Analysis and Simulation of Propagation Characteristics of SLF Communication

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Abstract-**From propagation characteristics of SLF communication, theoretical models have been deduced by wave-guide theory and formulas of vertical electric field and horizonal magnetic field also have been presented. Attenuation rates of SLF communication in earth-ionosphere and in the sea have been discussed.Normally the value of attenuation rate in daytime is more than that in nighttime. Atmosphere noises and direction effect also have an influence on SLF communication. By the way,in practice Schumann resonance frequency should be a avoided.**

Keywords-SLF Communication,Propagation characteristics, Wave-guide, Attenuation rate

I. INTRODUCTION

VLF(very low frequency:3kHz-30kHz) and SLF(super low frequency:30Hz-300Hz) can propagate stably between earth and lower ionosphere with low wastage.They are important means of communication for remote warships and submarines.Due to history reasons, propagation of VLF and SLF had been divided into three modes:earth wave, sky wave(radial theory) and earth-ionosphere wave-guide[1].The first theory believe that electromagnetic waves promulgate just along earth's surface because of no considerations of ionosphere at all.The radial theory take ionosphere and reflection effect into account. But the physical essence of propagation of electromagnetic wave in earth-ionosphere can be thoroughly explained by the last theory.Because SLF has less attenuation rate and more penetrated depth in the sea, earth-ionosphere wave-guide has been adopted for analysis of SLF communication.

II. PROPAGATION CHARACTERISTICS OF SLF COMMUNICATION

(ⅰ) More stability and less attenuation: take 100Hz SLF for instance,the attenuation rate in the air is (0.8-1.5) dB/Mm;

(ⅱ) More penetrated depth in the sea: the attenuation rate in the sea of 100Hz SLF is just 0.35dB/m(the conductance rate of sea water is 4S/m),which has a scalar level less than that of VLF.

(iii) The extremely low efficiency of SLF antennas:the size of antennas are incomparable with the wavelength of SLF(1Mm-10Mm). A antenna with 1 megawatt power only radiates several watts.In order to acquire high efficiency,the size of transmitting antenna unit should be a quarter of wavelength of SLF(750km required for 100Hz SLF).

(ⅳ) Bad Signal-to-Noise rate and low propagation rate:SNR of (-3dB- -11dB) of SLF receiver because of atmosphere noises and interior noises of receiver.The propagation rate is less than 0.1 bit/s with restrictions of bandwidth.

(ⅴ) High anti-jamming ability: the disturbance of ionosphere is small and any man-made disturbance is costly for SLF[2,3].

III. THEORETICAL MODELS OF SLF PROPAGATION

A. *Propagation of SLF in earth-ionosphere*

1) TEM wave-guide

The effective reflection altitude of ionosphere is between 70km-90km,which is far less than SLF's wavelength in freedom space.So only the lowest level pattern —TEM pattern will exist[4].

First on the assumption that the earth and ionosphere both have symmetrical and steep verge,so the earth-ionosphere waves can be treated as parallel flat waves.Define S as formula (1).S is a function parameter of time,frequency and geography position because of the time variation of ionosphere.

$$S = (1 - \frac{i(\eta_i + \eta_g)}{\omega\mu_0 h_i})^{\frac{1}{2}} \tag{1}$$

In this formula, η_i is the superficial impedance of ionosphere while η_g is that of the earth, μ_0 is magnetoconductivity of freedom space, h_i is the effective altitude of ionosphere, $\omega = 2\pi f$, f is the frequency. $\mu_e = S^2\mu_0$, μ_e is plural magnetoconductivity.

$$\frac{\partial E_z}{\partial y} = -i\omega\mu_e H_x \tag{2}$$

$$\frac{\partial H_x}{\partial y} = -i\omega\varepsilon_0 E_z \tag{3}$$

Formula (2) and (3) is propagation formulas of TEM wave with a plural magnetoconductivity μ_e.The wave-guide number is $k = \omega\sqrt{\varepsilon_0\mu_e} = Sk_0$, ε_0 is constant of

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capacitance rate of freedom space.And the wave-guide impedance is $\eta = \frac{\omega\mu_e}{k} = S\eta_0$.

Also the relative speed and attenuation rate of SLF propagation can be obtained as follows.

$$\begin{cases} c/v = \operatorname{Re} S \\ \alpha = 0.02895\omega \operatorname{Im} S \end{cases}$$

α is attenuation rate,whose unit is dB/Mm.

The effective conductivity of ionosphere is (10-5-10-7) S /m,which is less than that of the earth(10-4-1) S/m.So the the superficial impedance of the earth is less than that of ionosphere.The wave-guide attenuation is mainly absorbed by ionosphere.The attenuation rate will greatly increase as frequency heightens.So lower frequency is a priority in long-distance communication.

Vertical electric field and horizonal magnetic field are main fields of wave-guide propagation.Because the superficial impedance, propagation factor and effective altitude of ionosphere are obtained by measurement.It is difficult to calculate field intensity exactly.But we can do approximately as following formulas.

Horizonal magnetic field:

$$|H_\phi| \approx \frac{Idlf}{240\pi}\left(\frac{2\pi\mu_0}{c}\right)^{1/2} \frac{\cos\phi}{h_i[\sigma_e(c/v)]^{1/2}} \frac{e^{-\alpha\rho}}{[a_e \sin(\rho/a_e)]^{1/2}}$$

Vertical electric field:

$$|E_r| \approx \left|\frac{2\pi\mu_0}{c}\right|^{1/2} \frac{Idlf}{2h_i(\sigma_e)^{1/2}} \left[\frac{\rho/a_e}{\sin(\rho/a_e)}\right]^{1/2} \frac{e^{-\alpha\rho}}{\rho^{1/2}}\cos\phi$$

In formulas, Idl is source intensity,which is the product of electric current and length of antenna,(A·m); σ_e is the effective conductivity of the earth,(s/m); ρ is the circular distance between transmitter and receiver,(m); α is attenuation rate of vave-guide,(NP/m,1NP/m=8.686dB/m); a_e is radius of the earth, 6.37×106m; v is the wave speed in wave-guide,; c is the speed of light,3×108 m/s.

2) atmosphere noises

Atmosphere noises are mainly from thunder and lightning.The energy distribution of noises are variational with time,frequency and geography position.Thunder and lightning are more active in low latitude,while less in high latitude,and none in south and north pole.More in summer and less in winter,even in twenty four hours it is varied.The frequency spectrum is decided by the frequency spectrum characteristics of the source of noises, propagation path,excitation pattern, attenuation rate and strike times of receiver in effective accumulated time.For VLF,10kHz noises field can be obtained from noises chart for special position and time technically ,and then prediction of noises field can be drawed by frequency exchange[5,6].But for SLF,there is none integrated data at present,only some actual measurement data is refered.

3) direction effect

Due to anisotropism of ionosphere,the attenuation and relative speed vary with propagation direction.The attenuation rate is twice or triple from east to west as big as from west to east. The south to north propagation attenuation rate is between them.Normally the value of attenuation rate in daytime is more than that in nighttime.This is because the effective altitude of ionosphere is smaller in daytime than that in nighttime,and capacity of wave-guide is smaller.There is no evident difference along pole zone and temperate zone.

4) Schumann resonance

Usually horizonal low established or horizonal shallow buried antenna are adopted as SLF antennas which can be idealized as horizonal electric dipole.But when the frequency is as low as several hertz or tens of hertz,the wavelength is comparable with girth of the earth.There will be Schumann resonance when the wavelength and earth's girth accord with certain relationship(7.5Hz、14.5Hz、20Hz、27.5Hz、31.5Hz、37.5Hz).

B. Propagation of SLF in the sea

Electric parameters in seawater is greatly different from that in atmosphere,so underwater SLF propagation characteristics should be analysed when the receiving antenna is in sea.

In the seawater, the conductivity $\sigma = 4$ (s/m);and magnetoconductivity $\mu = \mu_0 = 4\pi \times 10^{-7}$; capacitance rate is eighty times more than that of freedom space, $\varepsilon_r = \varepsilon / \varepsilon_0$, $\varepsilon_0 = (1/36\pi)\times 10^{-9}$, $\varepsilon_r = 80$ .The higher temperature the less ε_r .

In seawater $\sigma >> \omega\varepsilon$,so the main electric field from aerosphere into the sea is horizonal electric field E_h induced by horizonal magnetic field H_ϕ on the sea surface.z is the depth from surface to receiver,z=0 is sea surface.The horizonal electric field can be calculated as follow.

$$E_h(z) = E_h(0)e^{-\sqrt{\pi f \mu\sigma} z} e^{-j\sqrt{\pi f \mu\sigma} z}$$

The field intensity will attenuate exponentially as increase in depth.And the formula of propagation attenuation rate in the sea with frequency and seawater conductivity is:

$$\alpha = 20\lg e \cdot \sqrt{\pi f \mu\sigma} = 0.03452 \cdot \sqrt{f} \quad \text{(dB/m)}$$

IV. RESULT AND ANALYSIS OF SIMULATION

Figure1 gives a sketch map of propagation path of SLF communication.The transmitting antennas are established in the land,so the propagation path of SLF is a mixed path of land and sea. Mil-ington,Wait and Walters had analysed and proved that when the path is from land to sea,the field intensity will increase as distance(called recovery effect).But in SLF, the influence of mixed path effect is little.A equivalent single sea path is adopted in this article.

Asymmetries of the earth and ionosphere along the propagation path are ignored in modeling,so is asymmetry of ionosphere induced by magnetic field.Ionosphere is idealized as a certain altitude reflecting wall,whose superficial impedance is a certain value.The earth is another reflecting wall.The two reflecting walls are idealized as parallel plane or concentric spherical surface.

The relations between attenuation rate and frequency in earth-ionosphere and seawater propagation path are presented in figure2 and figure3 separately. The value of attenuation rate in daytime is more than that in nighttime. The attenuation rate greatly increase as frequency is heightened.

V. SUMMARIES

It can be concluded after analysis of propagation characteristics of SLF communication that SLF can propagate long distance,so only one transmitter can afford global communications.SLF can propagate stably between earth-ionosphere with low attenuation,and penetrate certain depth of earth and seawater.It also has high anti-jamming ability.If the receiving antenna has enough sensitivity and interior noises,the signal is sure to be received.So SLF propagation can be applied to national defence field as an important communication,which is of strategic importance.

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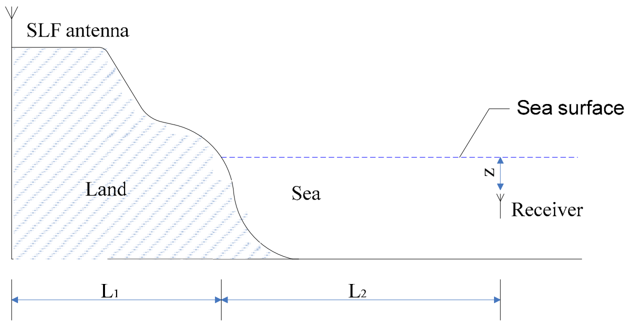

Figure 1 A sketch map of propagation path of SLF communication

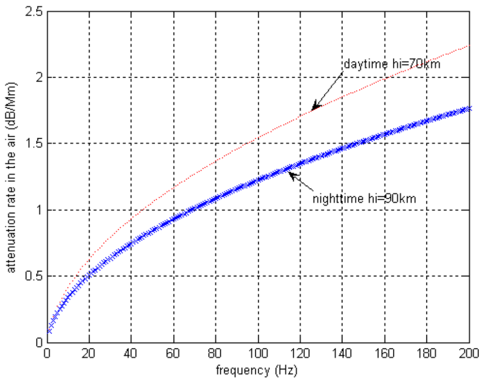

Figure 2. The relations between attenuation rate and frequency in earth-ionosphere propagation

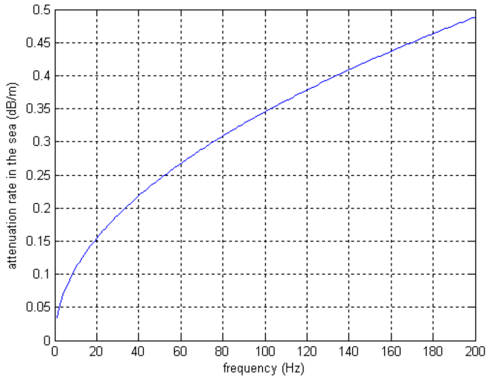

Figure 3. The relations between attenuation rate and frequency in seawater

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