Electromagnetic Fields and Radio Frequency Identification and Their Effects in our Bodies

YOLANDA RUIZ[1], JAVIER BILBAO[2], EVANGELOS MARKOPOULOS[3], TODOR STOILOV[4], CARLO FIGA' TALAMANCA[5] , CHARALAMBOS MAKATSORIS[6]

[1]Physiotherapist
Bilbao Region
Osakidetza
Basque Department of Health
Bilbao (Spain)

[2]Applied Mathematics Dept
University of the Basque Country
Alda. Urkijo s/n., Bilbao
SPAIN
javier.bilbao@ehu.es

[3]Department of Informatics
University of Piraeus
80 Karaoli & Dimitriou Str., Piraeus
GREECE
epm@unipi.gr

[4]Dept Hierarchical Systems,
Institute of Computer and Communication Systems
Bulgarian Academy of Sciences
Acad. Bonchev str. Sofia
BULGARIA

[5]Technology Division
ICT Area
Via Giacomo Peroni 386, Roma
ITALY

School of Engineering and Design
BRUNEL University
Uxbridge, Middlesex UB8 3PH,
London,
UNITED KINGDOM

Abstract: - In the last decades on the last century, applications of electromagnetic fields have increased both in number of them and in number of persons that use them. At the same time, a social worry regarding the use of these applications has spread. Some studies maintain that there is not any direct relation between electromagnetic field applications that are used normally by people and diseases such as cancer, and other studies assert that the use of these applications is the main cause of these diseases. The interaction of the electromagnetic fields with human beings depends on many parameters. Generally, occupational exposure concerns healthy adults working under controlled conditions. These conditions include the opportunity to apply engineering and administrative measures and, where necessary and practical, to provide personal protection. The basic restrictions are expressed in terms of limits on induced electric current and specific absorption rates.

Keywords: - electromagnetic fields, radio frequency identification, disease, interaction.

1 Introduction

In last years, information media have reflected some news with spectacular titles about the interaction of electromagnetic fields: brain cancer because of the use of mobile telephones, various diseases from living near powerful antennas, etc. The possible health effects due to exposure to radiofrequency fields have become a public concern. Living systems respond to many stimuli as part of the process of living. Such responses are examples of biological effects. Interactions leading to measurable biological effects that remain within the range of physiological compensation of the body and do not detract from the physical and mental well-being of humans should not be considered as hazardous.

Thanks to the Radio Frequency Identification (RFID) technology, data can be transmitted via radio waves without physical or line of sight contact. An RFID system infrastructure consists of a transponder, a reader, and an IT system running in the background. The heart of the technology is the transponder – a tiny computer chip outfitted with an antenna. It is integrated into a carrier object – such as an adhesive label or a plastic card. Generally, a number code is stored on the chip. The code encrypts information stored in a database. This process gives every object containing an RFID transponder an unmistakable identity.

Evaluating an EAS/RFId system (Electronic Article Surveillance based on Radio Frequency Identification) on the point of view of health means to understand the minimum distance of security between a device and a person that uses the devices or is under a continuous exposition.

Interactions that lead to biological effects outside the normal range of compensation of the body may be an actual or potential health hazard. The time course of the effect should be determined, that is, under what conditions the effect disappears after cessation of exposure, or if exposures are additive even after a rest period, or whether effects are permanent, such as the induction of cancer, [1]. That is to say, scientific community has to decide what it is hazard and what not. Moreover, something that can be considered as no-harmful because the body reaction is very small (and consequently it does not present any problem at the moment or in the next days or even months) can be subjecting this body to a stress that, with time, causes diseases.

On the other hand, reports of subjective effects (symptoms without concomitant signs or reactions that are difficult to measure quantitatively, such as headaches) are useful for identification of health consequences only if the studies are conducted in a truly scientific manner, are shown to be statistically significant and a direct causal relationship is demonstrated.

Subjective effects, if substantiated, can detract from the physical and mental well-being of a person, and should therefore be considered a health hazard. If it is determined that certain electromagnetic fields (EMF) exposure conditions exist that have a finite probability of being unsafe for even a very small part of the population, this should be addressed.

Generally, occupational exposure concerns healthy adults working under controlled conditions [2]. These conditions include the opportunity to apply engineering and administrative measures and, where necessary and practical, to provide personal protection. For members of the public, similar controls do not generally exist, and individuals of varying ages can have wider variability in health status and responses to exposures to EMFs. For these reasons exposure restrictions for the public are lower than those recommended for the working population.

2 Evaluation of the electromagnetic fields exposure

For the evaluation of the EM fields exposure, two thresholds are conventionally considered: *Basic Restrictions*, related to biological effects, and *Derived Reference Levels,* calculated indirectly and referred to easily measurable physical quantities.

At low frequencies (less than 10MHz) the physical data to monitor is the induced current density into tissues, while at higher frequencies (more than 100kHz) the measurement of the Specific Absorption Rate (SAR) is required. The SAR is defined as the power density absorbed by human body for mass unit. Induced current and SAR depend on both the intensity of EM field and on the position of device respect of human body. The thresholds for occupational exposure (adults consciously exposed to EM radiation) and general public exposure with people of all age are different. Limitations for general public exposure are stricter, because common persons are not aware of the danger.

The Derived Reference Levels are not directly connected to a biological effects. They are deducted or measured in absence of the human body. The reference levels are calculated from basic restrictions, supposing maximum coupling between EM field and individual. Also in this case the thresholds are different for occupational exposure and general public exposure. If there are simultaneous exposure to more frequencies the effects must be properly added (guidelines ICNIRP).

3 Electromagnetic fields: which their effects can be and how their interactions are

The interaction of the radiofrequencies fields with living systems may be appreciated in a macroscopic and microscopic (molecular, cellular) level, [3]. On the molecular level, two basic mechanisms govern the interactions: the space charge polarization at lower radiofrequencies and the field-induced rotation of polar molecules at higher frequencies (such as microwave frequencies). The polarization of the space charge is due to traveling charges, for example, the ions that are affected by the applied field and that are moving all around the space (a room, a laboratory, a ward, etc.). Polar molecules, that is to say, molecules that have uneven spatial distribution of charges (like water and proteins) suffer a torque, a rotation, when placed in an electric field.

Moderate exposure fields only affect to a small number of molecules or charges. Normally, they align with the direction of the applied field. The movements are hindered by the thermal motion of molecules and charges, and the kinetic energy transforms into thermal energy. So, the electromagnetic energy is converted into kinetic one (movement of the molecules) and afterwards consequently into thermal energy, [4].

Radiofrequency (RF) exposures are directly linked to absorption and distribution of RF energy in the body, and the absorption and distribution are strongly dependent on body size and orientation and on incident radiation frequency and polarization [5]. The protection quantity of interest to limit thermal effects in tissue is the Specific Absorption Rate (SAR), and it is defined as the rate of energy absorption per mass of tissue, measured in watts per kilogram of tissue. A rise in body core temperature of about 2.2 degrees Celsius is often taken as the limit of endurance for clinical trials. For RF radiation purposes, a limit of an increase of 1 degree Celsius in rectal temperature has often been postulated as a basis for determining a SAR limit for human exposure.

Most standards are based on a SAR of 4 W/kg divided by ten to give a further safety margin. Thus the general basis is 0.4 W/kg. Unfortunately, the SAR is not easily measured and cannot be used for practical measurement work. Therefore, derived measurable safety limits based on the SAR are determined in terms of measurable quantities such as power density, electric field strength, magnetic field strength, induced current, and contact current.

Biological effects of radiofrequencies have been investigated in several types of animals and the greater part (but not all) of the effects are thermal. However, this does not indicate that there is a mere heating, but the effects of the radiofrequency induced heating are: several depth of penetration, the existence of internal hot spots, and the rapidity of heating. Moreover, the induction of non-uniformities in the temperature of various parts of the brain may cause some alterations, [6], [7].

The thermogenic effects of the radiofrequencies where explained in 1979, [8]:

- Biological effects appear due to the thermoregulatory response when an animal is exposed at a rate equal to its basal metabolic rate (BMR).
- Numerous behavioral, endocrine, cardiac and respiratory effects for SARs below the BMR are manifestations of psychological responses to mild thermal stress.
- The thermal stress that results from and exposure of about twice the BMR, maintained over long periods of time, leads to important psychological effects.

4 The case of RFID

Special readers are needed to receive the stored information. This send-receive-unit produces an electro-magnetic field that is picked up by the antenna on the RFID transponder. The transponder then transmits the number code to the reader. Depending on the frequency, transmitting power and local environmental conditions, the read range of the data can be a few centimetres to several meters.

Information about objects can be stored in a manner similar to the way in which information about persons or companies can be presented on their home page on the Internet. For this the reader transmits the combination of numbers to the database. The IT system decrypts the code and links it to information stored in the database or on the Internet. The system's knowledge, or intelligence, is located in the database, not in the transponder, [9].

Information can also be stored on the chip. In these applications, the readers need not be linked to a database. Rather, decentralized administration and control are possible. A further benefit is that it is generally easier to alter data on the chip than in the system. The disadvantage, however, is that the reading process takes longer and the transponders are more expensive.

There are various types and sizes of transponder. Depending on the area of application they can be either active or passive. Active transponders are equipped with their own batteries. As a result, the data stored on them can be read at a greater distance. These transponders are used in areas such as electronic toll-collection systems. Passive transponders do not have their own power source. They draw their power from the reader's electromagnetic field. Their read range is relatively short. However, they are much less expensive and lighter than active transponders. Passive transponders are designed to optimize logistics in trade and retail and in the consumer goods industry.

In most RFId applications, passive or semi-passive tags are commonly used and they communicate with the reader by energy backscattering. The EM exposure issues are therefore related to the reader units only.

The laws and European recommendations for electro-magnetic fields are:

• 1"Guidelines for limiting exposure in time-varying electric, magnetic, and electromagnetic fields up to 300 GHz", (Health Physics, Volume 24, Number 4, April 1998, p.494). This document introduces the limitations of exposure for generic person at work. The maximum values are related to the biological effects on human body.

• 2 "European Council Recommendation 1999/519/EC of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz", Official Journal, L199, 30.7.1999., p.59). This document describes the limitation of exposure for inhabitants.

• EN 50357 (also Norma CEI EN 50357) "Evaluation of human exposure to electromagnetic fields (EMFs) from devices used in electronic article surveillance (AS), radio frequency identification (RFID) and similar applications". Contains the procedures of simulation and measures to value EM fields exposure level.

• Standard EN 50364 (also Norma CEI EN 50364) "Limitation of human exposure to electromagnetic fields from devices operating in the frequency range 0 to 10GHz, used in Electronic Article Surveillance (EAS), Radio Frequency Identification (RFID) and similar applications.

EAS and RFID systems, working at low frequencies (less than 10 MHz), produce fields with negligible propagating features. The exposure of people is therefore limited to the EM field in the close proximity to the reader and its intensity attenuates very fast as soon as the distance grows. In this condition, if there is more than a single reader, it is reasonable to consider the exposure inducted by each reader a time.

The systems working at the range of 300 MHz - 3 GHz emit microwave. In this case a true propagation phenomenon have to be considered verifying the threshold of exposure even at some meters from the reader.

The particular exposure to electromagnetic (EM) fields caused by EAS and RFID systems depends on different spatial and temporal characteristics of emission (frequency, power, modulation) and on typology and installation of device.

5 Recommendations on limiting exposure to RF fields

The most commonly used guidelines are those published by International Commission on Non-Ionising Radiation Protection (ICNIRP) [10].

These guidelines were developed in co-operation with the World Health Organisation (WHO) as part of the WHO Environmental Health Criteria Programme funded by the United Nations. The work was also supported by the International Labour Office and the European Commission.

The European Commission has published a Recommendation (1999/519/EC) requesting Member States to put in place national legislation setting down maximum limits of non-ionising electromagnetic fields. This Recommendation has largely adopted the ICNIRP 1998 guidelines.

The European Commission has also proposed the introduction of a Directive7 (93/C77/102) to ensure the protection of workers from a number of physical agents including electromagnetic fields. The aim of the Directive is to protect workers and will not specify levels for the public. The proposal has passed through the European Parliament and a proposed amended version has been published (94/C230/03).

CENELEC, the European Committee for Electrotechnical Standardisation, has published a number of standards which provide protection for both workers and members of the public. The standards, covering low and high frequency ranges, have been approved by Technical Committee TC106X which comprises the EU and European Free Trade Association member countries. The standards are based on basic restrictions as published by the ICNIRP and the EU EMF Recommendation.

In 2004, the European Commission published a new Directive (2004/40/EC). This Directive refers to the risk to the health and safety of workers due to known short-term adverse effects in the human body caused by the circulation of induced currents and by energy absorption as well as by contact currents. The EU Directive involves the assessment and, if necessary, the devise and implementation of the measures in order to prevent, reduce and control the risk. This Directive entered into force in April 2004 and the Member States shall bring the regulations necessary to comply with it, no later than four year after this date.

But, in the particular case of the medical workers, this Directive on electromagnetic fields does not address suggested long-term effects, and there is no recommendation nor directive nor law specifically developed in any country of the world. This field of the science, as many others, has to be covered by general guidelines, nowadays, [11], [12].

6 ICNIRP and IRPA guidelines radiofrequency fields, 100 kHz to 300 GHz

The ICNIRP guidelines are stated in the form of basic restrictions from which field strength values are derived. The basic restrictions are expressed in terms of limits on induced electric current and specific absorption rates.

The appropriate restrictions on exposure recommended by the IRPA (International Radiation Protection Association) are summarised below.

- The average specific energy absorption rate in the body over any 6 minute period should not exceed 0.4 W/kg for workers or 0.08 W/kg for members of the public at frequencies above 10 MHz.

- When taken in conjunction with the above restriction, the maximum value of the specific energy absorption rate in any 0.1 kg of tissue, other than in the hands, wrists, feet and ankles, should not exceed 10 W/kg for workers.

- The maximum value of the specific energy absorption rate in any 0.1 kg of tissue in the hands, wrists, feet and ankles should not exceed 20 W/kg for workers.
- If a current of 50 mA from point contact with an object in the field is exceeded there is a risk of producing RF burns.

- In addition to the time averaged limits in the case of pulsed fields the equivalent plane wave power density averaged over a pulse width should not exceed 1000 times the P_{eq} limits or the field strength should not exceed 32 times the field strength limits.

Limits for pulsed fields are suggested by the IRPA although they state that very little information is available on the relation of biological effects with the peak values of these fields. The justification given for the pulsed limit is to avoid prolonged or frequent exposures to the auditory effect produced by the instantaneous expansion of the skull that occurs for short pulses. Although there is no extensive scientific research works or studies where it is said that the auditory effect is harmful, some degree of caution is recommended in view of the underlying cause, and because of some articles describe harmful effects.

From the above basic restrictions field strength levels are derived as shown in Table 1 and in Figures 1 and 2. The basic restrictions are stated in terms of body current or SAR which are not easily measured quantities. Therefore, field strengths, which are easily measured, have been derived. At this point, it would be desirable that international commissions change methods of measurability from difficult measures like SAR to others easier like field strength.

The restrictions at the lower frequencies, typically below 10 MHz, are based on preventing a shock hazard from ungrounded metal objects. At higher frequencies the restrictions are based on limiting the specific absorption rate that can cause diseases such as cancer.

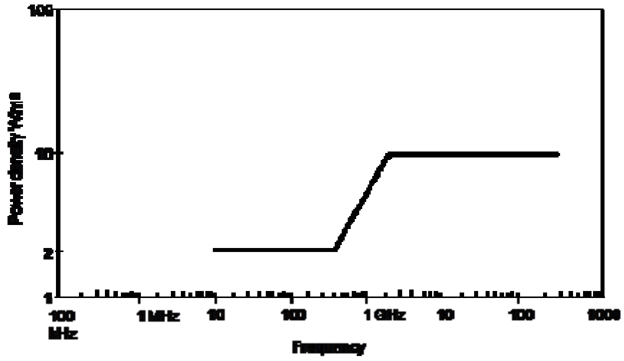

Figure 1. IRPA guideline levels for public environment (power density)

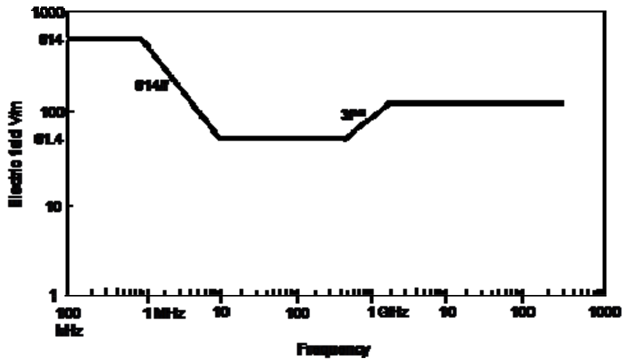

Figure 2. IRPA guideline limits for public exposure (electric field)

The levels in the VHF frequency range are one fifth of those in the microwave range because of the improved coupling of the field to the body at these frequencies.

These levels are based on preventing thermal effects. However, they state that protection against athermal effects was also kept in mind.

7 The European Community

Table 2 contains the exposure limit values fixed for 7 different frequency ranges with the intention of preventing adverse effects on different parts or functions of the human body, such as the cardiovascular and central nervous systems or whole-body heat stress and excessive localised heating of tissues. The exposure limit values do not apply to static magnetic fields in the Directive 2004/40/EC, as for the moment there is not enough scientific evidence about possible adverse health effects resulting from exposure to static magnetic fields. This means, for example, that there are no exposure limit values for the handling of magnetic resonance facilities in the medical sector. Nevertheless, the European Council adopted a statement to the Minutes inviting the Commission to closely monitor developments in this area in order to include exposure limit values for static magnetic fields in the Directive at a later stage, when scientific findings make this possible.

Table 3 contains action values fixed for 13 different frequency ranges. The action values are obtained from the exposure limit values according to the rationale used by ICNIRP in its guidelines on limiting exposure to non-ionising radiation (ICNIRP 7/99). In contrast to the exposure limit values of the Table 2, the action values also apply to static magnetic fields in order to prevent dangers like the projectile risk from ferromagnetic objects in static magnetic fields.

The European Directive 2004/40/EC says that once the action values are exceeded (from Table 3), the employer shall devise and implement an action plan comprising technical and/or organisational measures intended to prevent exposure exceeding the limit values. This obligation does not apply when the employer can demonstrate that the exposure limit values are not exceeded and that safety risks can be excluded. This obligation refers, *inter alia*, to other working methods, the choice of equipment, technical reduction methods or the design and layout of workplaces as particular elements of such an action plan. Another obligation triggered off in case the action values are exceeded is the identification, indication by appropriate signs and limitation of access to the areas concerned.

5 Conclusions

In recent years, applications of electromagnetic fields, for example RFID, have become increasingly important. Whether the area of application is logistics, trade and retail, or leisure-time activities, the technology is changing processes in many areas and creating new service opportunities. In this paper relation with health some methods to determine the exposition and some applications have presented.

The interaction of the electromagnetic fields with human beings depends on many parameters. Although there are studies that say there is not a direct relation among microwave exposure and the likely diseases or disorders in living systems, there are other investigations that conclude the opposite: some parts of the animals or persons (eyes, gonads, brain, etc.) are affected by microwave exposure. The most commonly used guidelines to prevent and limit exposure to RF fields are those published by International Commission on Non-Ionising Radiation Protection (ICNIRP).

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Frequency range (f) (MHz)	Unperturbed RMS Field Strength		Equivalent Plane Wave Power Density	
	Electric field (E) (V/m)	Magnetic field (H) (A/m)	(W/m^2)	(mW/cm^2)
0.1 – 1	87	$0.23 / f^{1/2}$	-	-
1 – 10	$87 / f^{1/2}$			
10 – 400	27.5	0.073	2	0.2
400 – 2000	$1.375 f^{1/2}$	$0.0037 f^{1/2}$	f / 400	f / 4000
2000 - 300000	61	0.16	10	1

Table 1. Derived power density and field strength limits for the general public. Whole body exposure

Frequency range (f)	Current density for head and trunk (J) (mA/m^2) (RMS)	Whole body average SAR (W/kg)	Localised SAR (head and trunk) (W/kg)	Localised SAR (limbs) (W/kg)	Power density (S) (W/m^2)
Up to 1 Hz	40	-	-	-	-
1 – 4 Hz	40 / f	-	-	-	-
4 – 1000 Hz	10	-	-	-	-
1 – 100 kHz	f / 100	-	-	-	-
100 kHz – 10 MHz	f / 100	0.4	10	20	-
10 MHz – 10 GHz	-	0.4	10	20	-
10 – 300 GHz	-	-	-	-	50

Table 2. Exposure limit values. All conditions to be satisfied

Frequency range (f)	Electric field strength (E) (V/m)	Magnetic field strength (H) (A/m)	Magnetic flux density (B) (μT)	Equivalent plane wave power density (S_{eq}) (W/m^2)	Contact current (I_C) (mA)	Limb induced current (I_L) (mA)
0 – 1 Hz	-	163 000	200 000	-	1	-
1 – 8 Hz	20 000	$163\ 000 / f^2$	$200\ 000 / f^2$	-	1	-

8 – 25 Hz	20 000	20 000 / f	25 000 / f	-	1	-
0.025 – 0.82 kHz	500 / f	20 / f	25 / f	-	1	-
0.82 – 2.5 kHz	610	24.4	30.7	-	1	-
2.5 – 65 kHz	610	24.4	30.7	-	0.4 f	-
65 – 100 kHz	610	1600 / f	2000 / f	-	0.4 f	-
0.1 – 1 MHz	610	1.6 / f	2 / f	-	40	-
1 – 10 MHz	610 / f	1.6 / f	2 / f	-	40	-
10 – 110 MHz	61	0.16	0.2	10	40	100
110 – 400 MHz	61	0.16	0.2	10	-	-
400 – 2000 MHz	$3 f^{1/2}$	$0.008 f^{1/2}$	$0.01 f^{1/2}$	f / 40	-	-
2 – 300 GHz	137	0.36	0.45	50	-	-

Table 3. Action values (unperturbed RMS values)

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