Microcomputer modelling, analysis and planning in terrestrial television broadcasting [a)]

Digital terrain maps, spectrum-related data banks, and computer simulation help to examine the operation of existing television broadcasting networks and find a place for new stations

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ABSTRACT

This article describes a simulation model of a national network of television broadcasting stations. The performance of a station depends on its sitting and its antenna, on its radiated power and frequency, and on surrounding terrain and electromagnetic environment. All these factors can be analysed using the simulation model. Simulation can help in the maintenance of the existing television stations and in the planning of new stations by making "what-if" considerations fast, simple and effective. The simulation model has been developed as an engineering aid in planning the low-power rebroadcasting stations.

1. Introduction

1.1 Background

Our society places increased demands on television. There are more television receivers in use throughout the world than there are telephones.[1] Broadcasting networks involve thousands of television transmitters. Without careful co-ordination, they would all dissolve in a chaos of mutual interference. High-power transmitting stations are coordinated at international conferences, [2] but many low-power television stations only require national co-ordination. Such stations, of less than 1 W and up to 1000 W, can operate unattended and are more and more popular. For only a fraction of the cost of high-power stations, they provide services complementary to the main broadcasting network, for example, local information, local market advertisement, services for special interest groups, clubs, minority communities, ethnic groups and church communities. In the United States, a local broadcast station is seen as a basic cultural force in the community it serves. [3]

Another application of low power stations is the delivery of television programmes to small communities in remote areas. Still another application is the filling of coverage gaps. Such gaps in the coverage by terrestrial and satellite transmitters are due to shadowing and reflections by terrain obstacles and man-made structures: although the signal can be delivered by cable, low-power rebroadcasting is often more practical. In spite of a spectacular growth of cable and satellite technology, terrestrial broadcasting remains the principal means for delivery of television to the home, and heavy investment in the

[a)] *Od redakcji TiTI: Niektóre rysunki zostały ponownie narysowane.*

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equipment indicates that it will continue for a number of years to come. The number of low-power stations is growing fast both in large cities and in small localities in remote areas. According to the statistics of the European Broadcasting Union (EBU), about 95% of all television transmitting stations in Europe are low power.[4] In Australia, about 80% of all television transmitting stations are translators.[5]

With the privatization of the broadcasting sector, a great demand for additional transmitters is to be expected. For example, some 6000 applications for such stations were registered in the United States during a period of one year. [6] However, to find space for a new station is not an easy task in regions with well-developed television broadcasting networks. Each application requires a detailed evaluation to ensure that the proposed station will neither suffer nor create interference. Often an existing station also requires an evaluation. A new transmitter, even distant, can modify signal environment, and man-made structures can modify the signal propagation conditions.

Ultimately, any evaluation of a station, existing or planned, is based on field measurements. From these measurements, one determines the station coverage and identifies any coverage deficiency. The volume of such measurements increases with the number of transmitters and with the coverage area. In the measurements, test transmitters must often be used to generate a test signal. [7, 8] As such experiments are expensive, weather-dependent and time-consuming, one avoids them as much as possible, especially in inaccessible areas.

1.2 Development of automated tools

Automated tools have been developed to reduce the labour and cost of the field experiments. [9] Signal levels can be predicted instead of being measured, and computers can do the job, if supplied with propagation models and data. In order to have accurate predictions, propagation models involving detailed topographic data must be used. [10-12] Manual extraction of the data from source maps for each propagation path is a time-consuming task that can be automated by converting these maps into computer-readable form. [13, 14] The data of transmitting and receiving stations, however, must still be prepared and introduced manually. The ultimate step is, therefore, to integrate all relevant models and data into one system that can simulate the operation of the complete transmitter network. [15] This article discusses the implementation of such a simulation system.

Computer simulation can radically reduce the number of the required "real life" experiments and offer substantial gains in cost and in time. What is, however, even more important is that such an approach can help in an economic use of the radio-frequency spectrum, as more decision variants can be examined within the imposed time and cost limits. The essential characteristic of simulation is the use of models for experimentation. A simulated experiment is less expensive and avoids all risks and difficulties of the "real world". It is easier to prepare, to perform, to control, to modify and to repeat. Another important characteristic of the simulation is its ability to examine systems that exist only in conceptual form, or are intractable to experimental manipulation and/ or exact mathematical treatment. Having a simulation model of a system, it is quite easy to alter the parameters of the model and observe how it operates with these changes. The conclusions drawn from these observations are applicable to the original system if the model and input data are correct. [16] The simulation can only give an estimate of the actual performance of the station, and an experimental verification in the field is usually required, but the volume of field measurements is minimized.

Underlying the software advances is the steady rise in hardware performance. The first automatic systems required large computers and highly qualified professional staff. The high hardware cost and complex user's interface limited their application to a few moneyed centres. The progress in computer technology has opened new perspectives. As recently as 1970, nearly 100% of the world's computer power was concentrated in large computers. By 1990, such machines held less than 1% of the world's computer power. Personal microcomputers, available at everyone's desk, became as powerful as an early 1970s mainframe, for a fraction of its price. Therefore, the interest in microcomputer-aided spectrum engineering has been fast growing.[17] The demand for microcomputer software is great, but only a few minicomputer spectrum engineering systems have been described in the literature [18, 19], possibly because firstly, frequency-spectrum engineering tasks are computing-intensive and involve huge collections of data (until recently, they exceeded the capabilities of microcomputers), and secondly, the spectrum-engineering software market is limited. [20] These factors do not encourage software developers.

1.3 Organization of the article

The rest of the text is organized as follows: section 2 describes the databases, among which, in particular, are digital terrain maps. The following section describes how the model can be used to analyse the performance of an existing television network, for example to identify the coverage gaps. Section 4 discusses the planning process of a new television station and its harmonization with the existing television network and topographic environment. Section 5 discusses the overall performance and limitations of the model and gives results of its verification. Section 6 contains concluding remarks. The presented system was demonstrated at seminars of the International Frequency Registration Board (IFRB) [21] and at other occasions. It is a new, simplified version of the software developed earlier for a large computer and described in reference [14].

2. The databases

The main aim of the simulation model is to imitate a network of television broadcasting stations. Another objective is to facilitate the storage, retrieval, and analysis of the information that is needed to evaluate the operation of the stations. The model integrates several elements, discussed below and shown in figure 1. It incorporates data banks, radio-wave propagation algorithms and electromagnetic compatibility (EMC) criteria. These are based, as much as possible, on the CCIR texts.

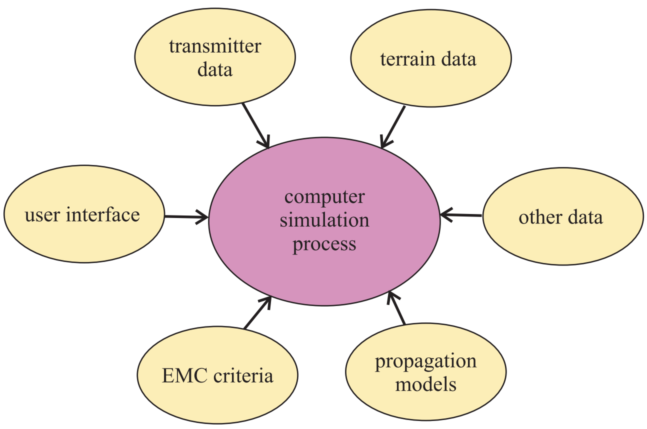
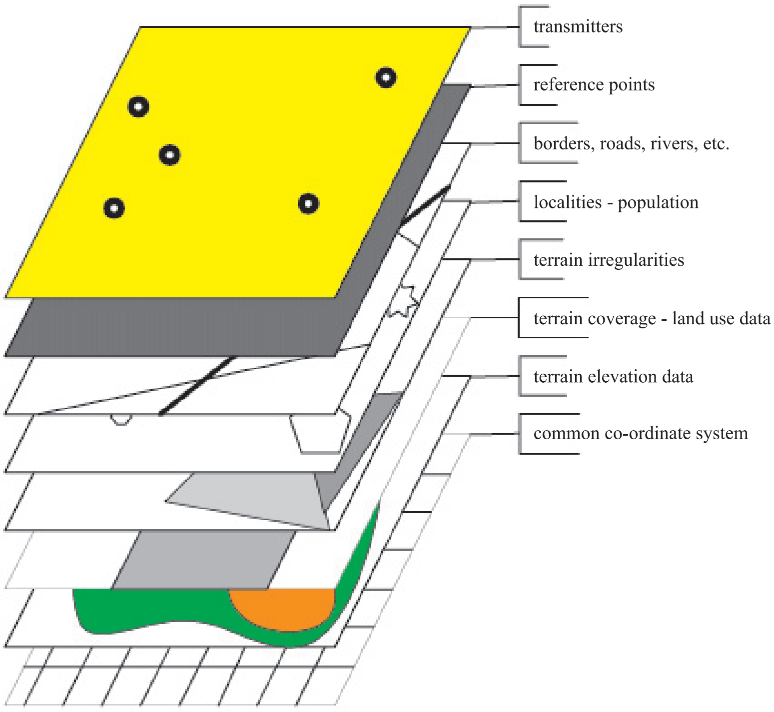


Figure 1-*Simulation model (simplified diagram)*

2.1 Geographical database

Numerous geography-related data are necessary to evaluate the effects of VHF/UHF signal propagation. In addition to the terrain relief, information is required about administrative boundaries, population distribution, roads, power line networks, etc. Usually, that information is extracted from various sources. Since no common standards exist, rarely the same scale, projection and co-ordinate systems are used. The data must be made mutually consistent and converted to a digital form before they can be used in a computer system. All geography-related data are thus referred to the Earth ellipsoid, independently of the projection system adopted in the source maps, and the points on the Earth surface are identified by their geographic coordinates (figure 2).



Object	Resolution/ Cell size
Individual terrain points	50 m
Lines (roads, borders, etc.)	100 m
Terrain elevation (regular points)	250 x 250 m
Terrain coverage/ land use	250 x 250 m
Terrain irregularity (“Delta h”)	25 x 25 km

Figure 2*-Geography-related data use common co-ordinate system. Data from maps in various scales can be automatically adjusted and superimposed*

2.1.1 Data representation

The way the geographic data are stored in a computer depends on the required accuracy and available computer memory. Table 1 compares the approximate resolution of various maps. A 1:50000 map offers about 50 m of the surface resolution and about 1m of the height resolution. Usually, such a precision is quite sufficient for planning UHF/ VHF television broadcasting. There are two methods of computer representation of geographic data. The first one uses regularly spaced discrete data, and the other irregularly spaced data, with interpolation between the discrete data points. In our simulation model, we use both methods. Such a combination results in the increased accuracy of terrain representation and economic use of the computer memory.

Table 1. Approximate resolution of various maps

Map scale	Surface resolution* (m)	Height resolution** (m)
1:1000000	1000	20
1:500000	500	10
1:250000	250	4
1:100000	100	2
1:50000	50	1
1:25000	25	0.5
1:10000	10	0.25

** The surface resolution is defined here as the distance (in terrain) between two points that spaced by 1 mm on a given map.*
*** The height resolution is defined here as one-tenth of the basic height-contour interval on a given map.*

- **Regularly spaced data**

The basic topographic data are the terrain elevations at regularly spaced points with implicit co-ordinates. Each point represents a terrain cell, in the form of a square. The location of an individual point is not specified but is calculated using its row number, column number and cell size. The data are stored in the matrix form. The regular structure assures a quick access to the data by its address derived from the geographical co-ordinates. The cell size must be small enough to reflect the terrain details with required accuracy. According to our experience, in hilly and undulated regions, the maximum cell size is about 250 m. In flat areas, larger cells of about 500m give practically the same elevation accuracy. On the other hand, the smaller the cell size, the greater is the number of cells for a given territory. Table 2 shows the approximate relationship between the cell size and cell number. For example, a territory of 1000 x 1000 km needs 4 million 500-m cells, or 400 million 50-m cells. In our simulation model, various scales of map and cell sizes can be used. The capability of automatically combining different map scales is one of the most important features of the system.

- **Irregularly spaced data**

In addition to the data just described, our digital terrain model also contains irregularly spaced data with explicit co-ordinates. These are terrain elevations at specific points that are important for the radio wave propagation, like mountain peaks or passes. In hilly regions, the number of such points reaches up to a few percent of the regular lattice points. Figures 3A and 3B show fragments of the topographic data bank.

Table 2. Cell size and cell number for an area of 1000 x 1000 km

Linear cell size [m]	Angular cell size on the Equator [arc-second]	Number of cells
1000 m	32.3"	1 million
500 m	16.2"	4 million
250 m	8.08"	16 million
100 m	3.23"	100 million
50	1.62"	400 million
25	0.81"	1.6 billion
10	0.32"	10 billion
1	0.03"	1000 billion

Table 3 compares cell sizes of digital terrain maps used in various countries. Many of these maps have been created for the purposes of the mobile radiocommunication service in the VHF/ UHF frequency bands.[22, 23] Digital maps with cell size of the order of 20 m are now in preparation in several countries.

Table 3. Cell size of various digital maps in use

Country	Cell size [m]	Notes
Canada	~500	Whitteker J. H.: Propagation prediction from a topographic data base, IEEE International CommunicationsConferenCe-ICC'83 (Boston, Massachusetts, 19-23 June 1983), Vol. 1, pages 44-48
Czech & Slovak Federal Republic	~100	Bak P.: private communication (1991)
Finland	~200	Karjalainen J.: private communication (1991)
France	~100	Meyer S. and Pihan J.: Coverage prediction for rural telephony systems, IEEE International CommunicationsConference-ICC'83 (Boston, Massachusetts, 19-23 June 1983), Vol. 1, pages 72-76
Germany	~100	Loew K. and Lorenz R. W.: Determination of service areas for mobile communication with a topographical data base, IEEE International Communications Conference-ICC '83 (Boston, Massachusetts, 19-23June 1983), Vol. 1, pages 54-58

Table 3 (cont.) Cell size of various digital maps in use

Ireland	1000	EBU: Planning parameters and methods for terrestrial television broadcasting in the VHFIUHF bands (Tech. 3254,1988)
Italy	~230	Del Duce V., Isola C. and Virgadamo G.: Interactive graphic procedure for broadcasting frequency management making use of terrain data bank on high-definition CAD workstations, Telecommunication Journal, September 1990, Vol. 57, No. IX, pages 620-629
Italy	~400	Freni A., Giuli D. and Fossi M.: Simulation models for meteorological radar siting, Alta Frequenza, 1989, Vol. LVIII, No.4, pages 419-426
Japan	~500	CCIR: Handbook on spectrum management and computer-aided techniques, ITU (Geneva, 1987)
Japan	~250	Niimi H., Hirabayasi T. and Kajiyama M.: Computer aided analysis of propagation characteristics using topographical mesh-data basis, IEEE International Communications Conference-ICC '83 (Boston, Massachusetts, 19-23 June 1983), Vol. 1, pages 49-53
Netherlands	~100	Mawira A. and Stortelder B.: The development of propagation models and CAD tools for the planning of mobile communication networks, Alta Frequenza, February/March 1988, Vol. LVII, No.2, pages 83-88
Poland (since 1950s)	~1000	Struzak R. G.: Radio frequency spectrum management; Telecommunication Journal, July 1981, Vol. 48, No. VII, pages 410-413-250
Poland	~250	Since 1975
South Africa	400	In rural flat areas, Koffeman A.; private communication (1992)
South Africa	200	In urban areas and mountainous terrain; Koffeman A.: private communication (1992)
Sweden	~50	Wieweg L.: private communication (1992)
Switzerland	~250	Kartachoff P.: private communication (1991)
United Kingdom	~500	Ibrahim M. F. A., Parsons J. D. and Dadson C. E.: Signal strength prediction in urban areas using a topographical and environmental database, IEEE International Communications Conference-ICC '83 (Boston, Massachusetts, 19-23 June 1983), Vol. 1, pages 64-67
United States	~100	Spies K. P. and Paulson S. J.: TOPOG: a computerized worldwide terrain elevation data base generation and retrieval system, NTIA-Report 81-61 (1981)
Yugoslavia	~100	Starcevic D.: Production of digital model of topographic map for radiocommunication planning, Proceedings of the Fifth International Wroclaw Symposium on Electromagnetic Compatibility--EMC 80 (17-19 September 1980), Part 2, pages 477-485

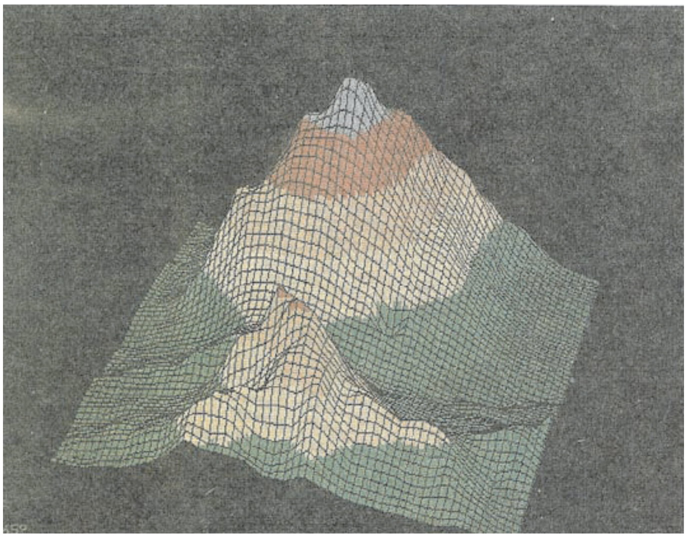


Figure 3A- *Terrain elevation data bank: pseudo-three dimensional visualization. A fragment of the terrain surface displayed on the screen. Terrain elevations at line intersections are stored in the computer memory. False colours and visual perspective are added to create a realistic appearance of the terrain. The scale of the picture and position of the observation point can be modified. Such a representation can be used for error detection in the database, as errors tend to give rise to unnatural-looking features*

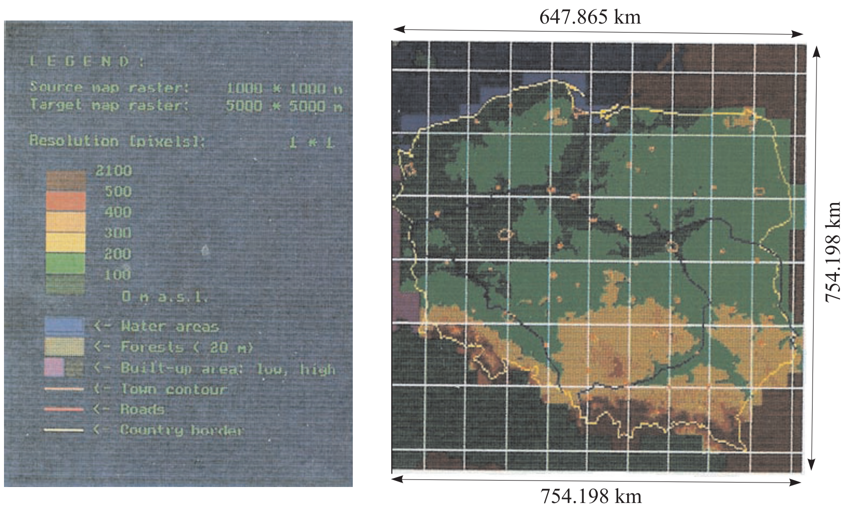


Figure 3B- *Terrain elevation data bank: two-dimensional visualization*

Right window*: physical map of the country derived from the topographic data bank, as displayed on the screen. A colour scale is used to differentiate terrain elevation classes, the scale can be modified. The horizontal and vertical lines on the map are the meridians and parallels. The country borders, main rivers and major cities are visible*

Left window*: each pixel on the map represents an area of 5 x 5 km, derived from a digital working map with a resolution of 1 km. The source digital map has the resolution of 50/50 m*

- **Terrain irregularity data**

For fast propagation predictions in accordance with the relevant CCIR Recommendation, [24] there is a map of terrain irregularity factor "Delta h" provided in digital form. The country is divided into geographic rectangles of approximately 25 x 28 km, and 12 numbers are stored for each rectangle. These are the ~h values at 12 azimuths taken every 30°.

- **Other data**

Associated with each cell is the information about the terrain coverage within the cell. The coverage is ranked in eight categories that include forests, built-up areas of various intensity, open area, sea, etc. Other information stored deals with the administrative borders, roads, contours of cities and localities, power lines, etc. These were coded by digitizing the co-ordinates of selected points along each line.

2.1.2 Data organization

The total area of the country has been divided into 60 "pages" or geographic rectangles of one degree latitude by one degree longitude. Each page of the digitized map is kept in a separate file, identified by the geographic co-ordinates of the south-west corner. Within the file, data are organized as a matrix $[h_{c,r}]$ where column index c = 0...287 and row index r = 0...443 for the smallest cells:

$$\begin{bmatrix} h_{0,0} & \dots & h_{0,287} \\ \dots & \dots & \dots \\ h_{443,0} & \dots & h_{443,287} \end{bmatrix}$$

Digital maps with larger cells are also possible. These are represented by smaller matrices. Each element of the matrix is 16-bit long. Twelve bits represent terrain elevation, covering the elevation span from the sea level up to more than 4000 m. Three bits describe the terrain coverage, allowing for a differentiation among eight coverage classes. One bit contains information on whether or not there exists an associated file with the specific terrain points. Such files are also identified by geographic co-ordinates. The data are record-structured, and each record contains three co-ordinates (x, y, z) of a point. The linearly-related geographical data are also record-structured. Each record contains (x, y) co-ordinates (6-bit real numbers), interpreted as the geographic longitude and latitude in radians. The terrain information covering the whole territory of Poland occupies about 20 megabytes disk space.

2.1.3 Data capture

The data were extracted manually from the 1:50000 source map, as automated tools were unavailable at the time of the data bank creation. Special temperature-insensitive transparencies were used for that purpose. A precise grid of geographic lines was drawn on each transparency, defining cell borders every 12.5 seconds in the north-south direction and roughly 8 seconds in the east-west direction. It is about 5 mm on the map, or 250 m in terrain, the same in both directions. The grid was then superimposed on the map, and the terrain height was coded at the intersections of the grid lines. The elevation values were estimated by visual interpolation from adjacent isarithms. Over flat regions it was sufficient to read the elevation every second line.

Conversion of data from the source map to the computer introduces inaccuracies, and special precautions were undertaken to minimize errors (figure 4). The elevations were read by well-trained professionals, recorded on magnetic (audio) cassette and then typed independently on two sets of perforated cards. Typing errors were identified by the computer and checked against the master map. To identify read-out errors, the elevation gradient between adjacent cells was examined. In case of inconsistency, the data were checked again. The inevitable random errors in elevation are estimated to be in the order of one-tenth of the terrain irregularity [25] ~h, or one-tenth of the contour interval over flat areas.[26] The uncertainty in reading the x, y position on the map is in the order of 1 mm (50 m in terrain).

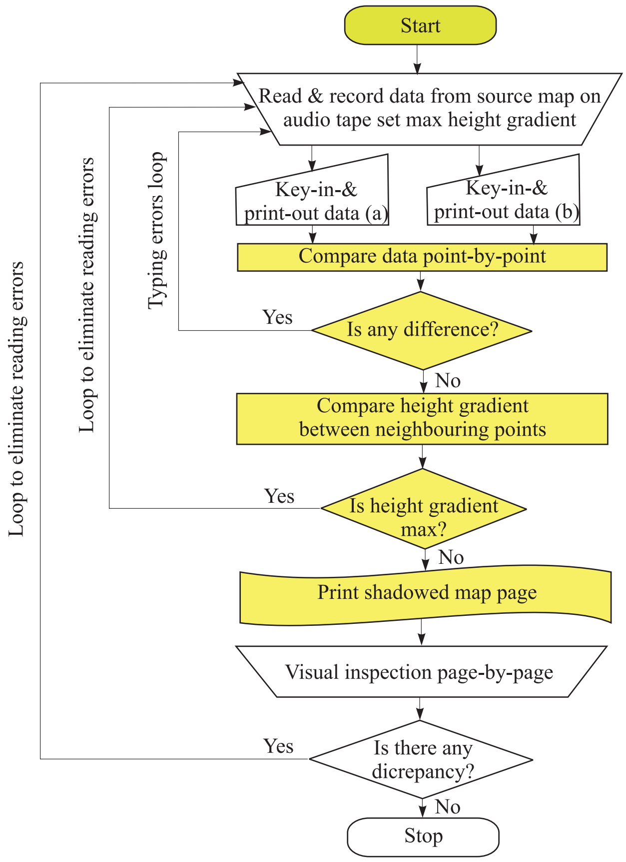


***Figure 4** – Extracting data from the source map (simplified diagram). The yellow-marked tasks are performed automatically*

2.2 Transmitter database

The transmitter database incorporates all needed information about television transmitting stations. The technical information includes the geographic co-ordinates, frequency channel, offset, polarization, effective antenna height and power radiated at various azimuths. The data format is compatible with the CCIR Recommendations and ITU/IFRB standards. The administrative data include the country, name and status of the station. There are three status categories foreseen. All legally operating stations belong to the first category. Their data must remain intact. The second category includes the stations that do not physically exist but are notified, or coordinated. Their data should not be changed, except for minor modifications allowed. The third category embraces all planned or tested stations whose data can be modified at will when alternative solutions are to be examined.

3. Analysing station operation

3.1 Tasks performed

With the simulation model, the manager can analyse the operation of an existing television broadcasting network and assess its performance. He can quickly identify all wanted and unwanted signals at any given location, and answer questions such as:

- what is the coverage area of the station? is there any coverage gap?
- what is the interference threat?
- what television programmes can be received at a given location?

Table 4 contains a non-exhaustive list of tasks that are facilitated by the simulation model. These are discussed in the following sections.

3.2 How it works

The simulation model is interactive with a user-friendly graphical interface. Such a visualization provides the most efficient way of man-machine communication, keeping in mind the large band of the human visual system and the computer speed. Relevant information is presented in the form of colour maps and diagrams on the screen in various scales, depending on the user's selection. All operations previously carried out on paper maps are performed on the cathode ray tube display with the computer aid. Special windows and cursors help to communicate with the computer. The results of simulation can also be presented in numeric form and/or written into computer files for further reviewing, processing, or printing. The model involves all major parameters of television rebroadcasting stations, shown in table 5.

3.3 Coverage analysis

In order to estimate the extent of the station coverage area at VHF and higher frequencies, visibility tests are usually performed. The classic approach involves the performance of such tests in the field in "real life" conditions, on a suitable topographic map, or on a scaled "physical" relief terrain model. [27] The terrain relief is analysed and the line-of-sight (LOS) coverage maps are produced. Such maps identify "shadow" areas (with excess attenuation due to terrain shielding) and "visible" areas. In our approach, the tests are accomplished in the computer memory, using the digital terrain data bank.[28] To produce a LOS map, the region considered is divided into small cells. The size of these cells is independent of the dimension of the cells of the digital terrain map. Each cell is represented by a point. The position of the transmitting antenna, borders of the region to be analysed and receiving antenna height are determined by the user. Two heights of receiving antenna are provided, maximal and minimal. The software simulates the displacement of the receiving antenna from one point to another, over the entire region. For every point, the terrain elevation profile between the transmitting and receiving antennas is produced, and the LOS is constructed. An alternative is to construct and examine the first Fresnel zone ellipse. (The elevation profile is discussed in the following section.) Then the relative position of the line against the terrain elevation profile is analysed (figures 5A, 5B and 5C).

Table 4. Examples of tasks performed automatically with the simulation model

• Determination of equipment characteristics
• Determination of signal environment at a given location
• Determination of the coverage area of transmitting station
• EMC examination
• Extraction and analysis of terrain elevation profile
• Extraction of terrain coverage data
• Field-strength prediction of wanted signals
• Field-strength prediction of unwanted signals
• Great circle computations of distance and bearing
• Maintenance of signal environment documentation
• Maintenance of technical documentation of stations
• Production of documents for frequency co-ordination/notification
• Production of various extracts, reports and maps
• Simulation of field-strength measurements
• Simulation of various experiments in the field
• Spectrum analysis

Table 5. Main characteristics of television rebroadcasting stations

• Power radiated by transmitter
• Transmitter frequency
• Transmitting antenna: height directive radiation pattern polarization
• Transmitting station site
• Minimum signal level
• Receiving antenna height directive radiation pattern polarization
• Reception frequency
• Receiving station site
• EMC scenario

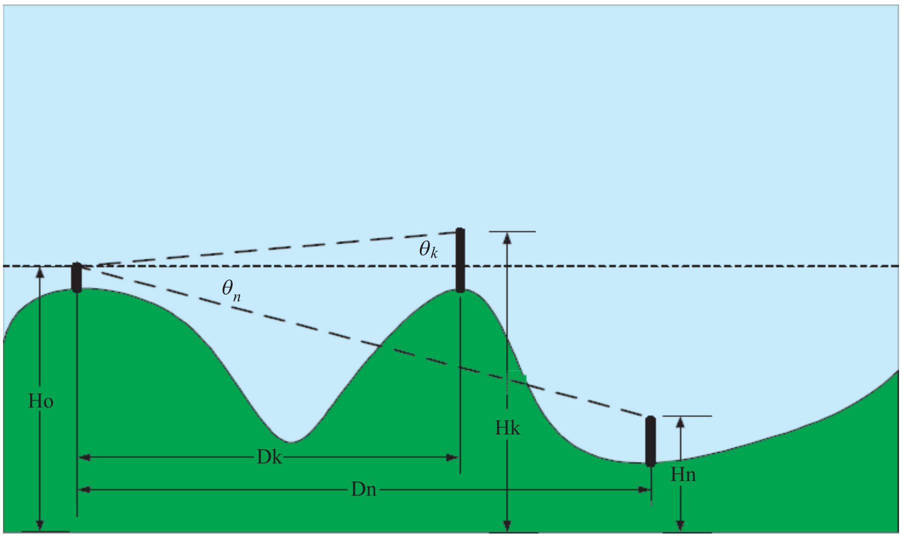


***Figure 5A**. LOS-maps: visibility test (principle). Indexes "0" and "n" indicate the endpoints of the propagation path. H0, H1, H2, ..., Hn are the elevations and D1, D2, ..., Dn are the distances of successive points from the point "0" along the path.*

Let $\theta_k = \arctan\left(\frac{H_k - H_0}{D_k}\right)$, *k = 1, 2, ..., n. If* $\theta_i < \theta_n$, *i = 1, 2, ..., (n –1) then the n-th point of the path is visible from point "0".*

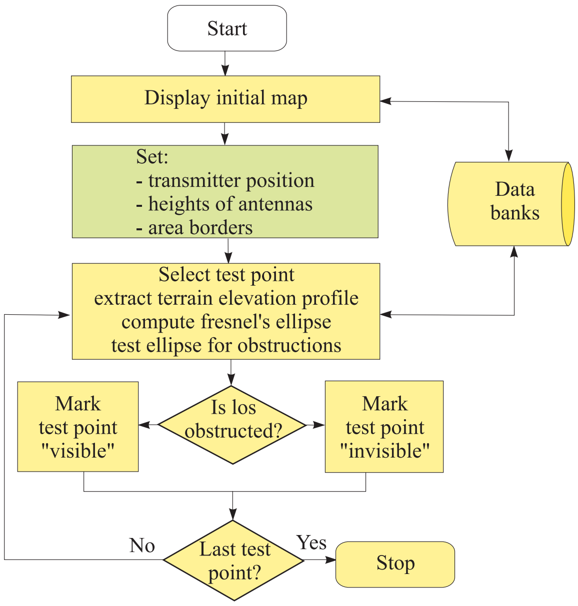


***Figure 5B**-LOS maps: production process (simplified diagram). The yellow-marked tasks are performed automatically. Instead of the LOS, the first Fresnel zone may be produced and examined for terrain obstructions*

3.4 Terrain elevation profile analysis

Terrain elevation profiles are automatically generated by the software, given the transmitter and receiver locations. For that purpose, a geographic map with two cursors is provided on the screen. One cursor symbolizes the transmitter and the other represents the receiver. Each can be moved freely by the user. Their current geographic co-ordinates are displayed in separate windows on the screen, together with the local terrain elevation, antenna height and terrain coverage symbol. The software extracts the terrain profile from the database along the great circle path connecting the transmitting and receiving antennas. The effective Earth's radius is introduced to allow for the tropospheric refraction of electromagnetic waves. To accelerate computations, the great circle path is approximated by a number of loxodromes.

The great circle is the shortest path between two points on a sphere. The loxodrome, or rhumbline, is the path of constant heading between two points on the Earth's surface; it intersects all lines of longitude at the same angle. On the Mercator projection, it is represented by the straight line between the two points. The software generates co-ordinates of 400 uniformly spaced points along the path, and determines the terrain elevation at each point. For points not included in the terrain database, linear interpolation between the nearest four database points is applied. If there is a specific terrain point (peak) in the vicinity, the result is corrected by taking the elevation of that point into account. In addition to the terrain elevation profile, the computer determines the terrain coverage, bearings and distance between the antennas, the first Fresnel zone, and parameter Delta h. Figures 6A and 6B illustrate the process.

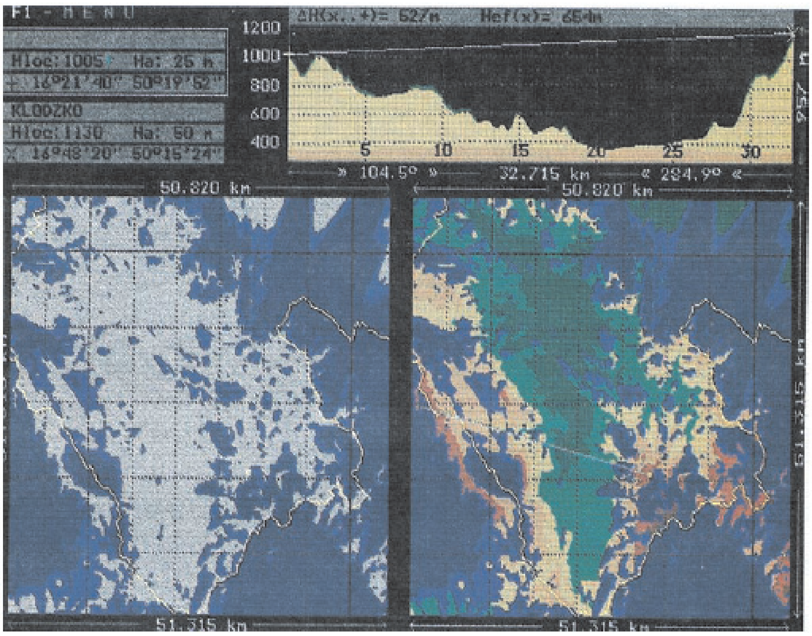


Figure 5C*-LOS maps: example*

Lower-left window*: map showing visible (grey) and invisible areas (blue and dark blue) of the region. The blue colour means that the LOS between the transmitting and receiving antennas is obstructed. The blue and dark-blue colours correspond, respectively, to the minimum and maximum receiving antenna height above the ground. These heights are selected by the user. Visible are: the position of the transmitting antenna (yellow point), geographic coordinates (vertical and horizontal black dashed lines), border of the country (yellow line) and distances (white lines outside the window)*

***Lower-right window**: the same as the lower-left window but with more details. The visible additional elements are: one position of the receiving antenna (the left end of the LOS), the transmitting antenna position and LOS (grey line from the transmitting antenna), and terrain elevation (various colours)*

***Upper-right window**: terrain profile between the two antennas. Visible are: distance and elevation markers, LOS connecting the antenna centres, direction angles and distance between the antennas (the bottom line), and propagation information specific to the path (the top line). The Earth curvature is corrected for diffraction effects*

***Upper-left and middle-left windows**: terrain elevation, antenna height and geographic co-ordinates of the transmitting (x) and receiving (+) antennas*

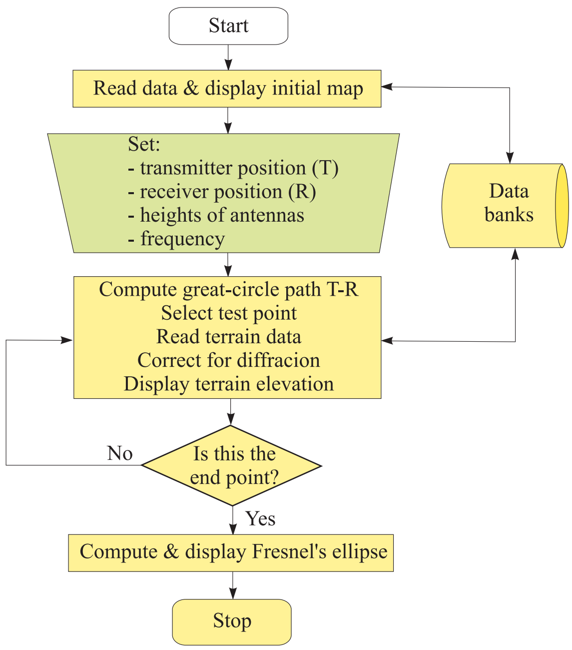


***Figure 6A**- Terrain elevation profile: production process (simplified diagram). The yellow-marked tasks are performed automatically*

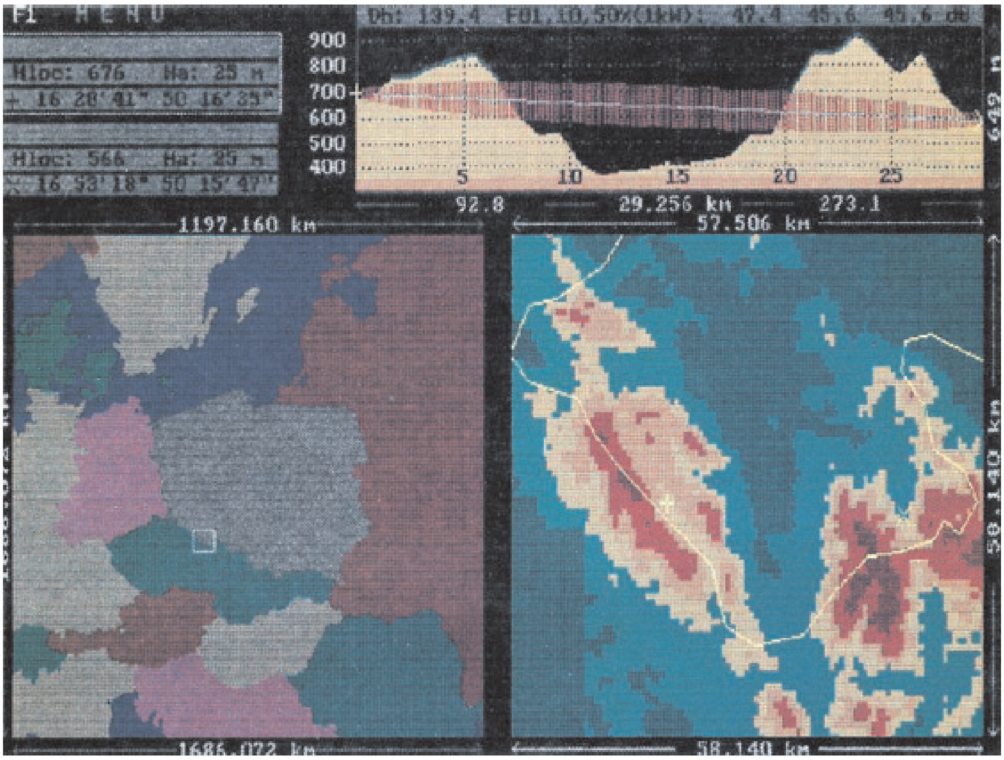


Figure 6B *- Terrain elevation profile: visualization*

Lower-left window*: administrative map of Central Europe (status of 1989). Visible are various countries and seas. The small (white) square near the centre marks the region displayed in the adjacent window. The distances are indicated outside the window*

Lower-right window*: a more detailed physical map of the region displayed in the adjacent window. The markers (+, x) indicate the positions of the transmitting and receiving antennas, respectively. Their co-ordinates are shown in separate windows in the left upper-side of the screen. The terrain elevation profile between the antennas is displayed in a separate window in the upper part of the screen. The user can move the antenna positions freely. Visible are the border of the country (yellow line), terrain elevation (represented by coloured pixels), and distances (white lines outside the window)*

Upper-right window*: terrain elevation profile between the transmitting and receiving antennas (+, x) automatically extracted from the data bank. Visible are: the distance and elevation markers and scales, LOS connecting the antenna centres and first Fresnel zone. The Earth curvature is corrected for diffraction effects. The direction angles and distance between the antennas (the bottom line) and propagation information (the top line) are also shown*

Upper-left and middle-left windows*: transmitting and receiving antennas data. Shown are: the terrain elevation, antenna height and geographic co-ordinates*

Note*: The interrelated information displayed in various windows is automatically updated.*

3.5 Field-strength prediction

The software automatically performs the propagation predictions necessary for the analysis of station operation. There are two approaches to field-strength prediction. The first is based on the analysis of many thousands of measurement results. It uses a set of curves indicating how the field strength changes with distance, without involving details of the path between the transmitter and receiver. The second approach employs calculations based on optical theories. It takes account of the unique terrain characteristics of the propagation path involved. The second method is generally more accurate than the first, but requires a large amount of detailed data. The software incorporates both. The first one is automatically selected if the propagation path is not covered by the digital map. In such a case, CCIR propagation curves are used (see reference [23]). The second approach is automatically applied if detailed terrain elevation and coverage along propagation path data are available in the computer memory. The field strength is determined for 1%, 10% and 50% of the time. Corrections for attenuation by forests and built-up areas are included, as appropriate. These models are described in reference [29]. Figure 7 shows the results as they appear on the screen.

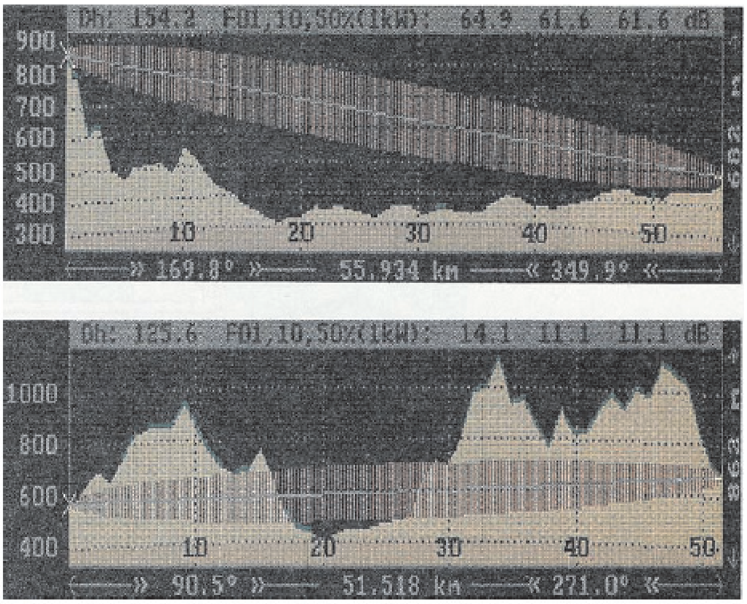


***Figure** 7-Point-to-point propagation prediction: visualization of the results.*

***The top line** indicates the terrain irregularity factor Delta h of the propagation path and field strength in dB(uV/m) for 1 kW e.r.p. exceeded for three different percentages of time (1%, 10%, and 50%). Visible is the terrain elevation profile along the propagation path.*

***The bottom line** shows the bearing angles and distance between the transmitting and receiving antennas.*

***The right scale** indicates the elevation in meters above the sea level.*

***The bottom scale** shows the distance in kilometres, and the right scale the elevation span in meters*

***Upper window**: case of the first Fresnel zone free; note the signal level about 60 dB*

***Lower window**: case of the first Fresnel zone obstructed; note the signal level about 10 dB*

3.6 Signal environment analysis

The model simulates two kinds of signal measurements, one using a field-strength meter, and another using spectrum analyser. In both cases it assumes an ideal equipment, i.e. a directive antenna without side- and back-lobes and spectrum analyser without spurious responses. For that purpose, tile model uses a transmitter working data file, terrain data bank and propagation models described in previous sections. The working file may contain all transmitters, or only transmitters pre-selected in accordance with specific criteria, in order to accelerate the process. The user fixes the position of the test point, and the software identifies all signals that would be observed there. The frequency, magnitude, polarization and direction of arrival are determined for each signal together with the distance to its transmitter. The software identifies, channel by channel and transmitter by transmitter, all signals that exceed a given threshold value (in our case 20 dB above 1 uV/m) and disregards signals below that level (figure 8A). The maximum signal is also identified for each frequency channel and offset category. Figure 8B shows the results.

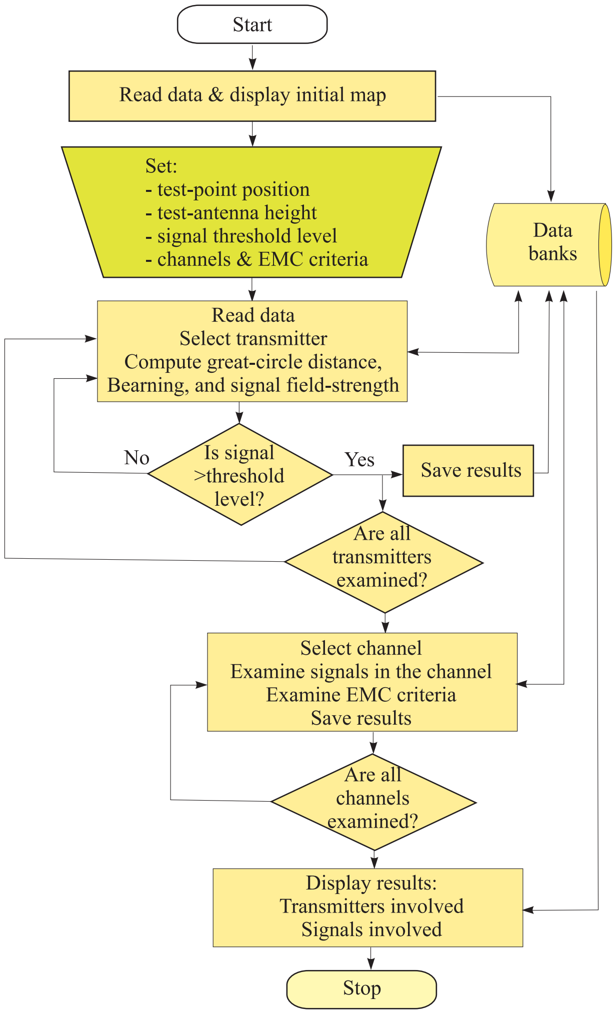


***Figure 8A**-Signal environment: flow diagram (simplified).*

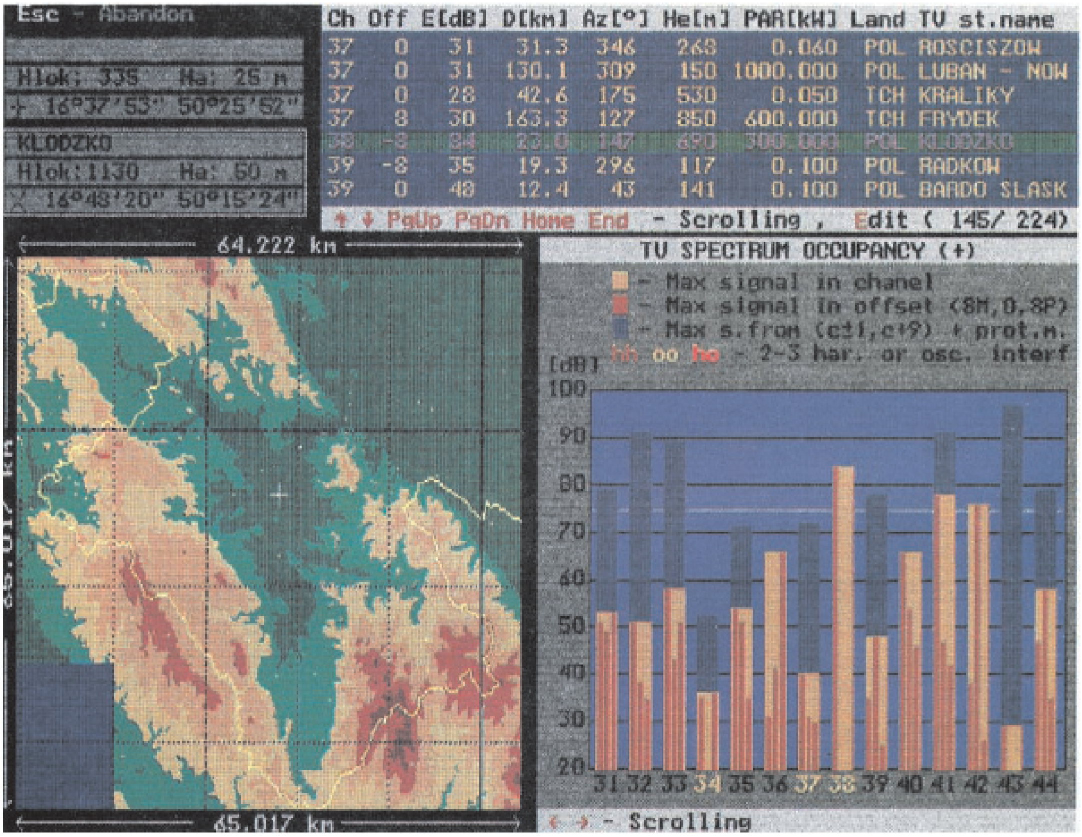


Figure 8B-*Signal environment: visualization*

Lower-left window: *a physical map of a region showing the position of the receiving test station (+). Visible are: the positions of the transmitting stations (yellow points), geographic co-ordinates (vertical and horizontal black dashed lines), border of the country (yellow line) and distances (white lines outside the window)*

Upper-right window: *list of television transmitting stations which produce, at the location of the receiving test station, signals equal to, or greater than, the fixed minimum level. Indicated are: the radio-frequency channel number and offset (Ch, Off), level (E) in dB(t fl Vim), distance from, and bearing to, the transmitting station (0, Az), effective antenna height and e.r.p. of the transmitting station (He, PAR), and name of the country and of the transmitting station (Land, TV st. name)*

Lower-right window: *an imitation of the screen of a "smart" spectrum analyser. The horizontal and vertical axes represent the radio frequency channels and the signal level observed at the station, respectively. The horizontal white line is the required minimum usable signal level. The orange bars are the maximum signal levels within the channels. The red lines are the maximum signal levels with specific offsets. The dark-blue bars indicate the signal level required to overcome potential adjacent- and image-channel interference. They involve signals in the adjacent and image channels and minimum acceptable interference margins. Channel numbers marked in red or orange are warnings about potential oscillator interference*

Upper-left window: *terrain elevation, antenna height and geographic co-ordinates of the receiving test station (+)*

Middle-left window: *The name, terrain elevation, antenna height and geographic co-ordinates of the selected transmitting station (x)*

3.7 EMC analysis

3.7.1 EMC models

EMC is the ability of a device or system to function satisfactorily in its electromagnetic environment without introducing intolerable disturbance to that environment. There are several possible mechanisms of incompatibility in television broadcasting. These fall in two categories: the co-channel interference and interference due to equipment imperfections. Limited receiver selectivity, limited linearity and local oscillator radiation are examples of imperfections. They are discussed below.

- **Co-channel interference**

If the wanted and unwanted signals fall in the same frequency channel and the two signals are commensurate, horizontal bars appear on the television screen, moving slowly up and down. The effect does not depend on the receiver design. It can be reduced by increasing the wanted-unwanted signal margin at the receiver input and/or by offsetting the carrier frequencies of the wanted and unwanted stations. For instance, with a frequency difference of about 10kHz, the required protection margin can be reduced by about 18 dB (table 4).

- **Interference due to limited selectivity**

Due to the limited selectivity of the receiver, the energy from the two channels adjacent to that to which the receiver is tuned can cause interference. Similarly, the signal that is separated from the received channel by twice the intermediate frequency of the receiver can cause the image-channel interference. To reduce the interference threat, adjacent and image signal levels have to be limited. Table 6 lists the limits incorporated in the model.

Table 6. Minimum tolerable wanted-unwanted signal margins

Unwanted signal type	Channel No.	Margin [dB]	Remarks
Co-channel	c*	45 27 22	No offset Offset (non-precision) Precision offset
Adjacent channel	c + 1 c - 1	-12 -6	Upper adjacent channel Lower adjacent channel
Image channel	c + 9	13	

* *Channel No. "c" is the channel to which the receiver is tuned in.*

- **Interference due to local oscillator**

Radiation from the local oscillators of nearby receivers can interfere with the wanted signal. The radiation at the oscillator fundamental frequency and at each harmonic frequency can affect one channel. It means that reception in frequency bands 3,4 and 5 may suffer interference from the harmonics of the local oscillator of receivers tuned to lower bands.

- **Interference due to limited receiver linearity**

If two stations deliver strong signals into the receiver and use channels separated by the intermediate frequency, they can mix due to the nonlinearities in receiver circuitry. The product can ride through into the IF amplifier and produce interference beat. The worst case is when these two strong unwanted signals are located around a relatively weak wanted television signal. Intermodulation interference may also appear with strong input signals. Usually, it is the two-signal, third-order intermodulation, involving twice the frequency of one station minus the frequency of the other. A non-linearity in the front of the receiver may produce two spurious signals, one above the higher and a second below the lower of the two channels involved.

3.7.2 Analysis

All signals are analysed above the specified threshold and potential conflicts are signalized. The recognized conflicts are co-channel, adjacent channel and image channel. The signal level required to overcome the interference is suggested, taking into account the required protection margins. The software signalizes also local oscillator conflicts. At UHF it is the fundamental oscillator frequency, and at VHF it is the second or third harmonic. Figure 8A illustrates the process. The results of the EMC evaluation and signal environment analysis are displayed together (figure 8B).

3.8 Reference points

The results of simulations can be stored in the computer memory. There are two reasons to save the results. Firstly, they may be used as a reference to identify any change or anomaly in the operation of stations. Secondly, if the parameters of a station do not change, the results of simulations of that station can be reused as many times as needed, offering a significant economy. For that purpose, a set of some 3600 reference points has been selected and signal environment at these points has been determined. There is at least one point for each transmitting station and for each locality. These are distributed over the whole territory, one reference point per 10 km x 10 km area on average. The frequency, level, polarization, azimuth of arrival and source of every signal that can be received at each reference point have been stored in the computer memory. Only signals above a threshold level are taken into account, and the information occupies about 60 megabytes of disk space. The results of simulation kept in memory can be complemented by the results of the field measurements. With this in mind, the control points are located in such places that are not only significant but also easily accessible and easily identifiable in the terrain.

3.9 Transmitter data visualization

The access to the information on transmitting stations is possible by the name of station, frequency channel, or location. The inter-related data from different files can be displayed simultaneously, as shown in figures 9A and 9B. The transmitter database includes all television transmitters existing and planned over the country and all foreign television transmitting stations that have been notified internationally and are situated within about 600 km distance from the country border.

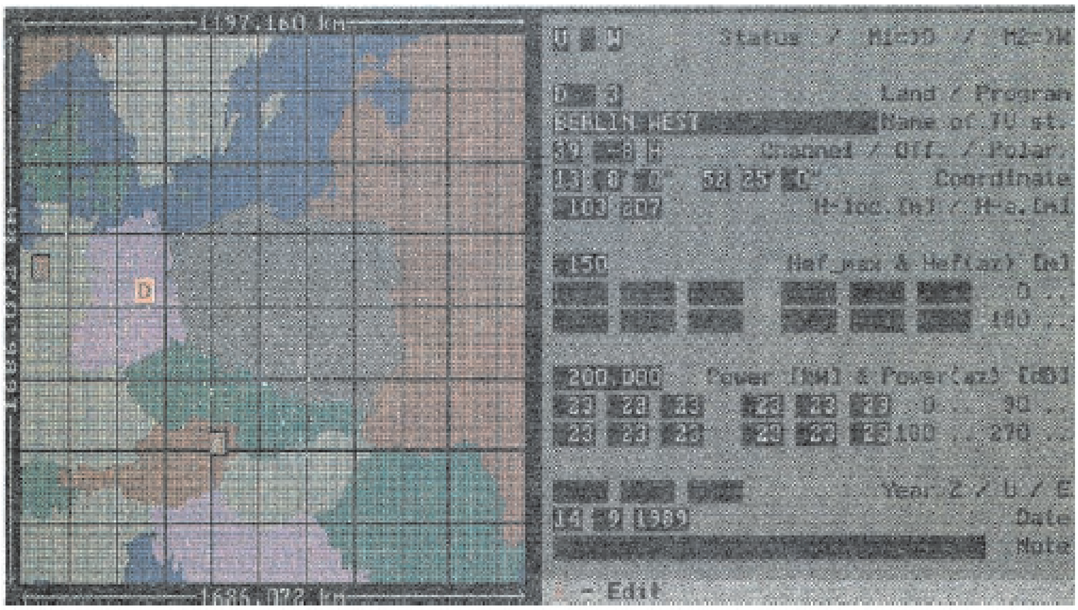


***Figure 9A**:Transmitter data visualization with large scale map (example)*

***Left window**: administrative map of Central Europe (status of 1989) showing the position of the television transmitting stations over a territory in a trapezoidal form of 1686 km x 1686 km x 1197 km. The horizontal and vertical lines represent the meridians and parallels. Distances are indicated outside the window. Different colours are used to distinguish between countries. Letters indicate positions of the transmitting stations. Note the position of station D*

***Right window**: standard form listing the main technical characteristics of station D*

***Note**: The interrelated information displayed in various windows is automatically updated.*

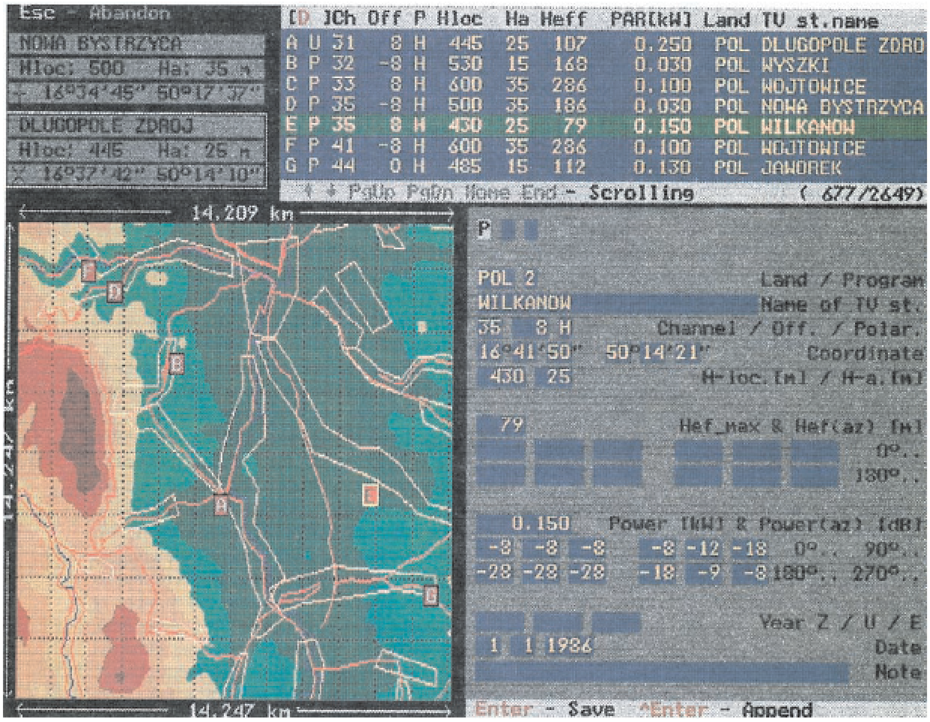


Figure 9B*- Transmitter data visualization with detailed map (example)*

Left window*: physical map of selected region about 14 x 14 km. Visible are: geographic co-ordinates (vertical and horizontal black dashed lines), roads (red lines), contours of built-up areas (orange lines), rivers (blue lines), terrain elevation above the sea level (areas in various colours), positions of selected television transmitting stations (framed letters), distances (white lines outside the window). Note the highlighted station E*

Upper window*: (partial) list of television transmitting stations displayed in the left window. Indicated are: the position on the map and formal status (D), number of frequency channel, offset and polarization (Ch, Of~ P), terrain elevation and actual and effective antenna heights (Hoc, Ha, Heff), effective isotropically radiated power (PAR), name of the country and station (Land, TVstname).*

Note the highlighted station E. The lowest row lists commands available, and, on the right side, the identification number of the highlighted station divided by the total number of the stations in the transmitter working database

Right window*: the form listing the characteristics of the station E highlighted in the other windows (the form is not completely filled in). It serves to view, add, modify, or delete the station characteristics Note: The interrelated information displayed in various windows is automatically updated.*

4. Planning new stations

This section deals with planning applications, with emphasis on the rebroadcasting.

4.1 Planning tasks

The computer simulation model can be used as a tool to examine effects of various planning decisions and/or project alternatives. With this tool, the planner can quickly answer such questions as:

- what is the distance from the planned transmitter to the nearest transport road?
- what signal will be the best for reception?
- what frequency channel will be the best for transmission?
- will the proposed radio link be obstructed by terrain obstacles?
- will the proposed station disturb the existing television network?
- will it suffer interference from the existing stations?
- what will be the coverage area of the proposed station?

To plan a new broadcasting station is a major undertaking. With an overcrowded radio-frequency spectrum, any new installation must be harmonized with all existing and planned stations. Each signal must be examined in detail to ensure that the investment is successful and the new station will neither suffer, nor produce, harmful interference. At VHF and higher frequencies, "terrain shielding" or "site shielding", that is the diffraction losses caused by the intervening terrain, can often be deliberately used to reduce the intensity of unwanted signals.[30] Thus, the likelihood of interference to, or from, another system can significantly be reduced. The station design depends on the geography of the country, the population distribution and the availability of broadcast frequencies, and a careful design and positioning of the antenna and selection of frequency channels are required. In addition to the signal coverage and EMC considerations, the selection must also accommodate such factors as physical access to the site, cost, legal aspects, and other limitations.

To select a feasible variant from the variety of possible deployment scenarios, many analyses and comparisons have to be made. The station siting, working frequency, power radiated, and antenna radiation pattern are among the parameters that can be varied to achieve the best cost performance ratio. In order to reach a practicable solution, it might be necessary to examine many combinations of these parameters. To select a station siting, Hufford [25], for example, examined some 80 potential locations. Such examinations may require a million of calculations or more.[31] To reduce the related labour to manageable proportions, computer-aided tools are indispensable.

Two characteristics of rebroadcasting stations are of major importance: the coverage area and EMC. The LOS coverage, approximating the potential coverage, is one of the decisive parameters for the selection of the station site. In this context, the coverage area (of a terrestrial transmitting radio station) means the area associated with the station within which, under specified technical conditions, the intended communication is feasible. The EMC decides about the frequency selections. Coverage area predictions and EMC evaluations require data about the local terrain and signal environment. The more precise the data, the better the selections.

Each rebroadcasting station needs two frequency channels, one for reception and one for transmission. These should be compatible between themselves and with the signal environment. Ideally, the transmission channel should be free from any other signal, and its use should not interfere with the actual and planned use of frequency channels. The reception channel should contain only the wanted signal, strong enough and interference-free. The simulation tool helps to make such a selection. In a preliminary planning stage, if the number of appropriate frequency channels is insufficient, only the transmitting channel is determined. The signal for retransmission must then be delivered by cable or microwave link. In more critical situations, special selection techniques may be required.[32] These, however, are beyond the scope of this article.

4.2 Planning through simulation

One of the main aims of our simulation tool is to help to select technical characteristics of television rebroadcasting stations listed in table 5. It covers only technical elements and figure 10 illustrates the approach. The user has to input the instructions. The software automatically extracts and processes all additional data needed and performs the analyses described in previous sections. The results of simulated experiments and examinations are displayed on the screen for the interpretation, analysis and evaluation of the user, who is to decide whether the current characteristics are satisfactory, or another variant should be examined. In the latter case he introduces new instructions, and simulation is repeated with new data.

This cycle can be repeated as many times as needed, until an acceptable version is selected, or the iteration process is discontinued. Ideally, this process would be automated to optimize the system for the wanted behaviour. The station planning is, however, too complex, and human reasoning is necessary. The final selection is based on a comparative analysis of several alternatives possible. The larger the number of alternatives analysed, the better the final solution. Extensive interaction between the planner and simulation model is necessary to tune parameters before embarking on experimental verification in the field.

To restrict interference effects, co-sited transmissions and overlapping coverage areas should avoid conflicting frequency channel combinations, and levels of the unwanted signals should be kept within the tolerable limits. Table 6 lists the minimum requirements built in the model. There are three measures to follow these requirements. Firstly, the attenuation of the unwanted signal over the LOS propagation path may be used. It means that minimum separation distances between the stations must be observed.[33] Secondly, additional attenuation due to terrain obstacles may be exploited. Finally, the required amount of attenuation may be obtained by the directional antenna design.

5. Verification, performances and limitations

This section discusses the overall performances and limitations of the model. It also gives results of the verification of the data banks and propagation models.

5.1 Verification

5.1.1 Terrain data verification

The terrain elevation profiles derived automatically from the digital map were verified against those extracted manually from the source (paper) map.[34] About 100 randomly selected paths in various regions were used for that purpose. A sample of about 6000 points at intersections of the paths with contour lines was tested, and table 7 summarizes the results. The mean difference did not exceed 1 m, the correlation coefficient was above 0.99, and the standard deviation of the difference did not exceed 15 m in mountainous terrain. It seems fair to conclude that our topographic data bank contains nearly all the elevation information one could reasonably expect to extract from the source map.

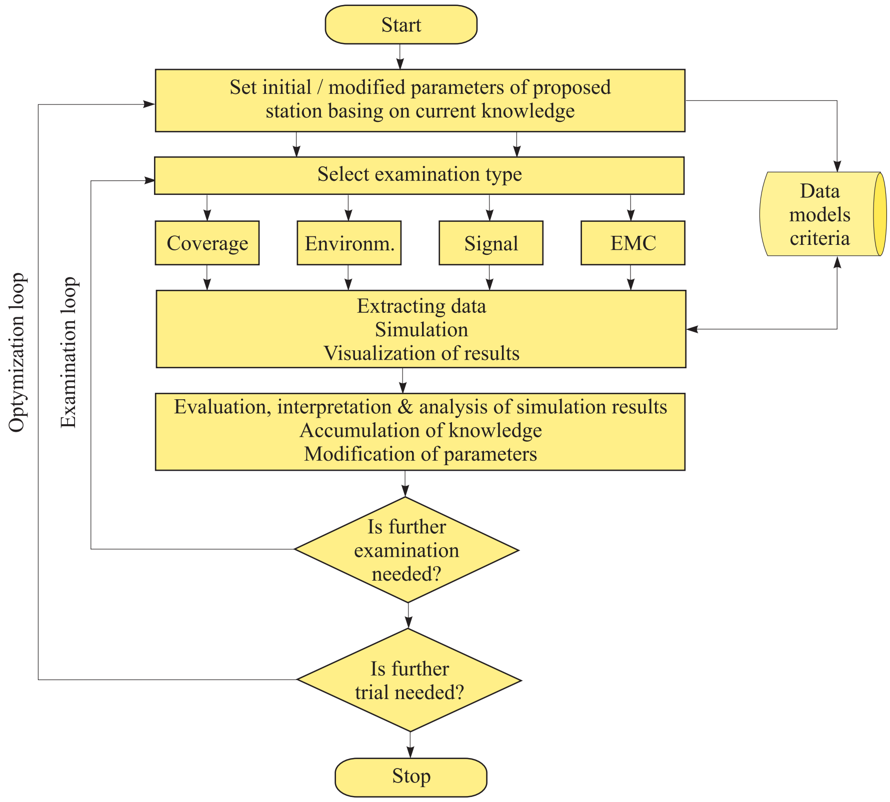


Figure 10-*Planning through simulation: the process (simplified diagram). The double-framed tasks are performed automatically*

5.1.2 Transmitter data verification

Transmitter data were checked against the master copies of notifications submitted to the national authority and to the I FRB. A part of the data was verified against the actual installations. Some discrepancies were discovered on that occasion.

5.1.3 Signal predictions verification

As the field-strength prediction models have already been verified by other authors, the software was checked only against errors. For that purpose, a comparison was made between the signal levels measured in the field and predicted by the simulation model. The test sample was limited to 36 transmitter-receiver links in a hilly region (400 to 1000 m above sea level). The mean difference between the measured values and predicted ones was 3 dB, the mean-square difference 5 dB and the correlation coefficient 0.87. These results correspond to the accuracy of the field-strength measurements [35] and are similar to those published in the literature.[36-38]

Table 7. Results of comparison of the measured and predicted values

Item		Sample size	Mean difference	Standard deviation	Correlation coefficient	Maximum difference	Minimum difference
Terrain elevation*	All terrain types (135-1300 m)	6117	0 m	12 m	0.998	143 m	-75 m
	Flat terrain (135-255 m)	1242	0 m	4 m	0.996	19 m	-30 m
	Undulated terrain (200-840 m)	1524	-1 m	10 m	0.994	40 m	-47 m
	Mountainous terrain (260-1300 m)	3351	0 m	15 m	0.996	67 m	-75 m
Field strength**		36	3dB	5 dB	0.875	12 dB	-8 dB

* Difference between the terrain elevation above sea level at the same points derived automatically from the digital terrain data base and extracted manually from the source map by skilled persons.

** Difference between the measured and predicted field strength levels.

5.2 Performances

Table 8 illustrates the overall performance in terms of time required to perform the specific task. Rows 1 to 3 of the table list the tasks relevant to the analysis of the station operation. Rows 4 to 9 list the tasks relevant to the planning of a new station. These performances were observed with the personal computer Compaq 386/20e with a mathematical co-processor, EGANGA graphic card, 4 megabytes RAM, 80 megabytes hard disk and OOS.5 operating system. Better performances may be expected with faster microprocessors and larger memory.

5.3 Limitations

The computer hardware limits the speed of simulation computations and the maximum number of transmitters processed within a reasonable time. The simulation model described in this article has been running successfully on a personal microcomputer type IBM-A T or compatible. The system allows to simulate a network of about 10 000 transmitters over a territory of about 1500 x 1500 km. At present, the simulation model is limited to Secam D/K television systems. The propagation prediction models refer to VHF/UHF frequency bands, land paths, standard atmosphere and temperate climate (the main-frame version includes four different propagation models). As they are based on measurements within some 500 km distance, the predictions for greater distances are less reliable. The model restricts the signal propagation path to the vertical plane connecting the transmitting and receiving antennas. Multipath propagation, effects of reflection from terrain obstacles, buildings, etc., as well as ducting phenomena, are disregarded.

Table 8. Simulation model performances

No.	Task	Time* (seconds)	Remarks
1	Transmitter-file search and data extraction	< 1	500 transmitters
2	Signal environment and spectrum occupancy estimation	< 10**	500 transmitters
3	EMC analysis and interference threat evaluation	< 10**	500 transmitters
4	Transmitter-receiver distance and bearing computing	< 1 ***	50 km distance
5	Terrain-profile extracting	< 1 ***	50 km distance
6	Terrain irregularity (Delta h) evaluation	< 1***	50 km, 400 points
7	First Fresnel zone determination	< 1***	50 km, 400 points
8	Point-to-point propagation predicting	< 1***	50 km, 50%, 10%, 1% of time
9	LOS coverage area predicting	< 20	50 km x 50 km, 90000 points

* The time required to perform the task; the task volume is defined in the column "Remarks".
** The total time of performing tasks 2 and 3 together.
***The total time of performing tasks 4 through 8 together.

6. Conclusion

6.1 Summary

The growing demand for frequencies can be satisfied by improving the control over interference among stations and by reducing the spectrum wasted due to interference. The interference reduction involves analyses of huge amounts of spectrum- and geography-related data. Without automation, the job would be hopeless. This article shows how the task can be facilitated by a computer system that integrates the analysis, design and documentation. The strength of the described system lies in its precision, efficiency, simplicity of use and low cost. As its earlier main-frame version, it has been used to analyse the operation of thousands of television transmitters and to plan several hundreds of new low-power rebroadcasting stations. It offered substantial economies:

- -in the time spent for technical examinations and analyses;
- -in the frequency spectrum used through tighter "packing" of stations;
- -in energy and in cost.

6.2 Future development

The experience indicated its possible further development, and appropriate work has already been initiated. This section contains some remarks in this connection. Two independent directions are being considered: to make the simulation tool more universal and to make it more accurate.

6.2.1 Other services

Our simulation model is restricted to a specific country and a specific radiocommunication service. Could it be applied to other services and other countries? The answer is: yes, but data banks, propagation models and criteria have to be modified as appropriate. Cellular mobile radio, rural radiotelephony, microwave links and sound broadcasting applications at VHF and higher frequencies could use the digital terrain elevation data banks and other elements of the model.

6.2.2 More accuracy

A better imitation of the real world requires more accurate propagation models and data. Three comments can be made in this connection. Firstly, more accurate digital maps are not a technical problem today. Digital maps of some regions are available on compact disks (CD-ROM). Microcomputer tools exist to convert conventional maps into digital format. In addition, satellite technology offers digital maps from the sky.[39] The ITU publishes various maps, [40, 41] but digital terrain elevation maps are not available within that organization. On an international scale, the Food and Agriculture Organization of the United Nations (FAO) is developing a worldwide geographic information system (see FAO: Geographic information systems in FAO (Rome, 1988). Unfortunately, FAO's terrain data cannot be used in VHF/UHF radiocommunication applications.

The resolution of generally available digital maps from satellites reaches about 10 m. A 1-m resolution or less is possible with today's technology. However, to collect and maintain these data with the corresponding degree of reliability might be difficult. Many man-made structures of such dimensions would have to be included in the data banks. As the structures can be created, destroyed, modified, or displaced, the data would need frequent updating. Otherwise, the data bank would be inaccurate. Secondly, in order to improve propagation predictions, multiple propagation modes should be included and a three-dimensional propagation model would be required for that purpose. Various ray-tracing techniques are possible here. Unfortunately, all of them are computing-intensive and require huge amounts of data. The existing personal computers are unable to cope with such tasks, and we have to wait for the next generation.

Finally, it seems unreasonable to require from simulation results more precise than field-strength measurements. It is the measuring uncertainty that defines the accuracy required from the computer simulation.

6.2.3 Wider application

The EMC examinations require data about the transmitting stations and terrain within the range of approximately 1500 km. With small countries, such distances spread outside the country's territory, so that the same data are used in two or more countries. An exchange could eliminate the need to duplicate data collection and maintenance. A common co-ordinate system, and common data structure would make such an exchange easier. The ITU maintains data banks on radiocommunication stations that seek international recognition, and it could also maintain digital terrain data banks and simulation models, similar to that presented in this article.

Many time-consuming technical examinations could be then automated and made more accurate. The system would be accessible for consultations and trial examinations by all those interested. Its operation would resemble an air-ticket reservation network, where a client can consult flight schedules, select connections, reserve seats and buy tickets in his local travel office. In our case, it would be the assignment of the frequency and position of a station, rather than the airplane seat, and the local spectrum management office rather than the travel office, but the concept is the same.

The results of the examinations could be available at the user's desk almost instantaneously. In the case of a positive finding, formal notification could be done automatically. Otherwise, potential conflicts would be identified and necessary negotiations among the involved parties could begin without delay. Facsimile and videoconferencing, complementing the computer communications, could facilitate the negotiations and consultations. A group of highly qualified experts would maintain the system at headquarters and be available for consultations. Such a group might also help in solving those spectrum management problems which result from the lack of sufficiently experienced professional staff, especially in developing countries. The border between national and international spectrum management would be blurred. The spectrum management would be more efficient not only in terms of the involved cost and time, but also in terms of spectrum conservation, which is even more important.

6.3 Acknowledgement

The software presented in this article, including the databases, has been developed and tested at the Institute of Telecommunications, Wroclaw Branch (Poland). Collaboration with the Institute of Telecommunications and Acoustics (Politechnika Wroclawska) and the Institute of Geography (Uniwersytet Wroclawski) is acknowledged. Several people collaborated with the author, and it is not possible to list all of them here.

The first working version of the software was developed by Messrs W. Sega and W. Waszkis in the 1970s, as a part of their doctoral dissertation. The topographic data were extracted under Mr. P. Adamczyk. For this work, the author's team was honoured by the Award of the Minister of Telecommunications of Poland (1984) and by other awards. Later, Mr. A. Marszalek converted the software to a personal microcomputer, and prepared an original graphic interface.[42] It brought him the "MicroLaur" award in a computer software contest in 1989. Messrs Z. Janek, J. Sobolewski and T. Stromich also collaborated. The Polish Administration has offered the software to CCIR, under CCIR Resolution 88. According that resolution, copies of the software are available on an "as is" basis directly from the Polish Administrations, Institute of Telecommunications, Wroclaw Branch, or from the CCIR Director, with a handling charge. The author also wishes to express his gratitude to Messrs P. Balz, K. Bjornsjo, P. Kartachoff, J. Karjalainen and L. Wieweg, for their comments during the preparation of the manuscript, and to Mr R. C. Kirby, CCIR Director, for his encouragement to publish the article.

(Original language: English)

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