

STUDY AND EVALUATION OF INDUCED CURRENT IN HUMAN BODY FROM EXPOSURE TO ELECTROMAGNETIC FIELDS AT LOW FREQUENCIES

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Abstract

- Extremely Low Frequency (ELF) Electromagnetic Fields due to low and medium voltages are normally low. But with the wide spread and increase in the use of electrical energy, the potential for exposure has been increased considerably.

- The current research has focused on potential health effects of magnetic fields because some epidemiological studies have suggested an increased cancer risk associated with estimated time of magnetic field exposure.

- Since the wavelength of ELF electric and magnetic field is sufficiently greater than the dimensions of the biological object, so the electric and magnetic fields can be independently treated.
- Our main topic in this research is to investigate the effect of magnetic field at power frequency and analyse the interaction between these fields and the living organisms

- The obtained results can demonstrate the degree of danger due to the induced currents from both magnetic and electric fields. Comparing these results by the values given by International Committee on Non-Ionizing Radiation Protection (ICNIRP) guidelines can tell the degree of danger.

- Experimental measurements were performed on distribution transformers, workshops with different machines and inside an office.

INTRODUCTION

- Many methods have been developed to calculate the induced current densities due to the magnetic and electric fields in the vicinity of the human body. The paper will present three calculation methods:

1- The first method uses the ellipsoidal model to calculate the induced current densities from the exposure to the magnetic fields

2- The second method used the dipole and image theory with prolate spheroid models after exposure to electromagnetic fields. It was illustrated that the induced currents due to the electric field are insignificant to be considered when compared to that due to the magnetic fields.

3- The third method is a very simplified one which considers the living organism as a homogeneous cylinder of constant conductivity. It utilizes the R.M.S measured values of magnetic field irrespective of its direction. This method showed to be the simplest method which gets quick indicative results but with less accuracy, than the earlier ones.



Prague, 8-11 June 2009



METHODOLOGY

First Method

- This method is based on the proposed ellipsoidal model as shown in Fig. 1. This model is placed at the origin of the rectangular coordinate system. The size and shape of ellipsoid are determined by the parameters of a , b and c .

First Method

- The ellipsoid is expressed as:

$$\frac{x^2}{c^2} + \frac{y^2}{b^2} + \frac{z^2}{a^2} = 1$$

Where the parameters a, b and c are the axes of the ellipsoid with $a > b > c$.

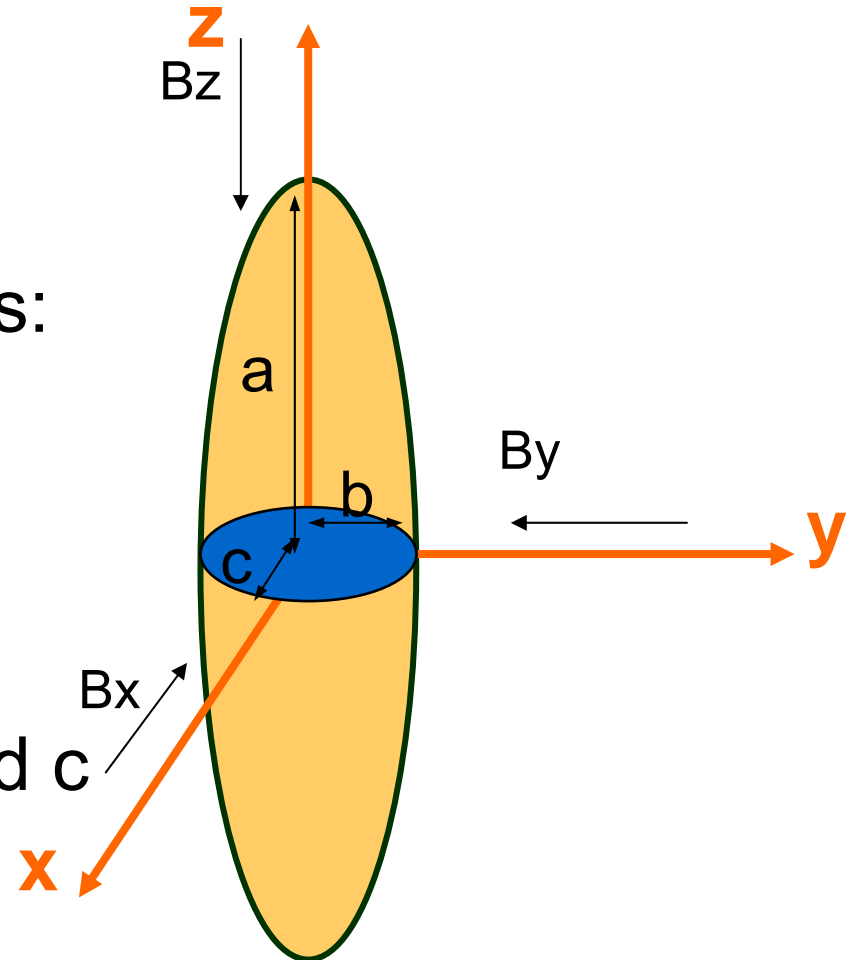


Fig.1. Calculation model

The induced electric field vector components in x , y and z-axis resulting from three orientations of the sinusoidal magnetic field are expressed as:

$$\vec{E}_{B_x} = \frac{\omega}{a^2 + b^2} (b^2 z \hat{y} - a^2 y \hat{z}) B_x | e^{j(-\pi/2 + \varphi_{B_x})}$$

$$\vec{E}_{B_y} = \frac{\omega}{a^2 + c^2} (a^2 x \hat{z} - c^2 z \hat{x}) B_y | e^{j(-\pi/2 + \varphi_{B_y})}$$

$$\vec{E}_{B_z} = \frac{\omega}{b^2 + c^2} (c^2 y \hat{x} - b^2 x \hat{y}) B_z | e^{j(-\pi/2 + \varphi_{B_z})}$$

Where

E_{B_x} : electric field around x-axis induced by B_x .

E_{B_y} : electric field around y- axis induced by B_y .

E_{B_z} : electric field around z-axis induced by B_z

ω =angular frequency = $2\pi f$, $f=50$ Hz

φ : phase angles of B_x , B_y , B_z

The total induced electric field in the model can be expressed as:

$$\vec{E} = \vec{E}_{Bx} + \vec{E}_{By} + \vec{E}_{Bz}$$

The total current density induced by magnetic fields is obtained from

$$\vec{J} = \sigma \vec{E}$$

J: the current density induced

σ : conductivity of tissue

- The parameters were taken as: $2a = 0.9\text{m}$, $2b = 0.6\text{m}$ and $2c = 0.3\text{m}$. for an ordinary human configurations. It is assumed that the model is filled with a homogenous biological tissue and the exterior medium is air. The human body conductivity is assumed to be 0.1 S/m ,

- and the circulating currents due to the measured magnetic fields are computed accordingly.

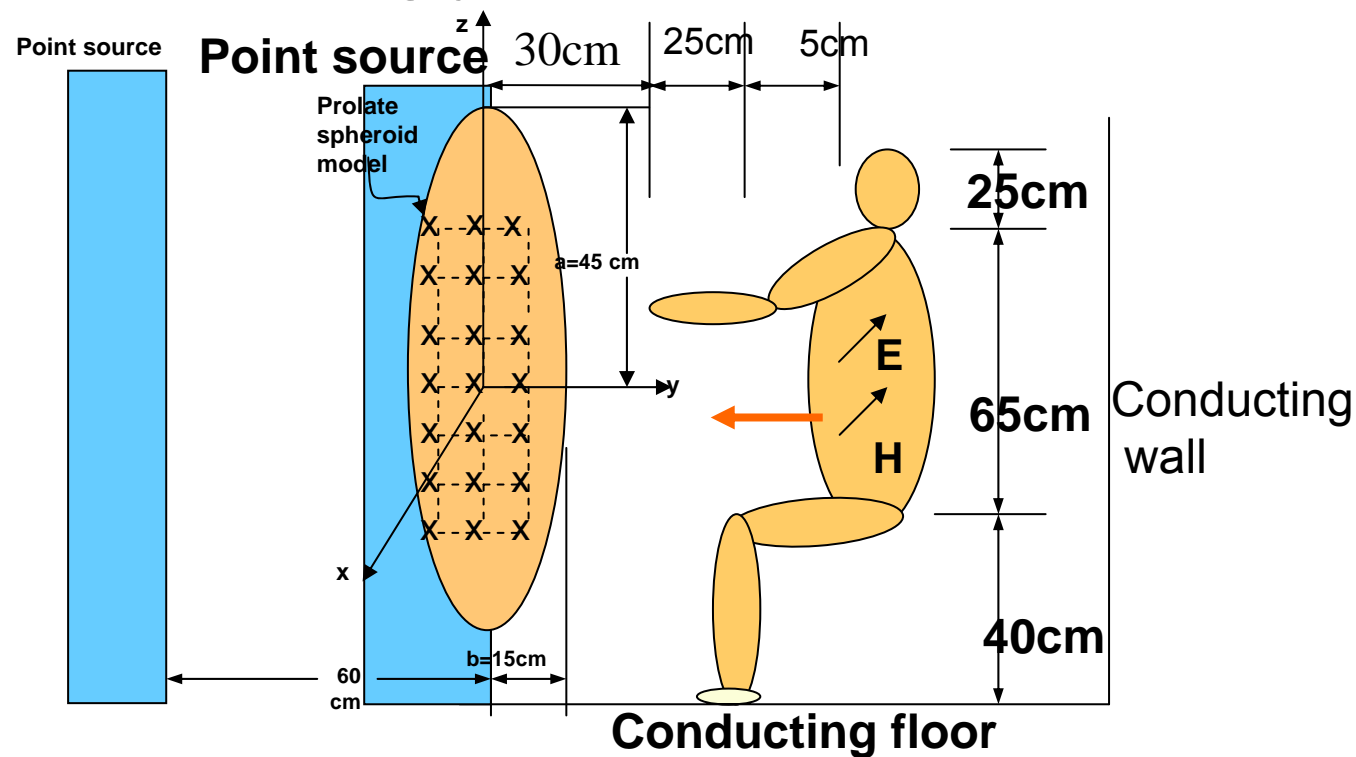


Fig. 2 A Model for a sitting person

- The results of, induced electric fields and induced currents at different values of y and z considering $x=0$ from magnetic fields shown in Figs[3-5]

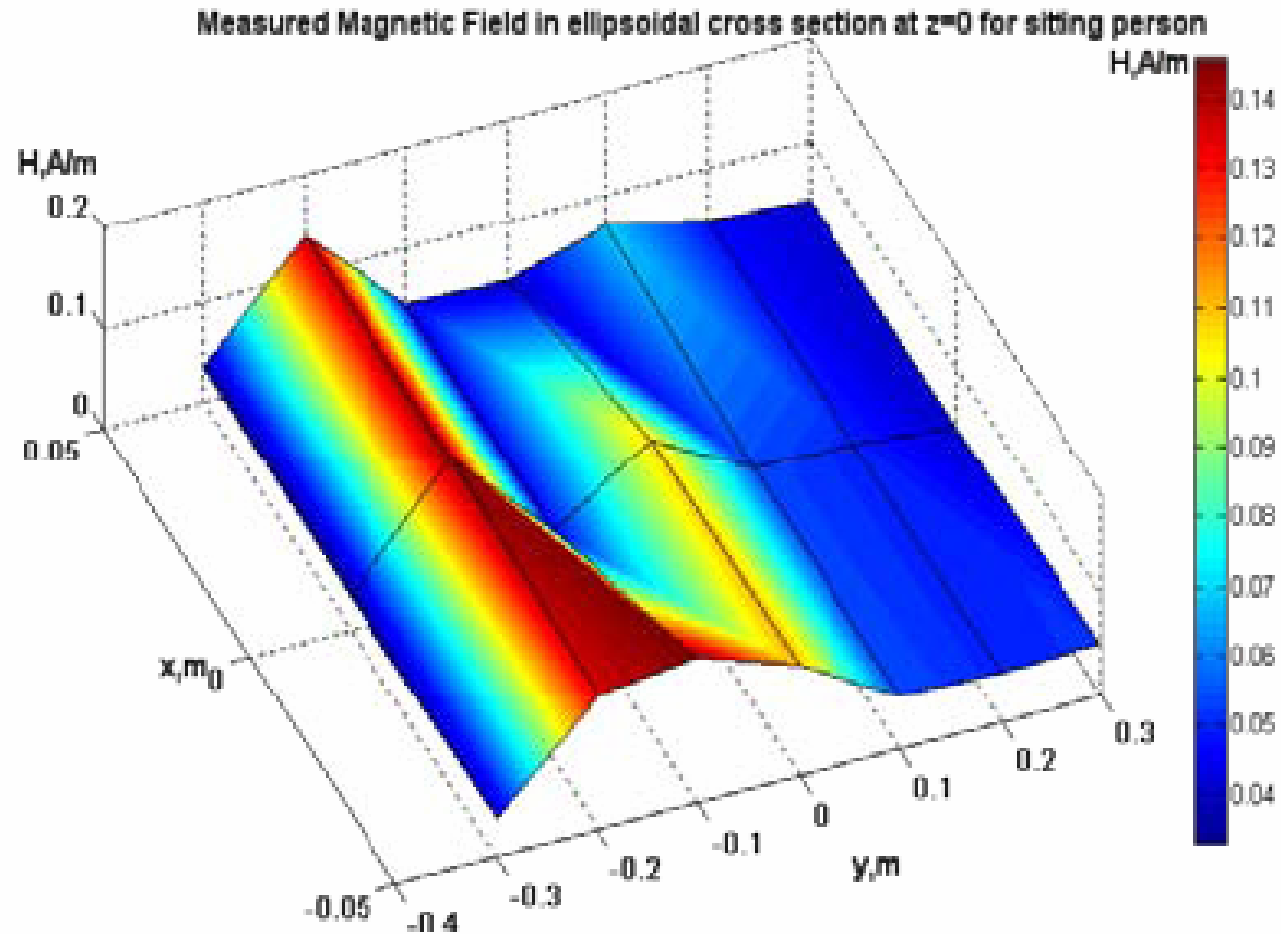


Fig. 3 The induced magnetic field from magnetic field exposure

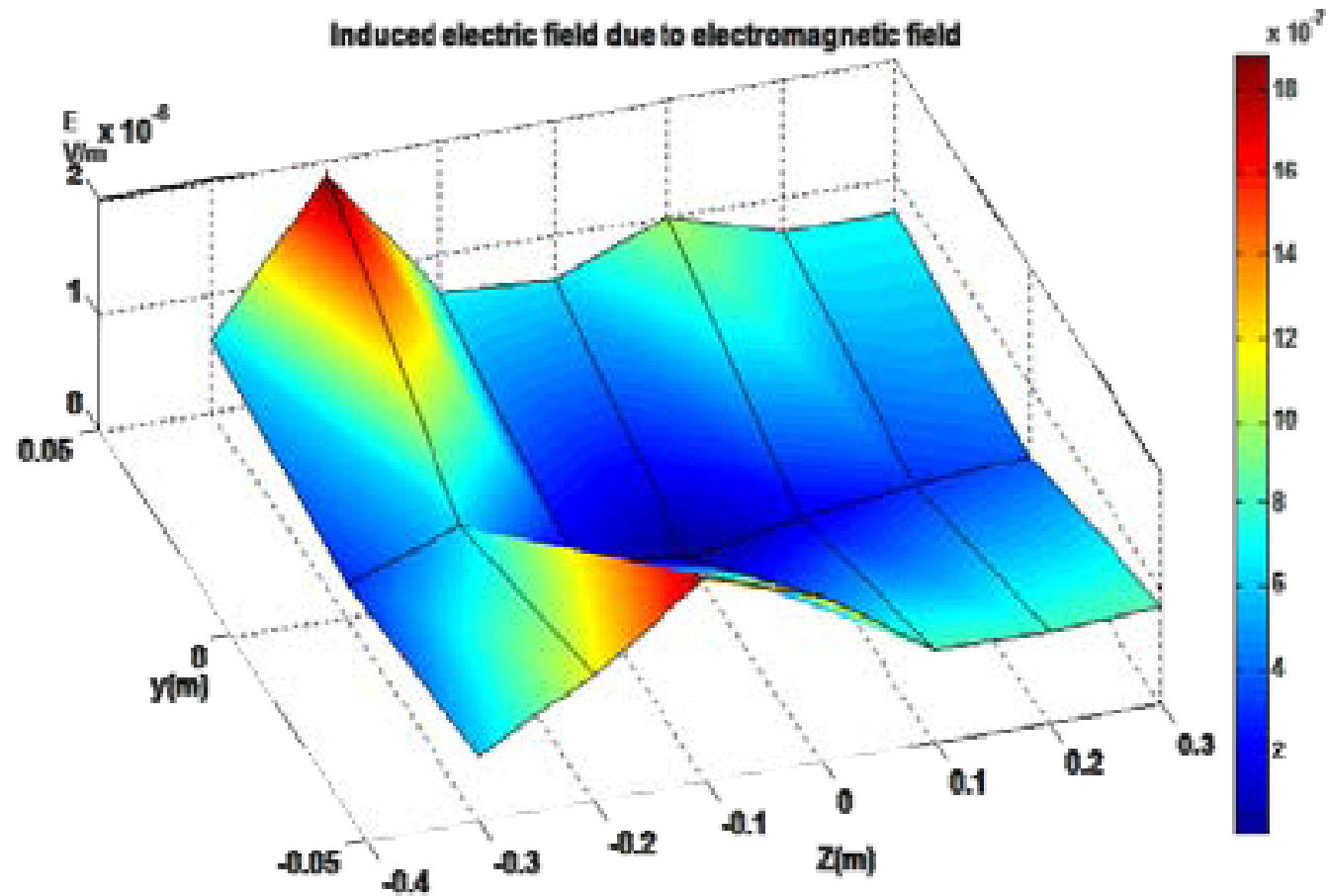


Fig. 4 the induced electric field from magnetic field exposure

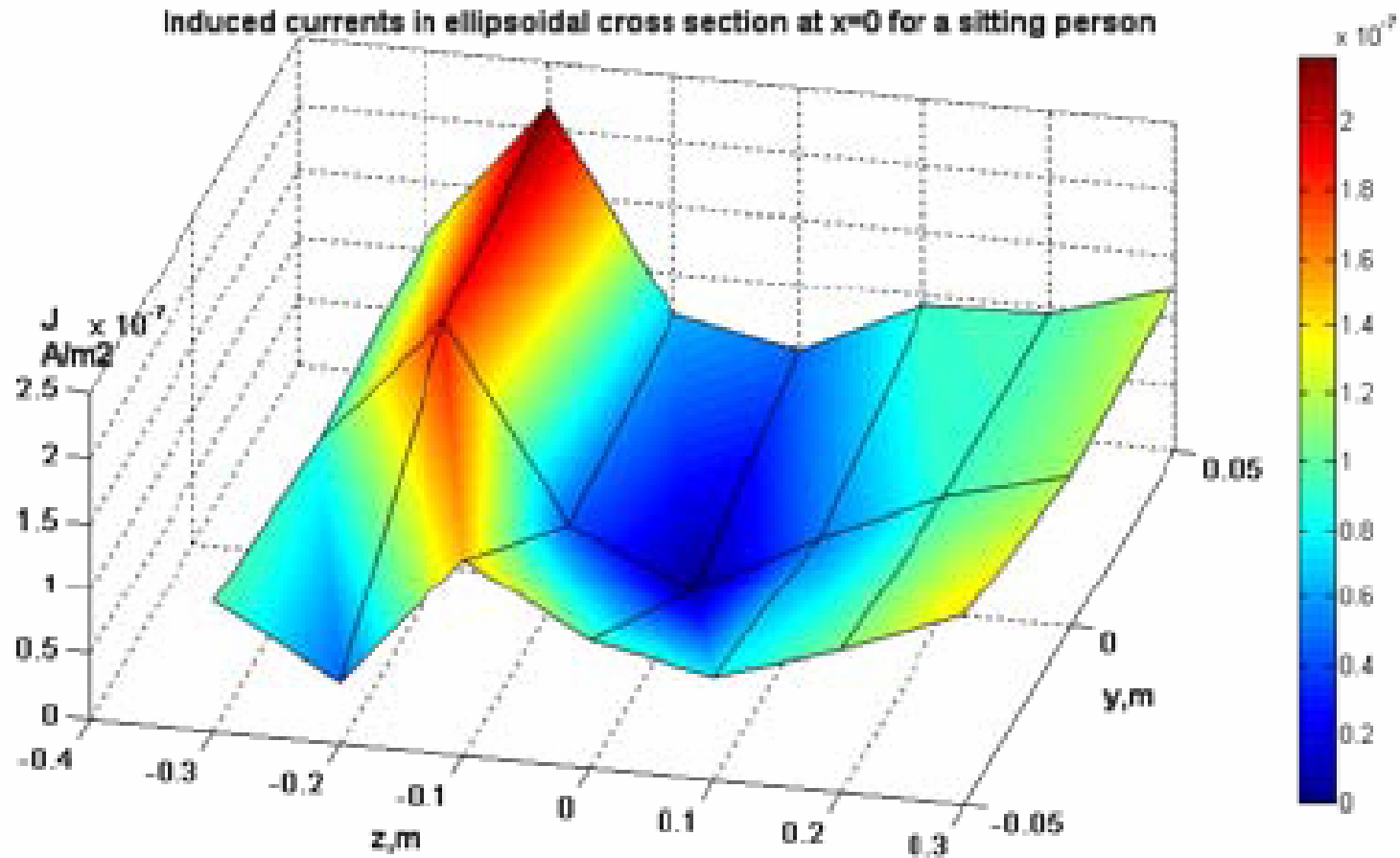


Fig.5 The induced current from magnetic field exposure

The Second Method

- This method considers the effect of the electric field, as well as the magnetic field. This method uses dipole and image theory with prolate spheroid models. The Field contributions are:

$$\vec{E} = \vec{E}_e + \vec{E}_m$$

$$\vec{H} = \vec{H}_e + \vec{H}_m$$

Where:

\vec{E}_e : Internal electric field caused by the external electric field \vec{E}_o

\vec{E}_m : Internal electric field caused by the external magnetic field \vec{H}_o

\vec{H}_e : Internal magnetic field caused by the external electric field \vec{E}_o

\vec{H}_m : Internal magnetic field caused by the external magnetic field \vec{H}_o

- The internal electric field \vec{E}_e , given by:

$$\overline{E}_{ex} = \frac{E_{ox}}{1 + A_b (\varepsilon_r^* - 1)} \hat{x}$$

$$\overline{E}_{ey} = \frac{E_{oy}}{1 + A_b (\varepsilon_r^* - 1)} \hat{y}$$

$$\overline{E}_{ez} = \frac{E_{oz}}{1 + A_a (\varepsilon_r^* - 1)} \hat{z}$$

- And the relative complex permittivity:

$$\varepsilon_r^* = \frac{\varepsilon^*}{\varepsilon_0} = \frac{\varepsilon}{\varepsilon_0} - j \frac{\sigma}{\omega \varepsilon_0}$$

- Where $\varepsilon_0 = 8.85 \cdot 10^{-12}$ F/m

$$\varepsilon_r^* = 1.2 \cdot 10^7 \angle 88.8^\circ$$

- The internal, circumferential electric field, \vec{E}_m induced by the external magnetic field:

$$\bar{E}_{m1} = -j\omega\mu_o H_{ox} \frac{\left[y\hat{z} - \left(\frac{b}{a}\right)^2 z\hat{y} \right]}{1 + \left(\frac{b}{a}\right)^2}$$

$$\bar{E}_{m2} = -j\omega\mu_o H_{ox} \frac{\left[\left(\frac{b}{a}\right)^2 z\hat{x} - x\hat{z} \right]}{1 + \left(\frac{b}{a}\right)^2}$$

$$\bar{E}_{m3} = -j\omega\mu_o H_{ox} \frac{[x\hat{y} - y\hat{x}]}{2}$$

The internal magnetic field \vec{H}_e by external electric field:

$$\overline{H}_{e1} = -j\omega\varepsilon^* E_{ex} \frac{\left[y\hat{z} - \left(\frac{b}{a}\right)^2 z\hat{y} \right]}{1 + \left(\frac{b}{a}\right)^2}$$

$$\overline{H}_{e2} = -j\omega\varepsilon^* E_{ey} \frac{\left[\left(\frac{b}{a}\right)^2 z\hat{x} - x\hat{z} \right]}{1 + \left(\frac{b}{a}\right)^2}$$

$$\overline{H}_{e3} = -j\omega\varepsilon^* E_{ez} \frac{[x\hat{y} - y\hat{x}]}{2}$$

- Adopting this technique for a person sitting in front of a point source taking the vertical ellipse at $x=0$. The results of the induced magnetic fields , induced electric fields and induced current densities at different values of y and z considering $x=0$ from electromagnetic fields are shown in Figs 6-8.

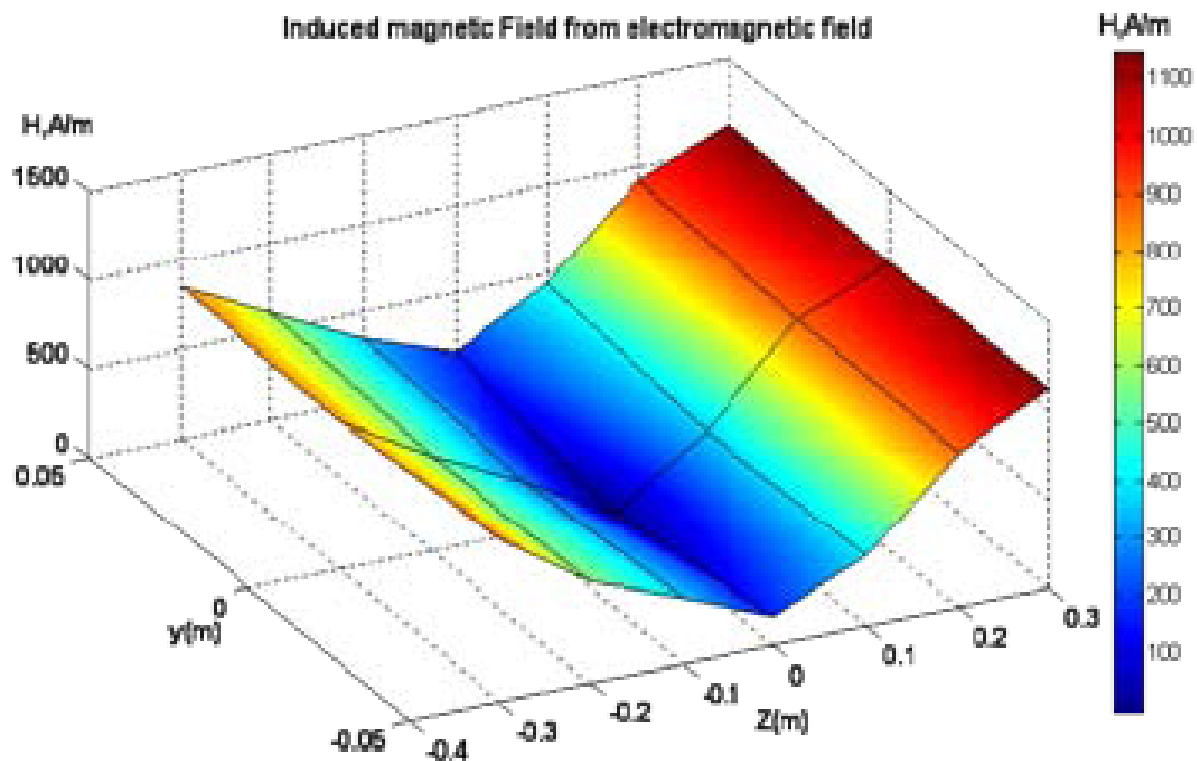


Fig. 6 Induced magnetic field due to electromagnetic field

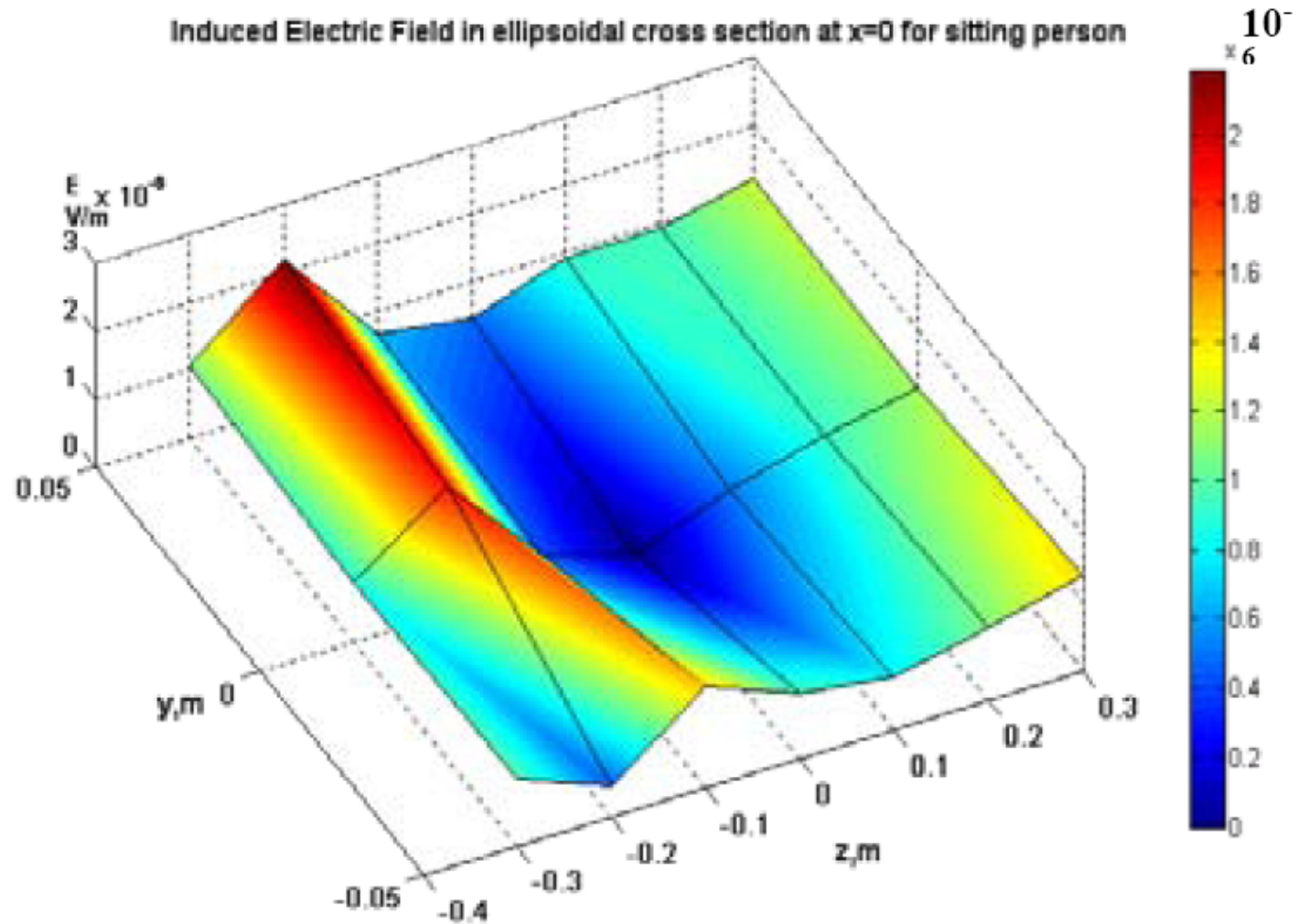


Fig 7 Induced electric field due to electromagnetic field

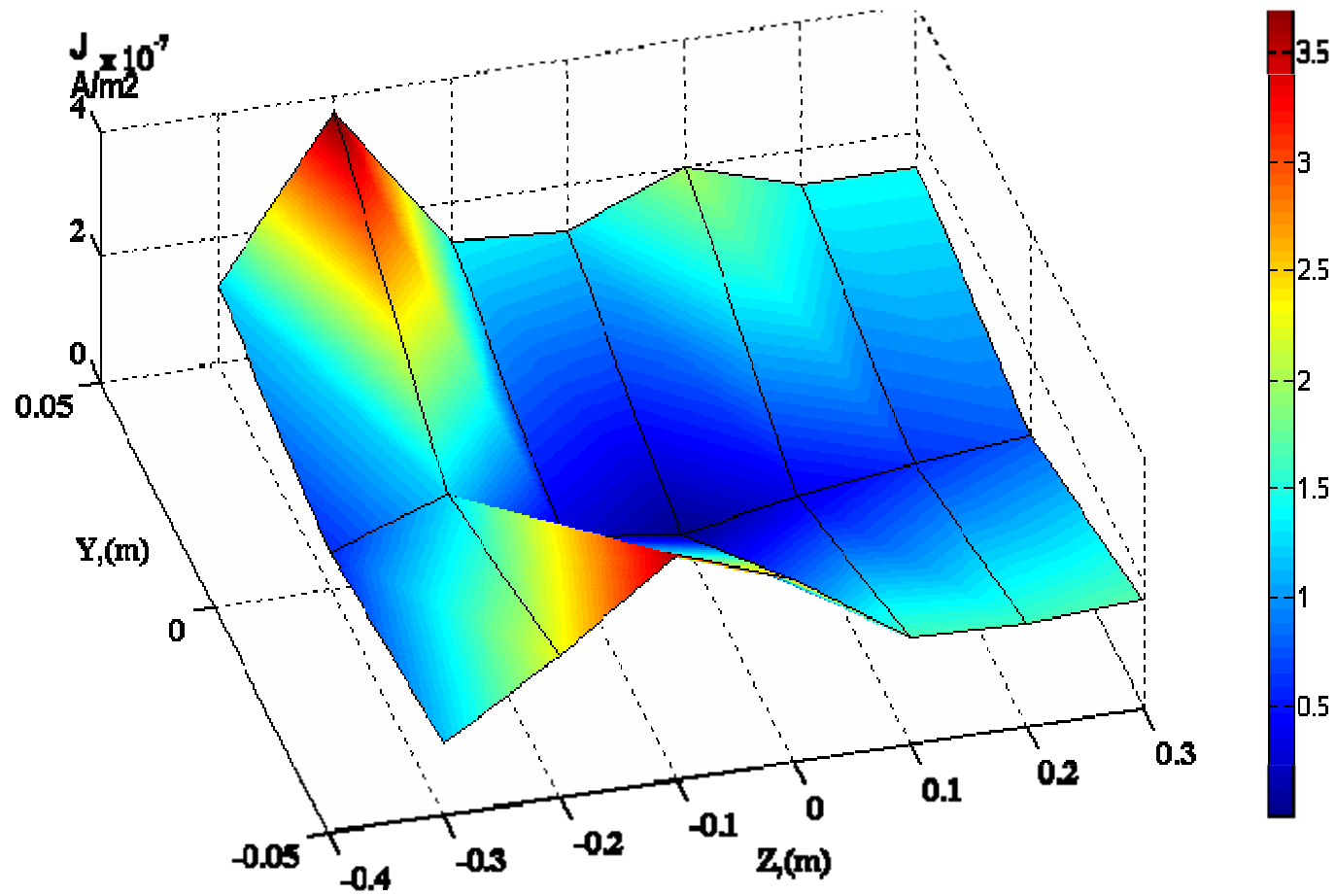


Fig.8 The total induced currents from electromagnetic field

- The induced current densities from electric field exposure only is shown in Fig 9 .The induced current densities from magnetic field exposure only is shown in Fig 10. These figures indicate that the induced current densities due to the electric fields are insignificant to be considered in calculations.



- These results are consistent with other researcher's findings

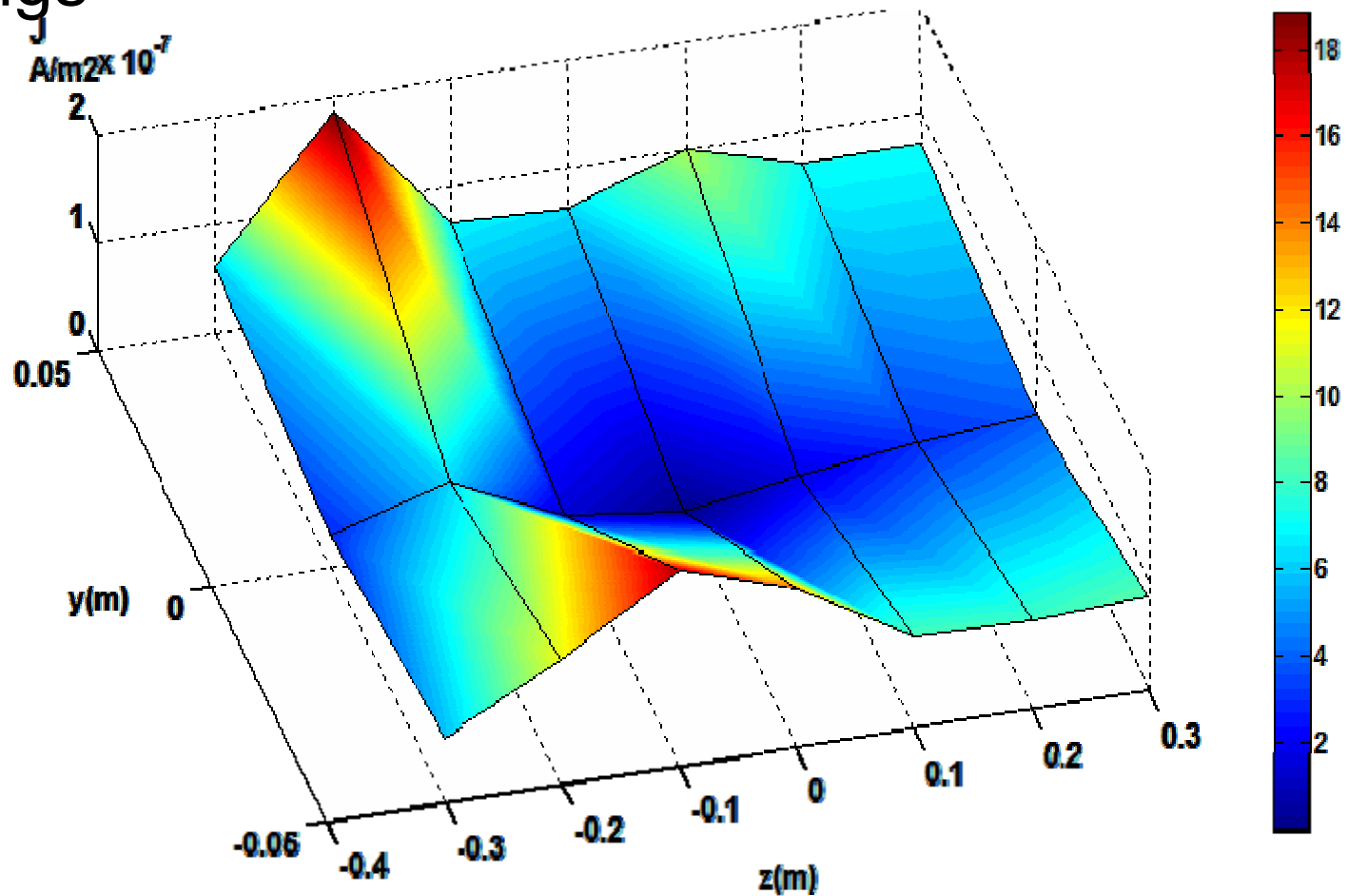


Fig.9 The induced currents from magnetic field only

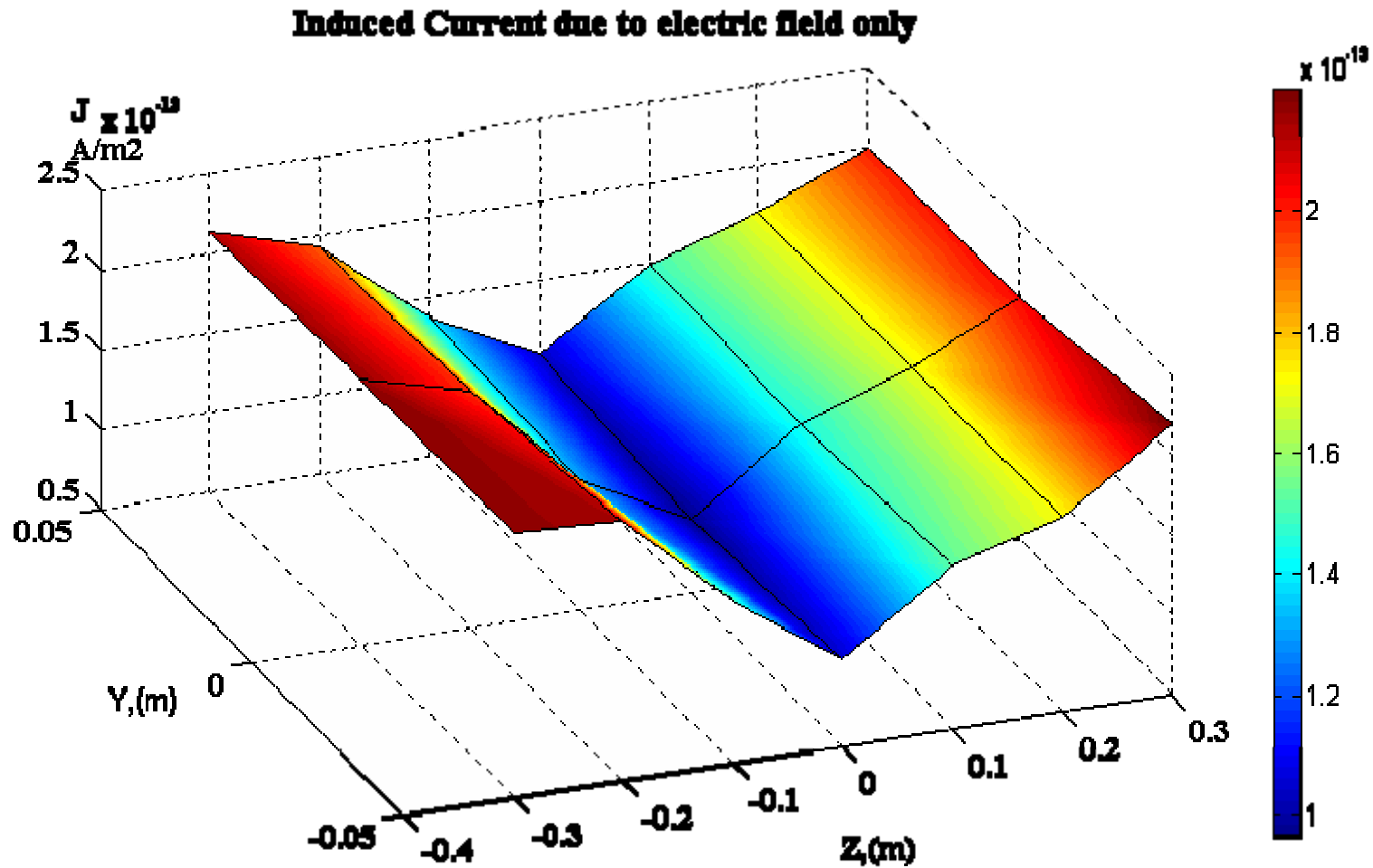


Fig.10 Induced Currents from Electric Field Only

The Third Method

- This method considers the living organism as an electrically homogeneous cylinder, which is electrically isolated from its surroundings by dry air. An axially oriented and spatially uniform magnetic field H will induce an electric field in the exposed body, according to Faraday's law,

- the electric field E_i

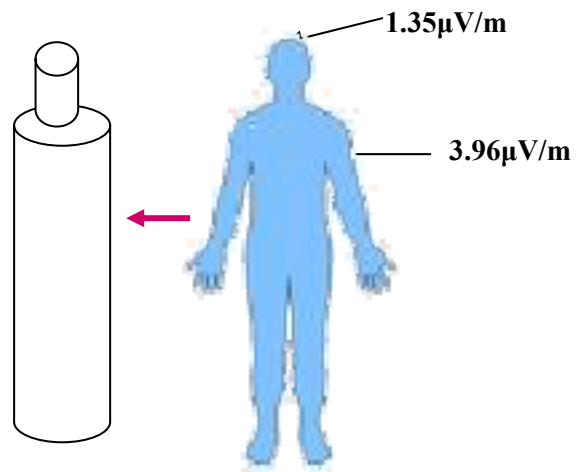
$$E_i = \left(- \frac{\partial B}{\partial t} \right) * \left(\frac{r}{2} \right)$$

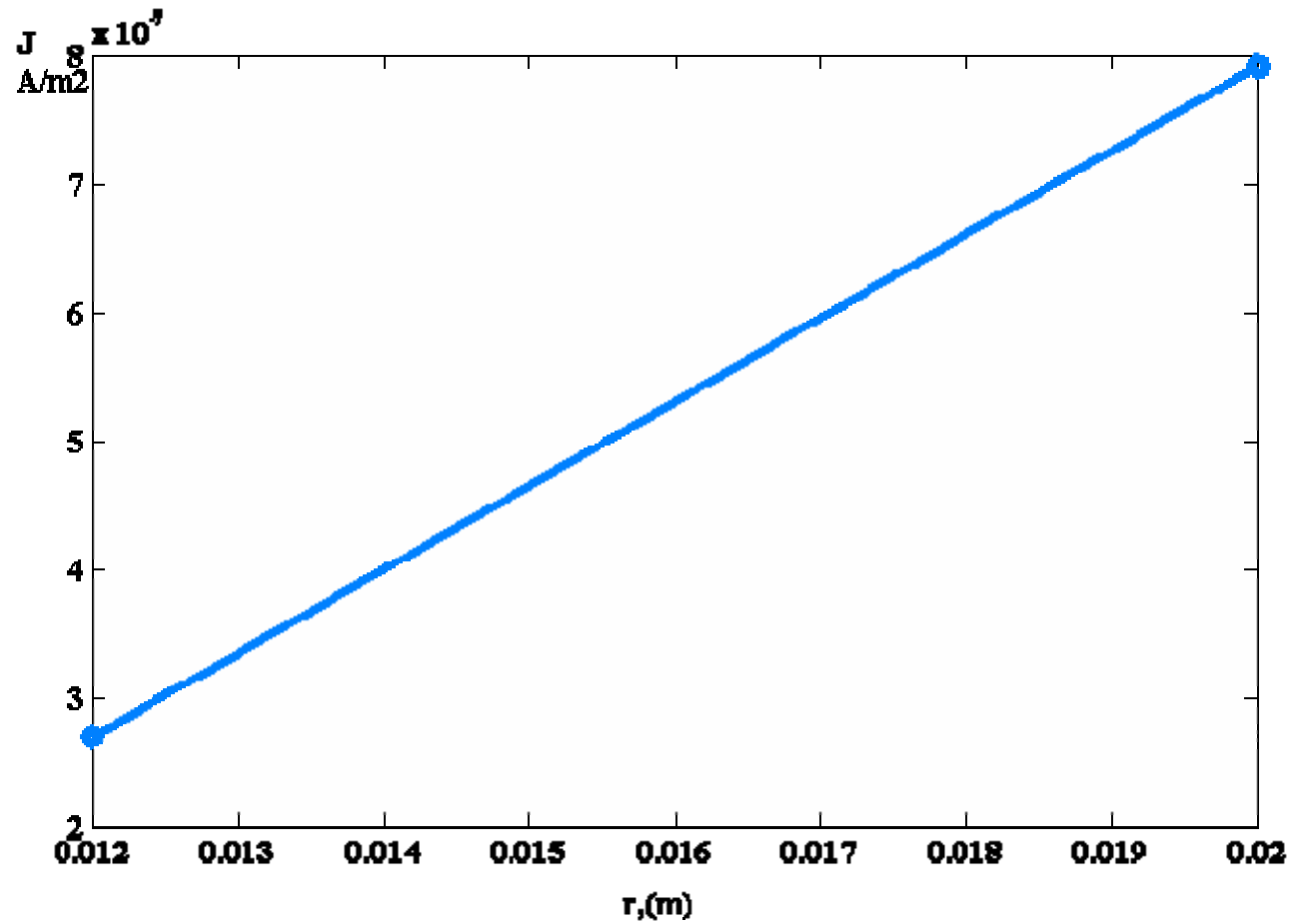
- Where:
- r : radial distance from the centre of the cylinder to the point where E_i is evaluated and
- E_i : vector lies in a plane perpendicular to B and is oriented tangentially to circles of radius r .

$$E_i = -j\omega B \left(\frac{r}{2} \right)$$

$$J = \pi r f \sigma B$$

- Applying this method on a person with head radius=0.1m and body radius =0.3m the results for induced currents are given in Figs 11.





The Induced Currents from Magnetic Field for Human Body

RESULTS AND DISCUSSIONS

- Time –varying magnetic fields induce currents within the body. It was noticed from the first method that the maximum measured magnitude of magnetic field was found at $z=-0.2\text{m}$. The induced electric field and corresponding currents are higher at the upper part of the body than at the lower part of it.

- The maximum induced electric field is $2.186 \cdot 10^{-6} \text{V/m}$ and the maximum induced current density is $2.186 \cdot 10^{-7} \text{A/m}^2$ at the upper part.

- In the second method, The following results were predicted. The magnetically induced electric field strength and the corresponding current density are greatest at the periphery of the body. The induced magnetic field values in the first method are less than the induced magnetic field in this case because here we use the electromagnetic field.

- The induced electric fields in this case due to electromagnetic fields nearly have the same shape but differ in values with the induced electric fields due to magnetic fields as in first method.

- Where the induced electric field is less than the first method by approximately 20%.which mean that the induced electric fields due to magnetic field decreases the total induced electric fields because it's direction is opposite to the induced electric field from external electric field.

- This method indicates that the induced currents due to the electric fields are insignificant to be considered in calculations. The maximum induced current from electric field only value is $1.097 \cdot 10^{-13} \text{ A/m}^2$, whereas the minimum induced current is $4.821 \cdot 10^{-14} \text{ A/m}^2$.

- where, The maximum induced current from electromagnetic field value is $1.793 \cdot 10^{-7} \text{A/m}^2$, whereas the minimum induced current is 0A/m^2 .

- The third method, we calculated the magnetically induced electric field and corresponding current density at the surface of human head and body. The calculated induced current densities at human head was $1.35 \times 10^{-7} \text{ A/m}^2$, and that at the human body was $3.96 \times 10^{-7} \text{ A/m}^2$.

- The average induced current was $2.65 \times 10^{-7} \text{ A/m}^2$ which is near to the calculated value using method one. From these methods it is recommended to use the first method for accurate and precise calculations these results are in quite agreement with the practical measured values.



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Experimental Result

Sampling Strategy

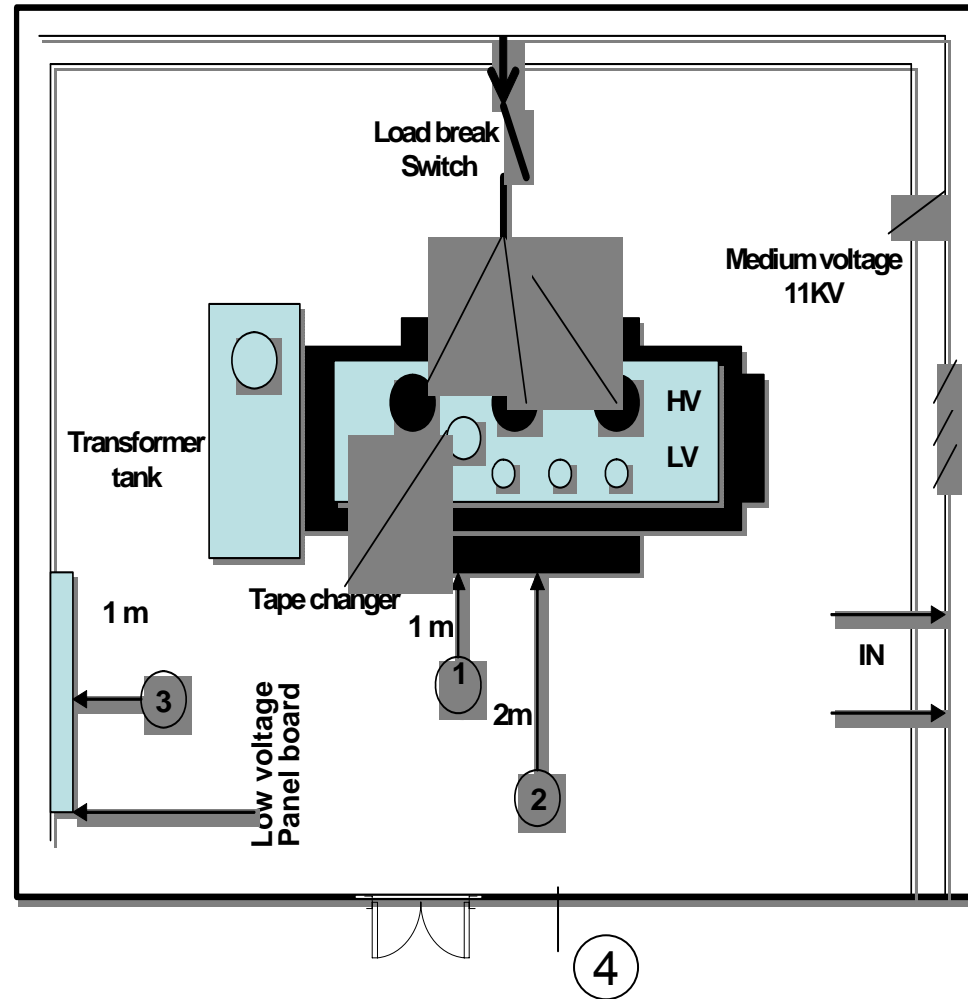
a- The electric room

b- workshops

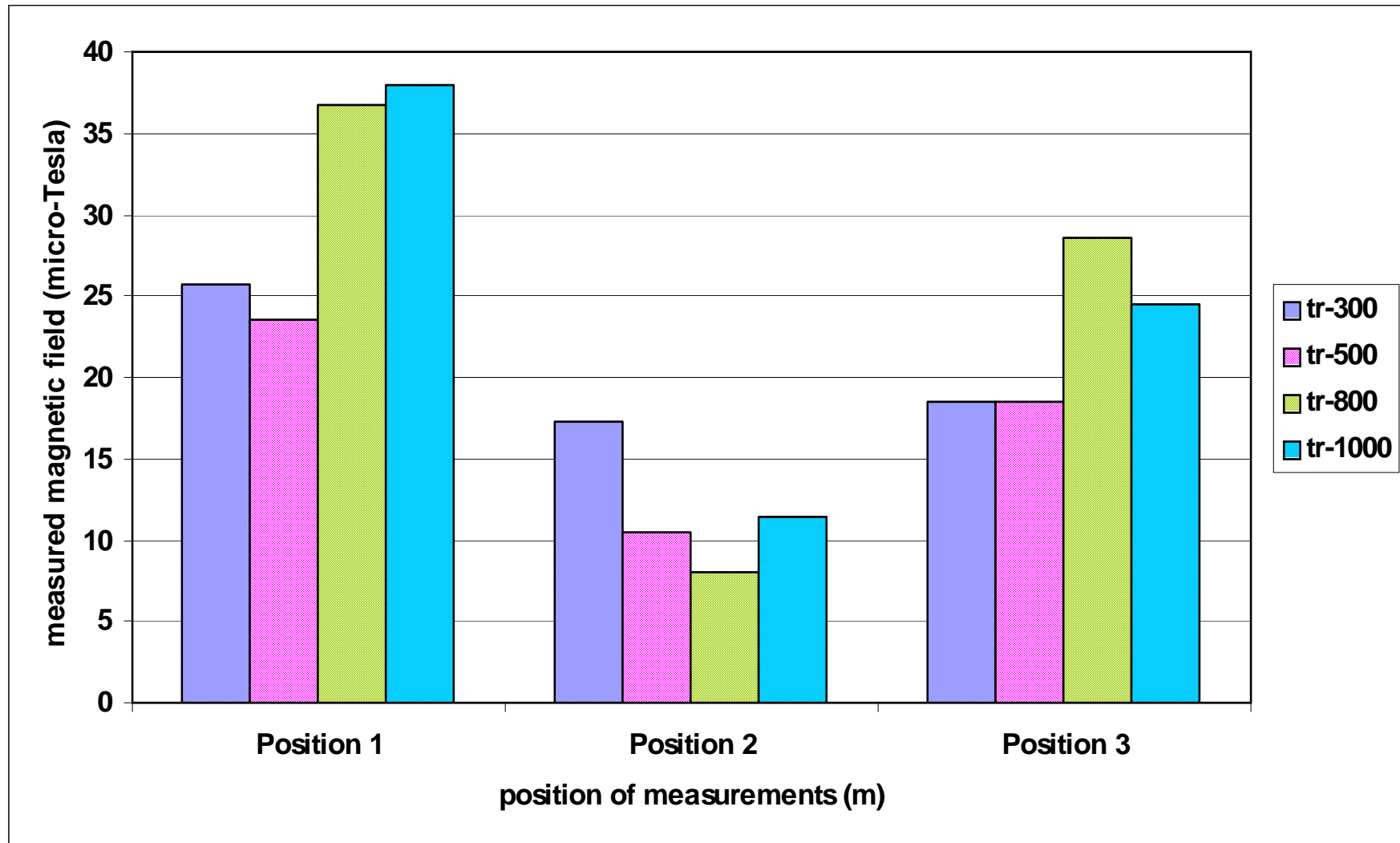
c- office equipments

d- Some home appliances

a- The electric room



Measurement Position in Electric Room

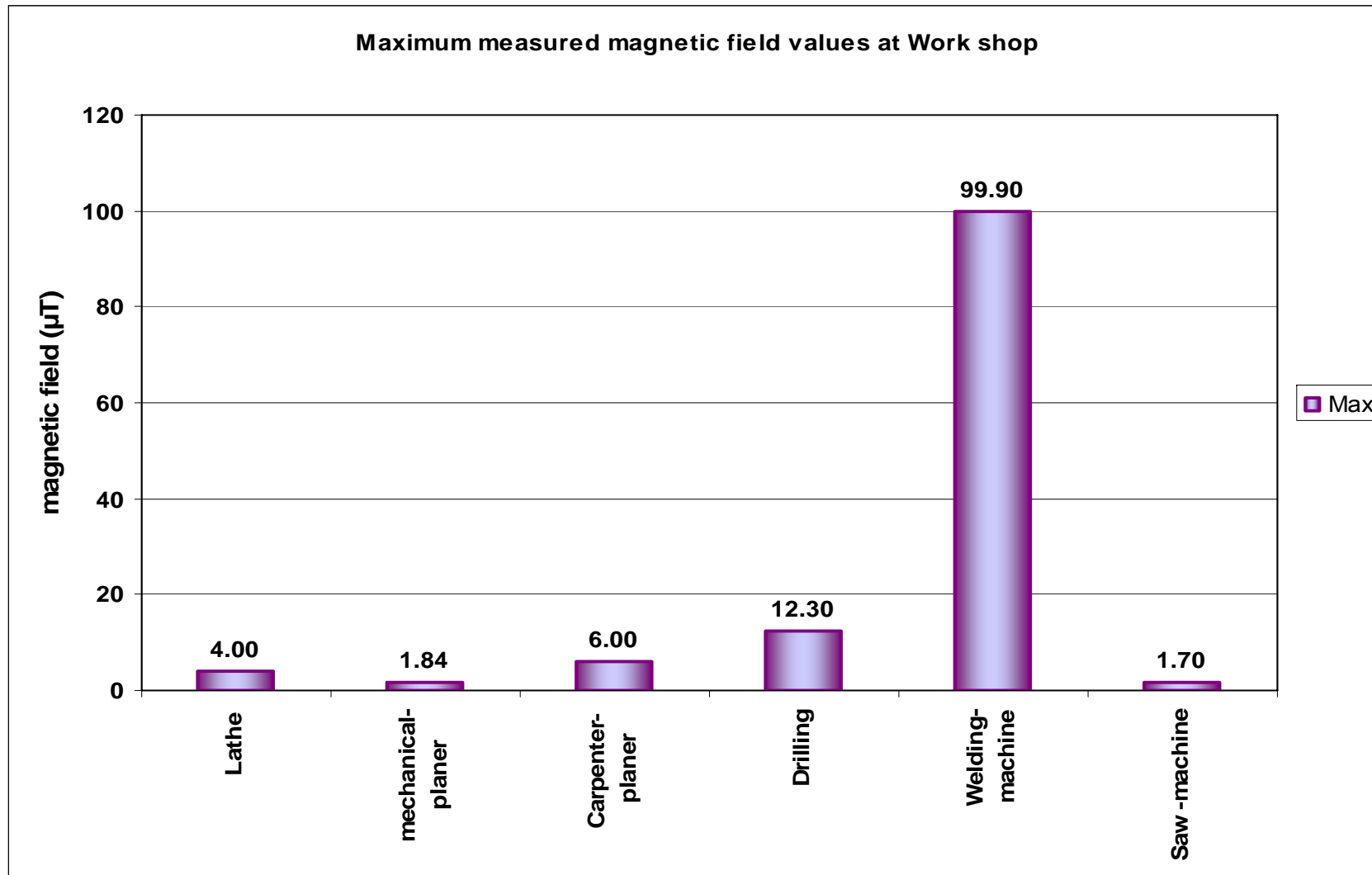


**The Average Magnetic Field for Different Transformers Capacity
at Different Positions**

b- workshops



the sampling point measured at operator position for many workshop machines. The magnetic field was measured 10 times with sampling interval 2 seconds for each workshop machine and the recorded values are the mean of these 10 measurements.



The maximum Measured Magnetic Field for Different Workshop Machines

The results for workshops machine showed that:

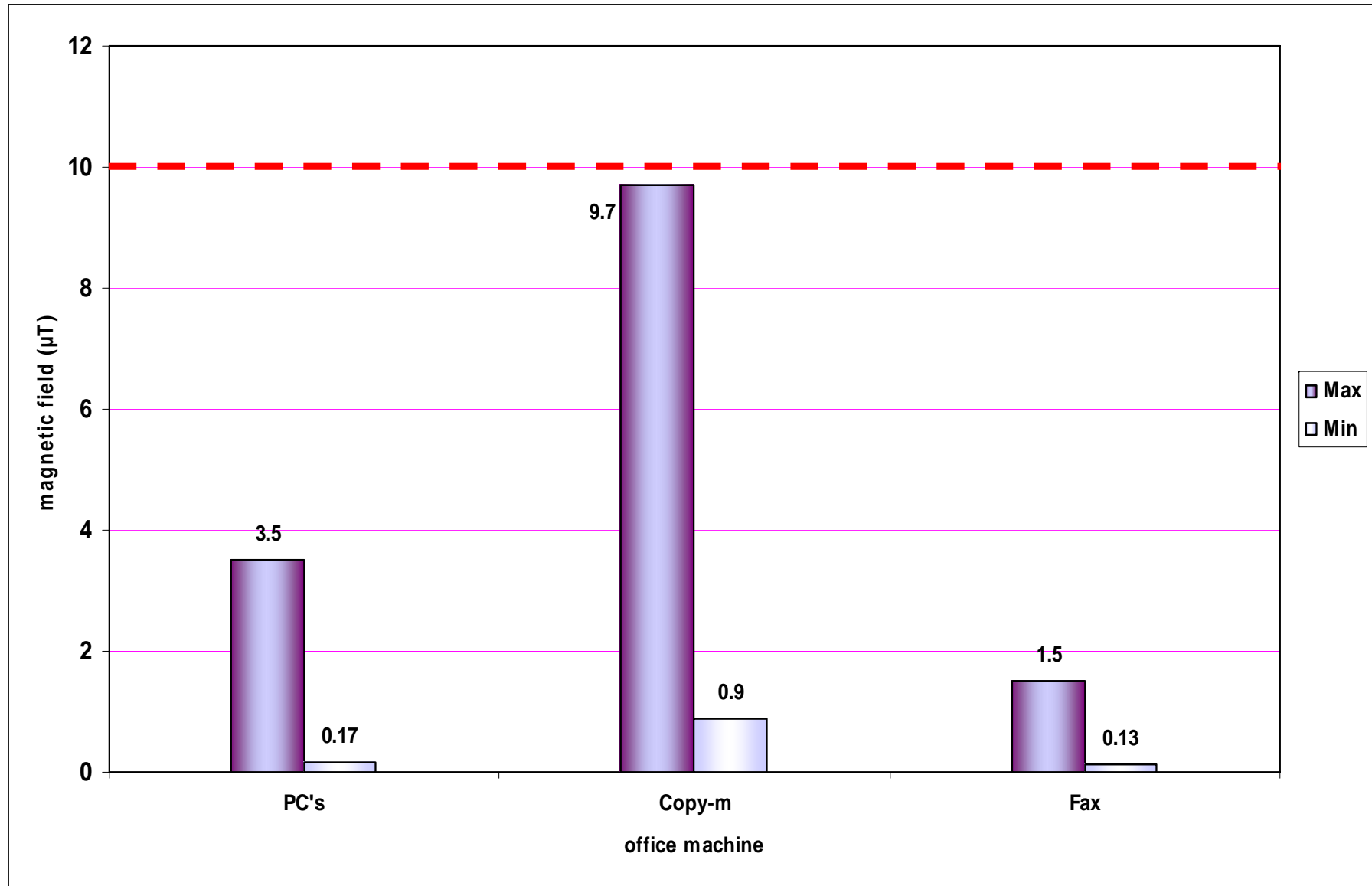
- The **maximum** measurement magnetic field values are for **the welding machines**
- The **minimum** measurement magnetic field values are for the **saw machines**
- All results are lower than the occupational exposure limits

c- office equipments

the measurements were taken at operator position.

Sampling points were taken for fax, copy machines, and PC computers

The maximum and minimum values for office measured equipments are shown in following Fig



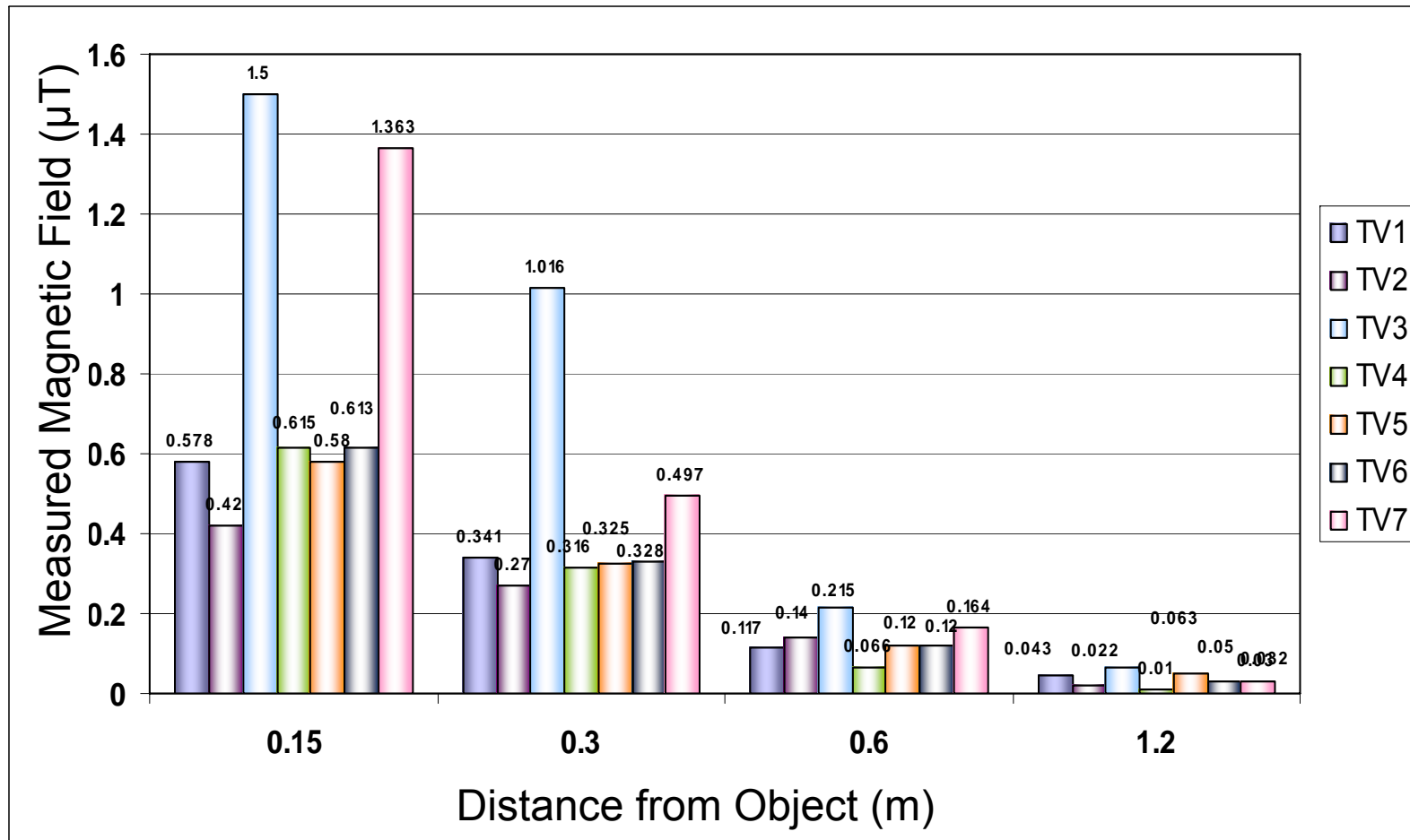
**The Maximum and Minimum Measured Magnetic Field
for Different Office Equipments**

The results for office devices showed that:

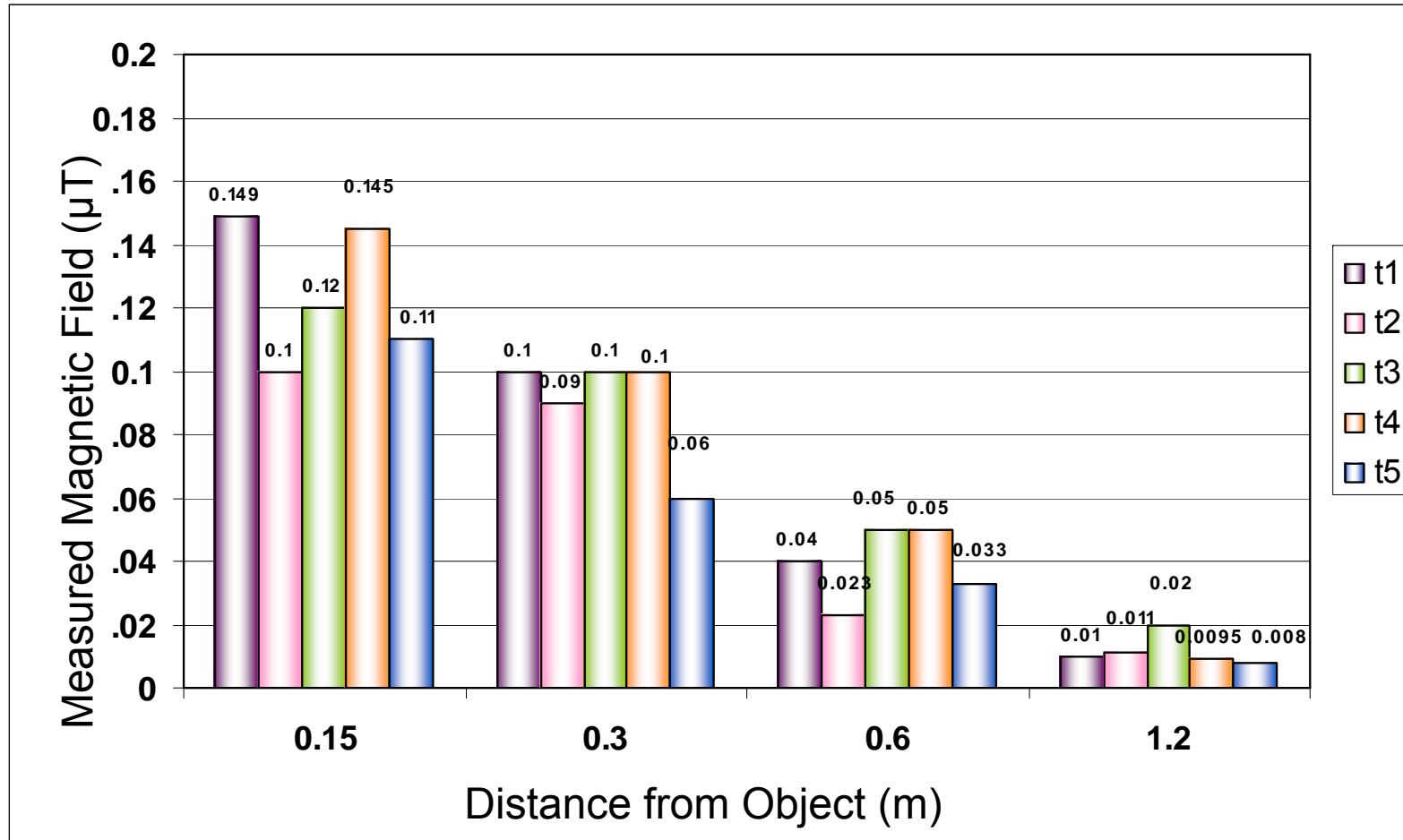
- The **maximum** magnetic field exposure is from **copy machine**
- The **minimum** magnetic field exposure is from **fax machine**

d-Some home appliances

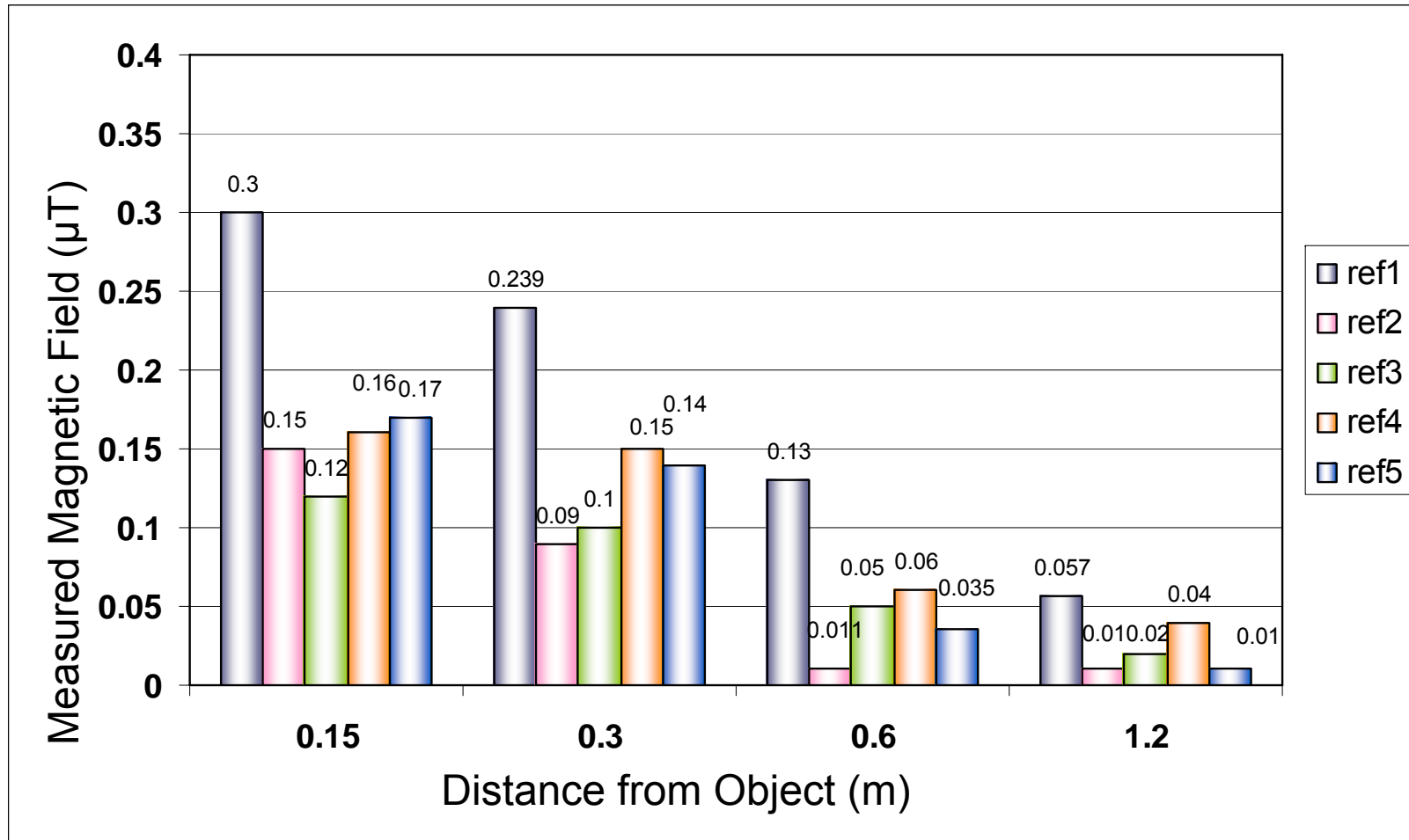
(TV sets, irons, toasters, cassettes, and refrigerators) were measured at different distances 0.15m, 0.3m, 0.6m and 1.2m. The magnetic field was measured 10 times with sampling interval 2seconds for each device and the average value taken.



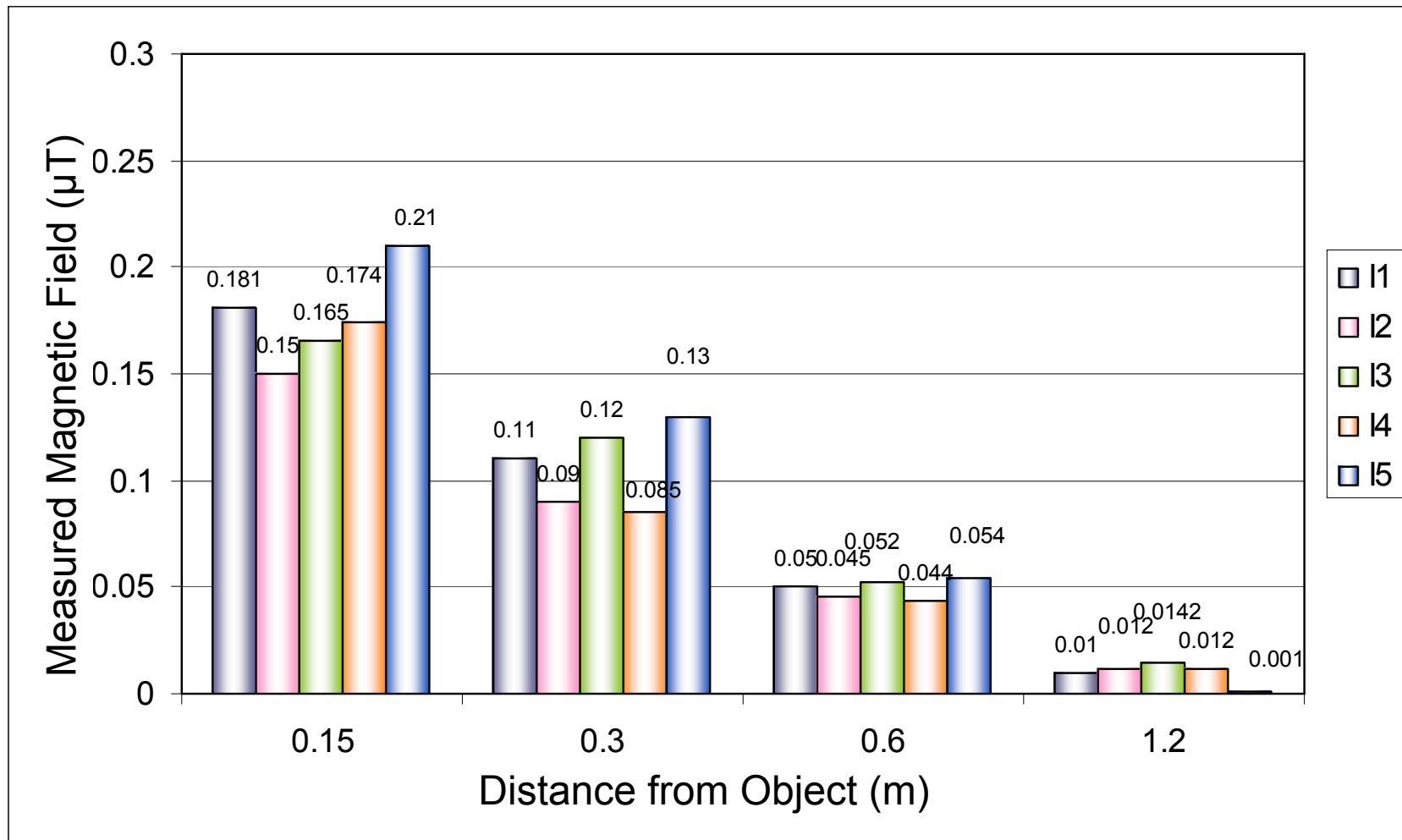
The measured magnetic field for seven TV at different positions



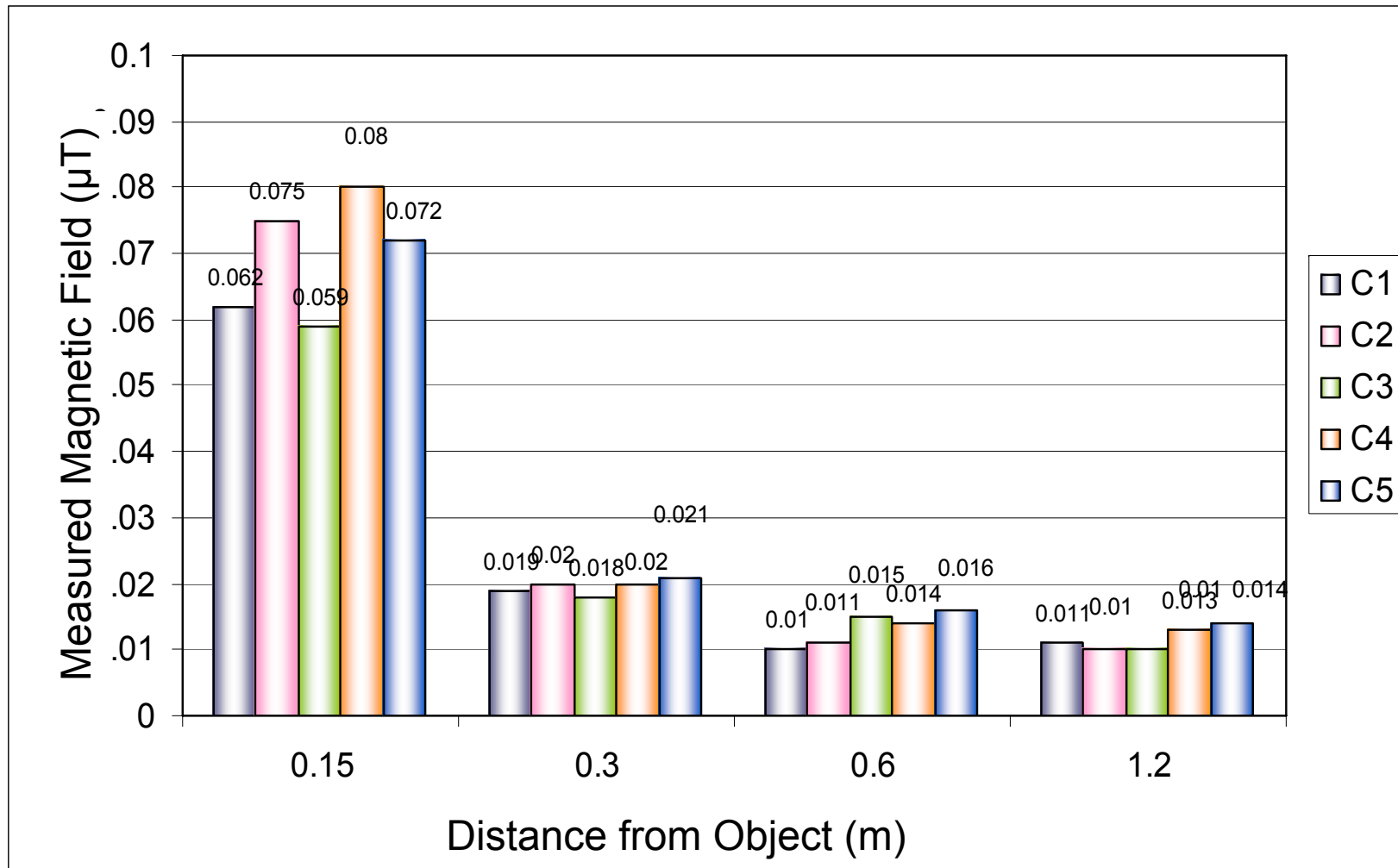
The Measured Magnetic Field for Five Toasters at Different Positions



The Measured Magnetic Field for Five Refrigerators at Different Positions



The Measured Magnetic Field for Five Irons at Different Positions



The Measured Magnetic Field for Five Cassettes at Different Positions

The results for home devices showed that:

- The **maximum** magnetic field exposure is from **televisions**
- The **minimum** magnetic field exposure is from **toasters**



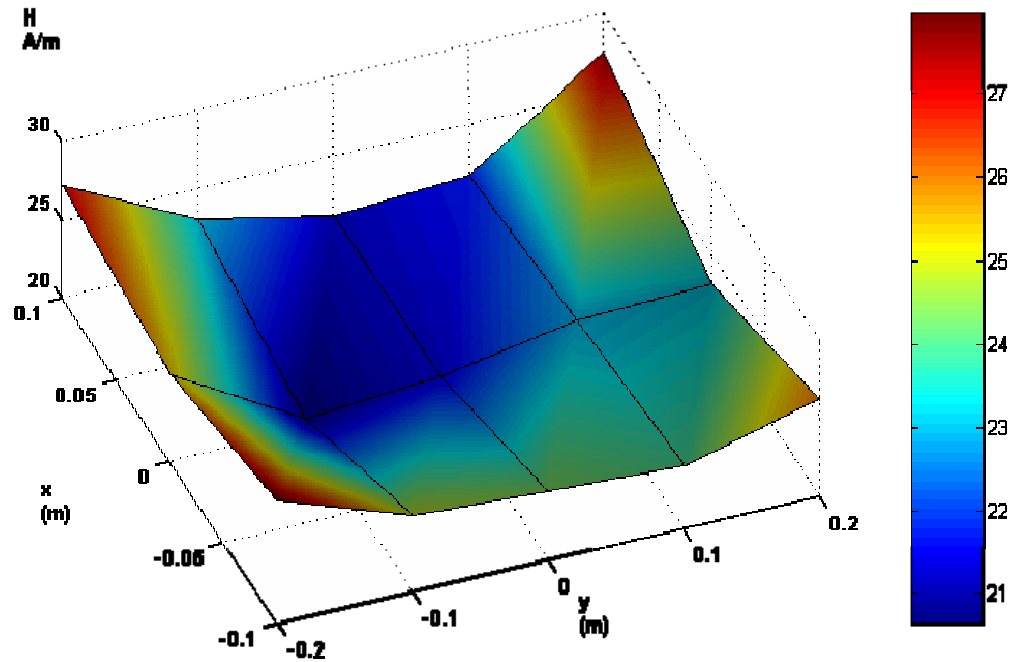
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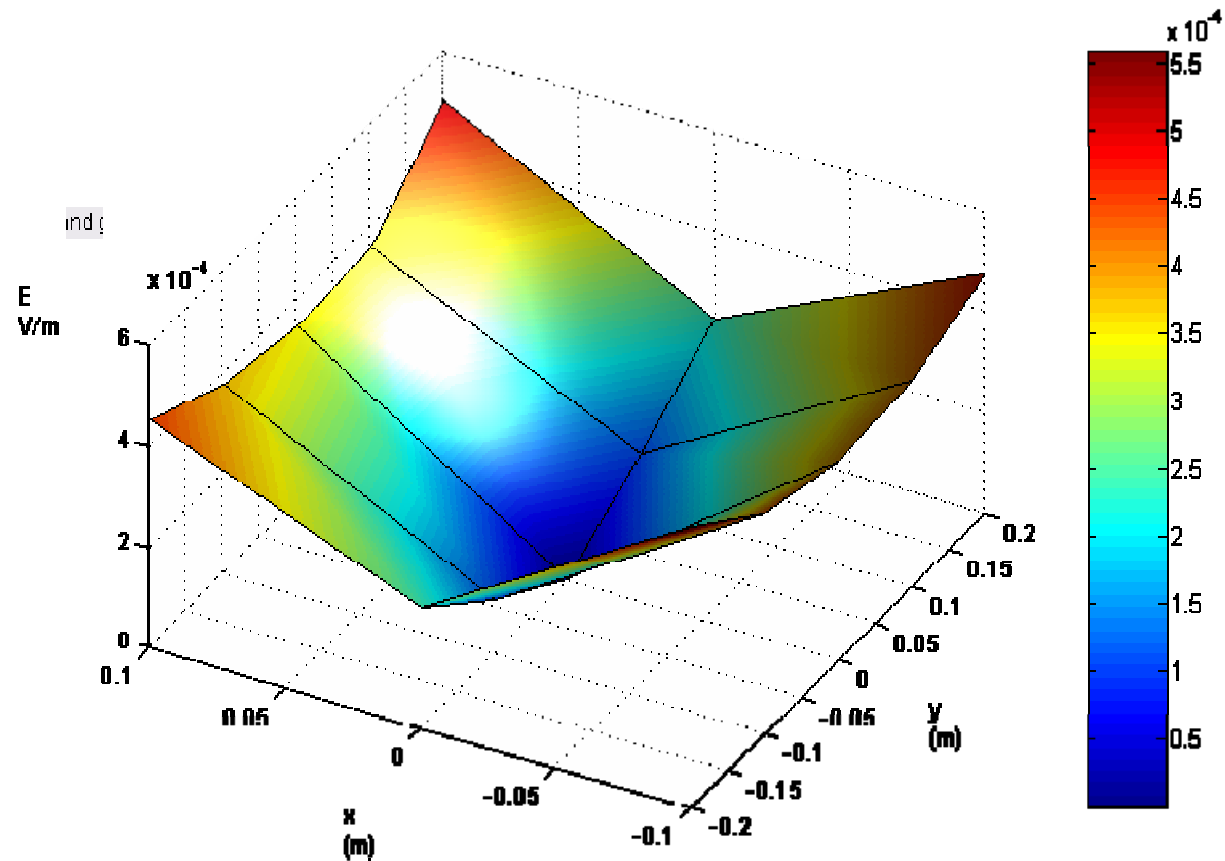
Applications and Results

Applying the first method on person standing at front of transformer (500KVA). The measurements of magnetic field taken at 1m from the transformer LV side at height 1m from the ground.

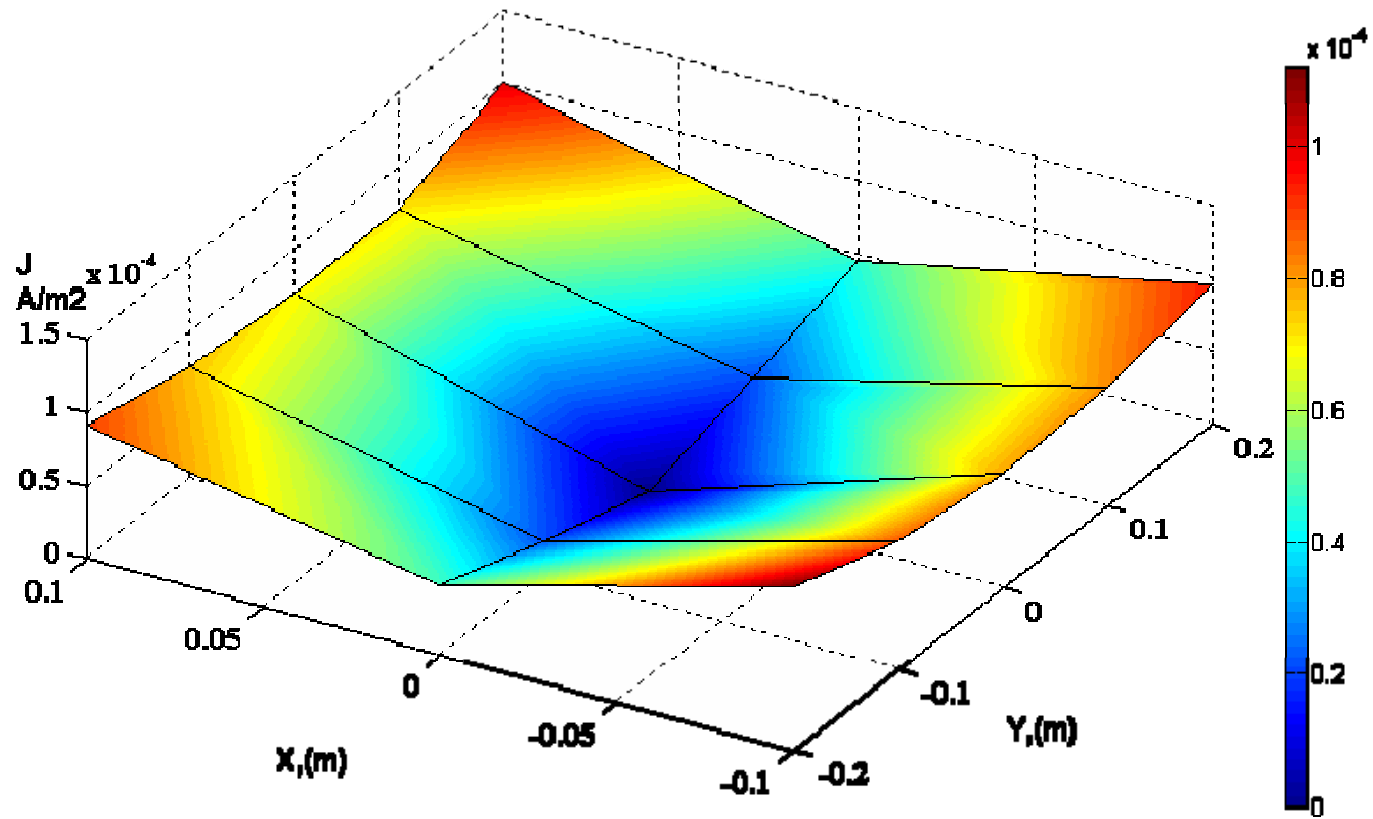
The induced magnetic field ,the induced electric field and, the induced current in human body shown in following Figs.



**Measured Magnetic Field in Human body
at cross section $Z=0$**

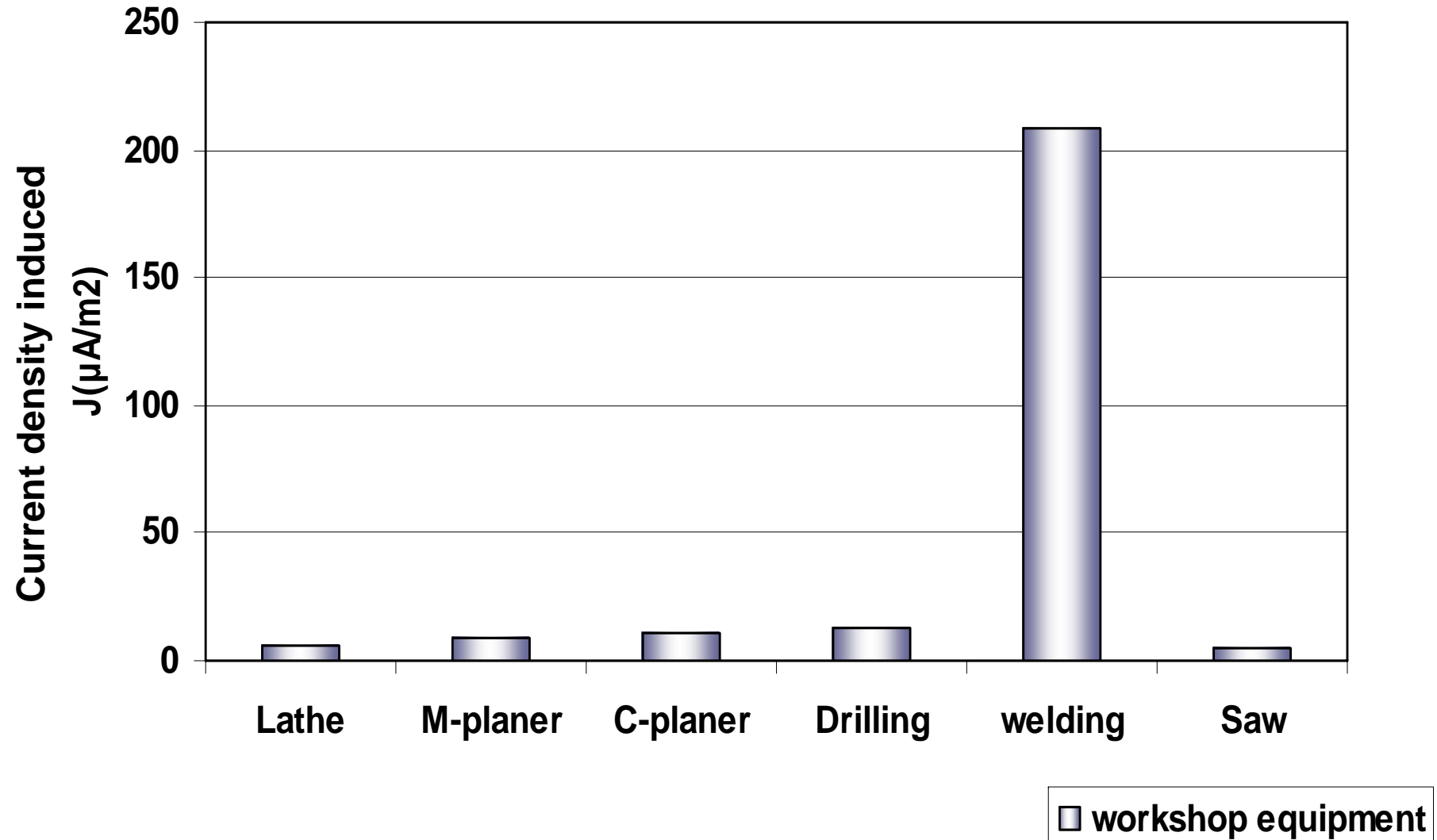


. Induced Electric Field in Human body at cross section $Z=0$



Induced Current in Human body
at cross section $Z=0$

- Applying the third method on the workshop machines operators.
- The results of the induced current inside human body shown in the following fig



**The Induced Current Density in human body
due to workshop machines (ICNIRP limit=10 mA/m²)**

CONCLUSIONS

- It is clear that the first technique express the values with great accuracy compared to the second technique (which supposed to be the most accurate). For that the first method will be adopted instead of the second method for measurements which have 3 coordinates and takes longer time.

CONCLUSIONS

- The third simplified and quick method could be used instead of the first for calculating the induced electric field and corresponding induced current density for the average measurements and for measurements without the three components which is more easy and simple.

- The magnitude of induced magnetic field from the applied magnetic field is virtually the same outside the body as inside it. Unlike The electric field for which the internal field strength is many orders of magnitude less than that of external field. This indicates the danger of magnetic field.

- It is noticed that the maximum calculated induced current densities was $3.96 \cdot 10^{-7} \text{ A/m}^2$ which is so small when compared to the ICNIRP standard (10 mA/m^2) that may produce any significant biological effects.

- But it has to be noticed that these induced current densities from short- term exposure (few hours) that it may cause minor transient effects on health. Long term exposures may cause dangerous effects



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Thank You