Variation of Microwave Leakage Exposure Levels Close to a Microwave Oven with Load, Container Type and Time.

Thushara Suraweera, Chandana Jayaratne
Department of Physics, University of Colombo.
Colombo 00300, Colombo, Sri Lanka.
tksuraweera.stu@phys.cmb.ac.lk, chandana@phys.cmb.ac.lk

ABSTRACT

Nowadays people are living in a rush world and most people seek efficient methods to complete their day to day work with less time. Microwave ovens are the best option to cook foods as well as for reheating precooked foods. Microwave ovens use radio frequency (RF) electromagnetic waves around the frequency 2.4 GHz for cooking and reheating food by dielectric heating or high frequency heating. Many scientific reports have been confirmed that eating microwave food is not a risk, because radio waves cannot ionize foods. But the problem is exposing to the leakage microwave radiation when operating the oven. Authorized bodies such as International Commission on Non-Ionizing Radiation Protection (ICNIRP) as well as Federal Communications Commission (FCC) have been published limitations for exposure to these RF waves. The limited plane wave power density for a microwave oven is 50 W/m^2 at any point 5 cm away from the oven. Over exposure to these RF waves with high plane wave power densities may lead to health effects such as cataracts in the eyes, infertility, and brain tumors. In this study, leakage microwave plane wave power densities were evaluated by using spectran HF6065 spectrum analyzer under three situations with newly brought microwave oven. In the first study variation of RF levels at 40 cm from the front glass of the microwave oven with the load (water) were evaluated, In the second study RF levels around the microwave oven for same load kept in plastic and ceramic containers were evaluated separately and, in the third study, time variation of the power density at a distance 40 cm in front of the microwave oven for a duration of 180 s was evaluated. Results in the first study show that negative correlation (r=-0.6136) between the load and leakage microwave emission around the oven as well as maximum average plane wave power density of (512.78 $\pm$ 0.01) mW/m^2 with no load inside the oven and maximum average plane wave power density with the load is 195.06 $\pm$ 0.01 mW/m^2 with 100 $\pm$ 1 g of load kept in a plastic container with mass 68 g. For the second study considerably low RF levels were recorded when using the ceramic container than plastic container. Results for the third study show that microwave emission around the oven is fluctuating rapidly with time and it can be varied between 0.01 mW/m^2 and 108.48 mW/m^2. Evaluated maximum RF plane wave power density among all three studies was (677.84 $\pm$ 0.01 mW/m^2) and this value is 1.35 % of maximum permissible leakage level for a microwave oven as well as it is found that frequency of the microwave radiation is also varying when it is operating. However, authors would like to request not to stay close to a microwave oven when it is operating, especially children and pregnant women because they are more sensitive for non-ionizing RF radiations.

KEYWORDS: *microwave ovens, radio waves, leakage microwave exposure, health effects*

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1 INTRODUCTION

1.1 Microwaves and Radiofrequencies

In the electromagnetic spectrum 100 kHz to 300 GHz region is considered as radio frequency region and according to most of the text books 1 GHz to 300 GHz region is considered as the microwave region and there are enormous applications of these radio waves. Wireless communication systems such as mobile communication, radar systems, television and radio broadcasting as well as special frequency band is allocated for industrial, science and medical applications (ISM band). Microwave Ovens use this frequency band to operate (Sorrentino, R., & Bianchi, G.,2010).

1.2 Operation of a microwave oven

A microwave oven converts electrical energy into radiofrequency electromagnetic waves produced within the microwave cavity to warm up and cook foods and this method is known as dielectric heating or high frequency heating (Liu, S., Ogiwara, Y., Fukuoka, M., & Sakai, N.,2014). Most of the domestic microwave ovens use frequencies around 2.45 GHz because high-power efficiency is possible around this frequency. Inside a microwave oven, these high frequency radio waves are produced by using a device called magnetron and the produced microwaves are transferred to the cooking area through a metal tube known as a wave guide. Continuous supply of these radio waves will produce a standing wave inside the cavity of the oven and foods which are exposed to this high intensity microwaves will heat up rapidly (Luan, D., Wang, Y., Tang, J., & Jain, D.,2017).

1.3 Risk of Microwaves

Leakage microwaves to the surrounding is the main risk of microwave ovens. Operating a microwave oven with damaged door or door seals will increase the risk of exposure to high intensity microwaves. According to international bodies such as International commission on Non-Ionizing Radiation Protection (ICNIRP) and Federal Communications Commission (FCC) there are some limitations for these leakage microwaves, 50 W/m^2 at any location 5 cm away from the oven is the maximum permissible level for any domestic microwave Oven (ICNIRP,2020; Matthes, R.,1992).

1.4 Health Effects of microwave exposure

Heath effects of microwaves are cause mainly due to thermal effects induced in the body tissues. Areas such as the eyes and testes are more vulnerable for this RF heating because of less heat dissipation due to relatively low blood flow. Exposure to very high intensity microwaves may cause painful skin burns and cataracts in the eyes. Non thermal effects also possible due to exposure for these microwaves, especially neuropsychiatric effects such as depression (Dean, A. L., Rea, W. J., Smith, C. W., & Barrier, A. L. ,2012; Pall, M. L.,2016).

1.5 Propagation of microwaves and plane wave power density

Since the microwaves are a type of electromagnetic waves, they carry the energy with the help of perpendicularly oscillating electric and magnetic fields. The electromagnetic energy per unit area passing through a surface perpendicular to the wave per unit time is defined as the energy flux (S) or plane wave power density and the expression for the pointing vector $\vec{S}$ to the direction of propagation is given by the expression,

$$\vec{S} = \frac{1}{\mu_0}\vec{E} \times \vec{H} \quad (1)$$

Here μ_0 is the permeability of free space.

At very high frequencies, energy flux variation is extremely rapid therefore most of the measuring devices measure only an average. Time average (S_{AVG}) of the energy flux of an EM wave is given by the following expressions,

$$S_{AVG} = \frac{1}{2} c \, \varepsilon_0 E_0^2 = \frac{1}{2\mu_0} c \, H_0^2 = \frac{E_0 B_0}{2\mu_0} \quad (2)$$

Here ε_0 is the permittivity of of free space, E_0-Amplitude of the electric field, B_0-Amplitude of the magnetic field and c is the speed of light in free space (Pozar, D.,2005).

1.6 Literature on microwave leakage levels.

A group of researchers in the Centre for Electromagnetic Compatibility at the University Tun Hussein Onn Malaysia were conducted a study about the microwave leakage levels from microwave ovens by using six ovens and they found that all the ovens emit a certain amount of microwave leakage levels and one microwave oven exceed the international standard level (Muhammad Zin, N., Mohamed Jenu, M. Z., & Ahmad Po'ad, F.,2011). Another study conducted by two scientists at Shiraz University, Iran conducted a study to find the relationships with microwave leakage levels emitted by a microwave oven with the body weight, thyroid hormones, and cortisol levels in adult female mice. The results in the study shows decrease in the body weight, increase T4 (Thyroxine) and cortisol levels (Jelodar, G., & Nazifi, S.,2010). A group of researchers at the Public University of Navarra and Carlos III Health Institute in Spain conducted a study about the microwave power leakage levels around a domestic microwave oven and exposure levels. As well as they have developed a model to estimate received electric field for the entire volume of an indoor environment. The results of the study revealed a strong dependence of the microwave exposure levels on the location, topology and morphology as well as some interference to the wireless communication systems (Lopez et al.,2015). An interesting research was carried out by a group of researchers in The University of Tokyo and Georgia Institute of Technology revealed a method to harness power from leakage microwaves by microwave ovens and they were able to harvest 9.98 mJ of electrical energy by operating a microwave oven for a duration of 120 seconds and that energy was enough to operate a digital timer for a duration of 180 s and beep for 2.5 s (Kawahara et al., 2013).

2. METHODOLOGY

A newly brought microwave oven (Model No: ABOVAMS25LGR) of a famous brand in Sri Lanka is used for the study. Table 1 shows the manufactures data for the microwave oven.

Table 1. Specifications of the microwave oven used for the study.

Specification	Details
Microwave Power	900 W
Power level	9
Cavity	White Painted Cavity Dimension:220mm(H)×340mm(W)×344mm(D)
Product Dimension	281mm(H)×483mm(W)×404mm(D)
Glass Tray diameter	270mm
Rotational Speed of the Tray	6 rpm

The oven is placed away from wi-fi sources and mobile phones to make sure no radio interferences as well as the experiment was carried out in a place having very poor ambient RF exposure levels within the frequency range 2200 MHz to 2800 MHz. Microwave power of the selected oven is 900 W and it is a kind of lowest power microwave oven. Figure 1 shows the instrumental setup used for the study.

Figure 1. Spectran HF6065 spectrum analyzer with the microwave oven used for the study.

2.1 Evaluation of microwave leakage levels with load in front of the microwave oven with 40 cm from the front door.

In this study a plastic container (Type 5 polypropylene) is used, and water is used as the load. Added mass of water is varied by 50 g steps and at each instance peak plane wave power density of the leakage microwaves and frequency of the strongest signal were detected by using the spectrum analyzer while allowing the oven to operate for a duration of 3 minutes. A digital balance with accuracy $\pm$ 1 g is used to measure the mass.

2.2 Evaluation of microwave leakage levels around the microwave oven for porcelain and plastic containers having same load.

In this study plastic (Type 5 polypropylene) container and porcelain cup is used and equal mases (250 g) of water was added to the containers and RF levels were recorded with a distance 50 cm from the centre of the oven and eight readings were obtained in 45 degree steps after placing the containers with the load separately. Peak microwave leakage level for one sweep of the spectrum analyzer within the frequency range 2200 MHz to 2800 MHz was measured. Reason for selecting 45 degree steps is the antenna used in the study has a beam width around 45 degrees. Figure 2 shows the measurement procedure for this situation.

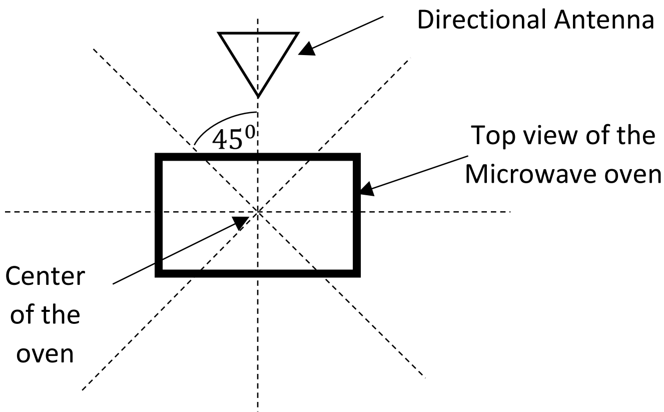

Figure 2. Measurement technique used to observe microwave leakage levels around the microwave oven.

2.3 Time variation of microwave leakage levels Infront of the microwave oven

In this study 250 g of water is poured into the plastic container used in the previous studies and the antenna is placed with a distance 40 cm from the front glass of the oven since a normal person stands approximately with this distance close to the oven so that he or she can open the door of the oven easily. The oven was operated for a duration of 180 s and microwave leakage levels were measured in each second.

3 RESULTS AND DISCUSSION

3.1 Study 01: Variation of microwave leakage levels Infront of the microwave oven with load.

Microwave oven is allowed to operate for 180 s period and the spectrum analyzer is used to collect the peak plain wave power density Infront of the oven for the above time period. Following are the readings obtained from the spectrum analyzer for each load when the system is loading and unloading with 50 g steps. Table 2 and Table 3 shows the variation of peak plane wave power density levels of leakage microwaves when the system is loading and unloading.

Table 2. Variation of Microwave leakage levels and frequency of the strongest signal when the mass of water (load) is increasing (Loading).

Load ± 1(g)	Frequency (MHz)	Peak plain wave power density ± 0.01(mW/m^2)
No Load	2469	677.84
50	2464	145.41
100	2466	82.99
150	2214	77.73
200	2368	169.21
250	2472	175.11
300	2478	102.15
350	2466	131.33
400	2469	181.34
450	2469	166.23
500	2466	95.99

Table 3. Variation of Microwave leakage levels and frequency of the strongest signal when the mass of water (load) is decreasing (Unloading).

Load ± 1(g)	Frequency (MHz)	Peak plain wave power density ± 0.01(mW/m^2)
500 g	2461	131.28
450 g	2466	85.39
400 g	2466	89.02
350 g	2469	120.11
300 g	2461	79.04
250 g	2602	81.59
200 g	2383	177.47
150 g	2334	80.73
100 g	2466	307.14
50 g	2281	241.67
No Load	2532	347.72

Variation of microwave plane wave power density with the load, when loading and unloading can be graphically represented as follows. Figure 3 shows the variation of plane wave microwave power density levels for the above two instances.

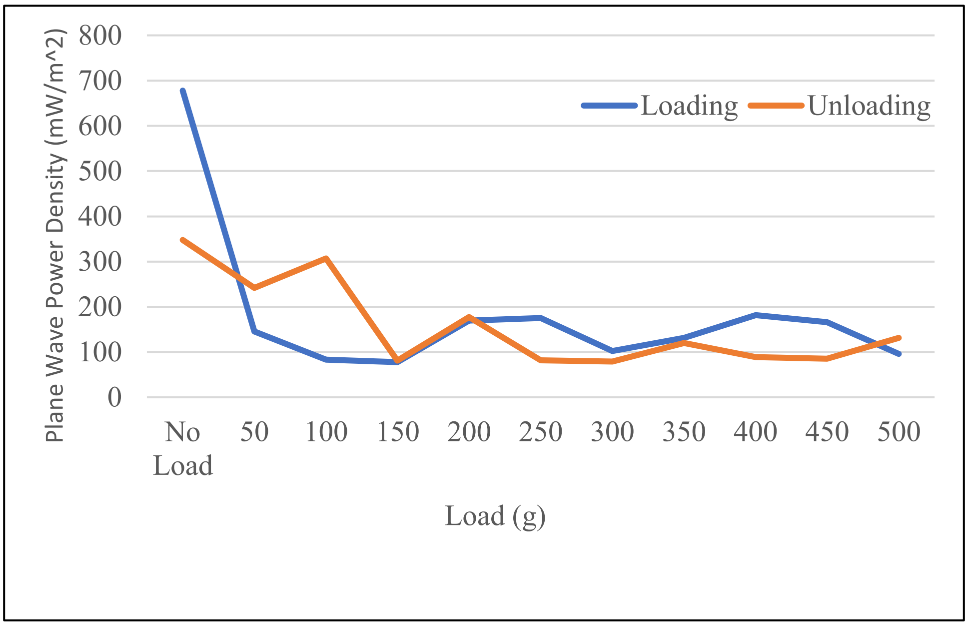

Figure 3. Variation of Microwave leakage levels with the load kept inside the oven.

According to the figure 3 microwave leakage levels are decreasing considerably when a load is inserted to the oven. Based on the results in Table 2 and Table 3, average microwave leakage levels were calculated to analyze the above situation conveniently. Table 4 shows the calculated average plane wave power densities with the corresponding load.

Table 4. Variation of the average microwave leakage levels

Load $\pm$ 1(g)	Average of peak plain wave power densities $\pm$ 0.01(mW/m^2)
No Load	512.78
50	193.54
100	195.06
150	79.23
200	173.34
250	128.35
300	90.60
350	125.72
400	135.18
450	125.81
500	113.66

Figure 4 shows the scatter plot of the average of peak power densities corresponding to each mass based on the values in Table 2 and Table 3 and the polynomial trendline which fits to the points.

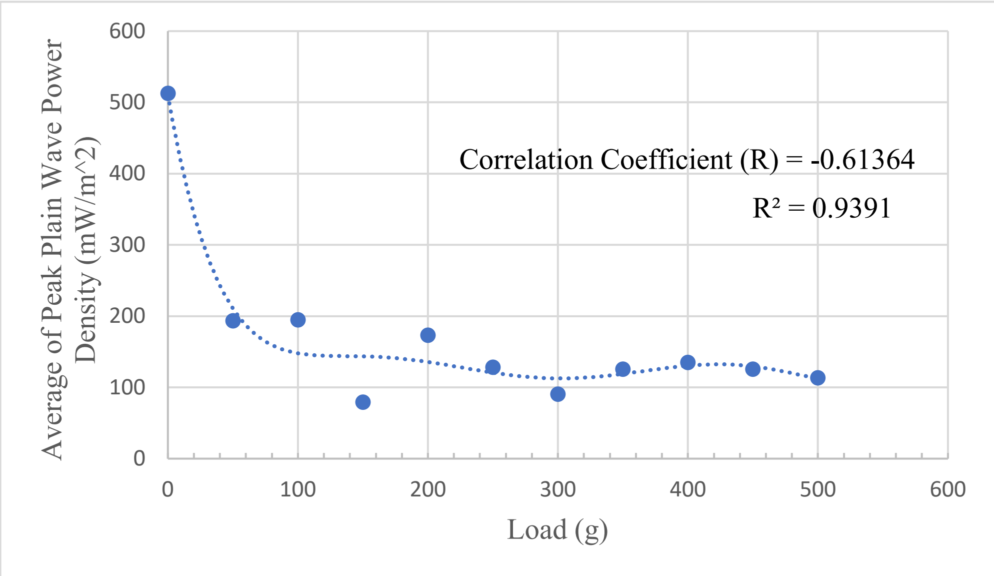

Figure 4. Scatter plot of the variation of the average of peak plain wave power densities with load and 6th order polynomial trendline fits to the data.

According to the Figure 4 it can be observed that the microwave leakage levels show a polynomial variation with the load inserted to the oven as well as a negative correlation with the load. A 6th order polynomial was the best fit with the highest value of R square according to trendline tool in Microsoft Excel. As well as the calculated correlation is -0.61364 and the reason for negative correlation may be due to absorption of microwaves by the load and thereby leakage microwave levels becoming lower. Figure 5 shows the variation of frequency corresponding to the strongest signal with the load for both situations shown in Table 2 and Table 3.

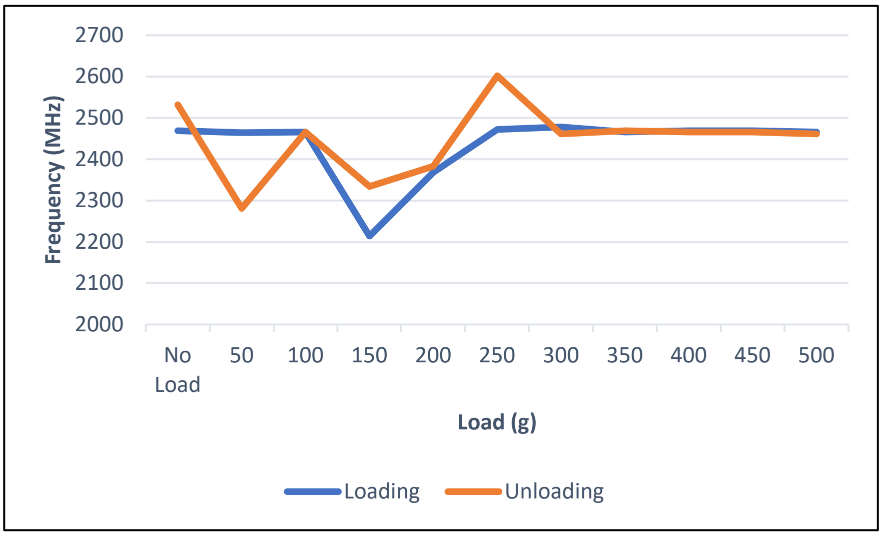

Figure 5. Variation of the frequency corresponding to the strongest signal when loading and unloading

According to Figure 5 rapid variation of frequencies can be observed for the strongest signal up to 300 g and then the variation limited to the range 2460 MHz to 2470MHz.

3.2 Study 02: Evaluation of microwave leakage levels around the microwave oven for porcelain and plastic containers having same load.

Table 5 shows the measurements obtained for microwave leakage levels for porcelain and plastic containers seperately according to the mesurement procedure given in Figure 2 . Mass of porcelain container and plastic container were 310 ± 1 g and 68 ± 1 g respectively.

Table 5. Measured peak microwave leakage levels around the microwave oven with 45-degree steps for one sweep within the frequency range 2200 MHz to 2800 MHz with distance 50 cm from the oven for a load of 250 g kept in a porcelain container and a plastic container.

Counter clockwise angle from the top view	Peak microwave leakage levels for porcelain container ± 0.01(mW/m^2)	Peak microwave leakage levels for plastic container ± 0.01(mW/m^2)
0°	75.89	52.1
45°	2.83	29.16
90°	2.52	23.78
135°	2.16	6.83
180°	15.77	19.51
225°	4.62	14.63
270°	7.52	10.54
315°	2.77	79.61

Figure 6 shows the radar chart for the for the microwave leakage levels for porcelain and plastic containers.

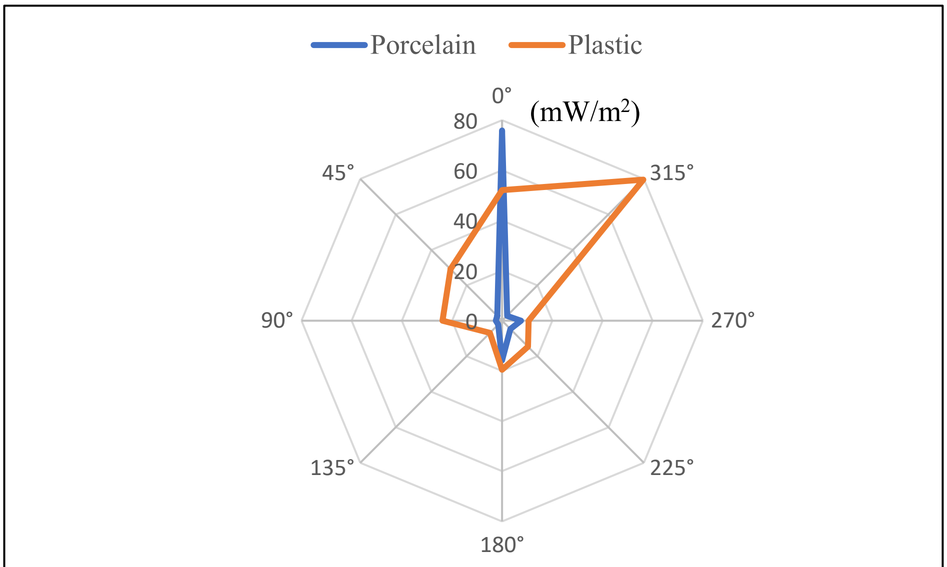

Figure 6. Variation of microwave leakage plain wave power density around the microwave oven for two instances (from the top view) for the same load (250 g) inserted into porcelain and plastic containers.

According to Figure 6, a considerable increase of microwave lekage levels can be observed around the oven when using the plastic container than the porcelain container. However, measured microwave leakage level infront of the oven is greater for the situation where the porcelain container is used.

3.3 Study 03: Time variation of microwave leakage levels Infront of the microwave oven

Table 5 shows time variation of microwave leakage levels infront of the microwave oven. The antenna of the spectrum analyser is located 40 cm from the centre of the front glass of the oven.

Table 6. Variation of Microwave leakage levels infront of the microwave oven with 40 cm from the front glass. T Represent time measured in seconds and P_D represent microwave leakage levels in mW/m^2 measured with an accuracy ± 0.01 mW/m^2.

T	P_D	T	P_D	T	P_D	T	P_D	T	P_D	T	P_D
0	0.43	30	0.14	60	3.03	90	32.5	120	2.13	150	39.89
1	3.70	31	0.10	61	2.7	91	1.13	121	4.77	151	0.06
2	0.04	32	2.40	62	4.59	92	3.6	122	0.11	152	0.79
3	0.05	33	4.53	63	3.01	93	108.48	123	5.32	153	3.72
4	5.76	34	0.10	64	2.05	94	0.03	124	3.17	154	2.75
5	22.39	35	5.80	65	1.57	95	3.63	125	4.04	155	0.11
6	0.28	36	2.37	66	4.59	96	0.08	126	8.05	156	0.02
7	88.60	37	3.02	67	0.01	97	4.88	127	6.09	157	0.07
8	1.07	38	3.55	68	3.66	98	7.47	128	57.78	158	0.46
9	2.94	39	5.10	69	5.58	99	2.47	129	4.47	159	2.49
10	0.07	40	3.66	70	0.36	100	0.23	130	0.31	160	0.01
11	1.03	41	2.79	71	0.19	101	0.04	131	0.02	161	5.4
12	0.13	42	0.09	72	3.38	102	2.64	132	0.19	162	2.76
13	3.72	43	0.38	73	0.05	103	95.59	133	2.45	163	19.02
14	4.67	44	4.31	74	0.09	104	4.73	134	0.06	164	7.64
15	0.06	45	2.12	75	0.15	105	0.27	135	0.51	165	0.12
16	0.38	46	5.59	76	0.09	106	0.01	136	4.87	166	0.01
17	5.00	47	0.03	77	2.8	107	0.04	137	0.62	167	28.64
18	1.52	48	0.03	78	2.25	108	2.23	138	4.79	168	0.01
19	6.39	49	8.46	79	7.01	109	0.37	139	0.51	169	2.9
20	4.22	50	2.90	80	0.05	110	65.01	140	0.03	170	4.29
21	0.08	51	0.53	81	14.34	111	0.69	141	6.32	171	1.93
22	5.80	52	5.84	82	2.95	112	3.39	142	0.2	172	1.73
23	0.12	53	2.22	83	37.65	113	0.05	143	2.23	173	0.04
24	0.40	54	4.55	84	0.01	114	20.91	144	3.58	174	4.07
25	0.07	55	0.24	85	2.07	115	3.64	145	33.75	175	3.78
26	0.03	56	0.11	86	3.81	116	0.32	146	3.11	176	0.01
27	0.23	57	5.34	87	0.03	117	3.21	147	6.11	177	0.06
28	0.03	58	1.49	88	0.07	118	2.44	148	3.39	178	8.75
29	0.35	59	4.28	89	0.4	119	4.06	149	105.04	179	2.36
										180	0.33

Figure 7 shows the variation of microwave leakage levels with time infront of the oven based on the data obtained in Table 6.

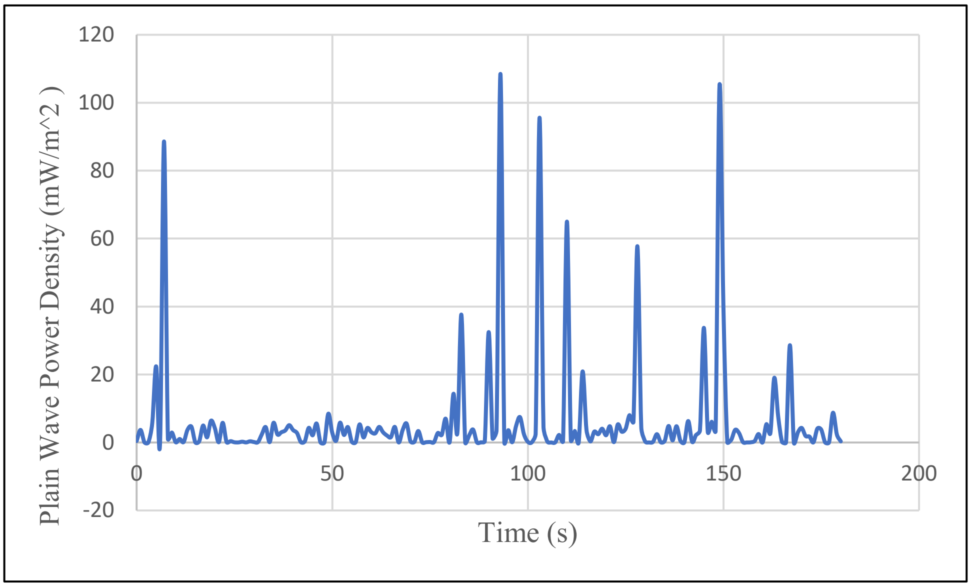

Figure 7. Variation of the plain wave power density of microwave leakage levels with time for a duration of 180 s.

According to Figure 7, It can be seen that microwave leakage levels are not continuous with time and the rate of having high plain wave power density spikes is increasing with time.

3.4 Ambient plain wave power density

The average value of the ambient plain wave power density of microwaves within the frequency range 2200MHz to 2800MHz was 360.46 nW/m^2 at the place where all the above studies were carriedout.

4 CONCLUSIONS

From the 1st study it can be concluded that the microwave leakage levels are highly depend on the load (mass of food) kept inside the oven and having a negative covariance (-0.61364) implies that these radiation levels decrease with the increase of the load. Based on the results of the 2nd study it can be concluded that using a porcelain container is more suitable to reduce average microwave leakage levels around the oven but further studies needed to investigate rate of heat generation in the food. Results of the 3rd study reveal that microwave legake levels are not persistant with time and they are varying rapidly with time. As well as leakage levels of slightly high intensity microwave levels are getting more frequent with time.

When considering all of the above three studies it can be concluded that considerable increase of microwave radiation is possible around a microwave oven when it is operating. Authors would like to request not no stay close to the microwave oven when it is operating since the effects of low power microwaves are still under research. Since pregnant women and infants are more sensitive for these radiation, it is advisable not to stay close to the microwave ovens when these devices are operating.

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