Evaluation and SAR Analysis of Low Frequency and Broadband Electric Field Exposure Measurement Values in the Home Environment

mustafa mutlu

mustafamutlu@odu.edu.tr

Research Article

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Posted Date: March 26th, 2024

DOI: https://doi.org/10.21203/rs.3.rs-4094999/v1

Additional Declarations: No competing interests reported.

Evaluation and SAR Analysis of Low Frequency and Broadband Electric Field Exposure Measurement Values in the Home Environment

Mutlu M.[1*]

[1*]Vocational School of Technical Sciences, Ordu University, Akyazi, Altinordu, 52200, Ordu, Turkey.

Corresponding author(s). E-mail(s): mustafamutlu@odu.edu.tr;

Abstract

In this study, the effective value of low frequency (50 Hz) and high frequency (700-2500 MHz) broadband electric field exposures were measured for 24 hours in four different selected environments in a house. All statistical values of 1000 data recorded with two measuring devices for 24 hours in each environment are calculated, the most appropriate curves are fitted to the data, and the curves are plotted by expressing their changes with respect to time. All statistical and parametric values of the density and cumulative probability functions of the curves are calculated and plotted. In broadband measurements, the broadband is divided into fifteen sub-bands, but the data are available in only six of these sub-bands. The six-layer human head model is created by using the middle frequencies of the six sub-bands used, and taking the permittivity $\boldsymbol{\varepsilon_r}$ and conductivity $\boldsymbol{\sigma}$ of each layer into consideration. The specific absorption rate (SAR) value in the brain is calculated by using total transmission coefficient of six layers. SAR value surrounding the head is obtained. These SAR values are interpreted by considering the federal communications commission (FCC) and the community european (CE) occupational and general public the SAR limits.

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1 Introduction

The rapid development of technology brings with it the result of living in an intense electromagnetic field. In our homes, there is a low (50 Hz) frequency electromagnetic field exposure from the mains which is required by all electrical household appliances, and from lighting. In addition, there is also broadband induced electromagnetic field exposure. Technology, which has an important role in shaping the society, necessitates living in electromagnetic fields of varying amplitude, from the low frequency (50 Hz) formed by network and overhead lines to the high frequency of the Ku (10-12 GHz) band of satellite broadcasts. Especially with the advent of the 5G system, the frequency used in communication has increased, and the damage it has caused on human tissue has increased even more since they have greater energy. Electromagnetic exposure has become destiny in modern societies. Therefore, knowing both low and GSM-induced electromagnetic field exposure in the environments we live in is very important for the health and mental relaxation of the people in the environment. Based on this result, both low and broadband based measurements were made in four places where people living in a home environment spend a lot of time. The measurements were carried out in such a way that the devices save 1000 data in their memory for 24 hours. In the measurements made, the effective value of the electric field was recorded. The data in all measurements were compared with the limit values determined by the international radiation protection association (ICNIRP). In broadband based measurements, the band between 700 MHz and 2500 MHz was divided into fifteen bands and the band of the data was determined and their statistical values were calculated. At the same time, the data received from the memory of the devices were plotted in MATLAB depending on the time. Some studies in this area are presented below. In addition to the low-frequency electric field measurements made in six minutes at 30 different points in the city center of Diyarbakir (Turkey), magnetic field measurements were made under the high voltage line within a one-hour period and these measurement values were shown graphically. In the 50 Hz electric field measurements made at 30 points, it was noted that the limit value of 5000 V/m determined by ICNIRP was exceeded at three points [1]. Internal substations (TSs) commonly used in Spain are located inside residential buildings on the ground floor. The electromagnetic field emitted by these transformers causes people living in the surrounding buildings to be exposed to these fields. The Spanish municipality of Silla (Valencia, Spain) made measurements to determine the electromagnetic field level that people living in the buildings near these substations are exposed to, especially in places where they spend most of their time, such as bedrooms and living rooms, and whether this level is above the limit values determined in terms of health. In the light of the measurements, it is recommended that the rooms in the house where the exposure is low should be used as living or bedroom [2]. Measurements were made within six minutes in three micro-regions (school, home and office) where the electromagnetic field is concentrated, and the average value of the field and its percentages in the GSM band are indicated (Belgium) [3]. In this study, a 24-question questionnaire consisting of different variables was applied to 80 selected personnel in Corlu (Tekirdag Turkey) state hospital to determine the level of electromagnetic field exposure and to investigate its effects on the personnel working in this hospital. In order to determine the electromagnetic field, measurements were made in different parts of the hospital, and according to these measurements and the analysis results of the questionnaire, a statistically significant relationship was found between headache, weakness, irritability, fatigue and forgetfulness and the electromagnetic field level in the environment where the hospital staff were [4]. Some studies have shown that the male reproductive system is one of the most sensitive organs to electromagnetic radiation. A study was conducted to elucidate the relationship between epigenetics and radiation. Studies on mice have shown that mice exposed to a certain magnetic field cause abnormal deoxyribonucleic acid (DNA) methylation on their genes [5]. In this study, magnetic field measurements were made around medium and high voltage transmission lines. In the regions 75 m away from the transmission lines in Antalya (Turkey), there are home, school etc. The electric fields and current densities induced on living people have been investigated [6]. There has been research on how electromagnetic fields affect multiple body functions [7]. In our world created by modern technology, low-frequency electromagnetic field values created by the use of electrical devices have been measured and compared with limit values [8]. Low (50 Hz) frequency and broadband (700 MHz-2500 MHz) high frequency electric field effective values were measured at 32 points between the hours of 10:00 am and 03:00 pm on weekdays in the central campus of Ordu University (Turkey). The measurements are set to save five values in the memory of the devices in six minutes at each point. Measurement results were plotted with MATLAB, curves were fitted to the measurement values [9]. 50 Hz and broadband sourced electric field effective value measurement was made in the selected region and it was observed that the measured values were below the limit values (Turkey) [10]. In a study, it is aimed to evaluate the suitability of the work areas in terms of occupational health and safety by comparing the electromagnetic field levels in the work areas with national and international limit values, to determine the possible health effects of electromagnetic fields on the employees, to contribute to epidemiological and experimental research by determining the awareness levels of the employees on this issue and to contribute to the electromagnetic field (Turkey) [11]. Electromagnetic field values created by television (Tv), radio, mobile phone and wireless communication devices in closed areas (offices, public transportation vehicles) have been measured and evaluated [12]. An Epidemiological study was conducted in France to investigate the effects of radiofrequency electromagnetic fields (RF-EMF) on humans. In that study, measurements were taken at a distance of 250 m from the base station in 354 houses. This study is the first to assess RF-EMF exposure of people living near an mobile phone base stations (MPBS) in urban areas in France. According to that study, there were significant differences in measurements between day and night, and between weekdays and weekends [13]. The health effects of exposure under high voltage have been investigated [14]. A study was conducted to review the findings of 50 Hz exposure measurement studies conducted in European countries [15]. A study was carried out in order to determine the electromagnetic field value to which health personnel working in magnetic resonance imaging devices and diathermy devices are exposed to in eleven different institutions operating in the health sector [16]. Electromagnetic field values were measured at 44 different points in Marmara University's Goztepe campus (Istanbul, Turkey) and it was observed that all of these measured values were below the limit values [17]. In a study, EMF values created by all wireless networks were measured five times on different days and times in business, entertainment and shopping centers in the city center of USA, Columbia, SC. Then, the statistics of these measurement values were made [18]. In addition to the RF-EMF measurement results and methods made so far, a forward looking study has been conducted asking which methods and parameters should be used to guide these methods in future studies [19]. Bursa Nilufer municipality (Turkey) has prepared and presented these results in a report as a result of measurements and observations made at 74 points on 5-6 march 2007 to determine the level of electromagnetic pollution originating from high voltage lines, transformers and base stations within the borders of Bursa [20]. Within the coverage area of the base station located in the Bahcelievler neighborhood in the city center of Ordu (Turkey), the effective value measurement of the broadband sourced electric field was made at 49 points, starting from the point close to the base station and moving away from the base station, provided that it remains within the coverage area. Results are shown on the map using Google earth [21]. Broadband sourced electric field effective value measurement was made at 500 points in the city center of Ordu (Turkey). In addition, 24-hour measurements were taken in the houses opposite the base stations in the measurement areas and the results of the measurements were evaluated [22]. The measurement of the exposure values of infants living in Turkey in the electromagnetic field originating from GSM, the city of Izmir was selected as the pilot region, and the results were evaluated by measuring the electromagnetic field in the environments where a total of 151 babies living in certain houses in this city lived [23]. Electromagnetic field created by transformers and high voltage lines in certain public areas in Konya city (Turkey) center was measured and the results were compared with the limit values [24]. The summary of these studies is provided in Table 1.

Table 1 Comparison of some studies in the literature in the field of electric field measurement and evaluation at 50 Hz and broadband.

Ref.	measured frequency range	measured time	measured quantity	measured area	Calculated and plotted values and tables
[3]	WiFi, FM, GSM, and UMTS	6 minutes	E	Schools, homes, and public places located in urban environments, in Belgium	E
[4]	GSM	6 minutes	E and H	Electromagnetic fields in Corlu state hospital (Turkey) measurements were made to determine its effects on healthcare workers	E and H
[5]	50 Hz	22 hours	H	Mouse spermatocyte-derived GC-2 cell line was exposed to 50 Hz ELF-EMF (in vitro)(5 min ON and 10 min OFF)	H
[6]	50 Hz	6 minutes	H	2000 families, about 200 workers and a thousand of primary school students are in the focus of this study 380;154 ve 34.5 kV (50 Hz)(Turkey)	H
[10]	DECT	6 minutes	E and H	Measurements were made from a certain distance from DECT phones, the phone was normal, on and at the moment of ringing (Turkey)	H, E tables
[11]	Wireless telephones:(1880-1900 MHz),Public purpose radios: (45-500 MHz),Bluetooth: 2450 MHz,Microwave ovens: 2450 MHz	6 minutes	E	Radio frequency level electromagnetic field intensity measurements were carried out in the offices of five different workplaces:two public institutions, one private company, one university and one hospital(Turkey)	E tables
[13]	FM, TV3-4-5, TETRA I-II-III,2-5 GHz, Wi-Fi, WiMax, GSM 900,GSM 1800, UMTS 900, UMTS 2100,LTE 800, LTE 1800 and LTE 2600	weekdays and weekends	E	This is the first study to evaluate RF-EMF exposure of people living near (250 m away) the mobile-phone base station MPBS in urban areas in France. Such spot measurements were performed in the homes of 354 people	E_{min}, E_{median}, E_{max},E_{mean},E_{std} and tables
[14]	50 Hz	4-24 hours	H	Adults aged 16 and over in Norway testing for exposure to electromagnetic fields from high voltage power lines.	H, table
[17]	GSM	24 hours	E	Outdoor measurements were made at 44 different points at Marmara university in Goztepe campus in Istanbul (Turkey)	E table and figure

2 Material and Method

In a home environment, there are low frequency electromagnetic wave emitters originating from the mains voltage used by lighting and electronic devices, and high frequency (broadband) electromagnetic wave emitters such as mobile phone modems. Fig. 1 shows the four environments in which measurements were made and the list of low and high frequency electromagnetic emitters in these four environments.

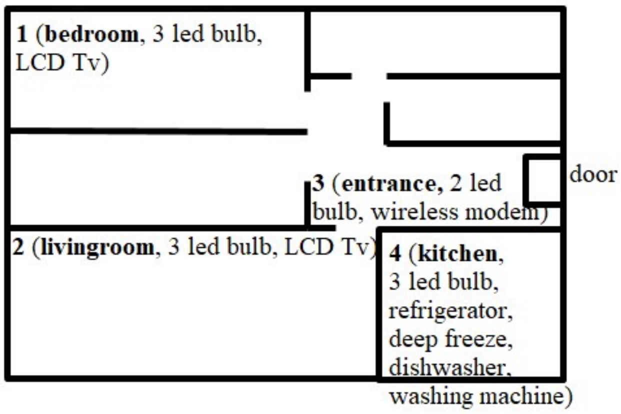

Fig. 1 Measurement environments and electronic devices in the environment

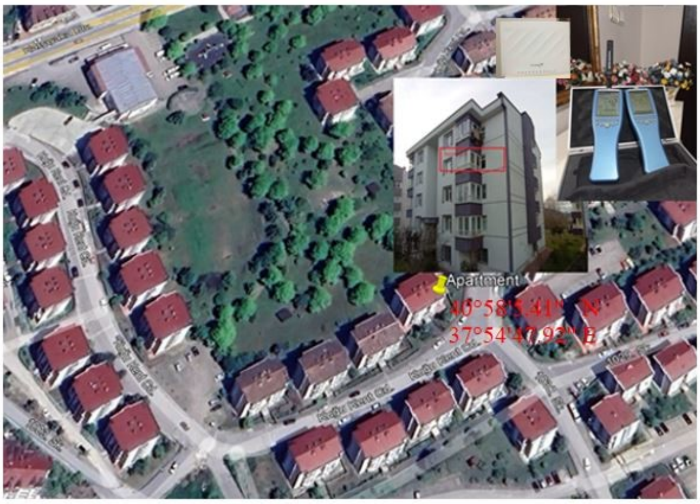

Fig. 2 Measurement place and measuring instruments

Fig. 2 shows the building, floor, wireless modem, devices where the measurement was made, and location and coordinate information via Google earth. There are institutions and organizations that determine the impact of both low and high frequency electromagnetic waves on human health, both the electric field and the limits of the SAR values created by these electric fields, especially on the human head, both nationally and internationally, depending on the frequency. While there may be countries that apply these international limit values as they are, there are countries that accept and implement values smaller than these values. While ICNIRP is the international organization that determines these limit values, information technologies and communications authority (ICTA) determines them in our country (Turkey). ICTA uses 70% of the value determined by ICNIRP. Fig. 3 shows the variation of ICNIRP and ICTA's general public exposure electric field limit values with frequency. In this study, low and broadband (700-2500 MHz) electric field effective values were measured in a house in four different environments for 24 hours. 50 Hz source measurements were made with the NF-3035 measuring device, and broadband measurements were made with the HF-60105 device and the Omnilog 90200 antenna connected to it. 1000 electric field effective values were recorded in every environment for 24 hours. The technical specifications of both measuring devices used for measurement are given in Table 2.

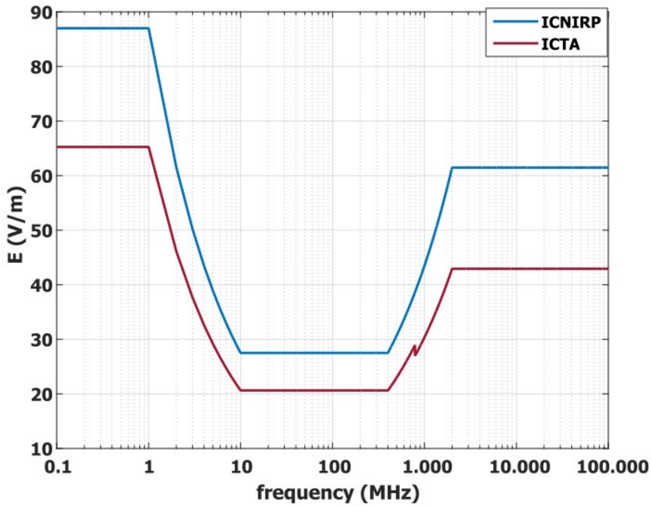

Fig. 3 Electric field limit values determined by ICNIRP and ICTA for humans ([25])

Table 2 Technical specifications of the measuring devices

	Spectran NF-5035	**Spectran HF-60105**
Frequency Range	1 Hz- 1 MHz	1 MHz-9.4 GHz
Magnetic field (Tesla)	1 pT-2 mT	
Magnetic field (Gauss)	10μG-20 G	
Electric field (V/m)	$0.1V/m - 20kV/m$	
Resolution (RBW)	0.3Hz-1MHz (1,3,10 step)	200 Hz-50 MHz
Analog Input	200 nV-200 mV	
Units	V/m, T, G, A/m	dBm, dBμV, V/m, A/m,W/m^2
Input	High impedance SMA input (f)	50 Ohm SMA RF-input (f)
Detectors	RMS	AM, FM, PM, GSM
Demodulator	AM, FM	

Broadband is divided into fifteen sub-bands, and the low and high frequency values of each sub-band and the middle frequency (f_r) of each sub-band are shown in Table 3. It can be seen from the table that broadband electric field measurement values are distributed only in six sub-bands (LTE 800, ETC 1, GSM 900, ETC 2, LTE 1800 and WLAN) and the other nine sub-bands are empty.

$$f_r = f_{lower} + \frac{f_{upper} - f_{lower}}{2} \quad (1)$$

Table 3 Division of broadband into fifteen subbands and frequency range

BANDS	$f_{lower}(MHz)$	$f_{upper}(MHz)$	$f_r(MHz)$
LTE 800	791	820.9	**805.95**
ETC1	821	925	**873**
LTE 900	925.1	935	930.05
GSM 900	935.1	961	**948.05**
ETC 2	961.1	1805	**1383.05**
GSM 1800	1805.1	1820	1812.55
LTE 1800	1820	1879	**1849.5**
DECT	1880	1899	1889.5
ETC 3	1900	2010	1955
UMTS 2100	2011	2170	2090.5
ETC 4	2171	2399	2285
WLAN	2400	2483	**2441.5**
ETC 5	2484	2569	2526.5
LTE 2600	2570	2670	2620
ETC 6	2671	3000	2835.5

By looking at the normalized root mean square error (NRMSE) values of all fitted curves, the curve with the smallest NRMSE value ($0 < R - squared <= 1$) was selected as the most suitable curve to determine whether the curves fitted to the density and cumulative probability (CP) values of the measured electric field effective values were the most suitable.

$$NRMSE = \frac{\sqrt{\frac{1}{N}\sum_1^N (x_i - \hat{x_i})^2}}{\max(x) - \min(x)} \quad (2)$$

where N is the total number of measurements, i is the sample taken, x_i is the measured electric field value, $\hat{x_i}$ is the electric field value of the fitted curve. In order to calculate the SAR values caused by broadband measurement values on the head and brain of people living in the measurement environments, the density values and density values of the six-layer human head model created using the middle frequencies (f_r) of the six sub-bands are shown in Table 4. To calculate the SAR values relative permittivity and electrical conductivity (S/m) (ε_r, σ) in Table 4.

Table 4 Electrical properties of the layers forming the head model according to the 6 sublayer frequencies

		skin	**fat**	**bone**	**dura**	**CSF**	**brain**
LTE 800	ε_r	41.66	5.47	12.51	44.55	68.85	46.04
(805.95 MHz)	σ	0.83	0.04	0.12	0.92	2.35	0.73
ETC 1	ε_r	41.44	5.46	12.46	44.42	68.72	45.84
(873 MHz)	σ	0.84	0.04	0.12	0.93	2.36	0.73
GSM 900	ε_r	41.26	5.45	12.41	44.31	68.61	45.67
(948.05 MHz)	σ	0.88	0.05	0.14	0.97	2.43	0.79
ETC 2	ε_r	40.05	5.39	12.10	43.59	67.89	44.56
(1383.05 MHz)	σ	1.03	0.06	0.21	1.15	2.68	0.97
LTE 1800	ε_r	38.83	5.33	11.76	42.83	67.12	43.42
(1849.5 MHz)	σ	1.2	0.07	0.28	1.34	2.96	1.17
WLAN	ε_r	38.04	5.28	11.38	42.04	66.23	42.53
(2441.5 MHz)	σ	1.45	0.1	0.39	1.66	3.44	1.5
$\rho(density)$ (kg/m^3)		1100	920	1850	1050	1060	1030

The six layer head model, which is given for each layer and density values (ε_r, σ) and created by taking these into account, is shown in fig. 4.

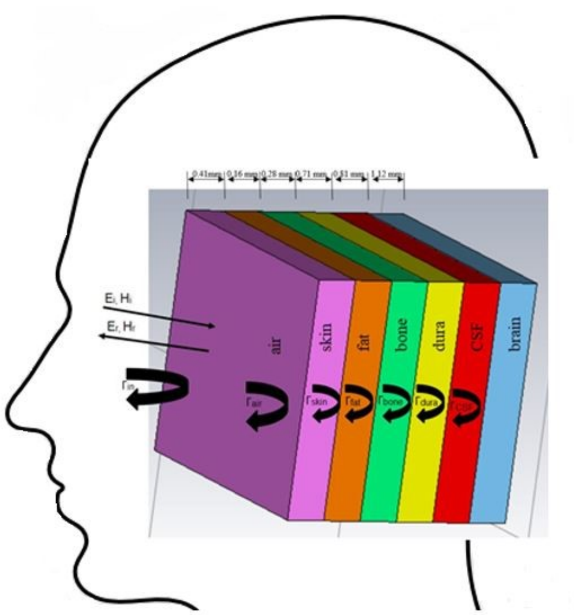

Fig. 4 Head model created for SAR calculation ([32])

Limits for SAR values are determined between 10 kHz and 10 GHz, taking as reference the 1 gr and 10 gr tissues of the exposed organ or the whole body. In this regard, while 1 gr of tissue is taken as reference in the FCC, 10 gr of tissue is taken as reference in the CE, and limit values have been determined for the working environment and public areas, as shown in the Table 5.

Table 5 Occupational and general public exposure SAR limits ([31, 32])

	Whole-body average SAR(W/kg)	**Localized SAR** (Head and Trunk)(W/kg)	**Localized SAR** (Limbs) (W/kg)
FCC (1 gr)			
Occupational Exposure	0.4	8	20
General Public Exposure	0.08	1.6	4
CE (10 gr)			
Occupational Exposure	0.4	10	20
General Public Exposure	0.08	2	4

To calculate the SAR values in the brain, all electrical components of the six-layer head model angular frequency (rad/s), permittivity (F/m), propagation constant, impedance of the medium (ω), reflection coefficient, transmission coefficient ($W, \hat{\varepsilon}, \hat{\gamma}, \hat{\eta}, \hat{\Gamma}\ and\ \hat{T}$) are found using the following equations 3-8

$$W = 2\pi f_r \tag{3}$$

$$\hat{\varepsilon} = \varepsilon(\frac{w\varepsilon_r\varepsilon_0 - i\sigma}{w\varepsilon_r\varepsilon_0}) \tag{4}$$

$$\hat{\gamma} = iw\sqrt{\mu\hat{\varepsilon}} \tag{5}$$

$$\hat{\eta} = \sqrt{\frac{\mu}{\hat{\varepsilon}}} \tag{6}$$

$$\hat{\Gamma_2} = \frac{\hat{\eta}_2 - \hat{\eta}_1}{\hat{\eta}_1 + \hat{\eta}_2} \tag{7}$$

$$\hat{T_2} = \frac{2\hat{\eta}_2}{\hat{\eta}_1 + \hat{\eta}_2} \tag{8}$$

Taking the head model (d1:0.41, d2: 0.16, d3:0.28, d4: 0.71, d5: 0.81 and d6:1.12 mm) the total reflection coefficient $\Gamma_{\hat{total}}$ seen from the entrance is calculated as

$$\hat{\Gamma}_{total} = \hat{\Gamma}_1 + \hat{\Gamma}_2 e^{-2(\hat{\gamma}_1 d_1)} + \hat{\Gamma}_3 e^{-2(\hat{\gamma}_1 d_1 + \hat{\gamma}_2 d_2)} + \hat{\Gamma}_4 e^{-2(\hat{\gamma}_1 d_1 + \hat{\gamma}_2 d_2 + \hat{\gamma}_3 d_3)} +$$
$$+ \hat{\Gamma}_5 e^{-2(\hat{\gamma}_1 d_1 + \hat{\gamma}_2 d_2 + \hat{\gamma}_3 d_3 + \hat{\gamma}_4 d_4)} + \hat{\Gamma}_6 e^{-2(\hat{\gamma}_1 d_1 + \hat{\gamma}_2 d_2 + \hat{\gamma}_3 d_3 + \hat{\gamma}_4 d_4 + \hat{\gamma}_5 d_5)} \tag{9}$$

Then, to find the electric field values reaching the brain, the total transmission coefficient is calculated using equation(10) ([30])

$$\hat{T_{in}} = 1 + \hat{\Gamma}_{total} \tag{10}$$

The electric field values reaching the brain of the broadband electric field effective values measured in four environments are obtained by

$$\overrightarrow{|E_{ibrain}|} = |\hat{T_{in}}||\overrightarrow{E_i}| \quad (11)$$

SAR value occurring in the brain is

$$SAR_{brain} = \frac{\sigma_{brain}}{\rho_{brain}} \overrightarrow{|E_{ibrain}|}^2 (W/kg) \quad (12)$$

The SAR value formed in the head part was calculated using the electric field effective values measured in four environments.

$$SAR_{skin} = \frac{\sigma_{skin}}{\rho_{skin}} \overrightarrow{|E_{iskin}|}^2 (W/kg) \quad (13)$$

where
$\overrightarrow{E_i}$: effective value of the measured electric field. (V/m)
ρ: mass density of the tissue (kg/m^3)

3 Research Results and Discussion

The variations of the low frequency and broadband electric field effective values recorded for 24 hours and the best fit curves fitted to these values are shown in fig. 5 and fig. 6, respectively.

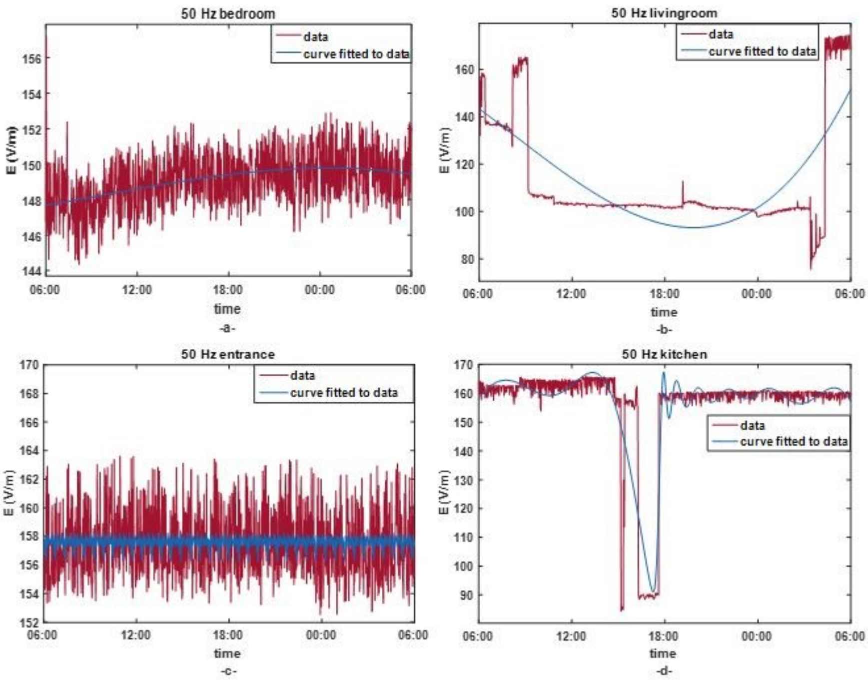

Fig. 5 Variation of 50 Hz electric field measurement values according to the number of measurements in the home environment

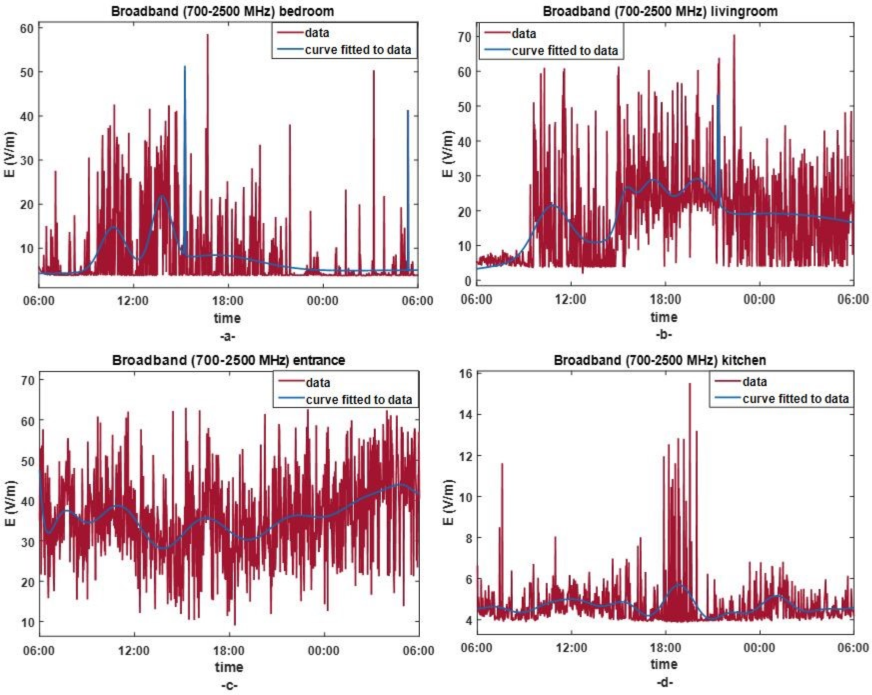

Fig. 6 Variation of broadband electric field measurement values in the home environment over time

In fig. 5, since it is the entrance of the house and there is a single lamp and modem in this environment, it is seen that the average electric field in this environment is the highest (157.55 V/m) but the change around this average (std) is 2.5 V/m. In other words, whether the lamp at the entrance is on or off does not have much of an effect on the electric field. It can be seen that the highest measured electric field value is 174 V/m and the lowest is 76 V/m. It is seen that all measured electric field values are well below the 5000 V/m limit value determined by ICNIRP for public environments, the highest measured value is 174 V/m, which corresponds to 3.48 % of the limit value. In fig. 6, it can be seen that the average and standard deviation (std) of the electric field in the entrance environment where the wireless modem is located and the livingroom environment located nearby are larger than the other two environments. As a result of using three led lamps and a mobile phone in the bedroom environment until going to bed and leaving it to charge without turning it off, the electric field value was measured higher than in the kitchen environment. It can be seen that the electric field values measured in the kitchen, which is far from the modem and where there are not many mobile phones, are quite low. Table 6 gives the statistical results of the 50 Hz electric field effective value for four environments, and Table 7 gives the statistical results of the broadband electric field effective value. According to Table 7, the highest electric field value is 71 V/m, which corresponds to 116.39% of the value determined by ICNIRP.

Table 6 Some statistical values of 50 Hz sourced electric field measurement in a home environment

50 Hz	bedroom	livingroom	break(entrance)	kitchen
Emin(V/m)	144	76	153	84
Emax(V/m)	157	174	164	166
Eaverage(V/m)	149.11	112.22	157.55	156.03
Estd(V/m)	1.63	22.65	2.5	17.56

Table 7 Some statistical values of broadband sourced electric field measurement in the home environment

Broadband	bedroom	livingroom	break(entrance)	kitchen
Emin(V/m)	4	2	9	4
Emax(V/m)	59	71	63	16
Eaverage(V/m)	7.75	18.31	35.78	4.66
Estd(V/m)	8	13.46	10.61	1.08

The lowest value is 2 V/m. Again, it is seen that the electric field value is very high in the environments where the modem is located and near it (livingroom and entrance), above the limit value of ICNIRP. According to the measurement results, ICNIRP's limit value was exceeded ten times, seven times in the living room environment and 3 times in the entrance environment. Fig. 7 shows the variations of low frequency density values and the best fit curves fitted to these values depending on the electric field values.

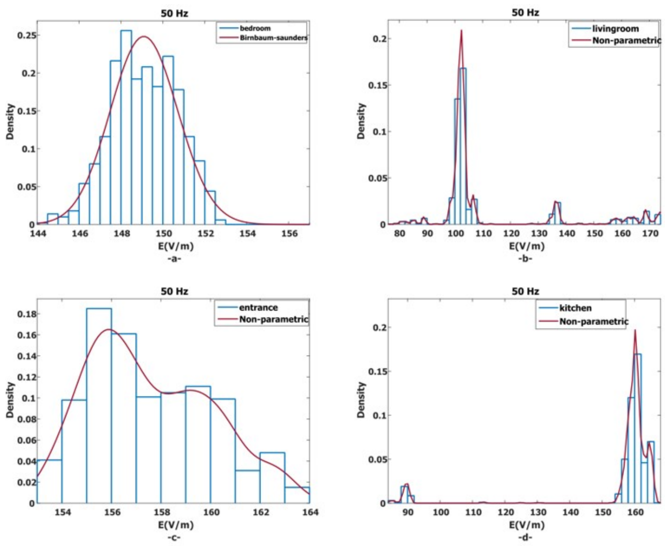

Fig. 7 Density changes of 50 Hz source electric field measurements made in four different environments and curves fitted to these changes

For example, the density (probability of occurrence) of 149 V/m in the bedroom is 0.2. Fig. 8 shows the variations of broadband density values and the best fit curves fitted to these values. Fig. 8 shows that the variations in the bedroom and kitchen are narrower band, while the variations in the other two environments where the modem is located are wider band.

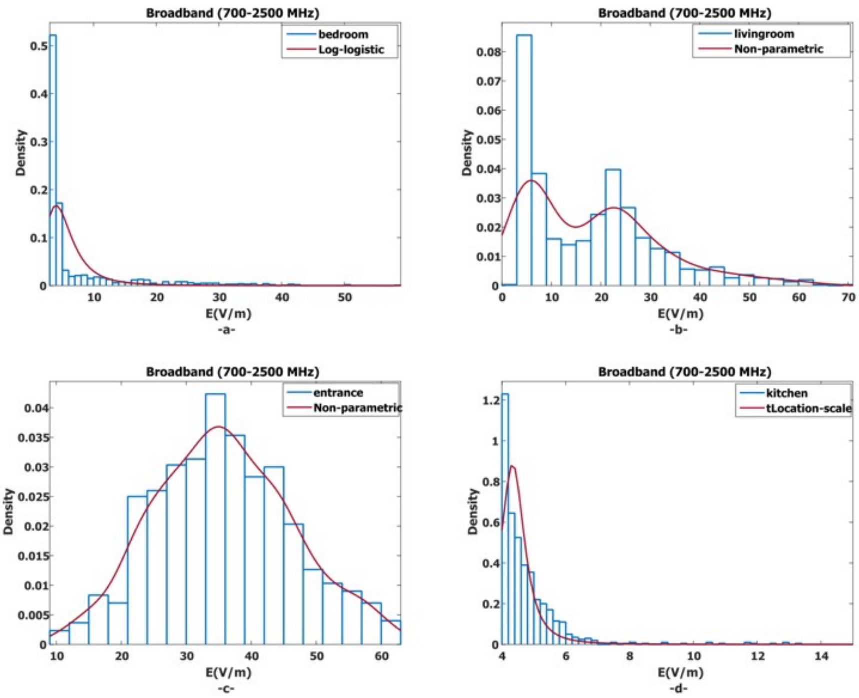

Fig. 8 Density changes of broadband induced electric field measurements made in four different environments and curves fitted to these changes

Fig. 9 shows the cumulative probability (CP) values (percentage of success) of 50 Hz measurements and the changes of the best fit curves fitted to them. It is seen that the variations curves in the bedroom and entrance are smoother and the variations in the other two environments are more variable.

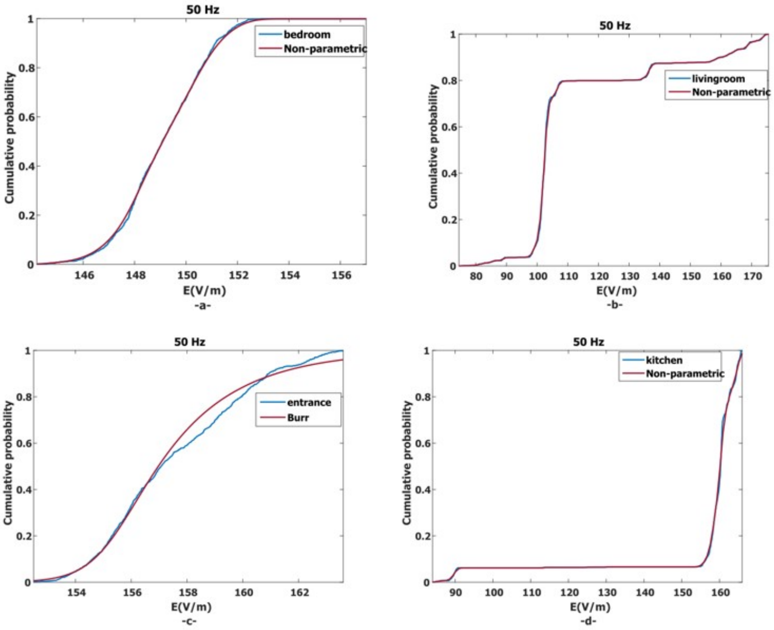

Fig. 9 Cumulative probability changes of 50 Hz source electric field measurements in four different environments and curves fitted to these changes

Table 8 Shows the distribution of measurements from GSM (700-2500 MHz) in fifteen subbands according to the number of data, total electric field and average electric field

BANDS	**Number of data (%)**				**Eaverage (V/m)/(%)**	
LTE 800	0	19/1.9	0	448/44.8	0	6.34/18.13
ETC1	30/3	0	1/0.1	1/0.1	11.36/42.68	0
GSM 900	10/1	21/2.1	0	1/0.1	7.62/28.63	5.26/15.02
ETC 2	960/96	959/95.9	998/99.8	481/48.1	7.64/28.68	18.84/53.81
LTE 1800	0	1/0.1	0	69/6.9	0	4.56/13.02
WLAN	0	0	1/0.1	0	0	0
	1	**2**	**3**	**4**	**1**	**2**
BANDS	**Etotal (V/m)/(%)**				**Eaverage (V/m)/(%)**	
LTE 800	0	120.64/0.65	0	2229.75/47.85	0	4.97/19.45
ETC1	341.03/4.39	0	26.34/0.073	6.96/0.15	26.34/34	6.96/27.24
GSM 900	76.26/0.98	110.49/0.6	0	4.68/0.1	0	4.68/18.31
ETC 2	7335.23/94.6	18070.33/98.71	35733/99.88	2101.47/45.1	35.8/46	4.36/17.07
LTE 1800	0	4.56/0.02	0	316.04/6.78	0	4.58/17.9
WLAN	0	0	14.98/0.041	0	14.98/20	0
	1	**2**	**3**	**4**	**1**	**2**
	1-bedroom	**2-livingroom**	**3-entrance**	**4-kitchen**		

In Table 8, the number, percentage, average and total of broadband electric field measurements within 1000 data in six sub-bands are given. In Table 8, of the 1000 electric field effective values measured for the 1st environment (bedroom), 960 (96%) are ETC 2, 10 of them are GSM 900 (1%) and the remaining 30 electric fields are measured in the ETC 1 (30%) sub-band. In the second environment it is seen that 959 electric field values for the medium are in the ETC

2 (95.9%), 21 in the GSM 900 (2.1%), 19 in the LTE 800 (1.9%) and 1 in the LTE 1800 (0.1%) sub-band. It can be seen from the table that the measurements are concentrated in the ETC 2 sub-band (96%;95.9%;99.8% and 48.1%).

Fig. 10 shows the cumulative probability values (percentage of success) of broadband measurements and the changes of the best fit curves fitted to them. It can be seen from the figure that the data for all four environments have a smooth change.

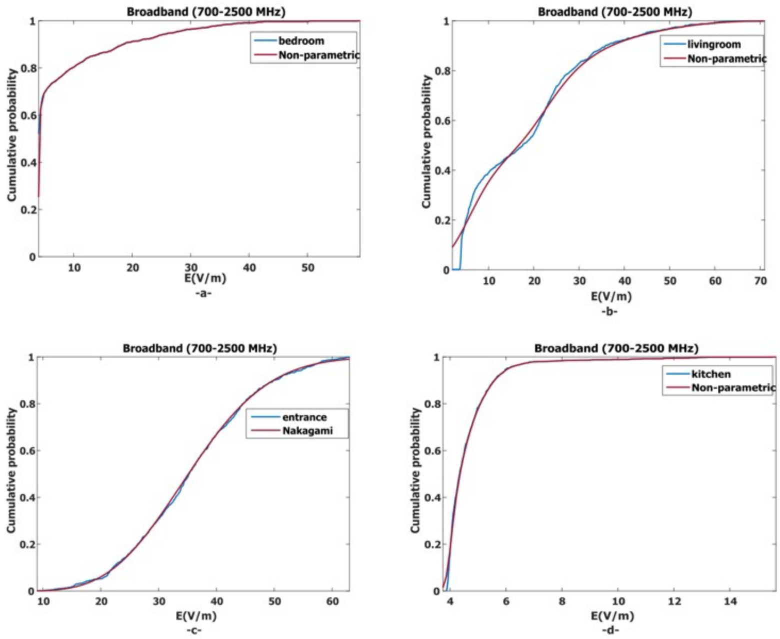

Fig. 10 Cumulative changes of broadband induced electric field measurements in four different environments and curves fitted to these changes

Tables 9-12 show the equation coefficients of the best-fit curves fitted to 50 Hz electric field measurements and the root mean square error (RMSE) values that show that they are the best-fit curve.

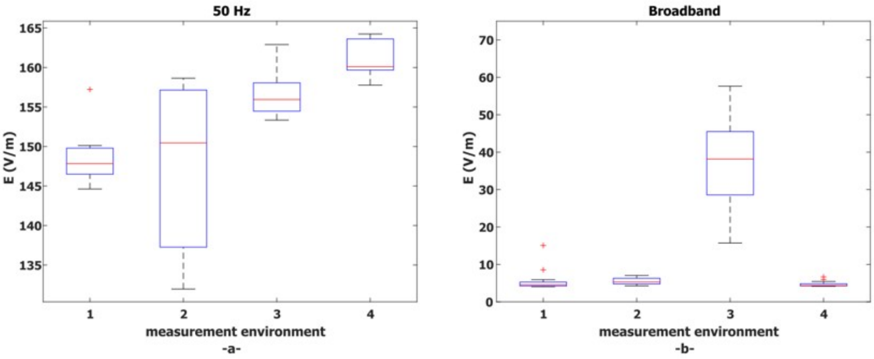

Fig. 11 Variation of the statistical values of the effective electric field values obtained in a-low frequency, b- broadband electrical measurement according to the environments

Fig. 11 shows the change of 50 Hz and broadband electric field statistical values depending on the measurement environment.

Table 9 Statistical values of curves fitted to measurements from 50 Hz in the bedroom

	Bedroom 50 Hz
$f(x) = p_1x^3 + p_2x^2 + p_3x + p_4$	**(Linear model Poly3) (Coefficients) with% 95 confidence bounds**
P_1	-3.218e^{-09}
P_2	1.419e^{-06}
P_3	0.003558
P_4	147.7
SSE	2155
R-square	0.1657
Adjusted R-square	0.1632
RMSE	1.471

Table 10 Statistical values of curves fitted to measurements from 50 Hz in the livingroom

	Livingroom 50 Hz
$f(x) = p_1x^3 + p_2x^2 + p_3x + p_4$	**(Linear model Poly3) (Coefficients) with% 95 confidence bounds**
P_1	1.759e^{-07}
P_2	-5.214e^{-05}
P_3	-0.1154
P_4	143.3
SSE	2.467e^{05}
R-square	0.5201
Adjusted R-square	0.5187
RMSE	15.74

Table 11 Statistical values of curves fitted to measurements from 50 Hz at the entrance of the house

entrance 50 Hz					
$f(x) = a_0 + a_1cos(xw) + b_1sin(xw) + a_2cos(2xw) + b_2sin(2xw)$					
$+a_3cos(3xw) + b_3sin(3xw) + a_4cos(4xw) + b_4sin(4xw) + a_5cos(5xw)$					
$+b_5sin(5xw) + a_6cos(6xw) + b_6sin(6xw) + a_7cos(7xw) + b_7sin(7xw)$					
$+a_8cos(8xw) + b_8sin(8xw)$**(General model Fourier8) (Coefficients (with 95 confidence bounds))**					
SSE			**5942**		
R-square			**0.031**		
Adjusted R-square			**0.01423**		
RMSE			**2.46**		
a_0	157.6	a_2	0.1703	b_3	-0.06462
a_1	-0.1061	b_2	-0.2106	a_4	0.01808
b_1	-0.2143	a_3	0.01614	b_4	0.1143
a_5	-0.1889	b_6	-0.1008	a_8	0.1048
b_5	-0.1366	a_7	0.2694	b_8	0.1386
a_6	0.1492	b_7	0.1988	w	0.2415

Table 12 Statistical values of curves fitted to measurements from 50 Hz in the kitchen

kitchen 50 Hz					
$f(x) = a_1exp(-((x - b_1)/c_1)^2) + a_2exp(-((x - b_2)/c_2)^2) + a_3exp(-((x - b_3)/c_3)^2) + a_4exp(-((x - b_4)/c_4)^2)$					
$+a_5exp(-((x - b_5)/c_5)^2) + a_6exp(-((x - b_6)/c_6)^2) + a_7exp(-((x - b_7)/c_7)^2) + a_8exp(-((x - b_8)/c_8)^2)$					
(General model Gauss8) (Coefficients (with 95 confidence bounds))					
SSE			**7.872**e^{04}		
R-square			**0.7445**		
Adjusted R-square			**0.7385**		
RMSE			**8.981**		
a_1	86.88	b_2	61.66	c_3	113.2
b_1	364.7	c_2	328.7	a_4	159.9
c_1	141.2	a_3	92.56	b_4	968.5
a_2	163.6	b_3	740.6	c_4	221
a_5	72.14	b_6	573.5	c_7	12.81
b_5	523.6	c_6	49.76	a_8	74.13
c_5	28.98	a_7	61.68	b_8	645.8
a_6	91.71	b_7	495	c_8	65.56

It is seen that the curves fitted in the first two environments are linear (linear model, Pol3), while the curves fitted in the other two environments are more complex (Fourier 8 and Gaussian 8). Table 13-16 shows the equation coefficients of the best fit curves fitted to broadband electric field measurements and the RMSE values showing that they are the best fit curve. It is seen that the curves fitted to broadband data contain more complex changes (Gaussian 6, Gaussian 8, Fourier 7 and Fourier 8) than the curves fitted to 50 Hz data.

Table 13 Statistical values of curves fitted to broadband sourced measurements in the bedroom

bedroom broadband					
$f(x) = a_1 exp(-((x-b_1)/c_1)^2) + a_2 exp(-((x-b_2)/c_2)^2) + a_3 exp(-((x-b_3)/c_3)^2) + a_4 exp(-((x-b_4)/c_4)^2) + a_5 exp(-((x-b_5)/c_5)^2) + a_6 exp(-((x-b_6)/c_6)^2)$					
(General model Gauss6) (Coefficients (with 95 confidence bounds))					
SSE			**4.504e^{04}**		
R-square			**0.2966**		
Adjusted R-square			**0.2844**		
RMSE			**6.772**		
a_1	3.828	a_2	3.29e^{13}	a_3	43.33
b_1	463	b_2	3.698e^{05}	b_3	386.1
c_1	165.1	c_2	6.79e^{04}	c_3	1.302
a_4	10.05	a_5	15.36	a_6	36.28
b_4	196.9	b_5	324.8	b_6	974
c_4	46.13	c_5	36.23	c_6	0.398

Table 14 Statistical values of curves fitted to broadband sourced measurements in the livingroom

livingroom broadband					
$f(x) = a_1 exp(-((x-b_1)/c_1)^2) + a_2 exp(-((x-b_2)/c_2)^2) + a_3 exp(-((x-b_3)/c_3)^2) + a_4 exp(-((x-b_4)/c_4)^2) + a_5 exp(-((x-b_5)/c_5)^2) + a_6 exp(-((x-b_6)/c_6)^2) + a_7 exp(-((x-b_7)/c_7)^2) + a_8 exp(-((x-b_8)/c_8)^2)$					
(General model Gauss8) (Coefficients (with 95 confidence bounds))					
SSE			**1.223e^{05}**		
R-square			**0.3249**		
Adjusted R-square			**0.309**		
RMSE			**11.19**		
a_1	20.72	b_2	640.9	c_3	3.996
b_1	1327	c_2	2.239	a_4	18.14
c_1	1047	a_3	33.95	b_4	158.3
a_2	28.71	b_3	377.2	c_4	9.626
a_5	13.99	b_6	578.9	c_7	57.2
b_5	433.5	c_6	138.6	a_8	13.7
c_5	51.52	a_7	14.06	b_8	520.9
a_6	14.71	b_7	218.1	c_8	1.777

Table 15 Statistical values of curves fitted to broadband sourced measurements at the entrance of the house

entrance broadband					
$f(x) = a_0 + a_1 cos(xw) + b_1 sin(xw) + a_2 cos(2xw) + b_2 sin(2xw)$					
$+a_3 cos(3xw) + b_3 sin(3xw) + a_4 cos(4xw) + b_4 sin(4xw) + a_5 cos(5xw)$					
$+b_5 sin(5xw) + a_6 cos(6xw) + b_6 sin(6xw) + a_7 cos(7xw) + b_7 sin(7xw)$					
(General model Fourier7) (Coefficients (with 95 confidence bounds))					
SSE			**9.633e^{04}**		
R-square			**0.145**		
Adjusted R-square			**0.132**		
RMSE			**9.894**		
a_0	8.07e^{05}	a_2	-9.395e^{05}	b_3	4.618e^{05}
a_1	-3.51e^{05}	b_2	4.973e^{05}	a_4	1.587e^{05}
b_1	-1.41e^{06}	a_3	4.118e^{05}	b_4	-2.3e^{05}
a_5	-8.65e^{04}	b_6	2.02e^{04}	w	0.0025
b_5	-3.35e^{04}	a_7	2275		
a_6	-2907	b_7	-166.1		

Table 16 Statistical values of curves fitted to broadband sourced measurements in the kitchen

kitchen broadband					
$f(x) = a_0 + a_1 cos(xw) + b_1 sin(xw) + a_2 cos(2xw) + b_2 sin(2xw)$					
$+a_3 cos(3xw) + b_3 sin(3xw) + a_4 cos(4xw) + b_4 sin(4xw) + a_5 cos(5xw)$					
$+b_5 sin(5xw) + a_6 cos(6xw) + b_6 sin(6xw) + a_7 cos(7xw) + b_7 sin(7xw)$					
$+a_8 cos(8xw) + b_8 sin(8xw)$					
(General model Fourier8) (Coefficients (with 95 confidence bounds))					
SSE			**1055**		
R-square			**0.09818**		
Adjusted R-square			**0.08257**		
RMSE			**1.037**		
a_0	4.661	a_2	-0.01501	b_3	-0.1376
a_1	-0.0946	b_2	-0.06967	a_4	0.1207
b_1	0.0768	a_3	-0.1605	b_4	0.2496
a_5	0.1179	b_6	0.1449	a_8	-0.1062
b_5	-0.1034	a_7	0.0322	b_8	0.0761
a_6	-0.02816	b_7	-0.1684	w	0.0064

Table 17 gives the naming of the most suitable curves fitted to the density and cumulative probability values of broadband and 50 Hz electric field measurements. For example, it shows the curve fitted to the broadband density function made in 11 bedrooms and the curve fitted to the 50 Hz cumulative probability (CP) values made in 82 kitchens.

Table 17 Measurement environments, the table showing the frequency of these media with density and cumulative probability (CP)

	Broadband Density	**50 Hz Density**	**Broadband CP**	**50 Hz CP**
Bedroom	11	51	12	52
Livingroom	21	61	22	62
Entrance	31	71	32	72
Kitchen	41	81	42	82

In Table 18, NRMSE values of the most appropriate values adapted to 50 Hz and broadband electric field density values in four environments are given. For example, it can be seen that the most suitable curve fitted to 50 Hz density values is in the Birnbaum Saunders structure and the NRMSE value is 0.001325, which is the lowest value in column 51 in the table.

Table 18 Function type and NRMSE value that gives the best result of curves fitted to the electric field density values found by measurement

Density	**NRMSE**							
	Broadband Density				**50 Hz Density**			
	11	**21**	**31**	**41**	**51**	**61**	**71**	**81**
Birnbaum-Saunders	0.002153	0.000137	9.47 10^{-05}	0.009598	**0.001325**	0.00067	0.002355	0.000579
Burr			5.71 10^{-05}		11.54964	0.000559	0.00195	
Gamma	0.002263	0.000275	6.89 10^{-05}	0.010405	11.55011	0.000675	0.002372	0.000573
Inverse Gaussian	0.002119	0.000149	9.57 10^{-05}	0.009587	11.55012	0.00067	0.002355	0.000579
Log-Logistic	**0.001985**	0.000135	6.68 10^{-05}	0.00707	11.55005	0.000641	0.002415	0.000506
Logistic				0.009096	11.55001	0.000661	0.002454	0.00047
Lognormal	0.002106	0.000138	8.97 10^{-05}	0.009424	11.55013	0.00067	0.002354	0.000578
Nakagami	0.002384	0.000102	5.77 10^{-05}	0.011523	11.55009	0.000681	0.002389	0.000568
Non-Parametric	0.002741	**0.000101**	**5.22** 10^{-05}	0.006546	11.55052	**8.68** 10^{-05}	**0.001763**	**5.89** 10^{-05}
Normal	0.00253	0.000123	5.59 10^{-05}	0.012344	11.55008	0.000686	0.002406	0.000562
Rayleigh	0.002528	0.000123	0.000197	0.015517		0.000719		
Rician	0.002528	0.000123	5.56 10-05	0.012308	11.55008	0.000686	0.002407	0.000562
t Location-Scale	0.002511			**0.005863**	11.55007	8.95 10^{-05}	0.002407	7.6 10^{-05}
Weibull	0.00229	0.000108	6.59 10^{-05}	0.013813	11.55004	0.000698		7.6 10^{-05}

In Table 19, the list of curves fitted to the electric field cumulative probability values measured in four environments and the NRMS values of the most suitable curves are given. For example, it is seen that the NRMSE value of the curve fitted to broadband cumulative probability values in a 12 bedroom environment is 4.7710^{-5}.

Table 19 Function type and NRMSE value that gives the best result of curves fitted to the electric field CP values found by measurement

CP	**NRMSE**							
	Broadband (CP)				**50 Hz (CP)**			
	12	**22**	**32**	**42**	**52**	**62**	**72**	**82**
Birnbaum-Saunders	0.001482	0.000672	0.000441	0.002497	0.00146	0.002134	0.003084	0.004198
Burr			0.00014		0.001468	0.001554	**0.002687**	
Gamma	0.001386	0.000548	0.000224	0.003034	0.001442	0.002201	0.003115	0.001892
Inverse Gaussian	0.00142	0.000761	0.000448	0.002496		0.002133		0.002012
Log-Logistic	0.001273	0.000766	0.000336	0.001971	0.001903	0.001915	0.00315	0.001154
Logistic		0.000763		0.002371	0.001885	0.002084	0.00315	0.00097
Lognormal	0.001346	0.000706	0.000406	0.00238	0.001456	0.002124	0.003082	0.00199
Nakagami	0.001614	0.000523	**9.7** 10^{-05}	0.003915	0.001423	0.002287	0.003147	0.001804
Non-Parametric	**4.77** 10^{-05}	**0.000456**	0.000127	**0.000554**	**0.000141**	**2.4** 10^{-05}	0.003147	**0.000189**
Normal		0.000796	0.000176		0.0014	0.002363		0.001691
Rayleigh	0.002607		0.001935	0.009986				
Rician	0.002607	0.001089	0.000155	0.004579	0.001404	0.00236	0.00318	0.001691
t Location-Scale	0.001607	0.000764		0.003233	0.001429	0.001387		0.000521
Weibull	0.001185	0.000518	0.000209	0.006876	0.001429	0.002551	0.005968	0.000852

The mathematical expressions of the curves applied to the measurement results are given below (Density function).

$$\frac{2m^m}{\Gamma(m)m^m} x^{2m-1} \exp\left(-\frac{mx^2}{\Omega}\right), \forall x \geq 0, \quad m \geq 0.5, \quad \Omega > 0 \tag{14}$$

$$\mu = mean_{nakagami} = \frac{\Gamma(m+0.5)}{\Gamma(m)} \left(\frac{\Omega}{m}\right)^{0.5} \tag{15}$$

$$\sigma^2 = varian_{nakgami} = \Omega \left(1 - \frac{1}{m}\left(\frac{\Gamma(m+0.5)}{\Gamma(m)}\right)^2\right) \tag{16}$$

$$f(x;c,k)_{burr} = \frac{ckx^{c-1}}{(1+x^c)^{k+1}}, \quad c > 0, \quad k > 0 \tag{17}$$

$$f(x)_{birn-sau} = \frac{\sqrt{\frac{\beta}{x-\mu}} + \sqrt{\frac{x-\mu}{\beta}}}{2\gamma(x-\mu)} \phi\left(\frac{-\sqrt{\frac{\beta}{x-\mu}} + \sqrt{\frac{x-\mu}{\beta}}}{\gamma}\right), \quad x > \mu, \quad \gamma, \beta > 0 \tag{18}$$

$$\mu_{birnbaum-saunders} = \beta\left(1 + \frac{\alpha^2}{2}\right) \tag{19}$$

$$\sigma^2_{birnbaum-saunders} = (\alpha\beta)^2\left(1 + \frac{5\alpha^2}{4}\right) \tag{20}$$

$$f(x|\mu,\sigma,\alpha)_{tLocation-scale} = \frac{\Gamma(\frac{\alpha+1}{2})}{\sigma\sqrt{\alpha\pi}\,\Gamma(\frac{\alpha}{2})} \left(\frac{\alpha + (\frac{x-\mu}{\sigma})^2}{\alpha}\right)^{(-\frac{\alpha+1}{2})} \tag{21}$$

$$f(x,\alpha,\beta)_{log-logistic} = \frac{\left(\frac{\beta}{\alpha}\right)\left(\frac{x}{\alpha}\right)^{\beta-1}}{\left(1 + (\frac{x}{\alpha})^\beta\right)^2}, \quad x > 0, \quad \alpha > 0, \quad \beta > 0 \tag{22}$$

The mathematical expressions of the curves applied to the measurement results are given below (CP).

$$F(x;m,\Omega)_{nakagami} = P\left(m, \frac{mx^2}{\Omega}\right)\frac{\gamma\left(m, \frac{mx^2}{\Omega}\right)}{\Gamma(m)} \tag{23}$$

$$F(x;c,k)_{burr} = 1-(1+x^c)^{-k}, \quad c>0, \quad k>0 \tag{24}$$

$$F(x)_{birnbaum-saunders} = \phi\left(\frac{\sqrt{x}-\sqrt{\frac{1}{x}}}{\gamma}\right), \quad x>0, \quad \gamma>0 \tag{25}$$

$$F(x;\alpha,\beta)_{log-logistic} = \frac{x^\beta}{x^\beta+\alpha^\beta}, \quad x>0, \quad \alpha>0, \quad \beta>0 \tag{26}$$

In Fig. 12, the SAR values created by the broadband electric field values in the human head and brain in four environments are given, as well as the limit values recommended by ICNIRP and accepted by FCC and CE for the general public, and their variations. As can be seen from Fig. 12, SAR values in the other three environments, except the kitchen environment, exceed both (FEC and CE) limit values. It is seen that the limit values are exceeded greatly in the entrance and living room environment where the modem is located. Especially in the entrance environment, the highest SAR value measured is 3.75 W/kg and its average is 1.74 W/kg, and this average is seen to be above the FCC's limit value. The highest SAR value measured was 4.69 W/kg in the living room environment, and this value is 293.12% of the FCC and 234.5% of the CE. It can be seen that most of the SAR value occurring in the head part of the entrance environment is above the limit values of both CE and FCC.

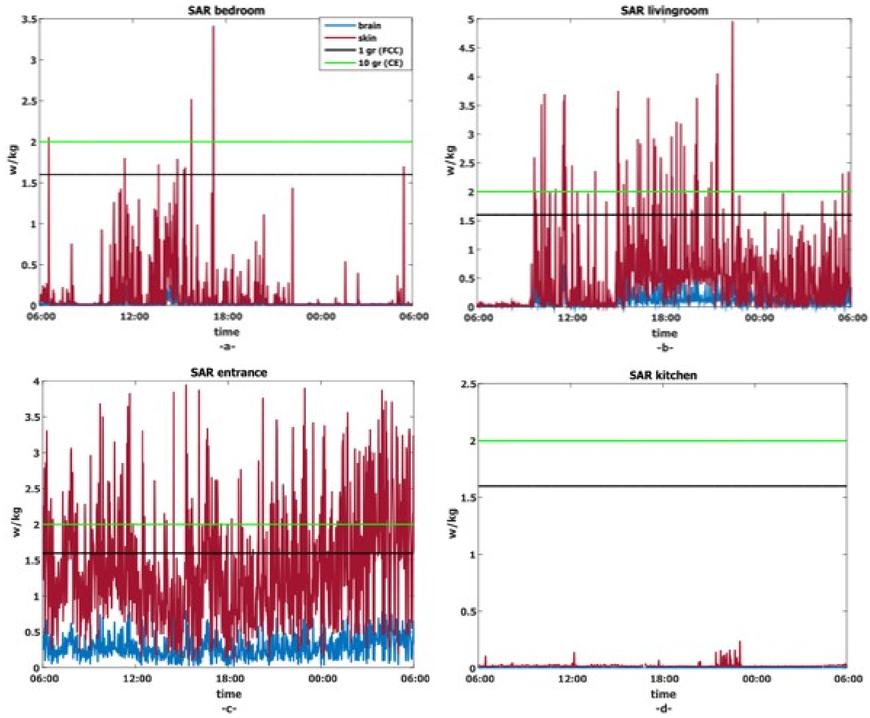

Fig. 12 Change of SAR values in the head and brain in four environments over time, taking into account the limit values of FCC and EC

In Table 20, considering the middle frequencies of the six sub-bands, all the electrical variations of each six layers are shown in the table by finding the (ε_r, σ) at these frequencies.

Table 20 All electrical properties of the head model created for SAR calculation

layer	LTE 800	ETC 1	GSM 900
	$\hat{\varepsilon}(\boldsymbol{permittivity})$	$\hat{\varepsilon}$	$\hat{\varepsilon}$
skin	$3.682 - 1.652i = 4.0358e^{-10}e^{-i24.15^{\circ}}$	$3.663 - 1.539i = 3.973e^{-10}e^{-i22.78^{\circ}}$	$3.647 - 1.487i = 3.9e^{-10}e^{-i22.18^{\circ}}$
fat	$0.4836 - 0.094i = 0.492e^{-10}e^{-i11.1^{\circ}}$	$(0.482 - 0.088i = 0.49e^{-10}e^{-i10.43^{\circ}}$	$0.482 - 0.087i = 0.489e^{-10}e^{-i10.34^{\circ}}$
bone	$1.106 - 0.24i = 1.13e^{-10}e^{-i12.56^{\circ}}$	$1.101 - 0.234i = 1.126e^{-10}e^{-i12^{\circ}}$	$1.097 - 0.247i = 1.124e^{-10}e^{-i12.69^{\circ}}$
dura	$3.938 - 1.82i = 4.338e^{-10}e^{-i24.79^{\circ}}$	$3.926 - 1.69i = 4.27e^{-10}e^{-i23.35^{\circ}}$	$3.917 - 1.64i = 4.247e^{-10}e^{-i22.74^{\circ}}$
CSF	$6.085 - 4.65i = 7.659e^{-10}e^{-i37.37^{\circ}}$	$6.074 - 4.31i = 7.451e^{-10}e^{-i35.38^{\circ}}$	$6.094 - 4.08i = 7.315e^{-10}e^{-i33.97^{\circ}}$
brain	$4.069 - 1.44i = 4.316e^{-10}e^{-i19.49^{\circ}}$	$4.051 - 1.34i = 4.26e^{-10}e^{-i18.38^{\circ}}$	$4.037 - 1.326i = 4.249e^{-10}e^{-i18.17^{\circ}}$
	$\hat{\gamma}(\boldsymbol{Propagation\ constant})$	$\hat{\gamma}$	$\hat{\gamma}$
skin	$23.861 + 111.46i = 113.984e^{i77.88^{\circ}}$	$24.21 + 120.1ie^{i78.57^{\circ}}$	$25.49 + 129.99i = 132.463e^{i78.87^{\circ}}$
fat	$3.854 + 39.646i = 39.833e^{i84.41^{\circ}}$	$3.917 + 42.882i = 43.060e^{i84.74^{\circ}}$	$4.212 + 46.6528i = 46.718e^{i84.79^{\circ}}$
bone	$6.614 + 60.043i = 60.407e^{i83.67^{\circ}}$	$6.823 + 64.861i = 65.219e^{i83.96^{\circ}}$	$7.83 + 70.351i = 70.786e^{i83.61^{\circ}}$
dura	$25.381 + 115.42i = 118.178e^{i77.5^{\circ}}$	$25.73 + 124.48i = 127.109e^{i78.28^{\circ}}$	$27.139 + 134.86i = 137.55e^{i78.58^{\circ}}$
CSF	$50.32 + 148.74i = 157.02e^{i71.27^{\circ}}$	$51 + 159.83i = 167.77e^{i72.27^{\circ}}$	$52.768 + 172.63i = 180.514e^{i72.97^{\circ}}$
brain	$19.96 + 116.18i = 117.88e^{i80.21^{\circ}}$	$20.293 + 125.37i = 126.99e^{i80.77^{\circ}}$	$21.74 + 135.85i = 137.582e^{i80.87^{\circ}}$
	$\hat{\eta}(\boldsymbol{impedance})$	$\hat{\eta}$	$\hat{\eta}$
skin	$54.516 + 11.67i = 55.751e^{i12.07^{\circ}}$	$55.077 + 11.103i = 56.185e^{i11.39^{\circ}}$	$55.377 + 10.859i = 56.431e^{i11.09^{\circ}}$
fat	$158.78 + 15.439i = 159.533e^{i5.55^{\circ}}$	$159.19 + 14.543i = 159.853e^{i5.21^{\circ}}$	$159.35 + 14.427i = 160.005e^{i5.17^{\circ}}$
bone	$104.57 + 11.519i = 105.198e^{i6.28^{\circ}}$	$104.96 + 11.043i = 105.543e^{i6^{\circ}}$	$104.95 + 11.683i = 105.602e^{i6.34^{\circ}}$
dura	$52.517 + 11.548i = 53.772e^{i12.39^{\circ}}$	$53.031 + 10.964i = 54.153e^{i11.67^{\circ}}$	$53.273 + 10.721i = 54.341e^{i11.37^{\circ}}$
CSF	$38.334 + 12.97i = 40.469e^{i18.68^{\circ}}$	$39.086 + 12.473i = 41.028e^{i17.69^{\circ}}$	$39.601 + 12.105i = 41.410e^{i16.89^{\circ}}$
brain	$53.126 + 9.131i = 53.905e^{i9.74^{\circ}}$	$53.505 + 8.660i = 54.201e^{i9.19^{\circ}}$	$53.649 + 8.585i = 54.332e^{i9.08^{\circ}}$
	$\hat{T}(\boldsymbol{Transmission\ constant})$	$\hat{T}$	$\hat{T}$
skin	$0.253 + 0.0472i = 0.258e^{i10.52^{\circ}}$	$0.256 + 0.044i = 0.259e^{i9.92^{\circ}}$	$0.257 + 0.043i = 0.260e^{i9.66^{\circ}}$
fat	$1.483 - 0.043i = 1.483e^{-i1.69^{\circ}}$	$1.48 - 0.041i = 1.481e^{-i1.6^{\circ}}$	$1.479 - 0.039i = 1.480e^{-i1.54^{\circ}}$
bone	$0.794 + 0.006i = 0.794e^{i}0.43^{\circ}$	$0.795 + 0.006 = 0.795e^{i0.47^{\circ}}$	$0.795 + 0.009i = 0.795e^{i0.71^{\circ}}$
dura	$0.675 + 0.047i = 0.677e^{i4.04^{\circ}}$	$0.677 + 0.044i = 0.679e^{i3.74^{\circ}}$	$0.679 + 0.039i = 0.680e^{i3.31^{\circ}}$
CSF	$0.858 + 0.053i = 0.860e^{i3.59^{\circ}}$	$0.861 + 0.051i = 0.863e^{i3.42^{\circ}}$	$0.864 + 0.048i = 0.866e^{i3.18^{\circ}}$
brain	$1.143 - 0.076i = 1.145e^{-i3.83^{\circ}}$	$1.139 - 0.072i = 1.141e^{-i3.66^{\circ}}$	$1.135 - 0.067i = 1.137e^{-i3.41^{\circ}}$
	$\hat{\Gamma}(\boldsymbol{Reflection\ constant})$	$\hat{\Gamma}$	$\hat{\Gamma}$
skin	$-0.746 + 0.047 = 0.747e^{i176.38^{\circ}}$	$-0.744 + 0.044i = 0.745e^{i176.55^{\circ}}$	$-0.742 + 0.043i = 0.744e^{i176.62^{\circ}}$
fat	$0.483 - 0.043i = 0.485e^{-i5.17^{\circ}}$	$0.48 - 0.041i = 0.482e^{-i4.93^{\circ}}$	$0.479 - 0.039i = 0.481e^{-i4.75^{\circ}}$
bone	$-0.205 + 0.006i = 0.225e^{i178.29^{\circ}}$	$-0.204 + 0.006i = 0.204e^{i178.15^{\circ}}$	$-0.204 + 0.009i = 0.205e^{i177.23^{\circ}}$
dura	$-0.324 + 0.047i = 0.327e^{i171.61^{\circ}}$	$-0.322 + 0.044i = 0.325e^{i172.16^{\circ}}$	$-0.321 + 0.039i = 0.323e^{i173^{\circ}}$
CSF	$-0.141 + 0.053i = 0.151e^{i159.516^{\circ}}$	$-0.138 + 0.051i = 0.147e^{i159.54^{\circ}}$	$-0.135 + 0.048i = 0.143e^{i160.41^{\circ}}$
brain	$0.143 - 0.076i = 0.162e^{-i28.13^{\circ}}$	$0.139 - 0.072i = 0.157e^{-i27.64^{\circ}}$	$0.135 - 0.067i = 0.151e^{-i26.55^{\circ}}$
$\hat{T_{in}}$	$0.4299 + 0.260i = 0.502e^{i31.15^{\circ}}$	$0.4558 + 0.234i = 0.512e^{i27.16^{\circ}}$	$0.4722 + 0.2032i = 0.514e^{i23.27^{\circ}}$
$\hat{\gamma_{in}}$	$-0.5701 + 0.26i = 0.626e^{i155.49^{\circ}}$	$-0.544 + 0.234i = 0.592e^{i156.74^{\circ}}$	$-0.527 + 0.203i = 0.565e^{i158.95^{\circ}}$

Table 21 continued from table 20

layer	ETC 2	LTE 1800	WLAN
	$\hat{\varepsilon}$*(permittivity)*	$\hat{\varepsilon}$	$\hat{\varepsilon}$
skin	$3.54-1.192i=3.735e^{-10}e^{-i18.6^\circ}$	$3.432-1.03i=3.584e^{-10}e^{-i16.74^\circ}$	$3.362-0.949i=3.494e^{-10}e^{-i15.76^\circ}$
fat	$(0.476-0.075i=0.482e^{-10}e^{-i8.97^\circ}$	$0.471-0.068i=0.476e^{-10}e^{-i8.29^\circ}$	$0.441-0.067i=0.447e^{-10}e^{-i8.68^\circ}$
bone	$1.069-0.247i=1.097e^{-10}e^{-i13.02^\circ}$	$1.04-0.248i=1.069e^{-10}e^{-i13.41^\circ}$	$1.006-0.255i=1.038e^{-10}e^{-i14.24^\circ}$
dura	$3.853-1.326i=4.075e^{-10}e^{-i18.98^\circ}$	$3.785-1.158i=3.959e^{-10}e^{-i17^\circ}$	$3.716-1.083i=3.87e^{-10}e^{-i16.24^\circ}$
CSF	$6-3.087i=6.748e^{-10}e^{-i27.21^\circ}$	$5.932-2.546i=6.456e^{-10}e^{-i23.22^\circ}$	$5.854-2.244i=6.269e^{-10}e^{-i20.96^\circ}$
brain	$3.938-1.12i=4.095e^{-10}e^{-i15.87^\circ}$	$3.883-1.012i=3.969e^{-10}e^{-i14.77^\circ}$	$3.759-0.979i=3.885e^{-10}e^{-i14.59^\circ}$
	$\hat{\gamma}$*(Propagation constant)*	$\hat{\gamma}$	$\hat{\gamma}$
skin	$30.425+185.72i=188.191e^{i80.66^\circ}$	$35.919+243.88i=246.513e^{i81.58^\circ}$	$44.093+318.25i=321.292e^{i82.07^\circ}$
fat	$5.294+67.445i=67.653e^{i85.47^\circ}$	$6.504+89.6511i=89.887e^{i85.81^\circ}$	$8.702+114.59i=114.922e^{i85.62^\circ}$
bone	$11.571+101.36i=102.016e^{i83.45^\circ}$	$15.737+133.72i=134.64e^{i83.25^\circ}$	$21.725+173.77i=175.31e^{i82.84^\circ}$
dura	$32.436+193.86i=196.551e^{i80.46^\circ}$	$8.315+256.22i=259.072e^{i81.46^\circ}$	$47.79+334.77i=338.16e^{i81.84^\circ}$
CSF	$59.525+245.83i=252.934e^{i76.35^\circ}$	$66.61+324.06i=330.837e^{i78.35^\circ}$	$78.33+423.19i=430.38e^{i79.48^\circ}$
brain	$27.212+195.15i=197.034e^{i82.02^\circ}$	$33.366+257.26=259.411e^{i82.57^\circ}$	$43.045+336.04i=338.789e^{i82.66^\circ}$
	$\hat{\eta}$*(impedance)*	$\hat{\eta}$	$\hat{\eta}$
skin	$57.184+9.368i=57.946e^{i9.3^\circ}$	$58.525+8.619i=59.156e^{i8.37^\circ}$	$59.349+8.222i=59.916e^{i7.88^\circ}$
fat	$160.7+12.614i=161.19e^{i4.48^\circ}$	$161.81+11.74i=162.235e^{i4.14^\circ}$	$167.03+12.684i=167.51e^{i4.34^\circ}$
bone	$106.21+12.125i=106.895e^{i6.51^\circ}$	$107.57+12.659i=108.31e^{i6.7^\circ}$	$109.08+13.638i=109.929e^{i7.12^\circ}$
dura	$54.721+9.155i=55.482e^{i9.49^\circ}$	$55.67+8.324i=56.289e^{i8.5^\circ}$	$56.356+8.045i=56.927e^{i8.12^\circ}$
CSF	$41.903+10.146i=43.114e^{i13.6^\circ}$	$43.176+8.874i=44.078e^{i11.61^\circ}$	$43.982+8.14i=44.729e^{i10.48^\circ}$
brain	$54.815+7.643i=55.346e^{i7.93^\circ}$	$55.748+7.23i=56.215e^{i7.38^\circ}$	$56.361+7.219i=56.822e^{i7.29^\circ}$
	$\hat{T}$*(Transmission constant)*	$\hat{T}$	$\hat{T}$
skin	$0.264+0.037i=0.266e^{i8.05^\circ}$	$0.269+0.034i=0.271e^{i7.23^\circ}$	$0.272+0.032i=0.274e^{i6.79^\circ}$
fat	$1.471-0.032i=1.472e^{-i1.27^\circ}$	$1.466-0.028i=1.466e^{-i1.12^\circ}$	$1.473-0.024i=1.473e^{-i0.93^\circ}$
bone	$0.797+0.016i=0.797e^{i1.21^\circ}$	$0.8+0.021i=0.8e^{i1.53^\circ}$	$0.792+0.023i=0.792e^{i1.68^\circ}$
dura	$0.683+0.023i=0.683e^{i1.96^\circ}$	$0.683+0.014i=0.684e^{i1.18^\circ}$	$0.682+0.007i=0.682e^{i0.65^\circ}$
CSF	$0.874+0.035i=0.875e^{i2.31^\circ}$	$0.878+0.026i=0.878e^{i1.74^\circ}$	$0.88+0.02i=0.88e^{i1.32^\circ}$
brain	$1.124-0.048i=1.125e^{-i2.48^\circ}$	$1.121-0.036i=1.121e^{-i1.85^\circ}$	$1.119-0.027i=1.119e^{-i1.40^\circ}$
	$\hat{\Gamma}$*(Reflection constant)*	$\hat{\Gamma}$	$\hat{\Gamma}$
skin	$-0.735+0.037i=0.736e^{i177.09^\circ}$	$-0.73+0.034i=0.731e^{i177.32^\circ}$	$-0.727+0.032i=0.728e^{i177.44^\circ}$
fat	$0.471-0.032i=0.472e^{-i3.96^\circ}$	$0.466-0.028i=0.467e^{-i3.54^\circ}$	$0.473-0.024i=0.474e^{-i2.9^\circ}$
bone	$-0.202+0.016i=0.203e^{i175.23^\circ}$	$-0.199+0.021i=0.2e^{i173.84^\circ}$	$-0.207+0.023i=0.209e^{i173.6^\circ}$
dura	$-0.316+0.023i=0.317e^{i175.77^\circ}$	$-0.316+0.014i=0.316e^{i177.44^\circ}$	$-0.317+0.007i=0.317e^{i178.59^\circ}$
CSF	$-0.125+0.035i=0.130e^{i164.3^\circ}$	$-0.121+0.026i=0.124e^{i178.25^\circ}$	$-0.12+0.02i=0.121e^{i170.4^\circ}$
brain	$0.124-0.048i=0.133e^{-i21.39^\circ}$	$0.121-0.036i=0.126e^{-i16.66^\circ}$	$0.119-0.027i=0.122e^{-i12.94^\circ}$
$\hat{T_{in}}$	$0.456+0.103i=0.467e^{i12.71^\circ}$	$0.484+0.135i=0.502e^{i15.6^\circ}$	$0.59+0.085i=0.596e^{i8.22^\circ}$
$\hat{\gamma_{in}}$	$-0.543+0.103i=0.553e^{i169.27^\circ}$	$-0.515+0.135i=0.533e^{i178.25^\circ}$	$-0.409+0.085i=0.418e^{i168.22^\circ}$

Table 21 shows the comparison between the changes revealed in the studies carried out in this field so far and my proposed study. In all this study, it is seen that the wireless modem is a very important electromagnetic wave transmitter, and people near its location are exposed to SAR above the limit values, and this situation creates health problems.

Table 22 Comparison of my work with existing studies

Ref.	measured frequency range	measured time	measured quantity	measured area	Calculated and plotted values and tables
[1]	50 Hz	One hour	E, H, GPS	Measurements were taken at 30 points outside Diyarbakir (Turkey)	E and H
[2]	50 Hz	6 minutes	H	at 31 points in houses close to transformer stations in municipality of Silla (Valencia, Spain)	H Location Age Mean Number Max Min Std Median The change of transformer age according to the average magnetic field is graphically
[8]	60 Hz	6 minutes	H	Magnetic field exposure measurement	H, table
[9]	50 Hz, broadband (700-2500 MHz), GPS	6 minutes	E, $P_r (W/m^2)$, measurement coordinate (GPS)	32 points Ordu university main campus (Turkey)	E, P_r, Google earth, E_{mean}, E_{pdf} and curve fitting
[16]	1.5 Tesla 63 MHz MR	6 minutes	E, H, S(W/m^2)	During the measurement phase of the study, measurements were taken from eleven different institutions in order to calculate the exposure of employees to MRI devices and diathermy devices, which are the strongest electromagnetic field sources in the healthcare industry, and the measurement results were evaluated by comparing them with limit values. Within the scope of the measurements, one university hospital, one state hospital, two private hospitals, four medical imaging centers, three physical therapy and rehabilitation centers were visited, and measurements were carried out by obtaining information about MR imaging procedures and diathermy device use in the institutions (Turkey)	E, H, S
[18]	4G, 5G LTE	6 minutes	E	Columbia, SC, In the city center in USA	Histogram of spatial field distribution measurements
[20]	50 Hz, broadband (700-2500 MHz)	6 minutes	E	Low frequency electric field measurement of broadband and high voltage was carried out in Bursa Nilufer municipality (Turkey)	E
[21]	50 Hz	6 minutes	E	A 6-minute measurement was made at 213 points at 6 base stations in Ordu	E, E_{pdf}
[22]	broadband (700-2500 MHz)	6 minutes	E	In Ordu 500 points broadband electric field in 6 minutes (Turkey)	E, E_{cdf},E_{pdf} pdf
[26]	100kHz-3GHz	24 hours	E	Outdoor at 5 points in Samsun city (Turkey) cross base stations	E, $E_{density}$ curve fitting, E_{max},E_{mean}, E_{std} table
[27]	100kHz-3GHz	24 hours	E	In house two locations in Samsun (Turkey)	E, $E_{density}$ curve fitting, E_{max},E_{mean}, E_{std} table
[28]	100kHz-3GHz	one week	E	In shopping mall in Samsun city (Turkey)	E, $E_{density}$ curve fitting, E_{max},E_{mean}, E_{std} table E_{cdf}
[29]	100kHz-3GHz	24 hours	E	In Samsun in (Turkey) 40 different home environments	E, $E_{density}$curve fitting, E_{max},E_{mean}, E_{std} table E_{cdf} and Curve fitting
[My study]	50 Hz, broadband (700-2500 MHz)	24 hours	E	In the entrance, livingroom, bedroom and kitchen on the 4th floor of an apartment building in Ordu kugukent (Turkey)	E, $E_{density}$, E_{max} E_{mean}, E_{std} table E_{cdf}, Curve fitting, SAR and head model

4 Conclusion

In this study, low and high frequency electric field effective value exposure measurements were recorded at four different points of a house for 24 hours, 1000 data in each environment. In 50 Hz measurements, it is seen that the lowest value of the electric field is 76 V/m, the highest value is 174 V/m, the highest average value is 157.55 V/m, and the highest standard deviation value is 22.65 V/m. The fact that the highest electric field value is 174 V/m and only 3.48% of the limit value of 5000 V/m determined by ICNIRP for general public environments shows that low frequency measurements do not cause any health problems. When we look at the broadband measurement values, it is seen that the electric field values, electric field averages and standard deviations in the entrance and living room located inside and very close to the modem are very high. It is seen that the electric field values increase in direct proportion to the time spent and the proximity of the modem to the environment. It is seen that the curves fitted to low frequency electric field measurement values are linear in the bedroom and living room, more complex in the entrance and kitchen environments, and broadband measurement values are more complex (Fourier 8, Gauss 8) for all four environments. It is seen that the most suitable curves fitted to 50 Hz density and cumulative probability data consist of non-parametric functions except bedroom (Birnbaum Saunders) and entrance (Burr). When we look at the best fit curves fitted to broadband measurement density data, it is seen that the two environments have the same (non-parametric, living room and entrance), bedroom log-logistic and kitchen location structure. It is seen that the most appropriate curves fitted to broadband cumulative probability values have the same (non-parametric) character for the other 3 environments, except for the entrance (Nakagami). In broadband measurements, it is seen that data is collected in the ETC 2 sub-band in 6 sub-bands, with the exception of the kitchen (48.1%) , and over 95% in the other 3 environments. The SAR values created by the broadband electric field measurement values in the living room and entrance area where the modem is located, are well above the limit values determined by ICNIRP for general public environments and accepted by FCC and CE, FCC corresponds to 293.12% CE corresponds to 234.5% , and these values appear to pose health risks. It turns out that the wireless modem is a significant high frequency electromagnetic emitter and should be away from the livingroom and bedroom where a lot of time is spent. This study, unlike the studies carried out in this field so far, is unique in terms of both the abundance of calculated values and the results presented, the creation of a head model in order to criticize the data in terms of health, and the calculation of the SAR values occurring in both the head and the brain and showing their changes over time together with the limit values.

Funding The author did not receive support from any organization for the submitted work. No funding was received to assist with the preparation of this manuscript. No funding was received for conducting this study. No funds, grants, or other support were received.

Declarations

Conflict of interest The author declare that I have no conflict of interest.

Replication of results The MATLAB codes used to generate the results will be uploaded in github after publication.

References

Cansiz, M. and Celik, A. R. and Kurt, M. B. (2014) Measurements of Electric and Magnetic Field Intensities at 50 Hz Mains Frequency and Comparison of Measurement Results to Icnirp's Reference Levels for General Public Exposure. Pamukkale Univ J Eng Sci.; 20 (8) (2014) 294-299.

Camba, A. N. and Garcia, J. S. and Perretta, C. G. (2018) Exposure to 50 Hz Magnetic Fields in Homes and Areas Surrounding Urban Transformer Stations in Silla (Spain): Environmental Impact Assessment. Sustainability. 10, 2641.

Verloock, L. and Joseph, W. and Goeminne, F. and Martens, L. and Verlaek, M. and Constandt, K. (2014) Assessment of Radio Frequency Exposures in Schools, Homes and Public Places in Belgium. Health Phys. 107 (6): 503-513.

Aksan, O. (2019) Bir Devlet Hastanesindeki Elektromanyetik Alan (ema) Tespiti ve Saglik Calisanlarina Olasi Saglık Etkileri. Tekirdag Namık Kemal Universitesi Fen Bilimleri Enstitusu Yuksek Lisans Tezi, 2019, Turkey.

Liu, Y. and Liu, W. and Liu, L. and Ao, J. and Zhong, L. and Cao, J. and Liu, J. (2015) Effect of 50Hz Extremely Low-Frequency Electromagnetic Fields on the DNA Methylation and DNA Methyltransferases in Mouse Spermatocyte-Derived Cell Line GC-2. Hindawi Publishing Corporation BioMed Research International, Article ID 237183, 10 pages, http://dx.doi.org/10.1155/2015/237183, 2015.

Helhel, S. and Ozen, S. (2010) Evaluation of Residential Exposure to Magnetic Field Produced by Power Lines Near Homes and Working Environments. International Journal of Engineering and Applied Sciences (IJEAS). 2 (3):1-10.

Singh, S. and Kapoor, N. (2014) Health Implications of Electromagnetic Fields, Mechanisms of Action, and Research Needs. Hindawi Publishing Corporation Advances in Biology 2014; Article ID 198609, 24 pages http://dx.doi.org/10.1155/2014/198609.

Calabrò, E. (2018) Introduction to the Special Issue, Electromagnetic Waves Pollution Sustainability. 10, 3326. https://doi.org/10.3390/su10093326.

Mutlu, M. and Kara, M. (2022) Low and High Frequency Exposure Electric Field Measurement in Ordu University Main Campus. 2nd International Technological Sciences and Design Symposium 2-5 June 2022, e-ISBN:978-975-2481-26-8, Giresun/ Turkey.

Baykan, P. and Unal, E. S. (2019) Measurement of Electromagnetic Radiation Emitted by Dect Phones Used in Office Environments and Evaluation of the Results in Terms of Occupational Health and Safety. Eastern Anatolian Journal of Science; 5 (1):7-22.

Silsupur, G. B. (2014) Ofis Ortamindaki Mesleki Elektromanyetik Alan Maruziyetinin Belirlenmesi ve Risk Duzeyinin Tespit Edilerek Cozum Onerilerinin Gelistirilmesi. T.C. Calısma ve Sosyal Guvenlik Bakanligi Is Sagligi ve Guvenligi Genel Mudurlugu, Is Sagligi ve Guvenligi Uzmanlik Tezi/Araştirma, Ankara, 2014, Turkey.

Chiaramello, E. and Bonato, M. and Fiocchi, S. and Tognola, G. and Parazzini, M. and Ravazzani, P. and Wiart, J. (2019) Radio Frequency Electromagnetic Fields Exposure Assessment in Indoor Environments: A Review. International Journal of Enviromental Research and Public Health, 16 (6):1-29.

Giudici, P.D. and Genier, J.C. and Martin, S. and Dor´e, J.F. and Ducimeti‘ere, P. and Sant, S. (2020)

Radiofrequency exposure of people living near mobile-phone base stations in France. Environmental Research journal

Tynes, T. and Klæboe, L. and Haldorsen, T. (2003) Residential and occupational exposure to 50 Hz magnetic fields and malignant melanoma: a population based study. Occup Environ Med. 60: 343-347.

Gajšek, P. and Ravazzani, P. and Grellier , J. and Samaras, T. and Bakos, J. and Thuróczy, G. (2016) Review of Studies Concerning Electromagnetic Field (EMF) Exposure Assessment in Europe: Low Frequency Fields (50 Hz-100 kHz). International Journal of Environmental Research and Public Health; 13 875; doi:10.3390/ijerph13090875, 2016.

Cal, S (2016) Saglik Sektorunde Calisanlarin Elektromanyetik Alan Maruziyetinin Belirlenmesi ve Cozum Onerilerinin Gelistirilmesi. T.C. Calisma ve Sosyal Guvenlik Bakanligi Is Sagligi ve Guvenliği Genel Mudurlugu Is Sagligi ve Guvenligi Uzmanlık Tezi, Ankara, 2016, Turkey.

Kunter, F. (2015) Students Exposure to Radio Frequency Electromagnetic Fields in Marmara University. Marmara Fen Bilimleri Dergisi. 1 (2015) 32-36. DOI: 10.7240/mufbed.70492, 2015.

Koppel, T. and Hardell, L. (2022) Measurements of radiofrequency electromagnetic fields, including 5G, in the city of Columbia, SC, USA. World Academy of Scıences Journal 4, 22. DOI: 10.3892/wasj.2022.157, 2022.

Röösli, M. and Frei, P. and Bolte, J. and Neubauer, G. and Cardis, E. and Feychting, M. and Gajsek, P. and Heinrich, S. and Joseph, W. and Mann, S. and Martens, L. and Mohler, E. and Parslow, R. C. and Poulsen, A. H. and Radon, K. and Schüz, J. and Thuroczy, G. Viel and J. F. and Vrijheid M. (2010) Conduct of a personal radiofrequency electromagnetic field measurement study: proposed study protocol. Environmental Health; 9 (23):1-14.

Cerezci, O. (2012) Bursa Nilufer ilcesi Elektromanyetik Kirlilik Raporu. Elektromanyetik Alan ve Saglik Etkileri, 1-132.

Mutlu, M. and Kurnaz, C. (2018) Evaluation of the Electromagnetic Field Levels in Ordu City Center for the Selected Base Stations' Coverage Areas. 1. International Techcnological Design Symposium (2018) 657-665. 27-29 June. Giresun/Turkey.

Kurnaz, C. and Mutlu, M. (2020) Comprehensive Radiofrequency Electromagnetic Field Measurements and Assessments: a City Center Example. Environ Monit Assess. 192 (334):1-14. https://doi.org/10.1007/s10661-020-08312-3, 2020.

Atikan, B. Y. and Bilgin, M.D. and Aksit, S. (2018) Turkiye'de bir Sehir Merkezinde Yasayan Sut Cocuklarinda ev ici Elektromanyetik Alan Maruziyeti. Balikesir. 2 (2):1-10.

Seyfi, L. and Akbal, B. (2018) Konya'daki Bazı Yuksek Gerilim Hatti ve Trafo Binalari Yakininda Yapilan Manyetik Alan Olcumlerinin Degerlendirilmesi. 2nd International Symposium on Innovative Approaches in Scientific Studies 2018, November 30-December 2, Samsun, Turkey.

Environmental Health Criteria 238-Extremely Low Frequency Fields;

1-543, 2024

Kurnaz, C. and Mutlu, M. (2021) Uzun sureli radyofrekansı elektromanyetik alan seviyesinin izlenmesi ve modellenmesi. Gazi Universitesi Muhendislik Mimarlık Fakultesi Dergisi.; 36 (2) :669-684. DOI: 10.17341/gazimmfd.641287

Engiz, B. K. and Kurnaz, C. (2017) Long-term electromagnetic field measurement and assessment for a shopping mall, Radiation Protection Dosimetry.; 175 (3):321-329. https://doi.org/10.1093/rpd/ncw343

Kurnaz, C. and Engiz, B. K. (2017) Distribution fitting for long term electric field strength measurements. 40th International Conference on Telecommunications and Signal Processing (TSP), Barcelona, Spain. pages 1-5, doi: 10.1109/TSP.2017.8075984.

Engiz, B. K. and Kurnaz, C. (2018) Ev Ortamında Maruz Kalinan Baz Istasyonu Kaynakli Elektrik Alan Siddetinin Izlenmesi ve Degerlendirilmesi. Afyon Kocatepe Universitesi Fen ve Muhendislik Bilimleri Dergisi. 18 (3):913-920.

Balanis, A.C (2012) Advanced engineering electromagnetics. John Wiley Sons, 2012.

Guidelines for Limiting Exposure to Electromagnetic Fields (100 kHz to 300 GHz) International Commission on Non-Ionizing Radiation Protection (ICNIRP)

Yekeen, O. O. and Nicholas, A. A. (2020) 3G, 4G, 5G Cell Tower and Theır Effects on Human Health: Case Study of the Brain, International Journal of Engineering Applied Sciences and Technology, 5(5):20-24.