A Scalable COntroller for Power Sources (SCOPS)

COUSINEAU Marc [1], MATHEWSON Alan[2], ALMEIDA Gregory[1], BARAMILIS Dimitrios[3], v.d BURGWAL Marcel[4], DEL POZO Matilde[5], PECOURT Frederic[6], FEULLIET Emilien[7], URIZAR Marta[5], AYZAC Philippe[6]

[1] LAPLACE, Université de Toulouse, CNRS, INPT, UPS, Toulouse, France
[2] ISD Aerospace Ltd., Cork, Ireland
[3] ISD S.A., Greece
[4] IMEC vzw, Belgium
[5] Thales Alenia Space, Spain
[6] Thales Alenia Space, France
[7] SynergieCAD, France

***Abstract* — The PROMISE Design Standard and Library is currently being used (and expanded) to develop a very high efficiency, low voltage, high current DC-DC power converter, based on a novel architecture of control, which allows it to be flexible and reconfigurable as a function of application and fault tolerance requirements. This Scalable power source controller IC (SCOPS) is targeted for use in space and satellite applications which require a robust power supply that can deliver the consistent low voltage and high current that is required to drive advanced electronic technologies, all of which are tending towards low voltage operation but which also exhibit very high currents as a function of the numbers of transistors being deployed.**

I. Introduction

The reduced size and increased computational capabilities of electronic devices is of major importance for the overall performance of any satellite. Many advanced circuits and systems are being deployed in the current generation of satellites and there is a significant effort to reduce the volume that they take up in the satellite as well as evident concerns about the burden imposed by the weight of the payload.

There is also an ongoing trend in the semiconductor industry which is seeing operating voltage reduce over each generation of technology. Operating voltage was always a major scaling factor in CMOS technologies and although it was held constant over many generations this has reduced over the last decade and many complex systems now have an operating voltage of around 1V with a system current requirement of 10s of Amps.

This requirement is easier to achieve in terrestrial applications where the additional constraints on volume and weight of the systems are less significant. In a satellite a compact, high efficiency power converter for generating the required ~1 V to power the digital devices from a 100 V power bus is a key element for the satellite digital payload.

Furthermore, the space environment is not a benign one, and in order to operate sophisticated microelectronic systems in space it is necessary to ensure that the radiation that is encountered in the space environment does not unduly affect the performance of the electronic systems in the satellite.

There are a number of domains where such advanced systems are being deployed which include. **telecommunications**, **navigation** and **observation** all of which have a requirement for high throughput, higher capacity and greater storage capability and all require high performance integrated circuits which exhibit the characteristics of high current and low operating voltage to achieve their mission and all of them need to have a stable, reliable, flexible and scalable power supply to be able to deliver the specific requirements of the satellite electronics.

For example, a flexible payload and multi-spot radiating elements of the active antenna, requires a multitude of dedicated signal processor elements scaling up the power demands dramatically. Thanks to the introduction of deep sub-micron technologies in radiation hardened digital electronic circuits, it is now possible to build large software radio systems to feed such an active antenna. The power supply requirements for these large digital processors have encountered a similar evolution: lower voltages (e.g. 0.5V and 0.9V) and higher current from 10 to 30A currently and up to 150A in the future, for each rail. This evolution is illustrated in Figure 1

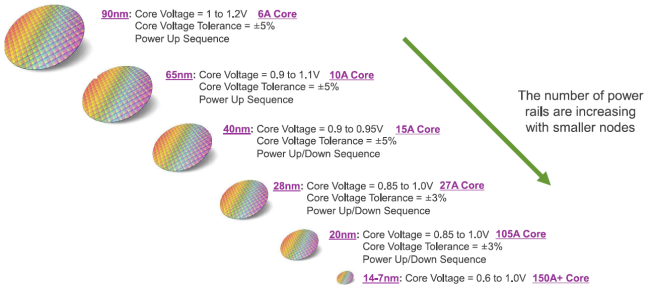


Figure 1 The evolution of power supply current as a function of technology generation

Concerning the design of the power supply with such constraints, i.e. low voltage with increasing load currents, the use of multiphase architectures becomes essential. As the number of phases increases, the complexity of the control system increases also and becomes a point to address.

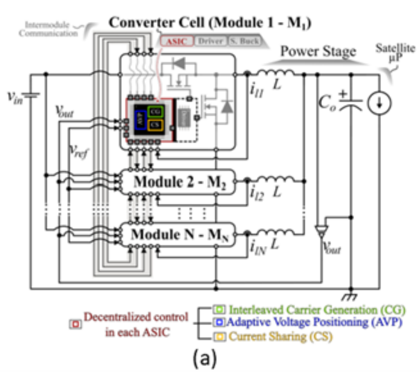
The same trends are also seen on the fast growing market of constellations; where, even if the capacity of each individual satellite is lower, the overall needs are bigger due to the total amount of satellites per program. As the size and mass of each satellite and unit are critical, this system level miniaturization including the active antenna is also a key asset.

System level miniaturization is a key aspect to the reduction of payload in satellites and with that in mind the **PROMISE** design standard and library [1] was established to facilitate the rapid and effective design of Mixed signal integrated circuits for space applications.

II. The Proposed Solution - SCOPS

In recent years, a patented solution using a decentralized method for the control of multiphase converters have been proposed [2]. Illustrated in Figure 2, it offers the possibility to use a local controller per phase in place of a centralized supervisor in charge of the voltage regulation, the inductor current balancing and the phase control signal interleaving. All local controllers are identical, i.e. no master/slave strategy required, and the appropriate local control signals are determined by communicating with their close neighbors. A second patent [3] also provides a solution for improving the robustness of the inter-controller communications. The main advantages of this decentralized control methodology are

- The full scalability of the power system, (i.e. all phases are identical including the local controllers),
- There is no limit to the number of phases used in the converter and,
- The potential for easily removing an active phase during operation in case of a fault occurrence to address functional safety concerns.



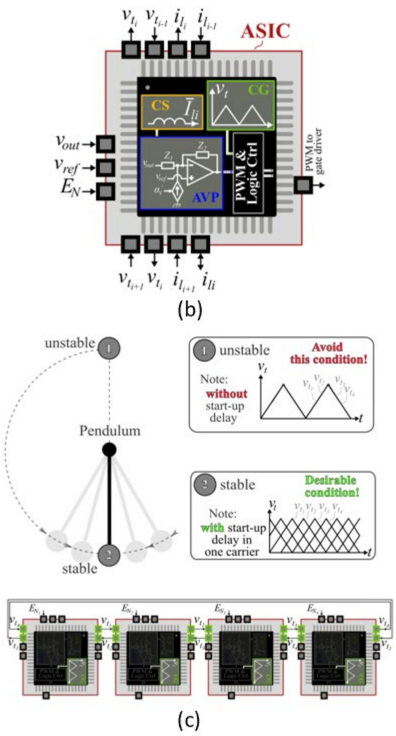


Figure 2 Decentralized control method for multiphase DC-DC converter. a) Converter topology with local controllers; b) ASIC internal blocs; c) ASIC involved in a chain of local communications.

The SCOPS (Scalable COntroller for Power Sources) project sets one clear and measurable main objective: To design an Application Specific Integrated Circuit, named SCOPS, to control several power supply phases in parallel, to evaluate its performance in the space environment. This will not only demonstrate the merits of the PROMISE Library and standards but will also ensure the resilience of European supply chains and reduce external dependencies. This is a key step for the EU's technological sovereignty.

To do so, it is anticipated that the availability of the SCOPS IC will provide the Space Community with:

- A flexible DCDC controller ASIC that overcomes the limitations of existing controllers in terms of phase paralleling possibilities & flexibility, performance, features and radiation robustness.
- A fair commercialization and intellectual property management that allows the purchase of the SCOPS outcomes at a competitive cost ahead of its non-European technological competitors for space applications.

SCOPS will be a Modular and Scalable Power Controller Architecture that not only addresses the need for existing complex digital systems but will also be able to adapt to the increasing need for next generations as a function of its scalability and robustness. The architecture will adapt to space use and radiation constraints based upon a patented and highly innovative, scalable architecture [4]

.

This control architecture will use analog blocks and introduce digitalization to reduce the need for tuning, configuration and external devices at the end-user side as much as possible and will also reduce the bill of materials. Partitioning between analog and digital blocks will be traded-off by intensive use of behavioral simulation.

A behavioral model of the circuit has been developed and was used extensively to simulate the global behavior of the circuit. This resulted in significantly improving the convergence of the architecture and helped to identify performance dependencies in the sub-blocks which originated from variations in corner parameters. The impact of these variations needed to be resolved in the final design. As a consequence, this model has also been successfully used to validate the main specifications of the circuit as well as it's sub blocks (e.g. DC gain, offset, bandwidth, etc…) and has led to the availability of dedicated model parameters for any new design requirements

SCOPS will be the first demonstration of the use of the PROMISE design library from outside of the project. The cost-effective design process will be supported by the Design Standard and Interface Standard documentation and this will ensure the top-level consistency of the mixed-signal ASIC with the re-used Ips from PROMISE. These Standards will be updated at the beginning of the design phase to include the best return-of-experience from the PROMISE project. The Standards will also define rules and recommendations on how to implement, access, modify or add reusable IPs in a mixed-signal ASIC.

The SCOPS Circuit design will be based on the XFAB XH018 technology, PROMISE libraries, including DARE180XH standard cells, that allow re-use of existing PROMISE IP blocks and will rely on Radiation Hardening By Design guidelines and tools.

The digital control will allow the implementation of features to ease the board and equipment design by allowing multiple DCDC architectures through configuration and versatile total power thanks to its scalability. Design digitalization will allow the implementation of auto-test and auto-calibration processes to help in design validation during tests and shortening the circuit screening and tuning to adapt to the technological variation (e.g. process corners due to device mismatch).

The circuit designed in SCOPS will demonstrate the compliance of the design to its electrical specifications during validation tests :

- Electrical validation tests will validate that the measurement of SCOPS circuit behavior is correlated with the simulated performance. Electrical validation tests will also explore SCOPS circuit performance over standard temperature and voltage ranges
- End-User use-case validation will ensure that the SCOPS Circuit can be operated as expected in a real DCDC converter. The End-User use-case validation tests will also explore SCOPS dynamic circuit capability in a product environment over typical temperature and voltage ranges.

The SCOPS Circuit will also demonstrate its compliance with its environmental requirements

- Radiation evaluation will cover Total Ionization Dose and Single Event Effects. The Radiation tests will evaluate :
  - SCOPS Circuit hardening against space environment constraints.
  - The radiation hardness of the XFAB non-hardened IP blocks.
- Life test evaluation will demonstrate the silicon reliability according the ECSS JESD22-A108 HTOL Standard.
- ESD evaluation will demonstrate the silicon robustness against JESD22-C101 HBM and CDM models to address ESD manufacturing and handling constraints.

III. Conclusion

The SCOPS Project addresses a leading-edge innovative technology to provide a fully scalable power solution for embedded microprocessor power supplies which are compliant with satellite-based applications and the space environment. The project has been ongoing for approximately two years, and everything is on schedule for the data from successful validation and evaluation test results to be reported over the next two-year period.

IV. Acknowlegements

"This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101082266. The authors acknowledge NXP Semiconductors for the licence agreement for the use of two patents in the frame of the SCOPS project and the active contribution of all the involved partners."

V. References

[1] Programmable Mixed Signal Electronics (PROMISE) H2020 Project ID 870358

[2] M. Cousineau, "Modular Static Converters with Parallel or Series Architecture and Decentralized Modular Control (DMC)". U.S. Patent WO/2014/005973, 28 March 2017.

[3] M. Mannes Hillesheim, M. Cousineau, E. Rolland, P. Goyhenetche, G. Aulagnier. "Distributed Interleaving Control of Multiphase SMPCS". US Patent 11,316,519 B2, Pub. N° 2021/0167780, 26 April 2022.

[4] G. Almeida, M. Cousineau, D. Le Bars, F. Pecourt, P. Ayzac, "Decentralized Control for a Fault-Tolerant, Fully Scalable Microprocessor Power Supply for Spacecraft Applications," 13th European Space Power Conference (ESPC), 2 - 6 October, in Elche Alicante, Spain, 2023