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# THE STRUCTURE OF ELECTROMAGNETIC FLUXES OF ELEMENTARY ELECTRIC RADIATOR IN NEAR AND INTERMEDIATE ZONES

*The paper contains theoretical research of flux density of electromagnetic field power of elementary radiator in near and intermediate zone. Directional power patterns of the radiator for distances of the 2.5…50cm at medium – frequency band of QSM standard - 900 and QSM – 180 of the system of mobile communication are constructed.*

***Key words:*** *elementary electric radiator, near, intermediate zone, flux of electromagnetic field.*

## Introduction

Electromagnetic field of elementary radiator is profoundly investigated in distant zone (zone of emission). It is already known in this part of the space flux density of field power has practically one radial component and is inversely proportional to the of the distance from radiator to the point to observation.

In near and intermediate zones electromagnetic field of the radiator has three components, which generate two fluxes : radial flux, determined by meridianal component of electric fields and equatorial component of magnetic field and meridianal flux, determined by radial component of electric fields and equatorial component of magnetic field.

The above- mentioned conditions do not allow to apply conventional for aerial problems methods and instruments for measuring fields parameters of radiator in near and intermediate zones. Besides, mutual influence of the radiator and measuring aerial will lead to distortion of such results due to small distance between them.

Study of the field in near and intermediate zones of radiators is an actual problem as a results of wide application of mobile phones of cellular communication; one of the problems to be solved is to give a definite answer regarding the level of harmful influence for mobile phones users , in case when the head of the user is in near- intermediate zone of radiation emitted by radiophone.

## Analysis of the recent research and publications

Known (1)general expressions for complex amplitudes of elementary electric radiator field components are:

$$\dot{E}_{mr} = \frac{I_m l k^2}{2\pi}\sqrt{\frac{\mu_a}{\varepsilon_a}}\cdot\sqrt{\left(\frac{1}{kr}\right)^4+\left(\frac{1}{kr}\right)^6}\cdot e^{-j\left(kr+arctg\frac{1}{kr}\right)}\cdot\cos\theta, \qquad (1)$$

$$\dot{E}_{m\theta} = \frac{I_m l k^2}{4\pi}\sqrt{\frac{\mu_a}{\varepsilon_a}}\cdot\sqrt{\left[\frac{1}{kr}-\left(\frac{1}{kr}\right)^3\right]^2+\left(\frac{1}{kr}\right)^4}\cdot e^{-j\left(kr+arctg\frac{kr}{k^2r^2-1}-\frac{\pi}{2}\right)}\cdot\sin\theta, \qquad (2)$$

$$\dot{H}_{m\varphi} = \frac{I_m l k^2}{4\pi}\sqrt{\frac{\mu_a}{\varepsilon_a}}\cdot\sqrt{\left(\frac{1}{kr}\right)^2+\left(\frac{1}{kr}\right)^4}\cdot e^{-j\left(kr+arctg\frac{1}{kr}-\frac{\pi}{2}\right)}\cdot\sin\theta, \qquad (3)$$

Where $\dot{E}_{mr}$ and $\dot{E}_{m\theta}$ – complex amplitudes of radial and meridial components of electric field, correspondingly; $H_{m\varphi}$ – complex amplitude of equatorial component of magnetic field; $I_m$ – amplitude of harmonic electric current in elementary electric radiator of $\ell$ length; $k=\omega\sqrt{\mu_a\varepsilon_a}=2\pi/\lambda$ – wave number; $\mu_a$, $\varepsilon_a$ – absolute magnetic permeability and electric permittivity of the environment, surrounding the radiator; r – distance from the radiator to the point of field observation; λ – wave length of harmonic current in the radiator; θ – meridional angle coordinate, centre of which is located in the start point of spherical system of coordinates (r, θ,φ).

In the distant zone kr <<1radial component of electric field can be neglected and it is assumed that there exists single flux of density vector of power flux, which is determined by the formula:

$$\overline{\Pi} = \frac{1}{2}\left[\dot{E}_{m\theta}\,\overset{*}{\overline{H}}_{m\varphi}\right] = \overline{r}_0\,\frac{I_m^2 l^2 k^2}{32\pi^2 r^2}\cdot sin^2\,\theta\,. \qquad (4)$$

As it is seen from the expression (4) there exists the flux of electromagnetic field, the intensity of the flux decreases proportionally to the growth of square of distance r. Maximum radiation is directed into equatorial plane (θ = π/2), but there is no radiation along the axis of the radiator (θ = 0,π).

By its character this flux is the flux of active power density, which participates in radiocommunication.

Proceeding from the expression (4), in [2] for computation of the density of power flux $\overline{I}$, formula for mean value of Pointing vector is used, on the basis of the given formula the expression for approximated computation of safe time of mobile phone usage was obtained. In accordance with computations performed, safe time was approximately one hour a day for mobile phones of GSM-900 standard.

**Problem set up**

The aim is to obtain the expression of densities of power fluxes of elementary electric radiator electromagnetic field in radial and meridial directions.

Study the distribution of these fluxes in all directions of near and intermediate zones of radiation field.

Applying the obtained formulas, calculate the revised values of safe time usage of cellular phones, operating in GSM-900 and GSM-1800 standards.

**Main material of the paper**

Using the expressions (2) and (3), we determine the flux density of power $\vec{I}$ R in radial direction:

$$\dot{\overline{\Pi}}_r = \frac{1}{2}\left[\dot{\overline{E}}_{m\theta}\,\overset{*}{\overline{H}}_{m\varphi}\right] = \overline{r}_0\,\frac{I_m^2 l^2 k^4}{32\pi^2}\sqrt{\frac{\mu_a}{\varepsilon_a}}\sqrt{\left[\frac{1}{kr}-\left(\frac{1}{kr}\right)^3\right]^2+\left(\frac{1}{kr}\right)^4}\times$$

$$\times\sqrt{\left(\frac{1}{kr}\right)^2+\left(\frac{1}{kr}\right)^4}\,e^{-j\left(\mathrm{arctg}\frac{kr}{k^2r^2-1}-\mathrm{arctg}\frac{1}{kr}\right)}\sin^2\theta\,, \qquad (5)$$

and using expression (1) and (3) – in meridial direction ;

$$\dot{\overline{\Pi}}_\theta = \frac{1}{2}\left[\dot{\overline{E}}_{mr}\,\overset{*}{\overline{H}}_{m\varphi}\right] = -\overline{\theta}_0\,\frac{I_m^2 l^2 k^4}{16\pi^2}\sqrt{\frac{\mu_a}{\varepsilon_a}}\sqrt{\left(\frac{1}{kr}\right)^4+\left(\frac{1}{kr}\right)^6}\times$$

$$\times\sqrt{\left(\frac{1}{kr}\right)^2+\left(\frac{1}{kr}\right)^4}\,e^{-j\pi h}\sin\theta\cos\theta\,. \qquad (6)$$

As it is seen, radial Pointing vector $\vec{I}_R$ is of complex character, i.e. $\dot{\overline{\Pi}}_r = \dot{\overline{\Pi}}_{ar} + j\dot{\overline{\Pi}}_{pr}$ where

$\overline{\Pi}_{ar}$ is its active part.

$$\overline{\Pi}_{ar} = \frac{I_m^2 l^2 k^4}{32\pi^2}\sqrt{\frac{\mu_a}{\varepsilon_a}}\sqrt{\left[\frac{1}{kr}-\left(\frac{1}{kr}\right)^3\right]^2+\left(\frac{1}{kr}\right)^4}\times$$

$$\times\sqrt{\left(\frac{1}{kr}\right)^2+\left(\frac{1}{kr}\right)^4}\cos(\operatorname{arctg}\frac{kr}{k^2r^2-1}-\operatorname{arctg}\frac{1}{kr})\sin^2\theta \qquad (7)$$

is the mean value of Pointing vector:

$\overline{\Pi}_{pr}$ -- is its reactive part.

$$\overline{\Pi}_{pr} = -\frac{I_m^2 l^2 k^4}{32\pi^2}\sqrt{\frac{\mu_a}{\varepsilon_a}}\sqrt{\left[\frac{1}{kr}-\left(\frac{1}{kr}\right)^3\right]^2+\left(\frac{1}{kr}\right)^4}\times$$

$$\times\sqrt{\left(\frac{1}{kr}\right)^2+\left(\frac{1}{kr}\right)^4}\sin(\operatorname{arctg}\frac{kr}{k^2r^2-1}-\operatorname{arctg}\frac{1}{kr})\sin^2\theta\ . \qquad (8)$$

Meridial Pointing vector, as it is seen from (6) has only reactive component

$$\overline{\Pi}_{p\theta} = -\frac{I_m^2 l^2 k^4}{32\pi^2}\sqrt{\frac{\mu_a}{\varepsilon_a}}\sqrt{\left(\frac{1}{kr}\right)^4+\left(\frac{1}{kr}\right)^6}\sqrt{\left(\frac{1}{kr}\right)^2+\left(\frac{1}{kr}\right)^4}\sin 2\theta\,. \qquad (9)$$

In expression (7), (8) and (9) the same multiplier is used, which does not depend on the distance $\vec{I}$, and angular coordinate

Let us reduce the given expression to the form, convenient for further analysis. From [3] it is known that the square of the amplitude of harmonic current in elementary electric radiator is

$$I_m^2 = \frac{2P_\Sigma}{R_\Sigma}$$

where $P_\Sigma$ - power of radiation; $R_\Sigma = 80\pi^2(l/\lambda)^2$ - resistance of radiation of the giver radiator in free space.

Then

$$I_m^2 = \frac{P_\Sigma}{40\pi^2(l/\lambda)^2}\,. \qquad (10)$$

Substituting (10) in the expression for A, we obtain:

$$A=\frac{P_\Sigma l^2k^2k^2}{32\pi^2 40\pi^2(l/\lambda)^2}\sqrt{\frac{\mu_a}{\varepsilon_a}}=\frac{P_\Sigma l^2\omega^2\mu_a\varepsilon_a 4\pi^2}{32\pi^2 40\pi^2(l/\lambda)^2\lambda^2}\sqrt{\frac{\mu_a}{\varepsilon_a}}=$$

$$=\frac{P_\Sigma 4\pi^2 f^2\mu_a\varepsilon_a}{320\pi^2}\sqrt{\frac{\mu_a}{\varepsilon_a}}=\frac{P_\Sigma f^2\mu_a\varepsilon_a}{80}\sqrt{\frac{\mu_a}{\varepsilon_a}}$$

Since the environment surrounding the radiator, is dry air, for which $\mu_a \approx \mu_0$; $\varepsilon_a \approx \varepsilon_0$, the latter expression will be written as

$$A=\frac{P_\Sigma}{80\lambda^2}\cdot 120\pi=\frac{3\pi P_\Sigma}{2\lambda^2}.$$

If $P_\Sigma$ is calculated in microwatts, and wave length $\lambda$ is measured in centimeters, then

$$A=\frac{3\pi P_\Sigma\cdot 10^6}{2\lambda^2}\left(MWt/cm^2\right).$$

Average value of radiation power of cellular phone operating in GSM – 900 equals 0,2 Wt, and average wave length $\lambda_1$ = 32,8 cm. Then

$$A=A_1=\frac{3\pi\cdot 20\cdot 10^4}{2\cdot 1075{,}84}=875{,}6\left(\mu Wt/cm^2\right). \tag{11}$$

In GSM – 1800 standard: $\lambda$ = 17,2 cm, average value of radiation power we will take as 0.1 Wt. Then

$$A=A_2=\frac{3\pi\cdot 10\cdot 10^4}{2\cdot 295{,}84}=1592{,}1\left(\mu Wt/cm^2\right). \tag{12}$$

Taking into account (7), (8), (9), (11) and (12) the following expressions will be functions of radiator orientation by power

$$\Pi_{ar}=A\sqrt{\left[\frac{1}{kr}-\left(\frac{1}{kr}\right)^3\right]^2+\left(\frac{1}{kr}\right)^4}\times$$

$$\times\sqrt{\left(\frac{1}{kr}\right)^2+\left(\frac{1}{kr}\right)^4}\cos(\mathrm{arctg}\frac{kr}{k^2r^2-1}-\mathrm{arctg}\frac{1}{kr})\sin^2\theta, \tag{13}$$

$$\Pi_{pr}=A\sqrt{\left[\frac{1}{kr}-\left(\frac{1}{kr}\right)^3\right]^2+\left(\frac{1}{kr}\right)^4}\times$$

$$\times\sqrt{\left(\frac{1}{kr}\right)^2+\left(\frac{1}{kr}\right)^4}\ \sin(\mathrm{arctg}\frac{kr}{k^2r^2-1}-\mathrm{arctg}\frac{1}{kr})\sin^2\theta\,, \tag{14}$$

$$\Pi_{p\theta}=A\sqrt{\left(\frac{1}{kr}\right)^4+\left(\frac{1}{kr}\right)^6}\ \sqrt{\left(\frac{1}{kr}\right)^2+\left(\frac{1}{kr}\right)^4}\ \sin 2\theta\,. \tag{15}$$

Having applied the expression (13), (14), (15) we obtain the expression for the dependence of power flux density on the distance r and angular coordinate $\theta$.

$$\Pi=\sqrt{\Pi_{ar}^2+\Pi_{pr}^2+\Pi_{p\theta}^2}\,. \tag{16}$$

Let us construct diagrams of directivity using standards GSM – 900 and GSM – 1800 for such values of r : 2.5 cm; 5 cm; 7.5 cm; 10 cm; 15 cm; 30 cm and 50 cm, substituting in the formula [16] the values of power fluxes densities by the expressions (13), (14), (15) taking into account that

$A_1=875{,}6\ {}^{\mu Wt}\!/_{cm^2}$, a $A_2=1592{,}1\ {}^{\mu Wt}\!/_{cm^2}$.

1). If $kr=1$ ($r=5{,}0$ см) and $A=A_1=875{,}6$ we have

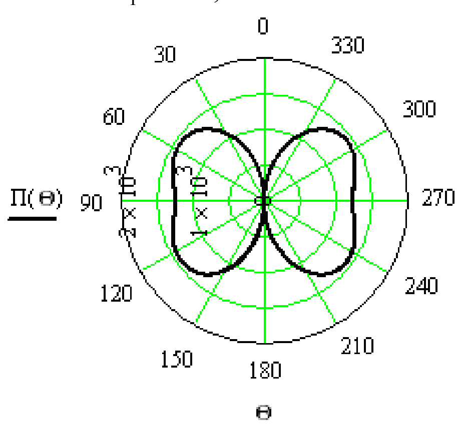


Fig 1 Directivity diagrams of elementary electric radiator by electric field if r = 5.0 cm.

2). If $K_r$ = 1 (r = 50 cm) and A = $A_2$ = 1592.1 we have.

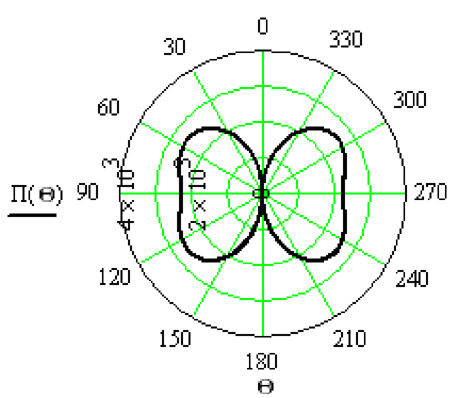


Fig 2 Directivity diagrams of elementary electric radiator by electric radiator by electric field if r = 5.0 cm.

Table 1 contains the most important data of directivity diagrams for other cases.

Table 1

| $r$, cm | $\theta$ | $\Pi$, $\mu Wt/cm^2$ | |
|---|---|---|---|
| | | GSM - 900 | GSM - 1800 |
| 2,5 | 30 | $2{,}5\cdot 10^4$ | $4{,}2\cdot 10^4$ |
| | 45 | $3{,}2\cdot 10^4$ | $5{,}9\cdot 10^4$ |
| | 90 | $1{,}8\cdot 10^4$ | $5{,}2\cdot 10^4$ |
| 7,5 | 30 | 360 | 650 |
| | 45 | 460 | 825 |
| | 90 | 420 | 750 |
| 10 | 30 | 200 | 360 |
| | 45 | 250 | 450 |
| | 90 | 230 | 410 |
| 15 | 30 | 75 | 160 |
| | 45 | 115 | 200 |
| | 90 | 100 | 180 |
| 30 | 30 | 22 | 40 |
| | 45 | 28 | 50 |
| | 90 | 25 | 45 |
| 50 | 30 | – | 14 |
| | 45 | – | 18 |
| | 90 | – | 16 |

**Analysis of the results obtained**

Assuming that the nearest point of the brain is located approximately at the distance of 5 cm under the angle of $30°$, we see from directivity diagram (Fig 1) that the density power equals $1{,}1\cdot 10^3$ $\mu Wt/cm^2$, which exceeds sanitary admissible level 44 times.

Hence, in the range of GSM – 900 standard , the time of safe usage of cellular phone during a day period (1440 minutes) equals:

1440:44= 32.72 min

In the range of the GSM – 1800 standard (Fig 2) at the same distance the excess of admissible norm is:

$$2\cdot 10^3\ \mu Wt/cm^2 : 25\ \mu Wt/cm^2 = 80 \text{ times},$$

Duration of the safe usage of cellular phone equals only 1440:80=18 min during a day.

In this standard (see Table 1) the nearest to the cellular phone users eye, located at the distance of approximately r = 7.5 cm, under the angle of $\theta$ = 45° and is radiated by power flux with the density of 825 $\mu Wt/cm^2$ that exceeds the norm 33 times. That is, the time of safe usage of cellular phone equals 1440:33= 43.64 min a day.

**Conclusions**

1.Fluxes of electromagnetic energy generated by elementary electric radiator in near and intermediate zones are concentrated mainly in the direction perpendicular to the axis of the vibrator (from $\theta = 15°$ to $\theta = 165°$ ) with expressed maximums in the direction $\theta = 45°$ to $\theta = 135°$.

2. The first of these maximums radiates the brain and the eye of the user which is at the shortest distance from the cellular phone.

3. If follows from the examples, that the correction of the calculation of the safe time of cellular phone usage is considerable, as its reduces its value practically to 33 min a day (GSM - 900) and 18 min a day (GSM-1800)

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