AN OBSERVING PLAN OF WAVE NORMAL DIRECTION OF AURORAL VLF EMISSIONS ON BOARD A ROCKET AT SYOWA STATION

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Abstract: Recent *in situ* observations of auroral VLF emissions have shown that there are two types of emissions; one is generated at high altitudes by incoherent Cerenkov radiation and the other is generated locally in the auroral ionosphere. Hence the determination of wave normal direction of auroral VLF emissions has been planned at Syowa Station, based on the measurement of the polarization ratio on a rocket. The measurement provides information on a 'cone angle' of the wave normal direction about the rocket spin axis. Since the rocket is planned to be launched along the geomagnetic field, such a cone angle is of sufficient use in the study of the generation and propagation mechanisms of auroral VLF emissions.

The exact measurement of the electric field intensity is also proposed by adopting a positive feedback amplifier in an antenna-preamplifier network, which will enable us to know the ambient field intensity independently of the variation of plasma parameters.

1. Introduction

The ground-based observation of VLF emissions has been continued at Syowa Station (NISHINO and TANAKA, 1969; TANAKA, 1972; KOKUBUN *et al.*, 1972; TANAKA *et al.*, 1976), which has indicated a close association of auroral VLF hiss with the auroral display and precipitating electrons. Low altitude polar-orbiting satellites such as Ogo, ISIS, Ariel and Injun have given *in situ* useful results on the generation and propagation of auroral hiss (JØRGENSEN, 1968; MOSIER and GURNETT, 1969; MOSIER, 1971; GURNETT and FRANK, 1972; BULLOUGH *et al.*, 1974; LAASPERE and HOFFMAN, 1976). JØRGENSEN is the first to have suggested, on the basis of the coordinated observation on board the satellite and on the ground (Byrd Station), that the auroral hiss is generated at higher altitudes than the satellite as the consequence of incoherent Cerenkov radiation by precipitating low-energy electrons ($\gtrsim 1$ keV). His idea has been supported by the satellite-borne measurement of the direction of Poynting flux of auroral hiss (MOSIER, 1971) and by the correlative studies between the occurrence of auroral hiss and the precipitating electrons with the relevant energy (LAASPERE and HOFFMAN, 1976).

In order to investigate the behaviors of VLF radio noises in the auroral ionosphere, several rockets have been flown (UNGSTRUP, 1971, 1975; KAMADA, 1975). UNGSTRUP (1971) has found the enhanced VLF radio emissions, which are interpreted as being locally generated in the ionosphere with the wave normal direction almost perpendicular to the geomagnetic field. This new kind of emissions seems to be essentially incompatible with Jørgensen's type emissions. Furthermore, UNGSTRUP (1975) has recently found an additional narrow band emission centered at 3 kHz, and explained it in terms of the two-stream instability within the ionosphere. This new type of local emissions is poorly understood, and needs further research.

In order to distinguish between the above two types of emissions, and also to get further information on their generation mechanisms, especially on the local emissions, the measurement of wave normal direction is most useful. Therefore, we propose a plan of estimating the wave normal direction of the VLF radio noises in the ionosphere based on the measurement of their polarization ratio. The rocket experiment will, of course, be carried out together with the ground-based direction finding (DF) of VLF waves.

Finally we comment on the exact measurement of the electric field intensity of the VLF radio noises. There was a controversy in the previous electric field measurements, *i.e.* whether the observed change in field intensity is the real variation of the ambient field intensity or not. In this paper we adopt a new antenna-preamplifier coupling system in which the ambient electric field can be measured independently of the change in ambient plasma parameters.

2. Measurement of the Polarization Ratio of Auroral VLF Emissions and its Application to the DF for their Wave Normal Directions

The measurement of wave normal direction by means of the polarization ratio is primarily based on the assumption that the wave is right-handed circularly polarized (equivallently to the quasi-longitudinal (QL) approximation). So, the problem is to which angle in the wave normal direction the right-handed circular polarization is justified. We examine the criterion of the validity of the QL approximation in the regions where the rocket traverses. The QL approximation is given by (BUDDEN, 1961),

$$\left|\frac{Y_T^2}{2Y_L}\right| \ll |1-X-jZ|. \qquad (1)$$

Here $Y_T = Y\sin\theta$, $Y_L = Y\cos\theta$, $Y = f_H/f$, $X = f_0^2/f^2$, $Z = \nu/2\pi f$. f_H and f_0 are the electron gyro- and plasma-frequencies, f the wave frequency and ν the collision frequency. θ is the angle between the wave normal and the geomagnetic field line. In the practical condition of auroral ionosphere, the electron density varies from $\sim 3\times10^5 cm^{-3}$ to $\sim 5\times10^4 cm^{-3}$ (MIYAZAKI, 1975), and the term of Z due to the collision frequency is negligibly small. The examination of eq. (1) yields that the QL approximation is obviously valid in θ of less than $\sim 89.9°$ at VLF. So, the VLF waves, except waves with wave normal angles very close to the resonance cone, have the right-handed circular polarization in the relevant ionospheric regions.

In the case of ground observation of VLF emissions and whistlers, their polarizations are, on many occasions, elliptical, as the result of the interference due to the multi-rays in the earth-ionosphere waveguide (OKADA *et al.*, 1977), or of the simultaneous detection of multi-sources (TANAKA, 1972; TANAKA *et al.*, 1976). However, these effects can be greatly reduced for the reception in the ionosphere.

The configuration of the principle of the measurement of wave normal direction is given in Fig. 1. To measure the x-(H_x) and y-component (H_y) of the magnetic

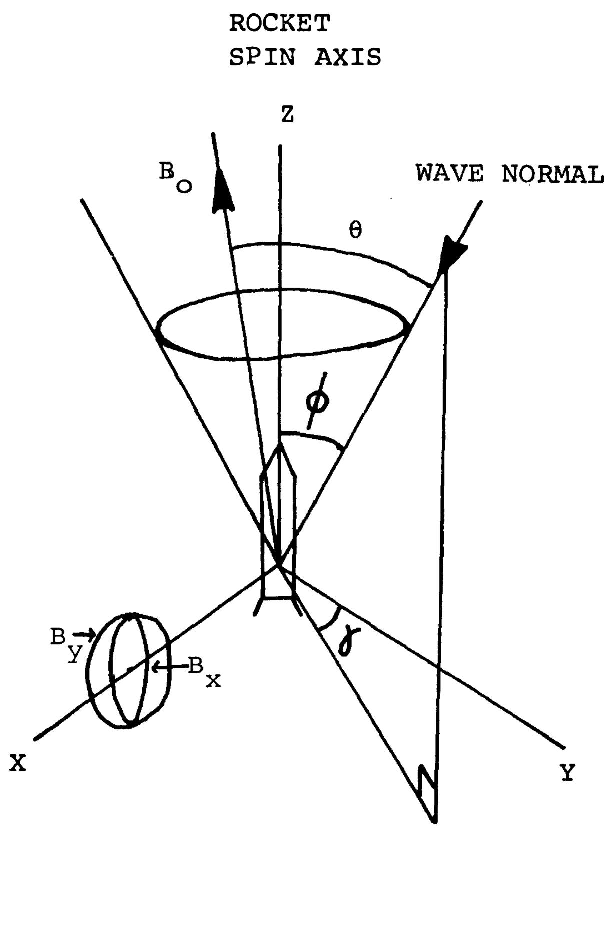

Fig. 1. The configuration of the measurement of wave normal angle referred to the rocket spin axis.

field, crossed loop antennas are installed on the rocket with the loop plane in the *y*-*z* plane (B_x antenna) and the other one in the *x*-*z* plane (B_y antenna), respectively. The signal of H_x is advanced or delayed by a right angle by passing it through phase shifters and each component is added to the signal of H_y. We then compare the amplitudes of the obtained two signals and then we get the following simple relationship in the case of the right-hand circular polarization.

$$\frac{\text{Amplitude}\,[H_x(-\pi/2)+H_y]}{\text{Amplitude}\,[H_x(+\pi/2)+H_y]}=\frac{1+\cos\phi}{1-\cos\phi}=\frac{R}{L} \quad (2)$$

This is the ratio of the right- to the left-handed circularly polarized component in the polarization plane projected onto the *x*-*y* plane. We call this the 'polarization ratio', which has already been measured on the ground for the auroral hiss (TANAKA, 1972; TANAKA *et al.*, 1976) and for the low-latitude whistlers (OKADA *et al.*, 1977). It is apparent from eq. (2) that the measurement of the polarization ratio enables us to estimate the cone angle of the wave normal direction about the rocket spin axis (ϕ). This method is a simplification of our previous wave normal direction measurement for whistlers by means of the three dimensional crossed loop aerials used on board the K-9M-41 rocket (IWAI *et al.*, 1974, 1976; HAYAKAWA and IWAI, 1975).

The previous DF experiments for auroral VLF emissions made at Syowa Station were to measure the direction (upward or downward with reference to the rocket axis) of the Poynting flux by using a pair of electric and magnetic antennas. Such restricted DF experiment had been made due to the limitations of the antenna space, and the weight of payload available on the single-stage sounding rockets. The obtained DF data are not sufficiently useful in the study. Considering the severe restriction in the antenna space, payload and telemetry channel, and the rocket orbit which is nearly along the geomagnetic field line with a small coning movement, we have planned a simple, but much more useful than the previous ones, DF method by only adding another loop aerial to measure the polarization ratio. For the rocket trajectory along the geomagnetic field lines our DF data of the cone angle (ϕ) will be useful in the study of the generation mechanism.

However, the data supply of only the cone angle seems to be not sufficient for the rocket trajectories with a significant departure of the spin axis from the geomagnetic field or with a large precession. In these cases another DF method on the basis of the spin modulation can be used complementarily, which has been usually made use of to estimate the wave normal angle θ from the spin modulation of the output signal of a loop aerial (CARTWRIGHT, 1964; UNGSTRUP, 1971). In reducing the value of θ, we have to find the direction of arrival of the wave referred to the rocket. It requires us to measure two angles; ϕ, the angle between the wave normal and the rocket spin axis, and the angle γ between the plane determined by the wave normal and the spin axis (the plane of incidence), and some reference plane (y-z plane is adopted in Fig. 1). For right-handed circularly polarized plane waves the root square signal voltages (E_x and E_y) at the detectors of the receivers connected to the loop antennas of B_x and B_y are given by

$$E_{\substack{x\\y}}=K\sqrt{1/2(1+\cos^2\phi)+1/2\cos 2\gamma(\pm 1\mp\cos^2\phi)}. \qquad (3)$$

Here K is a constant specified by the receiving system. So the ratio of the minimum to maximum signals, as the loop antennas rotate, is given by,

$$E_{min}/E_{max}=\cos\phi. \qquad (4)$$

Eq. (4) will allow us to find the cone angle without distinguishing between the upgoing and downgoing nature, and the obtained cone angle will correspond to the mean value, during the spin half cycle, of the cone angle obtained continuously from the measurement of the polarization ratio. As is easily seen from eq. (3), the angle γ can be determined from the position of the maxima with the ambiguity of 180°, since the signal shows a maximum when the antenna plane of a loop aerial lies in the plane of incidence. This method gives twice the average value of the DF data during one spin cycle if the arrival direction varies slowly enough to yield the clear spin modulation. Then it is possible to know the wave normal angle θ in combination with the data of the wave normal direction referred to the rocket and of the attitude of the rocket with reference to the geomagnetic field line. As for the measuring sensitivity, this method is sensitive for larger cone angles due to the deep spin modulation, while the DF method due to the polarization ratio is very useful for smaller cone angles. The performance of both the DF methods used complementarily is summarized in Table 1.

Both DF methods will be actually used complementarily in analyzing the

Table 1. Comparisons of the two DF methods.

Right-handed circular polarization

Measurement	Measuring interval	Directional data	Sensitivity	
			$\phi\to 90°$	$\phi\to 0°$, 180°
Polarization ratio telemetered signal $1-\cos\phi$	Continuous	ϕ (0°–180°)	Depressed	Enhanced
Spin modulation $E_{min}/E_{max}=\cos\phi$ $E_{max}\to\gamma$	Twice during one spin cycle, irresponsive to quick variation	θ (Ambiguity)	High deeply modulated	Low slightly modulated

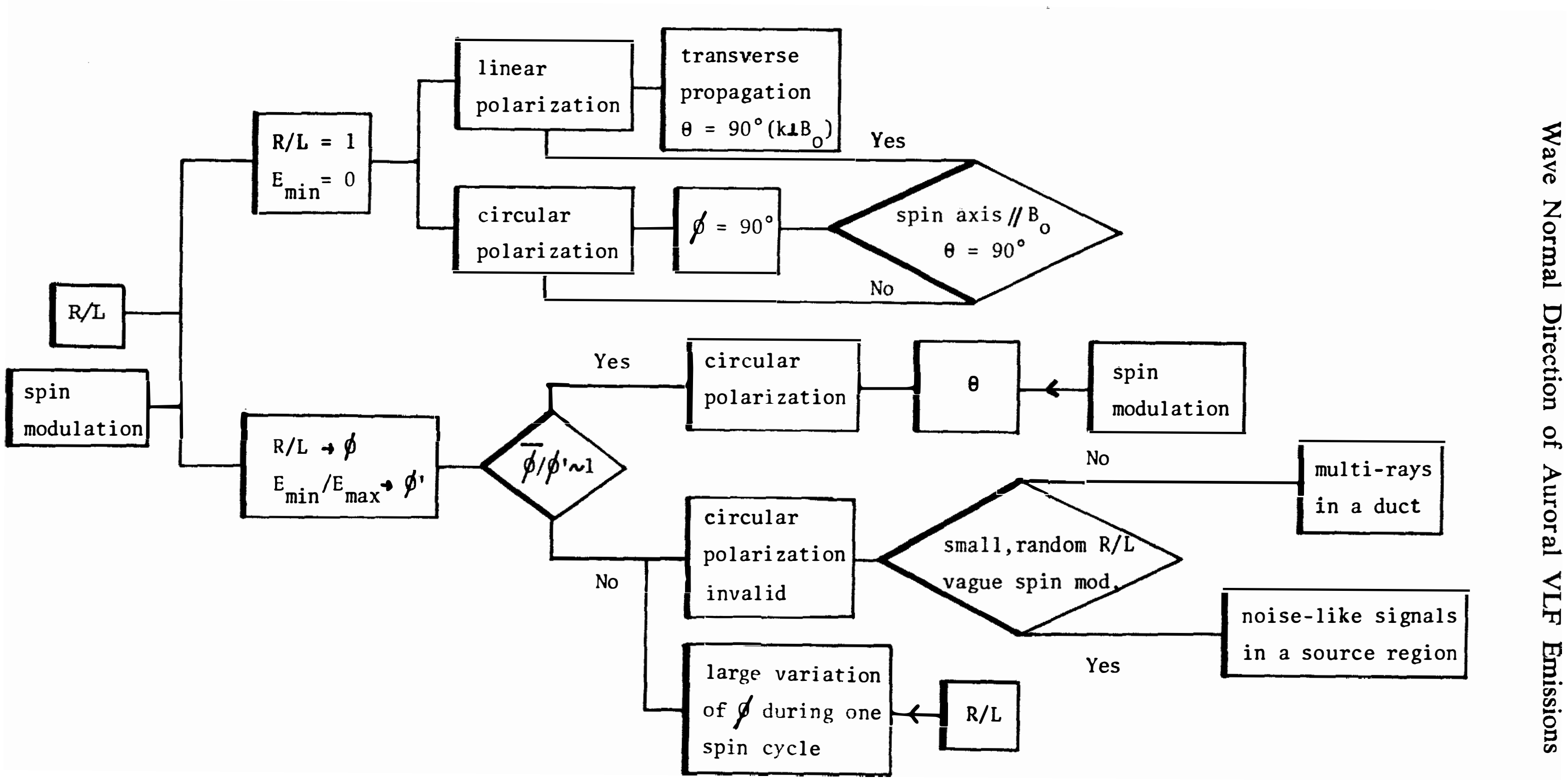

Fig. 2. Logical flow chart in analyzing the DF data by means of the polarization ratio and of the spin modulation.

data. When the mean value of the cone angles determined by making use of the polarization ratio during the spin half cycle is equal to the cone angle estimated from the spin modulation, the assumption of right-handed circular polarization is likely to be valid, enabling us to yield the wave normal direction θ. In other cases careful analyses of the DF data would be needed, a logical flow chart of which is shown in Fig. 2.

3. Measuring System of the Electric Field Intensity

Electric field measurements so far made seem to involve serious problems (AGGSON and KAPETANAKOS, 1966). As is known, the ion sheath is formed around an electric antenna and the antenna impedance is a strong function of height, depending on the electron density and temperature. Table 2 gives the sheath impedance for the typical values of plasma parameters. The sheath capacity might be approximated by that of a co-axial capacitor formed by the antenna and the boundary of the plasma sheath (STOREY, 1963; AGGSON and KAPETANAKOS, 1966). The formula of sheath conductance follows the work by MLODNOSKY and GARRIOTT (1963). Then the entire antenna-preamplifier network is shown in Fig. 3 (SCARF *et al.*, 1968), where C_{in} and R_{in} refer to the preamplifier, while C_a and R_a refer to the complete antenna-sheath system. Since the bulk impedance of the plasma is negligible at VLF, the antenna impedance is primarily determined by the sheath impedance.

Table 2. Variation of the sheath impedance with plasma parameters.

Electron density / Temperature	10^4(cm^{-3})	10^5	10^6
1000°K	Cs(m^{-1})=71 pF Rs=2.8×10^6 ohm	106 pF 2.8×10^5	282 pF 2.8×10^4
2000°K	Cs(m^{-1})=40 pF Rs=4.0×10^6 ohm	81 pF 4.0×10^5	206 pF 4.0×10^4

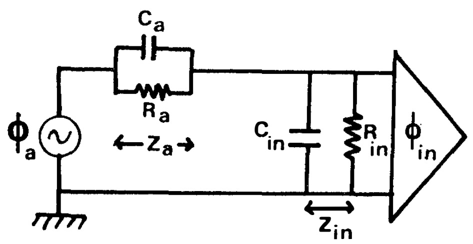

Fig. 3. Antenna-preamplifier coupling network.

For this network the pick-up factor (p) defined as the ratio of Φ_{in}/Φ_a is given by,

$$p=\frac{\Phi_{in}}{\Phi_a}=\frac{1}{1+Z_a/Z_{in}} \qquad (5)$$

where $1/Z_a=1/R_a+j\omega C_a$, $1/Z_{in}=1/R_{in}+j\omega C_{in}$.

As shown in Table 2, the sheath impedance is capacitive in the lower altitude, but it becomes resistive in the auroral region with high electron density, resulting in the complex variation in the pick-up factor of the electric antenna. AGGSON and KAPETANAKOS (1966) have pointed out this effect in the measurement of electric field intensity and also KIMURA *et al.* (1978) have found experimentally this effect. Hence, by using this network, it is probable that the observed variation in electric field intensity is attributed to the variations in antenna impedance as well as in ambient electric field. A method to overcome this effect is applying a constant DC bias to the antenna to destroy the ion sheath, but it is not so effective since it sometimes gives rise to an electron beam, triggering unwanted VLF noises (KAMADA and HIRASAWA, 1978). So, we propose a system which we believe the best way. The preamplifier should be installed as close to the antenna as possible and has sufficiently high input resistance of $\sim 10\,\mathrm{M}\Omega$. The high input resistance, however, introduces another interference problem. The high resistance, in turn, has a tendency to pick up the electrical noises generated in the rocket body by the presence of even a small stray capacity. Therefore, the foot of the antenna element should be electrically shielded to avoid these noises. The shielding, thus, makes the value of the input capacity very large, reducing the pick-up factor of the antenna. In order to compensate this reduction in pick-up factor, we use a positive feedback system as shown in Fig. 4. In this

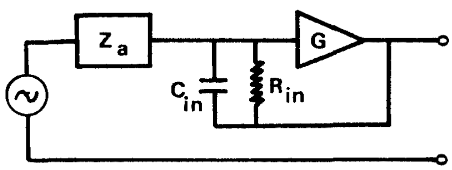

Fig. 4. Positive feedback amplifier system applied to the antenna-preamplifier network.

figure C_{in} is the equivalent input capacity. When the signal induced by the antenna goes to the positive feedback amplifier with the gain of G, the pick-up factor of the antenna-preamplifier network is given by

$$p=\frac{G}{1+Z_a/Z_{in}\cdot(1-G)}. \qquad (6)$$

By setting the gain G to nearly equal to, but less than unity, the electric field

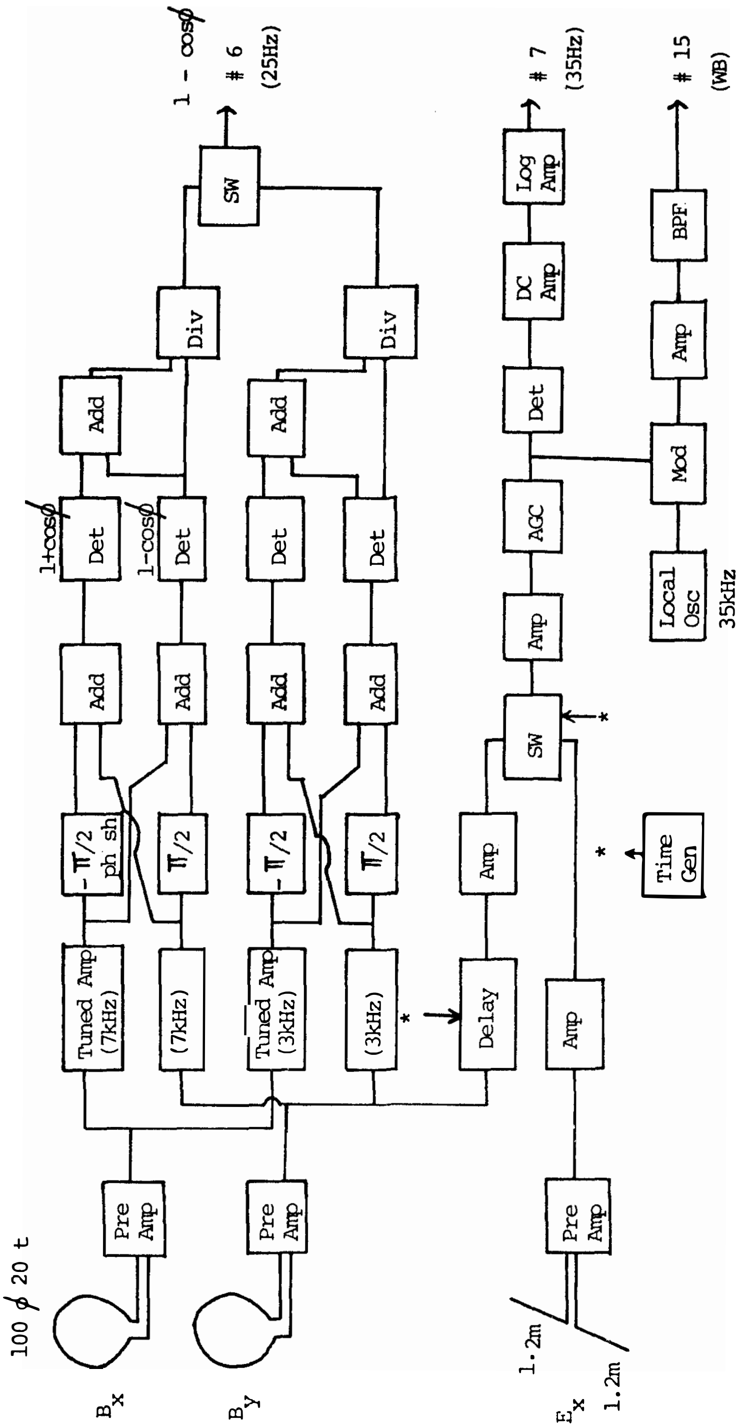

Fig. 5. Block diagram of the VLF equipment to be installed on the S-310JA-6 rocket.

intensity is expected to be measured with a high accuracy even in a wide altitude range where the nature of the sheath impedance varies from capacitive to resistive and additionally their values vary over a wide range. For example, a large value

~0.95 is taken as G and then the ambient electric field is measured with the ambiguity of about a few dB. So this system of the antenna-preamplifier will allow the measurement of the ambient electric field intensity with the receiver gain independent of the ambient plasma conditions. This system was already adopted on the Japanese REXS satellite (IWAI and OHTSU, 1968; IWAI *et al.*, 1973).

4. Measuring System to be Installed on the S–310JA–6 Rocket

Our experiment will be made by using the S-310JA-6 rocket which will be launched in 1978 at Syowa Station by the 19th Japanese Antarctic Research Expedition wintering members. Also the rocket is expected to be launched closer to the geomagnetic field line during the auroral display. At the same time we will make the coordinated ground-based DF by means of a new method (TANAKA *et al.*, 1976). Fig. 5 illustrates the block diagram of our VLF experiment. The polarization ratio will be measured at two specific frequencies of 7 and 3 kHz. The former frequency is selected so that we will be able to know the wave normal direction of the wide-band auroral VLF hiss so as to distinguish between the Jørgensen's type emissions and the local emissions. Then the polarization at 3 kHz will be of great use in the study of the emissions generated locally within the ionosphere such as those found by UNGSTRUP (1951, 1975). The wide-band signals (0–8 kHz) observed by both electric and magnetic antennas are also telemetered to the ground, the comparison of which will be important to know the electromagnetic or electrostatic nature of the observed VLF radio noises.

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