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Preliminary Feasibility Analysis of Proposed Constituents for Expanded Dosimetry for Nonionizing Electromagnetic Radiation

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Abstract: ***In-depth analysis of the reported bioreactivity of microwaves in non-thermal intensities in both epidemiology, animal studies and in vitro studies is impeded by the relative absence of a rigorous methodological protocol for exposure assessment. The aim of this study is to present a preliminary analysis of six proposed key parameters (Intensity, Frequency, Duration, Bandwidth, Modulation and Polarization) for exposure characterization, which, with further research, should be possible to develop into a fully quantifiable exposure measurement protocol.***

Keywords: Microwave, Dosimetry, SAR, Mobile Phone, Antenna Mast.

1. Introduction

As the recent years has seen a number of high-quality studies publishing results indicating bioreactivity of microwave radiation in intensities below current official guidelines in studies on model organisms [1]-[4], in epidemiological research [5]-[7], in meta-analysis [8] of case-control studies and furthermore in a recent meta-analysis [9] regarding oxidative effects it becomes pivotal to determine if these observed effects has pathogenic potential for human health.

Thorough epidemiological research could resolve such issues, but the relative absence of a adequate system of gauging chronic environmental radio frequency (RF) exposure has the potential to act as a significant confounder for epidemiological research into possible health effects of chronic non-thermal RF exposure.

2. Literature Survey

Current RF dosimetry is solely based on the SAR concept, which in its simplest form is calculated by the formula [10]: $SAR=(\sigma \cdot E^2)/\rho$, where σ is the conductivity of the tissue measured in S/m, E is the magnitude of the intensity of the electric field measured in V/m and ρ is the density of the tissue measured in kg/m³. For actual exposure modelling the conceptually simple calculation is usually done over a number of different types of tissues, but even given sufficiently detailed calculations the SAR concept cannot account for the fact that the conductivity for the tissue types encountered in the human body varies for different frequencies [11] as modern link aggregation and multiple-in, multiple-out (MIMO) technology implies concurrent transmission on several frequencies.

SAR values can be determined experimentally using a phantom human head and an actual mobile telephone, which validity, however, hinges on the tissue type representation used in the phantom. SAR values can furthermore be determined by mathematically modelling, usually using FDTD (finite-difference time-domain) software packages. The validity of this approach depends on the correct mathematical representation of the different tissue characteristics in the human brain. FDTD-calculations has shown, however, that slight changes in body posture effects significant changes in brain SAR [12], which would be very difficult to analyse using the experimental method.

The SAR-concept for modelled absorbed dose has been shown to be prone to a systematic underestimation of exposure, as the presumption of dielectric homogeneity inherent in the SAR formula is unable to correctly model the different dielectric properties of the human body [13], [14]. As it furthermore has been noted that similar biochemical reactions are observed during exposure in different frequencies and different SAR-levels [15] and in the light of the often quoted non-linearity between exposure and effect [16],[17] and as it earlier has been established the SAR concept posses serious validity issues in regard to low-level exposure [18] the suitability of the SAR concept as the sole measure for determining safe exposure levels for public exposure has been questioned.

Modern microwave based communication technologies are in many ways radically different from the earlier analogue radiobased technologies - mainly because of the vastly greater data throughput and the ensuing use of highly pulse modulated microwaves simultaneously over a large part of the lower microwave spectrum. Regulatory exposure limits [19] are, however, still mainly based on the thermal paradigm advanced by the US Navy in 1953 [20] - presumably mainly to protect against thermal damages from radar pulses.

One of the key requirements for a more thorough exploration of the possible adverse health effects from EMF at non-thermal intensities - as reported by a number of authors - including a new report from the European Academy of Environmental Medicine [21] and another report from the European Environment Agency [22] - is therefore a dosimetry scheme with the ability to correctly assess chronic exposure across the RF-spectrum.

A dosimetry based on DNA-effects has been proposed [23]. The exactness of such a method would probably be undisputed, but it would be very difficult to apply in actual use, as the effect in other research has been shown to be somewhat dependent on metabolic level of the cell [24], on the modulation of the RF-signal [25], on the proteomic composition of the exposed cell [26] and on the ability of the adaptive response to correctly respond to the exposure [27]

A number of mechanisms for the observed effects of microwaves in non-thermal intensities has been proposed which further complicates any traditional measure of RF dosimetry as most of these mechanisms are based on non-linear stochastic systems influenced by RF in much lower intensities than formerly thought possible. It has even been reported that microwaves in non-thermal intensities can alter diffusion rate of water [28] and that structural conformity of macromolecules can be affected by microwave exposure [29], which further has been experimentally verified by measuring heat-shock proteins during microwave exposure [30].

It should be noted that whereas a covalent bond is to strong to be directly influenced by RF in the microwave region (ibid), some of the structural conformity of proteins is maintained by much weaker van der Waal forces, London dispersion forces, hydrogen bonds, etc which might be influenced by microwave-induced effects.

A series of highly interesting theoretical papers from 1997 [31]-[33] provides a perspective on how microwaves might affect the structural conformity of macromolecules through local amplification of wring resonances. These theoretical considerations were, at least in part, experimentally verified in 2000 [34], [35]

Another pathway for non-thermal effects could be reactive oxygen species (ROS) for which a current meta-analysis already has been mentioned in the introduction. The exact mechanism for the ROS production has been associated with magnetic-field induced delay in the recombination process [36] and electrodynamic effects related to electron spin [37]. Effects on ROS can be readily measured - one research team reports [38] elevated levels of ROS in healthy human subjects after 15min GSM exposure.

3. Problem Definition

The purpose of this study is to provide a preliminary analysis of six proposed fundamental characteristics of any exposure situation and thereby suggesting a more comprehensive approach for gauging RF-exposure from both environmental sources and active use, and thus enabling epidemiological research to evaluate and compare both exposure levels of non-voluntary chronic environmental (anthropogenic) sources and exposure levels for (voluntary) active use of microwave-based communication technology.

It is not within the scope of this study provide a balanced pro-et-contra review concerning the claims of bioreactivity below current guidelines, rather it is to provide an analysis of some of the key technical exposure gauging parameters for resolving such claims.

4. Methodology

The proposed parameters for RF dosimetry are analysed in relation to the biophysical mechanisms proposed for the reported bioreactivity of microwaves in non-thermal intensities. Special considerations are made focusing on how some of the proposed mechanisms for such bioreactivity could be understood in terms of RF-technical measurements.

A experimental RF-analysis software was developed for this study, enabling graphical rendering and pulse measurements of RF-transmissions in both the frequency domain, the time domain and combined frequency/time domain. The software, together with suggestions for appropriate RF-acquisition hardware, is available for other researchers by contacting the author.

Ethical approval: The conducted research is not related to either human or animals use.

5. Results & Discussion

Current scientific debate regarding possible non-thermal effects can be seen as deadlocked regarding the viewpoint on whether such effects exists, and whether such effects in any way can affect human health. To overcome this deadlock it is vital that the subject is approached by objective science - which hinges on the development of a RF dosimetry scheme able to correctly asses all aspects of the received exposure. On this basis it is proposed that any electromagnetic field exposure can be fully described by six key parameters (Intensity, Frequency, Duration, Bandwidth, Modulation, Polarization), which, pending further exploration, should be possible to develop into a fully quantified exposure measurement protocol.

a) Intensity

The strength of the electromagnetic field can be measured either as power density or field intensity. Either of these measurements is a quantisation of the energy delivered by the electromagnetic field, and, given far-field conditions, one can be calculated from the other: $PD = E^2/Z_0 = Z_0 \cdot H^2$, ·where PD is the power density, measured in W/m^2, E is the magnitude of the field intensity for the electric field measured in V/m, H is the magnitude of the magnetic field intensity measured in A/m and Z_0 is the impedance of free air, $120\pi = 377\Omega$

For fully valid digital measurement of a pulsed signal the measurement device should, beyond satisfying usual demands regarding reproducibility and validity, qualify the sampling criterion set forth by the Nyquist-Shannon sampling theorem [39]. Sampling is, in a digital measurement, the process of making an actual measurement. For digital systems this can vary between one or two samples per second to several dozens of giga samples per second. The Nyquist-Shannon theorem states (in a slightly simplified formulation) that the sampling frequency should be at least twice the highest frequency contained in the signal. This constraint is actually rather intuitive, once the signal is shown in the time domain, as in figure 1.

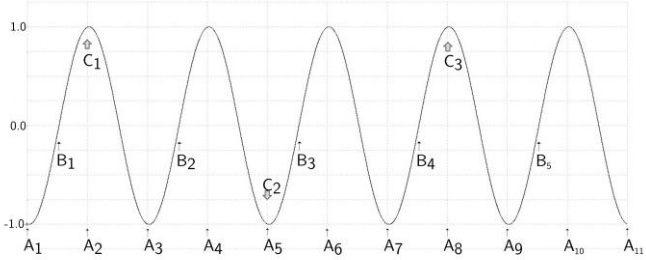

Figure 1: Graphical representation of various sample frequencies for a simple sinusoidal curve. If one consider sampling series "A", it is readily evident that the original signal can be reconstructed from the sampled points. If one consider sampling series "B" the sampling does not posses enough information to correctly reconstruct the original signal - in fact the sampling series "B" does not see a signal at all. If one considers sampling series "C" the reconstructed signal will be quite different from the measured signal.

The Nyquist-Shannon theorem has implications for RF-measurements used to evaluate possible adverse effects as most measurement standards and measurement probes developed for use in RF-engineering are calibrated for sinusoidal signals [40], while the actual signals are previously unknown and quite complex with ultrasharp pulses measured in fractions of milliseconds.

Any measurement device or measurement protocol with a digital sampling interval lower than twice the highest frequency contained in the measured signal will, therefore, not produce a measurement result with a fully valid representation of the measured signal.

b) Frequency

Both GSM, UMTS and LTE can, per specifications, operate in many different frequency bands, but most commonly in frequency bands between 700MHz and 2600MHz. The different frequencies used results in different propagation characteristics , where the lowest frequencies normally have the greatest penetration capability and normally reach longer than the shorter waves. The shorter waves propagate more light-like.

The frequency is furthermore the primary parameter determining the penetration depth in human tissue. The penetration depth is calculated as $\delta = \sqrt{(1/(\Pi \cdot \mu \cdot \sigma \cdot f))}$, where δ is the penetration depth measured in meters, μ is the tissue magnetic permeability measured in H/m, σ is the tissue electric conductivity measured in S/m, and f is the frequency of the electromagnetic field measured in Hz [41].

The frequency of the signal may therefore be a significant determining parameter for possible bioreactivity of a given electromagnetic signal. As biological systems are complex this might imply that a frequency not producing bioreactivity in one organism or in one subcomponent of an organism might produce pronounced bioreactivity in other organisms or other subcomponents.

c) Duration

Cumulated chronic exposure can only be fully quantified by aggregating both exposure duration and exposure intensity in the measurement scheme. The necessity of inclusion of cumulated exposure from antenna masts in RF dosimetry for epidemiological studies is furthermore supported by the observed reduction in bird population around antenna masts reported by different authors [42], [43] and an earlier study [44] showing degraded fertility continuing to permanent infertility in mice exposed for low-level microwave radiation for 6 months. More recent experiments [45] using other model organisms has shown similar degradation of reproductive capability with a nearly linear correlation to cumulated exposure.

Cumulated effects have also been shown to affect infertility for humans, although the exposure source in these studies [46], [47] has been handheld units and not base stations.

Furthermore a number of epidemiological studies of health anomalies in the vicinity of antenna masts have been conducted. An excess cancer incidence has been noted by several researchers [48]-[50]. The underlying connection between cumulated exposure and adverse health effects risk is further substantiated in a review from 2010 [51]. Similar effects have been noted in a study from India [52], where genetic damage was observed in inhabitants living near a antenna mast. An adverse health effect from antenna masts has furthermore been observed in Spain [53] and in France [54].

Whether or not such observed correlations are sufficiently methodological stringent to draw firm and final conclusions, it is crucial that any dosimetry scheme contains a metric for evaluating cumulated and/or aggregated exposure in order to investigate the issue objectively. As the biophysical mechanisms proposed has been indicated to show effect for low level exposure, the dosimetry must furthermore include a metric for evaluating aggregated exposure from different concurrent sources.

A number of telecommunication companies were contacted with a request for detailed transmitter specifications to enable a detailed analysis of possible aggregated effects using actual exposure data. None answered the requests. The dose calculation in this section is therefore based on textbook references for typical values for transmitter power and antenna gain. For a macro cell base station these values are stated as 43-48dbm [55, p225] transmitter power and typical antenna gain is stated as 15-21dBi [ibid, p224].

From these values the equivalent isotropically radiated power (EIRP) for two typical scenarios can be calculated:

Typical 65dbm macro cell:
48dbm effect, 1db cable loss, 18 dbi gain = 65dbm EIRP (= 3162 W EIRP)

Typical 60dbm macro cell:
43dbm effect, 1db cable loss, 18 dbi gain = 60dbm EIRP (= 1000 W EIRP)

For the above calculations it is assumed, as it is common practice today, that the power amplifier is situated close to the antenna array enabling a low cable loss and that the antenna output is quasi-unidirectional, which is commonly achieved by a impedance matched phasing harness connecting the sectorized antenna array to the power amplifier.

Using the above calculated EIRP the power density at various distances from the antenna mast can be calculated Pd = Pt / (4 * π * d²), where Pd is the power density measured in W/m², Pt is the transmitter effect measured in W and d is the distance measured in meters. In this calculation a duty cycle of 100% is assumed.

For the calculation of aggregated exposure it is assumed that the antenna mast is equipped with one antenna array for GSM, one antenna array for UMTS and one antenna array for LTE, as it is commonly seen. The transmitter effect is assumed to be within the typical specifications stated above. The calculated power densities for the various technologies at various distances is then cumulated across 24 hours and converted to KJ pr square meter pr 24h, as shown in figure 2.

To enable a comparison between active use and environmental exposure the 6-min RMS power density for a mobile phone in two different coverage scenarios was measured. As the mobile phone is equipped with an adaptive circuit constantly varying the transmitter output, and as the power levels for this transmitter is known through the technology specification, the power densities could have been calculated instead of measured - if the antenna gain and duty cycle of the transmission were known. The duty cycle is, however, dependent on the data throughput and therefore not known in advance for a given transmission and the antenna gain is not normally published in the specifications for the handheld unit. With modern smartphones the antenna gain can be as low as -5dbi. A measured value is therefore seen as most realistic representation, even though power density measurements so close to transmitter caries it own set of problems. The measurements were done with a TES-92 with isotropic probe situated in normal usage distance (per specification) from the phone. Measurements were corrected for the nonlinear frequency response for the probe and repeated 10 times. The average value is used.

The results of this comparison are plotted in figure 2. It is immediately evident that rural use yields a substantially larger exposure than urban use, as the phone is equipped with a adaptive circuit to enable the phone to adjust the transmitter output in order to conserve battery power. As such it results in a significantly smaller exposure if the phone is used in areas with good coverage. Upon comparison with the graph for aggregated environmental exposure it is, however, likewise immediately evident that the aggregated exposure from environmental sources amounts to a non-trivial portion of the total exposure if a person is situated close to an antenna mast: 24 hours aggregated environmental RF dose for a person situated within 100 meters of the antenna mast is of similar proportions as exposure from 5h active continuous use of a mobile phone in a rural setting.

d) Bandwidth

An interesting presentation [56] at the recent BioEM 2016 conference provides an epidemiological perspective on the importance of bandwidth considerations when measuring exposure, as the data presented strongly indicated that exposure to UMTS (which utilizes a bandwidth of 5MHz) has greater carcinogenic potential than exposure to GSM (which only utilizes a bandwidth of 200KHz), even though the radiated power (from the handset), measured as dominant frequency power density, is considerable lower for UMTS than GSM. (Note though, that there are other dissimilarities between the two signals).

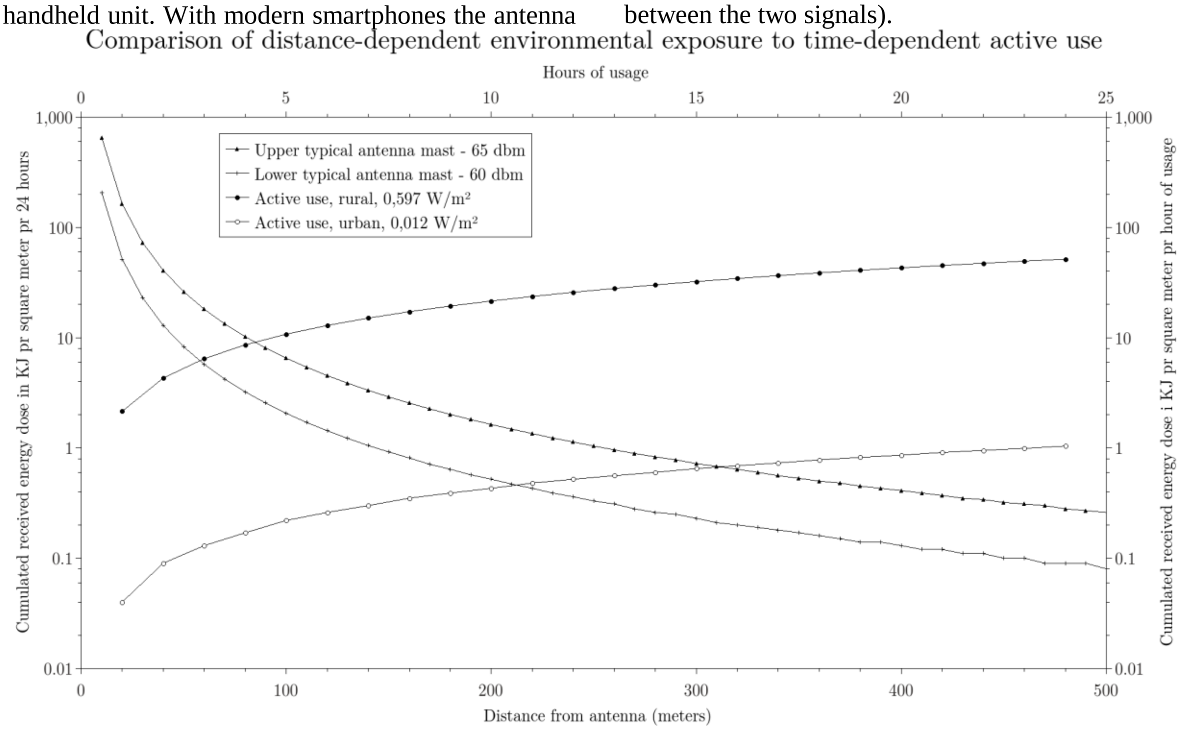

Figure 2: Aggregated distance-dependent environmental exposure compared with time-dependent exposure from different scenarios of active use. The graphs for aggregated environmental exposure are referenced to bottom x-axis and left y-axis. The

graphs for active use are referenced to top x-axis and left y-axis, enabling a direct comparison of distance-dependent (KJ pr m² per 24h) aggregated environmental exposure to time-dependent (KJ pr m² pr hours usage) active use. Both y-axes are log scale. The active use calculation is based on 6-min averaged RMS power density measurement (0,012W/m2 and 0,597W/m2, respectively) from a mobile phone (Nokia N900) in active use (flood-ping, UMTS) in both good coverage (urban, free sight, 320 meters from an antenna mast) and poor coverage (rural, forested, 5763 meters from an antenna mast)

Earlier research has found similar elevated bioreactivity for UMTS compared to GSM by analysing blood from both healthy and electrosensitive persons [57].

The rise in bandwidth has, as a consequence, given rise to the possibility of transferring much larger amounts of data as LTE utilizes a bandwidth of 20MHz. Carrier bandwidth and data throughput are, although not perfectly linear, closely related.

The many "apps" used by modern smartphones constantly poll the network for new data (facebook updates, instagram pictures, twitter messages, etc), which creates a situation where any switched on smartphone is nearly constantly communicating with the network infrastructure. Such intermittent exposure has, in at least one study [58], proved to be almost as effective as continued exposure for producing DNA damage. The actual exposure in the modern world is therefore both qualitatively and quantitatively radical different from the early GSM phones with only could be used for voice or SMS, and even then, most voice contacts were held relatively short as airtime was expensive.

A recent review [59] has demonstrated a significant difference between studies using controlled EMF-emissions and studies using real mobile phones as exposure sources, where close to 100% of the studies using real mobile phones showed adverse effects, but only 50% of the studies using controlled EMF-sources showed adverse effects. This difference could be explained by different (and varying) bandwidth use associated with real use.

The nominal spectrum utilized by any single technology can be found in the relevant licensing authorities databases, but the actual use of the allocated bandwidth is related to the number of connected users and the data throughput, which means that the only way to achieve a precise figure would be to base the calculation on usage statistics held by the telecommunication companies or direct measurements made with a spectrum analyzer. As there, per the proposed mechanisms, seems to be no reason why the proposed mechanisms only should be active for the dominant frequency it is readily visible from figure 3 that the bandwidth correction is of paramount importance to avoid a considerable underestimation of the total exposure.

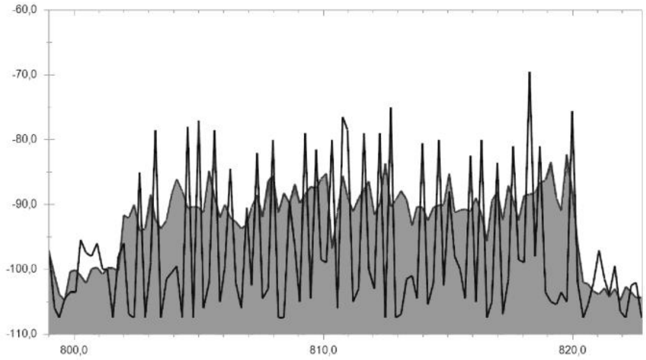

Figure 3: Graphical representation of 20Mhz bandwidth (located in LTE band 20) utilised by a downlink LTE at the antenna mast at UTM 32N 577742 6369593 measured at 1642 UTC at 26feb2017. X-axis denotes frequency in Mhz, Y-axis denotes antenna input in dbm. The grey area represents 6-min average, the black line is a single sweep snapshot.

e) Modulation

Modern microwave-based communication technologies use digital modulation, whereas older analogue technologies were based on modulations on a sinusoidal curve. A digital modulated signal does (normally) not produce any sinusoidal appearance when viewed in the time domain; instead it shows a rapid succession of ultrasharp pulses. The purpose of this digital modulation is to produce a signal with as high a information density as possible, both to maximise data throughput and to minimise frequency spectrum usage, which is a limited commodity, for which the telecommunication company has to pay a significant amount to the licensing authorities in the countries where the service is operated.

The different modulation schemes used might have different levels of bioreactivity, as it recently has been shown [60] that some effects to a very large degree depend on the waveshape of the magnetic field. The frequencies used in the experiment (20, 50, 75 Hz) is, to some extent, in the same range as the subcomponent frequencies produced by the different modulation schemes used for mobile telephony.

In the Ion Forced-Vibration Theory, suggested by Dimitris J. Panagopoulos et al [61]-[63], and experimentally verified [64]-[66], the ELF components of the digitally pulse modulated signal carries a inherent risk of bioreactivity with indications that even very weak (10^{-3} V/m) electric fields might effect irregular gating of ion channels, which in turn causes disturbance or disruption of the cells electrochemical function.

It should be noted that one commonly stated counterargument to the Ion Forced-Vibration Theory, namely the effect size of the forced vibration viewed in relation to the effect size of molecular vibration due to thermal noise, often omit the coherent characteristic of the ELF induced vibration, whereas the molecular and ionic vibration caused by thermal noise is random, and as such self-cancelling over averaged time/spatial observations.

Similar perspectives on Voltage Gated Calcium Channels (VGCC) in the cell membrane has been explored by Martin Pall and others [67],[68]. In this regard it is especially interesting that the effects from electromagnetic disturbance of the cell can be blocked with VGCC-blockers [69]. An experimental verification of such a specific reaction makes this theory a strong candidate for a more general understanding of some of the mechanism for non-thermal bioreactivity of microwaves. Downstream effects from the activation of the VGCC can furthermore explain the ROS formation widely observed.

The observed effects on VGCCs has two key implications for any RF dosimetry scheme. Firstly the need to expand the dosimetry to very low field intensities, and secondly the need to assess ELF subcomponents in the digitally pulse modulated signal.

For normal RF engineering purposes the signals are mostly viewed in the frequency domain, but by demodulating the signal and feeding the input to an oscilloscope the signal can be viewed in the time domain, whereby possible ELF subcomponents can be analysed and measured.

For this study such measurements were made with the purpose-built software, but in a more simple setup the same could be achieved by a simple diode-type receiver coupled to a digital storage oscilloscope.

For the GSM uplink signal (shown in figure 4) the modulation structure is based on a combination of FDMA and TDMA, where the initial FDMA provides for about 100 concurrent communication streams in one single frequency band and the subsequent TDMA splits each communication stream in 8 different timeslots. When viewed on a high resolution setting on a oscilloscope the pulse duration can be measured to ~0,57ms and the pulse interval measured to ~4,62ms. This produces a subcomponent frequency in the ELF range at ~217Hz, whereas the omission of each 26. pulse produces a yet lower subcomponent frequency at ~8,33Hz.

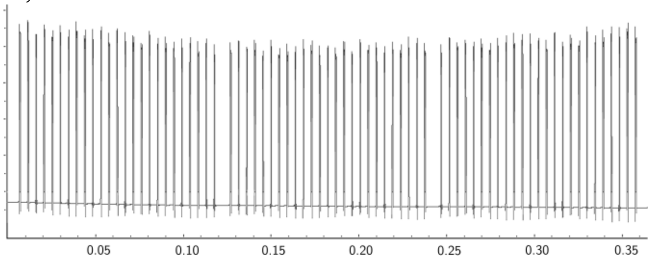

Figure 4: Uplink GSM voice signal. X-axis is measured in seconds. Pulse interval is ~4,62ms and pulse duration is ~0,57ms

A consequence thereof is that each handset only operates at 1/8 duty-cycle, when it is transmitting in GSM mode, whereas a base station normally operates in 8/8 duty-cycle.

The 217Hz subcomponent frequency in GSM has been linked to changes in HSP70 mRNA expression [70],[71] and DNA damage [72] whereas a unmodulated signal in the same frequency and intensity did not produce such results.

Another TDMA-modulated signal in widespread use is the TETRA system (shown in figure 5) used by the emergency services throughout Europe.

Using the virtual oscilloscope in the developed software the downlink TETRA signal can be analysed in detail. Each burst last ~14,4ms, which produces a ~70 Hz ELF subcomponent. frequency.

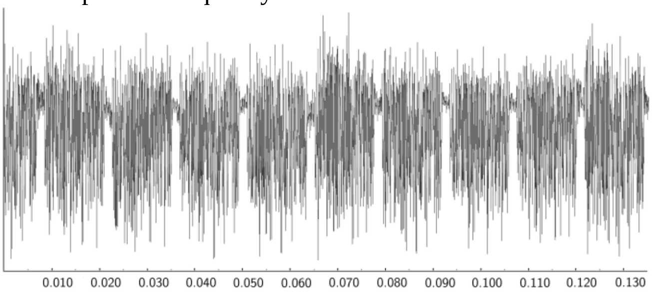

Figure 5: Downlink TETRA signal demodulated. X-axis is measured in seconds. Burst length of the signal is measured to ~14,4ms.

Almost every utilized digital modulation structure has some level of embedded ELF-components in the signal; but only the modulation structures based on TDMA contains the highly repetitive patterns shown above. The ELF-components for both UMTS (shown in figure 6) and LTE are dependent on the actual data throughput, which makes any analysis thereof unable to correctly represent the signal in all scenarios.

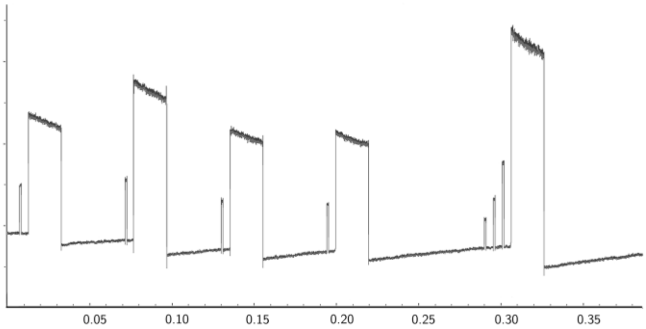

Figure 6: Uplink UMTS. X-axis is measured in seconds. The exact pulse pattern is dependent on the data throughput, making precise measurements of ELF subcomponent frequencies difficult.

f)Polarization

A counterargument against the possibility of bioreactivity from non-thermal RF exposure could be that the energy (or amount of photons) received from sunlight vastly outnumbers any RF dose received under normal conditions by several magnitudes, but in this discussion it should be noted that sunlight is neither highly pulsemodulated nor strictly polarized. Nor does any other naturally occurring electromagnetic field on earth exhibit both pulsemodulated and polarized characteristics. The combination of strict polarized and highly pulsemodulated RF represents a combination which neither mankind or any other earth-based creature has had any possibility of evolutionary adaptation for. It could, therefore, be argued that polarization measurements should be included in the dosimetry metrics, and should be accounted for in experimental and epidemiological studies. This viewpoint seems to be supported by a recent study [73] providing a deeper biophysical analysis of the different effects of polarization.

g) Exposure Aggregation in other research

The very idea of exposure aggregation is not a novel perspective - Martin Blank and Reba Goodman mentioned the need for exposure aggregation for regulatory purposes several years ago [74].

As many of the suggested biophysical mechanisms for the reported non-thermal bioreactivity are either much less dependent on power levels than modulation structure or provides pathways for bioreactivity at very low power levels it seems naturally that any exposure dosimetry only evaluating the power density of the dominant frequency is at serious risk of underestimating the actual exposure characteristics. By such argumentation some form of exposure aggregation calculation is needed where a person is exposed to several RF sources simultaneously. A simple addition is suggested in this study; but further research should be undertaken to fully develop a more precise aggregation metric - possibly by taking into account the possibility of the aggregated exposure inducing coherent influence on ions or electrons (possibly by similar polarized RF producing ELF subcomponents in phase with each other)

And although the theories developed regarding the VGCC mechanism for bioreactivity are strongly supported by experimental evidence, the claim that these effects are the only pathway for bioreactivity should be assessed more closely, as bioreactivity from magnetic fields has been demonstrated in cell-free systems, where the membrane components has been altered [75]-[76].

As a possible explanation for such bioreactivity it has been proposed that the DNA structure in itself could be evolutionary adapted to sensing electromagnetic fields at very low power levels in a very large part of the spectrum, as it has the structural qualities of a fractal antenna [77]. The exact target is proposed to be delocalised π-electrons, which, by their electrical charge and negligible mass can be influence by either electric og magnetic fields at very low power levels. Such qualities could have been a evolutionary advantage eons ago when life were primarily single cell based, and a larger number of mutations in a relatively short timespan would yield higher possibility of successful adaptation to the rapidly changing environmental conditions. Such mutations are, however, quite undesirable in a complex multi-cell organism as a human being.

As the influence presented upon either the calcium ions forcing the VGCC or upon the delocalised π-electrons in the DNA helix is not limited to the dominant frequency, and is stipulated to occur at very low power levels, it is vital that any dosimetry scheme employed while researching such subjects is able to correctly assess cumulated and aggregated exposure situations at very low power levels.

6. Conclusion

The presented approach for RF dosimetry could, with further development towards full quantisation, provide a methodological pathway for determining to what extent the reported bioreactivity conveys adverse health effects on humans. It is furthermore noted that by using the exposure characteristics proposed in this study, it is indicated that the aggregated exposure from environmental sources, calculated as shown in this study, in some instances is of comparable magnitude to actual use of microwave based equipment, which could have implications for selection of control groups in epidemiological studies.

There may be other characterizing parameters of a exposure scenario than those expanded upon in this study, but on the basis of this analysis it is suggested that no RF dosimetry scheme omitting any of these characteristics analysed in this study can claim a valid representation of the exposure scenario in relation to possible biological effects.

Conflict of interest

The author state no conflict of interests. The author received no external funding for the study.

7. Future Scope

The provided calculation on exposure comparison between distance-dependent environmental exposure and time-dependent active use can, as it is based on textbook data and assumed characteristics instead of real-world measurements, not be seen as representative of any specific or general antenna installation, but could, however, be valuable to provide a argument for the more detailed exploration of aggregated exposure and its possible usefulness in epidemiological studies.

a) Perspectives for further epidemiological research

The analysis lends support to a viewpoint that current epidemiological research could be prone to an unknown underestimation of risk of adverse health effects from exposure to pulsed microwaves from wireless communication equipment, as a indeterminate, but considerable (given the widespread use of the technology) number of persons are environmentally exposed to RF in amounts comparable to several hours of mobile telephone usage and still can be counted as non-exposed in much of the current epidemiological research.

The telecommunication companies have access to both detailed models of bandwidth use and power density distribution in the landscape (as this data is used extensively in their infrastructure planning) and detailed usage statistics. As such, it would be technically straightforward to combine the bandwidth/power density data and usage statistics from each of the telecommunication companies in a single database such that the environmental exposure can be mathematically modelled for the whole country. The metadata logging requirement in effect in much of Europe means that such databases in theory could be appended with historical data. Such a database would, combined with national health statistics, be very useful in determining if the reported bioreactivity of microwaves in non-thermal intensities has actual pathogenic potential for human health.

b) Perspectives for technological development

If the reported bioreactivity for the currently used pulsed microwaves are established to induce adverse health effects in humans, the emphasis on the pulsing characteristics in the biophysical mechanism for such bioreactivity might point to a future development of a biosafe modulation scheme for wireless infrastructure. The challenge is to develop a modulation structure which neither can be demodulated to show ELF subcomponents by analogue systems or trigger electron movement in the DNA helix. With further experimental verification such a modulation structure could therefore theoretically provide a technological pathway for continuing the technological development while minimizing its bioreactivity. Given the capabilities of modern digital signal processing this challenge should be within the realm of possibility in an acceptable timespan - the major hurdle would probably be the significant power consumption usually inherent with such modulation structures, which would have implications for battery life for mobile units.

Further research is urgently required in this regard, as the technological specification for 5G are in the process of being finalized. It should, however, be noted that some research suggest effects even unmodulated microwave radiation produces bioreactivity [78]. Such bioreactivity from unmodulated RF has been reported by others [79], but the levels of bioreactivity were still lower than for modulated RF.

c) Special cases for 5G Ultra Wide Band signals

If the rate of phase change for the electromagnetic field is sufficiently rapid the electromagetic field can, via a phenomenon known as Brillouin precursors, deliver energy significantly deeper in the tissue than pulse dispersion calculated by group velocity approximation usually predicts [80], [81]. The interesting point is that the group velocity approximation looses significant accuracy for pulses with extremely short rise times [82]. Harmful biological effects of such Brillouin precursors has been described [83], mainly in four different categories: Conformational changes in the three-dimensional composition of macromolecules, changes in reaction kinetics, effects on membrane permabillity and thermal effects, while Wang [84] provides a more recent, although SAR-based, analysis of effects on biological systems by Brillouin precursors.

d) Limitations and unresolved issues

The power density and transmitter effect is vastly higher for base stations than for handheld units, but it should also be noted that the ratio between peak power and the RMS of the signal is considerably higher in the signal from the handheld unit, as determined by the duty cycle of the chosen modulation. A handheld unit seldom reaches 100% duty cycle, whereas a base station quite often runs at 100% duty cycle. This can readily be measured by viewing the signal in the time domain.

The proposed parameters for exposure measurement are unable to distinguish between near-field and far-field exposure.

The peak field intensities for the mobile phone was measured with a TES-92 set to "max peak" detection. Some peaks reached 71,3 V/m in electric field intensity, and at the same time a power draw of nearly 2 amps from the battery were measured. The ultrashort RF peaks might convey a bioreactivity not similar to what is experienced from antenna masts. Similarly could the magnetic field produced by this current theoretically cause measurable biological effects not directly associated with the RF-signal.

The biological significance (if any) of these considerations are, at present time, unclear.

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