EXPOSURE ASSESSMENT OF MICROWAVE OVENS AND IMPACT ON TOTAL EXPOSURE IN WLANS

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Short title: microwave oven exposure in WLANs

Abstract- **In-situ exposure of electric fields of 11 microwave ovens is assessed in an occupational environment and in an office. Measurements as a function of distance without load and with a load of 275 ml tap water were performed at distances <1m. The maximal measured field was 55.2 V/m at 5 cm from the oven (without load), which is 2.5 and 1.1 times below the International Commission on Non-Ionizing Radiation Protection (ICNIRP) reference level for occupational exposure and general public exposure, respectively. For exposure at distances >1m, a model of the electric field in a realistic environment is proposed. In an office scenario, switching on a microwave oven increases the median field strength from 91 to 145 mV/m (+91%) in a traditional Wireless Local Area Network (WLAN) deployment and from 44 to 92 mV/m (+109%) in an exposure-optimized WLAN deployment.**

Key Words- **microwave oven, electromagnetic exposure, occupational exposure, measurement, wireless network, WLAN, Wireless Local Area Network**

I. INTRODUCTION

The EU-Directive 2013/35/EU [1] will result in new requirements on employers in the European Union concerning the exposure to electromagnetic fields. This directive will also affect microwave oven systems that workers are exposed to. Microwave ovens are very common equipment used in households but also in industry e.g., for drying of materials. They operate at a frequency of 2450 MHz and powers usually range from 600 to 1200 W. Microwaves are produced by an electronic tube (i.e., the magnetron) and dispersed in the oven cavity. There are radiation losses through the glass door of the oven[2,3]. These radiation losses have to satisfy the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines[4]. Also the IEC-norm 335-2-25[5] defines limits for the maximal leakage of household microwave ovens: before sales 1 mW/cm^2 or 61.4 V/m and after sales 5 mW/cm^2 or 137.3 V/m, measured at 5 cm or more from the oven and for a load of 275 ml tap water of 20°C.

A review on microwave power applications is provided in Ref. (6). Here also industrial use of microwaves is discussed. Microwave oven leakage was investigated in Refs. (7, 8, 9, 10). These studies show that microwave leakage mostly satisfies the International Electrotechnical Commission (IEC) norm of 5 mW/cm^2. Ref. (9) investigated 106 domestic and restaurant microwave ovens and showed that only one oven exceeded the IEC norm, 15 other microwave ovens had leakage levels of 1 mW/cm^2 or more. Ref. (10) mentions that that only 0.8% of microwave ovens (Australia) have leakage in excess of the IEC limit. However, the microwave ovens can still cause significant field exposure increases in everyday environments (e.g. office building).

Calculations and measurements of the radiation characteristics of a microwave oven were performed in Ref. (11). Studies have also been performed in the context of network interference due to microwave ovens: Ref. (12) characterized the impact of radiation leakage of microwave ovens on the deployment of sensor networks in the context of interference. Other studies about interference of the ovens with WLAN and Bluetooth can be found in Refs. (13), (14), respectively.

The objective of this paper is to determine the exposure levels of 11 different types of microwave ovens for different loadings and powers as a function of distance for users close to the oven (<1m). Also an evaluation in comparison with the ICNIRP reference levels(4) and IEC standard(5) is performed. A model of the electric fields as a function of the distance from the microwave ovens is proposed. These field levels and the resulting models can be used for exposure assessment and comparison with exposure guidelines for workers. Further, a model applicable to assess microwave oven exposure in a large office building is developed. It is then applied to two types of WLAN network deployments: a traditional deployment with few high-power access points and an exposure-optimized deployment with many low-power access points(15,16). Such an assessment of the impact of a microwave oven exposure on the total network exposure has not yet been performed according to the authors' knowledge .

II. MATERIALS AND METHOD

A. Configuration and sources

1) Occupational exposure (<1m)

In an application lab of a company producing plastic materials and tools, different domestic microwave ovens are installed for drying and testing of plastic material. The leakage of these microwave ovens was measured at locations where workers were present and as a function of distance, up to 110 cm from the microwave oven. Figure 1 shows the measurement setup and the considered measurements. Table 1 lists the 11 different microwave ovens considered for the electric field measurements. Also the maximum power (P_{max}), the presence of a turning table in the ovens and the positions around the oven where the maximal electric fields were measured, are provided. The ovens were 1-5 years old.

2) Environmental exposure (>1m)

In order to be able to assess the impact of the microwave oven on the overall exposure on a building floor, measurements at larger distances from the oven (>1m) need to be performed. Unlike in the previous section (occupational exposure), the aim here is not to assess the worst-case electric-field strengths close to and in line-of-sight with the oven, but to obtain a realistic distribution of the microwave oven field strengths in a realistic environment. The considered environment is the third floor of an office building of 90 m by 17 m with mainly concrete walls and layered drywalls and is displayed in Figure 2. In order to simulate a realistic scenario, the oven was set at full power and contained a 275ml load of tap water at a temperature of 20°C for each measurement (real situation). The oven is of type Whirlpool AMW210 and is located at the red dots in Figure 2(b) and (d). This location corresponds to the corner of a small kitchen. In the office environment, other sources in the 2.4 GHz band (e.g., WiFi networks) are also present and this influence needs to be excluded from the measured field strength to accurately assess the field strength due to the microwave oven. Measurements were performed at 10 locations (green dots in Figure 2 (b)) spread over the building floor.

B. Measurement equipment

In this study, electric-field strengths were assessed using broadband and frequency-selective narrowband equipment. For occupational measurements, the broadband measurements were used for the spatial measurements as a function of distance, while the narrowband setup was used for the identification of background noise. For environmental measurements, only the narrowband setup was used.

A broadband probe of type Narda NBM-550 (Narda, San Diego, USA, measurement equipment) equipped with EF0391 (measurement probe with a dynamic range of 0.2-320 V/m and a frequency range of 100 kHz to 3 GHz) was used to measure the total electric-field value. The measurement uncertainty is estimated to be 4.5 dB. This uncertainty represents the expanded uncertainty evaluated using a confidence interval of 95 %. The uncertainty consists of uncertainty due to the measurement device (4.0 dB including frequency response, linearity, anisotropy, temperature, relative humidity, and repeatability), the physical parameters (1 dB, environmental etc.), and the processing uncertainty (typically 3 dB). This uncertainty is higher than the one provided by the manufacturer where not all uncertainties were accounted for.

For the narrowband measurements (background radiation), the setup consisted of tri-axial Rhode and Schwarz R&S TS-EMF isotropic antennas (dynamic range of 1 mV/m – 100 V/m for the frequency range of 80 MHz – 3 GHz) in combination with a spectrum analyzer (SA) of type R&S FSL6 (frequency range of 9 kHz – 6 GHz) (R&S, Munich, Germany). The measurement uncertainty was ± 3 dB for the considered setup(17, 18). This uncertainty represents the expanded uncertainty evaluated using a confidence interval of 95%.

C. Measurement procedure

Depending on the type of exposure characterization, occupational or environmental, two different procedures were applied.

1) Occupational: separations < 1m

First, background radiation (i.e., all microwave ovens were switched off) was measured with the SA by performing an overview measurement from 80 MHz to 3 GHz. For this measurement, the measurement probe is positioned at a height of 1.5 m, as advised by ECC(02)04[19]. This background radiation was below 0.2 V/m, which is the sensitivity of the broadband probe.

Second, the broadband measurements (100 kHz to 3 GHz) of the average electric field E_{avg} as a function of the distance to the microwave ovens were performed with both a load of 275 ml tap water at 20°C and without any load. All ovens radiate while using maximal power continuously during the measurements. For all measurements around each of the 11 microwave ovens (single oven is put on at each measurement), the position with maximal electric-field strength in front of the oven was identified and at this position measurements as a function of distance were performed. This distance or separation is defined as the distance between the edge of the oven and the middle of the measurement probe. The resulting field values were then compared to the ICNIRP 1998 guidelines[4]. Next to these measurements in front of the oven, also measurements at the left side (position a in Figure 1), the right side (position b), and the top side (position c), each time at the height of the front panel at 5 cm from the oven were performed. Because the measurements with the broadband probe occur near the microwave ovens, the oven is the dominating source and the background radiation is negligible. We thus consider these measurements as the electric fields due to leakage from the microwave ovens. The obtained electric fields E_{avg} are the measurements values in mean mode until the displayed measurement value was stable (typically 10 to 20 s).

Third, the leakage of the microwave ovens was compared with the product norm of IEC[5]. For these measurements the microwave ovens were loaded with 275 ml tap water at 20°C and the maximal power of the oven was used. At a distance of 5 cm of the oven the measurements occurred and the values were compared with the values provided by IEC[5].

Fourth, we define the exposure ratio (*ER*) as the ratio between the measured electric field value due to the microwave oven and the corresponding ICNIRP reference level[4] or IEC norm[5].

Ratios smaller than 1 satisfy the ICNIRP reference levels. Finally, the measurement data was fitted to a distance-dependent model. It should be noted that absorption in the human body, expressed in Specific Absorption Rate (SAR) values, is proportional to the observed power density, and thus the square of the electric-field strength. Therefore, a comparison with the limits expressed in squares of the values, as proposed in Ref. (22), would also be valid.

2) Environmental: separations > 1m

Unlike for small separations from the microwave oven, the fields due to the oven at larger distances will often not be dominant over the fields that originate from other sources. Due to the losses induced by the load in the microwave oven, multi-frequency modes will appear and the induced signals will be broadened[20, 21]. Hence, the microwave signal cannot be isolated by the SA from the other signals that are present in the ISM 2.4 GHz frequency band (e.g., WiFi). Therefore, a different measurement procedure is applied.

First a 'maximum-hold' measurement is performed close to the microwave oven (distance of 1 m, dominant field of the microwave) to determine the operating frequency range. A 'maximum-hold' measurement is defined here as a narrowband measurement of the signal with the maximum-hold setting kept during a time interval until the spectrum on the SA stabilizes. Figure 3 shows the electric field as function of the frequency in the ISM 2.4 GHz frequency band for the background signal (microwave off) and for the active microwave signal (microwave on). At the different measurement locations, the electric field values were measured using a narrowband measurement setup for WiFi, as proposed in Ref. (22). Root-mean-square (RMS) traces were captured during 1.5 minutes (0.5 minutes for each component of the electric field), instead of capturing the values in 'maximum-hold' mode. The average of these RMS traces is assumed to be the realistic instantaneous exposure, that can be compared to the ICNIRP 6 minutes guidelines. This narrowband measurement was performed two times, once with the microwave on and once with the microwave off. The averaged instantaneous power contribution due to the microwave oven is then the difference between both values (on minus off).

D. Impact on total exposure in WLAN deployments

The impact on the total exposure level in a building when switching on a microwave oven can be assessed by modelling these field strengths in a realistic environment (e.g., office building) and comparing them with the electric-fields due to a WLAN deployment. The latter can be predicted by a wireless network planner. Here, the microwave oven exposure values will be implemented into the WiCa Heuristic Indoor Propagation Prediction (WHIPP) tool described in Ref. (15). It uses a heuristic planning algorithm, developed and validated for the prediction and optimization of wireless coverage in indoor environments. It accounts for the effect of the environment on the wireless propagation channel and bases its calculations on the determination of the dominant path between transmitter and receiver, i.e., the path along which the signal encounters the lowest obstruction. The model, constructed for the 2.4 - 2.6 GHz band, has shown excellent correspondence between predictions and validation measurements as shown in Ref. (15). The tool allows automatic network planning based on a user-defined throughput using a minimal number of access points (APs) (*traditional deployment*) or a planning for a minimal human exposure (*exposure-optimized deployment*). Further, WHIPP allows simulating the electric-field values corresponding to a certain deployment. For this research, it has been extended with a simulation of the fields due to an active microwave oven. The implemented microwave oven model will be derived from the environmental measurements. This allows investigating how exposure values are impacted when switching on a microwave oven.

III. RESULTS AND DISCUSSION

A. Occupational exposure measurements (<1m)

1) No loading of microwave ovens

Table 2 lists the average measured electric field values and the exposure ratio ER as a function of distance from the various microwave ovens. The values in front of the oven are higher than those left, right, top, back (see lower part of Table 2 and Figure 1 for indication of measurement locations). Thus, the highest leakage is in front of the oven due to the door and closings of the ovens. Figure 4 shows the field values in front of the microwave ovens as a function of distance. The fields clearly decrease rapidly with increasing distance from the microwave ovens.

At all locations the field values satisfy the reference levels of ICNIRP(4) for both occupational exposure and the general public. The highest field values are obtained at the nearest distance where the measurements were executed i.e., 5 cm. The maximal field value was measured at 5 cm in front of microwave oven 3 (900 Watt) and equals 55.2 V/m. This value is about 2 times below the ICNIRP reference levels (ER = 0.4) for occupational exposure(4). Not only the maximal power of the different microwave ovens (here ranging from 800W to 1300W), but also other characteristics like front door quality and wear will greatly influence the leakage and thus the measured field values. Microwave leakage always satisfies the IEC-norm 335-2-25(5) of 137.3 V/m (5 mW/cm^2) at 5 cm from the oven(7, 8, 9, 10).

2) Loading of microwave ovens: 275 ml tap water

Table 3 summarizes the average measured electric field values and the exposure ratio *ER* of the fields and the limits of the IEC-norm 335-2-25(5). At 5 cm all field values satisfy the IEC-norm 335-2-25. The maximal measured value at 5 cm was measured again for microwave oven 3 (900 Watt) and equal to 32.6 V/m. This value is 4 times below the limit of IEC-norm 335-2-25. The measured electric-field values decrease with increasing oven loads (values of Table 2 without load are higher than those of Table 3 with load) because the radiation is more absorbed by the load and consequently the electric field leakage reduces. This behaviour is also seen in Figure 5, showing the maximal measured field (max(E_{avg})) of all microwave ovens as a function of distance in front of the ovens with load of 275 ml and without load.

B. Modelling as a function of the distance

1) Occupational exposure (<1m)

In this section we model the leakage of electric fields due to the ovens, based on measurements collected according to the procedure of Section II.C.1. As the results of Section III.A.1) and III.A.2) show that the fields are not correlated to the maximal power of the ovens under consideration, we can consider all measurements in front of the (domestic) microwave ovens at maximal power as a worst-case leakage for the situation with and without load. This results in a total of 88 field samples as a function of distance. The provided model will enable us to estimate a worst-case exposure.

First, all measurement data without (with) load is merged for the modeling. To model the electric-field strength as a function of distance from the microwave oven, we use the following semi-empirical formula, expressed in dBV/m (E_{dB}) and based on the Friis formula:

$$E_{dB}(d) = E_{0,dB} - 10n\log(\frac{d}{d_0}) + X \ \ [\text{dBV/m}] \quad (1)$$

where the separation d is expressed in m in this paper, $E_{0,dB}$ is the electric-field strength in dBV/m at a reference distance d_0 (0.1m in this section), and n [-] is the (path) loss exponent. X is a zero-mean normally distributed random variable with standard deviation σ that accounts for variations around the model.

Figure 6 (a) shows the microwave oven leakage field strengths and the corresponding fits. Again highest values and models are obtained without loads. Table 4 (occupational) summarizes the values of n and $E_{0,dB}$ that were obtained using linear regression fitting (equation (1)). The path loss exponents for the fields with and without load are similar as they should be because the environment of the microwave ovens was the same for both oven loads (only influences of the operators performing the measurements). The electric field is considerably higher when no load is present ($E_{0,dB}$ is 24.6 dBV/m without load compared to 20.5 dBV/m at $d_0 = 0.1$ m). The regression models have R correlation coefficients of about 0.90 and 0.83, without and with load, respectively, which is good. An F-test concluded that the regression is significant for both no load and load at the 5% significance level (p-values < 10^{-18}). Standard deviations σ of 2.67 and 3.17 dB are obtained for no load and load, respectively. These regression models can be used for exposure predictions in the close vicinity of microwave ovens.

2) Environmental exposure (>1m)

In this section, we model the electric-field strength over the building floor depicted in Figure 2, based on the ten measurement values collected according to the procedure of Section II.C.2. Equation (1) is again used to build the field strength model, but a larger distance range is considered here (between 1 m and 70 m). Table 4 lists the resulting model parameters: n = 1.51, $E_{0,dB}$ = -2.56 dBV/m at $d_0 = 1$ m. The path loss exponent is higher than for the occupational exposure case, since most environmental measurement locations are non-line-of-sight with the microwave oven here. The standard deviation of the measurements around the model equals 5.75 dB. This is also higher than for the occupational case, due to the more diverse propagation environment for which the model is derived. Figure 6 (b) shows the ten measurements and the resulting fitted model. The results are in line with the corresponding received powers reported in Ref. (12). Assuming a receiver device with a cable loss of 0 dB and an antenna gain of 0 dBi, Figure 6 yields received powers of -39.1 dBm at 6 m and -43.7 dBm at 12 m from the microwave oven, vs. -37 dBm at 6 m and -40 dBm at 12 m from the oven for the spectrum analyzer measurements in Ref. (12). Figure 6 shows than the electric-field model for occupational exposure would predict significantly higher values than for environmental exposure (e.g. at a distance of 1m, 8.5 dBV/m vs -2.56 dBV/m). This is again due to the line of sight conditions under which the occupational measurements were performed.

It should be noted that the measured field strengths can be slightly disturbed as the measurement environment was not shielded and hence, it cannot be excluded that variations in the background field occurred between measuring with the microwave oven 'off' and 'on'. However, during the measurements, it was ensured that no people passed within a range of 3 m of the measurement setup. Moreover, each measurement took about 1.5 minutes and the averaged values over these periods were calculated to minimize the influence of short peaks and to assure a stable momentary averaged exposure environment. This was also successfully validated with a background measurement before and after each microwave measurement. In the following section, the obtained environmental model will be applied to assess the impact of microwave oven usage on the total exposure due to WLAN deployments.

C. Application: impact of microwave oven leakage on exposure in WLANs

The impact of the microwave oven leakage is assessed for two network deployments: (1) a traditional network, with maximal-power APs (20 dBm), and (2) an exposure-optimized network, with lower-power APs[16]. The networks are planned according to the WHIPP tool's automatic network planning algorithm described in Ref. (15).

Figures 2 (a) and (b) show the AP locations for the *traditional* network planning. Three APs with an EIRP of 20 dBm are required to cover the building floor for a throughput of 37 Mbps. The rooms enclosed by the rectangles do not require coverage as they are elevators, sheds, kitchens,… The location of the microwave oven is indicated with a red dot. Figure 2 shows that the field strengths over the building floor for (a) with the microwave switched off are clearly lower than (b) with the microwave switched on. Table 5 lists the median (E_{50}) and 95%-percentile (E_{95}) electric-field strength values over the building floor. When the microwave oven is switched on, E_{50} and E_{95} increase from 91 mV/m to 145 mV/m (+ 59 %) and from 406 mV/m to 455 mV/m (+ 12%) respectively.

Figures 2 (c) and (d) show the network layout of an *exposure-optimized* network planning. 17 APs with low EIRPs are required to cover the same area as for the traditional network planning

(37 Mbps)[16]. Table 5 shows that when the microwave is switched on, E_{50} and E_{95} increase from 44 mV/m to 92 mV/m (+ 109%) and from 129 mV/m to 254 mV/m (+ 97%), respectively. Figure 2 compares the field strength distributions over the building floor for (c) the optimized deployment with the microwave switched off and (d) with the microwave switched on: a clear increase in field strength is noticed, not only around the microwave oven, but throughout the entire building floor. The relative increases are higher for the exposure-optimized network than for the traditional network planning (see Table 5) due to the fact that in the latter case, the field strengths are already higher with the microwave switched off, e.g., E_{50} of 91 mV/m for traditional planning vs. 44 mV/m for exposure-optimized planning.

IV. CONCLUSIONS

In this paper electric-field leakage of eleven microwave ovens in an occupational environment is studied. Measurements as a function of distance without load and with a load of 275 ml tap water were performed. The maximal measured field was 55.2 V/m at 5 cm from the oven (without load), which is 2 times below the ICNIRP occupational reference levels. All field values satisfied the ICNRIP reference levels for occupational exposure and the IEC 335-2-25 norm. Two models of the microwave leakage (electric fields) as a function of distance for oven load and no oven load are proposed. The models show agreeable goodness-of-fit and can be used for estimations of occupational exposure.

Further, a model applicable for environmental exposure (larger distances) in a realistic environment was derived. When applying the model to an office building, median exposure increases of around 100% are observed, both for traditional and exposure-optimized deployments. Field strengths are more impacted for low-exposure deployments than for traditional deployments.

Further research will consist of optimizing the network performance in presence of microwave leakage, by assessing the impact of the microwave oven disturbances on the WiFi quality of service. This requires a thorough characterization of the time and frequency behaviour of the microwave oven.

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List of captions

Table 1: List of microwave ovens (number, ID, type, power) considered for the electric field measurements and description of the position of the maximal electric field in front of the oven.

Table 2: Mean measured electric field values (E_{avg}) near the different microwave ovens and comparison with the ICNIRP reference level for occupational exposure.

Table 3: Mean measured electric field values (E_{avg}) near the different microwave ovens and comparison with the IEC-norm 335-2-25.

Table 4: Parameters for models of leakage of microwave ovens.

Table 5: Median (E_{50}) and 95% percentile (E_{95}) electric-field strength values over the building floor for traditional and exposure-optimized deployment with and without microwave oven switched on (field strength increase due to microwave oven between brackets).

Figure 1: Measurement setup near the microwave ovens and indication of the measurement positions (a: left side, b: right side, and c: top side).

Figure 2: Spatial distribution of the electric-field strength over the floor of the considered office building for (a) the traditional deployment with the microwave oven switched off, (b) the traditional deployment with the microwave oven switched on, (c) the exposure-optimized deployment with the microwave oven switched off, and (d) the exposure-optimized deployment with the microwave oven switched on. (APs = large dot with EIRP inside, M= microwave oven location, X = electric field measurement location)

Figure 3:Electric-field as a function of the frequency in the ISM band for the background signal (microwave off) and for the active microwave signal (microwave on).

Figure 4: Measured electric-field values (E_{avg}) as a function of distance for the 10 different microwave ovens and comparison with the ICNIRP reference level for occupational exposure.

Figure 5: Maximum of the measured electric-field values (over all microwave ovens) as a function of the distance in front of the ovens without load and with a load of 275 ml.

Figure 6: Measured electric-field strength of (a) all microwave ovens and fitted models without and with oven load for occupational exposure and of (b) microwave oven in office environment with load

No.	**ID**	**type**	**P_{max} [W]**	**turning table**	**position front side oven where maximum field is measured**
1	Bosch1@1000Watt	Bosch HBC86P753	1000	no	at centre in middle of window
2	Bosch2@1000Watt	Bosch HBC86P753	1000	no	at centre in middle of window
3	Siemens1@900Watt	HF25	900	no	right from dooropening above 'start' –'stop' buttons
4	Whirlpool@950Watt	Whirlpool Assisted Chef JT379	950	yes	at centre in middle of window
5	Samsung1@900Watt	Samsung Combi CP1370	900	yes	at the top in front of display
6	Samsung2@800Watt	Samsung MG23F301ELW	800	yes	in the middle: at handle at opening door
7	LG@900Watt	LG Solar DOM MP9486SC	900	yes	at centre in middle of window
8	Samsung3@800Watt	Samsung MS23F301EAW	800	yes	at the bottom of at handle at opening door
9	Panasonic@ 1300Watt	Panasonic NNT664SFX	1300	yes	in the middle: right side of window
10	Siemens2@800Watt	Microwelle Plus HFT87921FB	800	no	at the door opening, left below
11	Siemens3@800Watt	Microwelle Plus HFT87921FB	800	no	at the door opening, left below

Table 1

distance to front oven	Oven 1 Bosch @1000 Watt		Oven 2 Bosch @1000 Watt		Oven 3 Siemens1 @900Watt		Oven 4 Whirlpool @950Watt		Oven 5 Samsung1 @900Watt		Oven 6 Samsung2 @800Watt		Oven 7 LG @900Watt		Oven 8 Samsung3 @800Watt		Oven 9 Panasonic @1300Watt		Oven 10 Siemens2 @800Watt		Oven 11 Siemens3 @800Watt	
[cm]	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)
5	22.9	0.17	28.8	0.21	**55.2**	0.40	29.0	0.21	17.0	0.12	24.0	0.18	17.6	0.13	34.6	0.25	43.3	0.32	18.6	0.14	23.8	0.17
15	17.0	0.12	14.7	0.11	20.1	0.15	10.7	0.08	6.7	0.05	11.6	0.08	11.3	0.08	20.5	0.15	14.1	0.10	14.2	0.10	9.6	0.07
20	12.7	0.09	12.2	0.09	17.0	0.12	9.4	0.07	6.7	0.05	9.5	0.07	8.1	0.06	16.7	0.12	13.0	0.09	10.9	0.08	8.6	0.06
30	8.3	0.06	9.8	0.07	11.3	0.08	7.8	0.06	5.7	0.04	7.2	0.05	5.8	0.04	12.5	0.09	13.0	0.09	9.4	0.07	6.9	0.05
50	6.2	0.05	5.7	0.04	7.3	0.05	6.1	0.04	3.5	0.03	3.7	0.03	4.8	0.04	5.4	0.04	*	*	7.0	0.05	5.0	0.04
70	3.8	0.03	4.4	0.03	7.0	0.05	5.0	0.04	3.2	0.02	3.0	0.02	3.6	0.03	2.7	0.02	*	*	6.7	0.05	6.2	0.05
90			2.7	0.02	5.0	0.04	3.7	0.03											5.9	0.04		
110					3.5	0.03																
positon (at 5cm)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)
left (a)							4.0	0.03	5.5	0.04	6.9	0.05	3.8	0.03	5.5	0.04	*	*	6.0	0.04	5.4	0.04
right (b)					11.9	0.09	6.6	0.05	3.7	0.03	4.1	0.03	6.7	0.05	6.8	0.05	*	*	8.4	0.06	4.9	0.04
top (c)	4.8	0.04					8.9	0.06	5.5	0.04	3.1	0.02	4.2	0.03	6.0	0.04	*	*	3.3	0.02	2.8	0.02
back (d)															5.5	0.04						

R = exposure ratio of measured electric-field strength and ICNIRP reference level.

* : not measured due to defect of of glass of turning table

Table 2

distance to front oven	Oven 1 Bosch @1000 Watt		Oven 2 Bosch @1000 Watt		Oven 3 Siemens1 @900Watt		Oven 4 Whirlpool @950Watt		Oven 5 Samsung1 @900Watt		Oven 6 Samsung2 @800Watt		Oven 7 LG @900Watt		Oven 8 Samsung3 @800Watt		Oven 9 Panasonic @1300Watt		Oven 10 Siemens2 @800Watt		Oven 11 Siemens3 @800Watt	
[cm]	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)	E_{avg} (V/m)	ER (-)
5	18.05	0.13	14.5	0.11	**32.6**	0.24	18.2	0.13	7	0.05	5	0.04	14.7	0.11	20.6	0.15	21.2	0.15	17.6	0.13	14	0.10
15	14.1	-	9.3	-	13.6	-	9.5	-	6.9	-	4.6	-	9	-	8.5	-	11.2	-	8.3	-	8.2	-
20	9.4	-	8.8	-	11.4	-	7.8	-	6	-	3.5	-	6.5	-	6	-	9.3	-	8.4	-	8.1	-
30	5.9	-	6.8	-	10.2	-	5.1	-	4.6	-	3	-	4	-	4.1	-	7.3	-	6.3	-	6	-
50	3.8	-	3.5	-	5.6	-	3.4	-	2.9	-	2.2	-	3.1	-	2.8	-	6.8	-	5.2	-	4.6	-
70	3	-	3.4	-	5.3	-	3.5	-	2.9	-	1.4	-	2.7	-	2	-	6.3	-	4.2	-	4	-
90		-			2.4	-	3	-									3.4	-	3.6	-		
110					1.9	-																

ER = exposure ratio of measured electric-field strength and IEC-norm 335-2-25.
'-': not applicape.

Table 3

model	E_0 (dBV/m)	d_0 (m)	n	σ (dB)	R
		Occupational (<1m)			
without load	24.65	0.1	1.36	2.67	0.90
load of 275 ml	20.50	0.1	1.20	3.17	0.84
		Environmental (>1m)			
load of 275 ml	-2.56	1	1.51	5.75	0.74

Table 4

		E_{50} [mV/m]	E_{95} [mV/m]
Traditional	**microwave OFF**	91	406
	microwave ON	145 (+91%)	455 (+12%)
Exposure-optimized	**microwave OFF**	44	129
	microwave ON	92 (+109%)	254 (+97%)

Table 5

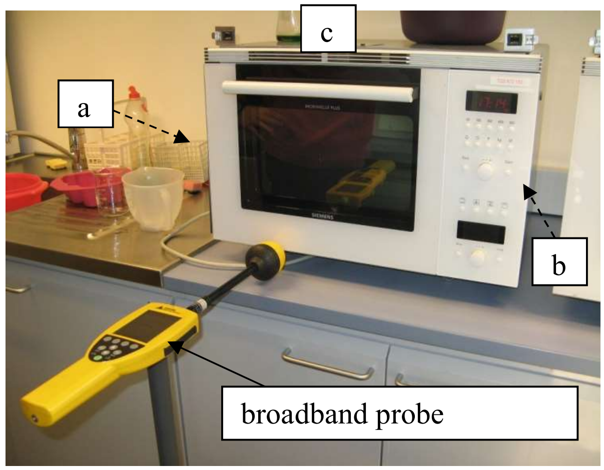


Figure 1

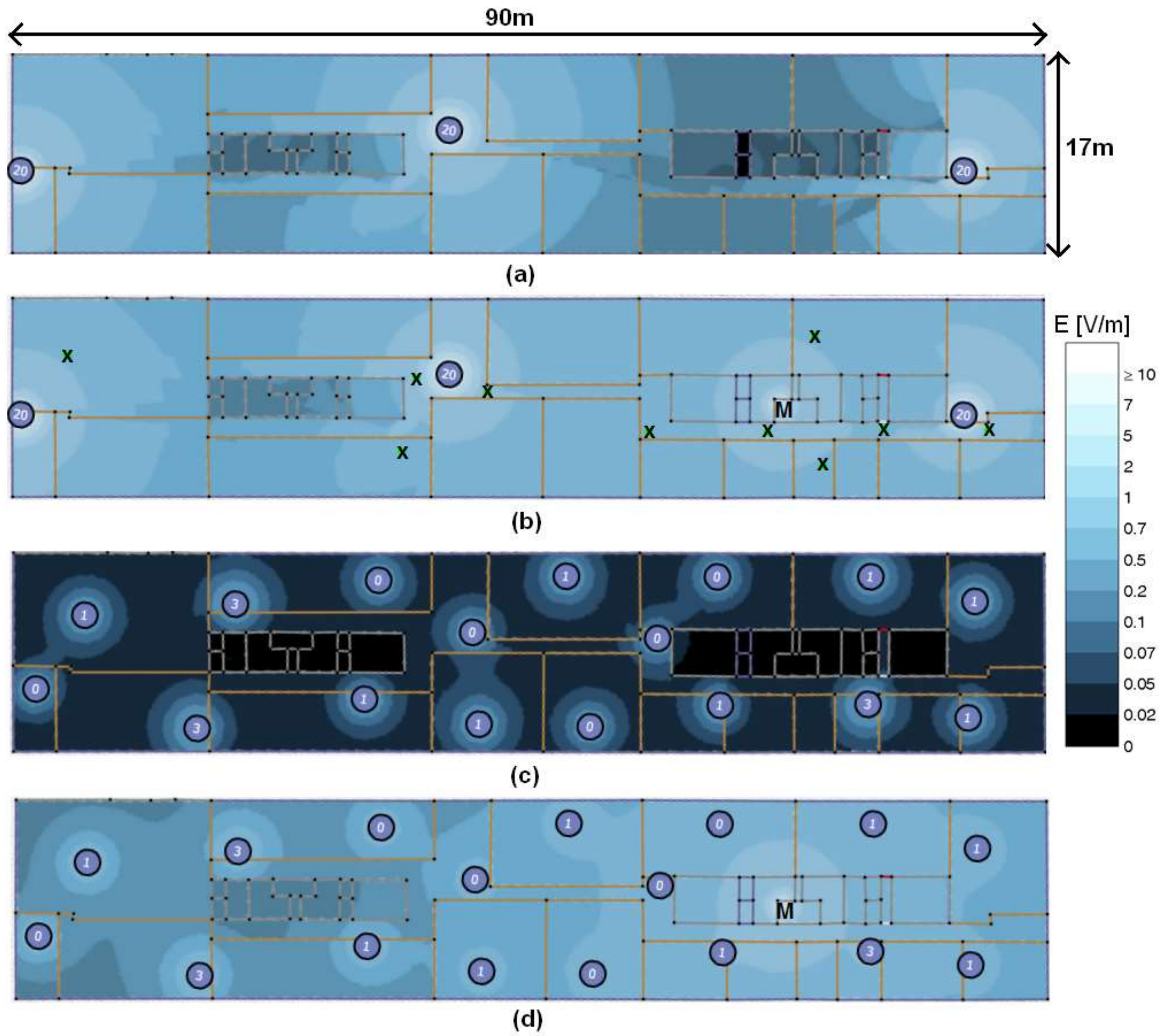
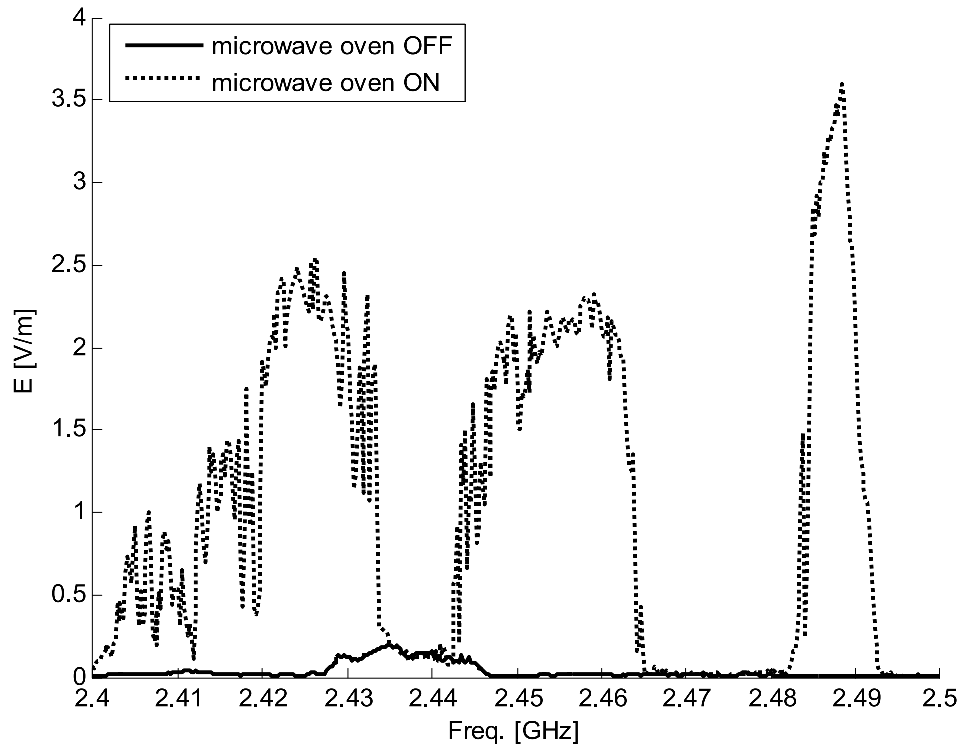
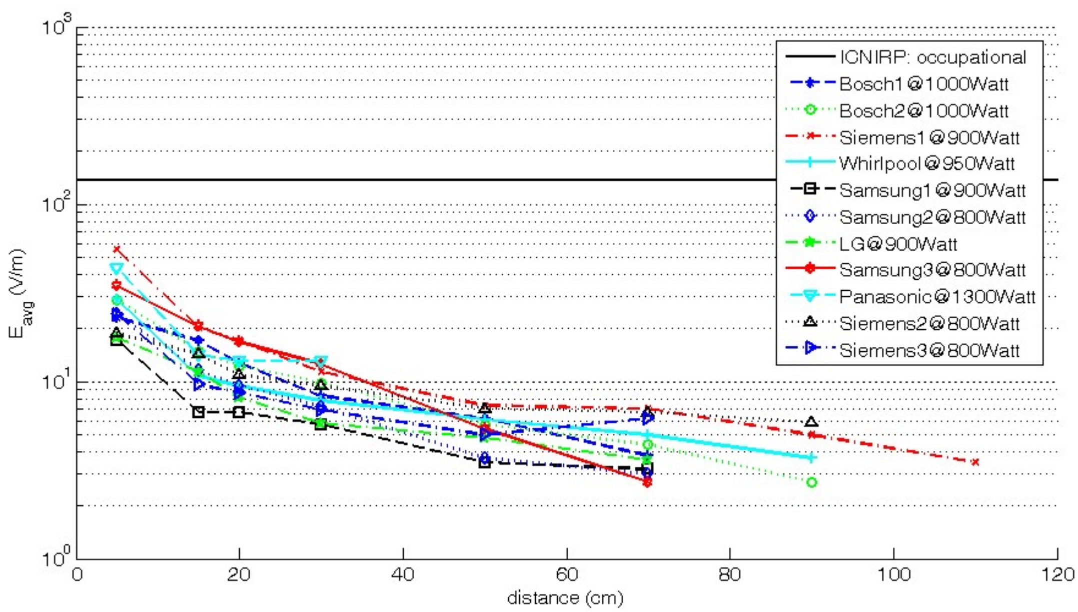


Figure 2



microwave oven OFF
microwave oven ON
E [V/m]
Freq. [GHz]

Figure 3



ICNIRP: occupational
Bosch1@1000Watt
Bosch2@1000Watt
Siemens1@900Watt
Whirlpool@950Watt
Samsung1@900Watt
Samsung2@800Watt
LG@900Watt
Samsung3@800Watt
Panasonic@1300Watt
Siemens2@800Watt
Siemens3@800Watt
E_{avg} (V/m)
distance (cm)

Figure 4

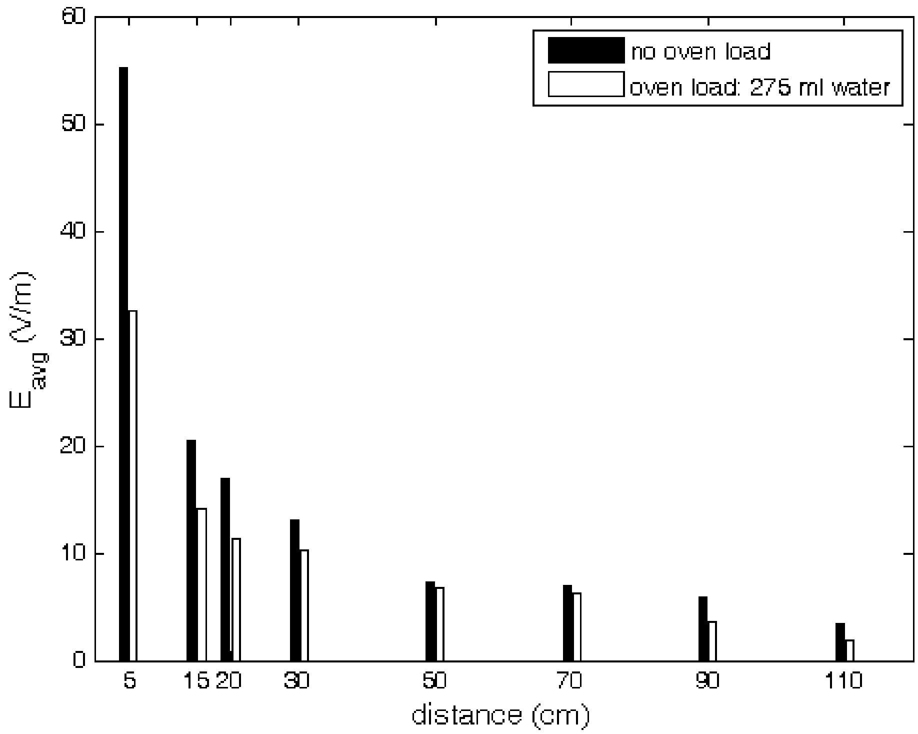
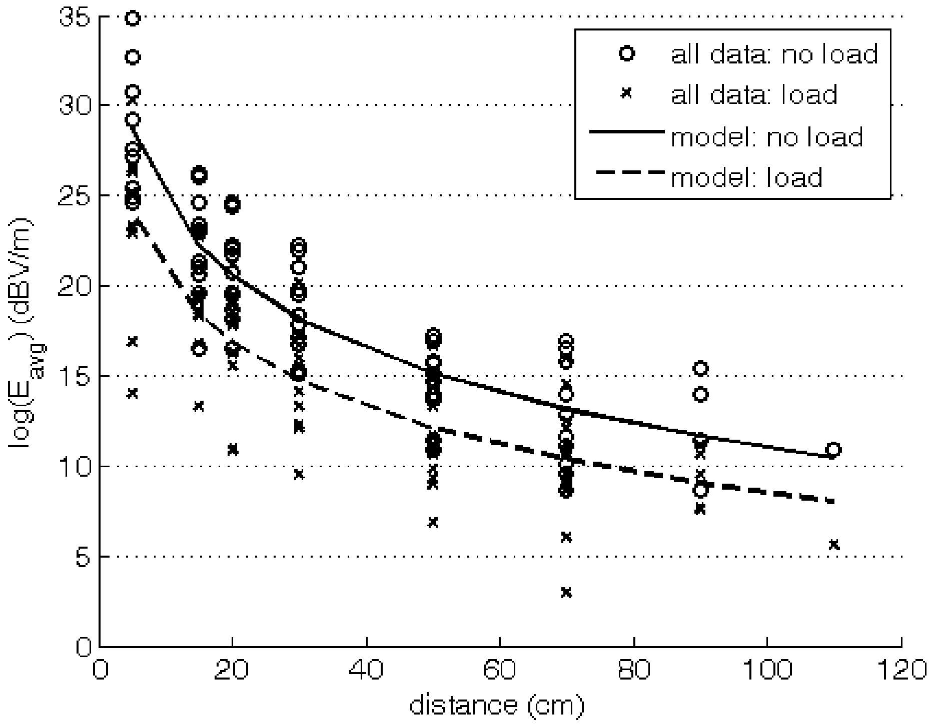
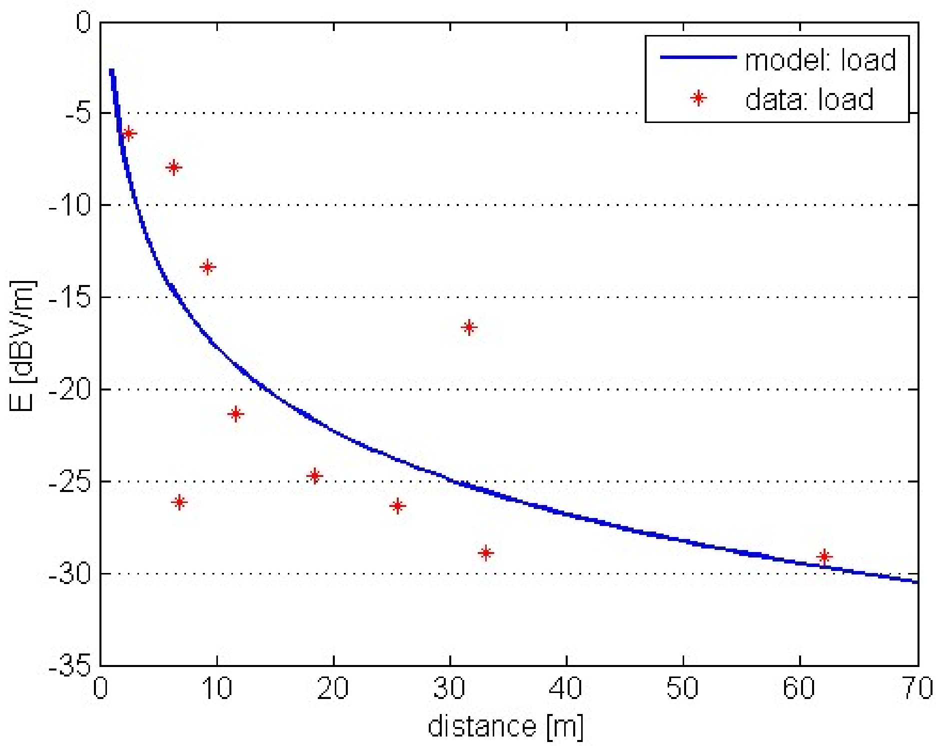


Figure 5



log(E_avg) (dBV/m)
all data: no load
all data: load
model: no load
model: load
distance (cm)

(a)



E [dBV/m]
model: load
data: load
distance [m]

(b)

Figure 6