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Consideration of Antenna Pattern by Elevation in Recommendation ITU-R P.2001

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Abstract—The question of the practical application of the comprehensive universal Recommendation ITU-R P.2001 in calculating the electromagnetic compatibility of electronic systems is considered. In this Recommendation antenna patterns are assumed isotropic in elevation plane. It is shown that to increase an accuracy of calculations by this technique, it is necessary to take into account the difference between the terminal antennas pattern and isotropic antennas. A detailed analysis of the propagation of radio waves sub-model for reflection from the sporadic layer E. The significant influence of the distance between the terminals and the types of their antennas on the calculation results for this sub-model. The quantitative corrections for typical short-wave and ultra-short wave antennas are determined. The directions of further research were selected to increase the accuracy of calculations of the propagation of radio waves when using the Recommendation ITU-R P.2001.

Keywords—antenna pattern, propagation radio wave, electromagnetic compatibility, sporadic-E reflection

I. INTRODUCTION

Formulation of the problem. When calculating the electromagnetic compatibility (EC) of electronic systems (ES), an important step is to predict the propagation of radio waves (PRW) on the path between two terminals, hereinafter referred to as the transmitter and receiver. This step should be carried out using standardized techniques. Their most complete selection has been implemented by the International Telecommunication Union (ITU) and is grouped in the appropriate group. P. The most commonly used ones are as follows [1-3]:

- Recommendation ITU-R P.2001-3 - A general purpose wide-range terrestrial propagation model in the frequency range 30 MHz to 50 GHz;

- Recommendation ITU-R P 452-16. - Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz;

- Recommendation ITU-R P 1546-6 - Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 4 000 MHz.

In accordance with the original data and constraints selected one or another technique. Moreover, such a choice is a special task and general recommendations and individual studies were devoted to its justification [4,5].

One of the most commonly used techniques for predicting PRW is Recommendation ITU-R P.2001 [1]. The following advantages are inherent in it: the widest range of frequencies and taking into account a large number of factors affecting the PRW. Its main drawback is the relatively high complexity of the calculation, but in most cases this is permissible, and sometimes the complexity of the calculation can be reduced by neglecting components that are insignificant under certain conditions.

When using this Recommendation in settlement information systems, its following feature was noted. The calculation is conducted only on path loss PRW. Direct ignored antenna pattern (AP) terminals in elevation plane, because these parameters are absent in the input of the Recommendation. At the same time, for the azimuthal plane, the gain of the antennas of the receiving and transmitting terminals is directly present in the input data and is used in the calculations. However, in some cases, AP variation in elevation plane will affect the result of the calculation of the RPW. The article describes for which PRW mechanisms of elevation AP affects the result and quantitative effect is analyzed for Recommendation ITU-R P.2001.

II. MAIN PART

In the Recommendation under consideration, the following sub-model of PRW are taken into account:

1. Propagation close to the surface of the Earth, consisting of diffraction, non-ducting clear-air effects and precipitation fading.

2. Propagation via atmospheric turbulence, consisting of troposcatter and precipitation fading for the troposcatter path.

3. Anomalous propagation due to stratified atmosphere, consisting of ducting and layer reflection.

4. Propagation via sporadic-E reflection (1-hop and 2-hop).

The effect of the elevation AP change is manifested in the implementation of the last two sub-model PRW. To reflect from the area with precipitation, the angle of deviation from the horizon, and, accordingly, from the direction of the maximum of radio emission in the elevation plane will be small. Accordingly, it will make a small contribution to the change in the calculation results for the corresponding sub-model. Propagation via sporadic-E reflection will largely influence, especially at low frequencies for closed PRW paths (out of line of sight). The contribution of this PRW sub-model

on the common result of calculation in accordance with the Recommendation ITU-R P.2001 in this article are not considered and is material for further study.

Consider in more detail the sub-model of propagation via sporadic-E reflection as the most dependent elevation AP in the elevation plane. The effect of changes in elevation AP is determined by the following two features. The direction angle to the sporadic layer E differs from the direction of the main maximum, which, as a rule, is directed tangentially to the Earth's surface (both at the receiving and transmitting antennas). The value of this angle varies depending on the distance between the receiver and the transmitter, and accordingly, the contribution of this parameter to the change in the power of electromagnetic radiation at the receiving point changes.

The ray take-off angle above the local horizontal at both terminals for 1 hop is given by [1]:

$$\theta_1 = \frac{\pi}{2} - \arctan \left[\frac{R_E \sin \alpha}{H + R_E (1 - \cos \alpha)} \right] - \alpha, [\text{rad}]$$

where:

$H=120$ km – is the height of the sporadic-E layer in km;

R_E – Median effective Earth radius;

$\alpha = d/(2R_e)$ – for 1 hop and $\alpha = d/(4R_e)$ – for 2 hop;

d – distance between terminals.

The dependence of the elevation angle under which the sporadic layer E is visible on the distance between terminals with a single hop propagation is shown in Fig. 1.

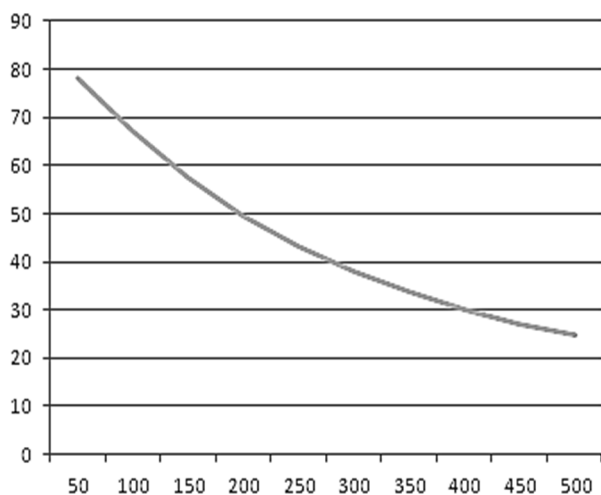


Fig. 1. Dependence of the elevation angle of sporadic layer E when changing the length of the distance between terminals.

This angle determines the deviation from the normal to the surface of the smooth Earth and in most cases determines the deviation from the direction of the maximum antenna gain. For the mechanism of PRW by 2-hop reflection, the value of the deflection angle will correspond to half the path length. So, for example, for a track length of 500 km, with a two-hop propagation, a distance of 250 km is chosen and, accordingly, the elevation angle of the sporadic layer E will be 43 degrees. We will evaluate the quantitative effect of the change in the

antenna pattern of the terminal antennas in the elevation plane on the results of the RRS calculations according to the considered method. To do this, we will consider typical AP and calculate the attenuation corrections for them at angles of direction to the E layer, which correspond to different path lengths.

The following models of AP of the short-wave and ultra-short-wave range in the elevation plane in general form are offered in the literature [6]:

$$f(\theta) = \left[\cos \left(\frac{\pi l}{\lambda} \cos(\theta) \right) \right] / \sin(\theta).$$

Here θ is the angle of deviation from the direction of the antenna axis, for the vertical antenna it is directed to the zenith, and the direction of the maximum of the beam is directed normal to the plane of the antenna and is shifted by $\pi/2$ relative to 0; l is the length of the antenna; λ is the wavelength.

For the most common particular cases:

- symmetric elementary vibrator (Hertz vibrator)

$$f(\theta) = \sin(\theta);$$

- half wave dipole

$$f(\theta) = \left[\cos \left(\frac{\pi}{2} \cos(\theta) \right) \right] / \sin(\theta);$$

- symmetric wave vibrator:

$$f(\theta) = \frac{1 + \cos(\pi \cos(\theta))}{2 \sin(\theta)}.$$

Their typical AP are shown in Figure 2.

The results of modeling the influence of elevation AP in the antennas describe above, defined as corrections with respect to the isotropic antenna, are given in Table 1.

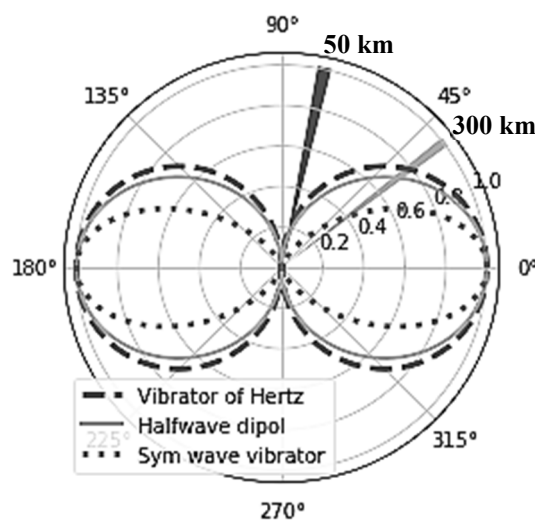


Fig. 2. Typical AP and the range of viewing angles of the sporadic E layer for PRW paths.

These values can be used as corrections in the calculations, additionally taking into account the following features. The table shows the calculations for single hop propagation and for one antenna. For two antennas, corrections are added. When calculating the double hop propagation, a correction is selected for the path length equal to half the distance between the terminals.

TABLE I. CORRECTIONS WITH RESPECT TO THE ISOTROPIC ANTENNA

Range, km	Angle, deg	Attenuation, dB		
		Vibrator of Hertz	Half wave dipole	Wave vibrator
50	78	-6,9	-7,9	-22,6
100	67	-4,1	-5,0	-14,0
150	57	-2,7	-3,4	-9,5
200	50	-1,9	-2,5	-6,8
250	43	-1,4	-1,8	-5,0
300	38	-1,0	-1,4	-3,8
350	33	-0,8	-1,1	-3,0
400	30	-0,6	-0,9	-2,4
450	27	-0,5	-0,7	-1,9
500	24	-0,4	-0,6	-1,5

Let's analyze the quantitative influence of the considered factor – the elevation antenna pattern diagram on the calculation of PRW due to the sporadic layer E according to the ITU-2001 method. To do this, let's look at this propagation mechanism in more detail and determine the components that are affected by changes in the angular AP using the example of single-hop propagation. Sporadic-E 1-hop basic transmission loss is now given by [1]:

$$L = L_{fs}(p) + L_{E1}(d, f) + L_{dif_tr} + L_{dif_rt}, \text{ dB}$$

where $L_{fs}(p)$ - Free-space loss can now be calculated for the slope distance p : [1]:

$$L_{fs}(p) = 32.4 + 20 \log(f) + 20 \log(p),$$

p - the slope path length: [1]:

$$p = 2 \sqrt{R_E^2 + (R_E^2 + H)^2 - 2R_E(R_E^2 + H) \cos\left(\frac{d}{2R_E}\right)};$$

$L_{E1}(d, f)$, - the ionospheric loss for one hop given by [1]:

$$L_{E1}(d, f) = \exp\left(\frac{d-1660}{280}\right) + \left(\frac{f}{f_{cr}}\right)^2 \times \left[\frac{40}{1 + (d/130) + (d/250)^2} + 0.2 \left(\frac{d}{2600}\right)^2 \right].$$

The diffraction losses at the two terminals to the local horizontal are: from transmitter L_{dif_tr} and from receiver L_{dif_rt} .

Losses consist of components, of which changing the antenna pattern in the elevation plane affects only the components $L_{fs}(p)$ and $L_{E1}(d, f)$. Let us evaluate the quantitative contribution to the total loss of the component $L_{E1}(d, f)$ for various values of significant factors. The main ones are distance and frequency. And also the critical frequency determined by the location of the terminals and taken into account statistically as a fraction of the time during which this frequency exceeds a certain value, given in a table and constitutes an integral part [1]. Let us analyze this contribution for a number of distances and two frequencies. We will choose the critical frequency from the table for the value $P = 0.1\%$.

We take into account that this frequency substantially depends on the location of the terminals (varies in the range of 6.09-20.43 MHz), which are not known in advance, we choose the maximum value of this frequency and the average. As the average value, select one of the possible options:

- median value of 11.57 MHz;
- arithmetic average of 11.73 MHz;
- average sample size of 13.26 MHz.

The numerical value of ionospheric losses as a function of the distance between the terminals for the maximum and average sample sizes of the critical frequency and for two frequencies is shown in Table 2.

TABLE II. THE IONOSPHERIC LOSS FOR 1-HOP $L_{E1}(D, F)$.

f_{cr} , MHz	20,43		13,26	
f , MHz d , km	30	40	30	40
50	60,7	107,9	144,1	256,2
100	45,3	80,6	107,6	191,4
150	35,8	63,6	84,9	150,9
200	29,7	52,8	70,5	125,3
250	26,0	46,2	61,7	109,6
300	23,9	42,5	56,8	100,9
350	23,1	41,0	54,8	97,4
400	23,2	41,3	55,1	97,9
450	24,1	42,9	57,3	101,8
500	25,7	45,7	61,0	108,5
550	27,9	49,6	66,2	117,6
600	30,6	54,3	72,5	128,9

As can be seen from the table, accounting for this propagation mechanism is appropriate for the lower frequency boundary.

We have calculated loss in free space for the above two frequencies of 30 and 40 MHz,. The calculation results are shown in Table 3.

Comparing the absolute values of the amendments from table 1 with the values of the losses (tables 2 and 3), it is clear that in some cases they make a significant impact on the result. Especially this effect will be noticeable at close distances (up to 300 km for types of antennas with a narrow angular beam pattern).

TABLE III. FREE-SPACE LOSS $L_{fs}(P)$

$f, \text{ MHz}$ $d, \text{ km}$	30	40
50	95,92	98,42
100	101,94	104,44
150	105,46	107,96
200	107,96	110,46
250	109,90	112,40
300	111,48	113,98
350	112,82	115,32
400	113,98	116,48
450	115,01	117,51
500	115,92	118,42
550	116,75	119,25
600	117,51	120,00

In addition, it is necessary to take into account the antenna gain for the terminals in the direction of the main maximum in comparison with isotropic antennas.

III. CONCLUSION

When using the Recommendation ITU-R P.2001 in terms of calculating the PRW with reflection sporadic-E, it is necessary to take into account the difference between the actual AP of the terminals in the elevation plane from the isotropic antenna. A significant influence of the type of antenna beam in the elevation plane will be in the analysis of closed paths at small (from 50 to 300 km) range values and for the two-hop propagation mechanism. With increasing range, the contribution of the antenna beam decreases due to the approach of the propagation axis to the antenna axis with a maximum gain level.

The type of terminal antennas also has a significant impact on the results. A quantitative analysis of the influence of

changes in the AP in the elevation plane on the results of the calculation of the PRW for the most common types of antennas is carried out. Taking this influence into account will make it possible to increase the adequacy of the results of the calculation of the PRW and, accordingly, the quality of the analysis of the EC of the ES. For this, the simulation results obtained in this article and given in the table can be used as corrections in the calculations.

The direction of further research is supposed to focus on the following issues:

- analysis of the influence of an antenna's height and underlying surface on elevation antenna patterns;

- the influence of other submodels. Recommendation ITU-R P.2001 (in addition to propagation.Sporadic-E) on the overall result of the calculation.

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