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Propagation Loss Analysis of High Frequency Radio Waves in Multihop Paths

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Abstract: High-frequency radio waves are the signal frequencies at 3-30MHz high-frequency radio waves can be reflected back to earth by the ionosphere in the atmosphere– a method known as "skip" or "sky wave" propagation–these frequencies are suitable for long range communications across intercontinental distances. When HF propagates through ionosphere, signal weakness is accompanied by signal attenuation, including the loss absorption in ionosphere and during reflection. Due to turbulent flow in the ocean, turbulence may affect the electromagnetic properties of the seawater, and also change the seawater reflection surface. The azimuth and the state of motion cause an increase in the reflection loss of the water surface, while the surface reflection loss changes continuously with the turbulence. So we study the impact of these three processes on the attenuation of radio waves.

Keywords: Plasma angular frequency; Propagation loss; High-frequency radio waves

1. Introduction

Let us first discuss the propagation of radio waves in the ionosphere. The ionosphere is affected by the sun and the seasons, mainly divided into D layer, E layer and F layer, as shows in Figure 1. In Figure 1, VHF U HF SHF EHF is ultra-short wave, microwave; HF, MF, VLF LF is shortwave, medium wave and long wave respectively. Table 1 is a detailed description of the thickness and characteristics of the ionosphere.

So we get the ionosphere birefringence n or complex relative permittivity e_r expression is

$$n^2 = e_r = 1 - \frac{w_p^{\ 2}}{w^2 + v^2} + i \cdot \frac{s}{e_0 w} \tag{1}$$

Where w_p is plasma angular frequency, s is ionospheres' conductivity, if the average collision frequency of electrons and neutral molecules is much lower than the radio wave, that is $v = w$, then:

$$n^2 = e_r = 1 - \frac{w_p^2}{w^2} \tag{2}$$

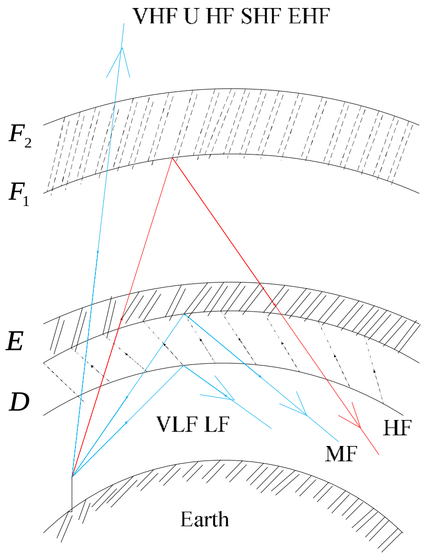

Figure 1. Relationship between Radio Wave Propagation and Ionosphere

N is charged particle concentration $10^8 \sim 10^{13} cm^{-3}$, $e = 1.6 \times 10^{-19} C$, $e_0 = 8.8542 \times 10^{-12} F/m$. The calculation results shows in Table 2.

Table 1. The Thickness and Characteristics of the Ionosphere.

	Thickness	Characteristics
Layer D	60~100 km	Only exists during the daytime, absorbing shortwave and medium wave, reflecting long wave
Layer E	100~120km	Reflects medium and short waves
Layer F	200~300km	F1layer is the lower part of F layer, F2 layer is the upper part of F layer, F1 layer is more obvious in the summer during the day, F layer reflects shortwave.

Table 2. The calculation results of w_p

The layer of ionosphere	The angular frequency of the plasma (MHz)
D-layer	**4.25**
E-layer	**14.17**
F-layer	**141.7**

2. The Absorption of HF in Ionosphere

When a heating radio wave propagates through the ionosphere, we describe the height distribution of radio wave energy flow density S by the following formula:

$$\frac{\partial S}{\partial Z} = -2KS \ . \tag{3}$$

Where K is absorption coefficient of HF, the following formula is energy flow S :

$$S(Z) = \frac{ERP}{4p Z^2} \exp\left(-2\int_0^Z K(Z')\,dZ'\right) \tag{4}$$

Where Z is the height and ERP is the effective radiation power, the following formula is absorption coefficient:

$$K = \frac{N_e v_e}{(w + w_1) + v_e^{\,2}} \ . \tag{5}$$

Where w is angular frequency, w_1 is electron cyclotron frequency, N_e is electronic density and v_e is the collision frequency of electrons and neutral electrons.

$$\Delta dB_E = 10\lg\frac{S_O}{S_I}\ , \tag{6}$$

where ΔdB_E is the change number of dB in ionosphere, S_O is the energy density projecting from the layer D and S_I is the energy density injecting in the layer D.

3. The Absorption of HF in Calm Sea

Then we consider the reflection of radio waves at sea level, and we first consider the reflection of radio waves on the calm sea surface. In the sky wave multi-hop propagation mode, the propagation loss should not only consider the wave reentry into the ionosphere, but also consider the loss of Marine reflection (L_O).

Considering the circular polarization wave, the calculation formula of Marine reflection loss is as follows:

$$L_O = 10\lg\left(\frac{|R_V|^2 + |R_H|^2}{2}\right) dB\ , \tag{7}$$

where R_V is the reflection coefficient of vertical polarization and R_H is reflection of horizontal polarization, the formula R_V and R_H is respectively:

$$R_V = \frac{(e_r - 60il s)\sin q - \sqrt{(e_r - 60il s) - \cos^2 q}}{(e_r - 60il s)\sin q + \sqrt{(e_r - 60il s) - \cos^2 q}}$$
$$R_H = \frac{\sin q - \sqrt{(e_r - 60il s) - \cos^2 q}}{\sin q + \sqrt{(e_r - 60il s) - \cos^2 q}} \tag{8}$$

Where e_r is complex permittivity, we take the complex permittivity of water $e_r = e_w = 81$; s is surface conductivity, we take $s = 4S/m$; l is working wavelength, we take $l = 10\text{m}\,(v = 30MHz)$; q is angle between electromagnetic wave and sea surface tangent

For turbulent sea surface, we need to replace the relative permittivity e_w of calm sea with equivalent relative definition of constant e_{reff} , by the Maxwell-Gamett mixing formula, we have:

$$e_{reff} = \frac{e_w(1 + 2f_a y)}{e_0(1 - f_a y)}$$
$$y = \frac{e_0 - e_w}{e_0 + 2e_w} \tag{9}$$

Where e_0 is the dielectric constant of air; f_a is a constant relate to water flow

At the same time, the reflection of radio waves is also related to the roughness of the sea surface, we correct the reflection coefficient of vertical polarization R_V and reflection of horizontal polarization R_H ,and we get the reflection coefficient of vertical polarization R_V^* and reflection of horizontal polarization R_H^* after correction from the following formula:

$$R_V^* = R_{si}R_V$$
$$R_H^* = R_{si}R_H \tag{10}$$

where R_{si} is rough surface scattering coefficient.

$$R_{si} = \exp\left(-2(2p M_i)^2\right) I_0\left((2p M_i)^2\right) \tag{11}$$

where $I_0(\ )$ is zero order Bessel function after correction and M_i is roughness, M_i express as:

$$M_i = \frac{d_h \sin q}{l} \tag{12}$$

where d_h is the root mean square of the changing height of the sea surface

4. Design of temperature field measurement scheme

Finally, we compare the effects of calm sea surface, turbulent sea surface, smooth terrain and mountainous terrain, the result shows in Figure 2.

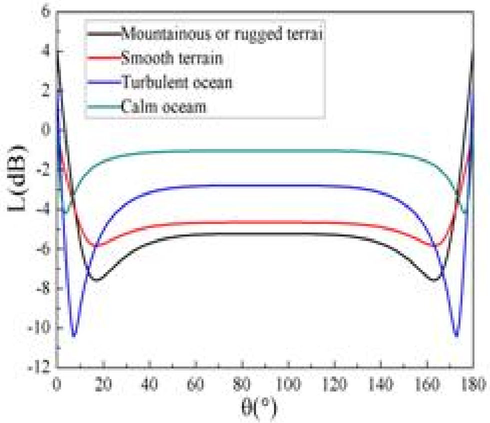

Figure 3. Comparison of the Effects of q on L in Ocean and Terrain

We can find that the reflection loss L_D of the ground is mostly greater than the reflection loss of the ocean L_O . In addition, the roughness of the reflection surface can increase the reflection loss.

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