MODELING AND EXPERIMENTAL STUDY OF ELECTROMAGNETIC POLLUTION IN A TURKISH HOSPITAL

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ABSTRACT

In this paper, we have measured and modeled the existing levels of electric and magnetic fields in a typical Turkish hospital and compared the results with the limits that are defined in the related standards. All measurements are done under the normal operating conditions in suitable designed hospital rooms.

I. INTRODUCTION

Sources that emit electromagnetic fields (EMFs) are generally related to the electromagnetic (EM) spectrum that represents the continuous set of frequencies within the EMF. Thus, the spectrum can be divided into non-ionizing radiation at the low end, and ionizing radiation at the high end. The point of division between the two is based upon the amount of energy contained in the radiation. The higher the frequency, the more energy it contains [1-2]. Recently, the usages of devices that emit EMFs have increased considerably. This proliferation has been accompanied by an increased concern about possible health effects of exposure and interference with sensitive medical equipments to these fields [1,2]. As a result, throughout the world, many organizations, both governmental and nongovernmental, have established safety standards or guidelines for exposure. Although there are dozens of standards and regulations, many refer to the limits from the major standards. Therefore, the four standards covered here are: IEEE/ANSI Standard, FCC Regulations, Safety Code 6 (Canada), ICNIRP [3, 5].

The estimation of the effective amount of EMF distribution in areas connected with human activities has grown in importance, in order to satisfy public and governmental safety regulations. The knowledge of the EMF distribution in the vicinity of cellular systems and broadcasting antenna systems operating on various frequencies is significant if the systems are to be placed around an inhabited area. The estimation of the field levels is required before the systems are installed in such area. Otherwise, when the systems are put into service, the permissible radiation levels established for human health protection may be exceeded.

There are several reports in the literature describing the results of EMF surveys within hospital areas; both for power frequency fields and wideband radio frequency (RF). Electrosurgical units and video display units (VDUs) are amongst the strongest sources [4]. Common types of system and the field levels close to these sources will be summarized and discussed in relation to ICNIRP recommended field levels. In Turkey, ICNIRP Guidelines were accepted and declared as regulations by Telecommunication Authority in 2000. This standard defines general details, the reference levels, exposure of the general public and basic restrictions for static electric and magnetic fields basics for time varying electric and magnetic fields up to 300 GHz.

It is often ignored the fact that the EMFs generated by medical equipments can endanger the health of the personnel operating them and the other medical devices. In this paper, three commonly encountered sources of EMFs in the hospital rooms such as 50 Hz ac power distribution, video display terminals (VDTs), and radio fields are surveyed. So that three special measurement instruments are used respectively in order to measure the existing levels of EMFs. EM radiation sizes were obtained by using these three different measurement devices within the hospital rooms in which medical equipments installed. In order to simplify the better understanding of this subject, graphical representation (3D) and table forms are utilized. All measurements are done under the normal operating conditions in suitable designed hospital rooms and all of the maximum measured values are below the standard values found in the literature.

II. EMF MEASUREMENTS IN THE HOSPITALS

Various measurements and analysis techniques were used in the literature to identify the sources of the electric and magnetic fields in hospitals [6]. Electromagnetic interference (EMI) is unwanted electrical signals that produce undesirable effects and it disrupts the control system circuits. Modern medical devices are packed with electronics, ranging from sensitive analog amplifiers to sophisticated microprocessors. EMI in these devices can cause problem in a way that it can disrupt a device's internal data flow, and cause corruptions on data cables between devices. When it occurs in life-supporting electronic devices it may have further fatal consequences.

Most medical devices are either life-supporting or have vital diagnostic importance.

In this work, measurements and modeling were done in suitable installed hospital rooms such as Operation Room, Intensive Care Unit (ICU), Angiography Room, Magnetic Resonance (MR) imaging rooms, Computed Tomography (CT), Physiotherapy and Security room.

METHOD OF MEASUREMENT

The measurement method to determine the existing level of EM pollution is quite simple and effective. The surface of the room to be measured is divided into square elemental cells so that a grid pattern is formed, and measurements are taken at the nodes. The number of nodes is determined based on size and shape of measured room. At each node, measurements are performed at one-meter height from the ground. In order to get a reasonable number of measurements, horizontal distances between two consecutive nodes are changed for each room.

Existing level of EM pollution were obtained within the hospital rooms in which medical equipments installed. Measurements are respectively performed in three ranges: ELF, VLF, and RF range. Data recording and consequent processing are carried out with the help of programs such as MS Excel and Matlab 6.5. In order to simplify the better understanding of this subject, graphical representation (3D) and table forms are utilized. This case study also allows the spatial variations of the fields to be measured which helps to identify the source.

Measurements for ELF range is utilized with Holaday Instrument (HI) 3604 Power Frequency Field Strength Measurement System which are associated with 50 or 60 Hz electric power transmission and distribution lines along with electrically operated equipment and appliances. The HI-3604 is sensitive to electric fields between the range of 1 V/m and 199kV/m, and to magnetic fields between the range of 0.1 mG and 20 G. Measurements of VLF (10 to 300 kHz) EMFs produced by video display terminals (VDTs), i.e., computer monitors, television receivers were measured with the HI-3603 VDT/VLF Radiation Measurement System operating within the frequency range from 10 kHz to 300 GHz. PMM 8053 System is a versatile and expandable test system suitable for measuring EMFs in RF range. The system consists of various electric and magnetic field

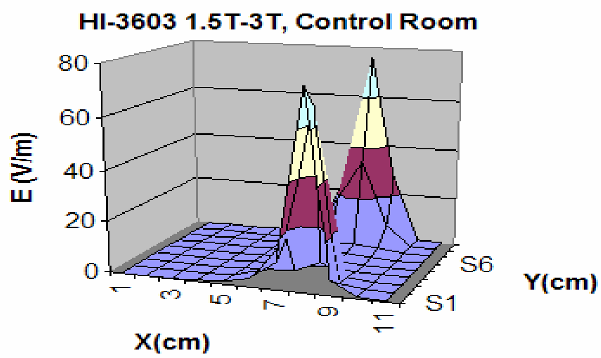

Figure 1: Electric fields distribution in VLF ranges in the MR Control Room taking place between 1.5T and 3T MR rooms

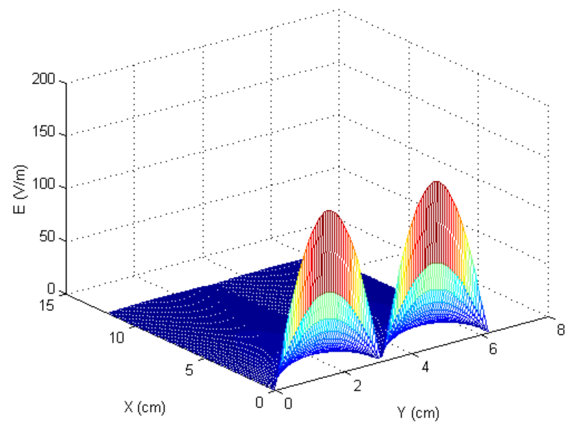

Figure 2: Modelling of electric fields distribution in VLF ranges in the MR Control Room taking place between 1.5T and 3T MR rooms.

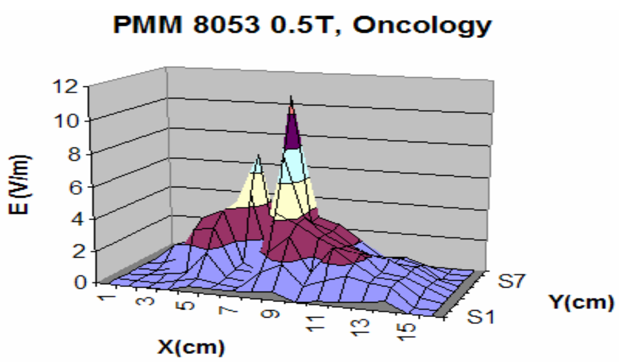

Figure 3: Electric fields distribution in RF ranges in the 0.5 T MR locating in Oncology.

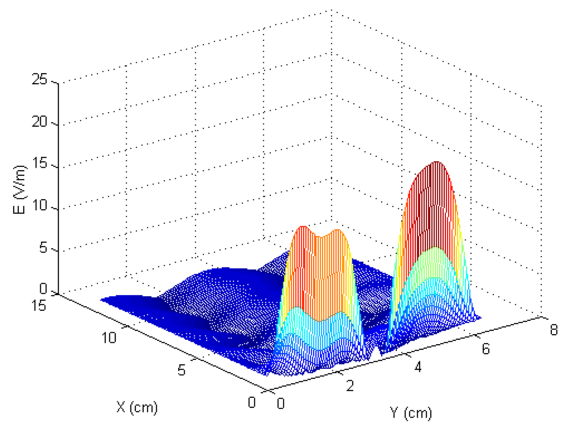

Figure 4: Modelling of electric fields distribution in RF ranges in the 0.5 T MR locating in Oncology.

probes and of a compact and portable meter equipped with a wide LCD display.

Especially, in selected rooms with medical devices, measurements are repeated many times for data reliability for each single node and maximum measurement value is taken into consideration. In case of considerable difference between maximum measurements, the medium of all maximum values is taken into consideration.

MODELING

Another method to determine the existing level of EM pollution is modeling. Assuming that medical devices behave like dipole antennas, electric field strength values can be calculated. Simulations are done using Matlab 6.5. Graphical representations are given nearby the measurement results in order to highlight the convenience in between.

In the second study, dipole antennas are positioned at different sites to approximate medical devices in the hospital including the ground reflections. New mathematical formula has been developed for antennas placed on ground instead of above plane. By the aid of this calculation, electric field patterns of every dipole antennas which coordinates are known can be simulated.

The total electric field for a group of dipole antennas at different locations is obtained from [6-8]. Image theory is illustrated graphically in Fig. 5. Based on the graphical model of, the mathematical expressions for footprint of the fields of a vertical linear element near a perfect electric conductor will now be developed. At hospital rooms far-field conditions are valid. Referring to the geometry of Fig. 5, the far zone direct component of the electric field of the infinitesimal dipole of length l, constant current I_0 is given by:

$$E_\theta^d = j\eta \frac{kI_0 l e^{-jkr}}{4\pi r} \sin\theta . \left(e^{jk(x'\hat{a}_x + y'\hat{a}_y + z'\hat{a}_z)(\sin\theta\cos\phi\hat{a}_x + \sin\theta\sin\phi\hat{a}_y + \cos\theta\hat{a}_z)}\right) \quad (1)$$

The reflected component can be accounted for by the virtual image, as shown in Fig. 5 and it can be written as:

$$E_\theta^r = E_\theta^d . R_v \left(e^{-jk.2h\cos\theta}\right) \quad (2)$$

since the reflection coefficient (R_V) is unity.

The total electric field for one dipole antenna at different locations can then be calculated using the equations (1) and (2):

$$\begin{aligned} E_\theta &= E_\theta^d + E_\theta^r \\ &= j\eta \frac{kI_0 l}{4\pi r} e^{-jkr} \sin\theta \left[e^{jkr'\cos\gamma} + R_v e^{jk(r'\cos\gamma - 2h\cos\theta)}\right] \end{aligned} \quad (3)$$

Here the reflection coefficient R_v , is assumed to be unity. For a group of dipole antenna at different locations the total electric field is $E_T = \sum_{i=1}^{n} E_{\theta_i}$.

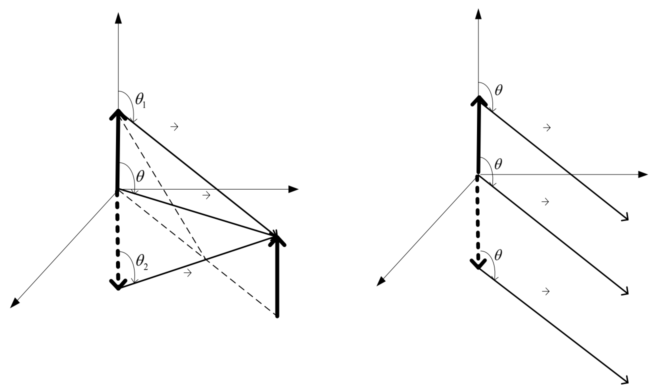

Figure 5. Vertical electric dipole on infinite electric conductor in near and far-field

In a similar manner, or by using the established relationship between the E_θ and H_ϕ in the far-field, the total H_ϕ component can be written as:

$$H_\phi = \frac{\sum_{i=1}^{n} E_{\theta_i}}{\eta} \quad (4)$$

While simulating dipole antennas at hospital rooms, the operating frequencies are adjusted according to the ELF, VLF and RF ranges. The effective radiated power for each dipole antennas are 10 kW. The simulation results include the reflections from the ground, and the ground is assumed to be a lossless (R_V=1).

Figures 2, 4, 7 and 9 indicate the three-dimensional illustrations of the total electric field strength of dipole antennas with estimated coordinates. They indicate the distribution of EMF strength values inside the rooms. All simulations are done in accordance with the measured results. So, this second study allows finding out the hazardous EM sources and keeping them far away at a safety distance.

III. RESULTS AND DISCUSSION

Measurements are taken within two different hospitals. One is in Istanbul the other is in Ankara. Therefore, experiments are performed in 2 hospitals, 24 rooms, 3 special measurement instruments in ELF, VLF and RF ranges for both electrical and magnetic fields. So, totally 24 X 3 X 2 = 144 different measurements were done. Therefore there are 144 surface plot of electric and magnetic fields in this study. For each room, 6 measurements were necessary.

Only four of six figures will be given since magnetic fields have more dangerous effects than electric fields in ELF range, only surface plot of electric field is displayed. Because in VLF range both fields have hazardous effects on human health and sensitive medical devices, two figures are displayed. Similarly only electric fields in RF range are given due to the fact that electric fields have more harmful effects than magnetic fields in this range.

There is a general pattern seen in all graphics. Fig. 8 shows magnetic fields distribution in the ELF range in the MR Control Room taking place between 1.5T and 3T MR rooms. It is clear that only medical devices' environment has considerably high values. Rest of the room has lower values. Fig. 1 and Fig. 6 display respectively electric and magnetic fields in the VLF range. Fig. 3 indicates electric field in RF range. For Fig. 1, 3 and 8 this general pattern is observed.

The measured maximum levels of electric and magnetic fields in some related location are listed in the following table. As seen from this table, the measured maximum values are lower than corresponding limits.

IV. CONCLUSION

As expected, high values are generally accumulated around the medical devices. In the rest of the room, there are no considerable values indicating abnormalities. This clearly indicates that standing at a distance from medical devices is much more safety.

Magnetic fields of 1.57 A/m, 0.467 A/m and 0.017 A/m were found in the ELF, VLF and RF ranges, respectively. The maximum values were obtained in ICU(BR) for ELF range, 0.5T Control Room for VLF range and ICU(SR) for RF range.

Electric fields of 227.2 V/m, 75.9 V/m and 14.86 V/m were measured in the ELF, VLF and RF ranges, respectively. The maximum values were obtained in ICU(BR) for ELF range, between 1.5T and 3T Control Room for VLF range and ICU(SR) for RF range.

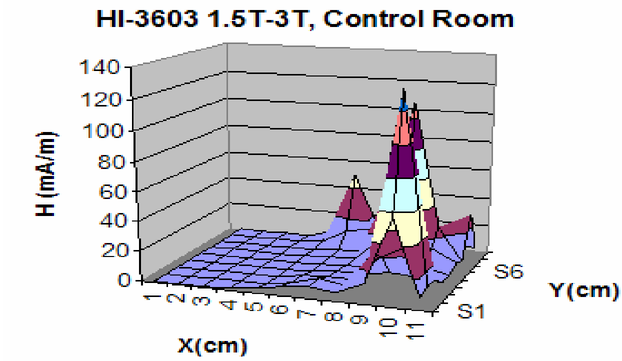

Figure 6: Magnetic fields distribution in VLF ranges in the MR Control Room taking place between 1.5T and 3T MR rooms.

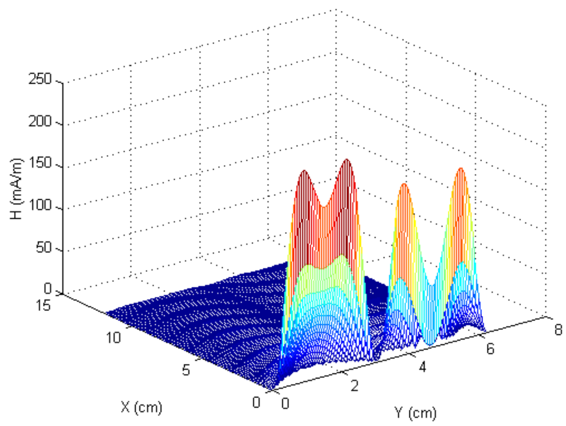

Figure 7: Modelling of magnetic fields distribution in VLF ranges in the MR Control Room taking place between 1.5T and 3T MR rooms.

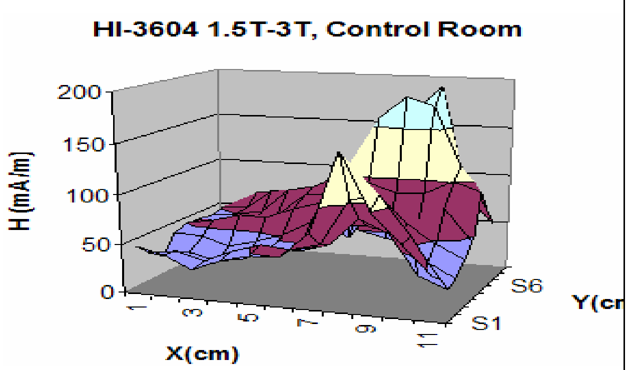

Figure 8: Magnetic fields distribution in ELF ranges in the MR Control Room between 1.5T and 3T MR rooms.

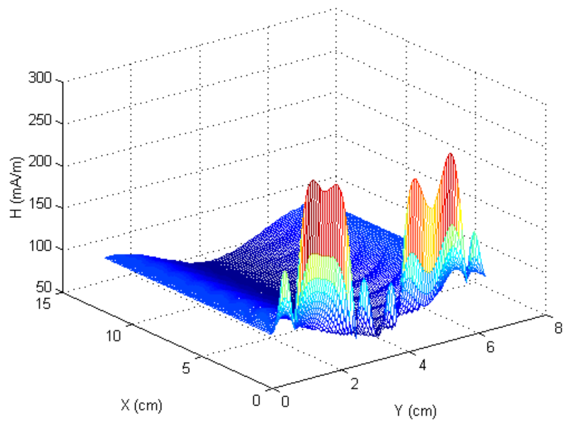

Figure 9: Modelling of magnetic fields distribution in ELF ranges in the MR Control Room between 1.5T and 3T MR rooms.

Units		Standards		Tool		Standards		Tool		Standards		Tool	
		ICNRP		HI-3604		ICNRP		HI-3603		ICNRP		PMM 8053	
		occup	general	ELF		occup	general	VLF		occup	general	RF	
0.5T MR Control Room	E_{max}(V/m)	61	28	97.4	<<	8.33 kV/m	4.16kV/m	11.22	<<	610 V/m	87 V/m	20.96	<<
	H_{max}(A/m)	0.16	0.073	0.603	<<	416.6 μT	83.3 μT	**0.467**	<<	24.4 A/m	5 A/m	0.025	<<
1.5T-3T MR Control Room	E_{max}(V/m)	61	28	50.31	<<	8.33 kV/m	4.16kV/m	**75.9**	<<	610 V/m	87 V/m	2.86	<<
	H_{max}(A/m)	0.16	0.073	0.19	<<	416.6 μT	83.3 μT	0.132	<<	24.4 A/m	5 A/m	0.009	<<
Intensive Care Unit (Big Room)	E_{max}(V/m)	61	28	**227.2**	<<	8.33 kV/m	4.16kV/m	42.3	<<	610 V/m	87 V/m	14	<<
	H_{max}(A/m)	0.16	0.073	**1.57**	<<	416.6 μT	83.3 μT	0.0256	<<	24.4 A/m	5 A/m	0.00323	<<
Intensive Care Unit (SR)	E_{max}(V/m)	61	28	68.8	<<	8.33 kV/m	4.16kV/m	1.7	<<	610 V/m	87 V/m	**14.86**	<<
	H_{max}(A/m)	0.16	0.073	0.18	<<	416.6 μT	83.3 μT	0.0095	<<	24.4 A/m	5 A/m	**0.018**	<<

None of the field strengths measured was above the limits set by ICNRP regarding the human exposure to EMFs.

An important observation from this study is that the levels of the electric and magnetic fields are considerably affected by shielding, distance and duration. Shielding works at the source of the hazard by blocking the emission of radiation so that it cannot endanger people and sensitive devices. Distance is a way of control along the path, because radiation decreases with the inverse square of distance rule. Radiation hazards increase with duration of exposure.

Generally, measured electric and magnetic fields in the ELF, VLF and RF ranges are in the same order with, or lower than those stated in the standards.

In this study an algorithm for the simulation of the total radiation patterns of electromagnetic waves in the vicinity of a group of dipole antennas, operating at the same frequency, has been presented. To make the problem more realistic, reflections from the side-walls or from other objects next to transmitters, can be all included to the simulations. This modeling can also be enhanced by increasing the numbers of reflections and by changing the complex dielectric permittivity of the ground.

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