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ESTIMATION OF IMPEDANCE OF WIRE ANTENNAS ONBOARD THE AKEBONO SATELLITE

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1. INTRODUCTION

Knowledge of the characteristics of wire antennas used as sensors for electric field observations by scientific satellites in geospace is necessary to determine the absolute intensity of the electric field. Two important characteristics are the effective length and the antenna impedance. Determination of the impedance can be especially difficult since the impedance depends on the medium surrounding the antenna, and the impedance is affected primarily by the plasma sheath created around the antenna.

The effective length of the 200 m tip-to-tip double probe antenna onboard the DE 1 satellite was estimated by *Sonwalker and Inan*[1], using observed whistler-mode wave data, to be 222±56 m. We have estimated the effective lengths of antennas for the electric field observations onboard the GEOTAIL and Akebono satellites[2][3]. The results for the two types of antennas onboard GEOTAIL (the long-wire antenna WANT and the double-probe antenna PANT) were nearly equal to the effective length in free space. However, we could see small differences in the effective length between the two types of antennas and their fluctuations depended on the the angle between the antenna and the sun which varied due to the satellite spin[2]. The effective lengths of the two long-wire antennas similar to WANT onboard Akebono were also nearly equal to that in free space. However, we could see a small variation depending on the angle between the antenna direction and the geomagnetic field. In our antenna study, we calculated the effective length from the ratio of the open voltage induced at the antenna terminal and the electric field theoretically calculated from Maxwell's equations using the observed plasma density and geomagnetic field.

The impedance of the antennas onboard GEOTAIL was measured by *Tsutsui et al.*[4] by using the calibration function onboard GEOTAIL where a modulated square wave test signal was applied to the antenna elements. They found that the impedance depended mainly on the electron density and the satellite spin. The impedance onboard Akebono was measured by *Hashimoto et al.*[5], where the results also depended on the electron density and the satellite spin.

For the GEOTAIL case, the dependences of the effective length and the impedance measurement on the satellite spin are caused by the fluctuation of the photoelectron emissions from the antenna surfaces. On the other hand, for the Akebono case, the photoelectrons do not play an important role in the effective length estimation and the impedance measurement, because the spin axis of Akebono always points to the sun.

In this paper, we estimate the impedance of the two wire antennas onboard Akebono, and show its dependence on the angle between the antennas and the geomagnetic field.

2. ANTENNA IMPEDANCE ESTIMATION

Figure 1 shows the sensors onboard Akebono and their coordinate systems. WAT is composed of four wire antenna elements whose lengths are 30 m each. WAT-1 and WAT-2 operate as a dipole antenna (60 m tip-to-tip), and WAT-3 and WAT-4 also operate similarly. The two dipole antennas are crossed and placed in the spacecraft X-Y plane. The antenna x-y coordinate system is in the spacecraft X-Y plane, but it is rotated 35°. The dipole antennas sense the two components of electric field as E_x and E_y. Akebono has an 8 second spin period, and the spin axis is Z and always pointing to the sun. The Poynting flux analyzers (PFX) onboard Akebono observe two components of the electric field and three components of the magnetic field simultaneously by using the above two dipole

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antennas for the electric field and three orthogonal open loop antennas and three orthogonal search coils for the magnetic field.

From Maxwell's equations and the cold plasma dispersion relation, the electric field is expressed by

$$\boldsymbol{E} = -cn\boldsymbol{\epsilon}_r{}^{-1}(\boldsymbol{u}_k \times \boldsymbol{B}). \tag{1}$$

Here $\boldsymbol{E}$ is electric field vector, c is the speed of light in free space, n is the refractive index, $\boldsymbol{\epsilon}_r$ is the dielectric tensor, $\boldsymbol{u}_k$ is the unit vector for the propagation vector $\boldsymbol{k}$, and $\boldsymbol{B}$ is the magnetic field vector. From this equation, the electric field can be theoretically calculated by using the electron density, the geomagnetic field and the magnetic field of the plasma wave. Here, $\boldsymbol{u}_k$ is calculated by Means' method[6] by assuming that $\boldsymbol{u}_k$ is normal to the wave magnetic field plane.

Figure 2 shows the equivalent circuit of the wire antenna and the pre-amplifier onboard Akebono. In this figure, $V = E{\cdot}l_e$ is the open voltage induced at the antenna terminal when the antenna observes the electric field E and l_e is the effective length of the wire antenna. Z_a is the antenna impedance which is assumed to be a parallel circuit with capacitance C_a and resistance R_a. $Z_{in} = 1/j\omega C_{in}$ is the input impedance of the pre-amplifier including the wire. Pre-launch measurements found $C_{in} = 100$ pF. From Figure 2, the expression showing the relation among these parameters is

$$Z_a = \frac{Z_{in}}{V_{in}}\left(El_e - V_{in}\right). \tag{2}$$

From this relation, the antenna impedance Z_a is obtained by using the input voltage to the pre-amplifier V_{in} and the theoretical electric field from equation (1) when the plasma wave is observed by Akebono. The observed data of V_{in} and $\boldsymbol{B}$ are transformed to the complex time series signal by using the analytic signal method[7], so that the antenna impedance Z_a is obtained as complex values. The effective length l_e is assumed to be 30 m, half of the total length of the antenna. Because the antenna impedance Z_a can be expressed as a parallel circuit with capacitance C_a and resistance R_a, their values are given by

$$\begin{cases} R_a = \dfrac{\mathrm{Re}(Z_a)^2 + \mathrm{Im}(Z_a)^2}{\mathrm{Re}(Z_a)} \\[2ex] C_a = -\dfrac{\mathrm{Im}(Z_a)}{\omega\left[\mathrm{Re}(Z_a)^2 + \mathrm{Im}(Z_a)^2\right]} \end{cases} \tag{3}$$

where $\mathrm{Re}(Z_a)$ and $\mathrm{Im}(Z_a)$ are the real and imaginary parts of the antenna impedance Z_a, respectively.

3. RESULTS AND DISCUSSION

We used the Omega signal (10.2 kHz) observations on August 3, 1990, and February 1, 1994, to estimate the antenna impedance. Figures 3 and 4 show the estimation results of capacitance C_a (upper panels) and of resistance R_a (lower panels), where the horizontal axis is ϕ_x or ϕ_y which is the angle between the geomagnetic field and the antenna direction x or y, respectively. On August 3, 1990, (7:35∼7:49 UT), the altitude of Akebono was about 9500 km, the electron density was $N_e \simeq 2 \times 10^3$ cm^{-3}, and the electron cyclotron frequency was $f_c \simeq 60$ kHz. On February 1, 1994, (0:16∼0:21 UT), the altitude was about 300 km, $N_e \simeq 3 \times 10^5$ cm^{-3}, and $f_c \simeq 100$ kHz. The plots in these figures have been averaged over 0.3 sec., when Akebono was observing Omega signals normally. The calculated results of C_a on August 3, 1990, have weak dependence on ϕ_x or ϕ_y, while the results of R_a have almost no dependence. The result of C_a on February 1, 1994, has strong dependence on ϕ_x or ϕ_y, while the results of R_a are similar to the former case. The measurement results by *Hashimoto et al.*[5], shown in Table 1, are in good agreement with our estimation of C_a, and are in roughly good agreement with our estimation of R_a.

The estimation results of the capacitance depend on the angle between the antenna direction and the geomagnetic field. *Hashimoto et al.*[5] reported the impedance fluctuation due to the satellite spin, so it is possible that the impedance is affected by anisotropic magnetized plasma without any change of the photoelectron emissions because two antennas onboard Akebono are placed on the spin plane, and the spin axis always point to the sun. The theoretical model of the antenna capacitance

Table 1: The capacitance and the resistance measured by *Hashimoto et al.*[5]

Altitude	400~800 km	8000~9000 km
N_e	$3 \sim 5 \times 10^4$ cm^{-3}	$\sim 10^3$ cm^{-3}
C_a	$300 \sim 350$ pF	$230 \sim 250$ pF
R_a	$250 \sim 330$ kΩ	$300 \sim 500$ kΩ

C_a in the plasma is known as a coaxial capacitance model, and C_a is given by

$$C_a = \frac{2\pi\epsilon_0 l}{\ln\left[(\lambda + a)/a\right]} \tag{4}$$

where ϵ_0 is permittivity of free space, l is the length of an antenna element, λ is sheath thickness, and a is the radius of an antenna element. In fact the electron density in the sheath region is distributed from the antenna surface out to the order of several Debye lengths, so the medium in this region should be treated as an anisotropic medium which therefore requires the constant ϵ_0 to be replaced by the dielectric tensor for analysis. The Debye length could also be affected by the geomagnetic field.

4. SUMMARY

We have estimated the antenna impedance onboard the Akebono satellite by using the electric field theoretically calculated from the wave magnetic field, the electron density and the geomagnetic field, and the input voltage to the pre-amplifier when Omega signals were observed by the Akebono satellite. The estimation results of the capacitance are in good agreement with the measurement results, and the resistance roughly agrees with the measurement results. It is especially satisfying that the capacitance depends on the angle between the antenna direction and the geomagnetic field, both theoretically and observationally.

In the future, we will consider improving the theoretical model by including the electron density distribution in the sheath region from the antenna surface out to the order of several Debye lengths as well as including the influence of the geomagnetic field on the Debye length.

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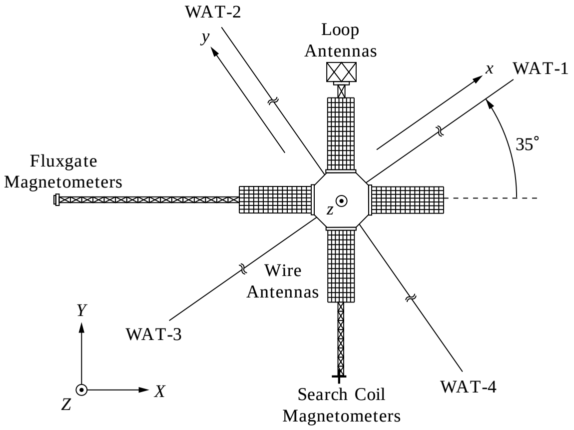

Figure 1: The sensors onboard the Akebono satellite and the coordinate systems.

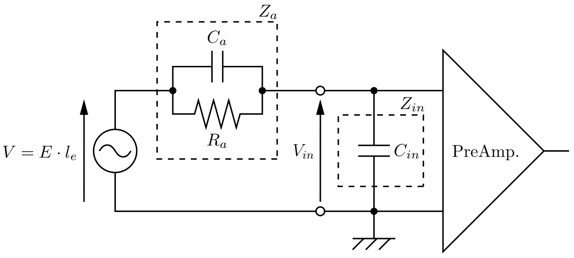

Figure 2: The equivalent circuit of a wire antenna and pre-amplifier onboard the Akeobno satellite.

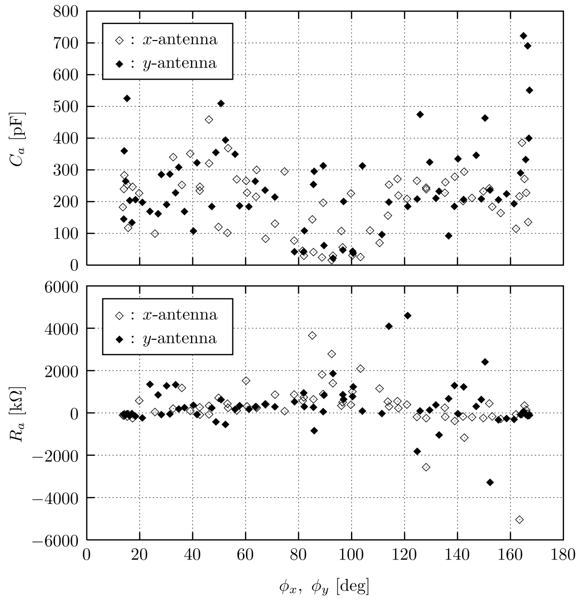

Figure 3: The estimation results of the capacitance C_a (top) and the resistance R_a (bottom) on August 3, 1990 (7:35~7:49 UT).

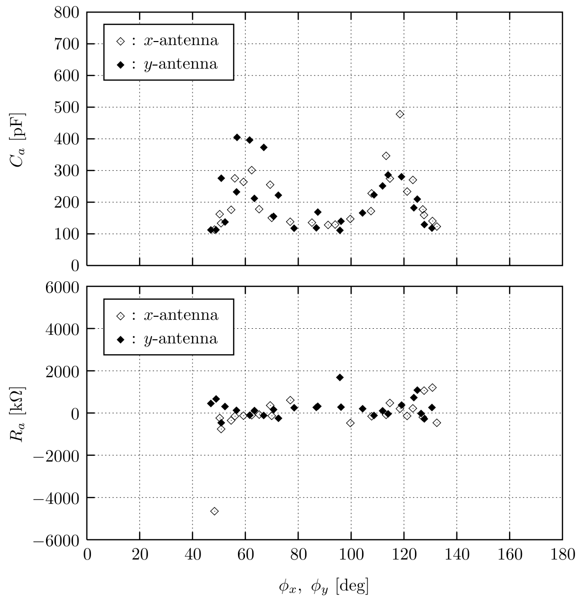

Figure 4: The estimation results of the capacitance C_a (top) and the resistance R_a (bottom) on February 1, 1994 (0:16~0:21 UT).