Advances in the design and performance of Langmuir probes and Plasma Impedance Probes built at Utah State University

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Abstract:

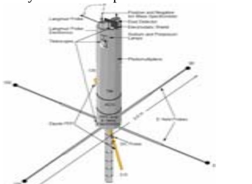
Electron density measuring instruments are one the most widely used class of space instrumentation. Two of the prime instrumentation techniques for measuring electron density are the Langmuir probes and Plasma Impedance Probes. While Langmuir probes are able to give higher resolution electron density and plasma temperature measurement, Plasma Impedance Probes give absolute electron density measurements irrespective of spacecraft charging. Over the last decade Utah State University has flown a number of Langmuir probes (both sweeping and fixed bias type), and Plasma Impedance Probes (dipoles, monopoles, and patch antennas) on sounding rockets with NASA. The various generations of these instruments have had variable degree of success and the lessons learned continue to help us improve their performance with innovative designs, miniaturization, and manufacturability. This paper shall talk about the various instrument designs flown, their performance and the geophysical results that the datasets have provided. In particular we emphasis the use of heated Langmuir probe sensors and novel patch antennas for impedance probes.

Advances in Langmuir Probes

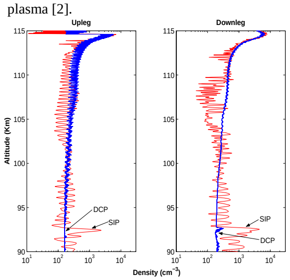
Langmuir probes were the first in-situ measurement technique used for ionospheric plasma density and temperature. The theory behind the instrument is simply to apply different voltages to a probe, measure the resultant current, and then deduce the density and temperature based on the obtained I-V curve. Utah State has pursued two implementations of this basic technique. The first being that of a fixed bias DC Langmuir probe giving high resolution relative electron density measurements, and the second being that of the traditional sweeping Langmuir probe which gives an I-V curve for determination of absolute electron density and temperature. Presented below are the various probe designs from recent flights along with the observed impedance data as well as the latest probe design.

SAL

The Sudden Atom Layer payload was launched February 19, 1998 at 20:09 LT from Puerto Rico into the nighttime D and E ionospheric regions [1]. The experiment was conducted in conjunction with Cornell University and the University of New Hampshire.



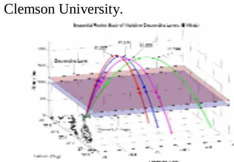
The payload carried a Utah State fixed bias DC Langmuir Probe (DCP) along with a Plasma Impedance Probe. The DCP dataset along with the payload skin channel showed an anomalous spacecraft charging event. An analysis of that event using a spacecraft charging model turned out to be the first reported observation of triboelectric charging event seen in space plasma [2].



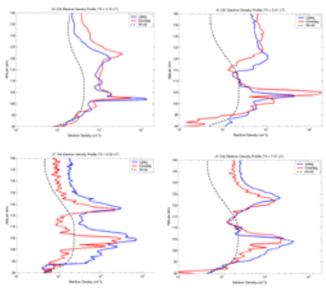
SAL Observed Electron Density

E-Winds

As part of the Sequential Rocket Study of Nighttime Descending Layers or E-Winds mission, Utah State instrument suites were flown on a series of four sounding rockets launched at 3:19, 5:41, 6:50 and 7:07 UT on July 1, 2003 from Wallops Island, Virginia into the nighttime D- and E-regions [3][4]. This experiment was conducted in conjunction with the University of Texas at Dallas and Clemson University.



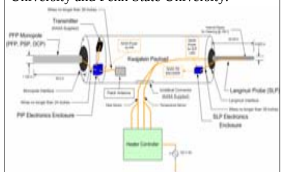
Similar to the SAL mission, all the four E-Winds payloads carried a DCP for relative electron density measurement. The instruments worked as expected and provided electron density profiles that showed the presence of intermediate layers.



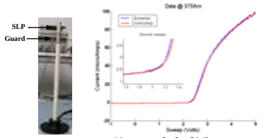
E-Winds Electron Density Profiles

EQUIS II

On August 7th and 15th of 2004 two payloads were flown as part of NASA's EQUIS II campaign conducted at Kwajalein Flight Facility[5][6]. This experiment was conducted in conjunction with Cornell University and Penn State University.

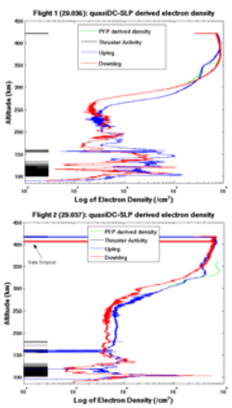


Besides carrying a DCP biased at +3 V on the PIP boom this payload also carried an internally heated Sweeping Langmuir Probe (SLP) that was swept from -1 to +5 Volts at 50 Hz. The cylindrical probe was guarded on one side. The internal heating of the probe for several hours at 150°C kept the surface clean and nearly eliminated any hysteresis between consequent sweeps.



Hysteresis in SLP sweeps

The area ratio of payload surface to that of the SLP surface was only about 300. This warped the I-V curves and makes extraction of temperature data extremely difficult. The SLP data was used in a Quasi-DC sense to derive electron density profiles.

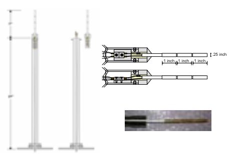


Electron Density Profiles

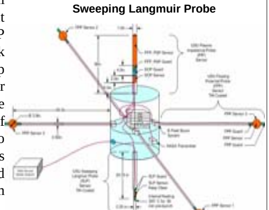
Storms Mission

USU is providing SLP and DCP for the NASA sounding rocket mission titled "Investigation of Mid-Latitude Ionospheric Irregularities Associated with Terrestrial Weather Systems" or Storms Mission, which is being led by the University of Texas at Dallas.

Although both the the instruments have the same electrical designs as that flown on the EQUIS II mission, the instrument sensitivity and operating voltages are different. The DCP situated on the PIP boom is being operated at -7 V, so as to work in the ion saturation region, while the SLP is going to sweep from -1 to +3 V once every 20 seconds and work as another DCP operating in electron saturation region at +3 V for the remainder of the time. The SLP noise floor was in units of nanoamps for the EQUIS II flights but has been now reduced to a few 100s of picoamps. Furthermore, the current SLP design is internally heated using a nichrome wire and the probe is guarded on both the sides. The probe is also coated with Titanium Nitride.



Sweeping Langmuir Probe



Storms Payload

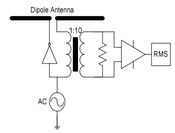
Advances in Plasma Impedance Probes

The impedance characteristics of an antenna immersed in an ionospheric plasma have been used to determine electron density for over 30 years. Utah State University has flown a number of Plasma Impedance Probes (PIP) on sounding rockets with NASA including dipoles, monopoles, and patch antennas. These probes have traditionally consisted of two parts: Swept Impedance Probe (SIP) that measures plasma impedances at various frequencies and Plasma Frequency Probe (PFP) that lock on and track the upper hybrid resonance. Presented below are the various probe designs from recent flights along with the observed impedance data as well as the latest probe design.

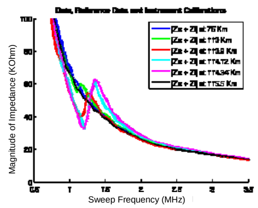
SAL

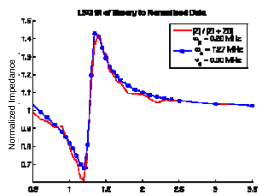
The SAL PIP antenna was differentially driven with a 1-Volt sinusoidal signal, with a frequency sweep at 40 fixed frequencies ranging over 0.2 - 12 MHz, at the rate of 96 sweeps per second. The magnitude of current flowing to the antenna was monitored using an RF current transformer.

The SIP Impedance data was fit using Balmain's model and profiles of electron density were recovered. A reference profile from 75 km, where there was no plasma, was used to normalize the data before fitting.



Impedance probe circuit

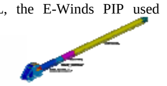


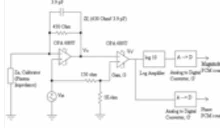


Balmain Curve Fit Example

E-Winds

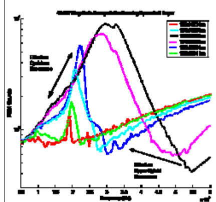
The E-Winds mission PIP suite, besides having the usual SIP and PFP working at electron frequencies, (0.5 to 20 MHz) also contained a SIP operating at ion frequencies (1-60 kHz). Both the electron and ion SIPs used a quasi logarithmic distribution of 256 sample frequencies, with the ion SIP sweeping at a much lower rate. Unlike SAL, the E-Winds PIP used a monopole boom.



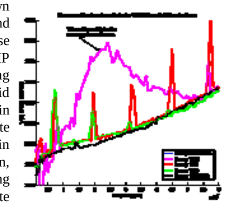


Impedance probe circuit

The current signal in this version of the PIP was sensed using an operation amplifier in a transimpedance configuration. The SIP operating at electron frequencies provided data throughout the flight. This dataset is still in the process of being analyzed. The PFP locked on to upper hybrid resonance only for a short while during #41.035 and was used to normalize the DC probe dataset giving electron density profiles.

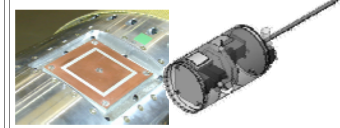


It was not until the down leg of flight #41.037, and upon entering a dense layer, that the Ion PIP observed something similar to lower hybrid resonance as is seen in Plasma Fluid – Finite Difference Time Domain (PF-FDTD) simulation, which is also being developed at Utah State University.



EQUIS II

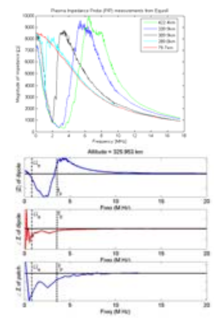
Each of the EQUIS II payloads carried two different types of PIPs. The first PIP was the traditional monopole boom and of the same design as flown on the E-Winds mission. The second PIP made use of an experimental patch antenna that was mounted on the side of the rocket.



Patch Antenna

The dipole PIP used a distribution of 256 sample frequencies, and the patch used 32 frequencies sampled at the same rate as the dipole.

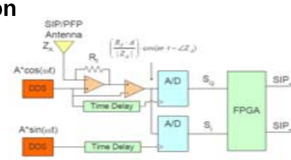
Both probes measured the expected results, when compared to model data, with the exception of an additional series resonance that appears to be the sheath resonance. Additional research is under way to validate this concept.



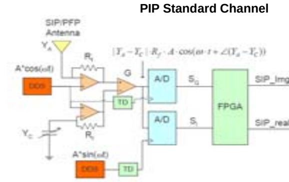
Storms Mission

Besides the SLP and DCP, USU is also providing the next generation PIP for the NASA Storms mission. The Storms PIP design reuses the magnitude detector used in E-Winds design but implements a different phase detector. As the reference-signal-comparator based phase detector implemented in E-Winds version of the instrument did not perform well under low signal conditions, the phase is detected in the Storms instrument using a quadrature sampling detector. In this method, two high-speed A/D converters are used to sample the current signal at the frequency of the drive signal, but one quarter of the period delayed from each other. The standard channel measures the antenna current in real and imaginary components, whereas the difference channel measures the change of the current signal from the free space capacitance current signal. Thus, the difference channel should be able to give a better dynamic range in high density plasma.

The Storms mission was to have flown in the Fall of 2006, but has been postponed indeterminately.



PIP Standard Channel



PIP Difference Channel

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