Computer Simulation of Space Interference of Low Frequency Electromagnetic Signals in the Human Body

Dimitar C. Dimitrov[1], Galina P. Peykova[2]

Abstract-**Low frequency interference devices have a wide range of application in medicine for successful treatment for rheumatism, skin diseases, liver diseases, muscular pain relief, contusions, sprains, chronic diseases. The main target of the article is to present a method of detailed description of low frequency electromagnetic signals in the human body.**

Keywords: **Space intereferece, Low frequency electromagnetic signals, Human body**

I. INTRODUCTION

In this example a low frequency interference device consists of two electrode couples (electrodes in each couple are parallel each other with rectangular shape). They make electromagnetic signals, whose vectors depend on time. The result of operating at the same time signals is a time - dependent signal ($\vec{E}(t)$). Its magnitude and direction change.

The voltage of the first electrode couple has constant low frequency f_1=4000Hz and for the second electrode couple it is variable: f_2=4000 ÷ 4100Hz, changing linearly. As a result two different angular frequencies are available ω1,ω2. And the result vector will certainly pass through quasi-resonant frequency of a fixed group of human muscles. The voltage at the end of electrode couples is constant and there are not side effects of inductance. The signal should reach deeply into the space of human body. Formulae below meet this requirements:

$$\vec{E}_1 = \left|\vec{E}_1\right| \times \cos(\omega_1 \times t) \tag{1}$$

$$\vec{E}_2 = \left|\vec{E}_2\right| \times \cos(\omega_2 \times t) \tag{2}$$

II. MATHEMATICAL ANALYSIS

Tension is a fundamental characteristic to every electromagnetic field. Its absolute value can be estimated, using the principle of Coulomb.

The tension magnitude in a fixed point can be found by placing there a positive charged particle Q and observing the force between two charged particles.

$$\vec{E} = \frac{\vec{F}}{Q} \Rightarrow E = \frac{q}{4 \times \pi \times \varepsilon \times r^2} \tag{4}$$

The principle of Coulomb is operative only for particle suppliers of energy. If each electrode from the first couple is a particle supplier of energy, the tension in the fixed point will be defined as:

$$E_1 = \frac{q}{4 \times \pi \times \varepsilon \times r_1^2} + \frac{q}{4 \times \pi \times \varepsilon \times (d_1 - r_1)^2} \tag{5}$$

r_1 and $(d_1 - r_1)$ are the distances between the fixed point and each "charged particle" of energy.

There are lots of charged particles on the surface of each electrode:

$$\begin{aligned} E_1 = & \int_0^{\varphi_1}\int_{r_a}^{r_b} \frac{q_1}{4 \times \pi \times \varepsilon \times r_1^2} \times drd\varphi \\ & + \int_0^{\varphi_2}\int_{r_a}^{r_b} \frac{q_1}{4 \times \pi \times \varepsilon \times r_1^2} \times drd\varphi \\ & + \int_0^{\sigma_1}\int_{r_c}^{r_d} \frac{q_1}{4 \times \pi \times \varepsilon \times \left(\frac{d_1}{\cos(\delta)} - r\right)^2} \times d\left(\frac{d_1}{\cos(\delta)} - r\right) d\sigma \\ & + \int_0^{\sigma_2}\int_{r_c}^{r_d} \frac{q_1}{4 \times \pi \times \varepsilon \times \left(\frac{d_1}{\cos(\delta)} - r\right)^2} \times d\left(\frac{d_1}{\cos(\delta)} - r\right) d\sigma \end{aligned} \tag{6}$$

The fixed point is T. The perpendicular lines from point T to the first and second electrodes from first couple are denoted respectively by TT_1 and TT_2. $T_1T_2 = d_1$, $TT_1 = r_1$, $TT_2 = d_1 - r_1$. There is a surface **α** through line d_1. **α** is perpendicular to both electrodes and its intersection with electrodes is parallel (respectively perpendicular) to electrode's boundaries (fig.3). $\alpha \cap Q_1Q_2Q_3Q_4 = AB$ ($AB \parallel Q_1Q_2, Q_3Q_4$; $AB \perp Q_1Q_4, Q_2Q_3$).

$\alpha \cap Q_5Q_6Q_7Q_8 = CD$

---

[1] PhD. Dimitar. C. Dimitrov Assoc. Prof. is with The Faculty of Communications and Communications Technologies, Technical University of Sofia, Email: dcd@tu-sofia.bg

[2] Galina P. Peykova is with Faculty of Computer Systems and Control, Technical University of Sofia, Email: galina_peykova@abv.bg

($CD \parallel Q_5Q_6, Q_7Q_8; CD \perp Q_5Q_8, Q_6Q_7$).

$TA = r_a$, $TB = r_b$, $TC = r_c$, $TD = r_d$.

Inside Integral Expression: Inside integral covers charged particles, situated in segments AB and CD. The result of integrating formula 5 is:

$$\begin{aligned} E_1 &= \int_{r_a}^{r_b} \frac{q_1}{4\times\pi\times\varepsilon\times r^2}\times dr \\ &+ \int_{r_c}^{r_d} \frac{q_1}{4\times\pi\times\varepsilon\times\left(\frac{d_1}{\cos(\delta)}-r\right)^2}\times d\left(\frac{d_1}{\cos(\delta)}-r\right) \\ &= -\left(\frac{q_1}{4\times\pi\times\varepsilon}\right)\Bigg|_{r_a}^{r_b} \\ &- \left(\frac{q_1}{4\times\pi\times\varepsilon\times\left(\frac{d_1}{\cos(\delta)}-r\right)}\right)\Bigg|_{r_c}^{r_d} \\ &= \left(\frac{q_1}{4\times\pi\times\varepsilon}\right)\times\left(\frac{1}{r_a}-\frac{1}{r_b}+\frac{1}{r_c}-\frac{1}{r_d}\right) \end{aligned} \tag{7}$$

The plane surface of **α** leads to the following conclusions:

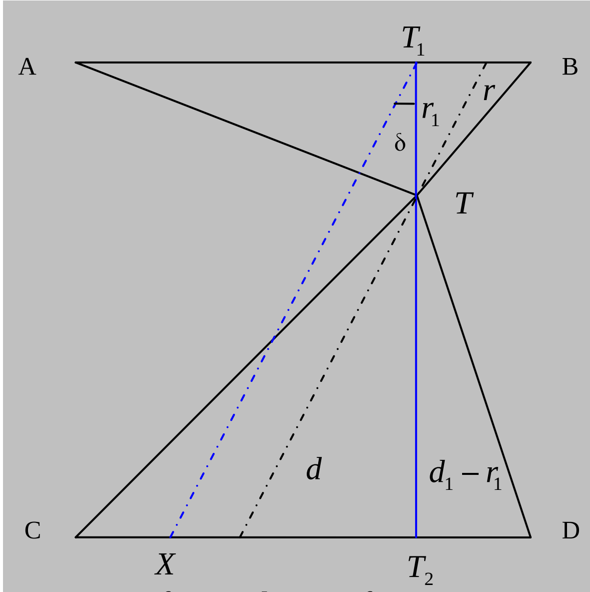

fig. 1. Plane surface α

r_1 starts at TA and ends at TB, and $(d_1 - r_1)$ starts at TD and ends at TC. If r_1 coincides with r, then $(d_1 - r_1)$ coincides with d. From triangle T_1T_2X:

$$\cos(\delta) = \frac{d_1}{d+r} \Rightarrow d = \frac{d_1}{\cos(\delta)} - r \tag{8}$$

d is the integration variable for the second integral from formula 7.

Outside Integral Expression:

The second integral takes all the charged particles on the surfaces of the electrodes under consideration. (formula 6.). It is the result of moving of AB and CD over the surface of electrodes at angles φ₁, φ₂, σ₁, σ₂.

$\angle ATQ_1 = \angle BTQ_2 = \varphi_1$, $\angle ATQ_4 = \angle BTQ_3 = \varphi_2$, $\angle CTQ_5 = \angle DTQ_6 = \sigma_1$, $\angle CTQ_8 = \angle DTQ_7 = \sigma_2$

After integrating formula 7.:

$$\begin{aligned} E_1 &= \left(\frac{q}{4\times\pi\times\varepsilon}\right)\times\int_0^{\varphi_1}\left(\frac{1}{r_a}-\frac{1}{r_b}\right)\times d\varphi \\ &+ \left(\frac{q}{4\times\pi\times\varepsilon}\right)\times\int_0^{\varphi_2}\left(\frac{1}{r_a}-\frac{1}{r_b}\right)\times d\varphi \\ &+ \left(\frac{q}{4\times\pi\times\varepsilon}\right)\times\int_0^{\sigma_1}\left(\frac{1}{r_c}-\frac{1}{r_d}\right)\times d\sigma \\ &+ \left(\frac{q}{4\times\pi\times\varepsilon}\right)\times\int_0^{\sigma_2}\left(\frac{1}{r_c}-\frac{1}{r_d}\right)\times d\sigma \end{aligned} \tag{9}$$

The rectangular triangles Q_1AT and Q_4AT have right angle at apex A. The rectangular triangles Q_2BT and Q_3BT have right angles at apex B. The rectangular triangles Q_5CT and Q_8CT have right angles at apex C. The rectangular triangles Q_6DT and Q_7DT have right angles at apex D. Therefore:

$$\begin{gathered} \cos(\delta_i) = \frac{r_l}{r_l'} \Rightarrow r_l = r_l' \times \cos(\delta_i) \\ \cos(\delta_i) = \frac{r_l}{r_l''} \Rightarrow r_l = r_l'' \times \cos(\delta_i) \\ where: \delta = \varphi, \sigma; i = 1,2; l = a,b,c,d \end{gathered} \tag{10}$$

$r_a' = TQ_1$ $r_b' = TQ_2$ $r_c' = TQ_6$ $r_d' = TQ_5$

$r_a'' = TQ_4$ $r_b'' = TQ_3$ $r_c'' = TQ_8$ $r_d'' = TQ_7$

The result from formulas 9. and 10. is formula 11.:

$$E_1 = \left(\frac{q}{4\times\pi\times\varepsilon}\right)\times\int_0^{\varphi_1}\left(\frac{1}{r_a^{'}\times\cos(\varphi)}-\frac{1}{r_b^{'}\times\cos(\varphi)}\right)\times d\varphi$$
$$+\left(\frac{q}{4\times\pi\times\varepsilon}\right)\times\int_0^{\varphi_2}\left(\frac{1}{r_a^{''}\times\cos(\varphi)}-\frac{1}{r_b^{''}\times\cos(\varphi)}\right)\times d\varphi$$
$$+\left(\frac{q}{4\times\pi\times\varepsilon}\right)\times\int_0^{\sigma_1}\left(\frac{1}{r_c^{'}\times\cos(\sigma)}-\frac{1}{r_d^{'}\times\cos(\sigma)}\right)\times d\sigma$$
$$+\left(\frac{q}{4\times\pi\times\varepsilon}\right)\times\int_0^{\sigma_2}\left(\frac{1}{r_c^{''}\times\cos(\sigma)}-\frac{1}{r_d^{''}\times\cos(\sigma)}\right)\times d\sigma \tag{11}$$

Revised formula is:

$$E_1 = \left(\frac{q}{4\times\pi\times\varepsilon}\right)\times\left(\frac{r_b^{'}-r_a^{'}}{r_a^{'}\times r_b^{'}}\right)\times\int_0^{\varphi_1}\frac{d\varphi}{\cos(\varphi)}$$
$$+\left(\frac{q}{4\times\pi\times\varepsilon}\right)\times\left(\frac{r_b^{''}-r_a^{''}}{r_a^{''}\times r_b^{''}}\right)\times\int_0^{\varphi_2}\frac{d\varphi}{\cos(\varphi)}$$
$$+\left(\frac{q}{4\times\pi\times\varepsilon}\right)\times\left(\frac{r_d^{'}-r_c^{'}}{r_d^{'}\times r_c^{'}}\right)\times\int_0^{\sigma_1}\frac{d\sigma}{\cos(\sigma)}$$
$$+\left(\frac{q}{4\times\pi\times\varepsilon}\right)\times\left(\frac{r_d^{''}-r_c^{''}}{r_d^{''}\times r_c^{''}}\right)\times\int_0^{\sigma_2}\frac{d\sigma}{\cos(\sigma)} \tag{12}$$

The solution of the integral is:

$$\int_0^{\varphi_1}\frac{d\varphi}{\cos(\varphi)} = -\ln\left|tg\left(\frac{\left(\frac{\pi}{2}-\varphi_1\right)}{2}\right)\right| \tag{13}$$

To compute the value of E$_1$ it is necessary to find $r_i, r_i^{'}, r_i^{''},\quad i=a,b,c,d;$ and angles $\varphi_1,\varphi_2,\sigma_1,\sigma_2$. The method is:

- Finding the equation of line TT_1. For that it is necessary to find the equations of the plains of electrodes by figuring out the determinant below:

$$\begin{vmatrix} x & y & z & 1 \\ x_1 & y_1 & z_1 & 1 \\ x_2 & y_2 & z_2 & 1 \\ x_3 & y_3 & z_3 & 1 \end{vmatrix} = 0 \tag{14}$$

The plane’s equation is:

$$A\times x + B\times y + C\times z + D = 0 \tag{15}$$

The normal vector of plains $Q_1Q_2Q_3Q_4$ and $Q_5Q_6Q_7Q_8$ coincides with the directional vector of TT_1: $T_1T_2 \perp Q_1Q_2Q_3Q_4$.

Point T is situated on TT_1. Point T has space coordinates T(t_1, t_2, t_3). Therefore the normal vector of plains $Q_1Q_2Q_3Q_4$ and $Q_5Q_6Q_7Q_8$, called vector ($\vec{N}$), is: $\vec{N}(A,\ B,\ C)$.

T_1T_2 equation is:

$$T_1T_2 \equiv \frac{x-t_1}{A} = \frac{y-t_2}{B} = \frac{z-t_3}{C} \tag{16}$$

- Finding x,y and z coordinates of point $T_1\left(t_1^{'},\ t_2^{'},\ t_3^{'}\right)$. For that purpose it is requiring to be solved the system of equations:

$$\left|\begin{array}{l} \dfrac{t_1^{'}-t_1}{A} = \dfrac{t_2^{'}-t_2}{B} = \dfrac{t_3^{'}-t_3}{C} \\ \\ A\times t_1^{'} + B\times t_2^{'} + C\times t_3^{'} + D = 0 \end{array}\right.$$

- Finding the equation of line AB.

$AB \parallel Q_1Q_2$. They both have the same directional vector. The equation of Q_1Q_2 is:

$$Q_1Q_2 \equiv \frac{x-x_1}{x_2-x_1} = \frac{y-y_1}{y_2-y_1} = \frac{z-z_1}{z_2-z_1} \tag{17}$$

And the directional vector has co-ordinates ((x_2-x_1), (y_2-y_1), (z_2-z_1)).Therefore the equation of Q_1Q_2 is:

$$AB \equiv \frac{a_1-t_1^{'}}{x_2-x_1} = \frac{a_2-t_2^{'}}{y_2-y_1} = \frac{a_3-t_3^{'}}{z_2-z_1} \tag{18}$$

where $A\left(a_1,\ a_2,\ a_3\right)$.

- Finding the co-ordinates of point A.

Q_1Q_4’s equation is:

$$Q_1Q_4 \equiv \frac{x-x_1}{x_4-x_1} = \frac{y-y_1}{y_4-y_1} = \frac{z-z_1}{z_4-z_1} \tag{19}$$

Solving the system of equations:

$$\left|\begin{array}{l} \dfrac{a_1-t_1^{'}}{x_2-x_1}=\dfrac{a_2-t_2^{'}}{y_2-y_1}=\dfrac{a_3-t_3^{'}}{z_2-z_1} \\ \\ \dfrac{a_1-x_1}{x_4-x_1}=\dfrac{a_2-y_1}{y_4-y_1}=\dfrac{a_3-z_1}{z_4-z_1} \end{array}\right.$$

The required coordinates are: $A(a_1, \quad a_2, \quad a_3)$.

Finding the coordinates of points B($b_1, \quad b_2, \quad b_3$), $C(c_1, \quad c_2, \quad c_3), D(d_1, \quad d_2, \quad d_3)$ is in the same manner. The necessary distances are:

$$TA=\sqrt{(a_1-t_1)^2+(a_2-t_2)^2+(a_3-t_3)^2}$$

$$TB=\sqrt{(b_1-t_1)^2+(b_2-t_2)^2+(b_3-t_3)^2}$$

$$TC=\sqrt{(c_1-t_1)^2+(c_2-t_2)^2+(c_3-t_3)^2}$$

$$TD=\sqrt{(d_1-t_1)^2+(d_2-t_2)^2+(d_3-t_3)^2}$$

$$TQ_i=\sqrt{(x_i-t_1)^2+(y_i-t_2)^2+(z_i-t_3)^2},$$

$$where: i=1\div 8$$

Angles $\varphi_1, \varphi_2, \sigma_1, \sigma_2$ comes from formulas 10. The tension E_1 in the fixed point T comes from formula 12. Finding tension E_2 is analogous to finding tension E_1.

Calculating charged particle on the surfaces of the electrodes: There is a solid body. Its volume is V, surface S, volume charges q. A definition says:

$$div\vec{D}=\rho, \tag{20}$$

The result after integrating of it is:

$$\iiint\limits_{(V)}\left(div\vec{D}\right)\times dV=\iiint\limits_{(V)}\rho\times dV=q \tag{21}$$

In a result of Maksuel’s postulate:

$$\iiint\limits_{(V)}\rho\times dV=\oint\!\!\oint\limits_{(S)}\vec{D}\times d\vec{S}=q \tag{22}$$

and material characteristic:

$$\vec{D}=\varepsilon\times\vec{E} \tag{23}$$

is Gauss’s law:

$$\oint\!\!\oint\limits_{(S)}\vec{E}\times d\vec{S}=\frac{q}{\varepsilon} \tag{24}$$

Putting it into practice for electrodes of the low frequency interference device, it assumes the following structure:

$$\oint\!\!\oint\limits_{(Se)}\vec{E}\times d\vec{S}=\iint\limits_{(Se)}E\times dS$$

$$=E\times\iint dS=E\times Se=\frac{q}{\varepsilon} \tag{25}$$

The charge on the surface of the electrodes is:

$$q=E\times\varepsilon\times Se=\frac{U}{d}\times\varepsilon\times Se, \tag{26}$$

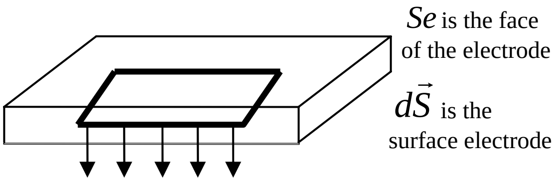

fig. 2. Charged particles on electrodes

There is tension only at the down side of the electrode. $E=\dfrac{U}{d}$, U-voltage at the end of each electrode couple, d - distance between electrodes. The charges on the surfaces of the couples are q_1 and q_2.

Finding The Vectors of The Tension: Using formulas 1. and 2. Total vector is : $\vec{E}=\vec{E}_1+\vec{E}_2$

It is a sum of space coordinates of $\vec{E}_1$ and $\vec{E}_2$.

$$E_i=E_{1i}+E_{2i} \quad i=x,y,z \tag{27}$$

III. CONCLUSION

1. A mathematical analysis of space-temporal configuration of low-frequency currents in the case of interference in the human body is given in the paper.
2. The presented mathematical description can be a base for computer simulation of space-temporal configuration of low-frequency currents in the case of interference in the human body is given in the paper.
3. An optimization of apparatus for intereferent currents in the process of design can be obtained using the above mentioned computer simulation

REFERENCES

[1] S. P. Papazov, S.L. Farhi, “Theoretical Electrical Engineering”, part 3, 1994.
[2] SIEMENS Medical Engineering Group, “Units for Physical Therapy And Diagnosis”.
[3] D. Dimitrov, “Communication systems in medicine”, Technical University, Sofia, 2005.
[4] “Higher Mathematics – lectures and exercises”, Technical University, Sofia.
[5] “Electrical Engineering - lectures and exercises” , Technical University, Sofia.