Analysis of Biological Effects and Limits of Exposure to Weak Magnetic Fields

Conference Paper · December 2010

DOI: 10.1109/ICIAFS.2010.5715697

Malka N. Halgamuge
University of Melbourne

Analysis of Biological Effects and Limits of Exposure to Weak Magnetic Fields

Chathurika D. Abeyrathne*†, Peter M. Farrell† and Malka N. Halgamuge*†, Member, IEEE,
Department of Civil and Environmental Engineering*,
Department of Electrical and Electronic Engineering†,
The University of Melbourne,
Parkville, VIC 3010, Australia.
Email: c.abeyrathne@pgrad.unimelb.edu.au, {pfarrell,malka.nisha}@unimelb.edu.au

Abstract—Adverse biological outcomes due to thermal effects of exposure to high power magnetic fields are well understood and are the basis for standards for limiting human exposure to such fields. Over the past few decades a controversy has arisen over possible adverse biological effects due to exposure to weak, low frequency magnetic fields. This paper involves a critical analysis of the voluminous literature with a view to a theoretical investigation and comparison of the most prominent limits of exposure to weak magnetic fields and geomagnetic field to elucidate the main points of contention. Most of the weak magnetic fields that have been used in these experiments are below international exposure limits and quite a few fields are below Adair's minimum theoretical exposure limit. There is a large variation in the response of biological systems for various AC magnetic field strength to frequency ratio with no clear correlation. These results demonstrate that characterizing the biological effects by AC magnetic field strength to frequency ratio does not appear to be a reliable technique.

Keywords—biological effects, biological systems, exposure limits, weak magnetic fields

I. INTRODUCTION

CONSIDERABLE work has been done to date to determine the effects of magnetic fields. The influences of high power magnetic fields are known due to heat generated by those fields [1]. For example, biological effects such as nerve excitation and cardio stimulation can be caused due to the current induced in the body from high power fields [2]. The energy absorption rate of these high power magnetic fields is measured by the specific absorption rate (SAR). There is an ongoing controversy over possible health effects of weak, extremely low frequency magnetic fields since these effects are non thermal. Epidemiological evidence in support of the hypothesis has been published as well as laboratory based measurements of biological activity [3] - [19]. To explain the mechanisms involved in the interactions of biological systems with these fields, variety of mechanisms have been proposed such as Faraday Induction, Ion Cyclotron Resonance (ICR), Ion Parametric Resonance (IPR), magnetite coupling and Radical Pair Mechanism (RPM) [20] - [22]. Both the proposed mechanisms and the empirical evidence have been subjected to considerable criticism on the basis of thermal electrical noise interactions [23] - [26].

In order to analyze the experimental results on human body, the characteristics of tissues such as conductivity, exposed part of the body, sensitivity and exposed area should be compatible with the characteristics of biological systems (plants, animals) that are used in these experiments. Even though there is evidence for biological effects of weak magnetic fields it is not known whether these effects arise from induced electric fields or currents, sensitivity of the part of the body, threshold to the exposure to fields and response (cumulative, statistical, linear and nonlinear). In daily life exposure to 50 or 60 Hz electromagnetic fields is unavoidable because of highly utilized electricity. This draws an attention to the importance of the limits of exposure to weak electromagnetic fields. Adair's theoretical limits of exposure to weak low frequency electromagnetic fields are basically based on the physical analysis of energy content in these weak fields and thermal electrical noise energy at cell level [23] - [25], [27]. The problem arises in the possibility of explaining the complex biology using these simple physics.

The remainder of the paper is organized as follows. In Section II, natural limit of exposure to magnetic fields that is the geomagnetic field, Adair's theoretical exposure limits and International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines are discussed. Some experimental evidence for biological effects of weak magnetic fields is compared with these exposure limits in Section III. In the discussion of the results (Section IV), the experiments that were done using weak magnetic fields below Adair's minimum theoretical exposure limit are studied. The conclusions are given in Section V.

II. EXPOSURE LIMITS

A. Geomagnetic Field (GMF)

The geomagnetic field has a number of sources both internal and external to the earth. Most of the fields generated by these sources are time dependent [28]. The geomagnetic field contains magnetic fields up to 3 Hz. The natural signals above this frequency mostly arise from geomagnetic pulsation such as thunderstorms and lightning [29]. The Schumann resonances which are resonants of electromagnetic waves also occur at extremely low frequency [30]. Figure 1 shows the variation of the geomagnetic field with frequency. Also, the strength and inclination of static GMF vary from one area to another with latitudes [31]. For example, it ranges from less than 30 µT in Argentina to over 60 µT in south of Australia [32].

B. Adair's Theoretical Exposure Limits

Adair has calculated several limits for biological effects of electromagnetic fields based on the electric field induced in the tissues, potential energy of biological magnetite, ionic and molecular flux due to external electromagnetic fields [23], [24], [27]. These limits are shown in the Fig. 1.

Limit 1: calculated using electric field induced in the tissues due to external magnetic field. The induced electric field E_i should be higher than the thermal electric field E_{kT} to cause any biological effect [23]. Taking the magnetic field B, $E_i = Br_{exp}\omega/2$, this limit becomes $B > 0.546/f$ (B in Tesla and f in Hz) where the membrane resistance is $4 \times 10^6\ \Omega$, frequency span is 100 Hz, cell radius is 10 µm, radius of the effective exposed area r_{exp} is 10 cm and $\omega = 2\pi/f$ is the angular frequency of the external field [23].

Limit 2: calculated based on the potential energy transmitted to the biological magnetite elements by the magnetic fields W_v and thermal potential energy. This gives $B > 2.03 \times 10^{-8}(1 + 1.21f^2 \times 10^{-6})^{0.5}$ (B in Tesla and f in Hz), where the GMF is 50 µT, the magnetic field characteristic of magnetite domains is 4.8×10^5 A/m and viscosity of water is 7×10^{-4} Ns/m^2 [27].

Limit 3: introduced considering geomagnetic field variation. According to this there cannot be any significant biological effect from static magnetic fields smaller than the earth's magnetic field of 50 µT and alternating magnetic fields weaker than 4 µT, 60 Hz fields which are equal in effect to that from walking in the earth's field [23].

Limit 4: calculated using ionic and molecular influx due to weak magnetic fields. When elongated cells of 1mm length are considered this limit becomes $B \approx 0.1596 / f$ (B in Tesla and f in Hz) [33]. Here, the exposure time is 10^4 s, barrier at the resting trans-membrane potential is $8kT$, noise energy density is kT, channel gating charge is 10 times electronic charge, the maximum possible influx rate is 5×10^9 s^{-1} and loop radius is 0.3 m where k is the Boltzmann constant and T is the temperature in Kelvin.

All these limits decrease with increasing frequency except the limit based on the energy transmission to the magnetite elements by the weak magnetic fields.

C. ICNIRP Guidelines

Limits on exposure to electromagnetic fields are designed as standards or guidelines by several worldwide organizations for both workers and general public [34]. ICNIRP guidelines introduced limits of exposure to non-ionized radiation based

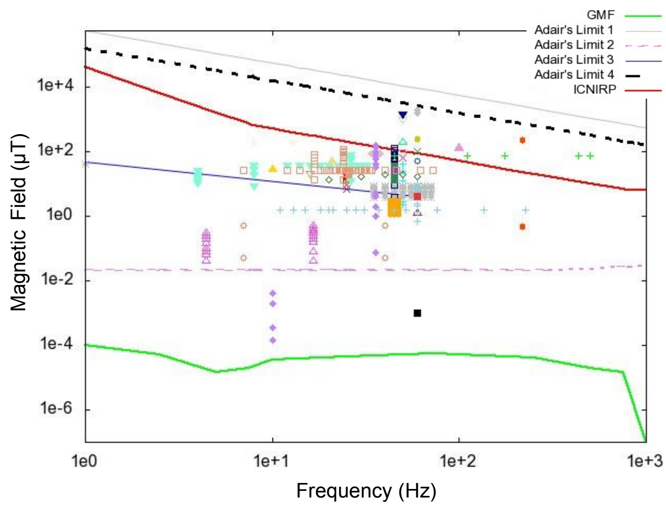

Fig. 1. Variation of the geomagnetic field with frequency, ICNIRP guide- lines, Adair's theoretical exposure limits and experimental demonstrations of biological effects of weak magnetic fields up to 1000 Hz.

on current density induced in the tissues. Also, there are other international standards introduced based on power density and electric field induced in the tissues [2].

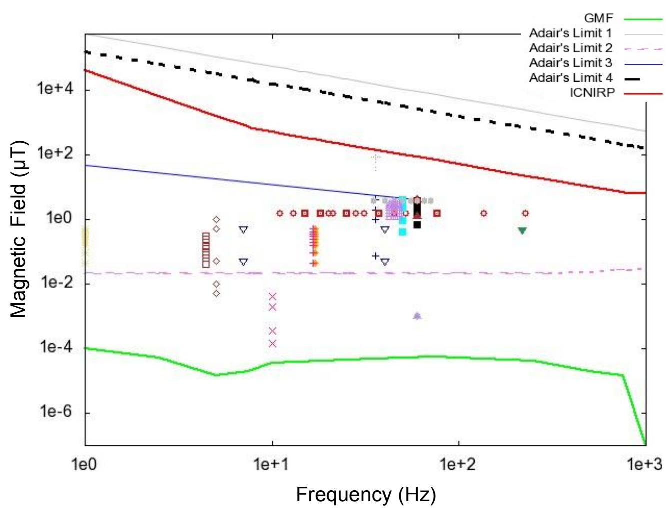

Fig. 2. Experimental demonstrations of biological effects of weak magnetic fields below Adair's minimum limit (limit 3).

III. Biological Effects

In most of the experiments biological effect is obtained from biological effect = (experimental data - control data) / control data. Since, the biological effect calculated in this way is dimensionless we can attempt to compare different biological effects. However, due to different characteristics of biological systems the responses to magnetic fields differ and this comparison becomes complex. Some of the experimental demonstrations of biological effects of weak low frequency magnetic fields up to 1000 Hz are shown in Fig. 1. Various biological effects such as neurite outgrowth (any projection from a cell body of a neuron), gravitropic bending (growth of stems in response to gravity), survival of animals, calcium influx (calcium ion flow through calcium channels), regeneration index (area of renewed part of a body that is cut before the exposure / whole body area) and mitotic index (number of cells that undergoes mitosis (cell division) / total number of cells) are measured in these experiments [9], [13], [35] - [37]. Biological effects depend on the magnetic field strength, frequency, exposure duration and biological system (animals, plants, and chemicals). The sensitivity of biological systems varies with their biological characteristics (tissues, chemicals involved in their biological processes, exposed body part, exposed area).

The measurements of biological effects can be confounded by the exposure conditions of the control system, coil configurations used to generate magnetic fields and instruments used to measure these fields. The generated magnetic field can be parallel, perpendicular or at an angle to the biological system. According to these different configurations the response of biological systems varies [38]. In some experiments, control system has been exposed to GMF or to a DC magnetic field which is equivalent to the DC field of the test system [13], [35]. Another set of experiments have been conducted by shielding magnetic fields of the control system [9]. The electric and magnetic field strengths are generally measured using field meters and the suitable electric or magnetic field sensors. Each measurement instrument has measurement limitations and uncertainties [39]. Also, background electromagnetic fields and environmental conditions (temperature, light, humidity) may affect these measurements.

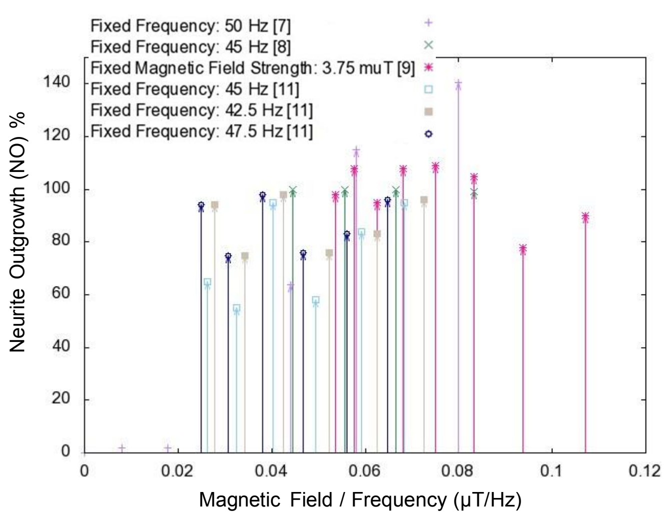

Fig. 3. Variation of the response of PC - 12 cells to weak magnetic fields below Adair's minimum limit (limit 3) with AC magnetic field strength to frequency ratio. In these experiments neurite outgrowth (any projection from a cell body of a neuron) of PC - 12 cells was measured by Blackman et al. in several experiments [7] - [9], [11].

IV. Results and Discussion

In this discussion of the results our analysis is limited to those experimental data below Adairs minimum exposure

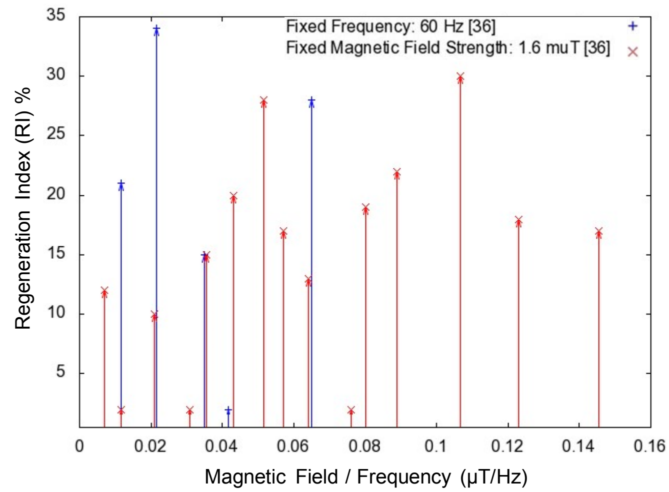

Fig. 4. Variation of the response of planarians to weak magnetic fields below Adair's minimum limit (limit 3) with AC magnetic field strength to frequency ratio. In these experiments regeneration index (area of renewed part of a body that is cut before the exposure / whole body area) of planarians was measured by Belova et al. in few experiments [36].

limit (limit 3). It is important to note that the results below Adair's minimum limit have been produced by independent research groups. There are several magnetic fields below Adair's minimum exposure limit (limit 3) that affect biological systems as shown in Fig. 2. The responses of these biological systems are analyzed to identify the influence of weak external magnetic fields on biological systems. In this study, responses of the same biological systems which were observed in several experiments are combined to analyze the correlation between biological effects and AC magnetic field strength to frequency ratio.

Figures 3, 4 and 5 show the responses of animals and plants that had been observed in few experiments. In Fig. 3 neurite outgrowth of PC 12 cells that were exposed to magnetic fields for 22 - 23 hours is depicted as a function of AC magnetic field strength to frequency ratio [7] - [9], [11]. In these experiments effect of different configurations of DC and AC magnetic fields were observed. This figure shows a large variation of neurite outgrowth for various AC magnetic field strength to frequency ratio. The regeneration index of planarians exposed to parallel AC-DC magnetic fields for 3 days was measured and compared with the response of the control system which was kept at the GMF [36]. There is no clear correlation between these responses of planarians for various AC magnetic field strength to frequency ratios as illustrated in Fig. 4. A comparison of gravitropic bending of flax segments exposed to parallel AC-DC magnetic fields and GMF for 2 hours was done in experiments and responses are shown in Fig. 5 [36], [40]. This illustrates similar to above figures that there is no association between the response of flax segments and AC magnetic field strength to frequency ratio. However, when the experiments of Belova et al. [36] are separately considered gravitropic bending and regeneration index follow Bessel function with AC magnetic field strength to frequency ratio.

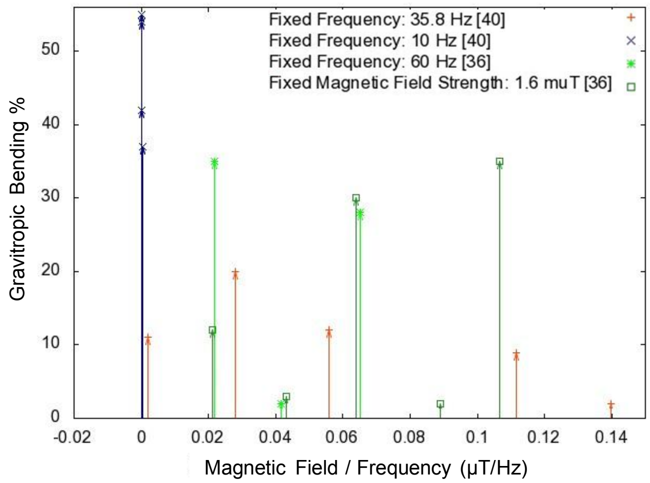

Fig. 5. Variation of the response of flax segments to weak magnetic fields below Adair's minimum limit (limit 3) with AC magnetic field strength to frequency ratio. In these experiments gravitropic bending (growth of stems in response to gravity) was measured by Belova et al. in several experiments [36], [40].

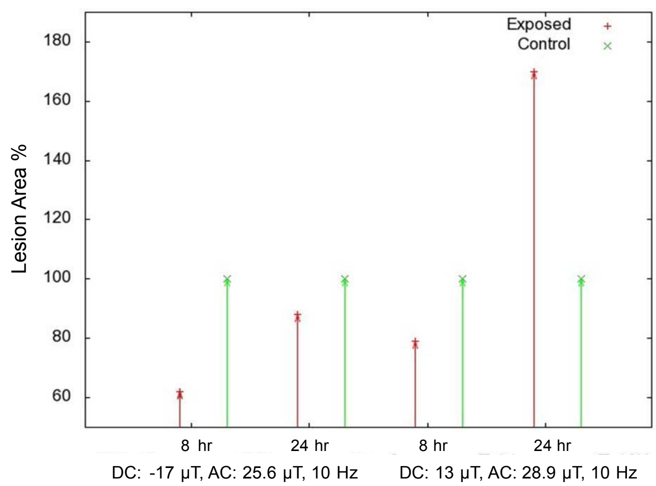

Fig. 6. Variation of the response of tobacco plants to weak magnetic fields with the exposure duration. In this experiment lesion area (any abnormal or damaged tissue) was measured by Trebbi et al. [19].

According to this analysis the effect of weak magnetic fields on the behavior of biological systems varies randomly. The fields in 35 to 70 Hz frequency and 1.18 to 3.75 μT intensity ranges which are below Adair's minimum exposure level influence more on neurite outgrowth of PC 12 cells. The regeneration index of planarians was higher for several magnetic fields below this minimum limit (60 Hz: 0.7, 1.3, 3.9 μT and 1.6 μT: 11, 13, 15, 18, 20, 28, 31, 37 Hz). According to these experiments, biological systems give different response to the same magnetic field. The magnetic field strengths and frequencies that give higher planarian's regeneration had caused only slight changes in plant's gravitropic bending [36]. As an example planarians show a higher response to magnetic fields of 1.3 and 3.9 μT at 60 Hz whereas flax segments show a moderate response to those fields [36]. Most of the other experiments do not show the strength of the response with variation of AC magnetic field strength and frequency [41] - [43]. Those experiments only observe the effect on biological system when exposed to a single value of weak magnetic field.

The variation of biological effects with the duration of exposure to magnetic fields have been demonstrated in some experiments [12], [44]. For example, Fig. 6 illustrates the response of tobacco plants that were exposed to two different combinations of magnetic fields for 8 hr and 24 hr [19]. This shows the influence of magnetic field strength and exposure duration on the spread of infection of tobacco plants to tobacco mosaic virus. Environmental conditions such as seasonal variations affect the measurements of magnetic fields as shown in Fig. 7. As in this figure the abnormality rate was measured during different seasons within 5 years when chick embryos were exposed to the magnetic fields [44]. Hence, rather than mentioning only the effect of weak magnetic fields it is important to illustrate the strength of the response of biological system to these fields with different conditions such as the exposure duration, seasonal variation, AC-DC magnetic field strength and frequency.

The evidence of biological effects should be acceptable since the exposure limits can be firmly introduced only on the basis of established experimental results. In some situations there is a high probability to unpublish the experiments which do not demonstrate any effect of weak fields. This confirmation bias affects the information processing of the influence of magnetic fields on biological systems. The materials and methods of published data should be sufficient to analyze the experiments. The results should be quantifiable and confirmed by independent studies [45].

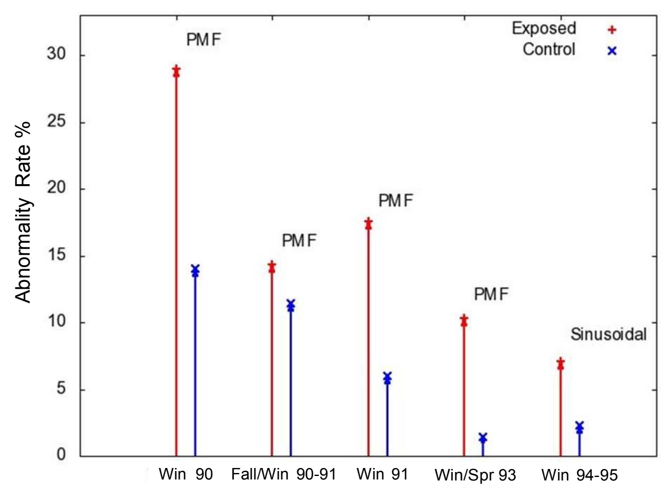

Fig. 7. The response of chick embryos to weak magnetic fields with seasonal variations during 5 years. In this experiment abnormality rate of chick embryos was measured by Farrell et al. [44].

V. Conclusion

There are some weak magnetic fields below Adair's minimum theoretical exposure limit (limit 3) that influence biological systems. We observe a large variation in the response of biological systems for various AC magnetic field strength to frequency ratio with no clear correlation. These results demonstrate that characterizing the biological effects by AC magnetic field strength to frequency ratio does not appear to be a reliable technique. Even though the results below Adairs minimum limit have been produced by independent research groups, these experiments have not been repeated independently. In order to identify an accurate limit for the exposure to weak magnetic fields the precision of these experiments should be further clarified.

REFERENCES

[1] J. A. D'Andrea, C. K. Chou, S. A. Johnston, and E. R. Adair, "Microwave effects on the nervous system," Bioelectromagnetics, vol. 6, pp. S107- S147, 2003.

[2] A. W. Wood, "Extremely low frequency (ELF) electric and magnetic field exposure limits: Rationale for basic restrictions used in the development of an Australian standard," Bioelectromagnetics, vol. 29, pp. 414-428, 2008.

[3] V. N. Binhi, and R. J. Goldman, "Ion - protein dissociation predicts windows in electric field-induced wound-cell proliferation," Biochimica et Biophysica Acta, vol. 1474, pp. 147-156, 2000.

[4] V. N. Binhi, Y. D. Alipov, and Y. I. Belyaev, "Effect of static magnetic field on E. coli cells and individual rotations of ion - protein complexes," Bioelectromagnetics, vol. 22, pp. 79-86, 2001.

[5] C. F. Blackman, S. G. Benane, J. R. Rabinowitz, D. E. House, and W. T. Joines, "A role for the magnetic field in the radiation induced efflux of calcium ions from brain tissue in vitro," Bioelectromagnetics, vol. 6, pp. 327-337, 1985.

[6] C. F. Blackman, S. G. Benane, D. E. House, and D. J. Elliott, "Importance of alignment between local DC magnetic field and an oscillating magnetic field in response of brain tissue in vitro and in vivo," Bioelectromagnetics, vol. 11, pp. 3159-3167, 1990.

[7] C. F. Blackman, S. G. Benane, D. E. House, and M. M. Pollock, "Action of 50 Hz magnetic fields on neurite outgrowth in pheochromocytoma cells," Bioelectromagnetics, vol. 14, pp. 273-286, 1993.

[8] C. F. Blackman, J. P. Blanchard, S. G. Benane, and D. E. House, "Empirical test of an ion parametric resonance model for magnetic field interactions with PC-12 cells," Bioelectromagnetics, vol. 15, pp. 239-260, 1994.

[9] C. F. Blackman, S. G. Benane, and D. E. House, "Frequency dependent interference by magnetic fields of nerve growth factor induced neurite outgrowth in PC-12 cells," Bioelectromagnetics, vol. 16, pp. 387-395, 1995.

[10] C. F. Blackman, J. P. Blanchard, S. G. Benane, D. E. House, and J. A. Elder, "Double blind test of magnetic field effects on neurite outgrowth," Bioelectromagnetics, vol. 19, pp. 204-209, 1998.

[11] C. F. Blackman, S. G. Benane, and D. E. House, "Experimental determination of hydrogen bandwidth for the ion parametric resonance model," Bioelectromagnetics, vol. 20, pp. 5-12, 1999.

[12] C. F. Blackman, S. G. Benane, and D. E. House, "The influence of 1.2 μT, 60 Hz magnetic fields on melatonin and tamoxifen induced inhibition of MCF-7 cell growth," Bioelectromagnetics, vol. 22, pp. 122-128, 2001.

[13] V. V. Lednev, "Bioeffects of weak combined constant and variable magnetic fields," Biophysics, vol. 41, no. 1, pp. 241-252, 1996.

[14] A. R. Liboff, J. R. Thomas, and J. Schrot, "Intensity threshold for 60-Hz magnetically induced behavioural changes in Rats," Bioelectromagnetics, vol. 10, pp. 111-113, 1989.

[15] A. R. Liboff, and W. C. Parkinson, "Search for ion cyclotron resonance in a Na^+ transport system," Bioelectromagnetics, vol. 12, pp. 77-83, 1991.

[16] A. R. Liboff, S. Cherng, K. A. Jenrow, and A. Bull, "Calmodulin dependent cyclic nucleotide phosphodiesterase activity is altered by 20
μT magnetostatic fields," Bioelectromagnetics, vol. 24, pp. 32-38, 2003.

[17] A. W. Wood, M. L. Sait, S. M. Armstring, and M. J. Martin, "Effects of 50 Hz magnetic fields on human physiology: plasma melatonin levels," in Second International Conference on Bioelectromagnetism, 1998, pp. 161-162.

[18] C. Rozanski, M. Belton, F. S. Prato, and J. J. L. Carson, "Real-time measurement of cytosolic free calcium concentration in DEM-treated HL-60 cells during static magnetic field exposure and activation by ATP,"Bioelectromagnetics, vol. 30, pp. 213-221, 2009.

[19] G. Trebbi, F. Borghini, L. Lazzarato, P. Torrigiani, G.L. Calzoni, and L. Betti, "Extremely low frequency weak magnetic fields enhance resistance of NN tobacco plants to tobacco mosaic virus and elicit stress-related biochemical activities," Bioelectromagnetics, vol. 28, no. 3, pp. 214-223,2007.

[20] A. R. Liboff, "The charge-to-mass ICR signature in weak ELF bio-electromagnetic effects," in Advances in Electromagnetic Fields in Living System, vol. 4, no. 6, E. C. Lin, Ed. Berlin: Springer Verlag, 2005, pp.189-218.

[21] V. V. Lednev, "Possible mechanism for the influence of weak magnetic fields on biological systems," Bioelectromagnetics, vol. 12, pp. 71-75, 1991.

[22] T. Yoshii, M. Ahmad, and C. Helfrich-Forster, "Cryptochrome mediates light-dependent magnetosensitivity of Drosophilas circadian clock," PLoS Biology, vol. 7, no. 4, pp. 0813-0819, 2009.

[23] R. K. Adair, "Constraints on biological effects of weak extremely low frequency electromagnetic fields," Physical Review A, vol. 43, pp. 1039-1048, 1991.

[24] R. K. Adair, "Constraints of thermal noise on the effects of weak 60-Hz magnetic fields acting on biological magnetite," Proceedings of the National Academy of Sciences, vol. 91, pp. 2925-2929, 1994.

[25] R. K. Adair, "A physical analysis of the ion parametric resonance model," Bioelectromagnetics, vol. 19, pp. 181-191, 1998.

[26] R. K. Adair, "Effects of very weak magnetic fields on radical pair reformation," Bioelectromagnetics, vol. 20, pp. 255-263, 1999.

[27] R. Deanastumian, J. C. Weaver, and R. K. Adair, "Rectification and signal averaging of weak electric fields by biological cells," Proceedings of the National Academy of Sciences, vol. 92, pp. 3740-3743, 1995.

[28] A. P. Hitchmn, F. E. M. Lilley, and W. H. Cmpbell, "The quiet daily variation in the total magnetic field: global curves," Geophysical Research Letters, vol. 25, no. 11, pp. 2007-2010, 1998.

[29] W. H. Campbell, Introduction to Geomagnetic Fields, Cambridge University Press, 1997.

[30] K. Schlegel, and M. Fullekrug, "Schumann resonance parameter changes during high-energy particle precipitation," Journal of Geophysical Re- search, vol. 104, no. A5, pp. 10111-10118, 1999.

[31] J. A. Jacobs, "Variations in the intensity of the earth's magnetic field Surveys in Geophysics," vol. 19, pp. 139-187, 1998.

[32] Geomagnetism. [online]. Available: http://www.ngdc.noaa.gov/geomagmodels/IGRFWMM.jsp?defaultModel=WMM

[33] J. C. Weaver, T. E. Vaughan, R. K. Adair, and R. D. Astumian, "Theoretical limits on the threshold fo rthe response of long cells to weak extremely low frequency electric fields due to ionic and molecular flux rectification," Biophysical Journal, vol. 75, pp. 2251-2254, 1998.

[34] R. Kavet, W. H. Bailey, T. D. Bracken, and R. M. Patterson, "Recent advances in research relevant to electric and magnetic field exposure guidelines," Bioelectromagnetics, vol. 29, pp. 499-526, 2008.

[35] V. V. Novikov, G. V. Novikov, and E. E. Fesenko, "Effect of weak combined static and extremely low-frequency alternating magnetic fields on tumor growth in mice inoculated with the Ehrlich ascites carcinoma," Bioelectromagnetics, vol. 30, no. 5, pp. 343-351, 2009.

[36] N. A. Belova, O. N. Ermakova, A. M. Ermakov, Z. Y. Rojdestvenskaya, and V. V. Lednev, "The bioeffects of extremely weak power-frequency alternating magnetic fields," Environmentalist, vol. 27, pp. 411-416, 2007.

[37] B. Koch, M. Sommarin, B. R. R. Persson, L. G. Salford, and J. L. Eberhardt, "Interaction between weak low frequency magnetic fields and cell membranes," Bioelectromagnetics, vol. 24, pp. 395-402, 2003.

[38] C. F. Blackman, J. P. Blanchard, S. G. Benane, and D. E. House, "Effect of AC and DC magnetic field orientation on nerve cells," Biochemical and Biophysical Research Communications, vol. 220, pp. 807-811, 1996.

[39] D. Stratakis, A. Miaoudakis, C. Katsidis, V. Zacharopoulos, and T. Xenos, "On the uncertainity estimation of electromagnetic field measurements using field sensors: A general approach," Radiation Protection Dosimetry, vol. 133, no. 4, pp. 240-247, 2009.

[40] N. A. Belova, and V. V. Lednev, "Extremely weak alternating magnetic fields affect the gravitropic response in plants," Biophysics, vol. 46, pp. 122-125, 2001.

[41] M. A. Persinger, "Differential numbers of foci of lymphocytes within the brains of lewis rats exposed to weak complex nocturnal magnetic

fields during development of experimental allergic encephalomyelitis," International Journal of Neuroscience, vol. 119, pp. 166-184, 2009.
[42] F. S. Prato, D. Desjardins-Holmes, L. D. Keenliside, J. C. McKay, J.A. Robertson, and A. W. Thomas, "Light alters nociceptive effects of magnetic field shielding in mice: intensity and wavelength considerations," Journal of the Royal Society, vol. 6, pp. 17-28, 2009.
[43] P. D. Whissell, E. W. Tsang, B. P. Mulligan, and M. A. Persinger, "Prenatal exposures to LTP-patterned magnetic fields: Quantitative effects on specific limbic structures and acquisition of contextually conditioned fear," International Journal of Neuroscience, vol. 119, pp. 1-14, 2009.
[44] J. M. Farrell, T. L. Litovitz, M. Penafiel, C. J. Montrose, P. Doinov, M. Barber et al. "The effect of pulsed and sinusoidal magnetic fields on the morphology of developing chick embryos," Bioelectromagnetics, vol. 18, pp. 431-438, 1997.
[45] M. H. Repacholi, "Radiofrequency field exposure standards: Current limits and relevant bioeffects data," in Biological Effects and Medical Applications of Electromagnetic Energy, O. P. Gandhi, Ed. Prentice Hall, Englewood Cliffs, NJ, 1990.