16-10-2018

Ref. = LP-PPU-PPT-18036-01-00

Ref. Model = 83230347-DOC-TAS-EN-005

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Presentation Plan

Thales Alenia Space in Belgium,

- previously named “ETCA” was created in **1963**,
- 54 years' experience in power supplies for space applications
- Electric Propulsion activities since **1996**

Outline

- **Background:**
  - PPU Mk1 & PPU Mk2
  - PPU Mk3
- **GEO Dual Mode PPU**
  - Activities
  - Heritage
  - Definition
- **LEO HEMPT PPU**
  - Activities
  - Heritage
  - Definition

Charleroi

Leuven

Hasselt

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TAS-B: a strong and efficient industrial base

A complete supply chain, from hybrids, magnetics, PCBA to products integration & test

Permanent & continuous improvement, with LEAN, to reach Industry 4.0 state of the art

High level set of production and test means

Electrodynamic Shaker

Thermal vacuum - test chamber

Pyroshock test facility

EMC tests chamber

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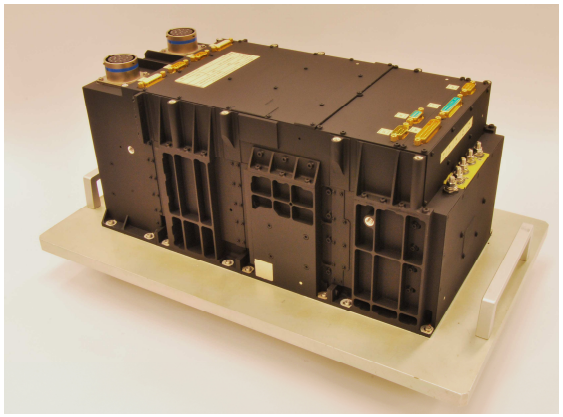
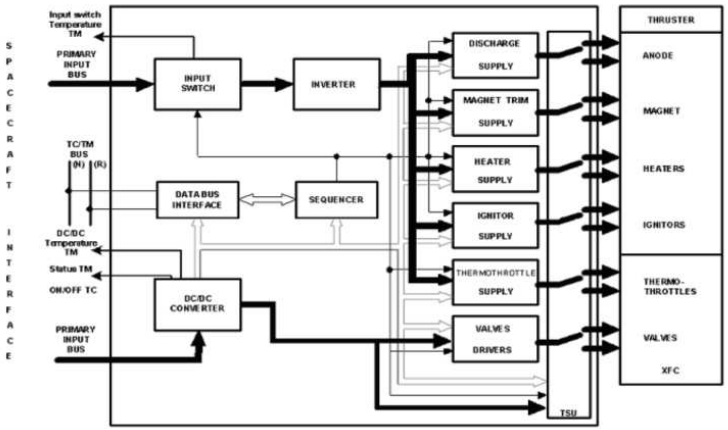
PPU Mk1: Product Overview

Power Processing Unit Mk1

Mass	10.9 kg
Dimensions	390x190x186 mm3
P anode	**1 500 W**
Input power bus	**50V** or 100V
Efficiency at nominal conditions	91.6% (50V) 92.4% (100V)
Reliability for one PPU + TSU	2996 fits
Operating up to pressure of	200 mPa
TC/TM plug-in module	Mil-Std-1553 OBDH-RS485 (RUBI) ML16/DS16
Thrusters	SPT-100 PPS1350-G





- **Flight Heritage** since September 2003
  - **Smart-1** reached the Moon, 4 958 hrs operation
  - **12 telecom satellites** in flight with 2 PPU Mk1
  - **40 000 hrs** cumulated flight operation
- **35 PPU Mk1 FM's** delivered to
  - ADS, ESA, IAI, OHB, Safran, TAS-F

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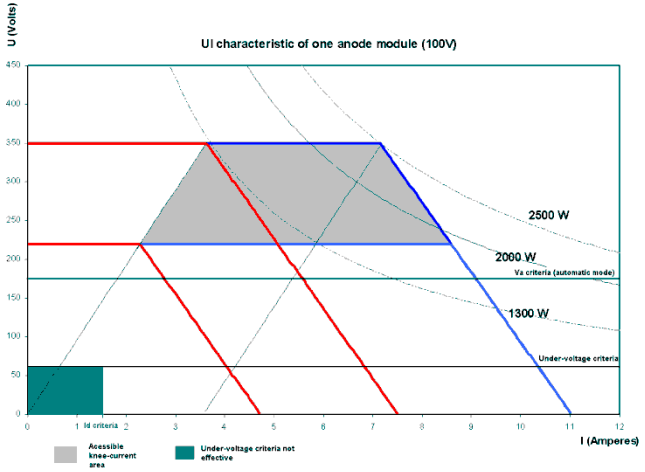
PPU Mk2: Product Overview

Power Processing Unit Mk2

Mass	11.8 kg
Dimensions	390x190x190 mm3
P anode	**2 500 W**
Input power bus	**100V**
Efficiency at nominal conditions	95%
Reliability for one PPU + TSU	1700 fits
Operating up to pressure of	1 Pa
TC/TM plug-in module	Mil-Std-1553
Thrusters	SPT-100 PPS1350-G PPS1350-E

- **Qualified** since July 2014
- PPU Mk2 EQM successfully coupled with
  - SPT-100; PPS1350 at 1.5 kW and 2.5 kW
- **16 PPU Mk2 FM's** ordered by 2 Customers



16-10-2018
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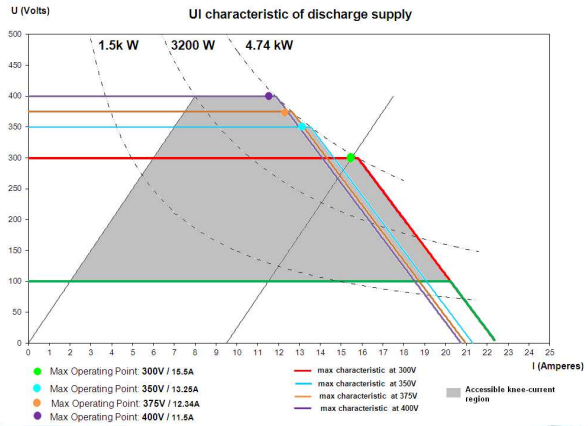
PPU Mk3 Description: Product Overview

Power Processing Unit Mk3

Mass	18.6 kg
Dimensions	390x315x263 mm3
P anode	**4 740 W**
Input power bus	**100V**
Efficiency at nominal conditions	95%
Reliability for one PPU + TSU	2300 fits
Operating up to pressure of	1 Pa
TC/TM	Mil-Std-1553
Thrusters single cathode	SPT140-D PPS-5000 Variant for XR-5 PFCV



- **Qualified** since March 2016
- PPU Mk3 DM/EQM successfully coupled with SPT140-D, PPS-5000, XR-5
- **36 PPU Mk3 FM's** have been **ordered** by four Primes
- **15 PPU Mk3 FM's** are already **delivered**
- **9 PPU Mk3 FM's** are **in-flight**.
- First European Electrical Orbit Raising from June 2017 till October 2017

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PPU Mk3 Development Timeline

Study Phase

Design & Development

DM Manufacturing & Test

EQM MF & Qualification

FM Manufacturing

FM1 Delivery

Orbit Raising with FM1,2,3

2013 | 2014 | 2015 | 2016 | 2017

RR | PDR | CDR | QR

Coupled tests Anode supply/SPT140-D at Fakel facilities

Coupled tests DM/SPT140-D at Aerospazio

Coupled tests DM/PPS-5000 at CNRS

Coupled tests DM/XR-5 at QinetiQ

Coupled tests EQM/SPT-140D at Aerospazio

Coupled tests EQM/PPS-5000 at CNRS

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GEO Dual Mode PPU (1/2)

In the frame of the EPIC H2020 CHEOPS project (GA 730135), TAS-B develops a Dual Mode PPU

CONSORTIUM FOR HALL EFFECT IN ORBIT PROPULSION SYSTEM

- To drive HET up to **7 kW** for Geo Telecom or Navigation either
  - High thrust mode: lower voltage and high current
  - High Isp mode: higher voltage and lower current

- Phase 1 includes:
  - PPU Specification → completed
    - Co-engineering with thruster and FMS manufacturer
    - PPU Specification and architecture
    - SRR held in April 2018
  - PPU Design → on-going
    - Anode supply, HIM supplies, FMS supplies
    - Baseline Design Review
    - Preliminary Design Review
  - PPU Breadboard MAIT
    - Breadboard manufacturing & test
    - Breadboard test bench implementation
  - PPU Breadboard coupling test with HET

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GEO Dual Mode PPU (2/2)

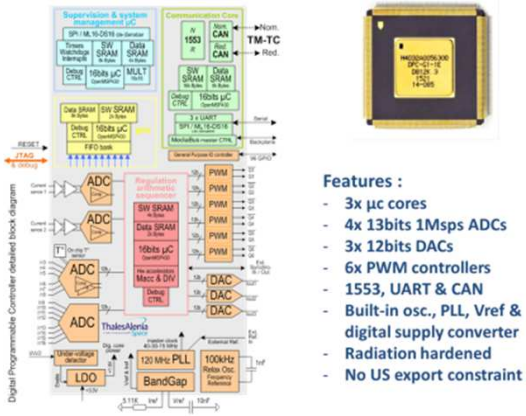
GEO Dual Mode PPU Definition

- Anode Module
  - Full-bridge with transformer
  - Two secondaries which can be configured in parallel or in series
- Cathode Module
  - Heater, Ignitor supplies
  - Magnet supply
  - FMS supplies with regulation loop for the discharge current
- Key technologies
  - Competitive High Power / High Voltage planar transformer
  - Use of TAS-B Digital Processor Controller (µcontroller dedicated to space applications)
  - Use of GaN transistors

Heritage from PPU Mk3 & CHVPS

- Single 5kW anode supply demonstrator tested in 2016
  - Configurable to deliver 500V or 1kV or 2kV
  - 100V Regulated bus
  - Innovative electrical topology
  - Digital Control

Digital Controller Architecture



Features :

- 3x µc cores
- 4x 13bits 1Msps ADCs
- 3x 12bits DACs
- 6x PWM controllers
- 1553, UART & CAN
- Built-in osc., PLL, Vref & digital supply converter
- Radiation hardened
- No US export constraint

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LEO HEMPT PPU (1/3)

In the frame of the EPIC H2020 HEMPT-NG project (GA 730020) TAS-B develops a HEMPT PPU

- To drive HEMPT for LEO application
- Phase 1 includes:
  - PPU Definition → completed
    - To define the **low-cost PPU** based on a thruster/PPU interface optimized with the thruster manufacturer
    - PPU Specification and architecture
    - SRR held in June 2017
  - PPU Design → completed
    - To design LEO-PPU, including the interface to **non-regulated power bus**, the power supplies for the thruster, the regulation loop and the PPU sequencing.
    - Internal Peer Design Review held
    - Preliminary Design Review held in July 2018
  - PPU Breadboard Manufacturing and Test → on-going
    - Breadboard manufacturing & test
    - Breadboard test bench implementation
  - PPU Breadboard coupling test with HEMPT

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LEO HEMPT PPU (2/3)

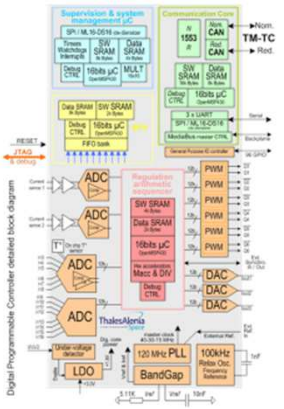
LEO HEMPT PPU Definition

- Anode Module
  - Delivering about **700W** up to **1kV**
- Neutralizer Module
  - Heater, Keeper supplies
  - EPG-limiter (clamping of the floating ground of the thruster)
  - FMS supplies with regulation loop for the discharge current
- Key technologies
  - Competitive PCB planar transformer
  - Use of TAS-B Digital Processor Controller (µcontroller dedicated to space applications)
  - Use of GaN transistors

Heritage

- 2 PHVC modules of 2.5kW connected in series, commandable up to 2kV / 4.7kW
- Demonstrator successfully coupled with
  - RIT-22: 900V-2kV in Giessen, followed with 500 hrs life-test
  - HEMPT-3050: 500V-1kV in Ulm

Digital Controller Architecture



Features :

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- 4x 13bits 1Msps ADCs
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- 6x PWM controllers
- 1553, UART & CAN
- Built-in osc., PLL, Vref & digital supply converter
- Radiation hardened
- No US export constraint

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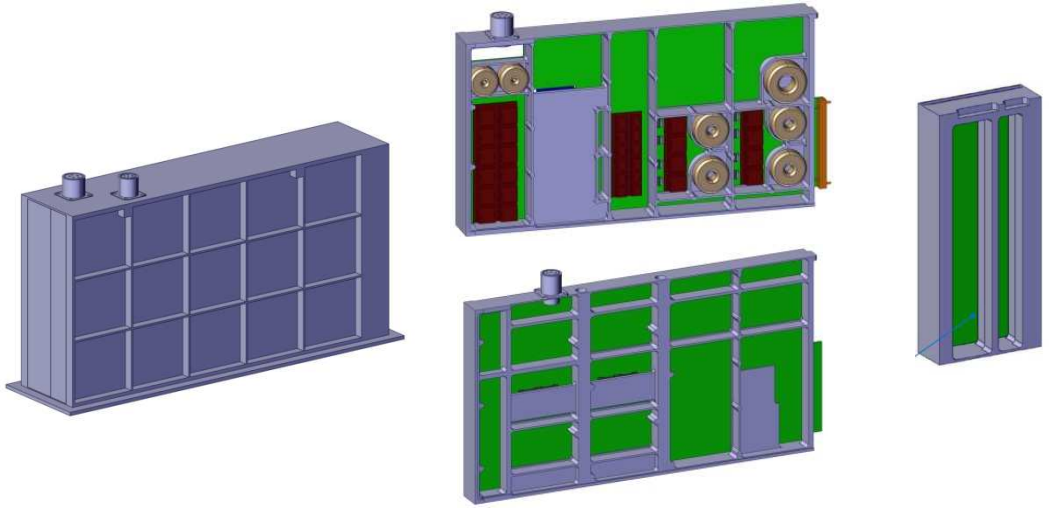
LEO HEMPT PPU (3/3)

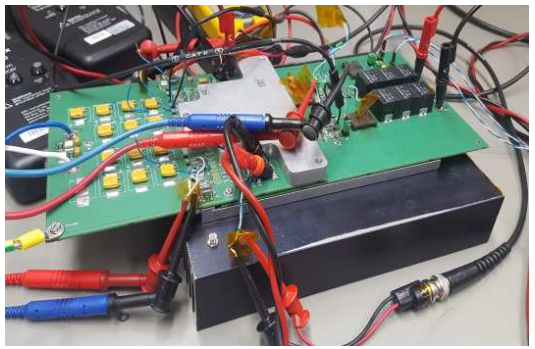
PDR outputs

- Electrical schematics, DJD,
- WCA, PSA, FMEA,
- Packaging,
- Thermal analysis



De-risking breadboard

- Push-pull inverter tested up to 850W
- Resonant topology
- PCB planar transformer
- GaN transistors



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Conclusion

- Based on strong heritage from PPU Mk1 and from PPU Mk2 , TAS-B has designed, developed and qualified the competitive **PPU Mk3** product dedicated to **5kW HET** and 100V satellite platforms.
  - Short time to market: KO in 2013, **QR** in **March 2016**
  - Coupling tests with **PPS-5000**, **SPT140-D** and **XR-5** thrusters.
  - **36** PPU Mk3 FM's **ordered**,
  - **15** PPU Mk3 FM's **delivered**,
  - **9** PPU Mk3 FM's **in-flight**

- Thanks to the EPIC H2020, TAS-B is designing and developing two PPU competitive products:
  - In the frame of CHEOPS, **Dual Mode HET PPU** for GEO/NAV applications,
  - In the frame of HEMPT-NG, **HEMPT PPU** for LEO applications

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730135 & 730020.

European Commission

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GEO Dual Mode PPU & LEO HEMPT PPU

Thank you for your attention

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