An Assessment of Potential Bioeffects from Exposure to Cellular Phone RF Signals Using TDMA, in Particular GSM-Type RF Signals

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Abstract
The rapid proliferation of personal wireless communications devices, in particular handheld cellular phones, has raised concerns regarding potential bioeffects from exposure to the radiation emitted by these devices. Numerous experimental studies have been conducted in the quest for answers to the question of possible biological effects, but often the RF signals used have not been fully representative of all aspects of typical RF fields transmitted by cellular phones in actual use. There is now considerable experimental evidence which shows that ELF amplitude modulated RF signals can produce biological effects. This includes continuous, constant power TDMA/GSM type signals. But amplitude modulation of the wireless RF signals in actual use can be considerably more complex. For instance, in the GSM system the transmitted power can increase or decrease in stepwise fashion to minimize power consumption while maintaining an acceptable connection. In addition transmissions can be voice activated if Discontinuous Transmission (DTX) is allowed by the network operator. In this paper we investigate how the response to RF GSM using DTX and power regulation might be expected to change relative to the previously observed response to continuous burst modulated TDMA/GSM RF. Our analysis makes use of two standard data sets of transcribed two party telephone conversations, SWITCHBOARD and CALLHOME, to predict the distribution of transmit ON and transmit OFF times. Bio-effectiveness of TDMA/GSM type transmissions having ON/OFF times specified by these distributions is determined by comparison with our previous experimental results describing the variation of the bio-response to exposure with signals which are periodically turned ON and OFF, as a function of the ON time interval. We conclude that transmissions from TDMA/GSM cell phones in which DTX implementation can be represented by ON/OFF distributions derived from CALLHOME and SWITCHBOARD, can still be significantly bio-effective regardless of whether or not power regulation is implemented.
Key words: cellular phones, bioeffects, speech corpora

Introduction

Cellular phones operate by transmitting and receiving microwave radiation which is modulated in a complex manner to encode both the information useful to the user and that useful to the system. There are various standard protocols in use today which can be loosely classified into two types, those using analog methods and those using digital methods. Analog cellular phones generally use narrow band FM which causes phase variations in the carrier with very little amplitude change. Digital cellular phones transmit digitized information encoded using by any of various modulation methods such as phase or frequency modulation. In addition other techniques are employed which add amplitude modulation to the transmitted signal. Regardless of the transmission protocol the guidelines to insure safe operation of these devices are based on the concept of Specific Absorption Rate (SAR). The SAR, which measures the time averaged energy deposition per unit volume, does not account for possible variations in biological interaction which may come about due to changes in modulation.

A large body of experimental evidence exists regarding possible biological effects from exposure to microwave radiation at non-thermal levels. Although some experimenters have reported no measurable effects, a general pattern seems to emerge when effects have been observed. In both in-vivo and in-vitro experiments in which weak (<5W/kg) continuous wave (CW) and amplitude modulation (AM) or pulsed microwaves have been studied together, the modulated microwaves produced enhanced effects [1, 2, 3, 4]. These results suggest that modulation plays an important role in eliciting the biological response to weak microwave fields.

Notwithstanding the experimental evidence, the question still remains as to the relevance of the

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observed effects with regard to RF exposure from cellular phones. As previously noted the transmission protocols can impart complex modulation characteristics onto the RF carrier which may change the bio-effectiveness of the signal. In view of the importance of amplitude modulation with regard to biological effects, we focus in this paper on the amplitude modulation characteristics of cellular phone RF fields, in particular the effect of operations such as DTX and power regulation in GSM systems. The impact of these procedures is analyzed by comparison with previous results which describe the variation of the bio-response to exposure with signals which are periodically turned ON and OFF, as a function of the ON time interval [5]

Amplitude modulation in GSM

There are three characteristics built into the GSM protocol which have an impact on the AM properties of the transmitted RF, these are, the use of Time Division Multiple Access (TDMA), power regulation, and discontinuous transmission or DTX. TDMA is employed by GSM and other digital systems to expand the channel bandwidth by allowing sharing of a physical channel amongst several users. When using TDMA the transmissions from any given user must be in bursts using an assigned frequency and time slot. In GSM the burst modulation is at 217 Hz with approximately 12.5% duty cycle. In order to save battery power at the mobile station the transmitted power is controlled according to the minimum requirements to maintain an acceptable connection. Power regulation is implemented in single 2 dB steps up or down within the power range of the mobile. Typically the data from the mobile is averaged over several seconds at the base station before a command to change power level is issued. Power regulation adds a random amplitude modulation aspect to the transmitted RF. To further reduce power consumption GSM allows voice activated transmission or DTX which disables the transmitter when the user is silent. The DTX option is available in all GSM phones but it does not have to be implemented by the network operator. When active DTX adds a random pulsed modulation component which can be relevant to the extent of the biological response. Changing between DTX active and inactive states involves a minimum 80 ms delay. In addition there are other aspects of the protocol which can impart AM components to the RF, but those already mentioned are probably the most relevant from the point of view of biological effects.

Use of temporal sensing to predict the effect of DTX implementation

We have previously found that the response to ELF AM modulated RF is equivalent to the response to the corresponding ELF signals [1]. Further proof of the equivalency of the bioeffects induced by these stimuli is the fact that ELF AM RF effects can be inhibited by superposition of ELF noise [6]. Therefore, effects of ELF AM RF exposure can be predicted from ELF exposure studies and vice versa. In the case of bursting TDMA cellular phone the exposure is both in the RF and in the ELF range, the source of the latter being variable current drawn from the battery which parallels the RF bursting.

The data relevant to analysis of the DTX effect comes from our studies on the role of "temporal sensing". The temporal sensing concepts hypothesizes that there are two basic time constants which direct the sensing and the response to external stimuli: the averaging time, and the memory time. The averaging time is the time over which the biological cell averages a sensed stimulus before it acknowledges a change in environmental conditions induced by the stimulus. The memory time is the time over which the cell remembers previously acknowledged changes. The newly acknowledged stimulus is compared against remembered measurements before a response is effected. In the case of EMFs we found in a previously published study that the averaging time is of the order of 50 to 100 ms, while the memory time is of the order of 5 to 10 seconds [ref]. This implies that in order to obtain the full response, that is the response equivalent to constant exposure, the stimulus must be ON for at least 10 seconds. Signals which are ON for less that 10 seconds induced a reduced response, in fact, the response could be completely inhibited if the ON intervals were sufficiently small. A empirical functional relationship was established in the temporal sensing study to predict the extent of the response of ON/OFF signals as a function of the ON time. This relationship, which will be herein referred as the temporal sensing equation, relates the extent of the bioeffect [BE] to the length of the ON interval [t] as follows: $[BE]=1+[0.7(1-e^{-t/5.1})]$. In the present work we make use of the equation to predict the change in the response as a result of implementation of DTX in GSM RF transmissions.

Representation of DTX ON/OFF intervals

The DTX characteristics which are relevant to the bio-effectiveness issue of GSM RF exposure are:

the distribution of ON intervals as a function of time duration of the ON interval, and the distribution of OFF intervals as a function of time duration of OFF intervals. Because GSM uses Voice Activated Detection (VAD), these characteristics may be predicted based on analysis of suitably selected data sets of two-party phone call transcripts from which the distributions of ON intervals and silence intervals can be extracted. The distribution of ON intervals can be used as a measure of the distribution of ON times of the transmitter in cellular RF transmissions using DTX. The net contribution to the total bioeffect can be calculated by weighing the contributions of the various components of the distribution based on the relationship of Figure 1 which expresses the bio-effectiveness as a function of the ON interval.

Standard data sets of transcribed telephone conversations can be used to calculate the expected distribution of contiguous speech (ON time intervals) and acoustic speech disfluencies (OFF time intervals). These data sets, which are referred to as speech corpora, are used primarily by researchers in the speech processing and voice recognition fields. To perform our analysis we selected two representative data sets called the SWITCHBOARD corpus and the CALLHOME corpus. Specifics about these data sets are described in the references. Use of these data sets for analysis of speech disfluencies and other issues relating to speech processing have been widely reported in the literature [7, 8, 9]. For our analysis we used a reduced subsets of the complete corpora containing the call identification, the speaker identification, and the time registry of each utterance.

Effect of DTX on the extent of the bio-response

The distributions of ON times of the SWITCHBOARD and CALLHOME data sets are expected to vary to some extent relative to each other because the each data set represents conversations between different types of speakers. Indeed, CALLHOME displays a peak at around 0.7 seconds while SWITCHBOARD peaks at around 1.5 seconds. This is to be expected since CALLHOME represents conversations between individuals who are familiar with one another and therefore would tend to speak using shorter utterances. On the other hand SWITCHBOARD has a broader distribution and includes a fair proportion of longer length utterances, which is possibly due in part to the participation of parties unfamiliar with one another. Because of these differences we have selected these two sets of data, which represent two extreme conditions, to estimate the bounds of possible biological effects from exposure to voice activated RF (and ELF) signals.

In the GSM protocol there is a delay of 80 ms between a detection of "no speech to transmit" and changing to DTX active. Therefore to better simulate the action of the transmitter the data was modified to eliminate pauses in speech of less than 80 ms. Other forms of synchronization are also uses in GSM which can lengthen the activation time of DTX. Simulation of these synchronization intervals was not implemented in our analysis, but it would result in a longer effective time ON, and therefore, a greater bioeffect.

The net bio-effectiveness of a signal with a distribution of pulse lengths, such as SWITCHBOARD and CALLHOME, can be predicted by making the reasonable assumption that effects from exposure intervals are cumulative and are increasingly persistent (for times longer than the ON interval) as the ON time increases. This hypothesis is supported by our own results which show that pulsing signals with 50% duty cycle, that is, signals which are ON half the time are up to 70% as bio-effective as continuous signals. The 70% figure (greater than 50%) indicates the persistence nature of the effect. For any given ON interval, its contribution to the net bioeffect was calculated by multiplying the total time the signal was ON at that ON interval by its expected bio-effectiveness as predicted by the temporal sensing equation. The total contribution to the net bioeffect is the sum of the contributions from each of the ON intervals. Differences in duty cycle (CALLHOME 40%, SWITCHBOARD 60%) were not considered but their effect should not be significant. If the differences in duty cycle are disregarded, the results show that the bio-effectiveness of CALLHOME is expected to be approximately 33% of the effect of a continuous signal, while that of SWITCHBOARD is expected to be approximately 56% of the effect of a continuous signal.

Effect of power regulation

One feature of the GSM protocol aimed at extending battery life is a method for regulating the power of the mobile unit. This method for power regulation can be optionally implemented by the network operator and therefore is not necessarily used by all GSM phones. When used this method allows operation of the phone at the lowest power level that will maintain a connection with acceptable quality. Adjustments in power level are generally needed as a result of changes in signal attenuation which can come about from the introduction of obstacles in the signal pathway or variations in the physical distance to the base station. Power levels can be stepped up or down in 2 dB increments within the specified range of operation of the phone. The relevant question from the point of view of potential bioeffects is how often in time these changes can occur. Within localized regions, the average field strength as measured from a distant transmitter can be shown to be approximately constant over intervals of 50 m to 500 m [10]. Accordingly, mobile phones used by pedestrians, whether in urban or rural environments are likely to operate at the same power level for intervals greater than 10 seconds. Phones used in moving vehicles may operate at a given power level over shorter intervals depending on the cell plan of the cellular network, the terrain, and the distribution of physical obstacles (buildings, etc.). However, regardless of the situation, the measurements which determine if a change in power level is required are typically averaged over a few seconds before action is taken [11]. Therefore, even if power regulation is implemented it is unlikely that the resulting signal would have amplitude fluctuation which would significantly inhibit its potential bio-effectiveness.

Conclusions

Based on the foregoing analysis we can predict that the extent of the bio-response to RF exposure from GSM cell phones using DTX and power regulation, in which the DTX feature can be modeled by the SWITCHBOARD and CALLHOME speech corpora, is reduced to between approximately 30% and 60% of the predicted effect when these features are not implemented. Therefore, the expected bio-response to cellular phone RF with DTX implementation can still be significant regardless of whether or not power regulation is implemented.

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