RIGA TECHNICAL UNIVERSITY

Faculty of transport and mechanical engineering

Railway Transport Institute

Yelena CHAIKO

Doctoral student of Computer Management, Information and Electronics systems of Transport (Student ID 001RED005)

MATHEMATICAL MODELS OF RADIO WAVE PROPAGATION IN WOODLAND FOR MOBILE COMMUNICATION SYSTEMS

Extended Abstract of Doctoral Thesis

Scientific Supervisor
Dr. habil. Phys. Professor
Valentin POPOV

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DOCTORAL THESIS
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OFFICIAL OPPONENTS

Asoc. Professor. Dr.habil.sc.ing.Guntars Balodis,
Rigas Technical University, Latvia

Professor.Dr.habil.sc.ing.AglimantasKajackas,
Vilnius Technical University, Lithuania

Professor.Dr.habil.sc.ing.ImantsMatīss,
Latvian Academy of Sciences

DECLARATION

I hereby confirm that I have elaborated the present doctoral thesis which is presented for review to the Riga Technical University for the acquisition of the degree of Doctoral of Engineering. The doctoral thesis has not been presented to any other university for acquisition of a scientific degree.

Yelena Chaiko.......

Date: 11 June 2004

The doctoral thesis is written in the Russian language and contains an introduction, five parts, conclusions, 51 illustrations - 178 pages in total. The thesis contains five bibliography lists (one for each part), which have accordingly 25, 18,20, 10 and 10 titles.

INTRODUCTION

Last decades are characterized by fast introduction of cellular systems for mobile communication intended to transfer telephone and digital messages to mobile subscribers. In such communication systems service area is devided on the big number of operating zones (cells) inside which communication between mobile and base stations is carried out by the radio channel.

When organizing cellular communication network to define optimum site place and number of base stations, and also to decide other problems it is necessary to be able to compute characteristics of radio signal in any point of space within the limits of service area. The forest environment creates specific conditions for propagation of the radiowaves, changing uniformity of service area.

The necessary precondition for the development of effective communication systems operating in the forest environment, the deep knowledge of channels propagation characteristics of radio signals is needed.

Actuality

While many authors were engaged in research of radiowaves propagation in cellular communication systems for city enviroment, influence of large forests on propagation conditions of radiowaves is investigated poorly enough, thus there is no regular approach from the point of mathematical modelling, and on the other hand practically there are no presentation experimental data which would take into account influence of structure, density, moisture and other characteristics of large forests on received signal level.

Thus, problem of mathematical modelling and experimental researches of radiowaves propagation in forest is an actual problem.

Except for this, these researches, besides cellular communication systems, can have various other scopes:

- for the solution of direct problems for ground and space radio relay system;
- for the solution of inverse problem on reflection and dispersion of radio signals from large forests on which define the key parameters of large forests.

Aims of the work

The purpose of this work consists in carrying out complex researches of radiowaves propagation for a decimeter range in large forests for base development when designing cellular systems for mobile communication in Latvia; construction of the mathematical models determining parameters of the forest environment; the description of the basic mechanisms of radiowaves propagation for decimeter range in conditions of forest depending on distance between a point of reception and base station, in view of real parameters of large forests: dielectric permeability of trees, the sizes, density, humidity, wind loadings and so forth.

Scientific novelty and the main results

At performance of work, scientific direction has received the further development in modern radiophysics - the theory of radiowaves propagation for a decimeter range in large forests, as in statistical - complex non-uniform environments.

In dissertational work carried out theoretical (construction of mathematical models of radiowaves propagation in non-uniform environments) and experimental researches of radiowaves propagation in large forests. Results of the given researches are original researches and for the first time carried out in Latvia.

The new scientific results received in this direction, it is briefly possible to formulate as follows:

- Carried out estimation of key parameters of large forests;
- The determined model of effective dielectric permeability of large forests as quasi-homogeneous non-uniform environments is constructed;
- Developed the determined mathematical models of radiowaves propagation in a large forest and comparative estimations with known experimental data carried out;
-Use of the approached mathematical models Tversky's and Ritov's has allowed to construct the statistical mathematical models determining coherent and not coherent components of an electromagnetic field in a point of reception in conditions of large forests;
-Carried out to experimental researches of radiowaves propagation in cell limits for the chosen base station of the mobile communication operator LMT in view of influence of a large forest.

Areas of questioning in the thesis

Definition of key parameters of large forests;

The generalized electrodynamic model which defines effective complex dielectric permeability of a large forest as quasi-homogeneous the non-uniform dielectric environment with losses, volumetric concentration of which disperse phase lays in limits $f_i \leq$ (0,02-0,2).

Definition of effective factor of running attenuation (and, accordingly, degrees of radio signal weakening on the corresponding wave length) for various models of forest environments.

The radiowaves propagation determined mathematical model in large forests.

Statistical models radiowaves propagation in large forests. Results of experimental researches of radiowaves propagation in large forests.

The comparative analysis of theoretical and experimental results by definition of radiowaves level in a point of reception in view of large forests influence.

Practical value of the work and its application

It is possible to specify the following basic areas of practical application of the received results:

cellular mobile communication systems;

Radiorelay ground and space systems;

Radar-tracking and radionavigating systems;

research Space systems of large forests parameters and the ecology problems of terrestrial forests connected to them.

The parities received in dissertational work for power characteristics of signal allow to predict operating conditions of radiomeans in woody district in view of large forests parameters . The communication signal depression determined in these parities with parameters of forest vegetation can be used for an estimation of a large forests condition and their basic characteristics.

Approbation of results

Results of researches on a theme of dissertational work were reported at the international conferences:

- 42. RTU Starptautiska zinatniska konference, 2001. gada 11.-13. oktobris, Riga, Latvija;
- 43. RTU Starptautiska zinatniska konference, 2002. gada 11.-13. oktobris, Riga, Latvija;
- 44. RTU Starptautiska zinatniska konference, 2003. gada 9.-11. oktobris, Riga, Latvija;
- The 1st International conference information technologies and management 2003. April 15-16. 2003, Information System Institute, Riga, Latvia.
- The 2nd International conference information technologies and management 2003. April 15-16. 2003, Information System Institute, Riga, Latvia.

The structure and size of **the work**

The dissertation will consist of introduction, five chaptersand the conclusion. Work is written in Russian and contains 178 pages, 51 figures and 19 tables, each chapter contains the list of the literature.

CONTENTS OF THE DISSERTATION

The first chapter

In the first chapter the analitical review of large forests parameters is carried out, the basic *mechanical* parameters of large forests which influence of their *dynamic characteristics* are considered.

In this work the forest is submitted by difficult vertical structure consisting of various layers (the ground, trunks of trees, foliage, air), each of these layers has the specific features and differently influences on radiowaves propagation.

It is necessary to notice, that elements of forest vegetation are randomly located, their parameters, the sizes and dielectric permeability essentially change at trees within the limits of a large forest.

Besides parameters of forest vegetation are influenced with weather conditions, such as loss of deposits, seasons.

In work it is revealed, that at low-sited BTS and MS by the basic elements of forest vegetation forming a coherent field, trunks of trees are and at modelling characteristics of dispersion it is necessary to take into account heights of trees, diameter, density of spreading and dielectric permeability of trees in UHF a range.

On the data [1.1], [1.2] values of height of trees h in a large forest achieve 10-30 meters, the radius at the basis of a tree a does not exceed 50 sm, values of dielectric permeability e and conductivity *a* of trees in UHF a range (7÷20) and (0,01÷0,1) Sim/m accordingly.

Average of trunks of trees on m^2: $(10^{-3} < N < 10^{-1})$ trunk / m^2

The density of large forests is defined by a season. Completeness of a forest of CD varies in limits: 0,3 <CD <1.

Speed of a wind above a forest can vary $0 < U_W < 20$ km/s, (excepting gale-force winds) thus speed of a wind inside a forest usually: $U_{inf} \approx (0,02 \div 0,03) U_{w,}$ i.e. $(0 < U_{inf} < (0,4 \div 0,6))$ m/s.

Humidity of plants of a forest depends on a season, weather conditions and is defined: $W \approx \chi f_B$ where $\chi \bar{=} \rho_B / \rho_{q,,л}$ – For trunks of trees and branches: $W \approx 2,22\ f_B$ The weight of green vegetation on unit of the area is defined: $M = f(h) d_B$, where f

- density of filling unit of volume vegetation; <h>-average height of a vegetative cover; da-densities of water.

The amount of the water contained in elements of a vegetative cover in height <h> on area S, will be defined:

$$P_B = fW\bar{h}Sd_B,$$

where W - relative volumetric humidity of vegetative elements.

All these features of parameters of woods influence their dynamic characteristics to which consideration the second chapter is devoted.

The second chapter

The second chapter is devoted to the construction of the generalized electrodynamic model determining effective complex dielectric permeability of a large forest as quasi-homogeneous non-uniform dielectric environment with losses, volumetric concentration of which disperse phase lays in limits $f_i \leq (0,02\text{-}0,2)$.

The size of effective running factor of attenuation (and, accordingly, degrees of weaking of a radio signal on the corresponding length of a wave) for various models of forest environments is determined.

The equation of an electric field average on volumes big in comparison with scales nonhomogeneous can be written down as:

$$\langle \mathbf{D} \rangle = \frac{1}{V} \int_V \mathbf{D} dV, \ \langle \mathbf{E} \rangle = \frac{1}{V} \int_V \mathbf{E} dV, \tag{1}$$

where (D) and (E) average values of vectors induction and intensity of an electric field,

And inside i-that element of a forest components of electric field:

$$\langle \mathbf{D}_i \rangle = \frac{1}{V_i} \int_{V_i} \mathbf{D} dV, \ \langle \mathbf{E}_i \rangle = \frac{1}{V_i} \int_{V_i} \mathbf{E} dV \tag{2}$$

Where D, and E, - components of electromagnetic field in any point of the non-uniform environment, Vi - volume of i-that components, V-volume all the environment long.

In relation to vectors <D> and <E> the non-uniform environment (at $f_F <$ 0.25) can be considered as quasi-homogeneous and linear and to characterize effective value tensor dielectric permeability $|\varepsilon_m|$:

$$\langle D \rangle = |\varepsilon_m| \langle E \rangle \tag{3}$$

Average value of a field inside i-that components equally to the average value of a vector determined by the geometrical sum of fields, determined volumetric concentration *f*, and average value of a field in all environment:

$$\langle \mathbf{D_i} \rangle = \sum_{i=1}^{n} \frac{V_i}{V} \langle \mathbf{D} \rangle = \sum_{i=1}^{n} f_i \langle \mathbf{D} \rangle, \quad (4)$$

Intensity of an electric field inside volume Vi will be.

$$\langle \mathbf{E_i} \rangle = \sum_{i=1}^{n} \frac{V_i}{V} \langle \mathbf{E} \rangle = \sum_{i=1}^{n} f_i \langle \mathbf{E} \rangle, \quad (5)$$

where fi=nVi/V-volumetric concentration of i-that components.

Thus, the equation (5) connects average value of a field inside i-that components <Ei> and average value of a field in all <E> environment.
Let's enter the concept about factor of field for such environment jocj|, which connects intensity of a field inside i-that components to intensity of a field in all environment.

$$\langle E_i \rangle = |\alpha_i| \langle E \rangle, \quad (6)$$

The factor of field $|\alpha_i|$ (generally, is tensor) depends on the form of particles of a disperse phase of i-that components, relative dielectric penetration ($\chi = \varepsilon_i / \varepsilon_j$), forms - factors of particles ($\delta_i = d_{max} / d_{min}$), orientations of the big axes of particles concerning a direction of an electric field (i.e. from a kind of polarization E and direction δ_i):

$$|\alpha_i| = |\psi(\chi, \delta_i)| \quad (7)$$

Introduction of factor of a field | 0i | allows the vector equations (4) and (5) to result in a kind:

$$\langle \mathbf{D} \rangle = |\varepsilon_m| \langle \mathbf{E} \rangle = \left[\sum_{i=1}^{n} f_i \varepsilon_i |\alpha_i| \right] \langle \mathbf{E} \rangle, \quad (8)$$

Thus expression (8) allows, with the account (6), to find tensor effective dielectric permeability 0_m for the linear non-uniform environment as:

$$|\varepsilon_m| = \sum_{i=1}^{n} f_i \varepsilon_i |\alpha_i|, \quad (9)$$

at performance of conditions:

$$1 = \sum_{i=1}^{n} f_i \varepsilon_i ,\ 1 = \sum_{i=1}^{n} f_i \tag{10}$$

Thus, expression for effective dielectric permeability ε_m linear quasi-homogeneous the dielectric environment with losses is received as (9), thus it is fair at performance of conditions (10).

The special cases are considered, allowing to estimate complex dielectric permeability for non-uniform environments with various disperse particles and their arrangement this Wednesday.

In work [Popov] expressions complex dielectric permittivity for the following environments are deduced:

If environment represents cellular environment, i.e. carrying phase - air, disperse phase - vegetation:

1) If in the n-componental non-uniform environment disperse particles are located in the correct order (in units of a crystal lattice - fig. 1) the formula (9) is resulted in the formula:

$$|\varepsilon_m| = \varepsilon_1 + \sum_{i=2}^{n} (\varepsilon_i - \varepsilon_1) f_i |\alpha_i| \tag{11}$$

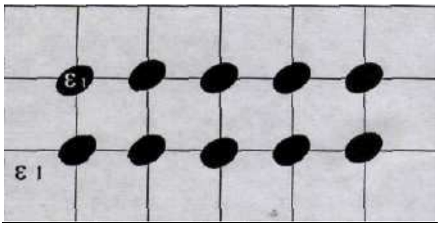


Figure 1. non-uniform environment with a correct arrangement of disperse particles

From expression (11), the following special cases follow:

1.1) If disperse particles ellipsoids, that, having defined factor of a field in view of factor depolarization, we shall receive expression (12) as:

$$\dot{\varepsilon}_m = \varepsilon_1 + \sum_{i=2}^{n} (\varepsilon_i - \varepsilon_1) f_i \sum_{\nu=1}^{3} \left[1 + \left(\frac{\varepsilon_i}{\varepsilon^*} - 1 \right) n_i^\nu \right]^{-1} \qquad (12)$$

Where $\varepsilon_1 < \varepsilon^* < \varepsilon_m$,

$$n_i^\nu = \frac{1}{2} abc \int_0^\infty \left[(\lambda + \gamma^2) \sqrt{(\lambda + a^2)(\lambda + b^2)(\lambda + c^2)} \right]^{-1} d\lambda$$ -factor

depolarization ellipsoid particles; $\gamma = a$ or b or c, depending on position of the big axis ellipsoid concerning vector E.

α_i - factor of a field:

$$\alpha_i = \frac{1}{3} \sum_{\nu=1}^{3} \left[1 + \left(\frac{\varepsilon_i}{\varepsilon_m} - 1 \right) n_i^\nu \right]^{-1} \qquad (13)$$

1.2) If disperse particles spherical the factor of a field will be written down as (14), and complex dielectric permeability will be written down as (15):

$$\alpha_i = \frac{3}{\left(\varepsilon_i \ldots + 2 \right)} \qquad (14)$$

$$\varepsilon_m = \varepsilon_1 + \sum_{i=2}^{n} \frac{3 f_i \left(\varepsilon_i / \varepsilon^* - 1 \right)}{\left(\varepsilon_i / \varepsilon^* + 2 \right)} \qquad (15)$$

Thus size ε^* at volumetric concentration $0{,}25 < f_i < 0{,}45$ can be equated to effective dielectric permeability of the non-uniform environment which we search $\varepsilon^* = \varepsilon_m$ and then expression (15) will be written down in an implicit kind:

$$\varepsilon_m = \varepsilon_1 + \sum_{i=2}^{n} \frac{3 f_i (\varepsilon_i - \varepsilon_m)}{(\varepsilon_i + 2\varepsilon_m)} \qquad (16)$$

In case of small volumetric concentration fi <0,25 this size can be counted dielectric permeability of carrying environment $\varepsilon * = \varepsilon_1 = 1$ and then the equation (15) will be obvious.

Let's consider more simple, two-componental environment for which expression (9) it will be written down in more simple kind:

$$\varepsilon_m = \varepsilon_1 f_1 \alpha_1 + \varepsilon_2 f_2 \alpha_2 \qquad (17)$$

Thus, for the carrying environment continuous $\alpha_1 \rightarrow 1$

$$\varepsilon_m = \varepsilon_1(1-f_2) + \varepsilon_2 f_2 \alpha_2 = \varepsilon_1 + (\varepsilon_2 - 1) f_2 \alpha_2 \qquad (18)$$

a) For elliptic particles expression of effective dielectric permeability will be written down as:

$$\varepsilon_m = \varepsilon_1 + \frac{1}{3}(\varepsilon_2 + \varepsilon_1) f_2 \sum_{\nu=1}^{3} \left[1 + \left(\frac{\varepsilon_2}{\varepsilon^*} - 1 \right) n_i^{\nu} \right]^{-1}, \qquad (19)$$

Where

$$\alpha_2 = \frac{1}{2} \sum_{\nu=1}^{3} \left[1 + \left(\frac{\varepsilon_2}{\varepsilon^*} - 1 \right) n_2^{\nu} \right]^{-1} \qquad (20)$$

b) For spherical particles expression of effective dielectric permeability will be written down as:

$$\varepsilon_m = \varepsilon_1 + f_2 \frac{3(\varepsilon_2 - \varepsilon^*)}{(\varepsilon_2 + 2\varepsilon^*)}. \qquad (21)$$

Let's consider the biphase environment and we shall define change of effective dielectric permeability for two cases:

- On the biphase environment at which disperse particles are submitted as ellisoids, the polarized electromagnetic wave so falls plainly, that its {her} vector coincides with the big axes ellipsoids;
- On the biphase environment at which, disperse particles are submitted as ellipsoids, the polarized electromagnetic wave so, that the big axis ellipsoid particles orthogonal intensity of a field falls plainly.

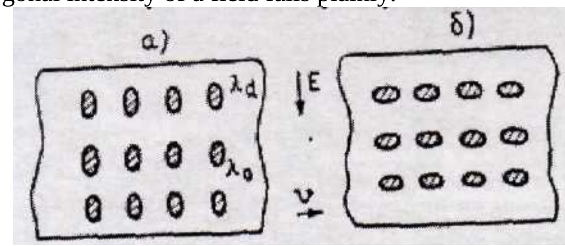


Figure 2. The circuit of the biphase environment

Change of effective dielectric permeability as shown in work [2.8] is defined by the formula:

$$\Delta\varepsilon = \varepsilon_1 \eta \cdot \eta_1 f_2 \frac{1-3n^x}{2+\eta_1+\eta_1(1+\eta_1)n^x-(\eta_1 n^x)^2}, \tag{22}$$

Where $\eta = \dfrac{\varepsilon_2}{\varepsilon_1} - 1$; $\eta_1 = \dfrac{\varepsilon_2}{\varepsilon^*} - 1$; $\eta^x = \dfrac{1-e^2}{2e^3}\left(\ln\dfrac{1+e}{1-e} - 2e\right)$;

$e = \sqrt{1-(b/a)^2}$; b/a – the relation of a smaller axis ellipsoid to the greater (b=c).

In this case the formula (22) is important enough for a large forest since branches submitted as ellipsoids, change the position rather plainly - polarized waves.

At concurrence of the big axis ellipsoid with a vector of intensity of a field effective dielectric permeability in this case is maximal, and at orthogonality - she{it} is minimal, i.e. it is possible to estimate at once change of intensity of an electric field - for vertically polarized waves in woods attenuation more, than for is horizontal polarized because effective dielectric permeability is more in the first case.

2) If the forest represents a statistical mix, i.e. a statistical mix of plants and air where plants are located by casual image, effective complex dielectric permeability will be from expression:

$$\sum_{i=1}^{n}(\varepsilon_m - \varepsilon_i) f_i \alpha_i = 0 \tag{23}$$

2.1) For the two-componental environment this expression will be simplified and will be written down as:

$$\left(|\dot{\varepsilon}_m| - \dot{\varepsilon}_1\right) f_1 |\alpha_1| + \left(|\dot{\varepsilon}_m| - \dot{\varepsilon}_2\right) f_2 |\alpha_2| = 0 \tag{24}$$

Thus if disperse particles ellipsoids are randomly located in space expression (23) is resulted in expression:

$$\sum_{i=1}^{n}(\varepsilon_m - \varepsilon_i) f_i \sum_{\nu=1}^{3}\left[1 + \left(\frac{\varepsilon_i}{\varepsilon^*} - 1\right) n_i^{\nu}\right]^{-1} = 0 \tag{25}$$

If particles as spheres randomly located in space effective dielectric permeability will be from expression (25):

$$\sum_{i=1}^{n}\left(|\varepsilon_m - \varepsilon_i|\right) f_i - \frac{3}{\left(\frac{\varepsilon_i}{\varepsilon_m} + 2\right)} = 0 \tag{26}$$

The given expressions for the two-componental environment will be simplified and will be written down as expressions (27-28): Particles ellipsoids:

$$(\varepsilon_m - \varepsilon_1) f_1 \alpha_1 + (\varepsilon_m - \varepsilon_2) f_2 \alpha_2 = 0 \tag{27}$$

Particles of sphere:

$$(\varepsilon m-\varepsilon_1)f_1\frac{1}{\varepsilon_1+2\varepsilon_m}+\frac{(\varepsilon m-\varepsilon_2)f_2}{(\varepsilon_2+2\varepsilon_m)}=0 \tag{28}$$

3) Is of interest to consider, how effective dielectric permeability of layered structure is defined at falling plane polarized an electromagnetic wave. From expression (9) expression (29) follows if intensity of a field is parallel to a plane of layers (fig. 3):

$$\varepsilon_m=\sum_{i=1}^{n}\varepsilon_i f_i \tag{29}$$

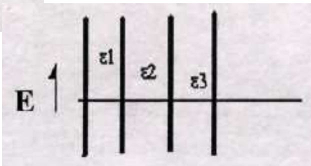


Fig. 3. vector E is parallel to layers.

If a field orthogonal to layers according to the formula (9) and fig. 4, we shall receive dielectric permeability as:

$$\varepsilon_m=\left[\sum_{i=1}^{n}\frac{f_i}{\varepsilon_i}\right]^{-1} \tag{30}$$

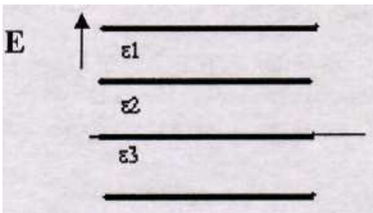


Fig. 4. vector E is perpendicular to layers.

For the two-componental environment these expressions become simpler and enter the name as (31-32)
If vector E is directed along layers,

$$\varepsilon_m = \dot{\varepsilon}_1 f_1 + \dot{\varepsilon}_2 f_2, \tag{31}$$

- If vector E is directed orthogonal to layers,

$$\varepsilon_m = \frac{1}{f_1 / \dot{\varepsilon}_1 + f_2 / \dot{\varepsilon}_2} \tag{32}$$

Thus, the generalized models considered above enable to define effective complex dielectric permeability ε_m both for two, and for multiphase environments, at corresponding approximation from the point of view of structure of the non-uniform environment.

Third chapter

In the third chapter are considered known and the determined models of propagation of radiowaves (PRW) are constructed, allowing to define a zone of the sure reception in which values of a level of a signal get under various conditions of propagation.

Models PRW considered in 3 chapter allow to define a zone in which values of a level of a signal in a point of reception get: 1) In case of *one-beam model* - mobile and base stations are in conditions of direct visibility and a field in a point of reception is defined on the basis of standard expressions - (33) and (34). Capacity of an accepted signal in a point of reception P_r in free space:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}, \text{(dBW)} \rightarrow P_r(dBm) = 10\log(P_r(d) \cdot 1000)) \tag{33}$$

Where P_t - capacity of the transmitter, P_r (d) - capacity on an input of the receiver which is function from distance between the receiver and the transmitter, G_t and G_r - factors of amplification of the transmitting and reception aerial.

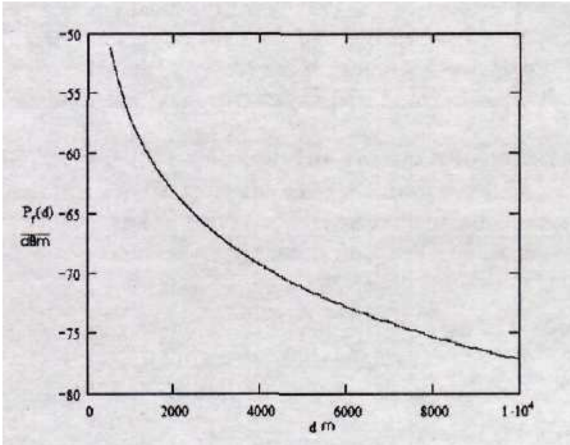


Diagram (1). Losses of capacity of a signal in a point of reception P (d) (dBm) as function from distance d (m)

The intensity of the field created in free space by not directed aerial we shall define from expression (34):

$$E_r(d) = \frac{245\sqrt{P_t G_t}}{d}, \text{(mV/m)} \tag{34}$$

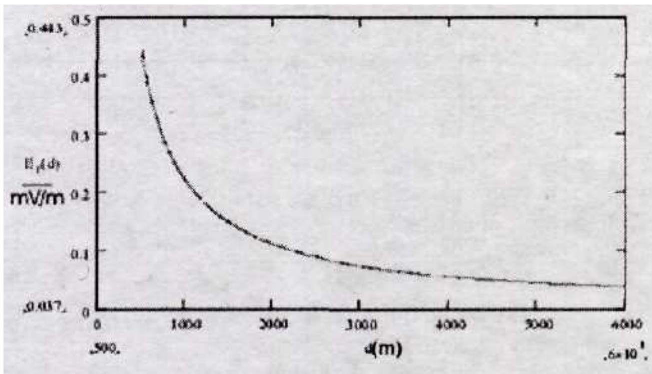


Diagram 2. Dependence of intensity of a field in a point of reception E_r (mV/m) from distance between stations d (m).

2) In case of the account of the radiobeam reflected from the Earth and absence of any obstacles between MS and BTS for calculation of a field in a point of reception use *of two-beam model* is necessary, thus there is an area in vicinity BTS for which the level of a signal and its phase make fluctuations (fig. 7).

Depending on a ratio of distance r and distances of direct visibility r_o=3.57 ([h]]$^{1/2}$ + [h_2]$^{1/2}$), are possible the following formulas for definition of intensity of a field in a point of reception, due to an interference of two beams:

a) Generally peak value of resulting intensity of an electric field will be defined

$$E_m = \frac{245\sqrt{P_{1KBT}G}}{r_{KM}}\sqrt{1 + R^2 + 2R\cos(\phi + \frac{2\pi}{\lambda}\Delta d)} \text{ (mV/m)}$$

under the formula:

(35)

Where R-the module of factor of reflection of electromagnetic waves of the set range from the ground; Φ - a corner of loss of a phase at reflection; Δr - difference of a course of beams: direct 1 and reflected 2 (fig. 5) (Δd=[(AC+CB)-AB]), (P, in kW, r in km., $\lambda\Delta$ and Δd in m).

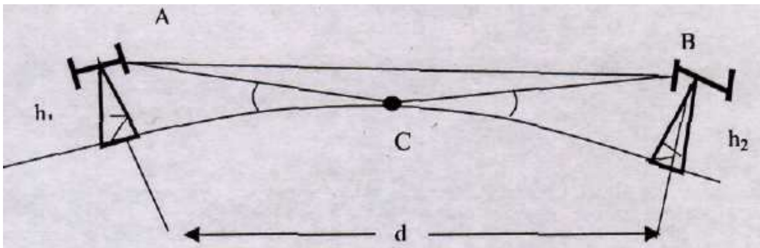


Fig. 5.

Thus, in comparison with one-beam model, peak value of intensity of an electric field depends from multiplier weaking:

$$F(R, \phi, \Delta d) = \sqrt{1 + R^2 + 2R\cos(\phi + \frac{2\pi}{\lambda}\Delta d)}\,, \quad (36)$$

Which in turn depends on the module of factor of reflection R, a corner of loss of a phase Φ at reflection and a difference of a course of beams Δd. For definition R and Φ it is necessary to know a corner of sliding y, a kind of polarization of an

electromagnetic wave and electric constants (dielectric permeability and electroconductivity) a reflecting surface.
The approached expression for Ar is defined under the formula:

$$\Delta d = 2mh_1h_2/d - \qquad (37)$$

Where m-the factor dependent on the relation of height of the reception aerial (or points of reception) above the ground $_h2$ and heights of a raising of the transmitting aerial h, (ath,> h_2), and also parameter

$$q = d/(2R\cdot h_1)^{1/2} \qquad (38)$$

Thus the factor m(h_2/h,, q) is defined from schedules fig. 6.

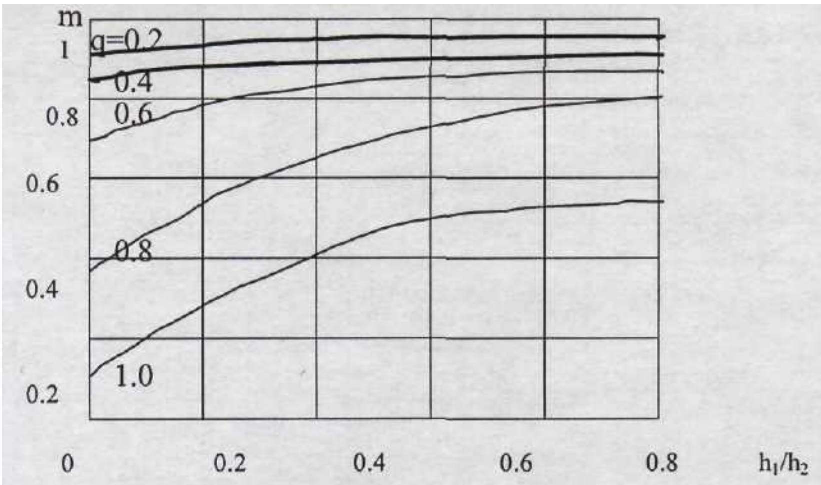


Fig. 6.

Let's consider more in detail the formula (36) which have been written down as:

$$F(R,\ \phi,\ \Delta d)= \sqrt{1+R^2+2R\cos(\phi+\frac{4\pi h_1 h_2}{\lambda d})}\ , \qquad (39)$$

As in distance d the corner of sliding Φ varies depends on distance d, and the multiplier of weaking F (R,Φ, Δd) passes consistently through a line of maxima:

when $\cos(\phi + \frac{4\pi h_1 h_2}{\lambda d}) = +1$ also *a* *line* of minima: when $\cos(\phi + \frac{4\pi h_1 h_2}{\lambda d}) = -1$, thus

Values *F* are equal points of a maximum: *F=1+R*, and in points of a minimum: *F=1-R*.

Thus, size F at F=1+R can be named a multiplier of weaking conditionally, since at R=0,8 F=1.8>1. On rice 7 change F (r) is shown depending on argument cosinus $\phi + \frac{4\pi h_1 h_2}{\lambda d} = \Psi$, thus if $\Psi_{max} = 2\pi$, the first maximum is observed at $d_{1\max} = \frac{4\pi h_1 h_2}{\lambda} \frac{1}{(2\pi - \phi)}$.

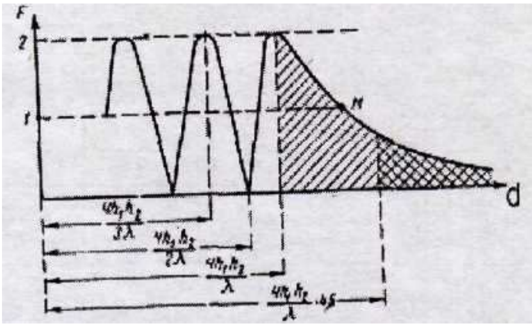


Fig. 7.

At increase d the argument cosinus will change in limits from 2π up to π, and multiplier F will monotonously decrease, in a limit aspiring to zero. Thus, at d< d_{1max} fluctuations of size F in limits F_{max}=l+R up to F_{min}=l-R are observed. We shall define points of maxima and minima multiplier F:

a. Conditions of maxima: $\phi + \frac{4\pi h_1 h_2}{\lambda d_{n\max}} = 2n\pi$, n=1,2,3 … r_k=var,

b. Conditions of minima: $\phi + \dfrac{4\pi h_1 h_2}{\lambda d_{k\,\min}} = (2k-1)\pi$,k=1,2,3 … r_k=var.

Thus, according to expression (39) peak value of resulting intensity of an electric field for two-beam model on distances d < d_{1max} undergoes the changes, named interference maxima and minima, i.e. in some points of space of a condition of reception will correspond {meet} F=l+R, and in others - F=l-R. Intensity of a field in a point of reception under the formula (40):

$$E_r(d) = \frac{173\sqrt{P_t}}{d} \cdot F \text{, (V/m)} \tag{40}$$

, thus in expression for a field appears interference multiplier F, where F - a multiplier of weaking at small corners of sliding

$$F = 2\left|\sin\left(\frac{2\pi h_t h_r}{d_{(m)}\lambda_{(m)}}\right)\right| = 2\left|\sin\left(\frac{0.360 h_t h_r}{d\lambda}\right)\right| \tag{41}$$

Where h, height of the transmitter (m) and h_r - height of the receiver (m). d - distance from the transmitter, up to the receiver, λ.-length of a wave (m). Substituting expression for (41) in expression (40), we shall receive (42) as:

$$E_r(d) := \frac{346\sqrt{P_t}}{d} \cdot \left|\sin\left(\frac{0.360 h_t \cdot h_r}{d \cdot \lambda}\right)\right| \quad \text{(V/m)} \tag{42}$$

The formula (42) characterizes interference structure of an electromagnetic field. At small values of a corner of sliding 6 for the majority of met kinds of a surface of the Earth the factor of reflection R is close to unit, and a corner of loss of a phase 180°.

On a measure of change of distance value of a corner of sliding θ varies.

Capacity of an accepted signal in a point of reception P_r looks like:

$$P_r(d) := 10 \cdot \log\left(\frac{E_r(d)^2}{120\pi} \cdot \frac{G_r \cdot \lambda^2}{4 \cdot \pi} \cdot 1000\right) \quad \text{(dBm)} \tag{43}$$

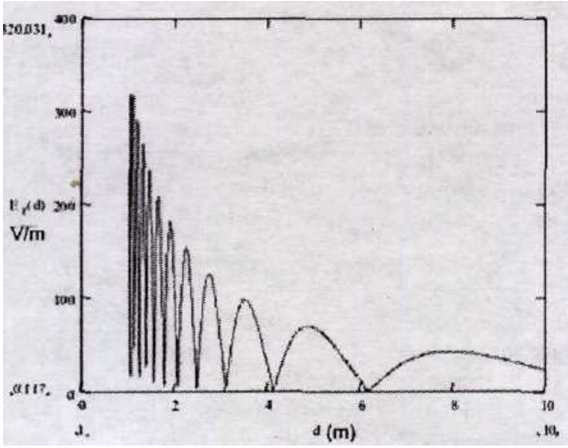


Diagram (3). Dependence of intensity of a field in a point of reception Er (V/m) from distance between stations d (m).

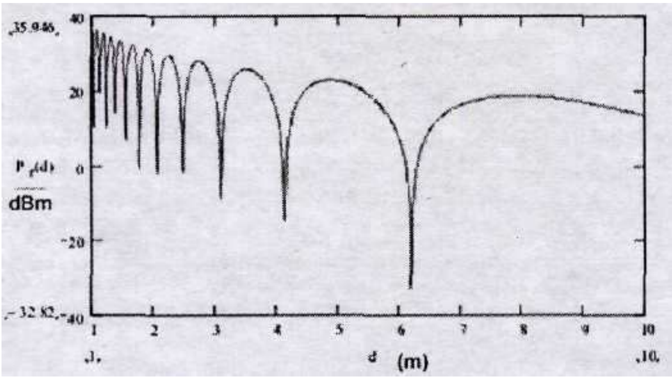


Diagram (4). Losses of capacity of a signal in a point of reception P (d) (dBm) as function from distance d (m) small distances.

At the big distances between the receiver and the transmitter, the corner of sliding becomes minimal, and the multiplier of weaking will monotonously decrease, then the formula for intensity of an electromagnetic field in the location of the reception aerial:

$$E_r(d) := \frac{2\,E_0 \cdot d_0 \cdot 2\,\pi \cdot h_t \cdot h_r}{\lambda \cdot d^2}$$, (V/m) (44)

Where $E_0 := \frac{\sqrt{30 \cdot P_t \cdot G_t}}{d_0}$ intensity of a field in a zone of direct visibility on distance of direct visibility from the transmitter d_0.

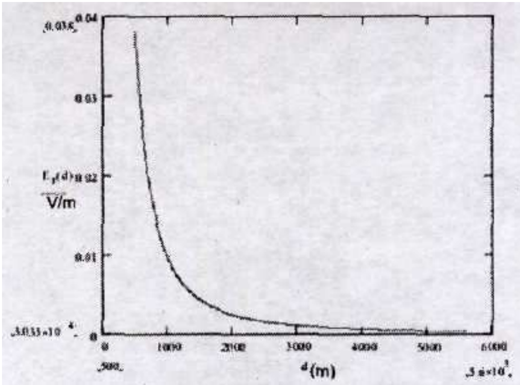
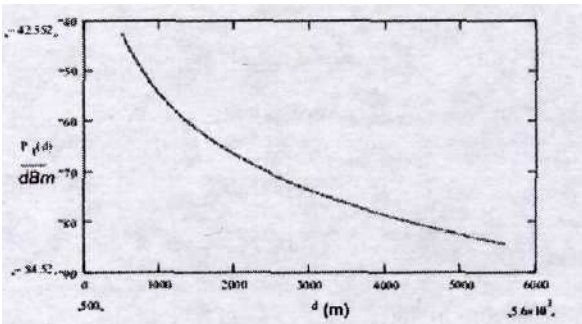


Diagram. (5). Intensity of an electromagnetic field in a point of reception E_r (d) (V/m) from distance d (m) without taking into account multiplier weaking.



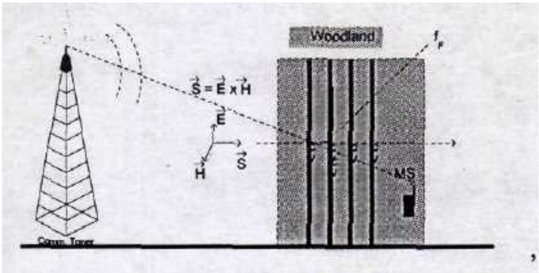
The diagram. (6). Losses of capacity of a signal in a point of reception P (d) (dBm) as function from distance d (m) without taking into account multiplier weaking.

As (42-44) intensity of an electromagnetic field generally follows from expressions is function of some parameters: $E_r=E_r(\lambda,\theta,d,h_r,h_t,P,G)$.

1) In cases when the mobile station gets in a large forest or goes on road between large forests, it is necessary to build mathematical models the using following of approximation:

3.1) If MS is inside a large forest in a UHF-range it is possible to present a forest as two types of non-uniform environments - layered biphase environments (fig. 8) and biphase environments (fig. 9) in which dispersed - trees - represent particles kvazi-spheres located in the correct order (at a condition of small density of a large forest).

Model I



,

Pic.8. Model I Effective complex

dielectric permeability for the given model is defined as:

$$\dot{\varepsilon}_m = \varepsilon_1(1-f_F) + \dot{\varepsilon}_F \cdot f_F, \tag{45}$$

or

$$\frac{\dot{\varepsilon}_m}{\varepsilon_1} = 1 + (\dot{\varepsilon}_F - 1) f_F \tag{46}$$

And size of factor of attenuation:

$$\alpha_{m1} = \omega\sqrt{\varepsilon_0\mu_0}\cdot\sqrt{\varepsilon_1}\cdot\sqrt{A_1^2+B_1^{\,2}}\cdot\sin[\frac{1}{2}arctg(B_1/A_1)], \tag{47}$$

In this case, as it follows from tab. 1, on the basis of these models (model Popov) it is possible to define a zone of change of numerical values running coefficients attenuations for the radiowaves extending through a large forest, so also a level of a field in a point of reception.

Table 1.

f, MHz	Theory ($-\alpha_m$), dB/m		Experiments		Standards	
	Model I F.(3.3)	***Model II*** F.(3.5)	$-\alpha_m$, dB/m	[ ]	($-\alpha_m$, dB/m	[ ]
10	0.0018	0.00378				
82	0.01435	0.03	0.0525	[10]		
100	0.018	0.0378	α_v=0.06 α_k=0.03	[9]	0.093	[5]
200	0.036	0.0756				
210	0.0378	0.079	0.0785	[2]		
300	0.0545	0.1145	0.1	[10]		
450	0.081	0.17				
500	0.09	0.189				
540	0.0972	0.204	α_v=0.2 α_k=0.18	[9]	0.25	[5]
900	0.162	0.34				
1000	0.18	0.378				
1200	0.216	0.4536	α_v=α_k=0.35	[9]		
1800	0.324	0.68				
1900	0.342	0.718				
2000	0.36	0.756				
3000	0.54	1.134				
3200	0.576	1.21	α_v=α_k=0.5	[8]		
5000	0.9	1.89				
9600	1.728	3.63				
10000	1.8	3.78				
15000	2.7	5.67				
30000	5.4	11.34				

3.2) If MS is behind a large forest or in area of the mixed line for UHF - a range it is possible to use model of diffraction of electromagnetic waves on a wedge (fig.

10 and 11) and accordingly to define a level of a field in a point of reception on analytical expressions offered in 3 chapter (52, 53) and item 3.6.

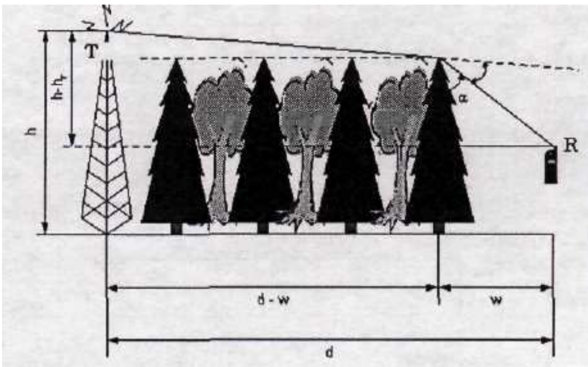


Fig. 10. Geometry of diffraction on a wedge.

Intensity of field $E_r(d)$ in a point of reception for a case of diffraction:

$$E_r(d) := .225 \frac{\sqrt{30 \cdot P_t \cdot G_t}}{d} \cdot \frac{1}{v(d)} \quad . \text{ (V/m)} \qquad (52)$$

Where,

$$v(d) := \left(\frac{\pi}{2} - \alpha(d)\right) \cdot \sqrt{\frac{2 \cdot [w \cdot (d - w)]}{\lambda \cdot (w + d - w)}}$$

parameter of diffraction Frenel

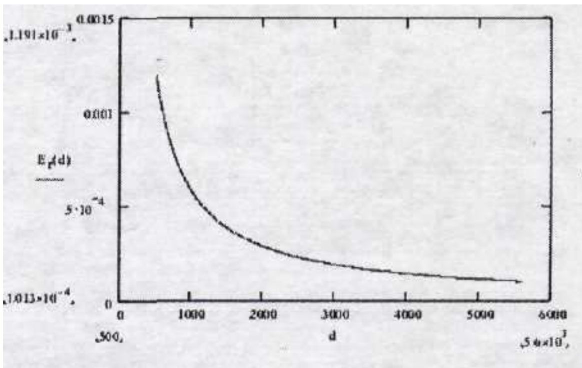


Diagram. 7. Dependence of intensity of electromagnetic field $_{Er}$ *(d)* (V/m) from distance d (m).

Power P_r (d) on an input of the reception device for a case of diffraction:

$$P_r(d) := 10\log\left(\frac{E_r(d)^2}{120\pi}\cdot\frac{G_r\cdot\lambda^2}{4\cdot\pi}\cdot 1000\right)$$

(53)

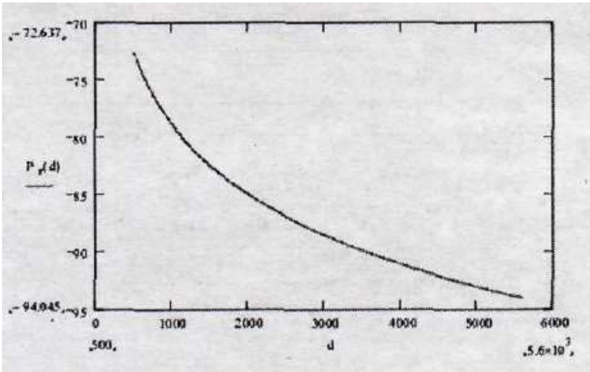
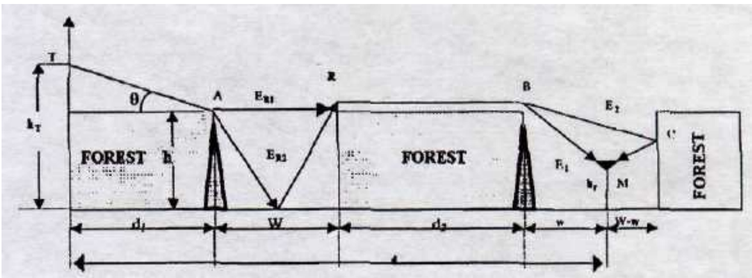


Diagram. 8. Losses of capacity of a signal in a point of reception P (d) (dBm) as function from distance d (m).



A Fig. 11. A kind of a forest with a side.

Intensity of field $_{Emobiie}$ (d) in a point of reception for a case of diffraction:

$$E_{mobile} = 0.225 \cdot \frac{\sqrt{30 \cdot P_T \cdot G_T}}{d} \cdot \frac{(d_2 + w)}{(d_1 + W)} \cdot \sqrt{5 + \left(\frac{R_{ROAD}}{v_R}\right)^2} \cdot \sqrt{\frac{\left(\frac{1}{v_{BM}}\right)^2 + \left(\frac{R_{FOREST}}{v_{BCM}}\right)^2}{\left(\frac{1}{v'_{BM}}\right)^2 + \left(\frac{R_{FOREST}}{v'_{BCM}}\right)^2}} \quad (54)$$

, (V/m)

Where $P_T G_T$ - effective power of radiation of base station, $_{FOREST}$ factor of reflection frenel from a forest and

$$v_{BM} = \sqrt{2}(h - h_r) \cdot \sqrt{\frac{d \cdot \cos^2\alpha}{\lambda(d\cos\alpha - w)w}} \quad (55)$$

$$v_{BCM} = \sqrt{2}(h - h_r) \cdot \sqrt{\frac{d \cdot \cos^2\alpha}{\lambda(d\cos\alpha - 2W + w)(2W - w)}} \quad (56)$$

$$v'_{BM} = \sqrt{2}(h - h_r) \cdot \sqrt{\frac{(d_2 + w) \cdot \cos^2\alpha}{\lambda[(d_2 + w)\cos\alpha - w]w}} \quad (57)$$

$$v'_{BCM} = \sqrt{2}(h - h_r) \cdot \sqrt{\frac{(d_2 + w) \cdot \cos^2\alpha}{\lambda[(d_2 + w)\cos\alpha - 2W + w](2W - w)}} \quad (58)$$

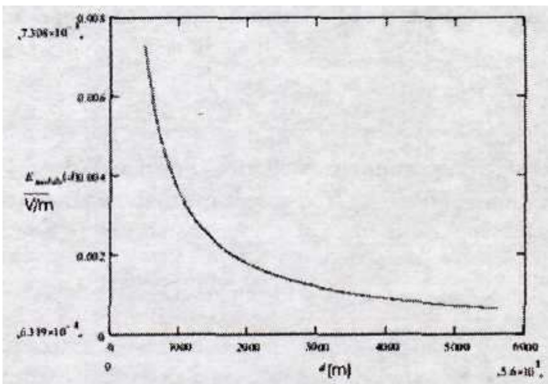


Diagram 9. Change of intensity of an electromagnetic field in a point of reception Emobiie (V/m) with distance d (m).

For calculation of losses of capacity of a signal with distance in a point of reception we use the formula:

$$P_R(d) := \frac{E_{mobile}(d)^2}{120\pi} \cdot \frac{G_r \cdot \lambda^2}{4 \cdot \pi}$$ (59)

$$P(d) := 10 \cdot log\left(P_R(d) \cdot 1000\right)$$ (dBm) (60)

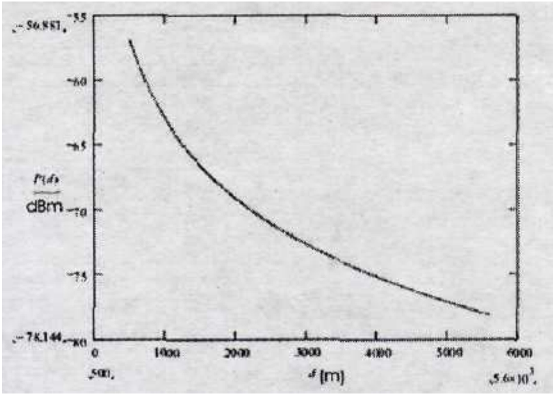


Diagram 10. Losses of capacity of a signal in a point of reception P (d) (dBm) as function from distance d (m).

The fourth chapter

Known models of multibeam distribution of radiowaves which are used basically at the limited quantity of absent-minded beams cannot be used at construction of mathematical models of propagation of radiowaves in a forest.

Therefore in the fourth chapter on the basis of the approached models Tver and Rytov mathematical models of propagation of radiowaves in large forests which have allowed to define coherent and not coherent components in a point of reception have been constructed.

The forest in these models was represented:

- In approximation Tver the forest is described as the non-uniform environment with a casual arrangement of trees on which repeatedly the electromagnetic wave and a field in a point of reception dissipates is defined{determined} as superposition of all absent-minded fields.

Approximation Tver - theories of repeated dispersion allows to take into account attenuation of an electromagnetic wave because of dispersion and absorption on a way of its propagation to the environment consisting of a plenty discrete scatterers. Thus, the description of the mechanism of propagation of an electromagnetic wave inside a large forest on the basis of the statistical theory of repeated dispersion of waves is extremely interesting with theoretical and practical points of view.

Using the theory Tversky we can estimate values of an average field, coherent intensity, running weaking, effective dielectric permeability of the forest environment in view of parameters of a forest: density of trees, distributions of the sizes and values of complex dielectric permeability of a tree.

The intensity of a field created in a point of reception $r_a(x_a, 0,0)$, according to the theory of repeated dispersion of waves on trees, in approximation Tver we shall write down as the sum:

$$E(\mathbf{r}_a) = \varphi^a + \sum_{s=1}^{N} \varphi^s \psi_s^a + \sum_{s=1}^{N} \sum_{m=1, m\neq s}^{N} \varphi^m \psi_s^m \psi_s^a + \sum_{s=1}^{N} \sum_{m=1, m\neq s}^{N} \sum_{t=1, t\neq m,s}^{N} \varphi^t \psi_t^m \psi_m^s \psi_s^a + \ldots \quad (61)$$

Thus the first composed represents a direct wave, and other composed are components of an absent-minded field of the certain frequency rate - unitary, double dispersion, etc. This line is written down for a case when in a large forest is N trees and all possible processes of dispersion are taken into account, except for the waves which are taking place one scaterrer more than once. Indexes of summation specify on concrete scaterrer, for example, s - sacterrer, found in a point r_s; φ - the falling wave, the top index specifies a point of supervision, for example, φ^s - a falling wave in a point r_s; ψ- a field, absent-minded an element of forest vegetation, for example, ψ^a_s - a field created in a point r_a sacterrer from r_s.

As trees settle down in a large forest area S in the casual image, we shall define probability of that a site (dS it is occupied with a tree as:

$$P(dS) = \frac{dS}{S}.$$

Let's count occurrence of trees on a line of propagation of a wave a stream of rare events with constant average density v.

It means, that the probability of occurrence on a site dS two trees is small on an alignment with probability of occurrence of one, and also that the probability of occurrence of a tree on any site dS does not depend on what number of trees has got on others, not crossed with given the sites. The probability of that all in large forest N of trees is defined by law Poisson

$$P(N) = \frac{(\nu S)^N}{N!}\exp(-\upsilon S). \quad (62)$$

Expression (63) describes average intensity of a field inside large forest E (r_a)

$$< E(\mathbf{r}_a) >= e^{ikx_a} \sum_{N=0}^{\infty} \left\{ \frac{\nu S^N}{N!} \exp(-\nu S) \left(1 + \sqrt{\frac{2\pi i}{k}} \frac{< f > x_a}{S} \right)^N \right\} \quad (63)$$

where, <*f*> - average value of amplitude of dispersion in a direction "forward" not dependent on coordinates x scaterrers; k - the big positive parameter (for a range 900-1800MHz k $\geq \pi$)

The model Tversky allows to estimate conditions of dispersion of electromagnetic waves on elements of the non-uniform environment located in the casual image.

The decision Tversky allows to define coherent and not coherent components of an electromagnetic field in a point of reception, thus for plane polarizedan electromagnetic wave from the point of view of real reception of a signal, the knowledge of a coherent component is necessary. However the model Tver is difficult for using because of complexity of their mathematical description of a level of a coherent field in a point of reception.

At small volumetric concentration of elements of a forest probably use of

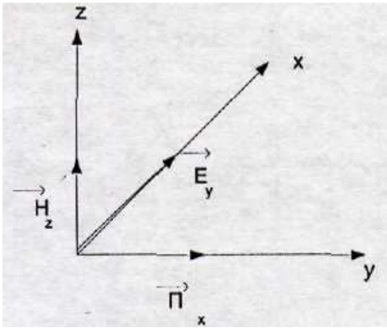
approximation Rytov in which effective dielectric permeability ε_m the non-uniform environment is function from spatial coordinates under condition of a

constancy in time $\varepsilon(r)|$ t= const, thus the forest is submitted as linear statistically non-uniform environment, effective complex which dielectric permeability had median value and indignations of the first order for the account of casually located trees.

Let effective dielectric permeability of environment will be expressed as ε_m = <ε_m> + ε (r,t), where <ε_m> - average value, ε(r,t) - fultuating a part (at an assumption, that non-uniform диамагнитна μ_r=1 environment), i.e. dielectric permeability is stochastic function of coordinates and time. The factor of refraction of environment will be written down as n = <n> + n_1(r,t). Thus, in the casual environment relative dielectric permeability ε_r and a parameter of refraction n vary from a point to a point and these changes cannot be predicted; moreover, even if they also were known, it is practically impossible to describe their values in all points of space during the any moment of time. Therefore parameters of environment are necessary for describing statistically and to search for statistical regularities of change of components of an electromagnetic wave in such environment.
Therefore it is necessary to set dielectric permeability as stochastic function of a radius - vector **r** and time t:

$$\varepsilon_r\,(\mathbf{r},t) = n^2(\mathbf{r},t)$$

Thus, for simplification of a problem it is allowable, that the electromagnetic wave is flat and is distributed along coordinate x.



Picture. 12. A direction of an electromagnetic wave

Ritov's approximation
Propagation of an electric field in space E_z (r) can be written down as E_2 (r) =e $^{\psi(r)}$ and to search for the decision for ψ (r) in the equation (64) as lines.

$$\left|\nabla^2 E_z(r) + k^2{}_m(1+2\delta n)\right| E_z(\mathbf{r}) = 0 \tag{64}$$

Let's find the approached decision of the equation for small values n:

$$\left|\nabla^2\psi + (\nabla\psi)^2 + k_m{}^2(1+2\delta n)\right| = 0 \tag{65}$$

This equation is the nonlinear differential equation of the first order be relative $\nabla\psi$
and refers to as equation Rikkatti.

In absence of fluctuations ($\delta n = 0$) we have

$$\left|\nabla^2\psi_0 + (\nabla\psi_0)^2 + k_m{}^2\right| = 0 \tag{66}$$

Let's solve the equation (66)

If $\psi=\psi(x)$, i.e. is function of one variable the equation (65) and (66) are the ordinary differential equations.

$$\frac{d^2\psi}{dx^2} + \left(\frac{d\psi}{dx}\right)^2 \psi' = \xi(y)\cdot 2\delta n) = 0\,,$$

$k_m{}^2(1+2\delta n)$=a^2 (a=const)

$$\psi'' + (\psi')^2 + a^2 = 0$$

Let's present a member $\psi=\zeta(y)$ then we have

$$\xi' + \xi^2 + a^2 = 0 \tag{67}$$

This equation is the equation with divided variables.

$$\frac{d\xi}{dy} = -\left(\xi^2 + a^2\right)$$

$$\frac{d\xi}{\xi^2 + a^2} = -dy$$

Integrating $\int\frac{d\xi}{\xi^2+a^2} = -\int dy$, we shall receive $\frac{1}{a}\,arctg\frac{\xi}{a} = -y + c_1$, (c1=const)

$$arctg\frac{\xi}{a} = a(c_1 - y)$$

$$\frac{\xi}{a} = tga(c_1 - y)$$
$$\xi = atga(c_1 - y)$$

Coming back to an old variable, we shall receive:

$$\psi' = atga(c_1 - y) \tag{68}$$

This alignment also is the equation divided variables

$$\frac{d\psi}{dy} = atga(c_1 - y)$$
$$d\psi = atga(c_1 - y)dy$$

Integrating $\int d\psi = \int atga(c_1 - y)dy$, we shall receive:

$$\psi = a\int \frac{\sin a(c_1 - y)}{\cos a(c_1 - y)}dy = \int \frac{d\cos a(c_1 - y)}{\cos a(c_1 - y)} = \ln\left|\cos a(c_1 - y)\right| + c_2,$$

(C2=const),
Thus:

$$\psi = \ln\left|\cos a(c_1 - y)\right| + c_2$$
$$\psi = \ln\left|\cos\left(k_m\sqrt{1 + 2\delta n}(c_1 - y)\right)\right| + c_2 \tag{69}$$

Similarly the equation (65.) is solved thus its decision looks like:

$$\psi_0 = \ln\left|\cos\left(k_m(c_1 - y)\right)\right| + c_2 \tag{70}$$

I.e. $E_0(r)=e^{\psi_0(r)}$ - a field in absence of fluctuations and $E(r) = e^{\psi(r)}$ - a field which is taking into account fluctuations of effective factor of refraction of environment. Approximation Rytov allows to estimate a coherent component of the radio signal extending in large forests at their small density when fluctuations of effective value of a parameter of refraction are sizes of the first order smallness, and the large forest is non-uniform weakly dispersive environment with statistically located imperfections (trees).

The fifth chapter

In the fifth chapter experimental researches, experiments results are described and the comparative analysis with experiments results of other authors.

Experimental researches of radiowaves propagation in large forests are extremely complex and expensive for the following reasons:

The forest from the electrodynamics point of view of is generally the random - non-uniform multiphase environment which electrodynamic parameters in the random image vary depending on a structure and a kind of a forest, seasonal, climatic and weather conditions and so forth;

The level of a radio signal in a point of reception depends not only on working frequency, a kind of polarization and heights of a raising of MS and BTS antennas, but also in the random image depends on influence of trees, their arrangement, a spreading surface of a forest and so forth;

For measurement of levels of a radio signal the expensive equipment -such as the high-sensitivity spectrometers is required, allowing to define on the chosen working frequency, not only a level of an accepted signal (concerning sensitivity of receiver MS), but also its polarization, a power spectrum and ratio S/N.;

Complexity of experiments on RWP in a forest will be, that the level of a signal at measurements constantly varies, fluctuating relatively median value which also is subject of slow fading, thus position BTS, height of a raising of its antenna, average working frequency and a kind of EMW polarization are usually fixed and position MS in space relatively BTS varies only.

In 3rd chapter it is already have been considered different results of experimental researches RWP in forests which basically are limited to definition of effective running attenuation coefficients on corresponding working frequencies, at corresponding kinds of polarization and for corresponding types of forests at through RWP.

However for systems of cellular mobile communication on average frequency of 900 MHz at through sounding a forest such experiments in the literature are not described.

Basically experiments were limited RWP in cities of various density of building in which microcellular networks of mobile communication have been created. Therefore below results of experiments on RWP in forests for standard GSM will be considered.

1. Experimental researches RWP on chosen line Malpils-Garkalne.

By present time practically are absent presentation results of experimental researches of through radiowaves propagation of a decimeter range in large forests. At the same time at designing cellular systems of mobile communication the precise knowledge of effective radiowaves attenuation factors in a forest in a range from 900 up to 2000 MHz is necessary, that finally it is necessary for a choice of the required macrocells radius at the requirement of a uniform radio covering of the chosen territory.

Therefore experimental researches of electric field intensity dependences and density of a capacity stream in a point of reception from distance up to chosen BTS have been carried out at through radiowaves propagation (RWP) in a forest. In the given chapter results of electric field intensity measurements and density of a capacity stream are submitted on frequency of 900 MHz who were carried out in a large forest in the summer and in the autumn when trees have been covered with foliage. *Experiment 1. Measurements RWP by the spectrum analyzer a such as* FSP30 (3 kHz-30 GHz),

Registration of electromagnetic field intensity an in a point of reception was carried out at reception of signals on horn antenna with factor of amplification on frequency 1GHz equal G=7dB. The height of the reception antenna concerning the ground was equaled approximately h_2 ~ 1,5 meters. The antenna of the transmitter was on tower BTS in height h,=100 m. located in *settlement Podkajas (Podkajs) and radiated vertically polarized electromagnetic wave.* Capacity of the transmitter made P ~ 50 W. Measurements have been executed on strictly fixed distances from BTS:

R - 1km; 2км; 3 km; 5Km; 10Km - along *highway Malpils-Garkalne* (fig. 13).

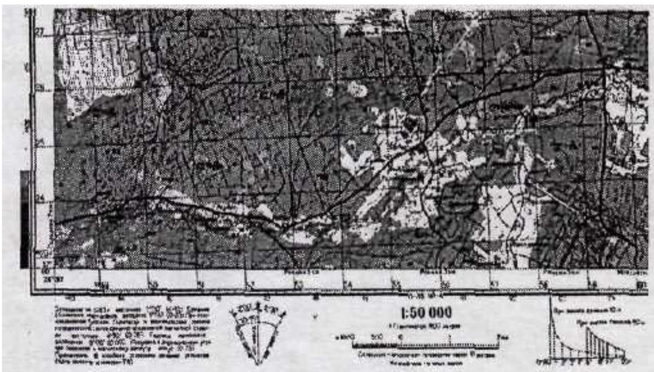


Fig. 13. map of district

For the analysis of a spectrum in a controllable range of frequencies and zones of the sure reception of signals the high-frequency analyzer of a spectrum such as FSP30 was used (working which range of frequencies makes - 3 kHz-30 GHz), allowing automatically to make measurements of a level of a signal in a range from 10 up to 6000 MHz. The circuit of measurements is resulted in figure 14.

On the monitor of the analyzer of a spectrum the spectrum of an accepted signal in
a strip of frequencies equal 200 MHz is displayed.

Results of experiments

As an example on fig. 15 the spectrogram of a level of capacity of an accepted
signal on working frequency of 939,6 MHz is shown.

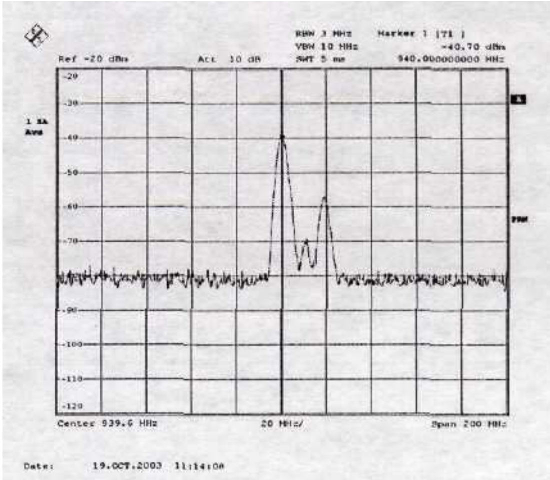


Fig. 15. The spectrogram of a signal in a point of reception.

The marker provides moving on spectral characteristics with simultaneous display of values of parameters of frequency and capacity of a signal. Results of measurements of a level of capacity of an accepted radio signal are displayed on the spectrogram in *dBm* as function from frequency MHz. As follows from fig. 15. on frequencies f_1=939.6, f_2=949.6, f_3=959,6 three maxima-40.7dBm,-70dBm,-57dBm corresponding to three sectors of one cell BTS are observed. *The principle of measurements* is standard and consists in consecutive reorganization of the analyzer of a spectrum on the set frequency and measurements of a level of a signal on the given frequency.

However accuracy marker measurements ±3 dBm, during too time she{it} is sufficient for operational measurements, as has caused wide application of analyzers of a spectrum at operation of radio-frequency systems of transfer. Records of spectrograms from the analyzer of a spectrum have been transferred on the paper carrier that has allowed to draw the diagram fig. 16.

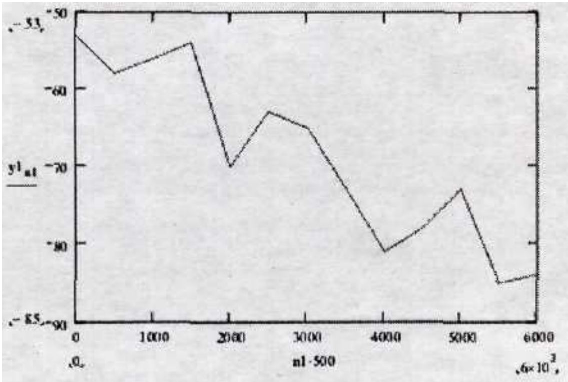


Fig. 16.

For recalculation of a level of an accepted signal of the spectrum measured by the analyzer (dBV) in capacity of a signal in a point of reception (dBm) (under condition of the coordination of an output of the reception antenna with an input of the receiver) the expression 71 was used.

$$P_r(d) = \frac{V^2}{4R} \quad \textbf{(71)}$$

$$P_r(d)dBm = 10\log\left[\frac{V^2}{4R_{ant}}\right] \quad \textbf{(72)}$$

Pr-capacity of a signal in a point of reception
Rant=50 Resistance of the reception antenna
V-working value of a voltage on an input of the receiver (a level of a signal).
The analysis of results of experiments:
On the basis of the carried out analysis it is possible to count, that at propagation of waves of a decimeter range to a forest on a cross-country terrain, various mechanisms of radiowaves propagation work.
For small distances from BTS (up to 2 kms) the field in a point of supervision is defined by a wave extending in free space.
On distance of 2 kms the field in a point of reception sharply falls on-12 dBm concerning a level of a field in free space (-75dBm) since on a way of propagation there is a large forest which weakens a direct wave and the field in a point of reception gets in area of values limited to curves for the mixed line (-69,159dBm) and diffractions on a wedge (-85,029-dBm).

On distance from 3-5 km the mechanism of repeated dispersion of waves on trees works and the mechanism of weaking is similar to weaking of a spatial wave. On distance 5 km the level of a field has made (-64 dBm), it speaks that the receiver was in a zone of direct visibility and in a field in a point of reception developed of a direct wave and a wave reflected from an edge of a forest.

Experiment 2.

Measurements with use of mobile station

Experiment 2 was carried out along the same site of highway, with the help of the specialized system of the analysis of a zone of the sure reception of signals of base stations of networks of mobile communication

Into the equipment of measurements entered four modules (fig. 17):

1) Mobile *phones Nokia 5110* having the program *service terminal, prograduated in terms of density of a stream of capacity (PD $\mu W/cm^2$).*

2) PC,

3) The external antenna - the vibrator,

4) A digital multimeter,

Besides it was used GPS the receiver connected to PC.

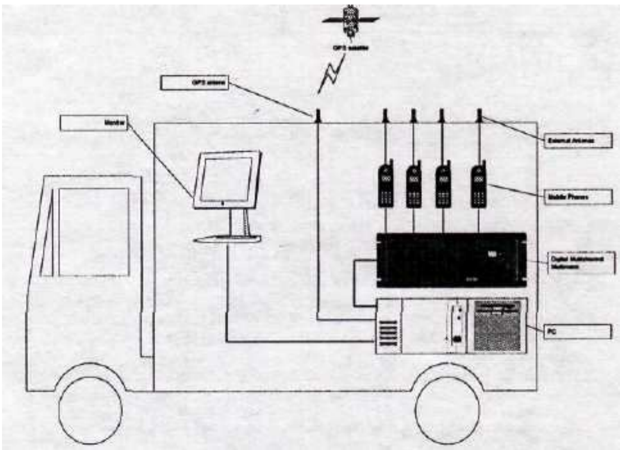


Fig. 17.

Measurement technique

1) The cover zone which included territory at the first experiment, was graphically displayed on a map districts (fig. 18)

2) The radio signal from BTS was measured on frequency of channel BCCH *{broadcast control channel).*

3) Values of a level of an accepted signal and coordinates of points of measurement entered the name as a special file (fig. 19),
4) The level of an accepted signal was measured in each point of a line adhered to graphic coordinates.
5) Scanning receivers (mobile phones) in structure of model of measurement, allowed to measure values of levels of accepted signals for each point of a line.
6) According to a file in which values of levels of accepted signals and coordinates on district have been written down, the diagram of dependence of capacity of an accepted signal from coordinate on a line of the measurements, shown on fig. 20. (it is necessary to note, that measurements were carried out along a line identical to the first experiment) has been constructed.

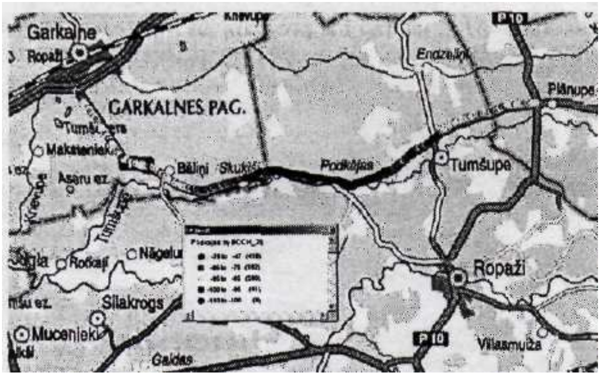


Fig. 18. (a) the Level of a signal from base station Podkaja

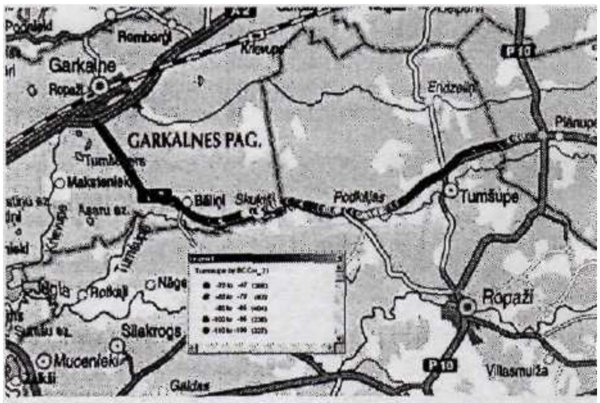


Fig. 18. (b) the Level of a signal from base station Tumshupe

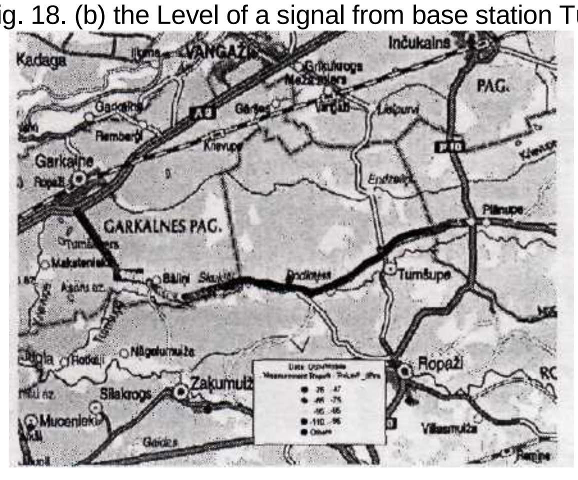


Fig. 18. (c) the Summary diagram of the measured level from three base stations

Device	GPS			Mob. 1 scan mode
Time	longitude	latitude	altitude	RxLev BCCH 25
10:34:58	24,41692	57,03746	14	-96
10:34:59	24,41706	57,03731	13,6	-96
10:35:00	24,41721	57,03715	13,1	-93
10:35:01	24,41729	57,03706	12,9	-98
10:35:02	24,41743	57,03692	12,75	-89
10:35:03	24,41763	57,03671	12,47	-96
10:35:04	24,41772	57,03662	12,1	-90
10:35:06	24,41805	57,03631	11,7	-92
10:35:07	24,41826	57,03611	11,47	-96
10:35:08	24,41836	57,03602	11,2	-88
10:35:10	24,41876	57,03566	11,1	-92
10:35:11	24,41894	57,0355	11	-96
10:35:12	24,41905	57,0354	11	-101
.....	.....	......	....	.,......
10:35:14	24,41938	57,03511	10,9	-103
10:35:15	24,4196	57,03494	10,85	-95

Fig. 19. An example of a file with coordinates of measured points and levels of a signal

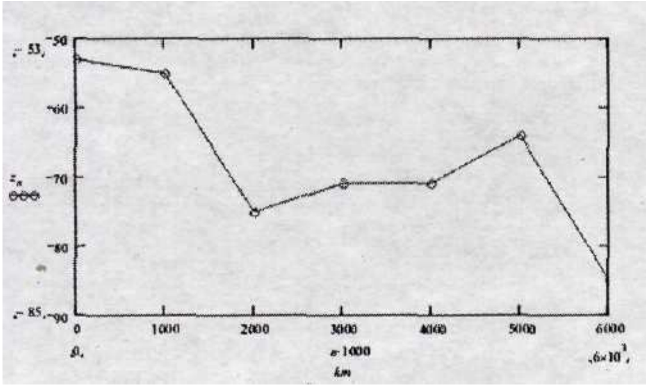


Fig. 20. A curve of dependence of capacity of signal P (r) (dBm) from distance r.

The analysis of experiments

Apparently from figures 16 and 20, levels of intensity of a field in identical points of the measured line are various, it speaks distinction of techniques of measurement of a level of a field.

In the first experiment the level of a field was measured in a concrete point of a line, at the stationary reception antenna, and in the second experiment a line of radiowaves propagation is not permanent, that is connected to moving mobile station along a line.

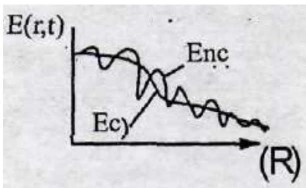


Fig. 21.

Where, Ec-median value (a coherent field); Enc - (fluctuations of a level of a signal) not coherent field. As a result of repeated reflection of radiowaves from sites of a forest at work of transmitter BTS in a mode of continuous radiation the picture resulting to fading accepted signal is created complex interference. The example such fading, connected with movement of the receiver is resulted on fig. 21.

Multibeam propagation results to that in a point of reception signals with various time delays are observed. Being imposed by one on another, they can result in appreciable distortion of a signal. This phenomenon refers to as time dispersion of a signal.

On fig. 22 characteristic dependences of amplitude of an accepted signal are resulted at presence random fading.

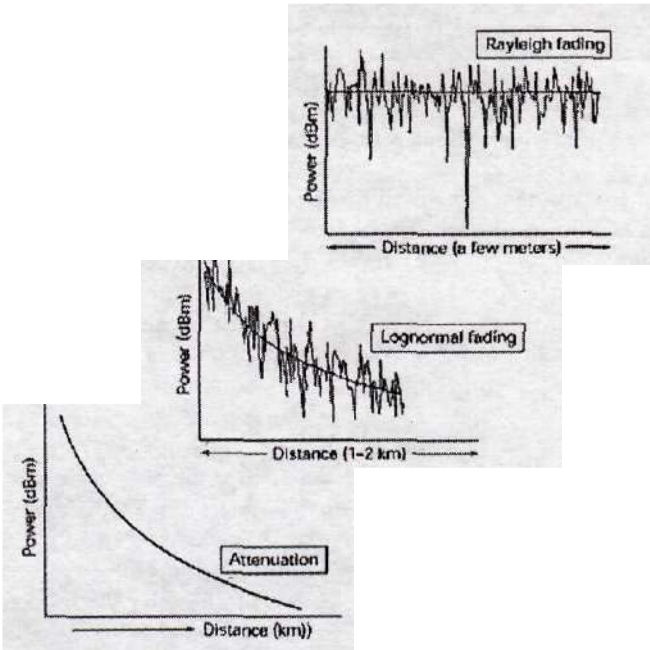


Fig. 22.

Measurements show, that losses of capacity are a random variable having логарифмически normal propagation in a vicinity of average value.

Conclusions

The received results allow to define median values of capacity of a signal (-51 dBm - -88 dBm) by averaging levels of accepted signals depending on discret distances (Таб.2.).

Table 2.

Distance between BTS and MS R (km)	Power of received signal Pr (dBm) Experiment №1	Power of transmitted signal Pr (dBm) Experiment №2
R =0,5	-53	-53
R=1	-55	-56
R=2	-70	-75
R=3	-65	-71
R=4	-81	-71
R=5	-73	-64
R=6	-84	-85

The approached estimations of character of radiowaves propagation in woody district are received.
However, these data cannot be used for the description of fluctuations of a level of an accepted radio signal be relative median values.
For reception of propagation of levels of a signal depending on the specified parameters the further experimental researches are required.
For calculation of intensity of electric field E in each concrete case it is necessary to construct a structure of a line and depending on character of this structure to enter calculation by that or other method.

Conclusions

Let's generalize experimental data of the limited number of works considered above enough on radiowaves propagation to large forests:
1) Results of measurements have shown, that influence of a forest on radiowaves propagation with frequencies up to 30 MHz insignificantly.
2) For frequencies in a range from 50 MHz up to 60 GHz the following facts are established:
2.1) Power characteristics UHF of the radiowaves extending in large forests, are connected to biometric parameters of forest vegetation.
Effects of dispersion on elements of vegetation and the more strongly, than above frequency are observed. Presence deep spatial fading is marked complex interference character of an electromagnetic field in the forest environment. Therefore for the analysis of the basic laws of propagation UHF of radiowaves in the forest environment it is necessary to consider the average power characteristics. The forest environment is considerably radio absorbent environment, and values of effective running factor of attenuation grow with increase in frequency. At propagation of a direct wave through the forest environment dependence of a level

of an electromagnetic field on range has exponential character, thus the degree exponential dependences of a level of an electromagnetic field at increase in distance changes. At some value of range the degree of attenuation decreases. The above frequency, this distance is less. For an explanation of the given fact put forward two assumptions: The first - occurrence of essential influence of the lateral wave, the second - effects of repeated dispersion on elements of vegetation. Seasonal variations of a level of a field are observed. *In the winter weaking of radiowaves is lower, than in the summer.* Two possible reasons of this phenomenon are put forward: 1) influence of leaves on absorption even on low frequencies of a considered {an examined} range; 2) change of electric properties of branches and trunks of trees depending on a level of their humidity (raises in the spring and it is reduced in the autumn). In the field of low frequencies of a considered range (up to 400 MHz) various weaking radio signals for different kinds polarizations is observed. At vertical polarization of radiowaves - attenuation is higher, than at horizontal.

It is supposed, that such behavior of a field on low frequencies is connected to vertical orientation of trunks of trees and their primary influence on process of radiowaves propagation. With increase in frequency the role of branches, and then and leaves which are focused chaotically raises. Values effective running coefficient on various frequencies have made attenuations:

In a range from 100 up to 500 MHz *a~(0,053-0,174)dB/m*

In a range from 500 up to 1200 MHz *-a~(0,2-0,35) dB/m*

In a range from 1200 up to 3200 MHz *-a~(0,35-0,5)dB/m*

The conclusion

The comparative analysis theoretical and experimental researches of propagation UHF of electromagnetic waves in large forests

For an estimation of adequacy of the received theoretical and experimental results on propagation UHF of electromagnetic waves to large forests it is necessary to lead{carry out} their comparative analysis and as to use the experimental results received by other authors.

1. The comparative analysis of experimental results and the models developed in work.

On diagram. 11 numerical values median the normalized levels of capacity of radio signals *P (d)* in locations MS as functions from distance between MS and BTS - *d* for working frequency of 900 MHz provided that electromagnetic waves emitted- are vertically polarized by antenna BTS are submitted.

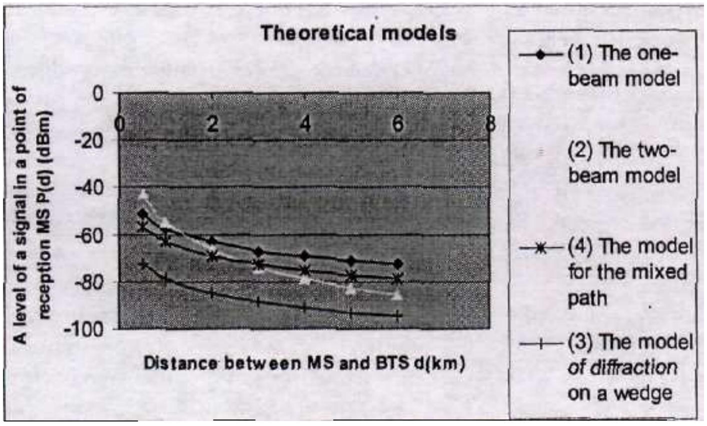
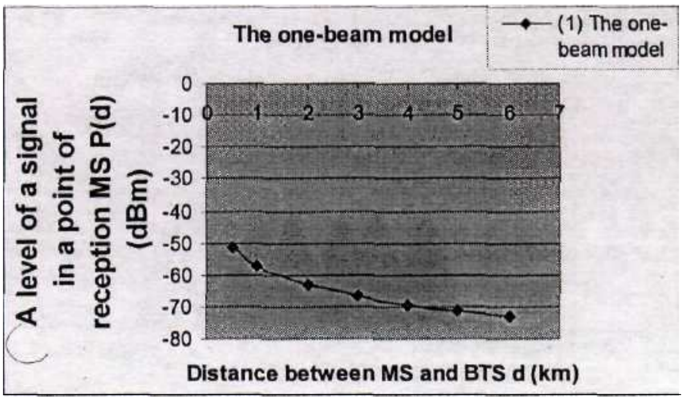


diagram 11. Dependences of changes of numerical values of the normalized levels of an accepted signal on average frequency of 900 MHz received on a basis theoretically of models.

a) The one-beam model submitted by a curve (1), gives the following numerical values (chapter 3.2) of function *P (d):*

Table 3

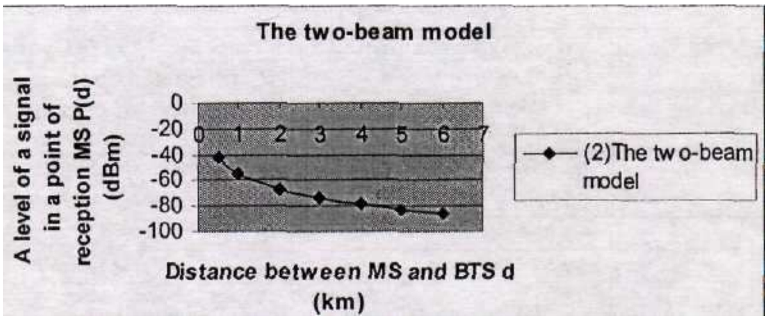
Distance between MS and BTS *d* (km)	A level of a signal in a point of reception MS *P (d)* (dBm)
0.5	-51.225
1	-57.246
2	-63.266
3	-66.788
4	-69.287
5	-71.225
6	-72.809



b) The two-beam model submitted by a curve (2), gives the following numerical values (chapter 3.3) of function *P (d):*

Table 4

Distance between MS and BTS *d* (km)	A level of a signal in a point of reception MS *P (d)* (dBm)
0.5	-42.552
1	-54.539
2	-66.634
3	-73.678
4	-78.675
5	-82.552
6	-85.719



At falling radiowaves on a large forest (fig. 23) when the marge of a forest is located on distance from base send-receive station on 1 km, values of a level of capacity in a point of reception pay off under the formula:

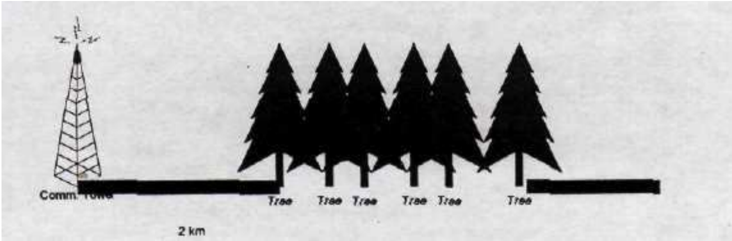


Fig. 23.

$$P(d) = P_0(d) + (-\alpha \cdot \Delta d), \tag{73}$$

Where P_o (d) - a level of capacity, defined for one-beam model dBm in a point do=1km (as the radiowave up to a marge of a forest is freely distributed), a -effective value of running factor of attenuation of the corresponding determined model forests (chapter 3) - or α = 0.162 dB/km (for layered structure), or α = 0.34 dB/rm - for a large forest in which trees as spheres are located by correct image in space, Δd - a difference of distances between position of a point of reception and position of a marge of a forest (do=1km), km.

For these cases of dependence of functions Po(d), P_1(d) and P_2(d) are submitted on diagram 12 as curves 0,1 and 2, and numerical values (chapter 3) of function P (d) in the table:

Table 5

Distance between MS and BTS *d* (km)	A level of a signal in a point of reception MS *P (d)* (dBm)	
	P_1(d) Layered forest	*P_2(d)* Sphere trees
1	-62,586	-62,942
2	-65,768	-66,302
3	-67,927	-68,639
4	-69,525	-70,415
5	-70,769	-71,837
6	-62,586	-62,942

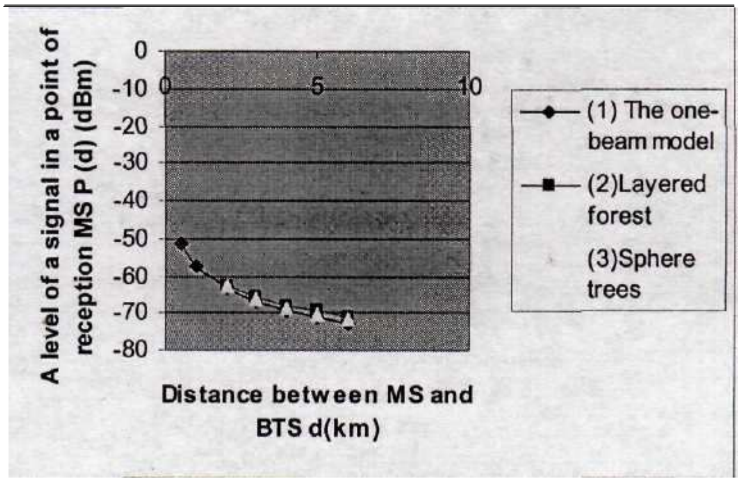


diagram 12.

d) The determined model for the mixed line (chapter 3 paragraph 3.6), submitted the curve 3 diagram. 13, gives the following numerical values of functionP *(d):*

Table 6

Distance between MS and BTS *d* (km) MS	A level of a signal in a point of reception MS *P (d)* (dBm)
0.5	-56.881
1	-63.062
2	-69.156
3	-72.702
4	-75.212
5	-77.157
6	-78.745

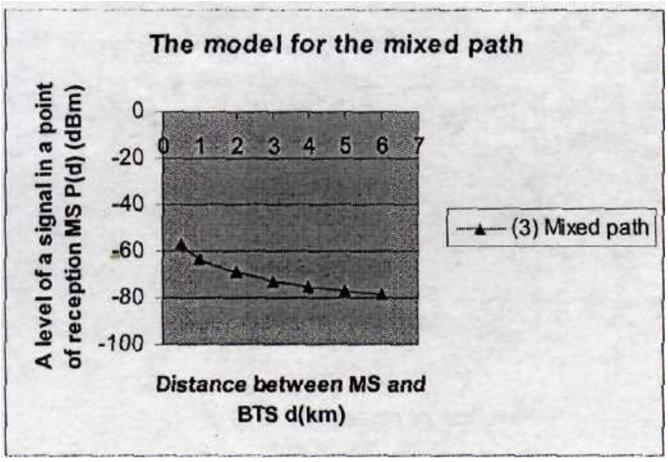


diagram 13.

e) The model of diffraction on a wedge, submitted the curve 4 diagram 14., gives the following numerical values (chapter 3 of item 3.4) to function *P (d):*

Table 7

Distance between MS and BTS *d* (km)	A level of a signal in a point of reception MS *P(d)* (dBm)
0.5	-72.637
1	-78.893
2	-85.029
3	-88.589
4	-91.107
5	-93.056
6	-94.647

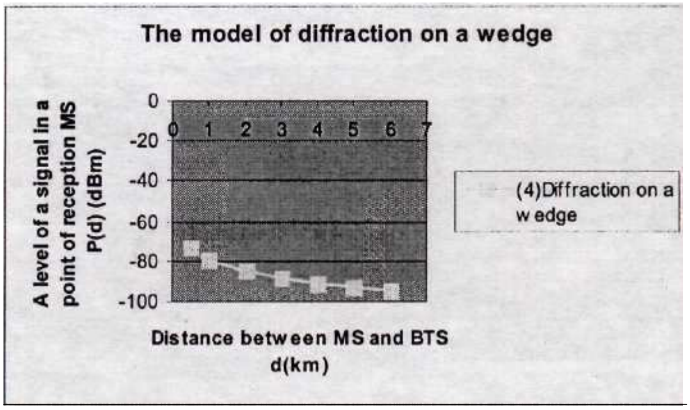


diagram 14.

Thus, from comparison of functions *P (d)* for theoretical models it is visible, that:
- For two-beam model at small distances from MS up to BTS:
$d_{max} < 4h_1h_2/[\lambda(2\pi-\phi)]$ in comparison with one-beam model fluctuations of a level of a signal (which are submitted in item 3.4) are observed, and with increase in distance d falling of values of function *P (d)* submits Vvedensky to law (shift downwards on a level of capacity makes about{near} - 9dBm.); For the determined models forests (diagram 1.2) (i.e. for layered and spherical structures) arises falling a radio signal, since a marge of a forest at its propagation inside of a forest, thus shift downwards on a level of capacity makes - for layered -0,680 dBm. for spherical - 0,324 dBm.);
For a case of diffraction on a wedge when a radiowave difracts on edges of trees on a marge of a forest, the level of a radio signal in comparison with free propagation falls approximately on 20 dBm. (i.e. on wide highway located between large forests the level of a radio signal will be lower on 20 dBm in comparison with free space);
- For the mixed lines when radiowaves are distributed a part of a line in free space, then inside a large forest, further again in free space, etc., i.e. there is a heterogeneous (non-uniform) attenuation of a radio signal on a line and it should be reflected at calculation by use of various models of propagation: on one part of a line one-beam, on another - determined with effective factor of attenuation, on the third part of a line model of diffraction on a wedge, etc.
On fig. 24. the line of measurement which becomes attached to discrets d, km - 0.5., 1.0., 2.0., 3,4, 5,6 is schematically displayed.

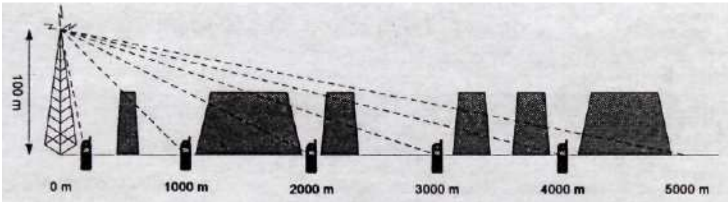


Fig. 24.

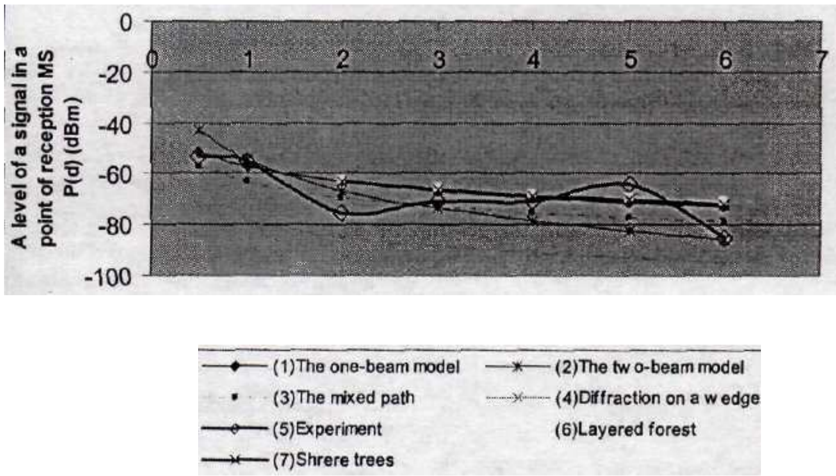
Let's carry out comparison of the results received in the experimental way with numerical values of capacity, designed on the basis of theoretical models (diagram 15).
At calculation it was supposed, that or the radiowave is distributed in a zone of direct visibility, or in a point of reception there comes the sum of the reflected and direct wave, or the radiowave is distributed inside a forest, or difracts on a wedge, or the radiowave is distributed in the mixed line.
In table 8 are submitted values levels of capacity experimentally measured in various points of reception with change of distance from MS up to BTS (d = 0.5., 1.0., 2.0., 3,4, 5,6) km.

Table 8

Distance between MS and BTS *d* (km)	Levels of a radio signal in a point of reception MS *P (d)* (dBm), received on a basis Experiment
0.5	-53
1	-55
2	-75
3	-71
4	-71
5	-64
6	-85

Apparently from diagram 15. experimental points get in a field of curves received theoretically and in various points can or coincide with the points received at calculations on the basis of various theoretical models of radiowaves propagation, or strongly differ.

Theory and experiment



The diagram. 15.

1) On distance d = 0.5km MS from BTS experimental value coincides with the value received on the basis of calculation on one-beam model (-53 dBm).
2) On distance of 1 km the level of a signal at experiment has made (-56 dBm), that is higher, than for value received on the basis of one-beam model (-57,246 dBm), that apparently, speaks that the resulting field in a point of reception grows out interferences of two or several radiowaves.
3) On distance 2 km from BTS sharp falling a level of a signal on the first 100м is observed, thus the radiowave was distributed inside a large forest and the level of a radio signal made (-75 dBm), i.e. was lower than for free propagation on 12 dBm. This value also is lower, than that follows from the determined models (layered - (-63.428 dBm) and spherical (-63.606 dBm) structures) for the given distance that testifies to sharper attenuation of radiowaves in a forest at through propagation. At the further deepening of the transmitter in a forest the level of a signal decreased according to weaking of a wave in free space.
3) On distance from 3 kms up to 4 kms value of levels of a radio signal - for experiment made - 71 dBm, for one-beam model - 69,287 dBm, for determined models-68,639 dBm (spherical structure)-67,927 dBm (layered structure), for the mixed line-72,702 dBm i.e. experimental values got in area limited to a curve for one-beam model and the mixed line.

4) On distance from 4 km up to 5.5 km values of levels of radio signals exceed levels for one-beam model and their value make for experiment – 64дБм, for one-beam model - 71 dBm, for determined models-69,525 dBm (layered structure) and-70,415 dBm (spherical structure).

Let's note, that dependence of a field level on range exponential, and for small depth of penetration into a forest the degree of attenuation is high, with increase in depth of penetration the degree goes down.

The analysis of results of experimental and theoretical researches of radiowaves propagation in mobile communication systems has shown, that radiowaves propagation in conditions of a forest, is accompanied by effects of repeated reflection, diffraction, dispersion of waves that results in formation of complex spatial propagation of an electromagnetic field, thus values effective median levels get in a field of values received on the basis of theoretical models. The divergence of the settlement and measured values naturally, nevertheless, character of dependence of weaking from range between a radiator and place of acceptance is defined by theoretical expression correctly.

2. The comparative analysis of work results and the results received by other authors on radiowaves propagation in large forests on frequencies of 900 MHz close to average frequency (800 - 1200 MHz)

In communication with distinction experiments of the author and other authors as on height of base stations antena, and on density and humidity of forest and a kind of the line, the received values of weaking of a signal differ from each other, (ch.3, Tab.3.5.1)

However results encourage that the developed models allow at designing macrocells in which there can be large forests, use the determined models and for an estimation of integrated influence forest areas on levels of a signal in points of an arrangement of mobile stations when they move inside a forest. Statistical models allow to describe disseminating properties of large forests in a decimeter range. On the basis of the theory of repeated waves dispersion it is shown, that for the description of an average field and intensity of a direct wave the model as a homogeneous layer with effective electric parameters is applicable. These parameters are defined by density, the average sizes, values of complex dielectric permeability of trees, and also frequency of radiation. The direct wave gives the basic contribution to intensity of an accepted signal. Results of work allow to predict conditions of a radio communication in forest areas depending on length of a line, heights of antena, frequency, parameters of a large forest. Besides the received results can be applied at the decision of the inverse problems necessary for research of forests by radiophysical methods.

In the conclusion theoretical and experimental results are generalized and the basic scientific results of dissertational work are formulated. Numbering of formulas and figures is carried out under chapters.

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2. V.Popov, J.Čaiko. Modelling of radiowave propogation through forestland. Rīga: Latvijas Fizikas un Tehnisko Zinātņu Žurnāls, 2001, No.5.
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