XVII IMEKO World Congress
Metrology in the 3rd Millennium
June 22–27, 2003, Dubrovnik, Croatia

INSTRUMENTATION FOR BIOLOGICAL EXPOSURE TO ELECTROMAGNETIC FIELDS

Roman Malarić[(1)], Mirta Tkalec[(2)],Krešimir Malarić[(1)]

[(1)]Faculty of Electrical Engineering and Computing, Unska 3, HR-10000 Zagreb, Croatia,
[(2)]Faculty of Science, Department of Botany, Rooseveltov trg 6, HR-1000 Zagreb, Croatia,

Abstract – *The effects of extremely low-frequency (ELF) electromagnetic fields (EMFs) on human beings, animals and plants have been the subject of debate and research for the last thirty years. The ELF EMFs are produced by power transmission and distribution lines and household appliances. The last ten years have also seen the wide use of mobile phones all around the world. The base stations that are needed for mobile communication have sprung all over the cities and neighborhood. They operate on the frequencies from 400 MHz to 1900 MHz. The instrumentation for generation of EMFs of both power frequency of 50 Hz and mobile phone frequencies are discussed in this paper. The instrumentation is used for experiments to learn how EMFs are affecting the plant physiology.*

Key words*:* Helmholtz coil, GTEM-cell, biological exposure experiments, EMF field, *Lemna mino**r***

1. BIOLOGICAL EXPOSURE TO ELECTROMAGNETIC FIELDS

Electromagnetic fields are part of everyday life in modern world, as they are produced by every electric home appliance from hairdryers to TV sets as well as by electric power transmission and distribution lines that cross our countryside and cities. They can extend far beyond their sources, and are mostly imperceptible to people. EMF consists of two parts: electric fields and magnetic fields. They are both created by flow of electricity, both radiate into surrounding space in the form of waves, and intensity of both diminishes significantly with distance. However, these fields also have significant differences. For example, electric field is produced wherever there is a potential difference, even when electric current is not flowing, while magnetic field is produced only by electric current flow. Another significant difference is their susceptibility to shielding. Electric fields are susceptible to shielding effects by almost anything that stands in their way, substantially reducing its effect. On the other hand, magnetic fields are passing through any object, except those that have high concentration of iron. Subsequently, the research has been focused to the magnetic field effects, and not electric field.

The electromagnetic spectrum is arranged according to its frequency and wavelength. The EMF waves with highest frequency such as gamma rays, x-rays and ultraviolet radiation are known as ionizing waves. Ionizing waves are highly energetic and are known to break chemical bonds, change the production of enzymes, alter chemical equilibrium and create thermal effects that can induce biological changes. Both mobile communication waves from 400-1900 MHz and especially ELF EMF waves are lacking energy to break chemical bonds or heat tissue. Because of that nature, they were not considered dangerous until recently. Some of the studies originating thirty years ago and beyond have suspected that the long rate exposure of low frequency waves can have the same effects as short term exposure to X and gamma ray. Although until now, there was no direct link between mobile phones and transmission lines and the risk of health hazard, the possibility for it cannot be ruled out [1,2]. Also, some authors suggest that EMF generated by mobile phones could change the cell membrane's permeability and interfere with organic molecule. EMF also create electric currents in the bodies of people and animals, which could also potentially cause biological effects, even though induced currents are lower than natural electric currents in the body such as currents caused by activity of brain and heart.

Most of the studies are concentrated on humans and animals, but the EMF effect on plants is equally important for agricultural and ecological reasons.

2. INSTRUMENTATION

The unit under test can be positioned in so called "near" or "far" field. The ratio of electric field (E) and magnetic field (H), which is the wave impedance (Z_w), is the characteristic impedance of the surrounding medium. In the far field (Fig. 1.), there is no way of knowing whether the measured electric and magnetic fields were created by a magnetic or electric filed source. In the far field, **E** and **H** are related by the characteristic impedance of the medium (120π or 377 Ω for a vacuum):

$$Z_w = E/H = 120\pi = 377\ \Omega \qquad (1)$$

For point sources, the far field is at the distances greater than $r > \lambda/2\pi$, where r is the distance from the source. The far field is 955 km away from the source for frequency of 50 Hz, while at 900 MHz the far field is just 5 cm from the point source. In the near field, the wave impedance may become any value ranging between:

$$120\pi\left(\frac{2\pi r}{\lambda}\right)\Omega < Z_w < 120\pi\left(\frac{2\pi\lambda}{r}\right)\Omega \qquad (2)$$

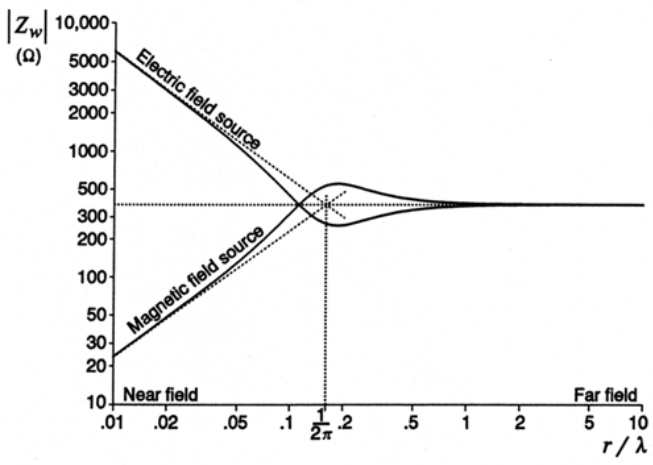

Fig. 1. Wave impedance versus distance

Therefore, the different kinds of equipment are used to generate EMF fields for power frequency and mobile phone frequency.

2.1. Helmholtz coil

Generation fields of known and uniform strength is important for accurate and repeatable susceptibility measurements. Power frequency uniform magnetic field is created by a Helmholtz coil arrangement. It can produce a uniform magnetic field ***H*** of known strength over a volume necessary to perform experiments. It consists of two parallel circular coils spaced one radius apart and driven in phase.

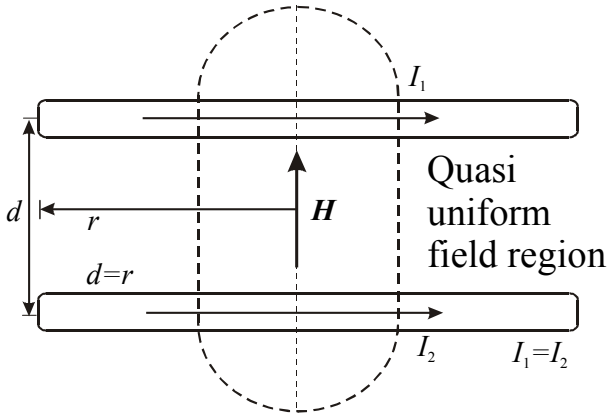

Fig. 2. The Helmholtz coil is an arrangement of two parallel coils driven in phase.

The large volume of uniformity results because there is a good deal of cancellation for the off axis field components generated by the coil. For two round coils in the standard configuration (Fig. 2.), which is a spacing equal to one-half of the side length for circular coils, the field is given by the formula:

$$H = \left(\frac{8}{\sqrt{125}}\right)\cdot\left(\frac{nI}{r}\right) \approx 1{,}43\cdot\frac{nI}{r} \qquad (3)$$

where H is the field strength in A/m, n is the number of turns in each coil, and I is the coil current. The coils used in experiments (Fig. 4.) have radius of r=0,27 m, they are spaced one radius apart, and have 100 turns of copper wire each. The arrangement can produce maximum magnetic field density of 1 mT, by applying current of 3 A.

2.2. Gigahertz Transversal Electromagnetic Mode (GTEM) cell

GTEM-cell is a transmission structure based on a TEM-cell approach [3]. Slightly spherical wave propagates from the source into a 50 Ω rectangular coaxial transmission line and its distributed hybrid termination without geometrical distortion of the TEM wave. The tapered section is used for transition of characteristic impedance of the wave-guide from 50 to 377 Ω. Since the opening angle of the wave-guide is small, the undistorted spherical wave can be considered as a plane wave. The TEM mode excited by either a Continuous Wave source or a pulse generator simulates an incident plane wave for immunity and emission tests.

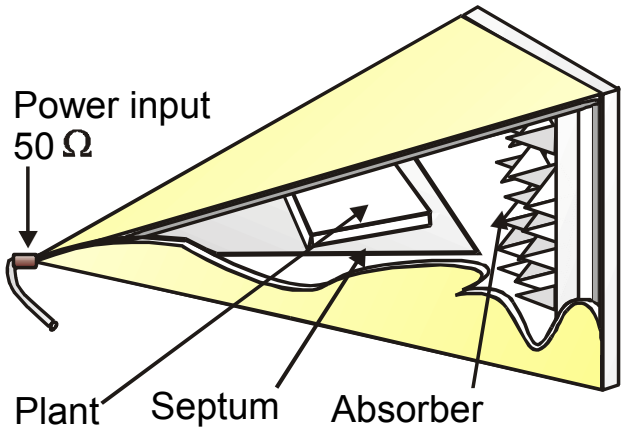

Fig. 3. GTEM-cell

3. TEST ORGANISM

Plants have important role in the living world as main primary producers so it would be beneficial to investigate their interaction with today's EM environment.

Duckweed *Lemna minor* is a small widely spread aquatic plant, which has been commonly used as a test organism for environmental monitoring [4]. Obtained results can also be useful in research on other higher plants like crops, even other organisms because of the cell's similarities.

Lemna minor plants were grown on sterile medium with addition of agar in plastic Petri dishes, easy to carry and manipulate. To study the effect of EMF generated by mobile phones plants were exposed in GTEM cell to the frequencies of 400, 900 and 1900 MHz with field strength of 10 V/m for 14 hours. For ELF EMF effect plants were exposed to 50 Hz with magnetic strength of 1 mT for 24 hours in Helmholtz coil. Five Petri dishes were used in each experiment. After exposure plant growth was monitored during two weeks by counting the number of leaves on days

0, 3, 5, 8, 10, 12, 14 and relative plant number was calculated [5]. Control plants have been kept in the same environmental conditions except they were not exposed to the EMF. Results are represented as mean values from ten replicates and expressed as percentages of control. The statistical significance of the results was measured by using the Student t-test ($p<0.05$).

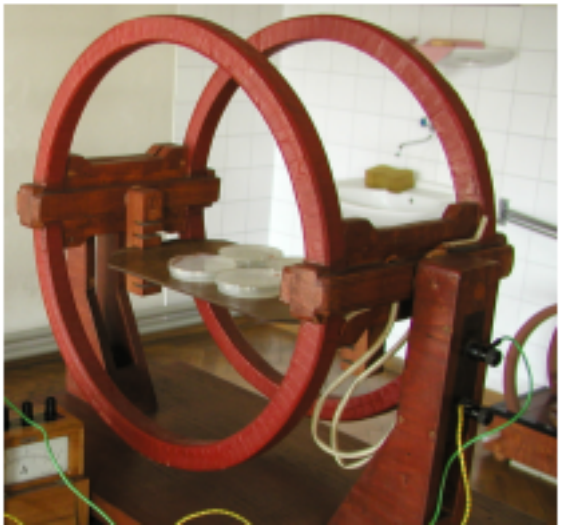

Fig. 4. *Lemna minor* inside Helmholtz coil

4. RESULTS

The field strengths for experiments are chosen to resemble strengths from household appliances and mobile phones. For example, microwave oven has ELF magnetic field of 0,2 mT at distance of 2,5 cm away from it, while other appliances produce magnetic fields that do not exceed 0,1 mT at the same distance. On the other hand, a mobile phone transmitter with 2 W, 2 cm away from the antenna is producing around 40 V/m field during conversation.

The 14 hours exposure to the electric field of frequencies 400, 900 and 1900 MHz with strength of 10 V/m did not have significant effect on plant growth (Fig. 5).

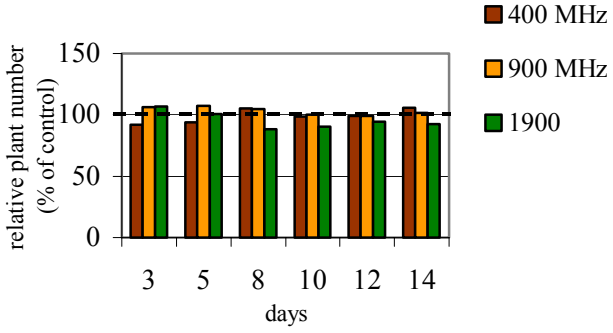

Fig. 5. The growth of *Lemna minor* after exposure to the EMF of 400, 900 and 1900 MHz with strength of 10 V/m for 14 hours. Control is represented as 100% (dashed line).

However, after exposure to 1900 and 900 MHz growth was stimulated at the beginning but than at the second week of experiment 1900 MHz slightly reduced it. Exposure to frequency of 400 MHz reduced the growth at the beginning but at the end some stimulation was noticed. The growth of plants exposed to magnetic field of 50 Hz for 24 hours was slightly stimulated in comparison with the control but it was not significant (Fig. 6).

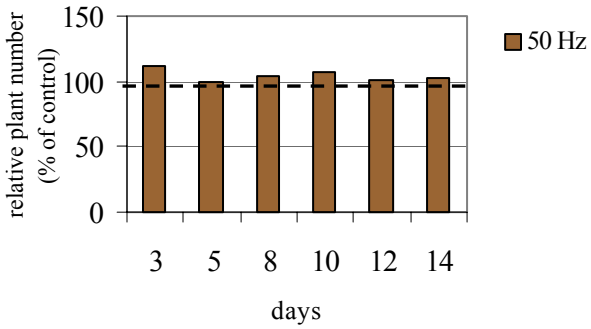

Fig. 6. The growth of *Lemna minor* after exposure to the magnetic field of 50 Hz with strength of 1 mT. Control is represented as 100% (dashed line).

5. CONCLUSION

Helmholtz coils and GTEM-cell have been designed at FER, Zagreb, and could be used for biological exposures. Plant *Lemna minor* was exposed to the electric field of frequencies 400, 900 and 1900 MHz with strength of 10 V/m and to the magnetic field of 50 Hz, strength 1 mT. There was no significant effect on growth of *Lemna minor*, which is in accordance with other investigations in that field. The future research will be focused on joint effects of EMF and other environmental factors.

REFERENCES

[1] J.C. Lin: "Microwave exposure and safety associated with personal wireless telecommunication base stations", IEEE Microwave magazine, September 2002

[2] M. Netzer: "Does radio frequency electromagnetic radiation (EMR) cause cancer?", ITEM Update, 2000

[3] D. Koenigstein and D.Hansen: "A New Family of TEM-Cells with Enlarged Bandwidth and Optimized Working Volume", 7th Zurich Symp. and Techn. Exh. on EMC, March 1987, Proc. pp. 172-132

[4] M.A. Lewis: "Use of freshwater plants for phytotoxicity testing: a review, Environ. Pollut. 87, 1995, pp. 319-336

[5] M. Tkalec, Z. Vidakovic-Cifrek and I. Regula: "The effect of oil industry "High Density brines on duckweed *Lemna Minor L.*", 1998, Chemosphere, Vol. 37, No. 13, pp. 2703-2715

Authors:
Roman Malarić, Faculty of Electrical Engineering and Computing, Unska 3, HR-10000 Zagreb, Croatia,
Phone: 385 1 6129 789 Fax: 385 1 6129 616
e-mail: roman.malaric@fer.hr
Mirta Tkalec, Faculty of Science, Department of Botany, Rooseveltov trg 6, HR-1000 Zagreb, Croatia,
Phone: 385 1 4877 743 Fax: 385 1 4826 260
e-mail: mtkalec@biol.pmf.hr
Krešimir Malarić, Faculty of Electrical Engineering and Computing, Unska 3, HR-10000 Zagreb, Croatia,
Phone: 385 1 6129 789 Fax: 385 1 6129 717
e-mail: kresimir.malaric@fer.hr