redin Revista Facultad de Ingeniería, Universidad de Antioquia, No. 76, pp. 39-45, 2015

Measurement of the extremely low frequency magnetic field in the laptop neighborhood

Medición del campo magnético de frecuencias extremadamente bajas alrededor de un computador portátil

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ARTICLE INFO

Received February 11, 2015
Accepted June 06, 2015

KEYWORDS

Exposure, laptop, magnetic field, non-ionizing radiation

Exposición, computador portátil, campo magnético, radiación no ionizante

ABSTRACT: The paper considers the level of the extremely low frequency magnetic field produced by the portable computers. Accordingly, the magnetic field characterized with the low frequencies up to 300 Hz has been measured. The experiment consists of testing 10 different portable computers in normal operating condition and under heavy load. The measurement of the magnetic field is performed in the laptop neighborhood. The measured data are presented and discussed. They are compared with the magnetic field safe limit values suggested by MPR II, TCO, ICNIRP, the SMEMSP (Serbian Ministry of Environment, Mining and Spatial Planning), and those given in the literature. It is shown that some of the portable computers radiate a very strong magnetic field. Hence, they should be used with caution.

RESUMEN: El artículo considera el nivel del campo magnético de frecuencias extremadamente bajas producido por computadores portátiles. Por consiguiente, se ha medido el campo magnético caracterizado por bajas frecuencias de hasta 300 Hz. Los experimentos consisten en la evaluación de 10 computadores portátiles diferentes, bajo condiciones de funcionamiento normal y bajo carga pesada. Las mediciones del campo magnético son realizadas en la vecindad del computador. Las mediciones obtenidas son presentadas y discutidas. Éstas son comparadas con los límites seguros de campos magnéticos sugeridos por MPR II, TCO, ICNIRP, el SMEMSP (Ministerio Serbio de Ambiente, Minería y Planeación Territorial), y aquellos encontrados en la literatura. Se muestra que algunos computadores portátiles irradian un campo magnético muy fuerte. Por lo tanto, éstos deberían ser usados con precaución.

1. Introduction

A laptop is a personal portable computer that can be used at any locations. It can be powered by AC or battery, which brings versality. Furthermore, it represents an all-in-one design, which means that computer, monitor, keyboard, mouse (typically given as touchpad), speaker and battery are sealed into one piece. This construction brings a full functionality as in desktop computers. However, the benefit of having a battery enables using a laptop if there is no AC power supply. At the end, it has an additional external component called AC adapter, which enables to be powered by AC supply.

EMF stands for electromagnetic field. Electromagnetic radiation is the energy projected from the electromagnetic field. The EMF radiation creates problems in the human body, which generally comes from sources originating from: electric, magnetic, wireless and ionizing radiation. It is the distance, strength and length of exposure that determine the health risk to the users of the portable computer. However, the only way to find out the level of EMFs is to test it with detectors.

In the last decade, the use of portable computer has rapidly grown. It is especially true for the younger population. Due to its portability, it is a quite common practice to use the portable computer at close contact with the body. In this way, it is in contact with the areas of skin, blood, lymph, bones, etc. Common and regular use of the portable computer in such cases might cause some negative effects to the user's health. Hence, the raised concern about detectable impairment to the health of the exposed individual is evident [1]. It is based on the effect of the non-ionized electromagnetic radiation characterized by the low frequency up to 300 Hz. Accordingly, the safe and adequate use of the portable computer is mandatory. In this way, the risk of the magnetic exposure of the portable computer users is in the focus. Still, it has been partly investigated [2].

Recently, some scientists have recognized the occurrence of hypersensitivity to electromagnetic radiation systems from a common exposure, such as gadgets, wireless

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ISSN 0120-6230
e-ISSN 2422-2844

DOI: 10.17533/udea.redin.n76a05

systems, computer systems and electrical appliances in the home or the office [3]. Similarly, World Health Organization (WHO) has reported that the electromagnetic hypersensitivity symptoms include dermatological, neurasthenic and vegetative symptoms [1]. Some symptoms of electromagnetic hypersensitivity are shortness of breath, arrhythmia, fatigue and nausea, memory and concentration problems, headache, blurred eyesight, limb pains, muscle stiffness, burning sensations, etc. [4, 5].

According to the safety rules of the SMEMSP [6], the safe limit level of the magnetic induction for the EMF (up to 800 Hz) is 2/f, where f represents the frequency of EMF. In this way, the safe limit level is defined as the critical level of the radiation above which the environmental conditions can be unsafe for humans. The safe limit level is determined between 0.2 μT and 0.4 μT in literature [2, 7-9]. Consequently, the SMEMSP protection brought the Law on the non-ionized radiation protection [10], which determines the risk conditions and protection measures in the critical situations. It can be noted that the international commission for the non-ionized radiation ICNIRP put the EMF safe limit value differently for the people and for the employee. Accordingly, the safe limit is 5/f for the people and 25/f for the employee [11].

In this paper, we address the problem of the magnetic field radiation received from the portable computers. The measurement of the magnetic field obtained from 10 different portable computers is carried out. The portable computers are tested in "normal" operating condition and under heavy load (under stress). Previously, nobody differentiated the EMF measurement in different operating conditions of portable computers. Consequently, the measurement results are presented and compared. Then, the risk assessment of the low frequency magnetic induction from portable computers to the humans according to the proposed EMF safe limits is discussed. At the end, the conclusions are made as well as the future research work direction.

2. Methods

The methods of the work consist of measuring the uniform extremely low frequency magnetic field which is produced by the portable computers. The portable computer is built-in of many electrical and electronic components, which are mutually connected. During the normal operation of portable computers, 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*. Eq. (1) determines the magnetic field B.

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

where the integral sums over the *wire length*, the vector *dl* is the vector line element with direction as the current *I*, μ_0 is the magnetic constant, *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*. During their work, the users of portable computers are exposed to such magnetic field. In the circumstances of uniform magnetic field (in the neighborhood of magnetic field emitter, i.e. portable computer), the time dependence of the field is the same in all points of the exposed subjects [2]. The magnetic induction B has direction and magnitude [12]. The direction is decomposed into the three-unit directional vectors, which are parallel to each one giving its direction along the Cartesian axis *x*, *y*, and *z*, *i.e.* $\hat{x}$, $\hat{y}$, and $\hat{z}$. The magnitude of the magnetic induction is decomposed into the scalar components B_x, B_y and B_z measured in the direction of the Cartesian axis *x*, *y* and *z*. Eq. (2) defines the magnetic induction B(*t*) [2, 12].

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

where *t* is the time, and $\hat{r}$ is a unit vector in the direction of *r*, which is decomposed into the $\hat{x}$, $\hat{y}$, and $\hat{z}$ components.

Typically, the devices measure the magnitude (scalar) components of the magnetic induction, i.e. B_x, B_y and B_z. Then, the magnitude of the magnetic induction vector |B|, which is usually called measured magnetic induction *B*, is calculated using these scalar components. Eq. (3) determines the measured magnetic induction *B* [12].

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

The measurement of magnetic field is usually performed by an EMF measuring device in the positions (typically in the office) where the influence of the magnetic field is negligible. It means that the level of the magnetic field has to be lower or equal to 0.01 μT [2]. The measurement of magnetic field is carried out by Lutron EMF 828 device [13]. The calibration of the measurement device is performed according to ISO 9001 by the producer of the equipment [14, 15]. Lutron EMF 828 device measures the magnetic induction from 0.01 μT to 2 mT in the extremely low frequency range between 30 and 300 Hz. The EMF 828 has three measurement extents: 20 μT, 200 μT and 2000 μT. The precision of the measurement largely depends on the measurement extent. It 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. Lutron EMF 828 measures all three components of the magnetic induction B, i.e. *x*, *y* and *z* as well as *B*.

2.1. Experiment

The experiment consists of measuring the magnetic field at 27 measurement points in the neighborhood of portable computer. Figure 1 illustrates these measurement points.

Measurement points are classified into three groups (see Figure 1 for reference):

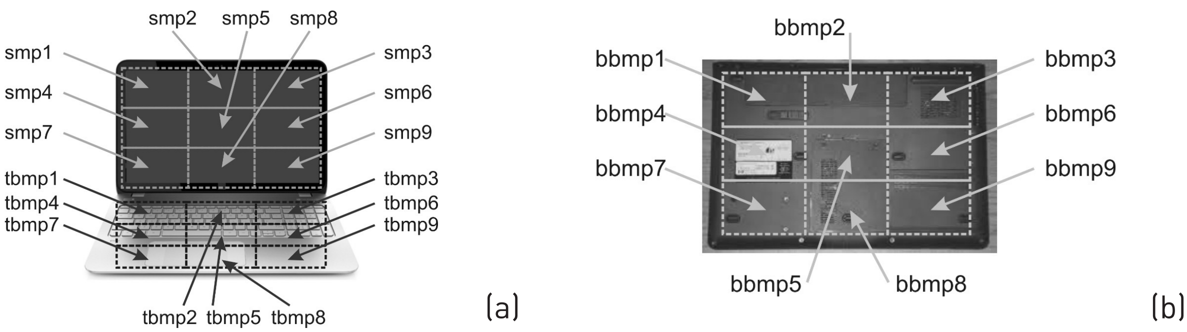

Figure 1 Measurement points in the portable computer neighborhood (a) at the top part of a portable computer, (b) at the bottom part of a portable computer

- Screen measurement points (smp1-smp9),
- Top body measurement points (tbmp1-tbmp9), and
- Bottom body measurement points (bbmp1-bbmp9).

To measure the correct value of the magnetic field *B* in the portable computer neighborhood, it is exposed to normal operating conditions and under heavy load (under stress). The normal operating condition means that portable computer is running programs like Word, Excel, Internet browsing, etc. As an addition to measurement, under stress operation is introduced. It defines the extreme computer operation which implies that all parts of the portable computer are under heavy load. It is accomplished by running the 3DMark Vantage program [16]. 3DMark Vantage program represents the well-known computer benchmarking tool created to evaluate the performance of a computer 3D graphic rendering and CPU workload processing capabilities. Its minimum hardware and software requirements are given in the Table 1.

Table 1 Minimum software and hardware requirements for running the benchmark tool program 3DMark Vantage [16]

Software requirements	
Operating system	Windows Vista, Windows 7, Windows 8
Hardware requirements	
Processor	Single-core Intel or AMD CPU
Memory	1GB of system memory
Graphics	DirectX 10 compatible
Hard disk	1.0GB free hard disk space
Additional requirements	
Internet	Internet connection required for some features

To test the portable computer, it has to be exposed to the same conditions. It implies that the portable computers should be tested in the same location with a similar or equal neighbor's magnetic field radiation, and away from direct sunlight and other heat sources.

3. Results and discussion

The measurement results show that the level of radiation at measuring points smp1-smp9 (in the area of the portable computer screen) is negligible or up to 0.02 μT. Hence, these results will not be presented below.

The measurement results of the magnetic field *B* obtained at the top, and at the bottom body parts of portable computers are given in Tables 2-7. Currently, 6 out of 10 portable computers (Laptops 1-6) are tested in normal operating condition and under stress, while the other 4 portable computers (Laptops 7-10) are tested only in normal operating condition. These 4 computers are tested in normal operating condition only, because they did not fulfill hardware requirements of the 3DMark Vantage program (see Table 1 for reference). All relevant technical

Table 2 The measured magnetic field B at the top parts of portable computers in normal operating condition (without stress)

Top parts	B (μT)					
w/o stress	Laptop 1	Laptop 2	Laptop 3	Laptop 4	Laptop 5	Laptop 6
minimum	0.0100	0.0141	0.0000	0.0173	0.0000	0.0548
maximum	0.5819	1.7686	0.6138	2.2011	1.3743	1.8958
average	0.1219	0.4805	0.1714	0.3709	0.4243	0.5468

Table 3 The measured magnetic field B at the bottom parts of portable computers in normal operating condition (without stress)

Bottom parts	B (μT)					
w/o stress	Laptop 1	Laptop 2	Laptop 3	Laptop 4	Laptop 5	Laptop 6
minimum	0.0224	0.0510	0.0100	0.0173	0.0245	0.0707
maximum	0.5190	3.6232	0.2573	3.5286	2.5267	4.3959
average	0.2308	0.8552	0.1110	0.7141	0.8680	1.1292

specifications of the tested portable computers are given in Table 8 in the appendix.

Tables 2 and 3 show the level of the measured magnetic field *B* at the top and at the bottom part of portable computers in the normal operating condition (without stress).

The maximum values of the measured magnetic field *B* are from 0.5819 to 2.2011 μT at the top parts and from 0.5190 to 4.3959 μT at the bottom parts of portable computers. Furthermore, the average values of the magnetic field B are from 0.1219 to 0.5468 μT at the top parts and from 0.1110 to 1.1292 μT at the bottom parts of portable computers. These magnetic field values are obtained in normal operating condition.

Table 4 The measured magnetic field B at the top parts of portable computers under stress

Top parts	B (μT)					
under stress	Laptop 1	Laptop 2	Laptop 3	Laptop 4	Laptop 5	Laptop 6
minimum	0.0141	0.0173	0.0000	0.0616	0.0245	0.0768
maximum	1.7750	1.4018	1.4057	2.5946	1.0852	5.0557
average	0.3724	0.3164	0.4673	0.8722	0.3914	1.5776

Table 5 The measured magnetic field B at the bottom parts of portable computers under stress

Bottom parts	B (μT)					
under stress	Laptop 1	Laptop 2	Laptop 3	Laptop 4	Laptop 5	Laptop 6
minimum	0.0173	0.0424	0.0000	0.1345	0.0173	0.1435
maximum	0.8526	3.6564	1.4320	4.5921	1.6506	10.9167
average	0.4143	1.0954	0.4606	1.3981	0.7267	2.2939

Tables 4 and 5 show the level of measured magnetic field *B* at the top and at the bottom parts of portable computers under stress.

The maximum values of the measured magnetic field *B* are from 1.0852 to 5.0557 μT at the top parts and from 0.8526 to 10.9167 μT at the bottom parts of portable computers. Furthermore, the average values of the magnetic field *B* are from 0.3164 to 1.5776 μT at the top parts and from 0.4143 to 2.2939 μT at the bottom parts of portable computers. These magnetic field B values, which are measured under stress, are 2 to 2.5 times higher compared to those obtained in normal operating condition.

Tables 6 and 7 show the level of the measured magnetic field *B* at the top and at the bottom parts of portable computers

Table 6 The measured magnetic field B at the top parts of portable computers (4 out of 10 portable computers are tested in normal operating condition only)

Top part	B (μT)			
w/o stress	Laptop 7	Laptop 8	Laptop 9	Laptop 10
minimum	0.0224	0.0173	0.0374	0.0316
maximum	1.5069	4.2164	1.6739	1.4279
average	0.2685	0.5475	0.3615	0.5323

Table 7 The measured magnetic field B at the bottom parts of portable computers (4 out of 10 portable computers are tested in normal operating condition only)

Bottom part	B (μT)			
w/o stress	Laptop 7	Laptop 8	Laptop 9	Laptop 10
minimum	0.1010	0.0283	0.0346	0.0245
maximum	5.7531	2.8986	1.7162	1.1891
average	1.5772	0.5850	0.5646	0.4267

in the normal operating condition (4 out of 10 portable computers are tested in normal operating condition only).

The maximum values of the measured magnetic field *B* are from 1.4279 to 4.2164 μT at the top parts and from 1.1891 to 5.7531 μT at the bottom parts of portable computers. Furthermore, the average values of the magnetic field *B* are from 0.2685 to 0.5475 μT at the top parts and from 0.4267 to 1.5772 μT at the bottom parts of portable computers. These values are obtained in normal operating condition of portable computers only. If we compare these values of the magnetic field B to those obtained with the portable computers used in condition without stress (see Tables 2 and 3 for reference), then the measured results are quite similar.

Figure 2 illustrates the comparison between the average level of low frequency magnetic field at the top and at the bottom parts of portable computers in normal operating condition and under stress.

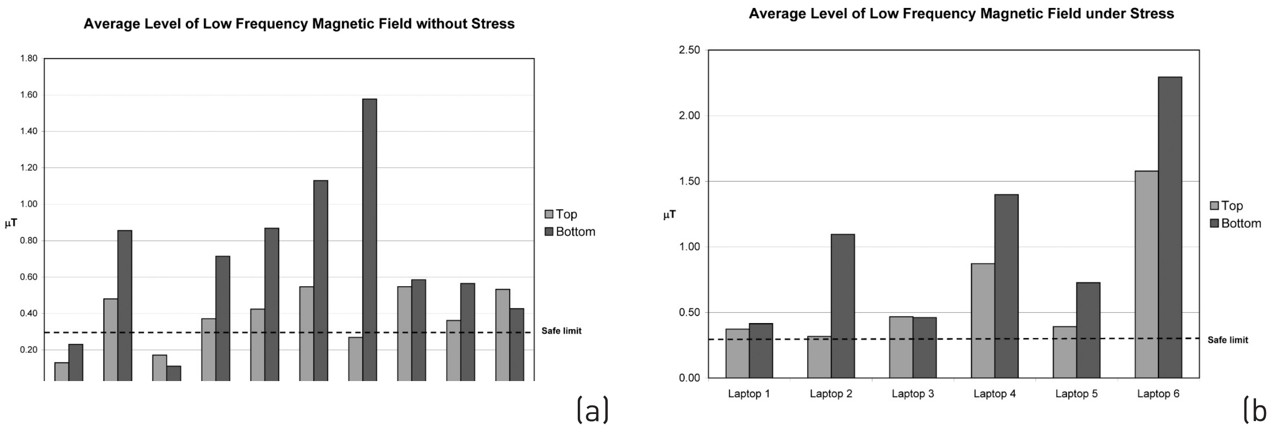

Figure 2 Comparison between the average level of low frequency magnetic field at the top and at the bottom parts of portable computers: (a) in normal operating condition (without stress), (b) under stress

Figure 3 illustrates the comparison between the maximum level of low frequency magnetic field at the top and at the bottom parts of portable computers in normal operating condition and under stress.

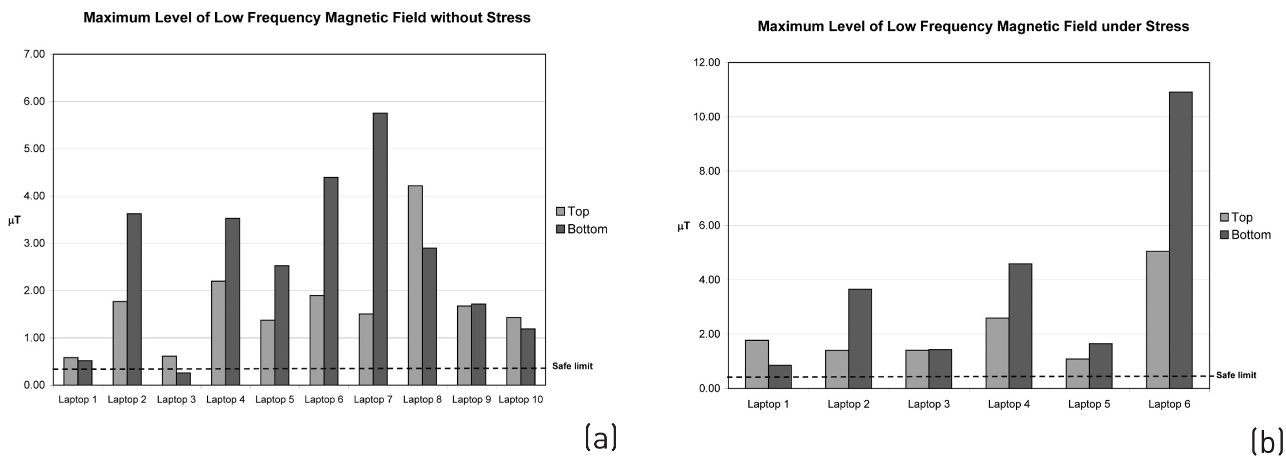

Figure 3 Comparison between the maximum level of low frequency magnetic field at the top and at the bottom parts of portable computers: (a) in normal operating condition (without stress), (b) under stress

The results of the experiment show that the critical measurement points are those close to the keyboard and touchpad, and at the bottom of the laptop. Furthermore, it is obvious that the level of the magnetic field measured at the bottom parts is usually higher than the level at the top parts of portable computers (see Figures 2 and 3 for reference). It is a very important observation, because the users of portable computer are usually in close contact with the bottom region. In this region, their exposure to low frequency magnetic field is high. It should be noted that *B* of 0.2 μT (TCO standard) [2, 8], 0.25 μT (MPR-II standard) [2], 0.3 μT [7], and 0.4 μT [9] are proposed as the safe limits for the electronic or computer equipment use. Unfortunately, the measured magnetic field values are considerably higher than those proposed by safe limits. Hence, an extreme caution is necessary in order to use properly the portable computers.

The only asset is a lower level of the low frequency magnetic field radiation in normal operating condition. It implies that using the typical office programs or the Internet browsing (not playing video or similar) contributes to smaller level of magnetic field exposure. In contrast, the users who play the games on a portable computer are exposed to very high levels of the magnetic field radiation (see measurement for under stress with 3DMark Vantage program consisting of video game fragments). Furthermore, the use of speed-step processor modes reduces the level of the magnetic field as well. Unfortunatelly, it leads to smaller processor calculating power typically evaluated by smaller CPU passmark [17] (see Table 8 for reference).

If we use the average level as a referent one, then the observations of the magnetic field level at the top parts of portable computers are up to twice the safe limit level (see Figure 2 (a) for reference) in the normal operating condition. The common sense tells us that using the portable computer with the break equal to the period of the work can be recommended. However, if we take into account the portable computer operation under stress, then the magnetic field levels at the top parts of portable computers are three to five times the safe limit level (see Figure 2 (b) for reference). Hence, the period of pausing between works should be longer.

At the end, the following suggestions are recommended: (i) to put the portable computers out of her/his lap, typically at the office desk, (ii) to use the external mouse, and (iii) to use the external keyboard if it is possible. However, the observation that the magnetic field is rapidly decreasing after a few cms from the magnetic field emitter represents an encouraging news.

4. Conclusions

The paper addressed the problem related to the magnetic field radiation, which exists in the neighborhood of portable computers. The measurement of the magnetic field was characterized by the extremely low level frequencies. It was carried out by Lutron EMF 828 devices. The obtained results showed that the critical levels of the measured magnetic field were sometimes considerably above the proposed safe limits [2, 7-9]. Consequently, the research pointed out the computer positions where the measured magnetic field radiation was significant. This information could be exploited to use the portable computer safely and without the risk.

Future research work will include the magnetic field measurements of the other computer office appliances such as desktop computers, printers, multi-operational devices, scanners, uninterruptible power supply, and so on.

Appendix

The list of portable computers with the general specifications

Laptop n.º	1	2	3	4	5	6	7	8	9	10
CPU Passmark [17]	2327	2327	1687	2113	1911	7493	961	795	1477	2646
CPU Total Dissipation (W)	17	17	25	35	35	45	17	31	25	35
GPU	integ.	integ.	integ.	integ.	discrete	discrete	integ.	integ.	integ.	integ.
Max. Power Consumption (W)	45	45	65	90	90	120	33	60	75	80

5. Acknowledgements

This work was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia TR33037.

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