THE WISP/HF SYSTEM FOR SPACELAB

H. G. James

Communications Research Centre, Department of Communications,
Ottawa, Ontario, K2H8S2 Canada

ABSTRACT

The high-frequency part of the Waves-In-Space Plasmas system, WISP/HF, is a flexible Shuttle/Spacelab instrument for transmitting, receiving and processing signals in the 0.3 to 30 MHz range. It will permit a wide range of plasma wave experiments in the ionosphere including studies of the transmitting antenna, fundamentals of electromagnetic (EM) and electrostatic (ES) waves in magnetoplasmas, instabilities and nonlinearities, and remote sounding of ionospheric structure. Collaborative investigations involving other WISP equipment (e.g. antenna and propagation studies with the WISP/VLF system) or other Spacelab facilities (e.g. beam-plasma interactions using charged-particle guns) are envisaged. A few specific examples illustrate the relevance of WISP/HF to current scientific interest. The overall goal is to help build a comprehensive understanding of plasmaspheric wave physics through group studies.

INTRODUCTION

The National Research Council of Canada (NRCC) has proposed to supply the WISP/HF [1,2] for Spacelab missions to be undertaken by the National Aeronautics and Space Administration (NASA). The system consists essentially of a transmitter and associated phase-coherent receivers, all of which are controlled by a programmable microprocessor. Upon a simple command, the transmitter generates signals with variable frequency, level and modulation. Frequency and amplitude can be swept, stopped or held constant, and are accurately known. The transmitter works into a dipole of variable length (up to 300 m tip-to-tip) and, when matched, can deliver 0.5 kW peak power. The system includes one receiver on the Orbiter and another on the Recoverable Plasma Diagnostics Package (RPDP) subsatellite [3]. Receiver gain, frequency and bandwidth settings are also variable and accurately known.

Figure 1 is one speculative interpretation of the components that will go to make up WISP/HF. They include:

1. A dedicated microprocessor-based Controller permits the Payload Specialist to carry out preprogrammed experiment routines which are stored in its memory. It accepts a simple command from the coordinating system and in turn sends detailed commands to the WISP/HF units. It provides time-base and frequency coordination between the transmitter and the receivers, monitors various circuit parameters or received signal characteristics, and adjusts the operating mode either by calling up preprogrammed responses or by implementing changes requested by the Payload

Specialist or by Payload Operations Control Centre. It detects, processes and formats data for the coordinating system and for CDMS.
2. A Frequency Synthesizer generates the basic RF required in the 0.3 to 30 MHz range and establishes the fixed- or swept-frequency cycles.
3. A Modulator creates pulses with appropriate width, rate, shape and coding.
4. A Driver produces the low-level wave forms.
5. A Power Amplifier amplifies the wave forms from the driver to output levels of at least 0.5 kW in the pulsed mode or 50 W CW.
6. A Transmit-Receive Switch isolates the input of the Orbiter receiver from the Power Amplifier output during transmission.
7. An Antenna Matching network is an electromechanical device which maximizes power transfer to the long dipole antenna during transmission and from that antenna to the Orbiter Receiver during reception. This unit could also control the transmitter power.
8. A Receiver amplifies wanted signals. It has about 100 dB of dynamic range and a bandwidth that is variable by command. One version is located on the Orbiter and has the long transmitting dipole as receiving antenna. The other receiver is on the RPDP where it is assumed that a 10-m dipole will be available for reception. NASA-supplied telecommand and telemetry links between the Orbiter and the RPDP provide control and data liaison between the RPDP receiver and the controller.
9. A Detector digitizes the received signal for processing by the controller. To permit Doppler measurements, it compares the phases of transmitted and received wave forms. It can also serve as a frequency comparator for swept-frequency work.

A working level agreement has been completed between the scientists in the U.S.A. who were responsible for the WISP Proposal [2] and scientists in Canada. The agreement is based on a recognized scientific interest of having an international team work on a comprehensive wave-injection project which encompasses active experimentation at frequencies between the extra-low-frequency range and the very-high-frequency range, inclusively. The team together will provide guidance on matters of general concern. Within this team will be the WISP/HF investigator group who will direct the definition, development and use of the WISP/HF hardware. This group comprises four Canadian scientists, four U.S. scientists and one Australian scientist who have all agreed on their responsibilities in the project. The group encourages scientists outside the team to associate with it in planning experiments.

Present NASA planning calls for a Spacelab mission in mid 1986, with an orbit of 57° inclination at 300 km altitude. The payload would include about a dozen instruments designed for atmospheric, magnetospheric and space-plasma experiments and these would be coordinated in various ways for collaborative investigations. The remainder of this article is a list of the major scientific categories to be addressed with the WISP/HF and includes a few specific illustrations.

ANTENNAS IN PLASMAS

In any radio science experiment, the antenna has a pivotal role, and research on the interaction of an active antenna with a magnetoplasma will be an important constituent of the WISP program. The research will deal first with the basic issues of driving-point impedance and fields of an antenna, in the linear domain. As signal level is increased, more complex descriptions of the antenna and its environment will be required, and a wide variety of phenomena will be investigated.

Figure 2 illustrates some antenna-related measurements. By measuring the voltage and current wave forms and their relative phase at the terminals of the long transmitting dipole, the complex driving-point impedance, Z_A, will be determined. The dependence of Z_A upon frequency, strength and direction of the ambient magnetic field, plasma composition and density, antenna length and dc bias will be measured. Measurement of current distributions, near and far fields and plasma properties will be carried out with use of detectors mounted on the RPDP as shown in the Figure 2. Current distributions and near fields will normally be made while the RPDP is manoeuvered by the Remote Manipulator System. This work is important to the program because presently there is very little understanding of wave propagation along an antenna in a magnetoplasma. Near-field research would include the investigation of resonance cones, conical high-field regions extending outward from points of high charge accumulation at the centre and ends of the dipole. Cone properties for finite-length dipoles are of special interest because they have never been predicted or measured.

Far-field measurements of antenna radiation patterns (both magnitude and phase) are crucial with respect to wave injection applications of the Orbiter antenna. These will be accomplished using the WISP/HF transmitter and the WISP dipole aboard the Orbiter and receiving antennas and a receiver aboard the free flying RPDP. In cases when the electric and magnetic antennas are available for reception on the RPDP, it will be possible to calculate the Poynting flux. It will be generally desirable to develop techniques for finding power flux, as a step toward the important specific objective determining the antenna radiation efficiency for electromagnetic (EM) and electrostatic (ES) modes at frequencies spanning the resonance frequencies of the plasma.

The nature of the antenna sheath and its contribution to the electrical characteristics of the antenna will first be investigated in the linear regime. Nonlinear phenomena associated with the antenna will also be examined. The impedance, current and field distribution will be measured for increasing signal levels, and will undoubtedly be affected by plasma energization and sheath expansion. Sheath asymetries may produce rectified rf current to the antenna resulting in the radiation of spurious harmonics. The interactions of particles accelerated by WISP/HF with dielectrics may provide a basis of study of the spacecraft charging [4]. It may also be possible to abserve multipactor discharge; this occurs when resonant oscillitions of electrons between dipole arms lead to a multiplicative increase in electron density through secondary emission [5].

Measured values of the impedance Z_A, and, eventually of radiated fields at the RPDP will be fed back to the WISP/HF controller (Fig. 2). In turn, the controller will command varactors in the antenna matching unit to maximize power output, optimize some field parameter, or perhaps intentionally set up interesting mismatch conditions.

PROPAGATION AND DISPERSION

WISP/HF will permit tests a number of fundamental concepts of propagation in anisotropic media; these include phase and group delay, polarization and power flux. Under certain conditions, collisional and collisionless damping formulas will be confirmed. Hypotheses about their energy flows can be examined.

The confirmation of the dispersion relations for a number of EM and ES waves can be obtained for hitherto unexplored regimes using the WISP/HF transmitter on Spacelab and a phase-coherent receiver on the RPDP. Of special interest are the ES waves occuring near the fundamental resonances at f_{pe} (plasma frequency) or at mf_{ce} (gyrofrequency harmonics). Figure 3 illustrates the possible geometries and relative sizes of reflected rays. It stresses that the bistatic configuration considerably enlarges the scope of propagation experiments over what has been possible in the past with monostatic systems. In particular, a variety of oblique paths can now be explored. At a given phase of an orbit, the Orbiter-subsatellite geometry will be favourable to at least one of several wave modes, and choices for operating parameters will be based on real-time information about the plasma conditions and geometry.

Wave mode coupling has been speculated to play important roles in certain laboratory and space plasmas. Coupling will be tested by seeking bistatic geometries that effectively place the transmitter and receiver in different frequency domains and thereby require energy transfer between modes for successful propagation.

INSTABILITIES AND NONLINEARITIES

The flexibility of the WISP systems and associated Spacelab instruments will ensure new understanding of instabilities which occur spontaneously in space plasmas. Unstable waves often grow in amplitude to a point where nonlinear effects become important. Intrinsic plasma nonlinearities can be triggered in a controlled fashion through the use of the variable high output power available from WISP/HF. Nonlinear processes excited for specific wave modes, frequencies and propagation directions typically produce waves with different frequencies, directions and modes. The WISP/HF transmitter and receivers will be independently tunable to specific frequencies of interest, and hence will be able to observe the controlled nonlinear excitation of waves.

Experiments on wave-wave interaction will investigate parametric decay at short range. Attempts will be made to detect both characteristic electron and ion waves resulting from the decay, by judicious use of transmitter geometries and frequencies. Two-frequency pumping to produce ion waves has also been proposed. Work on nonlinearities will include careful diagnosis of the transmitter-heated regions and attempts to clarify all the ES wave modes destabilized in the resulting nonequilibrium plasma. For instance, there is evidence from the topside sounders that temperature anisotropies may be set up which then produce Bernstein waves through the Harris instability.

WISP/HF can be used to investigate wave growth in the presence of streaming charged particles. Once the characteristics of normal propagation in an equilibrium plasma have been established, the transmitter-receiver link can then be applied to the study of net effects of wave growth in nonequilibrium distributions. Natural particle streams in which the stream dimensions greatly exceed propagation path length present an advantage; the assumption of a growth region of infinite extent will simplify analysis. On the other hand, charged-particle guns on Spacelab will have the advantage of complete control over beam parameters (flux magnitude, pitch angle, energy and modulation) and of absence of widespread noise from spontaneous emissions. ES waves like those in Figure 3 have wavelengths of the order of meters and reflect off gradients within about 1 km of the transmitter. This suggests the procedure symbolized in Figure 4. Assuming that the artificial electron beam has a certain radius about a field line, it may be possible to arrange ES ray paths that, after reflection (many wavelengths from the transmitter), cut back across the beam with plane waves. When orbital conditions permit, an RPDP with a receiver located on the ray path just beyond its intersection with the beam should be in a position to monitor incremental wave growth or damping caused by the beam. The shaded areas in Figure 4 indicate that the beam is pulsed. Normal propagation (A) is first studied using rays that are not affected by the streaming particles. The transmitter is off at B and the receiver measures the inherent beam instabilities, if any. Finally, the net results of convective growth or damping of a transmitter pulse can be obtained by measuring the total signal level in the presence of the beam (C), subtracting inherent noise (B) and comparing with ambient propagation (A).

SOUNDING AND SCATTER

The WISP/HF group is strongly interested in research on ionospheric and magnetospheric structure as the basis for understanding the dynamics of the neutral atmosphere and the plasmasphere. Experiments are proposed in remote HF sensing of ionospheric structure in which both the scale size of the structure and the distance to it from Spacelab vary up to thousands of kilometers. New coded-pulse and coherent-transmission methods wil be applied to research on traveling ionospheric disturbances and field-aligned irregularities of density. Near the upper-frequency limit of the WISP/HF, scatter from E- and F-region structures can also be studied. In situations where the Orbiter and RPDP fly through structure of interest, simultaneous use of the WISP/HF and other Spacelab systems will help to reduce ambiguities in calculations of density irregularity spectra.

Ionization structures will be measured, both along the orbit and remote from Spacelab. WISP/HF will operate in a number of programmed modes, including survey modes to search for natural phenomena of interest or modes to investigate specific features in detail. Frequency sweep range, pulse width, repetition frequency and power will be variable on command. WISP/HF will be capable of coherent detection, and will permit measurement of time delay, phase, amplitude and Doppler shift of received signals. Real-time data presentations may be used to help the operator focus on structure of particular interest. Since Doppler shift at a given frequency varies as the cosine of the angle between the wave normal and the receiver velocity, the shift is a measure of the angle of arrival of the return ray. This will provide a means of distinguishing returns from different regions with the same delay time.

With a Spacelab orbit in the F-region, WISP/HF will be useful for research on equatorial 'bubbles' [6] and associated field-aligned HF ducts [7]. WISP/HF may be used to find the shape, orientation and dimensions of bubbles, the relationship between bubbles and ducts, and the relationship between bubbles and Spread-F. Doppler data recorded in ducts will provide angle-of-arrival information which could be used to study the electromagnetic trapping mechanism and to distinguish trapped waves from scattered or reflected ones. Apart from bubbles, ducting phenomena deserve extensive study in their own right, and WISP/HF experiments will address wave modes whose guiding cannot be observed on the ground.

Figure 5 illustrates how the coherent bistatic transmitter-receiver could be used to clarify a long-standing question: are ducts of tubular (A) or laminar cross section (B)? In both cases, the transmitter-receiver separation vector is assumed horizontal and passes through the area of minimum density, N_1, i.e., the inside of the duct. Using the coherence facility, the phase change, $\phi(f)$, is found in a frequency range f_1 to f_3. The nature of the density contours and the rays consistent with them is such that there is much more dispersion in B than A. Iterative electron density modelling at the analysis stage could be used to deduce the density contours which give the best agreement with the observed $\phi(f)$.

REFERENCES

1. H. G. James, WISP/HF: A proposal for the investigation of medium- and high-frequency waves on Spacelab, Space Science Coordination Office, National Research Council of Canada, Ottawa, Ontario K1A 0R6, Canada, (1980).
2. R. W. Fredricks, Waves In Space Plasmas, TRW Defense and Space Systems Group, Proposal No. 34262.000, Redondo Beach, California, U.S.A. (1978).
3. S. D. Shawhan, A Recoverable Plasma Diagnostics Package (RPDP) for Spacelab, The University of Iowa, Iowa City, Iowa, U.S.A. (1978).

4. A. Rosen, Astronautics and Aeronautics, June, pp. 36, (1975).
5. P. F. Clancy, Microwave J., March, pp. 77, (1978).
6. S. Basu, and M. C. Kelley, J. Atmos. Terr. Phys., 39, 1229, (1977).
7. D. B. Muldrew, J. Geophys. Res., 68(19), 5355, (1963).

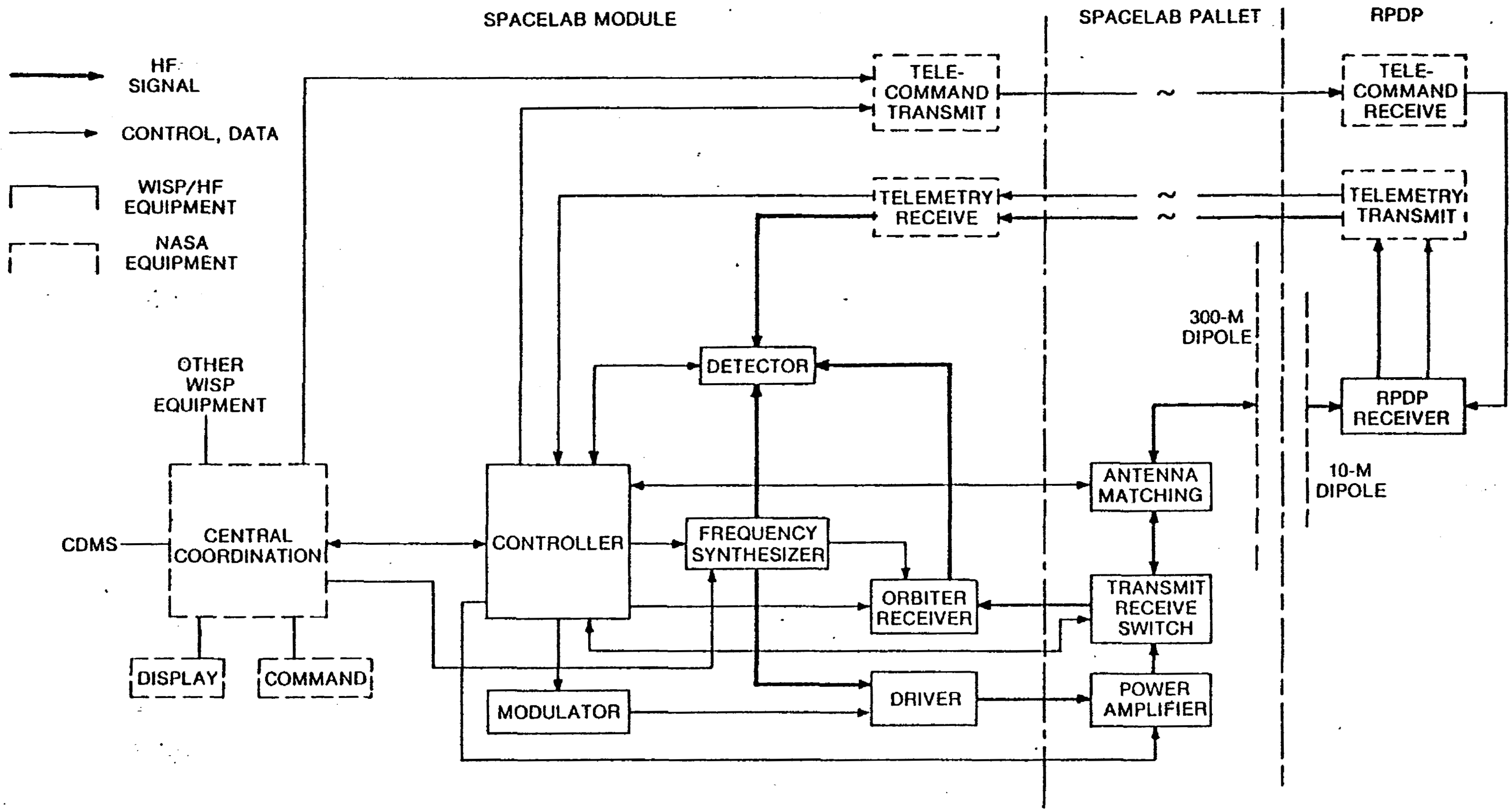

FIG. 1—FUNCTIONS OF WISP/HF

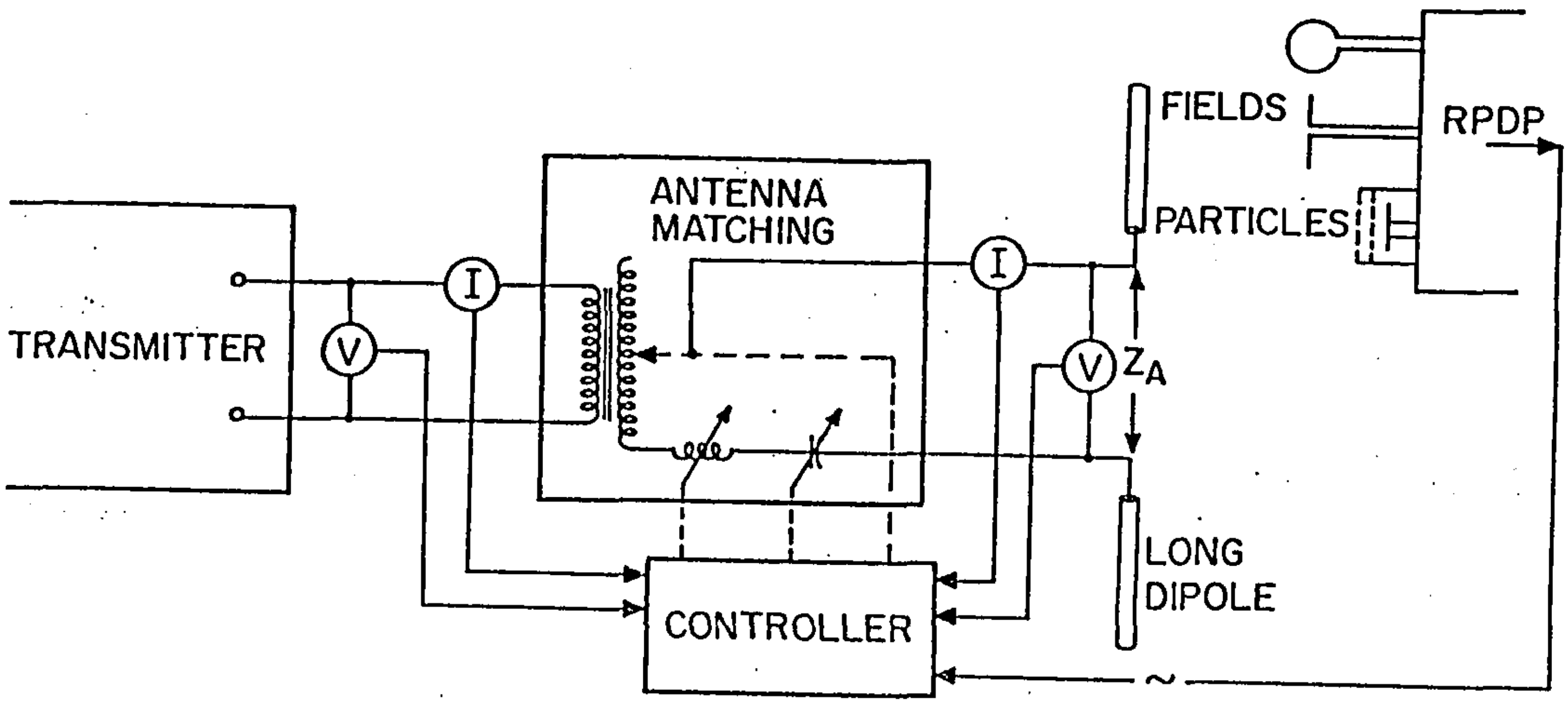
FIELDS
RPDP
ANTENNA
MATCHING
PARTICLES
TRANSMITTER
V
I
I
V
Z_A
LONG
DIPOLE
CONTROLLER
~

Fig.2

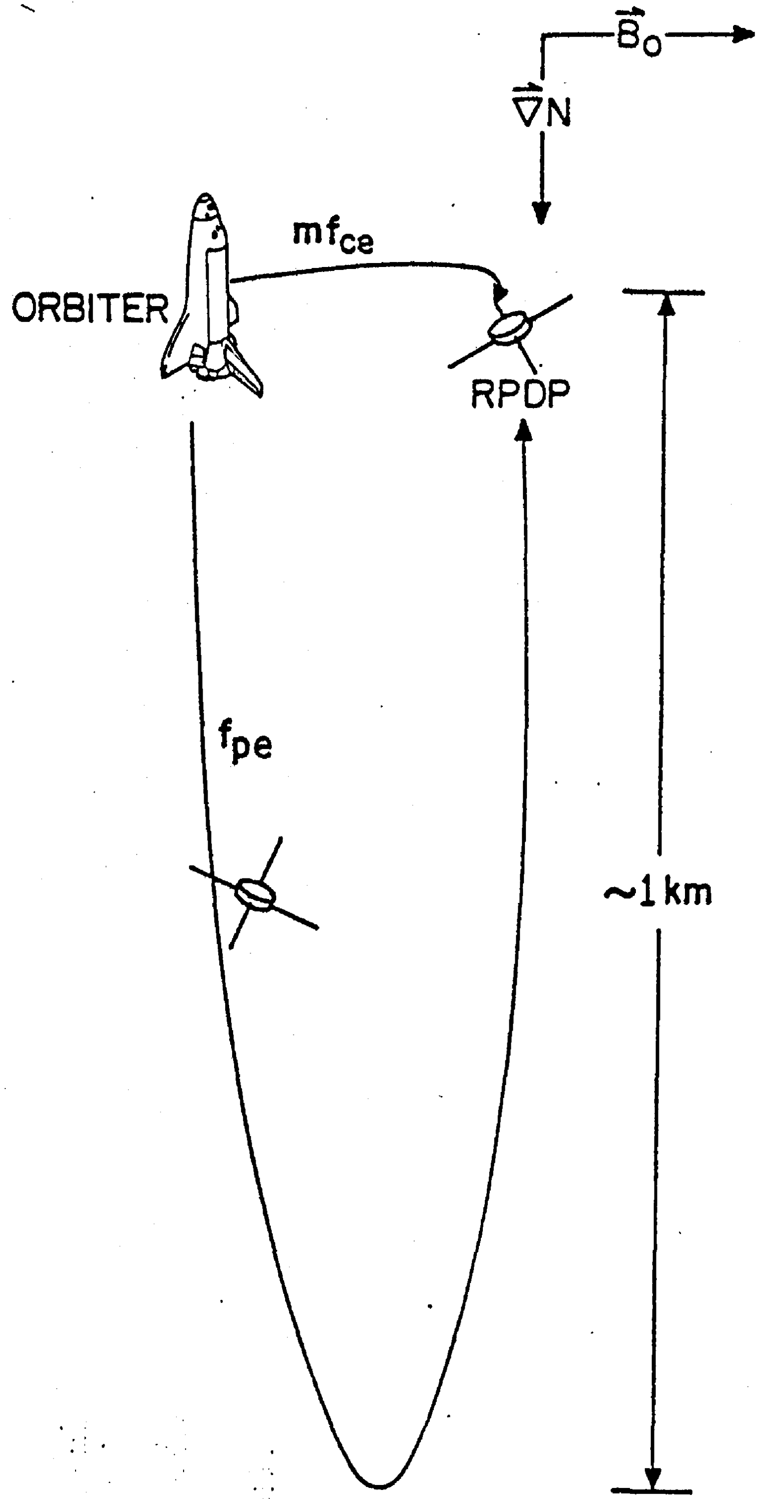

Fig. 3

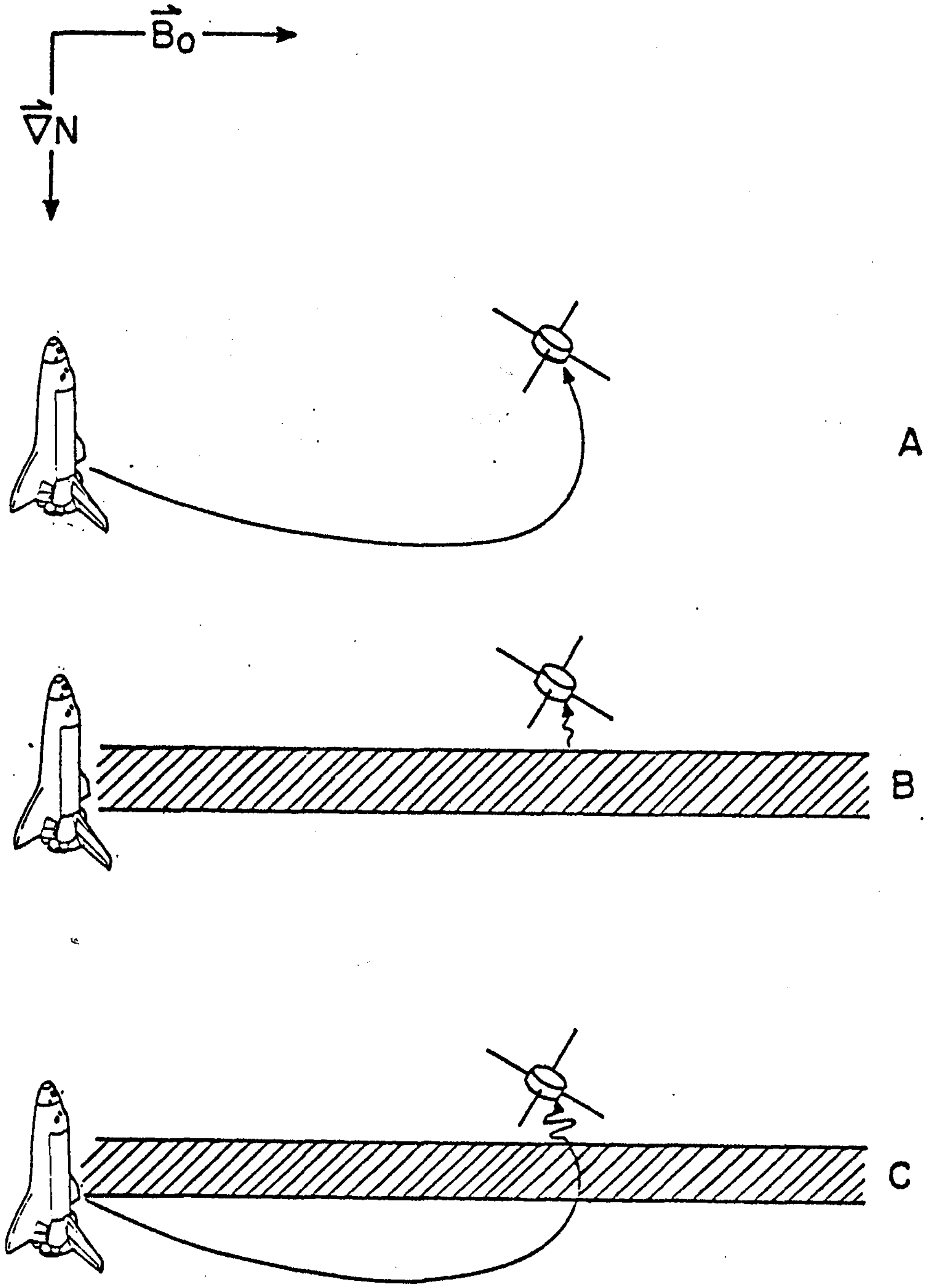

Fig. 4

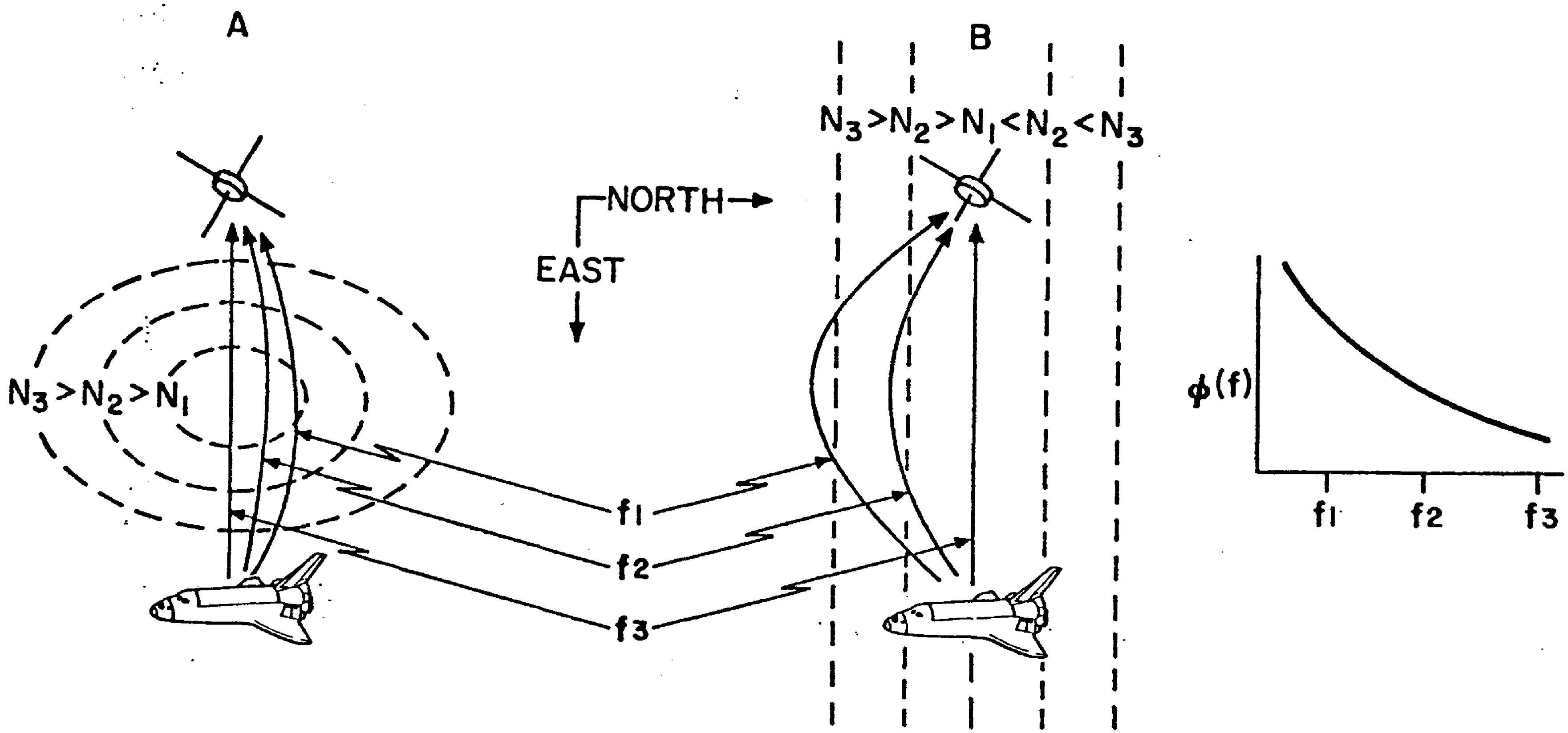

Fig. 5