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SIGNIFICANCE OF WEAK STATIC AND ELF MAGNETIC FIELDS AND THEIR GRADIENTS WITH RESPECT TO ELECTROMAGNETIC BIOCOMPATIBILITY. A NEW METHOD FOR PRECISE LOCALIZATION OF TECHNO- AND GEOGENIC STRESS ZONES

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ABSTRACT

Non-thermal effects of microwave (MW) radiation were found to parallel the biological effectiveness of weak extremely low frequency (ELF) magnetic fields (MF). Both seem to be rather paradoxical from the viewpoint of generally accepted physics. The coherent nature of the electro-magnetic system of the body is shown to bridge the gap between accepted physical mechanisms and well established biological effects. The divergence of MF gradient is introduced as a key factor of the vulnerability of biological systems to magnetic and electromagnetic stress. A new method for the precise localization of stress zones of this kind is presented, based on an evaluation of the spatial structure of MF in the static and quasi-static range. The need for further research is discussed as well as the equalization of MF gradients as a road to electromagnetic compatibility on a low-energy level.

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DIE BEDEUTUNG SCHWACHER STATISCHER UND EXTREM NIEDERFREQUENTER MAGNETFELDER UND IHRER GRADIENTEN FÜR DIE ELEKTROMAGNETISCHE BIOLOGISCHE VERTRÄGLICHKEIT.

EIN NEUES VERFAHREN ZUR PRÄZISEN LOKALISIERUNG TECHNO- UND GEOGENER BELASTUNGSZONEN

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DEUTSCHE KURZFASSUNG

Die niederländische TNO-Studie (ZWAMBORN et al. 2003) und die REFLEX-Studie der EU (ADLKOFER et al. 2004) haben jüngst sowohl die wissenschaftliche Gemeinschaft als auch die breitere Öffentlichkeit beunruhigt, zeigten sie doch Störungen des Wohlbefindens und genetische Schäden durch Mikrowellenstrahlung auf, wie sie für den Mobil- und Datenfunk verwendet wird. Das Auftreten solcher biologischer Effekte auf sehr niedrigem Energieniveau belegt, dass es sich um athermische, von der Energiemenge unabhängige Wirkungen handelt. Die genetischen Schäden nehmen innerhalb des Fensters der biologischen Empfindlichkeit (SAR-Werte von 1,3 bis 2 W/kg) mit abnehmender Leistungsflussdichte der Strahlung zu.

Auf der Suche nach physikalischen Erklärungen niederenergetischer biologischer Effekte stößt man zunächst auf das Prinzip der Ionenzyklotronresonanz, der Anregung von Ionen durch ein niederfrequentes magnetisches Wechselfeld vor dem Hintergrund eines Gleichfeldes wie des Erdmagnetfeldes (LIBOFF 1985, 1997, 2005, LIBOFF et al. 1987 a,b). Wegen der wichtigen Rolle, die Ionen in biochemischen und biophysikalischen Prozessen spielen, kommt diesem Prinzip grundlegende Bedeutung zu, und es ist experimentell gut belegt. Dennoch reicht es – wie zahlreiche andere Ansätze – per se nicht aus, eine Überwindung des “thermischen Rauschens“ zu erklären. Diese Frage verweist vielmehr auf die grundlegende Erkenntnis von PRESMAN 1970, dass man in biologischen Systemen vor der energetischen Wirkung die Signalwirkung elektromagnetischer Felder zu betrachten habe.

DAVYDOV 1984 konnte den Energietransport entlang spiralförmiger Proteinmoleküle durch einen Solitonen-Mechanismus erklären, BINHI 1997 a,b die Resonanzeffekte von Ionen, die in Hohlräumen von Proteinen gebunden sind, in Magnetfeldern bestimmter Frequenz und Amplitude. Daraus ergibt sich ein unmittelbarer Bezug zum Mechanismus des Transports von Ionen und Wassermolekülen durch die Zellmembran, dessen detaillierte Aufklärung durch Peter Agre und Roderick McKinnon mit dem Chemie-Nobelpreis 2003 ausgezeichnet wurde (VON HEIJNE 2003).

Biologische Effekte schwacher extrem niederfrequenter (ELF) Magnetfelder

Biologisch kritische Effekte sind im Bereich der Stärke des Erdmagnetfeldes (20 bis 70 µT) und seiner natürlichen Schwankungen zu erwarten. Langfristige Zyklen des geo-magnetischen Feldes (GMF) reichen von säkularen Variationen bis zu stündlichen Variationen, die eine Amplitude von ca. 100 nT erreichen. In ähnlicher Größenordnung bewegen sich die langsamsten der sogenannten Mikropulsationen. Deren höchste Frequenzen liegen bei ca. 5 Hz. Im anschließenden Frequenzbereich (bis ca. 60 Hz) ist das GMF durch die Schumann-Resonanzen zwischen Erde und Ionosphäre geprägt. Die Grundfrequenz liegt bei 7,8 Hz. Oberhalb des ELF-Bereiches, den man in der neueren Literatur bis 30 Hz ansetzt, machen sich zusätzlich atmosphärische Einflüsse durch Blitze (mit einem Maximum um 100 Hz) bemerkbar. An diese natürlichen Magnetfeldverhältnisse haben sich die biologischen Systeme evolutionär angepasst, d.h. sie haben gelernt, diese teilweise sehr schwachen Variationen als Signale zu verwerten und darauf zu reagieren.

Dennoch wurde die Empfänglichkeit des menschlichen Organismus für Magnetfelder so lange in Zweifel gezogen, bis KIRSCHVINK et al. 1992 a,b das Vorkommen von Magnetitkristallen im menschlichen Gehirn nachwiesen und einen plausiblen Mechanismus vorschlugen, wie die von diesen Rezeptoren empfangenen Signale in biologische Reaktionen auf Magnetfelder transformiert werden können. Die energetische Wechselwirkung magnetischer Nanopartikel in biologischen Zellen ergibt eine Schwelle der Empfindlichkeit gegen magnetische Wechselfelder bei 1-2 µT. Unter Berücksichtigung stochastischer Resonanz lässt bei einem im Hintergrund liegenden Gleichfeld bereits eine Variation von 0,2 µT einen detektierbaren biochemischen Effekt erwarten. Magnetfeldvariationen von einigen µT können so einem thermischen Effekt von einigen hundert Grad äquivalent sein.

Paralleleffekte von Mikrowellenstrahlung und ELF-Magnetfeldern

In einem zum internationalen Symposium „Kohärenz und elektromagnetische Felder in biologischen Systemen“, Prag, 1.-4. Juli 2005 eingereichten Beitrag (CEFBIOS 2005 b) weisen Blank und Goodman darauf hin, dass hochfrequente elektromagnetische Strahlung und ELF-Felder die gleichen athermischen Reaktionspfade auslösen, die zu Stressreaktionen von tierischen und pflanzlichen Zellen führen. Da die Absorption der Strahlung in beiden Frequenzbereichen völlig unterschiedlich ist, schließen die Autoren, dass die spezifische Absorptionsrate (SAR) keine gültige Basis für Sicherheitsstandards bietet.

Belyaev (CEFBIOS 2005 a) beschreibt, dass innerhalb spezifischer Frequenz- und Intensitätsfenster die resonanzartigen biologischen Auswirkungen von der Art des Signals, seiner Modulation und Polarisation abhängen. Er identifiziert die genomische DNA als Zielobjekt athermischer Wirkungen von Mikrowellenstrahlung.

Experimentelle Belege für die gleichartigen Wirkungen von Mikrowellenstrahlung und ELF-Strahlung wurden bereits seit 1987 gesammelt (Tabelle 4 auf Seite 13). Ein bemerkenswerter Nebeneffekt besteht darin, dass inkohärente ELF-Felder nachteilige biologische Folgen kohärenter hochfrequenter Wellen abmildern können.

Grundlagen für das physikalische Verständnis der Kohärenz in biologischen Geweben wurden von FRÖHLICH 1968 a,b und von DEL GIUDICE et al. 1988, 1989 gelegt. Die Wechselwirkung externer elektromagnetischer Felder mit Polarisationswellen in einem biologischen Medium ändert das Verhalten der Felder derart, dass sie die Anordnung von Ionen und Molekülen stark beeinflussen, also zu einem morphologischen (strukturbildenden Faktor) werden.

Del Giudice führte das Verhalten biologischer Systeme auf die Kohärenzdomänen in deren stofflichem Hauptbestandteil – nämlich Wasser – zurück. Aus dem Verhältnis der Wellengeschwindigkeiten lässt sich abschätzen, dass die Wellengeschwindigkeiten und Frequenzen der Kohärenzwellen in Wasser oder biologischen Medien um 8 dekadische Größenordnungen niedriger und die internen Feldstärken um 4 dekadische Größenordnungen höher sind als bei der Ausbreitung elektromagnetischer Wellen in Luft. Hochfrequenten Wellen im Mikrowellenbereich entsprechen im biologischen Medium Kohärenzwellen, die in den ELF-Bereich fallen.

Gradienten in statischen und ELF-Magnetfeldern

Die heute populäre, aber keineswegs unbedenkliche Anwendung von Magnetartikeln, die außerhalb des Körpers eingesetzt werden und Heilprozesse unterstützen oder schmerzlindernd wirken sollen, deutet nach BINHI 2002 auf die biologische Wirksamkeit von Magnetfeldgradienten hin. Experimentelle Arbeiten von CAVOPOL et al. 1995, YANO et al. 2001 und GAPAYEV et al. 1996 zeigen, dass Magnetfeldgradienten

- die Wahrscheinlichkeit des „Feuerns“ von Nervenzellen beeinflussen,
- bei der biologischen Orientierung im Magnetfeld eine wichtige Rolle spielen und
- biologische Kohärenz, die sich in Resonanzverhalten äußert, stören.

Die Geobiologie hat erkannt, dass sich pathogene Zonen geologischen oder hydro-geologischen Ursprungs durch erhöhte Gradienten des Erdmagnetfeldes (GMF) von ihrer Umgebung abheben. MERSMANN 1983, 1997 a,b konstruierte dafür ein Geo-Magnetometer, das die Messung der magnetischen Flussdichte des GMF im Gleichfeldbereich ermöglichte, und schlug tolerierbare Gradientenwerte für Schlafplätze vor. ASCHOFF et al. 1985 dehnten diese Untersuchungen auf technische Einflüsse (z.B. von Metallteilen in Möbeln) aus. Internationale Forschungsarbeiten auf den Gebieten des Bauwesens und der Veterinärmedizin bestätigen diese Erkenntnisse.

Das von technischen Geräten ausgehende „magnetische Rauschen“ im niederfrequenten Bereich zeigt typische Amplituden von 0,1-10 µT und trifft somit hinsichtlich Frequenzen und Intensitäten das Fenster der biologischen Empfindlichkeit. Auch Hochfrequenzgeräte für drahtlose Nachrichten- und Datenübertragung zeigen aus mehreren physikalischen Gründen magnetische ELF-Effekte von 0,5-5 µT. Durch diese technischen Einflüsse hervorgerufene Gradienten überlagern sich mit Gradienten im natürlichen Magnetfeld. Bei einem verstärkenden Einfluss werden nachteilige biologische Effekte verschärft.

Die vorliegenden Erkenntnisse liefern aber keinen zwingenden Beweis, dass die magnetischen Feldgradienten selbst die Ursache biologischer Probleme darstellen. Bekanntlich haben die geobiologischen Belastungszonen an besonderen Punkten oder Linien die stärkste Reizwirkung. Die präzise Erfassung biologisch wirksamer Störungen (auch solcher technischer Herkunft!) im statischen und ELF-Magnetfeld erfordert gegenüber dem Geo-Magnetometer eine erhöhte Genauigkeit und eine Erweiterung des erfassten Frequenzbereichs wenigstens bis ca. 15 Hz.

Um diesen Anforderungen zu genügen, wurde das IIREC Präzisions-Teslameter 05/40 mit einer Messwertabweichung von max. 0,5 % bei einer vertikalen magnetischen Induktion von 40 µT und einem Frequenzbereich von 0-18 Hz (- 3 dB) gebaut. Auf den damit durchführbaren Messungen beruht ein neues Mess- und Auswerteverfahren:

Bestimmung und biologische Bedeutung divergenter Magnetfeldgradienten

Das von uns zum Patent angemeldete Verfahren (MEDINGER und HOMANN 2004) erfasst die vertikale magnetische Flussdichte über einem regelmäßigen quadratischen Punktgitter mit Abständen von 10 cm auf einer Fläche von 1 m x 1 m, (auf Schlafplätzen 1 m x 2 m, für Labormessungen auch 0,5 m x 0,5 m mit 5 cm Abstand). Die an den Gitterpunkten gemessenen Werte in µT werden mittels eines Datenanalyseprogramms (z.B. Surfer 8 von Golden Software) interpoliert und als „Feldkohärenzmuster“ (FKM) dargestellt.

Abb. 7a (Seite 21-22) zeigt das Beispiel eines Messfeldes, in dessen Zentrum sich ein sendendes Mobiltelefon befindet. Die Differenzbildung gegenüber dem vorher ohne Mobiltelefon vermessenen Hintergrund (Abb. 7b) lässt die Störungen erkennen, die vom Mobiltelefon in einer Größenordnung bis zu 2 µT in einem Umkreis von 30 cm hervorgerufen werden. Die Gradientendarstellung des Feldes von Abb. 7a in Abb. 7c zeigt im Bereich des Mobiltelefons „Quellen" und „Senken". Daher wird schließlich das quellenhafte Verhalten des Feldes B(x,y) von Abb. 7a in Abb. 7d als „Feldgradientendivergenz" (FGD) dargestellt, die als div grad B für jeden Messpunkt berechnet wurde. Daraus ergibt sich rechnerisch die Einheit µT/m^2. Um besser handhabbare Zahlen zu gewinnen, empfiehlt sich die Umrechnung auf mT/m^2.

WÜST und WIMMER 1934 beschrieben bereits das Ausbleiben bestimmter biologischer Reaktionen über einer Fläche, auf der mit einer bestimmten Anordnung von Magneten ein gleichmäßiger (divergenzfreier) Gradient der magnetischen Flussdichte hergestellt worden war. Umgekehrt fanden wir bei unseren Versuchen mit verschiedenen Magnetfeldkonfigurationen, dass ein Gefühl des Unwohlseins bei anwesenden Personen mit dem Auftreten divergenter Magnetfeldgradienten zusammenhing.

Wir haben daher mit Untersuchungsreihen zu biologischen Reaktionen auf Magnetfelder mit homogenen und divergenten Gradienten begonnen, über deren Ergebnisse gesondert zu berichten sein wird. Aus unseren ersten Tests konnten wir ableiten, dass Versuchspersonen beim Aufenthalt in einer Zone mit 5 mT/m^2 oder noch höheren FGD-Werten über Kopfschmerzen und Benommenheit klagen. Die Bewertung solcher Divergenzen des magnetischen Feldgradienten muss aber auf die Stärke des erdmagnetischen Hintergrundfeldes Bedacht nehmen. Weiters sind im Hinblick auf die biologische Wirksamkeit das gehäufte (lineare oder flächenhaft aggregierte) Auftreten von Störpunkten zu beachten, sowie die Art des Aufenthaltsplatzes. Belastungen an Schlafplätzen sind besonders kritisch zu bewerten, aber auch Störungen an Arbeitsplätzen erfordern erhöhte Aufmerksamkeit. Unser internet-basiertes Auswerteportal (Measurement Analysis Portal, http://www.map.iirec.at) ermöglicht eine bequeme Auswertung solcher Messungen. Damit ist es möglich, einen vollständigen Messbericht einschließlich FKM- und FGD-Grafiken sowie einer standardisierten Bewertung zu erzeugen.

Schlussfolgerungen und Ausblick

Der gegenwärtige Forschungsstand zeigt, dass biologische Systeme gegenüber statischen und extrem niederfrequenten (ELF) Magnetfeldern äußerst empfindlich reagieren. Sie zeigen athermische resonanzartige Reaktionen. Die Bedeutung des Erdmagnetfeldes und seiner auch technisch beeinflussten Gradienten wurde von der geobiologischen Forschung aufgezeigt. Unsere laufenden Arbeiten haben gezeigt, dass die genaue Lokalisierung und Quantifizierung von biologischem Stress durch Magnetfeldgradienten die Auswertung der Feldgradientendivergenz (FGD) erfordert.

Die wissenschaftlich gut belegte Parallelität der biologischen Folgen von elektromagnetischer Strahlung im Mikrowellenbereich einerseits und ELF-Feldern andererseits wird theoretisch durch die Erforschung der Quanteneigenschaften von Wasser und biologischen Systemen untermauert. Sie erfordert es, moderne digitale Funktechnologien ernsthaft als Quelle von Magnetfeldstörungen in biologisch wirksamen Frequenz- und Intensitätsfenstern in Betracht zu ziehen.

Der Resonanzcharakter biologischer Effekte berechtigt zur Hoffnung, dass neue Methoden der Beeinflussung technischer elektromagnetischer Felder deren biologische Verträglichkeit erhöhen können. Führende Wissenschaftler von internationalem Ansehen empfehlen die Forschung auf diesem Gebiet und beteiligen sich aktiv daran (HYLAND 2001, HYLAND et al. 1999, YOUBICIER-SIMO et al. 1998). An freiwilligen Versuchspersonen ebenso wie an Hühnerembryos gelang der Nachweis, dass hyperschwache resonanzartige Magnetfeldwirkungen nachteilige Einflüsse von Videomonitoren und Mobiltelefonen ausgleichen können. Uns gelang jüngst die Entwicklung technischer Folien, die gleichfalls nach dem Resonanzprinzip in der Lage sind, Gradienten in Magnetfeldern auszugleichen. Dies scheint ein vielversprechender Ansatz, um athermischen biologischen Effekten auf niedrigsten Energieniveaus zu begegnen.

Ende der deutschen Kurzfassung

INTRODUCTION

Recently official studies on the biological effects of microwave (MW) radiation have troubled the scientific community as well as the broader public regarding potential detrimental effects of wireless communication and data transmission. This is especially true of (i) the study on effects of global communication system radio-frequency fields on well being and cognitive functions of human subjects charged by the Dutch government (ZWAMBORN, VOSSEN et al. 2003) and of (ii) the study on risk evaluation of potential entvironmental hazards from low energy electromagnetic field exposure using sensitive *in vitro* methods (ADLKOFER 2003) supported by the European Union.

In study (i) which became known as the "TNO study", a statistically significant relation between UMTS-like fields with a field strength of 1 V/m and the well being of test persons was found. The amplitude of the applied 2100 MHz wave corresponded to a maximum specific absorption rate (SAR) of 0.078 W/kg after averaging over 10 g of tissue. The result was quite surprising because exposure levels were far below the accepted SAR limit of 2 W/kg. With GSM-like fields, there was no such significant effect. The research was carried out according to rigorous scientific standards. Replications of the UMTS part of the study are going on in several countries (Japan, Switzerland and UK).

The so-called REFLEX study (ii) gave the surprising result that MW radiation as it is used for cellular phone communication causes genetic damage at certain power levels, depending on the time pattern of exposure. In particular, there was clear evidence for an increase of *micronuclei* formation and of DNA strand breaking after continuous wave (CW) exposure to 1800 MHz for 24 hours. The damage occurred in an energy window of SAR values from 1.3 to 2.0 W/kg, showing an increasing effect with decreasing SAR value (!). Prolongued exposure at 1.3 W/kg resulted in a further increase of *micronuclei* formation which after 72 hours arrived at a level equivalent to an X-ray exposure of 0.5 Gy. The crucial results were cross-validated by two renowned research groups within the framework of the study. So there is no longer doubt that in an SAR range which is generally accepted for GSM-1800 cellular phones according to ICNIRP recommendations (ICNIRP 1998), we are facing a considerable risk of genetic damage through excessive phoning.

Following these results from careful scientific investigations, it can not be questionned any more that non-thermal effects of electromagnetic fields (EMF) in the microwave range do exist. The problem in the scientific discourse, though, is not so much whether there are nonthermal biological effects, or not. The question which has not found a satisfying answer so far is to what mechanisms may be responsible for the occurence of nonthermal effects. As we will see, these are closely linked to the biological effects of weak magnetic fields (MF) in the lowest frequency range.

It is widely accepted that ions play a decisive role in biochemical and biophysical processes launched by EMF. The dynamics of ions in the presence of an AC MF against the background of a DC field (e.g., the geomagnetic field) – the cyclotron situation – is an important link to the understanding of biological responses to weak MFs. Quite often those fields show resonance-type effects close to cyclotron frequencies of ions such as Ca^{2+}, Na^{2+} etc. Ion cyclotron resonance (ICR) occurs at the frequency of the AC MF

$$\Omega = \frac{qB_0}{m} \qquad (1)$$

with B_0 being the magnetostatic component of the MF, q the charge and m the mass of the ion. ICR a basis for the observed biological phenomena was profoundly explored by LIBOFF 1985, 1997, and LIBOFF et al 1987b. A reversal of a maximum in the frequency spectrum of biological effect was found near a cyclotron frequency for $^{45}Ca^{2+}$ in a 21-μT DC MF, when the relative MF amplitude was growing from 1.4 to 10.1 (LIBOFF et al. 1987a). A survey of experimental evidence for ICR effects in biological systems is given in LIBOFF 2005.

In his concise monograph on the physical problems underlying magnetobiology, BINHI 2002, though, comes to the conclusion that “so far there is no physically acceptable understanding of how weak low-frequency MFs cause living systems to respond.“ At first sight the attempts to explain this type of biological effects are frustrated by the sheer inadequacy of energy terms available from various possible mechanisms – always in comparison to thermal energy *kT*. On the other hand, there are various arguments pointing in the direction that thermal equilibrium is no adequate approach to the understanding of interactions between EMF and biological systems. The thermal concept disregards that dealing with living matter, we are mainly facing non-equilibrium systems, and that an appropriate physical description of an EMF is only given by Maxwell’s equations. Biophysics again and again finds itself thrown back to Presman’s exhortation to take into consideration signal, rather than energetic, properties of an EMF (PRESMAN 1970).

A promising approach has to follow the lines of quantum states with a lifetime of about 0.1 s corresponding to a frequency of 10 Hz which seems to be the upper threshold of reproducible low-frequency magnetobiological effects. In search of long-living quantum states of this kind, spin relaxation offers itself as a most promising candidate. Theoretical considerations show that states of nuclear spins of protons and ions are able to explain magnetobiological effects. The metastability of certain orbital degrees of freedom may well result from specific features of their interaction with thermal oscillations. One application of this approach is the soliton mechanism for the energy transport along –spiral protein molecules (DAVYDOV 1984).

In BINHI 1997 a,b, a mechanism of the interference of quantum states of an ion bound in an idealized protein cavity is proposed. The ion has found its way via protein gates to a cavity where it stays in a superposition of quantum states and shows an inhomogeneous probability density distribution. A DC MF with a superimposed AC MF will then cause metastable angular modes of ion oscillations showing up as resonances with certain MF frequencies and amplitudes. The most remarkable changes of the oscillating interference pattern will occur in the range of the cyclotron frequency of particles.

Binhi’s model gains enormous importance as it links the role of MF interference parameters to the transport mechanism of ions and dipole molecules through membrane channels that was revealed in detail by the Nobel prize winners of 2003 in chemistry, Peter Agre and Roderick McKinnon (VON HEIJNE 2003). These findings underline the crucial role of gates and binding sites in the transport protein channels. The molecular details which had been totally unclear so far are suitable to explain, from the view point of Binhi’s interference mechanism, why these transport processes are influenced by the action of weak MF. In the case of the transport of water molecules through aquaporin channels dipole mechanisms, of course, play an essential role. It was found by TAKJORSHID et al. 2002 that the local electrostatic field switches polarity in the middle of the channel, forcing the passing water molecules into rotation performing an half-cycle of electric oscillation. Later on, we will return to the interactions of water with RF EMF to explain the enormous intensities of internal electric and magnetic fields which may occur in aqueous solution, especially in coherent biological systems.

BIOLOGICAL EFFECTS OF WEAK ELF MAGNETIC FIELDS

The question of biological effectiveness of weak MF has many dimensions, first of all: What order of magnitude of field intensity has to be considered, and what is the range of frequencies with a maximum biological effectiveness? A useful approach to answer these question will be to consider natural ELF magnetic fields: their amplitudes and their spectral characteristics. A tentative answer to this question will be given in this chapter.

Next, the question has to be answered which mechanisms can render biological systems, especially the human person, susceptible to weak MF effects. The answer to this question will, again, point towards thresholds or windows of biological effects. The scientific exploration of mechanisms proceeds in two directions: (i) biophysical and biochemical mechanisms on cellular level, and (ii) holistic responses of complex organisms such as the human body. This question will be dealt with in connection with gradients of magnetic fields.

Finally, there is the question of ELF MF impact from technical sources which modulates the natural background MF. For setting appropriate standards of biophysical electromagnetic compatibility, a comprehensive understanding of biological effects of this impact must be gained. This will be the objective of the following chapter.

Scope of investigation

Usually, 'weak' MFs investigated with regard to their biological effects have an intensity of less than 1 mT. The intensity of the earth's magnetic field keeps below 100 µT (i.e. 1 Gauss), ranging from 20 µT to 70 µT (LÜHR and HAAK 2000). MFs about or below 1 µT are denoted as 'hyperweak' fields, still showing biological effectiveness. PRESMAN 1970 already gave experimental evidence for the biological detection of hyperweak variable magnetic signals up to 1 nT.

In the frequency range to be considered here, there are the basically static (DC) geomagnetic field (GMF), and extremely low frequencies (ELF), in traditional terminology ranging from >0 to 300 Hz. In newer literature, the notion of ELF is restricted to 30 Hz as an upper threshold. The lowest frequencies of the ELF range were formerly denoted as ultralow frequencies, but the current terminology uses the notions of superlow frequencies (SLF) for 30-300 Hz, and of ultralow frequencies (ULF) for 300 Hz-3 kHz (Fig. 1). Here we will use the notion of ELF for >0 to 30 Hz and focus our evaluation on MFs within this range. AC fields at such low frequencies may be considered, from a physical point of view, as quasi-static fields, approaching DC or static fields as a limit.

Natural ELF fields

MFs in the ELF range surround us from atmospheric resonances which are imprinted to the non-static share of the geomagnetic field (GMF). These are the Schumann resonances, representing cavity

Frequency (Hz)	DC MF 0 → AC MF	30	300	3000
Traditional terminology	ultralow frequencies	extremely low frequencies	-	very low frequencies
Current terminology	ELF extremely low frequencies	SLF superlow frequencies	ULF ultralow frequencies	VLF very low frequencies

Fig. 1: Terminology of lowest frequency fields

resonance modes of the system earth-ionosphere. The basic Schumann frequency lies at 7.8 Hz, with overtones up to some 45 Hz (fig. 2, table 1).

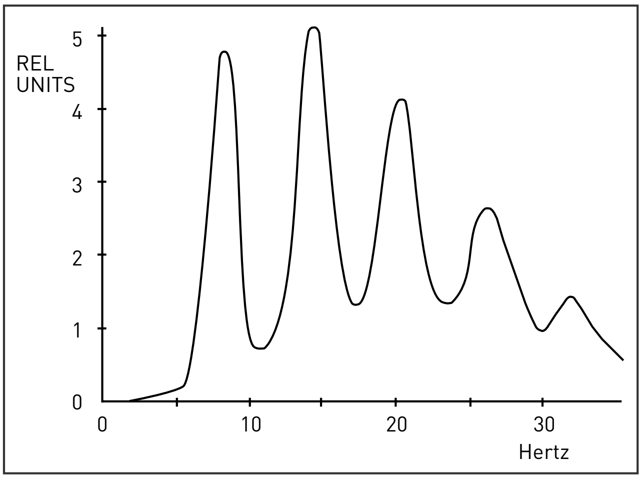


Fig. 2: Schumann resonance spectrum at day-time (according to POLK 1982) from 0 to 35 Hz

It is worth noting that the lowest Schumann frequencies of 7.8 Hz and 14.1 Hz resp. are very close to the upper and lower limit of the alpha band of brain waves (Fig. 3). From a close look to the frequency spectrum of brain activity, it can be seen that Schumann frequencies show up as small, but distinct spikes in the brain spectrum. Moreover, the basic Schumann frequency of 7.8 Hz was identified as the frequency of the heart meridian of traditional chinese medicine (TCM) by SMITH 2002. It is also represented as a peak frequency in the variations of the geomagnetic field (GMF).

Harmonic no.	Resonance frequency (Hz)
1	7.8
2	14.1
3	20.3
4	26.4
5	32.5
6	38.8

Table 1: Schumann resonance frequencies as an overtone series

The earth's magnetic field shows a variety of characteristic peaks at lowest frequencies (< 3 Hz). These micropulsations, as they are called, arise from the edge of the magnetosphere. They spread to the ionosphere from where they are irradiated as waves to the ground.

A broad maximum of geomagnetic variations sets in at about 7 Hz and covers the whole ELF, SLF and ULF region. This is caused by atmospheric waves, its peak at about 100 Hz mirrors the global frequency of lightnings (about 100 per second).

In the range from 7 to 60 Hz, GMF variations are modulated by the Schumann resonances. The basic frequency can be roughly estimated from a wavelength which equals the circumference of the earth (about 40,000 km), giving an approximative frequency value of 7.5 Hz.

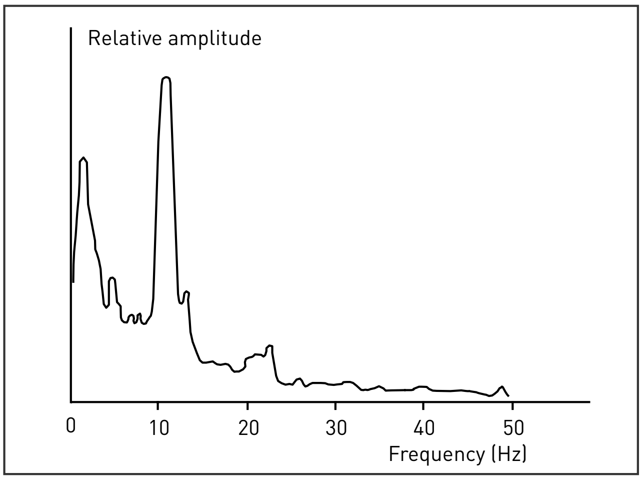


Fig. 3: Frequency spectrum of brain waves (from MALMIVUO and PLONSEY 1995)

Daily variations, micropulsations and magnetic storms can cause GMF variations of several 100 nT. Daily variations comprise solar and lunar variations, the former (20 nT to 30 nT) being about 10 times stronger than the latter.

There are 5 peaks of continuous pulsations (pc1-pc5) and 2 ranges of irregular pulsations (pi1, pi2) of the GMF. An overview of the geomagnetic variations is given in table 2.

Geomagnetic variation	time period	order of magnitude of peak frequency	order of magnitude of peak intensity
Long-term cycles			
secular variations	>> 1 year		
yearly variation	365 d (solar), 354 d (lunar)	$3.2 \cdot 10^{-8}$ Hz	5 nT
monthly variation	30 d (synodical), 27 d (siderical)	$4 \cdot 10^{-7}$ Hz	10 nT
daily variation	24 h	$1.2 \cdot 10^{-5}$ Hz	50 nT
hourly variations	0.5-5 h	$2.8 \cdot 10^{-4}$ Hz	100 nT
Micropulsations			
Continuous pulsations			
pc 5	150-600 s	$2 \cdot 10^{-3}$ Hz	80 nT
pc 4	45-150 s	0.01 Hz	1 nT
pc 2, 3	5-45 s	0.1 Hz	0.5 nT
pc 1	0.2-5 s	1 Hz	0.1 nT
Irregular pulsations			
pi 2	40-150 s	0.007-0.025 Hz	
pi 1	1-40 s	0.025-1 Hz	
ELF cavity resonances	0.015-0.15 s	7-60 Hz (several peaks)	0.02-0.05 nT
Lightnings	0.1-0.001 s	100 Hz	0.07 nT

Table 2: Variations of the geomagnetic field (according to BRASSE 2003)

Biological significance of natural magnetic fields

Based on the characteristics of natural MF, one could estimate which kind of MF would be most promising to cause distinct biological effects. Supposing that living organisms have undergone an evolutionary adaptation to natural magnetic conditions, their maximum magnetobiological sensitivity should be expected in the frequency range of weak ELF variations (0-30 Hz) at amplitudes not surpassing 1 μT, with a DC background up to the order of magnitude of 100 μT.

Supported by experimental results from genetics, radiobiology, cytology, plant physiology, and animal physiology, DUBROV 2003 draws a comprehensive picture of biological rhythms being synchronized with GMF variations. HECHT 2003 reviews magnetic storms as triggers of myocardial infarct and various other diseases. The Schumann peak of GMF variations between 7 and 12 Hz matches the natural frequencies of united cell structures. This might be explained by an endogenization of these frequencies which evolved the same way as of circadian rhythm.

craniosacral rhythm	author	cycles	period	frequency	matched GMF micropulsations*
cranial rhythmic impulse (CRI)	Sutherland	6-14/min	4-10 s	0.1-0.23 Hz	pc 2
additional rhythm	Jealous	2.5/min	24 s	0.04 Hz	pc 3
“big tide“, “breath of life“	Becker	6-10/ 10 min	60-100 s	0.01- 0.017 Hz	pc 4

Table 3: Craniosacral rhythms and micropulsations of GMF (according to LIEM 1998)

One more example may be added from complementary medicine: In craniosacral osteopathy, body rhythms play a crucial role. Remarkably, the very slow principal rhythms described by researchers in this field match the pc2 to pc4 pulsations of the GMF (table 3).

Findings such as the synchronization of the cell matrix with the alpha rhythm of 8-12 Hz **point to the natural variations of the GMF as a time base for biological rhythms**. The effect of magnetic storms show that a synchronized rhythm of this kind, though, is disturbed by pronounced deviations of the magnetic surroundings, which results in impairment of well-being and enhancement of pathological processes. Such disturbances are caused by MFs of technical origin, as well, if they match the frequency and intensity windows of natural signals. Biological systems have been trained through evolution to sense the weak ELF signals from the natural electric and magnetic fields.

Magnetic sensitivity of biological organisms

Perhaps the most prominent example of magnetic sensitivity is the internal compass which enables migrant birds to find their way without visible landmarks. The avian magnetic compass (AMC) has been shown by the group of Liboff to have a relatively narrow range of response centered about the local GMF intensity (LIBOFF and JENROW 2000). Abruptly increasing or decreasing this field intensity (by more than 30 %) renders the AMC temporarily useless. Adaptation requires a minimum of 72 hours. The AMC is apparently ineffective in purely horizontal magnetic fields.

The sensitivity of humans to magnetic fields, though, was denied for a long time. It was not before Kirschvink’s discovery of magnetite biomineralization in the human brain (KIRSCHVINK et al 1992a) that a plausible mechanism for a body response to magnetic fields seemed to be within grasp. Kirschvink’s group proposed a mechanism how a magnetic field can be sensed by an organism using magnetite (KIRSCHVINK et al 1992b). An ion channel may be opened by means of a filament attached to a magnetite grain. Following along these lines, even a link to cancer promotion was suggested (EMF SRS 1997). Supposing a magnetosome being bound to a mechanically activated ion channel in a calcisome, EMF exposure during cell division could lead to disruption of spindle fibers due to increased Ca^{2+}-levels and a chromosome non-disjunction event.

From the most plausible biophysical mechanisms, a threshold of 0.1 µT can be concluded for the possibility of DC MF effects on biological systems. AC field frequency dependence has been observed in experiment (KOBAYASHI and KIRSCHVINK 1995). Magnetite crystals that are magnetically saturated produce a peak MF of 0.25-0.5 T. These flux densities are sufficiently strong to alter radical pair reactions in cellular biochemistry. A strong varying magnetic field would be produced if magnetite grains began to rotate under the influence of an external ELF MF. The corresponding electric field would possibly alter membrane function. Experiments on honeybees with a threshold below 0.1 μT gave indirect evidence of a magnetite-based mechanism (WALKER and BITTERMAN 1989).

At the Fröhlich Centenary International Symposium "Coherence and Electromagnetic Fields in Biological Systems" held in July 2005 in Prague, Binhi presented calculation results on stochastic dynamics of magnetic nanoparticles in biological cells (CEFBIOS 2005b). For single-domain magnetite particles of radius *r* = 100 nm in the GMF the magnetic energy equals approximately 24 *kT*. For an additional AC MF capable of affecting a biophysical or biochemical system, a minimum intensity of 1-2 μT is required. By facilitation through thermal fluctuations, this limit value may be reduced. A 100 nm-magnetosome fixed in the cytoskeleton with plausible elasticity in the 13-μT AC MF and 46-μT GMF regularly turns at angles of the same order as the chaotic rotations. The 'resonance' effect will occur within a 'window' in constant MF. Computations show that a 1 % MF change causes 10-20 % change in the transition probability of biochemical reactions. Thus, the limit of detectable values of the constant MF variations is found to be 0.2 μT, the level of geomagnetic fluctuations.

The power of nonthermal effects is revealed by calculation of the effective temperature in magnetic noise. Supposing increased sensitivity of a biological system by stochastic resonance and setting appropriate parameters, according to Binhi's calculations **some μT turn out to be equivalent to several hundred degrees of temperature**.

PARALLEL EFFECTS OF MICROWAVE RADIATION AND ELF MAGNETIC FIELDS

Safety standards for EMFs should be based on relevant biological properties. In a paper submitted to CEFBIOS 2005 (c), Blank and Goodman suggest to consider specific cellular reactions to potentially harmful stimuli as a biological guide for electromagnetic safety. In particular, the stress response which is stimulated by both ELF and radio frequency (RF) EMF is a well documented protective reaction of animal and plant cells. Thermal and non-thermal stimuli affect different segments of DNA to initiate stress protein synthesis and utilize different biochemical pathways . However, **both ELF and RF stimulate the same non-thermal pathway**. The authors conclude that **the specific absorption rate (SAR) does not provide a valid basis for safety standards** because the same biochemical reactions are stimulated in different frequency ranges, obviously independent of SAR levels.

Belayev confirms in his presentation at CEFBIOS 2005 (a) the chromosomal DNA being the target for non-thermal effects of MWs. They feature as resonance type effects with specific frequency windows and intensity windows including extremely low power densities (PD) down to 10^{-13} W/m², the biological outcome depending on type of signal (frequency, amplitude), modulation, and polarization. With decreasing intensity, the resonance windows are narrowing and splitting into symmetrical sub-resonances with specific effects of circular polarization (helicity). Biological systems are more sensitive to exposure time than to PD in the range of 10^{-13} to 10^{-2} W/m². Thus, **attempts to establish dose-response-relationships are not promising at low intensities**. The dependence of effects on duration of exposure and PD is strongly non-linear.

Effects are influenced by physiological conditions, as well, and depend on cell density. This finding suggests cell-to-cell-interaction during response to MWs and intercellular electromagnetic communication. So, **it is not appropriate to explore non-thermal ef-**

fects on a cellular or subcellular level alone. The high degree of biological organisation requires researchers to take into account the holistic (one might say: holographic) nature of biological organisms. Genomic differences influencing the biological response to MWs evidence the crucial role of DNA as an interface in the wave-biosystem-interaction.

This function of genomic DNA resolves the 'C-paradox' meaning that the genome size (C-value) in almost all eukaryotic genomes encodes genes only to a few percent. Therefore, the major part of genomic DNA has been misunderstood as "junk DNA" for a long time. Now it was clarified that the whole genomic DNA is responsible for the natural spectrum of oscillations.

Analogy between effects of MW radiation and ELF magnetic fields

Beginning from 1987, several authors have pointed out a striking congruence of biological response to RF EMFs in the MW range and low-frequency MFs (table 4). Common features of both kinds of fields are similar magnitudes of biological effects and their disappearance upon application of an additional low-frequency fluctuating MFs. Frequency spectra of bio-effects are almost the same, whether a low-frequency MF or a modulated MW EMF be applied. From this, it can be concluded that modulated MW radiation is demodulated by biological systems, the final biological effect depending on modulation frequency.

A remarkable side-effect of the close relationship between effects of MW EMFs and ELF MFs is the ability of ELF noise fields to mitigate or even inhibit detrimental biological impact of a coherent ELF field or of MW radiation. Inhibition requires a noise level at 70-80% of the intensity of the coherent EMF. This was also demonstrated for the cellular phone type of MW radiation . There is already a practical application as a radioprotective device in cellular phones.

Author(s)	year*	object of investigation
Liboff *et al.*	1987 (b)	membrane transport (ICR)
Alipov *et al.*	1994	*E. coli* cells (systemic reaction)
Litovitz *et al.*	1994 (b)	modulated mm-band radiation /
Penafiel *et al.*	1997	ornithine decarboxylase activity in L929 cells
Kwee and Raskmark	1995	cell growth in human epithelial
Kwee and Raskmark	1998	amnion (AMA) cells
Blank and Goodman	1997	EMF-DNA interaction
Gapeyev *et al.*	1999	immune system cells
Belyaev *et al.*	1999	conformation of nucleoids in
Belyaev *et al.*	2000	*E. coli* cells and human lymphocytes
cf. Belyaev *et al.*	1994	dependence of effects of ELF MFs on collinear static MF
Mitigating effect of ELF noise :		
Litovitz *et al.*	1994 (a)	developing chicken embryos
Lin and Goodman	1995	human leukemia cells
Kwee and Raskmark	1996	human epithelial AMA cells
Litovitz *et al.*	1997	cellular phone radiation

**) Letters added refer to the bibliography.*

Table 4: Experimental evidence for congruent biological effects of MW radiation and ELF magnetic fields.

Again, these insights underline the non-thermal nature of biological effects and the crucial role of coherence in biological systems. Yet, from a physical as well as from a biological (rather biophysical) point of view, the mechanism of coherence remains to be cleared. As a physical substrate of biological coherence, water may be conjectured.

The role of water in electromagnetic bioeffects

DEL GIUDICE et al. 1988, 1989 outlined a quantum electrodynamic (QED) description of biological matter. It is based on different sets of states with non-zero macroscopic polarization *P* which serves as an order parameter for electret states. External influences such as metabolic energy induce transitions between different sets. Macroscopic dipole waves arise which may also be described as an occurrence of coherence through Bose condensation of particles in the ground state. The underlying basic idea of coherent dipole oscillation modes was formulated and for the first time applied to biological systems by FRÖHLICH 1968 a,b.

Now, external EMFs interact with the polarization waves in a biological medium due to its non-linear properties. This implies an altered behaviour of the EMF because its wave equation is no longer d'Alembert's, but it has to be expanded for a polarization term. As a consequence, it propagates thread-like, with high EM gradients at the edges where ions and molecules are organized with a high degree of order. Thus, the EMF becomes a morphological (structure-forming) factor.

Water as a dipole medium allows for the formation of polarization waves. The properties of these could be affected by a low-frequency MF which – by interaction with the spin magnetic moments of water protons – influences the orientations of water molecules. This offers an explanation to biological effects.

For a water resonance mode of ω_0 $1.5 \cdot 10^{12}$ Hz, the coherence domain has a radius of $R = 100$ µm and contains about $N = 10^{17}$ molecules. The number of molecules involved in a quantum fluctuation which does not spoil the coherence, ΔN, is about the square root of $N = 3 \cdot 10^8$ molecules. A response to an excitation by frequency ν that keeps the system in coherence must obey the condition:

$$\Delta N \cdot \nu \leq \omega_0 \qquad (2)$$

giving ν = 5 kHz.

The wavelength λ of the coherence wave is equal to the diameter *2R* of the coherence domain, so the velocity of the wave is $c' = \lambda \cdot \nu = 1$ m/s.

Vice versa, it may be stated that for a given velocity c' of coherence waves in water or in a biological medium and for a constant wavelength determined by the magnitude of coherence domains, a frequency ν occurs which relates to the EM frequency ω_0 in the same ratio as the velocity c' of coherent wave propagation in the medium to the velocity of light $c = 3 \cdot 10^8$ m/s. So, different velocity ranges correspond to different frequency ranges. To a MW EM frequency of 300 MHz = $3 \cdot 10^8$ Hz, in a medium with c' = 1 m/s there will be a parallel coherent frequency of 1 Hz.

This is only a rough estimation of the effects we can expect in water and in biological tissue, but it reveals that **coherence waves in the ELF range parallel EM frequencies in the MW range**. Vice versa, ELF magnetic fields inducing coherent oscillations in water or body tissue have biological effects of the same kind as MW EMFs. **This opens the door to the understanding of analogous experimental results in both frequency ranges**.

The tremendous loss of velocity of an EM wave incident to a certain cross-section of a dielectric medium such as water results in an equal increase of intrinsic energy density, i.e. by a factor of approximately 10^8. As the value of energy density is given by the product of electric field strength and magnetic flux density, each of them rises by 4 orders of magnitude! **Thus, the marked biological effects of lowest non-thermal power densities (PD) can be explained** because in coherent media such as water and biological tissue an amplification by a factor of 10,000 takes place.

A detailed account of coherence waves in water and in human body was given by SMITH 2002. He determined coherent propagation velocities in water being about 2 m/s and in the human leg being about 6 m/s. Based on these data, theoretical MF effects of low-energy MW radiation in the body tissue can be calculated, supposing a 100% absorption. PDs of 1-100 µW/m² suggested to ensure biological compatibility of cellular phone radiation correspond to ELF magnetic inductions of 0.45-4.5 μT. Bearing in mind that natural fluctuations of the GMF amount to only 0.1 μT and that – via stochastic resonance – this order of magnitude has to be regarded as a lower threshold of magnetosome response, the strict suggestions of PD limits obviously are not too low.

GRADIENTS IN STATIC AND ELF MAGNETIC FIELDS

Principal remark*: Magnetic fields are solenoidal, i.e. in terms of mathematical physics, they have a curl, but are not a gradient of a potential. MF gradients may be defined, though, of the local value of total magnetic induction or of the component of the MF vector in a pre-defined direction. In the geographical latitude of Europe, Siberia and North America, the vertical component of the geo-magnetic field is dominating. Therefore in these regions of the world it is suitable to choose the vertical component of the magnetic flux density or induction to characterize irregularities in the static and ELF magnetic field.*

Till now, the role of gradients in MFs has not been properly recognized. Hardly any experimental report refers to gradients of applied DC or AC MFs. Magnetic pads, bracelets, necklaces, etc., manufactured for popular self-application, as well as professional medical magnetotherapy seem to be effective due to spatial inhomogeneity of MF because they are applied to biological receptors from outside (BINHI 2002). In spite of reported benefits such as immediate relief of pain one must keep in mind that the use of magnetic devices, if not supervised by well trained medical practitioners, puts applicants to a considerable health risk. There has not been an adequate research so far, but it must be regarded that the permanent impact of MFs may have serious biological consequences.

Sensory neurons in a cell culture react to gradient MFs with a shift of the probability of "firing"(CAVOPOL et al. 1995, table 5). Thus, neural impulses can be blocked by magnetic gradients.

Gradient of DC MF	Blocked percentage of action potentials
1.5 mT/mm	80%
1 mT/mm	70%
0.02 mT/mm	no changes

Table 5: Impact of MF gradients on the "firing" probability of neuron action potentials (CAVOPOL et al. 1995)

MF gradients may serve as reference vectors in the biological detection of MF orientation, lying a physical basis for magnetotropism (YANO et al. 2001).

In the paper already cited, GAPEYEV et al. 1996 found a remarkable difference of biological response to near zone vs. far zone radiation. Comparing equal power flux densities, only far zone radiation with relatively small gradients evoked resonance-like cell responses with distinct spectral maxima. In the near zone with its strong field gradients, no frequency dependence of biological effect was found. This points to a disturbance of biological coherence by strong MF gradients.

The results discussed so far indicate that MF gradients are important for the orientation of biological systems, but strong gradients result in interruption of biological signals or even breakdown of coherence.

Results of geobiological research

Systematic research on the biological significance of MF gradients was conducted by German geobiologists during the last 70 years. Geobiology deals with pathogenic locations, i.e. qualities of locations due to geological or hydrogeological conditions such as geological faults, cavities, or water-lines, which were often found to conincide with zones of impaired well-being, disturbed sleep, and elevated risk of certain diseases, even cancer promotion. For a long time it seemed nearly impossible to locate such zones by physical measurements. So their exploration was reserved to the subjective capacity of dowsers, while it was neglected by scholarly science. One scientific approach to this field was monitoring body reactions on pathogenic locations as indicators for geopathic stress. But a physical detection required objective measurement techniques independent of subjective conditions. That was the agenda of the geobiological school. In search of candidates for physical indicators, among others such as increased radioactivity (γ-activity) and VHF radiowave interference, geobiologists turned their attention to the geomagnetic field (GMF).

WÜST 1941 showed by a simple magnetic variometer (variation of MF direction) that irritation zones could be detected by measurement. He documented a 20° magnetic declination at a spot which had been independently detected by a dowser.

Gradient of GMF	Biological assessment
≤ 3 μT/m	tolerable degree of disturbance
10 μT/m	imperiling degree of disturbance
≥ 20 μT/m	strongly effective degree of disturbance

Table 6: Suggested guide values for magnetic anomalies in sleeping places (MERSMANN 1983, 1997a,b)

For a refined exploration of anomalies in the GMF, Mersmann constructed a „Geo-Magnetometer“ for reliable measurements of DC magnetic inductions in vertical direction. He found that pathogenic zones were frequently related to GMF gradients. The registration technique of such gradients was dragging the probe of the meter along straight lines at a constant speed. Based on measuring results and medical experience (MERSMANN 1983, 1997a,b, ASCHOFF *et al.* 1985), guide values were suggested for MF gradients that would be tolerable in sleeping places (table 6).

ASCHOFF *et al.* 1985 found that biological effects would not only be due to MF gradients with geological causes but also to gradients of technical origin in beds, on chairs etc. Aschoff reports of a thyroid proliferation being remitted after removal of a single screw which had caused a considerable MF gradient close to the throat of the sleeping person.

The pioneering work of Wüst, Aschoff and Mersmann was confirmed by research papers in architectural engineering, and veterinary medicine (HAN 2001, MARX *et al.* 1989, TOMBARKIEWICZ 1996).

Interference of technical EM waves with GMF

The measurements of MF gradients in a technical environment introduced by Aschoff opened the door to a field of research which since then gained increased importance for the monitoring of technical impact on the natural MF. When dealing with issues of EM safety and compatibility, it is essential to have in mind that the technical alterations of the GMF are superimposed on natural variations, causing interferences with signals of high biological relevance.

The “magnetic noise“ of technical origin is able to aggravate (but also, in some cases, to equalize) MF gradients in the natural surroundings or in the body itself. **Typical amplitudes of magnetic noise amount to 0.1-10 μT in the static and ELF range** (up to 50 or 60 Hz from the mains supply) **matching the intensity window as well as the frequency window of maximum biological sensitivity**.

Our precision measurements have shown that MW devices of wide-spread everyday use such as cordless and cellular phones, bluetooth headsets or wireless LAN base stations typically cause magnetic alterations of 0.5 to 5 μT in the ELF range.

The ELF MF impact of MW radiation, in particular its interaction with ELF MF gradients in a critical order of magnitude, has so far been widely neglected, but it **seems to be the clue to the understanding of non-thermal biological effects**. Low-frequency side effects of MW devices are due to various physical reasons:

- ELF functions of the respective technology: In GSM cellular phones, e.g. the power is regulated from the base station in intervals of 104 frames = 480 ms corresponding to a frequency of 2.1 Hz. Time division multiple access (TDMA) which chops a frequency band into several channels or time slots uses a frequency of 8.3 Hz in the case of GSM communication. This frequency is very close to the basic Schumann frequency of 7.8 Hz which also governs the heart meridian and features at the lower threshold of brain waves.

- Digital technologies use low-frequency pulse sequences, such as 100 Hz for the DECT standard, or 217 Hz fort he GSM standard.

- According to Fourier analysis, the flanks of pulses break down to a broad range of frequencies, extending to the lowest frequency range.

- As explained before, supposing the presence of coherency domains in water or biological tissue, MW frequencies will be paralleled by coherent frequencies in the ELF range.

SMITH 2002 determined the ratio of MW/ELF wave velocities and frequencies resp. to be $1.09 \cdot 10^8$ in pure water, and $0.494 \cdot 10^8$ in body tissue. These data refer to EM wave propagation at light velocity in air and the respective propagation of coherent intrinsic fields in media. To give an example, GSM EM frequencies of approximately 900 or 1800 MHz resp. will produce parallel coherent frequencies in the biologically highly sensitive ELF range in water and in the body (table 7), resulting in sharp gradients of the intrinsic ELF MF. Note that the resulting frequencies about 16 Hz target at ion transport processes (Ca^{2+}, K^+) of high biological significance. Ca^{2+} is receptive to frequencies around 36 Hz, as well. **Gradients at the designated frequencies are extremely critical for the migration of these ions through biological membranes**.

The classical “microwave“ frequency of 2.45 GHz and, of course, its coherent parallel frequency, match a resonance line of water. Microwave cooking is based on that resonance. Water in meals is heated by bringing about a “resonance catastrophe“ which destroys coherency. It is worth noting, too, that in body tissue the widely used bands of W-LANs, bluetooth devices and microwave ovens have a parallel frequency in body tissue which is very close to the mains frequency of 50 Hz being used in many countries of the world.

Medium	GSM-900	GSM-1800	W-LAN, Bluetooth, microwave ovens
air	~ 900 MHz	~ 1800 MHz	~2450 MHz
pure water	8.3 Hz	16.5 Hz	22.5 Hz
body (human leg)	18.2 Hz	36.4 Hz	49.6 Hz

Table 7: Frequencies of technical MW radiation and their coherent parallel frequencies in the ELF range for water and body tissue

Critical review of geobiological findings

Geobiologists did groundbreaking work in the recognition of the biological significance of MF gradients, in the realization of their physical measurement, and in the introduction of monitoring of technical impact on the natural magnetic signals. Yet, they left some important issues unresolved:

- Strictly speaking, an empirical correlation between the occurence of MF gradients and health effects does not prove the gradient itself to be the crucial factor. A close look at the cases documented in geobiological literature indicates that the transition zones from an even MF to regions with a strong gradient might be the proper “trouble zones“.

- This question is also linked to the problem of precise location. Geobiological measurements have so far been indicative of biological risks, but the location of points or zones of irritation by pure measurement lags behind the precision of well-trained dowsers. In this respect it is important to mind that dowsers have known for long that spezial points or lines such as crossings and edges of fault zones or underground water flows are biologically far more irritating than the regions in between. This, again, calls for a more refined evaluation of inhomogeneity of MF gradients.

- Setting out from the exploration of GMF, the Geo-Magnetometer was constructed principally as a DC magnetometer. At 5 Hz, it has already an attenuation of -3 dB. This seems inadequate to the registration of technical interference with GMF in the biologically sensitive ELF region.

- The deviation of the Geo-Magnetometer was about ± 3% of measured values. For a vertical GMF induction of 40 µT, this means an uncertainty of as much as 1.2 µT. For a reliable detection of natural or technical disruptions, instrumental deviations should fall below 0.5 µT or approximately 1% of measured values. For regions with a weaker GMF, a deviation limit of 0.5% would be desirable.

- The perpetration technique of geobiologists is insufficient, for the precision of measurement as well as for the location of measuring points. There is a need for a more accurate registration and evaluation.

A new foundation for the diagnosis of points or zones of disturbance

Along these considerations, we had a measuring instrument constructed which meets the following requirements:

- maximum deviation 0.5% at a GMF intensity of 40 µT

- full sensitivity in the range from 0-15 Hz which is biologically most sensitive and covers geomagnetic variations from the static field to the range of Schumann harmonics #1 and 2

- attenuation setting in about the lowest technical ELF which is usually 16.7 Hz (railway frequency), amounting to -3 dB at 18 Hz

These requirements were fulfilled in our Precision Teslameter 05/40 which represents an optimum compromise for the reliable detection of GMF variations ≥ 0.2 µT, be they caused by natural or technical impact, in the static as well as ELF range. Along with improved registration technique for magnetic induction, it was necessary to enhance the evaluation of measured data. This led us to the development of new methods for the location and quantitative characterization of zones of biological trouble in the static and ELF magnetic field, comprising both geogenic and technogenic disturbances.

DETERMINATION AND BIOLOGICAL SIGNIFICANCE OF DIVERGENT MF GRADIENTS

For the new method a patent was filed (MEDINGER and HOMANN 2004). The technique is based on the determination of spatial distribution of vertical magnetic flux density on a regular measuring grid. Usually, a field of 1 m 1 m is used. For bed-places, it is extended to 1 m 2 m. For field measurements, distances of 10 cm between measuring points are chosen. For laboratory measurements (e.g. of MF disturbance caused by a cellular phone) distances between measuring points are reduced to 5 cm. Measurements are usually conducted in the static and ELF range with the Precision Teslameter 05/40 (fig. 4).

Fig. 4: IIREC Precision Teslameter 05/40

Series 01a, with Förster probe

The Förster probe is contained in a measurement bob that can be easily held vertically. Best results are obtained with a rack to keep the measurement probe in a fixed position (fig. 5).

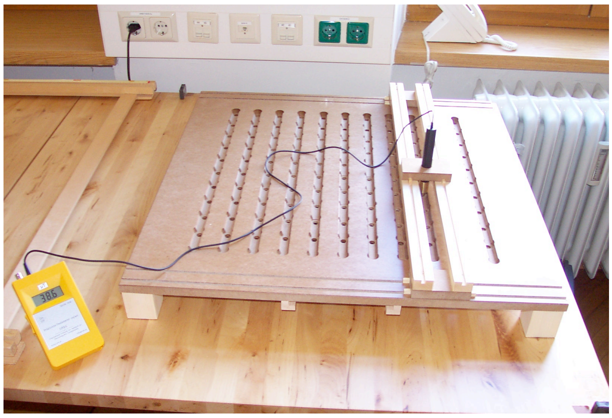


Fig. 5: Measuring rack for FCP laboratory measurements

Fig. 6: Measuring grid for FCP field measurements

But for field measurements, a measurement grid spread out from a tripod yields satisfying results (fig. 6).

The first step of evaluation is the mapping of measured and interpolated values. This is easily performed by a suitable data analysis or mapping tool. We use Surfer 8 from Golden Software, Inc. fig. 7a gives an example of a measured MF with a transmitting cellular phone in its center. fig. 7b represents the difference between the same situation and the original background field without the cellular. The disturbance by the energy of the transmitting cellular phone amounts to +1.5 µT. Note that besides this effect close to the cellular, there are also disturbances from -1 µT to 2 µT within a radius of 30 cm. Because such effects form a coherent pattern that can be attributed to a source of disturbance, we call the method '**field coherence pattern**' (**FCP**).

In fig. 7c, the field gradients of 7a are represented as vectors. The most striking feature to be seen in this map are the “source“ and “sink“ type points close to (0.5, 0.6) and (0.5, 0.4) resp. The vicinity of these points to each other indicates a high divergence of the gradient in the surroundings of the transmitting cellular phone.

The last step of evaluation consists of a computation of the divergence of field gradients. Consequently, we call it '**field gradient divergence**' (**FGD**). The result for the single measuring points is mapped in fig. 7d. If we denote the magnetic induction function that is mapped in 7a with $B(x,y)$, then the values in 7d represent div grad B = $\delta^2B/\delta x^2+\delta^2B/\delta y^2$, which equals the source intensity of *B*. Thus, mathematically the results have the unit of $\mu T/m^2$. This should not be misunderstood as a surface-related result; it merely indicates a second derivative of µT values. For obtaining more convenient figures, the results may be converted to mT/m^2.

Significance of diverging MF gradients

WÜST and WIMMER 1934 used the subjective reaction of a reliable dowser to detect waves which are now revealed as propagation of coherent oscillation modes. They found an arrangement of magnets that obviously shielded the cause of biological reactions. It consisted of two bar magnets along adjacent sides of a rectangle in a constellation with alternating poles along the circumference (fig. 8).

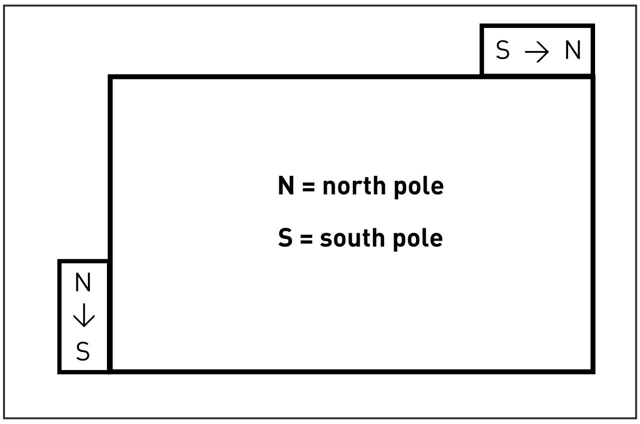


Fig. 8: Arrangement of magnets to generate an MF with constant gradient (WÜST and WIMMER 1934)

Vice versa, when experimenting with the shaping of gradients in MFs, we found that persons present in the vicinity of a field under investigation felt at unease when there were diverging gradients of the vertical magnetic flux density above a metal surface, but felt at ease again when gradients were equalized.

Test situation:	1	2	3
background DC and ELF magnetic induction	43 µT	43 µT	43 µT
MF gradient	12 µT/m	12 / 24 µT/m	12 µT/m
MF gradient divergence	0 mT/m^2	7 mT/m^2	0 mT/m^2
Trends of body parameters:	**1→2**	**2→3**	
Pulse amplitude (BVP*)	+5.4	0.0	
Breathing amplitude**	+1.1	-0.4	
Breathing rate (min^{-1})	-0.6	+4.7	
EMG (µV)	+0.7	+4.7	
Skin temperature (°)	+8.7	+1.3	

**) Blood Volume Pulse (measured by photoplethysmograph)*

***) relative intensity of breathing, range of measured values= 4 to 7*

Table 8: Typical trends of body parameters of a test person (female, age 37) on transition from a homogeneous gradient MF to a MF with divergent gradient and back

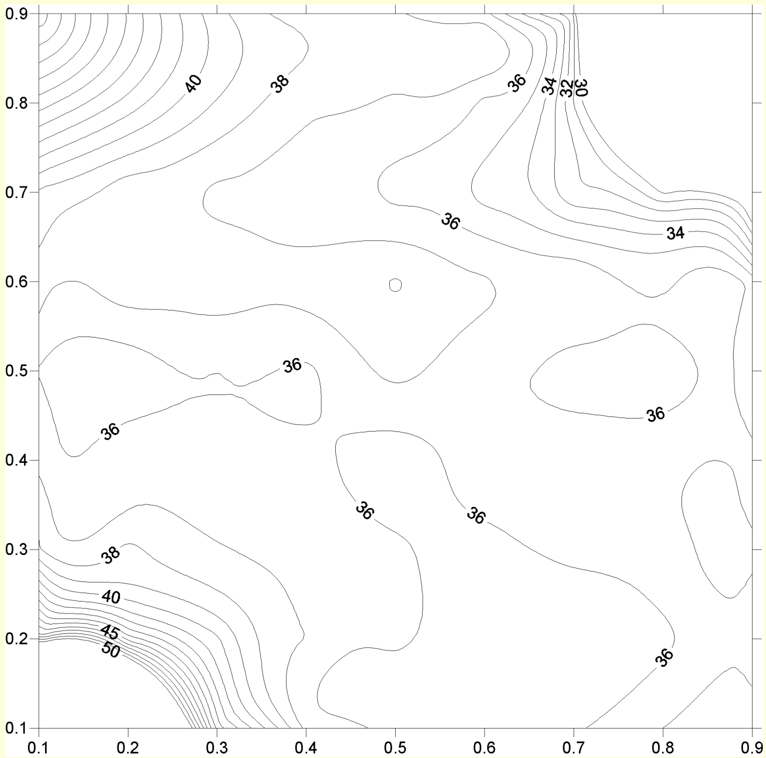
Vertical component of DC and ELF MF measured by Precision Teslameter 05/40, evaluation by Surfer 8 (Golden Software)

We have begun to test the biological reactions to homogeneous and divergent MF gradients. The detailed results will be published in a paper to follow, but a short account of a typical experiment is given here:

Table 7: Evaluation of field coherence pattern (FCP) measurement in a 1 m² test field with a transmitting cellular phone in its center *x* and *y* axes labeled with distances in m.

a.
Vertical component of DC and ELF MF measured by Precision Teslameter 05/40, interpolation by Surfer 8 (Golden Software)

Lines of equal vertical magnetic flux density labeled in μT.



b.
Differential FCP: The subtraction of background magnetic induction previously measured without cellular phone in the field, from the values as mapped under **a** shows the disturbing effect of the cellular on the test field.

Lines of equal difference of vertical magnetic flux density labeled in μT.

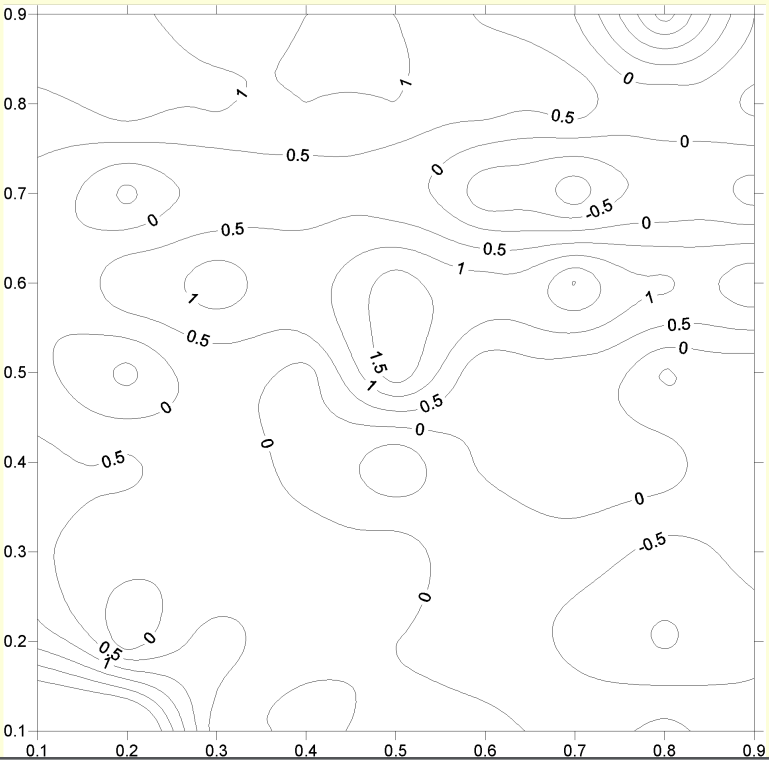
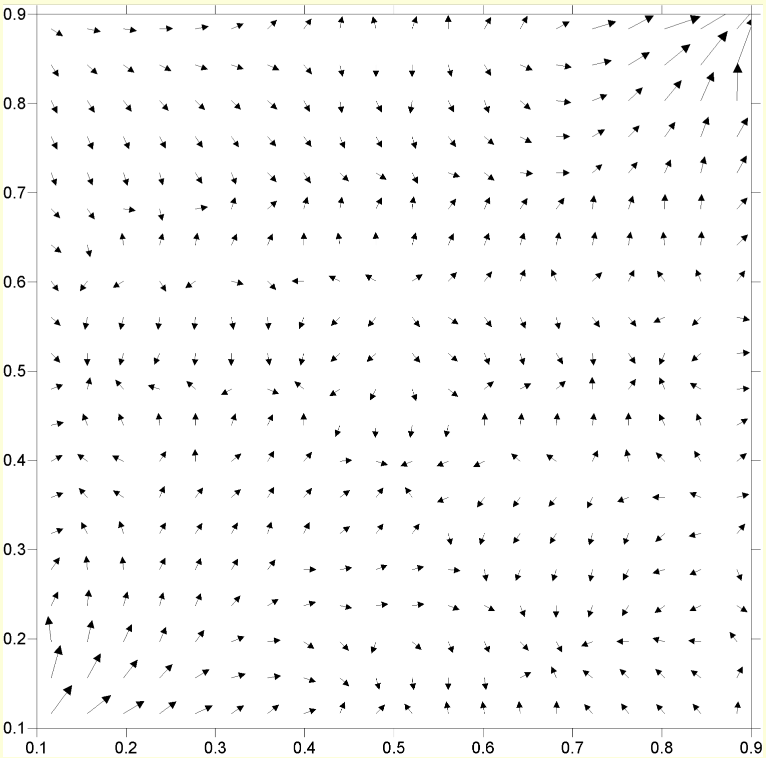


Table 7: Evaluation of field coherence pattern (FCP) measurement in a 1 m^2 test field with a transmitting cellular phone in its center *x* and *y* axes labeled with distances in m.

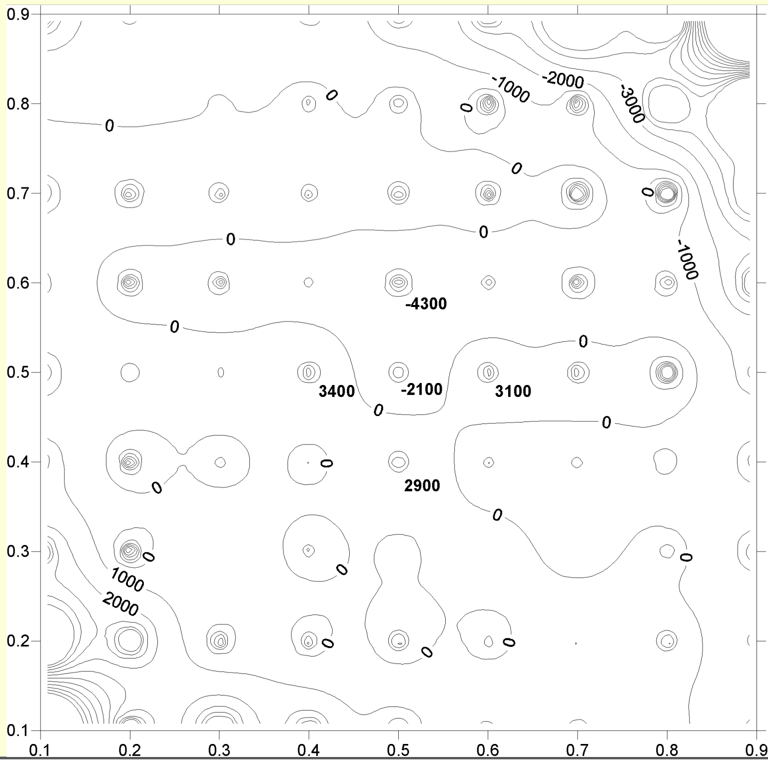
c.
Gradient of vertical magnetic flux density: In this diagram, the gradient of measured magnetic induction values is shown in a vector mapping.

The length of arrows represents the norm of the gradient vector.



d.
Field gradient divergence (FGD): This diagram shows the divergence of field gradients as mapped in **c**, calculated for every measuring point with Surfer 8 (Golden Software).

Lines of equal FGD labeled in µT/m^2.



A test person is taken into a field with a homogeneous gradient of the vertical component of DC and ELF MF (measured by Precision Teslameter 05/40) of about 12 μT/m against a background MF intensity of 43 μT. According to Mersmann, this would mean an imperiling degree of disturbance at a sleeping place. Then, within a certain zone of the test field, the gradient is raised e.g. to the double, the proband being exposed to the transition line from the original lower gradient to the elevated gradient, i.e. to a line of maximum divergence of MF gradient (FGD about 7 mT/m^2). In a third test run, the divergence is removed and the field restored to a homogeneous gradient of the original magnitude.

The perceptions of the test person and his/her body parameters are monitored. Trends are evaluated for the transition from (i) homogeneous to divergent gradient field and (ii) back to a homogeneous gradient. Probands complain of headache and obnubilation if the FGD surpasses 5 mT/m^2. These complains vanish after the third exposition phase. Body parameters show contrarious trends for the transitions (i) and (ii). Results of a typical experiment are given in table 8. Note that the significant trends of body parameters given in the table are no absolute values, but differences, i.e. reactions to the altered divergence of MF gradient. In this experiment, skin conductivity and heart rate which are often discussed as indicators for EM stress, showed no significant result at all. Further research of this kind is going on in our laboratory.

Application to electromagnetic bio-compatibility

The method of FCP measurement and FGD evaluation offers itself as a reliable tool for the analysis of the spatial structure of static and ELF MFs, in order to detect biological stress zones. Divergent gradients can be due to technical impact as well as natural causes. For a practical assessment of biological compatibility, guidelines and recommendations are needed.

From our experiments conducted so far we deduce that against a natural magnetic background of about 40 μT, FGD (the divergence of the vertical MF gradient) values from 5 mT/m^2 upward signal a strong, biologically effective disturbance on which most persons will react with complaints.

FGD values of 10 mT/m^2 and more occur very rarely and must be qualified as a strong or extreme disturbance in MF. Some more factors have to be noted:

(i) The spatial distribution of stress points seems to be indicative of possibly enhanced biological effects, if these points are aggregated along lines or cumulated on surfaces. An adequate assessment scheme has to mind this important factor.

(ii) An evaluation of possible risks to health and well-being has to differentiate between different places of dwelling. Electromagnetic stress in sleepling places seems to be most deleterious, but also working places and other places of dwelling need spezial attention.

(iii) The FGD values as interpolated for measuring points by a data analysis software program depend on the absolute measurement values. An altered magnetic background (e.g. in countries with reduced vertical component of the GMF) needs an adaptation of the assessment scheme.

To provide a comfortable tool to professionals who perform FCP field measurements and FGD evaluation, we have developed a web-based Measurement Analysis Portal (MAP) http://www.map.iirec.com .

It generates a complete measurement report including FCP and FGD charts, and a standardized assessment as well.

CONCLUSIONS AND OUTLOOK

Research data show that biological systems are extremely sensitive to the MF in the DC and ELF range, showing non-thermal reactions of a resonance-like manner. The role of MF has been somewhat neglected in this respect, but was underlined by geobiological research. Our ongoing investigations evidence that the accurate localization and quantification of biological stress caused by MF gradients requires the evaluation of field gradient divergence (FGD).

Due to the parallelism between MW EM radiation and coherent ELF modes in water and biological systems, modern wireless telecommunication technologies have to be minded as causes of MF disturbances in a biologically sensitive range, aggravated by the high degree of coherence in water and living tissue.

The insights and results presented here suggest that striving for electromagnetic biocompatibility, we have to go very different ways in addition to the traditional scheme of pollution reduction.

The biological effects of resonance type give rise to the hope that modifications of technical fields by application of low-intensity fields or even more subtle influences can help to cope with the problem of technical non-compatibility with biological sensitivity. We feel encouraged to research in this direction by the recommendation of a leading biophysicist (HYLAND 2001) to promote strategies which do not interfere with the features of EM fields that are used technically, but provide a higher degree of biological compatibility or even immunity.

Hyland himself took part in the investigation of devices based on the principle of neutralizing the action of weak deleterious EMFs by similar fields, only much weaker ones. (HYLAND *et al.* 1999). In this research task, they also tested a device which is essentially a metal vessel filled with an aqueous solution. When the device is located close to an object under study (chicken embryos, human volunteers), the harmful influence of videomonitors and mobile phones is more or less compensated for (YOUBICIER-SIMO *et al.* 1998). The active principle seems to be the hyperweak magnetic field reemitted in a resonance-like manner by the aqueous solution.

These results by renowned and distinguished researchers encourage us to go on in this direction. Recently we succeeded in the development of technical foils which – by a similar type of resonance – are able to equalize MF gradients and to “iron out“ their divergence. This seems to be a promising approach to coping with non-thermal biological effects on lowest energy levels.

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