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THE MEASUREMENT OF ARRIVING DIRECTION AND THE POLARIZATION OF WHISTLERS AT LOW LATITUDES

Toshimi OKADA and Akira IWAI

Research Institute of Atmospherics,Nagoya University,
Toyokawa,Aichi,442,Japan

1.Introduction

Whistlers are the V.L.F. electromagnetic waves which are originated from the lightning discharges,penetrate into the ionospere and propagate along the line of force of the earth's magnetic field in the magnetosphere (1).Recently the convincing in-situ observations of the field-aligned columns of enhanced ionization("ducts") which act as waveguides for whistlers have been reported at high and middle latitude(2,3). In addition to the ducted whistlers,the satellite measurements have yielded a lot of non-ducted whisltlers within the magnetosphere(4). The ground whistlers are considered to be attributed to the ducted propagation. However at low latitude there are very few evidence indicating the ducted propagation(5,6). According to the results of the ray tracings for whistlers in the model magnetosphers,the ray path of non-ducted whistler deviates from the line of force and the final latitude in the opposite hemisphere shows significant difference with varying the wave frequency.While in the case of ducted mode the ray path is along a simple line of force over a wide frequency range usually observable on the ground. These facts will allow us to be a key in distinguishing the mode of whistlers. The present paper is intended to identify the propagation mode of ground whistlers based on the direction finding at two specific frequencies of 5.6 and 2.8 kHz. We first give the principle of our measuring method and then some results are shown.

2. The principle of the measurement

The configuration of the problem is that the downgoing whistler wave makes an incident angle (i) with respect to the vertical and an azimuthal angle (θ) as measured clockwise from the north. The elliptically polarized wave is decomposed into the TE (transverse electric) and TM (transverse magnetic) mode waves. The electromagnetic fields at a point A whose height is much smaller than the wavelength are the superposition of the field of a direct ray and that of a ray reflected from the ground and they are written by (7,8,9).

$$H_x = 2\cdot A_{\perp h}\cdot\left[(\cos\theta - u\cdot\cos i\cdot\sin\theta)\cos\omega t - v\cdot\cos i\cdot\sin\theta\cdot\sin\omega t\right]$$

$$H_y = 2\cdot A_{\perp h}\left[-(\sin\theta + u\cdot\cos i\cdot\cos\theta)\cos\omega t - v\cdot\cos i\cdot\cos\theta\cdot\sin\omega t\right]$$

$$E_z = -2\cdot A_{\perp h}\cdot\sin i\cos\omega t$$

where,$H_\perp = A_{\perp h}\cos\omega t$,$H_\parallel = A_{\parallel h}\cos(\omega t - Q)$ and the second terms in the equations represent the TE mode component. The wave polarization (P) is defined by $P = u - jv = (A_{\parallel h} / A_{\perp h}).\exp(-jQ)$. For example the exact right-handed circular polarization is given by $(u,v)=(0,1)$. The fields are picked up by crossed loops and a vertical antenna. The responses of electric and magnetic antennas are equalized and the total gain including phase is g. The signals at the receivers are given by $V_x = g\cdot H_y$, $V_y = g\cdot H_x$ and $V_z = g\cdot E_z$

The block diagram of the signal analyzer is shown in Fig.1.
The cross- and auto-correlations among the signals of V_x, V_y, V_z and $\overline{V_x}, \overline{V_y}$ which are lagged in phase by a right angle of the corresponding signals,will yield

the polarization and arriving angles. For example, the signal (α) passing through the correlator 1 which makes the cross-correlation between $\bar{V}_x$ and V_y is defined by

$$\alpha = 2(g\,A_{1h})^2 \cdot v \cdot \cos i$$

Similarly, we obtain the expressions for β, γ, δ and λ,

$$\beta = -2(g \cdot A_{1h})^2 \cdot v \cdot \cos i \cdot \sin i \cdot \sin\theta \quad , \quad \delta = 2(g \cdot A_{1h})^2 \cdot \sin i \cdot (\sin\theta' + u \cos i \cos\theta')$$

$$\gamma = -2(g \cdot A_{1h})^2\, v \cdot \cos i \cdot \sin i \cdot \cos\theta \quad , \quad \lambda = 2(g \cdot A_{1h})^2 \cdot \sin i \cdot (-\cos\theta' + u \cos i \sin\theta')$$

The signals of V_z is auto-correlated such that it will give us the incident angle(i).

The measurement of the axis ratio of the Lissajous pattern driven by the V_x and V_y signals requires the detection of the low frequency(ρ)and high frequency(σ) components of the output of the addition between $V_x{}^2$ and $V_y{}^2$.

$$\rho = 2(g \cdot A_{1h})^2 \cdot [1 + (u^2 + v^2)\cos i]$$

$$\sigma = 2(g \cdot A_{1h})^2 \cdot [\{1 + (u^2 + v^2)\cos^2 i\}^2 - 4 v^2 \cos^2 i]^{1/2}$$

Using the values of ρ and σ, the axis ratio κ is given by

$$\kappa = ((\rho - \sigma)/(\rho + \sigma))^{1/2}$$

On the occasions when the ionospheric exit point is close to the observing station, the wave polarization is close to circular. While, in the case when the whistlers have propagated over great distances, after exiting from the ionosphere at the latitude far from the station, the wave polarization is nearly linear. So, it will be sufficient to discuss the following three cases; (I) the vertical incidence with nearly circular polarization, (II) the oblique incidence generally with elliptical, but rather circular, polarization, and (III) the horizontal incidence with the linear polarization.

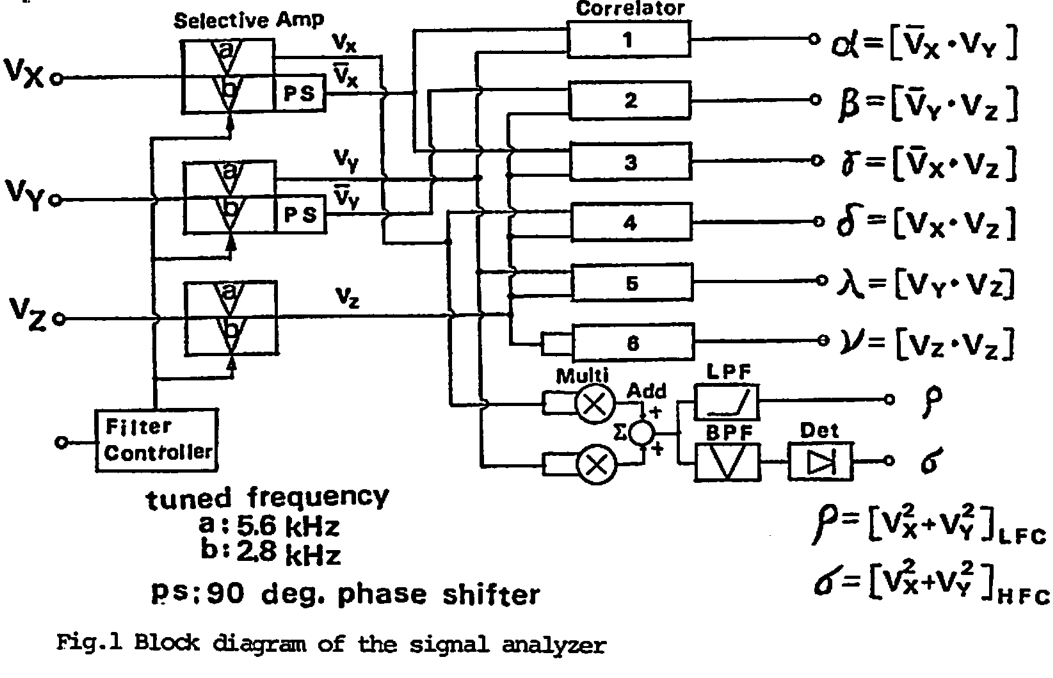

Fig.1 Block diagram of the signal analyzer

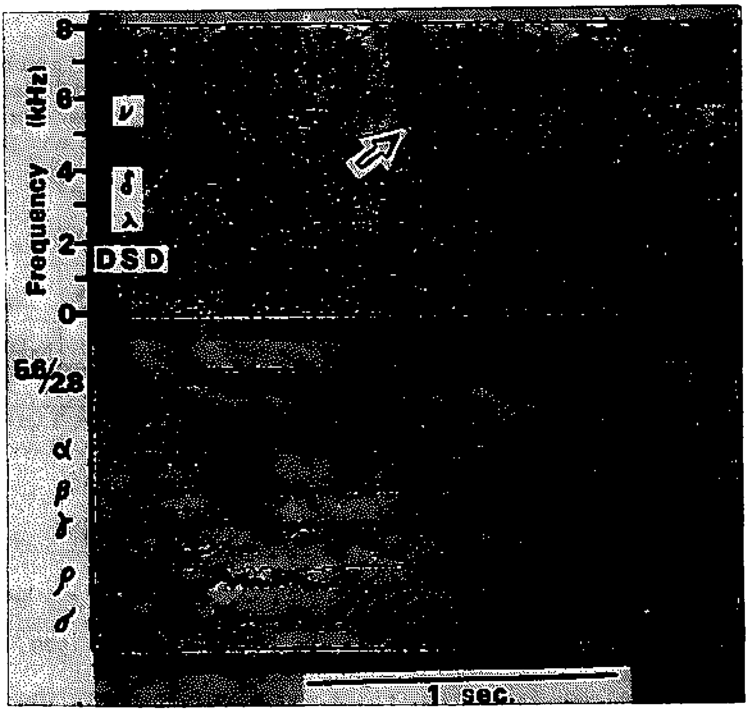

Fig.2 An example of the response of the analyzer to whistlers.

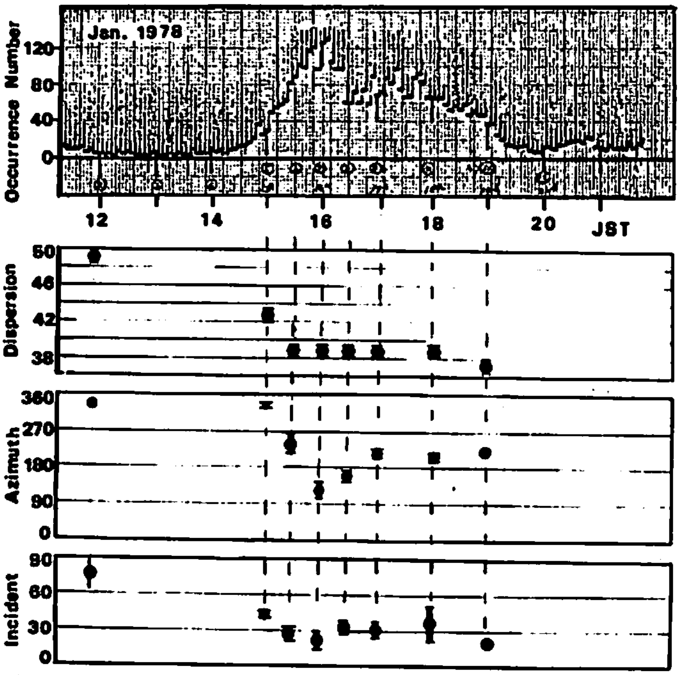

Fig.3 Diurnal variation of the whistler activity,dispersion,azimuthal and incident angles of whistlers.

In the case (I) only the signal of α is considerably enhanced, while the levels of β, γ, δ, λ and ν remain zero. In the case (II), we will have the outputs from all the channels(α to λ). Using the obtained data on those parameters we can get the azimuthal and incident angles and the polarization from the following equations.

$$\theta = \tan^{-1}(\beta / \gamma), \quad i = \sin^{-1} (\beta^2 + \gamma^2)^{1/2} / \alpha$$

$$u = 1/\cos i \cdot ((-\delta/\lambda) \cos\theta - \sin\theta)/ ((-\delta/\lambda) \sin\theta + \cos\theta)$$

$$v = \alpha/ \nu \cdot \sin i \cdot \cos i$$

The sense of the polarization is determined by the sign of α, that is, the polarization is right handed for positive α and left handed for negative α.

In the case(III), α, β, and γ become negligibly small compared with δ, λ and ν, and also ρ is nearly equal to σ. Then the azimuthal angle is given by

$$\theta = \tan^{-1}(-\delta/\lambda)$$

3.Results

The direction finding observations have been carried out at Moshiri (geomag.lat.34.5°N) during the period from January to February of 1978. During the period we have encountered a considerable high whistler activity amounting to 100 per 5 minutes. Fig.2 shows an example of the sonograms of several whistlers(top panel) and the values of α to λ for the corresponding whistlers(lower panel). The line with the notation of 5.6/2.8 in Fig.2 indicates the selection of tuned frequency. The tuned frequency is 5.6 kHz during the interval of the thick line and it changes to 2.8 kHz during the successive time with the thin line. From the data of the value of α, β, γ and so on, the whistler indicated by an arrow is found to correspond to the case(II), yielding the incident angle of 14° and azimuthal angle of 270° at 5.6 kHz and 19°, 270° at 2.8 kHz, respectively.

Fig.3 gives the temporal evolution during several hours of the ionospheric exit points and the dispersion of whistlers and the response to some of them is already shown in Fig.2.

A summary of the results deduced from Fig.3 and from other events is given as follows.

(1) The whistlers with a larger dispersion are likely to have propagated from the north, being consistent with the expectation.

(2) At the time when the occurrence rate at the station shows a peak value, the incident angle becomes very small, indicating the exit point being very close to the observing station.

(3) The frequency dependence of the exit points seems to be small during the period of high whistler activity.

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