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Shielding performance of a mobile phone's radiation with a good conductor

By

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Abstract:

In this study, shielding of radiation from a mobile phone towards user is analyzed. It includes both simulations of shielding of EM wave radiated from mobile phone and practically shielding measurements. Copper plate as a good conductor is utilized for shielding. Since the radiation mostly penetrates via user's ear, the shield is placed on the earpiece of the mobile phone. For simulations, a Finite Difference Time Domain (FDTD) program has been developed in Matlab programming language. FDTD simulations have been carried out in 2 dimensions with first order Mur's ABC. Shielding effectiveness (SE) values have been computed by using electric field values which the user is exposed to. Also electromagnetic radiation graphics with color code and field patterns can be showed as simulation outputs. Experimental measurements are carried out in an ordinary room. A radiation-meter and a mobile phone with internal antenna are used for these measurements. The results obtained from both simulations and measurements are compared.

Keywords:

Mobile Phone, shielding, FDTD, numerical computation, measurement

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1. Introduction:

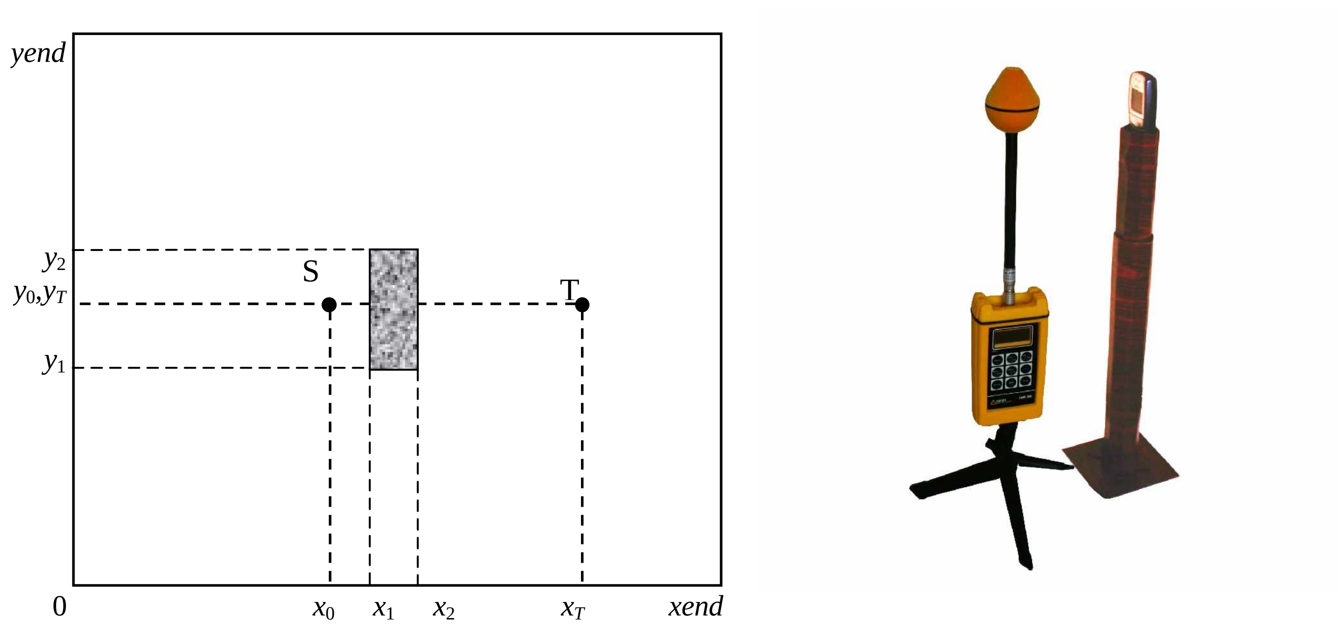
Mobile phones that provide wireless communication via electromagnetic waves have been used since 1991 all over the world. In many countries, over half of the population already uses mobile phones and the market is still growing rapidly. The researches on the effects of electromagnetic waves to human health have increased as wireless communication becomes widespread. Some organizations such as World Health Organization (WHO), International Commission on Non-Ionizing Radiation Protection (ICNIRP), National Radiological Protection Board (NRPB), and Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) have organized studies about possible health effects of electromagnetic waves and have declared the results [1-4]. These researches have been concentrated on using of mobile phone because it is continuously with user and near user's head during the talking. International standards that characterize the radiation limit values have been improved by the organizations. Also, some countries (Australia, Canada, Korea, Japan and Turkey) have various guideline and standards, which have lower limit values than those of international ones. According to the report of WHO, no research has shown adverse health effects at exposure levels below international guideline limits up to now, but there are gaps in knowledge that have been identified for further study to exactly assess health risks [4]. Similar results have been obtained in other researches as well.

User of mobile phone can not be isolated from electromagnetic field theoretically and practically. However, reducing the radiation penetrating into user's brain, during talking, is theoretically possible by using conductive shield if it is mounted on the earpiece of the phone since the antenna is backside of earpiece. Some studies on this subject have already been carried out [5-11]. Some of them contain only simulations and their results generally show that reduction of radiation can be possible. The others are practical studies and show that less reduction can be possible. An effective shielding affects far field radiation and so it affects connection performance of mobile phone, too. Consequently, the assessment of the simulations and measurements results show that more studies should be made.

In this work, both performing simulation of shielding of electromagnetic wave radiated from mobile phone by using FDTD method in Matlab and practically shielding of it have been aimed. FDTD simulations have been carried out in 2 dimensions with first order Mur's ABC. Therefore, they have not required a super computer system to perform the simulations. A copper plate has been used for experimental measurements. In the following part, the methods used for simulations and measurements are given. The results are given in the third part.

2. Method :

This work consists of simulations and measurements. 2D FDTD method has been used for the simulations, because it needs less computer memory and takes less time than 3D FDTD method. Successive measurements have been performed practically and the obtained values have been averaged in order to have stable results.
Lay-outs used for simulations and measurements are shown in Figure 1 (a) and (b), respectively. In this figure, 'xend' and 'yend' are related to dimension of the medium analyzed; x_1, x_2, y_1, and y_2 are related to position and dimension of the shield; x_0, y_0, and S is related to radiating source; x_T, y_T, and T is related to test point which electric field values are recorded at.



(a) ***(b)***

Figure (1): *Lay-outs used (a) for simulations and (b) for measurements.*

2.1. 2D-FDTD method:

In two-dimensional problems, there is no variation with respect to third coordinate in either the problem geometry or excitation. Here, it is assumed that no variation with respect to z, which means that all partial derivatives of the fields with respect to z equal zero and that the structure being modeled extends to infinity in the z-direction with no change in its geometry.
When three-dimensional FDTD formula is reduced to two-dimensions, there are two conditions; transverse electric (TE) and transverse magnetic (TM) modes. TE mode is the one that only includes electric field components transverse to the geometry axis (i.e. the z-

axis). TM mode is the one that only includes magnetic field components transverse to the z-axis. For two-dimensional TM mode, the formulas are

$$\frac{\partial H_x}{\partial t} = \frac{1}{\mu}\left(-\frac{\partial E_z}{\partial y} - \rho' H_x\right) \tag{1a}$$

$$\frac{\partial H_y}{\partial t} = \frac{1}{\mu}\left(\frac{\partial E_z}{\partial x} - \rho' H_y\right) \tag{1b}$$

$$\frac{\partial E_z}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} - \sigma E_z\right) \tag{1c}$$

For two-dimensional TE mode,

$$\frac{\partial E_x}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_z}{\partial y} - \sigma E_x\right) \tag{2a}$$

$$\frac{\partial E_y}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_z}{\partial x} - \sigma E_y\right) \tag{2b}$$

$$\frac{\partial H_z}{\partial t} = \frac{1}{\mu}\left(\frac{\partial E_x}{\partial y} - \frac{\partial E_y}{\partial x} - \rho' H_z\right) \tag{2c}$$

TM and TE modes are decoupled, namely, they contain no common field vector components. In fact, these modes are completely independent for structures comprised of isotropic materials. That is, the modes can exist simultaneously with no mutual interactions. Problems having both TM and TE excitations can be solved by a superposition of these two separate problems [12].
When two-dimensional TM mode is discretized, FDTD formulas are

$$H^{n+1/2}_{x,i,j+1/2} = D_a \cdot H^{n-1/2}_{x,i,j+1/2} + D_b\left(E^n_{z,i,j} - E^n_{z,i,j+1}\right) \tag{3a}$$

$$H^{n+1/2}_{y,i+1/2,j} = D_a \cdot H^{n-1/2}_{y,i+1/2,j} + D_b\left(E^n_{z,i+1,j} - E^n_{z,i,j}\right) \tag{3b}$$

$$E_{z,i,j}^{n+1} = C_a \cdot E_{z,i,j}^{n} + C_b \left(H_{y,i+1/2,j}^{n+1/2} - H_{y,i-1/2,j}^{n+1/2} + H_{x,i,j-1/2}^{n+1/2} - H_{x,i,j+1/2}^{n+1/2} \right) \quad (3c)$$

$$C_a = \frac{(2 \cdot \varepsilon - \sigma \cdot \Delta t)}{(2 \cdot \varepsilon + \sigma \cdot \Delta t)} \quad (4a)$$

$$C_b = \frac{2 \cdot \Delta t}{\Delta x \cdot (2 \cdot \varepsilon + \sigma \cdot \Delta t)} \quad (4b)$$

$$D_a = \frac{(2 \cdot \mu - \sigma^* \cdot \Delta t)}{(2 \cdot \mu + \sigma^* \cdot \Delta t)} \quad (4c)$$

$$D_b = \frac{2 \cdot \Delta t}{\Delta x \cdot (2 \cdot \mu + \sigma^* \cdot \Delta t)} \quad (4d)$$

where Δt is time increment, Δx and Δy is space increment in the x-direction and y-direction, respectively. Δx is assumed to be equal to Δy.

In a programming language, location for $n+1/2$ does not exist. So, these subscripts are completed to adjacent integer [12]. In our study, this is completed to the closest higher integer [13].

$$H_{x,i,j+1}^{n+1} = D_a \cdot H_{x,i,j+1}^{n} + D_b \left(E_{z,i,j}^{n} - E_{z,i,j+1}^{n} \right) \quad (5a)$$

$$H_{y,i+1,j}^{n+1} = D_a \cdot H_{y,i+1,j}^{n} + D_b \left(E_{z,i+1,j}^{n} - E_{z,i,j}^{n} \right) \quad (5b)$$

$$E_{z,i,j}^{n+1} = C_a \cdot E_{z,i,j}^{n} + C_b \left(H_{y,i+1,j}^{n+1} - H_{y,i,j}^{n+1} + H_{x,i,j}^{n+1} - H_{x,i,j+1}^{n+1} \right) \quad (5c)$$

2.1.1. Absorbing Boundary Conditions (ABCs):

The most commonly used Absorbing Boundary Conditions for open-region FDTD modeling problems are the Mur's ABC, the Liao ABC, and various perfectly matched layer (PML) formulations [14-17]. The Mur and Liao techniques are simpler than PML. Considering the E_z component located at $x = i\Delta x$, $y = j\Delta y$ for two-dimensional case, the first order Mur estimate of E_z field component is [17]

$$E_{i,j}^{n+1} = E_{i-1,j}^{n} + \frac{c\Delta t - \Delta x}{c\Delta t + \Delta x}(E_{i-1,j}^{n+1} - E_{i,j}^{n}) \qquad (6)$$

2.2. Measurements:

Experimental measurements of electric field values from a mobile phone with and without shielding have been conducted to confirm simulation results. A radiation-meter with isotropic electric field probe has been used to measure the radiation level from the mobile phone. The mobile phone has internal antenna with dual band.
The measurements with the radiation-meter can be both displayed and recorded by a computer. Therefore, average value of many measurements can be easily calculated. Since measurements have been done in a laboratory that is not an anechoic chamber, realistic reaction of the mobile phone could be observed. Furthermore, networks of 900 and 1800 MHz band have been accessible in the laboratory.

3. Results:

In this part, simulation and experimental results have been demonstrated. Simulations have been carried out in Matlab. Radiation pattern, maximum electric field intensity and also simultaneous radiation graphic have been obtained as simulation outputs. Measurements have been performed while the mobile phone is in connection with the other phone. Furthermore, many successive measurements have been carried out, so more stable values have been reached. Measured electric field values have been recorded by the computer and the average values of the records have been computed. Therefore, the accuracy of measurement could be increased [18].
The simulation and measurement results are given in the following sections, respectively.

3.1. Simulation Results:

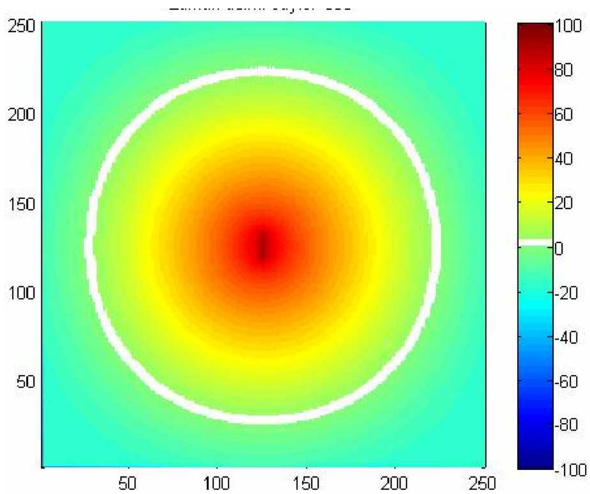
Simulation area has been selected as 250x250 mm. For $\Delta t = 2\,\text{ps}$ and $\Delta x = \Delta y = 1\,\text{mm}$, simulations have been carried out. Shielding effectiveness (SE) has been computed for 2 mm thickness copper shield (length of 3cm) at 900 and 1800 MHz frequencies. The shield has been mounted 10 mm far from the antenna on the right-hand side of it. The antenna has been selected as 15mm strip and mounted at the center of the area. The

maximum electric field values, used to calculate SE, have been obtained at 50 mm far from the antenna.
Computed maximum electric field values and shielding effectiveness of copper shield for two frequencies are given in Table 1.

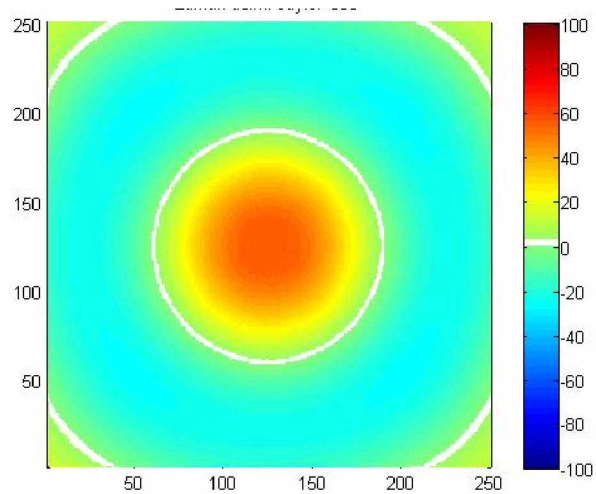
Table (1): *Maximum electric field values and shielding effectiveness (SE) from simulations.*

	Electric field values (V/m)		
Frequency	**Without shield**	**With copper shield**	**SE (%)**
900 MHz	60.98	7.81	87.2
1800 MHz	60.47	6.15	89.8

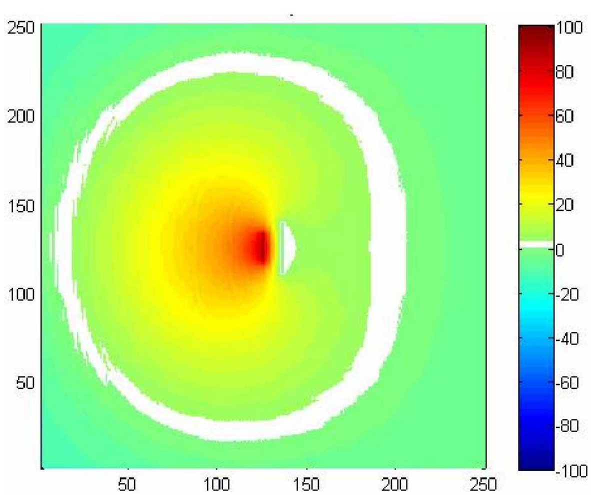
As mentioned before, electromagnetic radiation can graphically be displayed at each time step during the simulation. The graphics shown in Figure 2 demonstrate the radiation at the last time step of the simulation. They show how the waves at 900/1800 MHz frequencies propagate in a medium with and without copper shield.
Finally, radiation pattern can be displayed as output of the simulations. The radiation patterns for the same conditions as those in Figure 2 are shown in Figure 3.
As shown in Table 1, electric field level at 900 MHz frequency could be reduced from 60.98 to 7.81 V/m, corresponding to SE of 87.2%. Similarly, it has been decreased from 60.47 to 6.15 V/m (SE of 89.8%) for 1800 MHz. SE is expected to be higher for a frequency of 1800 MHz since more reduction occurs as increasing distance at higher frequencies.
As shown from radiation graphics in Figure 2(a) and (b), the wave has radiated almost omnidirectionally at 900 MHz and 1800 MHz. It can be seen from Figure 2(c) and (d) that the radiation has substantially been reduced by the shield on the right-hand side of the antenna, as expected.



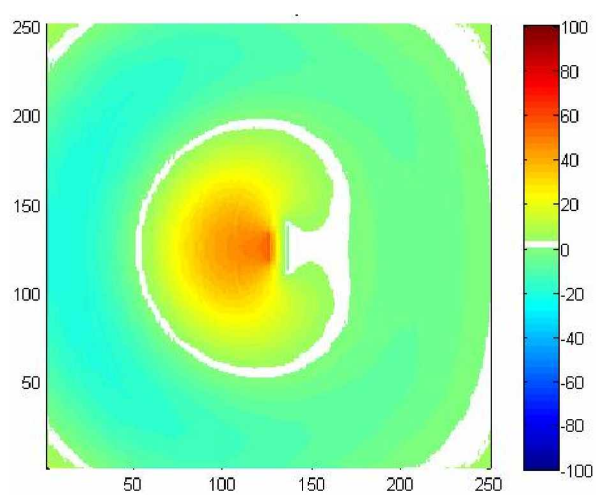
(a) *Without shielding at 900 MHz*



(b) *Without shielding at 1800 MHz*



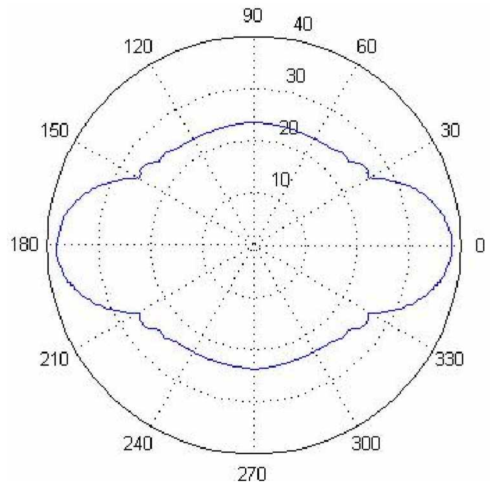
(c) *With shielding at 900 MHz*



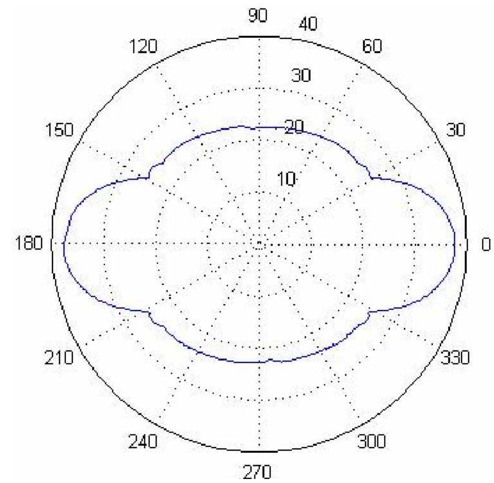
(d) *With shielding at1800 MHz*

Figure (2): *Radiation graphics with color code at the time of 600∆t at 900 MHz and 1800 MHz from simulations.*

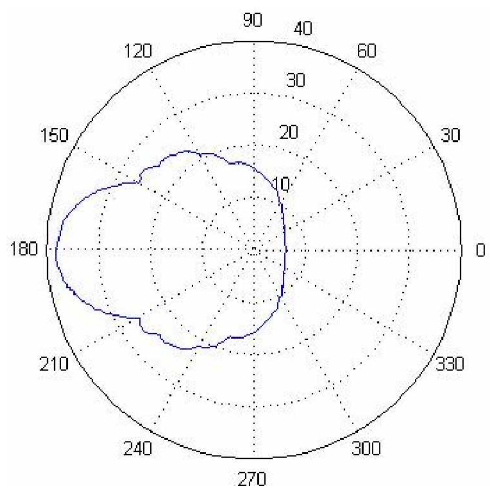
The radiation patterns at 900 MHz and 1800 MHz in Figure 3 (a) and (b), respectively, demonstrate that there is symmetrically radiation around the strip antenna without shielding. Figure 3 (c) and (d) show that the radiation has been reduced considerably on the right-hand side by the shield.



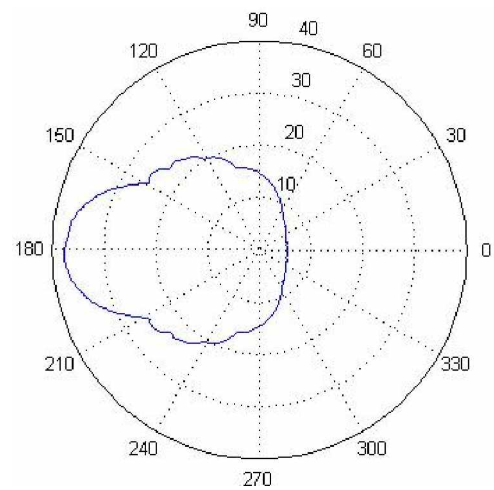
(a) *Without shielding at 900 MHz*



(b) *Without shielding at 1800 MHz*



(c) *With shielding at 900 MHz*



(d) *With shielding at 1800 MHz*

Figure (3): *Radiation patterns at 900 MHz and 1800 MHz from simulations.*

3.2. Measurement Results:

A copper plate has been mounted on the earpiece of the mobile phone. Its dimension has been selected as 3.2x1.4x0.2 cm. The radiation-meter has been placed 50 mm far from the mobile phone. As mentioned before, many successive measurement values have been recorded and averaged by the computer. The mean values for 900 and 1800 MHz frequencies are given in Table 2.

The averaged electric field value for 900 MHz frequency has increased from 2.10 to 2.14 V/m and for 1800 MHz frequency has been constant at 2.69 V/m with shielding.

These values correspond to SE of -1.9% and 0.0% respectively at 900 and 1800 MHz frequencies.

Table (2): *The measured electric field values and shielding effectiveness values.*

	Mean electric field values (V/m)		
Frequency	**Without shield**	**With copper shield**	**SE (%)**
900 MHz	2.10	2.14	-1.9
1800 MHz	2.69	2.69	0.0

4. Conclusions:

In this paper, reduction of the radiation from a mobile phone by shielding with a conductive material has been studied. A copper plate has been selected as conductive material. Both simulations and measurements have been performed and the results have been compared.

Simulations have been carried out in 2D and have shown that the radiation of mobile phone can considerably be reduced by using a conductive shield. Nearly same reduction of the radiation has been succeeded at both 900 and 1800 MHz frequencies.

Experimental measurements have been recorded and averaged by the computer. It has been observed that there was no reduction in practically measured radiation with shielding. Moreover, practically shielding in experimental measurements has even boosted the radiation instead of reducing it. Most probably, this case has occurred since the mobile phone has amplified the output power to keep connection.

As a conclusion, although the reduction of the radiation from the mobile phone has been succeeded in simulations, the similar results were not achieved in the case of practical measurements. The reason of this contradiction between these results may be attributed so that the output power of mobile phone has been constant in the simulations, while it was not in practice. Besides, the simulations for variable output power of the mobile phones have also been explicitly studied and reported elsewhere [19].

5. Acknowledgement:

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Nomenclatures:

ρ ... Electric charge density
ρ'… Equivalent magnetic resistance
ε ... Permittivity
μ ... Magnetic permeability
σ ... Conductivity
σ^*... Magnetic conductivity
c … Velocity of light