

RF Charging of Topside Sounder Spacecraft

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Evidence concerning RF-induced charging of topside sounder spacecraft is reviewed. The most direct evidence from the orbital sounders ISIS II and Cosmos 1809 is observations of sounder-accelerated ions at energies up to a several tens of electron-volts. These ions are interpreted as the flux to the spacecraft body to discharge the negative electrical potential induced on the body by the action of sounder near fields on ambient electrons. The situation on ISIS II was modeled for frequencies well below the electron plasma and gyrofrequencies, f_p and f_c , respectively. During the RF pulse, the body was found to go to a negative potential about equal to the peak amplitude of the voltage waveform applied to the sounder dipole. Other observations from the sounders at frequencies around f_p and f_c , including "floating" resonant signals on ionograms and impedance measurements, attest to RF sheaths and hence to charging. The OEDIPUS-C spacecraft potential measurement has provided proof of RF charging through the whole range of electron characteristic frequencies.

1. INTRODUCTION

There are several kinds of evidence from the topside sounders for the charging of spacecraft during RF pulses from onboard sources. One of the best documented phenomena is sounder-accelerated particles (SAP). When the sounder frequency $f \approx f_p, f_c$ (f_p and f_c are the electron plasma and gyrofrequencies, respectively), sounder-accelerated electron (SAE) fluxes are as high as moderate auroral precipitation fluxes. SAE fluxes of such magnitudes generally imply that charges are induced on spacecraft when RF fields are acting. However, full descriptions of the electrodynamics of RF-driven plasmas in the vicinity of a spacecraft including charging have hitherto remained an unaddressed challenge. The SAE evidence, although well documented, resists reaching quantitative conclusions about charging.

Sounder-accelerated ions (SAI) provide a directly usable measure of charging at very low frequencies. Measurements of active antenna impedance and of floating resonance spikes on topside sounder ionograms also permit measures of RF sheath thickness which is related to induced dc potential of the active antennas. Finally, the OEDIPUS-C payload, operated as a quadruple probe, has yielded direct measurements of sounder-body dc potential.

2. SAP WHEN $f < f_p, f_c$

In some respects, the situation with SAI is simpler than with SAE, and has permitted quantitative analyses of charging. Energetic-particle data from ISIS II and Cosmos 1809 contain ample proof of SAI fluxes at energies up to about 50 eV for sounder frequencies $f < f_p, f_c$ [James, 1983; Shuiskaya *et al.*, 1990]. SAI are interpreted as the flux to the spacecraft body to discharge the negative electrical potential induced thereon by the action of sounder-pulse near fields on ambient electrons.

James [1987] analyzed the ISIS-II spacecraft observations for the case $f < f_p, f_c$. This is the rectification regime where antenna and spacecraft body surfaces were modeled as a triple probe using dc electrostatic probe theory. Net charging during the 87- μ s RF pulse was found to occur because of differences between the probe characteristics of the spacecraft body and the dipole antenna. The charging time constant $\tau \approx 1/4f$. After the RF pulse on the antennas, the spacecraft body potential had fast and slow discharge phases. The fast discharge by ambient electrons of blocking capacitors in series with the dipole arms took place in $\tau \approx 100 \mu$ s. The slow discharge by ram ions had a time constant $\tau \approx V_s C_{sc} / I_r \approx 1$ ms, where V_s is the spacecraft potential, C_{sc} is the spacecraft body capacitance, and I_r is the ion ram current.

When $f \leq \min\{f_p, f_c\}$, SAE are not seen on the monostatic IK-19 and ISIS sounders [Galperin *et al.*, 1981; James, 1983]. However, SAE are observed on the part of the bistatic OEDIPUS-C payload remote from the transmitter

[Huang *et al.*, 1999]. This observation appears to be consistent with the VLF situation above, where ions are attracted and electrons are repelled by the transmitting spacecraft.

3. OBSERVATIONS WHEN $f \approx f_p, f_c$

SAE are widely observed on sounders for $f \approx f_p, f_c$. The potential of the OEDIPUS-C transmitting subpayload has been measured as a function of frequency (Wallis and Laframboise, private communication, 1997). The 0.025 - 8.0 MHz frequency sweep of OEDIPUS C covers the range from $f \ll f_p, f_c$ to $f \gg f_p, f_c$. The potential is observed to rise from large negative values (~ -100 V) to small positive values ($\sim +1$ V). Observations of small positive potentials at $f > f_p$ support the computations by *Rubenstein and Laframboise* [1970] of ponderomotive RF sheath effects in an isotropic plasma.

Based on measurements of the magnitude of the driving-point impedance of the ISIS-I,II sounder antennas, the radius of the RF sheath around the sounder dipoles was deduced to lie in the range from 1 to several meters [James, 1980]. *Baranets et al.* [1995] computed the impedance of the Cosmos-1809 sounder dipoles, and used resonant effects observed in SAI to infer sheath values of similar magnitudes. The existence of strong SAI for $f \approx f_p, f_c$ [Shuiskaya *et al.*, 1990] suggests that positive antenna and body potentials are created at such frequencies.

The " Q_n " resonant echoes observed on topside-sounder ionograms are associated with the n th harmonic f_c resonances [Muldrew, 1972]. In contrast to almost all other resonant spikes seen on ionograms, the Q_n resonances are seen to float from the zero of the time base: the signal begins about 1 ms after the cessation of the causative sounder pulse. The Q_n point on the hot-plasma electrostatic cyclotron dispersion curve is the point where the wave group velocity $\partial\omega/\partial k = 0$. On such curves, this point is at $k_{\perp} v_{th}/2\pi f_c \approx 1$, where k_{\perp} is the perpendicular wave number and v_{th} is the electron thermal speed. For ionospheric conditions, the implied wave length $\lambda \approx 0.4$ m. It is thought that for the first millisecond after the pulse, the RF sheath, having a dimension of about 1 m, shields the receiving dipole from the very-short-wavelength Q_n waves. The sheath collapses as ambient charged particles discharge the spacecraft potential, after which the electrostatic waves can be detected. The 1-ms time required means that it is ions that are discharging a negative potential, as in the case of $f \ll f_p, f_c$.

4. CONCLUSIONS

The SAI observations and analysis for $f \ll f_p, f_c$ show that large negative potentials, of about half the sounder peak-to-peak voltage, can be induced on the supporting spacecraft body. At higher frequencies, the magnitude of charging is difficult to infer from SAP. Indirect evidence comes from deduced sheath dimensions and collapse times. Potential measurements on OEDIPUS C coordinated with the sounder operation show that the dependence of the payload potential on frequency is as qualitatively predicted by a theory for an isotropic plasma.

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