

POWER PROCESSING UNIT FOR STATIONARY PLASMA THRUSTER

H. Declercq, E. Bourguignon, T. Scalais
Alcatel ETCA

B.P. 4008; B-6000 Charleroi (BELGIUM)
Tel. : 32/(0)71/44.23.20; Fax : 32/(0)71/44.23.04

J.J. Digoïn
Alcatel Space Industries

BP 99, 06322 Cannes La Bocca Cedex, FRANCE
Tel.: 33/(0)4.92.92.76.39; Fax: 33/(0)4.92.92.61.30

Abstract

Use of Stationary Plasma Thrusters propulsion system on-board spacecraft is profitable as a propellant mass saving is offered.

A power Processing Unit, to supply Russian (SPT-100) and Western (PPS-1350) Stationary Plasma Thrusters, has been designed and developed by Alcatel ETCA, under ESTEC contract.

This equipment presented herein delivers, from a primary regulated bus, the electrical power to the thruster electrodes and to the Xenon Flow Controller which regulates the thrust of the motor.

The development program included the manufacturing of a Bread-Board Model, an Engineering and a Qualification Model. Two Flight Models which will be used for the North-South stationkeeping on-board of the Stentor technological French satellite¹ were also manufactured.

The final objective is to provide, in 1999, PPU's in flight version for commercial telecommunication satellites.

Key words : PPU, SPT100, PPS1350, propulsion system, Alcatel ETCA

1. Introduction

First developed by Russian researchers, the Stationary Plasma Thrusters technology is known by Western world only for few years. Using a SPT propulsion system for North-South stationkeeping, a geostationary satellite can profit by the following advantages :

- ▼ higher payload mass fraction,
- ▼ reduced launch cost,
- ▼ increased on orbit mission life,
- ▼ a 100% mission success rate with over 70 thrusters flown

Alcatel ETCA has started the PPU development program since January 96 on basis of a specification built from the definition of :

- ▼ the electrical interfaces of the Russian SPT-100 and its Western derivated version : the PPS-1350
- ▼ the electrical interfaces, mainly primary power bus and TeleCommand-TeleMetry bus, of the most known European and American platforms
- ▼ the thermal and mechanical interface of these platforms.

Due to the particular characteristics of the signals to drive properly this type of thruster, the priority task has been to manufacture a PPU in breadboard version in order to start as soon as possible the test campaign coupled with thruster.

The paper describes the PPU, the integration tests and the development logic with details concerning the qualification of the equipment as well as the commercial applications.

2. Main functions of the PPU

2.1. Architecture of Electric Propulsion Subsystem

Typically, a redundant complete set of electric propulsion includes 2 PPU, 2 TSU and 4 Thrusters associated according to fig. 1 for the North-South stationkeeping of a geosynchronous satellite.

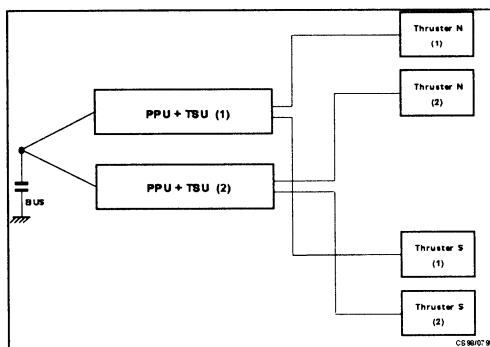


Fig. 1 Electric propulsion system for North-South station keeping of geostationary satellite

At thruster level, 2 heaters, 2 ignitors and 2 XFC's are working in cold redundancy for reliability and lifetime of the thruster (see fig. 2).

Inside PPU, the heater, ignitor and XFC supply are single but have two outputs via switches to select the working electrode or XFC.

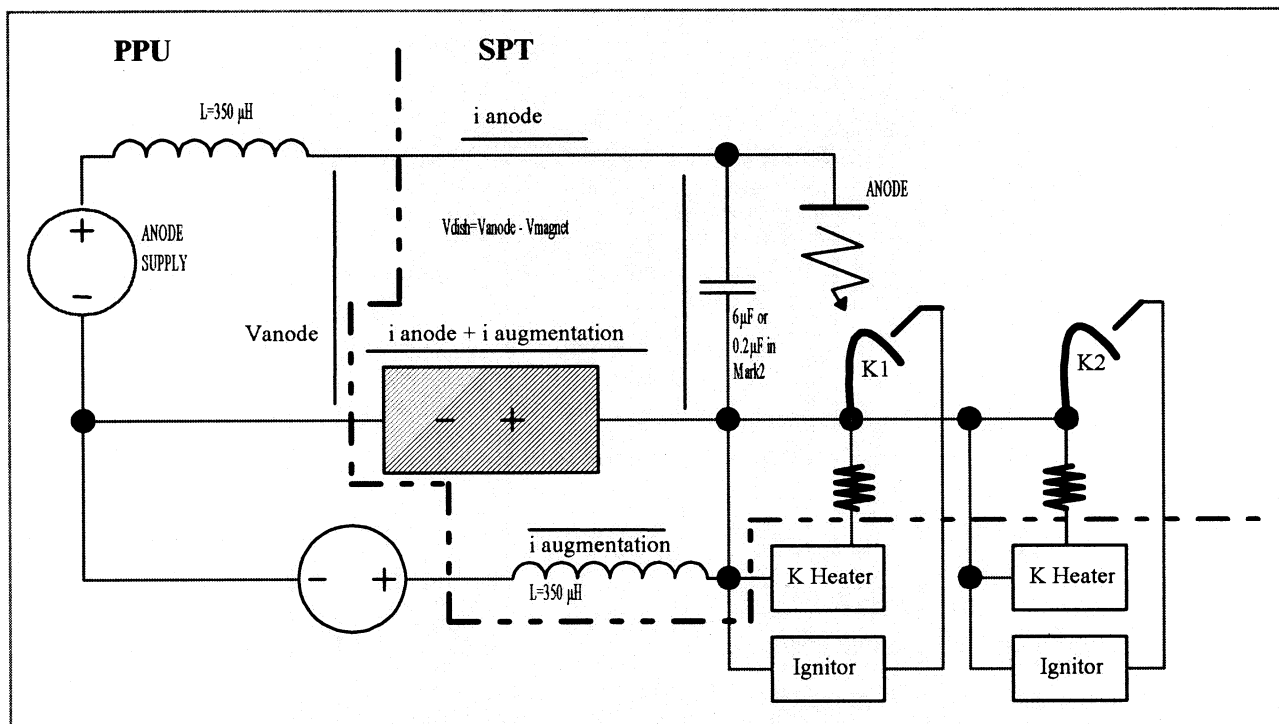
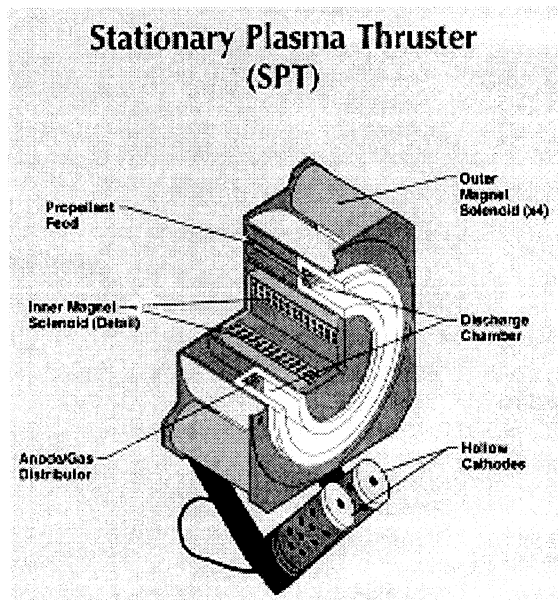


Fig. 2 PPU/SPT electrical interface

2.2. Main functions of the Thruster Selection Unit

TSU is a switching module, with relays, receiving all PPU outputs and transmitting them to North or South thruster.

The electrodes of the unsupplied thruster are connected inside TSU to defined impedances.

2.3. Main functions of one PPU

PPU is constituted by the following elements (see fig. 3):

- ▼ Primary power module :
main bus protection, voltage level conversion and galvanic isolation of the power required by the SPT supplies.
The PPU is designed to operate from a Regulated Bus; presently the bus voltage is 50V.
An adaptation to 100V is under development.
- ▼ SPT supplies :
the 4 types of electrodes of the Stationary Plasma Thruster (anode, magnet, heater, ignitor) are supplied according to their specific power profile.
The power of these supplies is provided by the primary power module.

These supplies must be floating. Their reference potential is determined by the plasma of the thruster.

- ▼ DC/DC converter :
insures voltage level conversion and galvanic isolation of the power required by the XFC supplies, the sequencer, the TC/TM interface and all the low level circuits
- ▼ XFC supplies
PPU supplies the Xenon Flow Controller. It opens the xenon valves and controls the SPT discharge by the regulation of the xenon flow via thermothrottle supply.
- ▼ Sequencer
automatic control and survey of the thruster operation : start-up, stop, regulated thrust, failure recovery, ...
- ▼ TC/TM interface
This part includes 2 interfaces :
- the interface between the satellite communication bus and the PPU, designed according to the MIL-STD-1553. An adaptation to ML16DS16 bus is also developed
- the interface with galvanic isolation between the sequencer and the different internal supplies.

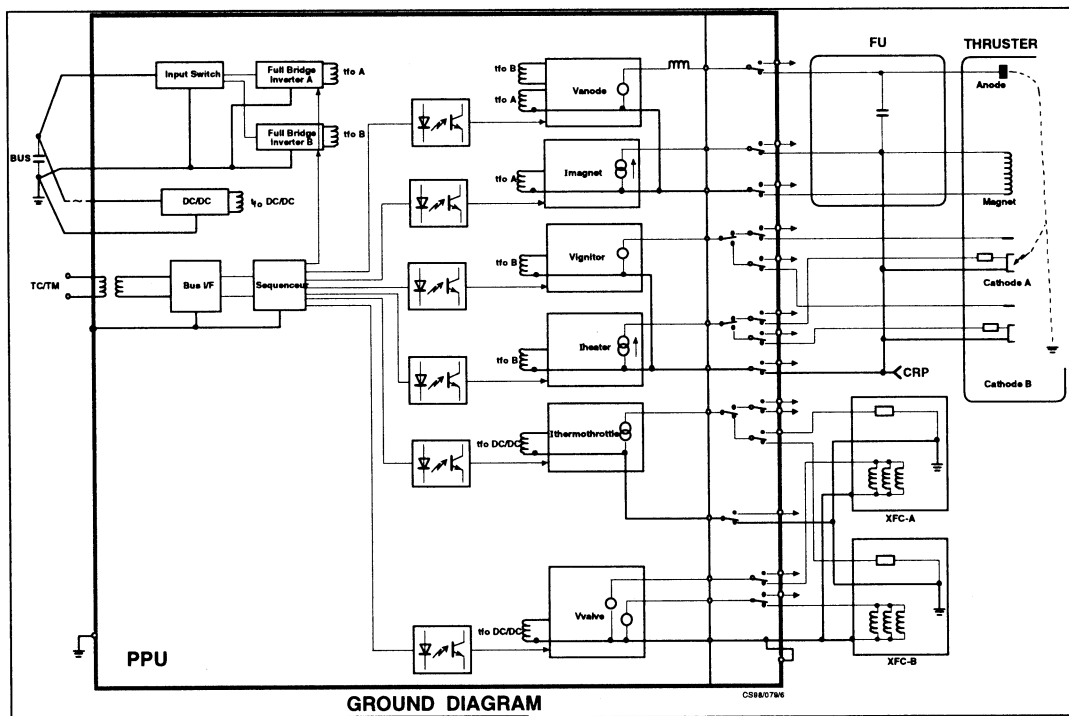


Fig. 3 PPU/TSU block diagram

3. General description of one ppu

3.1. Input switch

The input switch ensures the following functions :

- ▼ protection of the primary bus against short failure or overload. The input current is sensed and overcurrent detection leads to the switching OFF,
- ▼ inrush current control at powering up by means of a current limitation until the input capacitances are charged at the bus voltage.

The nominal current through the switch is 34A with maximum mode at 45A for an input voltage of 50V. The overcurrent threshold is $55A \pm 5A$.

All the input switch function is double isolated to avoid any single point failure leads to the loss of the primary bus.

3.2. Main inverters

Due to the high value of the primary current, the electrical power is handled through two inverters.

- ▼ Inverter A supplies half the anode electrode and the magnet
- ▼ Inverter B supplies the second half of anode electrode, the heater and the ignitor

They perform the galvanic isolation between the primary bus and the floating SPT electrodes.

A resonant topology leads to drastically reduce the commutation losses.

3.3. Anode supply

This supply produces the regulated voltage (300V or 350V) with power limitation at 1600W intended to drive the anode of a SPT100 or PPS1350. The fig. 4 shows the V-I characteristic of this supply, in SPT100 version. The nominal current is 4,5A.

The inductive output impedance of the anode supply combined with a capacitive filtering unit (FU) close to the thruster, confines the oscillation discharge current at thruster level.

The lack of high voltage qualified active parts impose to adopt a peculiar topology : the power converter is constituted by four voltage supplies in series.

3.4. Magnet supply

A dedicated secondary winding from the inverter A provides a DC source.

The magnet supply is a dynamic current controlled buck, which interfaces with a load consisting of magnet

coil. The buck current is controlled and regulated to be equal to a reference given externally by the sequencer.

The maximum current is 3A, the maximum power is 36W.

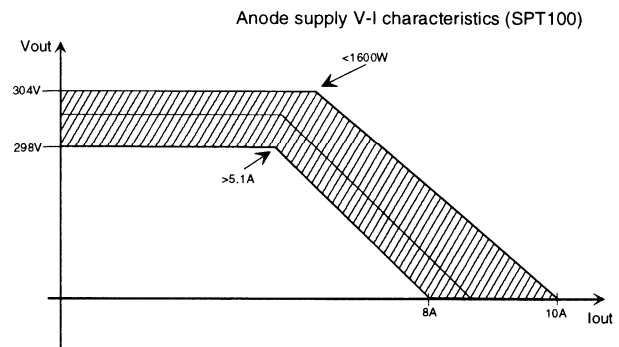


Fig. 4 Anode supply V-I characteristic

3.5. Heater supply

A dedicated secondary winding from the inverter B provides a DC source.

The heater source is a dynamic current controlled buck, which interfaces with a load consisting of low value resistance.

The buck current is controlled and regulated to be equal to a reference given externally by the sequencer. There is only one supply for both cathodes. The selection is performed by one relay.

This supply is used before thruster start-up, to heat the cathode.

The maximum current is 14A, the maximum power is 150W.

3.6. Ignitor supply

This supply produces either a high voltage low current or a low voltage high current depending on its load.

The fig. 5 shows the V-I characteristic.

The high voltage supply is intended to initiate the ionisation of the xenon around the cathode.

The low voltage is intended to maintain this ionisation. There is only one voltage supply for both cathodes. The selection is performed by one relay.

This supply is used only at thruster start-up.

3.7. DC/DC converter

The PPU DC/DC converter is an adaptation of a product developed by ETCA and designed for general purpose power applications requiring

excellent electrical performances in a minimum volume and mass.

Ignitor supply V-I Characteristic

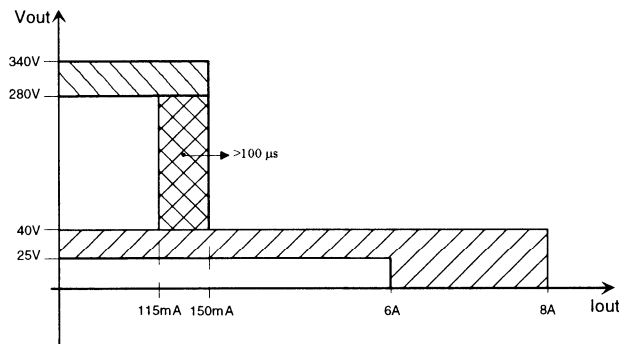


Fig 5 – Ignitor supply V-I characteristic

The present adapted circuit is a complete DC/DC converter of which the function is to convert a DC input voltage delivered by a main bus into various DC output voltages.

The DC output voltages are floating versus the primary bus.

Built in protection mechanisms protect the converter and the user against :

- ▼ input bus undervoltage,
- ▼ output overvoltage and undervoltage,
- ▼ output overcurrent.

3.8. XFC supplies

The XFC supplies are delivered from the DC/DC converter.

They consist in :

- ▼ Xenon Valves driving
- ▼ Thermothrottle supply

3.8.1. Valve driver

Two dedicated secondary windings of the DC/DC converter provide two common grounded DC sources.

These ones can supply one or two sets of three xenon flow valves whose solenoids are driven in parallel.

The valve driver applies an opening voltage (27V) followed by a sustaining voltage (10V) during all the thrust period.

3.8.2. Thermothrottle supply

A dedicated secondary winding of the DC/DC converter provides a DC source.

The thermothrottle supply is a dynamic current controlled buck, which interfaces with a load consisting of low value resistances.

The buck current is controlled and regulated to be equal to a reference given externally by the sequencer.

This reference is either the warm-up current reference (warm-up mode), either an error current resulting from comparing through a numerical amplifier, the anode current telemetry and the anode current reference (operate mode).

The maximum current is 4A, the maximum power is 14W.

3.9. Sequencer

The sequencer allows to manage the different power supplies and valve drivers of the PPU.

In automatic mode, the sequencer controls the thruster start-up sequence and regulates the discharge current according to an external reference provided via the TC/TM interface.

The discharge current depends on the Xenon flow, which is fixed by the thermothrottle temperature. The sequencer adjusts the thermothrottle current reference to perform the discharge current regulation.

In remote mode, each supply may be individually addressed and controlled through the sequencer by the PPU user.

The sequencer is based on a microcontroller.

Drivers allow to manage the different buses ensuring the data exchange with the different telemetries and telecommands.

Sequencer tasks

The sequencer must execute tasks allowing it to control the PPU. One task will manage the 1553 interface message coming from or sent to the Spacecraft Controller Unit. Another one will read the telemetries generated by the PPU. Another one will control the sequencing and timing of the different parts of the PPU, this task is in fact the heart of the sequencer.

3.10. TC/TM interface

The 1553 interface allows to communicate with the Spacecraft Controller Unit. It manages the 1553 protocol, receives the telecommands to the sequencer and transmits the telemetries from the sequencer.

An isolated interface allows to transmit the commands from the sequencer to the different power supplies of PPU and to receive the telemetries from the different power supplies to the sequencer.

4. Test results

PPU breadboard has been functionally tested at ETCA premises. The motor was simulated by dynamic loads. General waveforms; limitations, efficiency, regulators stability and conducted emission have been checked.

Two PPU-SPT100 integration test campaigns have been hold at SNECMA facilities.

▼ First in June 1996

- PPU configuration : Primary Power, Anode, Magnet, Ignitor and Heater Supplies

- External XFC control

The four SPT supplies have been successfully tested. Their robustness against noise injected by the thruster, stability and output impedance adequation with the thruster have been validated.

▼ Second in January 1997

- PPU configuration: adjunction of thermothrottle supply, valve driver and sequencer.

XFC supplies have been tested. Robustness of the sequencer and anode current regulation by action on the thermothrottle have been verified.

One PPU-PPS1350 integration test campaign has been hold in January 1998, at SNECMA facilities. The anode module of the breadboard has been adapted to the PPS1350 thruster.

The compilation of several ignitions shows the anode current consumption at thruster start up and the resulting anode voltage drop due to the anode supply power limitation (see fig. 6 and 7).

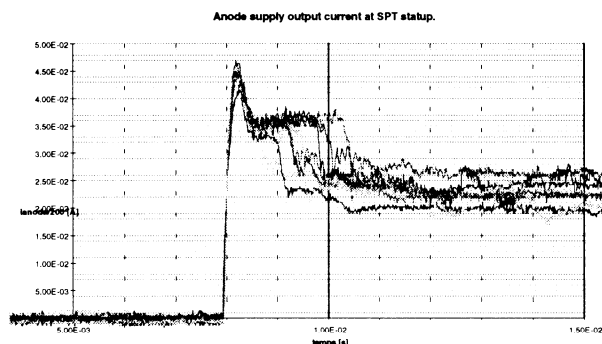


Fig. 6 Anode current at start-up

5. Main performances

5.1. Adaptability

The topology offers a great flexibility to regulated bus voltage (50V or 100V) or to anode voltage (SPT100 or PPS1350).

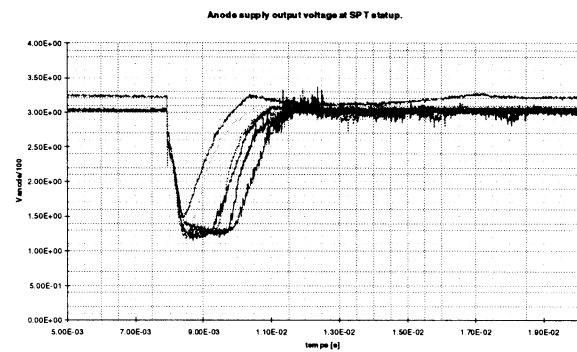


Fig. 7 Anode voltage at start-up

Two inverters adjust voltage level and perform galvanic isolation between bus and SPT supplies. The modification of the transformers ratio of the inverters realises easily the voltage adaptation.

5.2. Power level

The six PPU supplies (anode, magnet, heater, ignitor, thermothrottle and valve driver) deliver up to 2,2 KW in transient mode.

In steady state mode, 1680 W are provided to the PPS1350 thruster with 91% efficiency.

5.3. Reliability

PPU and TSU have no internal redundancy.

Their reliability figure computed according to MIL-HDBK-217 is 2790 fits at 40°C base plate.

Cold redundancy is achieved at satellite level by using two groups of PPU + TSU + thrusters.

No single failure inside PPU or TSU leads to the loss of the power bus.

5.4. Packaging

The maximum dimensions, for one PPU+TSU, including fixations are 390,1 mm x 190 mm on the base plate, 186 mm height (see fig. 8).

The weight is 10,4 kg.

The PPU mechanical design is based on a modular assembly, composed of 5 modules:

- primary power module (adaptable 50 or 100 V),
- anode buck module,
- him (heater, ignitor, magnet) module,
- TM/TC module,
- TSU module (optional according to system architecture).

6. Development plan

The priority objective has been to manufacture quickly a PPU in breadboard version in order to start as soon as possible the integration tests with the thruster.

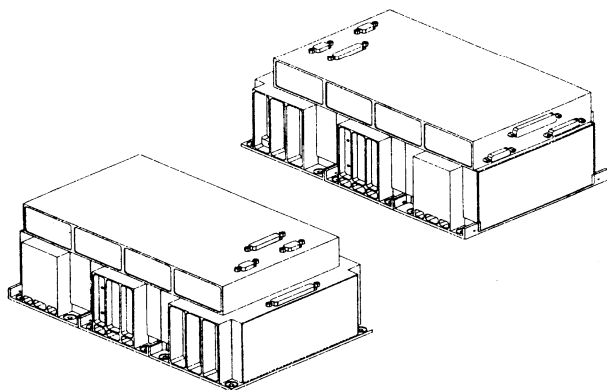


Fig. 8 PPU packaging

Three successful PPU-SPT100/PPS1350 integration test campaigns have been realized.

An Electrical Model has been successfully tested with PPS1350 thruster at SNECMA premises.

A PPU qualification model has been also manufactured and qualified firstly at Alcatel ETCA facilities with an EGSE simulating partially the thruster dynamic behaviour :

- ▼ Verification of the full performances at ambient temperature and pressure
- ▼ Vibration test (sinus-random-shock)
- ▼ Thermal vacuum cycles :

The final qualification at sub-system level is planned at SNECMA facilities with the following objectives :

- ▼ Performances verification at low pressure in :
 - steady state
 - transient mode
 with SPT-100 and PPS-1350 thrusters
- ▼ Life test with Thruster²

Alcatel ETCA plans to create an integrated workshop fully dedicated to PPU manufacturing and acceptance tests and so be able to delivery flight units for commercial applications with the shortest lead time.

Today, two PPU have been delivered to ALCATEL for STENTOR program (in version 50V, MIL-STD-1553, SPT-100 and PPS-1350). Two others will be delivered by the end of 1999 for the ASTRA-1K satellite (in version 50V, ML16DS16, SPT-100).

7. Conclusions

The PPU-SPT integration campaigns have confirmed and validated the design of the PPU.

The global performances measured during the tests conducted at Alcatel ETCA facilities with a thruster simulator and, at SNECMA facilities, with the SPT-100 or PPS1350 thruster, are compliant with the requirements of the program.

These results authorize the continuation, with complete confidence, of the development of additional versions of the PPU.

The PPU modular conception allows to fit with specific mission requirements. The equipment can therefore be used in different configurations onto the SPACEBUS platform and the SKYBRIDGE constellation for example.

The final objective to deliver flight units for the commercial market in 1999 is consolidated by the success of the already won contract.

LIST OF ACRONYMS

PPU	Power Processing Unit
PSS	Power SubSystem
SPT	Stationary Plasma Thruster
TC	Telecommand
TM	Telemetry
TSU	Thruster Selection Unit
XFC	Xenon Flow Control

References

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