Marián MOŽUCHA

CARTOGRAPHIC MODELLING OF INTERACTIONS OF FM SIGNAL WITH GEORELIEF

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Abstract: Calculations of optical visibility, insolation of georelief and spatial solar input are implemented into many GIS-es. But solar radiance is only an insignificant part of a huge frequency range of electromagnetic radiance around us. This article analyses a behavior of frequency modulated (FM) radio signal, and describes the interactions of FM radio signal with georelief, respectively with receiving antennas on it, on the level of a cartographic interpretation. The calculations run in a specialized program, containing modules for special morphometric analysis of georelief and analysis of radio visibility. Calculation process is decribed in block diagrams. Its results are map outputs of chosen parameters of radio visibility. Aim of this article is to point at an area that was wrongfully neglected in cartography and geoinformatics in Czech republic and Slovakia, and help develop it.

Keywords: GIS, optical visibility, radio visibility, geometrical optics, wave optics, georelief, curvature

Introduction

Principles of calculations of optical visibility, insolation of georelief, and surface solar input described mainly in J. Krcho (1965, 1967, 1970) are already implemented into many GIS-es, in the form of the modules (Page 1986, Dubayah, Rich 1995, Hofierka 1997). But solar radiance is a small part of huge frequency range around us. We can select a special range that is usable for a transfer of information – a radio communication. Frequency modulated (FM) signals means artificially produced electromagnetic waves of carrying frequency from 30 MHz to 300 GHz, with information modulated on it. FM signals are intensively used by various radiocommunication services – radio and television broadcasting, civil and military mobile communication, microwave connections, radio relays, radar detection and navigation etc. (Tab 1).

Tab. 1 Division of frequency band of radio waves used by radio communication

1 Internation. abbrev.	Frequency range (kHz)		Explanation
ELF	0.003 -	3	Extremely long waves
VLF	3 -	30	Very long waves
LF	30 -	300	Long waves
MF	300 -	3.000	Middle waves
HF	3000 -	30.000	Short waves
VHF	30.000 -	300.000	Very short waves (m)
UHF	300.000 -	$3.\ 10^6$	Ultra short waves (dm)
SHF	$3.\ 10^6$	$30.\ 10^6$	Super short waves (cm)
EHF	$30.\ 10^6$	$300.\ 10^6$	Extremely short waves (mm)

In: Klima, J.: Teória elektromagnetického poľa, 2004

Mgr. Marián MOŽUCHA, PhD., Trans World Radio – Slovakia, Banšelova 17, 821 04 Bratislava 2, e-mail: marian@twr.sk

This article will be focused on FM signal that propagates via air, along georelief, or in a relatively small distance above it. Georelief is a potential barrier for the FM signal propagated via troposphere. From viewpoint of a practical use it is necessary to know and analyse behaviour of propagated FM signal, respectively FM radio waves, and to describe its interactions with georelief.

System point of view

From system point of view, the FM signal is a part of electromagnetic field, generated between transmitter and receiver. FM signal is identified by its frequency, position of source, direction of propagation, and by carried information. FM signal interacts with other FM signals of the same or similar frequency, as well as with its environs (Fig. 1).

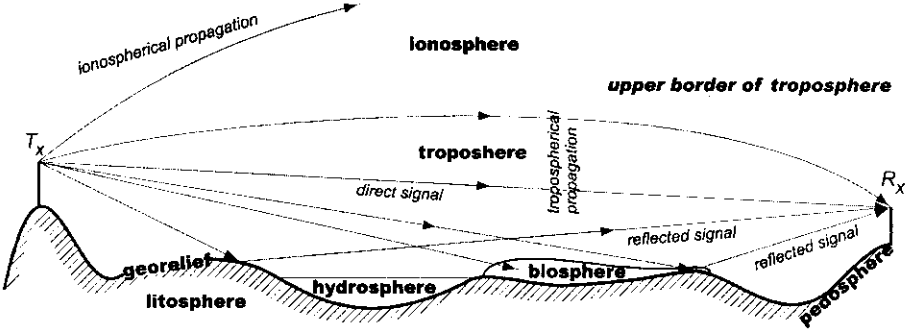


Fig. 1 System of FM signal propagated from transmitter (T_x) to receiver (R_x) within geographical sphere, and various modes of propagation from T_x to R_x

Georelief G_{RF} also belongs to the system where FM signal is propagated, and it is defined in papers of J. Krcho (1990, 2001) as spatial dynamic landscape subsystem. Its mathematical description is very complicated, however in principle, we can theoretically express it using system of differential equations. This solid but dynamic division line considered in the arbitrary scale 1:M_i (i =1, 2, ...), its distinctive level U_i, and without T time parameter as a static surface, described in the coordinates system $\langle O, x, y, z\rangle$ by a general function of two variables x, y, in form of $z = f(x, y)$. The altitude z is function of x, y position only. On the base of this function it is possible to generally express geometrical properties and geometrical structure of georelief, by means of differential geometry apparatus. Hence, georelief is described by the approximate function $z = f(x, y)$.

Set of morphometric parameters of G_{RF} (Krcho 1990, 1992, 1999) is expressed as:

$$G_{RF} = \{z, \Delta z, s_n, \gamma_N, A_N, (K_N)_n, (K_N)_t, K_r, N_nF, K_rF, \Delta N_n \ldots\} \qquad (1)$$

(Δz – relative altitude in the direction of slope curves, s_n – length of slope curves, ΔN_n- robustness of a form), where:

$$\gamma_N = \mathrm{arctg}\,(|\mathrm{grad}\, z|) = \mathrm{arctg}\left(\sqrt{z_x^2 + z_y^2}\right), \qquad (2)$$

$$A_N = \mathrm{arctg}\,(z_y/z_x)\,, \qquad (3)$$

$$(K_N)_n = -\frac{z_{xx}\, z_x^2 + 2 z_{xy} z_x z_y + z_{yy}\, z_y^2}{\left(z_x^2 + z_y^2\right)\sqrt{\left(1 + z_x^2 + z_y^2\right)^3}}, \tag{4}$$

$$(K_N)_t = -\frac{z_{xx}\, z_y^2 - 2 z_{xy} z_x z_y + z_{yy}\, z_x^2}{\left(z_x^2 + z_y^2\right)\sqrt{\left(z_x^2 + z_y^2 + 1\right)}}, \tag{5}$$

$$K_r = -\frac{z_{xx}\, z_y^2 + 2 z_{xy} z_x z_y + z_{yy}\, z_x^2}{\sqrt{\left(z_x^2 + z_y^2\right)^3}}, \tag{6}$$

$$(K_N)_t = K_r \sin \gamma_N, \text{ where :} \tag{7}$$

$$\sin \gamma_N = -\frac{\sqrt{z_x^2 + z_y^2}}{\sqrt{\left(z_x^2 + z_y^2 + 1\right)}}, \tag{8}$$

$$\Delta N_n = [(\Delta z_w)_i - \Delta n_i \operatorname{tg}(\gamma_N)_{str}] \cos(\gamma_N)_{str}, \tag{9}$$

We can also define a subset of parameters of georelief, selected on the basis of a relation to a FM transmitter, located on georelief:

$$G_{RF2} = \{z, \Delta z, \alpha, \gamma_{FM}, A_{FM}, (K_N)_{FM}, (\delta_{exp})_{FM}\}, \tag{10}$$

where:

$$A_{FM} = 180° - \alpha + \gamma_N = 180° - \alpha + \operatorname{arctg}(z_y/z_x) \tag{11}$$

is orientation of georelief (A_{pi} [x_{pi}, y_{pi}, z_{pi}]) to FM transmitter T_x as a point A_{vi} [x_{vi}, y_{vi}, z_{vi}] on georelief (fig.2), where the angle α is deviation of transmitter – receiver T_x – R_x line from x-axis of XY coordinates system. Variable α is computed from the relation:

$$\alpha = \arcsin\left(\frac{\Delta y_i}{Q_i}\right) = \arcsin\left(\frac{y_{pi} - y_v}{\sqrt{(x_{pi} - x_v)^2 + (y_{pi} - y_v)^2}}\right). \tag{12}$$

$$\gamma_{FM} = \gamma_N \cos A_{FM} = \operatorname{arctg}\left(\sqrt{(z_x)^2 + (z_y)^2}\right)\cos A_{FM} \tag{13}$$

is dimension of georelief slope in direction of propagated FM signal (Fig. 2) and:

$$(K_N)_{FM} = \frac{z_{xx}\cos^2\alpha + 2\, z_{xy}\cos\alpha\sin\alpha + z_{yy}\sin^2\alpha}{\left((1 + z_x^2)\cos^2\alpha + 2\, z_x z_y \cos\alpha\sin\alpha + (1 + z_y^2)\sin^2\alpha\right)\sqrt{\left(1 + z_x^2 + z_y^2\right)}} \tag{14}$$

is normal curvature in the direction of propagated FM signal and where $m = (dy/dx) = \operatorname{tg}(\alpha)$ (12) (according Krcho 2001, Možucha 2004).

$$\sin(\delta_{\exp})_{FM} = -\frac{z_x\,\Delta x_{vi} + z_y\,\Delta y_{vi} - \Delta z_{vi}}{\sqrt{z_x^2 + z_y^2 + 1}\,\sqrt{\Delta x_{vi}^2 + \Delta y_{vi}^2 + \Delta z_{vi}^2}} \tag{15}$$

$(\delta_{\exp})_{FM}$ is angle of irradiation of georelief with FM signal.

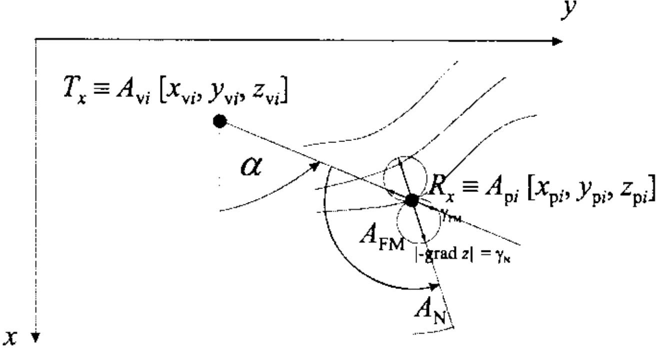


Fig. 2 Display of an angle A_{FM} on a map

Electromagnetic parameters of FM signal in the article are mentioned and implemented only in the scale necessary for understanding of basic phenomenon proceeding at its interactions with georelief.

FM signal is propagated from a point source of radiance into surrounding space. On the route from T_x to R_x an attenuation of electromagnetic field strength is increasing due to reduction of the radiated output, and due to interactions with georelief, water, and gases in troposphere. Inhomogeneities in spatial distribution of electromagnetic parameters of the field of FM signal are emerging.

Propagated FM signal behaves as a ray as well as a wave. Its behaviour can be expressed by means of two sets of relations. The first set reduces a propagation of FM signal to purely geometrical relations, it means counts with a zero value of it wavelength (geometrical optics – **GO, Fig.** 3a). Second set of relations expresses propagation of FM signal on the basis of **wave substance of** electromagnetic radiance (wave optics – VO, Fig. 3b).

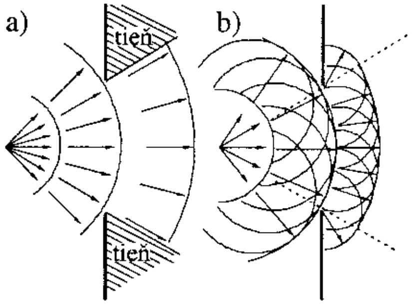


Fig. 3 Propagation of FM signal a) in sense of geometrical optics, b) in sense of wave optics
(From: Prokop – Vokurka, 1982)

The second mentioned set takes wavelength, electrical properties of a field of the FM signal, polarisation, and so-called Hugyens principle into account. (Hugyens principle says that every point of electromagnetic field of FM signal is a sum of all other points on the wavefront, it means on the plane of points with the same phase. Hence, every point can become a secondary radiator – FM signal can „overcome“ barriers with sufficient curvature – see Fig. 3b).

By means of these sets – GO a VO – we can explain interactions of **FM** signal on its route from T_x to R_x (both connected with georelief):

- **refraction** in troposphere due to spatial change of its parameters (discrete or continual), respectively in transition into an environment with different parameters (due to Snell law of refraction) (Vavra and Turan 1988). Its trajectories in vacuum, and in troposphere on short distances have a shape line; in inhomogeneous environ, respectively on the border between two different environs its trajectories are getting a shape of irregular curve – the are propagated on the trajectories with the highest velocity, it means toward to lower values of refraction index (Prokop and Vokurka 1982, Fig. 4). Within a standard atmosphere (Prokop and Vokurka 1982), FM signals have a shape of regular (monotonous) curves.

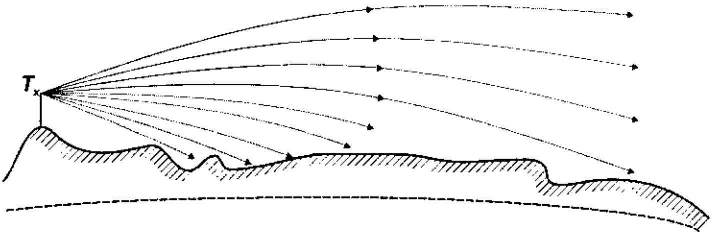


Fig. 4 Refraction of FM signal when propagated within troposphere

- **reflection** from a barrier, and **absorption**, by a barrier. Georelief is impermeable for propagated FM signal, it has ability to reflect, and absorb it. According to the theory, there is no perfect absorbing, respectively reflecting plane. (Born and Wolf 1975)
- **diffraction** of trajectories of FM signal - in geometrical interpretation – due to change of physical parameters, eg. On the border of two different environs: air and sharp barriers, air and water. In such cases, electromagnetic wave produces some other wave, which is impossible to express by geometrical optics. (STN IEC 60050, 2000) (Fig. 5). Range of diffraction depends on frequency of FM signal. In case of sunrays, diffraction is insignificant (Born and Wolf 1975).

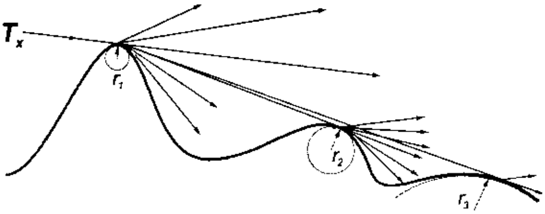


Fig. 5 Diffraction on a barrier - georelief with various curvatures (multiple case)

- **diffusion**, it means diversification of trajectories due to impact on a vertically divided, diffusive surface - soil, rocks, etc. – or on a group of quite numerous and accidentally located barriers or other inhomogeneities, that are bigger than a wavelength of FM signal (Klima 2004). Due to diffusion, reflected waves are impossible to express by means of geometrical optics.
- **propagation of energy in form of ellipsoid**. Even in case of existing optical visibility between T_x and R_x, distinctive reduction or increasing of field strength can be measured or expected in R_x. Distinctive transport of energy between T_x and R_x is processed in a space described as **Fresnel**

ellipsoid – an ellipsoid with its width as a function of wavelength and distance of a point A_i from T_x, respectively R_x (ITU-R 1145 2000, Hall and Barclay and Hewitt 1996, Fig. 6a – 6e).

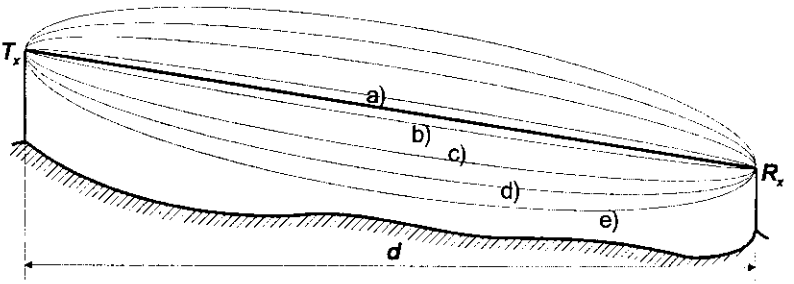


Fig. 6 Fresnel ellipsoid between T_x and R_x for FM signal of various wavelengths
a) with the highest frequency, e) with the lowest frequency

Influence of georelief as a barrier

Influence of a plane and the Earth curvature

In the global distinctive level, the biggest barrier effect to the propagation of FM signal is the curvature of the Earth. Thanks to that, every FM signal propagated within troposphere has its theoretical radio horizon, in a certain distance from Tx, it is its most distant border of interaction with georelief. Its distance is a function of altitude of Tx and of the points of georelief on the route Tx – Rx, respectively of their mutual relation.

On an ideal plane, at sufficiently big difference between height h_1 of T_x and length of route d_{tr} between T_x and R_x, visibility reaches the border of maximum optical horizon, given by curvature of the Earth. Neglecting a vertical differentiation of georelief, calculation of distance of this horizon means calculation of Q_1 a Q_2 – sides of two rectangular triangles, according the relation (1) (Fig. 7) and in assumption that $h_1 > 0$ and height of R_x $h_2 > 0$. In sense of papers M. Možucha (2003a, 2003b) and of these conditions, the horizon is in the distance d $(d \geq d_{tr})$:

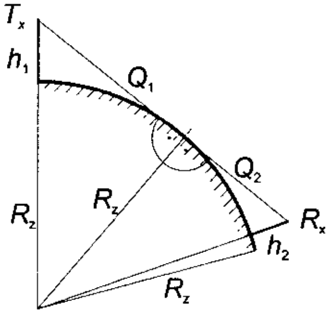


Fig. 7 Principle of calculation of optical horizon
(neglecting vertical differentiation of georelief)

$$d = Q_1 + Q_2 = \sqrt{(R_z + h_1)^2 - R_z^2} + \sqrt{(R_z + h_2)^2 - R_z^2} \tag{16}$$

$$d = \sqrt{2R_z h_1 + h_1^2} + \sqrt{2R_z h_2 + h_2^2} \cong \sqrt{2R_z}\ (\sqrt{h_1} + \sqrt{h_2}) \tag{17}$$

At refraction of FM signal in the standard atmosphere (average values of pressure, temperature gradient etc.) we get an approximative relation for a *radio horizon* (Klima and Klimeš 1988), where radius R_z of the Earth is replaced with an effective radius R_{ef} ($R_{ef} = 4/3\ R_z$):

$$d = \sqrt{2R_{ef}}\ (\sqrt{h_1} + \sqrt{h_2}) \qquad (18)$$

Influence of vertically differentiated georelief as a reflection plane

FM signal on its route from T_x to R_x is disturbed in result of multipath propagation of FM signal, it means by the FM signal reflected from natural and artificial barriers - mountains, high buildings, chimneys, water tanks, etc. The reflected FM signal has a certain time delay, and it causes a distortion of received information by R_x. Measure of this distortion depends on mutual phase difference of direct and reflected wave and its mutual strength (Klima – Klimeš, 1988). The biggest distortion is in the case that direct and reflected signals have an equal strength and the time delay is a half of a wavelength, respectively odd multiple of half-wavelength.. A vector addition of direct and reflected waves can cause increasing of field strength on R_x up to double, in dependence from h_1, or reduction of field strength down to absolute minimum. There is a rule of simultaneous receiving of direct and reflected FM signal within vertically differentiated georelief. The same situation is within high-rise flats of urban structures (Linhart 1981, Grosskopf 1991, Černohorský and Nováček 2001).

Influence of georelief forms

Analytical forms of georelief

Basic classification used in morphometric analysis of georelief into nine forms of georelief as a combination of three forms of normal curvature (convex, linear and concave) and three forms of horizontal curvature (convex, linear and concave) in an infinitely small environs of a point of georelief (Krcho 1990) can be reclassified into three analytical shapes, from the viewpoint of propagation of FM signal. In dependence of the axis a, b, c we can classify it as a sphere ($a = b = c$), cylinder ($a = b$, $c = \infty$) or plateau, ($a = 0$, $b = c = \infty$) (Raida 2001). By combination of these classes we can define any selected georelief, or an object on it.

Impacted waves incite on radiated georelief or an object new waves, called *diffraction waves.* These waves are propagated from the surface, not from T_x. Diffraction waves are produced only by such waves that impact on edges and rimes of an object, on border of different radiuses of curvature of georelief or surface of an object.

Once the diffraction waves leave an object, we can apply a geometrical optics on them. Amplitude of diffraction waves is in the direct proportion to amplitude of impacted wave. Ratio of proportion is called *diffraction agent.* Measure of diffraction agent is expressed as a function of local *parameters of* surface of the object, it means electromagnetic parameters, and have a radius of curvature R of the surface in the point where the ray slides on the surface. For all protracted objects that have the same curvature on a part of their surface, the diffraction agent has the same value. It must be the same as diffraction agent on exact cylinder with the same curvature (Hansen 1981).

Macroforms

By increasing of hierarchical order of the georelief form, the influence of other parameter is increasing – slope, orientation, and a vertical differentiation.

The most suitable georelief type from the viewpoint of optical visibility is a plateau that on the optical horizon d_0 created by curvature of the Earth is upper, and shifts the optical horizon further from the point of view ($d_0 \rightarrow d_1$) (Fig. 8). In sense of papers J. Krcho (1990), on macroform of higher order F_{XX} (the Earth) the concave georelief macroform F_{XX} (F_{KK}) of F_{XX} (F_{KX}) is created.

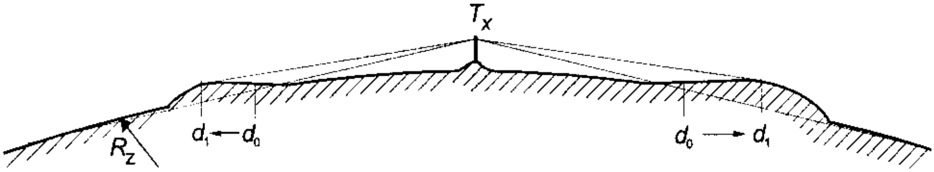


Fig. 8 The most suitable georelief type from the viewpoint of optical visibility

From the viewpoint of reception quality of FM signal, the most important thing is to detect formation of inhomogeneities in spatial distribution of the field strength of FM signal. For a good quality of received FM signal the high georelief edges that stop propagation of FM signal are the most suitable – field strength lower down to threshold – or they serve just as secondary radiator of FM signal – with a local reach.

In sense of papers Prokop and Vokurka (1982) and Klima and Klimeš (1988), convex forms of georelief F_{XX} – mountain ridge can affect as a planar radiator – if the vertical maximums are sufficiently sharp and orientation of the ridge is transverse to propagated FM signal, it means $A_{FM} \rightarrow \pm\alpha$ (Fig. 9).

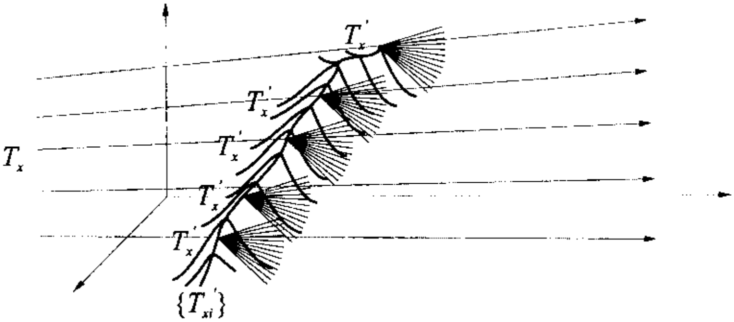


Fig. 9 Georelief as a planar radiator, respectively set of secondary radiators Tx'

In certain cases they can affect strong attenuation – if vertical maximums of a given georelief macroform have $(K_N)_{FM} \rightarrow 0$, if the ridge is oriented paralelly to propagated FM signal ($A_{FM} \rightarrow 90° \pm \alpha$), and if the length of the ridge is sufficiently long and wide – Fig. 10. (Hall and Barclay and Hewitt 1996).

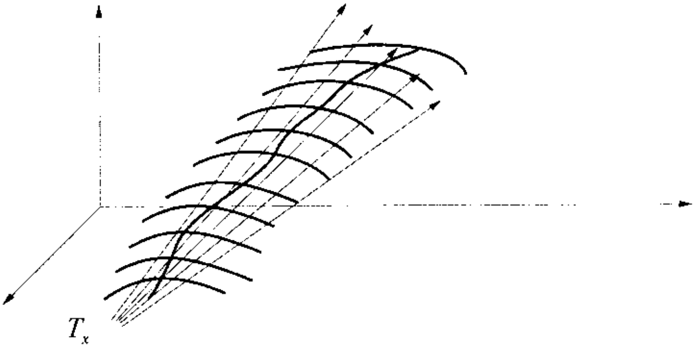


Fig. 10 Georelief as a distinctive attenuator for propagated FM signal

The most distinctive inhomogeneities in spatial distribution of the field strength of FM signal are displayed above significantly vertically differentiated georelief; permanent oscillation of the parameter γ_{FM} between positive and negative values causes fluctuation of field strength of FM signal. Though a big area can be covered with such FM signal, the subjective quality of received signal is not granted, the intensive noise, propagation disturbance, drops, etc.

Developed program *Šírenie*

Let us consider the selected area situated north from Bratislava (Malé Karpaty mountains), in a shape of 13 x 8 km quadrangle. The FM transmitter Kamzík is part of the selected area (in a left down corner of the map outputs). Digital terrain model (DTM) was created from he data provided by Topographic institute in Banská Bystrica, Slovakia, with distinctive level of 100 m. First, an optical visibility was calculated on the selected area. (Fig. 11). Map outputs and other outputs, are results of calculations within application developed by the author, and implemented into the program *Šírenie.* Calculated values are presented in a program *SURFER*.

In sense of wave optics, a radio visibility is expressed as a portion of rate of obscurence of Fresnel ellipsoid (Fig. 11).

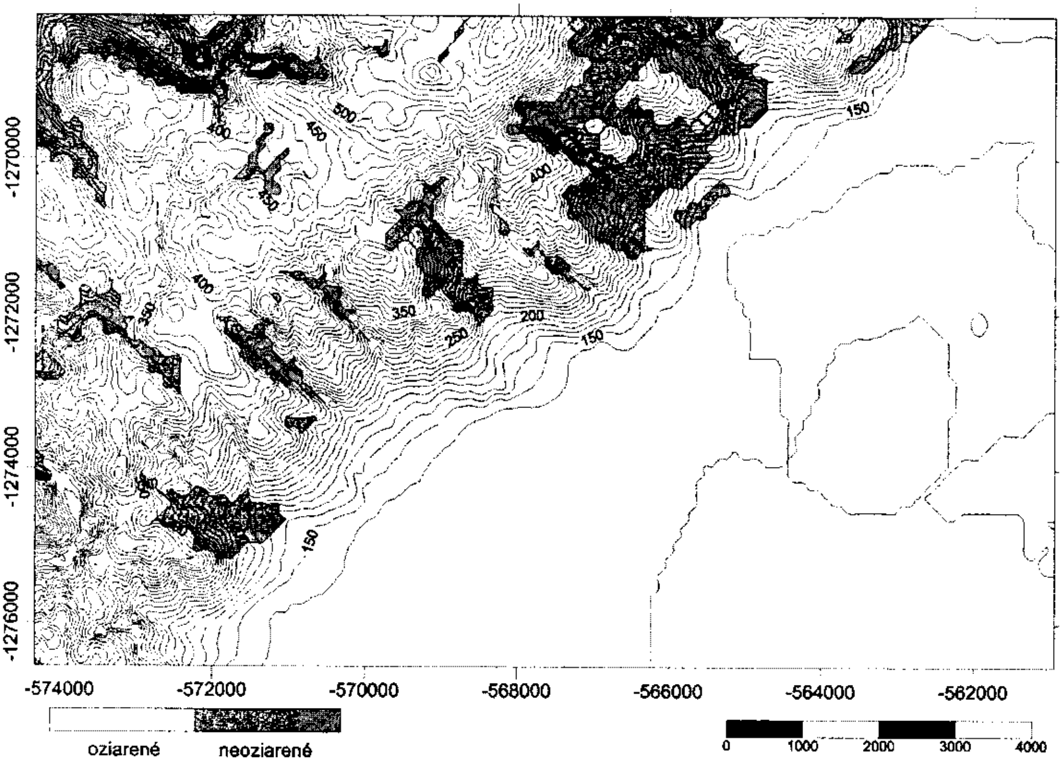


Fig. 11 Optical visibility of georelief of FM signal, in sense of geometrical optics

On the basis of long-term experiences, it can be said that such defined relative clearance of the route $T_x - R_x$ satisfactorily displays a spatial distribution of FM signals field strength (Prokop and Vokurka 1982, Možucha 2003b).

Radius r_{fz} of Fresnel ellipsoid is (Vavra and Turan 1989):

$$r_{fz} = \sqrt{\frac{d_1 d_2 \lambda}{d_1 + d_2}} \quad . \qquad (4)$$

where d_1 is a distance between point on the route and T_x, and d_2 is distance between point on the route and R_x. Distance between georelief and the Fresnel ellipsoid can be expressed with a simply relation where h is a height of the Fresnel ellipsoid axis, and z is an adjusted altitude.

$$h_{fz} = (h - r_{fz}) - z \tag{5}$$

On the basis of relations (4) and (5) we can quantitatively express a stage of obscurence – relative clearance (RC) of the ellipsoid (in %) (Fig. 12):

$$RC = 100(2r_{fz} + h_{fz})/(2r_{fz}) \tag{6}$$

For the route $T_x - R_x$ the maximum value of RC is chosen (taken from the values of the points of the route), omitting close environs of T_x and R_x, for other wave optics dependent phenomena prevail there (Halland Barclay and Hewitt 1996).

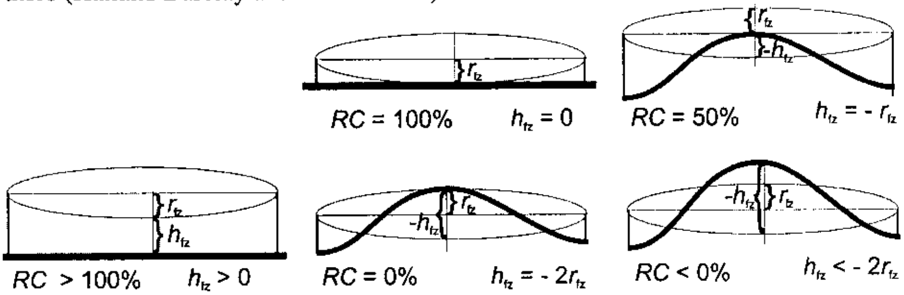
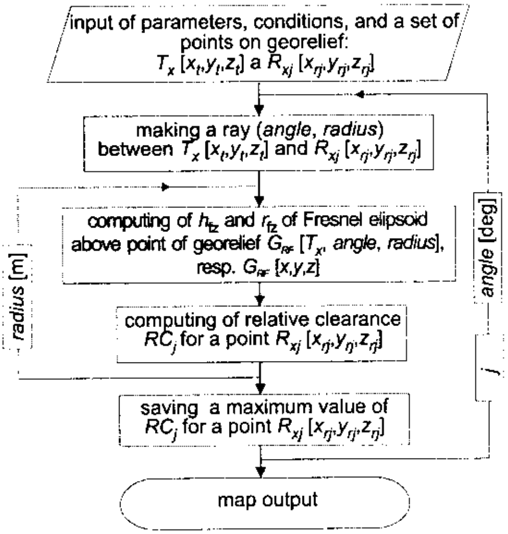


Fig. 12 Expressing of obscurence of Fresnel ellipsoid (RC), in sense of wave optics



Obr. 13 Calculation process of relative clearance (RC)

We reckoned a relative clearance RC of georelief of FM signal propagated from FM transmitter Kamzík on frequency $f = 104{,}8$ MHz (FM radio Okey), $f = 2$GHz (mobile communication) a $f = 10$ GHz (microwave communication), according the process displayed in Fig. 13. The results of calculations are displayed in Fig. 14, Fig. 15 and Fig. 16.

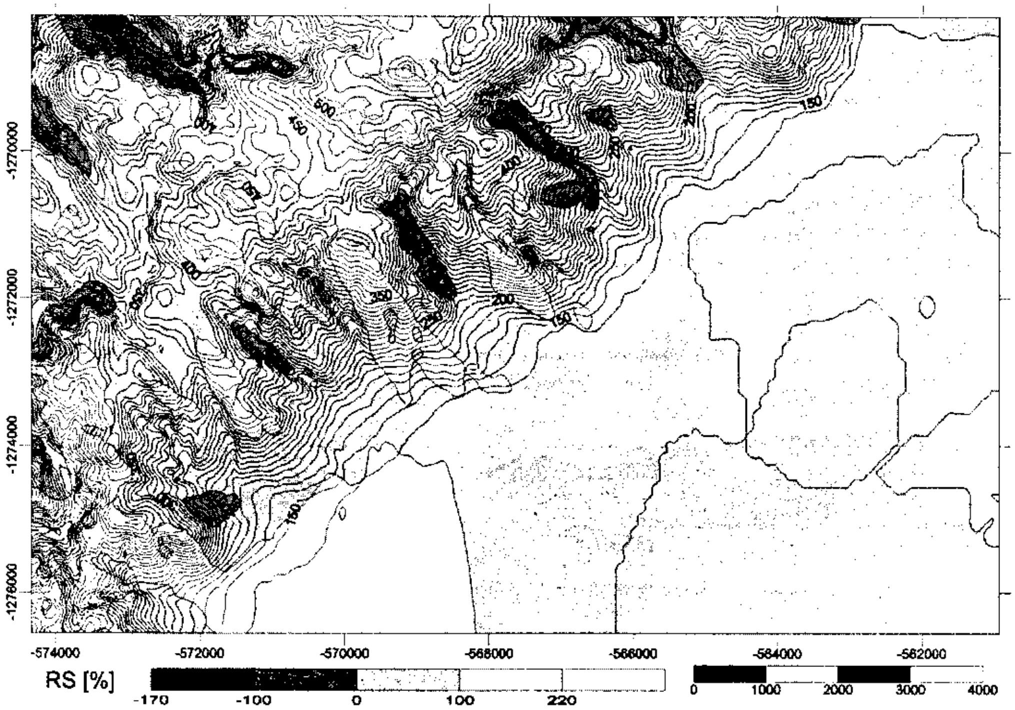


Fig. 14 Relative clearance RC of FM signal, frequency f = 104,8 MHz, in sense of wave optics

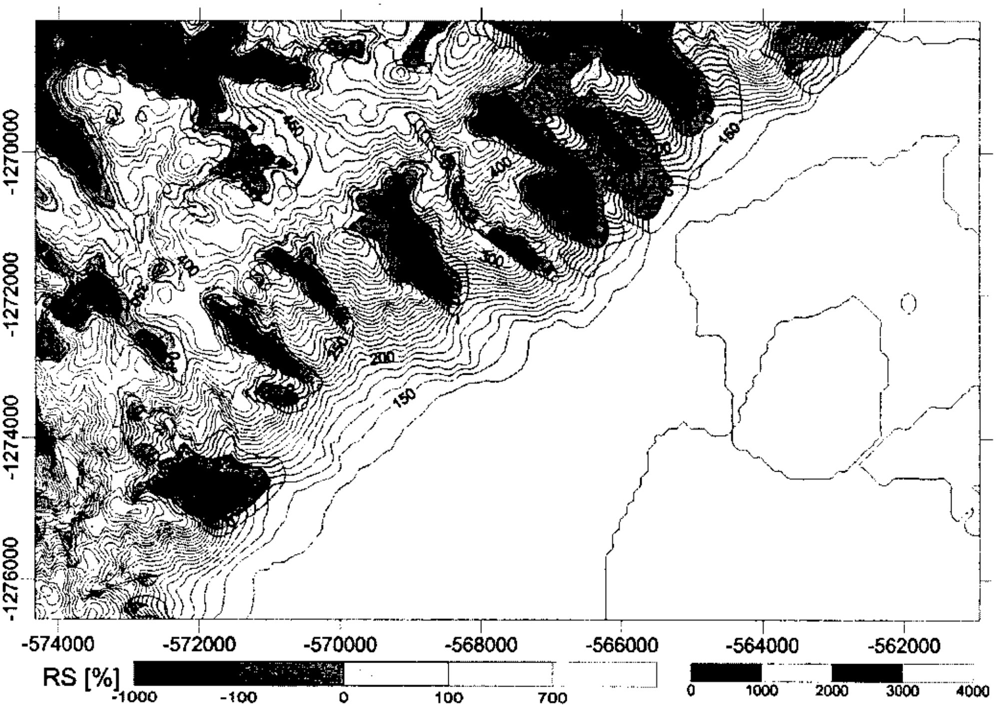


Fig. 15 Relative clearance RC of FM signal, frequency f = 2 GHz, in sense of wave optics

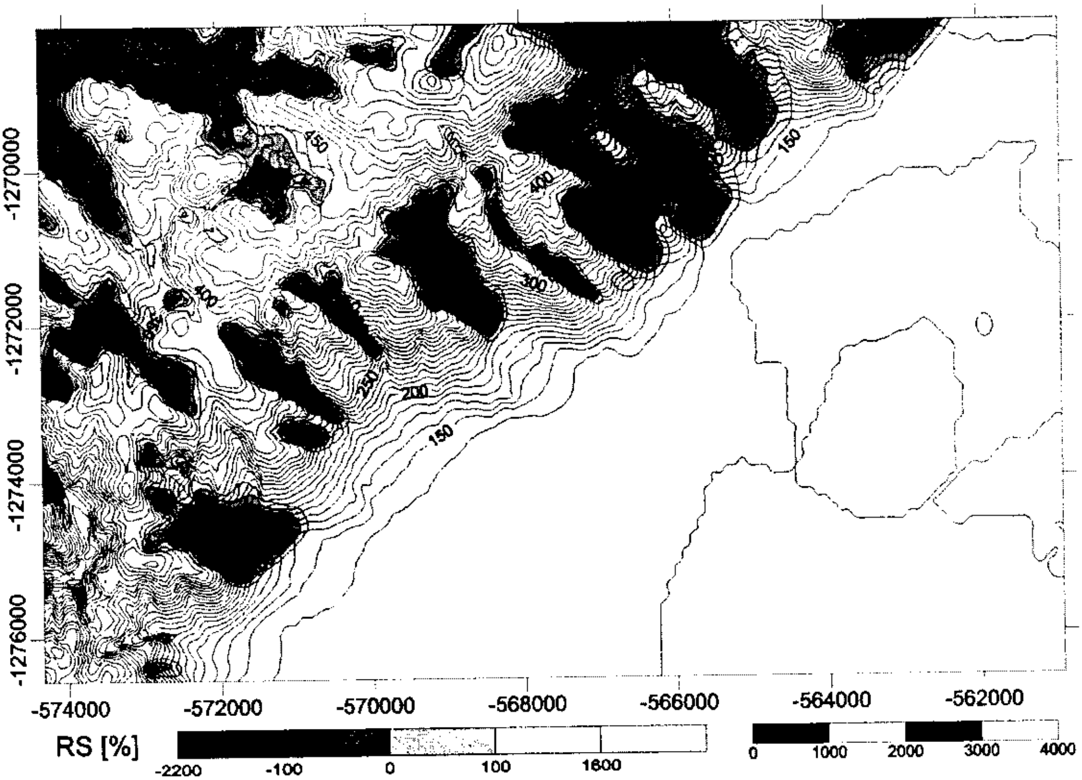


Fig. 16 Relative clearance RC of FM signal, frequency f = 10 GHz, in sense of wave optics

Conclusion

Map outputs displaying a relative clearance RC of FM signal at various frequencies on the route $T_x - R_x$ (fig. 14–16) prove influence of georelief on a measure of interactions of FM signal with georelief via its altitude, and in dependence from frequency of FM signal. From this point of view it is visible that the role of georelief grows together with increase of frequency, respectively values of *RC* on the border of visibility are changing much more rapidly, and the diffraction phenomena is getting limited.

These map outputs make the interactions of propagated FM signal with georelief more understandable, and help interpret of calculations (predictions) of spatial distribution of field strength of FM signal.

The cartographic modelling of these phenomena has its interdisciplinary importance; and can serve as a preparation at decision making over location and setting up of potential FM transmitter. It also points to the possibilities of geographical information systems (GIS), developing of methodics and its implementations in a form of an independent programs or a implemented dynamic linked libraries (dll files) (ArcView, GeoMedia, etc.).

Literature

BORN, M., WOLF, E. (1975). *Principles of Optics. Electromagnetic Theory of Propagation, Interference and Diffraction of Light.* Oxford (Pergamon Press).

ITU-R Report 1145 (2000). *Propagation over irregular terrain with and without vegetation.* Geneva (ITU – R, CD ROM).

ČERNOHORSKÝ, D., NOVÁČEK, Z. (2001). *Antény a šíření rádiových vln (in Czech).* Brno (FEI VUT, Ústav radioelektroniky).

DUBAYAH, R., RICH. P. M. *Topographic solar radiation models for GIS.* International Journal of Geographical Information Systems. 9, pp. 405-19.

GROSSKOPF, R. (1991). Field strength prediction in the VHF and UHF range including multipath propagation. *Proceedings 7th International Conference Antennas and Propagation* (ICAP 1991), York, Conf. Publ. 333, Vol.2, London, s. 965-967 (IEEE Press).

HALL, M. P. M., BARCLAY, L. W., HEWITT, M. T. ed. (1996). *Propagation of Radiowaves.* New York (IEEE Press).

HANSEN, R. C. ed. (1981). *Geometric Theory of Diffraction.* New York (IEEE Press).

HOFIERKA, J. (1997). Direct Solar Radiation Modelling within an Open GIS Environment. In: HODGSON, S., RUMOR, M., HARTS, J. J. (eds.): *Geographical Information '97: Third Joint European Conference & Exhibition on Geographical Information Proceedings,* Vienna, Austria, April 1997, 1, pp. 575-584.

KLIMA, J., KLIMEŠ, J. (1988). *Výpočet intenzity elektromagnetického poľa v pásmach VKV a UKV (in Slovak*. Praha (Nadas).

KLIMA, J. (2004). *Teória elektromagnetického poľa (in Slovak).* Banská Bystrica (Univerzita Mateja Bela).

KRCHO, J. (1990). *Morfometrická analýza a digitálne modely georeliéfu* (in Slovak). Bratislava (Veda).

KRCHO, J. (2001). *Modelling of georelief and its geometrical structure using DTM; positional and numerical accuracy.* Bratislava (QIII).

LINHART, E. a kol. (1981). *Pozemní pohyblivé služby* (in Czech). Praha (Nadas).

MOŽUCHA, M. (2003). Interakcie FM signálov s georeliéfom a ich zobrazenie v 2D a 3D priestore – priestorová presnosť (in Slovak). In: Čižmár, J., Čuláková, K.: *Geoinformatizácia kartografie.* Zborník 15. kartografickej konferencie vo Zvolene. Zvolen, pp. 192-201 (Kartografická spoločnosť SR).

MOŽUCHA, M. (2003). *Bariérové efekty georeliéfu pri šírení rozhlasového FM signálu v prostredí geografickej sféry* (in Slovak). Dizertačná práca. Bratislava (Univerzita Komenského Prírodovedecká fakulta).

PAGE, J. K. ed (1986). Prediction of solar radiation on inclined surfaces. *Solar Energy R&D in the European Community,* Series F: Solar Radiation Data, Vol. 3, Dordrecht (D. Reidel Publishing Company).

PROKOP, J., VOKURKA, J. (1982). *Šíření elektromagnetických vln a antény* (in Czech). Praha (SNTL).

RAIDA, J. et al. (2001). *Multimediální učebnice elektromagnetických vln a mikrovlnné techniky* (in Czech). Brno (Ústav rádioelektroniky FEI VUT) http://wes.feec.vutbr.cz/~raida/multimedia/index.html.iso-8859-2.

STN IEC 60050. (2000). *Medzinárodný elektrotechnický slovník,* Kapitola 705 – Šírenie rádiových vĺn. Bratislava (Slovenský ústav technickej normalizácie).

Resumé

Kartografické modelovanie interakcií FM signálu s georeliéfom

Frekvenčne modulované (FM) signály v rozpätí 30 MHz až 300 GHz ako komunikačný nástroj využívajú rozličné rádiokoumunikačné služby – rozhlas, televízia, FWA, GSM/UMTS mobilné siete, radary, ap.

FM signál šírený vzduchom bol opísaný ako subsystém interagujúci a limitujúci georeliéfom. Opísané a vysvetlené boli základné typy šírenia a interakcií FM signálu vo vzťahu ku georeliéfu.

Vplyv georeliéfu na šírený FM signál bol vysvetlený na analytických typoch georeliéfu (guľa, plocha a valec), na základných formách georeliéfu (konvexná, konkávna, lineárna), a na vybraných makroformách georeliéfu (ideálna rovina, pohorie ako plošná anténa, pohorie ako tlmiaca bariéra).

Jeden z vybraných parametrov rádiovej viditeľnosti – relatívna svetlosť (RC) Fresnelovho elipsoidu na trase vysielač (T_x) a prijímač (R_x) bol počítaný pomocou aplikácie vyvinutej v prostredí Visual Basic.

Modul Fresnel, súčasť programu Šírenie, bol opísaný v blokovom diagrame, sústavou vzťahov, a použitý na výpočet relatívnej svetlosti RC v DTM – oblasť okolo FM vysielača Kamzík (Bratislava). Vo výpočtoch boli použité tri frekvencie FM signálu, aby sa testoval význam georeliéfu pri rádiovej viditeľnosti FM signálu.

Porovnanie mapových výstupov relatívnej svetlosti na frekvencii 104,8 MHz, 2GHz a 10 GHz pomáha pochopiť úlohu veľkosti frekvencie FM signálu a nadmorskej výšky georeliéfu na šírenie FM signálu. Kartografické modelovanie tohto javu (RC) má interdisciplinárny význam – môže slúžiť na predprípravu pri rozhodovaní o lokalizácii a nastavení výkonu potenciálnych FM vysielačov. Zároveň však poukazuje na možnosti geografických informačných systémov, rozvinutie metodík a ich implementáciu formou samostatných programov (Sirenie.exe), skriptov (Sirenie.bas) alebo nadstavieb formou dll knižníc (ArcView, GeoMedia ap).

Obr.1 Systém šírenia FM signálu z vysielača (T_x) na prijímač (R_x) v prostredí geografickej sféry a rôzne módy šírenia z vysielača na prijímač
Obr.2 Zobrazenie uhla AFM na mape
Obr.3 Šírenie FM signálu a) v zmysle geometrickej optiky, b) v zmysle vlnovej optiky (podľa: Prokop – Vokurka, 1982)
Obr.4 Refrakcia FM signálu pri prechode troposférou
Obr.5 Difrakcia na prekážke- georeliéfe s rôznou krivosťou
Obr.6 Fresnelov elipsoid medzi vysielačom a prijímačom pre FM signál rôznej vlnovej dĺžky a) signál s najvyššiou frekvenciou, e) signál s najnižšiou frekvenciou
Obr.7 Princíp výpočtu optického horizontu (pri zanedbaní vertikálnej členitosti georeliéfu)
Obr.8 Najvhodnejšia makroforma georeliéfu z hľadiska optickej viditeľnosti
Obr.9 Georeliéf ako plošná anténa, resp. množina sekundárnych žiaričov T_x.
Obr.10 Georeliéf ako výrazný tlmiaci faktor pre šírenie FM signálu
Obr.11 Optická viditeľnosť georeliéfu pred FM signálom, v zmysle geometrickej optiky
Obr.12 Vyjadrenie stupňa zakrytia Fresnelovho elipsoidu (relatívnej svetlosti RC), v zmysle vlnovej optiky
Obr.13 Postup výpočtu relatívnej svetlosti RC
Obr.14 Relatívna svetlosť RC FM signálu s frekvenciou f = 104,8 MHz, v zmysle vlnovej optiky
Obr.15 Relatívna svetlosť RC FM signálu s frekvenciou f = 2 GHz, v zmysle vlnovej optiky
Obr.16 Relatívna svetlosť RC FM signálu s frekvenciou f = 10 GHz, v zmysle vlnovej optiky

Lektoroval:
Prof. RNDr. Jozef KRCHO, DrSc.,
Univerzita Komenského, Bratislava