Study on Shortwave Signal Coverage Based on ITU-R P.533 Model

Jialuan He¹², Zirui Xing²* and Feihong Wu²

¹ School of Mechanical Electronic & Information Engineering, China University of Mining & Technology, Beijing, 10083, China
² Beijing Aerospace Chenxin Technology Co., Ltd., Beijing, 102308, China
*Corresponding author’s e-mail: xingzirui1001@126.com

Abstract. In this paper, the short-wave signal propagation modeling, short-wave electromagnetic environment simulation modeling, short-wave electromagnetic environment level evaluation modeling, simulation modeling of receiving antenna commonly used in short wave and other contents are studied in depth, in terms of short-wave electromagnetic environment and antenna simulation simulation. A more complete propagation model of short-wave signal, simulation model of short-wave electromagnetic environment, evaluation model of short-wave electromagnetic environment level and simulation model of receiving antenna commonly used in short-wave are established. Finally, the effectiveness of each model is verified by repeated comparative tests and experiments.

1. Introduction

The simulation of short-wave electromagnetic environment and antenna refers to the simulation of signal propagation, and the simulation of multi-signal mixing, as well as the simulation of logarithmic periodic antenna, fishbone antenna, Angle cage antenna and other commonly used antennas, which is mainly by providing the actual time domain signal or manual input signal parameters (list) and other ways, and on the basis of simulation of shortwave communication signal, the electromagnetic environment and the noise with the specified position[1]. In combination with the communication signal to be simulated and the electromagnetic environment, the level of electromagnetic environment is evaluated, and the receiving effects of different types and parameters of antennas are compared, to provide support for decision making tools for the survey and selection of transmitting stations (positions), antenna selection and efficiency evaluation. Because signal simulation involves many aspects such as signal modeling, signal propagation, signal synthesis, antenna modeling, environmental assessment in the field of short-wave communication, it faces many practical difficulties and problems[2][3]. This paper will mainly study three issues.

(1) Signal and noise simulation modeling. For short-wave communication signal and electromagnetic environment simulation, providing real signal is the most practical, convenient, effective and accurate means of real signal and electromagnetic environment simulation[4]. This paper proposes a simple and effective method for modeling communication signals and noise, and constructs a short-wave communication electromagnetic environment assessment model for level assessment.

(2) The construction of signal propagation model. The propagation channel of shortwave signal is complicated, which is easily affected by natural environment, and its signal fading is great. It has ground wave propagation, sky wave propagation, multi-hop propagation and other ways, so its multipath...
phenomenon is serious, with extremely unstable signal[5]. In addition, useful signals, interference signals and environmental noise are intertwined, and the multipath propagation of the same signal and the simultaneous propagation of multiple signals are the normal state of short-wave communication[6]. This paper comprehensively considers these uncertain factors of shortwave communication propagation, and constructs a perfect signal propagation model.

(3) Accurate and efficient modeling and simulation of shortwave antennas. There are many types of shortwave antennas with different parameters, but the current general antenna simulation models have poor versatility, limited simulation accuracy, large amount of calculation and low simulation efficiency, thus causing greater difficulty in simulation modeling[7]-[8]. This paper proposes an analysis algorithm to calculate the antenna radiation pattern, which avoids many simplifying assumptions required by other algorithms, and provides a highly accurate and versatile tool for electromagnetic analysis.

2. Signal and noise simulation model
The signal and noise simulation model is mainly used to simulate short-wave communication signal, short-wave emission noise and headroom environmental noise, which can output time-domain sampling data, to provide support for multi-signal hybrid simulation, electromagnetic environment grade evaluation, reception effect evaluation.

2.1. Simulation of short wave communication signals
Most short-wave communication signals are generated by sine-wave modulation, but in practical applications, but the frequency, bandwidth, modulation type, modulation parameters and other parameters are used to describe the common amplitude modulation, frequency modulation and phase modulation signals. In this paper, the modulation values of carrier A, w and $\phi$ are calculated according to the signal modulation parameters, so as to generate time-domain sampling signals.

2.2. Simulation of short wave emission noise signals
Generally, shortwave emission noise signal can be considered as white noise signal uniformly distributed on infinite bandwidth, and its amplitude is mainly affected by the temperature of transmitting equipment. For convenience of use, the equipment temperature is not directly used as the input parameter, but the total noise power $P$, the noise start and end frequencies $f_s$ and $f_e$ are used as the input parameters to simulate the time domain sampling data generated noise signals.

A pseudo-random sequence with variance $N_0/2$ and mean 0 can simulate white Gaussian noise with power spectral density $N_0=P/(f_e-f_s)$, among which, the pseudorandom sequence can be generated by the Box-Muller method, a random number generation method.

2.3. Simulation of ambient noise in short wave headroom
The simulation method of ambient noise of short-wave headroom is the same as that of short wave emission noise signal. In the simulation process, the short wave clearance noise signal of a certain place or region can be set by the total power and the start and end frequencies of the noise.

3. Short wave communication propagation and field strength prediction
Sky-wave propagation is the major way of short-wave communication. For the prediction of its field strength, the method given by ITU-R P.533 is mainly used in this paper. As for its sky wave propagation within 7000km, ray path analysis method is adopted to predict. As for the path greater than 9000km, since it is not applicable to the studied scene, the study is not carried out in this paper, and only the median field intensity of the path less than 7000km is calculated.

3.1. Consideration of modules
A maximum of 3 E-modes (paths less than or equal to 4000 km) and a maximum of 6 F2 modes are selected, all of which meet the following conditions: (1) For Model E, specular reflection height start from height $h_r = 110$ km; (2) For mode F2, specular reflection height start from the specular reflection
height hr, where \( M(3000)F2 \) is estimated in the middle of the path (the path does not exceed \( d_{\text{max}} \) km), or is estimated at the control point in the middle of the path (the path is between \( d_{\text{max}} \) and 9000 km), taking the lesser of the two values; (3) \( E \) mode -- the lowest order mode with a jump distance of less than 2000 km, and the two subsequent two sub-high order modes; (4) \( F2 \) mode -- the lowest order mode with a jump distance of less than \( d_{\text{max}}0 \) km, and the five subsequent two sub-high order modes, but should be greater than the shielding frequency \( f_{s} \).

3.2. Determination of field strength

For each module \( w \) selected in the consideration of the module, the median value of the field strength is calculated as follows:

\[
E_w = 136.6 + P + G + 20 \log f - L_b \quad \text{dB(1\mu V/m)}
\]  

(1)

Where, \( G \) represents the transmitting antenna gain (dB) at a certain azimuth and elevation angle of the isotropic antenna, \( P \) represents the transmitter power (dB(1kW)), \( f \) represents the emission frequency (MHz), and \( L_b \) represents the transmission loss of the ray path of the current mode, calculated by the following formula:

\[
L_b = 32.45 + 20 \log f + 20 \log p' + L_i + L_m + L_g + L_h + L_z
\]  

(2)

And the virtual oblique distance (km) is:

\[
p' = 2R_0 \sum_{i=1}^{n} \left( \frac{\sin (d/2R_0)}{\cos \Delta + (d/2R_0)} \right)
\]  

(3)

\( L_i \) represents the absorption loss (dB) of n-hop mode calculated at the mth control point given by the equation below, which is determined by a fixed reflection height of 300km and a control height of 90km (two control points per jump).

\[
L_i = (1 + 0.0067R_{12}) \sec \sum_{i=1}^{m} \frac{AT_{jnoon} F(\chi_j) - F(\chi_j)}{f(f + f_i)F(\chi_j) - f_i f_{E_i}}
\]  

(4)

When \( F(x) = \cos p(0.881x) \) or 0.02, the larger one is selected, where \( f_v = f \cos I \). \( i \) represents the inclination at 110 km, \( m \) represents the number of control points, and \( fL_j \) represents the mean value of the specified electron spin frequency at a given control point \( j \). The electron spin frequency rotates around the longitudinal component of the Earth's magnetic field at an altitude of 100 km. The magnitude of the magnetic inclination \( I \) can be calculated by the following formula:

\[
f_L = |f_i \sin(I)|
\]  

(5)

The value of \( f_{jnoon} \) is the smaller one of solar zenith angle at the given control point \( j \) or 102°. \( \chi_{jnoon} \) is the local noon \( \chi \) value, and \( AT_{jnoon} \) is the local noon absorption factor when \( R_{12} = 0 \). It can be seen from Figure 1 that they depend on month, latitude and absorption layer penetration factor. It can be seen from Figure 2 that it can be \( \varphi_n(f_i/f_{0E}) \) function, where \( f_i \) is the frequency of the vertical incident wave. \( P \) represents the daily absorption index, which can be seen from Figure 3 as a function of months and the corrected magnetic inclination calculated at an altitude of 100 km.

![Figure 1. Absorption factors at noon.](image1)

![Figure 2. Absorption layer penetration factor \( \varphi_n(f_i/f_{0E}) \).](image2)
$L_m$ represents losses "above MUF", and for frequencies above the basic MUF, the absorption varies continuously with frequency and should have the same ray path assumptions as the calculation of the basic MUF. When the frequency $f$ is equal to or less than the basic MUF ($f_B$) of a given module: $L_m = 0$.

For module E, when $f > f_B$, $L_m = 130 \left( \frac{f}{f_B} - 1 \right)^2$ or 58 dB, choose the smaller. For F2 mode, when $f > f_B$, in the path $\leq 3000$ km, $L_m = 36 \left( \frac{f}{f_B} - 1 \right)^{1/2} + 5$ or 60 dB, choose the smaller. When path $> 3000$ km, $L_m = 70 \left( \frac{f}{f_B} - 1 \right) + 8$ or 80 dB, choose the smaller. $L_g$ represents the sum of the ground reflection losses at the intermediate reflection points. When $n$ hop mode $L_g = 2(n-1)$ dB, $L_h$ is a factor including aurora and other signal losses. Each value is calculated with the geomagnetic latitude $G_n$ (N or S at the equator) and local time $t$ of the geocentric dipole corresponding to its position at 78.5°N and 68.2°W. For $G_n < 42.5°$, $L_h = 0$ dB, where $L_z$ represents those effects of skywave propagation not otherwise included in this method, and this value is currently recommended to be 8.72 dB.

4. Simulation model of short wave antenna

For the simulation model of the receiving antenna commonly used in shortwave, a general electromagnetic field analysis algorithm based on the moment method is used to calculate the radiation pattern of the antenna. In this algorithm, the integral equation is used to analyse the antenna, which avoids many simplifying assumptions required by other solutions, and provides electromagnetic analysis a highly accurate and universal tool.

4.1. Ground modeling.

The algorithm can make the influence of the ground on the antenna pattern be taken into account, and modeling can be carried out on a ground plane which may be a perfect conductor or an imperfect conductor. Three methods are used to calculate the influence of ground surface on antenna radiation in this algorithm:(1) The Sommerfeld/Norton method is used for calculation of irregular ground with distance less than one wavelength;(2) For the ideal conductor ground, the current distribution on the ground can be calculated directly;(3) For irregular ground with a wavelength much larger than one, the reflected wave is calculated by physical optics method.

4.2. Division of integral unit of antenna.

In this algorithm, an adaptive non-uniform mesh partition method is adopted to divide the basic antenna radiation components, such as metal lines, arc lines, helix lines, rotating cylinders and regular reflectors.

(1) Line element principle. The antenna is divided into linear elements, which are expressed as endpoint coordinates and radius, and cannot overlap and be continuous; The antenna radius is $r$, the line element length is $\Delta l$, and the wavelength is $\lambda$. They must meet the following requirements:1) The electrical performance requirements of the antenna: $\Delta f \leq 0.1\lambda$; 2) When $\Delta l / r > 8$, the error is less than
1 %.(2) Surface element principle. The surface element covering the reflecting surface shall be continuous and seamless with an area of $s \leq 0.01\lambda^2$, and the surface element shall not be too narrow in length in order to ensure small errors and singular solutions. The accuracy is independent of the surface element without antenna, as shown in Figure 4. The symmetric interpolation function requires the node to be at the center of the approximate square. Any plane of any shape can be composed of triangles and rectangles, so all the nodes can be within the rectangle, and the remaining triangles can be calculated as the surface without antenna.(3) Line element and surface element partition algorithm: 1) Line element partition method: $n = \text{int}(10l/\lambda_{\text{min}}+1)$, where $n$ is number of segments, $l$ is the line length, the wavelength is $\lambda_{\text{min}} = c/f$, $f$ is the maximum frequency of the excitation source, and the line element $\Delta l = 0.1\lambda_{\text{min}}$. 2) Surface element partition method: Step 1: if area $S \leq 0.01A$, terminate, otherwise continue the following steps. Step 2: if it is a triangle, divide the midpoint connecting the longest side and the diagonal vertex into two triangles, then skip to Step 1. Step 3: if it is a quadrilateral, divide it into two triangles with the shortest diagonal, then skip to Step 1. Step 4: if it is a rectangle, divide the midpoint connecting the two long sides into two rectangles, then jump to Step 1.

4.3. Simulation of antenna feed.

The parameters of antenna feed modeling mainly include the position, voltage, frequency and phase of each feed port. In this paper, the anisotropic gain of the antenna is calculated by calculating the intensity of the far-field anisotropic electric field, so an excitation source must be applied to the antenna. The excitation voltage can be selected by the algorithm by default, but the position, frequency and phase of the feed must be specified.

4.4. Antenna current distribution calculation.

In this algorithm, the current distribution of each integral unit must be calculated first, and then the spatial electric field distribution can be calculated by using the free space integral equation. In the case of the constant voltage, frequency and phase of each feed port, the main factor affecting the current distribution of each unit is the impedance of each antenna unit. When the voltage matrix is known, the current matrix can be obtained when the impedance matrix is obtained, thus the current distribution can be obtained. The general antenna can be regarded as a good metal conductor with uniform impedance, and its impedance can be adopted as the default value.

4.5. Calculation of space radiation field.

After the current distribution of each integral unit is obtained, the electric field distribution at any position in the space can be iteratively calculated by using the free space integral equation. The simplified calculation method of the free space integral equation is that the Sommerfeld/Norton method is used to calculate the near reflector, and that the physical optics method is used to calculate the space field strength of the reflected wave if the far reflector is present. Space field strength vector can be obtained by vector synthesis of direct wave space field strength and reflected wave.

4.6. Antenna pattern calculation.

In this paper, the normalized gain and the maximum gain are used to describe the antenna pattern. The normalized gain is calculated according to the following equation:

$$G'(\theta,\Phi)=\frac{G(\theta,\Phi)}{G_{\text{max}}(\theta,\Phi)} \quad (6)$$

Where, $\theta$ represents the angle between plane E, $\Phi$ represents the angle between plane H, $G(\theta,\Phi)$ represents the absolute gain of the antenna in the direction($\theta,\Phi$), and $G_{\text{max}}(\theta,\Phi)$ represents the maximum gain of the antenna in each direction.

Based on the above formula, it can be calculated as the following steps: (1) Sampling is carried out in the horizontal and vertical directions, and the spatial field strength on the spherical surface with the distance of $R$ in each direction is calculated respectively. Then, the normalized antenna pattern can be obtained by normalization based on the maximum field strength; (2) The power density of ideal omnidirectional radiation point source at $R$ distance under free space condition is calculated, and then
the field strength is calculated by the free space impedance \(120\pi\); (3) The maximum antenna gain can be obtained by taking the ratio between the maximum actual antenna field strength and the field strength at the distance \(R\) of the omnidirectional antenna.

5. Conclusion
In this paper, a short-wave signal propagation model, a short-wave electromagnetic environment simulation model, a short-wave electromagnetic environment level evaluation model, and a short-wave commonly used receiving antenna simulation model were established. Through repeated comparative tests and experimental verification, the effectiveness of each model was confirmed. On the basis of modeling research and experimental verification of each model, combined with the actual needs of shortwave position selection, interference source evaluation, and receiving antenna selection, a technical verification platform was developed. In addition, the function simulation was also conducted, such as the electromagnetic environment simulation of short-wave signal, propagation simulation of short-wave signal, short-wave interference source simulation. The level of short-wave electromagnetic environment was evaluated based on the simulated electromagnetic environment, and the short-wave receiving antennas with different types and parameters were simulated based on specific signals, and the receiving effect is evaluated.

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