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Risk Assessments of Magnetic Field Radiation from AC and Battery Powered Laptop Computers

Abiola Olawale Ilori[1, 3, *], Omoniyi Ajoke Gbadamosi[2], Gilbert Akin Ibitola[1], Olanrewaju Ajanaku[1]

[1]Department of Physical Sciences, Ondo State University of Science and Technology, Okitipupa, Nigeria
[2]Department of Mathematical Sciences, Ondo State University of Science and Technology, Okitipupa, Nigeria
[3]School of Chemistry and Physics, University of Kwa Zulu-Natal, Pietermaritzburg Campus, South Africa

Email address

iloriabiola99@gmail.com (A. O. Ilori)

[*]Corresponding author

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Abstract: This paper evaluates the magnetic field radiation produced from top-body and bottom-body of laptop computers in the normal operation condition when powered by alternating current and battery and the risk assessment of the magnetic field radiation as compared to the known reference limit. The magnetic field of 10 selected laptops was measured by an electromagnetic field (EMF) measuring device, Lutron EMF-828, at a position where the influence of the environmental magnetic field is negligible. The average magnetic field values obtained for the top-body when powered by alternating current range from 0.08 μT to 0.59 μT with the highest value of 1.88 μT while the average magnetic field values obtained for the top-body when powered by battery ranges from 0.11 μT to 0.31 μT with the highest value of 0.92 μT. The average magnetic field values obtained for the bottom-body when powered by alternating current range from 0.20 μT to 0.84 μT with the highest value of 2.40 μT, while the average magnetic field values obtained for the bottom-body when powered by battery range from 0.11 μT to 0.37 μT with the highest value of 0.95 μT. The values obtained showed that magnetic field radiations emitted are at the highest level when laptops were powered by alternating current, also the bottom-body parts of the laptop radiated the highest level of the magnetic field than the top-body parts. The danger areas of the magnetic field radiation exposure from laptop computers were established to warn users of possible radiological hazards. The user of a laptop computer should be positioned at some distance at which the magnetic field radiation is 0.4 μT or less.

Keywords: Alternating Current, Battery, Laptop Computer, Electromagnetic Field, Radiation, Risk Assessment

1. Introduction

Advances in technology have made popular the use of laptops all over the world due to its portability. This made it easier for almost every technology-inclined person to possess one form of laptop or the other. Laptops have been reported to emit magnetic field radiation at various degrees depending on the types in use [1, 2, 3]. The magnetic fields exposed to humans can be characterized by its source which can either be of natural or man-made sources. Natural source of a magnetic field is from the earth with constant amplitude and frequency while the artificial source of a magnetic field is created by various technologies such as electrical devices including laptops with constant variations in its amplitude and frequency [4]. Exposure of the general population to radiofrequency fields from mobile phones and other communication tools such as laptops has become universal and continuous in recent years [5]. Electromagnetic exposures from electronic devices can be divided into three categories, which is high-level, medium-level and low-level exposures. These radiations are hazardous to all living organisms because effects are latent, painless and cumulative [6].

Laptop computers are a portable personal computer with a thin screen mounted on the inside of the upper lid of the clamshell and a keyboard on the inside of the lower lid. A Laptop combine all the capabilities of a desktop computer into a single unit, these capabilities includes the display screen, keyboard, hard disk drive, optical disc drive, pointing devices, a processor and memory. Laptops can be powered either from an internal battery or by an external power supply from an

alternating current (AC) adapter. When converting energy to perform the various functions, the internal parts of the laptop generate magnetic field radiation in the extremely low frequency between 30 and 300 Hz which then emits out of the outer shell of the computer [2]. Functions such as processor activity, hard drive operations, memory storage and other computing functions produce magnetic field radiations. Laptops are typically in close contact with the user's body than desktop computers, hence it has close contact with the skin, eyes, blood, bones and several organs of the body which raised concerned about the health effect of its usage [7, 8]. Laptop computers can be powered by AC or battery. The battery helps to provide power to the computer in the absence of an AC supply.

The risk of magnetic field radiation in the extremely low-frequency region has been extensively investigated with all pointing to the dangers of the emitted magnetic field to human's health [3, 7, 9, 10]. Some research has also linked magnetic field radiations to risks of several illnesses by humans such as brain cancer [11, 12], depression [13], leukemia [14], etc. Studies have shown that among developing nations, computers in the form of desktops and laptops play a major role in everyday routines leading to more exposure to computer radiations [15]. Thus, the aim of this present paper is to evaluate the magnetic field radiation produced from 9 different points at the top-body and bottom-body of 10 selected laptop computers when powered by AC and battery and discussed the risk assessment of the magnetic field radiation to the known reference limit. Magnetic field radiations from the left, right, front and back of the screen of the laptop computers are not reported in this paper as the magnetic field radiation values from such locations are negligible or up to 0.02 μT [16]. The reference limit used in this paper is 0.4 μT which was given by the Scientific Committee on Emerging and Newly Identified Health Risks [4]. The reference limit is the critical level of radiation above which environmental condition is tagged unsafe for laptop users.

2. Theory, Materials and Methods

2.1. The Concept of Magnetic Field Radiation

The magnetic field produced by laptop computers is measured in the present paper. Just like every other electronic device, the laptop computer is made of electrical and electronic components [17]. During operation of the laptop computer, these components are supplied by current I. The magnetic field is induced as a consequence of the current flow through these components. According to the Biot-Savart law, the magnetic field B is generated by a steady current I. This is given as:

$$B = \frac{\mu_0 I}{4\pi}\int_{wire}\frac{dl.\hat{r}}{r^2} \quad (1)$$

Where B is the magnetic field in teslas T, μ_0 is the magnetic constant, dl is an infinitesimal length of conductors carrying electric current I, r is the distance between the location of dl and the location where the magnetic field is calculated and $\hat{r}$ is a unit vector in the direction of r. The Biot-Savart describes the magnetic field around an electronic device and allows the calculations and measurements of the magnetic field at various point.

In the circumstances of uniform magnetic field exposure, while working on laptop computers, the time dependence on the field is the same in all point of the exposed subjects. Then, the measurement of magnetic field B can be split into three independent scalar fragments parallel to each other, and can then be calculated as [9]:

$$B(r,t) = B_x(t).\hat{x} + B_y(t).\hat{y} + B_z(t).\hat{z} \quad (2)$$

Where $\hat{r}$ is a unit vector in the direction of r, the positional vector, represented by x, y and z; t is the time while $B_x, B_y\ and\ B_z$ represent the magnitudes of the magnetic flux density in the direction of these vectors respectively. The measuring device measures the scalar components of the magnetic flux density B. Therefore, the root mean square of magnetic flux density B is calculated as:

$$B = \sqrt{(B_x^2 + B_y^2 + B_z^2)} \quad (3)$$

It is observed that the electromagnetic waves radiated from the laptop computers to the surrounding space satisfy the following Maxwell's equations:

i Gauss' Law-Electric Charge:

$$\oint E.dA = \emptyset_e = q/\varepsilon_{ss} \quad (4)$$

where:

E = electric field (V/m);

A = cross-sectional area of the magnetic field radiator in the laptop computer;

$\emptyset_e$ = electric flux $(c.m.F^{-1})$;

q = charge;

ε_{ss} = permittivity of the surrounding space around the laptop computer (radiator) $(F.m^{-1})$.

ii Gauss' Law-Magnetism

$$\oint B.dA = 0, \quad (5)$$

where:

B = magnetic field ($^{Wb}/_{m^2}$ or $Tesla$) in the surrounding space around the laptop computer/radiator.

iii Faraday's Law:

$$\oint E.dl = -d\emptyset_m/dt \quad (6)$$

where:

E = electric field (V/m) between the surrounding space and the laptop computer/electromagnetic radiator;

dl = infinitesimal length of the radiator in the laptop computer;

$d\emptyset_m$ = infinitesimal magnetic flux charge (Wb) around the radiator/laptop computer;

dt = infinitesimal time change (seconds).

iv Ampere's Law:

$$\oint B.dl = \mu_{ss} i + \mu_{ss}\varepsilon_{ss}\ d\emptyset_e/dt \quad (7)$$

where:

μ_{ss} = permeability $(Wb.(A.m)^{-1})$ of the surrounding space around the radiator/ laptop computer;

$d\emptyset_e$ = infinitesimal change of electric flux $(V.m\ or\ Wb.m.s^{-1})$ linking the surrounding space with the radiator/laptop computer;

i = current generated and radiated (Amperes).

If the current is generated and radiated (fully or like a black body) into the surrounding space by the electromagnetic radiator in the laptop computer is relatively large, then it can lead to shock waves, dizziness, mutation, etc. On the other hand, if the current generated and radiated (faintly or like a white body) into the surrounding space by the radiator/laptop computer is relatively small, then it will not cause any hazard or harm to the user.

The intensity I of the electromagnetic radiation from the radiator/laptop computer is:

$$I = 1/\mu_{ss}(EB). \quad (8)$$

The energy density of the magnetic field radiation is given by:

$$U_B = 1/(2\mu_{ss})\ (B)^2 \quad (9)$$

The magnetic field radiation from the radiator in the laptop computer is found to be expressed as:

$$B = M.\mu_{ss}/X \quad (10)$$

where:

M = magnetization $(A.m^{-1})$

H = magnetic field intensity (A/m)

B = magnetic flux density $(^{Nm}/_{A}\ or\ teslas, T)$

X = susceptibility.

2.2. Measuring Device

In the present paper, the magnetic field of the laptops was measured by an EMF measuring device Lutron EMF-828 at a position where the influence of the environmental magnetic field is negligible. This simply means that the environmental magnetic field is lower or equal to 0.01 µT [9]. EMF-828 can also be used to measure EMF nearby high voltage pylons, transformers, industrial high power machines, etc. The calibration of the measurement device was performed by the producer of the equipment according to ISO 9001. As earlier discussed, the measuring device measures the scalar components of the magnetic flux density $B_x, B_y\ and\ B_z$ from 0.01 µT to 2 mT, i.e., between 30 to 300 Hz which is at the extremely low-frequency range. The Lutron EMF-828 has three measurement extents: 20 µT, 200 µT and 2000 µT. The precision of the measurement largely depends on the measurement extent which is of the order 0.01 µT for the measurement extent of 20 µT, 0.1 µT for 200 µT and 1 µT for 2000 µT, respectively [18]. The block diagram of the measuring device, Lutron EMF-828, is shown in Figure 1. The Earth's magnetic field, on the average, is of the order of nT which is of negligible effect.

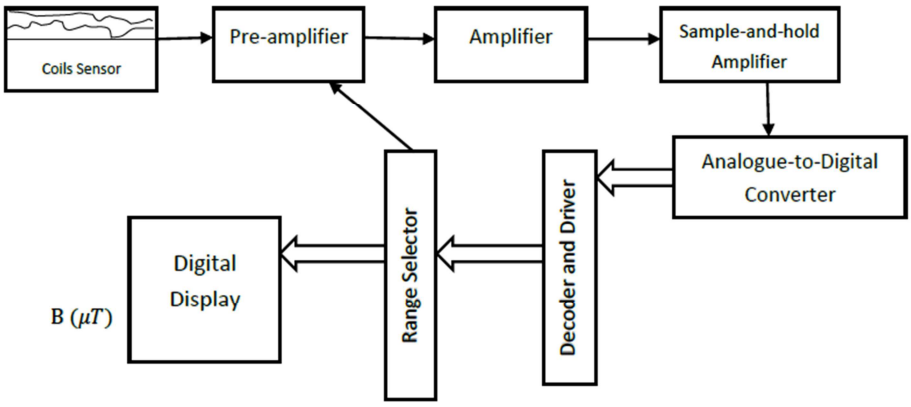

Figure 1. *Functional block diagram of Lutron EMF-828.*

2.3. Measurements Procedure

The procedure adopted was aimed at taking magnetic field measurements from 10 selected laptops of different models. Measurements were collected when laptops were supplied by alternating current (AC) and battery from the top and bottom of the laptops. The laptop computers were labeled L_1 - L_{10}. Measurements were taken from 9 points on the laptop as illustrated in figure 2 (a, b). The top measurements were labeled tm_1 - tm_9 while the bottom measurements were labeled bm_1-bm_9.

The laptops were tested under normal operating condition, i.e., the laptop operates with commonly used programs like Word, Excel, Internet browsing, Music player, etc. Four independent experiments were performed to take the magnetic field measurements.

tm_1	tm_2	tm_3
tm_4	tm_5	tm_6
tm_7	tm_8	tm_9

(a)

bm_1	bm_2	bm_3
bm_4	bm_5	bm_6
bm_7	bm_8	bm_9

(b)

Figure 2. *The laptop measurement points (a) at the top and (b) at the bottom.*

Experiment 1:

This considers the 9 magnetic field values of the top body points for each of the 10 laptops supplied by AC with

extracted battery.

Experiment 2:

This considers the 9 magnetic field values of the top body points for each of the 10 laptops supplied by a battery.

Experiment 3:

This considers the 9 magnetic field values of the bottom body points for each of the 10 laptops supplied by AC with extracted battery.

Experiment 4:

This considers the 9 magnetic field values of the bottom body points for each of the 10 laptops supplied by a battery.

All computer laptops used runs on either Window 7 or Window 10 operating systems, being the most used operating system by individuals. The laptops are of screen sizes $17'', 15''$ *and* $14''$ respectively.

3. Results and Discussion

The magnetic field radiations of 10 selected laptops had been obtained with the aid of an EMF measuring device (Lutron EMF-828). The values obtained for the top-body and bottom-body of the laptops at various points were reported in Tables 1 and 2 respectively.

Table 1. *Magnetic fields obtained from top-body of laptop computers.*

	tm_1 (μT)		tm_2 (μT)		tm_3 (μT)		tm_4 (μT)		tm_5 (μT)		tm_6 (μT)		tm_7 (μT)		tm_8 (μT)		tm_9 (μT)		Total (μT)		Average (μT)	
	AC	**Bat.**	**AC**	**Bat.**	**AC**	**Bat.**	**AC**	**Bat.**	**AC**	**Bat.**	**AC**	**Bat.**	**AC**	**Bat.**	**AC**	**Bat.**	**AC**	**Bat.**	**AC**	**Bat.**	**AC**	**Bat.**
L_1	0.16	0.09	0.05	0.03	0.18	0.09	*0.58*	0.28	0.24	*0.43*	0.15	0.10	0.12	0.06	0.09	0.18	0.20	0.11	1.77	1.37	0.20	0.15
L_2	0.28	0.09	*0.46*	0.31	0.06	0.04	0.08	0.05	0.20	0.16	0.26	0.11	0.03	0.03	0.06	0.14	0.13	0.06	1.56	0.99	0.17	0.11
L_3	*0.41*	0.36	0.28	0.10	0.35	0.16	*1.37*	0.25	*0.45*	0.33	0.08	0.04	0.16	0.08	0.19	0.14	0.12	*0.52*	3.41	1.98	0.38	0.22
L_4	0.34	0.18	*0.48*	0.36	0.24	0.15	*0.62*	*0.41*	0.21	0.09	0.08	0.03	0.11	0.05	0.17	0.08	0.26	0.15	2.51	1.50	0.28	0.17
L_5	0.27	0.08	0.07	0.06	0.22	0.10	0.16	0.07	0.06	0.51	0.10	0.04	0.35	0.20	*1.12*	0.18	0.06	*0.58*	2.41	1.82	0.27	0.20
L_6	0.17	0.07	0.04	0.34	0.13	0.06	0.10	0.04	0.03	0.25	0.04	*0.46*	0.06	0.11	0.10	*0.63*	0.03	0.09	0.70	2.05	0.08	0.23
L_7	0.12	0.08	0.30	0.14	0.33	0.10	*1.17*	*0.48*	*2.30*	*0.73*	*0.64*	0.30	0.25	0.10	0.08	0.04	0.15	0.08	5.34	2.05	*0.59*	0.23
L_8	*0.48*	0.20	0.36	0.19	0.14	0.09	*0.60*	*0.46*	*1.88*	*0.62*	*0.50*	0.21	0.17	0.08	0.10	0.04	*1.06*	*0.92*	5.29	2.81	*0.59*	0.31
L_9	0.36	0.11	0.18	0.08	0.09	0.06	*0.47*	0.35	0.30	0.16	*0.93*	*0.49*	*0.69*	*0.85*	0.06	0.09	0.14	0.22	3.22	2.41	0.36	0.27
L_{10}	*0.55*	0.36	0.25	0.10	0.20	0.09	0.07	0.04	*0.46*	0.22	0.33	0.10	0.03	0.14	0.15	0.09	0.28	0.05	2.32	1.19	0.26	0.13

Table 2. *Magnetic fields obtained from bottom-body of laptop computers.*

	bm_1 (μT)		bm_2 (μT)		bm_3 (μT)		bm_4 (μT)		bm_5 (μT)		bm_6 (μT)		bm_7 (μT)		bm_8 (μT)		bm_9 (μT)		Total (μT)		Average (μT)	
	AC	**Bat.**	**AC**	**Bat.**	**AC**	**Bat.**	**AC**	**Bat.**	**AC**	**Bat.**	**AC**	**Bat.**	**AC**	**Bat.**	**AC**	**Bat.**	**AC**	**Bat.**	**AC**	**Bat.**	**AC**	**Bat.**
L_1	0.36	0.14	0.22	0.10	*0.62*	*0.48*	0.28	0.30	*0.46*	0.75	*0.83*	*0.51*	0.18	0.07	*0.50*	0.39	0.24	0.14	3.69	2.88	*0.41*	0.32
L_2	*0.66*	0.37	0.39	0.16	*0.80*	*0.59*	*0.45*	*0.63*	0.18	0.39	0.16	0.38	0.24	0.12	0.35	0.16	0.30	0.09	3.53	2.89	0.39	0.32
L_3	0.37	0.04	*1.12*	*0.46*	*0.45*	0.12	0.30	0.03	*0.64*	0.34	*0.92*	0.24	0.26	0.09	0.15	0.06	0.38	0.06	4.59	1.44	*0.51*	0.16
L_4	*1.43*	*0.61*	*0.65*	0.40	0.37	0.24	*1.08*	0.18	0.36	0.10	0.11	0.05	0.29	0.08	0.30	0.13	*0.46*	0.17	5.05	1.96	*0.56*	0.22
L_5	*0.64*	*0.46*	0.35	0.18	0.16	0.10	*0.85*	0.30	0.26	0.32	*0.41*	0.23	*1.24*	*0.56*	*0.78*	0.20	*0.68*	*0.47*	5.37	2.82	*0.60*	0.31
L_6	0.20	0.24	0.09	0.06	0.26	0.06	0.39	0.16	0.06	0.10	0.34	0.16	0.10	*0.43*	0.24	0.32	0.13	0.04	1.81	1.57	0.20	0.17
L_7	0.28	0.10	*1.28*	*0.43*	0.22	0.15	*0.63*	0.24	*1.80*	*0.82*	0.18	0.09	*0.41*	0.20	*0.63*	0.37	0.34	0.11	5.77	2.51	*0.64*	0.28
L_8	0.76	0.30	0.26	0.09	0.37	0.11	*0.92*	*0.51*	*0.83*	*0.43*	*1.21*	*0.56*	*0.45*	0.16	0.35	0.19	*2.40*	*0.95*	7.55	3.30	*0.84*	0.37
L_9	0.24	0.16	0.38	0.09	*0.46*	0.23	*0.92*	0.23	0.18	*0.46*	0.30	0.08	0.13	0.09	0.11	0.24	0.22	0.06	2.94	1.64	0.33	0.18
L_{10}	0.32	0.11	*0.63*	0.06	*1.28*	0.06	*0.86*	0.09	*0.62*	0.10	0.41	0.24	0.20	0.06	*0.94*	0.06	0.35	0.18	5.61	0.96	0.62	0.11

As shown in Table 1, the average magnetic field values obtained from top-body of laptops when powered by AC range from 0.08 μT to 0.59 μT, with the highest value of 1.88 μT recorded at top-body point 5 for L_8 and lowest value of 0.03 μT recorded at top-body point 7 for L_2; top-body points 5 and 9 for L_6 and top-body point 7 for L_{10}, respectively. The average magnetic field values obtained when laptops were powered by battery range from 0.11 μT to 0.31 μT, with the highest value of 0.92 μT recorded at top-body point 9 for L_8 and lowest value of 0.03 μT recorded at top-body point 2 for L_1; top-body point 7 for L_2 and top-body point 6 for L_4, respectively.

The average magnetic field values obtained from bottom-body of laptops when powered by AC range from 0.20 μT to 0.84 μT, with the highest value of 2.40 μT recorded at bottom-body point 9 for L_8 and lowest value of 0.06 μT recorded at bottom-body point 5 for L_6. The average magnetic field values obtained when laptops were powered by battery range from 0.11 μT to 0.37 μT, with the highest value of 0.95 μT recorded at bottom-body point 9 for L_8 and lowest value of 0.03 μT recorded at bottom-body point 4 for L_3; these were shown in Table 2.

The magnetic field values obtained for laptop computers supplied by AC and battery showed that the magnetic field from the laptop computers when powered by AC was higher than when powered by battery, except for laptop top-body points 5, 6, 8 and 9 for laptop computers 1, 6, 3 and 5 and for bottom-body points 7 and 5 for laptop computers 6 and 9, respectively. On physical observations, such laptop computers' batteries were discovered to be swollen-up, depicting that such batteries were overheated, overcharged, or simply failing due to old age.

Three cluster colors were used on the results table (yellow, green and red). The yellow depicts power source from AC, the green depicts power source from the battery, while the reds are indicators to values greater than the magnetic field reference limit of 0.4 μT given by the Scientific Committee on Emerging and Newly Identified Health Risks for laptop computers.

To perform a risk assessment based on the magnetic field values obtained for this research work, it was observed that

the highest values for laptop computers supplied by AC and battery (top-body and bottom-body) were around the central zones of the laptops. This is attributed to the design of the inner architecture of a laptop computer where the processor, graphics card and cooling system are located. The lower values were mostly obtained at zones within the architecture where peripheral devices of the laptops are located as well as other core inner devices such as the hard disk.

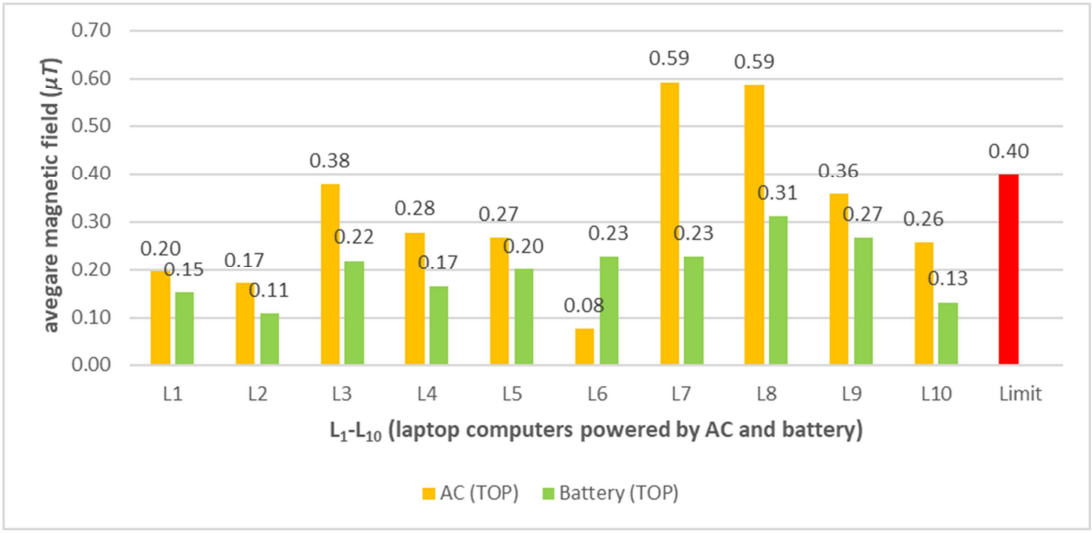

Figure 3. *Results of the average magnetic field radiation values of top-body points for the 10 laptops when powered by AC and battery.*

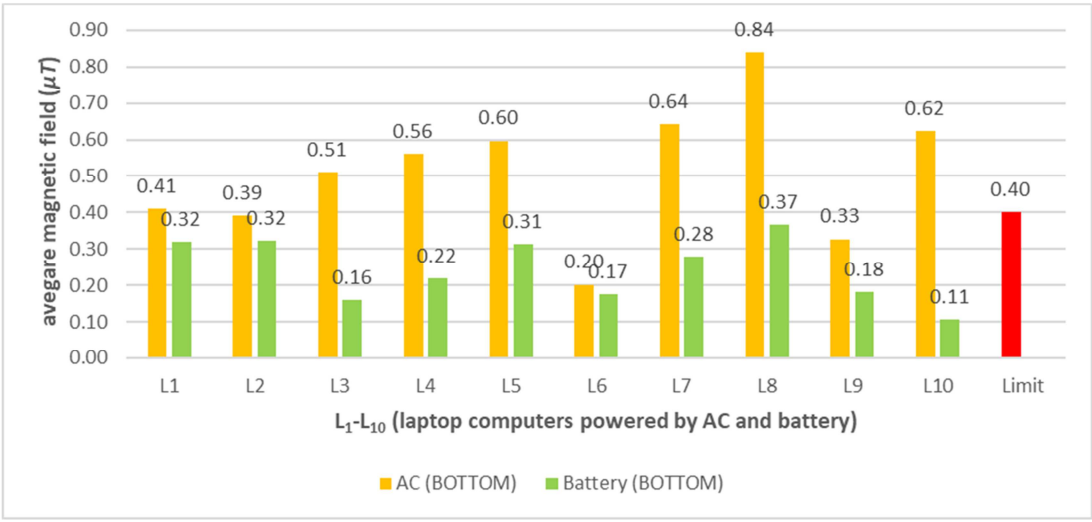

Figure 4. *Results of the average magnetic field radiation values of bottom-body points for the 10 laptops when powered by AC and battery.*

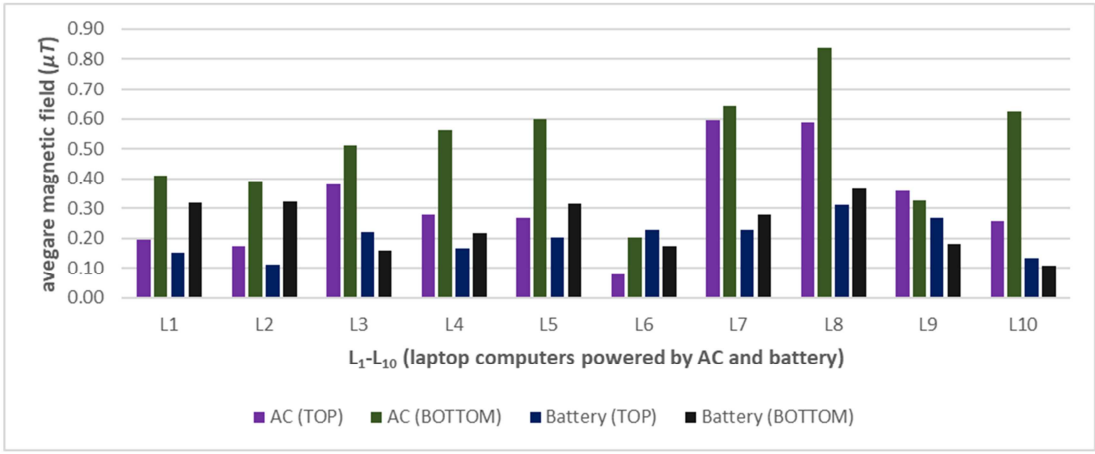

Figure 5. *Magnetic field radiation values of top-body vs. bottom-body points for the 10 laptops when powered by AC and battery.*

4. Conclusion

The present paper evaluates the magnetic field radiation produced from 9 different points at the top-body and bottom-body of 10 selected laptop computers in the normal operation condition when powered by AC and battery; it also discussed the risk assessment of the magnetic field radiation to the known reference limit. Values obtained showed that some points of the laptops emitted a higher magnetic field above the recommended limit of 0.4 μT. the values also showed that magnetic field emitted are at highest when laptops were powered by alternating current (AC) while the bottom-body parts of the laptop radiated the highest level of the magnetic field than the top-body parts. Considering the earlier results in other referenced literatures which reported that magnetic field rapidly decreases with distance, it can be suggested to use laptop computers by putting them on tables rather than putting each of them on a person's lap, chest or any parts of the body so as to reduce the influence of magnetic field on a person's skin or bone. Hence, the danger areas of the magnetic field radiation from laptops were established to warn users of possible radiological hazards.

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