Journal of ELECTRICAL ENGINEERING, VOL. 56, NO. 5-6, 2005, 113–120

INFLUENCE OF TERRAIN ON MULTIPATH PROPAGATION OF FM SIGNAL

Ján Klima * — **Marián Možucha** **

FM signal propagating through the troposphere interacts with the terrain as a reflecting plane. These reflected signals are not included into calculations and predictions of the field strength. The reason is simple — it is too difficult for processing, and demanding high quality data. For recent capabilities of computers and resolution level of digital terrain models this is not an irresolvable problem. In the report the authors show a practical demonstration how to include the reflected FM signals into the field strength calculations as well as the comparison with standard methods of field strength predictions.

K e y w o r d s: digital terrain model (DTM), reflections, diffraction, multipath propagation

1 INTRODUCTION

A digital terrain model, as a discrete field of representative and positionally expressed points of the terrain and its approximation equations securing its continuity [8] can serve, besides many other tasks, as a tool for locating, testing and calculating the reflecting planes for propagating FM signals. When calculating the reflected FM signals we cannot distinguish all, only statistically important directions expressed on the chosen resolution level. That is why measuring the field strength of FM signal is a measurement of an integral quantity — it means of all possible inducted streams on the receiving antenna. An antenna constructed in the form of antenna field receiving FM signals from different directions and summing them separately does not exist but we can find these directions iteratively.

In radiocommunication literature there are attempts to sum up direct and reflected waves [2], mainly those reflected from determined shapes of obstacles — buildings. Terrain with its irregular shape was not dealt with in these calculations. We will proceed from the assumption that thanks to the additional field strength of FM signal reflected from the terrain — not only on the line between the transmitter and receiver — we can get better predicted results. We will also assume that we can express that shape of objects of majority of obstacles on the terrain with statistical methods, so we will get most of reflected planes. As for the terrain, most calculation methods count with reflections only on a vertical profile though it does not correspond with reality. To take all reflections into accounts we can use effective values of morphometric parameters of the terrain such as elevation, form (convex, concave or linear), slope, aspect and angle of irradiation:

$$G_{RF} = \left\{z, \left(K_N\right)_{FM}, F_{FM}, \gamma_{FM}, A_{FM}, (\delta_{\exp})_{FM}\right\}. \quad (1)$$

Here G_{RF} represents a set of points of the terrain, z is the height in a point located in coordinates $[x, y]$, $\left(K_N\right)_{FM}$ is the curvature of the terrain as it is seen from the transmitter, F_{FM} is the form, γ_{FM} is the slope, A_{FM} is the aspect, and $\left(\delta_{\exp}\right)_{FM}$ is irradiation — all from the direction of the transmitter.

We will come from the known fact that the received field strength (E) of the radio signal propagated above a vertically dissected terrain can oscillate by $\Delta E = \pm 6$ dB due to the reflected signals (Fig. 1).

The existence of reflection planes σ_I [1] between the transmitter T_x and receiver R_x is taken without testing reflections in 3D dimensional space. The main reasons are:

- there is no exact procedure how to calculate statistically important reflected signals,
- it is assumed that these reflections can be neglected (though practice shows the opposite),
- it is difficult to describe the shapes and other parameters of all important obstacles on a huge area (though it is not a problem to get statistical values).

In some special cases, the terrain with its configuration and reflection parameters can become a massive reflecting plane, this is why we are to predict with some statistical error. If we considered a valley with dimensions responding to the 3D dimensions of the first Fresnel ellipsoid (Fig. 2), then we could get an extreme increase of the field strength [10].

2 INPUT CONDITIONS AND PRESUMPTIONS

1. We have a terrain G_{RF} (1) defined as a continuous topographic plane with continuous changes of its morphometric parameters, in the form of a digital terrain

* Department of Physics, Faculty of Natural Sciences, Universitu of Matej Bel, Tajovského 74, 974 01 Banská Bystrica, E-mail: klima@fpv.umb.sk; ** Trans World Radio–Slovakia, Banšelova 17, 821 04 Bratislava 2, Slovakia, E-mail: marian@twr.sk

ISSN 1335-3632

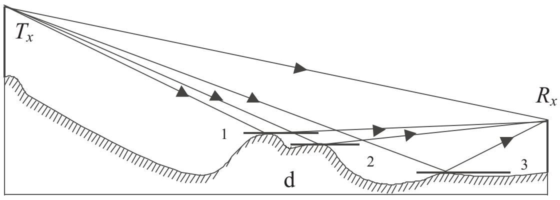

Fig. 1. Reflection planes σ .

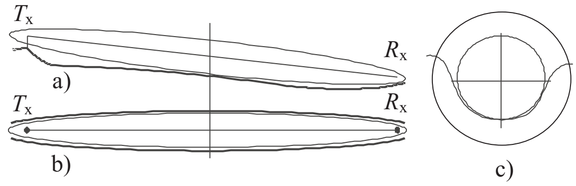

Fig. 2. Valley with dimension of the first Fresnel zone a) side view, b) upper view, c) profile view.

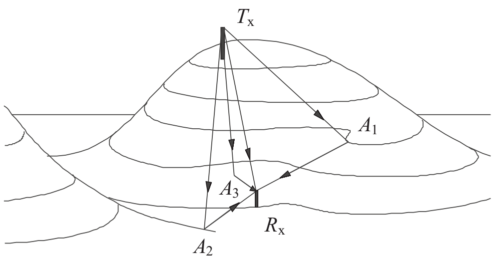

Fig. 3. Multipath of FM signal from transmitter T_x to receiver R_x .

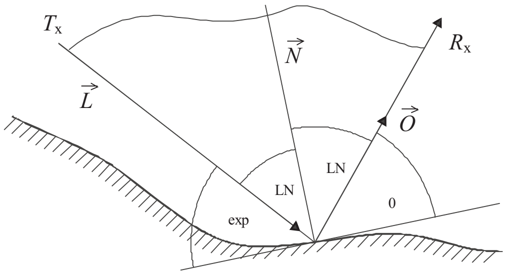

Fig. 4. Equal size of the angle of incident $\delta_{\exp}$ and angle of reflection δ_0 in the same plane.

model (DTM) defined by approximation equation

$$z = f(x, y) \,. \tag{2}$$

2. We have a known and definite set of objects (forest, water planes, urban objects *etc*) creating the land cover with its height and geometric (morphometric) parameters.
3. We will work with radio FM signal from the frequency band $\langle 87.5, 108 \rangle$ (MHz).
4. Important interactions between the terrain and FM signal are mathematically described by geometric and wave optics.
5. Only important and steady reflections will be taken into account. The neglected reflections are expressed by means of statistics (included in the mean values of the field strength).
6. Calculation of the field strength as a sum of direct and reflected signals in huge areas (Fig. 3) is still insufficiently examined, hence there is a problem how to verify the outputs.
7. DTM is created by means of interpolation, smoothing and various generalization methods — a lot of information is lost due to these processes. The angle of reflection can be rapidly changing in a real terrain, while there is a smooth terrain in DTM.
8. We do not know the reflection ratio of the terrain and its land cover, hence it would be best to find them iteratively.

3 GEOMETRIC EXPRESSION

The impact angle $\delta_{\exp}$ is equal to the angle of reflection δ_0, so the reflected signal will be in the same plane, (Fig. 4).

The normal $\vec{N}$ of the terrain in point $A_i[x_i, y_i, z_i]$ is expressed as:

$$\vec{N} = \{N_x, N_y, N_z\} \,, \tag{3}$$

where

$$N_x = |\vec{N}| \cos\alpha_N = \sin\gamma_N \cdot \cos A_N \,,$$
$$N_y = |\vec{N}| \cos\beta_N = \sin\gamma_N \cdot \sin A_N \,,$$
$$N_z = |\vec{N}| \cos\gamma_N = \cos\gamma_N$$

where $\cos\alpha_N$, $\cos\beta_N$, $\cos\gamma_N$ are direction angles (Fig. 5) which are expressed through relations

$$\cos\alpha_N = \frac{-z_x}{\sqrt{z_x^2 + z_y^2 + 1}} \,, \qquad \cos\beta_N = \frac{-z_y}{\sqrt{z_x^2 + z_y^2 + 1}} \,,$$
$$\cos\gamma_N = \frac{1}{\sqrt{z_x^2 + z_y^2 + 1}} \,.$$

where z_x and z_y are partial derivatives of function (2).

The unit vector $|\vec{N}| = 1$ is expressed by equation

$$\cos^2\alpha_N + \cos^2\beta_N + \cos^2\gamma_N = 1 \,. \tag{4}$$

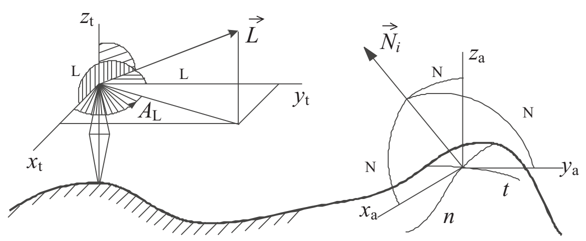

Fig. 5. Unit vectors $\vec{N}$ and $\vec{L}$.

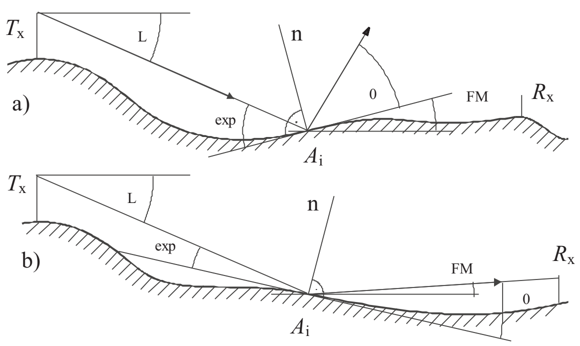

Fig. 6. Reflections.

FM signal represented by the electromagnetic wave and interacting with the terrain in a given point $A_i[x_i, y_i, z_i]$ can be expressed in a similar way:

$$\vec{L} = \{L_x, L_y, L_z\}\,, \tag{5}$$

where

$$\begin{aligned} L_x &= \cos\alpha_L = \sin\gamma_L \cdot\ cosA_L\,,\\ L_y &= \cos\beta_L = \sin\gamma_L \cdot \sin A_L,\\ L_z &= \cos\gamma_L = \cos\gamma_L\,,\\ \text{for } |\vec{L}| = 1 &\quad L_x^2 + L_y^2 + L_z^2 = 1\,. \end{aligned} \tag{6}$$

Direction angles $\cos\alpha_L$, $\cos\beta_L$, $\cos\gamma_L$ are expressed in a similar way, see Fig. 5:

$$\begin{aligned} \cos\alpha_L &= \frac{x_a - x_t}{\sqrt{(x_a-x_t)^2 + (y_a-y_t)^2 + (z_a-z_t)^2}}\\ &= \frac{\Delta x_{at}}{\sqrt{\Delta x_{at}^2 + \Delta y_{at}^2 + \Delta z_{at}^2}}\,,\\ \cos\beta_L &= \frac{y_a - y_t}{\sqrt{(x_a-x_t)^2 + (y_a-y_t)^2 + (z_a-z_t)^2}}\\ &= \frac{\Delta y_{at}}{\sqrt{\Delta x_{at}^2 + \Delta y_{at}^2 + \Delta z_{at}^2}}\,,\\ \cos\gamma_L &= \frac{z_a - z_t}{\sqrt{(x_a-x_t)^2 + (y_a-y_t)^2 + (z_a-z_t)^2}}\\ &= \frac{\Delta z_{at}}{\sqrt{\Delta x_{at}^2 + \Delta y_{at}^2 + \Delta z_{at}^2}}\,. \end{aligned}$$

In the sense of Fig. 4, let us define the plateau σ_{LN} where both vectors $\vec{L}$ and $\vec{N}$ are placed. We want to find the angle between these vectors. We will use the dot product of the two vectors $\vec{L}$ and $\vec{N}$ [8]:

$$\vec{L}\cdot\vec{N} = \cos\delta_{LN} = \sin\delta_{\exp} \quad \delta_{LN} + \delta_{\exp} = 90^\circ\,. \tag{7}$$

In scalar form

$$\begin{aligned} \vec{L}\cdot\vec{N} &= N_xL_x + N_yL_y + N_zL_z\\ &= \cos\alpha_N\cos\alpha_L + \cos\beta_N\cos\beta_L + \cos\gamma_N\cos\gamma_L =\\ &\frac{-z_x}{\sqrt{z_x^2+z_y^2+1}}\sin\gamma_L\cdot\cos A_L + \frac{-z_y}{\sqrt{z_x^2+z_y^2+1}}\sin\gamma_L\cdot\sin A_L\\ &+ \frac{1}{\sqrt{z_x^2+z_y^2+1}}\cos\gamma_L\,. \end{aligned} \tag{8}$$

From (7) and (8) we can get

$$\frac{(-z_x\Delta x_{at}) + (-z_y\Delta y_{at}) + \Delta z_{at}}{\sqrt{z_x^2+z_y^2+1}\,\sqrt{\Delta x_{at}^2 + \Delta y_{at}^2 + \Delta z_{at}^2}} = \sin\delta_{\exp}\,. \tag{9}$$

From relation (8) we can work with angles A_L and γ_L, γ_{FM}, A_{FM}, γ_0, A_0, in sense of Fig. 6.

$$\begin{aligned} &\gamma_N < 45^\circ,\ \gamma_{FM} < 45^\circ,\ \gamma_0 > 0^\circ,\ A_L = \langle 0^\circ, 360^\circ\rangle,\\ &A_{FM} = \langle 0^\circ, 360^\circ\rangle\,,\ A_0 = \langle 0^\circ, 360^\circ\rangle \end{aligned} \tag{10}$$

where $A_{FM} = 180^\circ - A_L + A_N = 180^\circ - A_L + \operatorname{arctg} z_y/z_x$, A_L is the direction of the FM signal towards the south (Fig. 5):

$$\begin{aligned} \gamma_{FM} &= \gamma_N\cos A_{FM} = \operatorname{arctg}\bigl(\sqrt{z_x^2+z_y^2}\bigr)\cos A_{FM}\,,\\ A_L &= \operatorname{arctg}\Bigl(\frac{y_a-y_t}{x_a-x_t}\Bigr),\\ \gamma_L &= \operatorname{arctg}\Bigl(\frac{z_a-z_t}{|\vec{L}|}\Bigr),\\ A_N &= z_y/z_x\,,\\ |\vec{L}| &= \sqrt{(x_t-x_a)^2 + (y_t-y_a)^2 + (z_t-z_a)^2}\,, \qquad (11)\\ |\vec{O}| &= \sqrt{(x_a-x_r)^2 + (y_a-y_r)^2 + (z_a-z_r)^2}\,. \qquad (12) \end{aligned}$$

Here $\vec{O}$ is the vector of FM signal reflected from the terrain (Fig. 4).

All cases of the behaviour of FM signal are derived from the laws of reflection and are implemented into the developed software application, with consideration of the visibility of the reflected FM signal.

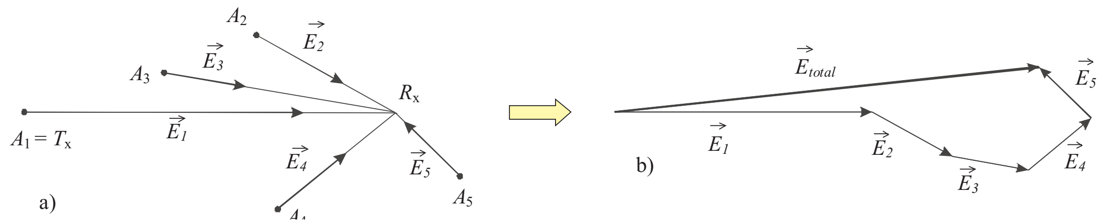

Fig. 7. Principle of summing of the field strength of FM signals: a) in space, b) graphically.

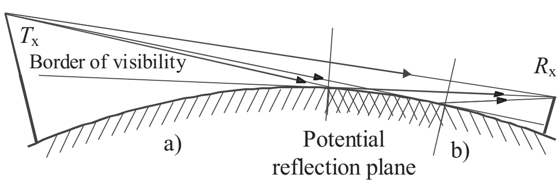

Fig. 8. Potential reflection plateau on a planar terrain, with curvature of the Globe a) visible from T_x, b) visible from R_x.

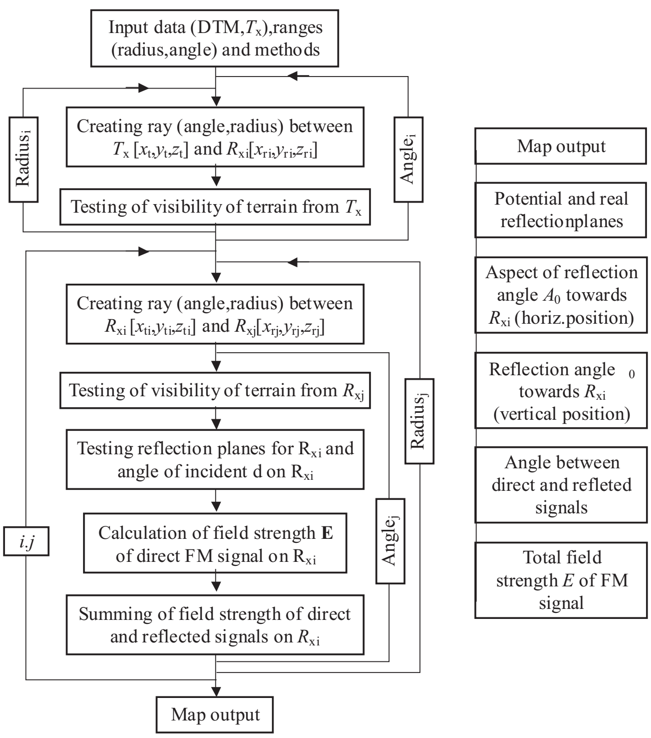

Fig. 9. Calculation algorithm of reflected signals.

4 SUMMING UP

Summing FM signals from individual directions will be made as scalar summing of angular differences (Fig. 7).

Let us suppose that we have made measurements by means of a directional antenna for the direction of transmitter T_x. Further let us suppose that from various directions we get signals of various field strengths, and this will be expressed in their summing and adding to the field strength from the direct FM signal by summing x, y, z components of particular vectors $\vec{E}$ representing the size and direction of the field strength:

$$E = \sqrt{\left(\sum X_i\right)^2 + \left(\sum Y_i\right)^2 + \left(\sum Z_i\right)^2}\,. \tag{13}$$

On the basis of experiences gained while developing module “Reflections”, a phase shift was also implemented into calculations. To get them we have to calculate the angles of A and γ see the Appendix). Then

$$E_i = f\big(P_t, d_i\big) R_i \cos \frac{2\pi d_i}{\lambda}\,, \tag{14}$$

$$E_0 = f\big(P_1, |\vec{L}|\big) \tag{15}$$

where P_t is the power of transmitter (kW), d_i is the sum of the incident and reflected trajectories of the signal ($d_i = |\vec{L}| + |\vec{O}|$) (km), and R_i is the reflection ratio of the terrain reflection plateau (to be continued in Appendix). According to (III of Appendix), the sum of all signals received by the antenna is expressed by relation

$$E = \sqrt{\left(\sum X_i + X_0\right)^2 + \left(\sum Y_i + Y_0\right)^2 + \left(\sum Z_i + Z_0\right)^2}\,. \tag{16}$$

5 LIMITATIONS

In the developed software application including the testing reflection planes (Fig. 8) and calculation of reflected signals (Fig. 9) some limitations were accepted:

– only points that are within the Fresnel zone were accepted [7], with possibility of setting also 1/3 of the first Fresnel zone,

– only points within an angle of 15° from the receiving antenna are considered in order to make the same conditions as during a measurement of the signal,

– relative to a given resolution level, the exact place of incidence of FM signal on the terrain was not calculated within a pixel of DTM, for we count with interpolated heights and its interpolated geometric (morphometric) parameters,

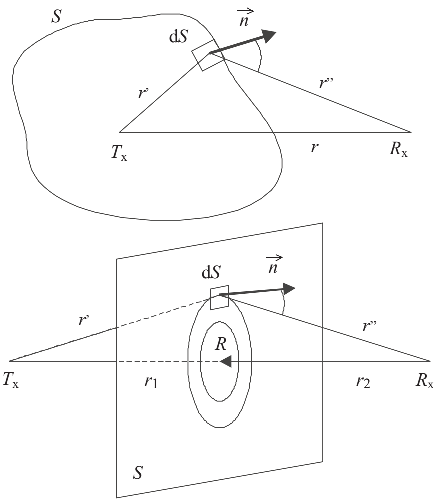

Fig. 10. Decisive area for propagation of radio waves.

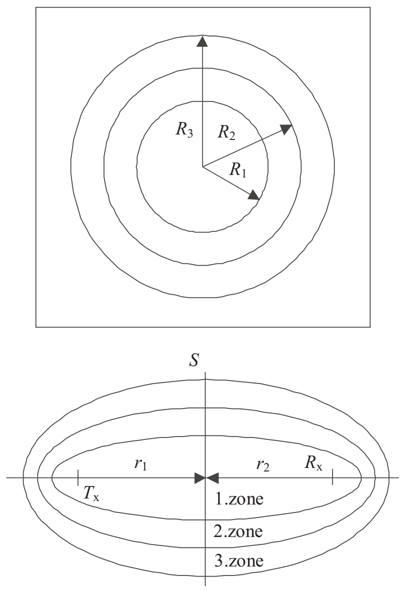

Fig. 11. Definitions of Fresnel zones.

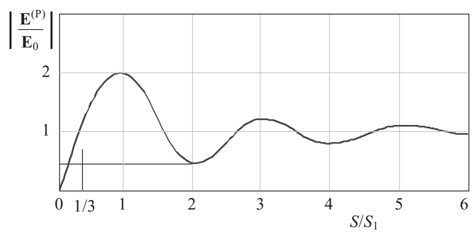

Fig. 12. Changes of the field strength in point receiver during enlargening of impermeable (shading) obstacle.

– a forest was not considered as a reflection plane, for its diffusive and absorption impacts

– urban objects were considered as a reflection plane under special conditions (sufficient height, suitable aspect, *etc*),

– the reflectivity ratio had to be found by means of iteration.

6 DECISIVE AREA OF PROPAGATION AND REFLECTION OF RADIO WAVES, FRESNEL ZONES

During the transfer of a radio wave from one space point to another we can ask a question whether the whole infinite space or only a finite part of it takes part in the transfer.

Fresnel showed that we could specify a certain area; behind its boundaries all the obstacles have no influence on the distribution of the field. This area is called a "decisive area" for the propagation of energy (or for the propagation of radio waves).

For the specification of the dimensions of the decisive wave and its shape the Huyghens principle is used. This principle says that every element of the S plane which bounds the transmitter is becoming a secondary source transmitting a spherical wave and the total field in the area of receiving is given by the sum of these elementary waves (Fig. 10).

As the shape of plane S can be arbitrary, we can have it as an infinitely big plane orthogonal to the trajectory of the direct wave (connection between T_x and R_x), Fig. 10. The distance of this plane from the point of T_x is r_1 and from point of R_x is r_2 $(r_1+r_2=r)$. We can calculate the field strength for this chosen area in a point of T_x on the basis of the known Kirchhoff solution or Kottler solution of discontinuities of derivations on a outline curve in a form of:

$$E^{(P)} = \frac{j}{\lambda} \int_S E^{(S)} \frac{1+\cos\alpha}{2} \frac{e^{-jkr''}}{r''} S \tag{17}$$

where

r'' is the distance of the elementary plane of $\mathrm{d}S$ of the plane of S from the point of T_x,

α is the angle between the vertical and the plane of S with the direction to the point of R_x,

k is the wave number,

λ is the wavelength.

For the present, let us consider the field strength in every point of the plane of S in the form

$$E^{(S)} = K \frac{e^{-jkr'}}{r'} \tag{18}$$

where K is some unknown constant value, r' is the distance of point T_x of from the elementary plane $\mathrm{d}S$, Fig. 10 a,b.

By inserting (18) into (17) we will get

$$E^{(P)} = \frac{j}{\lambda} K \int_S \frac{1+\cos\alpha}{2} \frac{e^{-jk(r'+r'')}}{r'+r''} \,\mathrm{d}S\,. \tag{19}$$

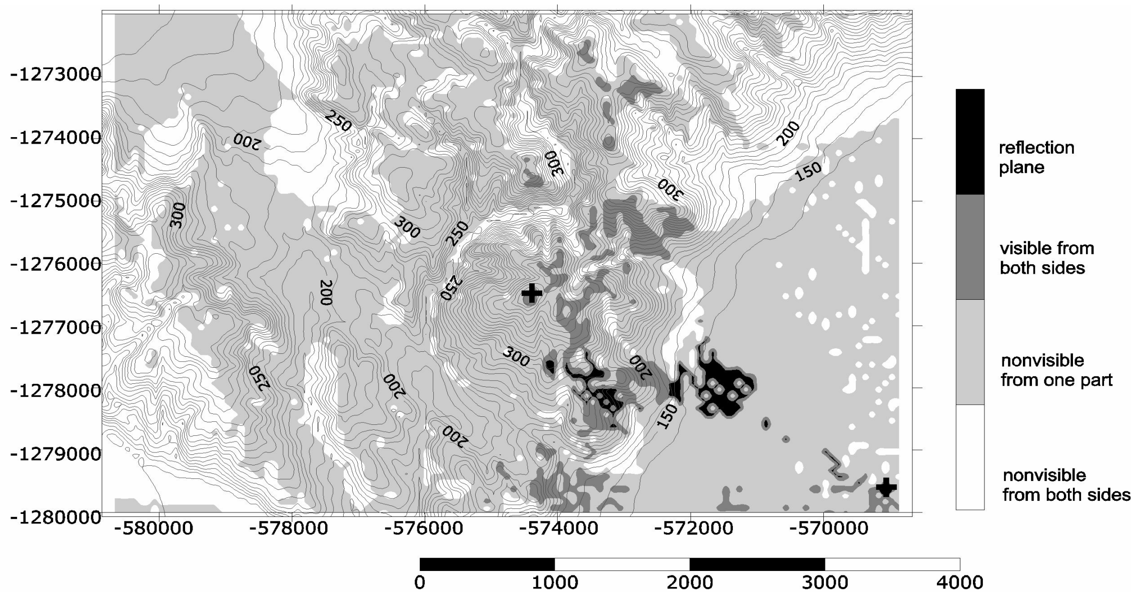

Fig. 13. Visibility from T_x and R_x, and reflection planes.

The phase of the wave on the way of $(r'+r'')$ is $\psi = k(r'+r'')$. The phase of the wave on the way of $(r_1 + r_2 = r)$ is $\psi_0 = k(r_1 + r_2)$.

To bound the "decisive area" for the propagation of radio waves, Fresnel was proceeding this way: he asked a question whether all elementary planar radiators of dS on a plane of S contribute to the total value of the field strength in a point of R_x with the same amount or not. To solve it, he divided plane S into the so-called Fresnel zones. Their dimension is specified with these conditions:

$$\pi(n-1) \le \psi - \psi_0 \le nT\,; \quad n = 1, 2, 3, \dots$$

or

$$(n-1)\lambda/2 \le (r'+r'') - (r_1 + r_2) \le n\lambda/2\,. \tag{20}$$

Every Fresnel zone includes secondary radiators on plane S, their phases in the point of R_x being different by about π at the utmost. The neighbouring Fresnel zones create an antiphase field in point R_x (with a phase different by π at the utmost).

From relations (19) it is seen that intersections of Fresnel zones with plane S have a circular shape. The radii of individual zones R_n, $n = 1, 2, 3, \dots$ can be determined from the conditions: $r' \gg \lambda$, $r'' \gg \lambda$, $R_n \gg r$. Then it is possible to write:

$$r' = \sqrt{r_1^2 + R_n^2} \cong r_1 + \frac{R_n^2}{2r_1}\,, \qquad r'' = \sqrt{r_2^2 + R_n^2} \cong r_2 + \frac{R_n^2}{2r_2}\,. \tag{21}$$

If we insert these relations into the equation of the external boundary of the n-th Fresnel zone $(r'+r'') - (r_1 + r_2) \le n\frac{\lambda}{2}$, by the simple modification we will get a relation for calculating its radius:

$$R_n = \sqrt{\frac{n\lambda r_1 r_2}{r}} \tag{22}$$

When we transfer plane S, then circles with radius R_n describe the surface of an ellipsoid. The areas of the space between two neighbouring ellipsoids (Fig. 11b) are spatial Fresnel zones.

Though the areas of individual Fresnel zones $S_F = \pi\big(R_n^2 + R_{n-1}^2\big) = n\lambda\frac{r_1 r_2}{r}$ in plane S are equal, the amplitude of field strength in point R_x decreases with increasing number of the Fresnel zone n, for the term $(1+\cos\alpha)$ is decreasing and the distance $(r'+r'')$ is increasing. So, the resultant field in point R_x is basically created by the secondary radiators that lay in the area of approx. the first eight to twelve zones. In a certain sense we can call this area as *decisive* area for propagation of radio waves that are propagating from T_x to R_x.

If we want to separate the field of the first Fresnel zones, we will hide the connection line T_x–R_x by a thin obstacle impermeable for radio waves, and we will cut it around the connection line T_x–R_x to get a circle aperture. We will gradually magnify the area of this aperture. In point R_x we will measure the field strength $E^{(P)}$. The result of this experiment is shown in Fig. 12 as a dependence $\left|\frac{E^{(P)}}{E_0}\right|$ on the ratio $\frac{S}{S_1}$, where E_0 is the field strength in point R_x during the propagation of radio waves in a free space (without shading obstacle). S is the area of the circular aperture in the shading obstacle and S_1 is the area of the first Fresnel zone.

The smallest aperture in the shading obstacle where $E^{(P)} = E_0$, $\left|\frac{E^{(P)}}{E_0}\right| = 1$, has a size of $\frac{S_1}{3}$. The radius is

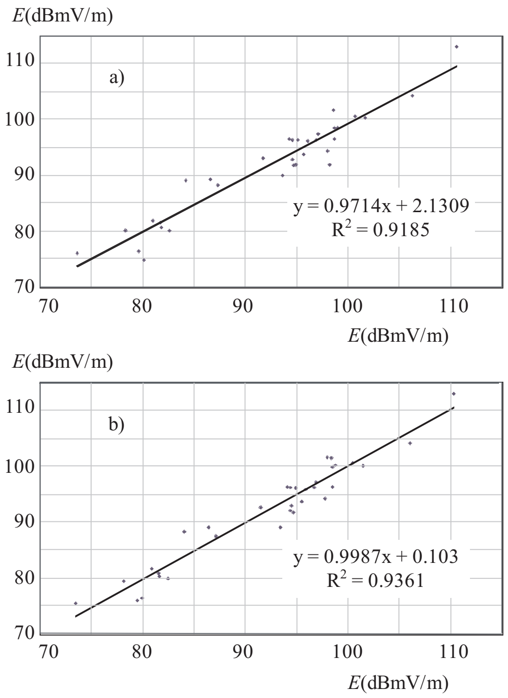

Fig. 14. Exactness of a) standard methods and b) the new method.

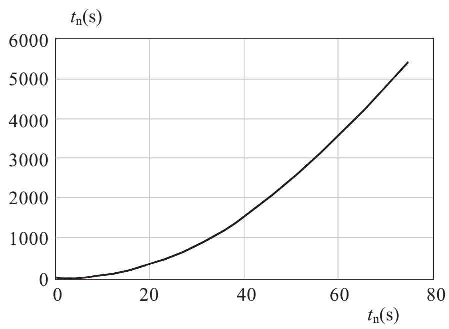

Fig. 15. Exactness of a) standard methods and b) the new method.

given by the relation:

$$R_{\min} = \sqrt{\frac{1}{3}\,\frac{\lambda r_1 r_2}{r_1 + r_2}}\,. \tag{23}$$

The shading area does not have a practical influence on the field strength $E^{(P)}$ when the aperture in this area includes approximately the first eight Fresnel zones.

In the point of receiving R_x mutual compensation occurs of the fields of the neighbouring Fresnel zones, and the results of calculation show that in the first Fresnel zone one half of the total energy of the radio wave is transferred. Finally, we can say that a decisive contribution to field strength in point R_x is brought by secondary sources that lay in a the pace of $1/3$ of the first Fresnel zone ($n = 1/3$), when $\left|\frac{E^{(P)}}{E_0}\right| = 1$. This area is called the *minimum Fresnel zone* and its radius is given by relation (23).

7 RESULTS

As it is seen in Fig. 13, reflection planes represent quite a small portion from the area visible from both the transmitter T_x and receiver R_x, and are quite scattered.

7.1 Exactness

Comparing the predicted field strength according to ITU-R and according to the new method with the measured data showed that the new method is quite exact and with good input DTM and land cover it provides better results that standard methods, Fig. 14 (see correlation coefficient). In some cases, comparison between the measured values and predicted values where reflections were included did not show a sufficient change. In 15 % of cases there was an improvement by more than 1 dB, in 9 % of cases by more than 2 dB.

7.2 Time

The time of calculations seems to be the biggest disadvantage in comparison with classical calculations by standard methods (ITU-R 370 and others). The new method counts the visibility of the terrain from every possible receiver, and makes tests of all suitable points of the terrain on reflections. These operations are quite time consuming, with an increase of the test area the calculation time increases exponentially (Fig. 15).

7.3 Effectiveness

The effectiveness of terrain reflection plateau tracing depends on geometric parameters of DTM. In the case of a planar terrain and with low density of urban objects between the transmitter and receiver, using the new prediction method is useless. Results will be almost identical with standard methods.

In other cases it depends on how big the differences are between the predicted and measured field strengths.

The new method could be used in special cases as an adjunct to the standard methods.

7.4 Importance

By means of this new method it is possible to find sources of unexpected mistakes in predictions made by standard methods.

8 CONCLUSION

Implementation of reflection phenomena in predictions of the field strength of FM signal is possible, with good results. On the other hand, it has big requirements — good quality DTM and time for calculations. For practical purposes it is suitable in the case of a small range of input data, for example a small city — it allows to make calculations more effectively. In the case of calculation of terrain reflections within a huge area we have to cope with unknown reflectivity of the land cover.

References

[1] ČERNOHORSKÝ, D.—NOVÁČEK, Z.: Antennas and Propagation of Radiowaves (Antény a šíření rádiových vln), FEI VUT, Ústav radioelektroniky, Brno, 2001. (in Czech)

[2] GROSSKOPF, R.: Feldstärkevorhersage mit Berücksichtung von Mehrwegeausbreitung, Rundfunktechnik Mitteilungen (München) **33** (1989), 155–161. (in German)

[3] GROSSKOPF, R.: Field Strength Prediction in the VHF and UHF Range Including Multipath Propagation, Proc. 7th International Conference on Antennas and Propagation (ICAP 1991), York, Conference Publication, 333, vol. 2, pp. 965–967, London, 1991.

[4] ITU–R.: Propagation over Irregular Terrain with and without Vegetation, Repor 1145, Geneva (CD), 2000.

[5] ITU–R.: VHF and UHF Propagation Curves for Land Mobile Services. Recommendation 529, Report 567-3, Geneva (CD), 2000.

[6] ITU–R.: Propagation Statistics Required for Broadcasting Services Using the Frequency Range 30 to 1000 MHz. Rec. 616, Rep. 239-6, Geneva (CD), 2000.

[7] KLIMA, J.: Measurement and Assessment of Slovak Republic Territory Coverage by Television and Radio Broadcasting Signal, Technical Regulation of Telecommunications TPT-R5. Ministry of Transport, Posts and Telecommunications of Slovak Republic (Meranie a posudzovanie pokrytia územia Slovenskej republiky televíznym a rozhlasovým signálom. Technický predpis telekomunikácií. TPT-R5. Bratislava: Ministerstvo dopravy, pôšt a telekomunikácií SR, 2001. (in Slovak)

[8] KRCHO, J.: Modeling of Georelief and its Geometrical Structure using DTM; Positional and Numerical Accuracy, Bratislava: QIII, 2001.

[9] MOŽUCHA, M.: The Barrier Effects of Georelief on the Radio FM Signal Propagated in Geographical Sphere (PhD. thesis, in Slovak), Bratislava: Faculty of Natural Sciences of Comenius University, 2003 (Bariérové efekty georeliéfu pri šírení rozhlasového FM signálu v prostredí geografickej sféry.

[10] RAIDA, J.*et al*: Multimedia Textbook of Electromagnetic Waves and Microwave Technology (Multimediální učebnice elektromagnetických vln a mikrovlnné techniky), Brno, Institute of radio electronics FEI VUT, 2001. (in Czech)

[11] BLAUNSTEIN, N.—GILADI, R.—LEVIN, M.: Characteristics' Prediction in Urban and Suburban Environments, IEEE Trans. Veh. Technol. **47** (1998), 225–234.

[12] KÜRNER, T.—CICHON, D.—WIESBECK, W.: Characteristics' Prediction in Urban and Suburban Environments, IEEE Trans. Veh. Technol. **46** (1997), 739–747.

[13] TONG, F.—AKAIWA, Y.: Effects of Beam Tilting on Bit-Rate Selection in Mobile Multipath Channel, IEEE Trans. Veh. Technol. **46** (1997), 257–261.

Receivd 26 November 2004

Appendix

$$d_{ar2} = \sqrt{(x_r - x_a)^2 + (y_r - y_a)^2}\,, \tag{I}$$

$$d_{ar3} = \sqrt{(x_r - x_a)^2 + (y_r - y_a)^2 + (z_r - z_a)^2}, \tag{II}$$

$$\cos A_{ar} = (x_r - x_a)/d_{ar2}\,, \tag{III}$$

$$\sin A_{ar} = (y_r - y_a)/d_{ar2}\,, \tag{IV}$$

$$\cos\gamma_{ar} = dar_2/d_{ar3}\,, \tag{V}$$

$$\sin\gamma_{ar} = (z_r - z_a)/d_{ar3}\,, \tag{VI}$$

$$X_i = E_i \cos\gamma_{ar} \cos A_{ar}\,, \tag{VII}$$

$$Y_i = E_i \cos\gamma_{ar} \sin A_{ar}\,, \tag{VIII}$$

$$Z_i = E_i sin\gamma_{ar}\,, \tag{IX}$$

$$d_{tr2} = \sqrt{(x_r - x_t)^2 + (y_r - y_t)^2}\,, \tag{X}$$

$$d_{tr3} = \sqrt{(x_r - x_t)^2 + (y_r - y_t)^2 + (z_r - z_t)^2}, \tag{XI}$$

$$\cos A_{tr} = (x_r - x_t)/d_{tr2}\,, \tag{XII}$$

$$\sin A_{tr} = (y_r - y_t)/d_{tr2}\,, \tag{XIII}$$

$$\cos\gamma_{tr} = d_{tr2}/d_{tr3}\,, \tag{XIV}$$

$$\sin\gamma_{tr} = (z_r - z_t)/d_{tr3}\,, \tag{XV}$$

$$X_0 = E_0 \cos\gamma_{tr} \cos A_{tr}\,, \tag{XVI}$$

$$Y_0 = E_0 \cos\gamma_{tr} \sin A_{tr}\,, \tag{XVII}$$

$$Z_0 = E_0 \sin\gamma_{tr}\,. \tag{XVIII}$$

Ján Klima graduated from the Faculty of Electrical Engineering, Slovak University of Technology, Bratislava, in 1971 and received the PhD degree in the theory of electromagnetism from the same university in 1979. Since 1991 till now he has been a member of the international TWG HCM of Vienna Agreement, now Agreement 2003. At present he is an associate professor at the Physics Department of the University of Mathias Bel in Banská Bystrica. He cooperates also with PTT Research Institute in Banská Bystrica. His professional domains are the theory of electromagnetic fields, radio waves propagation, frequency spectrum engineering and human exposure to electromagnetic fields.

Marián Možucha graduated from the Faculty of Natural Sciences, Comenius University, Bratislava, in 1995 and received the PhD degree in cartography and geoinformatics from the same university in 2004. At present he works for Trans World Radio — Slovakia in Bratislava. His professional domain is cartography programming connected with radio wave propagation.