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Digital Twin of a Power System (RTP)

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Complex Systems

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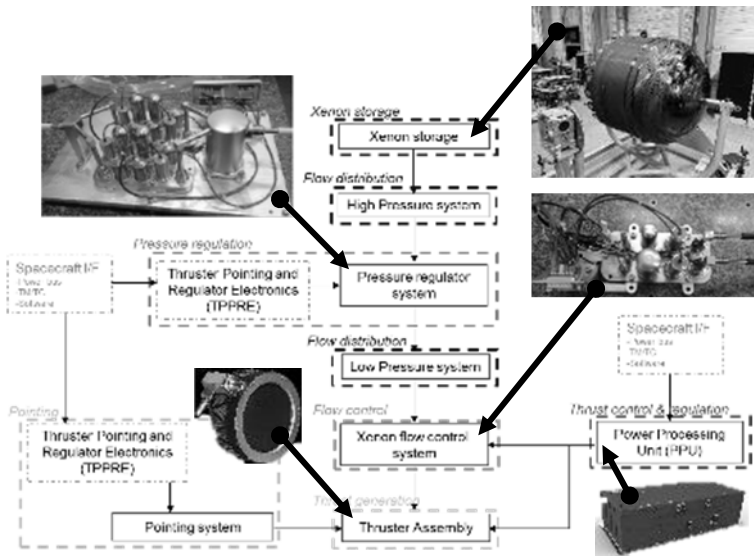
How to reduce development time



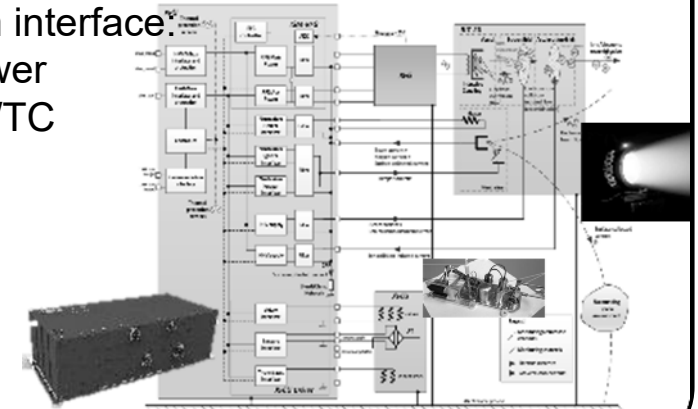
Simulating EMULATED PPS

COMPLEX SYSTEM: PPS for MSR ERO

- ❖ Xenon Sub-System: storage, distribution, pressure regulation, flow control
- ❖ Thruster Sub-System: pointing, thruster
- ❖ PPU



- ❖ Electrical supplies for RIT-2X:
 - ✓ Screen grid: 7.4kW @1800V
 - ✓ Acceleration grid: -250V
 - ✓ Low power supplies for neutralizer
- ❖ XFCU:
 - ✓ Temp. and press. Computation
 - ✓ Bang-bang control
- ❖ Platform interface:
 - ✓ Power
 - ✓ TM/TC



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Simulation Environment Requirements

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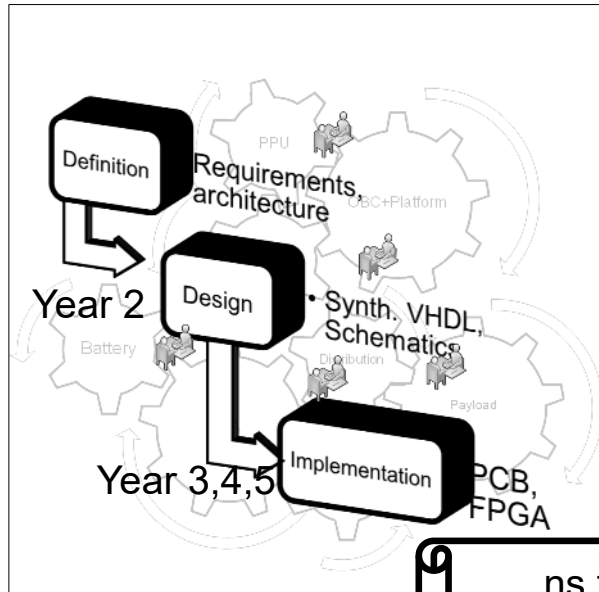
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Simulation environment: nano-seconds requirement

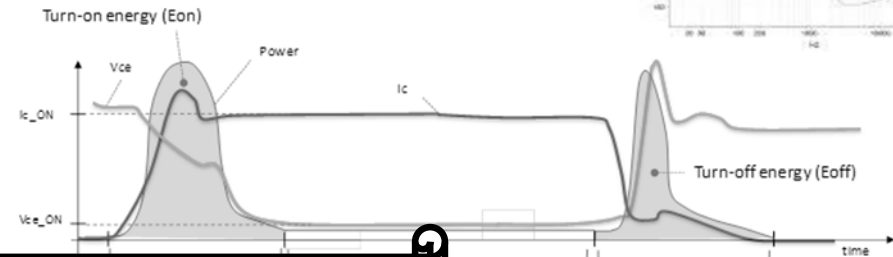
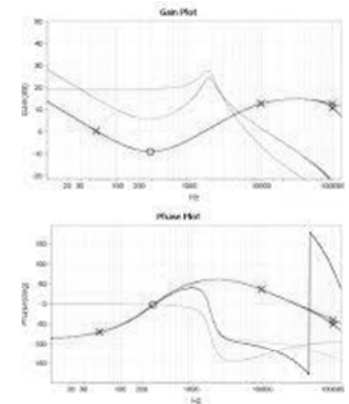
System requirements for simulation

Waterfall implementation:

- Time consuming
- Risk mitigation very late phase



- ❖ DCDC converters:
 - ✓ switching frequency 100-300 kHz
 - ✓ Time variant
 - ✓ Non linear differential equations
- ❖ FPGAs:
 - ✓ Clock cycles of 20 ns
 - ✓ High level TM/TX: MIL-1553



ns time resolution enables not missing important microscale phenomena impacting macroscale

losses = $I_{c_ON} \times V_{ce_ON}$ Turn-off switching losses = $V_{ce} \times I_c$

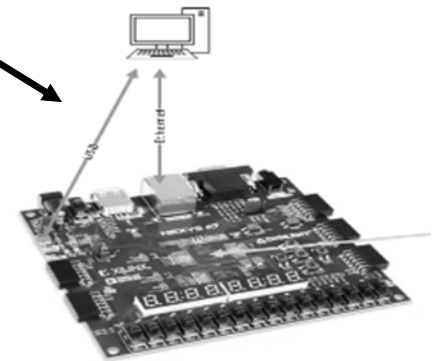
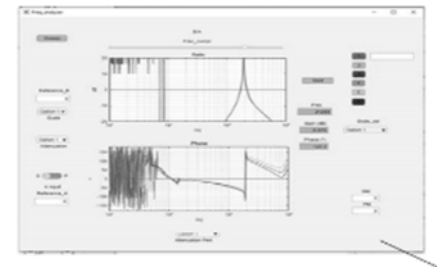
Simulation environment: real-time requirement

Computer simulation: requires very expensive computers, very time consuming, reduced simulations → not suitable for complex systems.



Real time simulation: → running in hardware

- More time available to test
- Test much closer to real operation.
- Humans interactions and their unexpected reactions can be part of the test campaign
- Easy and realistic interaction with digital control subsystems like unit FPGAs and OBC software.
- Easy to update elements and run delta tests.



Real time enables testing, testing and testing,
for days and weeks
without the risk inherent to hardware test

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RTP Simulation Tool

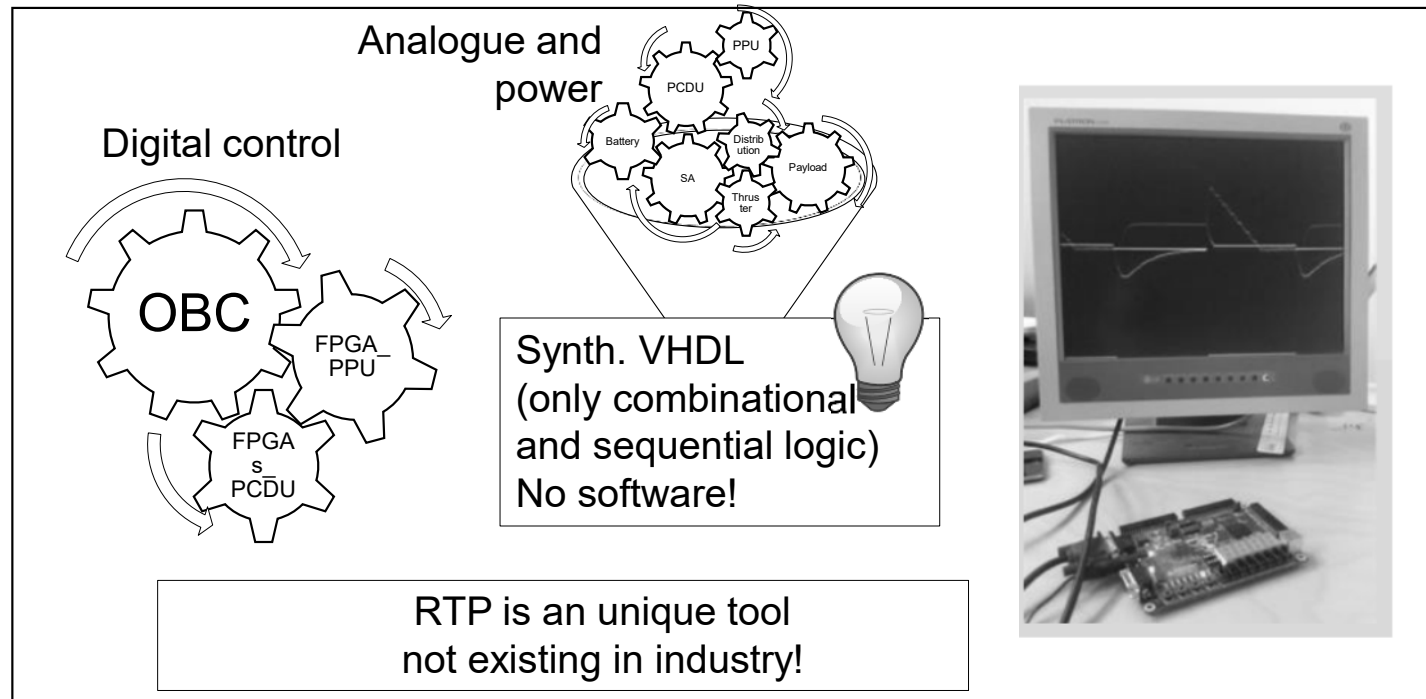
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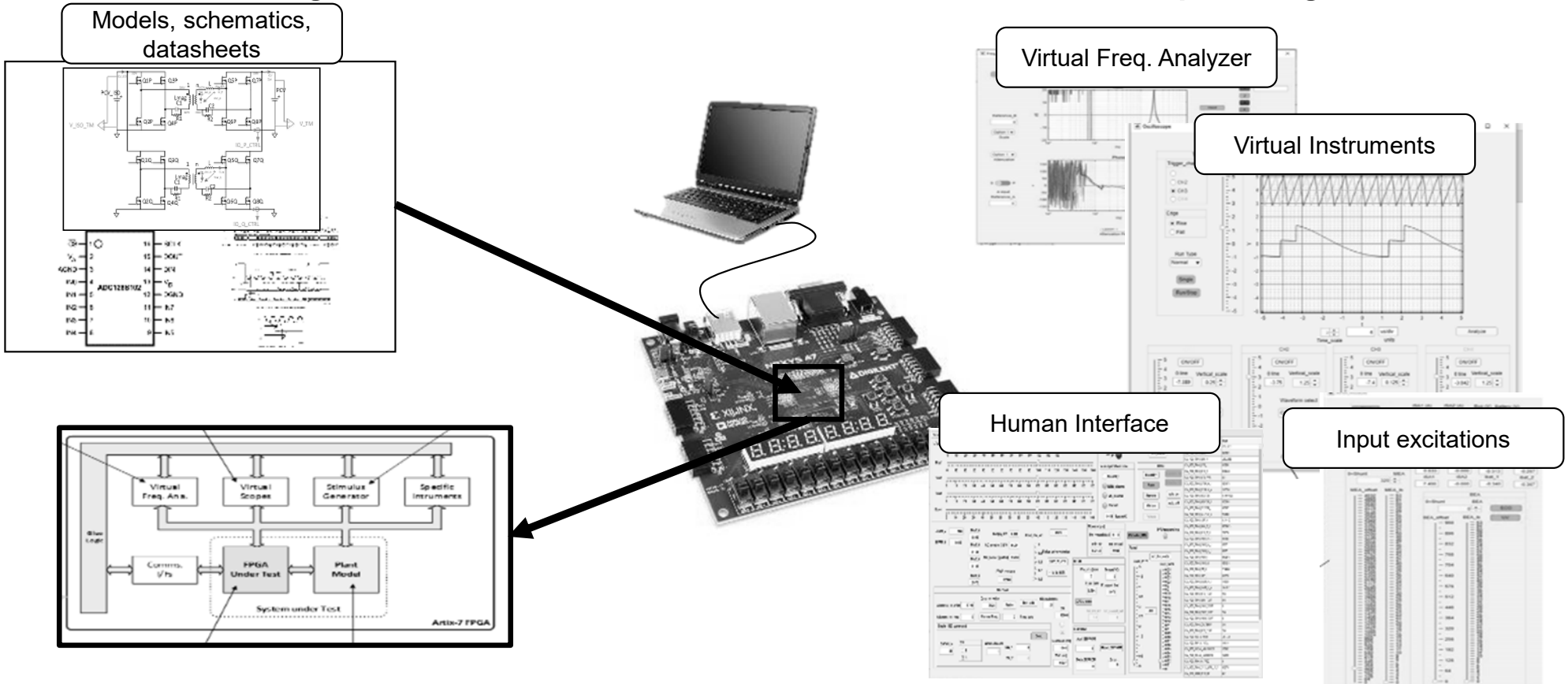
RTP: Real Time Power

- Describe power/analogue/digital electronics and their differential equations in **synthesizable VHDL (HW solution, no SW)** to solve them in real time with a time resolution of **tenths of ns**
- Direct emulation of digital integrated design **VHDL already done during design for FPGAs!**
- It is always possible **to increase resources as complexity increases with more FPGAs**
- Commercial products are very expensive and with less resolution time

RTP



RTP: Model generation, instrumentation, interface, reporting



Human interface

The screenshot displays a complex control interface with several key sections:

- Bus voltages:** Four horizontal progress bars for Bus1, Bus2, Bus3, and Bus4, each with a scale from 0 to 160.
- Main operation state:** Radio buttons for Standby, NTR plasma, VS plasma, and Thrust. A 'HV en' indicator is also present.
- Mode selection:** A 'Mode' panel with buttons for Standby, Auto, Remote, Manual, and Fail-safe.
- OP errors / Cmd conflict:** Two digital indicators showing 0.
- Flows (mg/s):** A panel with numerical readouts for Pin_vessel, mfr_ntr, mfr_vessel, P_ntr, and P_vessel.
- Periodic TMs / PPU responding:** A panel with 'ext_hv_loads' and 'load PHV'/'load NHV' indicators.
- ADC channel table:** A table listing various ADC channels and their values, such as 'ICM_ADC_TM0_PHV_TEMP' with a value of 0.
- MIL-1553 interface:** A section for sending and receiving data via MIL-1553, including 'Address to write', 'Data to write', and 'Single 1553 command'.
- EEPROM:** A section for adding and reading EEPROM data.

Callouts from the interface:

- Sequencer Mode of operation:** Points to the 'Mode' selection panel.
- Output Telemetries:** Points to the ADC channel table, listing parameters like current and voltages of power supplies and their status.
- Power elements:** Points to the 'ext_hv_loads' and 'load PHV'/'load NHV' indicators.
- MIL-1553:** Points to the MIL-1553 command interface.

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Application: Bidirectional Power Converter

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Emulation Power Converter

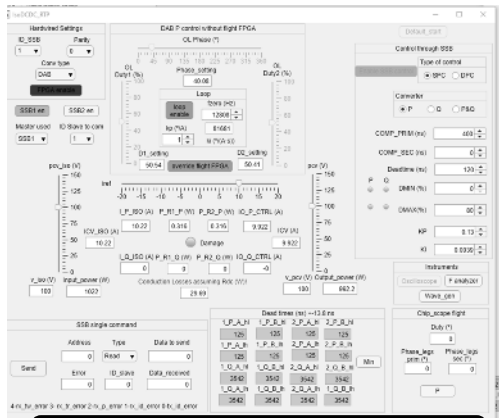
Dual Active Bridge (DAB) with Digital Control → RTP helped on:

- early issues discovery
- Enabled digital control testing prior building hardware

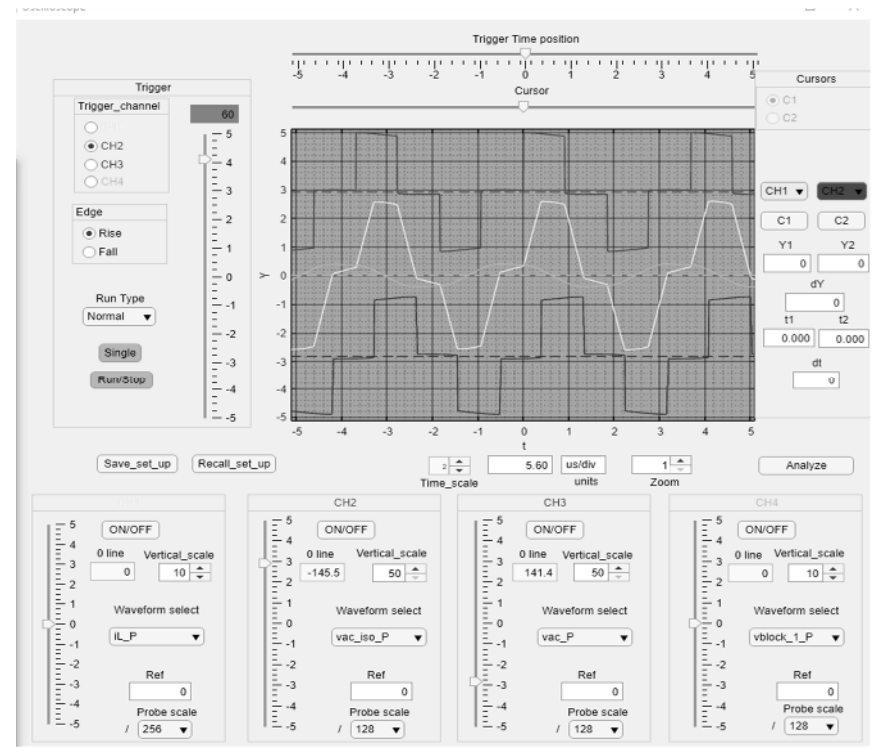
DAB Waveforms with the virtual RTP oscilloscope

FIRST STAGE

- Virtual testing of the DAB + simplified FPGA
- It was possible to perform the following activities:
 - Select the right control strategy of the bridges
 - Dead times for ZVS / ZCS
 - Stability margins with the embedded virtual analyser



RTP Interface



Emulation Power Converter

Dual Active Bridge (DAB) with Digital Control → RTP helped on:

- early issues discovery
- Enabled digital control testing prior building hardware

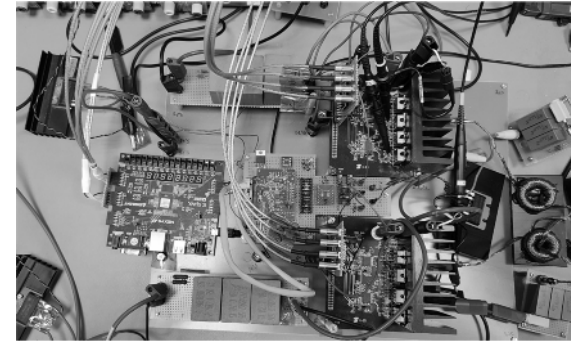
SECOND STAGE

- Real Hardware of the DAB + simplified FPGA
- So, the DAB is no longer emulated but control and ADC are still emulated.
- Astonish results as the first time the DCDC was switched it worked flawlessly
- It was possible to perform the following activities:
 - Measure characteristics of the DCDC
 - Measure efficiency
 - Stability margins with the embedded virtual analyser

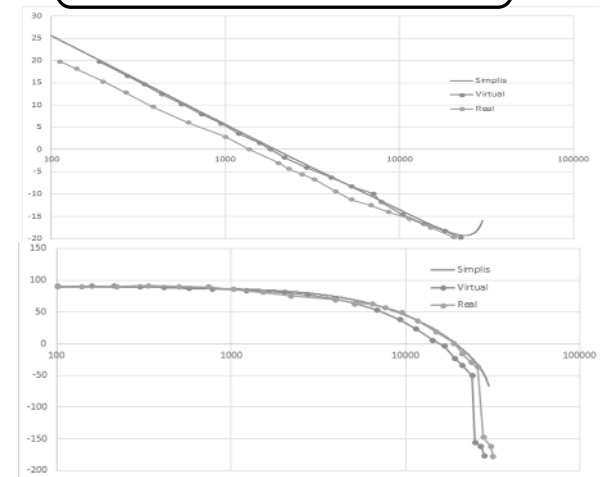
THIRD STAGE

- Virtual testing of the DAB + Final Flight FPGA on RTP setup
- It was possible to perform the following activities:
 - Test all FPGA requirements
 - Test without risk of damaging real hardware, knowing everything worked on the Second Stage.

RTP + DAB



Bode plots: Virtual +
Simulation + Real



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Application: Regulated Bus PCU

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Regulated Bus PCU

Power Board, interfacing with the Solar Array, battery and Primary Bus.

The characteristics of this power board are:

- Several DCDC converters GaN transistors based
- Digital Control by means of FPGAs
- External interfaces such as harness

Virtualization consists on:

- Virtualization of DCDC converters at component level
- Real code of the FPGAs (several Flight FPGA designs inside the same virtualization FPGA)
- MIL-1553B communication protocol embedded on the RTP real flight FPGA

→ RTP helped on:

- Enabled digital control testing prior building hardware
- Control Loop measurements
- early issues discovery → such as instabilities on some corner cases difficult to analyse on traditional simulations
- Commanding the PCU from the real TMTC MIL-1553B interface, in the same way the OBC would do it

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Conclusions

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RTP matches reality

Beam event simulation vs. test

Thank you

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