# Radio frequency exposure assessment of baby surveillance devices in the frequency range 400 MHz – 2.45 GHz

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Radiofrequency (RF) wireless communication devices facilitate communication, entertainment, and monitoring in our daily lives. In compliance testing of wireless devices, numerous studies focused on the exposure from mobile phones, as these devices are typically operated close to the human head. However, a lot more devices contribute to the exposure of the people, such as, tablets and wearables. In a home environment, the exposure from WLAN devices, DECT base stations, and (cordless) phones has already attracted a lot of attention as these are used in many households. Another source of exposure in homes and nurseries are RF baby surveillance devices or baby monitors. A baby monitor consists of a parent unit and a baby unit, which is placed in the bedroom of the baby. Although a baby monitor allows bidirectional communication, it is mainly a unidirectional device from baby unit to parent unit. As baby units are placed at short distance of the sleeping baby, governments and parents raised concerns about the electromagnetic field exposure of the baby by these devices.

Exposure to baby monitors have rarely been investigated: Schmid et al. [2007] and Kühn et al. [2007] investigated the exposure to baby monitors within a larger study on the exposure to short-range indoor wireless communication devices. We investigated the exposure, in terms of both the peak spatial-averaged specific absorption rate (SAR) in 10 g of tissue and the time-averaged root-mean-squared (RMS) electric (E) field, induced by baby monitors operating in the frequency range between 400 MHz and 2.45 GHz. We selected nine commercially-available baby monitors and evaluated their exposure against exposure limits established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [ICNIRP, 1998].

First, we describe the selected baby monitors and their communication technologies, the measurement setups, and the methodology to assess electric field and peak spatial-averaged SAR. Next, we present the observed exposure values and evaluate these values against current international exposure limits. Finally, we summarize the major outcomes of the study.

A baby surveillance device or baby monitor consists of a baby unit and a parent unit. We selected nine commercially available baby monitors communicating at radio frequencies. In the radio frequency range, baby surveillance appliances can use a variety of wireless communication technologies of which the following were considered in this study: Private Mobile Radio at 446 MHz (two devices), continuous transmission at 864 MHz (one device), Digital Enhanced Cordless Telecommunications (DECT) system in the frequency band from 1880 MHz to 1900 MHz (three devices), IEEE 802.11n at 2.45 GHz (one device), and proprietary technologies in the Industrial, Scientific and Medical (ISM) band at 2.45 GHz (two devices). Most baby units must be connected to the power outlet. Table 1 lists the selected baby monitors together with their communication technology and operating frequency.

A baby unit can be placed at any distance – it might even be placed inside the bed next to the (sleeping baby) – from the baby within the infant’s bedroom. The range of distances between baby and baby unit required exposure evaluation in terms of both peak spatial-averaged SAR in 10 g (psa$SAR_{10g}$) and RMS electric field. The former to evaluate compliance with established exposure limits [ICNIRP, 1998], the latter to determine exposures for typical baby unit placement.

Compliance assessment of radiofrequency exposure requires the wireless device to transmit at the highest time-averaged power. Worst-case exposure conditions are reached for maximum power and maximum duty cycle. To ensure maximum transmit power, devices were switched to maximum power and/or the parent unit was positioned in such a way that the baby unit had to radiate at maximum power. The latter was realized by placing the parent unit away from the measurement setup (whether for dosimetry or in free space) or, if needed, by placing it in a metallic enclosure with small openings to realize a bad connection.

We obtained maximum duty cycle, or minimum crest factor (CF; defined as the ratio of the peak value and RMS value of the signal), by assuring that: data were transmitted from the baby unit to the parent unit by switching on a portable radio that played loud music to activate the baby unit; baby unit and parent unit were connected when a link is required before data (i.e., audio and in some cases also video) were transmitted. The crest factor depends on the transmitted signal: for continuous wave signals, the CF equals one; for periodic pulsed signals, the crest factor is specified by the communication technology standard (e.g., DECT signals) or measured in case of proprietary technologies; for non-periodic signals, we selected a CF of one to obtain an upper limit on the worst-case exposure. We measured the duty cycle or crest factor using the spectrum analyzer FSEM 20 Hz – 26.5 GHz (Rohde & Schwarz, Munich, Germany) and tri-axial probe TS-EMF Isotropic Antenna (Rohde & Schwarz, Munich, Germany). The spectrum analyzer was used in zero span mode. For periodic pulsed signals, we determined the crest factor from the measured on and off duration of the signal; for non-periodic signals, we measured the crest-factor using the methodology of Verloock et al. [2010].

In this study, we measured electric field as well as SAR to evaluate the exposure induced by the baby unit of baby surveillance devices. We measured operating frequency, bandwidth, duty-cycle, and maximum RMS electric field of all devices in an anechoic chamber. The RMS electric field was measured at 50 cm at four sides (front, back, left and right) around the baby unit. We estimated 50 cm as the minimum distance in a typical positioning of the baby unit outside the bed. Manuals of baby monitors often specify a minimum distance of 1 m. A picture of the setup in the anechoic chamber is found in the Online Supplementary Materials.

The measurement setup for SAR compliance testing (See Online Supplementary Materials) consisted of the robot Pythron IXE α-C-T (DB, Waregem, Belgium), a DASY3mini measurement system (SPEAG, Zurich, Switzerland), the signal generator SMB 100 A (Rohde

& Schwarz, Munich, Germany), and the oval flat phantom ELI4 (SPEAG, Zurich, Switzerland) filled with head simulating liquid (HSL). The DASY3mini measurement system consisted of the data acquisition electronics DAE3mini (SPEAG, Zurich, Switzerland) and the dosimetric probe EX3DV4 (SPEAG, Zurich, Switzerland). The dosimetric system (probe and data acquisition electronics) was attached to a robot and managed through the graphical user interface of the measurement server. The devices under test were placed in touch position below the oval flat phantom (ELI v4, SPEAG, Zurich, Switzerland). The phantom was filled with head simulating liquid as suggested by IEC62209-2 [IEC, 2010]. Table 2 lists the measured and targeted dielectric properties according to IEC 62209-2 [IEC, 2010] and FCC Bulletin 65 supplement C [FCC, 1997]. The dielectric properties were measured with the dielectric probe kit HP-85070A (Hewlett-Packard Company, Santa Rosa, CA). The expanded standard uncertainty on the local-averaged SAR in 10 g was determined according to IEC 62209-2 [IEC, 2010] and equaled 18 %.

We assessed the $psaSAR_{10g}$ according to the measurement standard IEC 62209-2 [IEC, 2010]. First, a surface scan was performed to determine the location of maximum SAR for front, back, left and right side of the device touching the flat phantom. The surface scans were performed with the center of the detector of the dosimetric probe at 5 mm from the flat inner phantom surface. Next, a volume scan was performed around the location of maximum $psaSAR_{10g}$ for the side of the device that yielded the maximum SAR value in the surface scan. From this volume scan, the SAR values at the inner phantom surface were extrapolated using a $4^{th}$ order polynomial function along the direction perpendicular to the phantom surface. Finally, we determined the peak spatial-averaged SAR in 10 g of tissue in this volume.

Table 3 summarizes the assessed crest factors of the devices. The selected devices used three types of signals: continuous wave (CW), periodic burst signals, and non-periodic burst signals. The PMR 446 devices use CW communication with frequency modulation (FM) and allows a maximum output power of 500 mW according to the PMR 446 standard. The device at 864 MHz uses a proprietary technology based on CW communication with FM modulation. The crest factor for CW signals equals one. DECT devices use periodic burst signals with a duty cycle or crest factor of 27.2 (DECT standard specifies a pulse width of 0.368 msec and a period of 10 msec). The marmitek babyview 725 and the switel BCF 875 use proprietary technology consisting of periodic signals in the ISM band at 2.45 GHz. The crest factor for these devices was 3.2 and 1.9 with a pulse width of 0.6 msec and 0.8 msec, respectively. Finally, the D-LINK EyeOn DCS-825L communicates according to IEEE 802.11n, which uses non-periodic burst signals. The crest factor for this device equaled 18.5.

Table 3 also summarizes the measured time-averaged RMS electric field in free space induced by the baby units. The PMR 446 baby monitors (Alecto-DBX-82 and modern-electronics DBS-3) induced the highest exposure: the maximum time-averaged RMS E-field at 50 cm from the device occurred, for both devices, at the back side of the baby unit and equaled 1.4 V/m and 1.5 V/m for Alecto-DBX-82 and modern-electronics DBS-3, respectively. This is about 20 times below the ICNIRP reference level of 29 V/m at 446 MHz. Although, the marmitek babyview 725 exhibits a slightly higher time-averaged RMS E-field (1.6 V/m), its factor below the ICNIRP reference level is larger than for the PMR 446 devices due to the higher reference level of 61 V/m in the 2.45 GHz range. We remark that electric fields were not measured in the far-field of the radiating baby unit for baby monitoring devices operating at 446 MHz and 864 MHz, as the far-field condition for electrically short antennas ($r > 2\lambda$) – is not met at these frequencies for a distance r of 50 cm.

Although special care was taken to maximize the duty cycle of the baby monitors operating in the ISM band at 2.45 GHz, we cannot guarantee worst-case exposure values. Therefore, we calculated an upper limit on the exposure of these devices by assuming a crest factor of one, or a duty cycle of 100 %. Under the assumption of a continuous transmitted burst, the marmitek babyview 725 yielded the maximum RMS electric field of 5 V/m, which is about a factor 12 below the ICNIRP reference level. Schmid et al. [2007] reported electric fields ranging from 0.4 V/m till 1.1 V/m, which are in line with the values observed in our study. Kühn et al. [2007] observed larger electric fields (3.2 V/m), which might originate from a 40 MHz device. Remark that we did not consider a 40 MHz device in our study.

Table 4 lists the peak spatial-averaged SAR in 10 g of head simulating tissue in a flat phantom. The side with peak spatial-averaged SAR differed from the side with maximum field strength, because for the SAR measurements we tilted the devices towards the flat phantom to obtain a maximum SAR value while for the field measurements all the devices were standing upright. The Alecto DBX-82 (PMR 446 device) induced the largest peak spatial-averaged SAR in 10 g with a value of 0.37 W/kg. The modern-electronics DBS 3 showed a much lower SAR value than Alecto DBX-82 while their electric field values were similar. Possible explanations are: (1) a difference in separation between the antenna and the flat phantom when the devices were touching the flat phantom; (2) a difference in detuning of the antenna of the device by the presence of the flat phantom. We did not measure the peak spatial-averaged SAR for the D-LINK Wireless N EyeOn DCS-825L because the SAR exhibited too much noise (peak spatial-averaged SAR in 10 g below 0.05 W/kg). Considering all investigated devices, the peak spatial SAR in 10 g ranged from 0.09 W/kg till 0.37 W/kg, which is 22.3 till 5.4 times below the ICNIRP basic restriction. Schmid et al. [2007] only assessed the peak-spatial SAR for a PMR446 device. They found a value of 0.13 W/kg, which was in the range of values that we observed. Kühn et al. [2007] measured lower peak-spatial SAR, which might be caused by not considering the exposure from a PMR 446 device.

In summary, we measured the induced time-averaged root-mean-square electric field strength and the peak spatial-averaged specific absorption rate from the baby unit of nine commercially available devices and compared both with the ICNIRP guidelines. The communication technologies implemented in the baby monitors were: PMR446, continuous transmission at 864 MHz, DECT, and communication in the ISM band at 2450 MHz. The electric field has been measured at a distance of 50 cm from the baby unit of the baby monitor. We measured the SAR in a flat phantom filled with head tissue simulating liquid and the baby unit touching the flat phantom. The maximum time-averaged root-mean-square electric field value closest to the ICNIRP reference level over all investigated devices was 1.51 V/m (for modern-electronics DBS 3), which is 19.4 times below the ICNIRP reference level at 466 MHz. The peak spatial-averaged SAR in 10 g of tissue was 0.37 W/kg in head simulating tissue (for Alecto-DBX-82), which is 5.4 times below the basic restriction of 2 W/kg as specified by ICNIRP.

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**Table 1: Overview of the selected baby monitors, their communication technology, and operating frequency.**

| Baby monitor | Communication technology | Operating frequency (MHz) |
|---|---|---|
| Alecto DBX-82<br>(Hesdo, ‘s Hertogenbosch, The Netherlands) | PMR 446 (CW[1]) | 446 MHz |
| DBS 3<br>(modern-electronics, Gran Cane, LA) | PMR 446 (CW[1]) | 446 MHz |
| MBF 8020<br>(Hartig + Helling, Bochum, Germany) | Proprietary (CW[1]) | 864 MHz |
| Motorola MBP-8<br>(Binatone Telecom, London, UK) | DECT (periodic burst) | 1900 MHz |
| Alecto DBX-88 ECO DECT<br>(Hesdo, ‘s Hertogenbosch, The Netherlands) | DECT (periodic burst) | 1900 MHz |
| AVENT SCD501<br>(Philips, Drachten, The Netherlands) | DECT (periodic burst) | 1900 MHz |
| BabyView 725<br>(Marmitek, Eindhoven, The Netherlands) | Proprietary (periodic burst) | 2400 MHz |
| Switel BCF 857<br>(Telgo, Granges-Paccot, Switzerland) | Proprietary (periodic burst) | 2400 MHz |
| Wireless N EyeOn DCS-825L<br>(D-Link, London, UK) | IEEE 802.11n (non-periodic burst) | 2400 MHz |

[1] CW = Continuous Wave

**Table 2: Measured and targeted dielectric properties of the head simulating liquids used for the SAR assessment of the baby monitors.**

| Frequency | Measured properties | | Target properties | |
|---|---|---|---|---|
| (MHz) | $\varepsilon_r$ (-) | $\sigma$ (S/m) | $\varepsilon_r$ (-) | $\sigma$ (S/m) |
| 450 | 46.1 | 0.89 | 43.5 | 0.87 |
| 900 | 41.0 | 0.90 | 41.5 | 0.97 |
| 1800 | 37.2 | 1.18 | 40.0 | 1.40 |
| 2450 | 34.2 | 1.88 | 39.2 | 1.80 |

**Table 3: Overview of the exposure values induced by the baby unit from nine commercially available baby monitors at 50 cm from the device in free space. For the baby monitors operating in the ISM band at 2.45 GHz, the upper limit on the worst-case exposure, i.e., for a crest factor of 1, is mentioned in between brackets.**

| Baby monitor | Orientation of the baby unit with maximum exposure | Crest factor (-) | $E_{RMS}$ (V/m) | Factor below ICNIRP reference level (-) |
|---|---|---|---|---|
| Alecto DBX-82 | Back | 1.0 | 1.40* | 20.7 |
| modern-electronics DBS 3 | Back | 1.0 | 1.50* | 19.4 |
| H+H MBF 8020 | Back | 1.0 | 0.55* | 74.8 |
| Motorola MBP-8 | Front | 27.2 | 0.88 | 66.4 |
| Alecto DBX-88 ECO DECT | Back | 27.2 | 0.55 | 109.0 |
| Philips AVENT SCD501 | Front | 27.2 | 0.67 | 59.8 |
| Marmitek BabyView 725 | Right | 3.2 (1) | 1.60 (5.12) | 38.1(11.9) |
| Switel BCF 857 | Right | 1.9 (1) | 0.95 (1.81) | 67.8 (35.7) |
| D-Link Wireless N EyeOn DCS-825L | Left | 18.5 (1) | 0.22 (4.07) | 265.0 (14.3) |

* Electric field not measured in the far-field of the radiating baby unit; the far-field condition for electrically short antennas ($r > 2\lambda$) is not met at 466 MHz and 864 MHz for a distance r of 50 cm.

**Table 4: Overview of the exposure values induced by the baby unit of nine commercially available baby monitors in a flat phantom filled with head simulating liquid. All baby units were touching the flat phantom.**

| Baby monitor | Orientation of baby unit with maximum $SAR_{10g}$ | Head simulating tissue (HSL) | |
|---|---|---|---|
| | | $SAR_{10g}$ (W/kg) | Factor below ICNIRP BR for general public, i.e., 2 W/kg (-) |
| Alecto DBX-82 | Back | 0.37 | 5.4 |
| modern-electronics DBS 3 | Left | 0.10 | 20.0 |
| H+H MBF 8020 | Right | 0.04 | 50.0 |
| Motorola MBP-8 | Front | 0.15 | 13.8 |
| Alecto DBX-88 ECO DECT | Back | 0.03 | 60.6 |
| Philips AVENT SCD501 | Back | 0.10 | 20.0 |
| Marmitek BabyView 725 | Back | 0.09 | 22.3 |
| Switel BCF 857 | Back | 0.21 | 9.7 |
| D-Link Wireless N EyeOn DCS-825L | - | - | - |

# ONLINE SUPPLEMENTARY MATERIALS

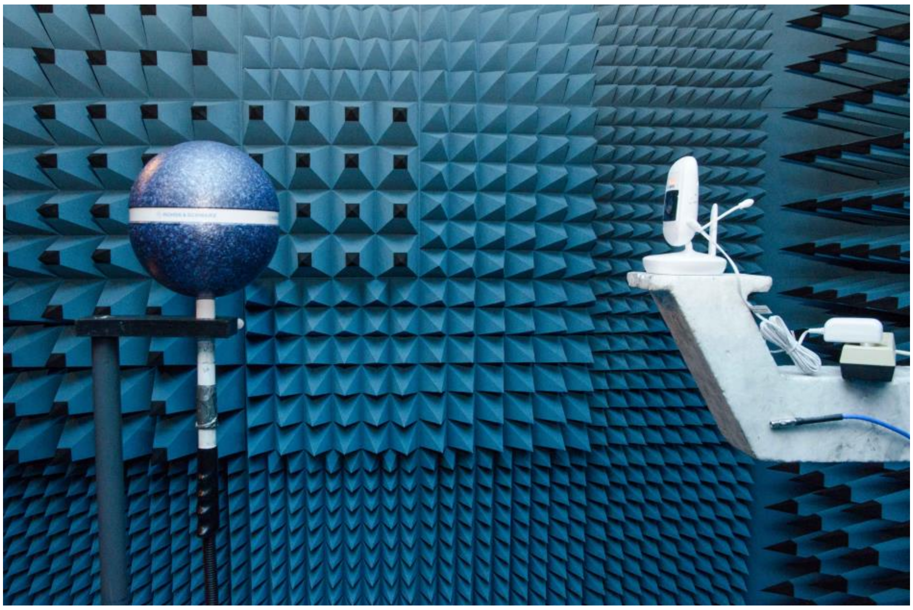

**Fig. 1: Free-space measurement in anechoic chamber: Rohde & Schwarz tri-axial probe (left) at a distance of 50 cm in front of baby monitor Switel BCF 857 (right).**

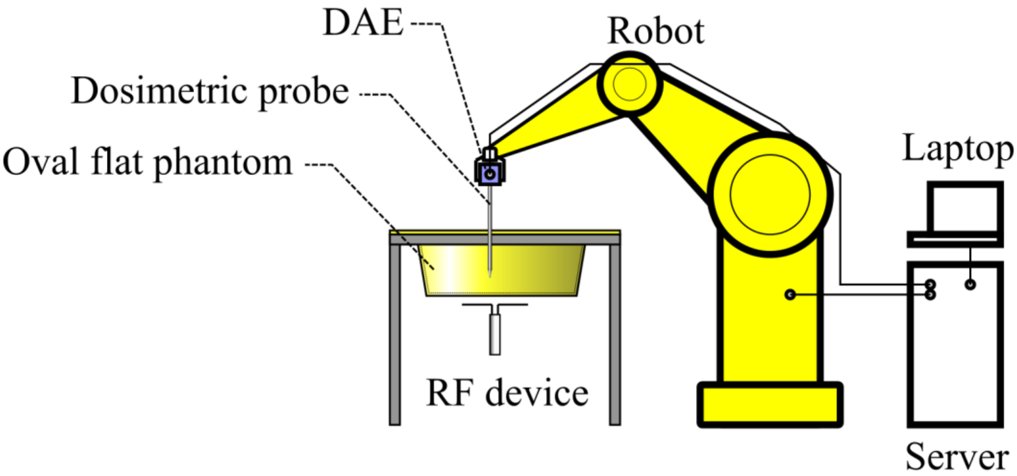

**Fig. 2: SAR measurement setup consisting of oval flat phantom, dosimetric probe, data acquisition unit, robot, and measurement server. Devices are placed in touch position below the flat phantom.**