Physical basis of adverse and therapeutic effects of low intensity microwave radiation

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A physical basis of adverse and therapeutic effects of low intensity microwave radiation is presented based on the concept of oscillatory similitude between the frequency of an external microwave field (together with any lower frequency modulations thereof) and those of certain endogenous dipolar coherent excitations allied to aliveness, which play the role of ‘tuned circuits’ via which a living organism is electromagnetically sensitised in a non-linear way to external fields too weak to be able to cause heating. From this perspective, an external electromagnetic field affects a living system not as a toxin but rather by perturbing its endogenous electromagnetic activity. The possibility of adverse perturbation is illustrated by reference to the microwave fields used in mobile telecommunications whose signals interfere in a non-thermal way with bio-functionality—in particular, undermining the efficacy of processes that would otherwise afford natural protection against the development of pathology. Therapeutic modalities of microwave exposure, on the other hand, are illustrated using the example of microwave resonance therapy—which can be considered as an electromagnetic version of acupuncture, and as an example of ‘quantum medicine’—whose normalising effect on a wide range of pathologies is striking, and which affords a novel alternative to conventional pharmacological interventions.

Keywords: Coherent excitation, Microwave, Resonance, Telecommunication, Therapeutic effects

Introduction

Absorption of energy from microwave radiation by the water contents of biological tissue results in heating, the degree of which is roughly proportional to the intensity of the radiation: it is this that existing safety guidelines regulate to ensure that homeostasis is not compromised. In exposure to the microwave radiation used in mobile telecommunications, these guidelines are generally not violated, even during use of a handset, whilst in base-stations, as has been repeatedly confirmed by field measurements, the levels of emission in publicly accessible places comply with the guideline limits by many orders of magnitude. What is currently disputed, however, is whether these fields can exert-under both far- and near-field conditions—other, more subtle, kinds of non-thermal influences that might of themselves entail adverse health consequences. The root of the continuing public concern is that if this is, in fact, the case, then the existing safety guidelines afford an inadequate level of protection, in that they leave an exposed person vulnerable to these potential non-thermal hazards.

Current preoccupation with such bio-negative influences has tended, however, to eclipse the beneficial effects of ultra-low intensity microwave radiation (at somewhat higher frequencies than those used in mobile telephony) in normalising a wide range of human pathologies, when applied under clinically controlled conditions at acupuncture points. This modality—known as ‘microwave resonance therapy’—may be considered as the (active) therapeutic counterpart to the (passive) diagnostic possibilities offered by biophoton emission in the visible (optical) region, as pioneered by Fritz Popp.

A necessary prerequisite to understanding how an external microwave field of sub-thermal intensity can exert both positive and negative influences on a living system is the identification of a possible mechanism whereby such a field can couple to the system. It is a commonly held view that there is no such mechanism, and that reported non-thermal effects are nothing more than experimental artefacts, and, as such, to be dismissed. Such an attitude betrays, however, a culpably appalling ignorance not only of the fact that electromagnetic processes are not alien to the alive organism—wherein they play a fundamental, regulatory role in maintaining its orderly functioning and control, in particular, in connection with the transmission of...
essential bio-information—but also that the alive organism itself supports a variety of oscillatory electrochemical processes that play similarly crucial roles, even if, in some cases, their purpose may at present elude us. The thesis of this contribution is that these oscillatory activities, which are intimately allied to bio-functionality, effectively endow the alive organism with the biological counterpart of ‘tuned circuits’, each characterised by a particular natural frequency, via which the organism can discern and, in turn, respond in a non-thermal way to external electromagnetic fields of similar frequencies, just as can a properly tuned radio receiver: i.e. the existence of endogenous oscillatory electrochemical processes in the alive body sensitises it to non-thermal influences of external electromagnetic fields. Thus the interaction of an external electromagnetic field with the alive body should not be considered as though it was a toxin, but rather as a perturbation of the body’s natural electromagnetic activities in vivo.

Quite generally, it may be noted that terrestrial organisms can be anticipated to have a high sensitivity to microwave radiation, particularly that in the millimetre (mm) range. For life on earth has evolved and developed essentially in absence of such radiation, that from the Sun being strongly absorbed in the atmosphere by molecules of water (via their electric dipole moment) and oxygen (via their magnetic dipole moment) before reaching earth’s surface. It would thus make eminent sense for living systems to utilise these frequencies for their own purposes, such as the endogenous control and regulation of essential life processes, since their absence in the natural environment minimises the possibility of any deleterious interference. With the advent of modern electro-technology, however, the natural electromagnetic environment has been changed dramatically, and living organisms no longer enjoy the isolation necessary to ensure the integrity of their own endogenous electromagnetic processes. Clearly, given the brief time over which such exposure has occurred (less than 0.01% of the time that Homo sapiens sapiens have existed), there cannot possibly have been any evolutionary adaptation to it. Comparison of the intensity of the microwave radiation in publicly accessible locations near a mobile telephony base-station illustrates just how dramatically the natural electromagnetic environment has been changed, for the intensity here is typically a factor of $10^{13}$ higher than that originating (over the same frequency bandwidth) from the sun! The situation is exacerbated by the fact that technologically produced electromagnetic fields have a much higher degree of coherence than do those of natural origin, a feature that facilitates their discernment by the alive organism. Further, cells in living biosystems are no longer impervious, as they are to static and low frequency fields, to frequencies above a few MHz; for at these frequencies the cell membrane is capacitively short-circuited, allowing high frequency fields—even when modulated at much lower frequencies—to penetrate and influence intracellular activities. Finally, it should be noted that technologically produced ‘electrosmog’ can interfere with the body’s ability to detect certain natural environmental electromagnetic fields, such as the Schumann resonances\(^1\), interaction with which appears to be essential to homeostasis.

Non-thermal microwave effects

Water is the majority constituent of biological systems, and an impinging microwave field loses energy to it, the amount transferred varying rather slowly with frequency, being largely governed by dielectric loss connected with the influence of the field on the electric dipole of the water molecules; within the realm of linear response, the loss is proportional to the intensity of the radiation. It is this that current ICNIRP safety guidelines\(^1\) to ensure that the additional thermal load – as quantified in terms of the specific absorption rate (SAR) - does not exceed what the body’s thermoregulatory system can cope with, as adjudged essentially by comparison with the magnitude of the body’s basal metabolic rate (BMR) under non-exposed conditions - the so-called ‘basic restriction’ on the SAR (for an exposure of the general public of 6 min) being about 7% of the BMR, after inclusion of a safety factor of 50. The only other way in which the frequency of electromagnetic radiation is taken into account in safety guidelines is

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\(^1\) The Schumann resonances are a set of spectrum peaks in the extremely low frequency (ELF) portion of the electromagnetic field surrounding the earth. They are excited by lightning discharges in the cavity formed by the earth’s surface and the Ionosphere. The lowest (and most prominent) peaks are at 7.8, 14.3, 20.8, 27.3 and 33.8Hz, which, it should be noted, fall in the range of the human EEG activity. At 7.8Hz, the spectral power density is of the order of $10^{14}$W/cm\(^2\)/Hz, which is strong enough to act as a potential Zeitgeber for the human alpha 1 rhythm.
in the context of size-resonance\(^{ii}\), which enters in the conversion of the basic restriction on the SAR (in W/kg) to the so-called ‘reference levels’ on the field intensity (in W/m\(^2\)). Under far-field conditions, the ICNIRP reference levels at the carrier frequencies used in mobile telecommunications are given in Table 1. Non-thermal effects, on the other hand, are often, but not invariably (see below), characterised by a very much sharper (resonant-like) frequency dependence (Q factors as large as 10\(^4\) being quite common), and often exhibit saturation at quite low intensities\(^{5}\). Evidence of the existence of such effects was first published in a report\(^{6}\) of a meeting of the (former) USSR Academy of Science in the early 1970s. The mm microwave spectra reported on at that time, which were obtained from a wide variety of living systems (ranging from yeast to the bone marrow of mice), were found to have the following properties in common: (a) the effects of irradiation were strongly dependent on the frequency of the microwaves, (b) there was an associated power (intensity) threshold below which no effect was observed, and above which the effects of exposure depended only weakly on power over several orders of magnitude, the threshold value being well below (sometimes by 3 orders of magnitude) that necessary to cause any heating, and (c) the occurrence of some effects depended on the duration of irradiation, a certain minimum time of irradiation being necessary for some effects to manifest themselves.

A notable example of a non-thermal influence whose frequency specificity is less apparent is the ability of low intensity microwave radiation to alter protein conformation, resulting in an alteration of its biological function; although this has been linked\(^{7}\) to collective excitation of their intrinsic modes by the radiation, further experimentation is needed to confirm this.

It is possible to rationalize these findings in terms of the concept of ‘coherent excitation’ of longitudinal modes associated with ubiquitous presence in biomatter of electric dipoles of various kinds. These excitations were introduced from quite general considerations by H Fröhlich a few years earlier\(^{8}\) in 1968, and are intimately allied to biological activity. By modelling an active biosystem (in part) as an open, dissipative system comprising a set of identical electric dipoles whose collective modes couple (non-linearly) to the (non-polar) surroundings (treated as a heat-bath in thermal equilibrium), the whole being held far from thermal equilibrium by an influx of (metabolic) energy - he showed that provided the rate of supply of energy supply, \(s\), is sufficient to overcome the inherent (dissipative) tendency towards thermal randomisation (i.e. equilibrium), the lowest frequency collective mode becomes (after a certain time) macroscopically occupied - i.e. its amplitude far exceeds the thermal equilibrium value, thus acquiring a macroscopic significance. In this single mode, which is stabilised through its non-linear coupling to the elastic field of its environment, the individual dipoles vibrate together in phase - i.e. for \(s > s_0\), the system is coherently excited mechanically, behaving as a macroscopic replica of any one of the constituent dipoles, oscillating (collectively) in a highly ordered\(^{iii}\).

### Table 1—Carrier frequencies used in mobile telecommunications

<table>
<thead>
<tr>
<th>System</th>
<th>Carrier frequency (MHz)</th>
<th>Public exposure limit (W/m(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>TETRA</td>
<td>400</td>
<td>2.0</td>
</tr>
<tr>
<td>GSM</td>
<td>900</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>1800</td>
<td>9.0</td>
</tr>
<tr>
<td>DECT</td>
<td>1880-1900</td>
<td>9.0</td>
</tr>
<tr>
<td>UMTS</td>
<td>2100</td>
<td>10.0</td>
</tr>
</tbody>
</table>

\(^{iii}\) That an influx of energy can, after a sufficient interval of time, actually impose a dynamical order (rather than simply increasing the degree of disorder, as might be expected intuitively) is now a rather well-established, quite general feature of non-equilibrium systems, reflecting their ‘self-organising’ ability in the non-linear regime far from equilibrium. It must be stressed, however, that the maintenance of this order is contingent upon the continued inflow of energy at an appropriate rate (\(s > s_0\)); in this way is established a state that in thermal equilibrium would be extremely improbable and highly transient.
way as a single ‘giant’ electric dipole. The frequency of the coherently excited mode depends on the particular dipolar species upon which it is based\textsuperscript{iv}, but is generally predicted to lie in the microwave region\textsuperscript{9}.

Experimental results consistent with the existence of such non-thermal coherent excitations in active biosystems comes from (a) laser Raman studies on metabolically active bacterial cells (such as \textit{E. coli}), which reveal (i) high intensity peaked spectra near \(5 \times 10^{12}\) Hz, which appear only at certain stages of the cell cycle and which are allied to metabolic activity\textsuperscript{10}, (ii) an anti-stokes/stokes intensity ratio close to unity (as opposed to the thermal value of 0.5 at physiological temperatures)\textsuperscript{11}, consistent with a strongly supra-thermally excited mode in the \textit{E. coli} system investigated, (b) the detection of coherent nuclear motion in membrane proteins\textsuperscript{v} at frequencies in the \textit{sub}-millimetre band (typically THz)\textsuperscript{12}.

Much other evidence consistent with the existence of a non-thermal influence of microwave radiation of specific frequencies on a variety of living systems has accumulated since the original Russian work was published, and includes:

(i) Resonant effects on cell division in the yeast \textit{S. cerevisiae}\textsuperscript{13} near 41GHz (modulated at 8kHz), and on the genome conformation of \textit{E. coli}\textsuperscript{14} near 51.75 GHz, the latter being found to be dependent on the polarisation of the microwaves.

(ii) Synchronisation of cell division in \textit{S. carlsbergensis}\textsuperscript{15} at 42.19GHz (at 0.12 mW/cm\textsuperscript{2}), and in \textit{E. coli}\textsuperscript{16} at 41.32GHz (at 0.1 mW/cm\textsuperscript{2}), both of which are again polarisation dependent.

(iii) ‘Switch-on’ of certain epigenetic processes, such as \textit{\textlambda-}phage\textsuperscript{17} in \textit{E.coli} at 0.1 mW/cm\textsuperscript{2} near 70.5GHz, and colicin synthesis\textsuperscript{18}, where the intensity threshold lies between 0.001 mW/cm\textsuperscript{2} and 0.01 mW/cm\textsuperscript{2}.

(iv) The efficacy of microwave resonance therapy—(see later part of the review).

Let us now consider how some of these non-thermal effects can be understood\textsuperscript{5} in terms of Fröhlich’s coherent excitations.

(a) The resonant effect on the growth rate of yeast under microwave irradiation becomes understandable if associated with the yeast cell cycle (in some as yet unknown way) is an underlying coherent excitation, the frequency of which matches that of the radiation. For the structure of the observed resonance spectrum is identical to the response of the amplitude of a limit cycling oscillator to an external stimulus varying harmonically with time\textsuperscript{13}. Further, the width of the resonance progressively decreases as the irradiating power density is reduced from mW/cm\textsuperscript{2} to pW/cm\textsuperscript{2}; the same is found\textsuperscript{14} in \textit{E. coli} upon reducing the power density from 0.1 mW/cm\textsuperscript{2} to \(10^{-17}\) W/cm\textsuperscript{2}.

(b) The ability of ultra-weak microwave radiation to switch-on (trigger) a particular epigenetic effect becomes understandable if associated with the effect is a coherent excitation for which the endogenous rate of metabolic energy supply, \(s_e\), is sub-critical (\(s_e < s_0\)); for then the radiation has to supply only the deficit power \((s_0 - s_e)\) which might be arbitrarily small - to achieve ‘switch-on’\textsuperscript{9}. Considerations\textsuperscript{9} based on a Hamiltonian formulation of Fröhlich’s original rate equation-based model suggest that the time of irradiation, \(\Delta t\), necessary to establish the coherent excitation will be minimum when the frequency of the radiation matches that of the coherent excitation; for it can then couple to it directly. Irradiation at other frequencies can also supply the deficit, provided the frequency falls within the band of collective dipolar modes, although \(\Delta t\) will be longer the greater is the difference between the external frequency and that of the lowest mode.

(c) The therapeutic effects of ultra-weak microwave irradiation at specific frequencies: See later part of the review.

The value of Fröhlich’s concept of coherent excitations is that it offers a novel insight into other, more familiar and better established electrobiorhythms of the alive human body, characterised by very much lower frequencies - such as heartbeat (as recorded by the ECG), and brainwave activity (as recorded by the EEG) – namely, that they are themselves in the nature of coherent excitations that

\textsuperscript{iv} Fröhlich’s original coherent excitation was based on the (anti-phase) vibrations of the inner and outer surfaces of the cellular dipolar membrane against one another, associated with which\textsuperscript{19} is a frequency of the order of \(10^{11}\) Hz.

\textsuperscript{v} The high electric field (~ \(10^5\) V/cm) that is maintained across the membranes of the cells of an active biosystem polarises the proteins, endowing them with an electric dipole moment.
are underpinned by a non-linear dynamics. A model for understanding the EEG was presented by Fröhlich in 1977, and has attracted a considerable amount of theoretical interest on account of the possibilities it offers for understanding not only the sensitivity of the brain to ultra-weak electromagnetic influences at certain ELF frequencies—both ELF electric fields per se, as well as ELF-modulated microwave fields—but also certain aspects of endogenous brain function.

One particular influence is that an external field imposes its coherent frequency on a particular biorhythm, entraining it to an unnaturally high degree of regularity that can be harmful. In this connection it should be noted that although bio-electrical rhythms are regular to a certain extent, they are not perfectly so, a certain degree of subtle irregularity—the amount of which can only be ascertained by sophisticated time-series analysis of their waveforms—being actually necessary for their protection and integrity under changing physiological conditions. This ‘flexibility’ is related to deterministic chaos, which is a consequence of the highly non-linear nature of the biological processes that underlie the rhythms; indeed, it is precisely their non-linear character that makes the bio-rhythms vulnerable to entrainment. Two other ways in which exposure to a microwave field of sub-thermal intensity can interfere with endogenous bio-electrical activity are (i) by resonant enhancement to a biologically undesirably high level, (ii) by interference, resulting in its degradation.

At the level of the entire body, the viability of this mechanism of ‘oscillatory similitude’, which is essentially informational in nature (in the sense that the biosystem is able to ‘recognise’ and respond to an external electromagnetic signal by virtue of the fact that the frequency is already ‘familiar’ to it), is clearly contingent on the system being alive, since then, and only then, are the biological tuned circuits activated: the dead have no ECG or EEG with which an external electromagnetic field can interfere. It is in this fundamental aspect that non-thermal effects on this level of organisation differ from dielectric heating, which depends on absorption of energy (as opposed to information) from a microwave field, and occurs irrespective of aliveness.

At a molecular level, on the other hand, a phenomenon such as microwave induced changes in protein conformation (where the frequency specificity of the effect remains to be established) may well be primarily energetic - but at the level of the microwave quanta whose energy, although insufficient to cause ionisation, is, nevertheless, sufficient to alter certain conformational features and, in turn, chemical reactivity, but without entailing any associated temperature rise—i.e. the phenomenon can still be classed as non-thermal.

In general, non-thermal effects are qualitatively distinguishable from thermal effects in a number of ways: (i) they cannot be replicated by conventional heating, (ii) are often ‘contra-thermal’ – i.e. the effects are opposite to those produced by conventional heating, as illustrated, for example, by de Pomerai et al. that microwave irradiation of nematode worms increases fertility, whilst heating decreases it - and, as such, are likely to be obliterated at microwave intensities high enough to produce heating; consistent with this is the seemingly paradoxical finding that non-thermal effects generally become more pronounced the lower the intensity.

Finally, it should be noted that difficulties sometimes experienced in attempts to independently replicate certain frequency-specific non-thermal effects are actually to be expected, since the specification of the state of a living system requires information on many parameters, such as the naturally prevailing level of metabolism (in relation the power density of the irradiating field and the duration of the exposure), the polarisation of the incident radiation, the stage of development at the time of irradiation, and the nature of essential nutrients. Accordingly, there are

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vi In this model, the frequencies of the EEG are identified with those of limit cycles associated with self-sustaining enzymatic electro-chemical oscillations between an essentially non-polar ground-state and an excited state characterised by a large electric dipole moment into which the enzyme gets lifted by the energy liberated by its chemical reaction with substrate molecules, the supply of which is assumed to be maintained by a long-range attraction based on coherent excitations.

vii It may be recalled in this connection that, under non-exposed conditions, certain kinds of heart attack are preceded by the onset of an extremely regular heartbeat.

viii An example of a harmful induced regularity is the ability of a regularly flashing light to entrain brain rhythms, thereby provoking seizures in people who suffer from photे-epilepsy; here, the regular flashing of the light turns it into a coherent signal that is ‘recognised’ by the brain because of the proximity of the flash frequency (~ 15Hz) to that of the endogenous electrical activity involved in epilepsy - i.e. the light exerts an ‘informational’ influence.
multidimensional ‘windows’ only within which a particular effect will be observed; thus, having the ‘correct’ frequency alone is not necessarily sufficient to ensure the observation of some effect. In addition, particular care needs to be taken to ensure that biological activity is not interfered with by the experimental interventions. Further, subtle differences in experimental protocols, which are not always apparent upon superficial perusal, can undermine the fidelity of the intended replication – i.e. the reason that a particular result is not corroborated can simply be because the purported replication was actually a different experiment. At a more fundamental level, however, in consequence of the highly non-linear, non-equilibrium nature of living systems, even the slightest differences in their physiological state and the conditions obtaining in a particular experiment, can, through deterministic chaos, assume singular importance.

An example of potential bio-negative influences–Mobile telephony

GSM/UMTS/TETRA/DECT signals are bioactive

Relevant to the consideration of possible non-thermal effects of exposure to the microwave radiation used in mobile telecommunications is the oscillatory similitude between the frequencies found in its signals and those that characterise certain bio-electrical activities of the alive body: (Table 2), whilst an explanation of the abbreviations used, together with some explanatory notes on the structure of the various signals, can be found in the Appendix

In connection with the sensitivity of the alive human organism to microwaves of sub-thermal intensity, it may be noted that the threshold for a GSM signal to be discernible against the level of the thermal noise emitted (over the GSM bandwidth) by the body at physiological temperature is typically of the order of $10^{-15}$ W/cm$^2$ – a value that is close to the intensity thresholds of hearing, sight and EEG response. Thus, the ability of the alive human organism to discern, for example, the microwave emissions from base-station (which is, in any case, many orders of magnitude more intense than this threshold value, even at a distance of several hundred metres), is not at all contingent on a sensitivity that is in any way superior to those that it already possesses (quite undisputedly) in the case of other exogenous fields of physiological relevance. It must, of course, be appreciated that whilst such discernibility is clearly necessary, it is not necessarily sufficient for the occurrence of non-thermal effects, which might well (from experience with cellular systems) require somewhat higher (but still sub-thermal) intensity thresholds.

Experimental evidence (from experiments involving exposure to the emissions of Handsets$^{ix}$) that the

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Mobile telephony</th>
<th>Biological activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.98Hz</td>
<td>TETRA Multiframe</td>
<td>Heart beat</td>
</tr>
<tr>
<td>2Hz</td>
<td>GSM DTX Mode</td>
<td>Delta EEG</td>
</tr>
<tr>
<td>4.25Hz</td>
<td>GSM BCCH Multiframe</td>
<td>Delta EEG</td>
</tr>
<tr>
<td>8.34Hz</td>
<td>GSM TCH Multiframe</td>
<td>Alpha 1 EEG$^{24,25}$</td>
</tr>
<tr>
<td>17.64Hz</td>
<td>TETRA Frame repetition</td>
<td>Alterations in Ca efflux$^{36,37}$, Increase in ODC$^{37,57}$, Opposing effects on inhibitory-excitatory brain chemicals$^{39}$, Photoepilepsy frequency, Beta EEG, REM sleep$^{27}$, Electromyography (EMG)</td>
</tr>
<tr>
<td>70.4Hz</td>
<td>TETRA Burst repetition</td>
<td></td>
</tr>
<tr>
<td>100Hz</td>
<td>DECT Frame repetition UMTS Control signals</td>
<td></td>
</tr>
<tr>
<td>217Hz</td>
<td>GSM Frame repetition</td>
<td>Hippocampal$^*$ coherent oscilla$^{81}$</td>
</tr>
<tr>
<td>1.5kHz</td>
<td>UMTS Control signals</td>
<td>Coherent cell wall oscillations$^{12}$</td>
</tr>
<tr>
<td>1.74kHz</td>
<td>GSM Burst repetition</td>
<td>Proton NMR$^{**}$ in Earth’s B-field$^{82}$</td>
</tr>
<tr>
<td>15kHz</td>
<td>3G Control signals</td>
<td>Electrical brain activity$^{13}$</td>
</tr>
<tr>
<td>400MHz</td>
<td>TETRA Carrier</td>
<td>??</td>
</tr>
<tr>
<td>900/1800MHz GSM Carrier</td>
<td>Endogenous coherent microwave oscillations$^{90}$</td>
<td></td>
</tr>
<tr>
<td>2.1GHz</td>
<td>UMTS Carrier</td>
<td></td>
</tr>
</tbody>
</table>

The hippocampus is involved in learning, memory, the storage and processing spatial information, and in epilepsy.

$^{**}$This is the resonance frequency at which an external electromagnetic field matches that at which the quantum mechanical spin of a proton precesses in the Earth’s (static) magnetic field. Protons are the majority component of water (which is itself the dominant component of living systems), and irradiation of living systems by low intensity microwaves modulated at this nuclear magnetic resonance (NMR) frequency has been found$^{82}$ to influence and potentiate certain bioprocesses, such as causing a doubling in the rate of cell division, and an associated reduction in the size of the daughter cells. A possible mechanism for such effects could be ‘spin-orbit’ coupling, via which the resonating spins affect the quantum mechanical orbitals upon which bonding, and in turn enzymatic activity, for example, depends.

$^{ix}$ Since the information content of a signal is independent of its intensity, the results are relevant to the much less intense exposure from Base-stations.
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human EEG is sensitive to the low frequency 8.34Hz structure of the GSM signal includes:

(i) A delayed increase24 in spectral power density particularly in the alpha band (8-12Hz), which has been corroborated25 in the EEG of awake adults, and which is consistent with its resonant enhancement by the 8.34Hz pulsing.

(ii) A delay in the onset of sleep as determined26 by the EEG, and differences in the effect on the awake and asleep EEG, consistent with the lower frequencies characterising the latter, particularly the delta waves (0.5-3Hz) of deep sleep.

(iii) Shortening of rapid eye movement (REM) sleep27 (with possible adverse effects on learning and certain other essential bio-restorative processes) during which the power density in the alpha band again increases.

(iv) Effects on non-REM sleep28.

(v) Significant decreases in the preparatory slow potentials in certain regions of the brain25,30, and influences on memory tasks31-33.

Other effects in which frequency specificity has been less thoroughly investigated include (a) the over-expression of heatx shock proteins34, (b) the under-expression of melatonin from the pineal gland35, (c) effects on a wide variety of other brain functions, such alterations in its delicately balanced electrochemistry36-39, an increased permeability of the blood/brain barrier40, and its degrading effect on the efficiency of the immune system41,42, xi.

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From non-thermal effects to adverse health effects

Whilst the effects of exposure to mobile telephony signals do not necessarily entail adverse health consequences, there is an undeniable consistency4 between some of these non-thermal influences and the nature of many of the health problems experienced by some people exposed to various kinds of signals from base-stations, as reported both anecdotally and via epidemiological studies43 - such as headache, sleep disruptionxii, and nose bleeds, whilst specific to chronic exposure to UMTS Base-station signals are: nausea, dizziness, confusion, impaired concentration and short term memory, and the sensation of pressure in the headxiii. More serious in the case of exposure to GSM Base-stations are increases in the frequency of seizures in children with epilepsy44, together with an elevated incidence of cancer which correlates with proximity and duration of such exposure45. In the case of exposure to handsets, on the other hand, statistically significant increases in the incidence of various kinds of brain tumour46,47 have been found, whilst a very recent study, done in Israel during 2007, suggests an association between mobile phone use and benign tumours of the parotid gland48.

Some examples of the consistency mentioned above are the following:

(a) Headache is consistent with the fact that microwaves are known to non-thermally affect the dopamine–opiate system of the brain38 and to increase the permeability of the blood-brain barrier40, both of which have been medically connected to headache49.

(b) Sleep disruption is consistent with the effect that GSM radiation has on REM sleep27 and on melatonin levels35 -the latter being found also epidemiologically in the case of exposure to radiofrequency fields50.

(c) Increased incidence of seizures is consistent with the finding that exposure to this kind of radiation induces epileptic activity in rat brain51, and with the established ability of a flashing visible light to provoke seizure in people who suffer from photoepilepsy (recall Footnote viii); for unlike visible light, microwave radiation is not reliant on ocular transmission, but can access the epileptic centre of the brain directly through the skull.

(d) Increased incidences of cancer are consistent with the findings that exposure to low intensity microwave radiation results in:

(i) an increased number52,53 of DNA strand breaks.

x The use of this terminology in a non-thermal context is in accordance with convention, and should not be taken as implying that the stress is here thermally provoked.

xi In exposure to a base-station, a much reduced neutrophil count has been found, which reverses in the absence of exposure. (A neutrophil is a kind of white blood cell, important to the immune system, which engulfs bacteria.) – E O’Connor, Sutton Coldfield, UK-personal communication of medical records, 2002.


xiii Many of these symptoms were found under controlled, laboratory conditions in the course of the Dutch TNO Study: TNO Report FEL-03-C148, (2003) - Effects of global communication system radio-frequency fields on well-being and cognitive functions of human subjects with and without subjective complaints.
(ii) the detection of chromosome aberrations and micronuclei in human blood,

(iii) changes in lymphocyte chromatin conformation, indicative of a stress response,

(iv) a promotional effect on the development of cancer, as evidenced by experiments on transgenic mice that have been genetically engineered to have a predisposition to develop cancer, and by the increased levels of the promoter orthinine decarboxylase (ODC) found under irradiation.

The above, and certain other considerations strongly suggest that many of the potential adverse health impacts of exposure to non-thermal influences of the microwave radiation used in mobile telephony arise not because the radiation causes any material damage (microwave radiation is non-ionising, and so cannot break molecular bonds to produce harmful free radicals), but because it deleteriously interferes with endogenous bioprocesses that would otherwise afford natural protection against the development of pathology. For example, (a) the decrease in the level of melatonin under exposure reduces its oncostatic efficacy, (b) the increase in the permeability of the blood-brain barrier under exposure deprives the brain of the protection against blood toxins that it would otherwise enjoy, (c) the over-expression of heat shock proteins (caused by subtle conformational influences of the microwaves on protein structure) has been hypothesised to undermine (i) the efficacy of apoptosis, whereby pre-cancerous cells, for example, kill themselves off, (ii) the ability of the body to be able to repair naturally occurring DNA breakage, which would account for the observed increase in breakage and its accumulation to a dangerous level.

The continued neglect of frequency (other than in connection with size-resonance) in the context of oscillatory similitude-as is currently done by Regulatory Bodies, such as ICNIRP - is equivalent to accepting that, when alive, our electromagnetic sensitivity is no different from that of a piece of dead meat. The ludicrousness of this position is well illustrated by the familiar prohibition on the use of mobile phones on aircraft and in hospital; for this is not because of any thermal concerns, but rather because of the possibility that their signals might - via their various frequencies-adversely electromagnetically interfere in a non-thermal way with the functioning of essential avionic and medical electronic control systems. To admit this possibility and yet deny the same for the alive human reveals an inexcusable ignorance of the inherently electromagnetic nature of the alive organism, which renders it an instrument of great and exquisite electromagnetic sensitivity that is susceptible to deleterious electromagnetic interference just as is a piece of activated electronic instrumentation.

Why everyone is not adversely affected

Because the occurrence of the initial provoking non-thermal effect, as well as the severity of any associated adverse health effect both depend on aliveness, they necessarily depend not only on the irradiating field, but also on the subject’s physiological state at the time of exposure. Since this cannot be anticipated to be the same for different people – depending as it does on a number of factors, such as the genetic predisposition of the exposed subject, the stability of their brain rhythms against interference or entrainment by the radiation, their already prevailing level of stress, and their immune robustness – it follows that (externally) identical exposure to exactly the same radiation can entail quite different (non-thermal) responses in different people (or even in the same person, depending on his/her condition at the time of exposure) (in contrast, incidentally, to the case of active electronic instruments). This is, of course, consistent both with the fact that even in an epidemic not everyone succumbs, and with the difficulties encountered in some laboratory attempts to replicate non-thermal effects in vivo. For stress is cumulative, it is quite possible that exposure to an electromagnetic field simply supplies the final contribution, which in the

xiv A 70% reduction in the level of melatonin (as measured in blood), which reverses in the absence of exposure, has been found in the case of human exposure to UMTS Base-station signals [H-C Scheiner, Munich – personal communication, 2005].
case of one particular individual, but not another, raises the stress level above the critical value necessary to trigger the manifestation of some pathology that is already in a well-advanced state, but which, in the absence of any exposure, would, for the time being, have remained latent.

Accordingly, the oft-repeated statement: ‘There are no established adverse health effects of exposure to GSM radiation (of sub-thermal intensity)’....... is actually quite true. In view of the above considerations, however, this is necessarily so, thus making the statement essentially vacuous. More meaningful, is to ask whether there is an established risk to human health. It must be concluded that such a risk does indeed exist, but that the actual number and identity of those at risk are necessarily unknown, a priori, although young children and highly stressed people - particularly those with already compromised immune systems (as well as those on certain prescribed psychoactive drugs) - must be considered more vulnerable.

Bio-positive influences of microwave radiation

Various treatment modalities employing microwaves of both thermal and sub-thermal intensity. To the former belong the following: microwave diathermy, transurethral microwave thermotherapy for the treatment of benign prostatic hypertrophy, microwave balloon angioplasty, microwave enhanced liposuction, and the creation of tissue anastomosis. All these modalities exploit the dielectric heating arising from absorption of energy from a microwave field (familiar in the context of microwave ovens), the temperature rise produced being governed by the intensity of the incident radiation and by certain dielectric/thermal properties of the bio-matter under irradiation (which, incidentally, could well depend on aliveness). It is to be stressed that whilst such heating is not contingent of the aliveness, aliveness does influence the magnitude of the temperature rise realised, through the mitigating influence of the body's thermoregulatory mechanism that is then activated; accordingly, the magnitude of the temperature rise realised is somewhat lower than it would be in the case of a cadaver exposed to the same field. Since the underlying physics is here well-understood, thermal effects will not be considered further, and attention will, instead, be directed towards more novel therapeutic modalities based on the more subtle and more contentious non-thermal effects of microwave irradiation – some bio-negative effects of which have just been considered. An obvious attraction of exploiting non-thermal effects therapeutically is that they are free from the hazards that currently plague some of the thermally-based therapies, such as that designed to shrink enlarged prostates.

Examples of bio-positive effects of microwave irradiation at sub-thermal intensities include (i) its mitigating effect of the severity of damage caused by X-rays, (ii) its acceleration of the regeneration of nerve fibres after surgical transection, and (iii) its ability to exert a corrective and immunomodulating influence in a wide range of human pathologies, when applied for a sufficient time at biologically active zones, such as acupuncture points. Being a variant of so-called ‘alternative medicine’, and one that is consonant with the idea of oscillatory similitude being promoted here, attention will be focused primarily on (iii). Because of the highly resonant nature of the diseased system's response, this modality is called ‘microwave resonance therapy’, and because its efficacy increases as the intensity of the radiation is reduced towards the (quantum) limit (where the interaction of individual microwave quanta with the diseased system is involved), it has been described as an example of ‘quantum medicine’.

Microwave resonance therapy

The first proposal of a microwave resonance therapy (although not referred to as such) was made by H. Fröhlich in 1978, in connection with restoring the control of cell division that is defective in the case of cancer, a situation that he attributed to a degradation in the coherence of an associated electromagnetic excitation of the whole affected organ, via which control would otherwise be implemented. He conjectured that it might be possible to re-establish coherence (and with it the control of cell division) by exposure to an external electromagnetic field having the same frequency as the degraded excitation - an idea, incidentally, that was adumbrated by Lakhovsky some years earlier.

Two years later in 1982, Sit'ko and co-workers in Kiev made the experimental discovery that ultra-low intensity microwave radiation of specific frequencies applied at certain acupuncture points has

\[xvi\] There is an evident parallel here with the ability of an external magnetic field to re-magnetise a de-magnetised magnet by re-imposing the necessary order on the quantum mechanical spins.
a quite remarkable efficacy in restoring homeostasis in a wide variety of pathological conditions, including traumatology, cardiovascular disorders, urology, gynaecology, gastroenterology, neurology and oncology; its deployment is contra-indicated in only a relatively few circumstances, such as during pregnancy and the menstrual cycle. To date, in Ukraine and Russia, well over half a million people have been rather successfully treated by this modality, which, because of the highly resonant nature in which a diseased body responds to the applied microwave field, is now known as microwave resonance therapy, the resonant frequencies being called body eigenfrequencies.

The modality involves applying microwave irradiation (either coherent or broadband) at the maximally distal acupuncture point of the meridian associated with the particular pathology being treated. When a coherent source is used, the frequency is varied between 52 and 70GHz until resonance is obtained, the realisation of which can be ascertained at a number of levels, ranging from local sensations at the point of application, to general sensations at the level of the whole body. Alternatively, a broadband (52–78GHz) source can be used, which not only expedites determination of the resonant frequency, but also permits resonance to be maintained, should it change during the course of the treatment. The applied power density usually ranges between 0.2 – 5μW/cm², but can be both higher (in the case of advanced pathology) and lower. The recommended duration of irradiation is 10 min at each acupuncture point, with a maximum of 20 min treatment per day. A course consists of 10 treatments, which may be repeated, if necessary, after an interval of at least 21 days, but one month is preferable.

The high efficacy of microwave resonance therapy is illustrated by the realisation of a significant improvement in about 80% cases, moderate improvement in 15%, and insignificant changes in only 5%.

The following characteristics of microwave resonance therapy should be noted:

(a) The sharp resonant nature of the response in the presence of pathology, which disappears once homeostasis has been re-established.
(b) The subthermal energy of the microwave quanta (hν << kT).
(c) The ability of the applied millimetre radiation to influence a diseased organ that can be one metre distant from the acupuncture point at which the radiation is applied.
(d) The very low intensities used, which can be as low as 10⁻²⁰W/cm² - a value that is close to the limit of validity of a quasi-classical treatment of a 50GHz microwave field.

In connection with some of these features, the following comments are in order:

(A) The occurrence of a sharp resonant response at the level of the whole organ/body extends to this much higher level of organisation the resonant responses already known at cellular and sub-cellular levels since at least 1973.
(B) Despite hν << kT, the magnitude of the applied microwave power density in coherent sources exceeds, by at least one order of magnitude, the intensity of the (incoherent) thermal emission (integrated over the bandwidth of the microwave signal) at physiological temperature.
(C) In connection with the deep penetration of the radiation, is to be noted that the acupuncture points are exposed to the near-field of the applicator antenna, the morphology of which is quite different to that of the far-field. In particular, in the near-field, the electric and magnetic fields are effectively decoupled, so that the magnetic field is here no longer subject to the attenuation suffered by the electric field (as happens in the far-field where the two fields are strongly coupled together). Depending on the particular design of the antenna, however, it is quite possible that the acupuncture points are exposed to the longitudinal electric near-field that is emitted along the axis of a dipole antenna - which although of longer range than that emitted transversely to it and more penetrative than is the plane wave that characterises the far-field - still cannot account for the highly non-local effects observed (discussed later in the review).
(D) In some cases, the efficacy is found to increase as the intensity of the irradiating field is decreased. This is dramatically demonstrated by the increase in therapeutic efficacy-as reflected in the observed decrease of the recurrence rate of polyps after polycetomy from 72 to 94%, and in an associated improvement in immune status--that is achieved by reducing the irradiating power density from 1mW/cm² to 10⁻¹⁴W/cm². Experience with
the mono-cellular systems referred to in earlier, suggests that this is connected with the fact that resonance is sharpest at the lowest intensity, consistent with an underlying non-linear electrodynamics.

Other points that should be noted are:

1. The fact that the radiation has an effect only in the case of pathology suggests that its role is to switch back on some process, which, once on, cannot be switched on any further.

2. The necessity to irradiate with a certain intensity for a finite interval of time is a feature in common with that found in vitro in connection with the switch-on of certain processes in the mono-cellular systems referred to earlier in this review.

Microwave resonance therapy from the perspective of oscillatory similitude

It is currently believed that the efficacy of this therapy derives from the existence in the alive body of an endogenous microwave field connected with the malfunctioning organ in question, which extends into the associated meridian, via which it is ducted to a surface acupuncture point where it can be externally accessed and modulated by the applied microwave field. Accordingly, whatever the penetration of the external millimetre microwaves, their influence is transmitted to the distant malfunctioning organ by this meridian microwave field, the meridian acting as an endogenous microwave field connected with the associated organ and restoring homeostasis. Since, however, the endogenous deficit is a variable quantity, depending, for example, of the how far a particular pathology is advanced, some irradiating power densities will be more efficacious than others; in addition, there will be a corresponding variation in the duration of irradiation necessary to re-establish the coherent excitation, depending on how far the field necessary to ensure adequate control of organ functionality, it is possible that the role of the irradiating field is to make up - after a sufficient time of exposure - the deficit in the endogenous rate of energy supply, thereby re-establishing coherence – i.e. the external microwave field switches the coherent meridian excitation back on, thereby normalising the functioning of the associated organ.

Another possibility is that the external field entrains the endogenous field back to the biologically 'correct' frequency, should it have become 'de-tuned' for some reason.

However, one factor militating against the efficacy of microwave resonance therapy should be noted. If the endogenous rate of energy supply to some coherent excitation essential to homeostasis is so low (perhaps because the pathology is too far advanced) that the intensity needed to make up the deficit actually approaches thermal levels, then although the excitation could still be switched back on, its influence would be effectively nullified should the effect of heating be in the ‘opposite direction’, as it is often found to be the case at the cellular level.

Other microwave modalities employing ELF modulation

Another kind of non-thermal therapy (but not involving acupuncture points) utilises mm
microwaves that are pulsed at frequencies lying in the range of human brainwave activity. Here, it is found\textsuperscript{78} that patients suffering from neurosis characterised by agitation can be calmed by 10 min exposure to 2mm radiation at 10$\mu$W/cm\textsuperscript{2}, modulated at 2Hz (which is in the range of delta brainwaves), whilst depressive neurosis can be relieved by using the same carrier frequency, but modulated at 20-21Hz (which is in the range of beta brainwaves). In the case of healthy people, on the other hand, the modulation at 2Hz causes depression, whilst that at 20-21Hz causes agitation – i.e. in both cases, 2Hz has a sedational effect, whilst the effect of exposure to the 20-21Hz modulation is opposite in the two cases. In this connection, mention might be made of reports in the Russian literature\textsuperscript{74} indicating the possibility of artificially manipulating the psychophysical condition of people by exposure to weak, ELF-modulated microwaves. Such psychoactive modalities, which have been known for some considerable time, have, however, a dark side, which has not escaped attention and exploitation in some quarters.

**Concluding remarks**

This contribution has attempted to explore the possibility of a unified understanding of both positive and negative effects of human exposure to ultra-weak electromagnetic radiation in the microwave band in terms of the concept of oscillatory similitude. Basic to this concept is the existence of endogenous non-linear, coherent electrical excitations that the organism supports when alive, via which the coherent radiation of technological origin can interact with it in an ‘informational’, non-thermal way.

The bio-negative potentiality of exposure low intensity microwave radiation has been illustrated by reference to that used in mobile telephony, which, within the paradigm of oscillatory similitude, derives from the fact that the some of the low frequency modulations that characterise the signals happen to be close to certain bio-active frequencies. This frequency/informational dimension is unaddressed by existing safety guidelines, which protect only against overheating; whilst obviously necessary, this is not sufficient, and, accordingly, the public is left vulnerable to any adverse health effects that might be provoked by associated non-thermal influences. There is ample evidence that such adverse effects do actually exist, from experience gained not only since the advent of mobile telephony, but also from that which has been available for a much longer time, in connection with exposure to other kinds of electromagnetic technologies—such as radar, for example—that employ RF radiation with characteristics similar to the microwave radiation now utilised in mobile telecommunications.

The bio-positive (therapeutic) potential of microwave radiation, on the other hand, has been illustrated by reference to novel therapies that have been developed in Russia and the Ukraine during the past 20 years or so. Of particular interest is microwave resonance therapy, with its integration of modern microwave technology with ancient Chinese medicine whose acupuncture points provide highly efficient (lossless) channels \textit{via} which a malfunctioning organ can be accessed electromagnetically, irrespective of its distance from the body surface. Undoubtedly responsible for this innovation is the very much greater appreciation in these countries, than is the case (with a few notable exceptions) in the West, of the inherently electromagnetic nature of the alive organism, and of the related fundamental role that information transfer between the external field and the alive organism plays in determining the organism’s response. This goes far beyond the current Western mindset, which remains fixated with purely thermal effects, quantified (not necessarily reliably) in terms of the SAR, which derive simply from the absorption of energy from an applied microwave field – a phenomenon that occurs irrespective of whether the subject is alive or dead. By contrast, the more subtle, non-thermal effects of informational origin are absolutely contingent on aliveness; for only then are activated the non-linear bio-oscillators, upon which the possibility of detection and non-thermal, frequency-specific response depends.

The possibility of novel electromagnetic therapies related to this enhanced level of non-linear understanding is an exciting and potentially far-reaching development that offers a much-needed alternative to conventional surgical and pharmacological interventions. In this connection, it may be remarked that just as microwave diathermy may be considered as an electromagnetic counterpart of mechanical surgery, so microwave resonance and other related therapies employing pulsed microwaves of sub-thermal intensity may be considered as an electromagnetic counterpart of pharmacological...
interventions\[^{\text{xix}}\] to physiological and psychological disorders. Indeed, given the increasing immunity of certain strains of bacteria, such as *Staphylococcus aureus* and *Pseudomonas aeruginosa*, to conventional antibiotics, the possibility of an alternative electromagnetic (antibiotic) therapy is a timely and welcome development meriting further investigation. In this connection, the possibility of non-thermally inducing lysis via the induction of lambda phage in *E. coli*\[^{17}\] by exposure to low intensity (non-pulsed) mm microwave radiation of a specific frequency is of particular interest.

A related area that has not been covered here is the use of such modalities *in conjunction* with conventional approaches; in this connection, mention may be made of the synergistic interaction between microwave radiation and certain drugs (particularly psychoactive ones\[^{79}\]), and the ability of microwave radiation to potentiate\[^{80}\] X-irradiation in cancer therapy, thereby entailing the possibility of using equally efficacious lower doses.

In conclusion, it can be said that the crucial importance of non-linear electrodynamics in understanding bio-functionality is gradually starting to be appreciated, and with it the possibility of a genuinely holistic approach to the living state, consistent with a living system being much more than simply the sum of its individual parts - a development that can be regarded as the dynamical (frequency) complement to the great advances that have been made in structural biology. One particular aspect of this new perspective that has been explored here is the role played by coherent excitations, the existence of which in a living system has here been taken as a valuable physical discriminant of aliveness, and in terms of which a novel understanding of the hypersensitivity of living organisms to ultra-low intensity coherent microwave radiation becomes possible.

Clearly, much remains to be done, but a start has been made with the introduction into biology of pertinent non-linear concepts from physics, so that it is now possible, for example, to confront the duality of both positive and negative health effects provoked by human exposure to microwave radiation of sub-thermal intensities in a unified way. More fundamentally, however, it may be hoped that an understanding of some of the deeper bio-physical mysteries of life will follow from future developments along these lines, in which will surely feature some of the many advances in ‘integrative’ biophysics that have already been made during the last 40 years through the ingenuity and insight of Fritz Popp to whom this contribution is respectfully dedicated on the occasion of his 70\[^{th}\] birthday:

*ad multos annos!*

### Appendix

**Glossary and some technical details of mobile telephony**

In GSM, transmission is *via* bursts of (carrier frequency) microwave radiation, between which the transmitted power falls to zero, the burst repetition rate being 1.74kHz. In the case of a TETRA base-station, where the carrier is transmitted *continuously*, the bursts are composed of electromagnetic oscillations (characterised by a spread of frequencies centred on about 11kHz\[^{84}\]), arising from the discontinuous way in which the information encoding phase modulation is implemented; the burst repetition rate is here 70.4Hz, during which the power ranges (oscillates) between +85% and –85% of the carrier value, as can clearly be seen from figure 7 of Ref. 84. The value of the power when *averaged* over the duration of a burst equals that of the carrier, so that on average the power is constant. In TETRA handsets and mobile repeaters, on the other hand, the situation is quite different owing to the presence of a burst in only the first of the 4 time-slots of any frame, the associated repetition rate being 17.6Hz.

\[^{\text{xix}}\] The current predominance of pharmacology is, of course, an accident of history, dating from a time when Man knew nothing about electromagnetism but was well-acquainted with environmental condensed matter in the form of herbs, whose therapeutic efficacy was gradually realised. Now that the fundamental regulatory role of electromagnetic processes in homeostasis is appreciated, however, the possibility of an alternate therapeutic strategy presents itself, based on non-material interventions of an electromagnetic nature, whereby a given pathology might be treated by external electromagnetic corrective modulation of the associated defective endogenous control system, which is itself electromagnetic in nature - *i.e.* there is the possibility of an electromagnetic homeopathy in which ‘like is treated with like’; in this way, negative side effects that often accompany pharmaceutical interventions might be avoided.
A ‘frame’ is a group of time-slots-8(4) time in GSM(TETRA)-each of which can accommodate a burst, into which voice information can be encoded; this allows a base-station to simultaneously communicate with more than one Handset. In GSM, the frame repetition frequency is 217Hz, whilst in TETRA it is 17.6Hz. A typical GSM base-station transmits one or more carrier waves (at slightly different frequencies), the first of which (because it contains important signalling information in the first time-slot) is known as the Broadcast Control Channel (BCCH) in which the remaining 7 time-slots are each occupied by a burst, even when there are no calls to handle, a feature that effectively obliterates the distinction between frames, and hence removes from this channel the 217Hz pulsing, but, of course, not the individual burst repetition frequency of 1.74kHz. Any call traffic (voice/data information) that cannot be accommodated in the 7 remaining time-slots of the BCCH is assigned to additional carriers, known as traffic channels (TCHs), each of which can accommodate up to 8 calls simultaneously; when only one time-slot of a TCH is occupied, the frame repetition rate is 217Hz, but this gradually becomes less marked as more and more of the remaining 7 time-slots become occupied with calls, and disappears altogether when they are all filled. It is common practice, however, in order to minimise interference and fading, not to fully occupy all 8 time-slots of the first TCH with calls before activating a second TCH, but rather to distribute (‘frequency hop’) the calls between a number of TCHs; in the event that there is only one time-slot occupied in each TCH, the 217Hz pulsing will, of course, then actually be more pronounced.

A typical TETRA base-station transmits (usually) up to 4 carriers, all of which (unlike in the case of GSM) are always transmitted, irrespective of call density. Further, (again unlike the situation in the case of GSM), each and every time-slot of every frame of every carrier always contains a burst; it may be concluded that this would actually remove the 17.6Hz frame repetition frequency (in the same way that the 217Hz frame repetition frequency is absent from the GSM BCCH), but this is not so. The reason is the regular absence of a gap between the 4th time-slot of each frame and the 1st of the next (see figure 7 of Ref. 84), which effectively preserves the 17.6Hz feature of the signal, and introduces an additional amplitude modulation to that at 70.4Hz considered above.

A ‘multi-frame’ is a group of frames. In GSM the multi-frame associated with the BCCH(TCH) contains 51(26) frames, in which the 51st(26th) frame is a dummy (or idle) frame; it is this feature that effectively distinguishes one multi-frame from the next, resulting in associated multi-frame (repetition) frequencies of 4.25Hz (=217Hz/51) and 8.35Hz (=217Hz/26), respectively. It is to be emphasised that these low frequencies continue to characterise the base-station emissions even under conditions where the 217Hz pulsing is minimal. An even lower frequency of 2Hz characterises GSM emission in the discontinuous transmission (DTX) mode that becomes active when the user is only listening (not speaking).

In TETRA, the multi-frame contains 18 frames (each multi-frame being demarcated by the 18th frame, which is a Control frame), the associated multi-frame repetition frequency being 0.98Hz.

UMTS differs from GSM in the way a Base-station communicates with more than one mobile handset at a time; consequently, the UMTS signals are very different from those in GSM, being much more random in time, and are devoid of the low frequencies in the range of the human EEG that characterise GSM and TETRA signals. Nevertheless, there are a number of rhythmically regular underlying features in the transmitted power, characterised by frequencies of 100Hz, 1.5kHz and 15kHz, which are associated with the four Control Channels that are always transmitted, irrespective of the level of call/data traffic. These 4 control channels constitute only about 20% of the total power output of a UMTS Base-station xx. Consequently, the periodic features just identified tend to get masked by the predominantly random traffic element, resulting in the effectively random, noise-like character of the overall UMTS signal mentioned above; exposure to the rhythmical features of the Control signals is thus most pronounced when the traffic is lowest.

In DECT, the frame repetition rate is 100Hz; pulses at this frequency are continually emitted by the (domestic) Base-station, irrespective of whether there are any calls, entailing a permanent exposure within its vicinity.

xx This is much larger than is the case with GSM, entailing a correspondingly overall increased exposure of the public.
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