Major Developments in our Understanding of Electric Antennas in Space Plasmas

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Abstract

Salient ideas in the history of the science of dipoles as an important part of space radio science are presented. From the onset of the space age, the study of spontaneous radio emissions in geospace has required accurate measurements of wave electric fields. This presentation starts with the work done early in the space age on distributed dipole behavior in cold magnetoplasmas. Evidence of the effects of hot-plasma wave modes and of the response of space plasma excited by active antennas led to a broadening of the dipole theory to include the generation and detection of electrostatic waves. The observations of plasma nonlinearities during the operation of active dipoles required further explanation. Indications of nonlinearity included spectra implying parametric processes and the RF-pumping of ambient ions and electrons, in the dipole near fields. The challenge today of understanding the inherent complexity of dipoles in magnetoplasmas may be met by recourse to particle-in-cell methods to predict classic antenna properties such as current distribution, impedance, radiated field and effective length.

Text

The development of the theory of electromagnetic (EM) wave propagation in cold magnetoplasmas set the stage in the 1950s and 1960s for solutions of the inhomogeneous wave equation applied to the active distributed dipole. This is an antenna whose two aligned arms are straight conducting tubes or wires. The historical development was stimulated partly by the start of the space age, where the storable-tubular and wire technologies provided practical means for exploiting the broadband character of distributed-dipole receiving antennas. The 1960s turned out to be a busy decade for progress of the dipole theory. One development was the inversion of the small-signal wave equation through Fourier transforms, providing Green's functions that were used to derive closed-form expressions for the impedance and radiation field of dipoles.

Shortly thereafter, experiments in space on dipole impedance began to explore the accuracy of the cold-plasma impedance theory. This theory has been useful in that a lot of radio scientific research in geospace has been concerned with passive-dipole observations of spontaneous EM emissions. A proper interpretation of these observations requires a knowledge of engineering concepts like the dipole impedance and effective length. Validations by experiment of the theory of fields radiated by active dipoles have been sparse. Research with active antennas in the laboratory and in space has concentrated on dispersion relations and understanding of plane-wave propagation parameters like phase, signal delay and spectrum; absolute amplitudes have been a secondary consideration. Also, tests on radiated fields ideally employ separated synchronized emitting and receiving dipoles, a relatively expensive experiment seldom achieved in space. A limited number of two-point measurements of radiated electric field (**E**) have indicated that the cold-plasma theory works for EM wave modes, when the refractive index is close to unity.

Dipole theory has been elaborated in response to reports of a number of active- or passive-dipole phenomena. The demonstrated ability of dipoles to emit or detect electrostatic (ES) waves has motivated work on warm- and hot-plasma theory. The complicated form of the dielectric tensor in a hot magnetoplasma expanded the amount of mathematical work needed in the Green's function approach to dipole behaviour.

Often in research on space-plasma waves, satisfactory interpretations of received long-wavelength EM waves have been obtained with the hypothesis that the effective length of the distributed dipole is half its physical length, L. But some evidence has been forthcoming from experiments on ES waves that the dipole effective length can be significantly larger than $L/2$. Effective length is important because knowledge of the absolute **E**-field component amplitudes is required to specify wave state vectors of ionosphere-magnetosphere emissions.

Given the magnitude of RF voltages that radio sounders place on their emitting dipoles, nonlinear reactions in the near-zone plasma are to be expected. Classifications of the menagerie of ES signals appearing in radio-sounder data at various sum and difference frequencies of the electron plasma and gyrofrequencies attest to the diverse possibilities of plasma physics. The observation of RF-pumped electrons, directly and by their effects, point to the richness of the

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“soup” around an active dipole. The complexities of the nonlinear processes and of the spacecraft-antenna physical structures have spurred interest in particle-in-cell (PIC) and other computer-based methods for understanding waves in space plasmas.

This Commission-H Tutorial Lecture covers some of the main points of the corresponding previous review [1].

Reference

1. H.G. James, "A Review of the Major Developments in our Understanding of Electric Antennas in Space Plasmas", *Radio Science Bulletin*, no. 336, 2011, pp. 75-94.