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# COMPARATIVE ANALYSIS OF ELECTRON DENSITY AND ELECTRIC FIELD FLUCTUATIONS IN HIGHLY ACTIVE AURORAS OBSERVED BY A SOUNDING ROCKET S-310JA-12: PRELIMINARY RESULTS

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***Abstract:*** The S-310JA-12 rocket was launched geomagnetically northward from Syowa Station, Antarctica, during a strong substorm period. The onboard instruments were a Faraday cup for measuring electron density and its fluctuations up to 8 kHz together with total flux of electrons with energies above 105 eV and a pair of double probes for measuring DC electric field and electric field fluctuations of 5–220 Hz, which detected various kinds of ELF-VLF band fluctuations during the flight. During the ascent, the Faraday cup observed strong VLF fluctuations in the $E$ region and burst-like fluctuations over the region from 140 to 200 km in altitude. The former might be caused by the two-stream instability and/or the cross-field instability, while the latter is considered to be generated artifitially around the rocket. Around the height of 220 km, quasi-sinusoidal waves with the frequency of about 150 Hz were observed by the both instruments. They are found to be right-hand circularly or elliptically polarized waves by cross-correlation analysis. During the descent, the rocket passed through highly active auroras and the both instruments observed strong ELF fluctuations. It is suggested by the Faraday cup measurement that the rocket was considerably charged up by the precipitating electrons in the auroras.

## 1. Introduction

During the auroral display, wave-particle interactions play a principal role in the acceleration and scattering of precipitating electrons in the ionosphere. In order to clarify the energy process in auroras, it is extremely important to make a simultaneous observation of the interacting waves and particles directly by sounding rocket.

We have once conducted a correlation analysis of the ELF wave data obtained by a Faraday cup and a pair of double probes aboard the S-310JA-7 rocket, and recognized that the combination of these instruments is very effective for the mode identification of the observed waves (MORI *et al.*, 1985). Consequently, we installed the same combination of instruments on the S-310JA-11 and -12 rockets (YAMAGISHI and FUKUNISHI, 1985).

The Faraday cup aboard the S-310JA-11 rocket succeeded in measuring precipitating electron flux and thermal electron current, but unfortunately failed in measuring electron density fluctuations due to some defect in the pre-amplifier circuit. Concerning the S-310JA-12 experiment, both instruments worked successfully and valuable data on wave-particle interactions were obtained in highly active auroras.

This paper presents some preliminary results of comparative analysis of the Faraday cup and the double probe measurements by the S-310JA-12 rocket. Result of the Faraday cup measurement aboard the S-310JA-11 rocket will be given elsewhere.

## 2. Instrumentation

The Faraday cup, 100 mm in diameter and 30 mm in height, consists of four grids (Gl to G4) and one collector, each of which is plated with gold. Appropriate DC voltages are applied to the grids and collector as shown in Fig. 1 to detect various

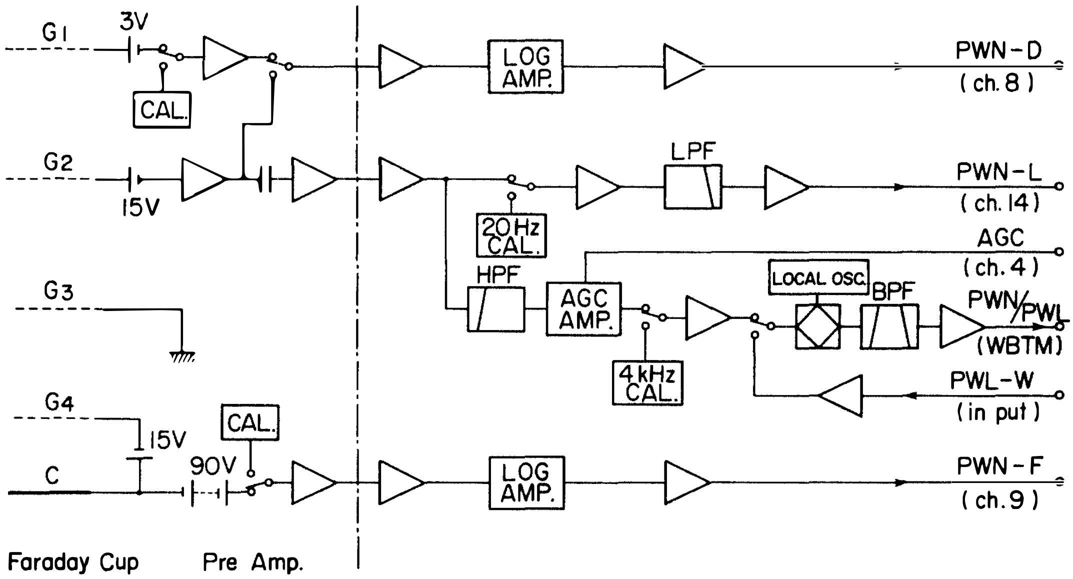


*Fig. 1. Block diagram of the PWN-D, -L, -W and -F payloads aboard the S-310JA-12 rocket.*

electron current components. The following is the outlines. A DC voltage of +3 V is applied to Grid 1 to measure the electron DC current (PWN-D). A DC voltage of +15 V is applied to Grid 2 to measure the electron AC current. The output from Grid 2 is devided into two frequency components; one is low-frequency component of 5–330 Hz (PWN-L), and the other is high-frequency one of 0.1–5 kHz (PWN-W) which is sent to a wide band telemeter. The wide band telemeter is time-shared with PWL mission at a ratio of 3 s (PWN) to 4 s (PWL). DC voltages of −105 V and −90 V are applied to Grid 4 and a collector, respectively, to collected precipitating electrons having energies beyond 105 eV (PWN-F). The Faraday cup was installed at the top of rocket body.

A pair of double probes are separated by 2.12 m and extending perpendicular to the rocket axis to measure DC electric field (AEF-D) and AC electric field in the frequency range of 5–220 Hz (AEF-L). Detail of the instrument is explained by OGAWA *et al.* (1981b).

## 3. Observation and Discussion

The S-310JA-12 rocket was launched geomagnetically northward (equatoward) at 1935:39 UT on July 12, 1985. It flew through highly active auroras during a strong substorm induced by a proton flare.

Figure 2 shows the time variations of PWN-D, PWN-F, PWN-$L_{rms}$ and AEF-$L_{rms}$ records, where the subscript rms means a root mean square average of the signal amplitudes. The PWN-$L_{rms}$ values are normalized by the corresponding PWN-D current. In the figure, the PWN-D current saturated during 66–90 s (95–129 km) due to a high electron density ($>5\times10^5$ cm$^{-3}$) of the ionospheric $E$ region. The PWN-F current abruptly increased at about 70 s (101 km) indicating that the ascending rocket encountered an aurora, then gradually decreased from 120 s (164 km) to 220 s (222 km). The descending rocket reentered highly active auroras at about 272 s (216 km), so the PWN-F current often saturated until 367 s (141 km). During the period, the PWN-D current was also considerably fluctuated.

In PWN-$L_{rms}$ and AEF-$L_{rms}$ time variations, several interesting periods of signal

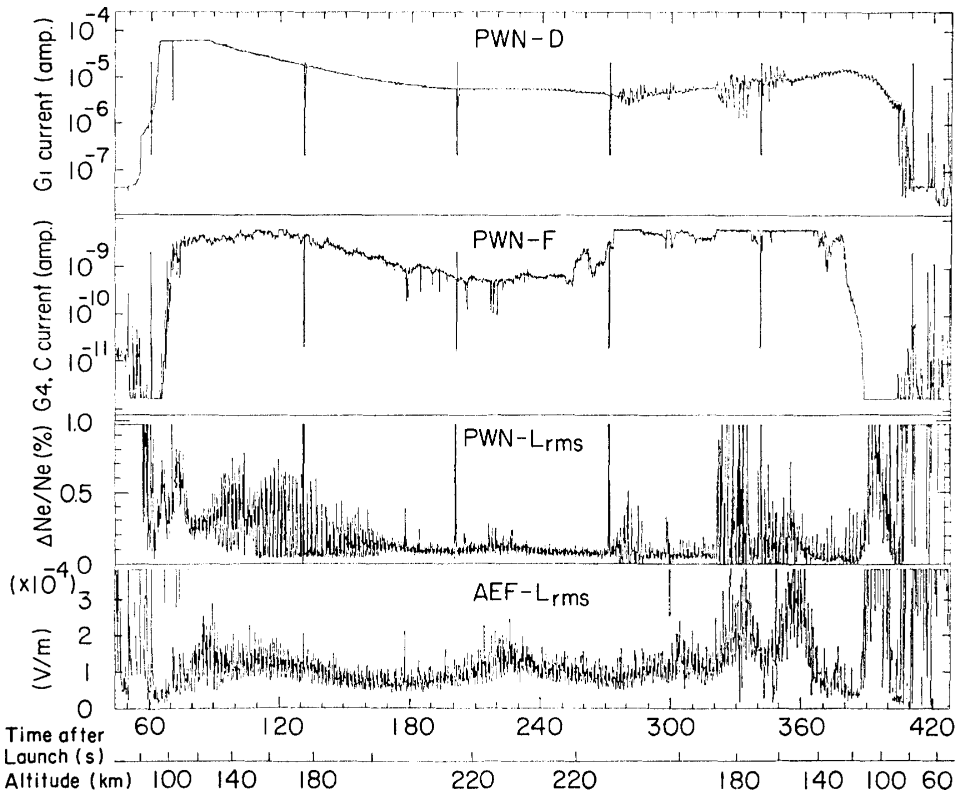


*Fig. 2. Time variations of PWN-D signal (top panel), PWN-F signal (second panel), signal amplitudes PWN-L (third panel) and of AEF-L (bottom panel).*

enhancement can be found. Characteristics of these regions will be discussed below with the results of a preliminary analysis.

### 3.1. Fluctuations during the ascent

Figure 3 is the dynamic spectrum of the wide band telemeter signal during the rocket ascending (22–169 s). It is found from the figure that the Faraday cup (PWN) observed very strong and continuous fluctuations in the $E$ region (90–130 km), dominant frequency of which was between 2–5 kHz. These fluctuations were also strongly detected by the PWN-L channel (see Fig. 2). Over this height range, the

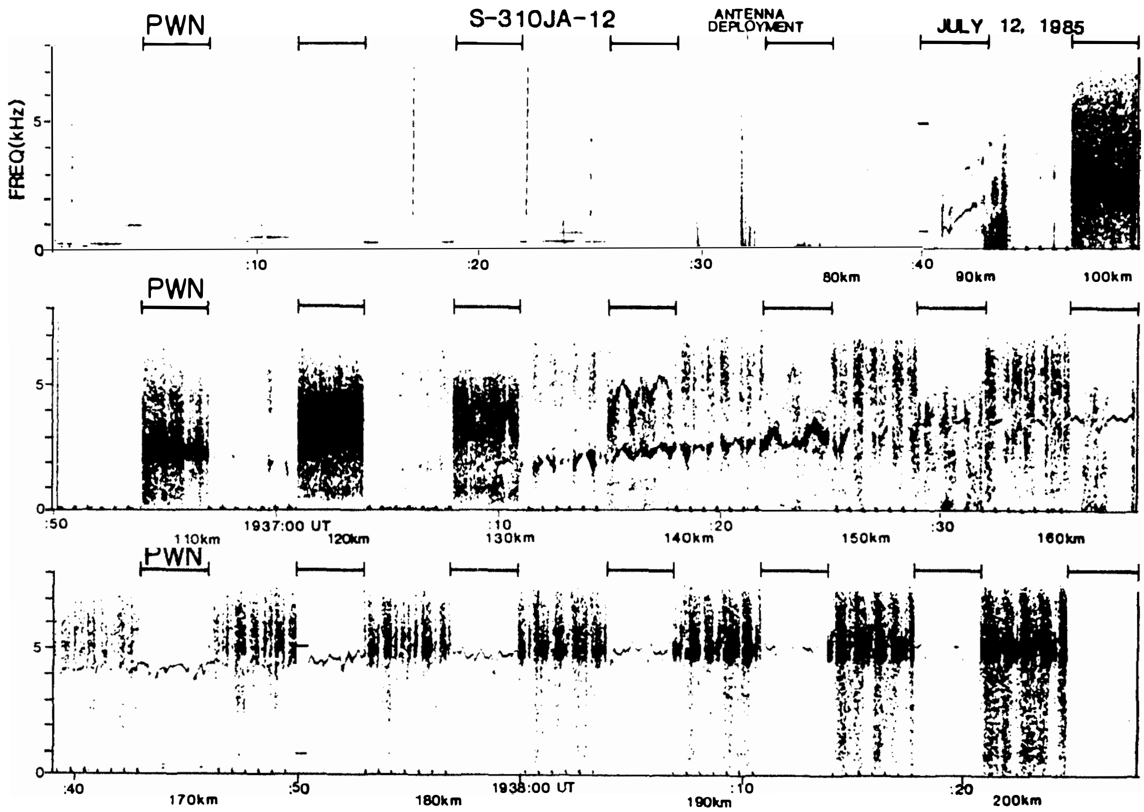


*Fig. 3. Dynamic spectrum of the PWN-W signal (regions shown by horizontal bars) during the rocket ascending (22–169 s).*

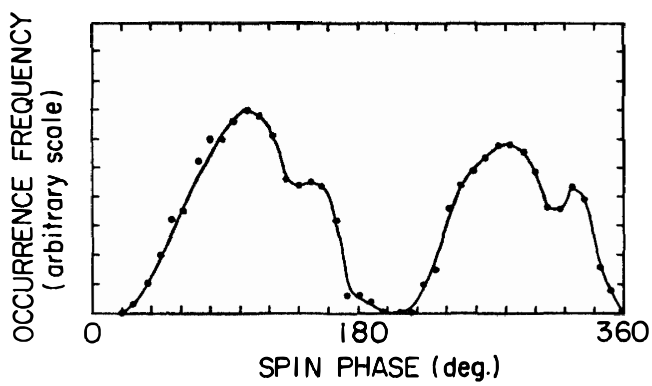


*Fig. 4. Spin angle dependence of the occurrence frequency of burst-like fluctuations observed during 105–170 s. The phase angle is taken to be 0 when the MGF-H (magnetic field measurement) sensor directs to the geomagnetic field line.*

fluctuations were observed intermittently. Occurrence frequency of the burst-like fluctuations is found to be closely related to the rocket spin period. Figure 4 is a spin phase angle dependence of the bursts observed during 105–170 s (148–204 km), where the phase angle is taken to be 0 when the MGF-H (magnetic field measurement) sensor is placed parallel to the magnetic field lines. It is remarkable that a pair of large peaks appear at about 106° and 284°, and a pair of second peaks at about 148° and 328°. This result strongly suggests that the burst-like fluctuations were not a natural phenomenon but artificially caused by two pairs of antennas spinning around the rocket axis. Considering a setting of antennas around the rocket (see Fig. 5) and their rotation, the most probable candidates for the two pairs of peaks are a pair of double probes and a pair of cylindrical antennas for PWH mission, respectively. Another interesting feature of the dynamic spectrum is that the Faraday cup observed monochromatic waves within the interval of the burst-like fluctuations. As their frequency changes periodically with the rocket spin, they might also be resonantly excited artificially around the rocket.

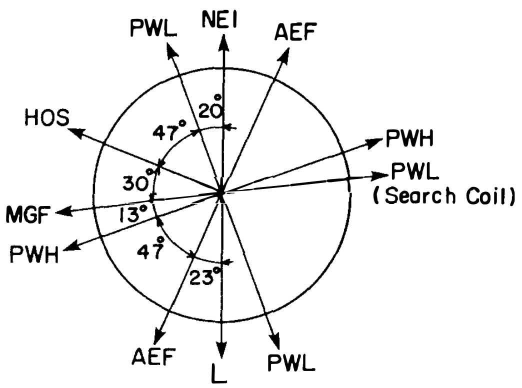


*Fig. 5. Orientation diagram of sensors and antennas of the S-310JA-12.*

Concerning the generation mechanism of the fluctuations observed in the *E* region, excitation of a two-stream instability by a local strong DC electric field (FARLEY, 1963) or a cross-field instability by a sharp gradient of electron density perpendicular to the DC electric field (SATO, 1971) seems to be most plausible.

*3.2. Quasi-sinusoidal waves observed around the apex*

Both the Faraday cup and the double probes observed intense quasi-sinusoidal waves as shown by Fig. 6 within 210–240 s around the rocket apex height. Their frequency is found to be about 150 Hz by FFT analysis. Similar quasi-sinusoidal waves were also observed by the double probes aboard the S-310JA-11 rocket at the height of 150 and 190 km of the ascending path, with their frequency between 130–140 Hz.

In order to compare the Faraday cup and the double probes data of the S-310JA-12 rocket more precisely, we made cross-correlation analysis of them. Figure 7 shows one of the results; the time variation of phase advance of the PWN-L waves to the AEF-L waves at three different frequencies 138, 150, and 162 Hz. In the figure, plots of the calculated phase advances are well along the solid lines indicating the

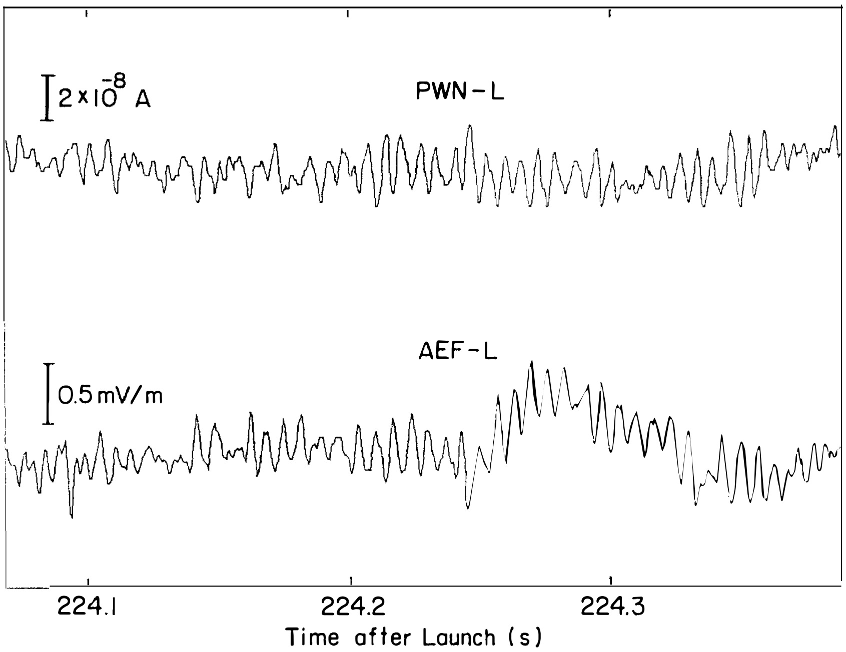


*Fig. 6. Computer plots of PWN-L (5–330 Hz) and AEF-L (5–220 Hz) signals during 224.1–224.4 s.*

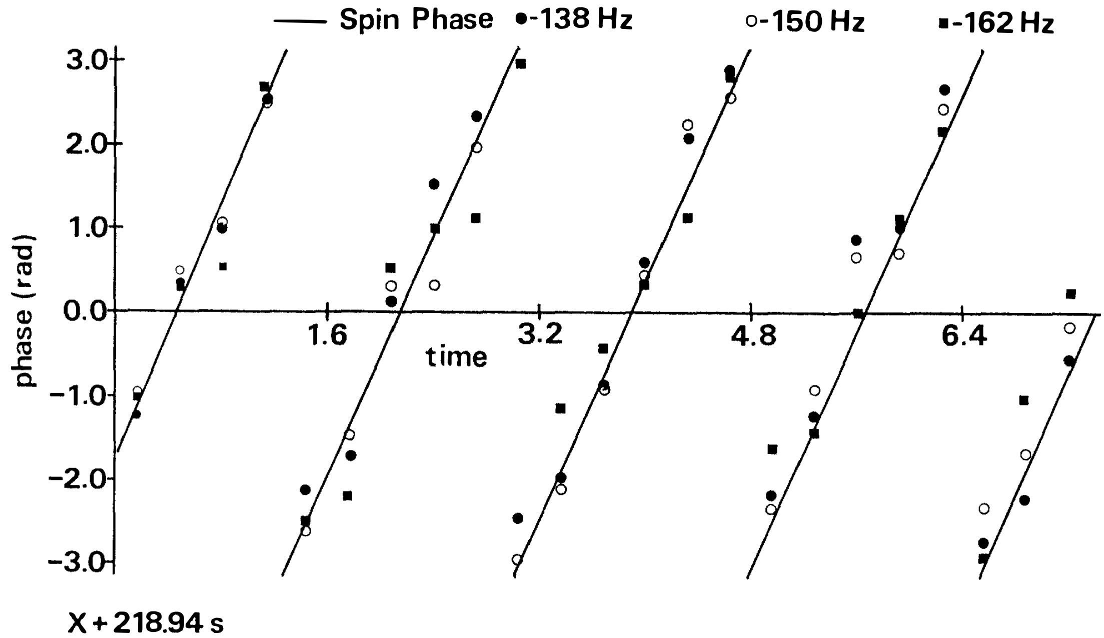


*Fig. 7. Time variation of phase advance of PWN-L waves to AEF-L waves at 138, 150 and 162 Hz. Solid lines in the figure indicate the time variation of the rocket spin phase.*

time variation of the phase angle of the rocket spin. Considering that the double probes measure waves as rotating clock-wise with the spin period and that the geomagnetic field points upward, the above result could be understood if the waves have spin-wise or right-hand circularly or elliptically polarized electric fields.

The same kind of quasi-sinusoidal waves were previously observed by the S-310JA-7 rocket experiment, with the frequency of 38–45 Hz and the same sense of polarization to the S-310JA-12 case (OGAWA *et al.*, 1981a; MORI *et al.*, 1985). The self-consistent identification of the both wave modes remains as a future problem.

*3.3. Fluctuations in active auroras during the descent*

The descending rocket passed through highly active auroras. During the traverse the PWN-F signal often saturated, and the PWN-D signal showed large fluctuations. Amplitudes of the PWN-L and AEF-L signals were also increased. As a typical example, Fig. 8 shows time variations of the PWN-F, PWN-D, and AEF-D data during

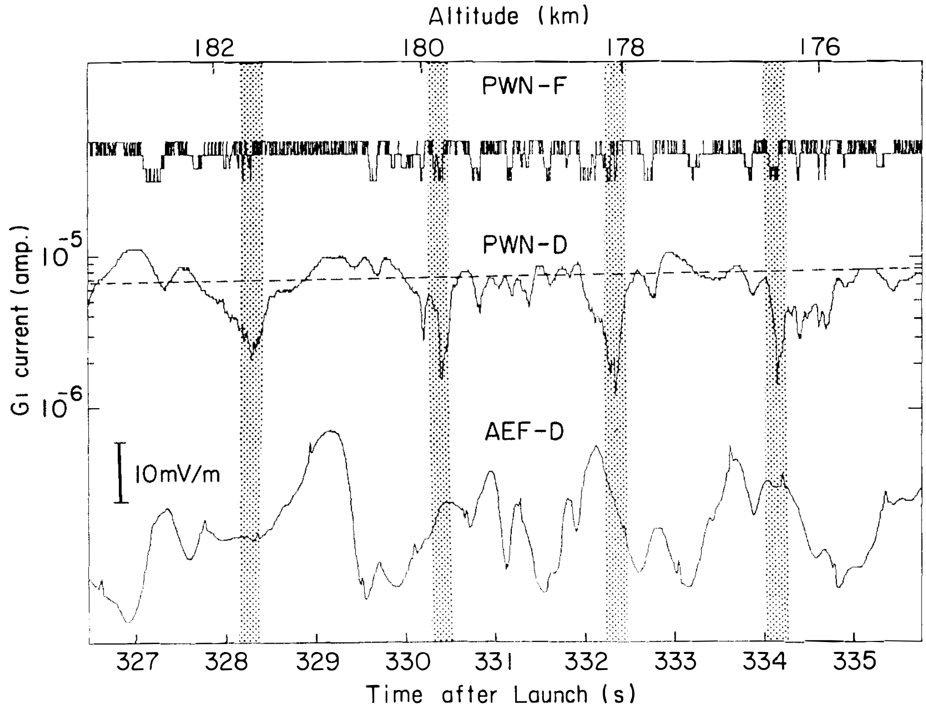


*Fig. 8. Time variations of PWN-F, PWN-D and AEF-D signals during 327–335 s.*

327–335 s (182–176 km) plotted by computer after being digitized by 8 bits/word. Vertical scale size per digit for each data is properly set to be useful to compare their time variations one another. As the PWN-F signal is almost saturated, variations of only uppermost four digits appeared in the figure. The broken line in the figure connects the quiet PWN-D signal levels before and after the flight through auroras. It is seen from the figure that the PWN-D current fluctuates greatly in association with the PWN-F variations. Particularly, the PWN-D levels at the shaded regions drop to nearly one-tenth of the quiet level (a broken line level). As it is unlikely that the local electron density dropped so much, it is supposed that the potential of Grid 1 of the Faraday cup became temporarily below the local plasma potential and the thermal electrons were rejected to flow into Grid 1. This phenomena might be possible if the rocket surface was severely charged up with the auroral high energy electron precipitations. The AEF-D signal also showed large amplitude variations in coincidence with the PWN-F variations. It may reflect a spatial distribution of complicated electric fields in the region. It is necessary, however, to pay attention to a possible unbalanced charging of the auroral particles to the probes, when we analyze the double probe data obtained in such an active aurora.

## 4. Conclusion

The S-310JA-12 rocket was launched into highly active auroras during a strong substorm period. A Faraday cup and a pair of double probes aboard the rocket observed various kinds of ELF-VLF band fluctuations during its flight. Preliminary analysis of both measurements indicates the following results.

(1) During the ascent, the Faraday cup observed strong and continuous electron density fluctuations in the *E* region and burst-like fluctuations over the region from 140 to 200 km altitude. They have broad frequency spectrum extending to several kHz. The former fluctuations might be caused by a two-stream instability and/or a cross-field instability, although this inference must be checked through a comparison with the DC electric field measurement. Concerning the latter fluctuations, rocket spin phase dependence of their occurrence frequency indicates that they are generated artificially around the rocket.

(2) Around the height of 220 km, quasi-sinusoidal waves with frequency of about 150 Hz were clearly observed by both the Faraday cup and the double probes. As a result of correlation analysis of them, it is found that they are right-hand circularly or elliptically polarized waves.

(3) During the descent, the rocket passed through highly active auroras. Both the Faraday cup and the double probes observed intense ELF fluctuations in the aurora. It is suspected from the Faraday cup measurement that the rocket was considerably charged up during its passing through the auroras.

Although it is very useful to measure waves directly at the region of their emission by means of rocket, the rocket itself might excite various waves locally by interacting the surrounding plasma. Therefore, ıt is important to distinguish carefully the artificially generated waves from natural ones. One of the methods for doing this would be to measure the waves at different points around the rocket and compare them. It is found that the combination of a Faraday cup and a pair of double probes is also very effective for that purpose as well as for the mode identification of waves.

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