A Product Line Approach to Space Power Systems

Vincenzo Catanza, Richa Sirohi, & Jennifer Atteberry

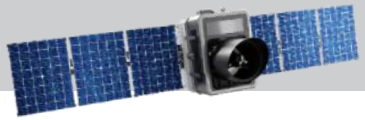
BAE SYSTEMS

Agenda

- What is the Elevation™ Product Line
- Product Line Buses
- Summit Product Itself
- Power System Design
- Scaling
- Production
- Test

BAE Systems Spacecraft Solutions

SUMMIT

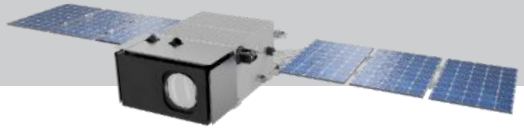


Capable multi-mission platform for rideshare missions

Summit is an ideal choice for rideshare or multi-vehicle missions.

Key features:
- Supports payloads up to 225 kg
- 400 to 850 watts orbit average power
- Precision pointing
- Disturbance and thermal isolation

TREK

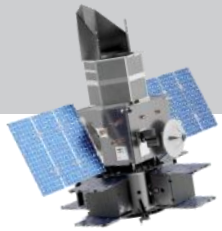


Increased payload accommodation for multi-launch spacecraft

Trek provides increased flexibility with the payload interface, enhanced ADCS, and increased communication capabilities.

Key features:
- Supports payloads up to 1000kg
- Up to 1,900 watts orbit average power
- EMI mitigation
- Precision pointing
- Disturbance and thermal isolation

ASCENT



High maneuverability, refuellable, high thrust propulsion & rideshare payloads

Ascent offers high maneuverability, high thrust propulsion, multiple-payload hosting and refuel-ability, offering enhanced versatility for enhanced space operations.

Key features:
- Multi-mission mobility
- Multi-manifest launch
- Rendezvous, proximity operations and docking

Elevation™

EVOLVE

Configurable spacecraft solutions

Evolve is our configurable spacecraft solution. We work collaboratively with our customers to build spacecraft solutions that meet specific mission requirements.

Key features:
- Modular building blocks for efficient configuration
- Suitable for moderate to high performance missions
- Offers flexibility and adaptability

EVOLVE+

Configurable spacecraft solutions for higher class missions

Evolve+ is designed to support high performance missions while providing extended mission life, meeting the most stringent of customer requirements.

Key features:
- Advanced fault management and autonomy
- Compatible with various sensors and actuators
- Suitable for large instrument suites and high-availability missions

Evolve

Elevation™ Spacecraft Product Line

BAE SYSTEMS

Elevation™ Summit Spacecraft Product

- Leverages substantial heritage from Evolve, e.g. software, algorithms, and I&T facilities
- Features in-house avionics and power management package
- Tailoring packages available for:
  - Wideband downlink
  - Data storage and network routing
  - Dedicated launch configuration

	Capability
Payload mass (kg)	Up to 225 kg
Payload power (orbit avg, EOL, watt)	400 to 850W (28 VDC)
Payload volume (l x w x h, meters)	2 x 0.9 x 0.7 m
Launch service compatibility	Rideshare baseline, compatible with worst case SpaceX cake topper loads
Orbit altitude (km)	400 to 1000km
Orbit inclination (deg)	40 deg to SSO
Propulsion or deltaV	Electric Propulsion, >380 m/s ΔV
Downlink band & data rate (Mbps)	500+ Mbps, Multiple Crypto Options
Pointing Performance (1σ)	Accuracy: <7 arcsec Knowledge: <4 arcsec Stability: <1 arcsec/1sec
Advertised mission life (yr)	5 years
Redundancy	Single-string w/selective redundancy
S/C Class (ESPA, ESPA Grande, etc.)	Rideshare (SpaceX XL Plate)

How to hit the Elevation™ Product Line Goals

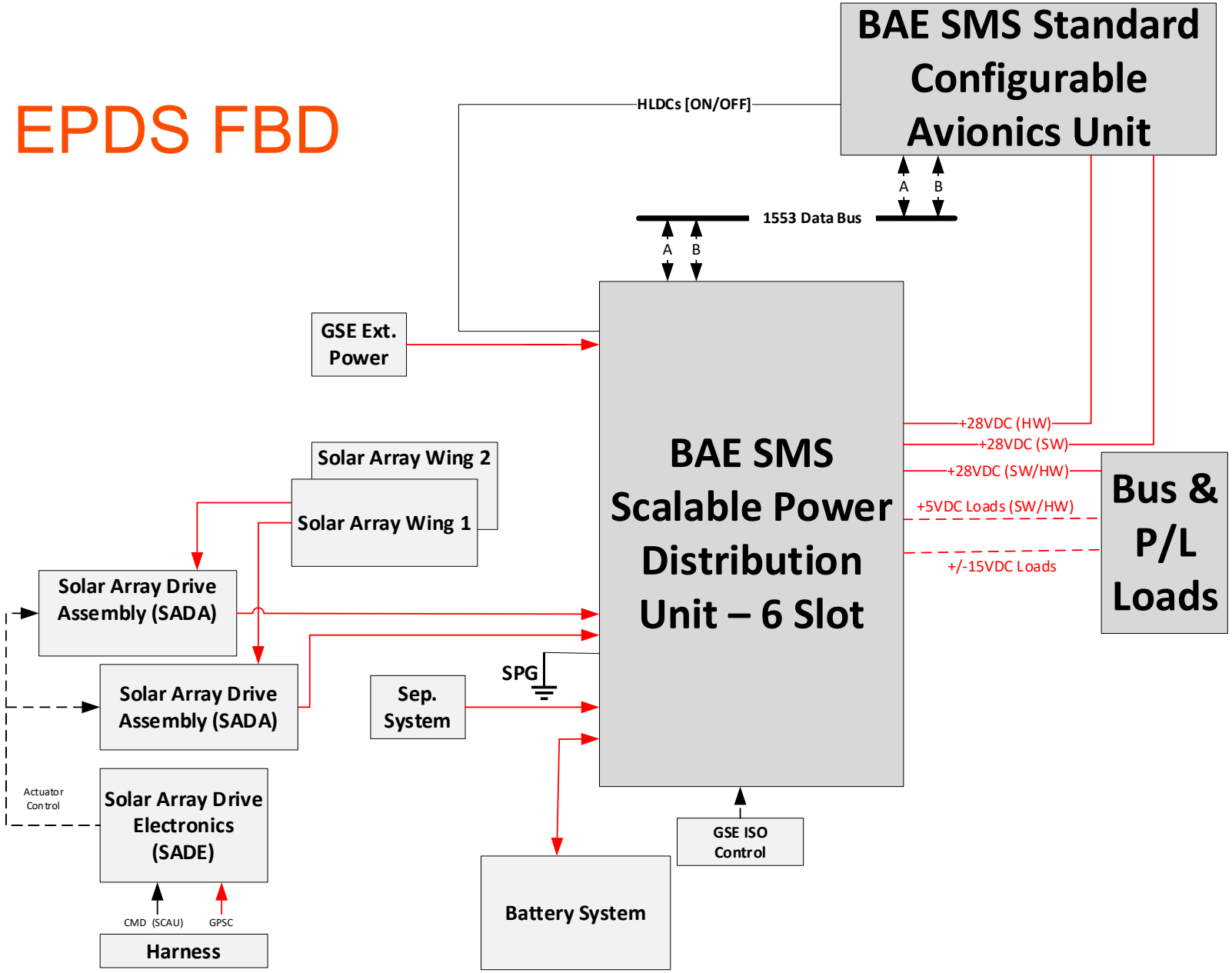
- Limit variations in power design to enable scaling for mission need while keeping non-recurring engineering (NRE) costs low
- Single harness design supports a large array of payload interfaces on the Summit Bus
- Analyses for the Summit bus envelop a range of orbit and mission life requirements, reducing NRE at the individual mission level
- Long term agreements (LTA) in work with suppliers to receive guaranteed cost/schedule for each product
- Production and testing streamlined to limit human interaction

Summit Product

- The Summit bus is the inaugural member of the Elevation™ Product Line (EPL)
- It brings the processes, engineering, and reliability of BAE SMS with the cost and schedule advantages enabled by standardization of design, analysis, procurements, production, and test to reduce non-recurring engineering
- Risk based assessment (RBA) process maintains BAE SMS reliability heritage while procuring commercial off the shelf (COTS) style products
- Power system uses a high heritage direct energy transfer (DET) architecture common to previous BAE SMS missions

The Summit Product is a high-reliability, low-cost spacecraft bus

Summit EPDS FBD



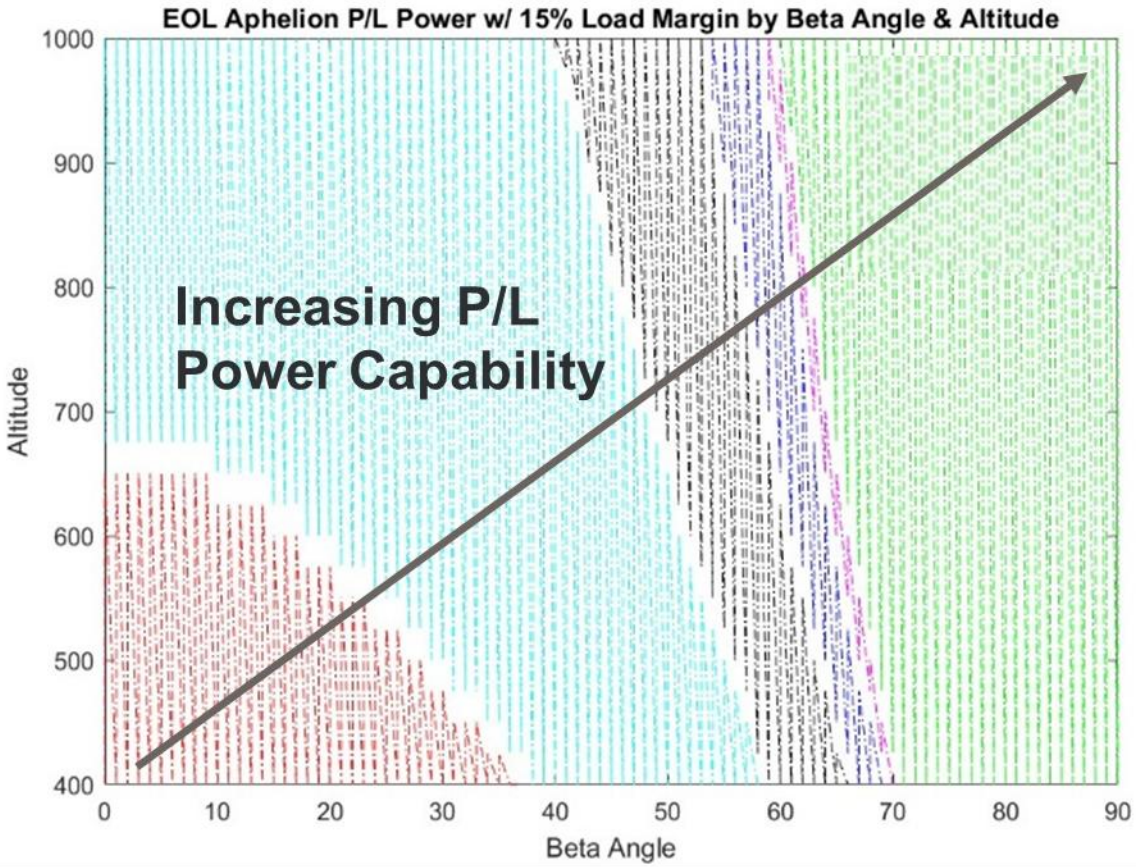
Summit EPDS Consideration Packages

- EPDS default hardware chosen to best support volume, & mass constraints while best accommodating power requirements
- Additional EPDS considerations packages can be selected to increase EPDS performance
  - Consideration 4 – EPDS Performance: Dual Battery System
- Doubles battery capacity to allow for increased mission capability including, but not limited to, longer electric propulsion burning, higher P/L duty cycles, increased capability in eclipse.
- Summit EPDS is designed to support the full range of missions and orbits under the Summit orbit requirements

Summit bus is not a point solution to a single mission

Summit Analyses

- Parametric analyses helps define EPDS capabilities based on mission specific requirements including mission's length, orbit altitude & inclination
- Fault Management UV Cascade verifies survival at EOL during worst case eclipse conditions
- As-measured power to be incorporated to continue to provide fidelity to the power models



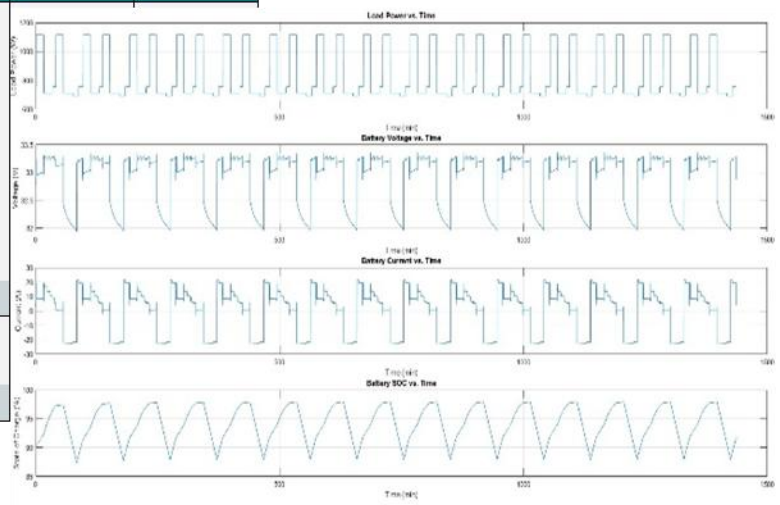
Summit Solar Array Parametric Analysis

Parametric analysis enables clarification of what is supportable based on mission specific requirements

Program Specific Analysis

- Each program will use Summit standard template to build its program specific:
  - Switch assignments
  - Static and Dynamic Power Analysis
- Utilizes BAE heritage Power Analysis Simulink Tool (PAST) for dynamic analysis
  - Dynamic outputs include solar array current, load current, battery & bus voltage, and battery SOC
  - Allows highly reliable predictions of dynamic power system behavior

Summit Power Budget		Mission - DITL	
		CBE Mode Avg	MEV Mode Avg
Observatory	**Subsystem**		
	Command and Data Handling - C&DH		
	Telecommunications - COM NB		
	Thermal Control Subsystem - TCS		
	Attitude Determination and Control Subsystem - ADCS		
	Electrical Power & Distribution Subsystem - EPDS		
	Mechanisms - MECH		
	Propulsion - PROP		
	Total Bus Loads		
	Payload Hosted		
	Telecommunications - COM WB		
	Total Observatory Loads		



Example Summit Power Analysis Outputs

Each program receives mission specific analysis to characterize mission performance

BAE SMS SPDU-6 Capability Chart

- BAE SMS (SPDU-6) EPDS Characteristics include:
  - 28V ± 6Vdc unregulated bus voltage
  - 90A throughput
  - Fuse-based overcurrent (OC) protection
  - Low voltage switched outputs for +5VDC and +/-15VDC equipment
- Summit SPDU-6 has a total of 21 switches allocated to the payload
- Harnesses designed out to a payload bracket to accommodate multiple different missions

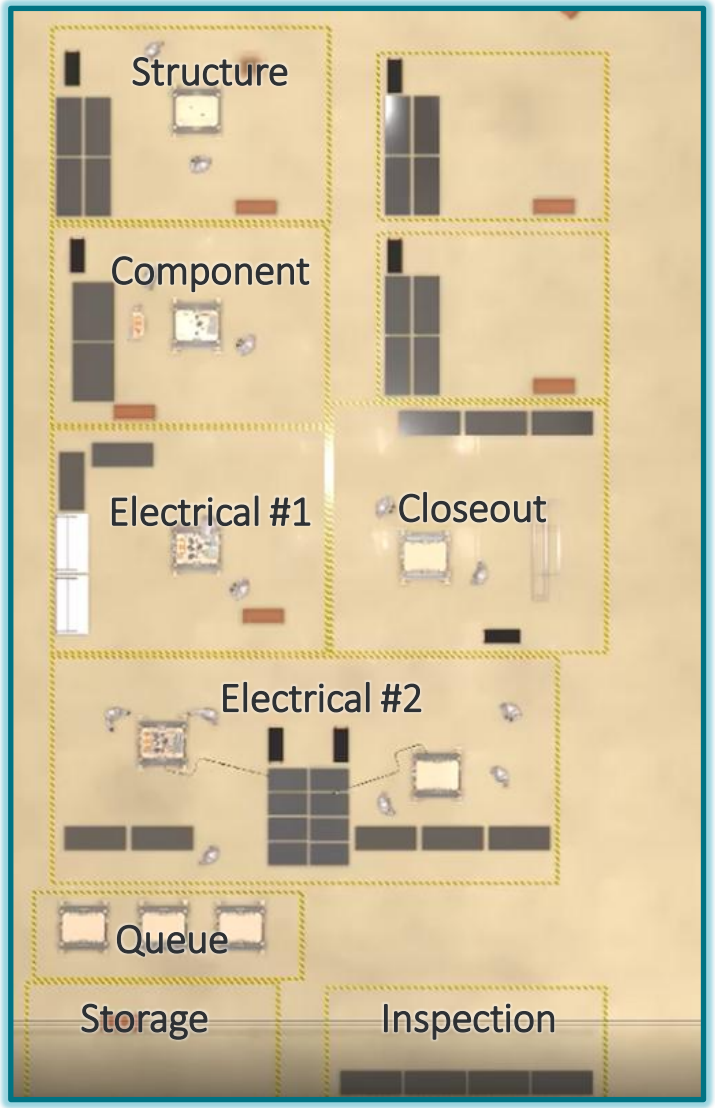
BAE SMS SPDU Flysheet

Summit SPDU can support a broad range of missions

Production

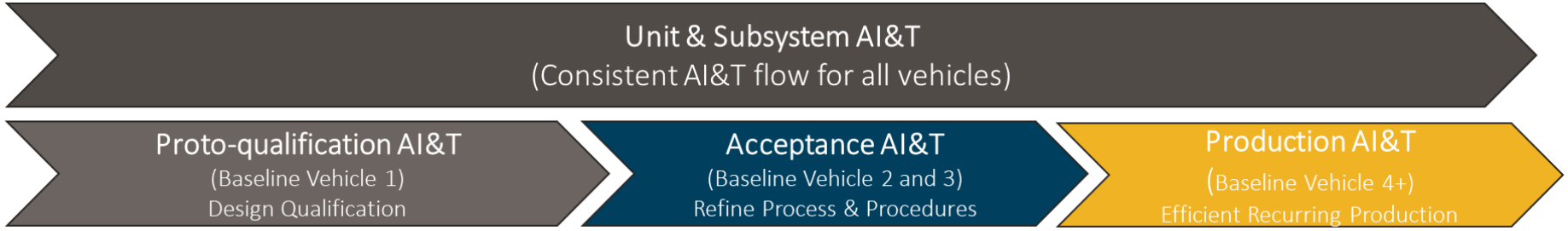
- 6 Cells
  - Structure Build Cell
  - Component Build Cell
  - Harness Cell – Electrical #1
  - Test Cell (2x) – Electrical #2
  - Bus Closeout Cell
- Bus on mobile work-stand that rolls from cell to cell
- Areas dedicated to incoming inspections, storage, cleaning, and queues
- Scalable as demand increases

Production cells allow for expansion of the production line



Testing

- Systematic refinement reduces testing to critical workmanship levels for production
- Minimal human interaction primarily automated processes where possible
- Bus functional for baseline performance
- Tailored workmanship verification
- Expect minimal redlines and anomalies
- CCB opportunities to improve efficiency on future builds



Increased repeatability and process refinement enables increased automation and testing reduction

Conclusion

- Summit EPDS key features include
  - Up to 850 watts orbit average power
  - Total system supports peak power (bus + payload) up to 2520W for ≤10s
  - Summit standard analysis coupled with program specific analysis characterize mission performance
- Standardized bus design minimizes mission unique NRE with an understood supplier management and production RE cost basis
- Program specific NRE understood and bounded, allowing broad range of missions from a common platform
- Production line approach scales for demand increases
- AI&T approach is repeatable and automated

Summit EPDS is well positioned to meet a wide range of customer and mission needs