Irena Ćosić
Professor

Dean Cvetković
Postdoctoral Research Fellow

Qiang Fang
Senior Lecturer
RMIT University
School of Electrical and Computer Engineering
Melbourne, VIC, Australia

Emil Jovanov
Associate Professor
University of Alabama in Huntsville
Electrical and Computer Engineering Dept
Huntsville, Alabama, U.S.A.

Harry Lazoura
Senior Design Engineer
Custom Systems Pty Ltd.
Melbourne, VIC, Australia

Human Electrophysiological Signal Responses to ELF Schumann Resonance and Artificial Electromagnetic Fields

In this paper we compare the experimental findings from human electropysiological signal responses to environmental "geomagnetic" and artificial extremely low frequency (ELF) electromagnetic fields in order to determine the transfer characteristic from acupuncture meridian analysis and EEG studies. The fundamental Schumann resonance frequency is claimed to be extremely benificial to existence of the biological cycle phenomena of plants, animals and humans. However, the results from our acupuncture meridian and EEG studies have shown that frequencies between 8.8 and 13.2 Hz, *which fall between peaks of the Schumann resonance, mainly correlate with analysed human electrophysiological signals, while one study proves a correlation between transfer function of Schumann resonance and electro-acupunture meridian. The results from our acupuncture meridians and EEG activity studies confirm that the human body absorbs, detects and responds to ELF environmental EMF signals. This is a classical physics phenomenon utilised in telecommunication systems, which definitelly needs to be further investigated for possible biological cell-to-cell communication phenomena.*

Keywords: *ELF, Electromagnetic Field, Schumann resonance, Acupuncture meridian, EEG, Alpha rhythm.*

1. INTRODUCTION

1.1 Schumann Resonance Electromagnetic Fields in the Evolution of Life

A continuous extremely low frequency (ELF) process is present in the geomagnetic field. Resonant oscillations in the ionosphere of the Earth and oscillations in the plasmasphere and the magnetosphere are caused by the solar wind. The peaks of the resonant characteristic of the system are called the Schumann resonances, and reside approximately on 100, 21, 14.1, 7.8, 5.7, 4, 1, 0.1 and 0.001 Hz [1]. The most common geomagnetic frequency is 7.8 Hz and plants, animals and humans living in such environment are known to benefit from it [1,2]. A number of studies have shown that geomagnetic fields have a major influence on the orientation of pigeons and sea gulls, protein synthesis and branching in plants and human physical and mental states [1]. It has been documented in the past that the existence of the biological cycle phenomenon is dependent upon the living organism having precise knowledge of its position on the Earth [3]. Various animals utilise geomagnetic field for migrational and direction-finding purposes with precision along definite geographical routes [3]. In 1992, Kirchvink et al conducted experiments on human brain samples and the results from these studies indicated that human brains contain trace amounts of magnetite or ferromagnetic material, which were found distributed over all cerebral lobes, the cerebellum, basal ganglia and midbrain [4]. The main conclusion from these findings was that the magnetic senses or magnetoreception should share many attributes of other sensory systems, which include neural amplification and transmission pathways to direct signals to the brain [5]. Kirschvink et al (2001) reported that it was still unclear whether people have a magnetic sense. However, the magnetite (4ng of magnetite per 1g of brain tissue) found in human brains was very similar to those in bacteria, insects and animals [6]. This magnetite or ferromagnetic material is shaped in such a way as to be optimal for use as a magnet. Considering that ferromagnetic materials interact strongly with magnetic field, there is a possibility that the interaction with external magnetic field could influence the brain tissue characteristics and possibly brain functioning. The mechanism of magnetoreceptors has not been identified conclusively but there has been an agreement with biophysical models proposing that the geomagnetic field interacts with photoreceptors.

Biological life has always taken place in a sea of naturally occurring EM radiation of cosmic, atmospheric and geomagnetic origin, which can be categorized as terrestrial or extraterrestrial radiation. Extraterrestrial radiation consists of electromagnetic waves of different wavelengths, such as visible "light",

Received: May 2006, Accepted: August 2006
Correspondence to: Irena Ćosić
RMIT University,
School of Electrical and Computer Engineering,
PO Box 2476V, Melbourne, VIC 3001, Australia
E-mail: irena.cosic@rmit.edu.au

infrared, microwave radiation and of subatomic particle radiation, in particular:

- Electrons, protons, ions and atomic nuclei;
- Magnetic fields originating from the sun, the earth and other planets;
- Cosmic radiation from all directions (not only from the sun), which reach the earth with nearly the velocity of light. This radiation consists of very high-energy elementary particles and nuclei - also called cosmic ultra radiation; and
- Electromagnetic radiation of nearly all wavelengths.

The main source of extraterrestrial radiation is the sun. Other sources are planets and suns outside our solar system. Extraterrestrial sources of magnetic and gravitational fields are the sun, moon and other planets of our solar system.

Natural terrestrial radiation originates in the earth's atmosphere and the earth's surface, such as natural radioactivity. It should be noted that the earth's atmosphere acts as a filter for much of the extraterrestrial radiation, mostly in the UV frequency band. Visible light and infrared radiation are able to penetrate the atmosphere in significant intensities..

Since life on earth has always taken place in such environment of EM radiation of cosmic, atmospheric and geomagnetic origin, and given the previous outline of how biological systems use resonant electromagnetic pathways at the molecular level and possibly for more morphogenic system wide communications, one could reasonably assume that living system have developed natural defense mechanism to ensure the integrity of their internal electromagnetic communications [7]. However, man-made or artificial EM radiation is a very recent phenomenon and may pose a new source of possible interference that naturally evolved biological systems would most likely not be prepared. Man-made fileds feature frequency ranges, intensities and modulations hitherto never encountered in the natural world.

2. EM RADIATION AND BIOLOGICAL FUNCTIONING

The effects of artrificial (man-made) EM radiation on living tissue can be broadly divided into two categories:

- *Thermal effects*, i.e. the destructive effects of gross thermal heating.
- *Athermal effects* or relatively 'weak fields' that produce temperature increases below the range of normal organism fluctuations.

There is no doubt about the actual damage of gross thermal effects; it has been found that strong microwave radiation can alter and does damage chromosomal material in live animals [8]. However, it is the weak field and associated athermal effects which have evoked most controversy and continue to be the current subject of much debated research. To aid in putting this debate into perspective it may be useful to make an educated guess as to what one is reasonably likely to encounter.

A biological system that uses electromagnetic communication pathways is not likely to do so in a static way, such as using one narrow frequency band for a relatively long time period. Complex biological systems would most likely also use complex electromagnetic communication systems. A number of filters and windows would be likely to exist, both in terms of frequency, intensity and modulation. One such effect has been reported in the treatment of myofacial pain using microcurrents where the effects of microcurrent therapy is extremely frequency dependent and will only produce positive effects in the range of 30 – 70 μA [9,10].

The effects of the simple man-made (artificial) externally applied weak radiation which is currently used in testing shuld also seriously need to consider that:

- Any complex biological modulation systems are not readily duplicated by human produced weak EM radiation as currently used for testing purposes.
- Effects produced by man-made EM radiation may be more due to the increase of the general stress load on the organism rather than because of distortion of information.

The frequencies used by investigators are currently heavily dependent on guess work and often chosen on the basis of equipment and licensing availability. Judging from anecdotal reports, human sensitivity to weak EM radiation seems to cover a very broad spectrum. Therefore, one might expect the effects of weak EM radiation used in laboratory tests to be masked and difficult to detect, unless the test radiation corresponded in some way closely to the fields naturally used by the biological system.

For weak EM radiation effects to be clearly demonstrable, one would surmise that human generated fields closely mimic biological communication methods, both in intensity, duration, frequency and modulation. However, as currently no clear understanding of the system wide electromagnetic communications channels used by biological systems currently exists, research into this area could greatly help in understanding athermal effects.

Given the current methods of investigation EM radiation effects would be more akin to the effects of a jamming transmitter that randomly interferes with communication channels rather than the insertion of new information into the communications channel. Nonetheless there is a growing body of evidence pointing to the existence of athermal effects in the field [11]. One hypothesis is that weak EM radiation stresses the whole organism and these stresses manifest in a variety of symptoms often in unpredictable ways [12]. Organisms as a whole may be able to compensate for the effects of EM radiation but only at the added expense of greater total stress burden. The human body as well as any other biological organism have specific electrical and electromagnetic properties that can be observed depending on the type of field (electric, electromagnetic and magnetic).

2.1 Electrophysiological Signals

Electrophysiological signals (ECG, EEG, EMG, etc.) mainly originate from the cell membrane. According to the widely accepted Hodgkin-Huxley model, the cell membrane behaves as a capacitor electrically with a constant potential difference between the inner and outer side of -50 mV to -100 mV. This potential is due to the diffusion and drift of ions through the membrane and is called the 'resting potential'. If a chemical or electrical stimulus raises the potential across the membrane for more than 20%, stimulus threshold is exceeded and the cell membrane resistance drops leading to membrane potential changes. It is becoming positive between +40 mV to +60 mV. This new potential can last for about 10 ms (refractory period) and is called an action potential. Bioelectric potentials originate from the action potentials of a number of cells and may be sensed by the appropriate electrodes.

Electrocardiogram (ECG) is an electrical signal produced by synchronised action potentials (depolarisations) of a number of muscles in the heart. Such electrical activity, which is regular, causes heart muscle to contract. This synchronised muscle activity is vital. Any disturbance in the ECG electrical activity could be fatal. The main frequency of ECG is at about 1- 2 Hz (60 to 120 beats per minute), as shown in Table 1. Similar electrical activity occurs in all other muscles but it is less synchronised. The electrophysiological signal produced during the muscle cells activation is called electromyogram (EMG).

Table 1. Common rhythmic biomedical signals.

Signal	Frequency	Magnitude (volt, pressure)
EEG	dc - 100 Hz	15 - 100 mV
EMG	10 - 200 Hz	depends on muscle activity
ECG	0.05 - 100 Hz	10 mV (foetal) and 5 mV (adult)
Heart rate	45 - 200 beats/min	-
Blood pressure	dc - 200 Hz	40-300 mm Hg (arteries) 0-15 mm Hg (ventricles)
Breath rate	12 - 40 breaths/min	-

In activated nerve cells, the cell membrane becomes depolarised and they also produce the action potential. A number of nerve cells in the brain are activated all the time. The collective signal produced by the action potentials in the brain is called electroencephalogram (EEG). EEG can be measured on the surface of the head and is vital to interpret the brain activity. The human body can be considered as a very complicated living system with a number of different chemical, electrical and mechanical processes running simultaneously and continuously. As such, the system would have a number of different transfer functions for different processes and is expected to have possible resonant points for different processes.

In this paper we compare the experimental findings of responses from all human electropysiological signals to environmental "geomagnetic" and artificial extremely low frequency (ELF) electromagnetic field radiation, and characterize:

- Acupuncture meridian (point LI4) [13];
- Acupuncture meridian (points LI4 and LI11) [14];
- Acupuncture meridian (points LI4 and LI10) [15,18-22]; and
- EEG activity (16 points) [16].

3. RESONANCE IN ACUPUNCTURE MERIDIANS

3.1 Electrical Properties of the Skin

Skin is an important organ in the body and the most exposed organ to the environment. Electrically, skin behaves as a capacitor. Measurement of the skin electrical resistance is important for understanding and modeling of skin electrodes used in the measurements of physiological signals, such as EEG, ECG, EMG etc. It has been found that there are specific points in the skin with much lower electrical resistance. Interestingly, these points coincide with acupuncture point, opening a possibility to explain acupuncture effects by electrical conductivity [17]. Acupuncture points in theory are joined via pathways (meridians) through the tissue. These pathways cannot be identified physiologically but it seems that they have specific electrical properties [18-22].

One of our earlier studies was to determine the transfer characteristics of the acupuncture meridians, reported by Ćosić et al. [13]. The measurements were performed by stimulating the chosen acupuncture points belonging to the meridian point LI4. The signal was taken from the symetric body meridian point. The stimulating sinusoidal signal was applied to point LI4 of one hand and measured on the point LI4 of the other hand. The chin was chosen as the grounding point. Lowest resistance identification for realisation of specific acupuncture point was undertaken using standard BETA 2L.

The measurements were performed using A/D converter via plane surface electrodes of the order of ¼ cm^2. The analysis was performed on 1000 points, in the frequency range of 1-15 Hz, and with sampling frequency of 300 Hz. This corresponded to 3.3 sec and the spectrum resolution of 150 Hz, and frequency resolution of 0.33 Hz . 12 healthy subjects were recruited for the experiment (equal number of males and females). The amplitude was maintained constant at 2 V. The peaks in the transfer function represent the maximal absorbtion. The results obtained as a mean and standard deviation of all subjects revealed three were well defined resonant frequencies: 6.72, 8.9 and 11.5 Hz, as shown in Table 2.

Table 2. The resonant frequency and amplitude results, represented by the mean and standard deviation values.

Frequency [Hz]	Amplitude	s.d. (frequency) [Hz]	s.d. (amplitude)
11.50	11.50	0.32	17.68
8.90	7.70	0.40	3.59
6.72	5.80	0.002	8.63

Cohen et al. study was conducted to investigate whether electromagnetic field phenomena could be involved in the practice of acupuncture by demonstrating that the lower electrical resistance of acupuncture points and meridians [14]. This study was established to determine the resonant frequencies of an acupuncture meridian, two points along the large intestine meridian located using the standard charts and confirmed by detecting the low impedance points in the vicinity. A sharp biphasic pulse (broad frequency spectrum) was introduced into the distal point (LI4) and recordings were taken from this point as well as from a point further along the meridian (LI11). An additional electrode was connected to the palm of the subject as a common reference point (ground). The recorded signals were subjected to frequency domain analysis to determine the transfer function and hence the spectral characteristics of the meridian, repeated on 12 subjects.

3.2 Electrical Resonance and Electro-Acupuncture

Due to the unique electric properties of the acupuncture points and the meridian system, a modern technique based on current technologies, the so-called Electro-acupuncture (EA), has been invented. EA uses an electrical stimulation applied on the needle. The electrical stimulation can also be administered through surface electrodes applied on the skin over the "acupoint" with very similar results. Many different stimulation frequencies have been tried and two frequencies, 2 Hz and 100 Hz are found to be of particular therapeutic effectiveness [23]. Specifically, the low frequency at 2 Hz triggers the release of enkephalin, endophine, while the high frequency at 100 Hz accelerates the release of dynorphin. Enkephalin and endorphins are two neurohormones that modify the way in which nerve cells respond to transmitters. Dynorphin is another neurohormone (endogenous neuropeptide) that inhibits sensory neurons via the activation of a Γ protein coupled inward rectifying potassium conductance. The experiment of EA indicates that the external electrical resonance can be utilized to stimulate the human nerve system, and therefore achieves the purpose of regulating the human body.

Traditional Chinese Medicine suggests that an energetic balance between organism and environment exists, and that this balance can be achieved by energy transfer through acupuncture points and meridians [24]. This concept is supported by the fact that these points and meridians have been shown to have distinct electrical characteristics compared to surrounding skin. Electro-acupuncture is a relatively new method of performing traditional acupuncture, and is now commonly being used for the treatment of a variety of illnesses [25]. Electro-acupuncture involves the stimulation of acupuncture points with electrical current with or without needles, to produce the same effects as traditional acupuncture [25]. This includes analgesia, treatment of soft tissue injury, wound healing and arthritic conditions [26].

A vast variety of different equipment has been designed for use in electro-acupuncture [25]. The current outputs in these devices vary in repetition frequency, amplitude, and shape. From an engineering perspective, since so many parameters are variable, it is important to distinguish the optimal parameters so that the desired effects can be achieved with preciseness, minimal energy and minimal danger to the patient. To begin with, it is critical to investigate the frequency response of the meridian system using techniques similar to those used to analyse the frequency response of various electrical system, along with the aid of mathematical analysis tools such as frequency domain analysis techniques. In other words, it is important to find out what frequencies can "travel" through the meridian with minimal attenuation, to achieve optimal stimulation. The knowledge of optimal stimulus signals could enhance the treatment of illnesses or disease using electro-acupuncture with minimal stress on the patient's system and with no adverse side effects.

Table 3. Unique Electrical Properties of Acupuncture Points.

1.	Low electric resistance, explored either by DC or AC current (20 to 250 kilo-ohms).
2.	High electric capacity values (0.1-1 micro-farad).
3.	High electric potential (up to 350 mV).
4.	Low threshold of painful sensitivity.
5.	High local temperature.
6.	Increased "cutaneous respiration" (great uptake of CO_2 at the level of the points).

Anatomically, acupuncture points are similar to surrounding skin. However, studies have found that these points have unique electrical properties. For the past 50 years, it has been well documented that the skin resistance on acupuncture points is lower than surrounding skin [27-29]. On average, dry skin has a DC resistance in the order of 200 KΩ – 2 MΩ while at acupuncture points this resistance drops down to as low as 50 KΩ, as shown in Table 3 [27]. In addition, while human skin has been shown to have a resting potential across its epidermal layer from 20 to 90 mV [30], acupuncture points have been found to have a potential difference 5 mV greater than surrounding skin [26].

Research has also shown that acupuncture points have a higher capacitance than the surrounding skin. Furthermore, the use of high-resolution thermography has allowed recording and comparison of the temperature differences of acupuncture points and surrounding skin. These studies have found that acupuncture points have a high local temperature than surrounding skin [26].

The unique electrical properties may influence the response of the meridian system by limiting the amount of external energy or signals absorbed or rejected/attenuated [13, 31]. The extremely low frequency (ELF) range has been of particular interest as low frequencies are usually more relevant for biological systems (e.g. EEG, ECG, etc) [32]. The unique properties of acupuncture points along with the success of electro-acupuncture with different pulse repetition frequencies at these points suggests that acupuncture points and meridians may respond differently to different frequencies, signal amplitude, signal shapes and total amount of energy delivered to the site.

With the aid of computers, high sample rate and resolution analog to digital converters, and the development of complex and powerful mathematical analysis algorithms, further meridian and point characteristics can be analysed so a greater understanding of this complex systems can be gained. This data will allow efficient administration and possibly in the future the development of a diagnostic tools based on the state of the meridians and energetic balance of the overall system.

Lazoura et al. study discussed the design and development of a fully automated system to systematically measure, log and analyse the low frequency responses of a section of the large intestine meridian [15, 18-22, 33].

The main design consisted of pulse trains of 10% duty cycle generated using Microchips PIC16C73A, 8-bit micro-controller running at 18.432 MHz. Sets of pulse trains each varying in frequency from 1 to 100 Hz in steps of 1 Hz were accurately produced within +/- 0.0001 Hz using the micro-controllers TIMER2 interrupt. The pulse sets had a 100 ms resting time in between frequency changes. This resting time was not sampled, as shown in Figure 1. A specially designed circuit converted the digital pulses to a bi-phasic, 2 volt peak to peak square wave over the entire frequency range. The signal generated was then coupled to the subjects via 32 gauge, acupuncture needles placed into the points. A surface electrode was used as ground reference.

The signal was injected into large intestine 4 (LI4) point on the right arm, with the palm as ground reference and measured at LI10. LI4 is located on the hand between the pointer and thumb and LI10 on the forearm, as shown in Figure 2. These points were defined both anatomically using traditional acupuncture charts, as well as electrically by locating points with a reduced skin resistance using a multimeter. Points were chosen based on convenience of experimental set up and reliability of detecting low resistance points.

The measured signal was amplified using specially designed low noise, high input impedance, bio-potential amplifier and then sampled at 10000 Hz by a second micro-controller, the PIC16f877 via its 10 bit A/D. Data upload via the RS232 serial port and was recorded using software specially written in Borland Builder 4.0 and C++ for this application. Transfer functions of the data were plotted in the frequency domain using Fast Fourier algorithm routines written for Builder. This procedure was repeated for 10 healthy subjects aged between 18 and 56 years of age as a preliminary study.

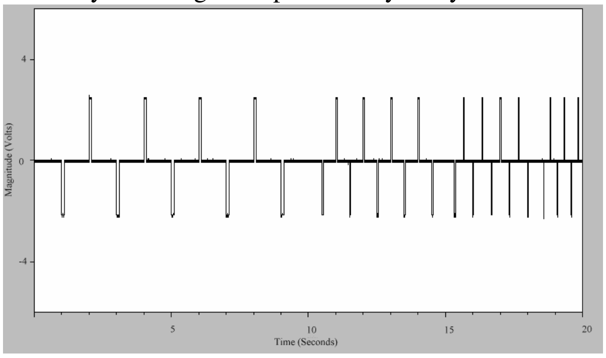

Figure 1. Generated digital bi-phasic pulses at 2 volt peak to peak square wave over the entire frequency range (1 to 100 Hz) in steps of 1Hz were accurately produced within +/- 0.0001 Hz.

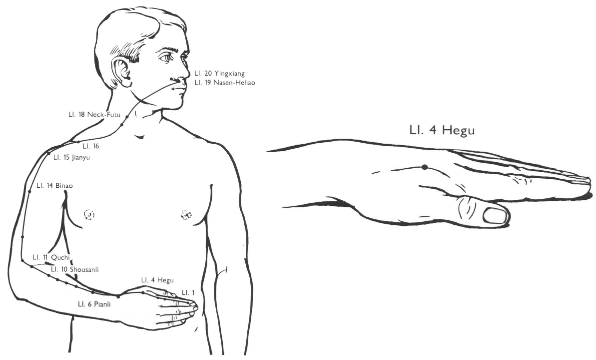

Figure 2. The signal was injected into large intestine LI4 point on the right arm, with the palm as ground reference and measured at LI10. LI4 is located on the hand between the pointer and thumb and LI10 on the forearm.

Analysis of transfer functions for the 10 examined subject revealed that frequencies above 20 Hz had an order of 50% reduction/attenuation than those below 20 Hz in all the subjects. Frequencies below 5 Hz had the least attenuation. Figure 3 shows a typical transfer function plotted of a 30-year-old healthy male ??subject.

These results suggest that acupuncture meridians have a selective response to frequency. This response coincides quite well with the electrical properties of acupuncture points and meridians [28]. Since acupuncture points have been found to have low resistance and a high capacitance, it is expected that they would act as a low pass filter with a cut-off set at a reasonably low frequency.

The low frequency response of the meridian correlates well with the low frequency manipulation of the acupuncture needle during traditional acupuncture treatment. This manipulation involves the needle to be twirled, rotated and flicked with varying speeds. Traditional Medicine suggests that this manipulation of the needle, promotes the flow of "chi" [34].

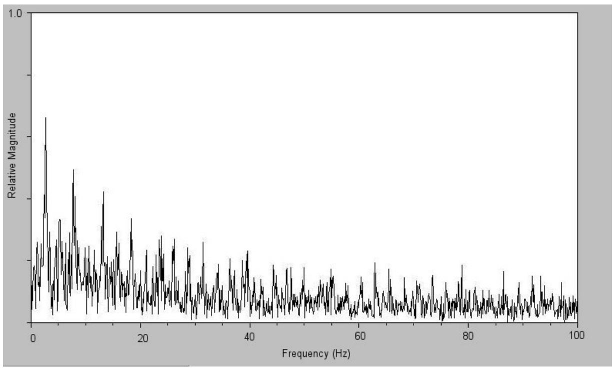

Figure 3. Typical transfer function plotted of a 30-year-old healthy subject.

In addition, these results correlate well to the low frequency peaks measured in EEG and ECG signals. This low frequency response may also have some association with the increase in alpha waves (7.5 – 13 Hz) during acupuncture stimulation [32]. Furthermore, a correlation with the resonant frequencies of our natural environment can be made. These natural resonant frequencies due to lightning-induced electromagnetic wave propagation between the earth and ionosphere have been shown to overlap with the characteristic spectral components of the EEG [31]. If the meridians do in fact have the ability to transfer these resonant frequencies and reject others, the resonant frequencies may influence the health of an individual. Therefore, the ancient Chinese claim that health is based on energetic balance between organism and environment would prove to be valid.

4. ARTIFICIAL EM AND HUMAN FUNCTIONING

4.1 Effects of ELF Magnetic Field Exposures on Human EEG Activity

Preliminary study by Cvetković et al. was conducted to investigate whether the ELF magnetic field of 8.33 Hz could effect the EEG activity in 8 subjects [35-41]. The preliminary results indicated substantial changes in specific bands, which encouraged further experiments with multiple sinusoidal extremely low frequency (ELF) (50, 16.66, 13, 10, 8.33 and 4 Hz). Linearly polarised magnetic flux density of 20±0.57 μT (rms) was applied to the human head over a non-continuous period of 12 minute, to determine possible alterations in the EEG rhythms on 33 human volunteers [16]. These artificial magnetic fields were generated using circular Helmholtz pair of coils with average radii of 65 cm, made with 250 turns of copper wire of 0.8 mm in diameter. Coils were designed to pass the current of approximately 140 mA, and had impedance 71 Ω. An ELF signal generator was developed using EXAR XR-2206 IC to generate accurate sinusoidal waveforms. An audio amplifier with the approximate gain of 10 is used to generate sufficient current to the coils. The magnetic flux density measurements were verified by direct measurement using "Wandel and Goltermann" EFA-200 EMF Analyser. The linearly polarized magnetic field was perpendicular to the Earth's North-South geomagnetic field.

Figure 4. The EEG signals recorded from the subject lying down between the Helmholtz coils after the ELF magnetic field exposure.

The EEG equipment used throughout testing was the Mindset MS-1000 recording system. Neuroscan 19 Channel Caps electrodes were used with referential montage of 16 channels. The left brain hemisphere electrodes: Fp1, F7, F3, T7, C3, P7, P3 and O1 were all referenced to M1 (left mastoid), while the right brain hemisphere electrodes: Fp2, F8, F4, T8, C4, P8, P4 and O2 were referenced to right mastoid M2. Figure 4 shows the EEG signals recorded from the subject lying down between the Helmholtz coils after the ELF magnetic field exposure. The baseline EEG was recorded prior to any stimulation for one minute. Each stimulation (50, 16.66, 13, 10, 8.33 and 4 Hz) lasted for two minutes followed by one minute post-stimulation EEG recording. Overall, the total length of an experiment was 19 minutes. The same procedure was repeated for the EMF control sessions. The order of control and exposure sessions was determined randomly according to the subject's ID number. Subjects with odd ID numbers were first tested with control condition (no EMF exposure) followed by EMF stimulation after 30 minute break. Double-blind counterbalanced condition was exercised. The two EMF sessions were highly considered in the analysis as a factor that might reveal that if the 1st session was EMF exposure, the EEG activity results during the 2nd EMF control session could still be influenced or dependent on the results of the 1st EMF exposure session.

All the collected EEG data was processed using Matlab procedures. The main Matlab script was written to process all 16 channel EEG data of all subjects and generate spectral power parameters used in the further statistical analysis, such as Total spectral power of each stimulation EEG data (i.e. before, 50 Hz, 16.66 Hz, 13 Hz, 10 Hz, 8.33 Hz and 4 Hz); Spectral power in the stimulated band, before/after; Central band frequency before/after; and Relative difference "ratio" between the individual band and total spectral power before/after [35]. The calculated EEG band intervals were Theta (3-5 Hz), Alpha 1 (7.5-9.5 Hz), Alpha 2 (9-11 Hz), Beta 1 (12-14 Hz), Beta 2 (15.5-17.5 Hz) and Gamma (49-51 Hz). Delta and Gamma band data was excluded from this particular analysis due to noise contamination. We compared the EEG activity "before" and "after" stimulation for each frequency stimulation and band. Throughout this method, "before" stimulation EEG data was regarded for every next recording of the "after". For example, if 1st recording was before any stimulation, 2nd was 50 Hz stimulation (gamma band), 3rd was 16.66 Hz stimulation (beta2 band). The script used for this signal processing computed all the parameters mentioned above as 1 second epochs, maximum of 60 epochs per recording. Throughout this investigation, only the relative difference (ratio) parameter between the individual bands and total spectral power (before and after) was used for the statistical analysis.

Multiple paired samples 2-tailed t-tests and ANOVA's 3-way mixed design for within and between-subject measures were employed. The factors considered were the "before and after", "exposure and control" and "first and second session." The first test conducted was for the first session of EMF exposure and there were 16 subjects used for this session. The second test was the second session EMF control ($df = 15$), the third test was the first session EMF control ($df = 16$) and the fourth test was the second session EMF exposure ($df = 16$).

For the 1st EMF exposure session, in Alpha1 band 8.33Hz stimulation under EMF control (2nd session), *t*-test results revealed a significant relative difference increase from before to after in channel T7. ANOVA test revealed a significant difference for the interaction between exposure/control and sessions factors (T7).

For the 2nd EMF exposure session, the *t*-tests were conducted for 8.33 Hz stimulation in Alpha1 band, that relative difference at electrodes Fp1, F7, F3, F4 and C4 was significantly higher before than after stimulation. There was a decrease in relative difference from before to after by 11.1% (Fp1), 11.3% (F7), 10% (F3), 9.8% (F4) and 8.8% (C4). The ANOVA results indicated a significant difference at F7 (exposure/control and sessions) and (before/after and sessions); F3 (exposure/control and sessions) and (before/after and sessions); F4 (exposure/control and sessions); and C4 (exposure/control and sessions) and (before/after and sessions).

In Alpha2 band after 10 Hz stimulation, 2nd EMF control session, the relative difference has decreased, highlighted by a high difference observed in parietal and occipital regions, P3, that the relative difference at before was significantly higher than after. At P4, the relative difference before was significantly higher than after. There was a large decrease in relative difference from before to after by 12% (P3), 18.4% (P4), 11.2% (O1), and 13% (O2) than at any other electrode and stimulation, as shown in Figure 5. The 3-way ANOVA revealed a significant difference at the interaction between *exposure/control* and *sessions* (P3) and the main factor *before/after*. At P4 electrode, there was a significant difference between *exposure/control* and *sessions* and *before/after*; O1 and O2 (*exposure/control* and *sessions*). The other factors at all the mentioned electrodes revealed a non-significant difference, including the between-subject factor "sessions". The *t*-test results for 13 Hz stimulation in Beta1 band revealed no significant differences at any electrode.

Under the 2nd EMF exposure session, the *t*-test revealed a significant difference between before and after stimulation of 10Hz in Alpha2 band at F4, where a relative difference was higher before than after the 10 Hz stimulation. ANOVA revealed a significant difference for the interaction between exposure/control and session's factor. For 13Hz stimulation, there was no significant difference.

For the 1st EMF exposure session, the t-test results revealed a significant increase at Fp1, Fp2, F7, F3 and C3 for 13Hz stimulation in Beta1 band. There was an increase in relative difference from before to after by 10.1% (Fp1), 8% (Fp2), 8.4% (F7), 10.8% (F3) and 9.3% (C3). The ANOVA results revealed a significant differences between before and after main factors at Fp1, Fp2, F7 and C3 (NS). In 1st EMF exposure Beta1 band (13Hz), ANOVA's significant results for before and after main factor, were very similar with the *t*-test results.

Overall, the alternative hypothesis (H_1) test for EMF Exposure 1st Session in Beta1 band (13 Hz), has highlighted that ANOVA's significant results for before and after main factor, were very similar with the *t*-test's results. The alternative hypothesis (H_1) test for EMF Control 2nd Session results signify a possibility that the EEG activity ***could remain altered for at least 50 minutes after the exposure*** (30 minutes break between the exposure and control conditions with additional 20 minutes for EMF control EEG recordings and stimulations). Overall, the conducted *t*-tests and ANOVA tests for the 1st EMF control session, revealed only two significant differences with an increase in Theta and decrease and Beta band at P3 and P8 electrode. When compared to other sessions where the exposure was present, it can be concluded that no significant differences could be found to assume that subjects' EEG activity could be altered without any EMF exposure. For the corrected alpha rate value of multiple tests, Bonferroni test was used with the new alpha rate was modified to $p < 0.0025$. However, no significant differences were revealed using Bonferroni's new alpha rate [16].

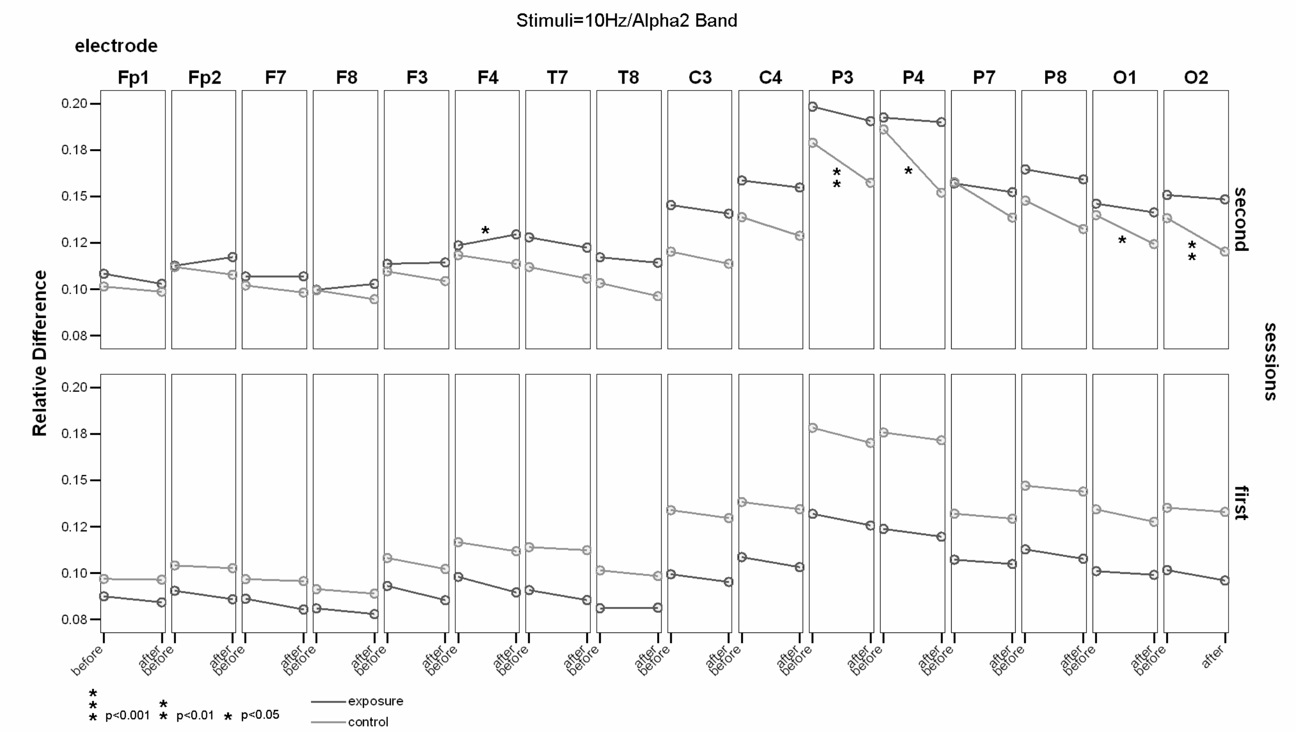

Figure 5. The relative diference results (y-axis) are represented by *before* and *after* exposures (x-axis) at 10Hz stimulation within the Alpha2 band. The first (bottom row) and second (top row) represent session conditions of EMF exposure (darker line colour) and control (lighter line colour) for 16 EEG electrode positions (columns). The significant differences, indicated by $p < 0.001$, $p < 0.01$ and $p < 0.05$ values, were shown at pariatel and occipital regions at EMF control second session condition [16].

5. DISCUSSION

The main comparison of different transfer function characteristics between our experimental findings of skin impedance of acupuncture meridians and EEG activity responses to environmental “geomagnetic” and artificial extremely low frequency (ELF) electromagnetic field radiation have been conducted.

Ćosić et al. [13] results revealed that up to three resonant frequencies were well defined as 6.72, 8.9 and 11.5 Hz, slightly different than the Schumann resonances, as shown in Figure 6. Furthermore, this study discussed the possibility that any substantial discreprancy of the patient’s transfer function from the given standard shape indicated not only individual specificities but the deterioration in the state of health as well. The acupunture meridian, being related to a specific group of organs, reflects on the respective transfer function and could indicate the possibile organic disfunction. This opens the possibility for a new diagnostic approach and the method for the possibility to optimise parameters for electropuncture therapy such as intensity, frequency, duration and direction of the current.

Cohen et al. [14] presents analysis of the transfer function of 12 subjects and its spectral characteristics of the two acupuncture meridian points (LI4 and LI11) along the large intestine meridian, indicated that there were characteristic resonant frequencies in the spectra of the large intestine meridian. The highest intensity was found at 5, 9, 13 and 15 Hz, which was initially thought to be within the Schumann resonance region, as shown in Figure 6. However, only 15 Hz was within the Schumann region and 5, 9 and 13 Hz were located between the peaks of Schumann resonance. The maximum intensity was recorded at 9 Hz which was well within the EEG alpha region.

Lazoura et al. [15] results indicated that acupuncture meridians act as filters and hence allow only certain frequencies to pass through and attenuate all other frequencies. The fact that this pass band was set to low frequencies corresponds with the characteristics of acupuncture points, and with the spectral components measured traditionally in ECG and EEG signals. Figure 6 shows the distinct spectral components of 4, 7.8 and 13 Hz which closely correlate well with the Nature’s own resonant frequencies. The correlation may indicate relationship between one’s existence and functioning as an integral part of nature and the Universe. It could also help explain the sensitivity of our bodies and mind to changes in the environment and even the universe, which has been used by our ancestors throughout time as a form of spiritual guidance and a form of healing.

Cvetković et al. [16] EEG study revealed that during 1^{st} EMF exposure session at the Alpha2 band 10Hz stimuli, the EMF treatment showed a higher relative difference than EMF control treatment, where for control post EMF treatment the relative difference was significantly lower at pariatel and occipital regions. Overall, it was evident that the highest relative difference was observed at the Alpha band and 10 Hz

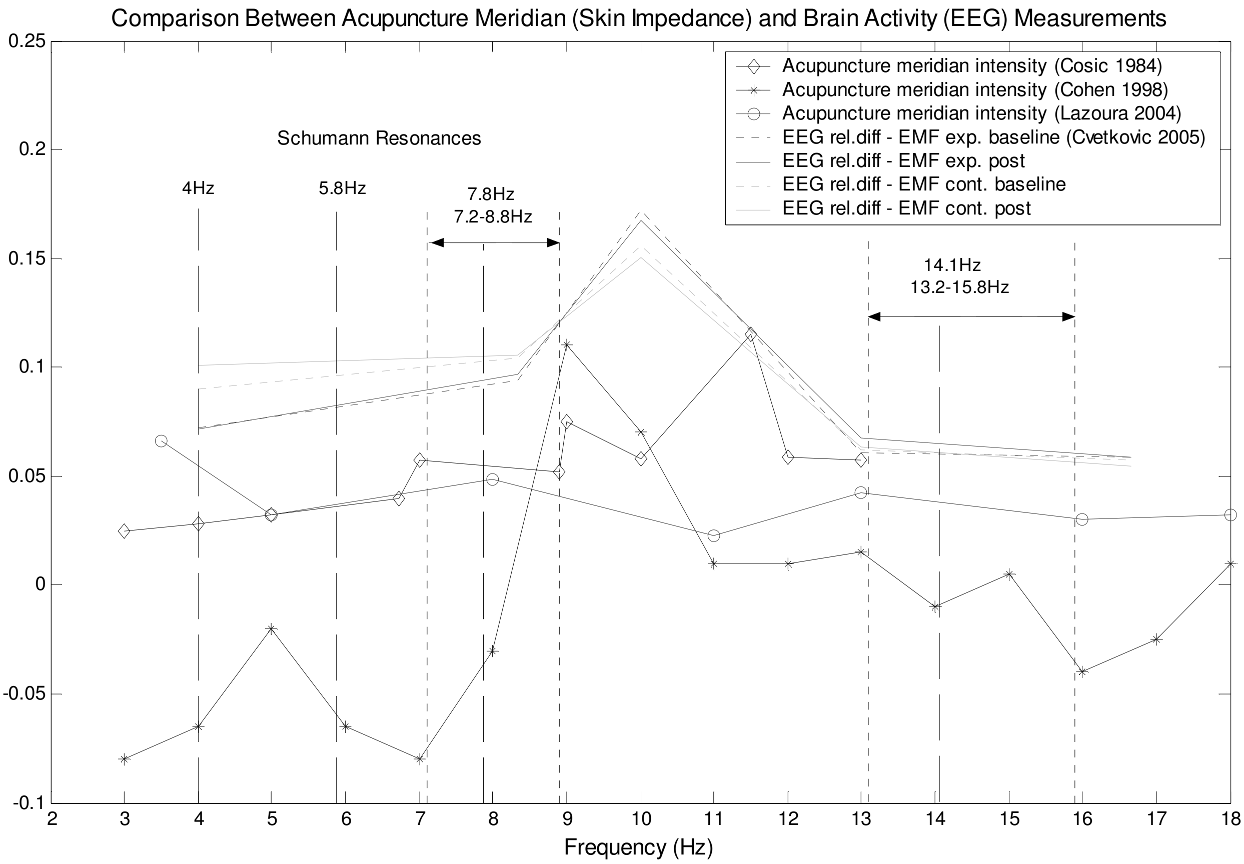

Figure 6. Transfer function comparisons between acupuncture meridian (skin impedance) and brain-wave activity (EEG) results conducted by Ćosić et al. [13], Cohen et al. [14], Lazoura et al. [15] and Cvetković et al. [16] studies. The fixed and daily fluctuations of Schumann resonances are indicated at 4, 5.8, 7.8 (7.2-8.8Hz) and 14.1Hz (13.2-15.8Hz).

Stimulation. The EEG activity can be altered using artificial ELF magnetic fields corresponding to a range between the two Schumann resonance (8.8 and 13.2 Hz), as shown in Figure 6. In addition, there is a possibility that the EEG activity could remain altered for at least 50 minutes after the exposure which consisted of 30 minutes break between the exposure and control conditions with additional 20 minutes for EMF control EEG recordings and stimulations. The explanations for this occurance is that human EEG Alpha2 band or 10 Hz naturally resonates for the remaining 50 minutes after the artificial magnetic field is terminated. However, this effect does not occur at EEG frequencies which are within the Schumann resonance region. These results slightly contradict the previous findings by Kenney [31] which claimed that natural earth-ionosphere resonances overlap with the principle spectral regions of the EEG. It is possible that the effect is caused by the stimulation frequencies at the border of physiological frequncy bands (4 and 8.33 Hz).

König studies [42] revealed that human reaction times were significantly correlated with intensity of ELF frequencies, primarily 3 Hz (signals generated from thunderstorms) and 8-10Hz Schumann resonances and relative magnetic flux intensity estimated in the range 0.6-1 pT. The results from this study also characterised a 10 Hz oscillation signal which was used to approximate the Schumann resonance signal, because the two dominant frequency peaks are 7.8 and 14.1 Hz. König and Hamer [42-43] experiments conducted in the mid sixties and mid seventies confirmed that the alpha rhythm related 10 Hz signal can increase the human reaction times and the delta rhythm related 3 Hz signal can decrease the human reaction time. These results therefore confirm that the human brain absorbs, detects and responds to ELF environmental EMF signals. Hence resonant absorption and reaction could be biophysically plausible. This phenomenon could influence possible biological communication phenomena in cell-to-cell communication.

Our results could be considered to be consistent with König resonant absorption and reaction findings and confirm that the whole-body changes in conjunction with geomagnetic and Schumann resonance influence, altering brain and acupuncture meridian patterns. The results from the three studies, Ćosić et al. [13], Cohen et al. [14], Lazoura et al. [15], and Cvetković et al. [16], discussed here, definitelly reveal that the peaks of maximum skin impedance intenisty and relative differences in EEG activity are shown to occur between the two Schumann resonance outer regions which is the actual higher EEG Alpha

10Hz region. In fact, Schumann resonance acts like a ‘band-pass’ filter which allows the maximum intensity of acupuncture meridian and EEG activity to penetrate between the two Schumann resonance outer regions. Only Lazoura et al. [15] study results prove that there is a correlation between the actual Schumann resonance peaks and electro-acupunture meridians.

6. CONCLUSION

The fundamental Schumann resonance frequency has been claimed to be extremely benificial to existence of the biological cycle phenomenon of plants, animals and humans living. However, the results from our acupuncture meridians and EEG activity studies, have shown that frequencies between 8.8 and 13.2Hz, between the Schumann resonance maximums, confirm that the human body absorbs, detects and responds to ELF environmental EMF signals. This is a classical physics phenomenon, utilised in telecommunication systems, which definitelly needs to be further investigated for a possible biological cell-to-cell communication implications.

REFERENCES

[1] Zhadin, M.N.: Review of Russian Literature on Biological Action of DC and Low-Frequency AC Magnetic Field, Bioelectromagnetics, Vol. 22, pp. 27-45, 2001.

[2] Fullekrug, M.: Schumann resonances in magnetic field components, Journal of Atmospheric and Terrestrial Physics, Vol. 57, No. 5, pp. 479-483, 1995.

[3] Becker, R.O., Marino, A.A.: Electromagnetism and Life, Albany, N.Y, USA: State University of New York Press, 1982.

[4] Kirschvink, J.L., Kobayashi-Kirschvink, A., Woodford, B.J.: Magnetite biomineralization in the human brain, Biophysics, Vol. 89, pp. 7683-7687, 1992.

[5] Kirschvink, J.L., Walker, M.M., Diebel, C.E.: Magnetite-based magnetoreception, Neuro-biology, Vol. 11, pp. 462-467, 2001.

[6] California Institute of Technology, Pasadena: Biological Magnets in the Human Brain - Could Magnetite Mediatehealth Effects of Electromagnetic Fields, IEEE Power Engineering Review, pp. 13-14, 1992.

[7] Kiontke, S.: Natural Radiation and its effects on biological systems, Naturheilpraxis mit Naturmedizin, Pflaum Verlag, (CD ROM), 2000.

[8] Lerner, E.J.: Biological effects of electromagnetic fields, IEEE Spectrum, pp. 57-69, 1984.

[9] McMakin, C.: Microcurrent therapy: a novel treatment method for chronic low back myofascial pain, Journal of Bodywork and Movement Therapies, Vol. 8, pp.143-53, 2004.

[10] McMakin, C.: Microcurrent treatment of myofascial pain in the head neck and face, Topics in Clinical Chiropractic, Vol. 5, No. 1, pp.29-35, 1998.

[11] Banik, S., Bandyopadhyay, S., Ganguly, S.: Review paper-Bioeffects of microwave, A brief Review Bioresource Technology, Vol. 87, pp. 155–159, 2003.

[12] Chuyan, E.N.: Interhemisphere Asymmetry of the Pro-Antioxidant Systems in the Rat Brain: Effects of Hypokinesia and Extrahigh-Frequency Electromagnetic Radiation, Neurophysiology, Vol. 36, No. 1, pp. 22-23, Jan 2004.

[13] Ćosić, I., Marinković, M. and Veljko, V.: Transfer Functions of Acupuncture Meridians, Digital Signal Processing , pp. 673-675, 1984.

[14] Cohen, M., Behrenbruch, C., Ćosić, I.: Shared frequency components between Schumann resonances, EEG spectra and acupuncture meridian transfer functions, Acupuncture and Electrotheraupetic Res., No.1, pp. 92-93, 1998.

[15] Lazoura, H.: The Design of Equipment to Measure the Electrical and Optical Properties of Acupuncture Points and Meridians, PhD Thesis, RMIT University, Melbourne, Australia, 2005.

[16] Cvetković, D.: Electromagnetic and Audio-Visual Stimulation of the Human Brain at Extremely Low Frequencies, PhD Thesis, RMIT University, Melbourne, Australia, 2005.

[17] Kwok, G., Cohen, M., Ćosić, I.: Mapping Acupuncture Points Using Multi-Channel Device, Australian Physical & Engineering Science in Medicine, Vol. 21, No. 2, pp. 68-72, 1998.

[18] Lazoura H., Ćosić, I.: Low level radiation as a stimulant in acupuncture, Proc. of the 2nd Conference of the Victorian Chapter of the IEEE EMBS, pp. 141-143, 2001.

[19] Lazoura, H., Ćosić, I.: Variation in Electrical Conductance Between Acupuncture and non-Acupuncture points before and after Stimulation, Proc. IEEE-EMBS Asia-Pacific Conference on Biomedical Engineering, Hangzhou, China, pp. 381-382, 2000.

[20] Lazoura, H., Srećković, M., Ćosić, I.: Changes in Electrical Resistance of Acupuncture Points when Stimulated by Laser Radiation, International Conference on Lasers, Quebec, Canada, pp. 249-252, 1999.

[21] Lazoura H., Cohen M., Lazoura E., Ćosić, I.: Do Acupuncture Points Have Different Absorption Properties to Laser Light than Surrounding Skin?, Proc. of 2nd International Conference on Bioelectromagnetism, Melbourne, pp. 171-172, 1998.

[22] Lazoura, H., Cohen, M., Srećković, M., Ćosić, I.: The absorption of Pulsed Infrared Laser Light at Acupuncture Points, Proc. of the International Conference on Lasers, New Orleans, USA, pp. 541-545, 1997.

[23] Han, J.S.: Acupuncture: neuropeptide release produced by electrical stimulation of different

frequencies, Trends in Neuroscience, Vol. 26, pp. 17-22, 2003.

[24] Tsuei, J.J.: The Science of Acupuncture - Theory and Practice, IEEE Engineering in Medicine and Biology, pp. 52-57, 1996.

[25] Noordergraaf, A.: Electro-acupuncture, IEEE Trans. Biomed. Eng., Vol. 20, pp. 364-366, 1973.

[26] Stux, G., Pomeranz, B.: Basic of Acupuncture, Springer-Verlag Berlin Heidelberg New York Fourth Edition, pp. 1-5, 1998.

[27] Becker, R.: The Basic Biological Transmission and Control System Influenced by Electrical Forces, Ann.N.Y.Acad.Sci., pp. 236-241, 1974.

[28] Becker, R.: Electrophysiological Correlates of Acupuncture Points and Meridians, Psychenergetic Systems, Vol. 1, pp. 105-112, 1976.

[29] Bergsmann, O., et al.: Difference in Electrical Conductivity Between Acupuncture Points and Adjacent Skin Areas, American Journal of Acupuncture, Vol. 1, p. 27, 1973.

[30] Reichmanis, M., et al.: Electrical Correlates of Acupuncture Points, IEEE Trans. Biomed. Eng., Vol. 22, p. 533, 1975.

[31] Kenney, J.: Resonance of Interest: EEG and ELF, Speculations in Science and Technology, Vol. 15, pp. 53-55, 1990.

[32] Saito, M., Kwoon, S.: Acupuncture Evoked EEG of Normal Human Subjects, American Journal of Acupuncture, Vol. 1, pp. 225-229, 1983.

[33] Lazoura H., Ćosić, I.: The Frequency Response of Acupuncture Meridians, in The Engineering of Sport, ed. By Subic A.J. & Haake S.J., Blackwell Science, Oxford, UK, pp. 309-315, 2000.

[34] Xiangru, M., Liahu, C.: Clinical Observation of the Propagated Sensation Along Meridians Excited by Acupuncture Manipulation, School of TCM, Boading District Hospital of TCM, Hebei, pp. 259-260, 1978.

[35] Cvetković, D., Ćosić, I.: Automated ELF Magnetic Field Stimulation of the Human EEG Activity, Integrated Computer-Aided Engineering (IOS Press), Vol. 13, No. 4, pp. 313-328, 2006.

[36] Cvetković, D., Ćosić, I.: Design and Development of Automate System for ELF/RF Bioelectromagnetic Experiments, ICINCO – International Conference on Informatics in Control, Automation & Robotics, Barcelona, Spain, pp. 316-321, 2005.

[37] Cvetković, D., Ćosić, I.: The Responses of Audio and Visual Rhythms on EEG Activity – Preliminary Results, MEDICON - 10th Mediterranean Conference on Medical and Biological Engineering, Ischia-Naples, Italy, IFMBE Proceedings, 6, (CD ROM), 2004.

[38] Cvetković, D., Ćosić, I.: The Induced Extremely Low Frequency (ELF) Electromagnetic Field Rhythms on EEG Activity, MEDICON - 10th Mediterranean Conference on Medical and Biological Engineering, Ischia-Naples, Italy, IFMBE Proceedings, 6, (CD ROM), 2004.

[39] Cvetković, D., Ćosić, I.: The Induced Rhythmic Oscillations of Neural Activity in the Human Brain, IASTED International Conference on Biomedical Engineering, Innsbruck, Austria, pp. 306-311, 2004.

[40] Cvetković, D., Ćosić, I.: EEG Activity Under Exposure to 8.33Hz Sinusoidal Low Intensity Electromagnetic Fields, ARPS, 28th Annual Conference, Hobart, Tasmania, p. 43, 2003.

[41] Cvetković, D., Ćosić, I.: The Effects of Extremely Low Frequency Electromagnetic Fields on the Human Brain, WC2003 - World Congress on Medical Physics and Biomedical Engineering, Sydney, Australia, IFMBE Proceedings 3, p. 4, 2003.

[42] König, H.L.: ELF and VLF signal properties: physical characteristics. In: Persinger, M.A. (ed.), ELF and VLF Electromagnetic Field Effects, Plenum Press, New York, pp. 9-34, 1974.

[43] Hamer, J.R.: Biological entrainment of the human brain by low frequency radiation, Northrop Space Labs, pp. 65-199, 1965.

УТИЦАЈ ЕЛЕКТРОМАГНЕТНИХ ПОЉА ВЕОМА НИСКЕ ФРЕКВЕНЦИЈЕ У ДОМЕНУ ШУМАНОВИХ РЕСОНАНЦИ И ВЕШТАЧКОГ ЕЛЕКТРОМАГНЕТНОГ ПОЉА НА ЕЛЕКТРОФИЗИОЛОШКЕ СИГНАЛЕ ЧОВЕКА

Ирена Ћосић, Деан Цветковић, Qiang Fang, Емил Јованов, Harry Lazoura

У овом раду смо представили резултате наших истраживања утицаја геомагнетског и вештачког електромагнетног поља на електрофизиолошке сигнале човека. Упоредили смо наше резултантне анализе три акупунктурна меридијана и анализу ЕЕГ сигнала. Предходна истраживања фундаменталних Шуманових резонантних фреквенција су показала да су од велике користи за егзистенцију биолошких бића. Међутим, наши налази из три предходна акупунктурно меридијанских и ЕЕГ рада су показали да фреквенције између 8.8 и 13.2 Hz, који се иначе налазе ван Шумановог резонантног региона, су корелантне са анализиарним електрофизиолошким сигналима човека, док једно наше истраживање доказује супротно и указује да постоје утицајне корелације између Шуманове резонанције и електро-акупунктурских меридијана. Резултати наших истраживања указују да је човечије тело зависно од геомагнетског и вештачког електромагнетног поља. Ово је класичан пример принципа физике, који се и данас примењује у телекомуникацијним системима и који може објаснити неке механизме у комуникацију биолошких ћелија.