Plasma Sheath Structures Around a Radio Frequency Antenna

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A one-dimensional particle-in-cell (PIC) simulation code is developed to investigate plasma sheath structures around a high-voltage transmitting antenna in the inner magnetosphere. We consider an electrically short dipole antenna assumed to be bare and perfectly conducting. The oscillation frequency of the antenna current is chosen to be well below the electron plasma frequency but higher than the ion plasma frequency. The magnetic field effects are neglected in the present simulations. Simulations are conducted for the cases without and with ion dynamics. In both cases, there is an initial period, about one-fourth of an oscillation cycle, of antenna charging because of attraction of electrons to the antenna and the formation of an ion plasma sheath around the antenna. With the ion dynamics neglected, the antenna is charged completely negatively so that no more electrons in the plasma can reach the antenna after the formation of the sheath. When the ion dynamics are included, the electrons impulsively impinge upon the antenna while the ions reach the antenna in a continuous manner. In such a case, the antenna charge density and electric field have a brief excursion of slightly positive values during which there is an electron sheath. The electron and ion currents collected by the antenna are weak and balance each other over each oscillation cycle. The sheath–plasma boundary is a transition layer with fine structures in electron density, charge density, and electric field distributions. The sheath radius oscillates at the antenna current frequency. The calculated antenna reactance is improved from the theoretical value by 10%, demonstrating the advantage of including the plasma sheath effects self-consistently using the PIC simulations. The sheath tends to shield the electric field from penetrating into the plasma. There is, however, leakage of an electric field component with significant amplitude into the plasma, implying the applicability of the high-voltage antennas in whistler wave transmission in the inner magnetosphere.