Effective lengths of the dipole antennas aboard GEOTAIL spacecraft

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1. Introduction

The plasma wave instrument (PWI) aboard the GEOTAIL spacecraft has been observing various kinds of plasma waves around the Earth. Two components of electric fields and three components of magnetic fields are measured by the PWI with two sets of dipole antennas and a tri-axial search coil. Accurately calibrating amplitudes and phases of electromagnetic fields observed by these sensors is very important to know propagation characteristics as well as to discuss generation mechanisms of the plasma waves. The calibration of the observed magnetic fields is relatively easy because we know exact frequency response of the search coil and of its electronics.

However, the calibration of the observed electric field is rather complicated. The absolute value of the electric field at each dipole antenna in plasma is calculated from an induced voltage at the base of the antenna, which becomes a function of an "antenna impedance"[1], which is caused by a plasma sheath created around the antenna, and of its effective length. GEOTAIL has two sets of dipole antennas, each with the tip-to-tip length of 100 m: One is a wire dipole antenna (wire antenna: WANT), and the other a wire dipole with a sphere probe attached on the tip of it (probe antenna: PANT), as shown in Figure 1. The PWI can measure the antenna impedance in situ in space plasmas. However, the antenna effective lengths have been assumed just simply as 50 m, half of their tip-to-tip lengths (the effective length for an infinitesimal dipole), and no attempt has been made so far to modify it. According to past studies, however, the antenna effective length of a dipole antenna aboard satellite seems longer than a half of its tip-to-tip length[2].

In this study we try to estimate accurate effective lengths of the dipole antennas aboard GEOTAIL. To estimate the effective lengths, we use the wave form data of chorus emissions[3]. Since a chorus emission is an electromagnetic wave whose electric and magnetic field polarization and propagation direction are well described by well-known cold plasma dispersion, we can calculate theoretical wave electric field components from the observed wave magnetic field components. Comparing those with the actually observed wave electric fields, we can evaluate the effective lengths of the antennas.

2. Analysis Method

The wave form capture (WFC) of the PWI aboard GEOTAIL can observe simultaneously wave forms of two electric and three magnetic components in the frequency range between 10 Hz and 4 kHz.

By using the calibrated wave magnetic fields $\boldsymbol{B}$ observed by the WFC, we can theoretically estimate the wave electric fields $\boldsymbol{E}$ by the Maxwell's equation for a plane wave propagating in plasma, as follows,

$$\boldsymbol{E} = -cn\tilde{\boldsymbol{\kappa}}^{-1}(\boldsymbol{u}_k \times \boldsymbol{B}) \tag{1}$$

where c is the light speed, $\tilde{\boldsymbol{\kappa}}$ means the dielectric tensor of a cold plasma, and $\boldsymbol{u}_k$ is a unit vector in the k-vector direction of the wave.

When the wave has a circular polarization, $\boldsymbol{u}_k$ can be calculated from the wave magnetic field, because the k-vector is always perpendicular to the polarization plane of the magnetic field. The refractive index n can be calculated from the equation of cold plasma dispersion (Appleton-Hartree's equation), which is a function of the wave frequency, the electron plasma frequency (f_p), the electron cyclotron frequency (f_H), and the angle between the k-vector and the geomagnetic field line (θ_{kB}).

Thus, when GEOTAIL observes chorus emissions, we have two kinds of electric field values: 1) the actually observed electric fields by the dipole antennas (E_{ob}), WANT and PANT, with their effective lengths assumed and with the measured antenna impedance used, and 2) the electric fields calculated theoretically from the observed magnetic fields (E_{th}).

The voltage at the base of each antenna (V) is given in terms of the assumed effective length (h_{asm}=50 m for GEOTAIL), the actual effective length (h_{act}), E_{ob}, and E_{th},

$$V = E_{ob} \cdot h_{asm} = E_{th} \cdot h_{act} \tag{2}$$

then h_{act} can be calculated as

$$h_{act} = \frac{E_{ob}}{E_{th}} h_{asm} = \alpha \cdot h_{asm}, \qquad \alpha \equiv \frac{E_{ob}}{E_{th}} \tag{3}$$

Since values of α are independently obtained for WANT and PANT, we can estimate the effective lengths of both antennas.

3. Analysis and Discussion

In order to evaluate the antenna effective lengths, we use wave form data of chorus emissions observed by the WFC in the dayside outer magnetosphere. Continuous 8.7-sec wave forms of five electromagnetic fields are short-time-Fourier-analyzed to give their frequency-time (f-t) structures (dynamic spectra). Since a chorus emission can be considered as a single plane electromagnetic wave propagating in the whistler mode[3], the electromagnetic fields at each f-t element of the emissions should be described by the cold plasma dispersion. Therefore we can evaluate the antenna effective lengths at each f-t component. On the other hand, in our analysis the plasma frequency f_p can be estimated from the electric static potential of the spacecraft observed by the EFD team[4], and the electron cyclotron frequency f_H is from the observed geomagnetic field data given by the MGF team[5].

Figure 2 shows an example of time variation of the effective lengths obtained by using the chorus emissions observed at 19:43:28 UT on August 25, 1993 in the dayside outer magnetosphere with the plasma frequency $f_p \sim$38.3 kHz. Figure 2(a) is for WANT, and 2(b) is for PANT. The horizontal and vertical axes are time and $|\alpha|$ in eq. (4), respectively. The vertical dashed lines in each figure indicate the timings when each dipole antenna points sunward. Each "+" mark represents $|\alpha|$ obtained for each f-t component of the emissions. In Figure 3 they are averaged over frequency at each time. Though the values of $|\alpha|$ fluctuate with time for both WANT and PANT, on the average they are close to unity, corresponding to their effective lengths of 50 m, just as assumed so far.

In Figures 2 and 3 we have calculated E_{ob} using the antenna impedance measured on April 29, 1993 (shown in Table 1) also in the dayside outer magnetosphere with the similar plasma frequency of 30 kHz. The antenna impedance is approximately described as a parallel circuit with a resistance and a capacitance, which depend on the electron density (so the plasma frequency)[1]. The temporal fluctuations in $|\alpha|$ seem to be correlated with the spin period of the spacecraft (3 seconds). In Figure 2 the values of $|\alpha|$ for each dipole antenna become largest when it points toward the sun. This would be caused by a periodic change in photo emissions from the spinning antennas, which would alter the electron density in the antenna sheath as well as the antenna impedances.

Such a change in $|\alpha|$ is clearly seen in Figure 4. Figure 4 shows the estimated $|\alpha|$ for the chorus emissions observed in the same region (the dayside outer magnetosphere) but with different plasma frequencies. Here for all of the cases the antenna impedance measured on April 29, 1993, with $f_p \sim 30kHz$ (see Table 1), are used to obtain E_{ob}. The lower plasma frequency (the lower electron density) corresponds to the higher antenna impedance[1], so that the antenna output voltage becomes lower, and E_{ob} as well as $|\alpha|$ becomes small. For the plasma frequencies above 30 kHz, $|\alpha|$ becomes almost unity since the ambient plasma condition approaches to the one when the antenna impedance was measured. Therefore, to calculate reliable effective lengths we must use the antenna impedance, which is measured with the plasma frequency close to the value when the chorus emissions are observed.

On the other hand, these results show that the effective length of PANT is a little longer than that of WANT, possibly caused by the effect of the spheres attached at the tip of PANT.

4. Conclusion

We have analyzed the effective lengths of the two sets of dipole antennas aboard the GEOTAIL spacecraft. Calculated results suggest that the estimated effective lengths for both WANT and PANT are most likely to be about 50 m, a half of their tip-to-tip lengths, as assumed in the past studies. However, the estimation seems sensitive to the antenna impedance, which changes greatly with the antenna spinning and with the ambient electron plasma frequency so that we have to use the "correct" antenna impedance to evaluate the accurate effective lengths. Conversely, this would suggest a possibility that our calculation method can be applied to evaluate the antenna impedance in more detail.

In the future we will analyze the effective lengths in more detail by comparing them with the antenna impedance. We will also analyze the effective lengths of dipole antennas aboard the Akebono satellite.

References

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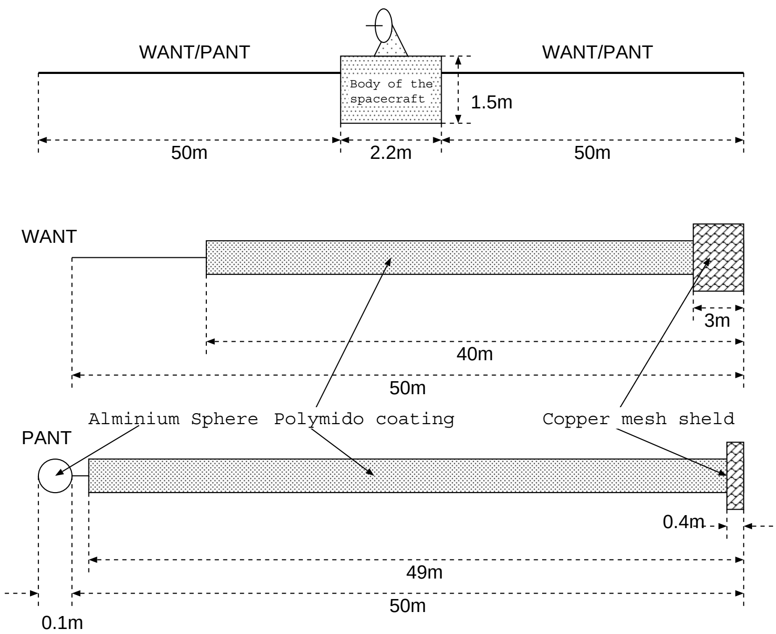
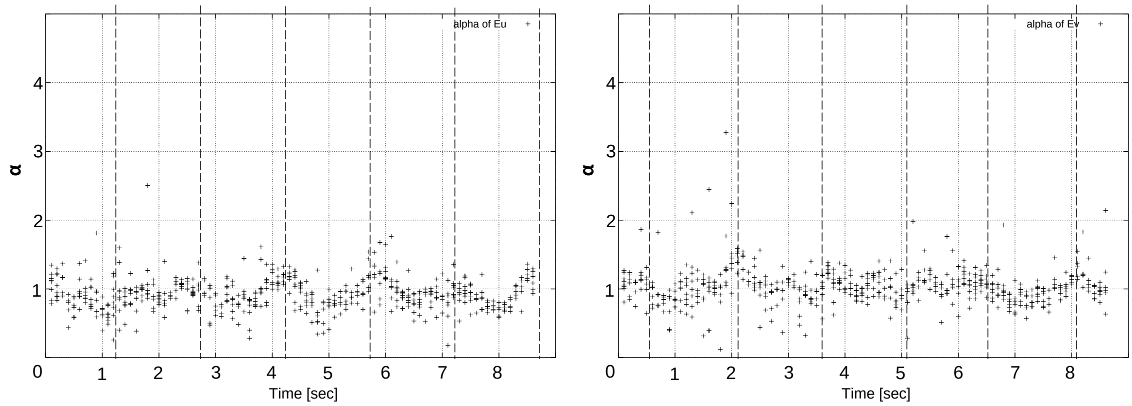


Figure 1: Electric dipole antennas aboard GEOTAIL spacecraft



(a) (b)

Figure 2: $|\alpha|$ of (a)WANT and (b)PANT on 19:43:28 UT, August 25, 1993
Dash lines show the timing when the antenna points sunward.

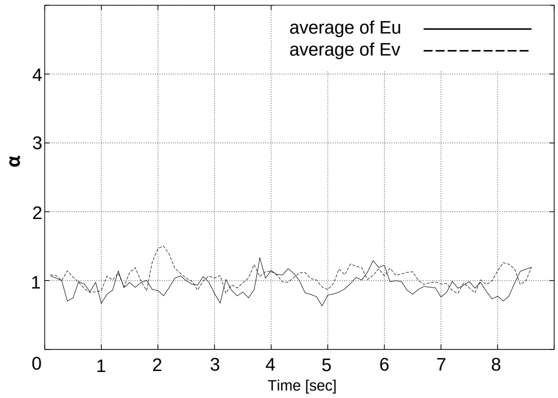


Figure 3: Average of $|\alpha|$ on each time for Figure 2
In this case their averages are 0.93(WANT) and 1.05(PANT).

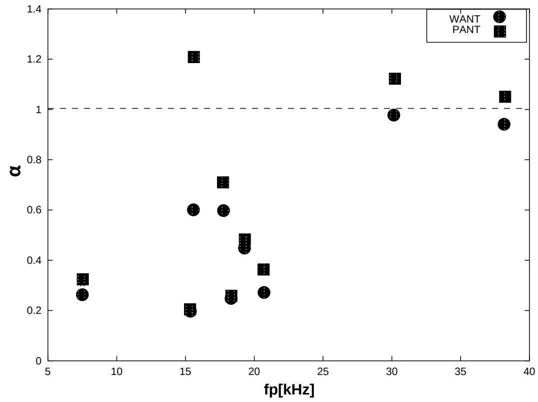


Figure 4: Relationship between α and f_p.
The antenna impedance used for this calculation was measured with f_p ~30 kHz.

Table 1: Antenna impedance measured on April 29, 1993

	Resistance	Capacitance
WANT	14.7 MΩ	318.0 pF
PANT	8.6 MΩ	296.0 pF