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# Human Body Impedance Calculations

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## ABSTRACT

*The paper deals with the problem of the average electrical impedance of the human body that is essential for the analysis of electromagnetic field (EMF) exposure. Considerations are focused upon a TEM cell. This paper reviews the problem of input impedance of a biological object.*

**Keywords**: bioeffects, human body impedance, mutual interaction

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## INTRODUCTION

The hazard to humans created by exposure to EMF caused the necessity of leading bio-electromagnetic studies. While such investigations, where a biological object is tested in an exposure system, some energy is absorbed. The energy changes as a result of the presence of walls of the exposure system and other objects in the enclosure. It allows us to suppose that such an object is characterized by input impedance. The considerations are based on the known theory of mutual impedance of an antenna and its mirror reflection in a conducting medium in its proximity.

## MATERIALS AND METHODS

The Transverse Electromagnetic (TEM) cell is widely used as the exposure system (Fig. 1) in compatibility studies, antenna's calibrations and biomedical investigations. The TEM cell was proposed as a new way of establishing the EMF standard (ML Crawford, IEEE Transactions on Electromagnetic Compatibility, EMC-16, 4, 189).

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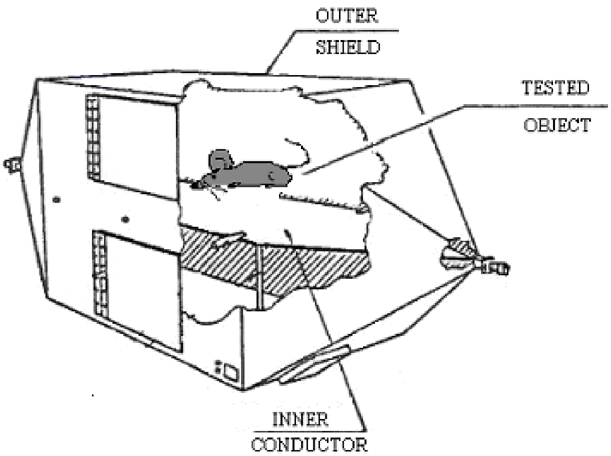


Fig. 1. A mouse as test object in the TEM cell

In each of these cases, the test object is placed between two conducting plates or between four plates in the case of a cell with side walls. It causes the exposure system to have an influence on the object.

There is no doubt that a conducting medium close to an antenna (during calibration for example) affects its input impedance. The input impedance of an antenna placed in the proximity of a conducting medium (between conducting plates in the TEM cell – Fig. 2a) is different in relation to that in the free space. This difference results from existing mutual impedance of antenna and its mirror reflection in the medium (Fig. 2b). As a matter of fact, the sensitivity of the antenna is different than in the free space conditions. The phenomenon limits accuracy of the measurements. Calculations performed for the case of an antenna close to an infinitely large, perfectly conducting plane shows the role of mentioned phenomenon that can be omitted if the distance of the antenna to the medium is larger than two lengths of the antenna. The same phenomenon exists while the antenna is calibrated in the TEM cell. In that case, the exposure system influences the antenna which causes changing input impedance of the calibrated antenna.

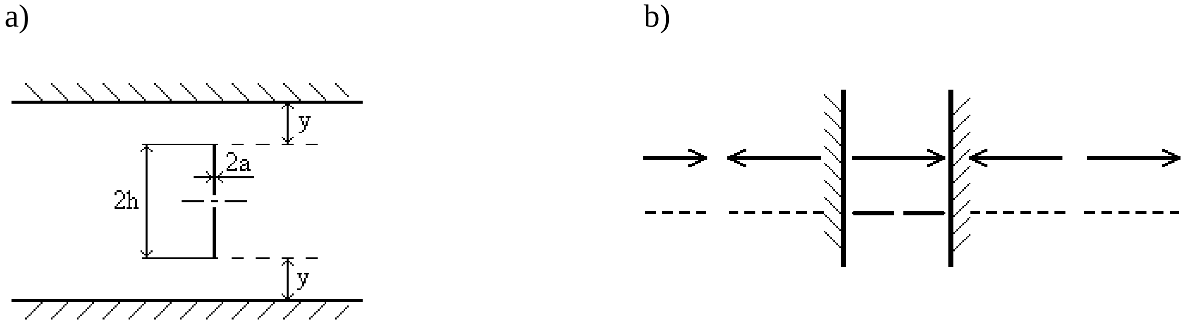


**Fig. 2.** An antenna in the TEM cell: a) geometry of calibration, b) mirror reflections.

This problem is widely discussed in literature, among other things in (T Dlugosz, H Trzaska.IEEE Transactions on Instrumentation and Measurements, 2009, 58, 3, 626; H Trzaska.IEEE Transactions on Instrumentation and Measurements, 2000, IM-49, /5, 1112).Similar phenomena exist in bioelectromagnetic investigations and in electromagnetic compatibility studies.

## RESULT AND DISSCUSION

Contrary to the antenna, the objects investigated in the studies are spatial and sometimes, semi-conducting ones. The possibility of a free space interpretation of investigated phenomena requires similar analyses as in the case of antenna calibration.

Influence of the TEM cell upon a biological object may be defined as a difference of power absorbed by the object inside the cell and that in the free space. If the electric field intensity and conducting current density are known then the loss of energy (absorbed power) may be calculated as follows:

$$P_{abs} = \int_V \mathbf{E} \cdot \mathbf{J} dV \tag{1}$$

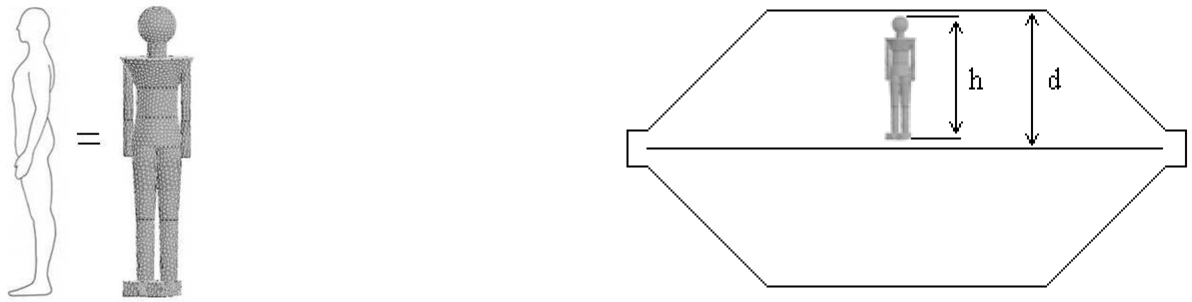
where:

$P_{abs}$ – absorbed power,
**E** – electric field intensity vector,
**J** – conducting current density vector,
V- volume of test object.

Formula (1) is valid for a homogeneous object. If the condition is not fulfilled, the power is represented by a sum of partial powers, absorbed in the separate elements of the object.

The primary results of the estimations of the influence of an exposure system upon a biological object have already been published (T Dlugosz, H Trzaska.4th International Workshop on Biological Effects of Electromagnetic Fields, 2006, Crete, Greece, Volume I, 89).

Let us consider the centimeter model of a man (Fig. 3) (TDlugosz.Central European Journal of Engineering, 2011, 1, 3, 253). Calculations were made with the use of different codes for constant field intensity within the cell (E = 1 V/m). The electric parameters of the object were assumed uniform and equal: $\varepsilon_r = 80$, $\sigma = 0.84$ S/m. Results of the simulations are presented in Fig. 4.



a) b)

Fig. 3. The considered case of a biological object inside an exposure system: a) man and equivalent cylindrical model, b) a cylindrical model of a man placed between parallel plates.

It can be noticed that if dimensions of the test object are small (d>>h), the absorbed power in the exposure system approaches the value in the free space. On the other hand, while the object is large (d ≈h), the power is remarkably different. Results from the latter case have nothing in common with the results obtained in the free space conditions and that means committed error increases and as a fact, the results of such biomedical investigations are inaccurate.

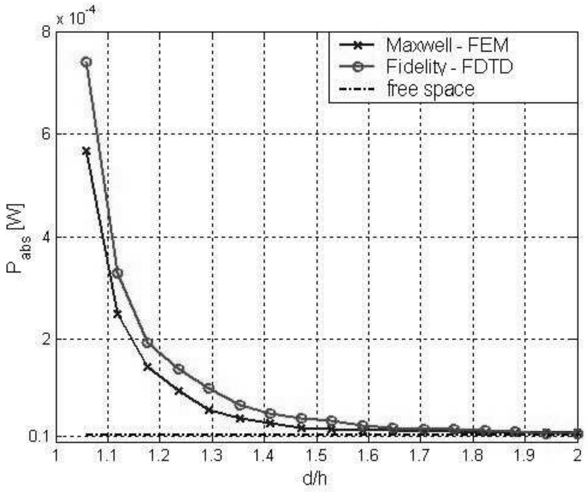


Fig. 4.Power absorbed by objects placed in the TEM cell versus distance between plates

As it is shown above (Fig. 4), the object immersed inside the exposure system absorbs power and that power is the function of the ratio dimensions exposure system (d) to the dimension of the test object (h). The power changes may be affected by mirror reflections of a biological object (Fig. 5) which suggests that there should be an input impedance of a biological object.

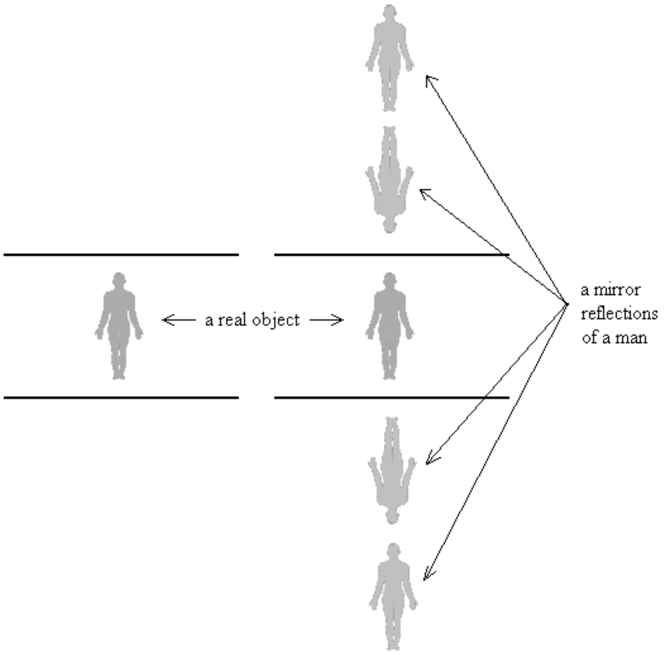


Fig. 5.A man inside the TEM cell and its mirror reflections.

## Bioelectrical impedance

The biological object may be characterized by input impedance. But what does "impedance of the human body" mean? Is this possible to present human body as an equivalent circuit?

The human body, as all living organisms, is made of different organs, tissues, and cells. The electrical properties of living tissues are different from each other (Table 1) (Italian National Research Council, http://niremf.ifac.cnr.it/tissprop/).

**Table 1.** Electrical parameters of selected tissuesfor the frequency of 1800 MHz

| Tissue | Conductivity [S/m] | Relative permittivity |
|---|---|---|
| Bladder | 0.20891 | 33572 |
| Blood | 0.7 | 5257.6 |
| Body Fluid | 1.5 | 98.984 |
| BoneCortical | 0.020223 | 1837.6 |
| BoneMarrow | 0.0023773 | 3200.4 |
| Brain Grey Matter | 0.10207 | 102370 |
| Fat | 0.022961 | 11863 |
| Heart | 0.11435 | 261880 |
| Kidney | 0.11717 | 147540 |
| Liver | 0.04277 | 66253 |
| Lymph | 0.5256 | 36638 |
| Muscle | 0.32846 | 194060 |
| Nail | 0.020223 | 1837.6 |
| Nerve | 0.029637 | 63583 |
| Skin Dry | 0.00020019 | 1135.4 |
| Spleen | 0.10484 | 59352 |
| Stomach | 0.5256 | 36143 |
| Tooth | 0.020223 | 1837.6 |

As a fact, different tissues are characterized by different electrical parameters so they must absorb different powers. Let's analyze the voxel model of a rat placed in the free space conditions like it is shown in Fig. 6a. The model was simulated with the FDTD (Finite Difference Time-Domain) method with the code FDTD99. Results of simulations are presented in Fig. 6b.

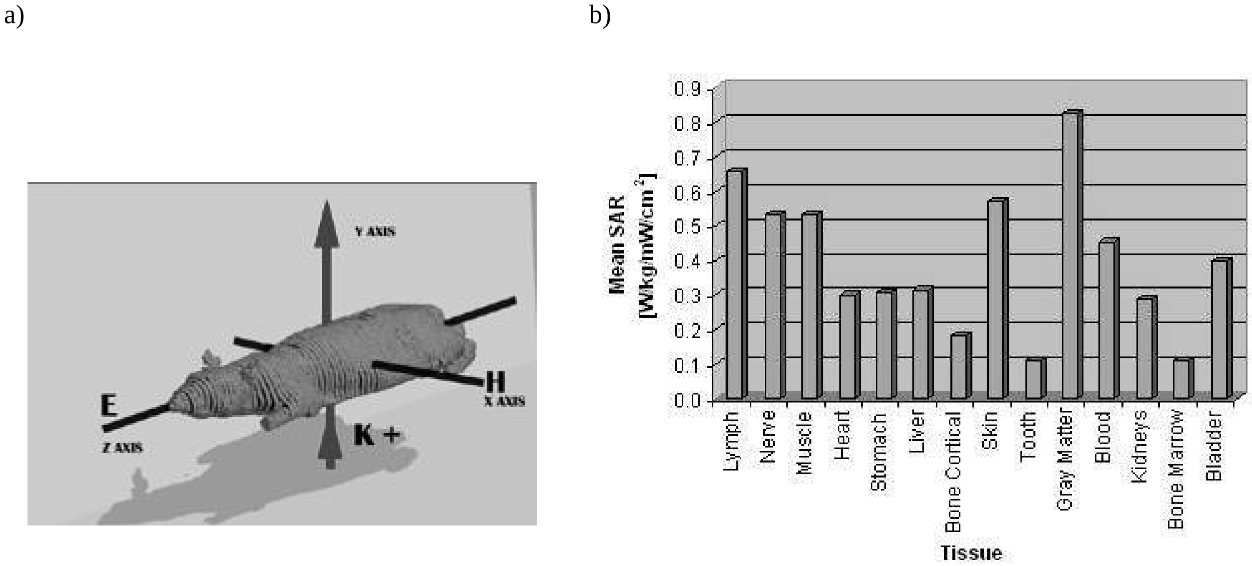


**Fig. 6.** Voxel model of a rat in the free space: a) orientated model,b) simulation results.

Like it was supposed each of the considered tissues absorbs a different power. It means that different tissues are built from different cells which are described by various electrical parameters. A cell may be represented by an electrical equivalent circuit (Fig. 7) where capacitance is analogous to intracellular volume and resistance is analogous to extracellular volume (RJ Liedtke.Principles of Bioelectrical Impedance Analysis, 1997, pp1-10).

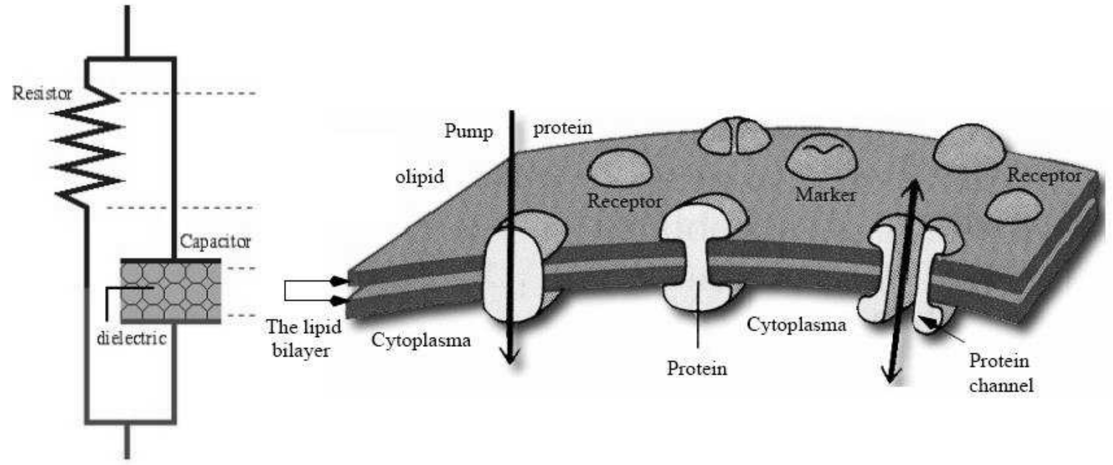


**Fig. 7**.The plasma membrane of a cell and its electrical equivalent circuit.

Of course the same results (as for the rat) are valid for the human body, where the same effects exist. In Fig. 6, the results for the rat are presented because computer simulation was faster for this case than for the model of a man and it required less RAM memory. If a cell may be presented by an electrical circuit, then tissues (that are made from cells) may be represented as an electrical equivalent circuit too.

The electrical properties of living tissues show that each tissue has its own dielectric parameters and phenomenon, known as β-dispertion. The electrical characteristics of tissues can be presented by a multi-time-constant circuit (Fig. 8). $R_e$ is the resistance measured at low frequency and represents the equivalent resistance of extracellular fluid. $C_j$ and $R_{tj}$ are the membrane capacitance and intracellular resistance of the various tissues comprising the body (H Kanai, I Chatterjee, OP Gandhi .IEEE Transactions on Microwave Theory and Techniques, 1984, MTT-32, 8, 763).

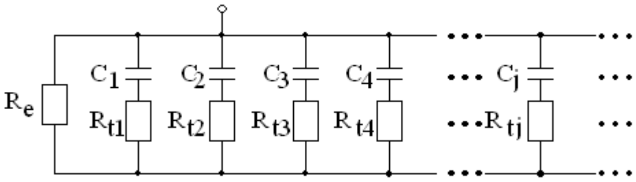


**Fig. 8**.Equivalent circuit of biological tissues (H Kanai, I Chatterjee, OP Gandhi.IEEE Transactions on Microvawe Theory and Techniques, 1984, MTT-32, 8, 763).

Untill now, the equivalent circuit of the cell (Fig. 7) and biological tissues (Fig. 8) were presented. It is known that tissues are made of cells and the human body is made of tissues, therefore, it can be represented in an electrical circuit too. Thus, the circuit of the human body may be proposed like it is shown in Fig. 9, but this one is supplemented to the RC circuit of a head. Each part of the human body (head, torso, arms, and legs) is presented by an electrical capacitor in parallel with a resistor.

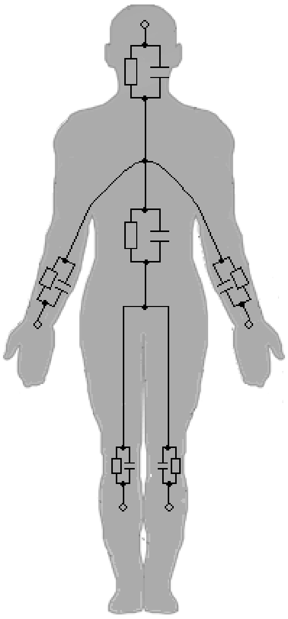


Fig. 9.Circuit of the human body.

If we have a circuit of a man, then the question arises: where to define input terminals of such an object? There are a lot of combinations: between hands, hand-foot, and head-foot. Each of these schemes seems to be proper. So if it is true, then input impedance will be different in each of these cases. How would it be in computer simulations, when for example, the centimeter model of a man is considered (Fig. 10a)?

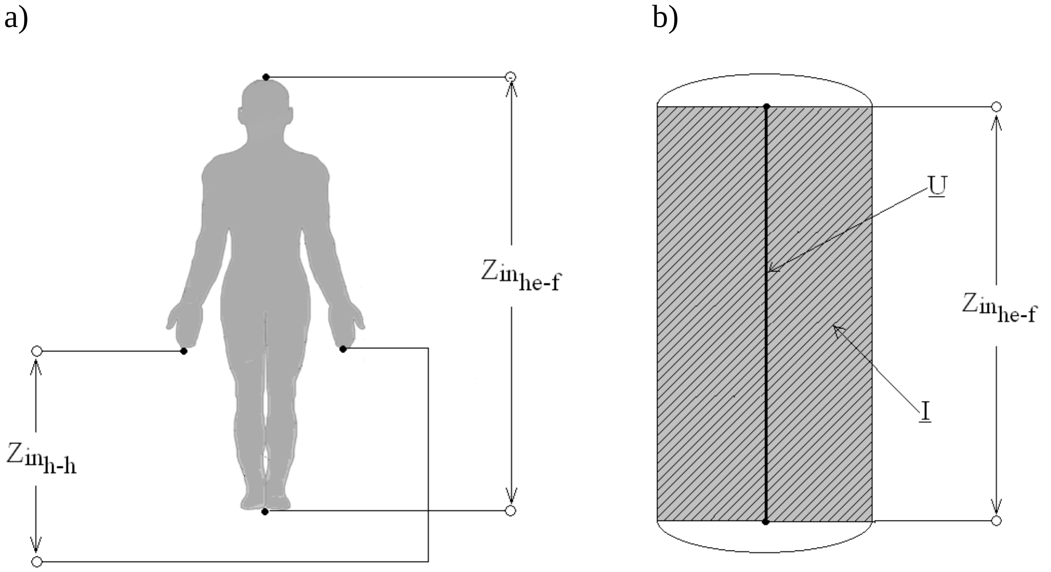


**Fig. 10.** Cylindrical model of a man: a) input terminals, b) proposal of calculating input impedance, $Z_{inh\text{-}h}$ – input impedance between hands, $Z_{inhe\text{-}f}$ – input impedances between head and foot, $\underline{U}, \underline{I}$ – the way of calculating complex voltage and current.

For the model presented in Fig. 10b, input impedance may be calculated in the simplest way – by current through the body and the voltage drop:

Results of calculations are presented in Fig. 11. Variation of resistance with the dimension of the human body can be sorted in three phases (Fig. 11a):
1) for the range $d/h$ = 1~1.1, resistance drops down sharply;
2) for the range $1.1<d/h<1.7$, reduction of resistance becomes quite slow;
3) if$d/h>1.7$ resistance starts to keeps a constant.
Calculation for equivalent capacitance ( Fig. 11b), a similar variation trend also appears here.
1) for the range $d/h$ = 1~1.1, capacitance drops down sharply;
2) for the range $1.1<d/h <1.4$ the speed of capacitance reduction becomes slower;
3) for d/h> capacitance has a more slow reduction speed.

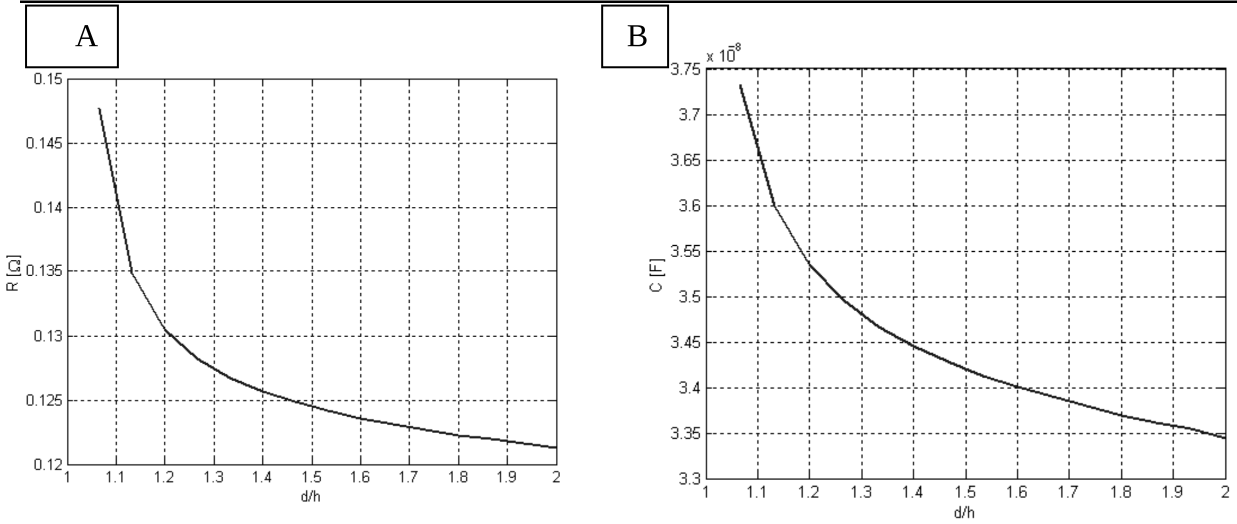


**Fig. 11**. Results of calculations with the centimeter model in the TEM cell: a) resistance varied with object size, b) capacitance varied with object size

Are the presented considerations above correct? That is a difficult question because the subject of input impedance of a biological object is difficult and it is not recognized until now.

### Biomedical applications

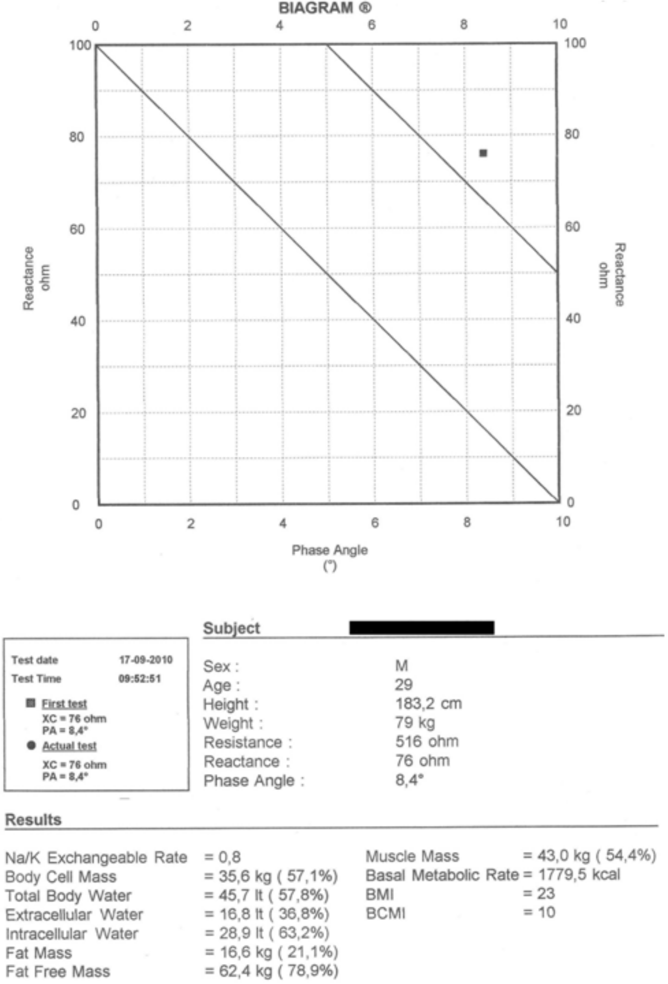
Let us try to answer the question: why is so important to find impedance of a human being? The answer may be the following: because when disease manifests, the functional changes of tissues and organs appear earlier than organic or another clinical symptoms. The human body is composed of charged or polar molecules dissolved in water, therefore, it is a good conductor and its impedance can be measured and calculated. Electrical properties of tissues and the organs of the human body contain information when each of them is healthy or not.

The Bioelectrical Impedance Analysis (BIA) method may constitute an example of such examination (J Vedru, OMakarova, VTina. 11th International Conference on Electrical Bio-Impedance. Oslo, Norway, 2001, 631). The composition of an organism tested using the BIA method provides us with information of key significance, including eg. the proportion of muscle to fat or the fluctuation of intracellular water volume equivalent to the body cell mass. Both of the said parameters are crucial as lean body mass is a sum of total body water volume, body cell mass and a slim fraction of bone mineralization, while the rest of a total body mass is attributable to fat tissue. Sample human body composition test (male, 29 years old) is presented in fig. 12 together with explanation of abbreviations referring to individual body mass ingredients as well as reference for individual age groups. The test result constitutes a so called biagram, a square shaped graph with reactance values on one of its sides and phase shift angle between the current and voltage vectors on a capacitive item, here a human body, on a perpendicular side. Inside the square there are two triangles of differing sizes with disjunctive hypotenuses separated by a certain space. If the test results in a point on the graph with appropriate values for reactance and phase shift angle between the current and voltage vectors, the result confirms that all the body mass components are normal. If, however, the resulting point falls inside one of the triangles like in the example shown in fig. 12, the body mass composition result is abnormal which could result in a medical condition that necessitates a consult

## CONCLUSION

The human body is characterized by electrical properties of body tissues (and/or organs). Its changes allow for the extraction of biomedical information about the physiology and pathology of a test object. Measurements, calculations or computer simulations will make it possible to find changes in our body and allow to detect them very quickly.

Considerations presented in this paper show that the idea of input impedance of a biological object exists, but still remains unsolved. There are known measurement methods of man's impedance (Body composition assessment. Obesity, physical activity. Organic foods tasting, XIII Lower Silesia Science Festival 2010), but it is too difficult to build a detailed model of man that would be an ideal reflection of the complicated human body. The electrical circuit which would represent the human body is complex and it will probably not give a synonymous solution. Such simulations or measurements that are based on some theory model are far from the real situation observed in a healthy lifestyle and the complex human body.



**Subject** [redacted]

Test date 17-09-2010
Test Time 09:52:51
■ First test
XC = 76 ohm
PA = 8,4°
● Actual test
XC = 76 ohm
PA = 8,4°

| | |
|---|---|
| Sex : | M |
| Age : | 29 |
| Height : | 183,2 cm |
| Weight : | 79 kg |
| Resistance : | 516 ohm |
| Reactance : | 76 ohm |
| Phase Angle : | 8,4° |

**Results**

| | | | |
|---|---|---|---|
| Na/K Exchangeable Rate | = 0,8 | Muscle Mass | = 43,0 kg ( 54,4%) |
| Body Cell Mass | = 35,6 kg ( 57,1%) | Basal Metabolic Rate | = 1779,5 kcal |
| Total Body Water | = 45,7 lt ( 57,8%) | BMI | = 23 |
| Extracellular Water | = 16,8 lt ( 36,8%) | BCMI | = 10 |
| Intracellular Water | = 28,9 lt ( 63,2%) | | |
| Fat Mass | = 16,6 kg ( 21,1%) | | |
| Fat Free Mass | = 62,4 kg ( 78,9%) | | |

**Fig. 12**. BIA test result with individual human body mass components and impedance (Body composition assessment.Obesity, physical activity. Organic foods tasting, XIII Lower Silesia Science Festival 2010)

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