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## A PHYSICAL ELECTRIC MODEL OF THE HUMAN BODY EXPOSED TO THE ACTION OF THE ELECTROMAGNETIC ENVIRONMENT ABOARD A NAVY SHIP

BY

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**Abstract.** The subject of the present paper subscribes to the trend of nowadays research in the field of EMC (Electromagnetic Compatibility) regarding the identification of some negative aspects of the electromagnetic field upon human body. More precisely, the paper presents, for the first time – on our acknowledgement – a physic electrical model with concentrated parameters of the human body exposed to the electromagnetic field on board of a navy ship. Based on measurements done on board it is analysed how the electric currents induced “into the body” obey the international standards regarding the admissible limit values, so that the health of the personnel on board not to be affected.

**Key words:** electric physical model; human body; electromagnetic environment; navy ship; negative effects.

### 1. Introduction

Identifying the negative effects of the electromagnetic field upon the human body and the adequate protective means has lately become one of the

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most important problems of EMC (Electromagnetic Compatibility) (Sotir & Moșoiu, 1997; Gary, 1993; Nair, 1993; Calotă *et al.*, 1998; King, 1998; Ianoz, 2003; Deviatcov & Betskii, 1994).

For a navy seagoing ship such an issue is a priority, taking into consideration the very high electromagnetic power density due to functioning together of a great number of electric and electronic equipment in a limited space (Mataluno, 1988).

Because *in vivo* measurements upon the human body are not possible, there was designed and made a physical electric model, with concentrated parameters, for such a body, that was subjected to the action of the electromagnetic field of radio antennas situated on board ship.

The experiment had a double purpose namely

- a) to verify the relevance of such a model for the issue analysed;
- b) to provide data, based on measurements onboard ship, about the levels of the currents induced in the “body” and the ways these are according to the limit values admitted by the standards or not.

## 2. A Physical Electric Model of the Human Body

According to the results obtained by Ianoz (2003), Zamfirescu *et al.* (2000), Rajewsky (1938), Schwan & Foster (1980), Herrich *et al.* (1950), there were identified a series of constituent parameters ( $\epsilon$ ,  $\mu$ ,  $\sigma$ ) both for different parts of the body (hand, trunk, leg) or organs (heart, liver, muscle, kidney) and of the body as a whole (such as, for example, conductivity,  $\sigma$ , whose values are between 0.2 and 0.6 S/m (Ianoz, 2003; Zamfirescu *et al.*, 2000).

At the same time there could be identified some electric models of the human body (Igneu, 1996; Sotir & Moșoiu, 1997; Ianoz, 2003; Zamfirescu *et al.*, 2000; Richman, 1985; Crist *et al.*, 2006) such as, for example, that referring to the study of the electrostatic discharge of a person and the effects of this discharge upon the electronic components and circuits.

Based on the information gathered, it has been designed an electrical model with concentrated parameters of a human body, excluding the head, whose form and material structure requires another type of model (Kriticos & Schwan, 1972; Miclăuș *et al.*, 2004). It was considered that the person holds a metallic object with both hands, for example a wrench, and is repairing an electric installation having both feet on the framework of the installation, the motor being insulated with respect to the metal deck. It was also estimated that the electric resistance between the person’s feet and the metallic work of the installation is not significant, to obtain maximum values for the currents induced in the body.

Establishing the values for the electric parameters concentrated for different parts of the body (trunk, upper arm, forearm, hand, thigh, calf, foot) was done starting from the values of the constituent or concentrated parameters

established by Crist *et al.* (2006), Rajewsky (1938), Schwan & Foster (1980), Herrich *et al.* (1950), Oswald (1937) and also from the average geometric dimensions of the considered body (Table 1).

**Table 1**  
*The Average Geometric Dimensions of the Human Body Used as a Model, [cm]*

Whole body	$h$	1.75	Hand	$d_m$ (average diameter)	0.075
Trunk	$d_m$ (average diameter)	0.35	Hand	$l_m$ (average length)	0.19
Upper arm	$d_{ab}$ (average diameter)	0.12	Thigh	$l_{ps}$ (average length)	0.40
Upper arm	$l_{ab}$ (average length)	0.30	Calf	$d_{pi}$ (average diameter)	0.12
Forearm	$d_b$ (average diameter)	0.10	Calf	$l_{pi}$ (average length)	0.50
Forearm	$l_b$ (average length)	0.30			

Accordingly, there were given values for inductivities and capacities of the parts of the “body”, whose scheme is shown in Fig. 1, and there were calculated the electric resistance values for these parts, starting from their conductivity known values. Thus, for the trunk it was considered for calculation an average resistivity of  $130 \Omega \cdot \text{cm}$ , and for the skeleton muscles, of  $140 \Omega \cdot \text{cm}$ .

To simplify it was considered that all these parts have cylindrical shape or that they consist of more “current ways” of cylindrical shape, connected in parallel; thus the resistance of the trunk was considered as a parallel equivalent resistance of 12 cylindrical current channels, with the diameter of 10 cm and the length of 60 cm, representing as many identical resistances (the value of a resistance of  $120 \Omega$ ). The skin effect was also neglected, considering that the current distribution into the body is uniform, to obtain maximum values for the induced currents.

Based on the theoretical electric model shown in Fig. 1, there was made a physical electric model, on a printed circuit plate with dimensions of  $0.420 \text{ m} \times 0.300 \text{ m}$ .

The calculated values of the resistances of the parts of the “body” and the values of the inductances and capacities, taken from the reference for the frequency of 30 MHz, are shown in Table 2.

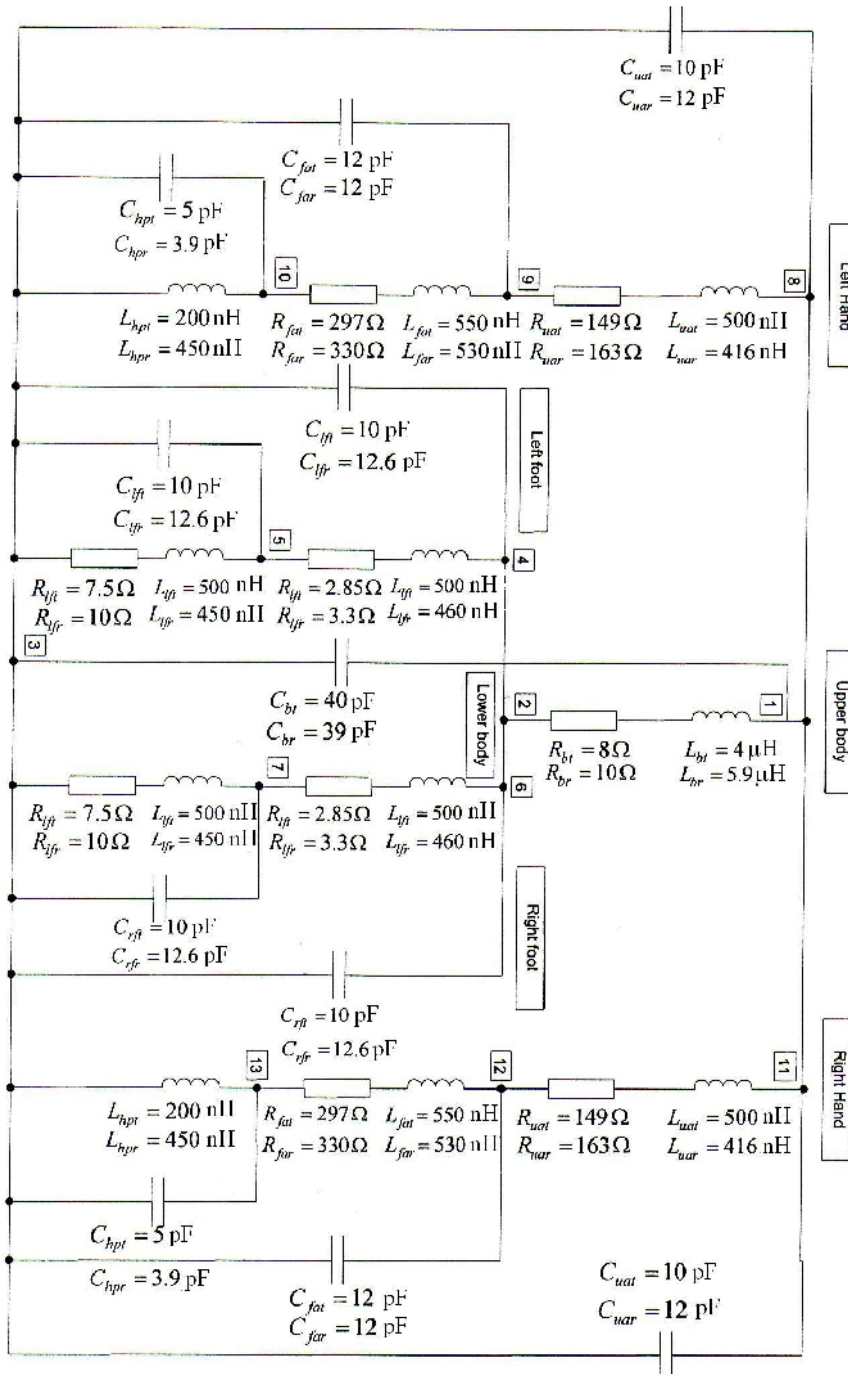


Fig.1 – Electric scheme with concentrated parameters of a human body (both the theoretical (index *t*) and real (index *r*) values are indicated).

**Table 2**  
*The Values of the Electric Parameters of Various "Parts of the Body"*  
*for a Frequency of 30 MHz*

Parts of the body/ parameters	Diameter cm	Length cm	$R$ $\Omega$	$L$ $\mu\text{H}$	$C$ pF	$\rho$ $\Omega\cdot\text{cm}$
Forearm (with elbow) side 8-9	9	30	148.61/163	0.5/0.416	10/12	150
Arm side 9-10	9	30	279.24/330	0.270/0.530	20/12	150
Hand with metal object side 10-3	7.5	12	–	0.02/0.45	5/3.9	150
Trunk side 1-2	35	60	7.96/10	4/5.9	40/39	130
Thigh side 4-5	17	40	2.85/3.3	0.5/0.46	10/12.6	150
Calf side 5-3	13	50	7.28/10	0.5/0.45	10/12.6	150
Skeleton muscle	–	–	–	–	–	150

**O b s e r v a t i o n.** The real values of the parameters on the equivalent electric circuit are those from the denominator of the fraction from Table 2.

### 3. The Experiment Performed Onboard Ship

The physical model was subjected to the direct action of the radiation of an electromagnetic field from an omnidirectional monopole antenna ( $P_r = 400 \text{ W}$ ;  $f = 29.975 \text{ MHz}$ ), placed onboard a seagoing navy ship, the antenna has transmitting continuously during the experiment.

As the distance to the antenna ( $r$ ) was of 6 m, it was considered that the electric model was mainly subjected to the far field (radiation field) of the antenna because the EMC condition for such a field was fulfilled, that is  $r > \lambda/2\pi$ , for this particular situation  $r = 6 \text{ m} > \lambda/2\pi \cong 1.6 \text{ m}$  (Sotir & Moșoiu, 1997).

For measurements it was used an oscilloscope having the following characteristics: Tektronix TDS 2014, 100 MHz Bandwidths, Sample Rates up to 2 GS/s, 4 channels, 2.5 k Points Record Length, Dual Time Base, Advanced Triggering, 11 Automatic Measurements, Waveform and Setup Memories.

*Prior* to any set of measurements, the background values of the tensions induced into different parts of the "body" by the ship's electromagnetic environment were registered.

### 4. The Results of the Measurements

There were made 60 measurements onboard ship. The obtained values for three of these, considered to be representative, are given in the Table 3.

**Table 3**  
*The Values of the Tensions Measured for Different Parts of the Tested "Body"*  
 (Average Values – RMS in mV)

No. channel		Channel 1 left forearm, [mV]	Channel 2 right forearm mV	Channel 3 trunk, [mV]	Channel 4 left calf, [mV]
Meas- urement no. 1	Background values (scale 5 V/div.)	58	22	$10^{-3}$	$80 \times 10^{-3}$
	Measured values (scale 500 mV/div.)	$U_{8-9} = 780$	$U_{11-12} = 820$	$U_{1-2} = 840$	$U_{5-3} = 180$
No. Channel		Channel 1 left thigh	Channel 2 right thigh	Channel 3 left arm	Channel 4 right arm
Meas- urement no. 2	Background values (scale 500 mV/div.)	18	1.60	19.7	24.6
	Measured values (scale 500 mV/div.)	$U_{4-5} = 480$	$U_{6-7} = 220$	$U_{9-10} = 120$	$U_{12-13} = 220$
No. Channel		Channel 1 left hand	Channel 2 right hand	Channel 3 trunk with leg	Channel 4 left forearm and upper arm
Meas- urement no. 3	Background values (scale 500 mV/div.)	18	1.60	19.7	24.6
	Measured values (scale 500 mV/div.)	$U_{8-3} = 4,000$	$U_{11-3} = 2,340$	$U_{1-3} = 140$	$U_{8-10} = 3,600$

These values refer to the electric tensions appeared on the different sides of the circuit (respectively, "parts of the body") as a result of the EMT induced by the time variable electromagnetic field of the antenna.

Knowing the tensions and the parameters of sides of the circuit there were calculated the currents induced into the sides and, accordingly, the current densities.

The values of the currents and current densities in the sides of the physic model are given in Table 4.

**Table 4**  
*The Values of the Currents and Current Densities into "the Body"*

Parts of the "body"	Induced current values, [mA]	Induced current density values, [mA/m <sup>2</sup> ]	
Trunk	82.35	10.49x10 <sup>3</sup>	For only one "channel of current"
Thigh	5.14	291	
Calf	17.64	1,560	
Forearm	5.02	444	
Upper arm	0.074	942	

**O b s e r v a t i o n.** According to "The Basic Restrictions for Time Varying Electric and Magnetic Fields for Frequencies up to 10 GHz" (Romanian Standard Project: SR EN 50166-1, 50166-2; Europ. Standard ICNIRP; 96/98/EC Norm ...; NATO Standard: STANAG ...) the limit of the current density for the head and trunk is  $f/100$  mA/m<sup>2</sup> (RMS values), where  $f$  is the frequency, [Hz], mentioning that it was taken into consideration the same value as for 10 MHz.

### 5. The Comparative Analysis of the Obtained Results

The obtained results for the current densities were compared with the limit admitted values into the human body, imposed both by the European standard (ICNIRP), and by the STANAG NATO standard, as basic restrictions for time varying electric and magnetic fields for frequencies up to 10 GHz. As these standards do not give values for the current density for more than 10 MHz, it was taken into consideration the same limit for  $f = 30$  MHz too.

So, for general public exposure, both standards indicate a limit admitted value for current density for head and trunk of  $f/500$  mA/m<sup>2</sup> (RMS values), where  $f$  is the frequency, [Hz]. It results

$$\frac{f}{500} = \frac{30 \times 10^6}{5 \times 10^2} = 6 \times 10^4 \text{ mA/m}^2. \quad (1)$$

This value is 5.72 higher than the maximum value of the current density resulting from measurements (10.490 mA/m<sup>2</sup>), but with the same order of magnitude!

Calculating SAR (Specific Absorption Rate) using the formula (Romanian Standard Project: SR EN 50166-2)

$$\text{SAR} = \frac{J^2}{\rho\sigma} \text{ W/kg}, \quad (2)$$

where:  $J$ , [A/m<sup>2</sup>] is the density of the current induced into the analysed part of the body;  $\rho$ , [kg/m<sup>3</sup>] – the mass density of the analysed part of the body;  $\sigma =$

= 0.2...0.6 S/m – the average conductivity of the analysed part of the body and taking into consideration the current density value measured on the “trunk”,  $J = 10.49 \text{ A/m}^2$ , it results

SAR = 0.1834 W/kg, for  $\sigma = 0.6 \text{ S/m}$ ; SAR = 0.5502 W/kg, for  $\sigma = 0.2 \text{ S/m}$ .

It is necessary to observe that in the second case SAR value is 1.375 higher than the limit value admitted by the standards (Romanian Standard Project: SR EN 50166-2; Europ. Standard ICNIRP; 96/98/EC Norm ...; NATO Standard: STANAG ...), respectively 0.4 W/kg, meaning that there is a risk of getting sick, in time, for the personnel onboard who works on the decks of the ship. Taking into consideration the circumstances, adequate actions of protecting the personnel are necessary.

## 6. Conclusions

The physical model designed for simulating the behavior of a human body exposed to the electromagnetic field onboard a seagoing navy ship “responded” positive to the proposed analysis, offering a viable way of research for such an approach, as long as *in vivo* measurements cannot be done.

At the same time, the authors realize the fact that the electric model of the human body can be improved. Further more, if such a model is completed with another one designed for the research of the behavior of a person’s head into an electromagnetic field, we consider that a very useful investigation instrument for this type of research can be ensured.

Finally, such a model could be used for other researches (respectively fields of activity) where there is an increased awareness of protecting the person against the harmful effects of the electromagnetic field.

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UN MODEL ELECTRIC FIZIC DE CORP UMAN EXPUS LA ACȚIUNEA  
CÂMPULUI ELECTROMAGNETIC LA BORDUL UNEI NAVE  
MARITIME MILITARE

(Rezumat)

Lucrarea de față constituie obiectul unei cercetări în domeniul Compatibilității Electromagnetice navale în ceea ce privește identificarea unor efecte negative ale câmpului electromagnetic al unei nave maritime militare asupra corpului uman.

Mai precis, lucrarea prezintă, pentru prima dată, experimentarea modului de acțiune a câmpului electromagnetic al unei nave asupra unui model electric fizic, cu parametri concentrați, al organismului uman. În cadrul experimentului au fost efectuate măsurători asupra tensiunilor și curenților induși în diferite părți ale *corpului* și au fost analizate, comparativ, valorile obținute cu standardele CEM, civile și militare, din punct de vedere al valorilor limită admise. Rezultatele obținute au evidențiat faptul că valorile măsurate sunt importante, astfel că, extrapolându-le pe acestea pentru un organism real, se poate trage concluzii că există riscuri pentru starea de sănătate a personalului de la bord. Ca urmare se impun a fi luate măsuri de protecție adecvate.

Un astfel de model ar putea fi folosit și pentru alte cercetări (respectiv alte domenii de activitate), în scopul de a proteja personalul împotriva efectelor dăunătoare ale câmpului electromagnetic.