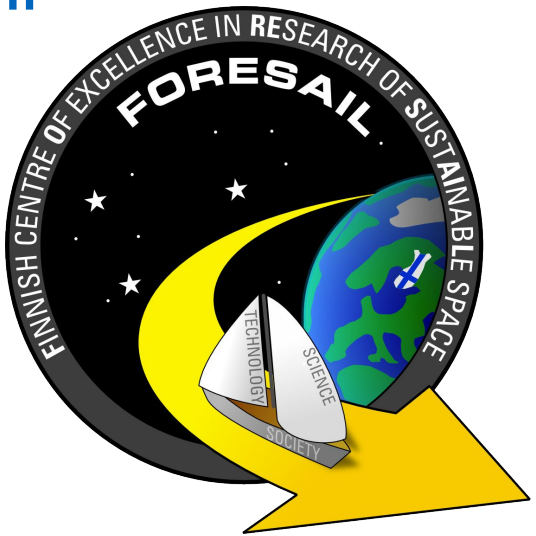
Fault Tolerant Electric Power System for FORESAIL Cubesats

13th European CubeSat Symposium



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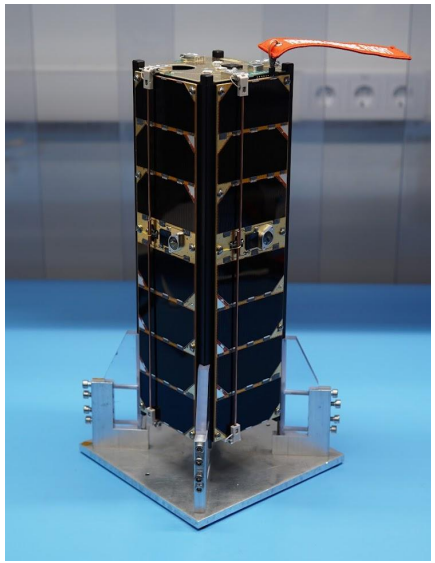
13.12.2023

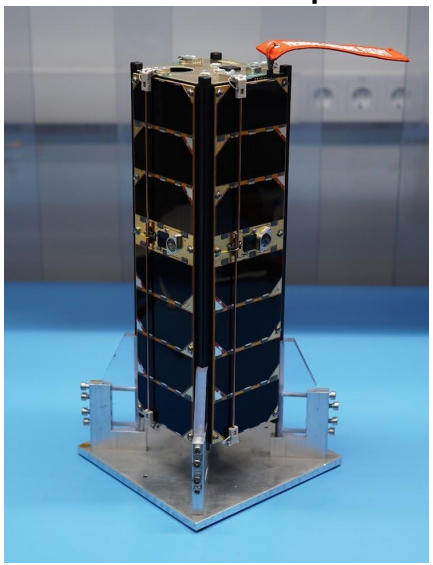
FORESAIL Missions

Foresail-1



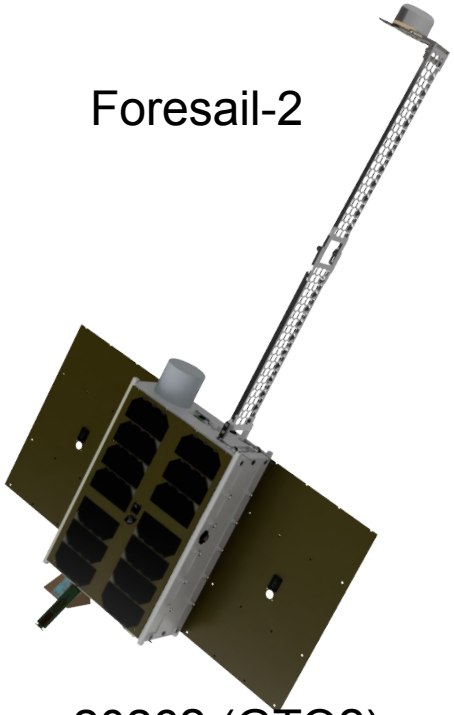
2022 (LEO)

Foresail-1p



2024 (LEO)

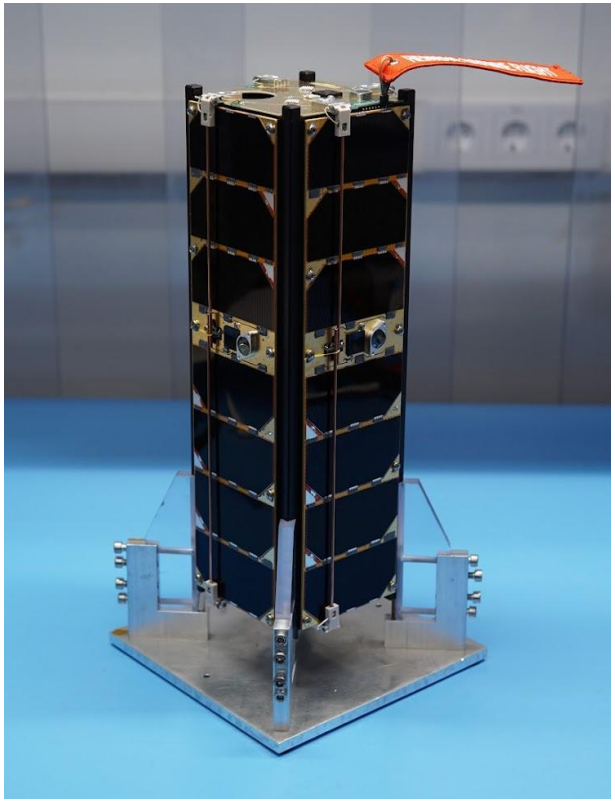
Foresail-2



2026? (GTO?)

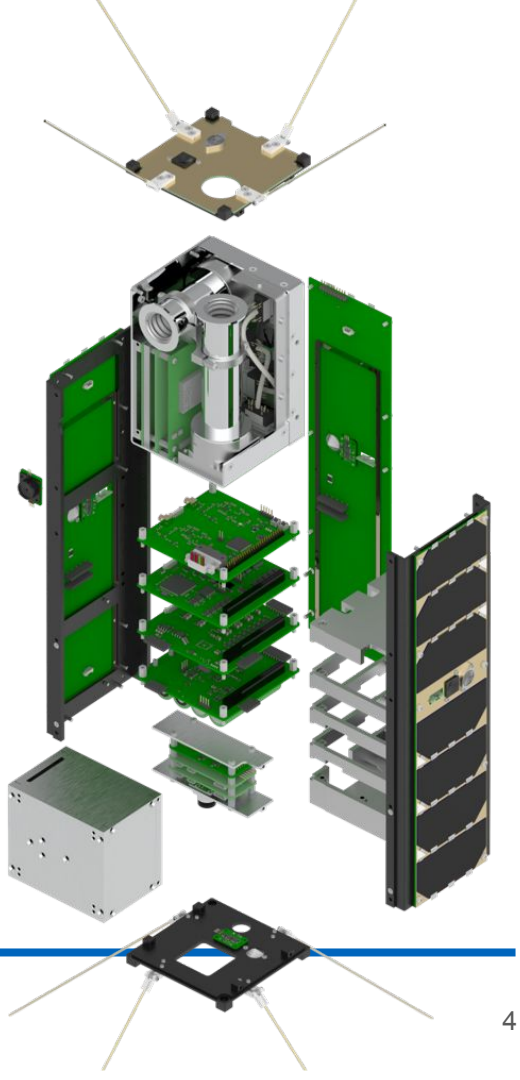
Foresail-1(p) Goals

- Scientific goals
  - Radiation measurements with PATE instrument
  - Deorbit experiment with Coulomb drag instrument
- Technological goals
  - Demonstration of new radiation and fault tolerance technologies (precursor to Foresail-2)
  - Gain flight heritage for the platform
  - Reusability (example: student satellite Aalto-3)



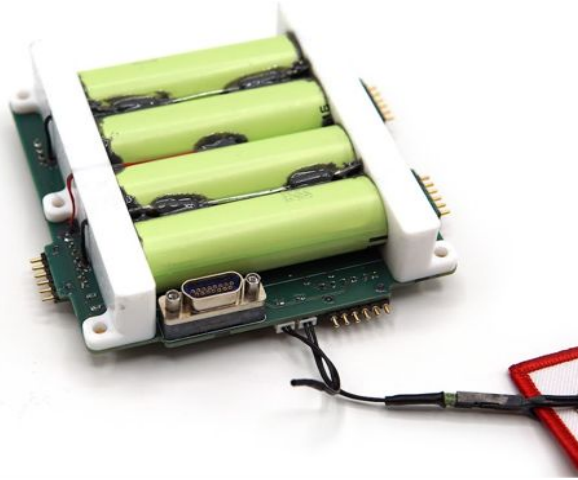
Foresail-1(p) Platform

- 3U Cubesat
- 1U Platform stack shielded with aluminum vault
  - UHF
  - OBC
  - EPS
  - ADCS
- Simplified integration with pogo-pins to reduce harness
- All done in house



Foresail-1(p) EPS

- Requirements
  - Provide on average 2.4 W of uninterrupted power for duration of the mission
  - Provide raw battery and nominal 3.6 V protected rails
  - Collect telemetry
  - Deploy antennas
- Constraints
  - Less than 0.5U volume (inside the radiation vault)
  - Only body mounted solar panels - requires MPPT



Fault Tolerance in Small Satellite

- Simplicity is appropriate for university CubeSats
  - Most failures happen early (< 1 year)
  - Focus on the core functionalities and testing, instead on lifetime (redundancy and space qualification of the components)

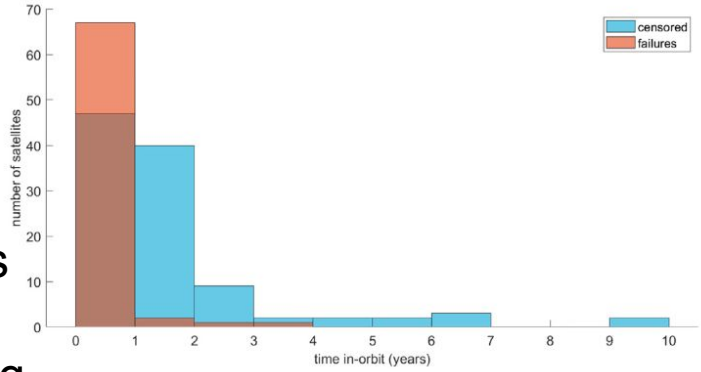


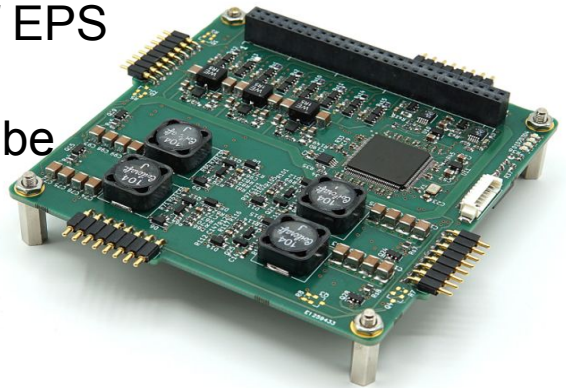
Fig. 2. Histogram of data from CubeSat failure database.

Bouwmeester, J., Menicucci, A. and Gill, E.K., 2022. Improving CubeSat reliability: Subsystem redundancy or improved testing?. *Reliability Engineering & System Safety*, *220*, p.108288.

- Emphasis on the tolerance against unexpected operating modes
  - **Detection**: current measurement, watchdog timers, memory scrubbing, etc.
  - **Isolation**: (resettable) latching current limiters, majority voting, etc.
  - **Recovery**: power cycling, bypassing, bit error correction, etc.

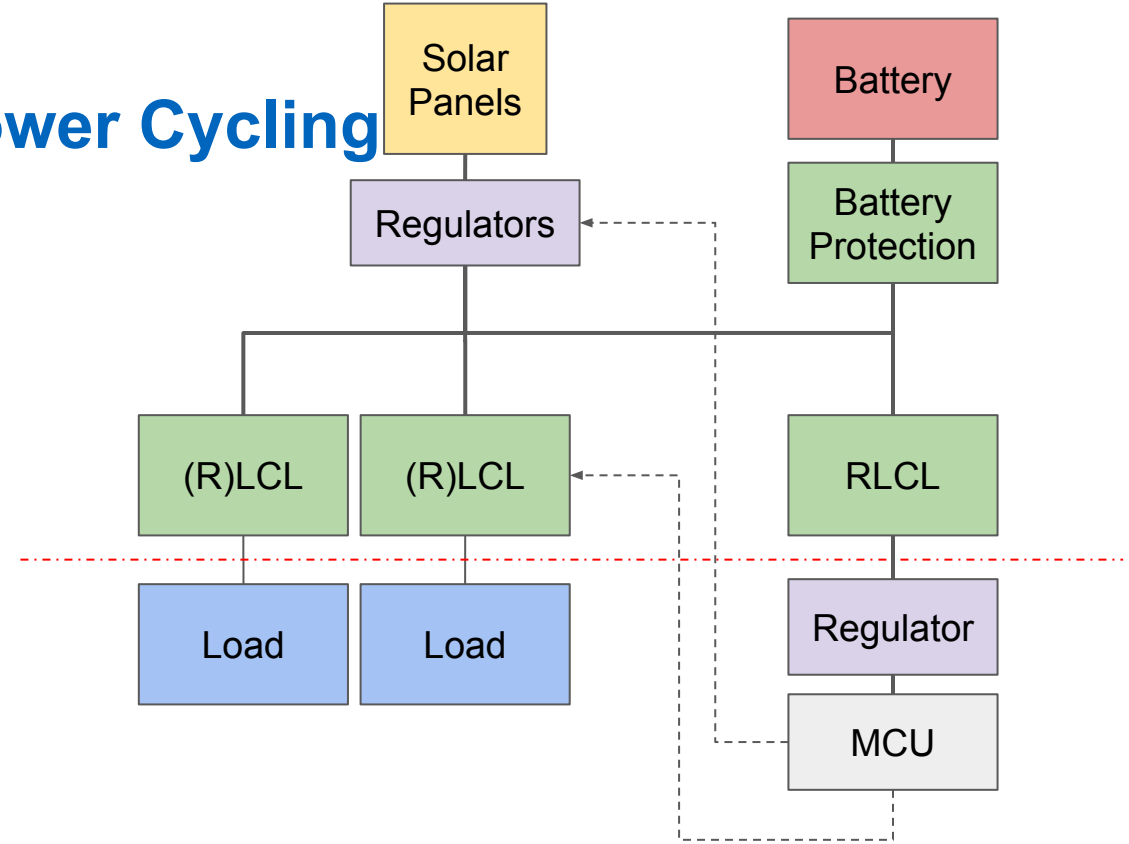
Fault Tolerance in Foresail EPS

- Avoid single-point-of-failures by having guaranteed means of power cycling
  - Portion of the EPS is always power cycled in shadow
  - Use of (R)LCLs to prevent latch-ups from causing permanent damage
- Continued (partial) satellite operation in case of loss of EPS
  - Bypassing
- Where possible, radiation tolerant components should be used (“spot protection”)
  - FRAM memory
  - Radiation tolerant MCU (at least in FS2)



How-to Guarantee Power Cycling

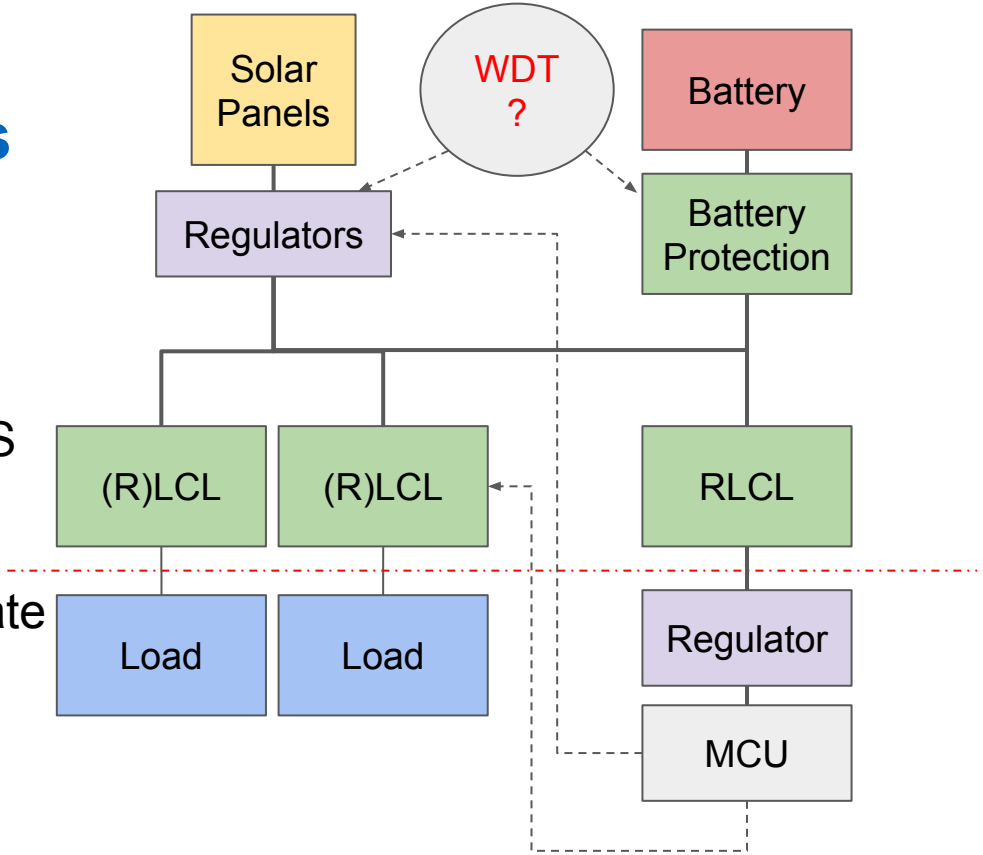
- Anything below redline can be power cycled
- What to-do with circuits above?
  - The main power bus is always powered
- Usual solution external watchdog



Usual CubeSat EPS

Problems with Watchdogs

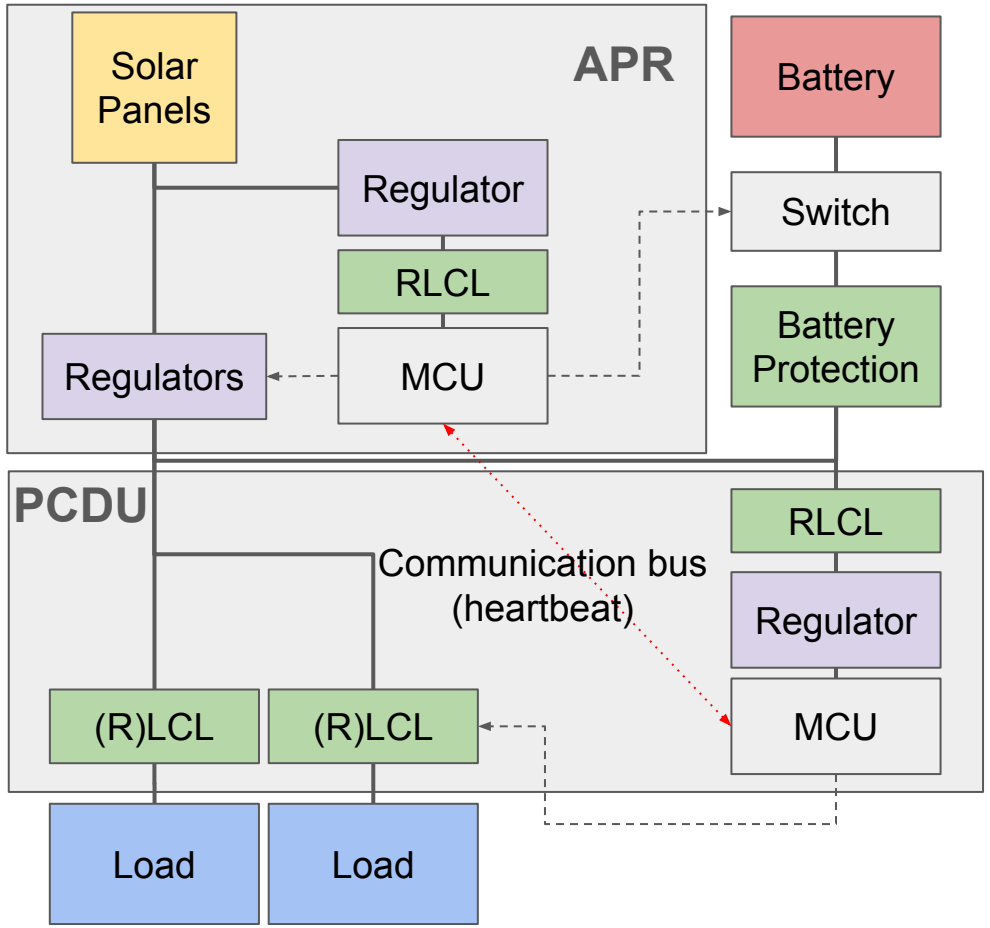
- We cannot give any reliability guarantees
- Who power cycles it?
- Preferably watchdog is on the EPS
  - Keep interfaces simple and clean
  - Low coupling between separate subsystems
- Shall not introduce any unwanted hiccups in the operation of the satellite
  - Like entering shadow



Usual CubeSat EPS

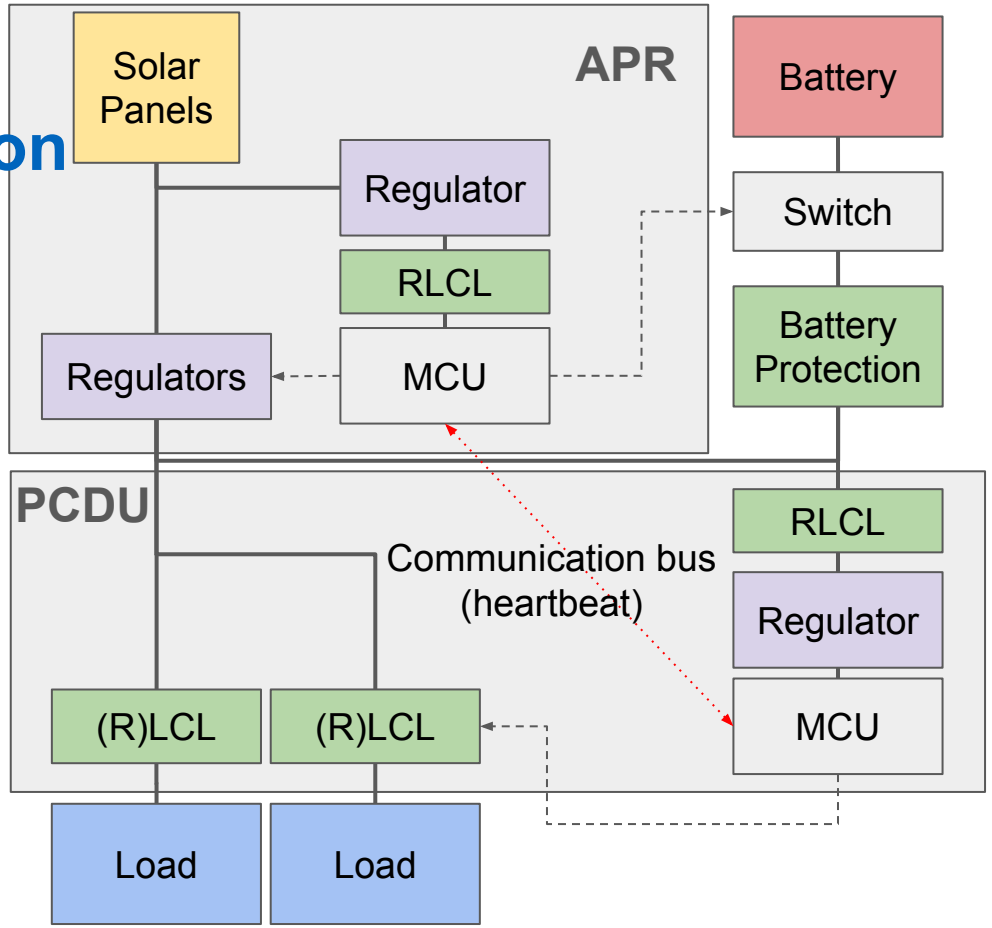
Our Solution

- Separate EPS in two parts:
  - Functions that are required only in Sun (battery charging - APR)
  - Functions that are always required
- APR is always power cycled when satellite enters shadow
- In Sun, APR power cycles the satellite if no heartbeat



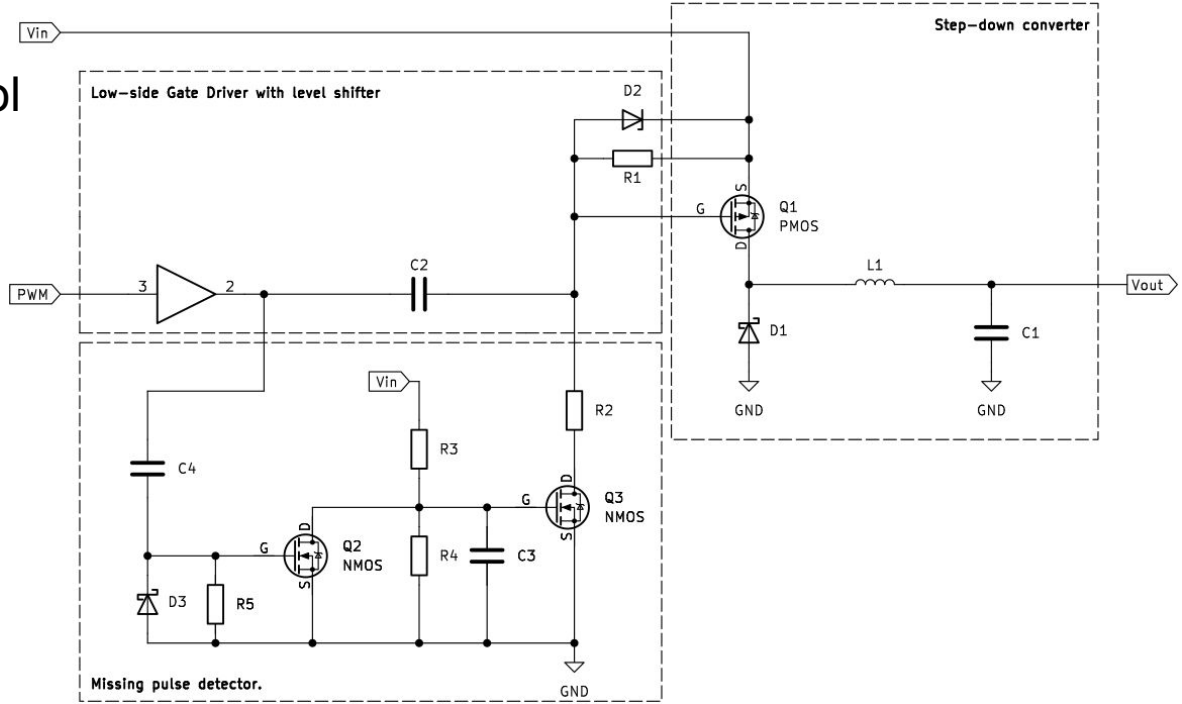
Notes on Implementation

- Isolation
  - Power
  - Communication
- Battery is now behind a discrete switch
  - NMOS MOSFETs have their own latchup mechanism (SEB) that can avoided with derating
  - BJTs can be used, but needs to careful with TID



When All Fails: Bypass

- Last chance if APR control is lost
- Simple implementation with only two additional transistors
- Works with MPPT
  - But only when stepping down
  - Note PMOS pass element



Conclusion

- Custom platform built at Aalto University for variety of missions, including beyond LEO
- Focus on radiation and fault tolerance
- EPS designed on emphasis on unexpected modes
  - Guaranteed power cycling with APR and PCDU separation
  - Simple bypassing if control fails
- Foresail-1p with updated platform based on the experience gained from Foresail-1 will be sent by the end of 2024