Electromagnetic Field Measurements at 900 MHz to Obtain the Effects of Mobile Communication on Risk Probabilities for the Human Health

I. Hakki Cavdar and N. Erol Ozguner

***Abstract*—The demand for mobile communication has been increasing rapidly from day to day. Resulting from this interest, many researches and studies have been conducted for the prediction of the effects of mobile communication on the human health. In this research, mobile propagation measurements are carried out in both side-base stations and mobile phones at 900 MHz. Using the results obtained from these experiments, some statistical properties such as averages and standard deviations of the electric field for various mobile phones are determined. Measurements are repeated for different base stations and mobile phones to obtain more realistic data to calculate important statistical parameters in the mobile systems. The widely used mobile phones in Turkey are selected in the experiments. Risk probabilities for human health are calculated using the standard values existing in the literature. It is not any risk on idle mode but some mobile phones have 100% risk on call setup and active modes for human health.**

***Index Terms*—Base station, electromagnetic field, GSM, human health, mobile phones, risk probability.**

I. INTRODUCTION

A NUMBER of scientific articles have been published about electromagnetic radiation and its effects on human health in recent years. The non-governmental organization accepted as an independent expert body by the United Nations (UN), the World Health organization (WHO), the International Labor Organization (ILO), the European Union (EU) and most of the developed countries is the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The commission is established for the purpose of advancing non-ionizing radiation (NIR) protection for the benefit of people and the environment and in particular to provide guidance and recommendation on protection from NIR exposure. In 1998, the ICNIRP published its latest guidelines for exposure limits, which were based on the evaluation of all available and known analytical/numerical/experimental study results [1]. In this guidelines, as well as in the others [2], [3], for example, electrical field strength at 900 MHz and 1800 MHz should not exceed 42 V/m and 59 V/m respectively, anywhere in public residence. Inadequacy of the up to date scientific information has led to worldwide controversial and heated debate, which in turn forces many countries lower these levels as low as 4-6 V/m [4]. Also, IEGMP (Independent Expert Group on Mobile Phones) published a guidebook about this subject in 2000. They stated that there were two direct ways by which health could be affected as a result of exposure to RF radiation. These are by thermal (heating) effects caused mainly by holding mobile phones close to body, and as a result of possible non-thermal effects from both phones and base stations [4]. TUBITAK (The Scientific and Technical Research Council of Turkey) published a guidebook about electromagnetic fields and human safety. They stated that there was no evidence relating the cancer and the use mobile phones [5]. Ozguner *et al.* investigated base stations measurements and reported that there was no over limit measurement for base stations at 900 MHz in Turkey [6].

In the last 4-5 years a number of studies have been done and on going about the effects of mobile communication on human health. Through determination of effects of EMF's on human, animals, plants or proteins, vitamins and some hormones. Although many researches were carried out, there are not enough data about electric and magnetic fields for BTSs and MSs in the literature. Medical and communications investigators require more data to design and decide optimum mobile systems. For this purpose, some experiments were carried out to obtain useful data. In this study, some measurements of mobile phones (MS) and base stations (BTS) are taken and compared with standards and limits. Electric and magnetic fields were measured on 1 m, 5 m and one street from base station antennas. Results of these measurements are shown on an average scale and explained. Measurements have been done using 10 BTSs being located in different cities. Mobile phones' measurements are taken at 3 modes. They are idle mode, which is silence mode of mobile phones, call setup mode, which is signaling between MS and BTS before speaking and active mode, which is speaking mode. MS's measurements are taken from 6 different mobile phones from different vendors. There are at least 75 measurements for every modes and every BTS. Finally, results obtained are compared with standards and limitations available.

Manuscript received October 16, 2002 revised July 9, 2003.

I. H. Cavdar is with Electrical and Electronics Engineering Department, Karadeniz Technical University, Trabzon 61080, Turkey (e-mail: cavdar@ktu.edu.tr).

N. E. Ozguner was with the University of Kocaeli, Kocaeli, 41100 Turkey. He is now with the Department of Electronic and Telecommunications, University of Kocaeli, Turkey (e-mail: eozguner@hotmail.com).

Publisher Item Identifier S 1682-0053(03)0181

TABLE I
THE STANDARDS, LIMITS AND SOME RECOMMENDATIONS IN DIFFERENT COUNTRIES AND INSTITUTIONS

Institutions/ Countries	E-Field 900 MHz	E-Field 1800 MHz	Power Density 900 MHz	Power Density 1800 MHz
NRPB, 1993	112	194	33	100
ANSI/IEEE, 1992	47	61	6	10
Canadian Safety	47	61	6	10
ICNIRP, 1998	41	58	4.5	9
Australia, 1988	27	27	2	2
Poland	19	6	1	0.1
Russia, 1988	6	6	0.1	0.1
Italy, 1999	6	6	0.1	0.1
Toronto Health Board, 2000	5	6	0.06	0.1
Swiss Ordinance, 2000	4	6	Not Specified	Not Specified
Turkey	10.2	10.4	0.28	0.56
Swiss Ordinance, 2000	4	6	Not Specified	Not Specified
Salzburg-Austria, 1998	0.62	0.62	0.001	0.001

TABLE II
THE LIMITS FOR PROFESSIONALS BY IRPA

Frequency (MHz)	Electric Field (V/m)	Magnetic Field (A/m)	Power Density (W/m2)
0.01-0.038	1000	42	---
0.038-0.61	1000	$1.6/f$	---
0.61-10	$614/f$	$1.6/f$	---
10-400	61.4	0.16	10
400-2000	$3.07\times\sqrt{f}$	$8.14\times10^{-3}\sqrt{f}$	$f/40$
2000-150000	137	0.364	50
150000-300000	$0.354\times\sqrt{f}$	$9.4\times10^{-4}\sqrt{f}$	$3.334\times10^{-4}f$

TABLE III
THE LIMITS FOR PUBLICS BY IRPA

Frequency (MHz)	Electric Field (V/m)	Magnetic Field (A/m)	Power Density (W/m2)
0.01-0.038	400	16.8	---
0.038-0.61	400	$0.7/f$	---
0.61-10	$275/f$	$0.7/f$	---
10-400	27.5	0.07	2
400-2000	$1.37\times\sqrt{f}$	$3.64\times10^{-3}\sqrt{f}$	$f/200$
2000-150000	61.4	0.163	10
150000-300000	$0.158\times\sqrt{f}$	$4.21\times10^{-4}\sqrt{f}$	$6.67\times10^{-5}f$

Risk probabilities were calculated using measured data.

II. PROPERTIES OF ELECTROMAGNETIC WAVES AND THEIR EFFECTS ON THE HUMAN BODY

It is well known that electromagnetic radiation (non-ionized radiation) absorbed by human body causes the biologocial effects such as tissue heating, depolarization, mechanical tension here are two stages dielectric and cut-off in the human bodies. In this section, SAR (Specific Absorption Rate) is described and formulated by

$$SAR=\frac{d(SA)}{dt}=\frac{d(\frac{dw}{\rho dV})}{dt}\ \text{(W/kg)} \qquad (1)$$

where SA is the specific absorption at unit mass and ρ is the body density. SAR can be described based on the electric field,

$$SAR=\frac{\sigma E^2}{\rho} \qquad (2)$$

where σ is the tissue conductivity and E is the electric field in the body.

The most important effect of the electromagnetic field on the human body is the heating. The relation between heating and SAR is given by;

$$\frac{dT}{dt}=\frac{SAR}{c} \qquad (3)$$

where T is temperature and c is the specific heat.

Electromagnetic fields affect the free electrons in the human body and these electrons move through to surface of the body. As a result of this electron mobility, electrical currents occur in the body. The magnitude of the currents depends on the distance to source, the body position, the direction of the body and the other factors [7].

It is clear that the biological effects due to electromagnetic radiation on the human body can not be calculated based on a theoretical approach, but on experiments. There are some standards and limits in different countries. Table I shows the standards, limits and some emf values which are recommended by city council or any other board of directors in terms of frequency, electrical field and power density in different countries and institutions. Although standards vary from country to country (Table I), similar base stations and mobile phones are commonly used.

On the other hand, the important point is the relation between human and mobile source on the em radiation. This relation can be classified into two groups :

1. Direct relation
2. Indirect relation.

In the direct relation, the human works and uses mobile sources during long period of time while in other group, the human uses mobile sources only for a short time. The standards and limits related to these cases are given in the different groups. Tables II and III show the limits of the effection developed by IRPA (The International Radiation Protection Association) respectively. IRPA and ANSI (American National Standards Institute) have defined the limit value of SAR for the human health to be 0.4 W/kg. If SAR is greater than 4 W/kg, it will result in serious health problems on the human body; so the limit value of one-tenth of 4W/kg SAR has been accepted. This value has been described as an average under the conditions of full

TABLE IV
E AND H FIELD AND POWER DENSITY MEASUREMENTS

BTS Nos.	Cell Nos.	Distance from BTS Antenna (m)	Measured E-Field (V/m)	Measured H-Field (A/m)	Measured Power Density (W/m2)
1	1	5	10.1	0.02679	0.270584
		25	0.28	0.000743	0.000208
	2	5	3.66	0.009708	0.035532
		25	0.11	0.000292	3.21E-05
	3	5	7.7	0.020424	0.157268
		25	0.28	0.000743	0.000208
2	1	50	0.327308	0.000868	0.000284
	2	50	1.22	0.003236	0.003948
3	1	5	1.3	0.003448	0.004483
		40	1.09	0.002891	0.003151
4	1	1.5	6.07	0.016101	0.097732
		10	5.6	0.014854	0.083183
	2	10	5.16	0.013687	0.070625
	3	10	5.15	0.01366	0.070351
5	1	5	1.29	0.003422	0.004414
		20	0.12	0.000318	3.82E-05
	2	5	1.29	0.003422	0.004414
6	1	40	0.8	0.002122	0.001698
	2	20	0.77	0.002042	0.001573
	3	20	1.02	0.002706	0.00276
7	1	1.5	12.6	0.033422	0.421114
		30	1.69	0.004483	0.007576
	2	1.5	12.5	0.033156	0.414456
		30	0.73	0.001936	0.001414
8	1	5	6.95	0.018435	0.128123
	2	5	5.79	0.015358	0.088923
9	1	5	9.72	0.025782	0.250606
		25	2.03	0.005385	0.010931
	2	25	4.53	0.012016	0.054432
10	1	30	1.59	0.004218	0.006706
	2	30	0.34	0.000902	0.000307
	3	1.5	13.6	0.036074	0.49061
		30	1.72	0.004562	0.007847

body radiation and for the period of 6 minutes. The ratio of direct radiation limit to indirect radiation limit is considered equal to 5 [7].

III. Propagation Experiments for Base Station and Mobile Phones to Obtain More Realistic Data

Propagation experiments were carried out to measure the electrical and magnetic fields of base stations and mobile phones. Experiments can be classified into two groups :

1. The effects of BTS
2. The effects of MS

Measurements were planned into two categories consisting of determination of the effects of BTS and MS independently. Firstly, BTSs and MSs which had been selected were determined. MSs were selected from widely used mobile phones in Turkey. In the measurements, Wandel&Goltermann – EMR 300 measuring equipment and its software were used as the measurement set.

TABLE V
SOME STATISTICAL PROPERTIES OF E-FIELD USING EXPERIMENTAL DATA FOR VARIOUS MOBILE PHONES

Mobile Phones	Electric Field (V/m) Idle Mode	Call Setup Mode	Active Mode
Phone-1	Limits: 0-0.1	Limits: 6.65-19.36	Limits: 0.82-23.49
	Average: 0	Average: 9.87	Average: 12.36
	St. Dev.: 0	St. Dev.: 3.79	St. Dev.: 5.06
Phone-2	Limits:0-0.79	Limits: 1.82-16.83	Limits: 2.09-11.09
	Average: 0.14	Average: 10.92	Average: 6.90
	St. Dev.: 0.19	St. Dev.: 4.53	St. Dev.: 2.50
Phone-3	Limits: 0-0.72	Limits: 11.83-40.39	Limits: 0.76-7.63
	Average: 0.12	Average: 18.45	Average: 3.70
	St. Dev.: 0.12	St. Dev.: 9.92	St. Dev.: 1.62
Phone-4	Limits: 0-0.53	Limits: 24.02-53.97	Limits: 2.76-23.55
	Average: 0.25	Average: 33.75	Average: 14.23
	St. Dev.: 0.10	St. Dev.: 9.16	St. Dev.: 6.18
Phone-5	Limits:0-1.09	Limits: 8.79-148.03	Limits: 2.1-22.41
	Average: 0.37	Average: 74.31	Average: 9.31
	St. Dev.: 0.17	St. Dev.: 50.95	St. Dev.: 3.32
Phone-6	Limits: 0.3-1.4	Limits: 2.81-29.47	Limits: 2.63-14.56
	Average: 0.46	Average: 16.57	Average: 6.60
	St. Dev.: 0.20	St. Dev.: 9.83	St. Dev.: 2.08

This measurement set calibration is made biennial by TUBITAK UME in Turkey. This calibration must be made biennial because of appropriateness to ISO9001:2000 that we have this certficate. This standard says that measurement equipments or systems must be calibrated periodically.

At the base-station measurements, measurement equipment was located far away from BTS. The distances were selected to be 5, 10, 15 and 25 meters. Measured BTSs which located in the different cities in Turkey are radiated maximum 20W and a lot of antenna types were used. Measurement procedure of BTS can be summarized as follows. Firstly, the equipment of measurement was located in the position of desired distance. The E and H fields were recorded on PC. The measurements were repeated for different BTS and different distances. The results obtained in these experiments are shown in Table IV.

After completing BTS experiments, experiments on the MSs are carried out in order to determine the effects of MSs on the human health. Widely used mobile phones were selected. It is well known that the radiated powers are different for the mobile phone working modes. The working modes are classified into three categories for mobile phones as idle, call setup, and active modes. At the MSs experiments, measurement equipment was located in the position of 1 cm from the mobile phone which was measured. The MSs measurements were repeated in each mobile phones working mode. In each measurement, it has taken approximately 100 samples in different times for each phone. The measured values were recorded on a PC for E fields. The database was obtained using the recorded results from the experiments for the various mobile phones in different working modes.

Measured values of both BTSs and MSs were evaluated to calculate some statistical properties supplying us with the decision of whether the mobile communication signals at 900 MHz may cause any damages or not. The averages and standard deviations of measured data files, BTSs and MSs, are calculated and shown in Tables V.

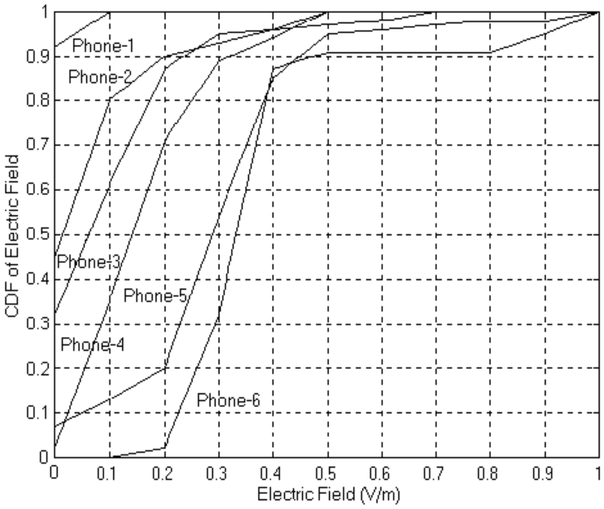

Fig. 1. CDF of the electric fields for various MSs for the case of idle mode.

Figs. 1, 2 and 3 show the cumulative distribution functions (CDF) of the electric fields of measured MSs for various MSs for the case of idle, call setup and active mode of MSs, respectively. In these figures, the horizontal axis is the electric field in V/m. Using the measured values for various MSs in different working modes and their CDFs, the risk probabilities for human health were calculated. Risk probabilities can be described as the exceed probability of the desired level. If the limit values determined by various countries and institutes in Table I are assumed, risk probabilities can be described as the probability of exceeding the limit values. Risk probabilities calculated for various mobile phones in the three working modes consisting of idle, call setup and active are given in Table VI. Risk probabilities are obtained for different standard and limit values.

It is clear that BTSs have low level radiation especially at the distance greater than 1m from their antennas. There is not any risk for human health comparing measured results and the standard levels for BTSs. It is not possible to draw the same conclusion for the MSs' radiation. Although there is not any risk at the idle mode, some types of MSs have high level radiation, especially at the call setup and active working modes. For some MSs, the risk probabilities can be as high as 100% at both call setup and active modes according to the some standards. In the designing of cellular mobile communications, human health effects must have been considered for optimum design.

IV. Conclusions

In this study, some useful experimental data were obtained from the electromagnetic field measurements at 900 MHz on the mobile communications for human health. Risk probabilities were calculated using the measured data for various MSs. Some useful conclusions and results can be drawn as follows:

1. BTSs have not any risk for human health especially at the distance greater than 1m from its base station antenna. It can be shown clearly that the establishment of base station system on the top of the buildings does not have any health risk for human health at the distance over a few meters. There are some useful experimental data presented at Table IV for the base station measurements.
2. Some type of mobile phones have electrical field which it can be dangerous for human health. Electrical fields are at the maximum level at the call setup and active working mode. The results of the measurements on some mobile phones are shown at Table V. The power levels of some mobile phones need to be reduced by their producers.
3. Mobile subscribers must be trained to use their phones properly and much more carefully at some working modes. Calling time period must be kept as short as possible. MSs should not be brought close to subscribers' head at the call setup period.
4. Communication system designers must consider human health as an important issue in the design of their systems. Health limits parameters are important parameters in the design of cellular mobile systems, cellular hardware, etc.
5. Medical researchers should be encouraged to conduct different research projects to determine danger limits for human health, since there is not any standard which can be used commonly in the world.

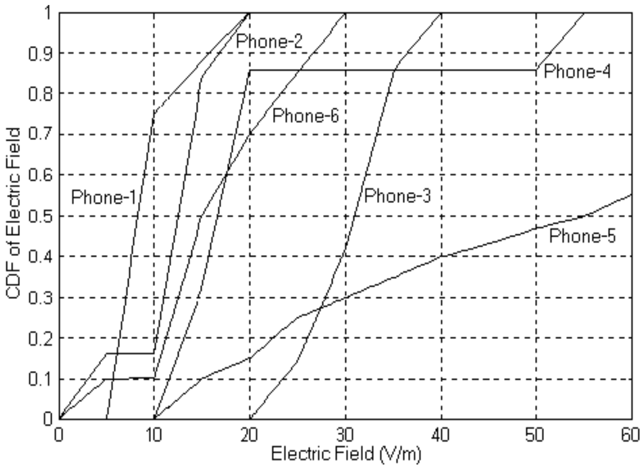

Fig 2. CDF of the electric fields for various MSs for the case of call setup mode.

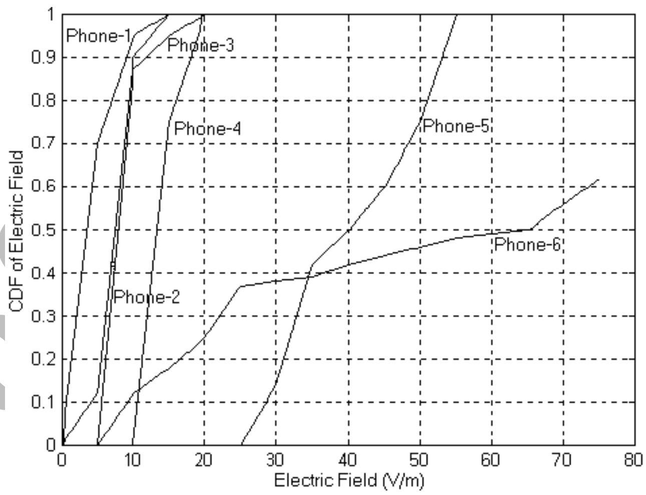

Fig. 3. CDF of the electric fields for various MSs for the case of active mode.

TABLE VI
CALCULATED RISK PROBABILITIES USING MEASURED DATA FOR VARIOUS MOBILE PHONES AT 900 MHZ

		Risk Probabilities (%)																	
		Phone-1			Phone-2			Phone-3			Phone-4			Phone-5			Phone-6		
STANDARD	Limit E-Field (V/m)	I	CS	A	I	CS	A	I	CS	A	I	CS	A	I	CS	A	I	CS	A
NRPB	112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ANSI/IEEE	47	0	0	0	0	0	0	0	0	0	0	0	0	0	53	60	0	0	0
Canadian S.	47	0	0	0	0	0	0	0	0	0	0	0	0	0	53	60	0	0	0
ICNIRP	41	0	0	0	0	0	0	0	12	0	0	0	0	0	72	63	0	5	0
Poland	19	0	8	4	0	5	0	0	14	5	0	100	0	0	85	75	0	30	0
Russia	6	0	60	100	0	90	100	0	100	100	0	100	100	0	100	100	0	90	100
Italy	6	0	60	100	0	90	100	0	100	100	0	100	100	0	100	100	0	90	100
Toronto	5	0	100	100	0	92	100	0	100	100	0	100	100	0	100	100	0	92	100
Turkey	10.2	0	25	13	0	85	10	0	100	100	0	100	100	0	100	88	0	90	10
Salzburg	0.62	0	100	100	0	100	100	3	100	100	0	100	40	4	100	100	8	100	100

I: Idle Mode, CS: Call Setup, A: Active

6. Cell planners must use small cell sizes such as micro and pico cells to obtain possibility of both small BTSs power and small MSs powers to reduce risk possibilies for human health.
7. Subscribers of mobile communication system must be trained to use the system more efficiently and more carefully.
8. To design the optimum cellular mobile systems various data have to be taken in different part of the world. System designers need the experimental data such as what obtained from this study in order to plan the optimum and reliable system design.

REFERENCES

[1] ICNIRP, "Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz)," *Health Physics*, vol. 54, no. 1, pp. 115-123, Jan. 1998.

[2] *IEEE Standards for the Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz*, IEEE Standard C95.1-1991, 1992.

[3] FCC, *Evaluating Compliance with FCC Guidelines for Human Exposure to Radio Frequency Electromagnetic Fields*, Washington DC, Aug. 1997.

[4] IEGMP (Independent Expert Group on Mobile Phones), *Mobile Phones and Health*, www.iegmp.org.uk, May 2000.

[5] TUBITAK (The Scientific and Technical Research Council of Turkey), *Electromagnetic Fields and Human Health*, p. 2, 2001.

[6] N. E. Ozguner and I. H. Cavdar, "Microwave electromagnetic field effects on human bodies and comparision of international standards and measurements of base stations and mobile phones," in *Recent Advances in Computers, Computing and Communications*, pp. 447-451, 2001.

[7] S. Seker, and O. Cerezci, *The Radiation in our Eenvironment and ProtectionMmethods,* Bosphorus University Press, pp. 6-44, 1997.

I. Hakki Cavdar was born in Trabzon, Turkey, in 1964. He graduated in Electronics from University of Gazi, Ankara, Turkey, in 1985. He received the M.Sc. and Ph.D. degrees in Electronics and Communications Engineering from Karadeniz Technical University (KTU), Trabzon, Turkey, in 1988 and 1994, respectively.

Since 1995, he has been an Assistant Professor in the electronics engineering at KTU. His research interests include communications, measurements and modeling of propagation. He published several papers in the international transactions and journals and many papers in international conferences.

Dr. Cavdar is a member of the Institute of Electrical and Electronics Engineers (IEEE).

N. Erol Ozguner was born in Kocaeli, Turkey, in 1971. He graduated in Electronics and Communication Engineering from Yildiz Technical University, in Turkey, in 1995. He received the M.Sc. degree in Electronics and Communication Engineering from Kocaeli University, in Turkey in 1999. He is now pursuing his Ph.D. studies at the Kocaeli University, Turkey.

Since 2000, he has been with Turkcell Mobile Communication Co., in Turkey. His research interests include mobile communications, measurements and cell planning in GSM.