Space-Friendly™

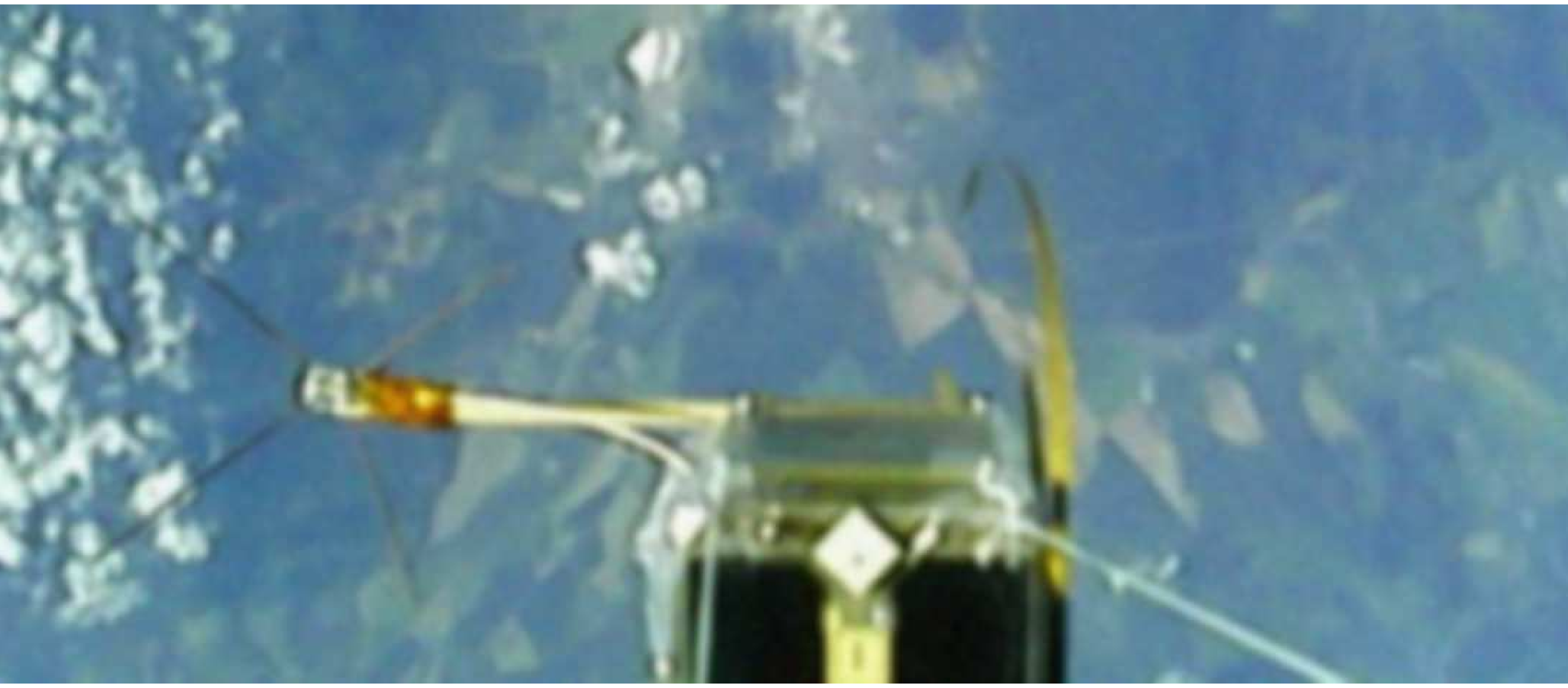
CubeSat **Space Flight & Weather Monitor**

piPLASMA

Product Datasheet

Rev. A/2025

Intended to cover all **CubeSat Project** needs.



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PRODUCT DATA SHEET piPLASMA

FEATURES

- **World's First Space Flight & Weather Monitor**
- **Ion Plasma Langmuir Probe instrument**
- **Langmuir Probe Negative Bias and Preamplifier**
- **Photoelectric Effect Sensor Input and sensing**
- **Solid State Low Power Dosimeter/Geiger Counter**
- **Low Power CubeSat GPS Receiver with DROP (Dead Reckoning Orbital Propagator)**
- **50nT$_{RMS}$ 3-axis AMR Magnetometer**
- **±250°/s (DPS) 3-axis MEMS Angular Rate Sensor**
- **Two ~0.07 Am^2 Magnetorquer Rods with bipolar drivers in X-Y standard CubeSat coordinates**
- **Sample rates 4 Hz, 1 Hz, 0.4 Hz, 0.1 Hz**
- **Ion Density measurements spatial resolution down to 1.9 km at SSO LEO velocity**
- **Housekeeping Measurements Engine**
- **Straightforward use – Plug-and-play device**
- **Allow Nonstop Operation with conventional**
  1U CubeSat power budget
- **Power consumption**
  165 to 640 mW (peak), 3.3 V @ 25°C
- **GPS L1 C/A signal, 15 channels, LEO operation**
  Altitudes up to 3600 km
- **Velocity**
  up to 9 km/s (Flight Model)
  up to 0.5 km/s (Engineering Model)
- **Cold start time in LEO (Time-to-First Fix t_{TTFF})**
  80 seconds (typical)
- **Sensitivity**
  Acquisition 38 dBc-Hz, Tracking 25 dBc-Hz
  Short term fading 18 dBc-Hz
- **Protocols**
  Base64 Encoded Output, 1-Byte Command
- **Easy-to-Implement Data Interface**
  UART 9600-8-N-1, 3V3-CMOS levels
- **Position update rate**
  1 Hz
- **2.9 to 3.6V power supply**
- **Low Dimensions, PC/104+ 95.9×90.2×32 mm**
- **Wide temperature range**
  -40˚C to +85˚C
- **Connectors**
  PC/104+ pin header (System Interface)
  3× MCX (GPS Antenna, Langmuir Probe, Photoelectric sensor)
- **Supports High Gain Passive and Active GPS Antennas, DC Bias Output (3.3V @ 50mA)**

APPLICATIONS

- **Space Weather Monitoring on Small Satellites**
- **CubeSats, Pico- Nano- Micro-Sats**
- **Space Science and Engineering**

Fig. 1 PC/104+ CubeSat Space Flight & Weather Monitor, Flight Model, Top side view.

GENERAL DESCRIPTION

The piPLASMA is the World's First Space-Friendly™ CubeSat Space Flight & Weather Monitor unit intended for in-situ orbital and environment measurements. The system consist of the full Langmuir Probe instrument electronics and Probe in Z+/- panel, 3-axis AMR magnetometer, 3-axis MEMS angular rate sensor (gyroscope), solid-state low power Dosimeter/Geiger Counter in non-magnetic finish, ultra low power 15 channel CubeSat GPS L1 receiver with DROP (Dead-Reckoning Orbital Propagator), Active GPS Antenna and a set of two magnetorquer rods to validate the magnetic field measurements and Coarse Attitude Control in X-Y plane, with drivers.

Flight heritage optimized firmware uses the SkyFox Labs' proprietary DROP (Dead Reckoning Orbital Propagator) algorithm to compensate for orbital regions affected by terrestrial jammers penetrating to LEO regions causing GPS signal outage as well as for signal fading caused by improper antenna pointing or satellite tumbling without the need for uplink data.

The Engineering Model (EM) with the same mechanical and electrical properties is available with software limitation to maximum velocity (500 m/s). Red Remove Before Flight Finish is applied to prevent interchange with the Flight Model unit.

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ABSOLUTE MAXIMUM RATINGS

V_{DD} to GND........-0.3 V to +4.2 V
DC Input Voltage: V_I .... -0.3 V to V_{DD} + 0.3 V (≤ 4.2 V max.)
DC Output Voltage: V_O ....-0.3 V to V_{DD} + 0.3 V (≤ 4.2 V max.)
DC Input Current: I_I at V_I < 0 V or V_I > V_{DD} ....±20 mA
DC Output Current: I_O at V_O < 0 V or V_O > V_{DD}........±20 mA
Other Pins to GND:........ -0.3 V to +(V_{DD} +0.3) V
Maximum RF Input Power:........ +15 dBm
Maximum Output Current to the Active Antenna:........50 mA
Operating Temperature Range:........-40°C to +85°C
Storage Temperature Range:........-55°C to +100°C

NOTE: Stresses beyond those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under specification conditions is not implied. Exposure to absolute maximum rated conditions for extended periods may affect device reliability. Voltage values are with respect to system ground terminal.

PARAMETRIC SPECIFICATION

T_A = −40°C to +85°C, V_{DD} = 3.3 V, Active 35×35 mm GPS patch antenna with LNA preamplifier used, unless otherwise noted.

Parameter	Symbol	Min	Typ	Max	Units	Notes/Conditions
Operating Supply Voltage	V_{DD}	2.9	3.3	3.6	V	
Operating Supply Current	I_D	50	155	194	mA	The maximum operational current of up to 185 mA is drawn when GPS and both MTQs are active with full operational mode after the GPS startup boot time of ~30 sec.
Active Antenna Current Feed Capability	I_{Ant}	0		20	mA	Use of an active antenna is recommended for improving the C/N_0 (SNR).
Operating Power Consumption with Active GPS Antenna	$P_{Oper\text{-}Act}$	165	512	640	mW	Minimum power is consumed with GPS and MTQs off.
Acquisition Sensitivity	$P_{RF\ IN\text{-}Acq}$		38		dBc-Hz	SNR required to acquire the GPS signal.
Elevation Mask Filter	ε		3		°	Sats below the mask excluded from PVT.
Tracking Sensitivity	$P_{RF\ IN\text{-}Trck}$	18	25		dBc-Hz	SNR to keep tracking the satellites in view.
PVT Calculation Filter			30		dBc-Hz	Sats below the level excluded from PVT.
Operating Frequency	f_{RFIN}		1575.42		MHz	GPS L1, C/A code.
Operating Bandwidth	BW		2		MHz	
Time-to-First-Fix	t_{TTFF}		80		s	The GPS Cold Start time.
Warm Start Time	t_{WST}		50		s	The GPS DROP Warm Start time.
Horizontal Position Accuracy (2σ)	HPA			10	m	No multipath signals (ionosphere and troposphere delay excluded), HDOP <3 caused by the noise and mutual acceleration of the LEO and GPS satellite ±16 m/s^2.
Dynamic Stress Position Error	$DSPE$			2	m	Caused by the satellite movement in LEO orbit.
Operating Velocity	v	0		9	km/s	For Flight Model only. Otherwise maximum of 500 m/s.
Operating Altitudes	h			3600	Km	Above the WGS84. All orbit inclinations.
Operating Acceleration	a	0		5	g	
Velocity Calculation Accuracy (2σ)	VCE			0.1+1‰·v	m/s	
Radiation sensor energy range	E	~0.2		10	MeV	Probability of capture is given by the sensor geometry, cross section and dose rate.
Doserate range per hour	$\dot{D}$	0.01		9000	µGy/h	Maximum dose rate given by system bandwidth.
Dosimeter Energy range	E	~0.2		10	MeV	Probability of capture is given by the sensor geometry, cross section and dose rate.
Langmuir Probe Impedance range	Z	0		250	GΩ	Maximum sensitivity in maximum resolution and x10 gain, LSB.
Magnetorquer Magnetic Moment	M			~0.07	Am^2	N = 4000 turns, l = 55 mm, I = 27 mA.
3-axis AMR Magnetometer RMS Noise	B		50		nT	1 LSB.
3-axis MEMS Gyroscope Range				±250	°/s	

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CONNECTORS DESCRIPTION

The piPLASMA monitor is connected to the target system via the System Interface **Quad Row 52 pin** connector header (**2.54 mm pitch, PC/104+**). Each pin, its function and direction or manner of use is indicated in the Tab.: 1 below. There are **three** options for RXD, **three** option for TXD and **six** options for Power input selection on the system PCB using zero ohm short connection pads. The connector location within the Flight and Engineering Models is displayed in Fig. 2.

Tab.: 1 The piPLASMA PC/104+ Pin Description.

Pin	Name	Input, Output, Power	Description
H1.1	RXD-A	Input	**Serial Data Input.** Command is expected by standard UART serial transfer at a rate of 9600 bps, no parity, 8 databits, 1 stop bit. LVCMOS compatible.
H1.5	RXD-B	Input	**Serial Data Input.** Command is expected by standard UART serial transfer at a rate of 9600 bps, no parity, 8 databits, 1 stop bit. LVCMOS compatible.
H1.9	RXD-C	Input	**Serial Data Input.** Command is expected by standard UART serial transfer at a rate of 9600 bps, no parity, 8 databits, 1 stop bit. LVCMOS compatible.
H1.3	TXD-D	Output	**Serial Data Output.** Datagrams are present on this pin. Data is provided by standard UART serial transfer at a rate of 9600 bps, no parity, 8 databits, 1 stop bit. LVCMOS compatible.
H1.7	TXD-E	Output	**Serial Data Output.** Datagrams are present on this pin. Data is provided by standard UART serial transfer at a rate of 9600 bps, no parity, 8 databits, 1 stop bit. LVCMOS compatible.
H1.11	TXD-F	Output	**Serial Data Output.** Datagrams are present on this pin. Data is provided by standard UART serial transfer at a rate of 9600 bps, no parity, 8 databits, 1 stop bit. LVCMOS compatible.
H1.47	3V3-0	Power	**Positive system power input.** Positive power supply input, connect to +3.3 V with respect to GND system ground pin.
H1.48	3V3-1	Power	**Positive system power input.** Positive power supply input, connect to +3.3 V with respect to GND system ground pin.
H1.49	3V3-2	Power	**Positive system power input.** Positive power supply input, connect to +3.3 V with respect to GND system ground pin.
H1.50	3V3-3	Power	**Positive system power input.** Positive power supply input, connect to +3.3 V with respect to GND system ground pin.
H1.51	3V3-4	Power	**Positive system power input.** Positive power supply input, connect to +3.3 V with respect to GND system ground pin.
H1.52	3V3-5	Power	**Positive system power input.** Positive power supply input, connect to +3.3 V with respect to GND system ground pin.
H2.29	GND1	Power	**System ground.** This pin is internally connected (equal) to pin piDOSE-DCD GND (3).
H2.30	GND2	Power	**System ground.** This pin is internally connected (equal) to pin piDOSE-DCD GND (3).
H2.32	GND3	Power	**System ground.** This pin is internally connected (equal) to pin piDOSE-DCD GND (3).

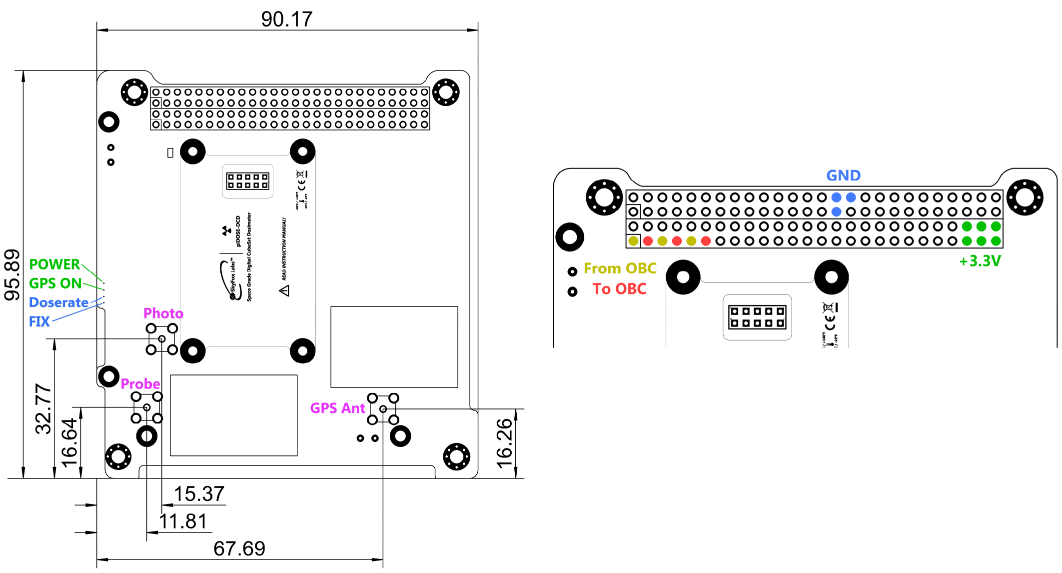

Fig. 2 **The piPLASMA Dimensions, Connector locations and device footprint (left), Main PC/104+ Connector Pinout (right), a set of indicating LEDs.** NOTE: Dimensions are shown in millimeters.

The piPLASMA is equipped with three **MCX-Female straight RF connectors** (located on the module). The Right Angle MCX-Male cable connector is recommended to fit the standard CubeSat structure/envelope.

Corner mounting holes (structural holes) are metalized but **electrically insulated from the system ground** to prevent grounding loops across the satellite body.

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FUNCTIONAL BLOCK DIAGRAM

The key functional blocks of the piPLASMA unit are shown in Fig. 3. There are three external inputs of signal, including: the GPS antenna RF input with DC bias feed (known as Bias-T), photoelectric (UV Light) sensor input, Langmuir Probe feed point and Guard Bias. Internal inputs of signal to the system are provided by the triaxial AMR ambient magnetic field sensor (magnetometer), MEMS triaxial angular rate sensor (gyroscope) and scalar dosimeter/Geiger counter input. The main microcontroller provides with the data acquisition, merging, processing the Telemetry and Telecommands, controls the currents to the magnetorquers and outputs the key info to a set of miniature LEDs.

The Langmuir Probe plasma current is collected via planar (or any other external) Langmuir Probe collection surface with a fixed negative bias of -5V_{DC} with respect to main ground. To close the current path, any GND potential connected to externally immersed conductive surfaces acts as electron collection areas. Not more than 1:100 ratio between the surface of the GND potential (1) and Langmuir Probe collection area (100) is recommended to be installed due to a different ion-electron mobility velocities. A ratio of 1:1 is usually possible to be achieved on a typical CubeSat walls, panels and structure (if not anodized, thus electrically insulated).

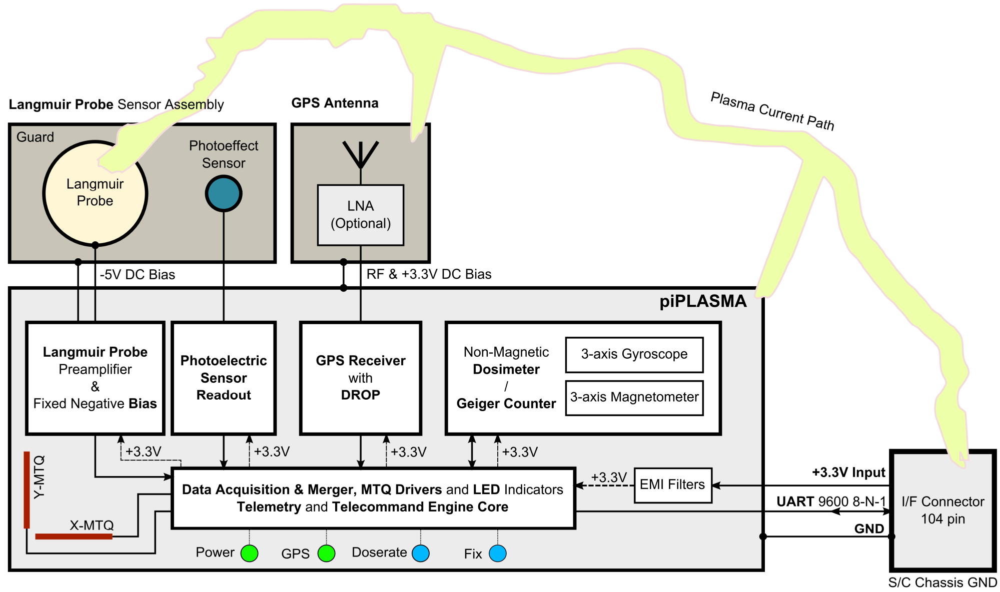

Fig. 3 The piPLASMA Block Diagram.

THEORY OF OPERATION

The piPLASMA unit is collecting multiple data about the flight profile and local (in-situ) environment and flight dynamics in order to compile a periodic data output datagram containing all the information based on the Telecommand settings. As a bare minimum, the dosimeter/Geiger counter is always active together with gyroscope, magnetometer, photoelectric sensor, telemetry (input bus voltage, current and temperature) as long as the power to the unit is applied on main +3.3V power bus. A unit uptime in seconds is calculated and provided since the power up, with no battery backup (volatile RAM). The Langmuir Probe current converted to voltage is read out and provided at four different sampling rates, which defines the period of the datagram output (4 Hz, 1 Hz, 0.4 Hz and 0.1 Hz).

Minimal required signal-to-noise ratio (SNR) for reliable GPS satellite signal acquisition by the GPS receiver is 38 dBc-Hz. Once the satellite is acquired, the receiver accepts its lower SNR while keep it tracking. The receiver permanent tracking capability is then ensured if the SNR is higher than 25 dBc-Hz. The tracking algorithm has been developed to be insensitive to the short (order of seconds) fading that may cause additional deterioration of the SNR as low as 18 dBc-Hz. The high tracking sensitivity feature provides excellent margin which could be efficiently exploited i.e. when the GPS signal reception is performed via side lobes of the antenna radiation pattern (i.e. when the satellite is slowly tumbling, etc.)

The firmware processes the acquired data, code and carrier phase measurement to calculate 3D position fix and velocity vector. The 2D position fix mode is not supported, since it is useless in LEO. The elevation mask of 3° and C/N_0 filter set to 30 dBc-Hz implemented in the Position, Velocity & Time algorithm (PVT)

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selects the GPS satellites used for position calculation. All the satellites below these limits are not included in position data processing in order to maximize the precision of the PVT data output.

The receiver channel management algorithm is programmed to seek for and to track all the satellites in view. If the position of the receiver is unknown (after power up), the elevation mask is not used. However, if the receiver does not process enough satellites above the elevation mask, but the number of the satellites including satellite below elevation mask is enough for 3D position solution, the position information is provided with uncertainty. To increase the position information precision, the elevation mask is applied on calculated data in the following period. In this case the next NMEA sentences can be provided as empty as a result of elevation masking. Once the receiver acquires at least **four GPS satellites above the elevation mask** (3° or higher), the navigation information is provided continuously.

The PVT does not implement satellite geometry filter. However, its quality is measured by the DOP parameters and provided to the user in the output data sentence. The user can decide then, whether the relevant DOP parameter meets or exceeds the target application requirements (i.e. the conventional ADCS based on magnetometer requires only coarse position data for determination of the orientation of the magnetic flux vector thus even high DOPs can be considered as fully sufficient). To reduce the data output, only the maximum SNR achieved is reported, with no information about the minimum SNR processed. A single byte in 0xYZ format is provided to announce how many satellites are tracked (Y) and used for Position, Velocity and Time calculation (Z). As this data is provided in hexadecimal form and the receiver is 15 channel device, the 0xFF means 15 satellites tracked, with 15 satellites used for PVT. Typical utilization is in order of 6-8 sats up to ~12 sats (i.e. 0x66-0x88 up to 0xCC, respectively).

GPS ANTENNA

The piPLASMA GPS receiver has been tested with various GPS antennas including passive and active (including/excluding local Low Noise Amplifier), helical, loop, GP and patch antennas to find the best setup providing maximum receiver performance, sensitivity and position fix capability onboard the CubeSat structure. The best results were observed with the patch antenna (35×35 mm) and local LNA (gain $P_{LNA} \geq +13$ dBm, noise figure NF approx. 1 dB) and Z-axis CubeSat panel serving as the Patch Antenna ground plane (copper PCB with square shape, outer dimensions 100×100 mm and milled corners fitting the standard CubeSat Structure Z-axis footprint). It is recommended to keep the antenna facing the Zenith with suitable ADCS (Attitude Determination and Control Subsystem). Recommended deviation from the Zenith allowing the GPS receiver to fix the position within the t_{TTFF} time is determined as a cone of ± 45° along the Z-axis as described in Fig. 4 in order to face to at least four active (healthy) GPS satellites with a free line of sight above the Elevation Mask.

NOTE: *The blocking of the satellite reception by the target satellite construction or improper orientation of the antenna deteriorates the GPS receiver performance and prolongs the Time-to-First-Fix (t_{TTFF}). The receiver disposes by sufficient tracking and acquisition margins and can be operated even if the part of the sky is blocked by the obstacle. However, the performance of the receiver cannot be guaranteed then. Note that the acquired satellite should be tracked at last 30 seconds with C/N_0 > 38 dBc-Hz to be able to receive ephemeris data and then the C/N_0 could not fall below 25 dBc-Hz permanently, otherwise the satellite tracking is not possible (typical Zenith GPS satellites are tracked on ground at approx.* ***43 to 48 dBc-Hz with Passive Antenna****, at* ***48-55 dBc-Hz with Active Antenna****).*

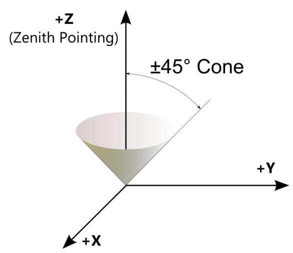

Fig. 4 The conical area borders of the vector perpendicular to recommended GPS patch antenna's ground plane.

After the position fix the antenna can be swapped or rotated or periodically rotated in attitude to Nadir position and back to Zenith, whilst the tracking of the satellites is kept. However, when the signal to noise ratio C/N_0 of at least four visible GPS satellites fall below the 30 dBc-Hz level at the RF_{IN} input of the receiver, the position calculation will not be available to avoid providing with too inaccurate position data. When the C/N_0 of

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the latest four satellites serving for navigation reception falls below the minimum $P_{RF\_IN-Trck}$ the receiver will be trying to maintain the tracking of the satellites while actively perform the seeking for the new satellites. The total loss of all satellite signals results in no position data output. To recover the position information output the receiver (without re-start) may take up to ~15 minutes, when the proper RF signal path is fully recovered (antenna looking towards the Zenith with no RF interference). **If the period with no PVT data is longer than ~20 minutes, the power re-cycle or Forced Reset is recommended to be performed externally, as it forces the receiver to work in Fast Acquisition Mode again, with TTFF below 80 seconds again.** The 20 minute timeout may be shortened/prolonged by user to force the Fast Acquisition tracking algorithm whenever needed. The antenna/signal quality can be analysed by the SNR parameter in the output datagram. The SNR of the satellite signal with the active antenna in the place with clear view to the whole sky shall be at least 48 dBc-Hz for peak (Zenith) GPS satellites and at least 43 dBc-Hz for satellites with elevation higher than 30˚.

CAUTION: *Because the central pin of the MCX coaxial connector is under DC bias when the GPS receiver is powered On, the special care has to be taken when handling with the coaxial cable, connector and antenna as well. Never connect the GPS antenna element designed as a closed dipole antenna, closed loop antenna, closed helical type, etc. to the receiver input to* ***prevent the short circuit of the DC bias feed****. Keep in mind, the central tap of the conventional patch antenna is galvanically connected to the DC bias feed. Prevent the tap against short circuit with the ground plane or GND potential when the receiver is turned On. Short circuit of the DC bias feeding or its overloading over the Absolute maximum ratings may affect device reliability, damage the device and void the product warranty.*

Special care should be taken to the installation of the GPS receiver Antenna. The antenna shall be installed on the sufficiently large ground plane. The shape of the ground plane, near objects and antenna matching affects the patch resonant frequency and radiation pattern.

LANGMUIR PROBE

To monitor the surrounding plasma density, the Langmuir Probe working in the Ion Saturation region with fixed negative bias is utilized to estimate the particle per cubic meter density causing the satellite braking forces. The piPLASMA/LP (Langmuir Probe) is the World's First Space-Friendly™ CubeSat Ion Saturation Region Plasma Langmuir Probe intended for Z+/- CubeSat side wall mounts and piPLASMA/FM (Flight Model).

It was designed to operate with $-5V_{DC}$ (negative) bias to collect positive ions at orbital velocities, assuming total ion collection velocity of roughly 8000 ms^{-1} (average LEO orbital velocity of ~7700 ms^{-1} + ion mobility ~300 ms^{-1}) and typical LEO plasma densities of ~10^2 to ~10^6 cm^{-3}, providing 5 - 5000 nA typical current range through its collection aperture area in Ram direction. The panel contains the guarding metallic structure necessary to prevent parasitic leakage currents between the collection area and mounting structure.

One MCX connector with coaxial cable (labeled as GUARD) is used to connect the Langmuir probe with the piPLASMA input, where the central pin is connected with collection area and the braiding/shielding to the Guard potential.

The unit contains the photoelectric sensor (solid state photodiode) working in a photovoltaic mode (requiring no external power) installed in a centric location under a pinhole with a 2.5 mm diameter, accessible via the second MCX connector, where central pin is a positive pole and shielding equal to the piPLASMA ground potential (GND, i.e. 0V system potential).

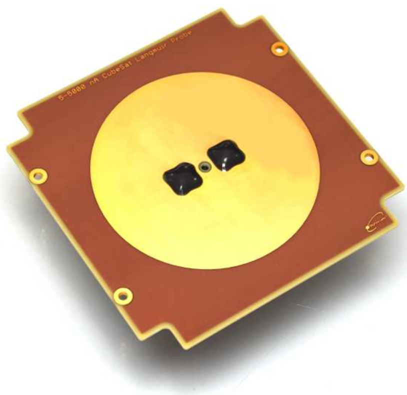

Fig. 5 The piPLASMA/LP Planar Ion Langmuir Probe Panel with Photoelectric Effect Sensor pinhole embedded, Flight Model.

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PROTOCOLS

The physical communication is realized via the standard UART data interface. The baud rate is set to 9600 bps, no parity, 8 data bits, 1 stop bit. Logical levels are equal to LVCMOS levels as defined in JEDEC JESD8C.01 standard. In order to provide with a fixed length datagrams with no binary data (human readable ASCII characters) the data is encoded into Base64 datagrams.

INPUT COMMAND DESCRIPTION

Commanding of the piPLASMA is performed using single-byte Telecommands set (TC) based on 256 different combinations of bit-addressed functions. Their description and each respective bit position is given in Tab.: 2. After unit power up, a preset command equal to 0x50h (80d) is set automatically as implicit value. Magnetorquers are inactive as implicit. Positive, negative or degaussing modes can be set upon respective TC.

Tab.: 2 Telecommand (TC) Set Table, impicit values active after Reset/Power Up are highlighted in bold.

Function:	LP Sampling Rate			LP Gain	GPS Power	Magnetorquer H-Bridges				
Bit Position:	7-MSB	6		5	4	3	2	1	0-LSB	
Description:	ADC Resolution			Gain	On/Off	MTQ-YB	MTQ-YA	MTQ-XB	MTQ-XA	MTQ Meaning
	0	0	15 bit @ 4 Hz	**0 = Low**	0 = OFF	**0**	**0**	**0**	**0**	X and Y Open
	0	**1**	**16 bit @ 1 Hz**	1 = High	**1 = ON**	0	0	0	1	X +, Y Open
	1	0	17 bit @ 0.4 Hz			0	0	1	0	X -, Y Open
	1	1	18 bit @ 0.1 Hz			0	0	1	1	X Degauss, Y Open
						0	1	0	0	X Open, Y +
						0	1	0	1	X+, Y+
						0	1	1	0	X-, Y+
						0	1	1	1	X Degauss, Y+
						1	0	0	0	X Open, Y-
						1	0	0	1	X+, Y-
						1	0	1	0	X-, Y-
						1	0	1	1	X Degauss, Y-
						1	1	0	0	X Open, Y Degauss
						1	1	0	1	X+, Y Degauss
						1	1	1	0	X-, Y Degauss
						1	1	1	1	X and Y Degauss

The last (active) TC set is reflected in the output datagram in order to recognize a correct TC reception. As the magnetorquer degaussing procedure is a single short duration event in order of hundred of miliseconds, the command to degauss the magnetorquer is still reflected as a confirmation of procedure performed, until a new TC is received and processed but is not performing degaussing process continuously. In order to perform multiple degaussing procedures, a respective amount of TCs have to be sent to the unit from upper level system (i.e. Onboard Computer).

OUTPUT DATA DESCRIPTION

In order to reduce the output data volume but yet not providing the string in binary form, which may cause string shifts and string bytes order uncertainties within the Onboard Computer Data storage or onboard parser, the raw output data is encoded in Base64 datagrams with '$' as a Start Character followed by the Data Field and '#' as End Character, terminated by CR+LF (0x13h + 0x10h) bytes as the datagram End. A total of 70 bytes + 2 bytes (CR+LF) i.e. 72 bytes in total are sent each preset measurement period, with fixed length.

RAW Base64 Datagram Output Example sent over UART Interface (70 bytes + CR+LF = 72B)

$UFKjceVKwRaWMp5QISXe1prsGmYQEqg3AAAAA2EDvAV4AAAAfQEAAAAHe3x7dKoAAABl#⇐↲

To translate the Base64 datagrams into usable value representations, it is necessary to perform the Base64 decoding. Once the string is cropped off from the Start, End and CR+LF characters (a total of 68 bytes), it is necessary to perform the Base64 to ASCII decoding.

Cropped Example RAW Base64 Datagram (68 bytes after the crop = 68B)

UFKjceVKwRaWMp5QISXe1prsGmYQEqg3AAAAA2EDvAV4AAAAfQEAAAAHe3x7dKoAAABl

As the Base64 to ASCII conversion is provided in length ratio of 2:3, the longer string with a total of 102 characters (68×3/2 = 102) is obtained as a result of decoding. Resulting string represents a series of ASCII

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HEX characters (upper or lower a-f or A-F characters are based on the selected Base64 decoder alphabet, the upper case as an example is used in following human-readable sample data). The data order is given in Tab.: 3.

ASCII "HEX" String Result after Decoding from Base64, 102 bytes long

5052A371E54AC11696329E502125DED69AEC1A661012A83700000003610 3BC057800000 07D0
1000000077B7C7B74AA00000065

Tab.: 3 piPLASMA ASCII HEX Base64 Decoded data format, including decoded value examples.

String Location	Amount of byte Positions	Value HEX	Value DEC	Physical Value	Meaning	Value Range	Note
0 to 1	2	50	80	See note.	Telecommand Returned Value	0h to FFh	Bit position description is mentioned in Tab. 2.
2	1	5	5	5	GPS Week modulo 16	0h to Fh	GPS time and date with up to 16 unique weeks period.
3 to 7	5	2A371	172913	172913 s	GPS Time	0h to 93A7Fh	Value in seconds in week 60×60×24×7.
8 to 13	6	E54AC1	-1750335	-1750335 m	GPS ECEF X Position	0h to FFFFFFh	ECEF coordinate in meters. Binary complement for negative values.
14 to 19	6	169632	1480242	1480242 m	GPS ECEF Y Position	0h to FFFFFFh	ECEF coordinate in meters. Binary complement for negative values.
20 to 25	6	9E5021	-6402015	-6402015 m	GPS ECEF Z Position	0h to FFFFFFh	ECEF coordinate in meters. Binary complement for negative values.
26 to 29	4	25DE	9694	4847 m/s	GPS X Velocity in m/s	0h to FFFFh	Velocity X in m/s, to get the velocity, the obtained value needs to be divided by 2.
30 to 33	4	D69A	-10598	-5299 m/s	GPS Y Velocity in m/s	0h to FFFFh	Velocity Y in m/s, to get the velocity, the obtained value needs to be divided by 2.
34 to 37	4	EC1A	-5094	-2547 m/s	GPS Z Velocity in m/s	0h to FFFFh	Velocity Z in m/s, to get the velocity, the obtained value needs to be divided by 2.
38	1	6	6	6	GPS Sats tracked	0h to Fh	Up to 15 sats tracked.
39	1	6	6	6	GPS Sats used for PVT	0h to Fh	Up to 15 sats used for Position, Velocity and Time calculation.
40 to 41	2	10	16	4	GPS DOP	0h to FFh	Dilution of Precision, to get the DOP, the obtained value needs to be divided by 4.
42 to 43	2	12	18	18 mA	GPS Antenna Current	0h to FFh	GPS Antenna DC Bias Current, in miliAmps.
44 to 45	2	A8	168	3.36 V	GPS Antenna Voltage	0h to FFh	GPS Antenna DC Bias Voltage, value in Volts is obtained by multiplying by 0.02 factor.
46 to 47	2	37	55	55 dBc-Hz	Maximum SNR	0h to FFh	Signal to Noise ratio of the strongest GPS satellite tracked.
48 to 49	2	00	0	0 °/s	DPS in X axis	0h to FAh	0 to 250 °/s angular rate in X axis. +/- Sign in signum (byte 74).
50 to 51	2	00	0	0 °/s	DPS in Y axis	0h to FAh	0 to 250 °/s angular rate in Y axis. +/- Sign in signum (byte 74).
52 to 53	2	00	0	0 °/s	DPS in Z axis	0h to FAh	0 to 250 °/s angular rate in Z axis. +/- Sign in signum (byte 74).
54 to 57	4	0361	865	21118.11 nT	Magnetic field in X axis	0h to FFFFh	Magnetometer X, to get the value multiply by 24.414 factor. +/- Sign in signum (byte 75).
58 to 61	4	03BC	956	23339.78 nT	Magnetic field in Y axis	0h to FFFFh	Magnetometer Y, to get the value multiply by 24.414 factor. +/- Sign in signum (byte 75).
62 to 65	4	0578	1400	-34179.6 nT	Magnetic field in Z axis	0h to FFFFh	Magnetometer Z, to get the value multiply by 24.414 factor. +/- Sign in signum (byte 75).
66 to 70	5	00000	0	0	Langmuir Probe output	0h to FFFFFh	RAW data. See text and Tab. 4.
71 to 73	3	07D	125	125	Light Sensor	0h to 3FFh	Light Sensor, to get the value in V multiply by 0.0012051 factor.
74	1	0	0	X+, Y+, Z+	Gyro signums	0h to 7h	0xyz, if x,y,z = 0 ⇨ +, x,y,z = 1 ⇨ -
75	1	1	1	X+, Y+, Z-	Magnetometr signums	0h to 7h	0xyz, if x,y,z = 0 ⇨ +, x,y,z = 1 ⇨ -
76 to 83	8	00000007	7	7 CPM	Counts per minute	0h to FFFFFFFFh	Incremental amount of Counts, with periodical reset. See text.
84 to 85	2	7B	123	23°C	Gyro Temperature	0h to FFh	To get the °C subtract 100.
86 to 87	2	7C	124	24°C	Magnetometer Temperature	0h to FFh	To get the °C subtract 100.
88 to 89	2	7B	123	23°C	Langmuir Probe Temperature	0h to FFh	To get the °C subtract 100.
90 to 91	2	74	116	116 mA	Bus Input Current	0h to FFh	Main input current in mA.
92 to 93	2	AA	170	3.40 V	Bus Input Voltage	0h to FFh	Main input voltage, to get the value in Volts multiply by 0.02.
94 to 101	8	00000065	101	101 s	Uptime	0h to FFFFFFFFh	Unit uptime in seconds since the last power up (or internal watchdog reset).

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The ambient plasma parameters (ion density, plasma current) can be interpreted from the measured Raw data from the Langmuir Probe working with a fixed negative bias of -5V_{DC}. Respective values can be calculated by multiplying the Raw data by factors listed in the Tab.: 4. Factors are mode-dependent upon selected sampling bit resolution. For High Gain, Offset needs to be subtracted from the Raw data first. The gain is ~11.

Tab.: 4 Langmuir Probe Raw Data factors, maximum values at given Gain, Offset constants.

Bits/Mode	$RAW_{MAXLowGain}$	$RAW_{MAXHighGain}$	Ion Density [ions/cm^3] | Low Gain	Ion Current [A] | Low Gain	High Gain Offset (typ)
15/4Hz	32736	32704	18.87156365	$-9.41467285156\times10^{-11}$	1029
16/1Hz	65742	65408	9.435781824	$-4.70733642578\times10^{-11}$	2063
17/0.4 Hz	130944	130816	4.717890912	$-2.35366821289\times10^{-11}$	4163
18/0.1 Hz	261888	261632	2.358945456	$-1.17683410644\times10^{-11}$	8331

Values provided by the Dosimeter are integrated over a measurement period of 60 seconds. After this period, the Counts Per Minute (CPM) counter is reset and starts from zero. As the output from the integration is sent via serial link from the piPLASMA unit at different rates per second, a certain trim off at the end of each measurement period is affecting the measurement precision. In case of 4 Hz sampling, the dosimeter precision is compromised by a factor of 1/(4 Hz × 60 s) = 0.416%. The 1 Hz sampling results in 1.6% error, and so on. Changing the measurement period (mode) resets the CPM as well as integration period (60 s counter).

DEAD RECKONING ORBITAL PROPAGATOR

The GPS receiver firmware is build around the key principle of processing an extremelly weak RF signal directly from the GPS constellation satellites. In case the antenna of the GPS receiver system is **unable to pick up a proper signal quality, signal strength** or locally (in-situ) the **signal** is **jammed** from (unfortunatelly) increasing amount of terrestrial sources powerfull enough to penetrate up to the LEO altitudes, making high areas of orbits without usable GPS signal, the **Dead Reckoning Orbital Propagator** (or **DROP**) algorithm serves as a mathematical solution implemented in the internal firmware to overcome the GPS PVT/Fix dropouts.

During the GPS position Fix, the DROP algorithm continuously integrates the data measured and improves the estimation of the satellite state vector by an infinite impulse response **Hatch filter** with a maximal time constant of **100 seconds**. The filter is initiated by the first Fix obtained after power up (Cold Start) and is continuously loaded up to 100 seconds of Fix data, during the flight. Once the GPS Fix is not available for a reasons such as: incorrect antenna attitude, in-situ GPS signal jamming, not enough GPS Satellites in View, less than 4 healthy satellites above the elevation mask or less than 30 dBc-Hz in at least 4 healthy sats SNRs, etc., the PVT output is estimated and provided by the mathematical principle using DROP algorithm.

The DROP algorithm position output is provided based on the last set(s) of valid position(s) and velocity(ies) vectors information by the numerical solution of the satellite motion equations, which considers only a gravitation field of the Earth's mass center. No other phenomenon, like satellite slowed down by the residuals of the atmosphere (atmospheric drag), influence of the non-uniform distribution of the mass in Earth's body (non uniform Earth's gravitational field), as well as the solar wind, is not considered. The propagated PVT data output precision thus depends on the quality of the last valid GPS Fix(es) and satellite orbit. A typical 3D precision error is in the order of **~6 000 meters per 15 minutes** in LEO and fully loaded DROP filter Fix dataset. An example of the error DROP algorithm error based on RF signal simulator output is given in Fig. 6 and Fig. 7.

NOTE: The implemented Dead Reckoning Orbital Propagator algorithm can predict only LEO (altitudes up to 3600 km above the sea level) satellite trajectory (standard orbital velocity movement) in the gravitation field of the Earth **without** artificial acceleration forces such as powered flight (with active propulsion), once it looses the nominal GPS constellation Fix. For other trajectories, such as propulsion-driven orbital parameters modification (powered flight with thrusters activated), do not provide relevant data and may act as a predictor of a ballistic freefall towards the gravitational center of the Earth or its escape. Moreover, the algorithm does **not implement nor utilize** the **Luni-Solar acceleration coefficients or gravity fields influence of other celestial bodies** in the PVT calculation output as they are not available in the GPS system transmission. Those, if known, may offer improved precision of the position and velocity prediction. The **propagator is activated** if the magnitude of the **velocity vector** is between **7000 - 9000 m/s**. Another DROP algorithm benefit for the GPS receiver system functionality is the fact that the firmware is able to implement the Warm Start (PVT Fix recovery based on available RF signal data from the GPS constellation) much faster than in case where all satellite channels tracking were lost/dropped such as during the Cold Start. The DROP estimated position is precise more than enough even after **15-30** minutes with no proper Fix to get the receiver an accurate information about the GPS satellite for the search and track (re-acquisition) algorithm. Typical **Warm Start time** is in order of **50 seconds**. As the GPS receiver does not store the navigation data in the non-volatile memory, the UTC time is available after reception of the ionospheric and UTC data from the satellites.

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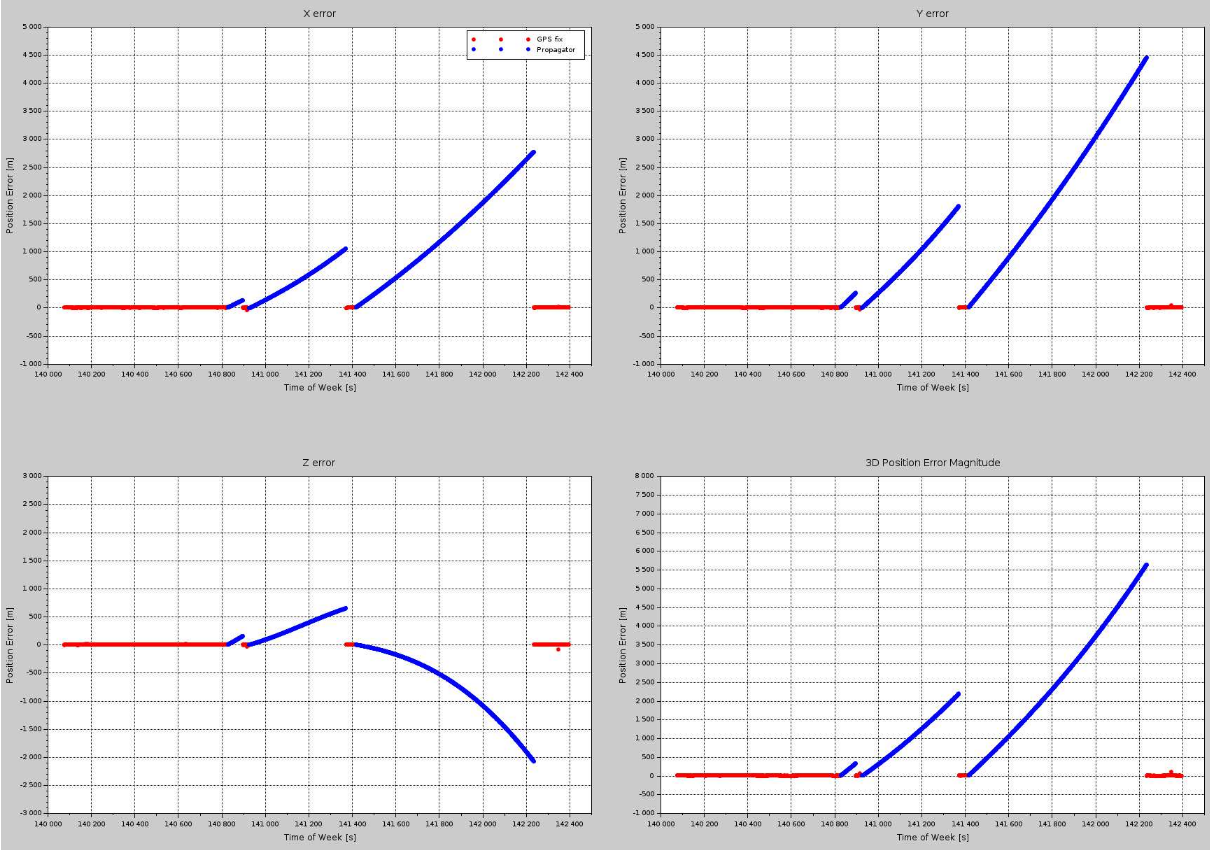

Fig. 6 DROP algorithm output data precision (error) based on RF Signal Simulator during LEO velocity flight.

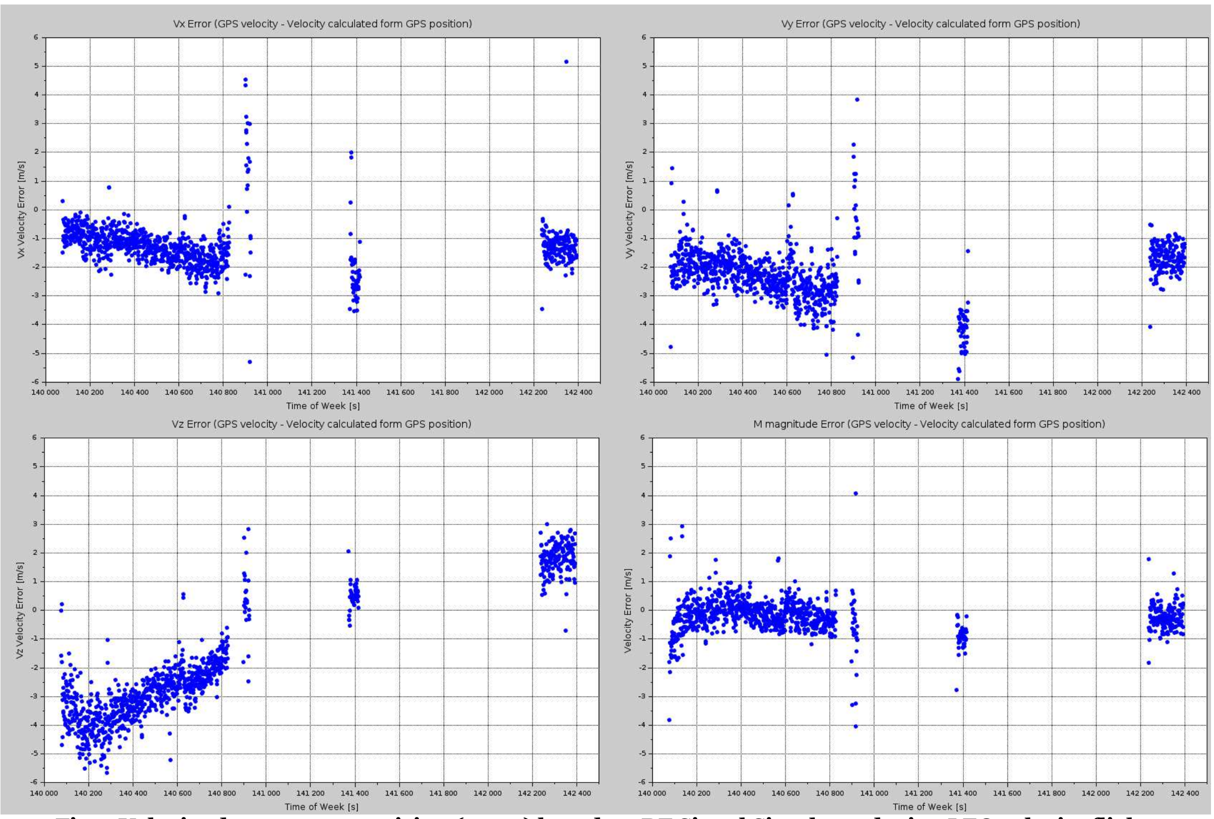

Fig. 7 Velocity data output precision (error) based on RF Signal Simulator during LEO velocity flight.

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ENGINEERING MODEL

The piPLASMA is available in the Engineering Model (/EM) grade version in order to support the Flat Sat design, as well as the onboard data output parsing software development (such as ADCS, OBC, etc.). A special care have to be taken to the EMC/EMI environment in order to maximize the receiver sensitivity yield. To test whether the satellite bus subsystems, Flat Sat or satellite Qualification Model (magnetorquers, MPPT solar controllers, DC/DC converters, transmitters, mixers, local oscillators, etc.) are not affecting the GPS receiver noise floor, the Engineering Model grade with identical electrical and RF properties is a perfect tool to perform an RF/EMI survey. **It is highly recommended to run the test before the flight and observe whether the fully operational satellite is not limiting the maximum available SNR values and/or functionality.**

The red **Remove Before Flight** finish **reminds to replace** the unit with the Flight Model grade unit suitable for the environment of space, in case it is used on Flight Model of the satellite. The firmware of the EM model is modified by the velocity limitation (500 m/s) and is also not intended for flight (not intended for vacuum use). The piPLASMA/EM (Engineering Model) unit is depicted in Fig. 8.

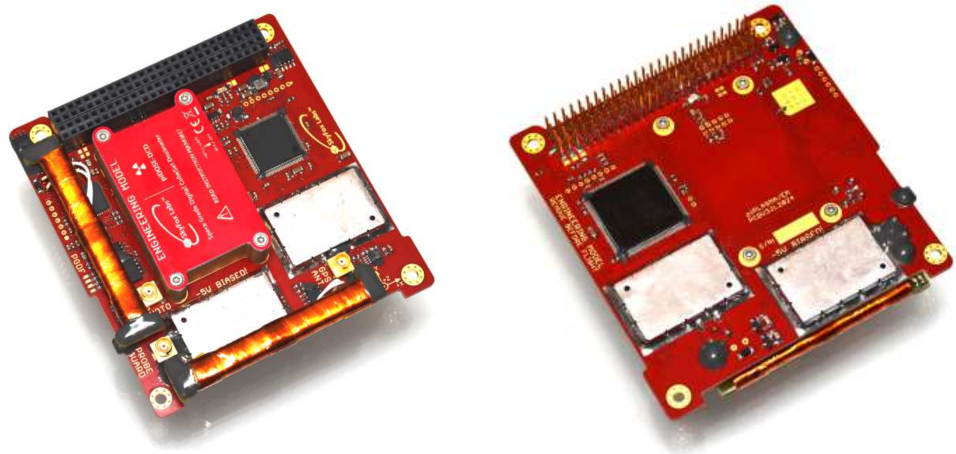

Fig. 8 Engineering Model of the piPLASMA unit with Red Remove Before Flight finish. Top side (left), Bottom side (right).

EVALUATION KIT

The piPLASMA Evaluation Kit in Fig. 9 has been developed to support the implementation together with the onboard parsing software development in engineering, development and breadboarding (AIV, AIT) phases. It enables to connect and power the piPLASMA from the USB port easily. Current consumption measurement and output data waveforms can be captured by conventional Ammeter and Scope probe using current sensing and serial port pin headers. Indicating LEDs inform directly about the signal statuses. The device is not intended for spaceflight. The associated parsing software for Windows is available to display, configure telecommands and plot all data and features in real time.

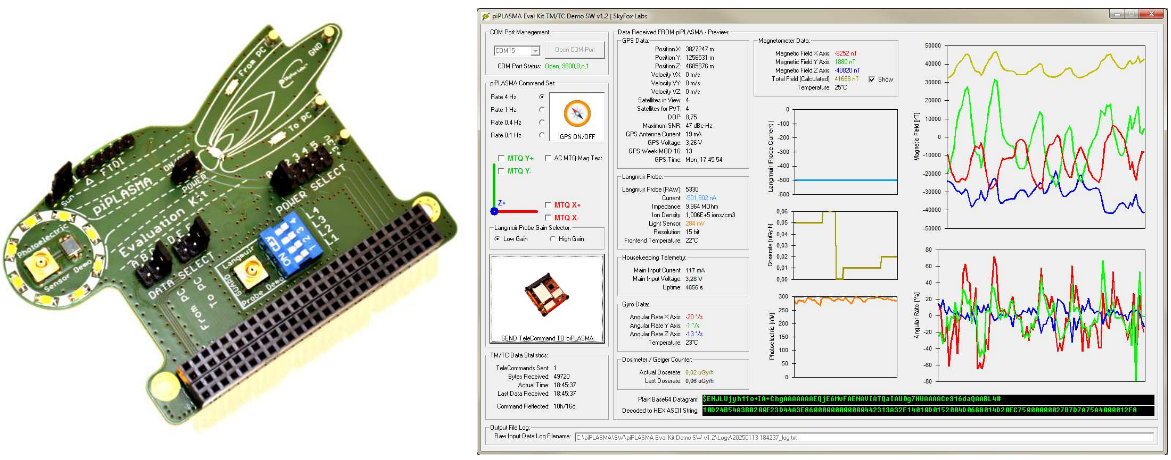

Fig. 9 The piPLASMA/EK Form Factor Evaluation Kit PCB Unit for development purposes (not for flight).

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APPLICATION NOTES & RECOMMENDATIONS

EMC CONSIDERATIONS

As the size of the small satellites imply the high level of integration of different electronic devices (switch mode power supplies, high speed digital electronics, pulse-width modulated electromagnetic actuators, etc.) into a limited satellite structure volume containing potential sources of disturbing signals, the electromagnetic susceptibility and compatibility is critical for implementation of any subsystems sensitive to electromagnetic radiation.

Proper ground planes and PCB design rules minimizing the radiated and conducted emissions shall be applied within the whole small satellite structure, including custom payloads, conventional (Communication and Data Handling, Power Supply and Power Distribution, Onboard Computer, Attitude Determination and Control) and third party electronic subsystems. The small satellite electronics should be properly designed to not disturb the GPS receiver input with harmonic frequencies falling to the GPS L1 frequency band.

NOTE: The C/N_0 parameter provided in output datagram (position byte 46 to 47, maximum SNR) can be exploited as a diagnosis tool to check whether the EMC issues affect the piPLASMA reception capability (especially satellite mounted antenna as a source of the GPS signal, such test may require open sky testing). **Always observe the C/N_0 levels and switch On/Off each electronic subsystem to identify the potential source of the disturbance. If needed, using open-sky signal level and quality!**

ANTENNA LOCATION

Special care should be taken to the interference with the small satellite communication subsystem, as an active electronic device radiating the high power electromagnetic waves. The manufacturer recommends installing the GPS antenna as far from the (transmitting) communication antennas as possible.

Be sure to test the target small satellite subsystems against affecting the performance of the piPLASMA GPS receiver under all satellite operation conditions. Keep in mind the receiver may be sensitive to harmonics of the downlink (transmitter) frequency (i.e. 1575 MHz /9, /8, /7, /6, /5 /4, /3,/2, etc.) or uplink receiver spurious emissions, local MPPT EMC radiation, magnetorquer PWM EMC radiation, etc. **It is highly recommended to perform full functional test on the flight or flight-representative satellite model to ensure the EMC compatibility!!!** The piPLASMA unit has been successfully tested onboard the 1U CubeSat with omnidirectional antenna and FM modulated transmitter with 1000 mW_{EIRP} output power at the UHF band (435 MHz) and 7-order Pi LC harmonic filter with no functional degradation of the receiver performance.

QUALITY ASSURANCE

GENERAL INFORMATION

Since the piPLASMA unit has been designed for the operation in harsh space environment as a specially featured electronic device based on Commercial Off-the-Shelf (COTS) components, the special care is taken to follow the standardized space-grade product assembly procedures, materials and components where possible (i.e. no Radiation Hardened integrated circuit are used).

MATERIALS

Components are soldered on the 6-layers FR-4 PCB, using 60/40% (Tin/Lead) compound. No PCB solder mask is used on the Flight Model units to exclude the outgassing. A conformal coating is applied instead. Engineering Models contains red solder mask and is not intended for flight/vacuum environment. The volume of the gold is limited to a minimum by implementing the only gold-plated MCX connectors providing excellent RF and contacting performance and main interface connector for improved conductivity.

Vacuum-proof electronic components from ESA and NASA-preferred space-grade vendors are used (i.e. no electrolytic capacitors) in industrial or military temperature grade, where possible.

PACKAGING & SHIPPING

Once the piPLASMA successfully passes the screening, electrical, radio and firmware test, it is finally cleaned, optically inspected and shipped encapsulated in ESD protective packaging.

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EXPORT CONTROL

Since the country of origin of this product (the Czech Republic) is a valid participating member of the Wassennaar Agreement (http://www.wassenaar.org) and agrees with the Missile Technology Control Regime (http://www.mtcr.info) and the **piPLASMA/FM, piPLASMA/EM, piPLASMA/LP, piPLASMA/EK (Space-grade Flight Model, Engineering Model, Langmuir Probe, Evaluation Kit)** functional parameters are considered as a regulated (Dual Use) goods, the export is controlled and needs special Export License approved by the Ministry of Industry and Trade of the Czech Republic (the local control entity). The request for the Export License has to be submitted by the manufacturer to the local control entity, based on the binding order, including all the information as: the characteristics of goods, target country (territory), detailed end-user and target application information, etc.

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