Characteristics of a Dipole and a Loop Antenna for Plasma Waves Observed by the S-310 JA-1 Rocket

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S-310 JA-1 号ロケットで観測されたプラズマ波に対するダイポール，ループアンテナの特性

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要旨　S-310 JA-1 号ロケットにより観測された VLF 波動現象のうち，プラズマ波現象と思われるものについて特に詳細に調べられた.

この現象は次の特長をもつ　すなわちその周波数はロケットスピンにしたがって変化し，1 スピン周期毎にダイナミックスペクトル上で逆U字形が 1 つ現れる．また，ループ，ダイポールアンテナ両者で検出された

この現象は，波長 10 cm 程度の静電的波動であろうと結論された　ループアンテナでは，実効長数 mm のホイップアンテナ効果によって検出されたと考えられ，また，2 8 m ダイポールは，上記の波長の縦波に対しては，実効長が 1 mm 程度となることが明らかとなり，観測された現象の特性が，定量的にも理解されたと考えられる

Abstract: Among VLF wave phenomena observed by the S-310JA-1 rocket, what is thought as a kind of plasma wave phenomenon has been investigated in detail The phenomenon is characteristic in that its frequency was spin-modulated and it appeared once during one spin period, and it was detected with a ferrite core loop antenna as well as with a 2 8 m dipole antenna

It is concluded that this phenomenon may be an electrostatic wave with a wave length of the order of 10 cm The loop antenna is considered to have worked as an electric sensor by the whip antenna effect, when the phenomenon was detected. It is also found that the 2 8 m dipole antenna is a very short antenna with an effective length of ~1 mm for the above plasma wave Therefore, the phenomenon can be quantitatively understood from these characteristics of the antennas

1. Introduction

In rocket observations of VLF wave phenomena in the ionospheric plasma, the loop antennas have been usually used in order to discriminate electromagnetic waves from plasma waves As will be described here, in our rocket experiment it was shown that the antenna could be a better sensor for plasma waves than a dipole antenna, and an

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electrostatic wave phenomenon was observed.

2. Characteristics of Plasma Waves Observed by the S-310JA-1 Rocket

VLF wideband (10 kHz bandwidth) noise in the ionosphere was observed as shown in Fig. 1, by the S-310JA-1 rocket at Syowa Station in Antarctica, on February 13, 1976. The electric (E) and the magnetic (H) fields were picked up by a dipole antenna (15 mmϕ, 2.8 m tip to tip) and a loop antenna (8000 turns on a 10 mm$\phi \times$150 mm long ferrite core) respectively. The E and H field outputs were telemetered to the ground by time sharing as shown in Figs. 1 and 2; 16 seconds for E and 8 seconds for H. During the first half of the above 16 seconds for E, a 3 volt DC bias was applied to the dipole antenna to remove ion sheath around the antenna, while for the second half no DC bias was applied. There was a difference in gain of the both preamplifiers; $G_D = G_L + 16$ dB (refer the block diagram in Fig. 2).

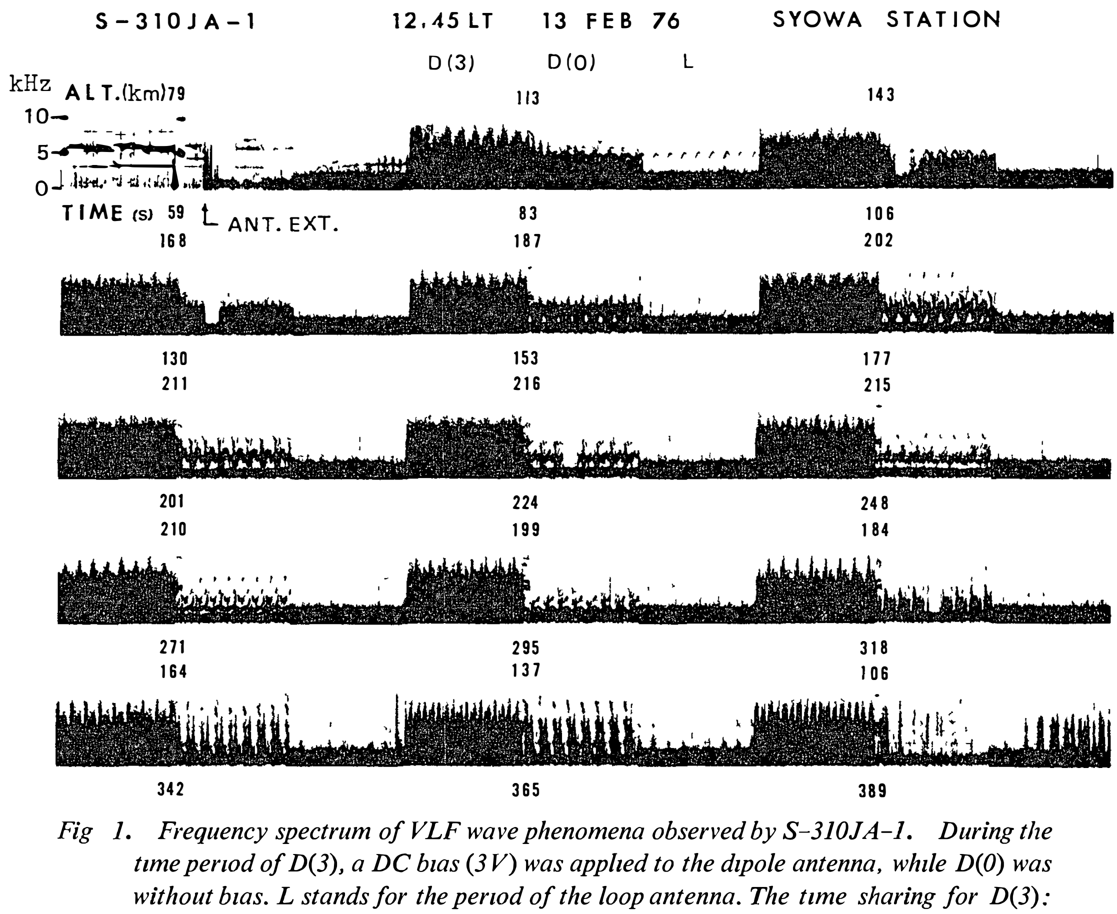


Fig 1. Frequency spectrum of VLF wave phenomena observed by S-310JA-1. During the time period of D(3), a DC bias (3 V) was applied to the dipole antenna, while D(0) was without bias. L stands for the period of the loop antenna. The time sharing for D(3): D(0): L was 8 8 · 8 seconds respectively (for details refer to the paper by KIMURA *et al, 1978).*

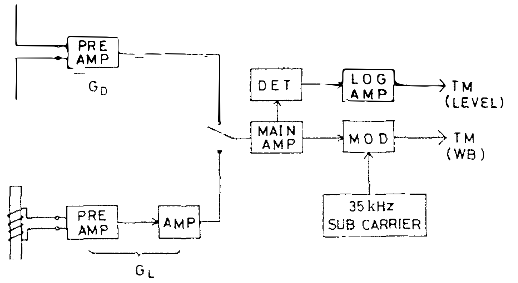


Fig 2 Block diagram of the VLF wide-band receiver (PWL) on board S-310JA-1

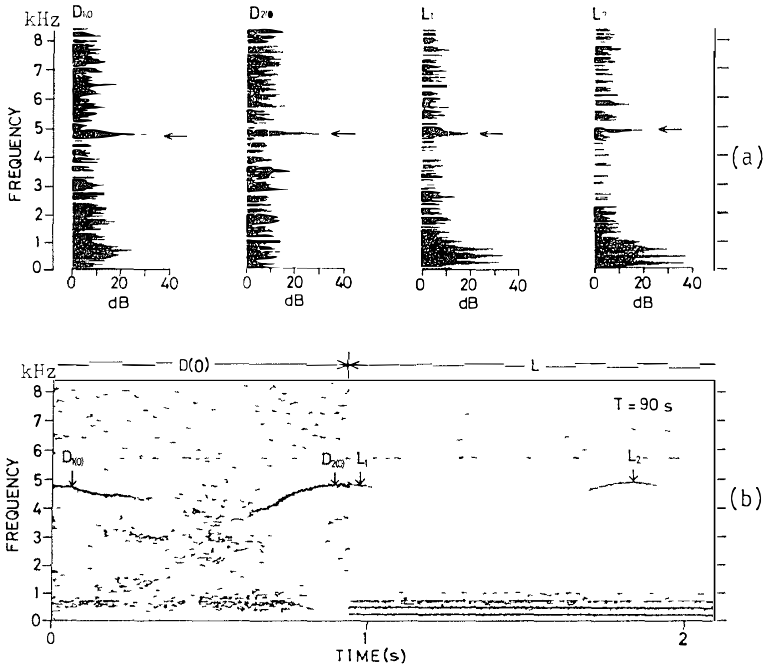


Fig 3 A typical dynamic spectrum, so-called sonagram, including inverse U-shaped emissions (a) shows the sonagraph section of (b)

The rocket reached an altitude of 215.6 km 226 s after launch, and during the flight electrostatic wave phenomena as well as electromagnetic wave phenomena such as "chorus" were observed in the ionosphere (KIMURA *et al*, 1978) This paper concerns with the electrostatic ones, especially "inverse U-shaped emissions" on spectrum as shown in Fig 3, which correspond to the discrete emissions clearly seen in Fig 1 for the 'L' period from $t=91$ to 99 s These emissions have the following features

1) The inverse U-shaped spectra appeared once in a spin period of the rocket, and the frequency of the spectra around 5 kHz was spin modulated

2) This type of emission was observed not only by the dipole with DC bias (denoted hereafter by D(3)) and without bias (D(0)), but also by the loop antenna (L) The signal level at the inlet of the preamplifiers after the sensors was a few to 10 dB higher for L than for D(0) and D(3) as shown in Fig 4, where the gain difference for the

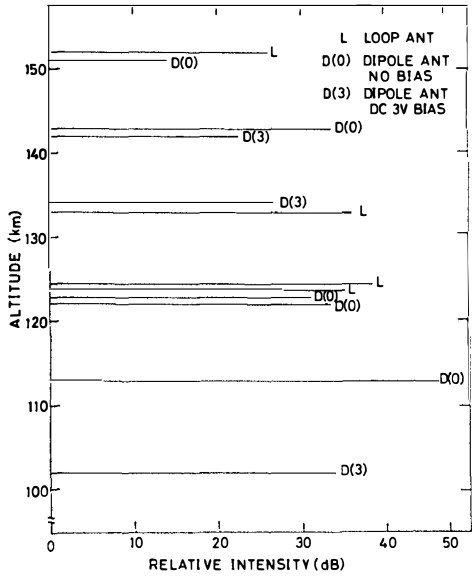


Fig 4. Signal intensity of the inverse U-shaped emissions at the outputs of the loop and dipole antennas themselves

both channels was taken into account.

3) These emissions disappeared when a Langmuir probe and a fixed biased probe were switched off, which were used for measurements of electron density and temperature (such an effect is seen in Fig 1 at t=107, 133, 226, 322 s). These two probes were both a 20 cm long whip, and 0–4 volt sweep voltage and 6 volt fixed voltage were applied to LP (Langmuir P.) and EP (fixed biased P.) respectively when they were switched on.

3. Characteristics of a Loop and a Dipole Antenna for the Observed Plasma Waves

From the fact that this phenomenon is strongly associated with DC bias on the LP and EP and is spin modulated, it can be concluded that this is not an electromagnetic wave phenomenon. If the emission is electrostatic, we understand that while the emission was detected by the loop antenna, it must be detected by the whip antenna effect of the loop antenna. By a later measurement, the effective length of the whip antenna effect of the same core loop antenna was found to be about 3–5 mm that was deduced from the directivity characteristics of the loop antenna as shown in Fig. 5 for a distant known signal on the ground. Then the effective length of the dipole antenna must be of the order of 1–a few mm because of the above-mentioned fact 2).

This result is unreasonable if the signal is an electromagnetic wave, because the dipole antenna length is 2.8 m tip to tip. In the following we discuss whether or not the above result is conceivable. From the observational fact 3) previously mentioned, the inverse U emissions could be an electrostatic wave generated by a current-driven instability which was caused by 6 V DC bias to EP. Possible modes for the electrostatic waves are ion acoustic mode and electrostatic ion cyclotron modes, both of which are

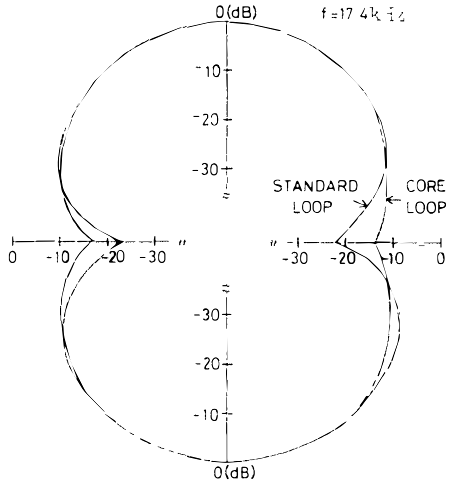


Fig. 5. Characteristics of '8'-shaped directivity of the core loop antenna compared with a standard antenna.

known to show almost the same dispersion characteristics.

From the simultaneous measurements of electron density N_e and temperature T_e by LP and EP (OGAWA *et al.*, 1978), N_e was $\sim 10^5$ cm^{-3} being almost constant and T_e was from 800 to 2000 K, almost linearly increasing with altitude above an altitude of 120 km. If the effective ion mass M_i is assumed to be 31 (equal number density of O_2^+ and NO^+), the ion sound velocity V_s determined by $\sqrt{\kappa T_e/M_i}$ lies between 460–730 m/s for the observed T_e as mentioned above, where κ is the Boltzman constant. Then from the dispersion relation of the ion acoustic wave, $\omega = kV_s$ (ω; wave angular frequency, k; wave number), the wave length λ $(=2\pi/k)$ for $f\,(=\omega/2\pi)=5$ kHz must lie between 9 and 15 cm, if a Doppler frequency shift due to the rocket velocity is not taken into account. However, the rocket velocity in an altitude range from 120 to 150 km was in the range of 1.46–1.25 km/s, so that the frequency f_{obs} to be observed by the rocket must be Doppler shifted from the original source frequency f_s, as

$$f_{obs} = f_s\{1 \pm (V_R/V_s)\cos\sigma\}$$

σ in this formula is the angle between the rocket velocity vector V_R and wave propagation vector $\boldsymbol{k}$.

As we have not known the location of the source, σ can not be estimated. Therefore, we estimate a possible range of the Doppler frequency shift by assuming $\sigma=0$. If f_{obs} is around 5 kHz as observed, the source frequency f_s at h=150 km for example must be in the vicinity of 1.57 and 4.24 kHz, where $V_R/V_s=2.18$. In such cases the wave length λ $(=V_s/f_s)=0.37$ or 0.14 m.

4. Effective Length of a Dipole Antenna for Plasma Waves in a Magneto-Plasma

In order to calculate the effective length of the 2.8 m dipole antenna for an ion acoustic wave with $\lambda \sim 0.1$ m, the transmission line theory (ADACHI *et al.*, 1977) is adopted as a rough approximation. A dipole antenna of a radius ρ and a length $2l$ is considered to make an angle ϕ with the external magnetic field $\boldsymbol{B}_0$ (see a configulation inside Fig. 6 a).

A plasma wave is incident to the antenna in such a way that the $\boldsymbol{k}$ vector (and therefore E field) is assumed to make an angle θ with the antenna and that the $\boldsymbol{k}$, $\boldsymbol{B}_0$ and the antenna lie on the same plane. The effective length l_{eff} of the antenna for this plasma wave is then represented by

$$l_{eff}=\frac{\cos(kl\cos\theta)-1}{k^2\cos\theta}\,2k_a\frac{Z_L}{Z_o} \tag{1}$$

where Z_L is the terminal impedance of preamplifier connected to the antenna, and k_a and Z_o are the propagation constant and characteristic impedance respectively, of the antenna as a transmission line in a magneto-plasma, given by

$$k_a=\frac{\omega}{c}(K'K)^{1/4} \tag{2}$$

$$Z_o\sim\frac{1}{\pi}\left(\frac{\mu_0}{\varepsilon_0}\right)^{1/2}\frac{\ln l/\rho}{(K'K)^{1/4}} \tag{3}$$

$$K=K_0\sin^2\phi+K'\cos^2\phi\,. \tag{4}$$

K_0 and K' in the above are elements of the specific plasma dielectric tensor

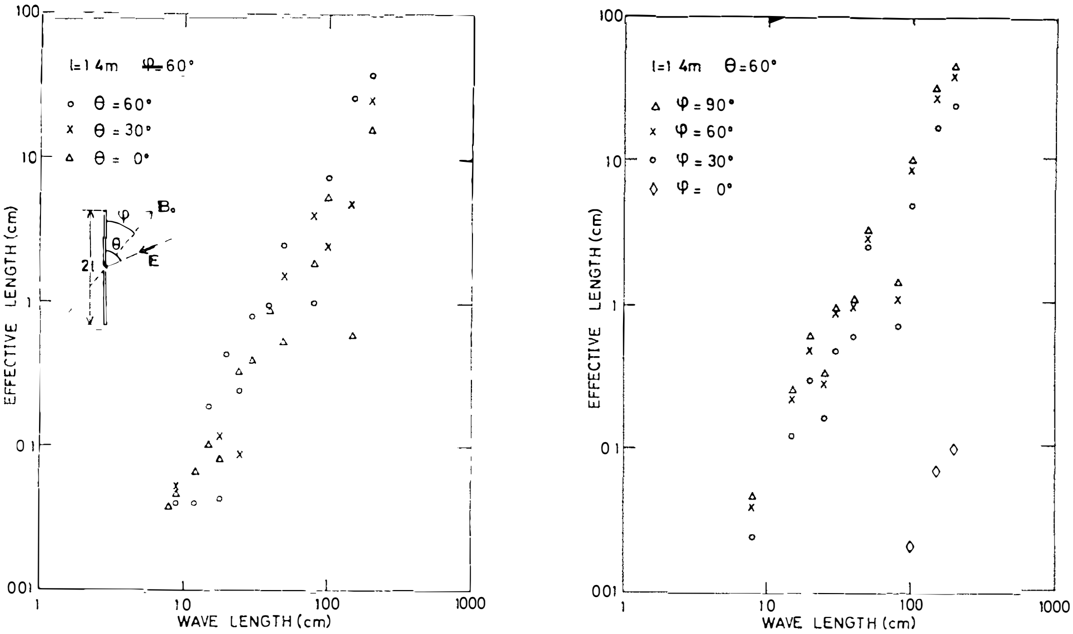
$$\begin{pmatrix} K' & jK'' & 0 \\ -jK'' & K' & 0 \\ 0 & 0 & K_0 \end{pmatrix}$$

namely

$$\left.\begin{aligned} K'&=1-\frac{\omega_{pe}^2}{\omega^2-\omega_{ce}^2}-\frac{\omega_{pi}^2}{\omega^2-\omega_{ci}^2} \\ K''&=\frac{\omega_{ce}\omega_{pe}^2}{\omega(\omega^2-\omega_{ce}^2)}-\frac{\omega_{ci}\omega_{pi}^2}{\omega(\omega^2-\omega_{ci}^2)} \\ K_0&=1-\frac{\omega_{pe}^2}{\omega^2}-\frac{\omega_{pi}^2}{\omega^2} \end{aligned}\right\} \tag{5}$$

where ω_{pe} and ω_{pi} are the electron and ion plasma frequency, and ω_{ce} and ω_{ci} are the electron and ion cyclotron frequency respectively.

l_{eff} determined by eq. (1) is calculated for $l=1.4$ m and $\rho=0.75$ cm and for the electron plasma frequency of 2.85 MHz, and the cyclotron frequency of 1.57 MHz with the effect of ions being included. In Figs. 6 (a) and (b) is shown the calculated l_{eff} for $Z_L=5.7$ kΩ for $\phi=60°$ with θ as a parameter and for $\theta=60°$ with ϕ as a parameter.



a. $\phi=60°$ *b.* $\theta=60°$

Fig. 6. Effective length of a dipole versus the waves length of plasma waves for Z_L *of 5.7 kΩ.*

From the figures it is found that l_{eff} is of the order of 1 mm for the wave length of plasma wave being ten to several tens cm for a wide variety of the parameters of θ and ϕ. This result agrees well with the observed fact, although the above l_{eff} calculated might be very rough for a large number of l/λ such as those greater than 10.

5. Discussion and Conclusion

Inverse U-shaped emissions observed by the S-310JA-1 rocket have been carefully analyzed. From several characteristics of the emissions, it is concluded that they might be an electrostatic phenomenon, more concretely an ion acoustic wave or electrostatic ion cyclotron wave phenomenon. According to our recent laboratory experiments (TSUTSUI *et al.*, 1979), a similar wave phenomenon was observed when a possitive DC bias was applied to a spherical probe, which has shown some evidence that it was an electrostatic ion cyclotron wave generated by a current driven instability. The mechanism of the frequency variation of the inverse U-shape which was synchronous with the rocket spin is not clearly interpreted but may be ascribed to the Doppler effect that was mentioned in Section 2.

Even though the effect of Doppler shift is taken into account, the wave length of the phenomenon is of the order of ten to several tens cm. It is, then, experimentally and theoretically ascertained that this plasma wave could be effectively observed with the core loop antenna by the whip antenna effect than by the dipole antenna whose length was much larger than the wave length of the ion acoustic wave.

As to the spin-modulated wide band noise also observed by the same rocket, which was observed only by the dipole antenna as seen in Fig. 1 can not be explained by the above ion acoustic wave model. It may be generated by another mechanism such as shock waves produced by the rocket itself.

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