univerSAS 2.0 - Power SCOE of the future
Unified, freely programmable function blocks for the realization of a configurable Power Supply, based on innovative pure switch mode technology achieve a unique SCOE density

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INTRODUCTION

The aerospace industry is home to brilliant engineers committed to leading-edge missions in both Commercial markets and Government funded projects, combining advanced technologies to meet unique challenges, relentlessly optimizing every part of a spacecraft without compromising reliability.

As the space industry enters a new era of cost consciousness, improving on TCO-dimensions including a lowered facility footprint, simplified services and increased availability, also the development of our high-density power supply followed suit in applying those principles.

AtoS Space and Avionics worked closely together with commercial space industry leaders (Airbus, Airbus OneWeb Satellites) to optimize its product univerSAS to an unprecedented level of integration for the world's first satellite mass production. Our new product univerSAS 2.0 is a versatile, cost-effective, low volume, universal, reusable and green power product.

WHY POWER SCOE?

It's evident that the Power SCOE (Special Check Out Equipment) is not the main cost driver of space missions. However, for more complex satellites, the Power SCOE's often occupy significant area in the test facilities as bigger or many racks are required to test the complex power functionality, they also demand a large amount of electrical supply putting extra burden on the supply network and they produce large amounts of heat, which needs to be addressed constantly.

Today, Power SCOEs are mostly composed of modular blocks, which are integrated together with COTS (Commercial Off The Shelf) equipment and a bespoke interface system to connect to the spacecraft driven by the selected connector strategy used. A typical conventional example can be seen in Figure 1 for a standard Solar Array Simulator composition.

Figure 1: Conventional Solar Array Simulator

In more general terms, the following list itemizes a conventional composition of a Power SCOE, including their standard height requirements:

- PDU/MITU (mains isolation, circuit brackets, power meters): 4-6 HU (height unit)
- Controller PC: 1-2 HU
- Battery simulator: 2-3 HU
- Battery conditioning unit: 2-3 HU
- Electronic load: 1-2 HU
- Solar array simulators: 2-20 HU (very variable)
- SLP (second level protection): 1-10 HU (very variable)
- Analog/digital discrete interface related to power as LCL modules, telemetry I/F: 2-4 HU
- Auxiliaries as RIO panel, LAN infrastructure: 1-2 HU

In the majority of cases such a solution is a full 19" 40 HU rack, but often the solution rises to a couple of racks (SAS SCOE, BS SCOE, etc.). Mechanical complexity and internal cabling are often challenging due to limited space within the racks compared to relatively simple functions, which Power SCOEs should provide. Verification processes as well as commissioning become also complex and time-consuming tasks. It is not difficult to estimate that MTBF (Mean Time Between Failures) of many integrated components is high, posing overall stability challenges during critical AIT phases such as thermal vacuum tests or launch with potentially very high cost in case of failures.

HOW CAN SUCH A DEVICE BE DEVELOPED AFTER ALL?

For many decades the solution for Power electronics was bulky and relied on large sets of functional blocks. However, the technology has advanced and matured to a stage, where developing high density and small size power electronic solutions becomes feasible.

AtoS Space and Avionics overcame the above challenges by taking advantage of the advancements in technology and developed univerSAS 2.0.

univerSAS 2.0 substitutes all the COTS equipment normally needed in a Power SCOE, absorbs all functions (e.g. SAS - Solar Array Simulation) of a Power SCOE and has a vast electrical parameter envelope with the ability to standardize on a **single device** (see Figure 2, which is according to scale). This minimizes costs over the entire lifecycle (TCO), optimizes spare policy, simplifies service, ties up less capital and cuts inventory costs. Above all, all the above mentioned interfaces in the previous section can now be shrank from 40 HU to a remarkable single 2 HU device.

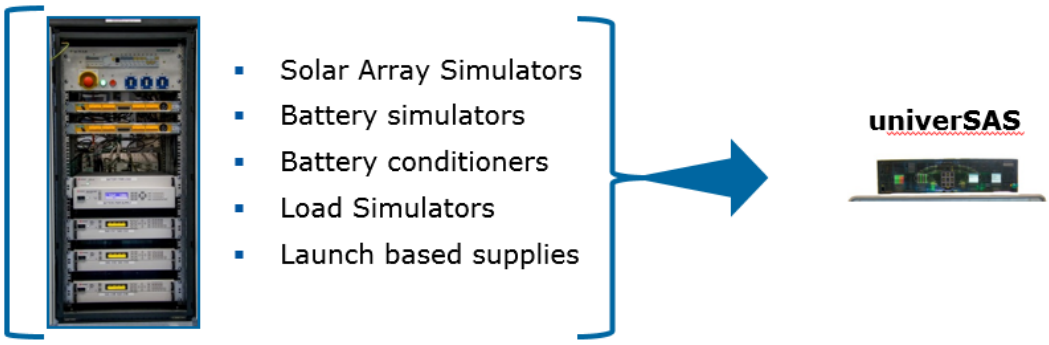

Figure 2: univerSAS - Standardization on a single device

Although the physical space requirements and electricity supply needs can be overcome, shrinking the device to a very small size introduces other complex challenges such as thermal management, isolation, electromagnetic compatibility, cross talks and so on.

THE ARCHITECTURE: UNIVERSAS 2.0

To introduce univerSAS 2.0 in a nutshell is very difficult, since its main innovation potential is hidden in hundreds of innovative solutions, which are based on decades of expertise. In the following chapter, we are going to introduce the main building blocks. Besides AtoS' core team know-how, there were great contributions coming from academia (and their spin-offs) into the development of univerSAS 2.0:

- ESA (mentor and supervisor)

- ETH Zurich (Power design)
- Technical University of Vienna (Control)
- STU Bratislava (EMC)

The power architecture can be decomposed into four main blocks (see Figure 3):

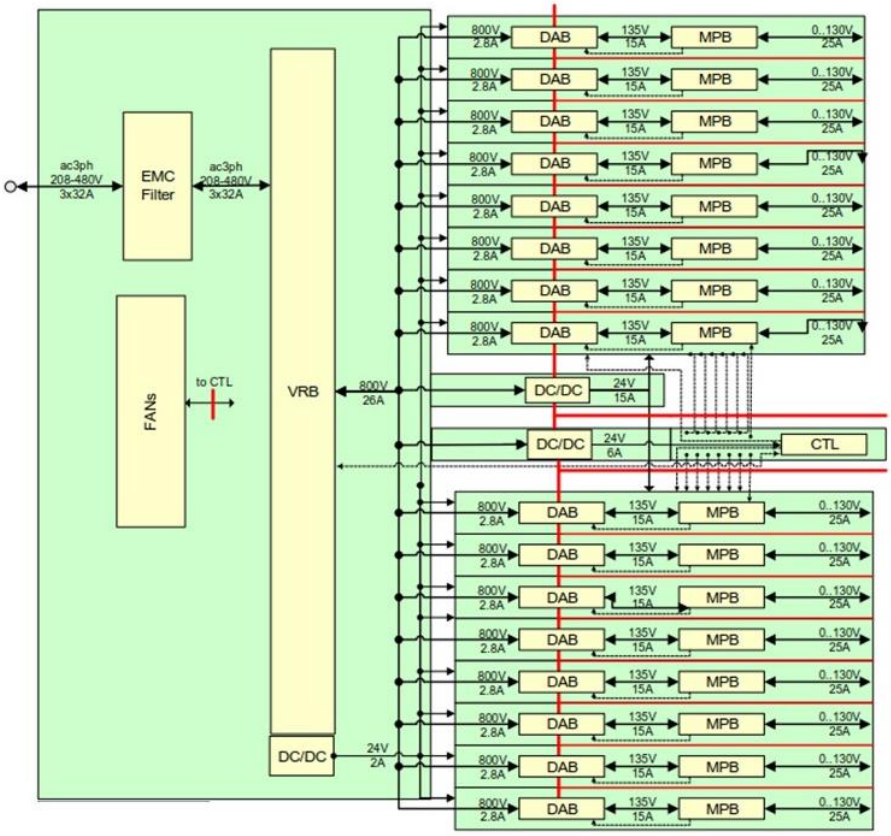

Figure 3: univerSAS - Architecture

- Mains EMC filter
- VRB (Vienna Rectifier Bidirectional by ETH Zurich)
    - 20kW AC to DC (800V)
    - SiC based (Silicon Carbide FET)
    - Dynamic PFC (Power Factor Correction) typically > 0.99
    - Operational with 1 to 3 AC phases worldwide network support
    - VRB output drive 16 power module cards composed of DAB/MBP
- DAB (Dual Active Bridge by ETH Zurich)
    - 2 kW, DC 800V (from VRB) to 100-135V DC
    - 5kV isolated supply (reinforced/double isolation)
    - SiC based (Silicon Carbide FET)
    - Special magnetics for high efficiency with integrated coils
    - Efficiency >0.98%
- MPB (Multi Phase Buck by AtoS)
    - 1,8 kW 100-135V DC from DAB to a variety of applications (SAS, BS, PS, load)
    - GaN based (Gallium Nitride FET)
    - Efficiency >0.95%

Each MPB can then provide a 1.8kW/25A/130V symmetrical two quadrant (bidirectional) power interface, which allows parallelization and serialization of up to 8 modules. Efficiency up to 92%

The Output performance is summarized in following table:

Parameter	Conditions	Unit	min.	typ.	max.
Voltage Range	parallel configuration	V_{DC}	0		130
	serial configuration	V_{DC}	0		1000
Current Range	One channel/Parallel configuration; source	A	0		25/200
	Serial configuration; source	A	0		25
	One channel/Parallel configuration; sink	A	0		25/200
	Serial configuration; sink	A	0		25
Power	source	W			1800
	sink	W			1800
Overall Power	16 channels; source	kW			18
	16 channels; sink	kW			14
Voltage Accuracy	output voltage	%			1
	absolute	V			0.2
Current Accuracy	of output current	%			1
	absolute	A			0.2

Table 1: univerSAS 2.0 output characteristics

All power stages use advanced control methods. The VRB has a hybrid DSP/FPGA controller, while DAB and MPB are purely FPGA controlled with extremely low control latencies <1µs and a fast data exchange (DAB and MPB control sit in one FPGA).

This architecture allows for a massive performance boost involving the usage of multi-megasample ADCs, and special control methods for highly responsive simulations such as SAS.

Aside of power functions univerSAS 2.0 contains many other features to absorb conventional Power SCOE HW:

- MITU functionality:
  - Input mains SWITCH
  - Replaceable Mains Fuse protection (32A Europe or 25A US)
  - Power ON/OFF soft buttons
  - Device contains a proprietary Power LOOP allowing chaining of up to 4 univerSAS 2.0 devices starting from master device ON button
  - Electrical 24V generic safety loops I/F (univerSAS 2.0 can provide also dedicated 24V supply for this safety chain).
  - Each MPB output has reinforced double isolation to MAINs as well as to PE (AC coupled high voltage connection to PE is established)
- PC controller functionality:
  - Device is equipped with Quad-core Arm Cortex-A53 MPCore with Dual-core Arm Cortex-R5 with CoreSight
  - 16 GB of flash internal memory
  - Running LINUX OS with
    - Webserver local mode control
    - SCPI over LAN
    - CCS I/F (EDEN, C&C)
    - Wide Javascript support
    - JSON (JavaScript Object Notation) based SCOE configuration
  - I/Fs
    - Gb LAN
    - USB 3.0
    - SD Card (SDHC/SDXC)
    - Debug UART
- Auxiliary functions:
  - Each MPB contains also auxiliary I/Fs:
    - PYRO channel 2.0 capable of:
      - Fuse protected (8A) current measurement with up to LCL (latching current limiter) class 6
      - Voltage measurement up to +/-160V (variety of ranges available)
      - Voltage and current measurement can be done in parallel
      - Possible to use as safety source or optional MPB power control input
    - NO/NC strap I/F (up to 60V/1A)

        - RS485 20 Mbps half-duplex bus
        - 10bit Electronical potentiometer (resistor simulation)
        - Cable detect/current source/resistor measurement I/F (5 orders of resistor measurement, 2 levels of current source)
    - Device auxiliary I/F:
        - 4x PYRO channel 2.0 (together with MPBs 20 pcs per device)
        - 2x GP relays
        - 4x24V digital inputs
        - LED Lamp power (2*24V/125mA outputs) to indicate important states on LED light tower
- Second level protection
    - Build-in fully redundant (details below)
- Front panel
    - Mains switch
    - 4 pcs 1.5" OLED displays providing the majority of important system and telemetry information. The content of the display can be tailored by JSON configuration
    - Status LEDs:
        - VRB status (run/error state)
        - SLP status (configured and valid)
        - Embedded SW keep-alive LED
        - Large SAFETY/ONLINE LEDs (yellow and red addition to LED light tower)
    - Rotary encoder with push button for basic local mode operation (with OLED feedback)
    - On/Off SW buttons providing MILU like start/stop actions
    - Key switch used for allowing safety related operations (e.g. overwrite of SLP protection settings)
    - 3W speaker for safety event signalling

THE SAFETY

One of the most sensitive topics in space is safety and univerSAS 2.0 was from the beginning designed to fulfil all safety requirements known across the space industry, especially in the ESA environment. The product safety features are fully software configurable, but execution of safety is purely hardware (FPGA) dependent. Product safety consisting of:

- FLP (first level protection)
- SLP (second level protection)
- TLP (third level protection)
- Each MPB has a user defined replicable fuse
- Mains monitoring
- Thermal management (5 thermistors in each DAB/MPB) with overheat protection
- FAN speed watchdog
- Variety of other watchdogs (SW alive, clock, FPGA consistency)
- Auxiliary power supplies monitoring

MPB protection:

- First level protection (FLP):
    - Implemented directly in MPB control FPGA
    - Utilizing same measurement as used for MPB control loop
    - User defined thresholds
    - Reaction time is by default fixed (320µs), but can be tailored on request
- Second level protection (SLP):
    - Implemented in central device FPGA
    - Every MPB is equipped with a redundant power supply independent monitoring of current and voltage SLP logic (so even if complete MPB power and AUX fails, SLP still works and can stop the MPB).
    - There are 2 independent SLP units for 8 + 8 MPB boards
    - SLP has CRC protected protection parameter sets stored in flash
    - SLP parameter update is protected by front panel key, which is directly connected to Flash write protect pin
    - SLP can propagate individual events as
        - local event (to particular MPB, where event happened)

        - device event (to all MPBs within given group of 8 MPBs)
        - device global event (to all 16 MPBs in device)
        - global event to all other EGSE associated in generic safety loop

      The reaction time is from 1µs up, window is using true moving average filters
- Third level protection (TLP)
    - Since MPB besides load voltage/current measurement performs also internal buck voltage/current measurement, which are completely independent from load measurements, these are also used as additional protection, which yield device safety capabilities above single point of failure.
    - Additionally, there is a protection implemented also in DAB and VRB controllers, voltages and current in case of a massive failure, which protects the HW and the facility.

THE VERSATILITY AND FLEXIBILITY

The product is by its nature extremely versatile and configurable. Therefore, the basic functionality is available with a wizard-oriented approach, where the user can define the end functions through a web interface.

The controlling can be done through a web interface, SCPI or via the front panel.

The variety of EGSE requirements often means specifically tailored HW or at least complex HW setups with chains of devices and harnesses. The aim of AtoS has been to bring into this product the ability to cover the majority of requirements through SW configuration alone and preferably additional harnesses. This then allows for massive reuse of the basic HW platform and often gives the end user the choice to integrate a new or modified requirement later at very low cost and time impact without having to send the unit back to the supplier for modifications.

THE NON-STANDARD POWER FEATURES

univerSAS 2.0 comes with CE and UL/FCC certification by TUV and radiated EMC class A (aiming for class B).

univerSAS 2.0 besides already mentioned “standard” power feature contains numerous handy features.

It was mentioned that univerSAS 2.0 is a two-quadrant power device. This simply means that all energy, which is sunk (as electronic load or battery simulation charging), is either consumed by sourcing interfaces or returned to mains.

Second quadrants operation is however also used in other cases, e.g. in crowbar operation, when PS is released from short and energy stored in inductances that turns to overvoltage is recuperated instead of being dissipated as heat.

This makes univerSAS 2.0 a very green solution, which not only safes energy, but reduces also acoustic noise and the thermal footprint in the testing facility.

This Snapshot feature provides a comprehensive analog/digital information source in case of a safety event across the whole device. There is a snapshot for each individual MPB, which enters in a safety loop. A Snapshot can also be invoked by the user to see an “oscilloscope” like view on the power interface.

Snapshot has a 16ms (8ms before and after safety event) time window with 1µs per sample including the most important system variables such as Load voltage, Load current and Duty cycle.

The Snapshot is stored by default as .csv file, so any plot program or even excel can be used for analysis.

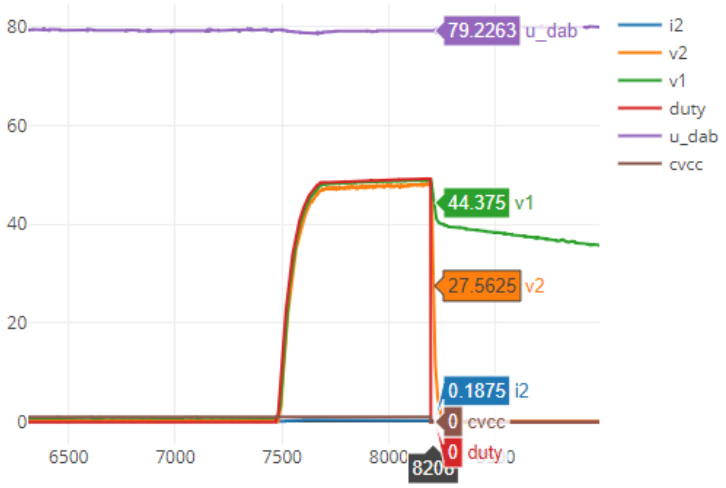

Figure 4: Real snapshot with overvoltage safety event (displayed by WebGUI plot)

univerSAS 2.0 implements EGSE Virtualization. The Software concept of the univerSAS 2.0 embedded application allows for the split of control distributed over several instances utilizing different resources of the device. This allows e.g. that 8 MPBs work as SAS and the remaining 8 MPBs as BS, what practically yields a 1 HU Power SCOE.

Such EGSEs are then running as independent Linux processes, so even a crash of one is not affecting the other. Of course, some shared resources are there, but this is inevitable, like loss of mains.

Each virtual EGSE application has a unique IP address, although using the same ethernet controller, what creates from a CCS point of view 2 unique EGSEs.

There is no hard limit for the amount of virtual EGSEs

The Isolation concept of univerSAS 2.0 is unique and provides 5kV reinforced/double isolation for each MPB individually. Each MPB has 1kV isolation to its PYRO channel, so this one can be independently used without grounding compromise. 4 PYRO channels (those which are not equipped on MPB) have also a 5kV isolation. There is basically 2.5kV between MPBs.

Due to the fact that housing is full metal (steel – ferromagnetic) PE grounded, the EN standard for CE requires only basic insulation, while reinforced insulation is provided.

The S/C harness shielding has a special pin on the MPB connector, which provides an AC connection to PE over the Y1 (reinforced/double isolation) capacitor, that improves EMC but does not compromise S/C grounding.

Since all MPB boards in the device are equivalent it is very simple and cheap (in case not all 16 MPBs are used) to populate redundant MPB boards, which, in case of some other MPB malfunction, can overtake its duty. Since DAB/MBP power supplies are off if not used, this feature is especially advantageous in long term missions, where some MPB may be highly utilized and reaches their natural EOL (end of life).

Each MPB is equipped with a set of very accurate components, which allows to calibrate DAB/MPB voltage and current measurements. The Auto-calibration accuracy reaches <0.1% FS (full scale). Since MPB has a dual output isolation, both (PS+ / PS-) have a series FET and relay. Therefore, the auto-calibration feature can be called any time (even with S/C harness connected), e.g. on start-up or on user command. If external high accuracy calibration is required, the auto-calibration is simply not applied.

Some components of the auto-calibration are also used to self-test MPB measurements to validate if their function is present (malfunction detection) and if they are within the expected accuracy range. S/C safety is HW protected in case of auto-calibration, relays and series FETs are kept offline. Interfaces which are in scope of this feature are all MPB measurements (FLP, SLP, TLP) plus DAB output voltage and current.

In case of Mains loss, it is possible to keep the Embedded SW alive and have access to the latest logs and the capability to safely shut down the Linux OS. The function is available as a dedicated 12V/1A DC input connected to a battery or 12V AC/DC power supply connected to a commercial UPS (uninterruptable power supply) device.

univerSAS 2.0 utilizes for harness connection Phoenix contact high isolation connectors (see Figure 5) with screw locking mechanism preventing unintentional dismount. All connectors are finger prove so standalone use is also possible. Connectors guarantee excellent safety and isolation properties vs. e.g. DSUB or MIL.

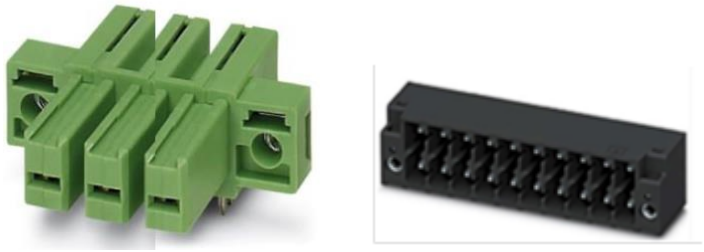

Figure 5: MPB power and signal connectors

CONCLUSION

univerSAS 2.0, with its multitude of optimizations, implementing highest power density and including advanced energy recuperation capabilities, demonstrates our commitment to power efficiency and an energy-conscious future. These combinations have created a product, which exceeds the boundaries of space and aerospace.

Figure 6: univerSAS 2.0