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THE ELECTROMAGNETIC RADIATION FOR BIOLOGICAL STRUCTURES IN THE CASE OF MOBILE TELEPHONY

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***Abstract**: The frequencies used have wavelengths that can be compared to the physical dimensions of the skull and the power emitted by portable phones is quite high, around 0,6W. Because of the proximity of the head (just a few centimeters away), with all the reflections from the surface of the skull and the attenuations that intervene, the field intensities that manage to get inside the skull can induce in the cerebral mass currents of the same size with the intensities of normal biological currents.*

Introduction

Cellular telephony uses a frequency domain ranging between 800 MHz and 2000 MHz with emission powers of 0,6W to 2W.
According to the 1999/519/CE 12th of July 1999 Recommendation, the reference levels of radiofrequency fields used in the GSM system are (table 1):

Table 1.

Frequency (MHz)	Electric field E (V/m)	Magnetic field H (A/m)	Density of Power (W/m²)
900	41	0.11	4.5
1800	58	0.16	9

The respective norms, also called basic restrictions and reference levels establish safety coefficients in the case of electric, magnetic and electromagnetic field exposure variable in time, based directly on the obvious effects on health and biological considerations. Depending on the field frequency, the physical units used in order to specify the restrictions are the magnetic induction (B), the density of current (J), the specific absorption rate (SAR) and the power density (S). The SAR unit is used within the 100 kHz – 10 GHz frequency range to define the basic restrictions concerning the electromagnetic fields in order to prevent a generalized thermal stress of the body and an excessive localized heating of tissues.
It is worth noticing that in the case of simultaneous exposure to different frequency fields there is a possibility that the effects of the exposure are cumulative. As a convention, each effect will be studied using separate calculations and based on the hypotheses, separate evaluations of the effects of thermal and electric strain of the organism will be covered.
Knowing the electric properties of biological environments is essential to the study of the interaction phenomena between these and the electromagnetic field. The electrical properties involve permittivity and electric conduction.
The magnetic properties (with some exceptions that do not concern the present paper) are not defined for the biological matter; the relative permeability of biological entities is considered to equal a unit (μ_r= 1) and the losses obtained through the magnetic effect are thought to be negligible.

The electric properties that intervene in the study of the biological effects of electromagnetic fields are the electric permittivity ε and the conduction σ defined over the unit of volume of matter. Permittivity characterizes the interaction between the environment and the electromagnetic wave that is propagated through it. The permittivity of free space is a constant: ε_0 and the permitivity of any other environment is a complex measurement ($\varepsilon_c = \varepsilon' - j\varepsilon''$) in which ε' is an indicator of the property of the environment to store energy while ε'' indicates the property of the environment to dissipate the energy carried by the electromagnetic field.

Relative permittivity measures the net effect of the electric dipoles alignment that characterizes the intimate structure of the matter that is under the influence of an electric field applied from the outside.

The energy dissipated per second per unit of volume of homogenous material by an electromagnetic wave incidence is proportionate to the square of the amplitude of the electric field component and is calculated with the help of this formula [1]:

$$P = \pi f\, \varepsilon_o \varepsilon'' E^2 = \sigma\, E^2/2 \qquad (1)$$

where σ is the conduction of the environment in which the dissipation of energy takes place. The conduction is itself dependent on the frequency.

All these units (σ, ε'' or tan δ) characterize the possibility of the environment to absorb the energy from the electromagnetic field.

Calculating the values of the dielectric units (permittivity, conduction, wavelength, intrinsic impedance, penetration depth etc) that characterize the human tissues at the frequencies of 800 MHz and 900 MHz used by the Romanian mobile telephony was done by using a program in EXCEL based on formulas [2], [3] that allows for finding these measurements up to the frequency of 300 GHz.

Formulas used in calculation of dielectric properties:

complex permittivity :

$$\varepsilon_c = \varepsilon' - j\varepsilon'' \qquad (2)$$

rel. complex permittivity:

$$\varepsilon_{cr} = \varepsilon_r' - j\varepsilon_r'' = \frac{\varepsilon_c}{\varepsilon_0} \qquad (3)$$

$$\varepsilon_r'' = \frac{\sigma}{\omega\varepsilon_0} \qquad \varepsilon'' = \frac{\sigma}{\omega}$$

permittivity, permeability impedance and wave velocity ε_0, μ_0, η_0 and c.

angular frequency: $\omega = 2\pi f$

loss tangent of material:

$$\tan(\vartheta) = \frac{\sigma}{\omega\varepsilon'} = \frac{\varepsilon_r''}{\varepsilon_r'} \qquad (4)$$

attenuation constant of material: y = α

$$\gamma^2 = j\omega\mu(\sigma + j\omega\varepsilon') = -\mu_r\left(\frac{\omega}{c}\right)^2(\varepsilon_r' - j\varepsilon_r'') \qquad (5)$$

attenuation constant of material:

$$\alpha = \left(\frac{\omega}{c}\right)\sqrt{\frac{\mu_r\varepsilon_r'}{2}\left(\sqrt{1+\left(\varepsilon_r''/\varepsilon_r'\right)^2} - 1\right)} \qquad (6)$$

skin depth material

$$\delta = \frac{1}{\alpha} \qquad (7)$$

phase constant of material,

$$\beta = \left(\frac{\omega}{c}\right)\sqrt{\frac{\mu_r\varepsilon_r}{2}\left(\sqrt{1+\left(\ddot{\varepsilon}_r/\dot{\varepsilon}_r\right)^2} + 1\right)} \qquad (8)$$

wave velocity in material

$$u = \frac{\omega}{\beta} \qquad (9)$$

wavelength in material, $\lambda = \frac{2\pi}{\beta}$ (10)

intrinsic impedance of material,

$$\eta = \sqrt{\frac{\mu}{\varepsilon_c}} = \eta_0\sqrt{\frac{\mu_r}{\dot{\varepsilon}_r - j\ddot{\varepsilon}_r}} \qquad (11)$$

$$|\eta| = \eta_0\sqrt{\frac{\mu_r}{\dot{\varepsilon}_r\left[1+\left(\ddot{\varepsilon}_r/\dot{\varepsilon}_r\right)^2\right]^{0.25}}} \qquad (12)$$

$$\text{phase}(\eta) = 1/2\tan^{-1}\left(\ddot{\varepsilon}_r/\dot{\varepsilon}_r\right) \qquad (13)$$

$0^0 \leq \text{phase}(\eta) \leq 45^0$

Formulas used for □r' and □r'' are: [2]

$$\varepsilon_r' = \varepsilon_3 + \frac{\varepsilon_1}{1+\left(\frac{f}{f_1}\right)^2} + \frac{\varepsilon_2}{1+\left(\frac{f}{1000\cdot f_2}\right)^2} \qquad (14)$$

$$\varepsilon_r'' = \frac{\sigma_0}{2\pi\varepsilon_0\cdot f\cdot 1000} + \frac{\varepsilon_1 f}{f_1\left[1+\left(\frac{f}{f_1}\right)^2\right]} + \frac{\varepsilon_2 f}{1000 f_2\left[1+\left(\frac{f}{1000 f_2}\right)^2\right]} \qquad (15)$$

The values of the units used in calculating these dielectric parameters are given in the table 2:

Table 2a.

TISSUE	bone	skin	blood	Brain	Heart
ε3	4,9	3,3	4,3	7,5	4,3
σo (S/m)	3,1E-07	0,231	0,768	0,313	0,63
f1 (MHz)	2360	137	37,8	43,3	90,6
ε1	2,22	34,3	136	122	49,4
f2 (GHz)	20,4	17,7	21,3	16,5	15,6
ε2	1,8	32	54,3	38,7	55,9

Table 2b.

TISSUE	muscle	kidney	liver	lung	spleen
ε_3	4,3	4,3	4,3	4,3	4,3
σo (S/m)	0,301	0,551	0,406	0,325	0,44
f1 (MHz)	8,3	24,7	44,2	81,8	26,6
ε1	475	166	136	69,1	289
f2 (GHz)	15,2	24,5	21,6	15,1	19,8
ε2	49,9	43,2	41,6	28,3	48,1

Results of the Experiment

The results of these calculations corresponding to the two bands are presented in the table 3a, b for f=800 MHz and in the table 3 c, d for f=900 MHz

Table 3a. .: f=800 MHz

TISSUE	bone	skin	blood	brain	Heart
εr'	8,688429	36,212	58,82646	46,4656	60,67894
εr"	0,745467	12,34021	25,70435	15,48868	22,53825
σ (S/m)	0,033178	0,549214	1,143998	0,689339	1,003087
μr	1	1	1	1	1
tan(θ)	0,0858	0,340777	0,436952	0,333337	0,371434
α (1/m)	2,118257	16,95389	27,47556	18,79632	23,86113
β (1/m)	49,46731	102,3108	131,5008	115,8271	132,7692
u (m/s)	1,02E+08	49130166	38224479	43397013	37859280
λ (m)	0,127017	0,061413	0,047781	0,054246	0,047324
δ (m)	0,472086	0,058984	0,036396	0,053202	0,041909
|η| (Ω)	127,6914	61,75043	48,05721	54,54375	47,58779
?η (deg)	2,451985	9,408961	11,80151	9,217559	10,18837

Table 3b.

TISSUE	muscle	kidney	liver	lung	Spleen
εr'	54,11328	47,61208	46,2569	33,23576	52,64076
εr"	14,30979	18,90983	18,15213	15,7899	21,42521
σ (S/m)	0,636871	0,841601	0,807879	0,702745	0,953551
μr	1	1	1	1	1
tan(θ)	0,264441	0,397165	0,39242	0,475088	0,407008
α (1/m)	16,16963	22,55025	21,9707	22,37002	24,27742
β (1/m)	124,3946	117,8704	116,132	99,2159	124,0483
u (m/s)	40408097	42644715	43283050	50662729	40520887
λ (m)	0,05051	0,053306	0,054104	0,063328	0,050651
δ (m)	0,061844	0,044345	0,045515	0,044703	0,041191
|η| (Ω)	50,78194	53,60689	54,40852	63,70586	50,93874
?η (deg)	7,406157	10,83061	10,71302	12,70591	11,07336

Table 3c. f= 900 MHz

TISSUE	bone	skin	blood	Brain	heart
ε_r'	8,634636	35,99427	58,74271	46,36694	60,51015
ε_r''	0,818382	11,33951	23,33097	14,21199	20,71992
σ (S/m)	0,040976	0,567761	1,168164	0,711584	1,037431
μr	1	1	1	1	1
tan(θ)	0,094779	0,315037	0,397172	0,306511	0,342421
α (1/m)	2,623734	17,61374	28,17931	19,46225	24,77099
β (1/m)	55,48936	114,5292	147,2909	129,9078	148,8052
TISSUE	bone	skin	blood	brain	Heart
u (m/s)	1,02E+08	49374911	38392510	43529846	38001813
λ (m)	0,113232	0,054861	0,042658	0,048366	0,042224
δ (m)	0,381136	0,056774	0,035487	0,051382	0,04037
|η| (Ω)	128,0628	62,05502	48,26162	54,70811	47,76366
?η (deg)	2,707131	8,743167	10,8308	8,520446	9,451129

Table 3d.

TISSUE	muscle	kidney	liver	lung	spleen
εr'	54,06606	47,56672	46,15513	33,06596	52,55305
εr"	13,33614	17,14191	16,50214	14,40076	19,50378
σ (S/m)	0,667731	0,858282	0,82625	0,721035	0,97654
μr	1	1	1	1	1
tan(θ)	0,246664	0,360376	0,357536	0,435516	0,371126
α (1/m)	16,97889	23,08073	22,56177	23,10114	24,96166
β (1/m)	139,7314	132,1244	130,1189	110,8984	139,0013
u (m/s)	40469540	42799564	43459223	50991404	40682126
λ (m)	0,044966	0,047555	0,048288	0,056657	0,045202
δ (m)	0,058897	0,043326	0,044323	0,043288	0,040061
|η| (Ω)	50,8583	53,79605	54,62482	64,10789	51,13597
?η (deg)	6,928098	9,908974	9,836909	11,76695	10,18059

The external field incident to the biological structure can be expressed in terms of density of power (mW/cm^2), of amplitude of the electric field component (V/m) or of the magnetic field component (A/m). None of these parameters is appropriate for expressing the effects induced by the penetration of the electromagnetic radiation inside the biological domain. Considering this situation a specific parameter has to be defined. It is called the "Specific Absorption Rate – SAR" and it is the variation in time of the elementary energy quantity (dw) absorbed by an element of volume (dv) having a density (ρ) and an elementary mass (dm) [1].

$$SAR\ (W/kg) = \frac{d}{dt}\left(\frac{dW}{dm}\right) = \frac{d}{dt}\left(\frac{dW}{\rho\, dV}\right)$$

The Specific Absorption Rate (SAR) is correlated to the penetration depth (δ) in the tissues. If the penetration depth (δ) is the distance from the surface of the tissue for which the amplitude of the electric field component reduces with factor e = 2,71, than the specific absorption rate at this depth reduces to a value equal to 13,5% of its initial value.

Sometimes it is useful to define the depth d (frequently used in hyperthermia cases) at which the power incident to the surface of the irradiated structure is reduced to half (3 dB attenuation). Between (δ) and (d) there is the relation:

$$d = 0{,}345 \times \delta$$

In order to determine the value of the SAR parameter the TEMS (Test Mobile System) system was used. This system was offered by the ORANGE firm and the measurements were taken at the frequency of 900 MHz.

The applications of TEMS for an operational network are:

it simulates and verifies possible changes in the network;

it evaluates the quality of the received signal;

it measures the space covered /range;

it tests the system (checks new or already present functions)

it signals in real time aberrant values of any parameter (for example the large number of interrupted calls);

it identifies areas with problems of signal coverage or with high levels of interference;

it presents the data in graphs, maps;

The equipment used for measuring contains:

special software made by Erricsson-TEMS (Test Mobile System)

laptop, mobile phone, special data cable that insures the PC-mobile phone connection

The TEMS mobile phone is an Erricsson ordinary phone that uses the TEMS program. No supplementary calibrations are necessary for using the TEMS software.

This mobile phone has four different operation modes:

No Service (when it is in an area with no signal coverage)

Limited services (only emergency calls)

Inactive

Dedicate (during a conversation)

The measurements were taken during a conversation, therefore in the dedicate mode.

Taking the measurements involves:

initiating a call

choosing the unit to be measured, in this case the power of the transmitted signal (TxPwr) the display of the unit to be measured and information about the distance from the base station (TA – Time Advance), the base station code (BSIC – Base Station Identity Code), local code (LAC Local Area Code), the channel of the communication (TCH – Traffic Channel).

In order to calculate the value of SAR the situation when the telephone is in dedicated mode t_0 is used. At t_0 these units have the following values:

TxPwr =18dBm=62,5mW

TA = 2, d = TAx 500m

Therefore the distance (d) to the base station is 1 km.

BSIC = 23 ,LAC = 05500

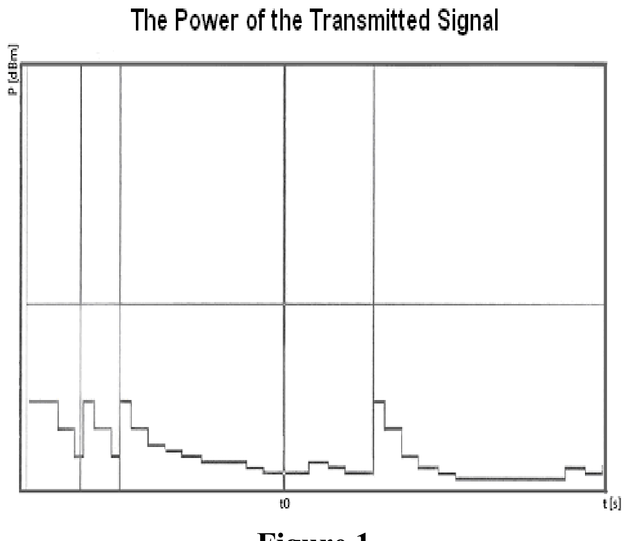


Figure 1.

The value of the SAR unit for the measured

	Telephone type / Area	with internal antenna			with external antenna	
		Speaker	Micro-phone	back	speaker	antenna
STATE	On	9.81	6.68	11.26	-	9.86
	Called	23.51	7.55	17.8	36.77	21.32
	Calling	21.42	19.66	33.98	29.94	24.18
	Speaking	28.71	19.7	38.43	36.72	28.2
	Off	2.45	6.87	10.32	-	

power is determined according to [1]:

$$SAR\left[\frac{W}{kg}\right]=\frac{\omega\varepsilon_0\varepsilon_r'' E^2}{\rho}=\frac{\sigma E^2}{\rho}=\frac{2P}{\rho}=\frac{2\cdot 0.0625}{1000}=$$

$$=0.1255\cdot 10^{-3}\left[\frac{W}{kg}\right]$$

where:

ε_0 = permittivity of free space

ω = angular frequency

ρ = the density of the biologic environment $\approx 1000\ kg/m^3$

E = the intensity of the electric field

$P = \pi f\,\varepsilon_0\varepsilon'' E^2 = \sigma E^2/2$

$$\varepsilon_0 = 8.8541878176\ E\times 10^{-12}\ \ F/m$$

$$\varepsilon_r'' = \frac{\sigma}{\omega\varepsilon_0}$$

It is observed that the specific rate of absorption SAE is under the maximum admitted level of 0,4 W/kg.

The value of SAR can also be determined according to the dielectric parameters ε'', σ and the electric field generated by the mobile phone.

In this case the system of measurement contains:

the type 8 electric field probe (Wandel & Goltermann) with the EMR 20 measuring device;

software for processing the values measured by the probe;

mobile phone with/ without the antenna.

The measurements were done considering the following three positions for the measurement probe:

positioning the electric field probe in the speaker area;

positioning the electric field probe in the inferior keys area;

positioning the electric field probe next to the inner antenna behind the telephone or next to the extended antenna in the case of telephones with exterior antennas.

The results obtained are succinctly presented in the following table.

The maximum values of the electric field registered in each area of measurement and expressed in V/m are also presented.

Table 4.

Are presented the results of the measurements:

for the A mobile phone in the speaker zone:

when the mobile phone is in service - Figure 2;

when is initiating a call – fig 3;

during the conversation – Figure 4;

at the switch on – Figure 5;

at the switch off – fig 6;

for the A mobile phone in microphone zone:

during the conversation – Figure 7;

for the A mobile phone, behind the phone in the antenna's zone:

when the mobile phone is in service - Figure 8;

when is initiating a call – fig 9;

during the conversation – Figure 10;

for the B mobile phone in speaker zone:

when the mobile phone is in service - Figure 11;

when is initiating a call – fig 12;

during the conversation – Figure 13;

for the B mobile phone in antenna's zone:

when the mobile phone is in service - Figure 14;

when is initiating a call – fig 15

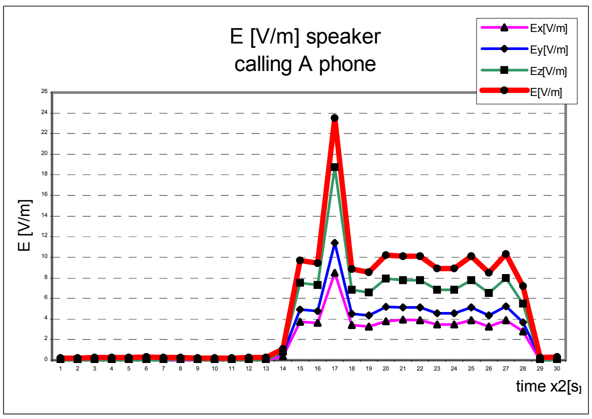


Figure 2.

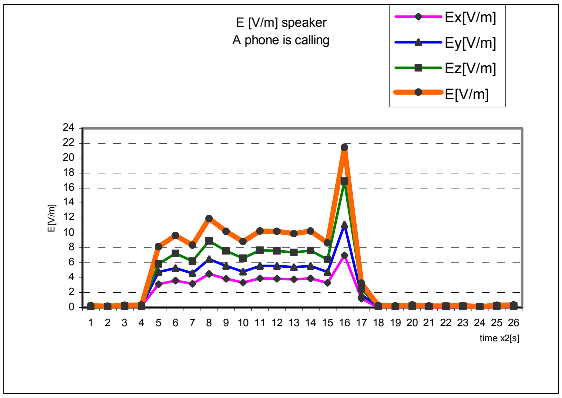
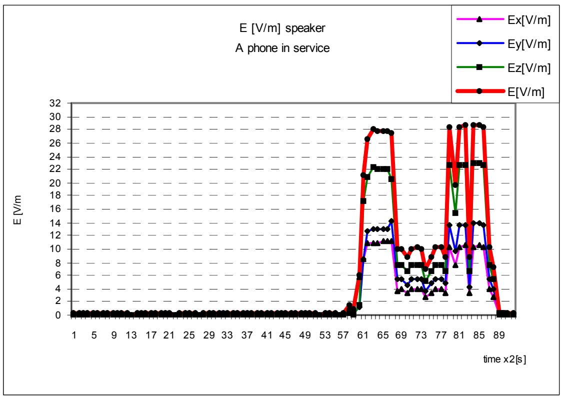


Figure 3.



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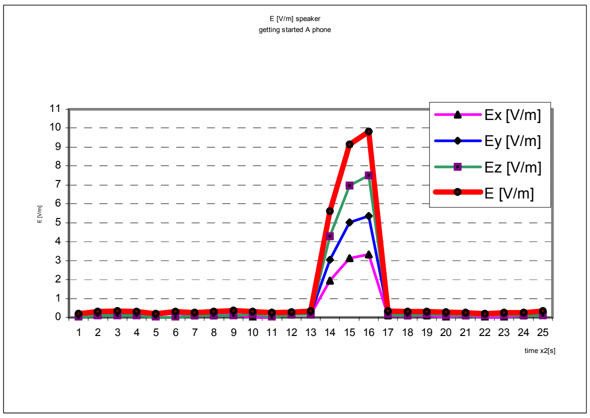

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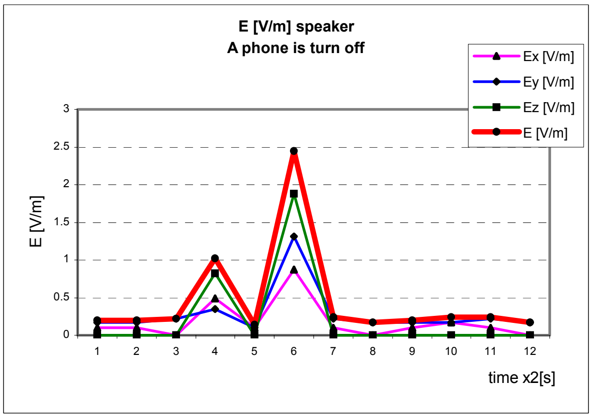

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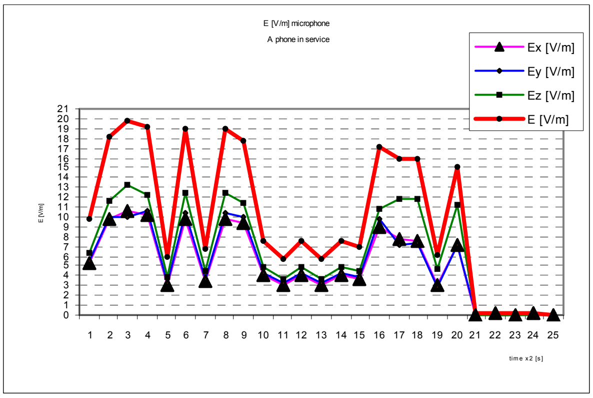

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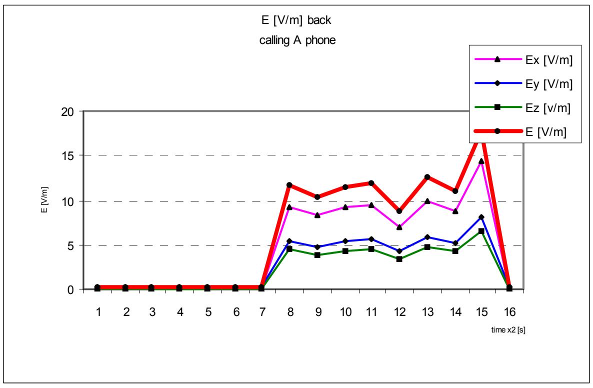

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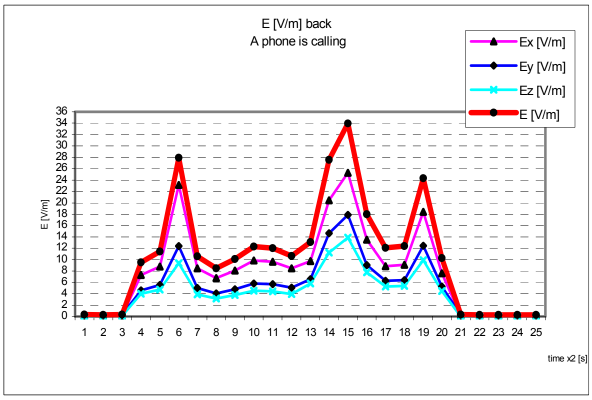

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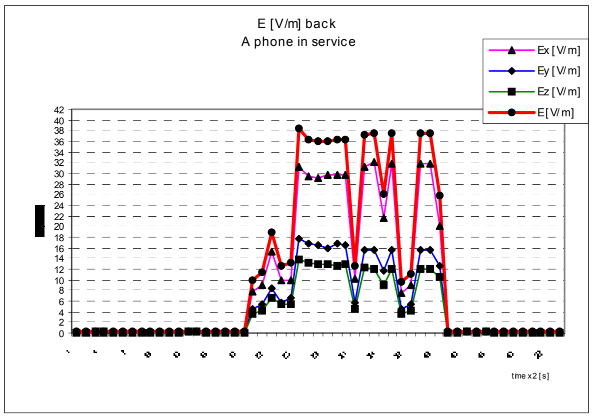

Figure 10.

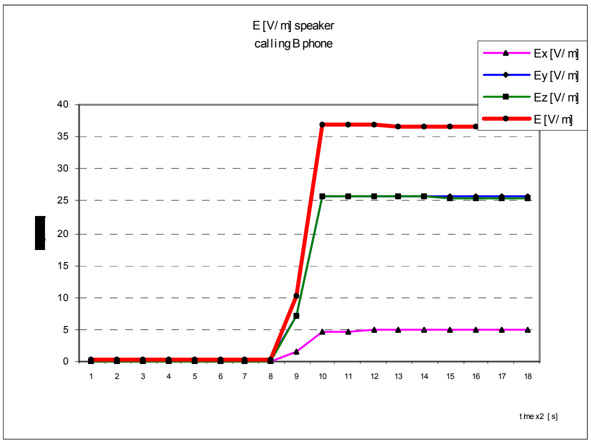

Figure 11.

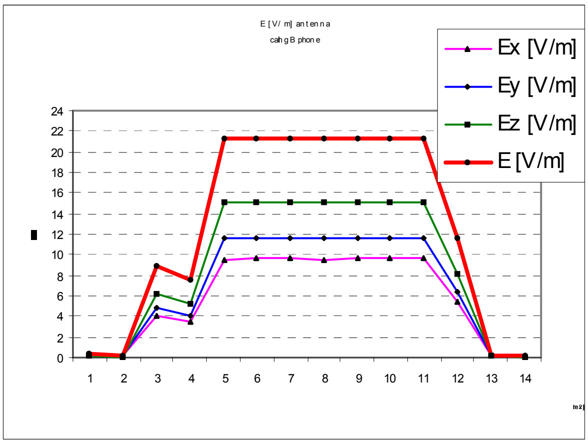

Figure 14.

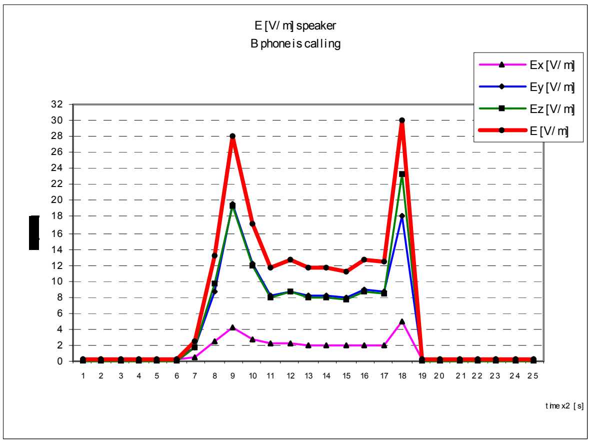

Figure 12.

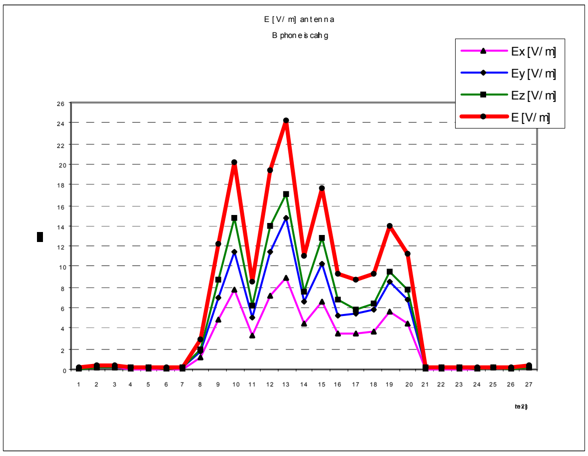

Figure 15.

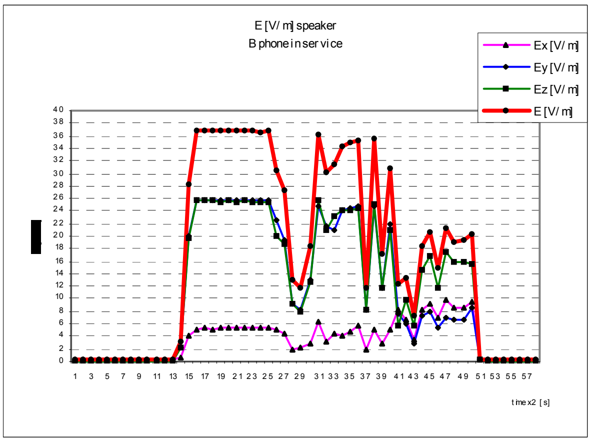

Figure 13.

Conclusions

The following observations can be drawn on the basis of the date from the table:

– the internal antenna has directivity by having a weaker emission in the area of the user's head;

– the emission is larger in the superior area of the internal antenna phone;

– the emission is stronger in the states where the telephone is in contact with the head of the user (when he calls and speaks); the antenna type does not matter;

– the telephone with an external antenna has a stronger emission at the level of the speaker than at the extremity of the antenna;

– the telephone with an external antenna does not have a weaker emission at the level of the speaker in comparison to the internal antenna telephone.

The difference in values from the experimental data provided by our bibliography and from the theoretical models is due to the various uncertainty factors that are linked to the measurements in a close-range field and the digital character of the signal:
the size of the detecting field unit that disturbs the measuring field;
the link between the measuring probe and the emission antenna of the telephone;
the measuring technique of the digital signal.

It was observed that at low levels of power density some effects take place after a longer exposure time. They are called “low level power effects” or “athermic effects”, effects that also appear in the case of using mobile phones. It is best to consider the following recommendations even if the SAR value is situated between the limits established by the European Commission:
to reduce using mobile phones in conditions of low signal; to avoid wearing mobile phones close to the sensitive tissues;
using car kits;
constantly informing the population of the level of radiation around the base stations by operating frequent measurements that would be accessible to the public;

The conclusion is that the general objective should be to reduce the degree of exposure of the population to radiofrequency fields.

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