RPC-LAP: THE ROSETTA LANGMUIR PROBE INSTRUMENT

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Abstract. The Rosetta dual Langmuir probe instrument, LAP, utilizes the multiple powers of a pair of spherical Langmuir probes for measurements of basic plasma parameters with the aim of providing detailed knowledge of the outgassing, ionization, and subsequent plasma processes around the Rosetta target comet. The fundamental plasma properties to be studied are the plasma density, the electron temperature, and the plasma flow velocity. However, study of electric fields up to 8 kHz, plasma density fluctuations, spacecraft potential, integrated UV flux, and dust impacts is also possible. LAP is fully integrated in the Rosetta Plasma Consortium (RPC), the instruments of which together provide a comprehensive characterization of the cometary plasma.

Keywords: Rosetta, Langmuir probes, space instrumentation, cometary plasma, plasma density measurements

1. Introduction

Rosetta provides a unique opportunity to study a comet at close range for a long time and in conditions varying from the (at least relative) inactivity at 3–5 AU through the onset and development of full outgassing activity at perihelion close to 1 AU. The Rosetta Plasma Consortium (RPC; Carr *et al.*, in press) exploits this opportunity to study the comet and its environment by providing a set of instruments covering most aspects of the cometary plasma, among them a two-probe Langmuir probe instrument (LAP; Figure 1).

The primary tasks of LAP are to measure the fluid parameters of plasma density, electron temperature, and plasma flow speed, essential for any characterization of the cometary plasma. However, LAP is a multipurpose instrument, also providing information on a number of secondary science goals: plasma density fluctuations, electric field measurements up to 8 kHz, spacecraft potential, the integrated solar UV flux, the effective ion mass and dust particle impacts (see also Table I). The scientific problems to be investigated are discussed in Section 2, while the measure-

†The LAP Team is listed in Table III.

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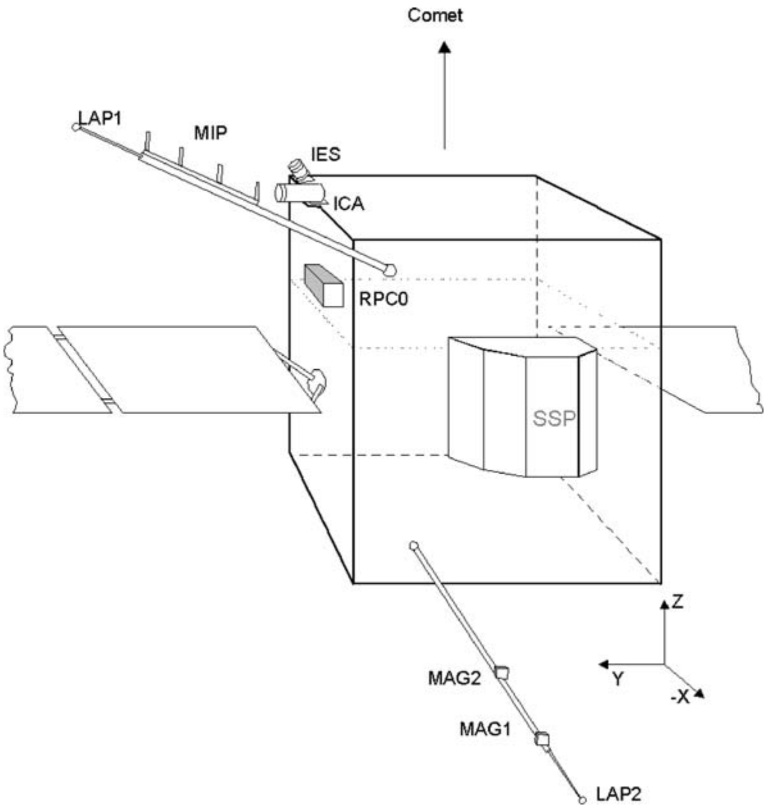

Figure 1. Mounting of the RPC sensors on the Rosetta spacecraft. The LAP spherical probes, LAP1 and LAP2, are mounted at the tips of the stiff booms. Table II gives additional detail on the geometry of the probe mounting. The LAP electronics boards are housed in the common electronics box, RPC-0, described by Carr *et al.* (in press).

ment principles are outlined in Section 3. Section 4 is an overview of the instrument design, and Section 5 presents the LAP team.

2. Scientific Objectives

The LAP science objectives relate to the general scientific objectives of the Rosetta mission and of the RPC consortium. The special features of LAP make it particularly useful for the following studies, among others:

1. By monitoring the development of plasma density, electron temperature, and flow speed from the onset of cometary activity to the perihelion, LAP will significantly improve our view of cometary outgassing and the formation and structure of the cometary plasma environment.

TABLE I
Summary of parameters accessible for LAP.

Quantity	Range
Plasma density	1–10^6 cm^{-3}
Electron temperature	~10 meV–10 eV (100–10^5 K)
Plasma drift velocity	Up to 10 km/s
Electric field fluctuations	Up to 8 kHz
Plasma density fluctuations	0.05–50%
Spacecraft potential	±30 V
Effective ion mass (weighted harmonic mean[a])	1–100 AMU
Integrated solar EUV flux	For $n_e < 1{,}000\,cm^{-3}$

The entire parameter range for a given parameter may not be accessible in one single operational mode, or for any plasma parameters. For example, the lowest limit of sensitivity to plasma density fluctuations can only be obtained in the highest density plasmas.
[a]The density and flow speed are assumed to be known.

2. By studying the time and space variations of the fluid parameters of the inner coma, LAP will pave the way for a detailed understanding of this region, including the diamagnetic cavity where no in-situ observations have been made previously.
3. By its ability to measure the plasma density structures, LAP can investigate the dynamic features in the cometary environment that can be compared to and linked to comet surface events as observed by other Rosetta orbiter instruments.
4. By measuring the density fluctuations and the electric field variations from zero frequency up to 8 kHz, LAP will be able to investigate the stability and dynamics of the cometary plasma environment in different stages of cometary activity. This is of particular interest on and inside the contact surface (diamagnetic cavity boundary), which defines the inner limit of penetration of magnetic fields and plasma of solar wind origin into the cometary plasma environment (Cravens and Gombosi, 2004).
5. By the analysis of the LAP data together with the data from other RPC instruments, the investigation of a broad range of problems that no single RPC instrument could cover on its own will be possible. Examples are interactions between low-frequency waves and plasma particles (LAP-ICA-IES), MHD waves and contact surface properties (LAP-MAG), and wave–wave interactions (LAP-MIP).

3. Measurement Principles

A spherical Langmuir probe is a conceptually simple device but is nevertheless able to provide data on a multitude of plasma parameters. The use of two probes extends

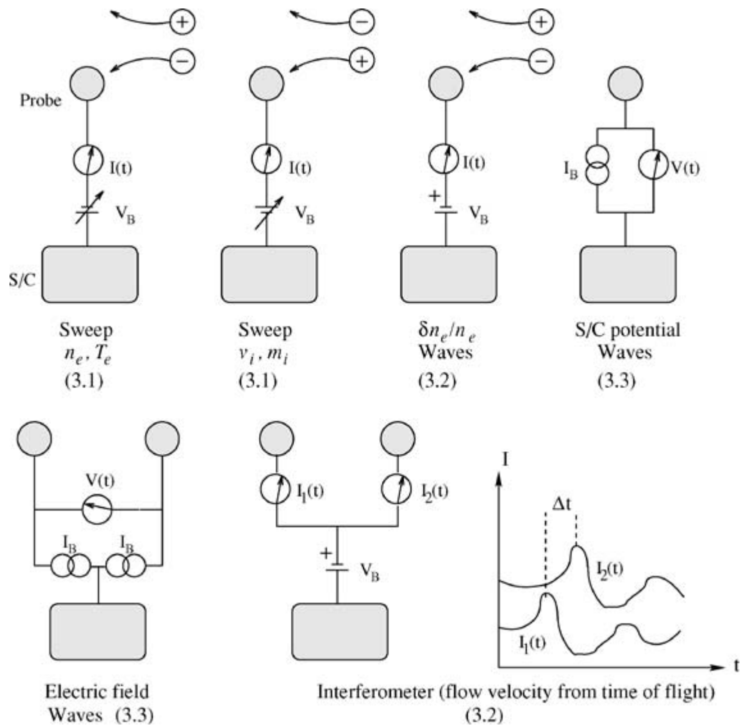

Figure 2. Principles for LAP measurements. Numbers in parenthesis refer to sections in the text.

these possibilities further, particularly when coupled with versatile electronics. LAP implements several measurement principles, as described later and illustrated in Figure 2.

3.1. Bias Voltage Sweeps

For the measurement of electron number density and electron temperature, the standard measurement technique is the Langmuir probe bias sweep. The probe potential with respect to the spacecraft, V_B, is varied and the current collected by the probe, I_P, is recorded. On comparison with the theoretically predicted current–voltage relations, the plasma parameters can be inferred, as is routinely done in the laboratory as well as in space, including the Vega flyby of comet Halley (Grard *et al*., 1989) and Cassini at Saturn and Titan (Wahlund *et al*., 2005b). During the Rosetta mission, LAP will encounter wide range of different plasma regimes, and the appropriate probe theory will vary accordingly. A few sample bias sweeps, obtained in different space environments, are found in Figure 3.

For a probe at positive potential with respect to the plasma, electrons dominate the collected current. The electron number density n_e and the electron temperature

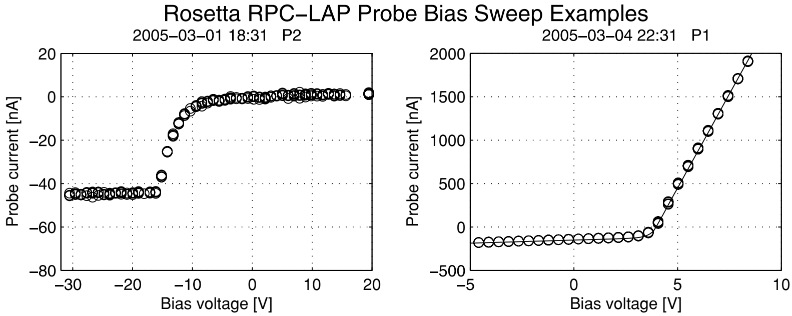

Figure 3. Two LAP probe bias sweeps obtained in very different plasma environments during the first Rosetta Earth flyby. *Left*: Sweep dominated by probe photoemission in a very tenuous plasma in the geomagnetic tail. *Right*: Central part of a sweep obtained in a dense plasma in the terrestrial plasma sphere, with the theoretical curve for $n_e = 1{,}100\,\mathrm{cm}^{-3}$ and $T_e = 0.32\,\mathrm{eV}$ indicated.

T_e can be determined from this part of the probe curve, if T_e stays above a limit, which depends on the spacecraft electrostatic cleanliness and stability as well as on the homogeneity of the probe surface (Section 4.1). Below this limit, only combinations like $n_e/\sqrt{T_e}$ can be directly obtained. The lowest T_e values yet encountered by Rosetta in space have been a few tenths of an electronvolts (during the first Earth flyby). These could be well resolved, but still cooler plasmas are only expected in the inner coma, so the low-temperature limit cannot be verified in space until Rosetta arrives at the comet. From the observed noise levels and probe performance, we expect the temperature to be in the tens of millielectronvolts range.

At negative potentials, positive ions are collected. For supersonic ion flow (flow speed above thermal speed), which is expected to be the case in the inner coma, one can derive an average ion drift kinetic energy. If the flow speed (Section 3.2) and ion charge are known, an estimate of the effective ion mass m_i (Wahlund *et al.*, 2005b) is provided.

In a sufficiently tenuous plasma in sunlight, photoelectrons emitted from the probe and the spacecraft dominate over the actual plasma particles in the collected probe current. In order to control this effect, the position of the LAP probes on Rosetta has been chosen so as to increase the probability of one of them (probe 2, Figure 1), being at times shadowed by the spacecraft structure. When the photoelectron current emitted by the probe can be measured, it can be used to estimate the integrated solar EUV flux (Brace *et al.*, 1988; Mahajan *et al.*, 1998), which, in turn, can give information on the gas and dust in a column of the coma from the spacecraft towards the Sun.

Two example probe bias sweeps from the first Rosetta Earth flyby are shown in Figure 3, which illustrates the wide variation in the plasma regimes encountered by Rosetta. The sweep on the left was made in the far tail of the Earths magnetosphere, where the plasma density is well below $1\,\mathrm{cm}^{-3}$. For negative bias, the current is nearly constant at the probe photoemission saturation value. A hint of electron collection can be seen at the positive end of the sweep as a slight positive slope (around 0.1 nA/V) of the curve. While this can possibly be due to the natural plasma electrons, we cannot exclude that this small current is due to the photoelectrons emitted by the spacecraft and solar panels.

In this very tenuous plasma, the parameters that can be safely derived therefore mainly relate to different aspects of photoemission. The photosaturation current, which can be used for solar EUV flux estimates (Brace *et al.*, 1988; Mahajan *et al.*, 1998), is found to be 45 nA. From the curved part of the measured sweep, we can infer the energy distribution of the emitted photoelectrons (Grard, 1973), which, in this case, yields a main population with a characteristic energy of 1.2 eV and a second population at 7.1 eV.

The spacecraft potential with respect to the location of the probe, $V_S = 16.5$ V, is found from the negative of the bias value at the knee of the current, indicated by the vertical line. As the Debye length is long in a tenuous plasma, there is no significant shielding over the boom length. A significant portion of the spacecraft potential field may therefore decay outside of the probe location, so that our value is likely to be an underestimation of the true spacecraft potential to infinity. Even if the characteristics of the very tenuous natural plasma cannot be directly observed by the probe, the plasma density n_e is still accessible indirectly from V_S (Section 3.3).

The example on the right in Figure 3 shows the central part of a probe bias sweep acquired in the Earth's plasmasphere, where the plasma is much denser. Consequently, the probe current was some 2 orders of magnitude greater than in the previous example, reaching $10\,\mu$A at the positive end of the sweep (not shown). A fit of the sweep to theoretical expressions (Brace, 1998; Fahleson *et al.*, 1974; Mott-Smith and Langmuir, 1926) is also shown. From this fit, we get the plasma density $n_e \approx 1{,}100\,\mathrm{cm}^{-3}$, electron temperature $T_e \approx 0.32$ eV, and spacecraft potential -3.9 V. The photoelectron saturation current, here found to be 74 nA, is more uncertain than in the first example, as the plasma ions and electrons now dominate the probe current.

3.2. Probe Current Fluctuations

By keeping the probe bias voltage constant (usually positive), one can study the changes in the probe current caused by variations in plasma density and temperature. By assuming isothermal or adiabatic conditions, we can estimate the relative electron density variations, $\delta n_e / n_e$, up to a frequency, which varies with the plasma frequency but can be determined from a probe bias sweep and electronics performance (Eriksson and Boström, 1998). Above this frequency, the current is mainly due to the capacitive coupling with the voltage fluctuations in the plasma, so that we measure the electric fluctuations rather than the density fluctuations at high frequencies.

By using two probes separated in space, one can study the propagation properties of the waves and the plasma structures (Holmgren and Kintner, 1990). LAP will use this to derive the plasma flow velocity component in the direction of the probe separation by a time-of-flight measurement. In the inner coma, particularly inside the contact surface, the plasma flow is coupled with the neutral gas by frequent ion–neutral collisions (Gombosi *et al.*, 1999), so LAP can also provide information on the flow speed of the neutral gas. This coupling also limits the plasma flow speed to around 1 km/s, corresponding to a time delay of a few milliseconds between the LAP probes. The LAP fundamental sampling frequency of 18,750 Hz (Section 4.2) ensures that such time delays can be well resolved. In addition, the high sampling frequency for these flow speed range enables resolution of plasma scale lengths below 1 m.

The affects of dust on the spacecraft can produce plasma clouds, which, in turn, result in voltage pulses on the exposed probes. This effect has been used during comet flybys for dust studies by wave electric field instruments (Trotignon *et al.*, 1987) and by Langmuir probes (Laakso *et al.*, 1989), which are both possible modes of operation for LAP. For particle sizes on the order of 1 mm, the expected threshold velocity for producing a plasma cloud whose expansion causes a detectable signal on the probes is of the order 100 m/s, which is sufficiently small to enable LAP to detect dust particles around the comet.

3.3. Electric Fields and Spacecraft Potential

As an alternative to controlling the probe bias voltage, the LAP probes can also be operated with a controlled bias current, I_B, generally chosen to be such as to minimize the affect of changes in the plasma parameters on the probe sheath voltage. In this current bias mode, the measured quantity is the potential between the probe and the spacecraft, V_{PS}. The difference in V_{PS} for the two probes provides an electric field estimate when divided by the probe separation. This technique has been widely used for electric field measurements in space, including the Vega comet encounters (Grard *et al.*, 1989; Pedersen *et al.*, 1987). Letting the probe potentials float freely, with no applied bias current, is also possible, as is usually advantageous for electric field measurements in dense plasmas (Maynard, 1998). While measurements of the quasi-static electric field in low-density situations (Debye length $\lambda_D >$ boom length L) are complicated by asymmetries in the boom mountings and potentials from the spacecraft, the ac electric field is well monitored up to 8 kHz. Frequencies above 7 kHz are covered by the MIP instrument (Trotignon *et al.*, in press).

The value of V_{PS} also gives a proxy for the spacecraft potential with respect to the plasma, V_S. This is the basic parameter determining the spacecraft–plasma interaction and provides an estimate of the number density in tenuous plasmas (Pedersen, 1995). Pedersen *et al.* (1987) used V_{PS} measurements from Vega to infer electron densities and temperatures during the encounter of Vega with Halley

Figure 4. LAP hardware. On the *left*, one of the two probes; On the *right*, the top of the RPC-0 electronics box with the lid open, exposing the LAP analog board. The probe and its supporting rod (stub) are made of titanium with a titanium nitride coating.

comet. In addition, the knowledge of V_S can support the analysis of the data on the low-energy ions and electrons from particle instruments like ICA, IES, and ROSINA (e.g., Engwall *et al.*, 2006).

4. Instrument Description

4.1. Sensors

The LAP sensors are spheres of 2.5 cm radius, mounted on 15 cm "stubs," which, in turn, are attached to the ends of the spacecraft booms by a "foot" (Figure 4). Probe 1 (often referred to as P1 or LAP1) is mounted on the "upper" spacecraft boom, also carrying the MIP antenna (Trotignon *et al.*, in press). This boom, which is 2.24 m in length from hinge to probe, is protruding from the spacecraft at an angle of 45° to the nominal comet direction (the z axis in Figure 1; see also Table II). By pointing to the comet, probe 1 will get access to a plasma flow from the comet as undisturbed as possible by any spacecraft sheath or wakes, without interfering with the field of view of other instruments. Probe 2 is mounted on the "lower" boom, 1.62 m in length, which also carries the MAG sensors (Glassmeier *et al.*, in press). The distance between the probes is 5.00 m, and the probe separation in the nominal comet direction, relevant for flow measurements with the interferometry technique (Section 3.2), is 4.55 m.

TABLE II
Positions in the spacecraft coordinate system, indicated in Figure 1, for the LAP probes and for the hinges at the boom roots.

	x (m)	y (m)	z (m)
Probe 1	−1.19	2.43	3.88
Hinge 1	−1.19	0.85	2.30
Probe 2	2.48	0.78	−0.65
Hinge 2	−1.19	0.65	0.30

The probes are lightweight (40 g) titanium shells, and the stubs are made from the same material (Figure 4). The probes are electrically insulated from the stubs, but the stub is bootstrapped to the same potential as the adjacent probe by the instrument electronics (Section 4.2). Probes and stubs have a coating of titanium nitride (TiN), applied by TiSurf International, Uppsala, Sweden. The work function of TiN is very homogeneous: about 15 meV variation over the probe surface has been found in the laboratory (Wahlström *et al.*, 1992), enabling electron temperature measurements down to the same range of values (Brace, 1998). In addition, TiN is mechanically robust and chemically inert. This is a major advantage for Rosetta, designed for a long cruise phase and a long time in the dusty and ion-rich environment of the coma. A single probe, identical to the LAP sensors, is operational with the Cassini RPWS instrument (Gurnett *et al.*, 2004), providing excellent data (Wahlund *et al.*, 2005a,b) with no sign of degradation with time since the launch in 1997. TiN probes were also successfully used by the LINDA (Holback *et al.*, 2001) and EMMA (Blomberg *et al.*, 2004) instruments on the Astrid-2 microsatellite. The foot, interfacing the probe to the tip of the spacecraft boom and seen at bottom of the probe in Figure 4, is made of aluminium with an anodized surface.

4.2. Analog Electronics

The LAP electronics are mounted on two circuit boards in the RPC-0 common electronics box (Carr *et al.*, in press). One of the boards holds the digital processing unit (DPU), while the other (Figure 4) contains the sensor analog electronics interfacing the DPU to the LAP sensors.

The analog electronics are designed so that the two probes have identical capabilities and can be operated independently of each other. For example, both can be operated in any of the two bias modes (voltage or current bias, see Section 3), and the bias mode of one probe can be chosen to be the same or different from the other. This concept of independently operating combined electric field and Langmuir probes is inherited from previous instruments designed by the LAP team, including Freja F4 (Holback *et al.*, 1994) and Cluster EFW (Gustafsson *et al.*, 1997). With this design, it is, for example, possible to do a bias sweep on one probe while monitoring the spacecraft potential with the other probe, or to run one probe at positive voltage bias (ion collection) and the other at negative bias (electron collection).

The two spheres can be individually biased within the range ± 31 V when in Langmuir mode, and within ± 44 nA in electric field mode. At the comet, the spacecraft potential is expected to stay between a fraction of a volt negative in the densest plasmas at the comet (Roussel and Berthelier, 2004) and below 10 V positive in the solar wind, so the bias voltage range will be sufficient in all plasmas of interest. During commissioning and the first Earth flyby, the photoemission saturation current from the probes at 1 AU has been observed to be around 50–80 nA (see Figure 3 for an example). Optimal biasing for electric field measurements in tenuous plasmas typically is around half the saturation current, so the bias current range is sufficient for all mission phases.

Probe bias voltage sweeps can be performed over the full measurement range at resolutions down to 0.25 V using one 8-bit digital-to-analog converter (DAC) for each probe. In the inner coma, electron temperatures (in eV) are expected to be below this minimum step size value. To properly resolve lower values of T_e, it is possible to perform high-resolution sweeps at step sizes down to 10 mV over ± 1.2 V around an offset bias, which can be set by command or onboard software to values in the range -8 V to $+9$ V. The offset bias is provided by a third 8-bit DAC, using 4 bits for each probe, while the output from the two other DACs is divided by 25 to give the desired bias resolution. Electrostatic cleaning (Brace, 1998) of the probes is provided by the ± 31 V bias voltage.

Probe 2 can be used by the MIP instrument for its long-Debye-length (LDL) mode (Trotignon *et al.*, in press). In this mode, MIP uses LAP probe 2 for transmission and the MIP antenna on the upper boom for receiving, thereby getting a longer base line, appropriate for low plasma densities. Electronics for the generation of the MIP signal are included on the LAP analog circuit board. LAP cannot use probe 2 at the same time as MIP but can continue measurements using probe 1 only or time-share probe 2 with MIP. There is also an internal LAP Tx mode, where we can generate a signal for a limited propagation experiment at frequencies well below MIP (up to 1 kHz) and at small amplitude.

The input stage of the electronics for one of the probes is illustrated in Figure 5, showing this probe configured for measurements in the current bias (electric field) mode. The diagram includes the switches for bias mode (electric field or current), calibration modes, and measurement range, to be described later.

The plasma densities expected during the Rosetta mission spans some 6 orders of magnitude, from sometimes below 1 cm^{-3} in the solar wind to possibly as high as 10^6 cm^{-3} in the fully developed cometary coma. This implies an approximately equal variation in probe currents, though there is little need to cover the full bias voltage range in the densest plasmas. Two measurement ranges are therefore

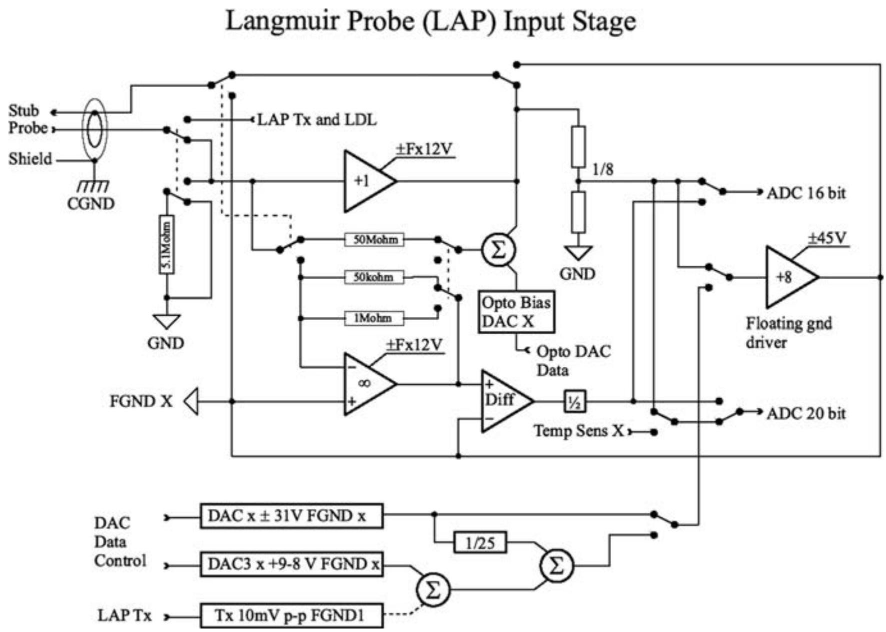

Figure 5. Block diagram of the input stage for one of the two LAP probes. With switches in this position, the instrument is configured for electric field mode.

implemented: low gain spanning $\pm 10\,\mu$A, and high gain spanning $\pm\,200\,\mu$A. The voltage measurements (electric field mode, Section 3.3) always cover $\pm\,40$ V.

There are two internal calibration possibilities. The bias circuitry can be decoupled from the probe, so that no current flows to or from the probe: any current recorded when performing a bias sweep in this mode is entirely due to offsets in the electronics, particularly temperature dependent offsets in differential amplifiers, which can thereafter be removed from the data. By sweeping over a 5.1 MΩ resistor, it is possible to obtain the calibration factor of the probe current. This is not expected to vary during the mission, but this internal calibration verifies the integrity of the instrument.

Two analog-to-digital converters (ADCs) are connected to each probe: one 16 bit, operating at 18 750 samples/s, and one 20 bit, acquiring 57.8 samples/s. The inclusion of two ADCs for each probe makes it possible to save processing power in low-telemetry mode operations and provides some redundancy. Three four-pole analog low-pass filters are implemented for each probe: two filters, selectable by multiplexor, for the 16-bit ADCs with corner frequencies at 4 and 8 kHz, and one for the 20-bit ADC, with corner frequency 20 Hz. Additional digital filtering is available in software (Section 4.4). The frequency response characteristics of the LAP analog electronics, including the filters, are shown in Figure 6.

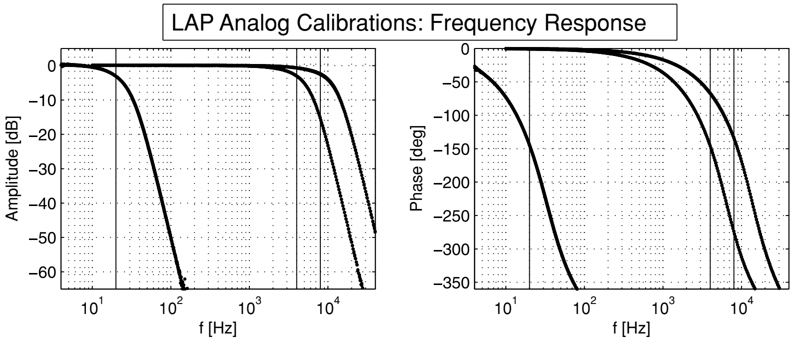

Figure 6. LAP frequency response as measured during pre-flight calibrations, identical for both probes to the accuracy of this plot. All three filters are shown, with nominal corner frequencies indicated by vertical lines at 20 Hz, 4 kHz, and 8 kHz. The filters are linear to good accuracy in the pass band, with group delay times of 20, 0.1, and 0.05 ms, respectively.

4.3. Digital Electronics

The LAP DPU, illustrated in Figure 7, is designed around a Texas Instruments TMS320C50 DSP, running at 24 MHz, and an Actel 1020 field-programmable gate array. In addition to controlling the operations of LAP, the processor can perform onboard signal processing in order to optimize the use of limited telemetry (see Section 4.4). The FPGA includes a watchdog functionality to catch possible radiation induced anomalies in the processor operations. For redundancy, there are two oscillators, of which one is selected by the FPGA at boot time.

The flight software is stored in a 256-kbit rad hard PROM, with the possibility of in-flight patching to a 4-Mbit EEPROM. The flight software, written in Assembler, runs from a 1-Mbit RAM. There is also an 8-Mbit mass memory, which is mainly used for buffering raw data before processing and for storing data packets waiting for transmission. All data, commanding and power links to and from LAP goes to the Plasma Interface Unit, RPC-PIU (Carr *et al.*, in press). The communications with the PIU are handled by a dedicated link chip, implemented in an Actel 1280 FPGA provided by Imperial College.

4.4. Telemetry and Mode Concept

LAP can transmit data to the PIU at three different rates: 1.6 bits/s (low telemetry rate, or LM), 62.5 bits/s (normal telemetry rate, or NM) or 2,253 bits/s (burst telemetry rate, or BM). Even the highest telemetry rate barely allows the transmission of all data produced by even the two low rate 20-bit ADCs, and nothing near the 600 kbits/s produced by the two high rate 16-bit ADCs can ever be transmitted. The flight software includes routines for digital filtering, downsampling, and Fourier (FFT) analysis in order to bring down the data volume. For the highest frequencies,

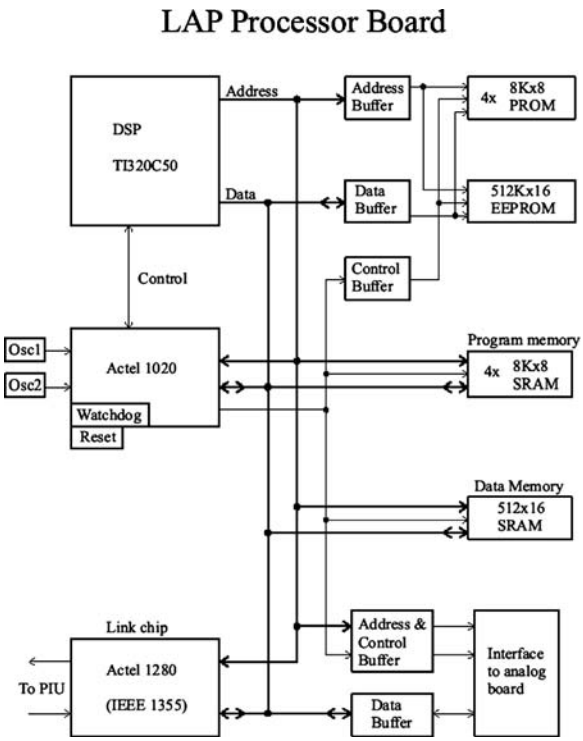

Figure 7. Block diagram of the LAP digital electronics.

the main approach is to take data at full time resolution during a short time span to get information on phase as well as amplitude for any observed waves. This "snapshot" technique proved fruitful on, e.g., the Freja mission (Holback *et al.*, 1994).

To provide flexibility over the mission lifetime of more than 10 years, the instrument operational modes are defined as "macros," i.e., repeatable command sequences that can be uploaded to the spacecraft and stored either in EEPROM for execution at any time or directly into RAM for immediate use. A set of basic macros are also included in PROM. The macros can control any aspect of the instrument, including bias modes, bias values, measurement range, sweeps, analog and digital filtering, and ADC selection. There is one default macro for each telemetry mode, mixing the basic measurements of probe bias sweeps and snapshot sampling at 18,750 Hz, and other macros have been defined for specific scientific tasks, e.g., interferometric measurements or electric field monitoring. There are also macros for use with MIP in its LDL mode (Section 4.2 above), using only probe 1, or time-sharing probe 2 with MIP. The macro programming makes it possible to optimize operations for each science task and mission phase without need for large command uplink volumes: the macros are short lists, and once loaded, they are

TABLE III
LAP institutes, RPC co-investigators tied to LAP, key technical personal, and their contributions.

Institute	Co-investigators and key technical personnel (italics)	Main responsibilities and scientific expertise
Swedish Institute of Space Physics, Uppsala	A. I. Eriksson (PI), L. Åhlén (TM), M. André, R. Boström[a], R. Gill, G. Gustafsson, B. Holback[b], G. Holmgren[b], S.-E. Jansson, K. Stasiewicz, H. Thomas, J.-E. Wahlund	Overall management, design, sensors, analog electronics, flight software, harness, ground testing, flight operations; expertise on waves, Langmuir probes, plasma structures, data analysis, planetary plasma measurements
Finnish Meteorological Institute, Helsinki	A. Mälkki, P. Riihelä	Digital electronics; expertise on planetary system plasmas, data analysis
Alfvén Laboratory, Royal Institute of Technology, Stockholm, Sweden	L. G. Blomberg, P.-A. Lindqvist, G. Olsson	DC/DC converter; expertise on probe measurements, electric fields
Department of Physics, University of Oslo, Norway	J. A. Holtet, B. Lybekk, A. Pedersen, E. Trondsen	Ground support equipment, ground test support, flight operations support; expertise on data analysis, probe measurements
Space Science Department, ESA/ESTEC, Netherlands	R. Grard, J.-P. Lebreton	Expertise on Langmuir probes, comet plasma measurements, propagation experiments
Astronomical Observatory, Uppsala University, Sweden	H. Rickman	Expertise on comets and asteroids
Swedish Institute of Space Physics, Kiruna	C. Norberg	Expertise on Langmuir probes
Rutherford Appleton Laboratory, Chilton, Didcot, England	R. Bingham	Expertise on plasma dynamics, dusty plasmas

[a]Former PI (retired).
[b]Now at Uppsala University.

invoked by a single command sequence. The instrument can also be operated by ordinary direct telecommands. In addition to the science modes, LAP supports a maintenance mode for software patching, memory dumps, and macro uploads.

5. The LAP Team

LAP is a joint effort by groups from several institutes, coordinated by Uppsala Division of the Swedish Institute of Space Physics, which carries the Principal Investigator and Technical Manager responsibilities. The co-investigators and key engineers of each group are listed in Table III, which also shows the hardware responsibilities of each group and some of the areas of scientific expertise contributed to the team.

Acknowledgements

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