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OBSERVATIONS OF ELF AND VLF WAVES ON THE REXS SATELLITE

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Abstract

The REXS satellite was launched into an elliptical orbit on August 19, 1972. VLF electric and magnetic field experiments covering the frequency range from 300 Hz to 21 KHz was made with this satellite. The operation of the satellite in orbit was satisfactory during several revolutions, except that the satellite was noisy in lower frequency bands of electric field and also in all frequency bands of magnetic field. Though, unfortunately, the telemeter system was damaged by accident on the third day after launching, preliminary analysis has shown some new distinctive features on the record of dynamic spectra.

1. Introduction

The REXS (*Radio Exploration Satellite*) is the second scientific satellite planned by the Institute of Space and Aeronautical Science of the University of Tokyo. The purpose of the REXS satellite is to observe the natural phenomena in the ionosphere and magnetosphere. For this purpose, the experiments on board the REXS satellite included a plasma density measurement (IPS), an electron temperature probe (TEL), an electron beam analyser (EBA), a cyclotron instability experiment (CIE), electromagnetic and plasma wave experiments (PWP) and an earth's magnetic field measurement (MGS). Among these experiments, we have taken charge of a part of the electromagnetic and plasma wave experiments (PWP). The aim of observing the electromagnetic and plasma waves in the ionosphere and magnetosphere, is to study emission mechanism and transmission characteristics of ELF/VLF radio waves in relation to the interaction between plasma particles and electromagnetic waves. As the observing frequency range was limited from 300 Hz to 21 KHz, the phenomena which are expected to be observed are whistlers, VLF signal waves from the trans-

mitters on the ground, VLF emissions, lower hybrid resonances, equatorial VLF hisses, plasma waves, etc. In order to study these electromagnetic wave phenomena in the ionosphere and magnetosphere, it was planned to observe the spatial and temporal distributions of the frequency spectrum of the electric and magnetic field intensities within these observing frequencies on the REXS satellite.

This paper describes the outline of the observing equipment and the preliminary results obtained with the REXS satellite.

2. Equipment

The experimental equipment consists of two electric monopole antennas, a magnetic loop antenna and a step-frequency receiver. The antenna system is mounted on the top of the satellite, and its position and orientation on the satellite are shown in Fig. 1. The magnetic loop antenna, whose axis is perpendicular to the spin axis of the satellite, consists of a 20 turn shielded loop of rectangular form $0.58 \times 0.23 \text{ m}^2$. The loop wires are electrostatically shielded by an aluminium pipe to reduce the antenna effect. Three electric monopole antennas, whose axes are perpendicular to the spin axis of the satellite, are arranged with the angle of 120° to one another, as shown in Fig. 1. Two of the three monopole antennas are used for the PWP experi-

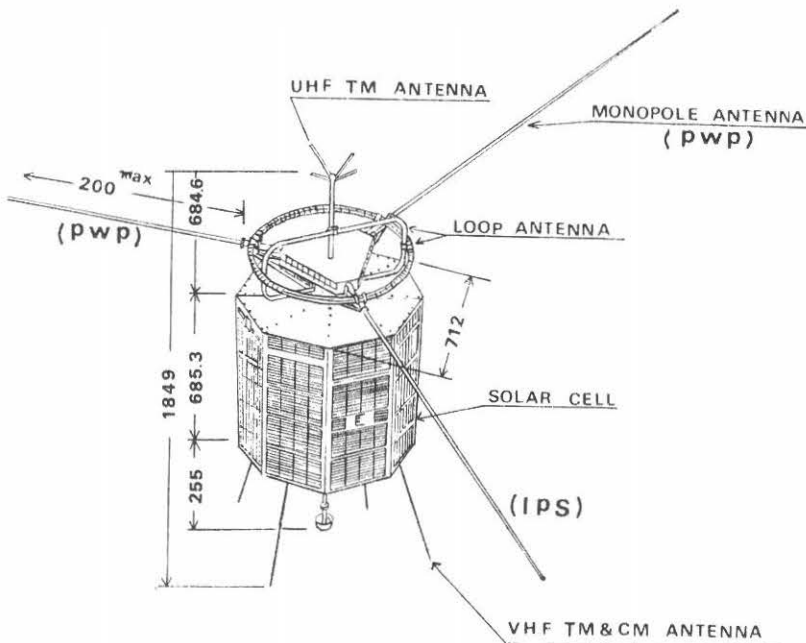


Fig. 1. General view of the REXS Satellite.

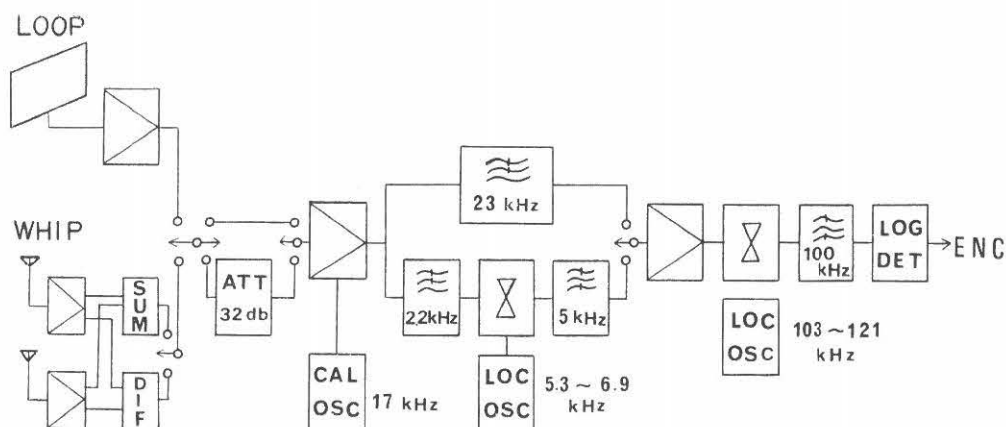


Fig. 2. Block diagram of the PWP equipment.

ment and the other for the IPS measurement. The base of the antennas which contains the extension mechanism of the antenna, is shielded to reduce interfering noises generating in the satellite to an acceptable level. The pre-amplifiers which are desirable to be mounted just below the base of the antennas, are installed in the satellite body to avoid the variation of temperature. Therefore, the signals from the antennas are introduced to the pre-amplifiers by a doubly shielded coaxial cable having a length of about 50 cm. In order to avoid the lowering of sensitivity due to a plenty of distributed capacitance, an unity gain amplifier which acts as an impedance transformer for driving the shield case of the base of the antenna and the inner shield of the coaxial cable, is used to cancel this harmful distributed capacity. The input impedance of the pre-amplifier for the electric field can be represented equivalently by a 10 meg-ohms resistor in parallel with a 30 pF capacitor. A pair of outputs from the pre-amplifiers connecting to the monopole antennas is added to and subtracted from each other, as shown in the block diagram of Fig. 2. The outputs through the adder and the subtracter are named as W_s and W_d , respectively, and the output from the loop as L . At the beginning of the design, two spherical antennas, supported by two booms arranged with the angle of 180° , were planned to be used for the electric field measurement. Therefore, W_s and W_d represented the field intensity components which were parallel and perpendicular, respectively, to the spin axis of the satellite. But, as another monopole antenna was added for the IPS measurement, the three monopole antennas were re-arranged with the angle of 120° on the top of the satellite. As a result, W_s still remains unchanged to represent the electric field component perpendicular to the spin axis, while W_d becomes to contain the electric field components not only parallel but also perpendicular to the spin axis. In this antenna system, the effective length for W_d is about 1 m for the electromagnetic waves perpendicular to the spin axis and that for W_s is about 10 cm for the parallel component of the wave.

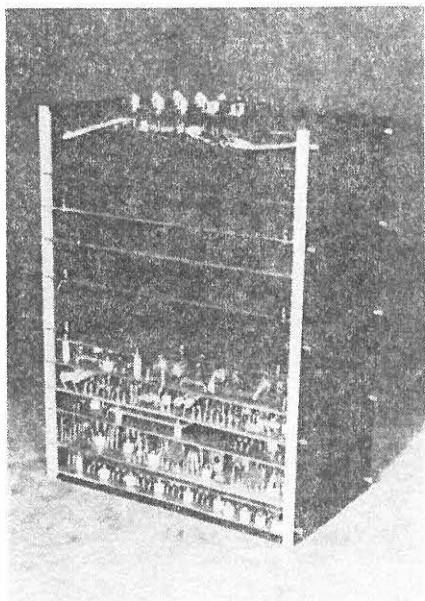


Fig. 3. Photograph of the PWP receiver.

Because of the restriction on weight and power consumption, only a step-frequency receiver is mounted on the satellite. And the outputs through three pre-amplifiers of L, Wd and Ws are connected in turn to the input of the step-frequency receiver. The receiving frequency range which is divided into 15 channels, is from 300 Hz to 21 KHz. The receiving system employs the heterodyne system whose oscillators are stabilized by the crystals. The double heterodyne system is used for the channels of 300 Hz to 1.9 KHz and the single for 3 KHz to 21 KHz. The block diagram of this receiving system is shown in Fig. 2. A photograph of the receiver is also shown in Fig. 3. For all receiving channels, the observable dynamic range of about 60 dB can be obtained by means of a logarithmic compressor and an attenuator of 32 dB which

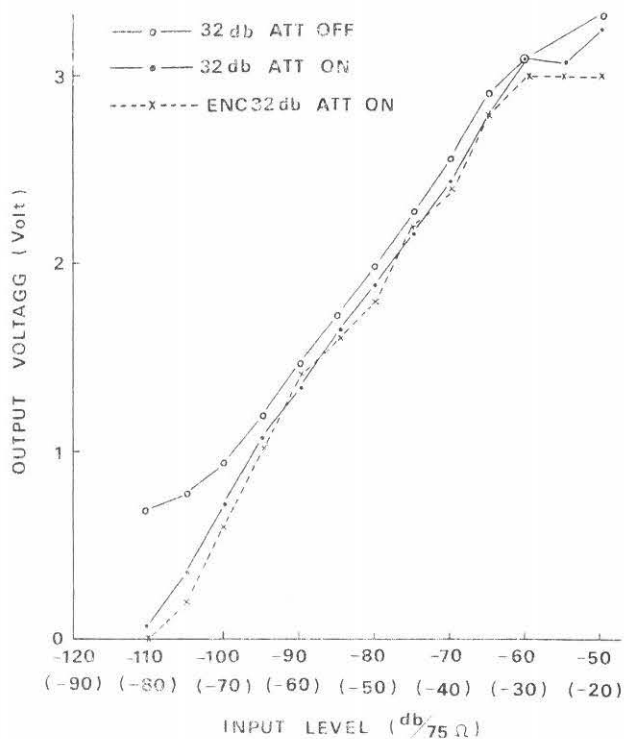


Fig. 4. Example of an amplitude characteristics of the receiver

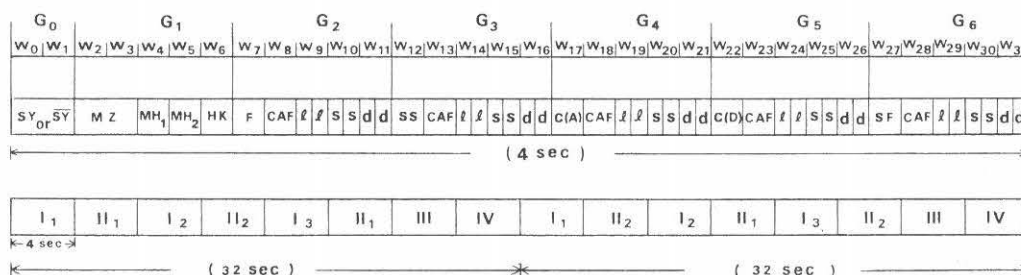


Fig. 5. Time sequence pattern of the telemeter in the REXS experiments

can be operated by command from the ground. An example of the amplitude characteristics of the receiver is shown in Fig. 4. And then, the output from the receiver is supplied to an encoder which transforms a d-c input signal less than 3 Volts to a PCM code of 4 bits.

The experiments on board the REXS satellite are made in the time sequence shown in Fig. 5. In this time sequence, the frame modes for the PWP experiment are I₁, I₂ and I₃, and the observing frequencies in each frame are tabulated in Table 1.

The observed data coded in a PCM are telemetered by the transmitters on board and are also recorded by a tape-recorder on board which can reproduce the data above the Kagoshima Space Center.

With a view to quickly looking the data which is coded time-sequentially, at the ground station, a quick look apparatus is used to display the amplitude for each frequency on a chart paper. Moreover, an apparatus recording the dynamic frequency spectra on a roll of facsimile paper is also used in parallel. The purpose of this apparatus is to watch the operating condition of the receiver on board and also to find out the remarkable phenomena in orbit without delay. These dynamic spectra of L, W_s and W_d are displayed by the densities of discharged spots on the

word Frame Mode	No.	w ₉ w ₁₀ w ₁₁			w ₁₄ w ₁₅ w ₁₆			w ₁₉ w ₂₀ w ₂₁			w ₂₄ w ₂₅ w ₂₆			w ₂₉ w ₃₀ w ₃₁		
		L	w _s	w _d	L	w _s	w _d	L	w _s	w _d	L	w _s	w _d	L	w _s	w _d
I ₁		0.3 kHz			0.7 kHz			1.1 kHz			1.5 kHz			1.9 kHz		
I ₂		3 kHz			5 kHz			7 kHz			9 kHz			11 kHz		
I ₃		13 kHz			15 kHz			17 kHz			19 kHz			21 kHz		

Table 1. Observing frequency allocation

same facsimile paper moving with the speed of 1.7 mm/min. for real time data and 0.4 mm/min. for reproduced data. An example of this dynamic frequency spectrogram is shown in Fig. 6.

Rev. 17

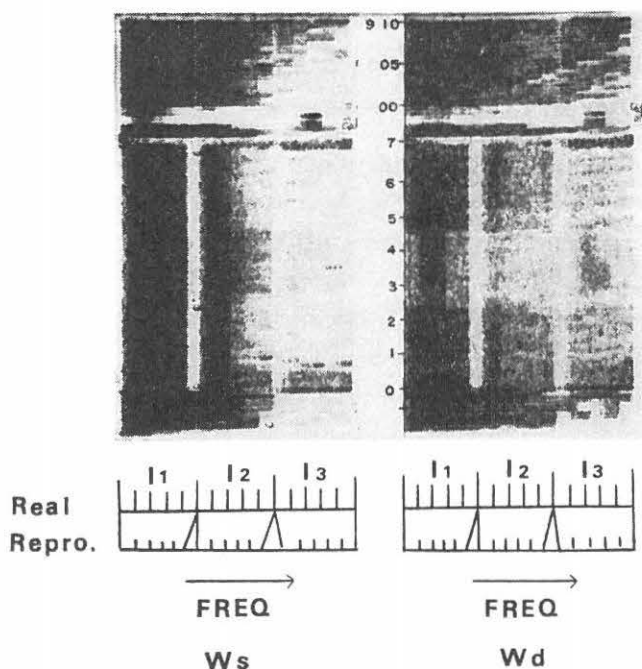


Fig. 6. Example of a dynamic spectrogram

3. Satellite Performance

The REXS satellite was launched at 02 h 40 m (U.T.) August 19, 1972 into an elliptical orbit with an inclination of 31° , an apogee altitude of 6570 km, a perigee altitude of 240 km and a period of 160 minutes. The operation of the REXS satellite in orbit was satisfactory with the exception of the electron beam analyser (EBA). The operation of the EBA was delayed three days in order to avoid the electric discharge due to the residual gases in the apparatus. At 00 h 04 m (U.T.) on Rev. 26, the power of the EBA was switched on and at that instant, the apparatus of the EBA was damaged. At the same time, the encoder on board was also damaged by an accident to the EBA and no significant data have, thereafter, been sent from the

satellite.

In spite of this failure, a number of useful data concerning the PWP experiment were obtained with the revolutions from Rev. 0 to Rev. 26, except for the measurement of magnetic field. The observing levels of the magnetic field indicated almost saturation values more than 3.5×10^{-8} gammas by the interfering disturbances from the other apparatus on board. Therefore, the high sensitive observation for the magnetic field was impossible. And as has been reported by previous workers (Osborne et al., 1967; Scarf et al., 1968; Laaspere et al., 1969), the electric field observation on the frame mode I_1 was also disturbed by the interfering noises more than 300 $\mu\text{V/m}$ except for the period when the satellite entered the shadow region of the earth. The observations of these disturbed frequency ranges were expected to be made satisfactorily, if the sensitivity of the receiver had been changed to the lower side by the command from the ground. However, there was no chance for measuring the electric field in lower frequency range and the magnetic field for a low sensitivity, because the telemeter system of the satellite was damaged too soon.

4. Summary of Preliminary Results

As the magnetic field data obtained indicate almost saturation values for most orbits as mentioned above, only the results for the electric field are described in this paper. The orbits obtained available data are Revs. 5, 6, 7, 8, 14, 15, 16, 17, 23, 24, 25 and 26. An example of the electric field strengths observed for a typical orbit is shown in Fig. 7 and a dynamic frequency spectrogram for the same orbit is also shown in Fig. 8.

Investigating the data of the electric field strength and the dynamic frequency spectrogram for each orbit, a summary of distinctive features is shown below;

1) *Electric Field Enhancement near the Perigee in the Ionosphere*

Near the perigee, the electric field level of Ws kept increasing during the period of about 20 minutes. The altitude of the satellite corresponding to this period is lower than 800 km. In this altitude range, the electric noise levels for all observing frequencies are enhanced remarkably and their maximum intensities are of the order of 30 $\mu\text{V/m}$ for all frequency bands. On the other hand, the electric field intensities for the altitude higher than 800 km show the order of 2~3 $\mu\text{V/m}$. These electric field intensities are remarkably small compared with those in previous worker's reports. (Scarf et al., 1966, 1968) For the electric field of Wd, the similar enhancements are recognized, but these are not so remarkable as Ws.

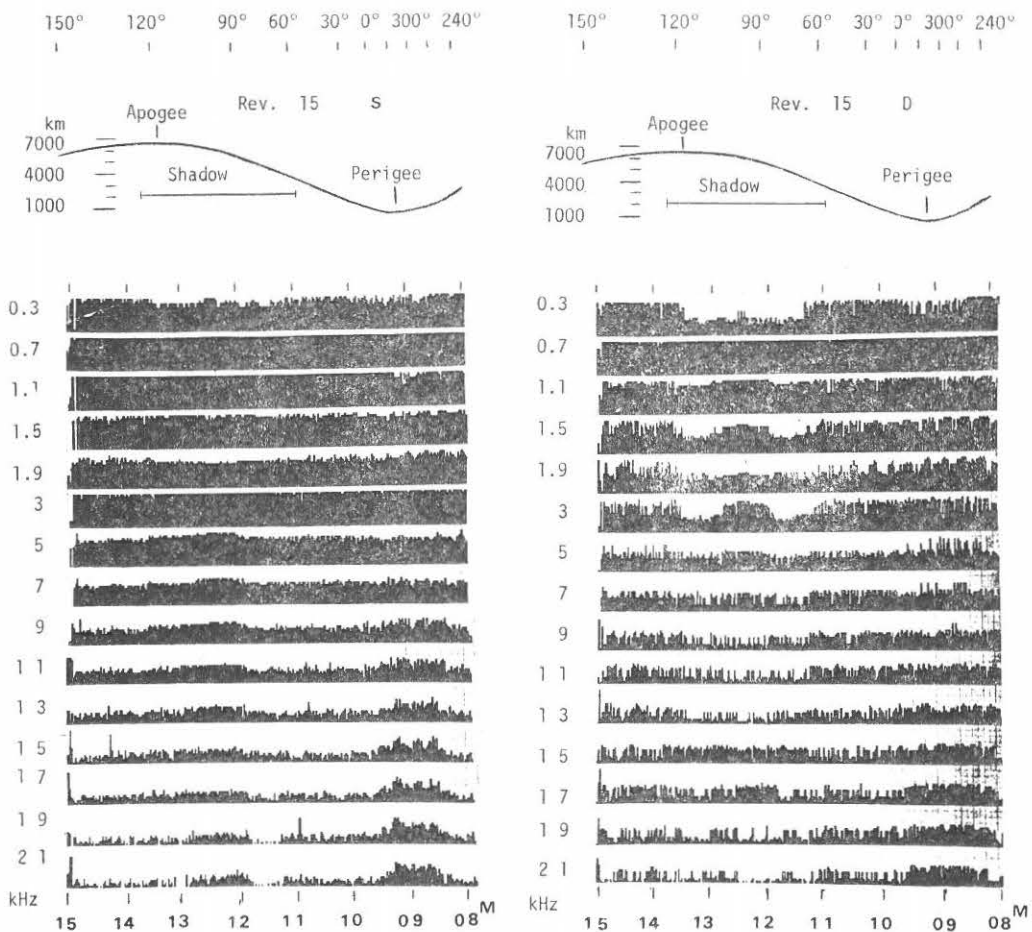


Fig. 7. Example of an electric field strength measurement.

2) Electric Field Decrease in the Shadow Region of the Earth

When the satellite enters the shadow region of the earth, the electric field intensities of W_d below 3 KHz show a sharp decrease except for 700 Hz band. The electric field level of 700 Hz always shows the saturation value due to the interference from the amplitude modulated wave of the telemeter, including the sub-carrier of 768 ± 128 Hz. Therefore, the electric field noises of W_d below 3 KHz are believed to be due to receiving the interfering disturbances by the antenna which are generating in the satellite and leaking into the surrounding plasma through the solar pannels. On the other hand, the electric field levels of W_s below 3 KHz do not show such a shadow effect but always indicate the saturation value for the substantial portion of the orbit. It may be considered that these saturation levels exceeding 40 dB are due

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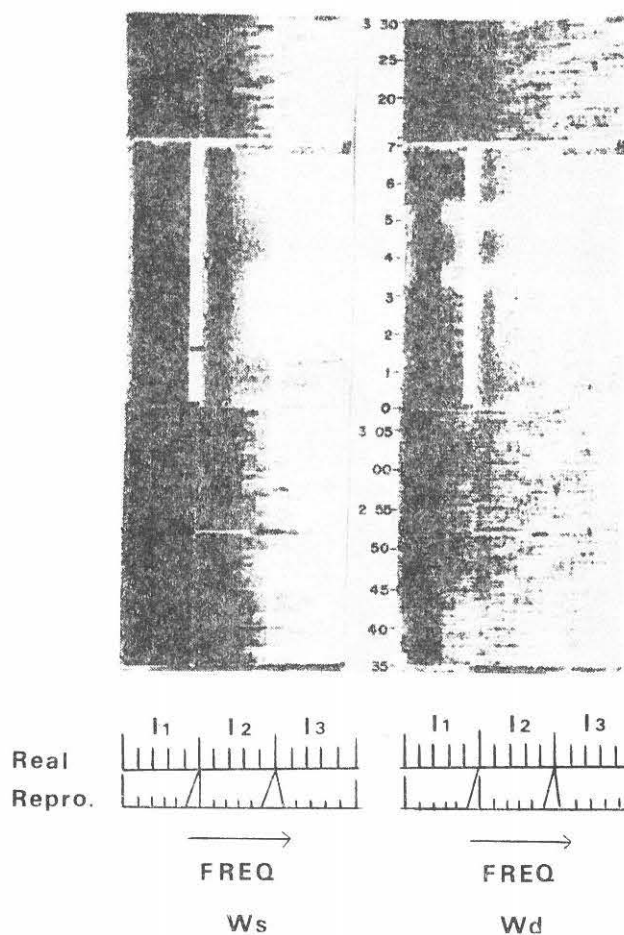


Fig. 8. Dynamic spectrogram of Rev. 15.

to the direct leakage of interfering noises generating in the satellite into the pre-amplifiers. If the attenuator of 32 dB had been used on board, the measurement in these disturbed frequency ranges would have been possible for the natural noises beyond the level of interfering disturbances. Unfortunately, there was no chance to confirm this fact, for the telemeter system on board was damaged on the third day after launching.

3) *Noise Level Enhancement in the Shadow Region of the Earth*

In the shadow region, there are some cases with a strong noise level enhancement of Wd. In these occasions, the noise level of Ws always indicates the enhancement corresponding to Wd. But, the noise level of Ws sometimes indicates the enhancement even in a case when the noise level of Wd is quiet in the shadow region. Judging from these results, the noise level of Ws has two kinds of case which is either correlated or not correlated to that of Wd. Therefore, it may be assumed that these phenomena of the noise level enhancement in the shadow region which are limited up to 13 KHz band, are different from the one in the perigee, which extends more than 21 KHz band.

4) *Receiving of Signals from the VLF Station in the Shadow Region of the Earth*

As shown in Fig. 7, when the satellite enters the shadow region, the signals having an almost constant level are received only in 15 KHz and 17 KHz bands of Wd. Considering their intensities and the frequency ranges, it is concluded that these signals will be the whistler-mode waves from the VLF transmitting stations on the ground. These VLF signals in 15 KHz and 17 KHz bands have the intensity of the order of 20–25 dB. But, they can not be observed in the sunlit region. This will be due to the high attenuation in the ionosphere in the day-time and this result is consistent with the results which have been observed with the rockets.

5) *Striped Pattern on Dynamic Spectrogram*

As can be seen in Fig. 8, there are striped patterns on the dynamic spectrogram in most of revolutions. The interval of the stripe which has a few differences between each revolution, is about 5–8 minutes, and moreover, its slow inclination indicates the frequency dispersion of about 2–4 KHz per minute.

Although the reason for the occurrences of these frequency dispersion phenomena is not known at present, this striped pattern may be an interesting subject for a future study.

5. *Concluding Remarks*

The above is the summary of the preliminary results obtained from the dynamic spectrogram and some noise level data by the quick look. More detailed analysis of the data ought to be done by the data reduction from the magnetic tape with a

computer.

The REXS satellite has been planned to have a life-time of more than three months. And it has been expected that the satellite will encounter with various kinds of abnormal phenomena such as solar bursts occurring during this period.

To our regrets, however, we had no chance to observe these expected phenomena, because the damage of the satellite occurred too soon.

Since the results present only a brief survey of the data available, it is expected that more comprehensive studies of the various phenomena mentioned above will be published in the near future.

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