units of the specific absorption rate (SAR). For devices at distances larger than a wavelength, compliance can be evaluated against the derived limits or secondary limits. The derived limits are defined in terms of the incident magnetic and electric fields. The concept of the derived limits is such that if they are met then the primary limits are met under all circumstances. Since the derived limits are more conservative, in many cases compliance could still be demonstrated with respect to the primary limits, i.e., the SAR limits.

Measurement standards are available for far-field type conditions (e.g. EN50392 and IEC61983 [6]) as well as for transmitters operated at the ear, such as mobile phones, e.g., EN50360 [7] and EN50361 [10], IEC62209 Part I [2], IEEE1528 [3], etc. A standard for body-mounted devices IEC62209 Part II [1] will be completed before the end of 2007. Switzerland has issued guidelines for *in situ* measurements for fixed stations [8].

3.1 Theoretically Based Exposure Assessment

The space surrounding an antenna can be separated into 3 regions: the reactive near-field, radiating near-field (Fresnel region) and the far-field (Fraunhofer region). For most antennas it is very difficult to solve for the antenna fields everywhere in space. However, approximations can be made, especially for the far-field region, which is usually the one of most practical interest. The assumption for the plane wave condition, where the power flux density and the fields are straightforwardly related, is valid if the following condition is fulfilled:

$$r > \frac{2D^2}{\lambda}$$

whereby $D > \lambda$ is required [11]. D is the largest antenna dimension, λ is the wavelength in free space and r is the distance to the antenna. Under these conditions the relation between the electric field, magnetic field and power flux density is:

$$S = \frac{EH}{2} = \frac{E^2}{2Z_0}$$

where E is the electric field, H is the magnetic field, S is the power flux density and Z_0 is the wave impedance in free space. In the far-field the antenna can be approximated as a point source, and the related power flux density can be calculated as:

$$S = \frac{PG(\theta,\phi)}{4\pi r^2}$$

P is the power fed into the antenna, $G(\theta, \phi)$ is the antenna gain, which is normally a function of direction relative to the antenna.

Straightforward worst-case estimations are possible based on these simplified assumptions. They are an important instrument to demonstrate compliance.

Reliable theoretical assessments are not possible in the near-field. The near-field is the region of space immediately surrounding the antenna in which the reactive field components predominate and is also known as the reactive near-field region. The size of this region varies for different antennas. For most antennas, however, the outer limit is on the order of a few wavelengths or less. For the particular case of an electrically small dipole ($D << \lambda$), the reactive field predominates to a distance of approximately $\lambda/2\pi$. Beyond the reactive near-field region, the radiating field predominates.

3.2 Numerical Methods

The applicability of numerical methods for solving electromagnetic problems is continuously expanding due to the exponentially increasing processor power of computers. Large volumes of several cubic meters can be computed with high resolution within a reasonable amount of time. However, the uncertainties of exposure assessment are generally large to very large since the Device Under Test (DUT) needs to be modeled, i.e., simplified. Therefore, the precision and effort needed for testing compliance with measurements is often significantly better than with numerical methods. However, there are situations in which measurements are impossible, e.g., implants, trunk radios. In the following, the different currently applied methods are briefly discussed.

3.2.1 Finite-Difference Time-Domain Method

The finite-difference time-domain (FDTD) method for the solution of Maxwell's equations was originally proposed by K. S. Yee in 1966 [12]. The algorithm uses a finite-difference approximation of the first two of Maxwells equations. Yee's innovation is the particular arrangement of the field components in two staggered rectangular grids. One of these grids carries the components of the E-field vector, and the other one carries the components of the H-field vector. This arrangement yields a straightforward and accurate approximation of the rotational operator of the differential forms of Maxwell's equations. The time derivatives are calculated alternately on the E-field grid and on the H-field grid ("leap-frog scheme"). Thus, all derivatives are approximated with second order accuracy.

The FDTD algorithm is conditionally stable. The maximum possible time step to advance the fields in time is limited by the grid step size [13]. This means that a higher spatial resolution leads to a reduction of the time step, causing a superproportional increase of the computation time if fine geometrical details have to be rendered in the numerical model.

For the majority of applications of the FDTD algorithm, such as scattering or antenna problems and dosimetric applications, open or absorbing boundary conditions are needed to truncate the computational domain. This difficulty could not be satisfyingly overcome until the so-called perfectly matched layers (PML) absorbing boundary conditions were proposed by [14].

The simple, rectangular structure of the FDTD grid allows easy modelling of the complex anatomical structures which are used in numerical dosimetry. The material properties (permittivity, conductivity) must be assigned to the corresponding grid locations. The computational effort does not increase due to the details of a complex model. Nonuniform grids and subgrids allow local refinement of the computational domain only at locations at which high accuracy is required [15]. A detailed description of the method can be found in [16]. New developments allow an increase of the time step beyond the Courant limit, e.g., ADI-FDTD [17].

FDTD is the most powerful method for dosimetry. The most elaborated commercial code today is [18]. Other commercial codes also offer dosimetric features, such as [19], [20].

3.2.2 Method of Moments

The method of moments (MoM) is based on the numerical solution of Pocklington's integral equation for the current distribution on a perfect conductor. The conductor is discretized into separate segments. A base function with an unknown current amplitude is assigned to each segment. The base functions define the current along the segments. They can, e. g., have triangular shapes or can simply be constants. The electrical field can be calculated for the current distribution, which is set up by the basis functions with the unknown amplitudes, using the free space Green's function. The condition to solve the integral equation is the vanishing tangential electric field on the surface of the conducting segments. This leads to a system of equations to calculate the amplitudes of the basis functions, and in turn all currents and fields. For dielectric objects, special Green's functions can be used. This, however, is limited to comparatively simple structures. Complex geometries are modelled by triangular elements using the surface equivalence principle or the volume equivalence principle. For complex models such as a human body, the computational effort to solve the systems of equations can increase dramatically. The method of moments is therefore only used for the simulation of homogeneous models. A detailed description of the method is given in [21]. In [22], the integration of dielectrics into the integral equation is explained.

MoM is the most powerful method for estimation of the incident fields, although FDTD is becoming a serious competitor. Several commercial codes are available.

3.2.3 Generalized Multiple Multipole Method

For the solution of a boundary value or eigenvalue problem with the method of multiple multipoles (MMP), the field is separately developed into a series of basis functions in each homogeneous domain. Multipoles which represent the solution of the Helmholtz equation in spherical coordinates are most advantageous for the treatment of general three-dimensional problems. Matching points are defined on the boundaries of the homogeneous domains. On these points, all six constitutive relations for the electric and magnetic fields must be enforced. This leads to an overdetermined system of equations with the unknown amplitudes of the basis functions which is solved using least squares. A detailed description of the method is given in [23]. The main advantage of the MMP method is its efficiency and accuracy for spherical-like bodies. In particular the least square scheme implicitly allows the estimation of the numerical error. It was successfully applied in the late 80's for basic studies in exposure assessments and antenna design, e.g., [24]. The main disadvantage is that the resources and modeling complexity grow dramatically for more complex models. Nowadays the method is only used to generate reference solutions; the growing power of FDTD has made MMP largely obsolete in dosimetry.

3.2.4 Finite Elements

The finite element (FE) method represents the space or the geometry to be modelled in a triangulated mesh. For the elements of the mesh, linear or polynomial basis functions with unknown amplitudes are defined. The unknowns are assigned the field values in the nodes of the mesh. A variational method or the method of weighted residuals is used to set up a system of equations which is then solved by matrix inversion.

In electrodynamics, the method of finite elements is generally used in the frequency domain. Its applicability has long been restricted due to spurious unphysical solutions [25]. Further, open boundary conditions for the truncation of the computational domain were not without problems. Novel methods with edge elements assign the unknowns to the edges of the mesh and not to its nodes. These are completely free from spurious solutions [26]. Since the edges implicitly fulfill the boundary conditions on material interfaces, they are much better suited for the solution of problems with strongly inhomogeneous geometries. Improved absorbing boundary conditions which make use of the principle of perfectly matched layers have also been developed for the finite element method.

In spite of the significant effort needed to generate triangular meshes of complex anatomical structures, the finite element method is often used in numerical dosimetry and hyperthermia treatment planning (e.g., [27]). However, it lags behind the power of FDTD.

3.2.5 Hybrid Methods with Geometrical Optics

The only numerical methods which are capable of handling complex anatomical models (FDTD, FE) require discretization of the whole computational domain. For the simulation of exposure in the far field of a (base station) antenna, this can lead to a tremendous increase of the computational effort both in memory and in simulation time. Hybrid methods use, e. g., ray tracing methods (geometrical optics) or MoM to calculate the incident field at the location of the exposed user. Ray tracing methods are generally used to simulate the wave propagation of base stations in urban environments or inside buildings. In hybrid simulations of user exposure, absorption and scattering effects of the body do not interact with the source of the radiation. Hybrid methods are trendy but are greatly overestimated, due to the difficulties involved in generating easy-to-use graphical user interfaces.

3.3 Experimental Exposure Assessment

3.3.1 Exposure Measurement in the Far-Field of the Transmitter

The methods for far-field measurement which are available today can be categorized into broadband and frequency-selective methods. The pros and cons of these two methods are briefly discussed in the following.

Broadband measurements: Broadband electric field probes consist of three geometrically orthogonal dipoles, each of which is loaded by a diode. The non-linearity of the diode delivers a DC voltage which is proportional to E^2 below and proportional to E above the DC voltage of the diode's compression point. The response of each sensor is linearized and calibrated. The resulting total electric field value is calculated conservativly as

$$E = \sqrt{E_x^2 + E_y^2 + E_z^2}$$

The DC voltage is transmitted over RF-transparent highly resistive lines (usually several $k\Omega$/square). This measurement principle prevents the derivation of information on the frequency and phase. Broad-band probes for exposure assessment are therefore often tapered, such that the frequency response approximates the different E-field weighting of the standards. Examples of such survey probes are shown in Figure 12. High-spatial-resolution high-precision probes are built according to the same principles, the most advanced of which are shown in Figure 13. These probes enable highly accurate measurements but only when the spectral information is known. Electric field probes are currently available for the frequency range up to 50 GHz. Magnetic field probes are analogously constructed, whereby the electric dipoles are replaced by three orthogonal loops enabling measurements up to 3 GHz.

Figure 12: Typical broadband E-field and H-field probes and integrated amplifier and display unit (products from Narda Inc.)

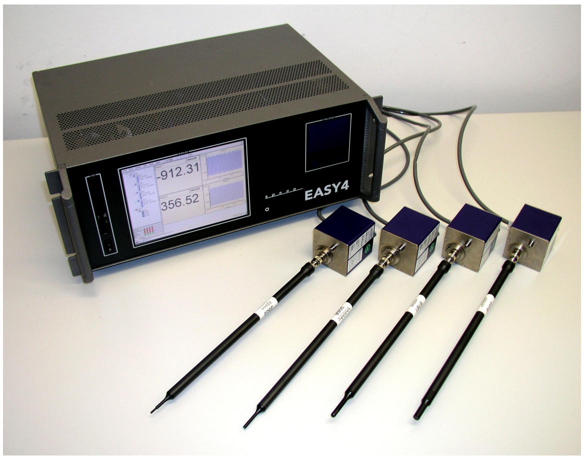


Figure 13: Probes with deviations from spherical isotropy of less than 0.3 dB and spatial resolutions of better than 1.2 mm are commercially available (product of SPEAG).

Frequency-Selective Measurements: Frequency-selective measurements are conducted with a calibrated receiving antenna combined with a spectrum analyzer. The benefit of this method is that it provides the spectral and phase information. The latter, however, is hardly used in exposure assessments. An examples of a broad-band antenna is shown in Figure 14; these probes were also used in this study (see Section 5). Frequency selective methods are necessary to determine the worst-case exposure from base stations by selectively measuring a channel of known power, e.g., the BCCH of GSM or the pilot channel for UMTS [8]. The same concept was applied in the following section in order to extrapolate worst-case exposures from home and office devices.

Figure 14: Broadband antenna (Product of ARCS Seibersdorf Austria)

3.3.2 Dosimetric Scanners

Several dosimetric scanners are commercially available. The principles and applications are described in [28] and [29]. The most advanced scanner with a market share of over 90% is shown in Figure 15. This scanner is compatible with all guidelines for testing transmitters operated at the ear (e.g., EN50360 [7], IEEE1528 [3], IEC62209 Part I [2]) but also with the latest draft of IEC62209 Part II [1] which provides the guidelines for testing body-mounted devices and devices operating within 200 mm from the body. The latter has an extended frequency range from 30 MHZ to 6 GHz. The DASY4 system was also used to conduct the dosimetric evaluation of Section 5, following the concept of IEC62209 Part I [2].

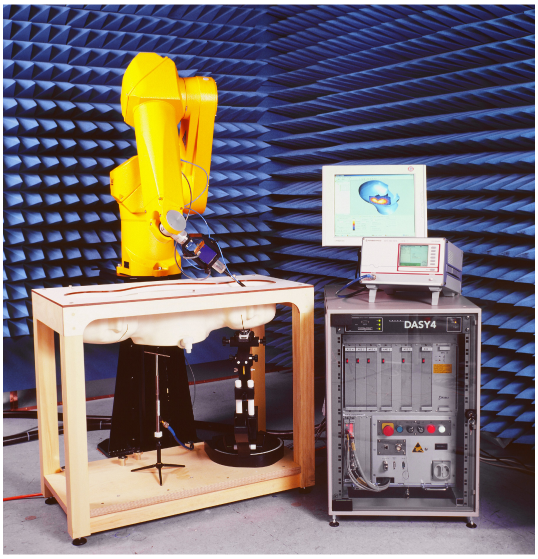


Figure 15: DASY4 (Schmid and Partner Engineering AG [28]) enables doimetric measurements according to all standards worldwide. This scanner was also applied in this study.

4 Literature Review of Exposure Assessment Studies

Most of the publications in recent years regarding the absorption of electromagnetic radiation in the near-field of antennas deal with the dosimetry of mobile phones. A review on this is given in [30], [31]. Today, dosimetric evaluation of mobile phones is a standard procedure for device authorization. The spatial peak SAR values are also made publicly available by the manufacturers or authorities, e.g., FCC.

Much less information can be found about the exposure from short-range wireless devices. The results of the few reports are summarized in the following:

- A study conducted by the Nova Institute in Germany reports on the measurement of exposure by the WLAN infrastructure in rooms of the University of Bremen (http://www.nova-institut.de, Ref.): Far-field measurements with a biconical antenna and a dipole antenna coupled to a spectrum analyzer at different distances from the radiators (base stations as well as PC cards in laptops) provided exposure values far below the German limits ($10\,W/m^2$ according to 26. BlmSchV). The highest power density at work places was 0.03% of the limit for access points (no distance indication) and 1.6% of the limit for a laptop PC card (20 cm distance). A comparative measurement with a DECT base station is also reported where a maximum value of $0.17\,W/m^2$ was seen (distance 40 cm), which corresponds to 1.8 % of the limits ($9.5W/m^2$ according to 26. BlmSchV). The Nova Institute also performed measurements of UKW radio exposure and GSM exposure, of which the power density was in the same order of magnitude or less. The exposure of each source was in every case not more than 0.04% of the limits.

- Another study conducted by the Austrian Research Center Seibersdorf, Austria, reports on exposure measurements from a notebook with integrated WLAN module (IEEE802.11b). The maximum power of the antenna, integrated into the upper edge of the diplay, was 39.5 mW. Measurements at 6 cm distance from the notebook resulted in a power density of 5% of the corresponding limit. A SAR measurement with a homogeneous body phantom according to the standard EN 50383 resulted in 0.06 W/kg (10 g average), which is 3% of the corresponding limit (2 W/kg).

- A study from the University of Zagreb reports on far-field measurements of DECT signals with a tuned dipole antenna connected to a spectrum analyzer [32]. Field exposure measurements at different distances (1.5 m, 4.5 m, 5.5 m) from the DECT base station and with the base station behind a wall are reported. The maximum detected value was $0.76\,mW/m^2$, which is far below the considered limit ($12.6W/m^2$).

- A study from Ericsson Research Department deals with the SAR testing of wireless devices with simultaneous transmission in multiple bands [33]. The approach of their test procedure was to measure SAR for the transmitters in the device separately, add the measured SAR distributions and then calculate the 1g and 10g mass averaged SAR from the resulting distribution. They have tested a GSM mobile phone (1800 MHz, 1W peak power) with an integrated long-range Bluetooth transmitter (2450 MHz, 100 mW peak power). The device was tested on a SAM phantom filled with tissue simulating liquid. The results show that the evaluated multi-band averaged SAR values were slightly lower than those resulting from adding the separate maximum SAR values for each frequency band. The authors comment this as being due to a SAR maxima separation (2 cm) of the two distributions and an averaging 10g cube of 2.15 cm. Absolute SAR values cannot be extracted from the paper.

In summary, very little information has been published on short-range indoor communication devices. Furthermore, the studies were conducted such that no general conclusions can be derived. The objective of the next chapter is to close this gap.

5 Experimental Exposure Assessment

5.1 Free Space Measurement Setup

Devices not commonly used close to the human body have been tested by means of their electric field over distance. The measurement setup used to conduct these experiments is described in the following.

The measurements were carried out in a semi-anechoic chamber. The dimensions of the chamber are 4 m x 3 m x 2.9 m (L x W x H). The devices under test were mounted about 40 cm in front of the horizontal center position of the shorter side wall about 80 cm above the chamber floor. The walls of the chamber are entirely equipped with pyramidal absorbers providing a reflectivity below -20 dB over the considered frequency range. However behind the device under test an area with the dimension 1.22 m x 1.22 m was not covered. This configuration was chosen to ensure a worst-case field distribution by including also the reflected field. A tripod was used as the main carrier of the measurement antenna. The antenna was mounted on a cantilever. The other end of the cantilever was mounted on the pivotal point of the tripod. With the pivotal point located below the center of the transmitting antenna, reproducible and sound azimuthal scans around the antenna are possible. To perform elevation scans, the device under test was transformed appropriately by rotation. With such a setup it is possible to identify the antenna main beam of the device. The main beam direction is necessary for a worst-case assessment. Two E-field scans in the azimuth and elevation with the DUT's antenna at the center position were performed in a distance of 20 cm. From the scans the maxima were determined. Afterwards the orientation of the DUT was transformed such that the previously determined maxima are both located on the azimuthal scanning circle. A third scan in the azimuthal direction between the two maxima was carried out to identify the antenna main beam. A photograph of the free space measurement setup is shown in Figure 16. Subsequently, in the direction of the main beam radial distance measurements of the E-field were carried out through outward movement of the tripod.

For E-field measurements at distances above 20 cm and an operating frequency range from 80 MHz to 2500 MHz, a Rohde & Schwarz FSP spectrum analyzer together with a precision conical antenna (PCD8250, ARC Seibersdorf, Austria) were used. To ensure the measurement of the entire E-field, measurements in horizontal and vertical orientation of the antenna were superimposed (a radial field component was not assumed). For measurement situations smaller than the previously defined minimum distance of 20 cm, miniature broadband E-field probes together with the EASY4 (Schmid and Partner Engineering, Switzerland) exposure acquisition system were used. In contrast to measurements with broadband field probes the measurements using the spectrum analyzer were carried out frequency-selective, and the time-domain signal power of the considered band was averaged over time. Based on this the actual time averaged E-field was derived. A summary of the free space measurement setup parameters is given in Table XVI for the far-field measuring system and in Table XVII for the near-field measuring system. The uncertainties for the far-field and near-field measuring setups in air are given in Table XVIII and XIX, respectively. The uncertainties were determined according to [34], [35] and [36].

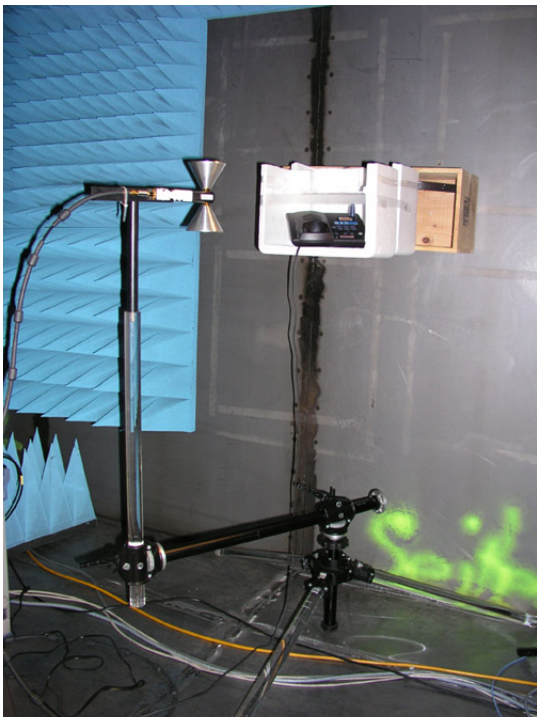


Figure 16: Far-field measurement setup

Spectrum Analyzer	Type:	Rohde & Schwarz FSP 9 kHz...30 GHz
	Software:	Firmware V1.20
	Manufacturer:	Rohde & Schwarz (D)
Attenuator	Type:	VAT-10
	Manufacturer:	Mini Circuits (USA)
Cable	Type:	RG142
	Serial No:	K171/02
	Calibrated on:	April 2002
	Manufacturer:	ARC Seibersdorf (A)
Antenna	Type:	PCD 8250
	Serial Number:	3158/02
	Calibrated on:	April 2002
	Manufacturer:	ARC Seibersdorf (A)

Table XVI: Far-field measurement system

System	Type:	EASY4-1
	Software:	EASY4, V4.1.13
Data Acquisition System	Type:	DAE3
	Serial No:	355
	Calibrated on:	March 2004
	Manufacturer:	Schmid & Partner Engineering AG (CH)
Probe	Type:	ER3DV6
	Serial Number:	2316
	Manufacturer:	Schmid & Partner Engineering AG (CH)
	Calibrated on:	October 2003
	Tip Diameter:	8 mm
	Frequency Range:	100 to 3000 MHz
	Dynamic Range:	2 V/m to $\geq$ 1000 V/m
	Dev. Axial Isotropy:	$\leq \pm 0.2$ dB (30 to 2500 MHz)
	Dev. Spherical Isotropy:	$\leq \pm 0.4$ dB
	Calibration Uncertainty:	±6.0% (k=2)

Table XVII: Near-field measurement system

Error Description	Uncertainty value ± %	Probability distribution	Divisor	(c_i)	Std. unc.	$(v_i)^2$ or v_{eff}
Measurement Equipment						
Antenna Factor Cal.	±25.9 %	normal (k=2)	2	1	±13 %	∞
Cable Loss Cal.	±1.8 %	normal (k=2)	2	1	±0.9 %	∞
Attenuator Cal.	±7.2 %	rectang.	$\sqrt{3}$	1	±4.2 %	∞
Receiver Spec.	±6.4 %	normal (k=2)	2	1	±3.2 %	∞
Mismatch	±9.4 %	rectang.	$\sqrt{2}$	1	±6.6 %	∞
Setup						
Antenna Positioning	±8.1 %	rectang.	$\sqrt{3}$	1	±4.7 %	∞
Power Drift	±5.0 %	rectang.	$\sqrt{3}$	1	±0.6 %	∞
Combined Std. Uncertainty					**±16.2 %**	
Coverage Factor for 95%		**kp=2**				
Expanded Std. Uncertainty					**±32.4 %**	

Table XVIII: Uncertainty budget of the far-field measurement setup

Error Description	Uncertainty value ± %	Probability distribution	Divisor	(c_i)	Std. unc.	$(v_i)^2$ or v_{eff}
Measurement Equipment						
Probe calibration	±2.0 %	normal	1	1	±3.0 %	∞
Axial isotropy of the probe	±4.5 %	rectang.	$\sqrt{3}$	1	±2.6 %	∞
Spherical isotropy of the probe	±9.6 %	rectang.	$\sqrt{3}$	0.7	±3.9 %	∞
Probe linearity	±4.7 %	rectang.	$\sqrt{3}$	1	±2.7 %	∞
Readout electronics	±1.0 %	normal	1	1	±1.0 %	∞
Integration time	±2.6 %	rectang.	$\sqrt{3}$	1	±1.5 %	∞
Response time	±0.8 %	rectang.	$\sqrt{3}$	1	±0.5 %	∞
Setup						
Probe Positioning	±11.1 %	rectang.	$\sqrt{3}$	1	±6.4 %	∞
Power Drift	±5.0 %	rectang.	$\sqrt{3}$	1	±0.6 %	∞
RF Ambient Conditions	±3.0 %	rectang.	$\sqrt{3}$	1	±1.7 %	∞
Combined Std. Uncertainty					**±9.0 %**	
Coverage Factor for 95%		**kp=2**				
Expanded Std. Uncertainty					**±18.0 %**	

Table XIX: Uncertainty budget of the near-field measurements

5.2 Measurement Setup for Dosimetry

The dosimetric measurements were also carried out in a semi-anechoic chamber. The Specific Absorption Rate (SAR) was determined using a SPEAG DASY4 system. In Table XX the parameters of the dosimetric measuring system are shown.

The particular electrical parameters of the tissue simulating liquids used for dosimetric evaluation are given within the following subsections.

The preliminary uncertainty budget has been determined for the DASY4 measurement system according to Clause 7 of CENELEC EN 50361[10] (see Table XXI).

System	Type:	DASY4professional
	Software:	DASY4, V4.4 Build3; SEMCAD, V1.8 Build 1.30
Positioner	Robot:	RX90L
	Serial No:	F99/5A80A1/A/02
	Range:	1185 mm
	Repeatability:	±0.025 mm
	Controller:	CS7MB
	Serial No:	F99/5A80A1/A/02
	Manufacturer:	Stäubli France
Phantom	Type	TWIN SAM v4.0
	Dimensions:	Length: 1000 mm; Width: 500
	Shell Thickness:	2 ± 0.2 mm; Center ear point: 6 ± 0.2 mm
	Filling Volume	Approx. 25 l
	Manufacturer:	Schmid & Partner Engineering AG (CH)
Data Acquisition System	Type:	DAE3
	Serial No:	355
	Calibrated on:	March 2004
	Manufacturer:	Schmid & Partner Engineering AG (CH)
Probe	Type:	ET3DV6
	Serial Number:	1680
	Manufacturer:	Schmid & Partner Engineering AG (CH)
	Calibrated on:	February 2004
	Tip Diameter:	6.8 mm
	Frequency Range:	10 to 3000 MHz
	Dynamic Range:	5 μW/g to $\geq$ 100 mW/g
	Dev. Axial Isotropy:	$\leq \pm 0.2$ dB (30 to 2500 MHz)
	Dev. Spherical Isotropy:	$\leq \pm 0.4$ dB
	Calibration Uncertainty:	±9.7% (k=2)

Table XX: Dosimetric measurement system

Error Description	Uncertainty value ± %	Probability distribution	Divisor	$(c_i)^1$ 10g	Std. unc. (10g)	$(v_i)^2$ or v_{eff}
Measurement Equipment						
Probe calibration	±4.8 %	normal	1	1	±4.8 %	∞
Axial isotropy of the probe	±4.7 %	rectang.	$\sqrt{3}$	0.7	±1.9 %	∞
Spherical isotropy of the probe	±9.6 %	rectang.	$\sqrt{3}$	0.7	±3.9 %	∞
Probe linearity	±4.7 %	rectang.	$\sqrt{3}$	1	±2.7 %	∞
Detection limit	±1.0 %	rectang.	$\sqrt{3}$	1	±0.6 %	∞
Boundary effects	±1.0 %	rectang.	$\sqrt{3}$	1	±0.6 %	∞
Readout electronics	±1.0 %	normal	1	1	±1.0 %	∞
Response time	±0.8 %	normal	1	1	±0.8 %	∞
Noise	±0 %	normal	1	1	±0 %	∞
Integration time	±2.6 %	normal	1	1	±2.6 %	∞
Mechanical Constraints						
Scanning system	±0.4 %	rectang.	$\sqrt{3}$	1	±0.2 %	∞
Phantom shell	±4.0 %	rectang.	$\sqrt{3}$	1	±2.3 %	∞
Probe positioning	±2.9 %	rectang.	$\sqrt{3}$	1	±1.7 %	∞
Device positioning	±2.9 %	normal	1	1	±2.9 %	145
Physical Parameters						
Liquid conductivity (target)	±5.0 %	rectang.	$\sqrt{3}$	0.5	±1.4 %	∞
Liquid conductivity (meas.)	±4.3 %	rectang.	$\sqrt{3}$	0.5	±1.2 %	∞
Liquid permittivity (target)	±5.0 %	rectang.	$\sqrt{3}$	0.5	±1.4 %	∞
Liquid permittivity (meas.)	±4.3 %	rectang.	$\sqrt{3}$	0.5	±1.2 %	∞
Power drift	±5.0 %	rectang.	$\sqrt{3}$	1	±2.9 %	∞
RF ambient conditions	±3.0 %	rectang.	$\sqrt{3}$	1	±1.7 %	∞
Post-Processing						
Extrap. and integration	±5.4 %	rectang.	$\sqrt{3}$	1	±3.1 %	∞
Combined Std. Uncertainty					**±10.2 %**	18125
Coverage Factor for 95%		**kp=2**				
Expanded Std. Uncertainty					**±20.4 %**	

Table XXI: Uncertainty Budget of DASY4

5.3 DECT Devices

Fixed Part: To evaluate the exposure due to the electromagnetic field of DECT base stations, the distance dependence of the E-field of three DECT base stations was determined.

The antenna main beam was identified; the E-field was then measured in the main beam direction over distance.

During the measurements the base station was in idle mode. To ensure this operational mode, the length and the frequency of the DECT TDMA bursts were determined. The measured E-fields in idle mode are given in Figure 17. These measured field values do not represent the worst-case field values. Hence the measured E-field was projected to the case where the maximum amount of downlink slots are in use and double slot length is assumed for every second slot. From the duty cycle in idle mode a factor of 10.4 ($E_{max} = \sqrt{10368bit/96bit} \cdot E_{idle}$) follows for the calculation of the maximum E-field. The resulting values of this case are given in Figure 18. DECT devices are mostly used as cordless phones. Here, asymmetric and double slot data transmission as discussed above is not applied; therefore it is also valuable to discuss the fields of a fixed part during a normal phone call. Assuming a voice connection with one portable part an extrapolation factor of 2.1 has to be applied with regard to the fields in idle mode ($E_{singlecall} = \sqrt{424bit/96bit} \cdot E_{idle}$). Figure 19 displays the resulting E-fields by a base station during a single telephone call.

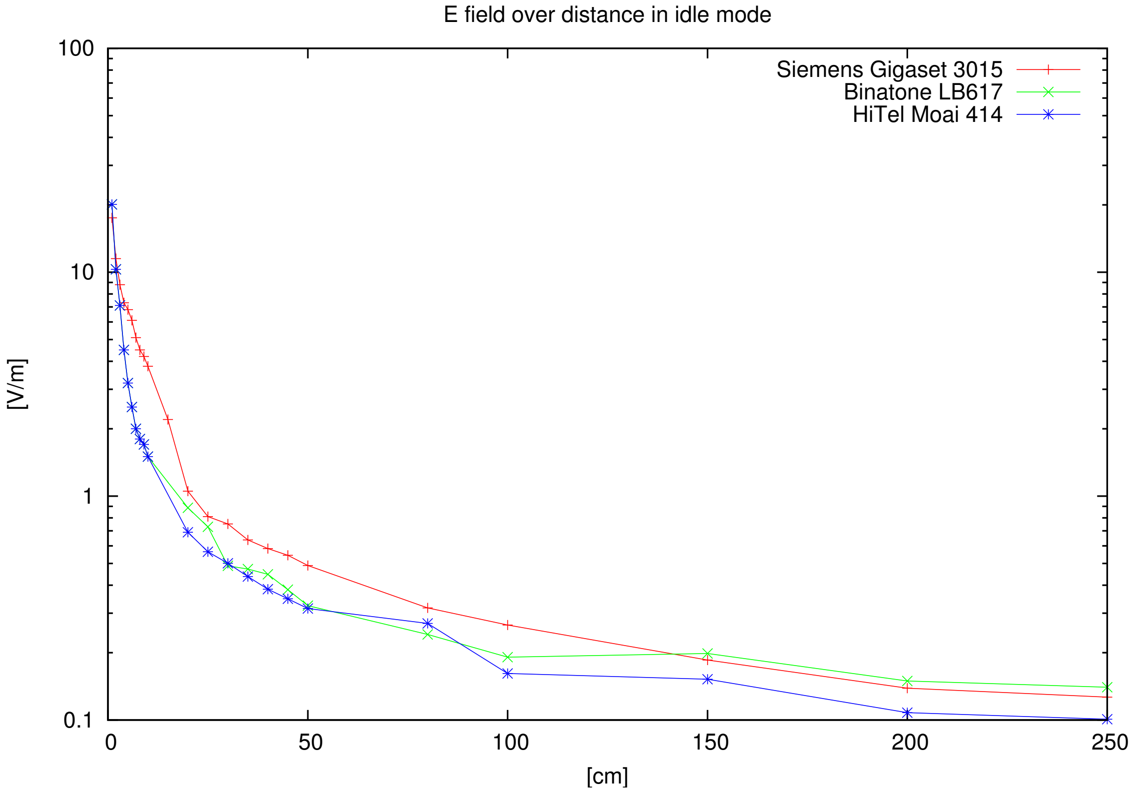


Figure 17: E-field distributions of three DECT base stations in idle mode over distance in the antenna main beam

In [9, page 511] the ICNIRP reference levels for general public exposure to time-varying electric and magnetic fields are defined. For the DECT frequency range a maximum E-field of 60 V/m

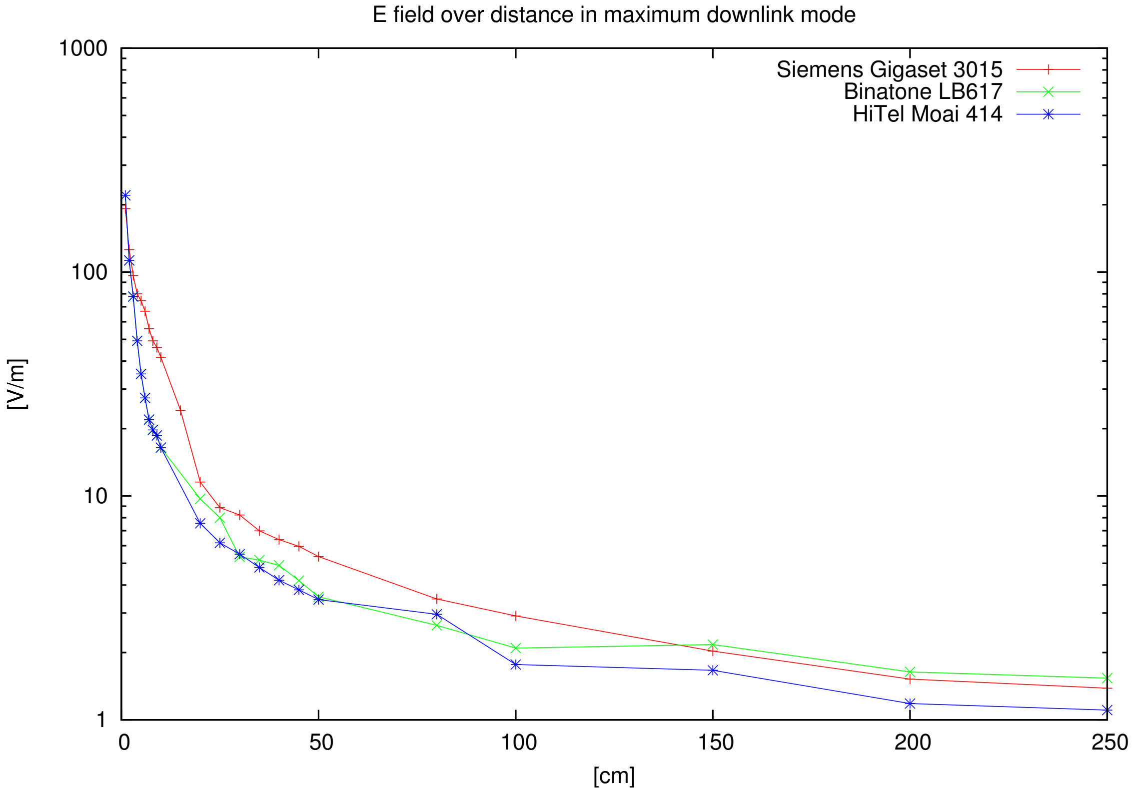


Figure 18: Maximum E-field distributions (extrapolated) of three DECT base stations over distance in the antenna main beam

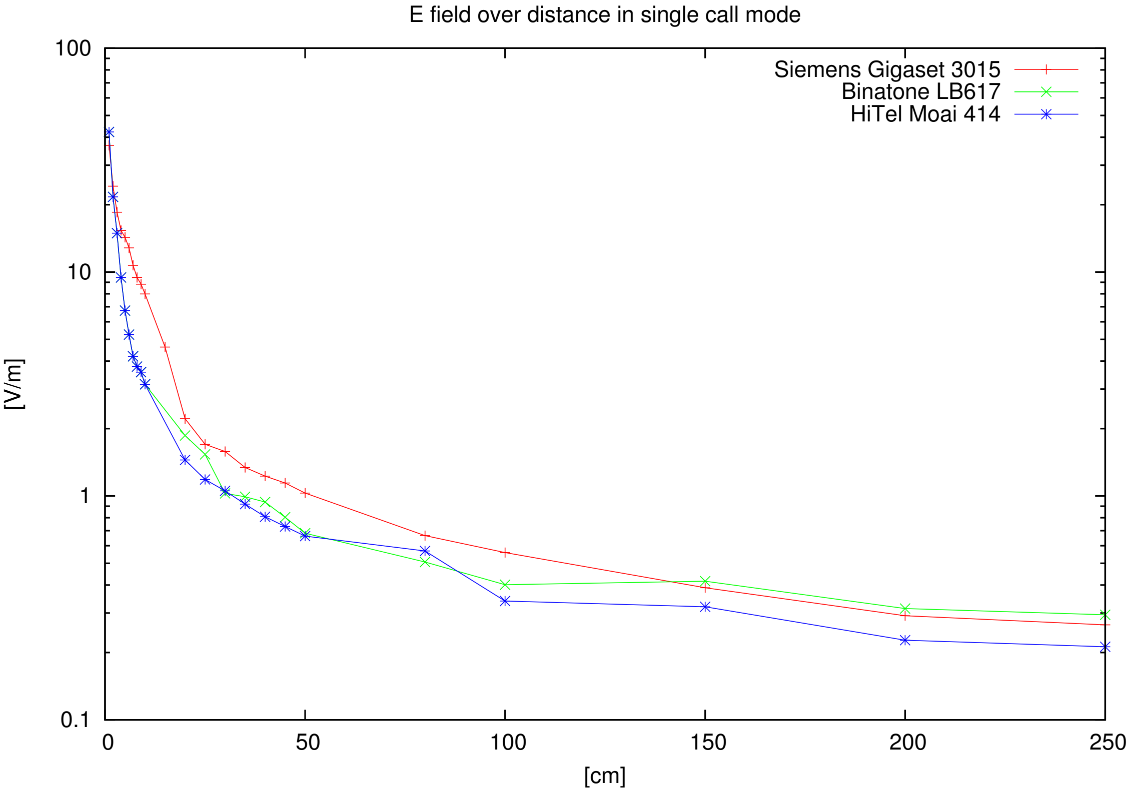


Figure 19: E-field distributions (extrapolated) of three DECT base stations in single call mode over distance in the antenna main beam

is recommended. The measured and projected maximum E fields for the single call mode are entirely below this level. Only close to the transmitting antennas of DECT base stations in office environments, the recommended limit may be exceeded as shown in Figure 18. However, at such small distances to the transmitting antenna the probing antenna is in the near-field. Since for the DECT base stations a far-field cannot be assumed below 4 cm, distance such a case should be evaluated in terms of a SAR measurement.

Portable Part: In Section 6 of the standard EN 50360 [7] states: “if the average power emitted by the mobile phone is less than or equal to 20 mW, then the mobile phone is deemed to comply with the basic restrictions without testing”. DECT cordless phones have a maximum average power of 10 mW (see Table IV); consequently, they comply with the basic restrictions.

In addition to that we verified the compliance of DECT telephones by SAR measurement. The DECT handsets were tested according to IEEE1528 [3]. IT'IS has evaluated four DECT handsets in accordance with the requirements for compliance testing defined in CENELEC EN50360 [7].

During measurement, the DECT handsets were operated against their particular base station. Thus the communication channel was not adjustable but chosen by the base station. IEEE1528 requires a SAR analysis in defined channels within the communication technology's frequency band. However with an overall bandwidth to operating frequency ratio of about 1%, the SAR values are not likely to vary extremely over the possible frequency range. The activity of the transmission was monitored using a spectrum analyzer and a broadband antenna. A head simulating liquid providing the electrical parameters of human head tissue at the DECT operating frequency range was used. The electrical parameters of this tissue simulating liquid are summarized in Table XXII.

Frequency	ϵ_r	σ
1880 MHz	39.74	1.45
1900 MHz	39.84	1.46

Table XXII: Head simulating liquid electrical parameters for the DECT frequency range (23° C)

Due to very low measured electric field values in the 3-D scans, the measured data for the Ascom Avena and the Siemens 2000C handsets was incorporated by noise. The normal extrapolation algorithm applied to noisy measurement data for SAR evaluation may lead to incorrect and amplified values. Therefore, the estimation algorithm described in [37] was applied to the surface scan data for these two handsets. The maximum spatial peak SAR values for the DECT handsets averaged over 1 g and 10 g cubes are displayed in Table XXIII.

	right hand				left hand			
	cheek		tilt		cheek		tilt	
	1g [mW/g]	10g	1g	10g	1g	10g	1g	10g
Ascom Avena	0.023	0.014	0.018	0.011	0.017	0.019	0.022	0.013
Siemens 2000C	0.016	0.00986	0.013	0.00794	0.019	0.011	0.013	0.00804
Siemens 3015	0.087	0.052	0.058	0.035	0.078	0.047	0.06	0.036
Swisscom R106	0.047	0.027	0.037	0.021	0.039	0.023	0.037	0.022

Table XXIII: 1g and 10g average SAR of DECT handsets in different positions

From the measurement results a relatively broad range of Specific Absorption Rates can be identified. Two reasons could explain this finding. The average output power of DECT handsets can be less than 10 mW ([38]). Additionally, in contrast to, for example, GSM cellular phones, DECT handsets are in general of larger size. Consequently, the position of the transmitting antenna can significantly vary in relation to the phantom head.

In conclusion, the tested devices were found to be in compliance with the requirements of EN50360 [7] and [3].

5.4 WLAN Devices

E-Field Measurement in Air: For wireless LAN access points the E-field distribution over distance in the particular antenna's main beam was measured. Again, measurement was carried out in a semi-anechoic chamber. During measurement the access point was mounted in the same position as previously described.

The tested access points were operated in IEEE 802.11b mode. To provide a worst-case E-field situation, the base station was operated at maximum output power and with a maximum data rate. The maximum transmitted data was ensured by setting up a UDP (User Datagram Protocol) connection and streaming artificial data at a rate above the maximum data rate provided by the access point. The access point was thus operated at maximum time averaged output power. WLAN devices may adjust the type of modulation according to the channel quality. Therefore the quality of the transmission channel was manipulated by operating the sender and receiver at different distances to each other. Dependence of the output power level in relation to distance was not detected for the devices under test. Starting from the point of maximum E-field the field intensity was measured using isotropic broadband E-field probes up to a distance of 20 cm. For distances larger than 20 cm the E-field, was measured using the PCD8250 conical antenna and a spectrum analyzer. Again, the E-fields measured in horizontal and vertical polarizations were superimposed. Using the spectrum analyzer, the average power in the 22 MHz band was measured. The access points were set to operate at channel 5; this results in an operating frequency range from 2421 MHz to 2443 MHz. Due to the relatively large bandwidth, the maximum antenna factor and the maximum cable attenuation must be used to calculate a worst-case determination of the E-field. The corresponding E-fields measured over distance are displayed in Figure 20. In summary both WLAN base stations comply with the 61 V/m limit for uncontrolled (public) exposure recommended by the ICNIRP guideline [9].

Dosimetric Evaluation: WLAN network interface cards or built-in solutions are an increasing method of accessing networks from portable computers. Therefore a SAR evaluation of the WLAN communication system is necessary for this study.

However, instead of WLAN network interfaces WLAN access points were used for dosimetric evaluation. Typically, WLAN network interfaces are built into a notebook. Such systems are difficult to position on the phantom. In general the WLAN modules on a network interface and a WLAN access point should not differ widely. Therefore WLAN access points can also be used to assess the WLAN communication system dosimetrically.

The measurement setup and its parameters for the dosimetric evaluation of WLAN base stations is described in Section 5.2. Portable computers are generally not used in the proximity of the human head but are rather placed on the human lap. Therefore a tissue simulating liquid providing the electrical parameters of human muscle tissue was chosen. The corresponding liquid parameters for the WLAN operating frequency range (WLAN channel 5 / 2419.5 MHz to 2444.5 MHz) are displayed in Table XXIV. Figure 21 displays the setup used for dosimetric measurement of the SMC access point.

During dosimetric measurement the devices were operated in the same manner as for free field

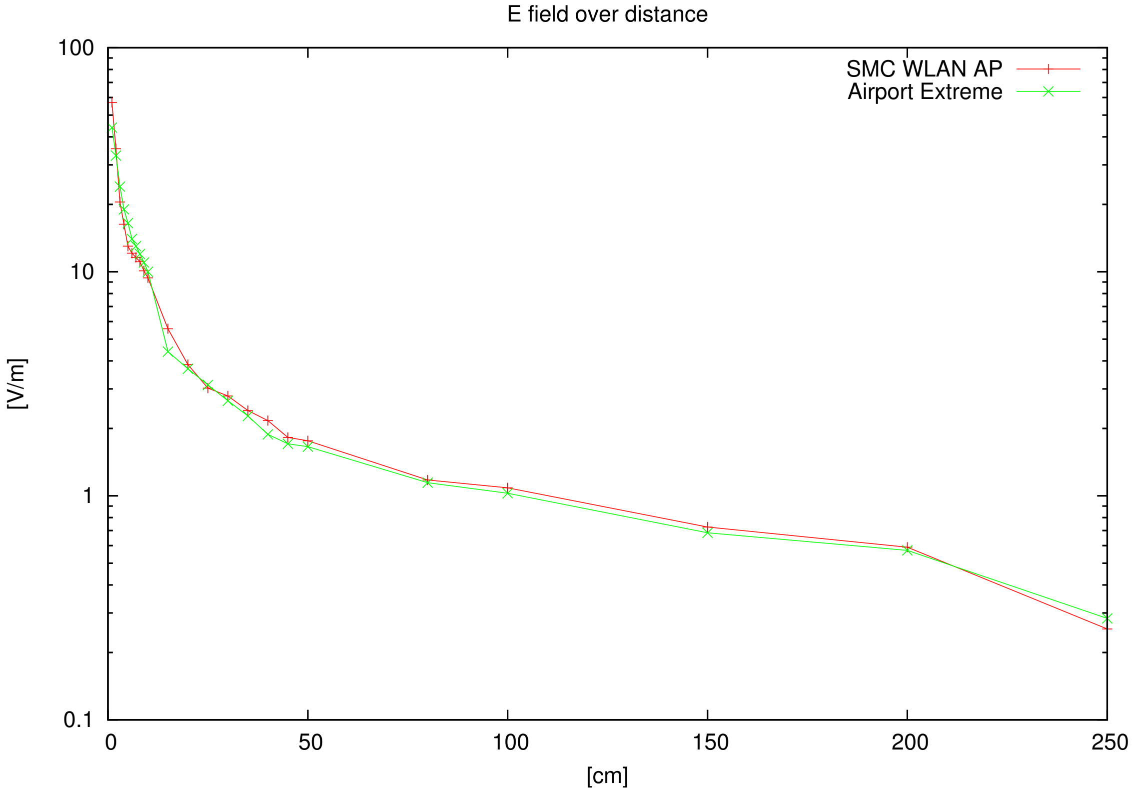


Figure 20: E-field distributions of WLAN access points over distance in the antenna main beam

Frequency	ϵ_r	σ
2400 MHz	50.77	1.868
2450 MHz	50.66	1.936

Table XXIV: Muscle simulating liquid electrical parameters for the WLAN frequency range (23.5° C)

Figure 21: Dosimetric measurement setup for the SMC access point

measurements. Consequently, the highest available time averaged output power of the devices can be assumed. For determination of the maximum SAR, the devices must be measured in different positions. However, a measurement of the devices in every possible position often would be very time consuming. Hence the devices were positioned with the transmitting antenna near the phantom surface. Additionally, the previously determined antenna main beam was taken into account, such that the antenna main beam pointed inside the phantom. The acquired maximum SAR values are summarized in Table XXV. For the Apple Airport Express access point the location of the antenna and its main beam was not previously determined. Therefore this devices was tested with all possible surfaces touching the phantom surface. The dosimetric measurement was carried out in the flat region of the phantom with a shell thickness of 2mm. From Table XXV it is obvious that for the SMC access point a much higher maximum SAR was determined than for the Apple access points. This is due to the fact that the Apple access points are equipped with built-in antennas while the SMC access point is equipped with an external antenna. During the measurement the external antenna touched the phantom surface. Hence in addition to measurement with the antenna of the SMC access point touching the phantom shell, the SAR for this device was measured at distances of 2 cm and 5 cm displaced from the phantom shell. These results are summarized in Table XXVI. As expected, the SAR value of the SMC access point at a distance of 2 cm is similar to that of the Apple Airport Extreme. Furthermore, this measurement gives information about the SAR to be expected if the transmitter is not directly touching the human body. In summary the measured WLAN access points comply with EN50360 [7]. However, the maximum determined 10g average SAR of 0.81 mW/g is relatively high in relation to the recommended exposure limit of 2 mW/g for the head and trunk [39]. Additionally, it should be mentioned that the manner of usage for WLAN devices is completely different than, e.g., for cellular phones. Much longer exposure duration must be expected for WLAN devices. However, the determined SAR values for WLAN devices also represent a worst-case situation. During normal usage the time averaged transfer rate will be lower than applied during the measurements. Consequently, this results in a lower time averaged output power and in a directly proportionally lower time averaged SAR.

	maximum SAR	
Device	1g [mW/g]	10g [mW/g]
SMC access point	1,93	0,81
Apple Airport Extreme	0,11	0,06
Apple Airport Express	0,52	0,19

Table XXV: maximum SAR of different WLAN access points

	SAR	
Distance to phantom surface	1g [mW/g]	10g [mW/g]
0 cm	1,93	0,81
2 cm	0,15	0,09
5 cm	0,05	0,03

Table XXVI: SAR of the SMC access point over distance

5.5 Bluetooth

Exposure by Bluetooth devices was determined in the far-field by E-field measurements in air as well as by dosimetric measurements in tissue simulation liquid.

E-Field Measurement in Air: E-field measurements in air were carried out to assess the exposition by the particular device in the far-field. For far-field measurement a class I device and a class II device were selected. These two power classes are likely to produce the highest E-fields in the far-field. Two Bluetooth USB dongles were chosen for free field investigation. The two dongle devices were set up to operate as network interfaces on two personal computers (PC's). To provide a worst-case E-field situation the dongle under experimental investigation was operated at maximum output power and with a maximum data rate. The maximum possible transmitted data was ensured by setting up a UDP (User Datagram Protocol) connection and streaming artificial data at a rate above the maximum data rate provided by the dongle. The actually transmitted data rate was monitored to exclude measuring errors with the near-field probe due to data rates below maximum.

Since Bluetooth is a broadband based technology, it was not possible to cover the complete spectrum with the given measurement equipment. Additionally, the time averaged power inside a particular 1 MHz Bluetooth channel is near the measurement system noise level. Therefore the averaged 625 μs slot power was determined over 1000 slots inside a single Bluetooth channel (channel 1 at 2402 MHz) in the time domain. The slot average power is 2.8 dB lower than the slot peak power in that particular channel. In contrast to the average slot power the peak power is not dependent on the actual package lengths. The slot power over 1000 measurements showed a standard deviation of 1.01 dB and the peak power a standard deviation of 0.1 dB. Later only the peak power is determined experimentally over distance. The method described above is used to deduce the E-field from the slot peak power.

The highest time averaged output power for Bluetooth is achieved in asynchronous data channel mode with an asymmetric transmission (721kBit/s uplink, 57.6kBit/s downlink). Consequently, the time averaged slot power equals the time averaged channel power. Hence the time averaged uplink power can be extrapolated from the time averaged channel power by taking the uplink to downlink ratio into account. This results in the uplink power being 0.33 dB below the entire channel power. The thus determined and extrapolated E-field distributions over distance in asynchronous transmission mode are displayed in Figure 22. From the Figure a significant difference in the emitted E-fields between the Acer Dongle (Power Class II) and the Mitsumi Dongle (Power Class I) can easily be identified.

Both Bluetooth USB dongles comply with the 61 V/m limit for uncontrolled (public) exposure recommended by the ICNIRP guidelines [9].

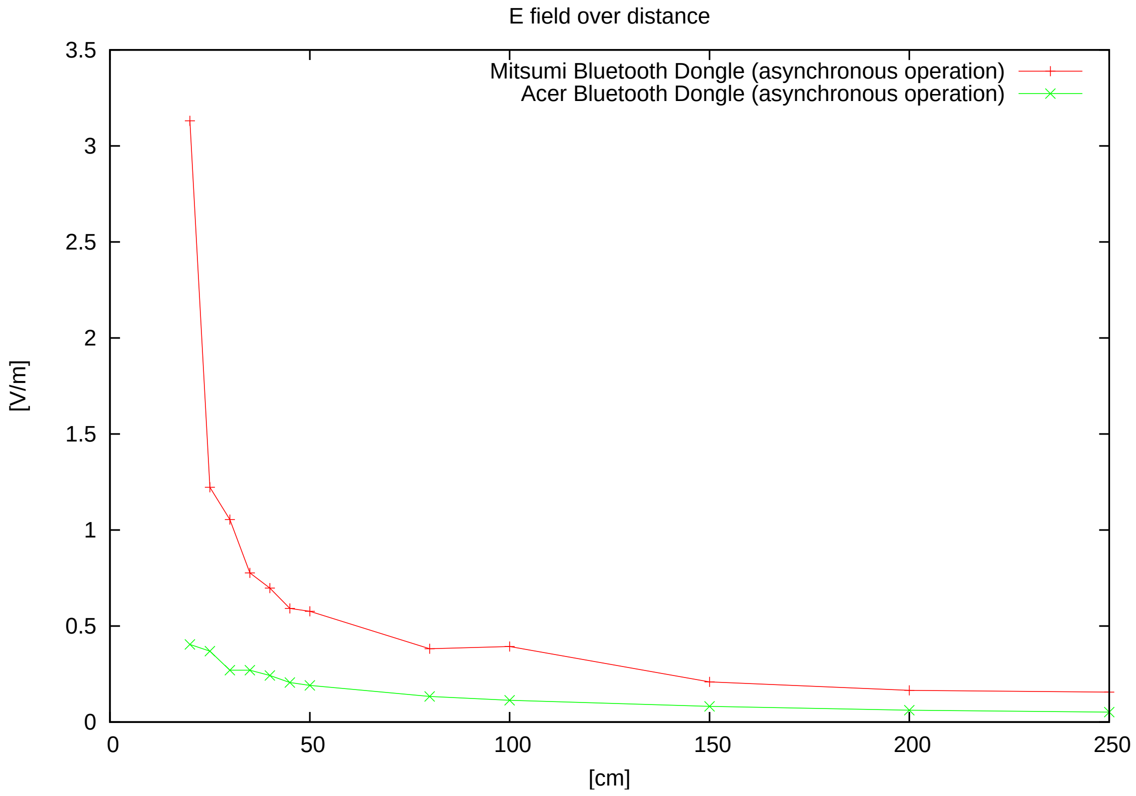


Figure 22: E-field over distance of Bluetooth dongle devices

Dosimetric Evaluation A dosimetric evaluation was carried out especially for Bluetooth headsets. However, the Bluetooth USB dongles were also evaluated, since these devices may also be operated in near-body configurations. Two Bluetooth headsets were analyzed dosimetrically: a Sony Ericsson HDH-300 and a Nokia HDW-2. For the dosimetric measurement of the Bluetooth devices a head simulating liquid was used. The electrical parameters of this liquid are displayed in Table XXVII. The dosimetric measurements were again carried out in the flat region of the phantom (shell thickness 2 mm). Figure 23 displays the global and local setups for the dosimetric analysis of the Bluetooth devices. On the left side the entire measurement system together with the personal computer used to produce the necessary communication traffic is shown. On the right side the Acer Bluetooth dongle applied to the phantom is displayed. The USB dongle devices were measured with the antenna main beam pointing inside the phantom while touching the phantom shell.

Frequency	ϵ_r	σ
2400 MHz	38	1.761
2450 MHz	37.78	1.817
2500 MHz	37.55	1.875

Table XXVII: Head simulating liquid electrical parameters for Bluetooth frequency range (23.5° C)

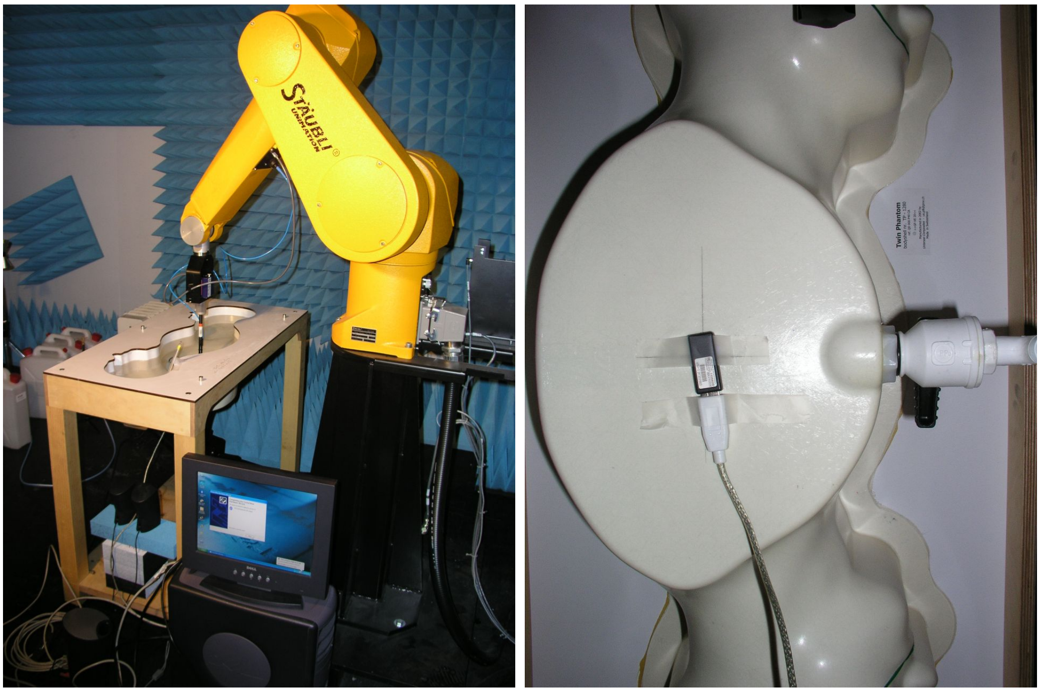


Figure 23: Dosimetric measurement Setup for Bluetooth devices

The Bluetooth headsets were operated under normal telephone call conditions. Therefore they were connected to a cellular phone. The cellular phone was located at a distance of approximately 1.5 m. Using the cellular phone, a telephone connection was established. Loudspeakers were used to generate an acoustical signal that was transmitted by the headset devices over Bluetooth to the cellular phone. The headset devices were applied in their normal operational position. Hence the headset earpiece and microphone touched the phantom shell during measurement.

The results of the SAR measurements are summarized in Table XXVIII. With the exception of the values displayed for the Mitsumi USB Dongle, these values were again extrapolated using the algorithm given by Kanda [37]. The SAR values determined for the headset are very low and smaller than or equal to the sensitivity of the dosimetric probes (5 μW/g). As expected, the Mitsumi Dongle with 100 mW peak output power gives values comparable to the SMC WLAN access point, which also has 100 mW peak output power. The measured Bluetooth devices comply with EN50360 [7] and with exposure limits from [39]. A very positive finding is that the body-worn devices such as Bluetooth headsets showed the lowest SAR.

	SAR	
Device	1g [mW/g]	10g [mW/g]
Acer Dongle	0.02	0.0092
Mitsumi Dongle	1.31	0.466
Sony Ericsson HDH-300	0.00307	0.00117
Nokia HDW-2	0.00925	0.00319

Table XXVIII: SAR of different Bluetooth devices

5.6 Baby Surveillance Devices

In general the communication of baby surveillance devices is based on proprietary standards. Hence it was necessary to determine the communication parameters of these devices. For each device parameters such as the operating frequency, wave form type, modulation, bandwidth and antenna main beam had to be determined experimentally. Basically, all baby surveillance devices available on the market in Switzerland have to be voice controlled (i.e., no radio frequency signal is transmitted if there is no environmental sound above a specific threshold).

From these parameters worst-case operational setups (i.e., the highest time averaged output power) for the particular devices were derived. Subsequently, the field distribution was measured using field probes (SPEAG); when applicable, a far-field measurement of the E-field was performed using the PCD8250 antenna and the spectrum analyzer. The same operational mode was used during the SAR measurements.

E-Field Measurement in Air:

Philips SC263 This device provides two communication channels in the 40 MHz ISM frequency band. During measurement the device was operated at a frequency of 40.695 MHz. The transmitting device sends a pilot reference to identify itself against the receiver. A frequency modulation is applied to the carrier signal. Other than the voice controlled transmission the signal is not modulated in amplitude. Hence the transmitting device was excited by applying an sinusoidal signal at 800 Hz during measurement. The transmitting device provides an adjusttable threshold for voice control. This threshold was set to the lowest level during measurement. The near E-field values measured in the antenna main beam of the device are given in Figure 24. Due to the low operating frequency, the far-field assumption cannot be used for this device at the considered distances (0.2-2.5 m). Hence no far-field measurements were carried out for this device.

Vivanco BM800 The BM800 baby surveillance device operates at a frequency of 863 MHz. Four manually adjusttable channels are provided. During measurement the device was operated

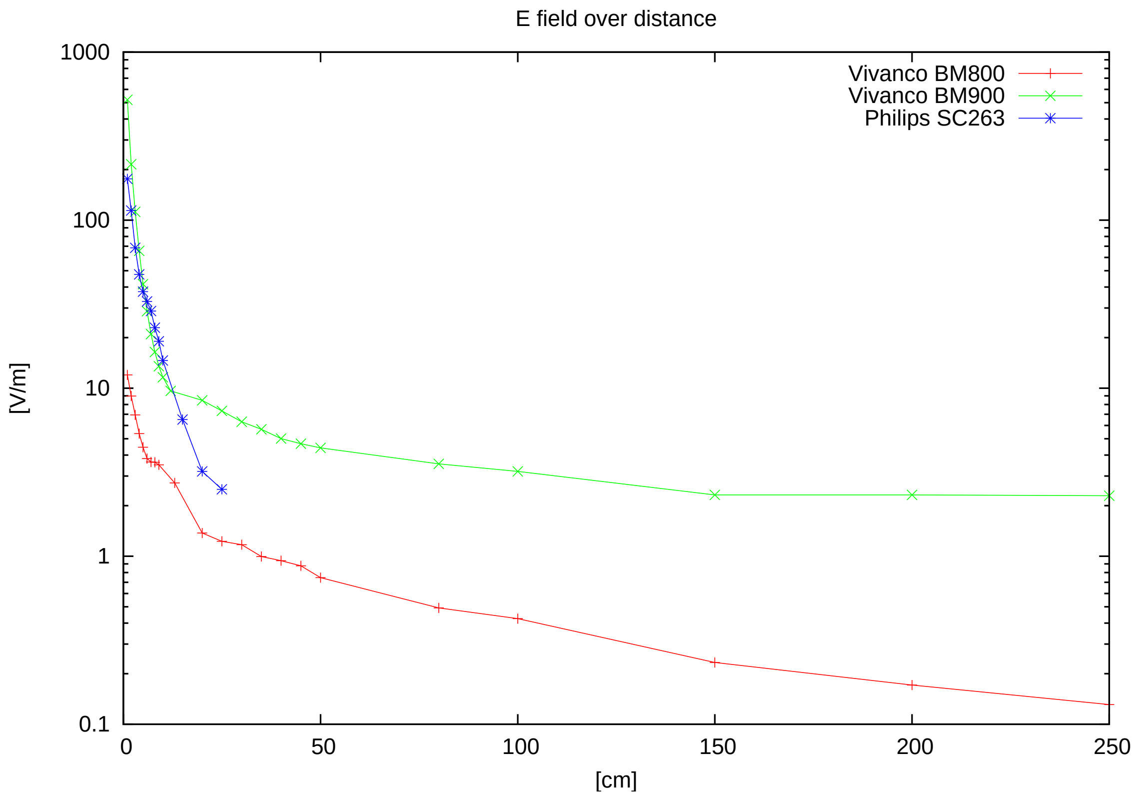


Figure 24: E-field of the BM900 and BM800 baby surveillance devices over distance in the antenna main beam and E-near-field distribution of Philips SC263

on channel 1 with a center frequency of 863.23 MHz. The maximum output power provided by the device is 10 mW. The adjusttable transmission power was set to maximum. The pilot signal technology is used to identify the transmitter against the receiver. The device is equipped with an adjusttable threshold for the acoustical detector. During measurement this threshold was set to the lowest possible level. The transmitted signal is not pulsed or modulated in amplitude. Hence if the acoustical detector is continuously excited, a continuous wave transmission can be assumed. The Vivanco BM800 is equipped with range control. The range control is realized by transmitting a test signal every 5 seconds. Hence this operational mode causes exposure even if the baby is quiet.

Vivanco BM900 The BM900 baby surveillance device operates at a frequency of 446 MHz. It is able to transmit on eight channels that can be set manually. For the experimental analysis the device was operated on channel 1 with a center frequency of 446.0062 MHz. Again a pilot signal is used to identify the transmitting device. The BM900 has the highest output power of all devices under test (500mW). The transmitted signal is not pulsed or modulated in amplitude. Therefore if the acoustical detector of the device is excited permanently, a continuous wave signal can be assumed. As for all other devices, the acoustic threshold is adjusttable. The device can be equipped with an external microphone (included in delivery). This microphone can be placed near the monitored baby, while the transmitter may be placed at a further distance (up to 1.5 m). The Vivanco BM900 is also equipped with range control. The range control is realized by transmitting a test signal every 5 seconds. Hence this operational mode causes exposure even if the baby is quiet.

The BM800 and the BM900 devices were both analyzed in the same manner. The acoustic detector was excited by a 800Hz acoustical signal produced by two loudspeakers located at a distance of about 1 m to the device. Thus a continuous transmission was ensured during measurement. For far-field analysis the E-field was mapped over distance using the PCD8250 antenna and the spectrum analyzer. The spectrum analyzer was used in zero span mode with the center frequency set to 446.00625 MHz with a resolution bandwidth of 10kHz (BM800). For the BM900 device the spectrum analyzer was operated at 863.23 MHz with a resolution bandwidth of 1 MHz.

The acquired E-field for the BM800 and BM900 baby surveillance devices over distance is displayed in Figure 24.

Dosimetric Evaluation The Vivanco BM800 and BM900 baby surveillance devices were additionally analyzed dosimetrically. Baby surveillance devices may also unintentionally be operated very close to the human body and head. For dosimetric analysis of the baby surveillance devices, head simulating liquids were used. The corresponding parameters for the BM800 and BM900 devices are displayed in Table XXIX and Table XXX, respectively.

Frequency	ϵ_r	σ
850 MHz	41.5	0.95
902.2 MHz	40.27	0.94

Table XXIX: Head simulating liquid electrical parameters for Vivanco BM800 frequency range (23° C)

Frequency	ϵ_r	σ
450 MHz	43.77	0.8332
500 MHz	42.77	0.8764

Table XXX: Head simulating liquid electrical parameters for Vivanco BM900 frequency range (23° C)

Again, the challenging problem is to define the normal operational position for the devices. In general there is no such position, since there is no intended manner of usage. However an analysis of all possible configurations would be very time consuming. Therefore it was decided to measure the devices in a mutually comparable position. The cuboid body was placed touching the flat region of the phantom with the largest surface. Since two largest surfaces exist, the surface was chosen for which the distance between the antenna and the phantom shell is smallest. The measurement setup with the Vivanco BM800 applied to the phantom is shown in Figure 25.

The SAR acquired from these measurements is shown in Table XXXI. For an analysis of the SAR variation under a different orientation the BM800 device was rotated by 90° around the antenna axis. The considered positions together with the evoked SAR distribution are visualized in Figure 26. On the left the original position is sketched, and the position after rotation is given on the right. The results gained from this measurement configuration are summarized in Table XXXII. The 1g SAR is 50% and the 10g SAR is 20% higher after the rotation.

PC Peripheral Devices For wireless PC peripheral devices using proprietary communication standards, an experimental determination of the signal parameters was necessary. Therefore the radio frequency output behavior was monitored using a broadband antenna and a spectrum

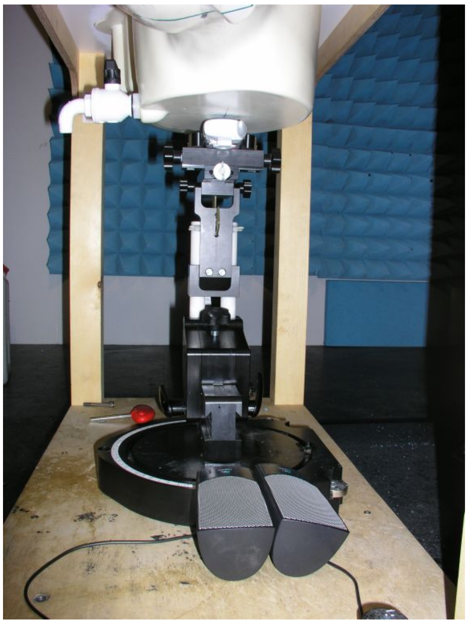


Figure 25: Dosimetric measurement setup for baby surveillance device evaluation

	max SAR	
Device	1g [mW/g]	10g [mW/g]
Vivanco BM 900	0.115	0.077
Vivanco BM 800	0.012	0.00958

Table XXXI: Measured SAR values for Vivanco BM800 and BM900 (23° C)

	max SAR	
Device	1g [mW/g]	10g [mW/g]
Vivanco BM 800 (normal)	0.012	0.00958
Vivanco BM 800 (90° tilt)	0.018	0.012

Table XXXII: Measured SAR values for Vivanco BM800

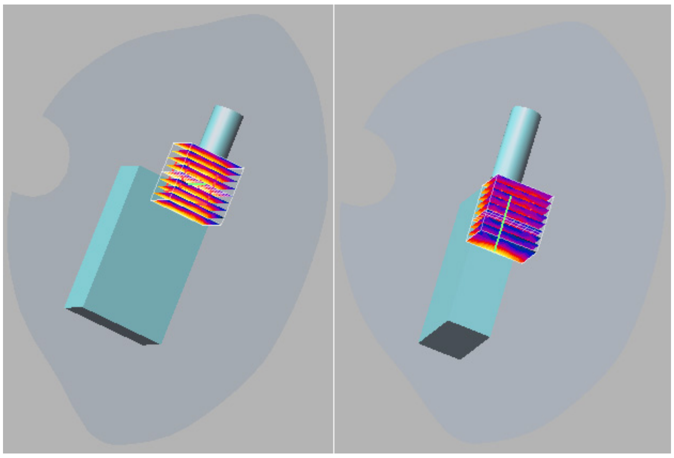


Figure 26: The SAR distribution with different orientations of Vivanco BM800

analyzer. During the later E-field measurements, this setup was also used to monitor the activity of the particular devices during measurement.

E-Field Measurement in Air:

Wireless Mice Two optical wireless mice were tested. In general the emitted power of these devices is very low, since their intended operational radius is very small and they are additionally optimized for power consumption. The operating frequencies of the investigated devices do not permit the use of the far-field assumptions for the considered distances (0.2-2.5 m). Hence only the near-field region (0-0.1 m) of the devices was measurable with the given equipment.

The tested devices only transmit if they detect movement or another action (clicking, scrolling). During measurement the devices under test were not in motion, since this would add additional positioning uncertainty. The optical sensor of the mouse was excited by a moving laser beam. The experimental setup is shown in Figure 27. The measured field values again represent worst-case values. In a normal application scenario the mice would not transmit permanently. Neither of the tested wireless mice transmits a signal modulated in amplitude during permanent operation. The Gyration Wireless Optical Mouse operates at a frequency of 49.8 MHz; the Microsoft IntelliMouse Explorer operates at a frequency of 27.145 MHz. Figure 28 gives the E-field intensity of the Gyration Wireless Optical Mouse over distance in the antenna main beam. For the Microsoft IntelliMouse Explorer the E-field was measured at different points on the surface of the device. These points and the corresponding field values are shown in Table XXXIII. The Gyration Wireless Optical Mouse provides an operational radius of up to 10 m. Hence a higher output power can be expected for this device, resulting in higher E-fields compared to the Microsoft IntelliMouse Explorer.

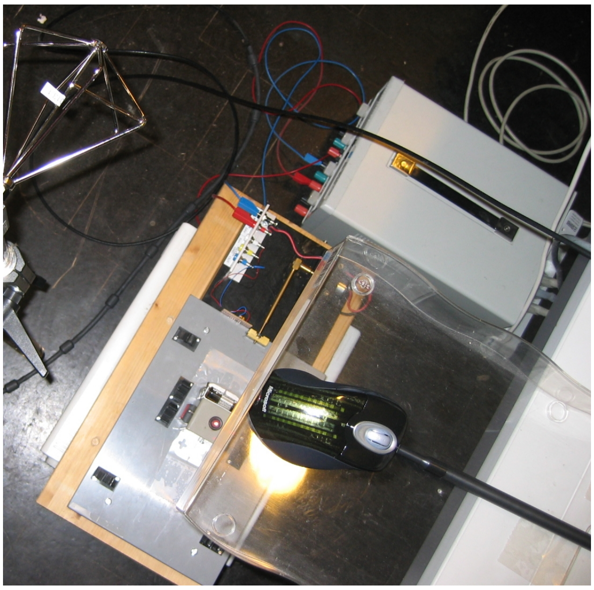


Figure 27: Measurment setup for the optical mice

Wireless Keyboard The signal shape of the Logitech Wireless Desktop Keyboard is a pulse form. In general the protocol includes 8 slots with a slot length of 25 ms each. Within such a

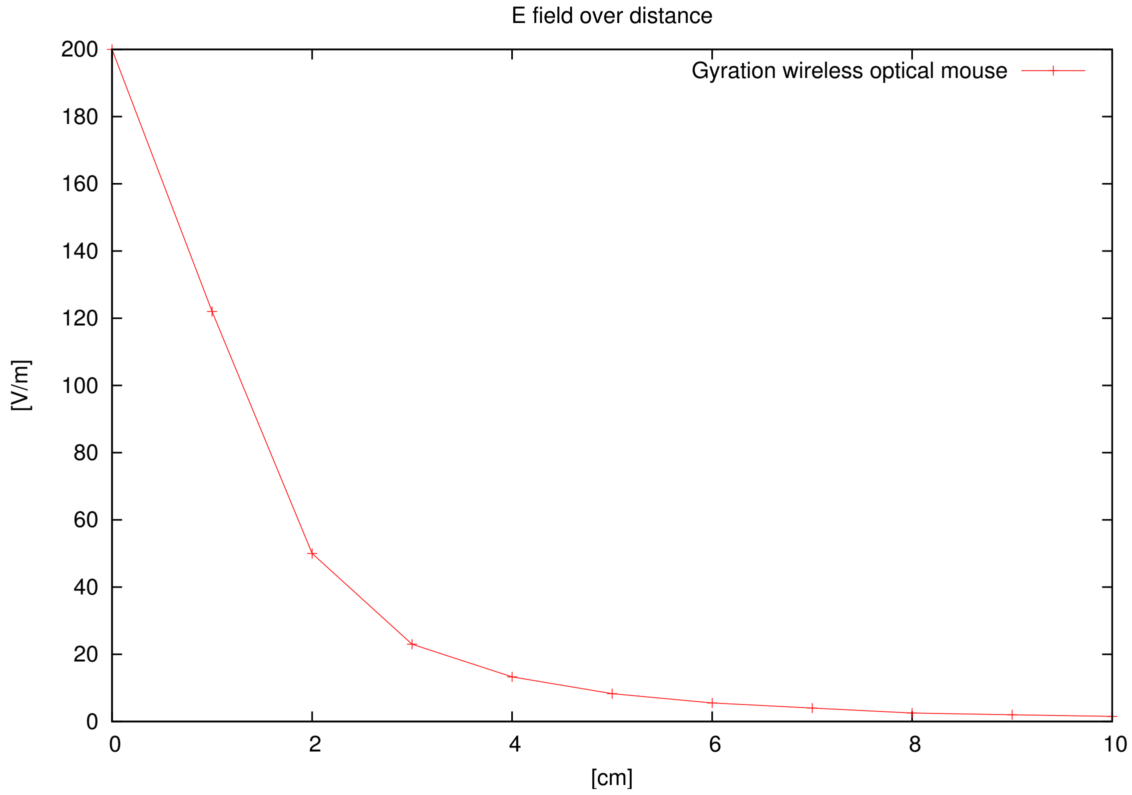


Figure 28: E-near-field distribution of the Gyration Wireless Optical Mouse over distance in the antenna main beam

Position	E-field [V/m]
thumb	5.5-6.5
little finger	5.0
trigger finger	2.0-2.5
mouse tip	2.0

Table XXXIII: E-field at specific points on the surface of a wireless Microsoft IntelliMouse Explorer slot the information of a single key pressed permanently is transmitted by a 20 ms burst. Hence the maximum time averaged output power for the wireless keyboard under test is obtained by pressing eight keys simultaneously. The keyboard transmits at a frequency of 27.145 MHz. Due to the pulsed waveform type, additional low frequency components between 5 Hz and 40 Hz are added.

The E-field over distance for the case of maximum output power is displayed in Figure 29.

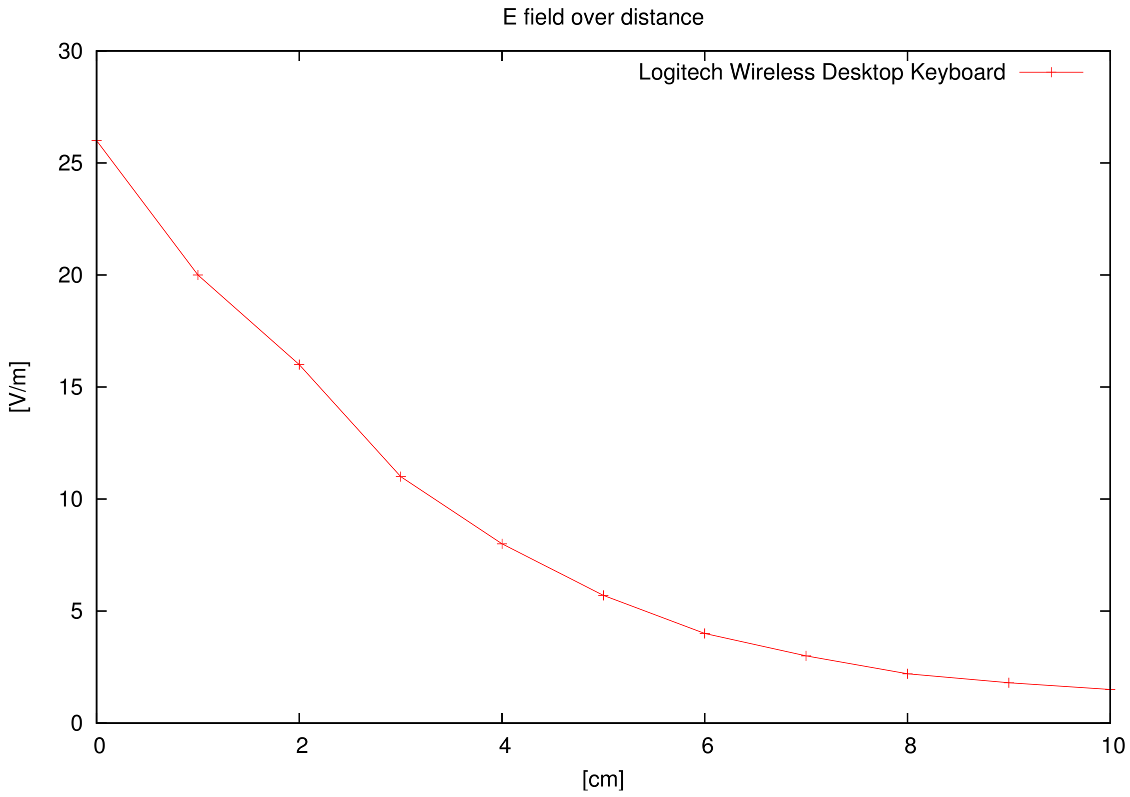


Figure 29: E-near-field distribution of Logitech Wireless Desktop Keyboard over distance in the antenna main beam

Dosimetric Evaluation Basically, wireless PC peripherals transmit at very low power levels. Nevertheless, the energy absorption in human tissue was investigated for two wireless devices. The Logitech Wireless Desktop Keyboard and the Microsoft IntelliMouse Explorer were chosen for an experimental investigation of the SAR. Both devices operate at 27 MHz. A muscle simulating liquid with the parameters shown in Table XXXIV was applied in the experiment. Again, the challenging task is to determine positions under which the DUT is applied to the phantom. The wireless mouse was tested in three positions touching the phantom shell. The three measurement configurations are displayed in Figure 30. With the mouse applied in these orientations, 2-D area scans normal to the phantom surface were performed. In all three positions the SAR values were below the probe sensitivity. Therefore a zoom scan was not performed.

The wireless keyboard was applied with the previously determined antenna location as near as possible to the phantom surface. The antenna main beam determined in air pointed inside the phantom for this experiment. The keyboard as applied to the phantom is shown in Figure 31. Again, the measured peak SAR was below the sensitivity of the dosimetric probe.

Frequency	ϵ_r	σ
27 MHz	96.4	0.64

Table XXXIV: Muscle simulating liquid electrical parameters for 27 MHz (23° C)

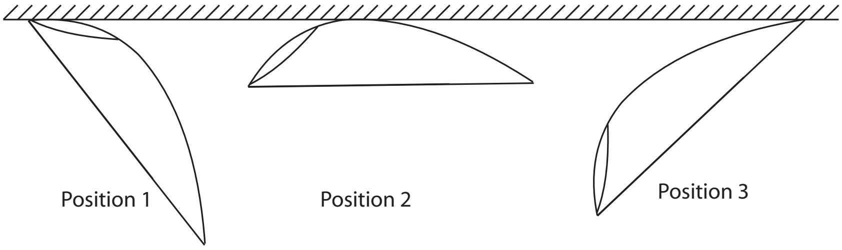


Figure 30: Positions of the wireless mouse on flat phantom (on top) during SAR measurements

Figure 31: SAR measurement setup for the Logitech Wireless Desktop Keyboard

5.7 Summary and Discussion

In this study a set of wireless devices operated in home and office environments has been investigated experimentally. The devices are listed in Table XXXV together with the applied methods for experimental exposure assessment. Figure 32 summarizes our exposure results,i.e., 10g SAR and E-fields at 1m distance of the investigated device classes.

	E-field (in Air)		**Dosimetry**
	far-field	**near-field**	
DECT:			
Siemens Gigaset 2000c			Handset
Siemens Gigaset 3015	Base Station	Base Station	Handset
Binatone	Base Station	Base Station	
Hitel, Moai414	Base Station	Base Station	
Ascom Avana 265			Handset
Swisscom R106			Handset
Bluetooth:			
Headset: Nokia HDW-2 (Class III)			X
Headset: Sony Ericsson (Class III)			X
Acer dongle (Class II)	X	X	X
Mitsumi dongle WML-C51APR (Class I)	X	X	X
WLAN:			
SMC 2804WBR 11b/g	X	X	X
Apple Air Port Extreme	X	X	X
Apple Air Port Express			X
Babyphone:			
Philips SBC 363 91U		X	
Vivanco BM 900	X	X	X
Vivanco BM 800	X	X	X
Wireless Mouse:			
Gyration Ultra GT optical		X	
MS Intellimouse optical	X	X	X
Wireless Keyboard:			
Logitech Wireless Desktop	X	X	X

Table XXXV: Summary of exposure measurements of short-range wireless devices

As it can be seen in Figure 32, the maximum and minimum E-field strengths in the groups of WLAN and DECT devices do not differ widely. This can be explained by the high degree of standardization of the particular device classes. For DECT a peak power of 250 mW and for WLAN (802.11b) a peak power of 100 mW is permitted. However for DECT the exposure values for the single call mode are displayed in Figure 32. To cover large areas the manufacturers of these devices use output power levels near to these limits. Although the device exposure is similar regarding E-fields, this does not hold for the corresponding SAR. Figure 32 shows that the maximum and minimum SAR of the particular device classes differ by nearly 10 dB for DECT and up to more than 10 dB for WLAN. This can be explained as follows: DECT handsets and WLAN access points are in general relatively large and arbitrarily shaped devices. Therefore the statistical spread of the position of the transmitting antenna is larger, which manifests itself

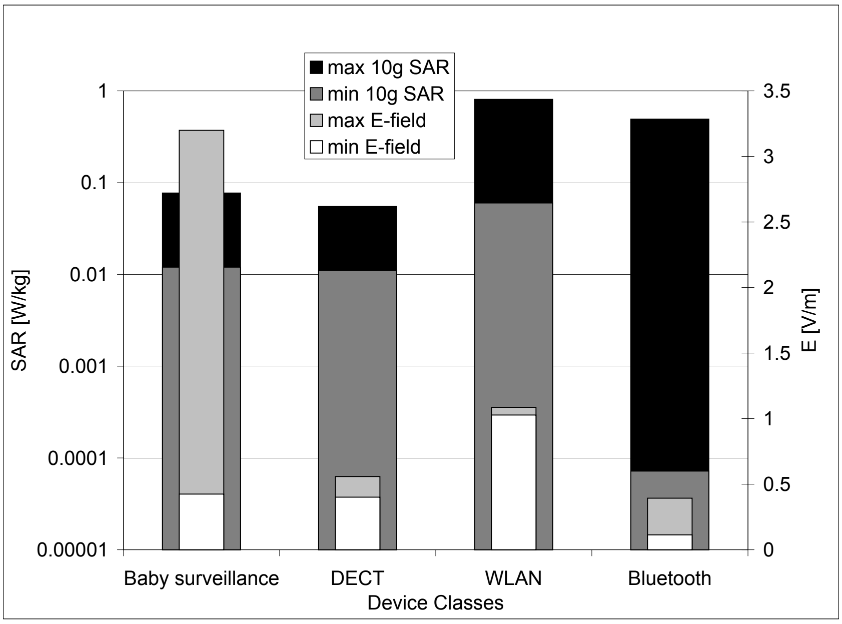


Figure 32: Overview of maximum and minimum measured E-fields (1m distance) and maximum and minimum determined 10g SAR of different device groups

in the dosimetric evaluation. A coverage of all possible positions with respect to the phantom is not feasible or would be very time consuming with currently available methods.

Although Bluetooth is well standardized, the E-field variation at a distance of 1 m is large compared to WLAN and DECT, since the Bluetooth standard allows three different output power levels. Bluetooth is often applied in devices critical to power consumption; therefore manufacturers prefer the low power classes. For Bluetooth the maximum and minimum E-fields in Figure 32 result from a class I device and a class II device, respectively; thus the E-field variation is not surprising. The difference in the output power between the particular power classes is also reflected in the corresponding SAR values. For devices of power class III no significant SAR could be measured with a dosimetric probe with a detection limit of 5 μW/g. For the class II device a 10g SAR of 9.2 μW/g was determined. Significant SAR values can only be expected for class I devices (output power: 100 mW).

Within the group of baby surveillance devices there exists a variety of devices with different specifications. General comparisons within the group are difficult. Nevertheless, it is an alarming result that the overall highest E-field was determined in this device class.

Figure 32 excludes the device class of wireless PC peripheral devices. From this class only a very low contribution to the SAR exposure can be expected. Due to the low operating frequencies of these devices (27 MHz, 40 MHz), the far-field region is still not reached at a distance of 1 m. With the given equipment a region from 0.01 m to 0.1 m was measurable. However, comparison of these values with the reference levels is not recommended.

Basically, all of the considered devices comply with the limits recommended by the ICNIRP [9] and EN50360 [39] guidelines. In comparison to the mean SAR value of cellular phones (see Figure 33), the maximum SAR of DECT handsets is 10 dB lower. However, the maximum SAR determined for WLAN and Bluetooth class I devices is of the same order of magnitude as for mobile phones. This is not surprising, since Bluetooth and WLAN operate in the same frequency range and have comparable output power. It must be mentioned that the manner of normal operation for short range wireless devices and cellular phones fundamentally differ. Usually, exposure from DECT, Bluetooth and WLAN devices is present for a longer period than, e.g., from cellular phones. However, the expected average SAR for WLAN and Bluetooth devices is generally smaller, since the average data rate and hence the average output power is normally below the maximum applied in this study.

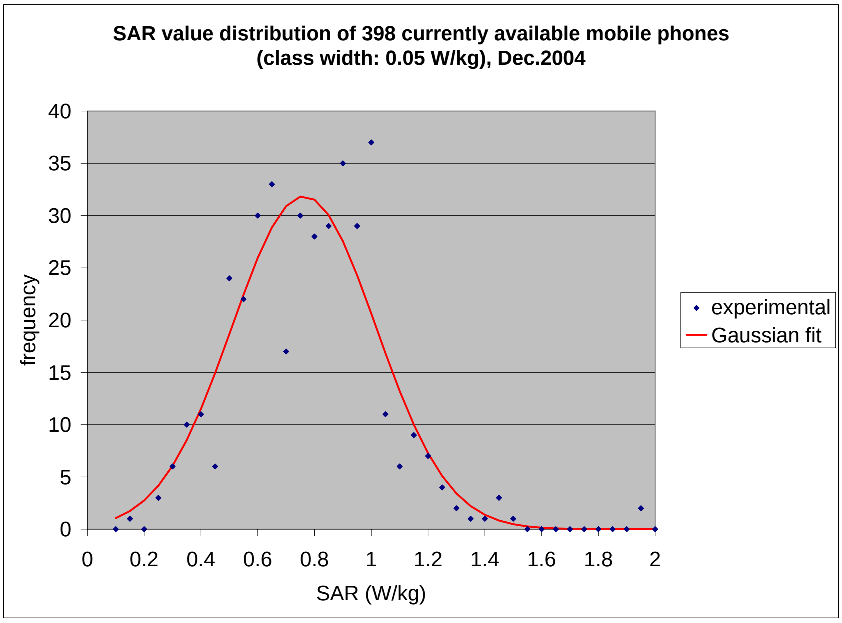


Figure 33: SAR distribution of currently available cellular phones (Source: BfS Germany)

For baby surveillance devices the determined 10g SAR is comparable to DECT handsets and is 10 dB below cellular phones. It must be mentioned that under normal conditions a baby phone is not operated close to the body, but at approximately 0.5-1 m distance. The manuals of these devices generally recommend chosing a distance above 1 m.

It can be summarized that the dominant source of near-field exposure remains the cellular phone. However, the average SAR values for cellular phones can be reached by some home and office devices.

It is also interesting to compare our results with exposure from outdoor sources. Typical values inside buildings at distances up to 100 m from GSM base station sites are in the range of 0.1-1 V/m [40]. Consequently, the electric field exposure caused by wireless home and office devices is in the range of exposure from a base station operated in close vicinity to an office or appartment (10-200 m). However, with the growing pervasiveness of home and office wireless devices the exposure by a single device underestimates the cumulative exposure by a set of these devices. Therefore, in future methodologies will be necessary to assess the combined exposure.

6 Conclusion

The results of the worst-case spatial peak SAR evaluations are summarized in Table XXXVI. WLAN and Bluetooth (class 1) devices can lead to exposure levels similar to those of mobile phones, i.e., in the range of 0.1 - 1 W/kg. These evaluations reflect extreme exposure scenarios in terms of signal transmission and proximity to the body. Under normal operational circumstances these devices are operated at lower output power than applied in this study. Additionally, the devices are in general not operated as close to the body as during assessment of the SAR.

Exposures from DECT handsets are rather low, i.e., below 0.1 W/kg. Surprisingly high are the exposures incurred in the close vicinity of baby phones; their SAR values are similar to those of DECT phones. As expected, the SAR exposure from computer peripherals operating at 27 MHz is low. In summary, all tested devices satisfy the spatial peak SAR limit of 2 W/kg under all circumstances when evaluated following the guidelines of IEC 62209 Part II [1]. This is also true when considering the multiplication factors currently discussed for consideration of the increased absorption occurring in skin/fat layers below 800 MHz.

The results of the incident exposure evaluations are summarized in Table XXXVI for distances of 200 mm and 1 m. The incident exposure posed by the investigated devices is below the ICNIRP limits for all distances, even when taking into account a reflective environment. It is also evident from Table XXXVI that the cumulated worst-case exposures from indoor wireless communication devices can be significantly larger than exposure limits from base stations and broadcasting transmitters.

Device Class	**Frequency Range** [MHz]	**worst-case 10g SAR** [W/kg]	**worst-case E-field** [V/m] (200 mm)	**worst-case E-field** [V/m] (1000 mm)	**ICNIRP limit** [V/m]	**NISV limit**[1] [V/m]
Baby Surveillance	40 - 863	0.077	8.5	3.2	29	4
DECT[2]	1880 - 1900	0.055	11.5	2.9	60	6
WLAN	2400 - 2484	0.81	3.9	1.1	61	6
Bluetooth	2402 - 2480	0.49	3.1	1.0	61	6
PC Peripherals	27 - 40	$\leq$0.005	$\leq$1.5	$\leq$1.5	28	4

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[1] NISV limits for fixed transmitters with ERP of $\geq$ 6 W

[2] Extrapolated maximum for asymmetric transmission mode

Table XXXVI: Worst-case E-field and spatial peak SAR of the investigated devices. (An absolute worst-case for all commercially available products cannot be estimated based on this data)

Based on the review and the results obtained, we can identify the following open issues for a systematic evaluation of exposure from short-range communication devices typically used in office and home environments:

- Extension or adaption of IEC 62209 Part II for general short-range wireless communication devices. We suggest that the Swiss National Committee propose a corresponding recommendation to the IEC.
- The discrepancy between the safety limits defined for fixed and mobile transmitters becomes more evident when evaluating exposures posed by indoor wireless communication devices. The incident fields of indoor devices are in the same range as those from base

stations. Whereas the base stations must comply with the limits defined by NISV [4], the limits for wireless indoor devices are 10 times higher. A dialog between the agencies and other competence centers should be initiated in order to prevent confusion during communication with the public. For example, it might be worth considering that indoor wireless communications not be evaluated *in situ* as base stations but characterized in exposure classes based on dosimetric evaluations and usage considerations.

- Development of a classification system including corresponding evaluation guidelines.
- Dissemination of results to standardization committees.

Acknowledgments

This study was generously supported by the Swiss Federal Office of Public Health (SFOPH/BAG).

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