PEARL CubeSat Bus
Building Toward Operational Missions

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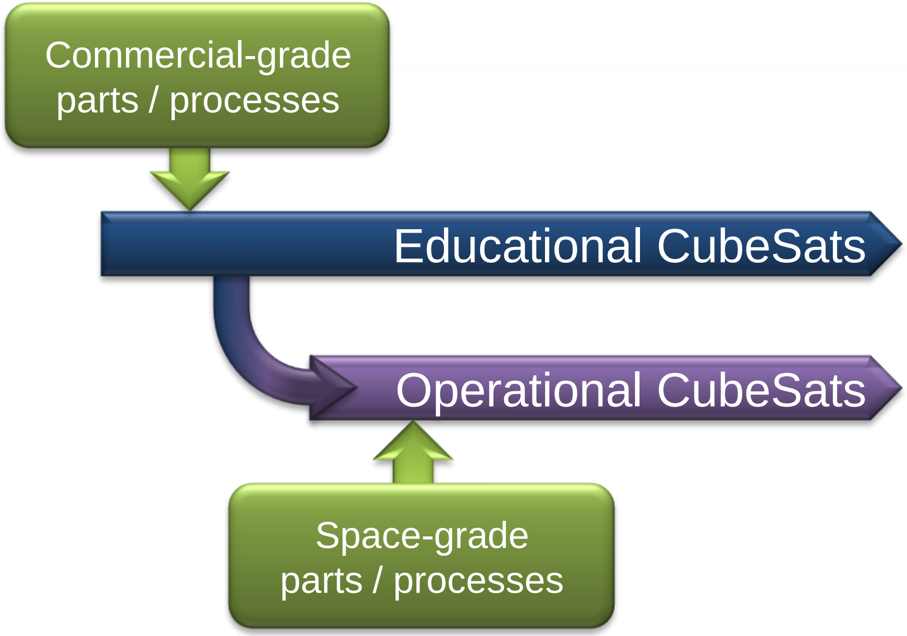
Building Toward Operational Missions

- **Proven Value**
  - CubeSats have proven they can perform valuable scientific missions
- **New Interest**
  - Significant interest has been generated within the scientific community, with both funding agencies and principal investigators
- **New Platform to Meet New Interest**
  - SDL has evaluated the needs of the science community and is developing a CubeSat platform for the higher-end science mission

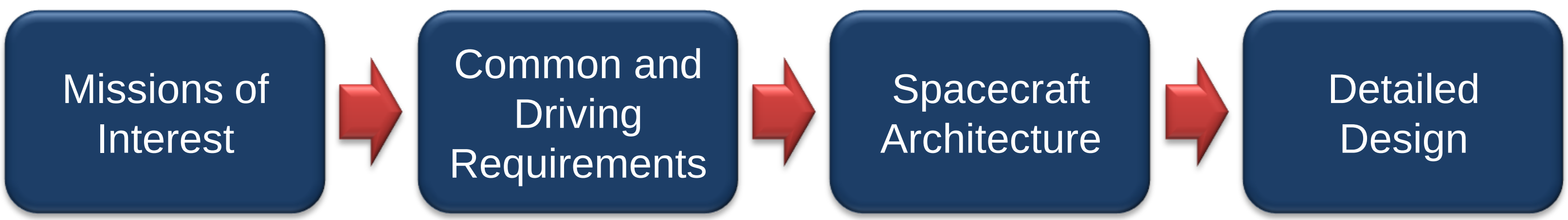
Higher Capabilities – Different Mindset

- **Operational missions tend to push the capability envelope**
  - More power
  - More processing capability
  - Higher data throughput
  - Better pointing control
  - Higher reliability
  - Longer mission lifetime
- **Operational missions tend to require a different mindset**
  - Requirements-based design
  - Quality standards/certifications
  - Traceability
  - Risk averse
  - Higher profile, higher cost, higher payoff



Requirements/Capabilities Traceability

- **Design based on requirements and mission needs:**
  - Design CubeSat platform with capabilities traceable to scientific mission needs
  - Architecture must be flexible and adaptable to support multiple mission types
  - Architecture must be upgradable to incorporate new capabilities as they are developed



What types of missions are scientists interested in, and which are compatible with CubeSats?	What are the common set of requirements? What are the driving requirements?	What architecture is best suited to these requirements and the need for design longevity and upgradability?	What detailed design will deliver the required capabilities?

Missions & Mission Needs

- **Technology Demonstration Mission**
  - Just needs to be in space
- **Simple Science Mission** (simple mission, not simple science)
  - Pointing control requirements are low
  - Processing requirements are low
  - Data requirements are low

Next Step for CubeSats

- **Sophisticated Science Mission**
  - Higher pointing control requirements
  - Higher processing requirements
  - Higher data requirements
- **Operational Mission**
  - High reliability (higher quality parts, traceability, QA, etc.)
  - Longer design life (higher quality parts, more radiation tolerance)

Approach Summary

Follow CubeSat standard, but not "commercial" philosophy

- The CubeSat standard and philosophy were designed for educational use
  - Very effective
  - Very well adapted for the educational missions they were designed for

Challenges*:

- Moving from academic to industry model
  - Industry/Government Customers
  - Higher Performance/Cost Satellites
  - Increased Quality Required
  - Potential Cost Increases

* Jordi Puig-Suari, CubeSat Developers Workshop 2009

- The SDL approach:
  - Follow the CubeSat standard (it's still very effective)
  - Incorporate the reliability, parts quality, performance, and design rigor required of high-profile, operational missions

Design Approach

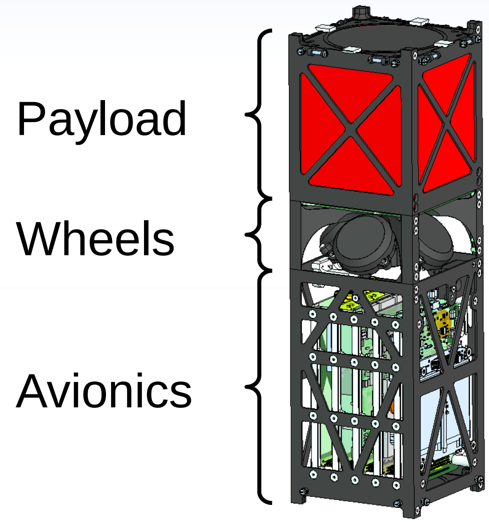
- **Meet Increased Process and Capability Requirements**
  - Reliability
    - Space and military grade parts
    - NASA certified parts program
    - Certified assembly and testing processes
    - Traceability
  - Performance
    - Increased pointing knowledge and control
    - Increased processing capability
    - High throughput data bus
  - Environmental tolerance (especially radiation)
  - Design rigor
    - Configuration control
    - Risk tracking
    - Detailed analysis, worst-case analysis, failure modes analysis
    - Design reviews
    - Design verification

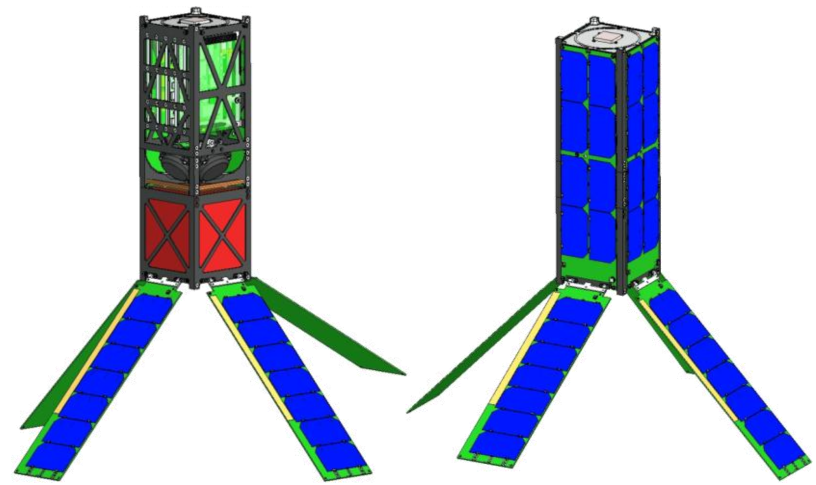
Environmental Tolerance

- **End-goal is to migrate to all space-grade components**
  - Higher reliability in space environment
  - Increased radiation tolerance
  - Longer mission life
- **Architecture and form factor allow for migration**
  - Increased size of the card allows for the larger components
  - PCI architecture has space flight heritage and larger selection of space parts to choose from
- **Incrementally improve parts quality in each card design**
  - Begin with CPU card

PEARL* Architecture

- **Modular Chassis Sections**
  - Payload Chassis: 1.0 U
  - Reaction Wheels: 0.5 U
  - Avionics Chassis: 1.5 U
- **Monolithic Aluminum Structure**
  - Utilize efficient on-site advanced machining practices
  - Maximized strength-to-weight ratio
- **Solar panel arrays**
  - 4x stationary
  - 4x deployable with adjustable deployment angle

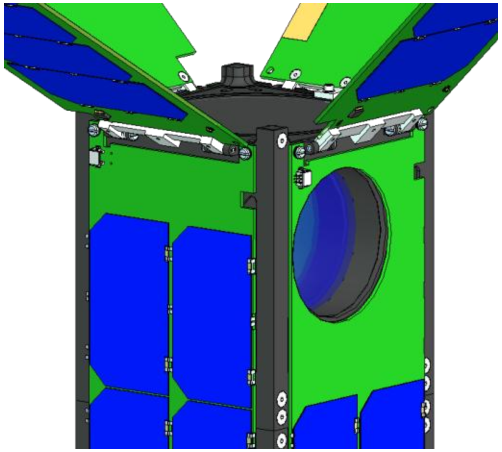


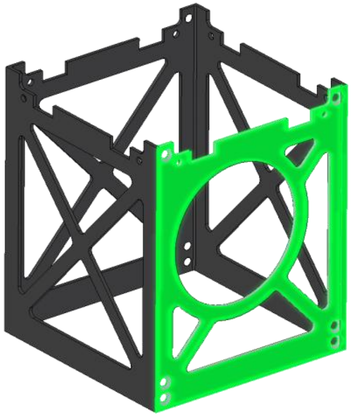


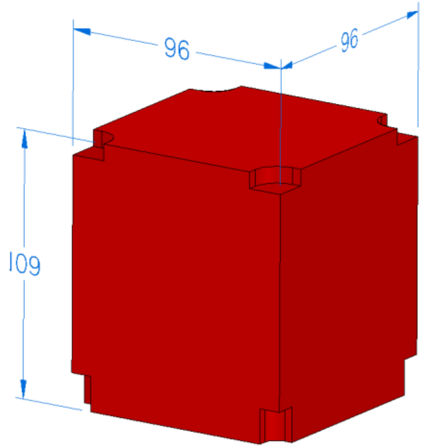
* PEARL development is sponsored in part by the Air Force Research Laboratory (AFRL)

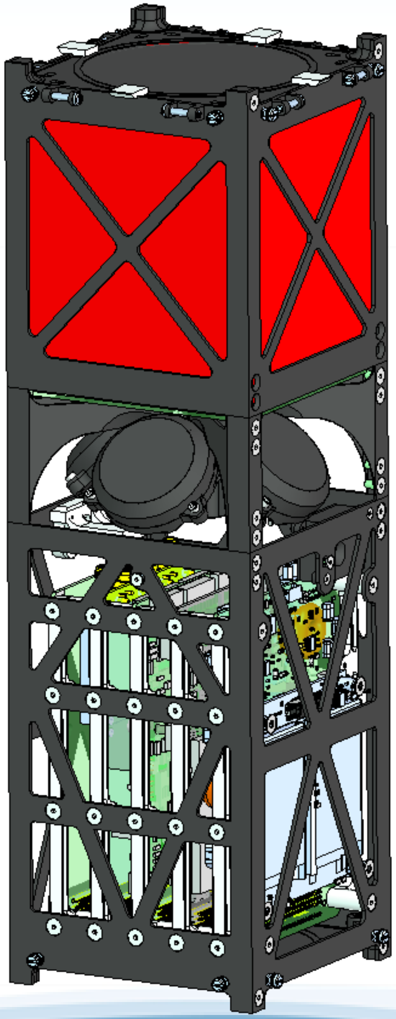
Payload Support

- 1U available for payload + 1 PCI card in avionics
- Up to 1Kg of payload mass
- Up to 2W continuous for Nadir Pointing mission
- Chassis modifications possible to support viewing
- Mounting bosses on top and bottom corners
- Chassis sides can support additional mounting points







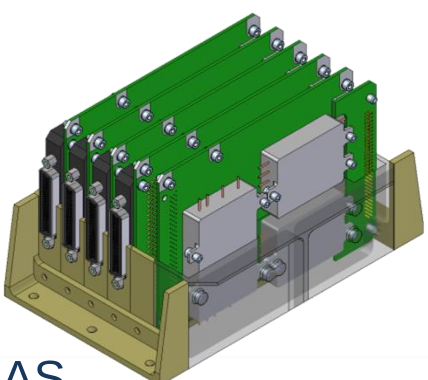


Space Dynamics Laboratory
Utah State University Research Foundation

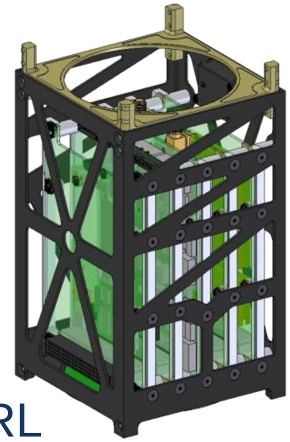
Avionics Layout

Vertical vs. Horizontal Card Stack

- Data throughput and processing requirements meant the data bus architecture had to change
- Chose to leverage off of existing space-designed avionics targeted for Plug-and-Play distributed small satellite applications (MODAS)
- Same card standard can be used in both applications
- Significant harness improvement – connectors for all cards are located in a harness set-aside volume at top of avionics stack



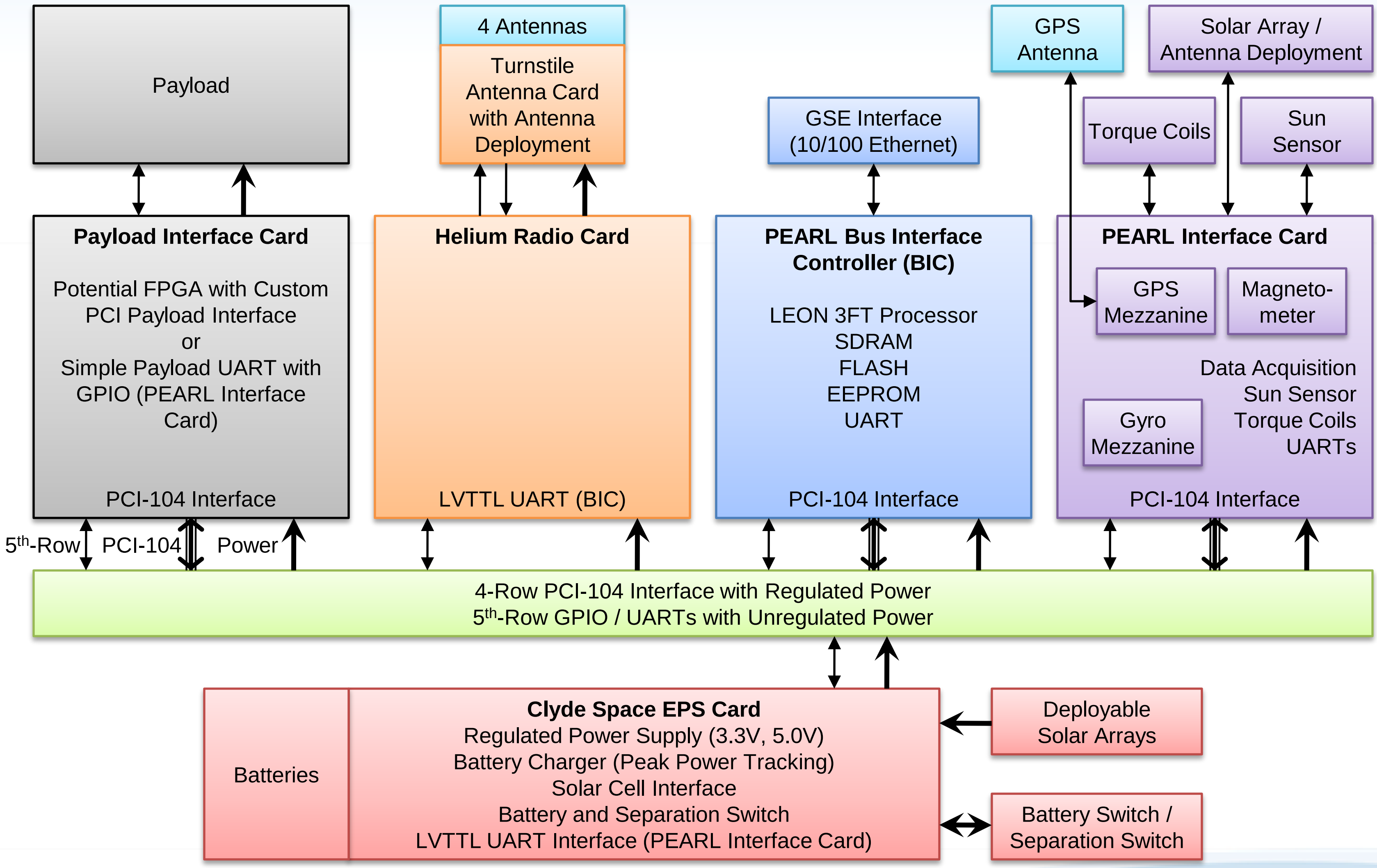
MODAS



PEARL

- 5 cards plus batteries
- 1 card reserved for payload
- Modified PCI-104 form factor
  - CPU
  - EPS
  - Transceiver
  - ADCS Interface
  - Payload

PEARL System Block Diagram

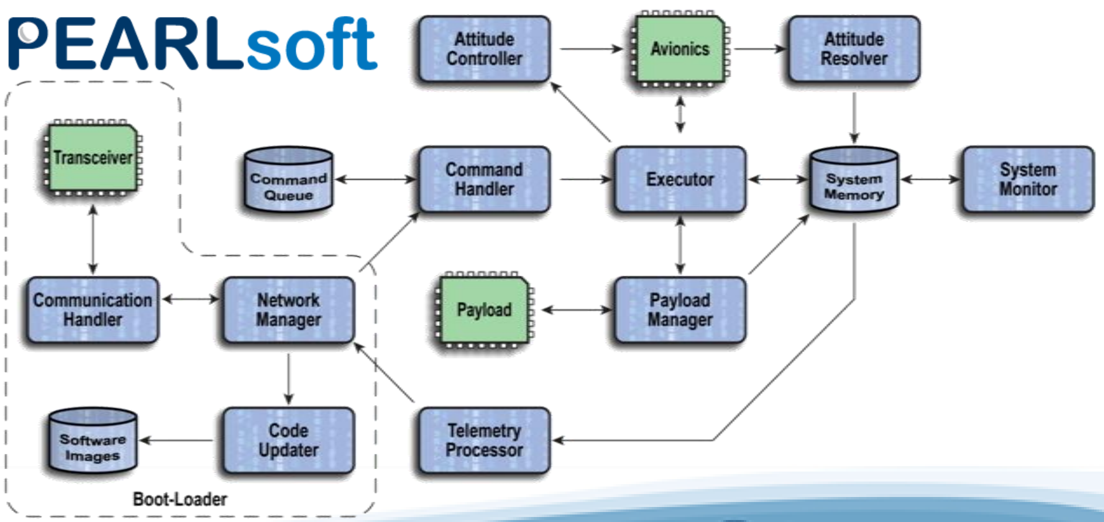


Bus Architecture & Processor

- **PEARL uses an industry standard PCI bus architecture**
  - 33 MHz, 32-bit,
  - LEON 3FT general purpose CPU
  - Serial Ports: UART, SpaceWire, Ethernet
  - IEEE-754 Floating Point Processor
  - Electrically compliance: PCI-104
  - CPU Radiation Tolerance: 300Krad
  - Memory (EDAC Protected + radiation test data)
    - SDRAM: 128M bytes
    - EEPROM: 512K bytes
    - Flash: 512M bytes
  - Upgrade path to 100Krad(Si) tolerance for the entire card

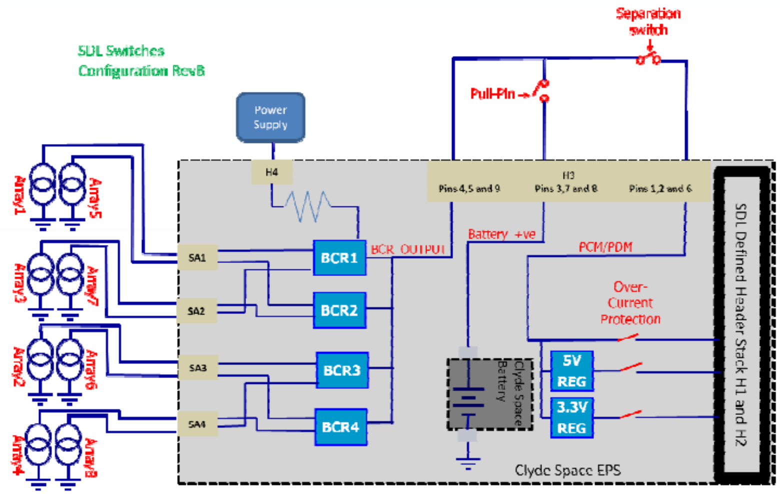
PEARLsoft Flight Software

- **Real-time flight software**
  - Adapted from software currently flying on NASA AIM-SOFIE mission
  - Supported by VxWorks 6.5
  - ISO-9001 Development process with configuration control
- **Multi-threaded architecture to provide design modularity**
  - High level of reuse
  - Adaptable for broad range of mission requirements
  - The following separate threads enable easy modification:
    - Communications
    - Attitude Control
    - Payload Management



EPS & Communications

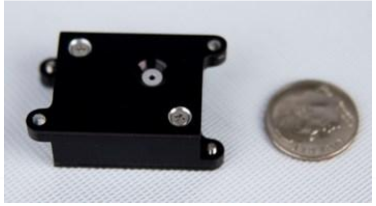
- **Electrical Power System**
  - Extended PCI-104 form factor
  - Clyde Space Peak Power Tracking system
  - Max Power: 36W
  - Input voltage: 10 – 25 Volts
  - Efficiency: > 90%
  - 4 Lithium Polymer: 8.2 Volts, 2.5 A-hr
  - Solar Array: 4 body mounted, 4 deployable

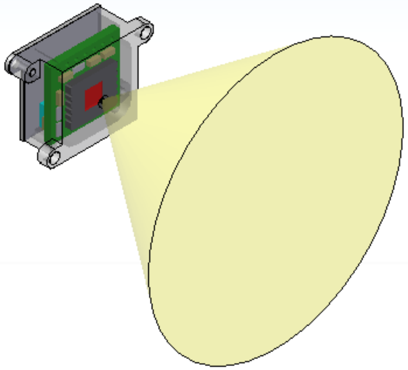


- **Transceiver**
  - Extended PCI-104 form factor
  - Astronautical Development He-100
  - Uplink/downlink: UHF, 9600 baud (higher rates available)
  - Output Power: 100 mW to 3W
  - UHF antennas embedded in solar array panels

Attitude Control

- **Higher accuracy sensors**
  - Miniature Sun Sensor
    - 72° full-angle field of view
    - Targeted accuracy to 0.01°
    - Very low power
  - Star Camera / Star Tracker





- **Kalman-filter based attitude and attitude rate determination**
  - Used to estimate error sources
  - Provides attitude control solution for entire orbit (including eclipse)
  - Variable number of states to match available processing and desired accuracy
  - Steady-state Kalman filter option for significantly reduced computational complexity
- **Reaction wheel assembly**
  - Compact ½U size
  - 4-wheel pyramid layout
  - Space-compatible lubricants and control electronics

Summary

- **More sophisticated operational missions are possible**
  - Higher performance
  - Higher reliability
  - Longer life
- **SDL's PEARL spacecraft is designed to support these missions**
  - LEON 3FT processor with Vx Works and PEARLsoft
  - PCI-104 data bus
  - Attitude control improvements
  - Transitioning to space-grade parts
  - Quality controls and traceability
  - Operational design philosophy