Introducing a Low Cost and High Performing Interoperable Satellite Platform based on Plug-and-Play Technology for Modular and Reconfigurable Civilian and Military Nanosatellites

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Outline

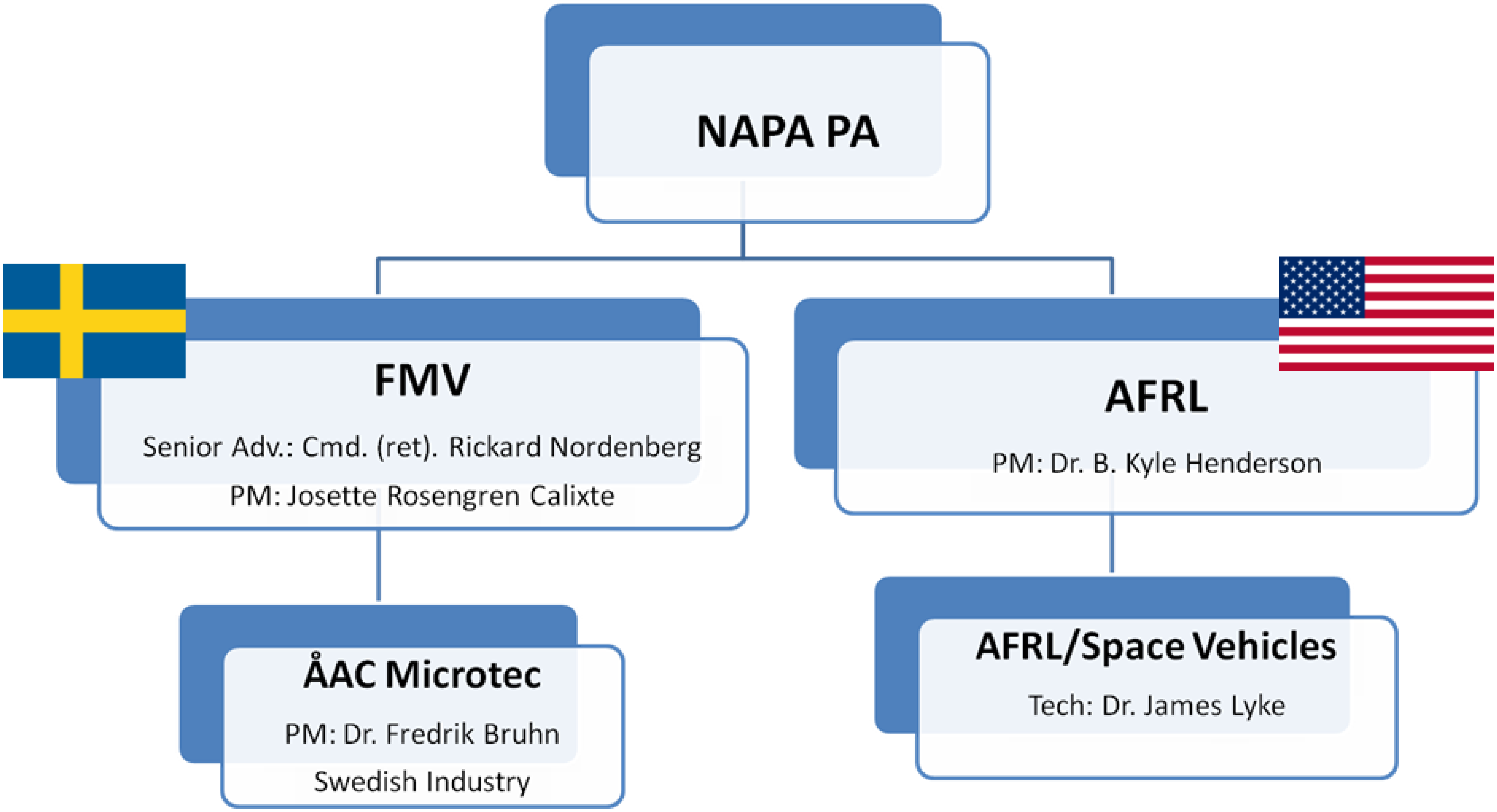
- Introduction – International agreement in plug-and-play spacecraft
- Space plug-and-play Avionics (SPA)
- Improved miniature plug-and-play
  - –Protocol
  - –Hardware
- New SPA avionics and power hardware
- QuadSat-PnP spacecraft based on SPA

Introduction – The ”NAPA” Agreement *

- **Project name**: Nanosatellites Plug-and-Play Architectures (NAPA)
- This agreement (U.S./Sweden – AFRL/FMV) seeks:
  - To engage in international cooperation regarding research development test and evaluation (RDT&E), activities which may lead to the development of miniaturized aerospace systems.
  - To jointly research rapidly reconfigurable nanosat technologies to conduct R&D in miniaturized avionics components.
  - To investigate PnP implementation and unification at an international level to include PnP ground prototyping, qualification of new methodologies for flight worthiness of nanosat components, and R&D of a flight worthy component.

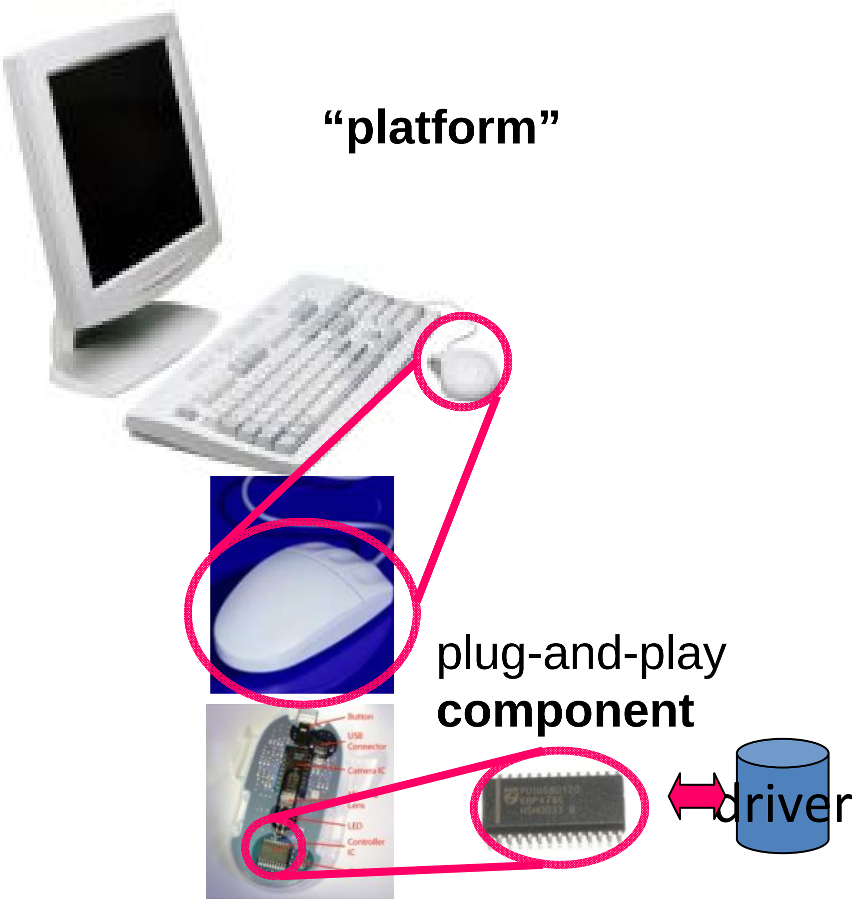
**Bi-lateral Project Agreement (PA-TRDP-US-SW-AF-09-002).*

NAPA organization

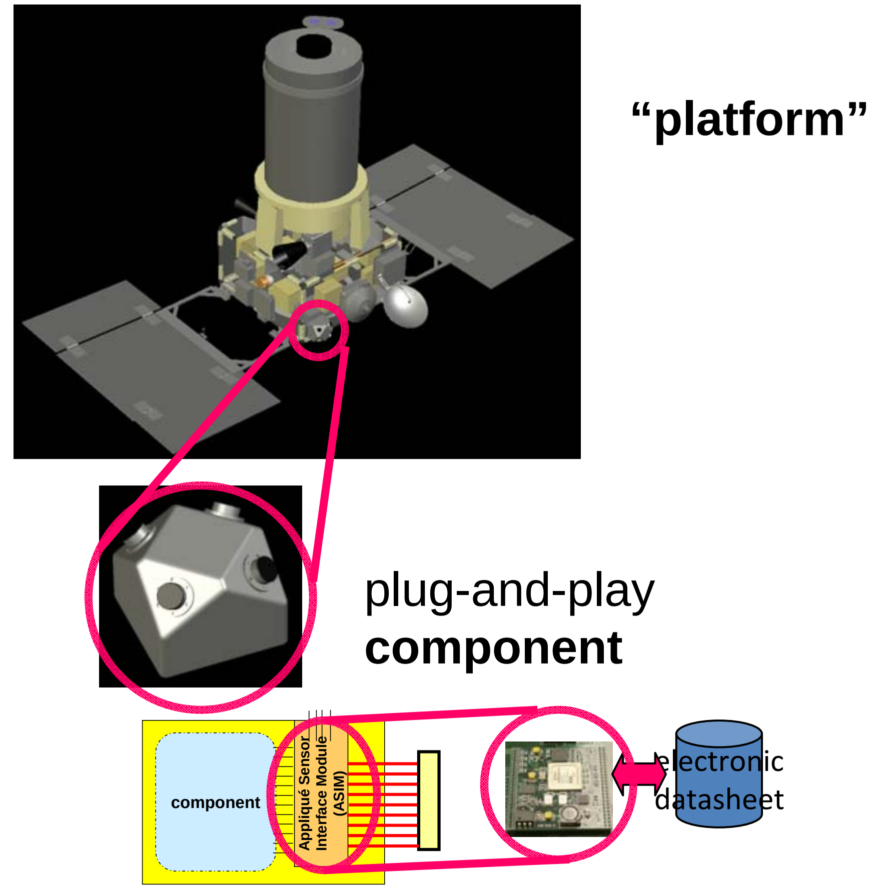


Space Plug-and-Play Avionics (SPA)

In search of a standard approach for spacecraft



USB **interface** chip



Applique sensor **interface** module

SPA – The technologies

Electronic Datasheets

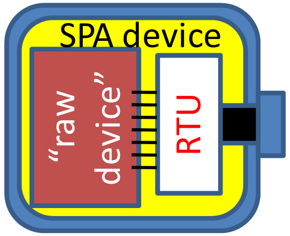
Black box components

Self-organizing networks

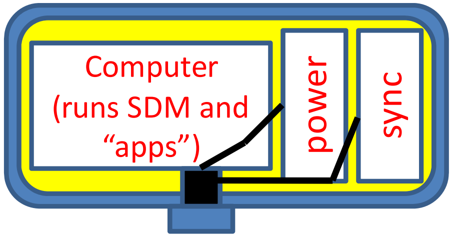
Enhanced testability

Push-button toolflow

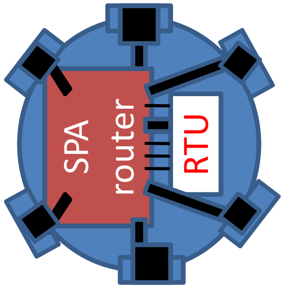
Building spacecraft with SPA: you’ll need



components…

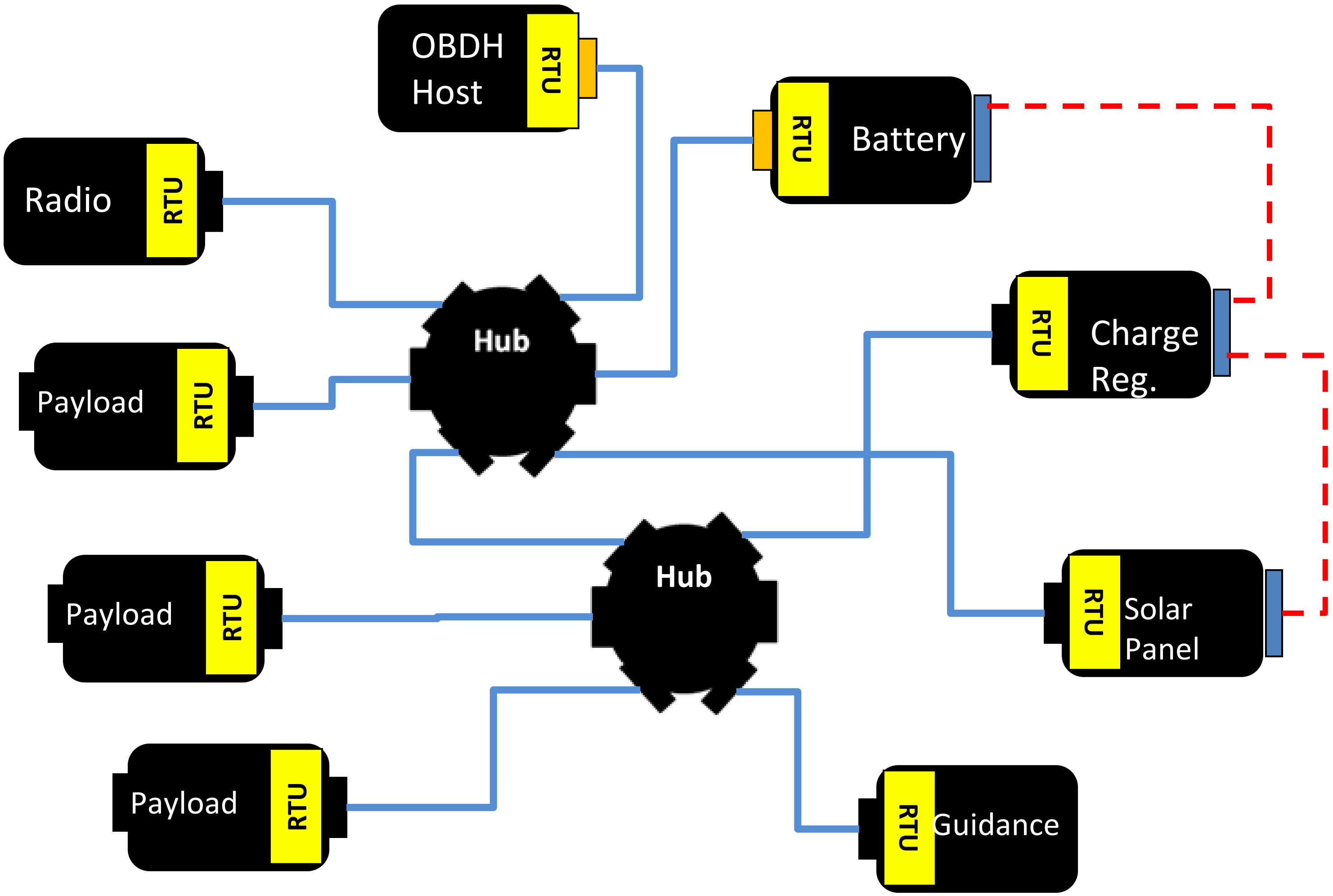


..at least one computer…



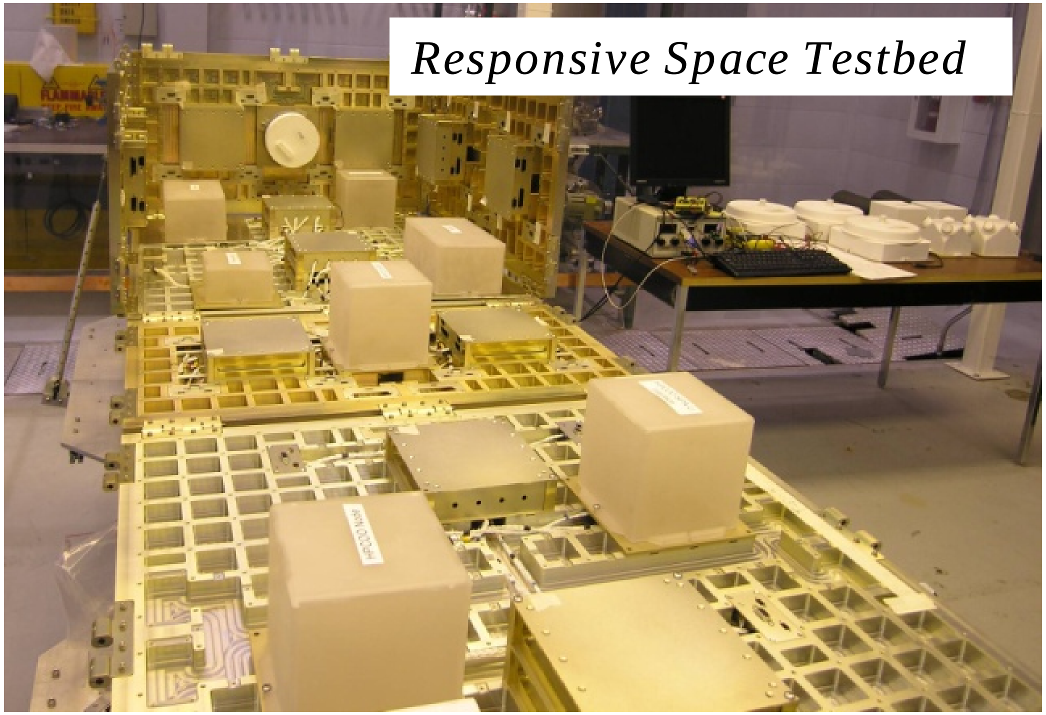
… and routers

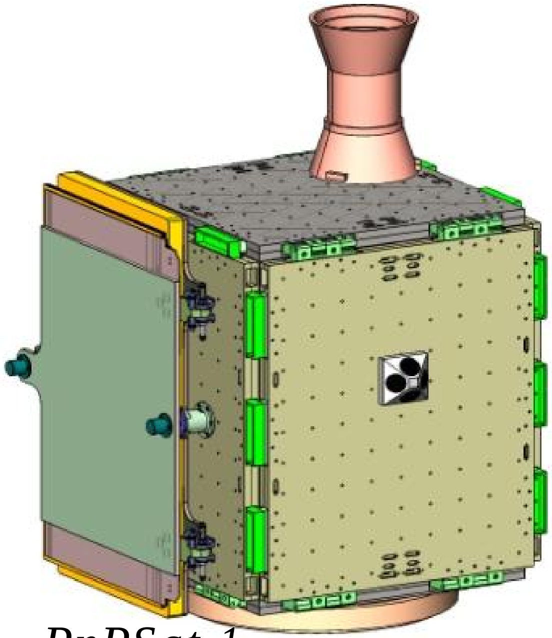
Connect together to form a spacecraft…

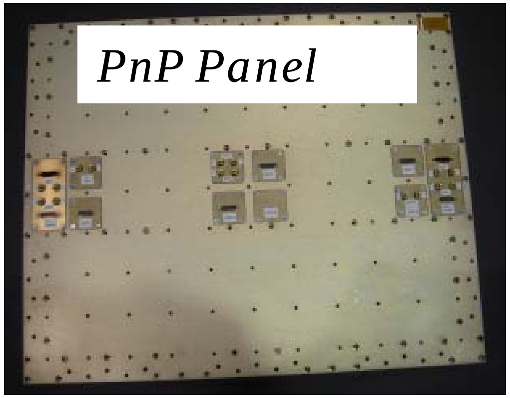


Space Plug-and-Play Avionics (SPA)

Making the Complex Simple through Architecture


Responsive Space Testbed


PnPSat-1


PnP Panel

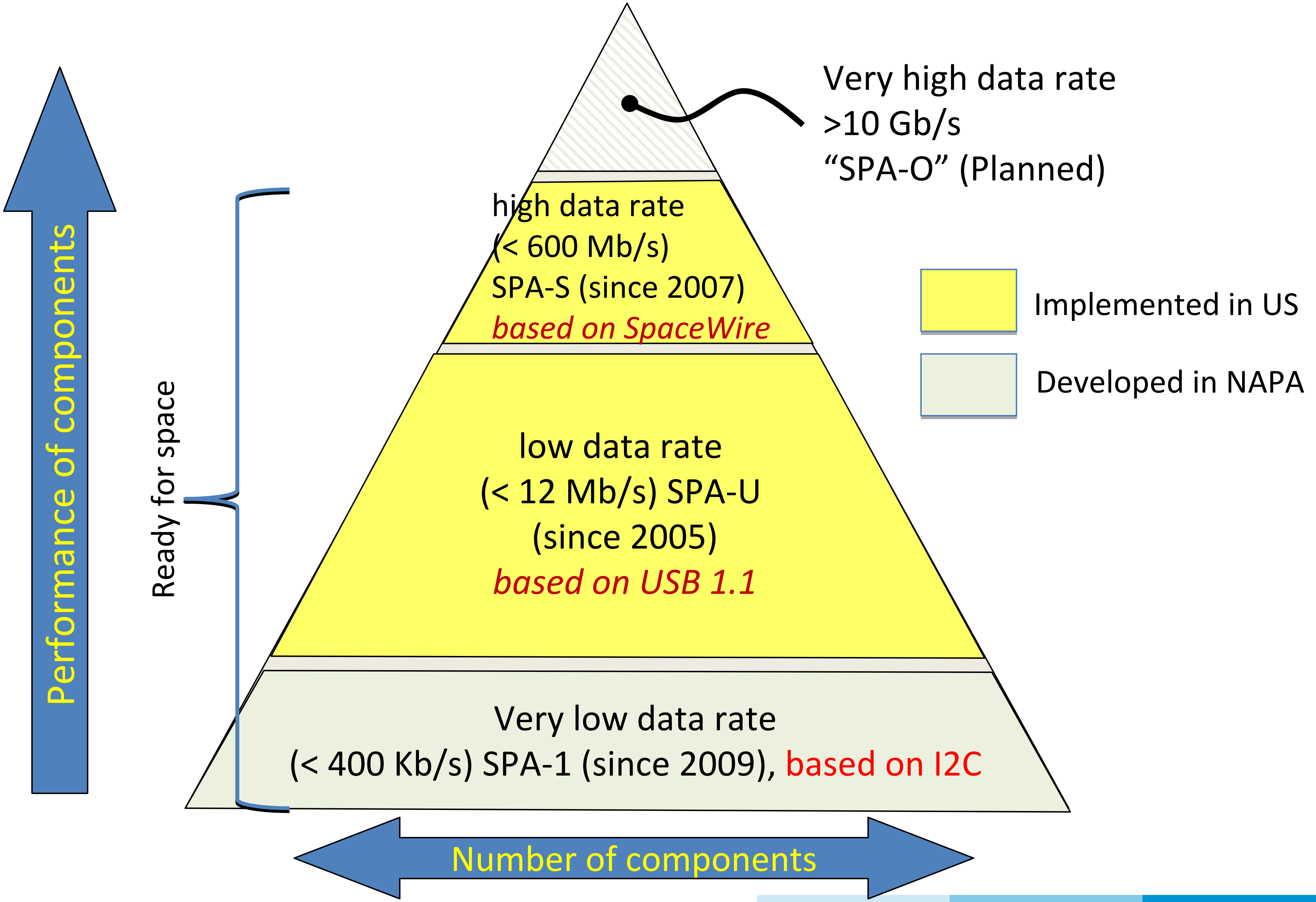

CubeFlow Kit


TacSat-3 Spaceflight

AFRL PnPSat-1 assembly in 4 hours

- Approx: 50 x 50 x 50 cm3
- SPA-SpaceWire (SPA-S) network
- Integrated harness in structural elements

One Size Doesn't Fit All…



One Size Doesn’t fit All - Simple Example

- Spacecraft has 200 components
  - “One Size Fits all” – 2000 W for interfaces. No good.
  - Four SPA levels – 65 W (5 x SPA-O, 10 x SPA-S, 30 x SPA-U, 155 x SPA-1) …. VAST SAVINGS!!! (~ 95%)
- Nanospacecraft *need* better SPA-interface
  - Smaller
  - Less weight
  - Lower power
  - Lower cost

Conclusion: Developing a Minimalistic SPA was a harmonization priority!

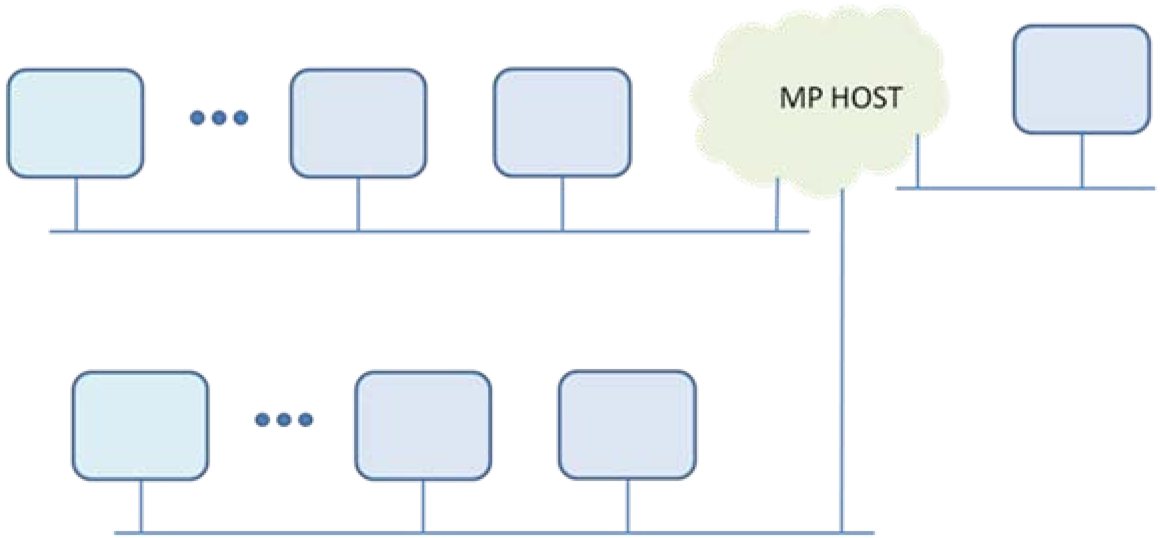
Minimizing Cost with Open Source

- Space Plug and Play Avionics is conceived to use to the largest extent possible open source which is well recognized and maintained.
- ÅAC ‘s Plug and Play avionics features the following Open Source tools:
  - Same tool chain for regular and Fault Tolerant processors
  - Soft core OpenRISC 1200 32 bit processor (RTU, RTU “lite”, µRTU)
  - Soft core PIC16F84 (nanoRTU)
  - GNU Project Debugger (GDB) (RTU, RTU “lite”, µRTU)
  - GNU Compiler Collection (GCC) (RTU, RTU “lite”, µRTU)
  - Linux Operating System (2.6) (RTU, RTU “lite”)
  - SourceBoost C compiler (nanoRTU) *(license required for full nanoRTU functionality)*
- Flight hardware Fault Tolerant (FT) processors derived from open source
  - Soft core OpenRISC 1200-FT (fault tolerant enhanced by ÅAC)*
  - Soft core PIC16F84-FT (fault tolerant enhanced by ÅAC)*

* Fault tolerant (FT) versions are not provided as open source.

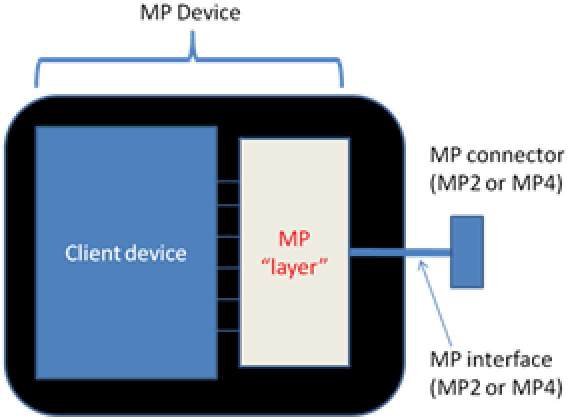
Approach to Harmonized plug-and-play for nanosatellites

- Select an interface
- Develop a generic plug-and-play protocol around it = ”mini-PnP” (MP)
  - Open source
  - ITAR free
- Mini-PnP can be used for any system
  - When converted into space-capable form = ”SPA-1”



Interface Selection

- Examined SPI,I2C,SMBus, micro-wire, UART, RS-485, and others
  - SPI – Good, fast, scalability problematic
  - *I2C – Simple, now license-free, but lacking generic discovery /registration protocol*
  - SMBus – Essentially I2C derivative, some undesirable constraints
  - Micro-Wire – Proprietary, no hopes to make rad-hard
  - UART – Simple and effective, but point-to-point
  - RS-485 – Multidrop, but lacking generic discovery
- We chose **I2C**
  - Need to develop additional protocol for address resolution
  - Possible to create a four-wire interface (two pins for I2C, two for power) or two-wire version by modulating data on power (Transducers Bus).



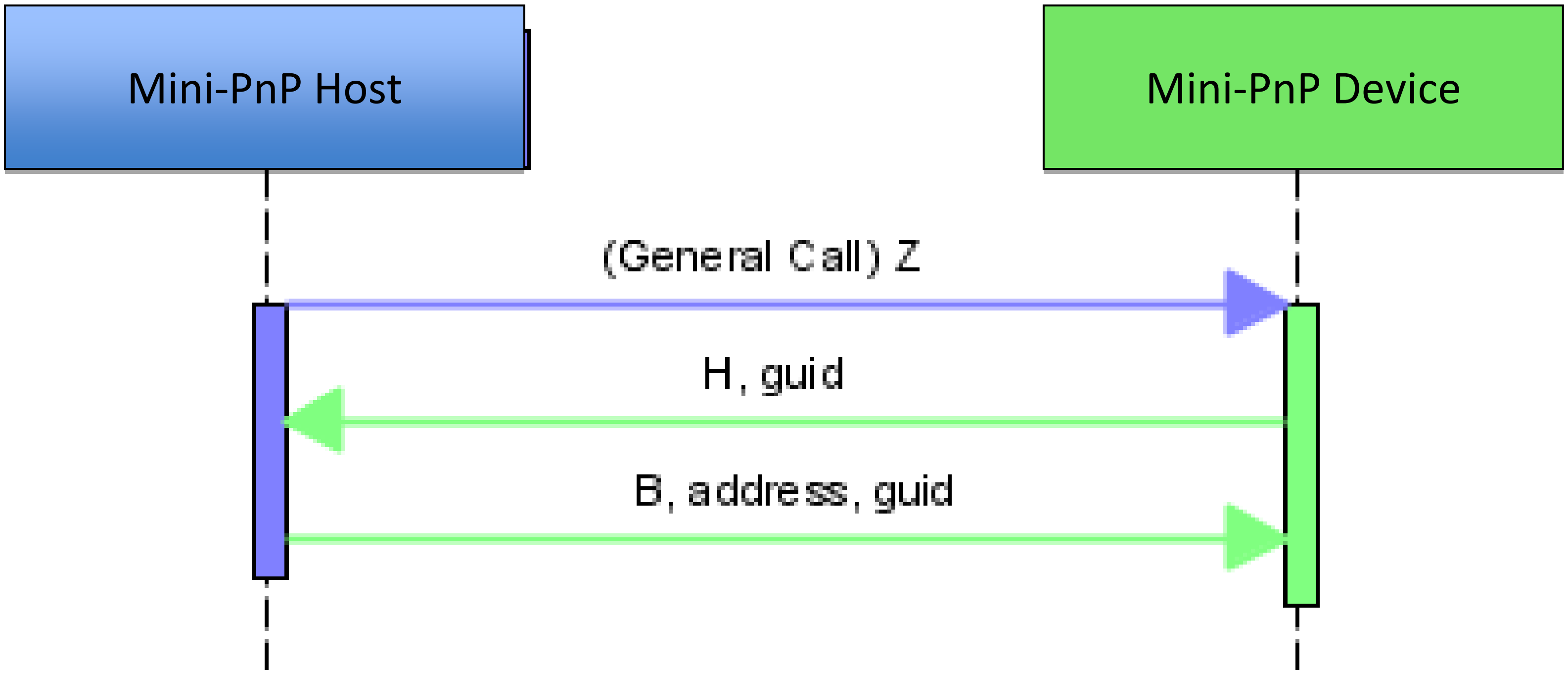
MP/SPA-1 message format

opcode (1 byte)	message length (2 bytes)	payload (length bytes)

Commands (opcode)	Responses (opcode)
Self test	Status
Reset	Data
Initialize	xTEDS
Request version	xTEDS & PID
Request xTEDS	Version
Request data subscription	Hello
Cancel data subscription	
Power on	
Power off	
Command	
Time at tone (SCET)	
General call for registration	
Update address	
Ack	
Not Ack	

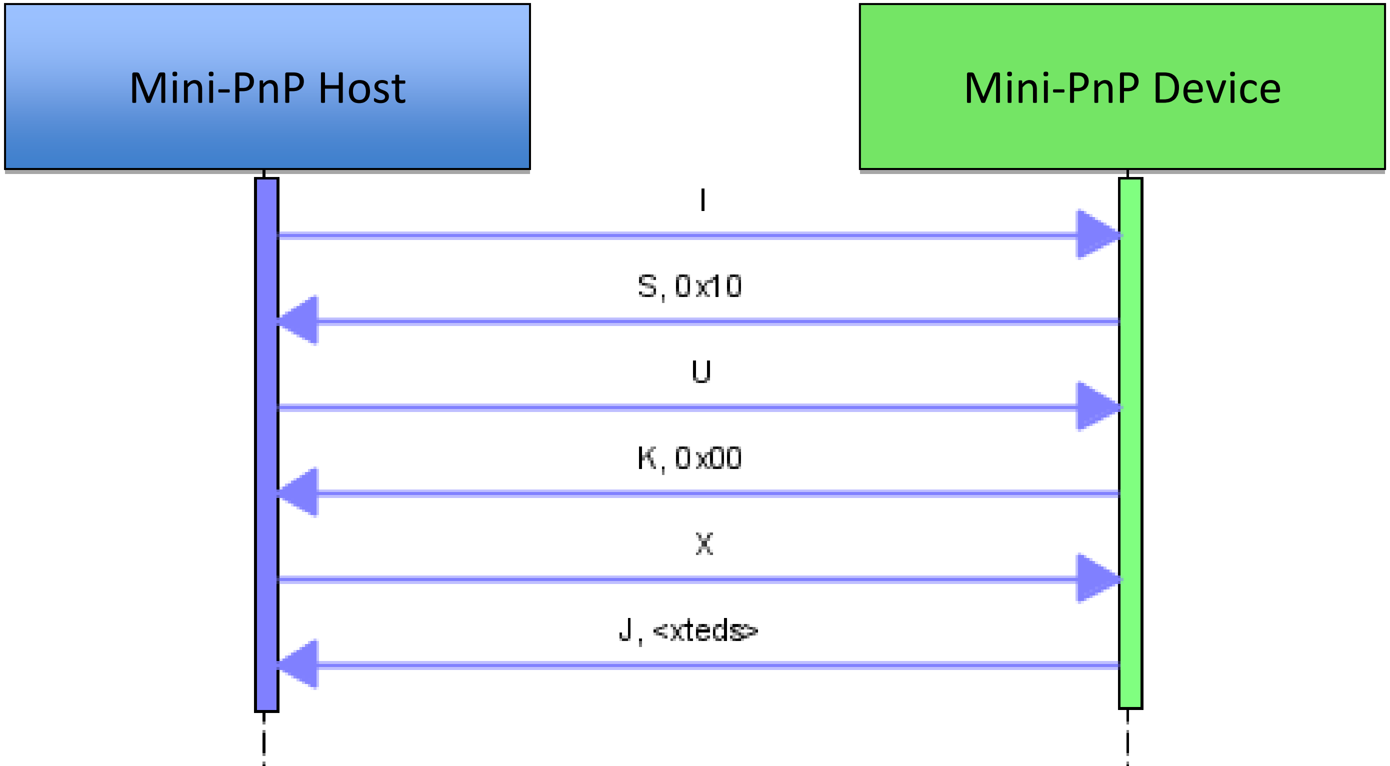
Mini-PnP/SPA-1 Address resolution

- All mini PnP devices have unique global identification (guid)
- Implement address resolution by performing a ”general call”
- All devices use 0x11 as an initial address
- Devices become multi-master and ”walk up” address space until they find an open spot and claim it



Mini-PnP/SPA-1 Electronic Data Sheet (xTEDS*) registration

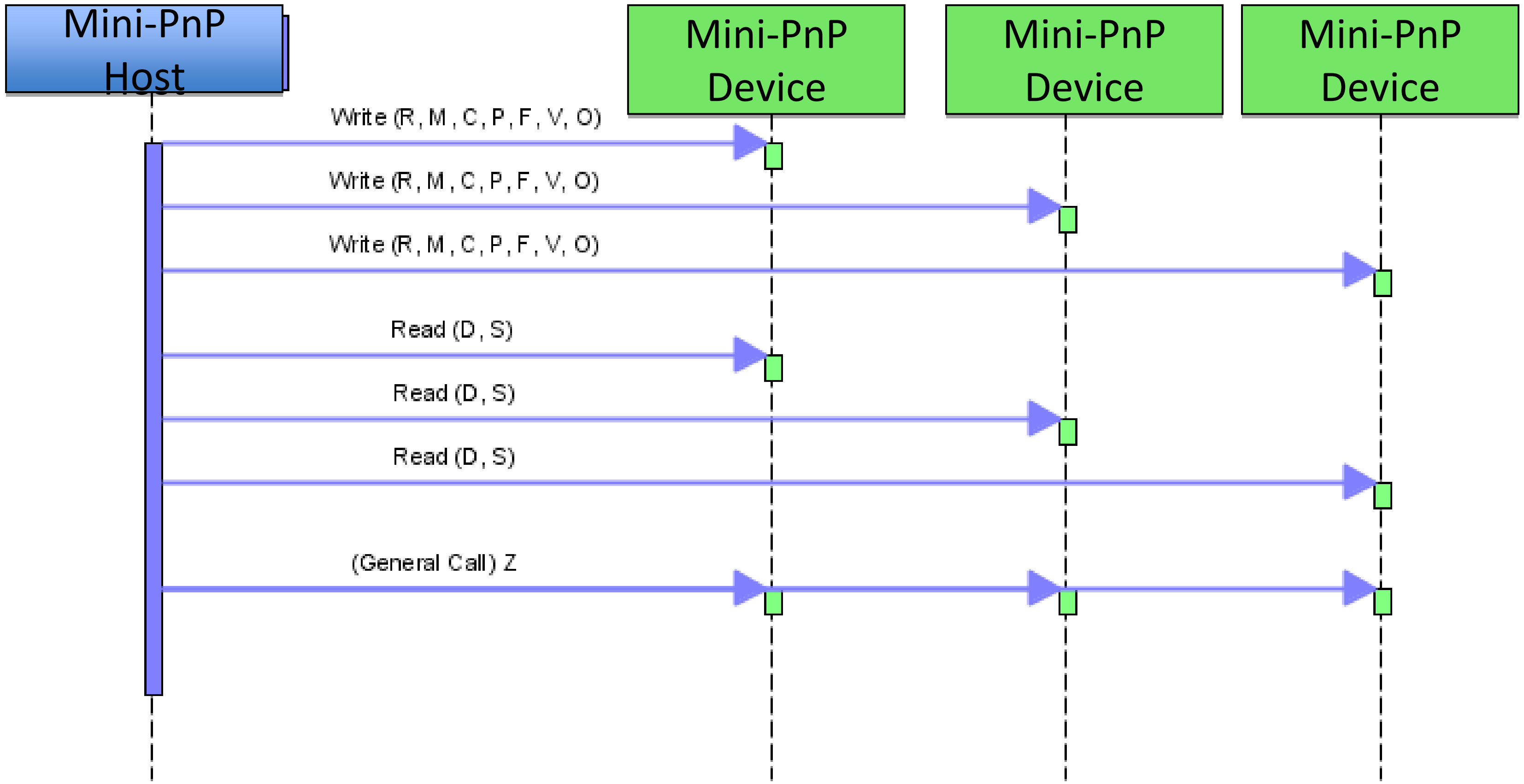
- Mechanism defined to permit the extraction of electronic datasheets from mini-PnP device
- Host parses xTEDS* and registers device services for use by other devices and applications

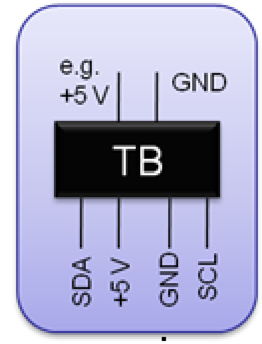


** XTEDS = eXtensible Transducer Electronic Datasheet*

Mini-PnP/SPA-1 Round Robin communication

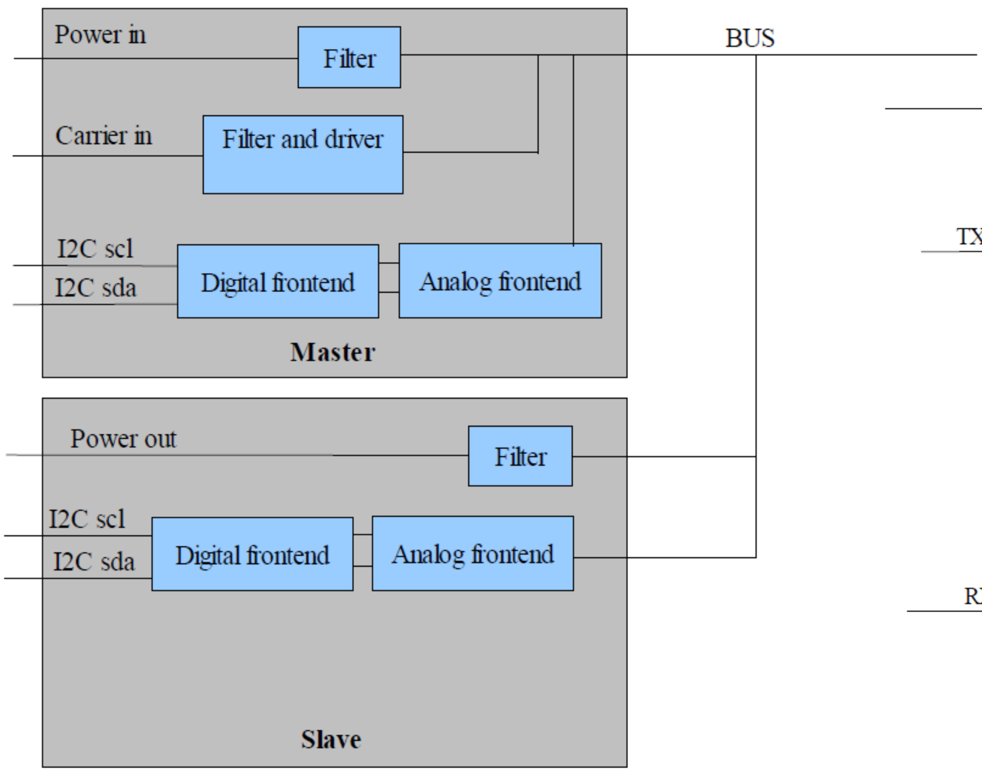
- Mini-PnP Implements a Command (”write”), Response (”read”), and General Call as a continuous cycle using a non-weighted round-robin, visiting all known devices and looking for new ones

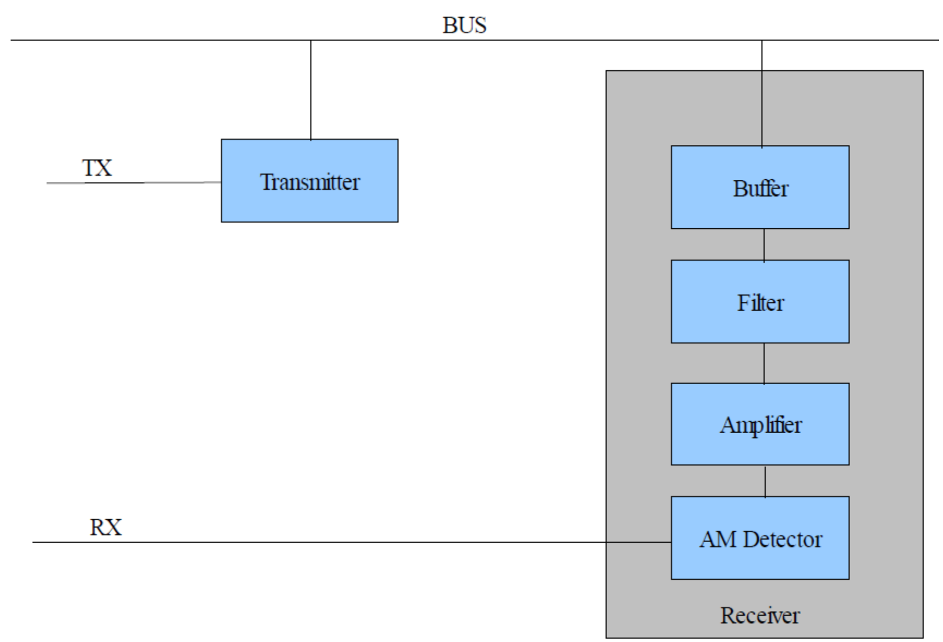




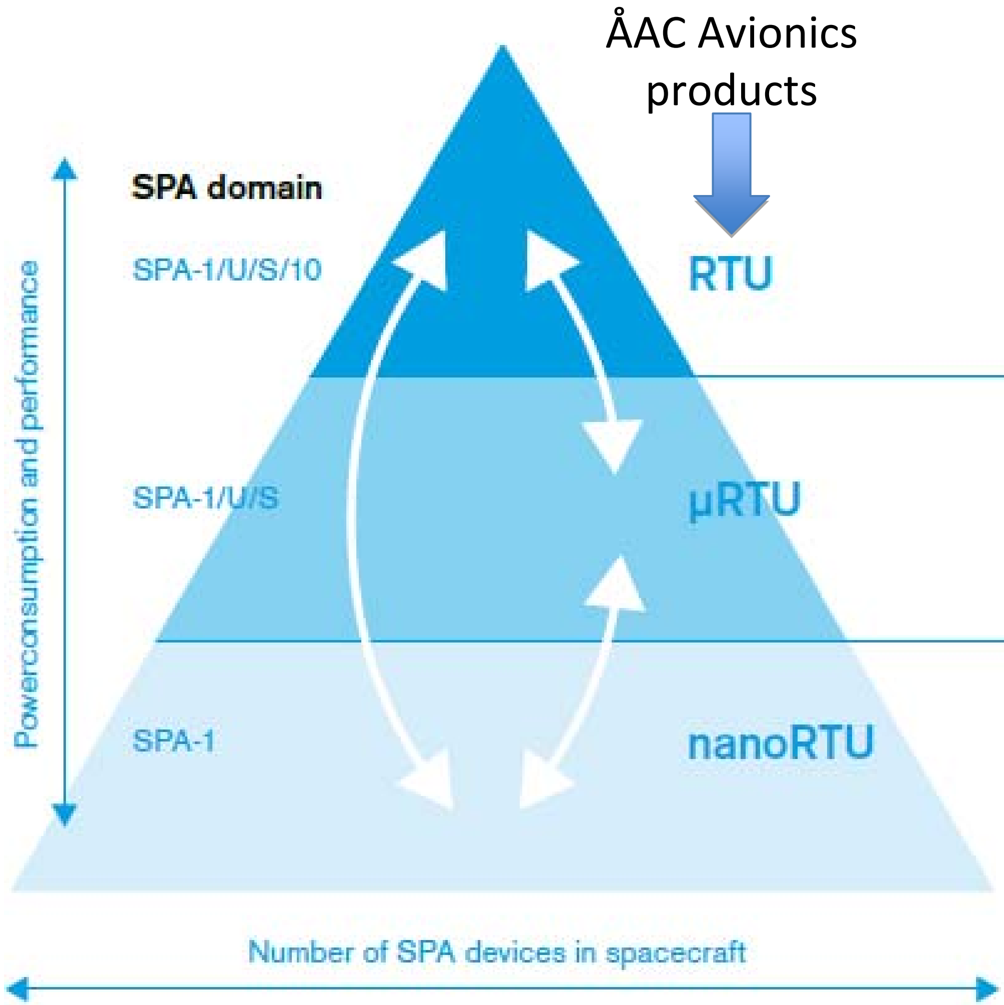
Mini-PnP 2 wire (MP2) / Transducers Bus

- Innovation allow elimination of all wires except for power
- Modulation of data on power allows I2C signals (SDA, SCL) to be superimposed on power lines
- Simple transceiver allows MP2 devices to convert to MP4 and vice versa for systems and components as needed





Three tier division – where mini-PnP/SPA-1 fits



Device examples:

SAR radars, high-resolution cameras, on-board computer, etc.

Propulsion control, inter-satellite communication, mass memories, S-band communication, etc

Temperature sensors, electrical power switches, magnetic torquer control, active heat control, house-keeping, solar arrays, batteries, etc.

ÅAC 3-tier avionics products (1)

SPAready avionics

Feature	RTU 2.0™	RTU ”lite”™	µRTU™	nanoRTU™
Processor architecture	19-24 MHz 32 bit RISC DSP FPU MMU	19-24 MHz 32 bit RISC DSP FPU MMU	19-24 MHz 32 bit RISC DSP	16 MHz PIC16
Radiation protection	EDAC, Parity, Scrubber, TMR	EDAC, Parity, Scrubber, TMR	EDAC, Parity, Scrubber, TMR	EDAC, Parity, TMR
Memory [instruction words]	TBD	12 Mword	12 Mword	4 kword
PCB Dimensions [mm^2] NMF facet size	70 x 70 1 NMF	34 x 70 ½ NMF	34 x 70 ½ NMF	34 x 34 ¼ NMF
Communication	Ethernet (1) SpaceWire (4) USB Host (2) I2C (6) CAN (1) UART (2) GPIO	Ethernet (1) USB Host (1) I2C (4) UART (2) GPIO	SpaceWire (1) USB slave (1) I2C (4) UART (2) GPIO	I2C (2) UART TTL (1) GPIO (12)
Average power [W]	3	1.2	1	0.25
AD/DA	8 x 12 bit	8 x 12 bit	8 x 12 bit	4 x 12 bit
OS	Linux 2.6.34	Linux 2.6.34	Mem. Mapped	Mem. Mapped

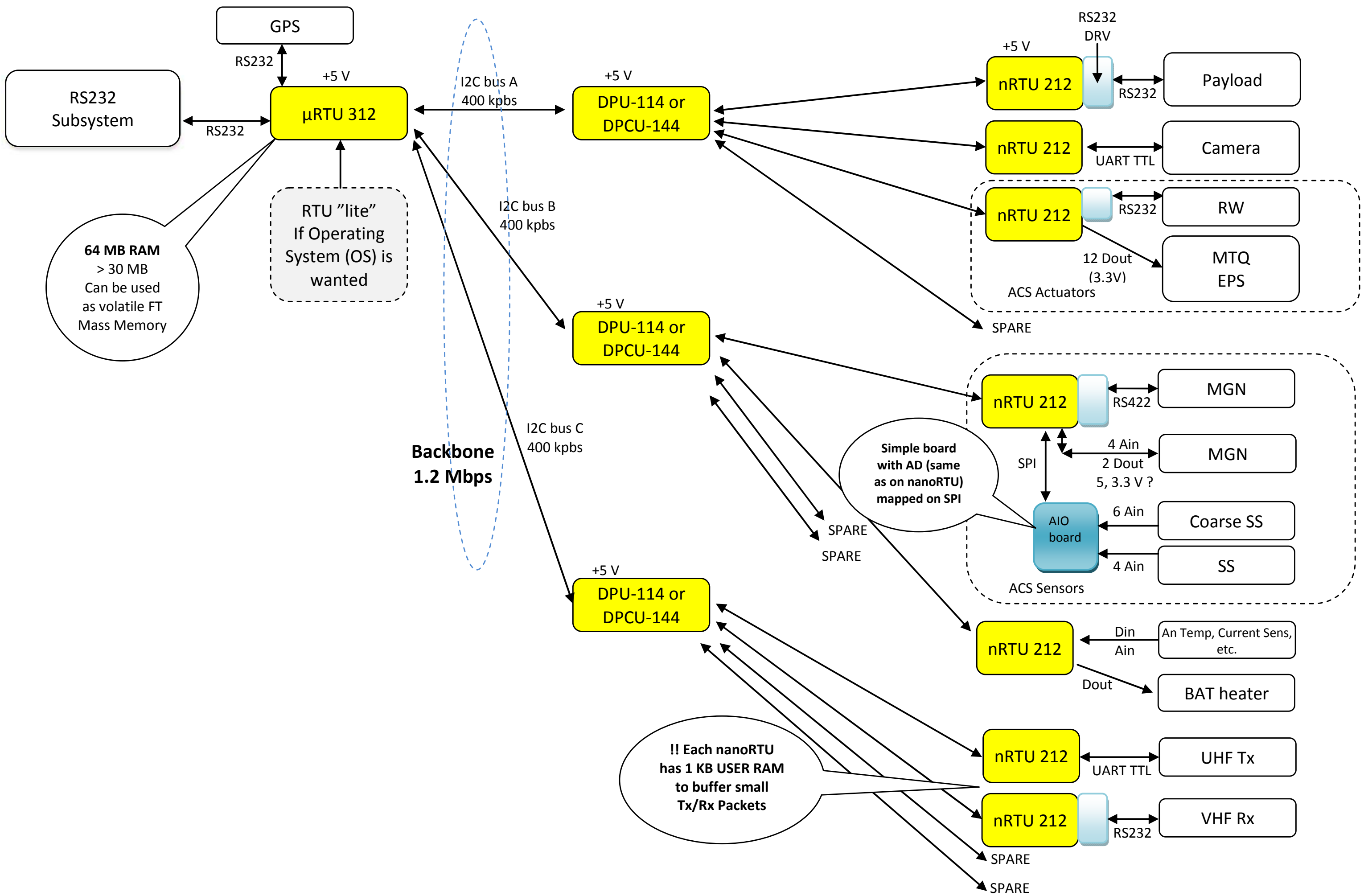
ÅAC subsystems products (2)

SPAready avionics

Feature	DPCU-S	DPCU-U14	DPCU-144	GNC	MM
Description	Distributed Power Control Unit (SPA-S)	Distributed Power Control Unit (SPA-U)	Distributed Power Control Unit (SPA-1)	IMU + MGN + Kalman filter	Non-volatile Mass Memory
SPA interface	nanoRTU	nanoRTU	nanoRTU	µRTU	µRTU
PCB Dimensions [mm^2] NMF facet size	34 x 70 ½ NMF	34 x 34 ¼ NMF	34 x 34 ¼ NMF	34 x 70 ½ NMF	34 x 34 ¼ NMF
Radiation protection	LCL	LCL	LCL	-	EDAC
Capacity	4 x SPA-S i/f 3 A each	4 x SPA-U i/f 3 A each	4 x SPA-1 i/f 1 A each	MEMS Gyro MEMS Accel.	Flash 16 GByte
Power consumption [W]	~ 0.6	~ 0.3	~ 0.3	~0.8	~ 1.2
Extra	4 x SPA-S	1 Upstream USB port, 4 downstream	4 redundant SPA-1 ports	-	

User case (1), Plug 'n' Play architecture

- Example of medium performance distributed nanosatellite architecture based on SPA components



PnP Virtual Satellite Integration Equipment

Virtual Satellite Integration over internet with TCP-IP. Simulate or link plug-and-play subsystems together for cost efficient satellite integration

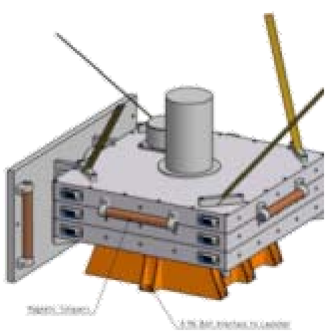
- VSI interface: Ethernet T-base 10/100
- Version 1 protocol support: SpaceWire, CAN, RS485, RS232
- Version 2 protocol support: SpaceWire, USB 1.1, I2C, RS422, RS232

ÅAC nanosatellite offerings

- QuadSat-PnP is offered together with OHB and University of Applied Sciences in Bremen.

Nanosatellite plattforms

- QuadSat-PnP



- Virtual Satellite Integration

Nanosatellite Core components

Avionics	Power	GNC	Thermal
RTU 2.0	PDU-114	IMU+MGN Kalman	Thermal Switch
RTU ”lite”	DPCU-144		
µRTU	PDU-U14		
nanoRTU	PDCU-U14		
NVM Mass Memory	PDCU-S		

Education

- SPA/Plug’n’Play training
- SPA/Plug’n’Play educational kits

QuadSat-PnP 1 spacecraft details

- Flight heritage from 10 previous flights (”RUBIN platform”)
- ”SPA*ready*” (rapid integration with self describing subsystems)
- Modular and scalable
- 4U QuadSat Formfactor , 25 x 25 x 20 cm
- ~15 W continous power
- Weight < 15 kg
- PSLV launch in H2 2011
- Sun pointing stabilized (magnetorquers)
- Intersatellite, S-band, and VHF data downlink
- ÅAC miniaturized POL main payload
- AFRL, NASA Ames, TNO payloads
- Support from US DoD/ORS

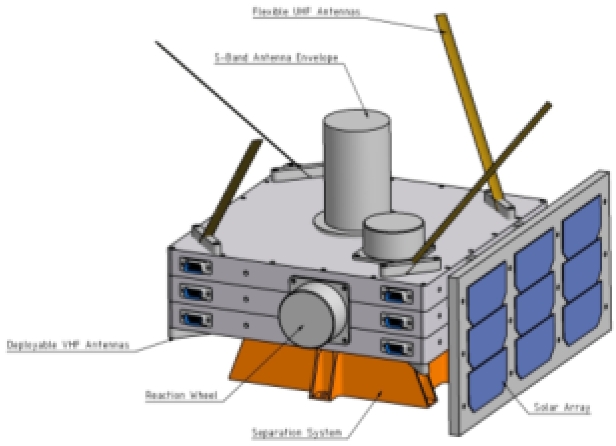
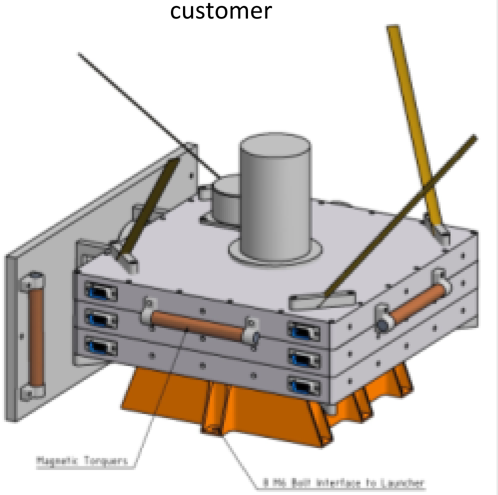
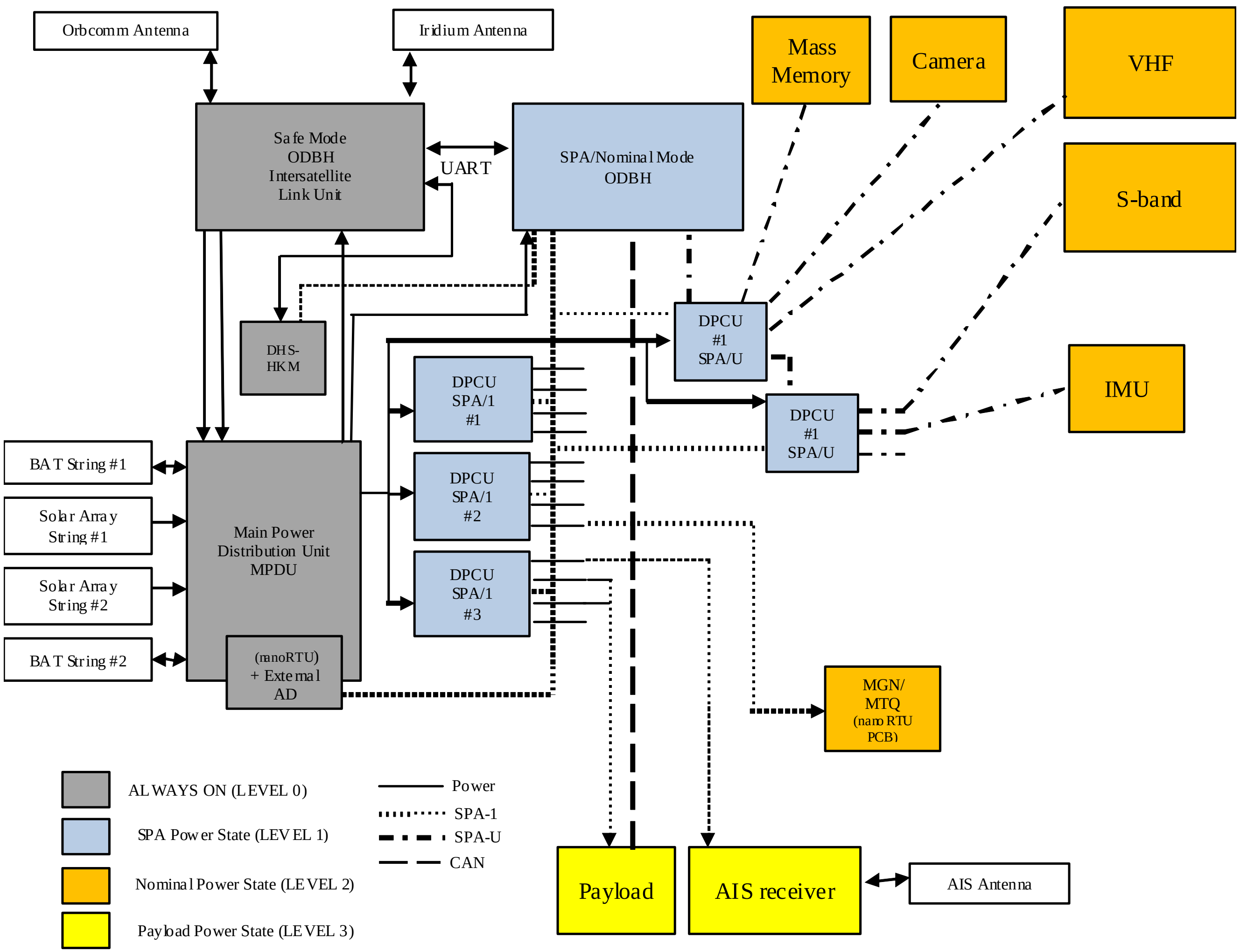


Illustration of OHB QuadSat for Latvian customer



System design example (QuadSat-PnP)



Conclusions

- The SPA Plug-and-play architecture offers a new model for rapidly and flexibly building spacecraft through intelligent modularity
- A joint US/Sweden program (”NAPA”) has developed improvements to SPA to allow simple spacecraft components to support plug-and-play
- The development of the generic minimalist protocol has been described
- The mini-PnP protocol will be open source / ITAR free, but space adaptation of mini-PnP (referred to as ”SPA-1”) results in ITAR restrictions (when performed in the US)
- AAC Microtec (Sweden) has created ITAR-free interface modules that implement mini-PnP (SPA-1), SPA-U, SPA-S in rad-tolerant form
- The existing Satellite Design Model (SDM) source code is ITAR
- QuadSat-PnP platform has been presented

Acknowledgments and Questions

- Configurable Space Microsystems Innovations & Applications Center (COSMIAC), Albuquerque, New Mexico
- Utah State University/Space Dynamics Laboratory, Logan, Utah
- OHB System AG, Bremen, Germany
- University of Applied Sciences, Bremen, Germany
- Swedish National Space Board (SNSB)

- For more information, see http://pnp.aacmicrotec.com