The Pioneer Venus Orbiter Plasma Wave Investigation

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Abstract-The Pioneer Venus plasma wave instrument has a self- contained balanced electric dipole (effective length = 0.75 m) and a 4-channel spectrum analyzer (30-percent bandwidth filters with center frequencies at 100 Hz, 730 Hz, 5.4 kHz, and 30 kHz). The channels are continuously active and the highest Orbiter telemetry rate (2048 bps) yields 4 spectral scans/s. The total mass of 0.55 kg includes the electronics, the antenna, and the antenna deployment mechanism. This report contains a brief description of the instrument design and a discussion of the in-flight performance.

INTRODUCTION

SINCE DECEMBER 5, 1978, the electric field detector on the Pioneer Venus Orbiter has been providing measurements of wave activity in the plasma environment of Venus. The Orbiter plasma wave instrument uses a short self-contained electric dipole to detect the signals which are processed in 4 continuously active bandpass channels covering the frequency range from 100 Hz to 30 kHz. The instrument is gathering data on many aspects of the mode of interaction between the solar wind and the ionosphere (e.g., on processes that develop in the upstream solar wind region, near the bow shock and ionopause and within the ionosphere, ionosheath, and wake cavity). The instrument was also designed to collect data on whistler mode electromagnetic noise bursts from the atmosphere, and it appears that lightning from Venus is being detected by the Orbiter wave instrument.

BACKGROUND

The original proposal for a plasma wave instrument on the Pioneer Venus Orbiter was based on the design of the electric field detectors operating on Pioneer 8, 9 [1]. In fact, it was first proposed that an existing Pioneer 9 flight spare unit be flown, using a spacecraft element (boom or antenna) as an unbalanced electric field dipole. With this plan, the requirements on the spacecraft would have been minimal (the Pioneer 9 spare has four analog telemetry outputs, no internal commands, a mass of 0.36 kg, and total power consumption of 420 mW; the proposed antenna concept would have required some mass addition for the antenna diplexer and cabling, but no deployment mechanisms or deployment commands were required). This proposal was accepted in principle, but it turned out to be impossible to use the Pioneer 9 spare or to use a spacecraft element as an antenna. At this point it became necessary to design a new Pioneer Venus plasma wave instrument with the following constraints: a) total mass near 0.5 kg, including antenna and deployment mechanism. b) power consumption near 0.5 W; c) no commands for antenna deployment; and d) 4 analog telemetry outputs. Another significant constraint on the antenna design involved the need to provide sufficient rigidity so that the antenna would not strike the spacecraft or the solar arrays during powered flight (such as the Centaur burns near earth and the burn of the Orbit Insertion Motor at Venus).

INSTRUMENT DESCRIPTION

The constraints discussed above presented a number of serious mechanical and electronic problems and it was clear that the instrument would have to have a limited number of bandpass channels and a relatively small antenna. The science requirements of the Venus mission provided additional constraints, such as the need to cover a frequency range from below the anticipated electron cyclotron frequency up to the nominal interplanetary electron plasma frequency. The high speed of the spacecraft through the shock, ionopause, and ionosphere required the use of continuously active channels to measure rapid temporal variations without error. Finally, in order to use a body-mounted sensor on a spinning spacecraft with irregular solar arrays, it was evident that a balanced electric dipole would be needed to achieve common mode rejection of interference signals.

The resulting design is shown in Fig. 1, which contains a block diagram of the electronics circuit and a drawing of the mounting of the deployed antenna on the Orbiter spacecraft. The electronics is packaged in a two level box, as shown in Fig. 2. The dimensions of the upper part are 12.2 cm X 6.6 cm X 5.5 cm, and those of the base are 19 cm X 6.6 cm X 2 cm, with a total unit mass of 0.5 kg. The key to the overall instrument design was fundamentally related to the plan for mounting and deploying the antenna. As shown in Fig. 3 and Fig. 4,the entire 50-g antenna unit was mounted directly on the electronics box, and the individual spring-loaded antenna elements were stowed against the inside surface of the launch vehicle fairing, so that they deployed automatically as the fairing was ejected. In the deployed position the center of each wire grid is 0.69 m from the point of connection to the electronics unit, and the sphere-to-sphere separation is 0.76 m. The wire grids are placed at the ends in order to provide a lumped capacitance with small collecting area. The individual wire circles have diameters of 10.5 cm, and the antenna effective length is 0.75 m. Since this antenna system with small collecting area responds to induced electric fields, the transfer function for the antenna/input circuit is determined by placing the entire unit in a large parallel-plate capacitor. The capacitor is driven with a calibrated signal generator, and the preamplifier output is measured as the frequency is varied.

The differential preamplifier input uses a pair of 2N5556 field effect transistors specifically selected to provide matched gains and low noise levels. The input circuit was designed to have low input capacitance in order to minimize possible effects of varying antenna capacitance associated with changing plasma sheath conditions. Some additional characteristics of the 4-channel spectrum analyzer are worth noting. The four filters have frequency response curves similar to those used in the 400-Hz, 22-kHz, and 30-kHz channels on Pioneer 8, 9 [1], but for the Pioneer Venus Orbiter we selected filters with 30-percent fractional bandwidth rather than the l5-percent units used previously. The automatic gain control amplifiers used here have rise times on the order of 50 ms, with decay times of approximately 500 ms.

Finally, the telemetry interface with the Orbiter spacecraft is straightforward. The 4 analog outputs converted to digital form by the spacecraft and transmitted to earth in a way that depends on the selected format and on the telemetry rate. One minor frame has 512 bits, and the spacecraft transmission rates range from 4 minor frames/s down to 1 minor frame/64 s. Near periapsis the customary rates have been 2 to 4 minor frames/s during the first year in orbit.

In two of the spacecraft telemetry formats (Periapsis D-the "Optical" format, and Periapsis B--an "Aeronomy" format) no plasma wave measurements are made. In format E ("Radar Mapping" format) only the 100-Hz channel is sampled. For the other 6 telemetry formats an entire 4-channel spectral scan is obtained with every minor frame readout. This has generally provided 2-4 scans/s near periapsis.

IN-FLIGHT PERFORMANCE

The wave instrument has been acquiring data almost continuously since launch on May 20, 1978, and we find that the in-flight operation is remarkably free of interference associated with pickup of noise from spacecraft or experiment subsystems. The only known instrumental effect involves the detection of regular low level amplitude ripples when the spacecraft is in sunlight. This is illustrated in Fig. 5, which shows wave measurements from the region of an outbound bow shock crossing (top four panels), along with a profile of the ***B***-field magnitude (bottom panel; data supplied by C. T. Russell). The amplitude modulation is evident only when the natural plasma wave activity is low, and this effect is a measure of the sun-oriented anisotropy of the plasma sheath surrounding the spacecraft, which is not an equipotential. The observed ripple arises because the antenna on the spinning spacecraft is at a different angular position with respect to the sun during each successive sampling.

Fig. 5 shows that near the shock the plasma wave instrument readily detects mid-frequency waves that we identify as ion acoustic waves (730 Hz and 5.4 kHz), and high-frequency upstream waves (30 kHz) that are thought to be electron plasma oscillations associated with suprathermal electrons. The 100-Hz activity shown here probably represents electromagnetic whistler mode turbulence. Even in sunlight, the minimum detectable field strengths are close to the intrinsic threshold levels for the various channels. We find electric field spectral densities in units of (volts/ meters)^{2}/(hertz) to be about 1.2 X 10^{-10} at 100 Hz; 1.3 X 10^{-11} at 730 Hz, 8.8 X^{-10} at 5.4 kHz, and 3 X 10^{-13} at 30 kHz. In terms of equivalent sine waves, these in-flight thresholds are approximately 30 to 60 (µV/m. The instrument is capable of detecting signals up to 90 dB above these minimum levels before reaching saturation, but no very strong signals of this nature have ever been detected.

When the spacecraft is in darkness the ripple is absent, but as expected, the achievable sensitivity is not really improved.
Fig. 6 shows some high resolution measurements taken near periapsis on the night side. The isolated impulsive signals may well be associated with detection of lightning. It is also possible that the more continuous enhancements in the high-frequency-wave channels represent detection of ion acoustic waves associated with currents flowing near the bottom of the ionosphere. Many other examples of Orbiter plasma wave measurements are contained in a number of additional reports [2], and these papers should be consulted for more comprehensive discussions of the wave observations.

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[2] F. L. Scarf, W. W. L. Taylor, and I. M. Green, "Plasma waves near Venus: Initial observations," Science, vol 203, p. 748, 1979; W. W. L. Taylor, F. L. Scarf, C. T. Russell, and L. H. Brace, "Evidence for lightning on Venus," Nature, vol 279, p. 614, 1979; W. W. L. Taylor, F. L. Scarf, C. T. Russell, and L. H. Brace, "Absorption of whistler mode waves in the ionosphere of Venus," Science, vol 205, p. 112, 1979.

Fig. 1 Block diagram and drawing of the Pioneer Venus Orbiter showing the orientation of the antenna elements after deployment.

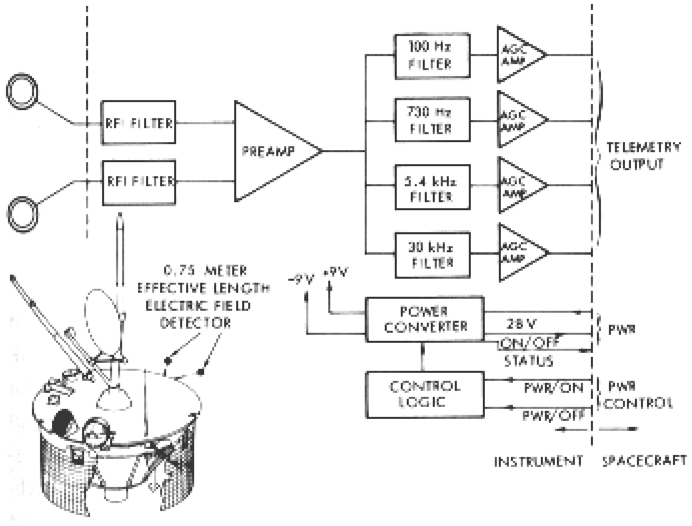

Fig. 2. The electronics unit of the plasma wave instrument (electric field detector).

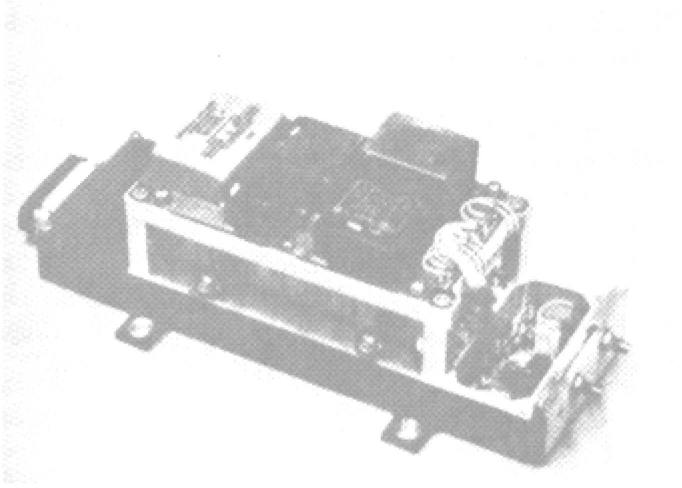

Fig. 3 The complete Pioneer Venus plasma wave instrument with the antenna unit mounted on the electronics box.

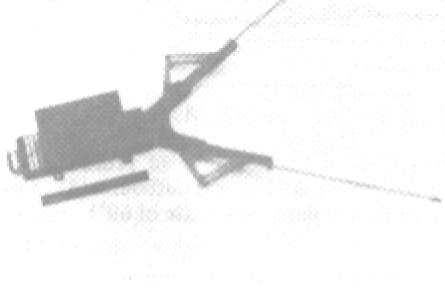

Fig. 4 Drawings of antenna in the stowed and the deployed positions.

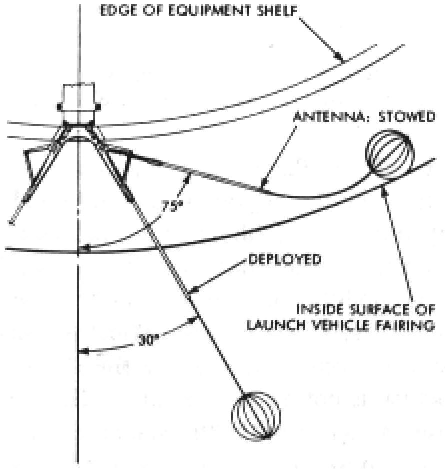

Fig. 5 Wave amp1itude variations and magnetic field profile near a bow shock crossing. At this time the Orbiter was outbound (5245 km above the surface) and in sunlight (solar zenith angle of 69º).

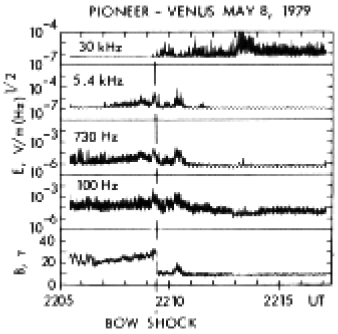

Fig. 6 Wave amplitude variations near periapsis (169 km above the surface) in darkness (solar zenith angle of 132°).