Abstract

Polarization and direction of arrival of VLF emissions have been observed at Syowa Station in the Antarctic by a combination of a vertical antenna and a crossed loop antenna with their planes oriented in geomagnetic E–W and N–S directions. The results obtained with a polarimeter show that the emissions at 750 Hz, 12 kHz and 25 kHz were roughly left-hand polarization waves (whistler mode) in all seasons, when one viewed towards the observation site on the earth's magnetic field. But there seemed to be some seasonal variations in the ratio of right-hand polarization waves to left-hand ones. A pronounced example is that the emission at 25 kHz was linearly polarized in winter (July and August).

The oscillographic patterns obtained with a direction finder seem to indicate that the emission at 12 kHz arrived simultaneously from various directions, and that the emission was almost elliptically polarized. But in a few cases, the emission seemed to come down roughly from a vertical direction along a geomagnetic field line, and to be circularly polarized.

1. Introduction

We have already discussed the occurrence of VLF emissions at Syowa Station and their correlation with geomagnetic disturbances, auroral displays, and radio absorptions in the ionosphere. We were able to know the character of occurrence of VLF emissions at high latitudes. In this paper, we will discuss geophysical aspects of the emissions, such as polarization and direction of arrival.

We have made the observation of polarization and arriving direction of VLF emissions (4-6 kHz) at Moshiri, too. As shown in Fig. 1, the result obtained at Moshiri shows that the emissions at low latitudes were almost linearly polarized and they arrived roughly from north (auroral zone). When VLF emissions do not occur, the direction tends toward southwest (source region of atmos-

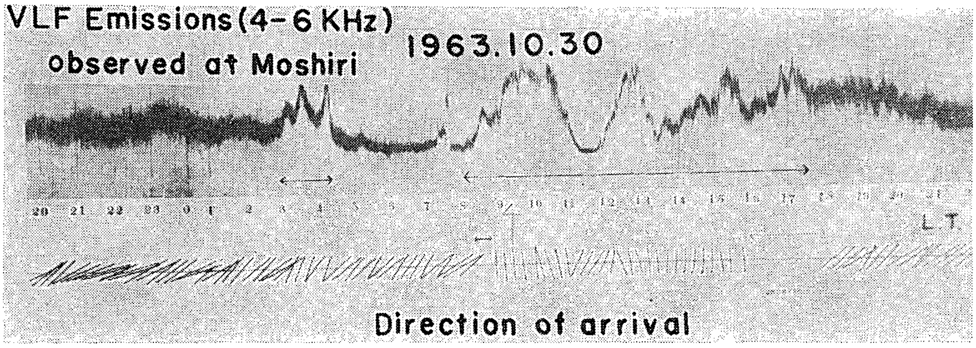


Fig 1. An example of the record showing the arrival direction of VLF emissions observed at Moshiri.

pherics). Namely, VLF emissions can be thought to propagate from the auroral zone to low latitudes in a wave-guide mode between the ionosphere and the ground. As shown in the previous report, the character of VLF emissions at high latitudes is much different from that at low latitudes. Therefore, observation of polarization and arriving direction at Syowa Station (in an auroral zone) is very important in the study of propagation mode and generation mechanism of VLF emissions.

HARANG (1965) observed polarization and direction of arrival of 8kHz band emissions at Tromsö, auroral observatory, using two crossed loops with their planes oriented in E-W and N-S directions. Analyzing the emissions data he came to a conclusion as follows. Ordinary broad and irregular VLF emissions come from all directions and change their aspects, the polarization reversing the sense of rotation. An isolated sharp burst comes down vertically along the geomagnetic field line, and is circulary polarized keeping the sense of rotation unaltered.

He (1968) also observed the VLF emissions at 8 kHz at stations close to the auroral zone and at stations in lower latitudes.

He suggested various possible modes of propagation, as shown in Fig 2.

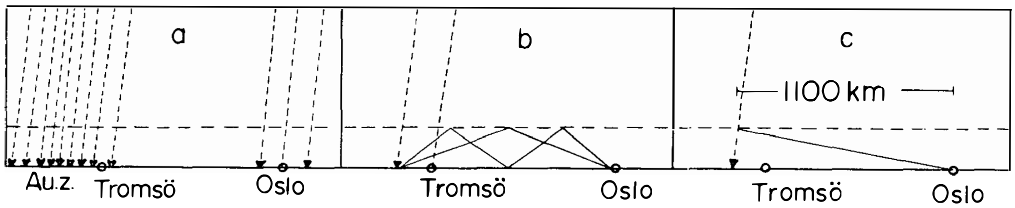


Fig. 2. Various possible modes of propagation for polar VLF events observed at Oslo (by HARANG).

2. Polarization and Direction of Arrival of VLF Emissions

It is usually assumed that VLF emissions propagate through the ionosphere in a whistler mode, and are circularly polarized as an extraordinary component. The energy propagates in various direction from a source with a wave-guide mode between the ionosphere and the ground. Syowa Station, as an auroral observatory, is located within an area of precipitation of the emissions, hence they will come from a vertical direction and will show the state of a nearly circular polarization with only one possible sense of rotation against the magnetic vector. However, the observations to conform the above assumption have not been carried out successfully yet. Therefore, the polarization records to be obtained at Syowa Station are very interesting and important to the study of physical aspects of the emissions.

Observing techniques were reported previously by A. IWAI and Y. TANAKA (1968). The block diagram of the apparatus is shown in Fig. 3. Apparatus (1) is for the observation of sense of rotation of the polarization plane. Observation

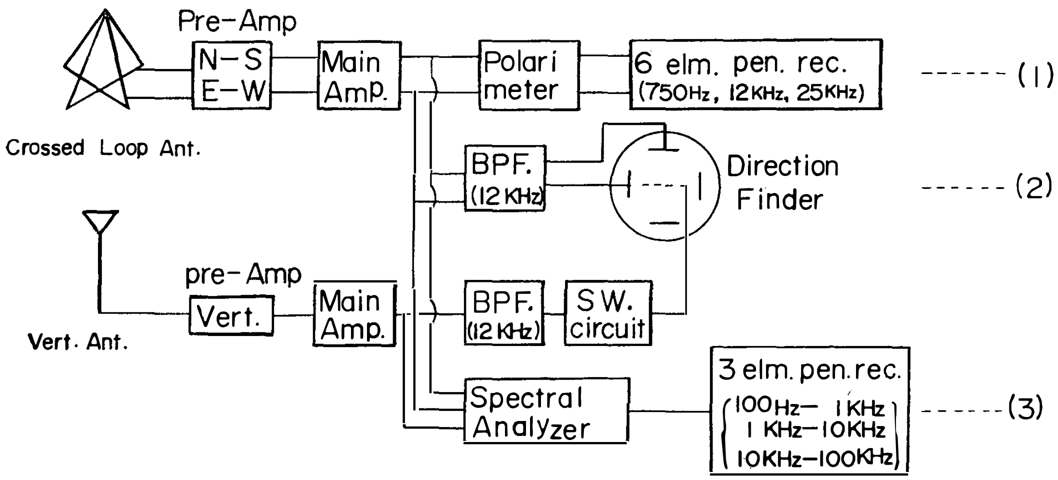


Fig. 3. Block diagram of the apparatus at Syowa Station.
Crossed loop antennas: triangle type, 20 m high, 40 m long, 2 turns
Vertical antenna: 10 m high

frequencies are 750 Hz, 12 kHz and 25 kHz, and their band width are 10 Hz, 150 Hz and 250 Hz, respectively. Detectors used are of minimum detecting method, and their time constant is about 10 s. Recording was made continuously on the chart of 6-elements pen recorder. Apparatus (2) is for observation of the direction of arrival and the polarization pattern of emissions at 12 kHz. The band width of the direction finder is 20 Hz. LISSAJOU's figures on an oscillograph are modulated applying the brightness control by the output of the vertical antenna in order to avoid 180° ambiguity and to obtain the sense of rotation of polarization. The LISSAJOU's figures on the oscillograph are photographed continuously during the emission event. The results obtained by apparatus (1) and (2) will be given in the next section.

3. Observation Results

Fig. 4 shows seasonal variations of the polarization at 750 Hz, 12 kHz and 25 kHz. The values of C were picked up from many records, where C represents the ratio of amplitude of right-hand polarization waves to that of left-hand polarization waves. So, if C>1, the emissions have right-hand polarization, and if C<1, left-hand polarization, and if C=1, linear polarization. From these figures the emissions at three frequencies are found to have roughly

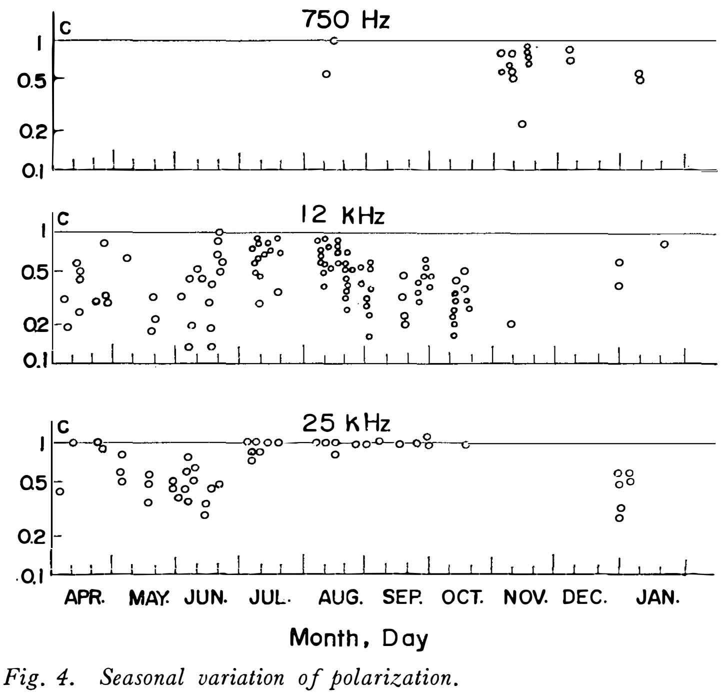


Fig. 4. Seasonal variation of polarization.
C: ratio of right-handed polarization wave to left-handed polarization wave

left-hand polarization, when one viewed toward the observation site on the earth's magnetic field line. However, there seems to be a seasonal variation of the C value at 12 kHz and 25 kHz. Namely, dispersing of C values at 12 kHz in winter (July, August) approximates to 1, which is smaller than that in other seasons. Moreover, it is remarkable that the emissions at 25 kHz are quite linearly polarized in winter. And the emissions at 750 Hz, which occurred in November, December and January, are roughly left-hand polarized, too. We will show some examples of records with geomagnetic horizontal component variations.

Fig. 5 shows that the emissions occurred during a gradual decrease of geomagnetism, on May 17, 1967, and were almost left-hand polarized at both 12 kHz and 25 kHz. C value of each spike at 12 kHz is smaller than that at 25 kHz in this event. The intensity record at 12 kHz obtained from the hiss recorder of the University of Tokyo are shown in the same figure.

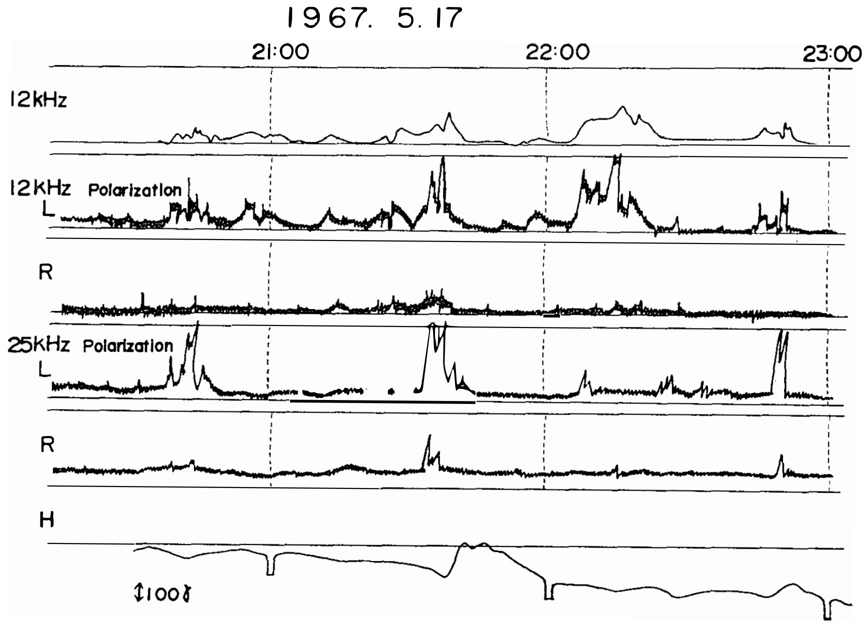


Fig. 5. An example of polarization in May, 1967.

Fig. 6 shows that the emissions occurred in an initial pulsive phase of a small geomagnetic disturbance, on August 8, 1967. The emission at 750 Hz were very rare in August, occurring in the hours from 1800 to 0100U.T. The first spike was almost linearly polarized, but the successive spikes were strongly left-hand polarized. The emission at 12 kHz was roughly left-hand polarized, while the emission at 25 kHz was quite linearly polarized in this seasons.

Fig. 7 shows the emissions which occurred in the morning of January 10, 1968. The emission at 750 Hz was left-hand polarized clearly. No emissions occurred at 12 kHz and 25 kHz on this occasion.

Fig. 8 shows the time variation of C value for an emission event in winter on August 18, 1967. The polarization of this emission has an interesting character. The gradual rising spikes indicated by the broken line arrow ⇡ were strongly left-hand polarized, while the sharp rising spikes indicated by the solid line

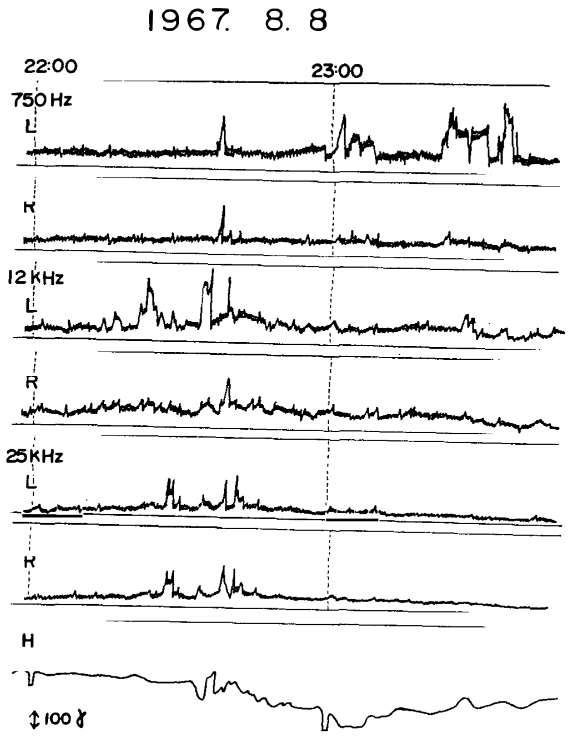


Fig. 6. An example of polarization in August, 1967.

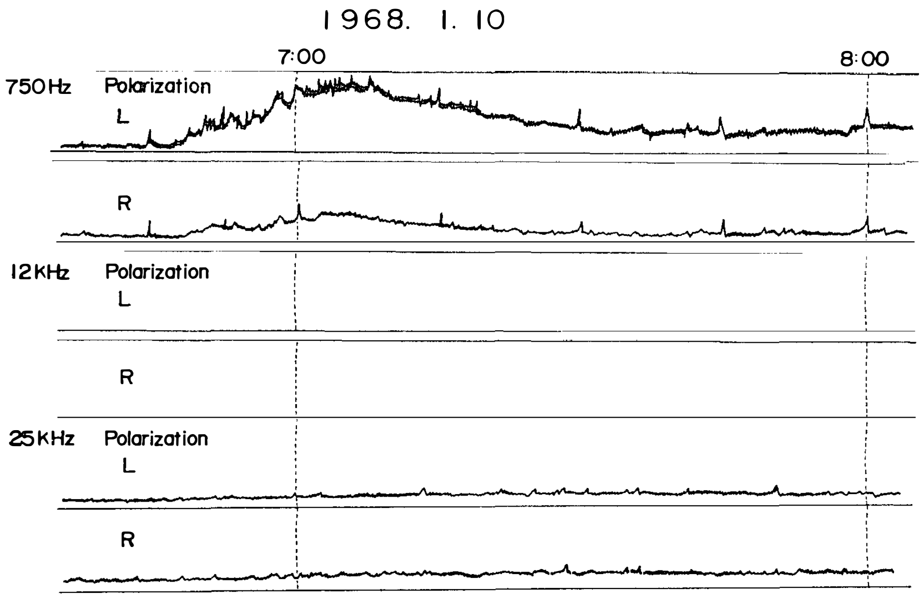


Fig. 7. An example of polarization in January,1968.

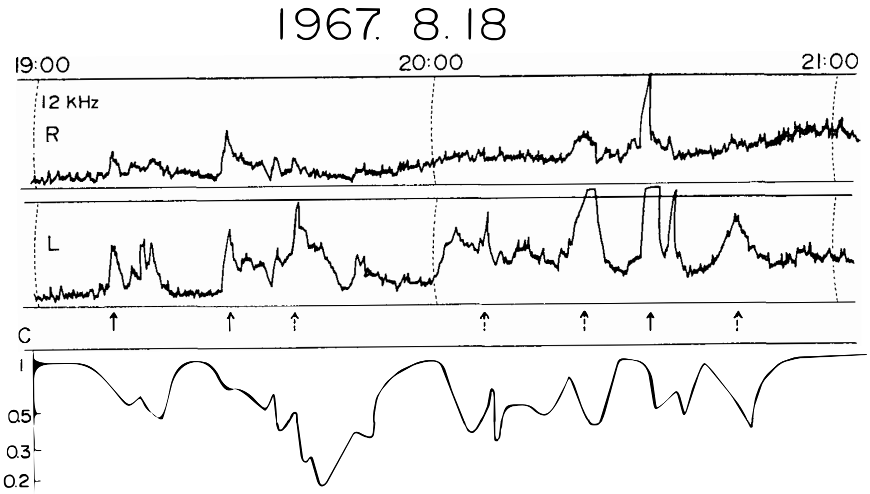
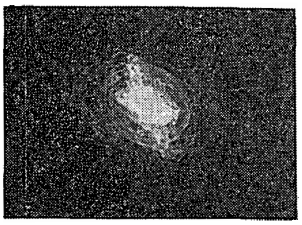


Fig. 8. Time variation of C value for a record in August, 1967.

arrow ↑ were weakly left-hand polarized.

Fig. 9 illustrates irregular oscillographic patterns of the emission at 12 kHz on July 4, 1967. These two patterns were not modulated applying the blightness control by the output of the vertical antenna. They seem to suggest that this emission arrived simultaneously from about two directions with various amplitudes, and was elliptically polarized at an oblique incidence. Intensity of this emission was stronger in the E-W geomagnetic direction than in the N-S direction.



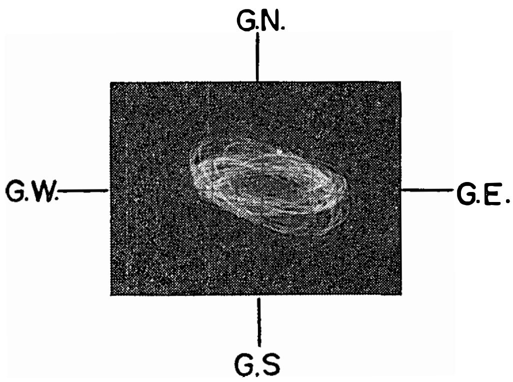


Fig. 9. Oscillographic patterns of the emission at 12 kHz on June 4, 1967.

Fig. 10 shows the oscillographic patterns obtained continuously on August 18, 1967. Pattern (A) shows the start of a single spike of the emission. This spike arrived from the direction between geomagnetic N and W. The flat elliptic pattern shows atmospherics. Pattern (B) shows a different arrival direction from Pattern (A). Pattern (C) shows an expanding spike of Pattern (A), and it came down at an oblique incidence, and was circularly polarized. Pat-

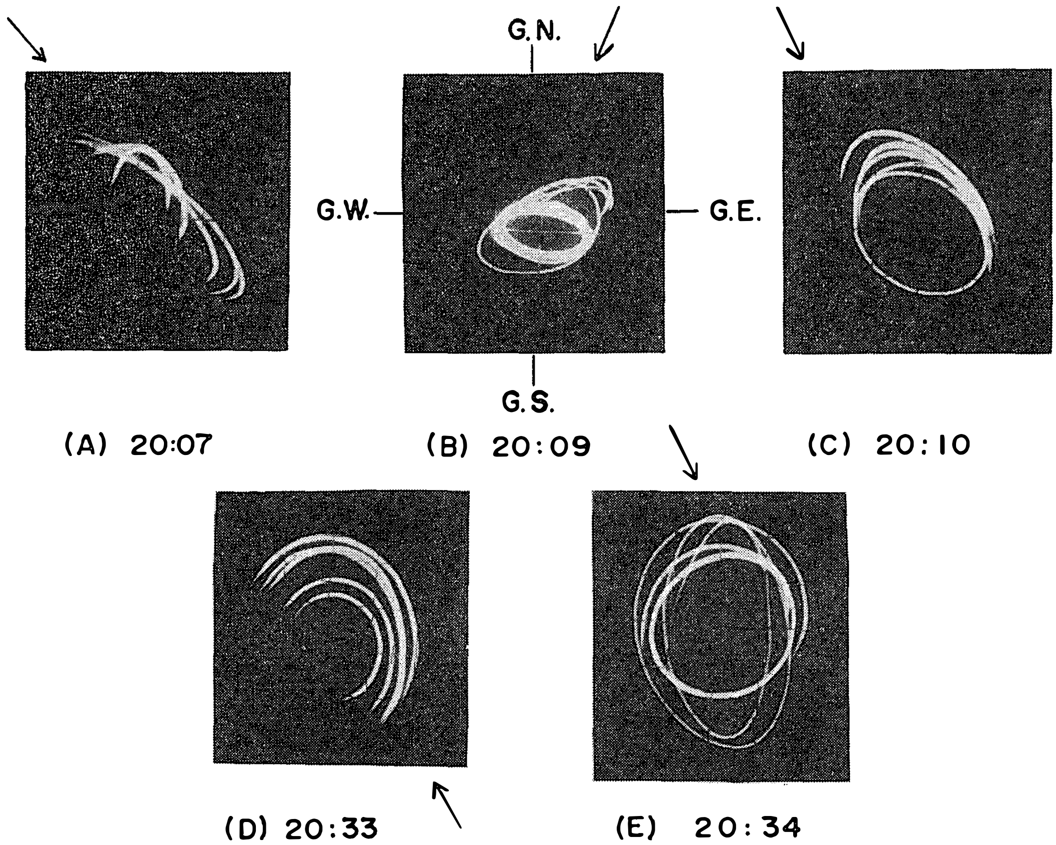


Fig. 10. Oscillographic patterns of the emission at 12 kHz obtained continuously on August 18, 1967.

tern (D) and Pattern (E) show a peak of the emission which arrived from a vertical direction and was circularly polarized.

The intensity of atmospherics at Syowa Station was very strong at 12 kHz. So it seemed to be difficult to catch the exact patterns of the start of emissions, and the obtained patterns might be due to the emission whose wave expanded over a wide area near the ground. It seems to be desirable to observe at higher frequency than 12 kHz (for example, 25 kHz), because 25 kHz is not so much interfered with atmospherics, and is strongly correlated with luminous auroral activity.

4. Discussion

We will discuss the physical aspects of the emissions, taking into consideration the occurrence of the emissions and their correlation with other phenomena.

For the generation of the VLF emissions, one considers the primary process to be the impact of a cloud of charged particles in the ionosphere or the exosphere. STURROCK (1962), in his discussion of various theories, divided the possible process into the 'direct' and the 'indirect' ones. The process of direct nature are Cerenkov-radiation and Cyclotron-radiation. OMHOLT (1957) supposed that Cerenkov-radiation may be caused by electrons in the velocity range of 0. 06-0. 03 c (c:light velocity) which is the same order of magnitude assumed for electrons causing auroral displays. In fact, we observed 25 kHz and higher frequency band emissions at Syowa Station which are strongly correlated with active auroral displays. Since we were unable to determine the intensity of the higher band emissions quantitatively, we cannot estimate Cerenkov-radiation, but in the emisssions strongly correlated with auroral displays, we may suggest that the generating mechanism is Cerenkov-radiation.

ELLIS (1959) pointed out that the narrow band hiss up to several kHz which occurs only during a limited time of 1800-2400U.T. in winter is generated by electron cyclotron-radiation. It is not clear in the present observation whether the limited hours of the occurrence are due to a diurnal variation of radio absorption in the ionosphere or to the mechanism of generating VLF emissions. From the riometer records observed simultaneously at Syowa Station the constant radio absorption occurred mostly during 0100-0600 U.T. in winter, and in the nighttime in summer. So, the radio absorption may be a factor to determine the seasonal variation of the emission. However, any definite correlation between the emission and the radio absorption is not seen in the present observation, so that the mechanism of generating VLF emissions (Cerenkov-radiation and cyclotron-radiation) seems to be a predominant factor which determines the diurnal variation of the emissions.

HELLIWELL (1965) reported that if the emissions propagated along the geomagnetic field lines in a whistler mode, the sense of rotation of polarization would be left-hand when one viewed towards the observation site on the earth's magnetic field line in the Southern Hemisphere. This hypothesis seems to have been substantiated by the results in Fig. 5-Fig. 8 obtained at Syowa Station. Namely, the generating mechanism of the VLF emissions depends upon electrons. However, as shown in Fig. 4, the emissions at 25 kHz were quite linearly polarized in winter (July, August and September), and the emissions at 12 kHz were less polarized in winter than in other seasons. This result suggests that the precipitation area of the emissions is slightly apart from the auroral zone, and the energy propagates from the precipitation area towards the low latitudinal stations in a wave-guide mode formed between the ionosphere and the ground. Or, the generating source point of the emissions comes down to the lower ionospheric area in winter than in other seasons. To clarify these phenomena, several simultaneous and successive observations along some meridional stations will be needed. Moreover, the observation of intensity, polarization and arriving direction at their stations have to be carried out correctly.

AARONS (1960) reported that gyro-frequency of protons of 100 km high in the Kiruna area (geomagnetic lat. 65.3° N) is nearby 750 Hz. Our observation results showed that the emission at 750 Hz in the daytime is left-hand polarized clearly. If the effects of protons are considered for generating mechanism and propagation, the emission at 750 Hz will show a different state of polarization from that at 12 kHz and 25 kHz. Occurrence of the emissions at 750 Hz were found to be dependent upon electrons in the present observation at Syowa Station.

As mentioned by HELLIWELL and GALLEY, emitting sources are not single pulsive such as atmospherics, but radiate wide band energy on the move. And they propagate in a whistler mode along the geomagnetic field line. We may receive simultaneous signals coming from various vertical directions. Namely, the obtained oscillographic patterns sometimes are not modulated applying the brightness control by the output of the vertical antenna. From these patterns it seems difficult to judge the sense of rotation of the polarization. The emissions were almost elliptically or circularly polarized, and seem to have arrived from an oblique or vertical direction. Therefore, we will measure the incident angle of the emissions by a combined use of the vertical antenna and the loop antenna in the next observation, then more exact directions of arrival of the emissions will be obtained. In order to investigate the polarization and arrival direction of the emissions with the direction finding technique, a large number of the patterns must be analyzed statistically. Or, it is necessary to observe them at two stations with different techniques. These problems can be discussed only after successive observations and several simultaneous observations near auroral zone were made.

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