FULL WAVE ANALYSIS OF WHISTLER MODE WAVES EXCITED BY CIRCULARLY POLARIZED SPHERICAL WAVES INCIDENT FROM BELOW

S. Yagitani[1], I. Nagano[1] I. Kimura[2] and M. Mambo[1]
[1] Dept. of Electrical Eng., Kanazawa University
[2] Dept. of Electrical Eng. II, Kyoto University

Abstract. The polarization experiments conducted by Stanford University using Antarctic Siple VLF transmitter have shown that the signals were observed at the geomagnetic conjugate point in Canada even if a left-hand circularly polarized wave is radiated from the transmitter, with an intensity 12dB lower than those observed at the time of transmission of right-hand circular polarization [1]. In order to quantitatively interpret this result, spatial energy distributions of whistler mode waves at an altitude of 105km in the ionosphere are calculated by the full wave method, under the assumptions that spherical waves are radiated with a right- and a left-hand circular polarizations by crossed dipole antennas on the ground. It is found that the 12dB difference in the signal strength at the conjugate point due to the difference in polarization is understood if the transmitted signal penetrates the bottom of the ionosphere horizontally about 80km away from the transmitting point, where an end point of the field aligned VLF ducts may exist.

1. Introduction

In recent years, a series of experiments have been conducted using a high power VLF transmitter and a set of crossed dipole antennas facilitated at Siple station, Antarctica, in order to transmit the whistler mode wave power into the magnetosphere as effective as possible by selecting polarization of radiation and to find an appropriate entrance point to be guided by a field aligned VLF duct in the magnetosphere [1]. One of the interesting results is that the signals were observed at the geomagnetic conjugate point in Canada even if a left-hand (LH) circularly polarized wave was radiated from the transmitter, with an intensity 12dB lower than those observed at the time of transmission of right-hand (RH) circular polarization, when there was no temporal amplitude variation and no triggered emission found around that observation period.

It is known that the signal strength of whistler mode waves in the ionosphere which is originated from the waves transmitted from a ground based transmitter, is greatly dependent on the gradient of the electron density at the bottom of the ionosphere and on the polarization of the original transmission. So far there has been no quantitative study to interpret the results of above mentioned experiments.

In this paper, by using the full wave method we calculate the spatial energy distributions of the whistler mode waves at an altitude of 105km in the ionosphere for a RH and a LH polarization of VLF spherical wave transmissions from the ground.

2. Model of calculation

Our calculation was made in the coordinate system shown in Fig.1. The horizontal crossed dipole antennas are set at the origin and radiate arbitrarily polarized spherical waves with a certain radiation pattern. In order to apply the full wave method [2] to the ionospheric propagation of a spherical wave incident from below, it is required to express the spherical wave in terms of plane waves. Therefore we have developed a calculation technique using Fourier analysis, in which a polarized spherical wave is represented by the sum of a number of elementary plane waves. The procedures for the calculation are summarized as follows: The radiated spherical wave is expanded into a number of elementary plane waves at the bottom of the ionosphere by using the two dimensional Fourier transform. For each plane wave, the full wave method is applied to calculate the full set of wave field components like Ex, -Ey, Hx and Hy in the lower ionosphere. Then by synthesizing all of these elementary plane waves at a level of interest in the ionosphere, a spatial distribution of the excited whistler mode wave at that level can be calculated.

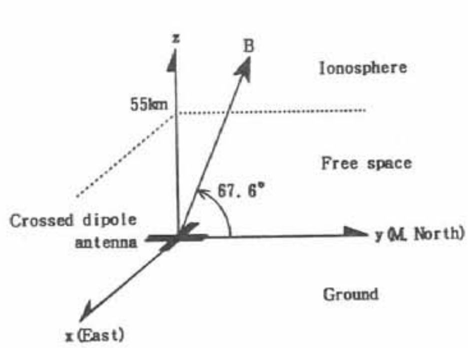


Fig.1 The coordinate system used in our calculation

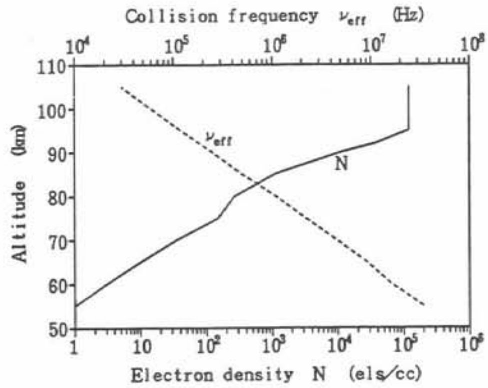


Fig.2 Ionospheric model

In our calculation the following approximations are made. The ionosphere is assumed to be horizontally stratified on a area over about a thousand kilometers square in order to apply the full wave method to each plane wave. The reflection at the ground surface is neglected. These two assumptions are valid in the short distance propagation.

The full wave calculation requires the altitude profiles of electron density and collision frequency between electrons and neutral particles. The profiles adopted are shown in Fig.2, where the electron density profile is that obtained from the rocket experiment made at the Siple Station [3]. The other parameters used in the present calculation are listed below.

Geomagnetic dip angle	67.6°
Electron gyro frequency	1.6 MHz
Altitude range of the full wave calculation	55 km - 105 km

3. Calculated results and discussions

We present some calculated results for waves at a frequency of 3.48kHz and discuss the wave entry point into the ionosphere and magnetosphere.

Figure 3 shows the Poynting flux distribution of the radiated wave over the area of 1200km x 1200km at the lower boundary of the ionosphere at an altitude of 55km when a spherical wave of the above mentioned frequency is radiated with a LH or a RH polarization. The center of this figure is the point just above the transmitting crossed dipole antennas. The upper panel shows the direction and magnitude of the Poynting flux in linear scale. And the lower panel shows the magnitude of the vertical component of

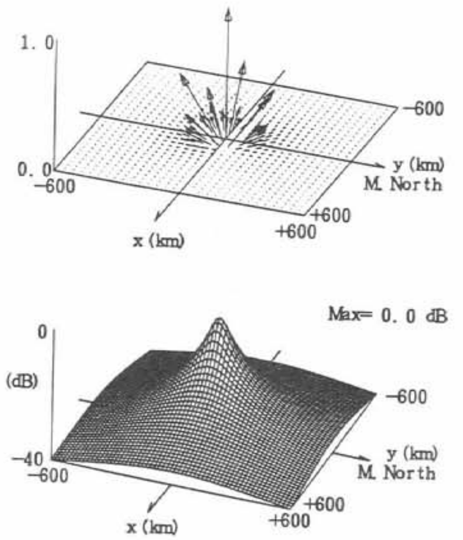
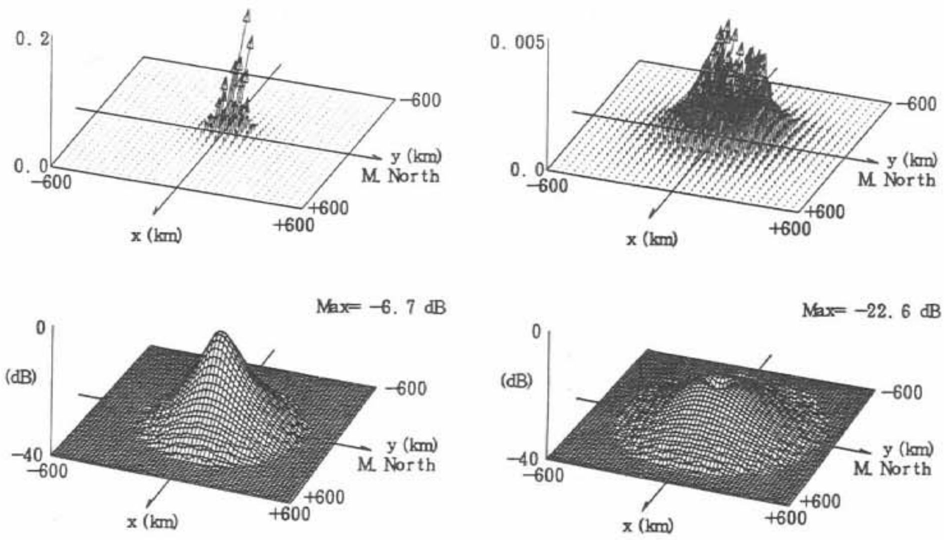


Fig.3 Poynting flux distribution of the circularly polarized spherical wave at the bottom of the ionosphere

the Poynting flux in logarithmic scale, where the maximum level is taken as 0dB.

Figure 4 shows the Poynting flux distributions of the excited whistler mode waves at an altitude of 105km in the ionosphere. The figures (a) and (b) correspond to the cases that the waves are radiated with RH and LH circular polarizations, respectively. The maximum levels of the energy flux corresponding to the RH and LH polarizations are 6.7dB and 22.6dB, respectively, lower than the maximum level at the bottom of the ionosphere, shown in Fig.3. The difference in attenuation in the lower ionosphere for these two polarizations is about 16dB, which is much larger than those observed at the conjugate point in Canada. And it is interesting that each whistler mode wave obviously propagates just like a beam wave along the geomagnetic field line in spite of the spherical wave incidence. The shapes of the energy distributions shown in Figs.4(a) and 4(b) are significantly different. Now we have to investigate how to explain this difference between the results of observation and calculation. In Fig.5 the ratio of the whistler mode wave intensity at an altitude of 105km excited by the RH polarization to that excited by the LH polarization is plotted as contour lines with 10dB steps in the area of 600km x 600km. The equi-ratio contour lines have a concentric configuration which is shifted slightly toward the



(a) (b)

Fig.4 Poynting flux distributions at 105km of the whistler mode waves excited by (a) RH and (b) LH circularly polarized waves geomagnetic north because of the field-aligned propagation. From this figure we can infer that if the entry point to the ionosphere is deviated further from the point above the transmitter, the ratio of whistler mode intensities excited originally from the RH and LH respectively approaches to unity (0dB). This fact implies that from the observed ratio how far the entrance point to the ionosphere is deviated from the source can be determined. If the observed ratio is as large as 30dB the entry point should be in the very vicinity of the point just above the antenna. The actually observed ratio of 12dB will infer that entrance point is located about 80km away from the transmitting antennas, where an end point of ducts to guide the wave to the conjugate point might be located.

These calculated results can be applicable for finding the location of the VLF duct termination point without other information on the duct if we assume that the whistler mode waves excited by the two different polarizations propagate in the duct.

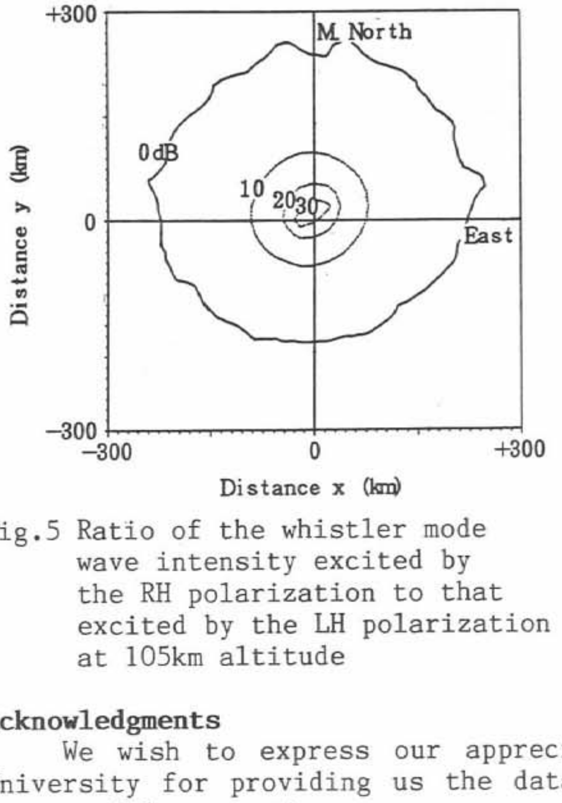


Fig.5 Ratio of the whistler mode wave intensity excited by the RH polarization to that excited by the LH polarization at 105km altitude

4. Conclusion

The spatial energy distributions of whistler mode waves in the lower ionosphere were calculated using the full wave method when spherical waves with a right- and a left-hand circular polarizations respectively are radiated by crossed dipole antennas on the ground. By taking account of the calculated ratio of these two whistler mode wave intensities, we have interpreted that the whistler mode waves observed with the ratio of about 12dB in the polarization experiment might have propagated from the transmitting antennas to a distance of about 80km. Our calculation results will contribute to the interpretation of data to be obtained by our satellite EXOS-D, launched on February 22, 1989.

Acknowledgments

We wish to express our appreciation to Prof. U.S.Inan of Stanford University for providing us the data of the polarization experiments and many useful suggestions.

References

[1] R.A.Helliwell: "VLF wave-injection experiments from Siple Station, Antarctica", Cosper, A.D.V.Space Res., 8, 297(1988)

[2] I.Nagano, et al.: "Numerical calculation of electromagnetic waves in an anisotropic medium", Radio Sci., 10, 6, 611(1975)

[3] P.M.Kintner, et al.: "In situ measurements of transionospheric VLF wave injection", J. Geophys. Res., 88, A9, 7065(1983)