Distribution of 2.4 GHz Range Radiowaves Indoors

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Abstract— **The article reports the results of the research on reducing handicaps level to radio signal in a Wi-Fi network. The authors consider the theory of multi-media in order to understand the processes taking place during reflection of electromagnetic waves with a frequency of 2.4GHz. The resulting numerical modeling conclusions are used to develop measures for the processing of premises multilayer materials. Experiments have shown that the rate of data transmission in wireless IEEE 802.11n standard after treatment of premises increased by 15-20%.**

Keywords - RadioEthernet; wireless interference; disturbance; Wi-Fi, reflectance.

I. INTRODUCTION

Recently, content of data transmitted has more changed to the side of multimedia. This leads to an increase in the volume of data transmitted. To transmit large volumes of data need to increase the data rate. Adopted in 2009, the IEEE 802.11n declares transmit rate of 300 Mbit/s, but the real data transmit rate is 20-30% of the declared. The statistical theory of radiowave distribution indoor is described in our paper [1]. It offers a way to increase the speed of the network. Let us consider another way.

Section "Interference handicaps" is devoted to research features the work of the interference noises of wireless networks. In the section "Definition of factor of reflection interference materials», we consider the theory of the behavior of the reflection coefficient of the vertical and horizontal polarization plane waves at oblique incidence in the controlled environment. The section "Definition of permittivity" is devoted to research of one of the methods for determining the different materials dielectric permittivity ε *. On the basis of the developed theory, we conducted a pilot research that is presented in section "Application of the geometric theory at construction of Wireless Networks".

II. INTERFERENCE HANDICAPS

Interference handicaps, arising due to repeated radiowaves reflection from surrounding subjects, are shown in simultaneous receipt in the receiver of useful signal "copies" set with the displaced phases that can result in its easing or even full disappearance on separate sites of the spectrum (so-called "fading").

Under the same system Direct Sequence Spread Spectrum (DSSS) external conditions appear steadier to fading, than Frequency Hopping Spread Spectrum(FHSS) (as well as in case of the narrow-band handicaps, the useful signal appears deformed only on separate frequencies); however, they are much more sensitive to displacement in time of the protected binary signal - because of considerably shorter (approximately ten times) pulses duration the levels wrong interpretation probability 0 or 1 grows at gate.

At electromagnetic radiation interaction with materials in the last absorption (dielectric and magnetic decreasees), dispersion (due to structural heterogeneity of a material) and radiowaves interference take place. Non-magnetic materials from the radio signal absorption view subdivide on interference, gradient and combined. Interference materials will consist of alternating dielectric and conducting layers. The waves reflected from electro conductive layers and from a protected object metal surface interfere among themselves in them. Gradient materials (the most extensive class) have multilayered structure with smooth or step change of complex dielectric permeability on thickness (it is usual under the hyperbolic law). Their thickness is rather great and makes> 0.12-0.15 λmax, where λmax - the maximal working wave length (in our case 0.12м). The external (matching) layer is made from firm dielectric with the big maintenance of air inclusions, with the dielectric permeability close to unit, with other (absorbing) layers - from dielectric with high dielectric permeability with absorbing conducting stuff. Also materials with a relief external surface (formed by ledges as thorns, cones and pyramids), named subulate materials are conditionally related to gradient materials. Reflection's factor reduction is promoted by repeated waves reflection from thorns surfaces (with waves energy absorption at each reflection) in them. The combined materials - a combination of gradient and interference materials. They differ in action efficiency in the expanded wave band.

The greatest level interfering handicaps is provided with signals at direct falling a radiowave on a material. At application of not directed aerial access point is a wall or a ceiling to which the aerial fastens. Application gradient material for processing a wall or a ceiling in the aerial fastening point can provide increase in a ratio signal/noise up to 6 dB. The aerial direction on a concave surface is inadmissible, as it results in a high level interfering handicaps and high non-uniformity of a radio signal. Walls on which the direct radiowave gets are processed interfering or gradient materials.

III. DEFINITION OF FACTOR OF REFLECTION INTERFERENCE MATERIALS

The most difficult for practical work is reflection factor definition of materials premises used for processing. Radiophysical diagnostics systems work and the control interference environments are based on the reaction analysis of the researched environment on probing signal.

One of the most actual the problem is problem of the electromagnetic waves interaction adequate description with sound the environment characterized by complex dielectric permeability (ε *) by the sounding data interpretation methods development. It is connected by that sound material environments represent complex dielectric structures. These environments constantly contact to a variable temperature field and water in its various modular conditions in real conditions. These variable components define, basically, dielectric properties of such environments.

It is necessary to take into account spatial distribution ε * at the of radiowave diagnostics of a condition and properties of such environments problems decision. The data about profile distribution ε * can be received or from the aprioristic data, or using the approached theoretical models, or experimentally. One of the reflected signals interpretation methods perfection directions is connected with the modeling tasks decision of which are taking into account flat waves interaction with the layered environment which is described by real geometrical parameters and real dielectric characteristics.

Let us analyze reflection factor behaviour of flat waves of vertical and horizontal polarization at inclined falling on the controllable environment. Sharing of vertically and horizontal the polarized waves results allow to take the information on dielectric properties layers.

Statement of a task

On the flaky-non-uniform dielectric environment from free space ($\varepsilon^* =1,\ \mu^* = 1$) the flat electromagnetic wave under various Θ angels (Fig. 1) falls.

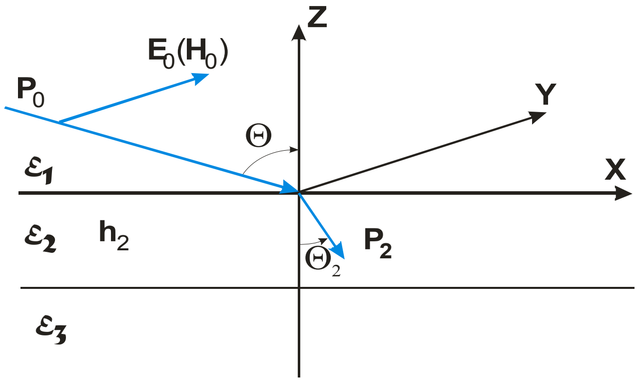


Figure 1. Geometry of a problem

It is required to define values of factor of reflection K from the researched environment depending on a horizontal and vertical polarization waves falling angel in case of a presence on the dielectric layers environment surface. The top and bottom layers have half-infinite thickness, and thickness of second rather thin layer is a variable quantity and commensurable with a wave length. Values ε * the second and third layer change during experiment.

Physical model

Environment with profile distribution ε usually is represented as multilayered system for carrying out of numerical modeling. In this case, ε * will be function of coordinate Z, and on borders between layers this function can be explosive. Dependence $\varepsilon^*(Z)$ inside each layer is set by numerical values in some points Z_i. We consider ε * between points Zi and $Zi+1$ constant and homogeneous in X and Y directions on layers for simplification of calculations.

Mathematical model

The multilayered environment reflection factor is defined under the recurrent formula [2]:

$$K_{1,n}=\frac{K_{1,2}+K_{2,n}e^{-j\frac{4\pi h_2}{\lambda\sqrt{\varepsilon_2}}}}{1+K_{1,2}K_{2,n}e^{-j\frac{4\pi h_2}{\lambda\sqrt{\varepsilon_2}}}} \tag{1}$$

$$K_{i,i}=0,\quad K_{i,i+1}=\frac{\sqrt{\varepsilon_{i+1}}-\sqrt{\varepsilon_i}}{\sqrt{\varepsilon_{i+1}}+\sqrt{\varepsilon_i}} \tag{2}$$

$$K_{i,k}=\frac{K_{i,i+1}+K_{i+1,k}e^{-j\frac{4\pi h_{i+1}}{\lambda\sqrt{\varepsilon_{i+1}}}}}{1+K_{i,i+1}K_{i+1,k}e^{-j\frac{4\pi h_{i+1}}{\lambda\sqrt{\varepsilon_{i+1}}}}}$$
$$k\neq i,k\neq i+1 \tag{3}$$

Using formulas (1-3), we will find formulas for reflection $K_{1,3}$ factor in case of the research model accepted by us:

$$K_{1,3}=\frac{K_{1,2}+K_{2,3}e^{\gamma_1}}{1+K_{1,2}K_{2,3}e^{\gamma_1}},$$
$$\text{где}\quad \gamma_1=-j\frac{4\pi h_2}{\lambda\sqrt{\varepsilon_2}} \tag{4}$$

Then for horizontal polarization:

$$K_{1,2}=\frac{\sqrt{\varepsilon_1}\cos\Theta-\sqrt{\varepsilon_2-\varepsilon_1(\sin\Theta)^2}}{\sqrt{\varepsilon_1}\cos\Theta+\sqrt{\varepsilon_2-\varepsilon_1(\sin\Theta)^2}} \qquad (5)$$

$$K_{2,3}=\frac{\sqrt{\varepsilon_2}\cos\Theta_2-\sqrt{\varepsilon_3-\varepsilon_2(\sin\Theta_2)^2}}{\sqrt{\varepsilon_2}\cos\Theta_2+\sqrt{\varepsilon_3-\varepsilon_2(\sin\Theta_2)^2}}, \qquad (6)$$

$$\text{где } \Theta_2=\arcsin\left(\frac{\sin\Theta}{\sqrt{\varepsilon_2}}\right)$$

For vertical polarization:

$$K_{1,2}=\frac{\varepsilon_2\cos\Theta-\sqrt{\varepsilon_1(\varepsilon_2-\varepsilon_1(\sin\Theta)^2)}}{\varepsilon_2\cos\Theta+\sqrt{\varepsilon_1(\varepsilon_2-\varepsilon_1(\sin\Theta)^2)}} \qquad (7)$$

$$K_{2,3}=\frac{\varepsilon_3\cos\Theta_2-\sqrt{\varepsilon_2(\varepsilon_3-\varepsilon_2(\sin\Theta_2)^2)}}{\varepsilon_3\cos\Theta_2+\sqrt{\varepsilon_2(\varepsilon_3-\varepsilon_2(\sin\Theta_2)^2)}} \qquad (8)$$

Reflection factors modules for wave's horizontal $|KH|$ and vertical $|KV|$ polarization have been designed at various falling Θ angels on sound environment by formulas (4−8) for different environment conditions (Fig. 1). Thus thickness of a thin layer $h2$ varied, various values ε * a thin layer and the third layer were set. For presentation thickness of a thin layer was set in relative units and normalized thus to a wave length in the environment

$$\gamma_1=-j\frac{4\pi h_2}{\lambda\sqrt{\varepsilon_2}}=-j\frac{4\pi H}{\varepsilon_2},\quad \text{где } H=\frac{h_2}{\lambda_{avg}},\ \lambda_{avg}=\frac{\lambda}{\sqrt{\varepsilon_2}}$$

The formulas (4-8) analysis and diagrams on Figs. 2-4 shows, that factors of reflection $|KH|$ and $|KV|$ on Figs. 2-3 behave classically, as in case of falling a flat wave on the homogeneous dielectric environment. Diagrams $|KH|$ monotonously grow from the minimal value at $\Theta = 0$ up to maximal - at $\Theta = 90$. Dependence |KV| from a falling angel has more complex kind. In the beginning of coordinates diagrams monotonously decrease up to zero, and then grow up to unit more sharply. Position of a minimum on the diagram depends on thickness and ε * thin a layer, and also ε * the third layer (Figs. 2-7). Besides concurrence of diagrams $|KV|$ and $|KH|$, received is observed in case of a thin layer absence, with diagrams when a thin layer thickness is equal $0.5\lambda\varepsilon$ (Figs. 2,3-6,7). This fact indicates that the reflected waves from a thin layer and environment are summarized in a phase.

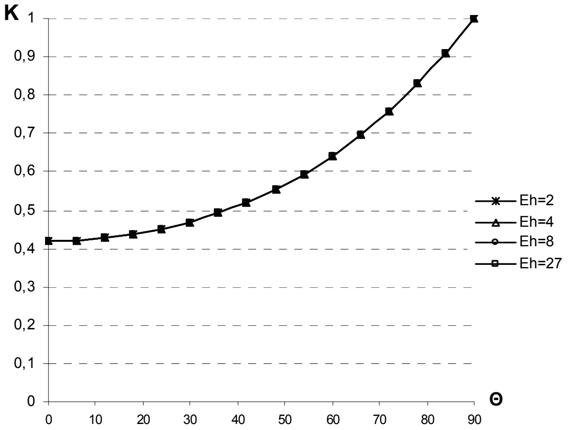


Figure 2. $K=\varphi(\Theta)$ (H=0, horizontal polarization)

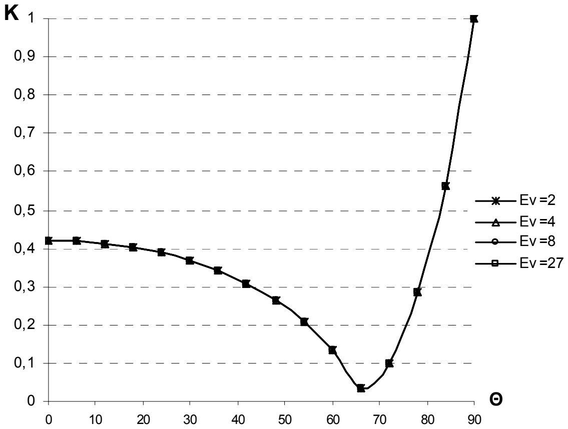


Figure 3. $K=\varphi(\Theta)$ (H=0, vertical polarization)

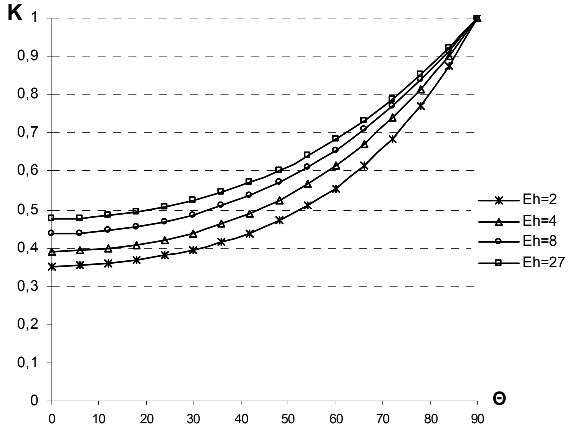


Figure 4. $K=\varphi(\Theta)$ (H=0.25, horizontal polarization)

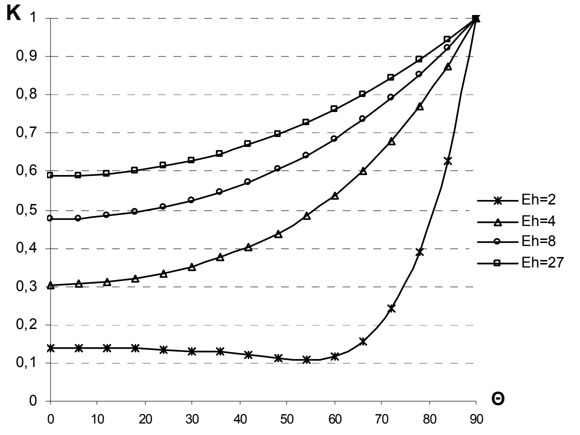


Figure 5. $K = \varphi(\Theta)$ (H=0.25, vertical polarization)

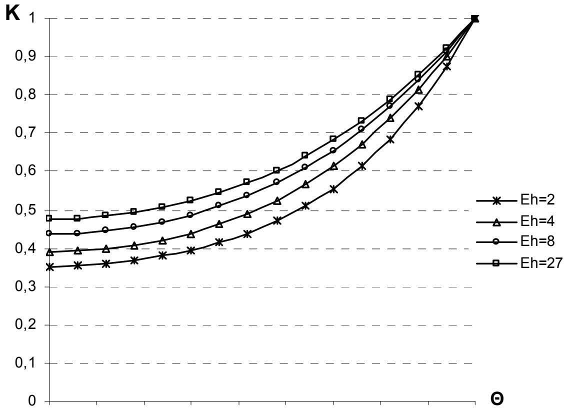


Figure 6. $K = \varphi(\Theta)$ (H=0.5, horizontal polarization)

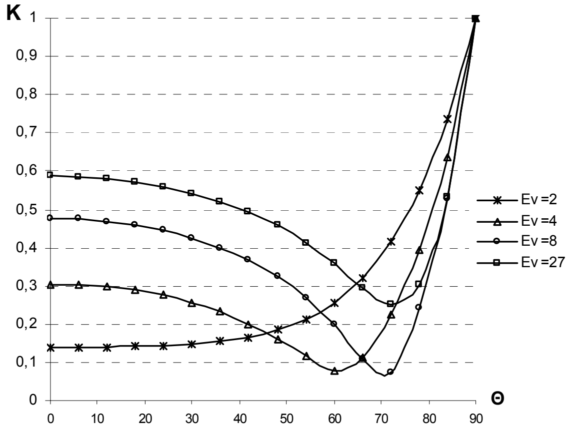


Figure 7. $K = \varphi(\Theta)$ (H=0.5, vertical polarization)

In certain situations the behavior of diagrams |*KV*| and |KH| differs from considered above (Figs. 8-9). At the certain values *ε1, ε2, ε3* layers and thickness of a thin layer equal *0.25λε* the reflected waves from the top layer and a spreading surface are summarized in an antiphase, as results in change of a kind of diagrams |*KV*| and |*KH*|.

For reflection |*KV*| and |*KH*| factors behavior presentation from a falling angel *Θ* and thin layer *H* thickness are constructed three-dimensional diagrams (Figs. 8-15). Value $\varepsilon_3 = 6 - 0.1i$ was supported to constants, value ε2 changed in limits from $2 - 0.1i$ up to $27 - 0.1i$. Thin layer *h2* thickness changed from 0 up to *λmax*.

The figures analysis confirms characteristic failures presence on diagrams |*KV*| and |*KH*| which appear at certain parities *ε1, ε2, ε3* layers, a falling angel *Θ* and a thin layer thickness *N*. Depth of failures on diagrams depends on presence of decreases in the environment and a thin layer. The fact of presence of special points in behavior of factors of reflection |*KV*| and |*KH*| can be used for development of algorithms of definition *ε* * or thickness of a thin layer.

Presence of characteristic failures on diagrams at small values *ε2* allows picking up such material, the reflection factor from which will be minimal (Figs. 8-11). At the big size *ε2* characteristic, dependence is observed; the increase in a thin layer *h2* thickness results in increase in reflection factor (Figs. 12-15).

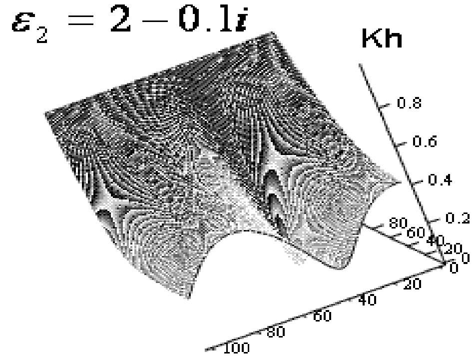


Figure 8. $K = \varphi(\Theta)$

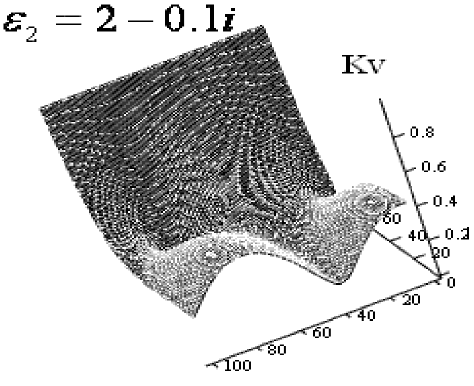


Figure 9. $K = \varphi(\Theta)$

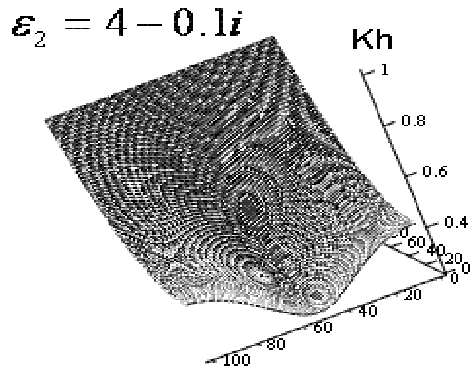


Figure 10. $K = \varphi(\Theta)$

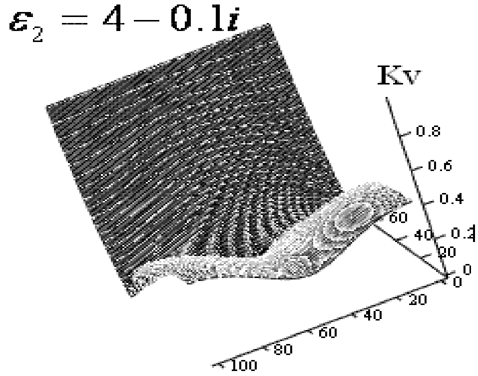


Figure 11. $K = \varphi(\Theta)$

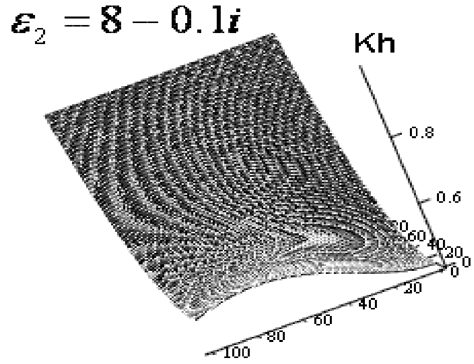


Figure 12. $K = \varphi(\Theta)$

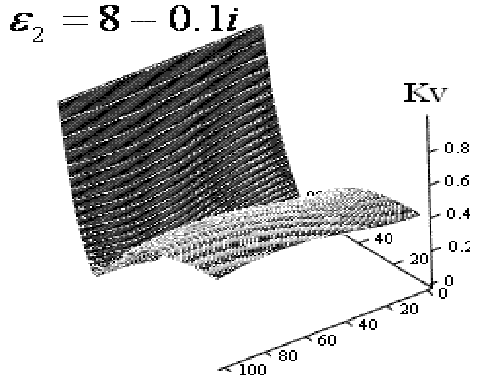


Figure 13. $K = \varphi(\Theta)$

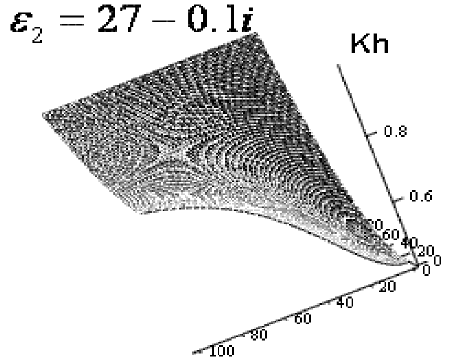


Figure 14. $K = \varphi(\Theta)$

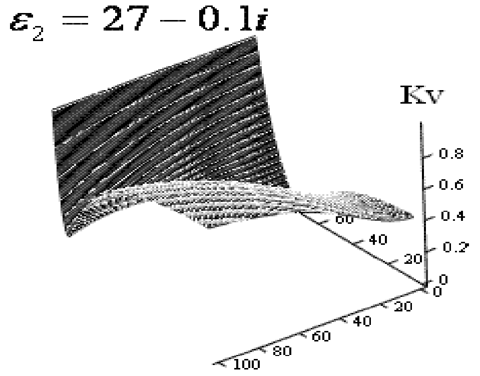


Figure 15. $K = \varphi(\Theta)$

IV. DEFINITION OF PERMITTIVITY

For reflection coefficient definition method use is necessary to know size of permittivity $\varepsilon^* a$ material. For the majority of the materials used in premises furnish, the given value is unknown and there is a permittivity value definition problem.

We research theoretically an opportunity of application of linear aerials for measurement of thickness (*h2*) and permittivity (*ε2*) first layers of the two-layer environment on a variable frequency method. Let us define *h2* and *ε2* by measurement results of an ultrahigh-frequency linear aerials entrance impedance available above environment in turn. Linear aerials impedance measurements are carried out with the help of a transfer complex factors measuring instrument.

Let us assume, that *aerial A* in length *2l* is set at height *h* above the horizontal - layered environment in parallel a surface of environment (Fig. 16). Environment consists of two layers. The first layer is characterized by thickness *h2* and complex permittivity *ε2 **, the second layer - thickness h3 and complex permittivity *ε3**.

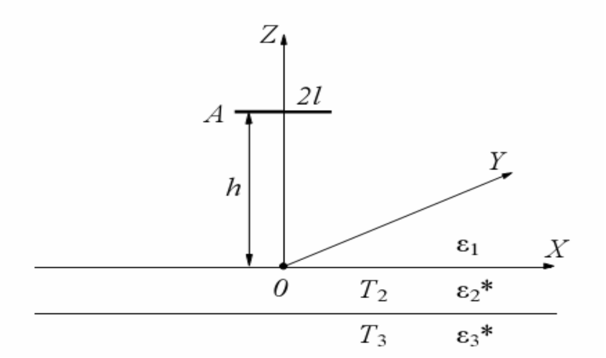


Figure 16. The plan to a problem about definition of an impedance of the linear aerial located above the two-layer environment

Assume that the environment first layer is dielectric, and the second layer - conductive. The first layer thickness is finite, the second layer represents half-subspace (*h3* → ∞). Let us consider three cases. In the first case the first layer will be a pine board (*ε2 = 2.73, h2 = 0.07 м*), in the second case - a burnt brick (*ε2 = 5.5, h2 = 0.066 м*), in the third case - the block from a glass (*ε2 = 6, h2 = 0.117 м*). In all three cases value of the factor of decreases of the first layer we shall accept equal 0.01. Let aerials will be adjusted on frequencies 300, 350.. 2200 MHz (with step 50 MHz).

The length of each aerial without taking into account the aerial thickness is determined n the following way:

$$2l = \frac{\lambda}{2} = \frac{c}{2f}, \tag{9}$$

where
λ – length of a wave in free space, *m*,
c – speed of distribution of waves in free space, *m/s*
f – frequency of tuning of the aerial, *Hz*.

Each aerial is above environment at the height equal to optimum height of the half-wave linear aerial arrangement above a homogeneous environment $h = 0.28\lambda$.

Under condition of an the half-wave linear aerial arrangement above a homogeneous environment at the height equal or not enough distinguished from 0.28λ, the maximal value of the module of an impedance of the aerial is observed.

Results of the calculation executed with use of theoretical model [3], are submitted in Fig. 17 as diagrams of dependences of the half-wave linear aerial impedance module located above the two-layer environment, from the aerial tuning frequency. The curve 1 conforms to a case when the environment first layer is the pine board, curve 2 - a burnt brick, a curve 3 - the block from a glass.

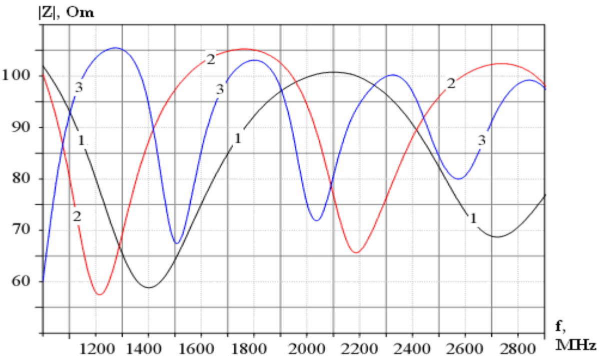


Figure 17. Dependence of the module of an the half-wave linear aerial impedance located above the two-layer environment, on frequency of tunnig at various characteristics of the first layer

1: *ε2** = 2.73 – 0.01*i* (pine board), *h2* = 0.07 *m*;
2: *ε2** = 5.5 – 0.01*i* (burnt brick), *h2* = 0.066 *m*;
3: *ε2** = 5.3 – 0.0035*i* (glass), *h2* = 0.12 *m*

Under the diagrams submitted in Fig. 17, it is possible to determine one of first layer parameters of the two-layer environment (*h2* or *ε2*) if another is known. For calculation of thickness of the first layer we shall use the formula

$$h_2 = \frac{c}{4\sqrt{\varepsilon_2}\cdot\Delta f}, \tag{10}$$

where Δ*f* - *A* difference of the frequencies corresponding to two next minimum of frequency dependence of the module of an impedance of the linear aerial, Hz,

$$\Delta f = \frac{\left|f_{\min 2} - f_{\min 1}\right|}{2}, \qquad (11))$$

For example, for a case when the environment first layer is the pine board; on a curve 1 in Fig. 17, we find *fmin1* = 1401.542 MHz and *fmin2* = 2711.424 MHz.

Thus Δ*f* = 654.941 MHz. Having substituted values *ε2* and Δ*f* in the formula (10), we receive value *h2*, equal 0.069 m. In this case, the deviation of settlement value of thickness of the first layer from a preset value *(*Δ*h2)* is equal 1.4%.

Similarly we determine a material thickness for a burnt brick and glasses. We use the minimal values close to frequency researched by us 2.4GHz.

Results of calculation under the formula (10) the two-layer environment first layer thickness of are Table I. In the considered cases the deviation of settlement value *h2* from a preset value does not exceed 2%.

TABLE I.
RESULTS OF CALCULATION OF THICKNESS OF THE FIRST LAYER OF THE TWO-LAYER ENVIRONMENT

Materials	**Set point h2, m**	**Design value h2, m**	**Δh2, %**
Pine board	0.07	0.069	1.4
Burnt brick	0.066	0.067	1.50
Glass	0.12	0.122	1.7

For calculation of the two-layer environment first layer permittivity we use the formula

$$\varepsilon_2 = \left[\frac{c}{4h_2\Delta f}\right]^2 \tag{12}$$

Let us define size of dielectric permeability for three materials at known thickness of the first thin layer.

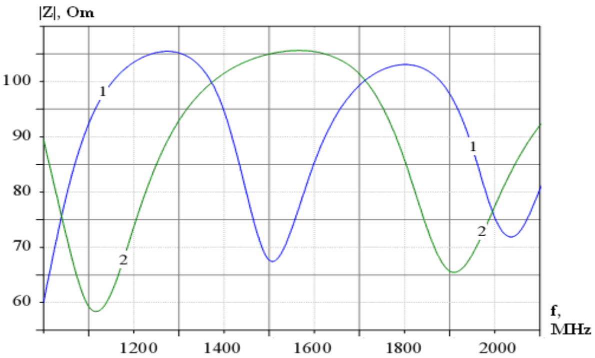
Results of calculation under the formula (12) permittivity of the first layer of the two-layer environment are Table II. In the considered cases the deviation of settlement value *ε2* from a preset value does not exceed 3%.

TABLE II.
RESULTS OF CALCULATION OF PERMITTIVITY OF THE FIRST LAYER OF THE TWO-LAYER ENVIRONMENT

Materials	**Set point ε2,**	**Design value ε2,**	**Δ ε2, %**
Pine board	2.73	2.68	1.8
Burnt brick	5.5	5,58	1.5
Glass	5.3	5.449	2.8

For the definition of permittivity dielectric, which thickness is unknown, the following algorithm is applied. First the difference of frequencies Δ*f1* is defined, corresponding to unknown thickness of a layer *h2* then the superficial part of a layer having thickness Δ*h2* is removed. Then the difference of frequencies Δ*f2* is defined, corresponding to the stayed thickness of a layer (*h2* - Δ*h2*), and depend on *ε2*. For research of a permittivity dielectric measurement opportunity with unknown thickness we return to third of the considered cases.

Let us reduce thickness of the first layer (the block from a glass) by 0.036 *m* and we calculate the module of an linear aerials impedance, serially available above the two-layer environment.



1: *ε2** = 5.3 – 0.035*i* (glass), *h2* = 0.12 *m*;
2: *ε2** = 5.3 – 0.035*i* (glass), *h2* = 0.084 *m*

Figure 18. Dependence of the module of an impedance of the half-wave linear aerial located above the two-layer environment, on frequency of tuning at various thickness of the first layer

Results of calculation are submitted in Fig. 18 as a curve of 2 the half-wave linear aerial impedance module dependences located above the two-layer environment, from frequency of tunnig of the aerial. The curve 1 corresponds to a case when a glass layer thickness is equal 0.12 m, and is a part of the curve 3 represented in Fig. 17.

Under the diagrams submitted in Fig. 18, it is possible to define *ε2*, not knowing *h2*. For calculation of the first layer permittivity when its thickness is unknown, we shall use the formula

$$\varepsilon_2 = \left[\frac{c(\Delta f_2 - \Delta f_1)}{4\Delta h_2 \Delta f_1 \Delta f_2}\right]^2 \tag{13}$$

where
Δ*f1* – The difference of frequencies corresponding to thickness of the first layer *h2*, Гц,
Δ*f2* – The difference of frequencies corresponding to thickness of the first layer (*h2* - Δ*h2*), Hz,
Δ*h2* - a difference of thickness of the first layer, m.

Having substituted in the formula (13) values Δ*f1* and Δ*f2*, found under the diagrams represented in Fig. 18, we receive the value *ε2* equal 5.256. In this case, the deviation of settlement value *ε2* from a preset value is equal 1 %.

V. APPLICATION OF THE GEOMETRIC THEORY AT CONSTRUCTION OF WIRELESS NETWORKS

Having received theoretical calculation results the wireless network practical research in indoor is carried out. For treatment premises, we used the multi-layered materials, combining materials with high and low dielectric constant. We used the wireless network Radio Ethernet, making with standard equipment IEEE 802.11n usage. Router Linksys WRT610N, Netgear WNDR3700 and TRENDnet TEW-671BR are used as POP.

The research was carried out on the basis of method [4] and rate was measured by IxChariot [5].

TCP-traffic (with max size package mainly) is generated by the program and different situation as receiving, transmission and both synchronous (direction to adapter in PC) is modeling. POP (Depending from model no all point was available) is set to operate with 802.11n range on channel 1(5) in regime «40 MHz», previous generation network security regime was switched off, ciphering WPA2-PSK whit c AES algorithm was switched on. Other settings were standard.

That network works sufficiently stable should take into account, as data transmission rate negligible changed during all test. After the first cycle of measurements, we treated the room multilayer materials. Special attention was given to surface where the falling electromagnetic wave at the first reflection. Then there was held the measurements second series.

Test results are shown on Figs. 19, 20, 21, and 22.

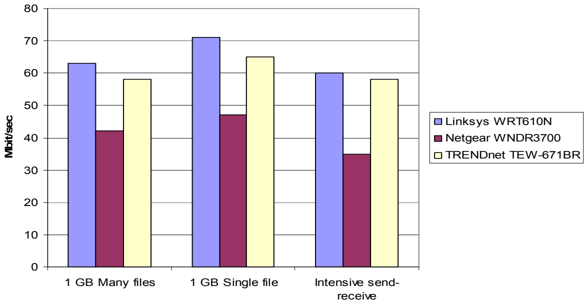


Figure 19. 2.4 GHz before processing

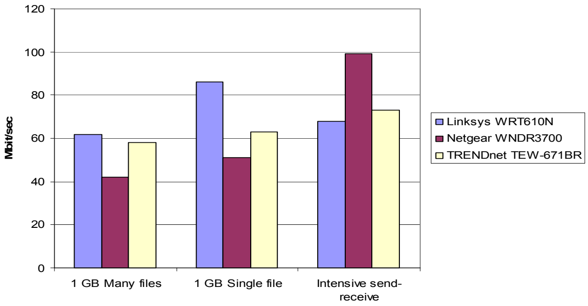


Figure 20. 5 GHz before processing

In the range 2.4GHz we received max rate in transmission regime from adapter (about 71 Mbit/s) for POP Linksys WRT610N. Receiving rate is a little smaller – on the order of 61 Mbit/s. The second indicator in the POP TRENDnet TEW-671BR. Worst performance in terms of in the POP Netgear WNDR3700. The second indicator in the POP TRENDnet TEW-671BR. Worst performance in terms of in the POP Netgear WNDR3700. In the range 5GHz, we received max rate (about 104 Mbit/s) for POP Netgear WNDR3700 only on test Intensive send-receive. When transferring files, the best result shows an POP Linksys WRT610N. After processing premises speed increased by 15-20%.

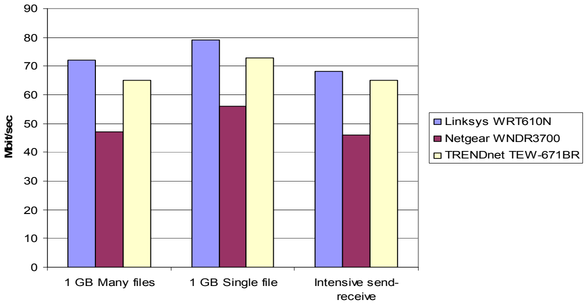


Figure 21. 2.4 GHz after processing

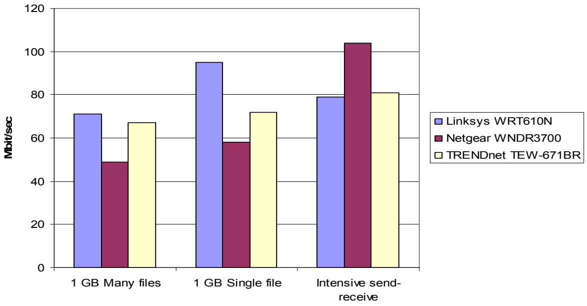


Figure 22. 5 GHz after processing

VI. CONCLUSIONS

The results of the modeling calculations carried out by the authors allow to draw a conclusion that the layered environments parameters control is possible with the helt of electromagnetic waves of vertical and horizontal polarization in the range of 2.4 GHz. To determine the dielectric layers were suggested the method of using half-wave antenna. The given theory we used for the treatment premises. The model calculations results were approved in the experiments. The experimental results at frequencies of 2.4 GHz and 5 GHz have shown that after a special treatment of premises rate increased by 5-10%.

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