Computer Experiments on Electric Antenna Characteristics in Space Plasma Environment

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An electric antenna commonly occupies an essential part in plasma wave instruments onboard scientific spacecraft. Though principles of electric antenna measurements are fundamental, antenna behavior, modified under the influence of surrounding plasmas, is often problematic, because it could disturb reliable measurements of an electric field component of plasma waves. Then, strong demands arise regarding a better understanding of antenna characteristics in space plasma environment. However, the antenna behavior in plasmas is often too formidable to evaluate quantitatively by means of theoretical approaches because of complex antenna--plasma interactions. Therefore, we must establish a numerical approach for the self-consistent analysis of antenna characteristics in space plasmas.

For the self-consistent numerical analysis of antenna--plasma interactions, we construct a numerical simulation code based on an electromagnetic Particle-In-Cell description of the plasmas [4]. The code can include inner boundaries corresponding to perfect conducing surfaces of an antenna and a spacecraft. At the boundaries, as well as perfect conducting conditions required for electromagnetic fields, we also introduce numerical treatments for the charge and current densities computed from plasma particles interacting with the boundaries. These treatments are necessary for accurate descriptions of the charge accumulation exactly on conducing surfaces and its redistribution to realize a floating equi-potential over the surfaces. By using the constructed code, we perform two basic tests regarding plasma environment around a conducting body. One is the plasma sheath formation as a result of the spacecraft charging. The other is the dispersion relation of a sheath wave, which is a peculiar electromagnetic-wave mode propagating only in an electron-sparse sheath. For both tests, the reproduced environments show a good agreement with results obtained by previous well-proven theories.

Using the code, we begin the antenna analysis in plasmas with a simple situation. First, we apply the code to the impedance calculation in a homogeneous plasma environment and compare the result with the conventional kinetic theory. We correctly confirmed characteristic impedance changes such as an impedance resonance and a finite resistance below the plasma frequency by the computer experiment. Next, we examined the impedance of an antenna surrounded by an ion sheath that is created simultaneously with the antenna charging. We found that the sheath mainly influences reactance values below the electron plasma frequency, which is consistent with empirical knowledge that the ion sheath functions as a capacitance in the low-frequency range. Meanwhile, when we expand the sheath thickness artificially by biasing the antenna potential negatively, it is found that the sheath capacitance less contributes to the total antenna impedance. The trend indicates that the antenna reactance recovers its free-space value in the limit of large sheath dimensions, which corresponds to dilute and hot plasma environment as in the outer magnetosphere of the Earth [1].

As more realistic situations in space plasmas, we focus on effects of the photoelectron emission from sunlit surfaces of an antenna and a spacecraft. To illustrate the photoelectron effects, we perform computer experiments of the electron emission from inner boundaries corresponding to sunlit conducting surfaces. The emitted electrons have higher density but lower temperature than the plasma electrons. We confirmed the positive charging of the antenna and spacecraft bodies, and the formation of an electron-rich region in the vicinity of the sunlit surfaces. It is revealed from impedance calculation that the dense photoelectrons enhance the real part, and decrease the absolute value of the imaginary part, of antenna impedance at low frequencies. The antenna impedance in the photoelectron environment is represented by a parallel equivalent circuit consisting of a capacitance and a resistance. We also show that the above resistance can be well estimated semi-analytically using the numerical results of the electron currents flowing into and out

of the antenna. This suggests that the impedance change is caused by the conduction current induced by the actual motion of photoelectrons contacting with the antenna surfaces [2]. The results also imply that the impedance varies with the spin of the spacecraft, which causes the variation of the photoelectron density around the antenna.

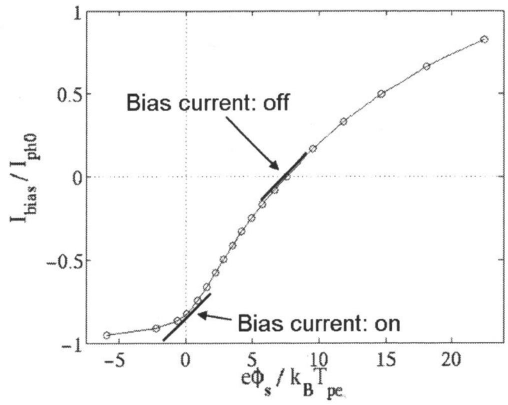

Figure 1. The voltage-current characteristic curve obtained by changing the magnitude of the bias current. The zero potential corresponds to the background space potential.

Finally, we introduce a numerical technique for the direct analysis of receiving antenna behavior and also develop a new model of modern electric antennas toward future satellite missions. In the new analysis technique, we set up wave fields propagating in a computational space and simulate the process of wave reception by the antenna. By using the technique, we examined the effective length of a probe-like antenna, which has a configuration such that sensing wire elements are attached at both ends of a center boom conductor. For this type of the antenna, the effective length becomes shorter than the physical separation between the centers of two sensing elements. It is found that this effect is caused by the distortion of equi-potential surfaces due to the presence of the center boom conductor [3]. We next introduce numerical models of guard electrode and current biasing, which are planned to be installed on future electric field instruments. We performed computer experiments by using the standard setting of electrode potentials, the values of which are not optimized but determined empirically. We found that the guard electrode decreases the photoelectron-current coupling of the sensor conductor with the boom and spacecraft bodies. The effect suggests that the electrode can reduce the influence of large amount of photoelectrons emitted by the spacecraft body on electric field measurements. On the other hand, the bias current draws the sensor potential close to the background plasma potential. The electrode and the current biasing have a small effect on antenna behavior for oscillating fields created by external plasma waves, compared with their significant impacts on the static plasma environment. This result is understood from the voltage--current characteristic curve of the sensor shown in Figure 1, the gradient of which indicates the inverse of the dynamic resistance of the sensor for the oscillating fields. The observed voltage--current curve is considerably deformed by the effect of the photoelectron current coupling even though it is decreased by the operation of the guard electrode. The result emphasizes the significance of more optimal electrode potentials in order to effectively mitigate the influence of the photoelectron coupling.

References

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