DENSITY MEASUREMENTS ABOVE AND WITHIN A SPORADIC-E LAYER USING IMPEDANCE PROBES AND LANGMUIR PROBES

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ABSTRACT

A Black Brant sounding rocket was launched during the presence of strong Q-P echos and a well-developed sporadic-E layer as measured by radar and ionosonde. The rocket was equipped with E-field sensors, Langmuir probes and an impedance probe. Enhanced electron densities were encountered during the upleg and during the downleg at altitudes between 102 km and 107 km. The Langmuir probes also revealed plasma density structures including quasi-periodic oscillations with $\sim$0.8 sec periodicity, corresponding to $\sim$400 m for horizontal structures aligned with the rocket velocity. These structures appear both above and within the sporadic-E layer and do not appear to be gradient-drift driven.

INTRODUCTION

The plasma number density is a critical measurement parameter for most ionospheric physics experiments. At low altitudes (< 200 km) at mid-latitudes at night, the plasma density can be quite low (10^3 electrons $/\mathrm{cm}^{-3}$ or lower). The presence of sporadic-E layers, however, can produce sharp increases of several orders of magnitude in the plasma density in less than 1 km of altitude. Further, structuring of the plasma density due to large scale instabilities associated with the sporadic-E layer (e.g., Rayleigh Taylor waves that create Q-P echoes [2]) and other wave phenomena produce modulation of the electron density on time scales of 10's of minutes to less than 1 second. Fixed-bias Langmuir probes are traditionally used to measure the plasma density in-situ as they cover a large amplitude variance with excellent time resolution. However, such probes are difficult to calibrate. Indeed, the collected current depends to second order on the plasma temperature and position within the saturation region. Impedance probes offer the ability to provide calibrated measurements. When used in the phase locked loop configuration, such Plasma Frequency Probes or PFP [1] they also provide high time resolution measurements. Traditionally, such probes do not work as well at low densities (where the plasma frequency is less than the ambient electron gyro frequency). The impedance probe also provides other potentially very important data. When the response is investigated at all frequencies, it provides evidence of both a series and a parallel resonance. The parallel resonance occurs at the upper hybrid frequency. From our knowledge of the electron gyro frequency, the plasma density is easily found. The lower resonance is a function of the plasma temperature and the collision frequencies. This resonance is more difficult to observe in the data, as is represents a dip in the received data [3]. The phase, however, shows a 180° change at this resonance, which is much easier to detect.

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MOTIVATION

A broadband, digital impedance probe was included on a recent NASA sounding rocket investigation. The motivation for including this probe included the following reasons:

1. Provide calibration data for the Langmuir probe.
2. Determination of the peak plasma density at low densities where the electron gyro frequency is higher than the plasma frequency (a regime were traditional PFPs do not work optimally).
3. Search for the series resonance in an effort to determine the collision frequencies and ambient plasma temperature.

PROBE DETAILS

The impedance probe consisted of a transmitter antenna and a receiver dipole spaced 1.0 m apart, as shown in Figure 1. The Langmuir probe was situated at the end of the mast that also held the science magnetometer. The frequencies were stepped in a staircase pattern. In all, 127 frequencies were stepped in 0.1 seconds. The staircase frequencies were controlled by a DDS chip at discrete, pre-determined intervals. The transmitted and received waveforms were each digitized at 3 MHz at 12 bit resolution and stored in a buffer. Due to telemetry considerations, the sweep data were only collected every 1.6 seconds. To our knowledge, this was the first time that the entire broadband waveform of both the transmitted and received impedance probe signals was telemetered to the ground for detailed analysis on the ground.

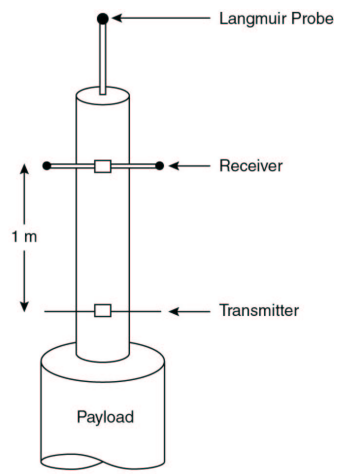

Fig. 1: Sketch of the payload indicating the location of the probes.

EXPERIMENTAL BACKGROUND

The rocket (NASA 21.125) was launched on June 29th, 2001 at 04:44 UTC (00:44 EST) from Wallops Flight Facility (WFF), Virginia, achieving an apogee of 122 km. The rocket was launched in the presence of strong quasi-periodic echoes, as observed by the Univ. of Illinois VHF radar set up at Ft. Macon, N.C. the beam of this radar was directed towards Wallops. Indeed, the beam was perpendicular to the magnetic field at 105 km near the apogee point of the rocket. An ionosonde at Wallops shows the presence of strong sporadic-E activity overhead at Wallops during the time of the launch, as shown in Figure 2.

RESULTS

For each sweep, power and phase of the received signal are determined for each frequency of the staircase. One sweep that was recorded at 234 s flighttime when the rocket encountered the sporadic-E layer on the downleg is shown as line plot in Figure 3. Note that the phase changes direction at 600 kHz which is precisely where the amplitude of the resonance

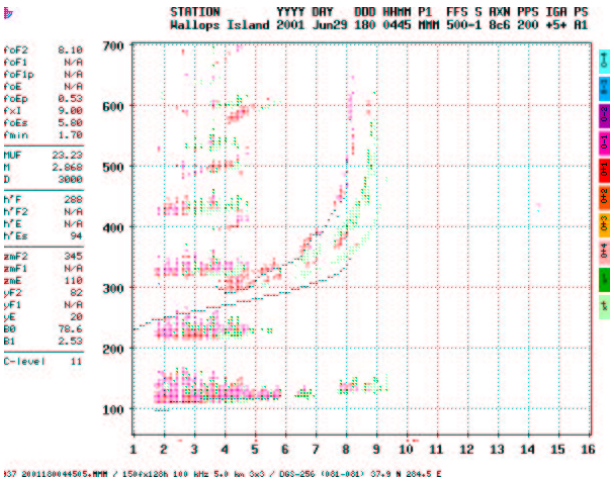

Fig. 2: Ionogram recorded by the Wallops digisonde during the flight.

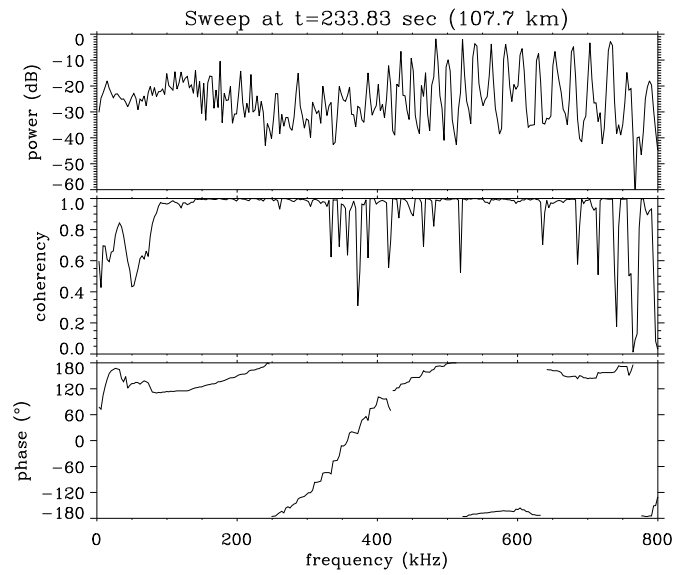

Fig. 3: Phase and coherency of the received signal for 234 s flighttime. In this sweep two maxima are seen in the received signal as well as two phase changes.

reached its maximum. This sweep also shows a second resonance in power at a lower frequency, as well as a second phase change.

We combine all of the sweeps for the flight into a spectrogram format by mapping each staircase into a single time bin. Figure 4 shows the received power during the entire flight. Note the two large increases in signal and frequency corresponding when the rocket encountered the sporadic-E layer on the upleg and downleg. Plotting the phase relation in a spectrogram format yields a similar picture, with the sporadic E-layer clearly visible in the spectrogram.

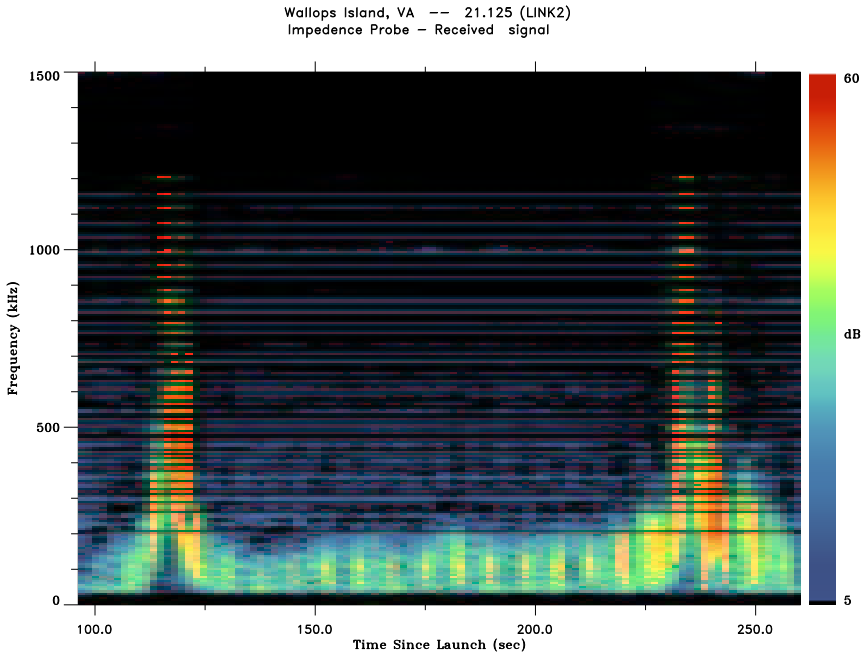

Fig. 4: Spectrogram of power of the received signal.

CALIBRATION

In Figure 5, the plasma density is shown versus time on the same scale, derived from the amplitude data (blue) and the phase data (green). The Langmuir probe data is also shown (red) and shows the same basic structure.
We now compare the Langmuir probe and impedance probe data in more detail. This is done versus altitude for the upleg and downleg. The Langmuir probe data is corrected for the vehicle potential and a temperature of 300 K. The result of this calibration for the upleg and downleg is shown in Figure 6. Note that the probes agree fairly well if the vehicle potential and plasma temperature are taken into account, no further calibration factors are necessary.

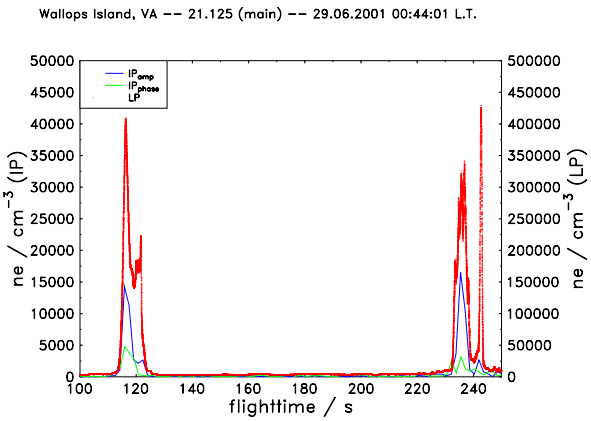

Fig. 5: Electron density versus time as derived from the impedance probe amplitude and phase data, as well as from the Langmuir probe.

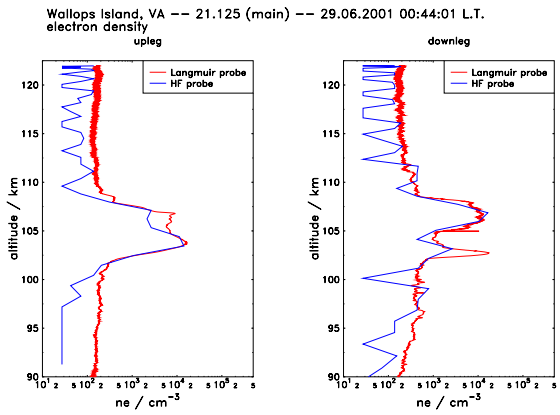

Fig. 6: Electron density profiles for upleg and downleg from the impedance probe and the calibrated Langmuir probe.

THE LOWER RESONANCE

The lower frequency amplitude increase is observed only in the layer and is not a regular feature of all of the data. This second “peak” does not represent the dip in the resonance, but the phase change might be related to the phase change which appears between the two “peaks”. The increase at the lower frequency is currently unexplained. It may be due to the dominance of metallic ions in the layer. It is not likely due to spatial or temporal changes during the 100 msec sweep. Additional work is being carrier out using these data to search for the lower resonance.

ACKNOWLEDGEMENTS

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