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A UMTS test signal
for bioelectromagnetic experiments

Introduction

The commercial introduction of UMTS (Universal Mobile Telecommunication System), a mobile radio system of the so-called 3rd generation, planned for the near future has rekindled the discussion about possible health hazards that had already taken place in connection with the existing GSM system. In view of the expected installation of about 60,000 additional base station antennas by the end of 2003, the fears of the general population concerning exposure to electromagnetic fields seem to grow. However, in the light of the results of published scientific research on the effects of radio-frequency fields on biological organisms, the Commission for Radiation Protection established by the Federal Government has in its most recent recommendation [1] continued to conclude that the protection of the general population is guaranteed by the present legal limit value regulations based upon the recommendation of the European Council [2] or the conclusions of the International Commission on Non-Ionizing Radiation Protection [3]. Still, although limit values were defined which include a precautionary safety margin with respect to the threshold of thermal tissue stress, it is sometimes claimed that biological effects or even a damaging impact are observed at field strengths distinctly smaller than the limit values. Often those observations are not explained by the radio-frequency field itself but by its modulated signals; in the case of the GSM system, for example, by the typical low-frequency impulse formation of the signals. Until now, the corresponding results have not been able to be reproduced and thus are not seen as valid scientific knowledge. Nevertheless, the Commission for Radiation Protection recommends the close monitoring of evidence which would be able to confirm or disprove the above-mentioned findings by intensified research efforts. As until now there are no models for mechanisms which explain how weak mobile radio electromagnetic fields might affect biological systems, no theoretical but only an experimental approach to this issue – at least for now – has been possible. Here, the time evolution of the mobile radio signal plays a key role.

Therefore, it is planned that the research projects on UMTS and biological systems initiated by the Research Association for Radio Applications (Forschungsgemeinschaft Funk) will apply a uniform UMTS signal pattern (in the following referred to as "generic UMTS test signal") to permit later comparison with other experiments. To this end, it is neither required nor desirable to select an authentic UMTS signal having all necessary properties for communication. Rather – as already done concerning the test signal applied during bioelectromagnetic experiments on the GSM system [4] – from the great variety of highly-complex UMTS signals, only those components will be combined that are seen (at least by critics of mobile radio) as potentially having biological effects. These are the mainly temporal amplitude variations of antenna transmission signals in

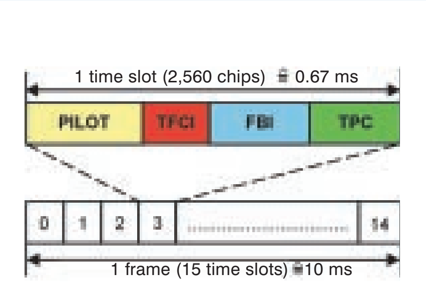

Fig. 1: Structure of the control channel showing, as an example, the "uplink" [9]

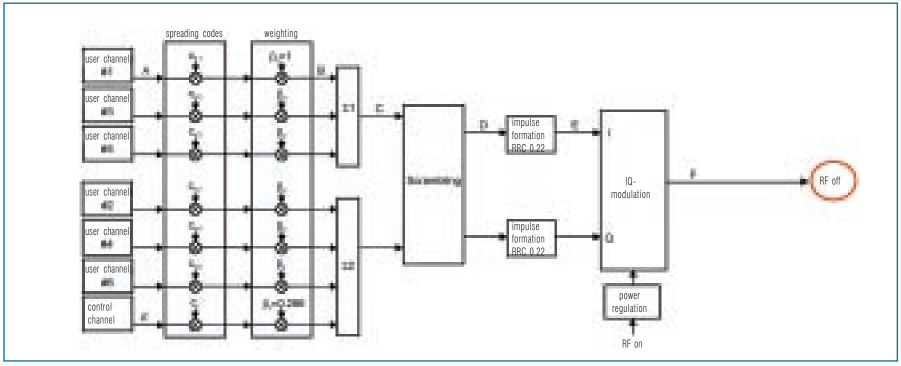

Fig. 2: Circuit block diagram for signal processing within the transmit component of a UMTS mobile telephone

Annotations to Fig. 1:
PILOT field: The pilot bits are required for assessing transmission quality and for frame synchronisation (FSW: Frame Synchronisation Word).
Transport Format Combination Indicator (TFCI): The TFCI bits contain information on user channel data rates.
Feedback Information (FBI): FBI information supports the so-called downlink closed loop transmission diversity mode. In this mode, a user signal is transmitted from the base station via two antennas to improve unfavorable reception conditions at the location of the mobile telephone. The FBI bits transmitted by the mobile telephone contain the necessary commands for post-regulation of phases and amplitudes of both transmission signals.
Transmit Power Control (TPC): TPC bits contain the commands for power regulation applied for equalising fast fading.
Annotation: PILOT and TPC bits are constantly available in the control channel, whereas TFCI and FBI bits are optional.

the low-frequency region where also natural biological processes occur.

This article describes the process of designing an appropriate generic UMTS test signal [7] for exposure experiments based upon the essential properties of typical signals at the UTRA air interface (UMTS Terrestrial Radio Access [5, 6]).

Properties of UMTS signals

This paragraph deals briefly with the main characteristics of UMTS signals sent between transmitter and receiver. For a more detailed overview see [8]; comprehensive information may be found in [9]; detailed technical specifications can be found on the web on [10], especially at [5, 6, 11-15).

UMTS is a digital, fully-duplex-capable mobile communication system. As a duplex mode for the separation of the two transmission directions, either the Frequency Division Duplex mode (FDD) or the Time Division Duplex mode (TDD) can be applied.

In the TDD mode the transmission signals from the base station (downlink) and from the mobile telephone (uplink) are of the same frequency, and are separated from each other by using different time slots resulting in a pulsed signal structure. Initially, after the introduction of UMTS, it is not planned to use the TDD mode. Later use of the TDD mode will be limited to local systems (pico cells). Therefore, we here consider only the FDD mode.

The FDD mode of the UMTS system is characterised by simultaneous transmission of uplink and downlink channels in separate frequency bands with a duplex distance of 190 MHz. For the FDD operation mode frequency ranges from 1.92 to 1.98 GHz (uplink) and from 2.11 to 2.17 GHz (downlink) are planned.

UMTS applies the Code Division Multiple Access (CDMA) technology as a multi-access system. This method permits the simultaneous use of radio resources of a mobile radio system by several participants. The main difference from the Frequency

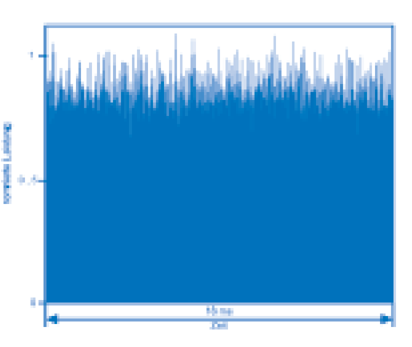

Fig. 3: Time evolution of a UMTS signal without power regulation

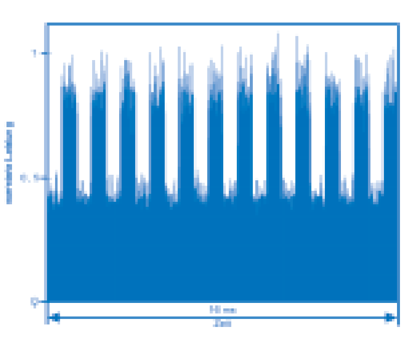

Fig. 4: Time evolution of a UMTS signal with power regulation

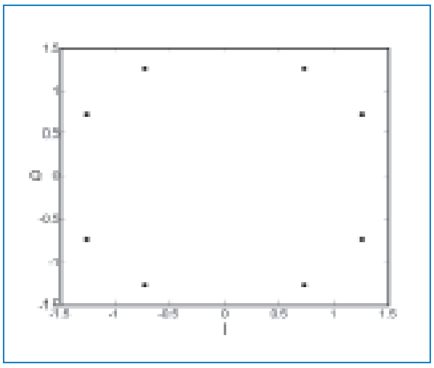

Fig. 5a: Constellation diagram (1 user channel with 960 kbit/s, 1 control channel) without impulse formation

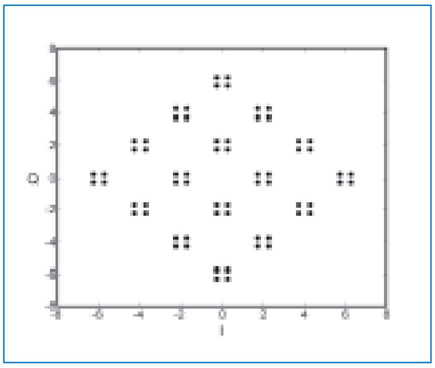

Fig. 5b: Constellation diagram (6 user channels with 960 kbit/s, 1 control channel) without impulse formation

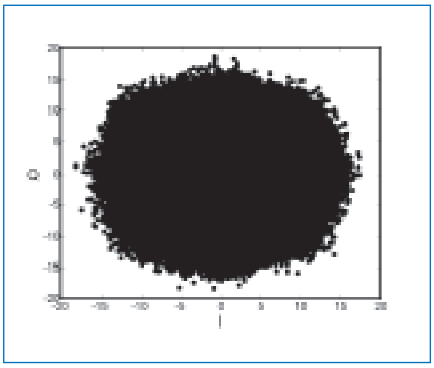

Fig. 5c: Constellation diagram (6 user channels with 960 kbit/s, 1 control channel) with impulse formation

Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA), applied for example in the GSM mobile radio system, is that in CDMA all participants simultaneously communicate within the same frequency band. The separation of user signals is accomplished by weighting via orthogonal spreading and scrambling codes, permitting the identification of individual base stations and callers and ensuring that received information can be decoded only by the callers to whom it is addressed. Codes consist of binary chip sequences of the chip rate 3.84 MChip/s, by which both user signals and control signals required for transmission of necessary system control information are multiplied. By means of the spreading codes the bandwidth of each channel is widened up to about 5 MHz independent of the gross data rate of the signals which may amount to 960 kbit/s maximum.

Uplink, the control channel is transmitted with its own spreading code parallel to, and downlink with an identical spreading code serial to, the user channel (see [8]). Whereas user channels can be filled continuously with the signal contents, the control channel always employs a logical structure, in which defined time periods are connected with certain command functions [12] (see Fig. 1).

The uplink and downlink user and control channels of a given connection are coded, weighted and (after a 90°phase shift of a part of the signals) overlayed. The result is a complex chip sequence from which – after further ("complex scrambling") coding and impulse formation by a root-cosine filter (root raised cosine filter RRC 0.22 with a roll-off factor of 0.22) – the input signals for the in-phase and/or the quadrature input of an IQ modulator (QPSK modulator) are developed by redigitalising the phase position of the radio-frequency carrier signal in accordance with the phase of input signals.

Fig. 2 shows the circuit block diagram for the signal preparation, using the example of the transmission component of a UMTS mobile telephone; Fig. 3 shows a segment of the calculated time course of a UMTS signal at the air interface (at point F in Fig. 2, here shown as the power of the equivalent low-pass signal) produced by the overlay of a 960-kbit/s (gross data rate) user signal by a typical control signal and following QPSK modulation. Obviously, the envelope of the RF signal is time-varying; the form of the variation depends of the number of overlayed channels, their data rate and signal form.

A fundamental property of UMTS is the implementation of a very rapid transmission power regulation. This ensures that variations of the reception field strength caused by time-varying radio field dampening or interference arising from multipath reception – even in the case of a rapidly moving mobile user – do not lead to an impairment of transmission quality, and in addition is necessary for minimising the power of all signals so that the signal intended for a certain receiver is not interfered with by a superposition of simultaneously-transmitted stronger CDMA signals in the same frequency band. During an given connection the receiver tell the transmitter end whether the power should be increased or decreased, via transmit power control (TPC) commands which are transmitted in the time-slot phase of the control channel (1500 Hz) . Uplink, the power can be regulated every 0.67 ms = 1/ 1500 Hz in steps of 1, 2 or 3 dB up to a total dynamic range of 83 dB [11], whereas a power increment downlink amounts to 0.5 dB and/or 1 dB over a dynamic range of at least 18 dB [6]. For example, the power regulation of the signal in Fig. 3 could be modified as shown in Fig. 4. It is obvious that variations of the envelope caused by power regulation can significantly exceed the variations which have hitherto been discussed.

Apart from the described normal transmission mode, the UMTS system employs other special operation modes, of which we will mention only a few: DTX (key word: transmission break), packet mode (key word: SMS), compressed mode (key word: handover), power save mode (still in planning), and PRACH mode (key word: conversation set-up).

Generic UMTS test signal

In designing a uniform exposure signal for biological experiments conducted to prove or exclude an effect of mobile communication radio-frequency fields, it is important that mechanisms which could lead to temporal amplitude variations of transmission signals in the practical system are adequately combined as a kind of

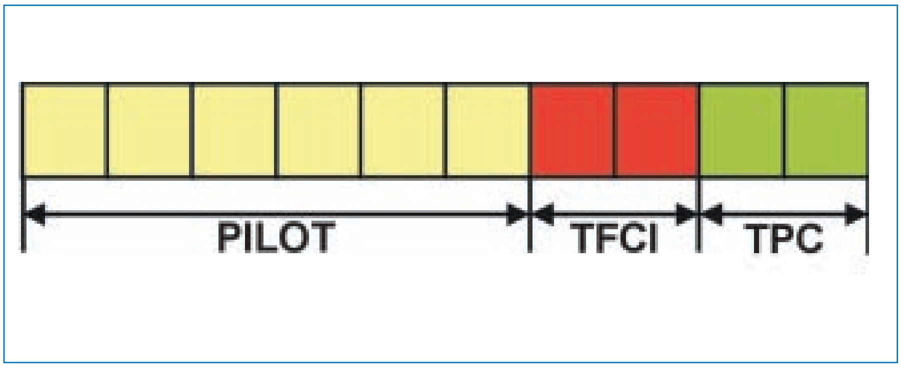

Fig. 6: bit structure of a control channel time slot as an example of the uplink

Explanation of Fig. 6:
The UMTS control channel has a data rate of 15 kbit/s. This is equivalent to 10 bits per slot. In the following, the exact filling of time slots of the simulated control channel is described.
The PILOT field is realised as a deterministic bit sequence with 6 bits per time slot. Filling of the respective time slots within a frame is specified in [12] and shown in table 1.

bit number	**1**	**2**	**3**	**4**	**5**	**6**
time slot number 1	1	1	1	1	1	0
time slot number 2	1	0	0	1	1	0
time slot number 3	1	0	1	1	0	1
time slot number 4	1	0	0	1	0	0
time slot number 5	1	1	0	1	0	1
time slot number 6	1	1	1	1	1	0
time slot number 7	1	1	1	1	0	0
time slot number 8	1	1	0	1	0	0
time slot number 9	1	0	1	1	1	0
time slot number 10	1	1	1	1	1	1
time slot number 12	1	1	0	1	1	1
time slot number 13	1	1	0	1	0	0
time slot number 14	1	0	0	1	1	1
time slot number 15	1	0	0	1	1	1

Table 1: Filling of control channel time slots: For TFCI the value 0 was selected and corresponding to the specification [12] coded to a 30 bit long word sequentially distributed to the time slots with 2 bits each. The selection of TFCI is arbitrary, since no information is to be transmitted.
TPC bits are realised by a random generator filling subsequent time slots in pairs in accordance with [12].
Here, the FBI bits mentioned (see Fig. 1) are not considered since they are transmitted in only one particular transmission mode.

worst-case cocktail. Each mechanism has to be sufficiently weighted; there must be a certain probability that it may occur in the real system.

In the following we will explain on which principles the selection of the respective parameters for the generic UMTS test signal are based.

Essential selection criteria are:

1. Settings have to comform to the technical specifications of the UMTS system for adapting the test signal as far as possible to real conditions.

2. An important point is to consider the signal properties which deviate from those of 2nd generation mobile radio systems (GSM, DECT).

3. The aim is to identify parameters which affect time-variations of the radio-frequency signal at the air-interface.

4. The different parameters have to be combined in a way that leads to a maximum signal variation with low-frequency spectral components in the sense of a worst-case observation.

5. For application as an exposure signal in biological experiments, the signal must be repeated periodically with a repeat rate being significantly below the modulation frequency of real UMTS signals and below the frequencies relevant for biological processes.

To conform with these requirements,the following properties are set for the generic UMTS test signal: *FDD or TDD mode:* For the reasons mentioned above, and on the basis of results already available from several biological experiments with GSM sig-

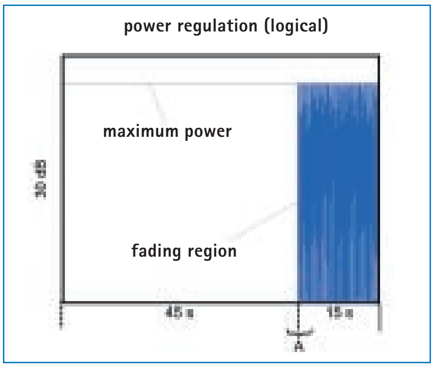

Fig. 7a: Power regulation (segment of entire signal)

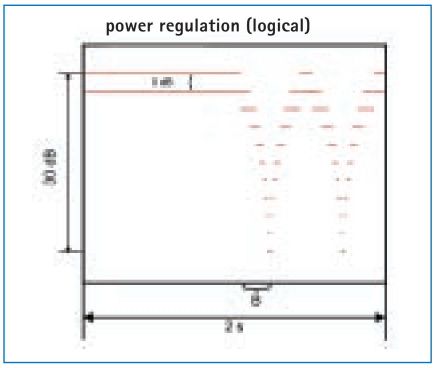

Fig. 7b: Power regulation (segment A)

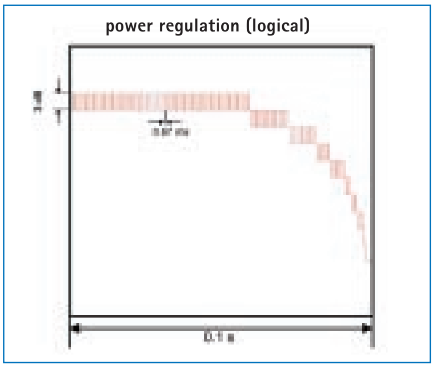

Fig. 7c: Power regulation (segment B)

nals of a time slot structure similar to the TDD mode of UMTS, it seems appropriate to simulate a UMTS test signal in the FDD mode.

Carrier frequency: There is general agreement on the fact that so-called "window effects" are not to be expected in biological systems within a frequency interval of only 15% relative bandwith as used in the FDD operation mode. Therefore, a given specification of the carrier frequency forthe generic UMTS test signal has no significant relevance for a given biological experiment.

Modulation: The technologically simplest solution of applying an RF signal with the addition of noise as being able to represent the UMTS signals [8] often characterised as "similar to noise" has to be ruled out because this procedure cannot simulate the typical bandwidth and discreet spectral components of a real signal. Therefore, it is necessary to produce the generic UMTS signal via a processing scheme being as near as possible to the function blocks specified for the UMTS system as shown in Fig. 2: spreading coding of the serial binary data channels (user and control data), weighting, (/2 phase shift and combination of two or more channels in a "complex" chip sequence (1 + j(2)), multiplication by a "complex" 'scrambling' code and physical separation of I and Q channels, impulse formation and I/Q modulation.

Thus, two causes of realistic signal variations have now been considered: whereas, for example, from only one binary input signal (+ 1 control signal) a constellation diagram such as Fig. 5a follows representing only few (approximately discreet) phase states and hence only slight amplitude variations, a greater number of used input channels is connected with a filling of the constellation diagram (see Fig. 5b for 6 user channels + 1 control signal). The phase has a significantly higher value, and the connected signal amplitudes show considerably bigger differences, too. In addition, the root-cosine filter for impulse formation leads to a clipping of the spectrum causing further signal distortions, i.e. an increase of the number of different amplitudes (see ill. 5c). The actual time variations of the RF signal envelope at the air interface also depend fundamentally on the nature of the input signal, which has to be specified for a reproducible test signal.

Control signals: Because of the control channel structure described in point 2 above, periodically-recurring control sequences can be manifested in the frame (1/100 Hz) or in the slot phase (1/1500 Hz) in the form of corresponding low-frequency variations of the envelope. Therefore, for simulation of control signals in the generic UMTS test signal it is necessary to apply data sequences similar to real formats in accordance with [12]. As for the filling of time slots of the control channel for the generic UMTS test signal the settings shown in Fig. 6 are applied.

User signals (communication signals): During normal operation mode, user signals have no structure comparable with the above-mentioned frame format. Therefore, their actual simulation for a generic UMTS test signal is of secondary relevance. Thus, for a signal with low data rate, an arbitrary speech signal could be selected, and for a broadband signal a sequence of computer network data could be used. In both cases, pseudo-bit sequences could be also be applied, which are of additional advantage for technological realisation.

A number of computer simulations of the highest data rate planned for UMTS in the FDD mode (uplink) of 960 kbit/s showed stronger signal variations with the frequency components relevant here than at smaller bit rates. Thus, according to the worst-case rule, the generic UMTS test signal should function at the high data rate.

The contents of the data channel are simulated by a so-called pseudo-noise bit sequence (PN sequence). A PN sequence is an artificial periodic time-discreet binary sequence showing similar poperties to a random sequence (randomly-distributed binary signs of the same occurrence probability [16]. Here, a binary "maximum length" sequence is applied as the PN sequence.

Number of user channels: At the downlink (base station transmission signal), there is in practice an overlay of several channels (for example > 50) being transmitted by a base station of the same (long) scrambling code, but different spreading codes. Apart from the control channel, an uplink mobile telephone can process a maximum of six user channels with different spreading codes and a common scrambling code.

Code name		Code length	Chip sequence
user channels	$C_{ch,4,0}$	4 Chips	{1,1,1,1}
	$C_{ch,4,1}$	4 Chips	{1,1-1,-1}
	$C_{ch,4,2}$	4 Chips	{1,-1,1-1}
	$C_{ch,4,3}$	4 Chips	{1,-1,-1,1}
control channel	$C_{ch,256,0}$	256 Chips	{1,1,1,1,1,................,1}

Table 2: spreading codes of the generic UMTS signal

Apart from details of importance only for signal processing, the signals of the individual channels are similar to each other in their basic time and frequency structure.

The dominant signal variations triggered by the fast power regulation show a stronger effect uplink than downlink. At the mobile telephone they affect the total transmission power. In contrast, the base station emits a common channel of constant power in addition to the many non-synchronic power-regulated traffic channels. Thus, the variations of the total signal here are less deterministic and rather more similar to noise.

Therefore, for the generic UMTS test signal, similar to that of a fully-operating mobile telephone, an overlay of six synchronous power-regulated user channels of the gross data rate 960 kbit/s (plus a control channel) is planned for.

Special operation modes: The operation modes of the UMTS system used only temporarily, such as DTX, packet mode, and so on, should not be incorporated as part of the generic UMTS test signal. Biological experiments are usually conducted over longer time periods longer than those used for such modes, so that they are not relevant compared with the normal transmission mode. Moreover, most of the operation modes are connected with a signal structure similar to that of the TDD mode; thus, the knowledge already gained from biological studies in the GSM range is probably portable to the UMTS situation.

Spreading codes: The selection of the rather precisely-defined spreading codes [14] does not lead to any significant differences in the time variation of the signal at the air interface. For the spreading codes employed in the generic UMTS test signal, the chip sequences as shown in Table 2 are used.

"Scrambling codes": Considering signal variations it is very important whether long or short sequences are applied as scrambling codes [14]. Basically, for long scrambling codes 100-Hz components and harmonics occur, whereas for short scrambling codes additional 1.5-kHz and 15-kHz components and their harmonics are possible. The latter have to be seen as a worst case, and thus should be used for the generic UMTS test signal. The short scrambling codes described in [14] have a length of 256 chips and are clearly specified by their code numbers. Out of the total of 224 possible codes for the generic UMTS test signal, the code with the code number 30 is selected.

Power regulation ("inner loop power control"): As shown in paragraph 2, power regulation is the second fundamental cause of alterations of the RF transmission power, in other words, for further low-frequency variations of the signal envelope at the air interface. It is meant to minimise the variations of the transmission power caused by the – mostly unknown – time variation of the transmission function of the air interface. For a description of the spatial alterations of the radio field attenuation for the frequency range around 2 GHz, there are semi-empirical standards based upon measurements (extended COST Hata model, COST Walfisch-Ikegami model). However, they allow only conclusions to be drawn on the average with respect to the radio field attenuation to be expected, depending on the quality of the environment (rural, urban, etc), on the distance of the mobile telephone to the base station and on the antenna height [17]. The superimposed spatial and time variations of radio field attenuation that need to be analysed for the simulation of an actual regulation signal can be found only with the help of stochastic models [18], or by a deterministic field analysis of selected scenarios for the shape of the landscape or the layout of building development schemes.

For the generic UMTS test signal a time evolution of the initial power is set (ill. 7a. 7b and 7c), on one hand containing typical characteristics of fast power regulation, and on the other hand providing a periodic total signal as well as a relatively small difference between mean and maximum power (about 2 dB).

In practice, such an exposure signal for example could occur when a mobile radio user is initially at a location with very bad reception conditions for 45 s (transmission power remains at maximum value with superimposed regular variation, 3 dB here), then moving within an area of varying reception conditions for a duration of 15 s; transmission power is adapted anti-correlated to the fading every 0.67 ms (1/1500 Hz) in 3-dB steps.

Absolute RF power: The maximum initital power of a mobile telephone (user equipment) specified for UMTS is 2 W. However, the total power transmitted from a base station reaching a person at a permitted distance is normally much smaller than the power transmitted by a mobile telephone. Moreover, because of the already above-mentioned need for equalised reception signals for different channels, the transmission power is always regulated to the smallest possible level.

However, the power applied during biological experiments does not correspond to the very small values which in practice occur with the use of a mobile communication system, since the aim is to prove or disprove a biologically-relevant effect, as related to the specific absorption rate which can be expected in a system without exceeding the SAR limit values which are based on the thermal threshold. To achieve such high SAR values in experiment during *in vivo* tests in general an RF power significantly higher than those occurring within the UMTS system is required. Basically, the RF power required depends on the number, forms, and material parameters of the objects under test, as well as on the type of the exposure set-up employed (see [19]).

Thus, the power of the generic UMTS test signal to be used has to be adjusted to each experiment planned.

Summary: This article describes in detail the properties of a generic UMTS test signal which is planned to be used as an exposure signal in experiments with the purpose of examining the compatibility of biological systems with modulated electromagnetic fields. The signal contains a cocktail of the new UTMS features that could be seen as biologically relevant because of their contribution to low-frequency signal fluctuations.

For a practical realisation of the suggested generic UMTS test signal a signal generator was developed (GUS 6960 S) which provides an average initial power between -20 dBm and + 10 dBm with a fixed programmed steady-signal form. This is fed into an RF power amplifier.

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References

[1] Grenzwerte und Vorsorgemaßnahmen zum Schutz der Bevölkerung vor elektromagnetischen Feldern. Empfehlung der Strahlenschutzkommission, Juli 2001.(Limit values and precautionary measures for the protection of the general population against electromagnetic fields. Recommendation of the Commission for Radiation Protection.)

[2] EU-Kommission: Empfehlung des Rates zur Begrenzung der Exposition der Bevölkerung durch elektromagnetische Felder (0 Hz-300 GHz), 1999/519/EG, Juli 1999.(Recommendation of the Council for limiting the exposure of the general population to electromagnetic fields)

[3] ICNIRP: Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz). Health Physics, 74, 494-522, 1998.

[4] Schüller, M., Streckert, J., Bitz, A., Menzel, K., Eicher, B.: Proposal for generic GSM test signal. Proc. 22nd BEMS Annual Meeting, Munich, Germany, 122-123, 2000.

[5] 3G TS 25. 102: Universal Mobile Telecommunication System (UTMS); UTRA (UE) TDD; Radio Transmission and Reception (FDD), Version 3.1.0, January 2000.

[6] 3G TS 25. 104: 3rd Generation Partnership Project (3GPP): Technical Specification Group Radio Access Networks UTRA (BS) FDD; Radio transmission and reception, Version 3.2.0, March 2000.

[7] Bitz, A., Bökelmann, V., Gerhardt, D., Hansen, V., Hombach, V., Streckert, J., Ndoumbè Mbonjo Mbonjo, H.: A generic UMTS test signal for bio-experiments. 5th International Congress of the European BioElectromagnetics Association (EBEA), Helsinki, Finland, 173-174, 2001.

[8] Steiner, B.: Neue Technologie UMTS - das Mobilfunksystem der nächsten Generation. FGF Newsletter, 8, 16-22, 1/2000.

(New technology UMTS - the mobile radio system of the next generation)

[9] Holma, H., Toskala, A.: WCDMA for UMTS, John Wiley & Sons, Ltd., Chichester, Revised Edition, Spring 2001.

[10] http://www.3gpp.org

[11] 3G TS 25.101: 3rd Generation Partnership Project; Technical Specification Group Radio Access Networks; UE Radio transmission and Reception (FDD), Version 3.2.2, April 2000.

[12] 3G TS 25.211: Universal Mobile Telecommunication System (UMTS); Physical channels and mapping of transport channels onto physical channels (FDD), Version 3.3.0, June 2000.

[13] 3G TS 25.212: 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Multiplexing and channel coding (FDD), Version 3.2.0, March 2000.

[14] 3G TS 25.213: 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Spreading and modulation (FDD), Version 3.2.0, March 2000.

[15] 3G TS 25.214: 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Physical layer procedures (FDD), Version 3.2.0, March 2000.

[16] Lüke, H.D.: Signalübertragung. Springer-Verlag, Berlin Heidelberg, 1999.(Signal transmission)

[17] Geng, N., Wiebeck, W.: Planungsmethoden für die Mobilkommunikation: Funknetzplanung unter realen physikalischen Ausbreitungsbedingungen. Springer-Verlag, Berlin 1998.

(Planning methods for mobile communications: radio network design under realistic physical distribution conditions)

[18] Proakis, J.G.: Digital Communications. McGraw-Hill, New York, 2000.

[19] Streckert, J., Bitz, A., Hansen, V., Buschmann, J.: High SAR exposure of 24 rats at 900 MHz: problems of temperature limits and uniform field distribution. Millennium Workshop on Biological Effects of Electromagnetic Fields, Heraklion, Greece, October 2000, 185-195.