VLF HISS AT SYOWA STATION, ANTARCTICA

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Abstract

Analyzing the VLF hiss (or auroral hiss) record at Syowa Station (geomagnetic latitude −69.7°), Antarctica, which induced the observation on polarization, incident angle and intensity, we have found the evidence that VLF hiss is right-handed, and elliptically polarized, wave (whistler mode wave), and its incident angle into free space below the ionosphere is small. We have also found that the upper frequency of VLF hiss which appear in advance of the break-up of over-head aurora reaches more than 100KHz and that the maximum energy of the spectrum is received at a frequency near to 10 KHz.

Further it is suggested that VLF hiss in the auroral zone is generated by Cerenkov radiation process in the low altitude dark magnetosphere, and that it does not propagate to the middle and low latitudes.

1. Introduction

Correlation of the VLF hiss with the other geophysical phenomena (aurora, cosmic noise absorption and magnetic activity) have been studied by some workers. As a result, it has become to be well known that VLF hiss activity is the greatest before magnetic midnight and definitely has a close correlation with the geophysical phenomena (Helms and Turtle 1964, Harang and Larsen 1965, Morozumi and Helliwell 1966).

Jörgensen (1966) summarized the result of VLF hiss ovservation carried out at thirteen stations in the both hemispheres and found that VLF hiss activity, observed at about 70° geomagnetic latitude is the greatest about one hour before the magnetic midnight and suggested a close correlation between VLF hiss and inflowing flux of electlons of about 40Kev energy using Satellite data. Fritz and Gurnett (1965) detected soft electlons (−10Kev) in the dark magnetosphere which comes in the auroral zone at low altitude by using satellite, and Gurnett and Jörgensen pointed out that the low energy auroral particles can generate VLF hiss (Gurnett 1966, Jörgensen 1968).

On the other hand, polarization, incident angle and arriving direction of VLF hiss have been studied by Harang and Hauge (1965), Iwai and Tanaka (1968), Nishino and Tanaka (1969). Nishino and Tanaka showed that VLF hiss is R-wave (whistler mode wave) and comes from all directions within source area at Syowa Station. In the present paper, we discuss the generation mechanism of VLF hiss, using polarization, incident angle, and intensity, data observed by one of the authors (Tanaka) at Syowa Station in 1968.

2. Occurrence of VLF hiss

2—1 Diurnal and seasonal variation

Fig. 1 shows the diurnal and seasonal variation of VLF hiss at 12KHz. The occurrences in the other frequencies (2, 5, 8 and 25KHz) also have been found more or less to be of the same tendency (not shown in this paper). Fig. 2 shows the occurrence probability variation with time of peaks in the noise events. It is seen in the figure that the activity is the greatest before magnetic midnight and the occurrences concentrate in the local midnight. Also Fig. 1 tells the fact that the occurrences are limited in winter and in equinoxes, and are very few in summer, because of the ionospheric absorption.

Fig. 1: Diurnal and seasonal variation of the occurrence hours of VLF hisses at Syowa Station. Dots show the peaks of events.

2—2 General aspects of the hiss observed

The usual VLF hiss which appears in association with moderate activity of aurora and geomagnetism, continues from ten to several tens of minutes, and dominates in

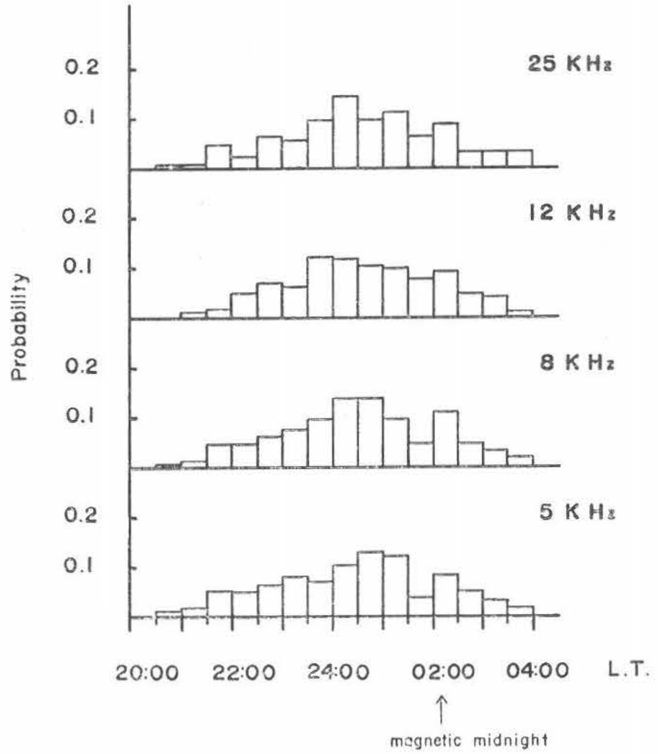


Fig. 2: Occurrence probability variation with time of the peaks in the noise events.

the frequency range from 5 to 12KHz. The sample datum is illustrated in Fig. 3. VLF hiss which occurs just before the break-up of a over-head aurora, falls sharply in short periods (about a few minutes). Typical example is shown in Fig. 4. The frequency range extends from 1KHz to more than 100KHz, whereas at Byrd Station, Antarctica, the hiss is often observed at 500KHz (Jörgensen 1968).

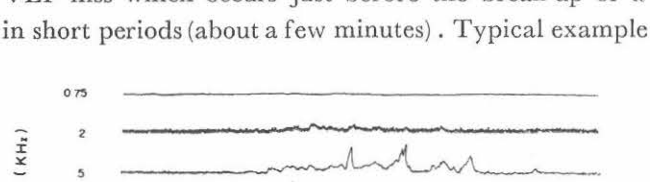


Fig. 3: VLF hiss associated with moderate activity in aurora and geomagnetism.

2–3 Energy spectrum

Fig. 5 shows the seasonal aspect of energy flux density of the peaks appearing in noise events at 12KHz. Fig. 6 gives the frequency spectra of the flux density of the peaks in several events which occurred through the wide band frequency range at the same time. Fig. 7 gives occurrence probabity of the peaks as a function of energy flux density at several frequencies on all events observed in 1968.

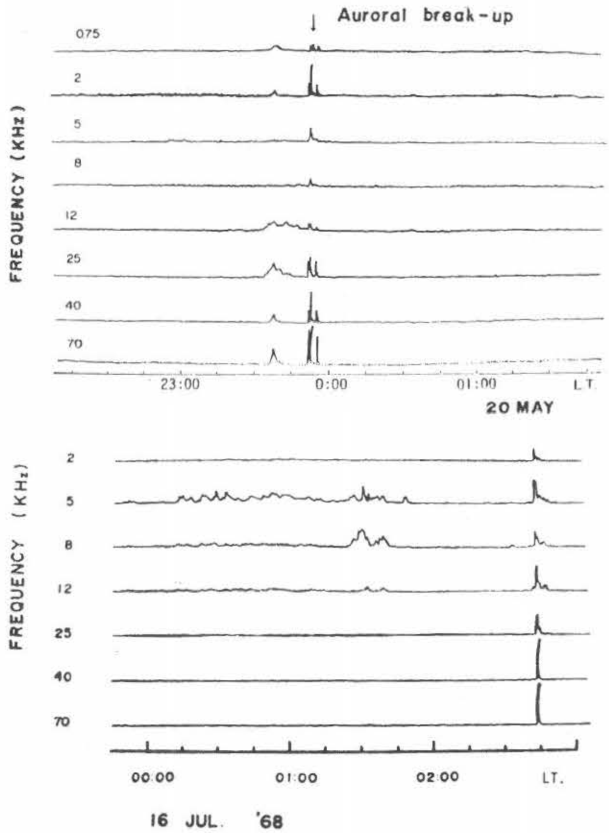


Fig. 4: Wide band VLF hiss preceding the active aurora.

It is seen in Fig. 7 that the maximum energy is received near 10KHz and this is consistent with the result induced from the ground observation and from the satellite observation (OGO 2) at Byrd Station (Jörgensen 1968).

3. Polarization, incident angle and direction

3–1 Observational method

Polarization, incident angle and arriving direction of the VLF hiss have been studied through the analysis of Lissajous' figure which was obtained by means of an equipment adopting a crossed loop and a vertical antenna (hereafter it will be ab-

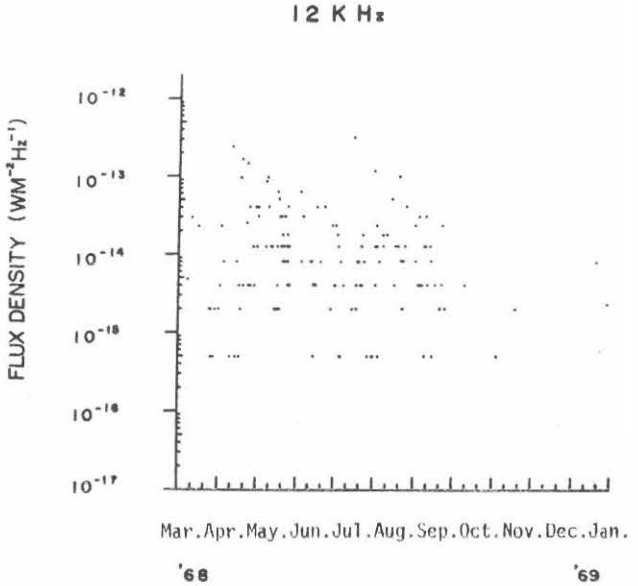


Fig. 5: Peak energy flux density of VLF hiss at 12KHz.

breviated to CRT method).

Sense of rotation of the polarization plane was investigated by means of a method using a crossed loop antenna and a polarimeter, and the right-handed and left-handed polarized components at 0.75, 12 and 25KHz were respectively recorded on the pen oscillograph (hereafter it will be abbreviated to pen oscillograph method). A detailed description of these methods will be found in the papers already published by Iwai et al. (1964), and by Iwai and Tanaka (1968). (Correction for this paper will appear in the appendix of this paper.)

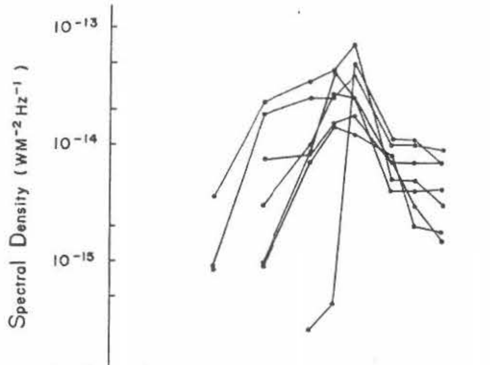


Fig. 6: The frequency spectra of energy flux density of the peaks in 7 events, which occurred through a wide frequency range at the same time.

3−2 Observational results

3−2−1 Observation of polarization with pen-oscillograph method

Following magneto-ionic theory, (Ratcliffe, 1959) the polarization R can be exp-

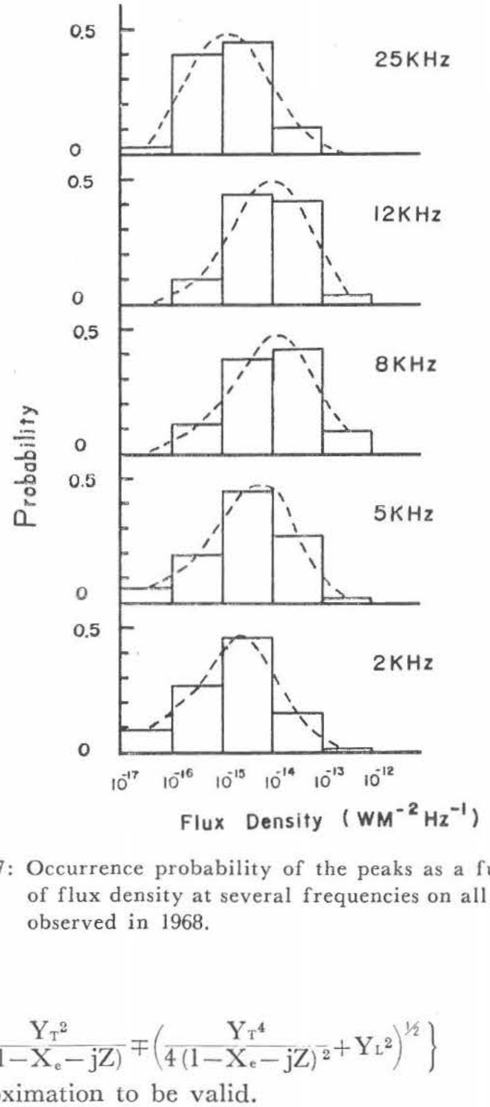


Fig. 7: Occurrence probability of the peaks as a function of flux density at several frequencies on all events observed in 1968.

ressed as

$$R=\frac{E_{\perp}}{E_{\parallel}}=-\frac{j}{Y_L}\left\{\frac{Y_T^2}{2(1-X_e-jZ)}\mp\left(\frac{Y_T^4}{4(1-X_e-jZ)^2}+Y_L^2\right)^{1/2}\right\}$$

assuming Q. L. approximation to be valid.

$$R=-\frac{j}{Y_L}\left|Y_L\right|$$

For electlon-ion mixture we get

$$R(X_e/n_i^2)$$

To satify Q. L. approximation we must have

$$Y_T^4/4Y_L^2\ll(1-X_e-jZ)^2$$

where

$$X_e=(f_0/f)^2,\quad Y=f_H/f,\quad Z=\nu/2_f,\quad Y_L=-Y\cos\theta$$

$E_{\parallel}$: electric vector parallel to the incident plane

$E_{\perp}$: electric vector perpendicular to the incident plane

θ : angle between imposed magnetic field and wave normal

f_0: electron plasma frequency

f_H: electron gyrofrequency

ν : collission frequency

For the downcoming wave in the southern hemisphere, the sign of $\cos \theta$ is minus and so the sign of Y_L is plus. Hence, the polarization for the downcoming whistler wave is

$$R = -j$$

which means that the electric and magnetic vector for the propagating wave rotate anti-clockwise (left-handed sense) when the observer is looking in the propagating direction, or clockwise (right-handed sense) when the observer is looking in the direction of imposed magnetic field as sketched in Fig. 8. Hereafter, we will take the latter expression in discussing the sense of field vector rotation. The ratio of the right-handed polarized component to the left-handed polarized component observed on the ground is given by the formula (Iwai and Tanaka 1968) as follows,

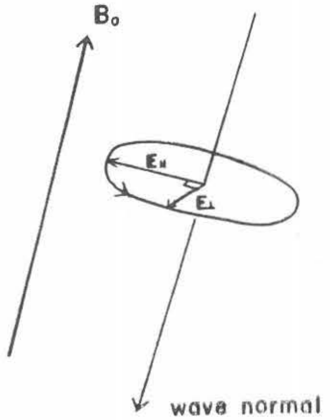


Fig. 8: Whistler mode wave down-coming in the southern hemisphere.

$$C = \left\{ \frac{|E_\perp/E_\parallel| \cos^2 i + 1 - 2|E_\perp/E_\parallel| \cos i \sin\phi}{|E_\perp/E_\parallel| \cos^2 i + 1 + 2|E_\perp/E_\parallel| \cos i \sin\phi} \right\}^{1/2}$$

where $\phi = \arg (E_\perp/E_\parallel)$

i: incident angle

under the assumption that the wave emerging into free space preserve the polarization which the wave has attained in the ionosphere. The assumption is a problem of so-called limiting polarization discussed already by Ratcliffe 1959, Budden 1961, and Pittway and Jespersen 1966.

Supposing that the right-handed circular wave come down through the ionosphere, C values will be found to be

130 at $i = 10°$, which is equal to the angle between the earth magnetic field and the vertical direction at Syowa Station.

14 at $i = 30°$

3.2 at $i = 60°$

The C values given in Fig. 9 are estimated to be,

1−8 (average 2−3) at 25KHz

1−10 (average 3−4) at 12KHz

1−5 at 750Hz (linealy polarized or slightly right-handed polarized).

These values describe, of course, the average polarization of the waves. Considering that the wide band noises, which appear just before the break up of the over-head aurora decline in the auroral active phase, and that the incident angles observed with CRT method are not large, we may suppose that the waves observed on the ground are elliptically polarized.

The slight difference in C values between 12KHz and 25KHz may be thought to depend on the propriety of Q. L. approximation. The polarization data at 750Hz correspond to the polarization of polar chorus. If it is acceptable to suppose that a polar chorus is generated by electron cyclotron instability near the equatorial plane

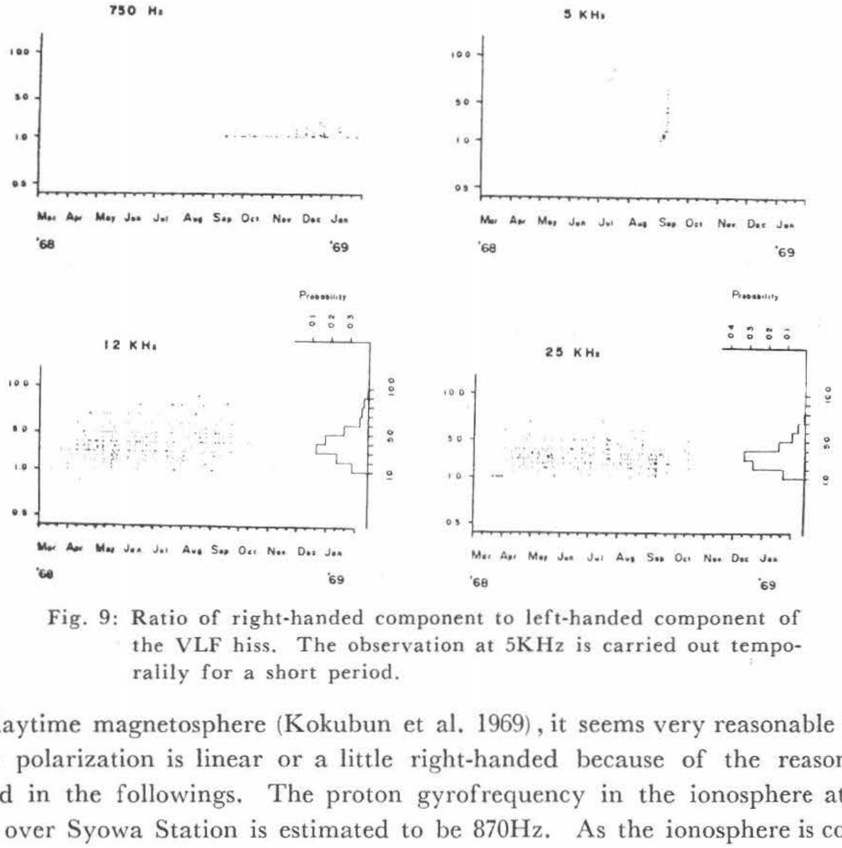


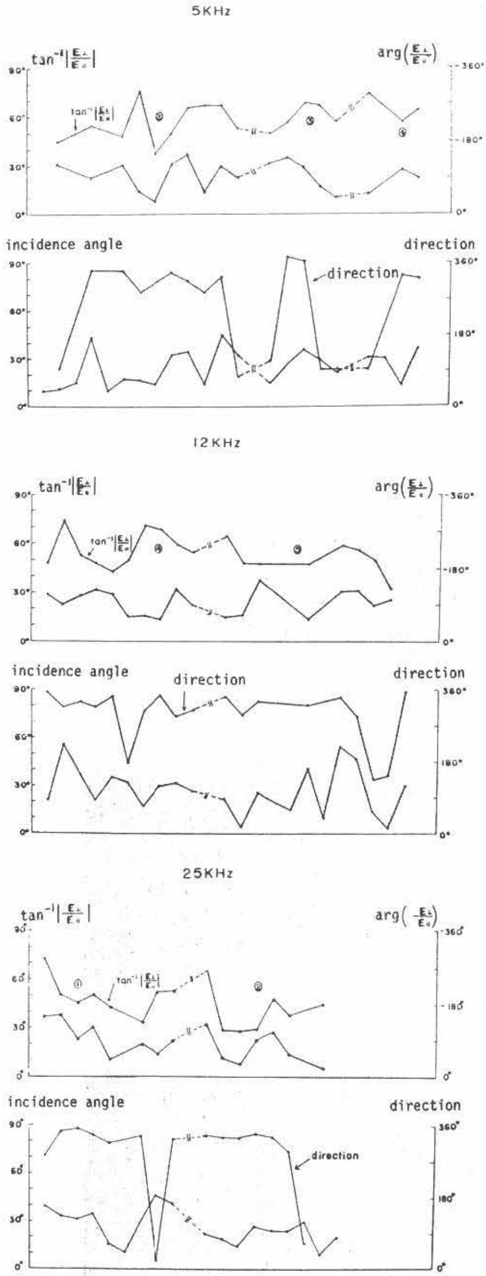
Fig. 9: Ratio of right-handed component to left-handed component of the VLF hiss. The observation at 5KHz is carried out temporalily for a short period.

in the daytime magnetosphere (Kokubun et al. 1969), it seems very reasonable to think that the polarization is linear or a little right-handed because of the reason to be described in the followings. The proton gyrofrequency in the ionosphere at 100km altitude over Syowa Station is estimated to be 870Hz. As the ionosphere is composed of electron, proton and positive ions, it is necessary to consider the cross-over frequency problem, when the propagation below the proton gyrofrequency is to be discussed (Smith and Brice 1964, Gurnett and Burns 1968).

So, it may be true that the polarization which has been circular in its initial stage gradually becomes to be elliptic for ions on the way of the propagation, and it approaches to be linear near the cross-over frequency.

3-2-2 Observation with CRT method

The observation with CRT method is very delicate and difficult because of the technical problem involved in the observation timing and in the separation of the hiss from unwanted atmospherics. Fig. 10 gives polarization, incident angle and arriving direction of hiss, obtained with



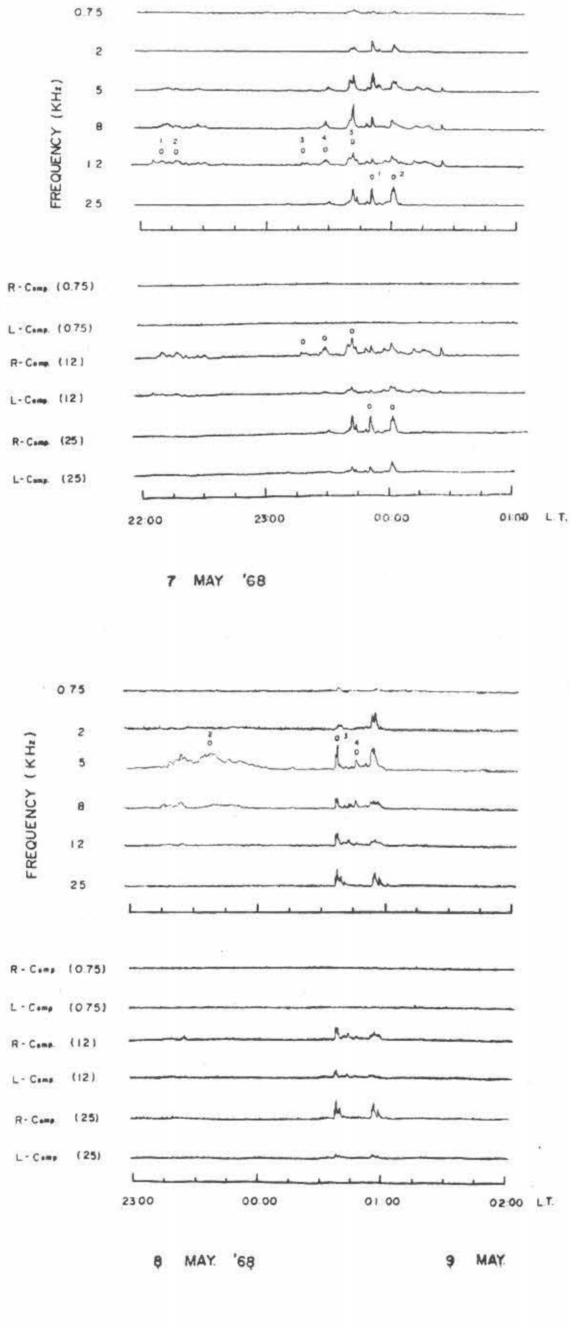


Fig. 10: Polarization, incident angle and arriving direction analyzed on Lissajous' figure; The number in the figure are the same as those of the events shown in.

Fig. 11: The direction angle is measured clockwise from the geomagnetic north,

CRT method on the noise events shown Fig. 11. It is evident in the figure that the waves which came down to the ground had rather a small incident angles and were nearly parallel with the magnetic meridian plane that passes through Syowa Station. C values analyzed on the Lissajous' figure are found to be roughly consistent with the C values respectively obtained from Fig. 11. Fig. 12 shows the examples of oscillographic patterns.

From the observational evidences that the incident angles mostly are not of large values as indicated in Fig. 10, and that the ionosphere in the active period of VLF hiss is disturbed, it is difficult to infer that the waves actually propagate to the lower latitudes in a wave guide mode.

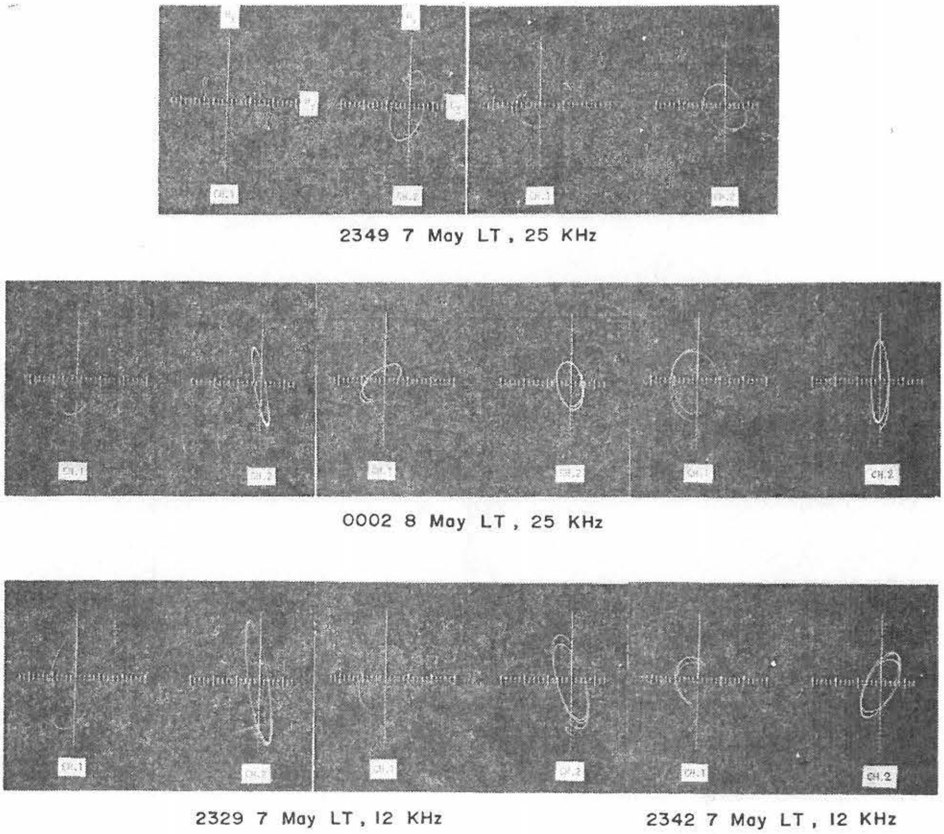


Fig. 12: Oscillographic patterns, horizontal magnetic field, H_x the geographic east component, H_y the geographic north component, and E_z the vertical component of electric field,

4. Discussion

A charged particles spirally moving along the line of force of the earth's magnetic field is thought to generate Cerenkov radio waves, then we have the following relation

$$\mu \cos \theta = c/v_{\parallel}$$

where μ is refractive index, and $v_{\parallel}$ longitudinal velocity of the particle, c light velocity and θ angle between wave normal and imposed magnetic field. If it is acceptable that the radiation power generated by Cerenkov process varies in an inverse proportion to the square root of the particle energy of from 1 to 20Kev (Jörgensen 1968), then the low energy particle is to be effective to the generation of the waves, and the angle between wave normal and magnetic field is restricted to small values when the waves propagate through the field-alighned crest irregularity (crest trapping) and the frequency of the waves dose not exceed one half of the electlon gyrofrequency. The frequency range of the waves generated by Cerenkov process can cover the whole range of the VLF hisses observed, while cyclotron instability process gives the upper limit of the frequency range (Kennel and Petshek 1966). The limit is not of advantage for the explanation of VLF hisses observed at high frequencies and the mechanism dose not seem to be effective for the generation of the waves by soft electlons ($\leqq$10Kev) in the lower ionosphere. On the other hand, we have the observational evidences that the frequency ranges of VLF hisses observed reach more than 100KHz, and that the incident angles are not so large, and that the maximum energy is received near 10KHz which is consistent with the frequency of maximum intensity in the hiss spectrum theoritically deduced from Cerenkov radiation in the model region of generation in the lower ionosphere by Jörgensen (1968) who explained successfully the generation mechanism of VLF hiss by Cerenkov radiation. So, we may conclude that VLF hiss in the auroral zone is generated by Cerenkov radiation.

The polarization data limited to one point frequency at 750Hz is of course insufficient to discuss the propagation and generation mechanism of polar chorus, so that we are preparing a sweep polarimeter to observe the polarization from 0.5KHz to 2KHz. Moreover, the observation of polarization on multichannel from a few hundreds to a few thousands Hz with rockets launched in the auroral zone, are being planed to study the ion compoistion in the lower ionosphere, and the propagation as well as the generation mechanism of the polar chorus.

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Appendix

Correction to the paper by A. Iwai and Y. Tanaka entitled as "Measurement of polarization, incident angle and direction of VLF emissions—(1)" Proc. Res. Inst. Atmospherics, 5, 16, vol. 15 (1968).

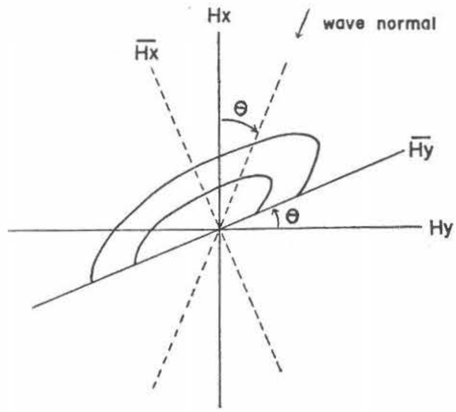

Fig. 4: $H_x - H_y$, the figure during plus half cycle of E_z.

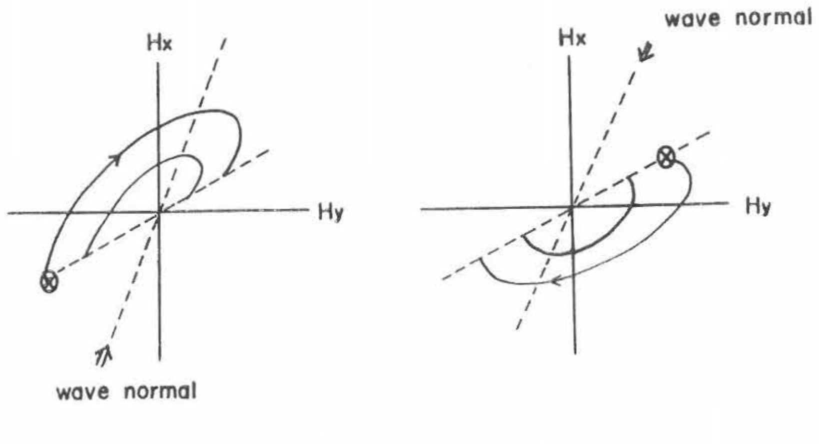

Fig. 15: $H_x - H_y$, the figure during plus half cycle of E_z.
* : starting point of the locus

When the locus exists above the cutting line, θ for left-handed polarized wave is an angle in the quadrant below the line $H_x=0$ and viceversa. In the other cases, θ can be easily decided without ambiguity in the same way.

Fig. 4 and Fig. 15 in the previous paper should be replaced respectively with figures as follows in the text.