Design Process and Modular Breadboard for Rapid Development of Mission Specific Power Conditioning and Distribution Units

SSC19-P1-16

Problem Statement

Scientific satellite missions present a **wide range of requirements** for small satellite electrical power systems. Off-the-shelf components oftentimes cannot meet the specific combination of:

- power handling capability
- provided supply voltages and currents
- interface preferences
- number of switchable outputs

Modular Power Conditioning and Distribution Units (PCDUs) can adapt to those needs, but they provide only a very limited design space resulting in far from optimal solutions.

Especially the **overhead with respect to mass and volume** can be problematic for pico- and small satellites. On the other side the development of a bespoke solution can be hard to fit in the budget and time constraints of fast paced projects.

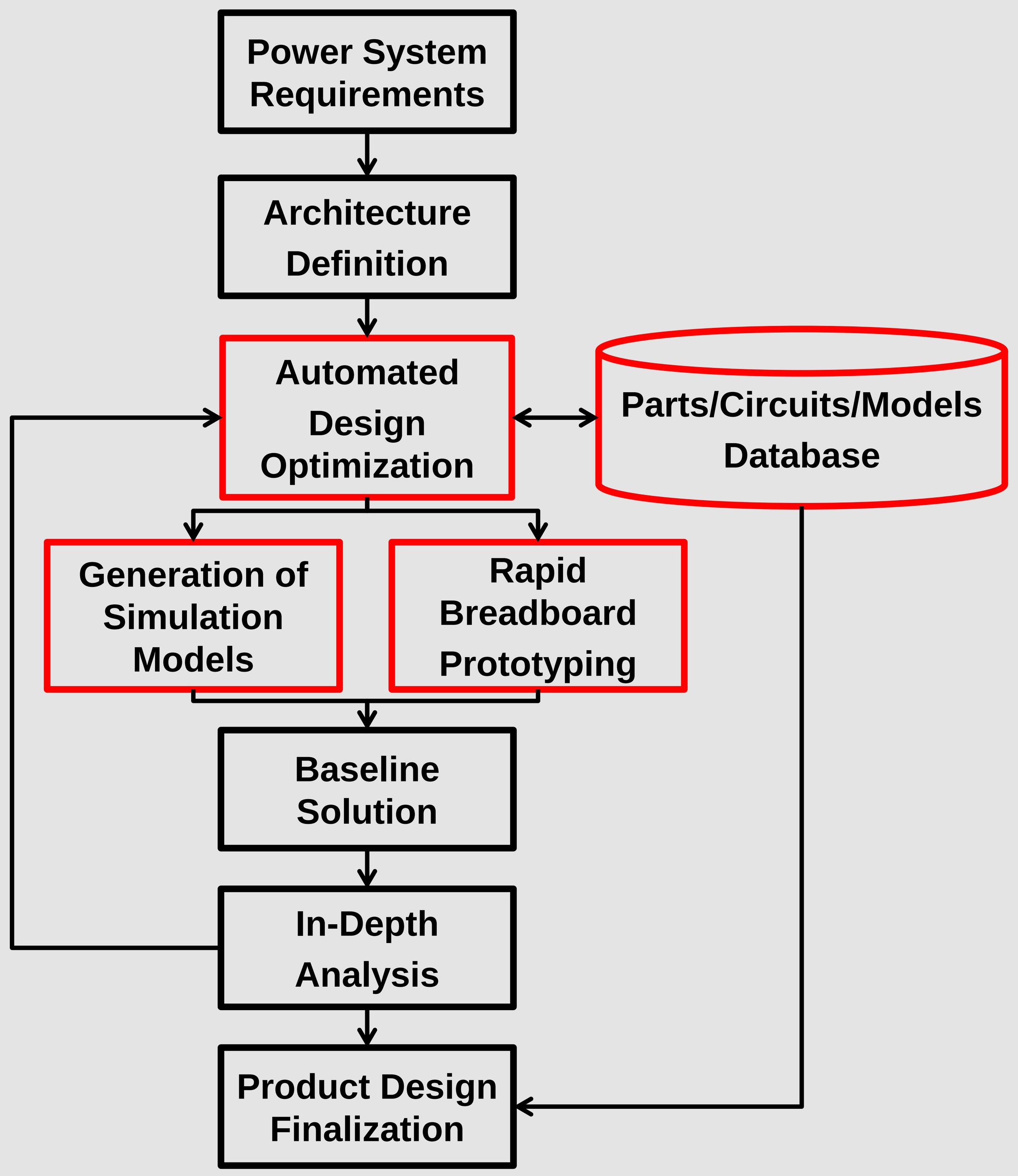
Our Work

We introduce a development platform for the design of mission specific PCDUs and related software. We try to push the **level of modularity to the circuit level** and introduce **design automation techniques** to lower the manual labor involved in the bespoke PCDU design. This approach is heavily depending on a **database of pre-designed electronic circuits** including PCB layouts and simulation models. These can be used early in the project life cycle to find possible design solutions that can meet the power system requirements. Automated tradeoff studies and optimization techniques can find the most suitable configurations and highlight areas of the design that could benefit from newly developed or optimized circuits. In this way the process ensures that design work is done where it provides the highest benefit.

PCDU Design Process

The PCDU Design process uses the Platform Based Design methodology[1]. This approach is heavily based on a database of pre-designed circuits with their simulation models and PCB layouts. For these circuits also standardized evaluation modules are available for environmental testing and breadboarding.

1. The PCDU architecture is generated taking into account the power system requirements.
2. Available implementations from the database are mapped to needed functionalities. Optimizations methods are used to select the circuits with the best performance (efficiency, power handling capability, board space, etc.).
3. From the architecture together with the implementations an overall power system simulation model is generated. At the same time a breadboard prototype can easily be assembled using the PCDU Modular Breadboard.



PCDU Design Process

4. The result is a preliminary baseline solution that can be evaluated virtually (simulation model) and physically (breadboard setup)
5. An in-depth analysis is performed to validate if the generated baseline solution can meet all PCDU requirements. If non-conformances are encountered, the design can be refined by removing the problematic circuits from the design space.
6. Steps 2 to 5 are repeated until all requirements are met and a valid baseline solution is found. If needed new models can be added to the database to meet specific requirements.
7. If the baseline solution satisfies all requirements the design can be transferred to the final form-factor. The PCB layouts for all circuit elements are present in the database and can be used like component footprints. Also the embedded software can be auto-generated for the present architecture and circuit selection. Furthermore test plans and documentation are composed of pre-written snippets from the database.

PCDU Modular Breadboard

This mindset is also present in our hardware prototyping solution. **Standardized evaluation modules** are built for power conditioning and distribution circuitry like DCDC converters and load switches. These can not only be used for electrical, environmental and radiation testing of the components, but also for assembling a fully functional PCDU breadboard. Additional hardware allows for the **simulated command and telemetry circuitry** and embedded software, providing a functional equivalent interface to the onboard computer early on. If new revisions of existing circuits or completely new circuits are built, these can be integrated into the setup by swapping modules without a re-spin of the whole PCDU hardware. In this way hard- and software testing can start early ensuring much higher test coverage. Additionally this modular setup allows for the acquisition of extensive measurements taken in relevant scenarios. These can be used to continually refine the simulation models of the system that can be used to perform analysis, run optimization routines and provide them as part of training tools to the satellite operators. If the PCDU design converged to a solution that fulfills the mission requirements and has been verified in extensive tests all the documentation can be generated to ensure an **easy transition to hardware in the final form factor.**

Simulation Environment

Modeling of the PCDU on system level is done using **SystemC-AMS**. It is built upon the SystemC standard of C++ classes and macros and offers extensions necessary for modelling analog and mixed signal (AMS) systems. It offers following models of computation: 1) Timed Data Flow (TDF), describing sampled data points at fixed or dynamic time steps, 2) Linear Signal Flow (LSF) describing continuous time systems and 3) Electrical Linear Networks (ELN) being electrical circuits that can be described in time continuous voltages and currents.[2] It is based on C++, so standard C++ and ANSI C code, as well as libraries, can be used in the model. This makes it easy to include code used in embedded systems. The overall model can make use of all these elements and is finally compiled to a single binary. It contains the model as well as the necessary infrastructure like schedulers and solvers, which are practically **black box models**. They can be used without any additional software tools and can be supplied to third parties without disclosing intellectual property.

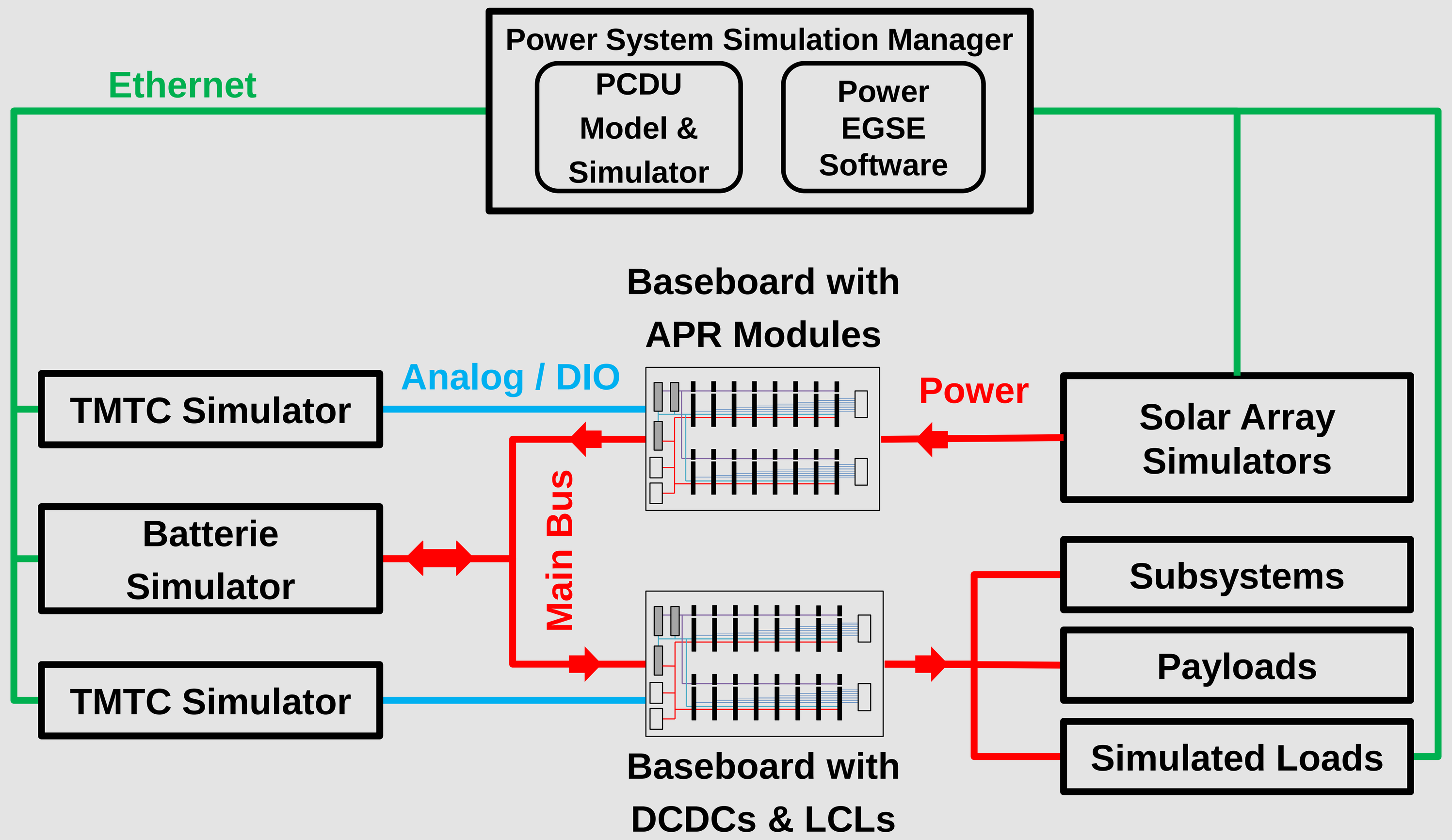
On hardware level LTSpice is used for design and simulation of new circuits as well as generation of models for the system level simulation.

Conclusion

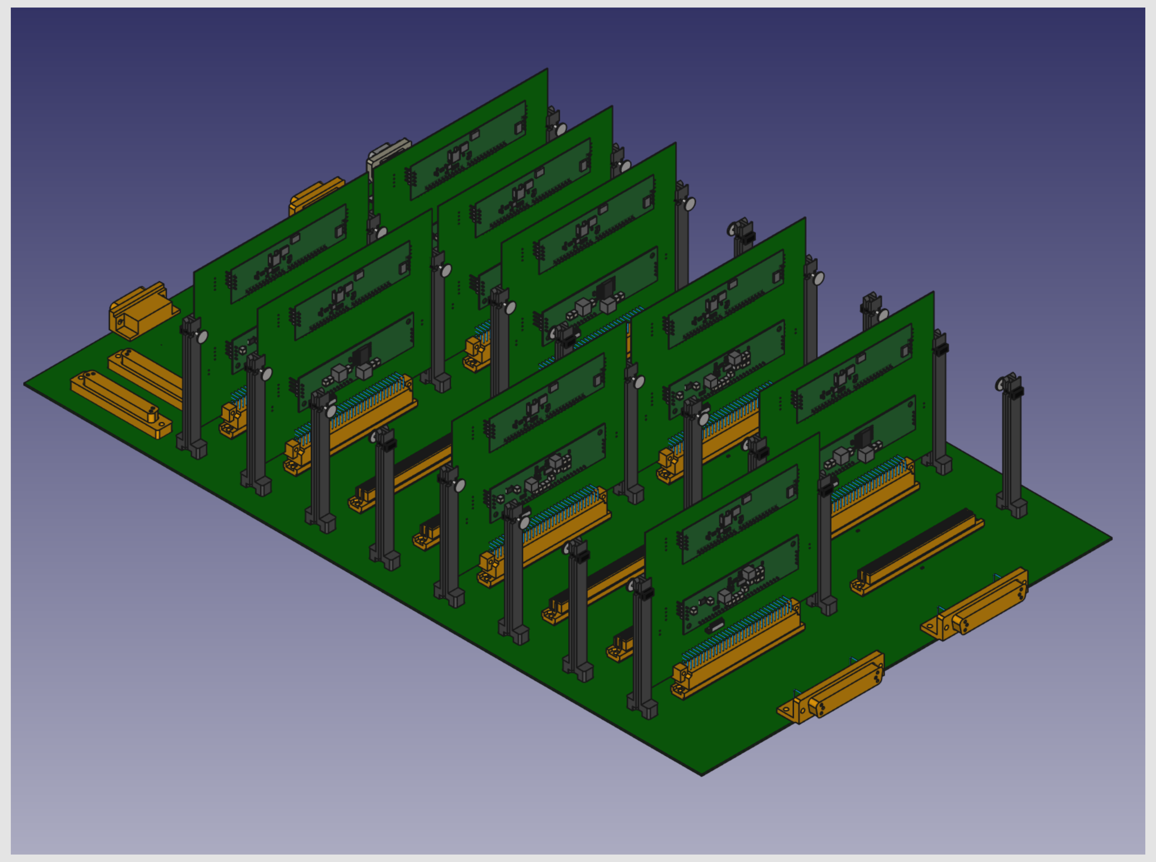
This PCDU design process enables us to provide bespoke solutions for small satellite power systems by reducing manual and recurrent work, enforcing correct design, broaden test coverage while reducing cost and time to flight-ready hard- and software.

Our PCDU design solution is build upon following ideas:

1. Use of design automation techniques
2. Modularity on circuit level
3. Co-Design of simulation Models and prototyping hardware
4. Rapid prototyping of fully functional breadboard units
5. Continuous integration in hardware and software
6. Fail early and iterate quickly



Block Diagram of PCDU Modular Breadboard with Test Infrastructure



PCDU Modular Breadboard with DCDC and LCL Modules

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References

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2) IEEE 1666.1-2016 - IEEE Standard for Standard SystemC(R) Analog/Mixed-Signal Extensions Language Reference Manual, https://standards.ieee.org/standard/1666_1-2016.html (accessed April 11, 2019).