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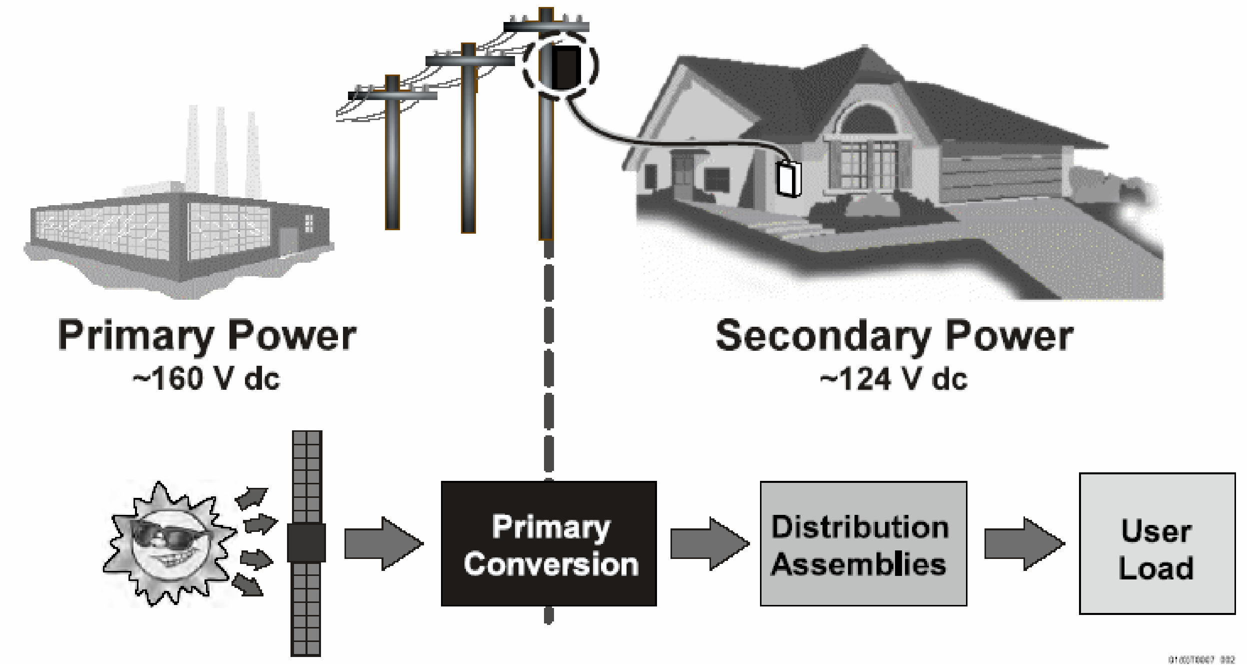
International Space Station Electric Power System (EPS):



Analogy between municipal utility and the station's EPS

The International Space Station (ISS) electrical power system consists of power generation, energy storage, power management, and distribution (PMAD) equipment. Electricity is generated in a system of solar arrays. Besides the solar arrays on the Russian element, the station currently has two photovoltaic modules on orbit, with two more scheduled to be delivered.

The Electric Power System (EPS) provides all user loads and housekeeping electrical power and is capable of expansion as the station is assembled and grows. Eight independent power channels for high overall reliability supply the electric power.

A photovoltaic (PV) electric power generation subsystem was selected for the space station. A PV system has solar arrays for power generation and chemical energy storage (Nickel-hydrogen) batteries to store excess solar array energy during periods of sunlight and provide power during periods when the station is in Earth's shadow (eclipse). The station orbits the earth every 90 minutes and for about 35 minutes, the station must run on batteries while the station is in eclipse.

Flexible, deployable solar array wings that are covered with solar cells provide power for the ISS. Each PV module contains two wings and each wing consists of two blanket assemblies. The solar array wings are tightly folded inside a blanket for launch and they are deployed when on orbit and supported by an extendable mast.

Nominal electrical output of each power channel is about 11 kilowatts (kW), or 20.9 kW per PV module. Four PV modules will supply approximately 83.6 kW.

The primary purpose of the Energy Storage Subsystem (ESS) is to provide electrical power during periods when power from the solar arrays is not enough to support channel loads. The ESS stores energy during periods when solar arrays can generate more power than necessary to support loads. The ESS consists of three nickel-hydrogen (Ni-H2) batteries per power channel and each battery consists of two battery Orbital Replacement Units (ORUs). A battery charge/discharge unit (BCDU) controls the charge and discharge of each battery. The Ni/H2 battery design was chosen because of its high energy density (lightweight) and proven heritage in space applications since the late 1970's to early 1980’s.

The entire EPS may be divided into two power subsystems. The primary power subsystem operates at a voltage range of 137 to 173 volts direct current (Vdc) and consists of power generation, storage and primary power distribution. The secondary power subsystem operates at a voltage range of 123 to 126 Vdc and is used to supply power to user loads. Direct Current-to-Direct Current Converter Units (DDCUs) are used to convert primary power to secondary power.

The U.S. power system is also integrated with Russian power sources, so that power from the American power bus can be transferred to the Russian power bus and vice versa. The Russian power system operates at a nominal voltage of 28 Vdc. American to Russian Converter Units (ARCUs) and Russian to American Converter Units (RACUs) are used to convert power from the American secondary power bus to the Russian power bus and vice versa.

Solar Power

The most powerful solar arrays ever to orbit Earth capture solar energy to convert it into electric power for the ISS.

Eight solar array wings supply power at an unprecedented voltage level of 137 to 173 Vdc that is converted to a nominal 124 Vdc to operate equipment on the ISS. The Space Shuttle and most other spacecraft operate at nominal 28 Vdc, as does the Russian ISS segment.

The higher voltage meets the higher overall ISS power requirements while permitting use of lighter-weight power lines. The higher voltage reduces ohmic power losses through the wires. Some eight miles of wire distribute power throughout the station.

Each PV module contains two solar array wings. Each solar array wing is 110-foot. long by 38-foot wide. Each solar array wing consists of two array blankets that are covered with solar cells. The blankets can be extended or retracted by a telescopic mast which is located between the two blankets. Each solar array wing is connected to the ISS's 310-foot long truss and extend outward at right angles to it (P4 and P6 are currently on orbit). There are 400 solar cells connected in series, called a string, to generate electricity at high primary voltage levels and 82 strings are connected in parallel to generate adequate power to meet the power requirement for each power channel. There are a total of 32,800 cells per power channel or 65,600 solar cells on each PV module.

A solar cell assembly is about three inches square. The cells are made of silicon and have a nominal 14.5 percent efficiency for sunlight-to-electricity conversion. Cells are welded on to a flexible printed circuit laminate that connects cells electrically. The sun-facing surface of the cell is protected by a thin cover glass. Each group of eight cells, connected in series, is protected by a bypass diode, to minimize performance impact of fractured or open cells on a string. Solar arrays are designed for an operating life of 15 years.

Two mutually perpendicular axes of rotation are used to point solar arrays towards the Sun. Each solar array wing is connected to one Beta Gimbal Assembly (BGA), located on each PV module that is used to rotate that solar array wing. Another rotary joint, called Solar Alpha Rotary Joint (SARJ), is mounted on the truss and rotates the four solar array wings together. At assembly complete, there will be eight BGAs and two SARJs. These rotary joints are computer controlled and ensure full sun-tracking capability as the ISS goes around the earth under a wide range of orbits and ISS orientations.

Electric Power System Overview

Like a city's central power plant, the PV modules generate primary power at voltage levels too high for consumer use, ranging from 137-to-173 Vdc. The primary power is routed to BCDUs for charging batteries and to switching units that route it to local distribution networks..

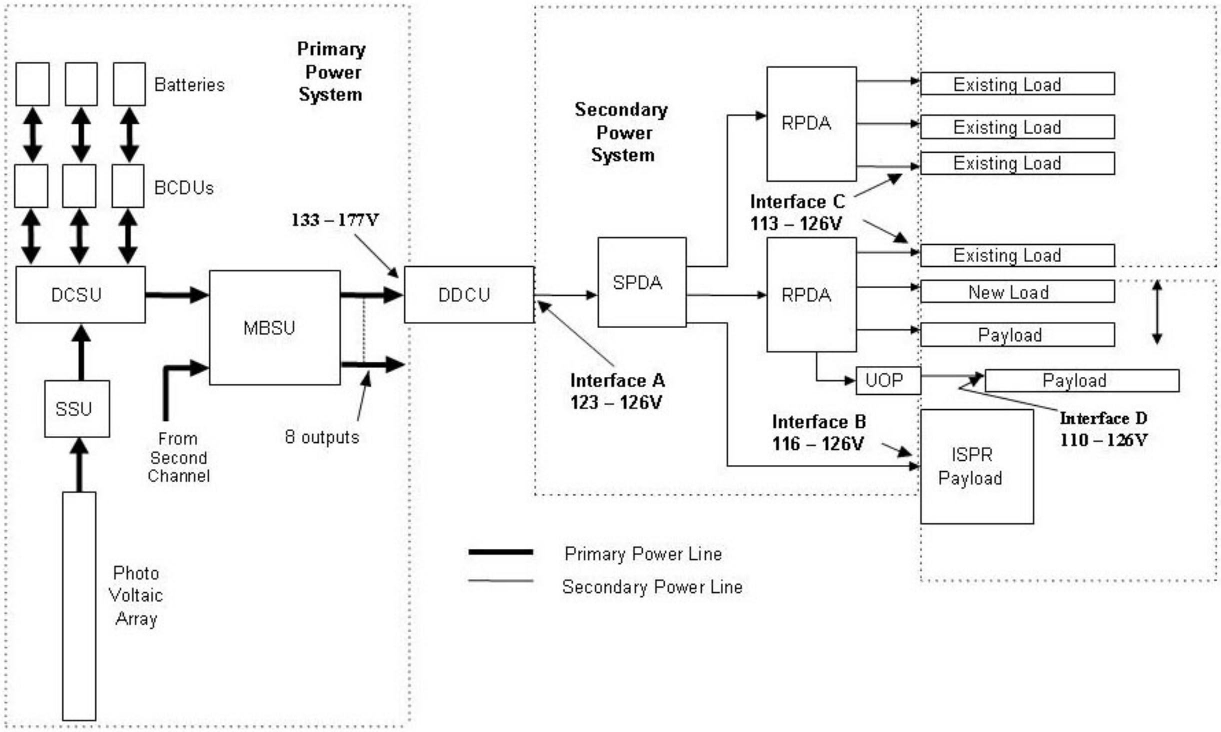
The DC-DC Converter Units, DDCUs, "step-down" the primary power to a more tightly regulated secondary power voltage, nominally 124.5 Vdc that is regulated plus or minus 1.5 Vdc and distribute it to ISS loads. On Main Street, USA, the users would be shops and homes. On the ISS, they are laboratories, living quarters and the like.

Even though the Station spends about one-third of every orbit in Earth's shadow, the electrical power system continuously provides usable power (about 84 kW at assembly complete) to ISS systems and users. When the ISS is in eclipse, the batteries, that stored energy from solar arrays during the sunlit portion of the orbit, supply power.

The power system is cooled by a thermal system through which excess heat is removed by liquid ammonia coolant in tubes that ultimately loop through radiator panels that radiate the heat to space.

Russia's segment of the ISS provides its own power sources, supplying 28-volt-dc to the Russian modules. Power is shared between the two segments when required to support assembly and operations for all ISS partners. Russian-to-American Converter Units (RACUs) and American-to-Russian Converter Units (ARCUs) step-up and step-down converters, respectively, deal with the difference between U.S. and Russian bus voltage levels. As ISS assembly continues, Russian solar arrays (a 72-foot pair on Control Module Zarya and a 97-foot pair on the Russian Service Module) will receive more shadow and that will diminish their power generation capability.

The overall design and architecture of the ISS EPS was managed by NASA's Glenn Research Center in the early 1990's. Boeing's Rocketdyne Propulsion and Power division (now Pratt & Whitney RPP) built most of the hardware for the electrical power system. Lockheed Martin built the solar arrays and the Solar Alpha Rotary Joint for Rocketdyne. Boeing, along with Pratt & Whitney RPP, as a subcontractor, continues to provide EPS sustaining engineering to NASA. Most EPS components and cargo assemblies undergo final acceptance testing at Kennedy Space Center before flight to ISS.



Electrical Power Distribution Overview

EPS Block Diagram Overview

This block diagram gives an overview of how the station electrical system functions at assembly complete. The Solar Array Wing (SAW) can generate power at a wide range of voltage, however, the Sequential Shunt Units (SSU), located close to the SAW in the Integrated

Equipment Assembly (IEA), regulate the voltage that comes out of the solar arrays at an established setpoint of about 160 Vdc. When a solar array can produce sufficient power, then the surplus power is routed to the Battery Charge/Discharge Units (BCDU), which charge the batteries. When a solar array cannot produce sufficient power to satisfy ISS loads then the bus voltage starts to drop below the SSU setpoint, and when it drops below the BCDU setpoint, then the BCDUs start to discharge batteries to support ISS loads. The primary bus voltage varies between the SSU and BCDU voltage setpoints plus a small voltage regulation band.

The primary power is provided to the Main Bus Switching Units (MBSU) for subsequent distribution to ISS electrical loads. Four MBSUs are located on the S0 truss that is fed by eight independent power channels and the MBSU outputs supply all ISS loads. Under normal operations, each power channel supplies power to a specific set of loads. However, if that channel fails, the MBSU enables feeding power to those loads from another channel. This greatly enhances the failure tolerance of the EPS.

All EPS operations are computer controlled and controls can be exercised by the on-orbit crew or by operators on ground. Operators on the ground to free up crew time for more important on-orbit operations perform most of these functions. All control setpoints are stored on on-orbit computers and can be changed when needed.

The MBSUs route power to the DC-to-DC Converter Units (DDCUs). The DDCUs convert primary power to secondary power at 123 to 126 Vdc. Several DDCUs are located inside pressurized compartments, such as US Lab, while several are located externally on trusses. DDCUs supply regulated secondary power to Remote Power Controller Modules (RPCMs). RPCMs are boxes with multiple switches with several different load ratings to route power to user loads. The RPCMs provide remote switching of loads and over-current protection. An RPCM can also feed other RPCMs and can feed Russian power converters, outlet panels, etc. There will be thousands of individual switches in approximately 184 RPCMs on the station at assembly complete. There are about 119 RPCMs on the station currently.

The European and Japanese laboratory modules have their own internal power distribution system. Those modules will draw power from DDCUs, from Node 2. Their unique transformers and power control modules equivalent to U.S. RPCMs will handle power. NASA and Boeing have responsibility for distributing power to those elements, but the individual international partners will be responsible for power within their respective elements.

Primary Power Distribution Overview

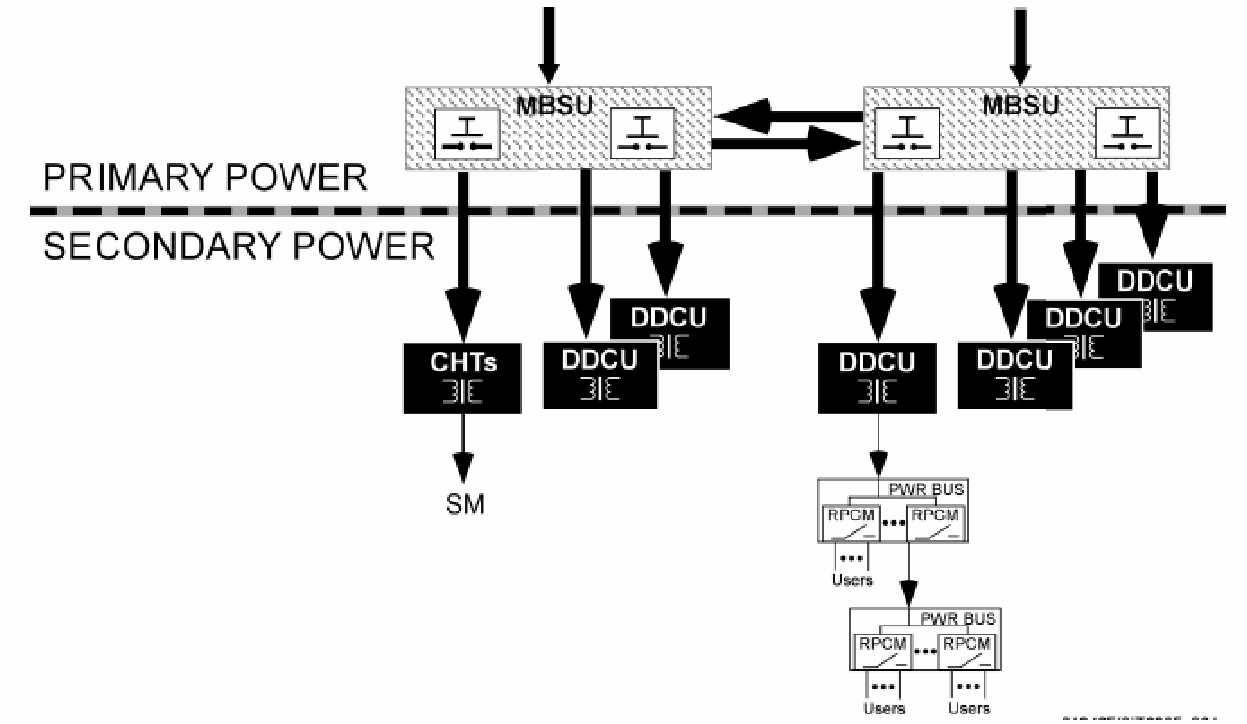
Primary Power Distribution provides a commandable interface between generated or stored power to loads that are located down stream. Power distribution within a power channel is performed by a DC Switching Unit (DCSU) and the power distribution to loads is performed by the MBSU. At ISS assembly complete, there will be eight DCSUs and four MBSUs involved in primary power distribution. The DCSUs and MBSUs use a network of high power switches called Remote Bus Isolators (RBIs) to direct the power flow. The RBIs do not physically control the direction of the current flowing through them but they do provide a means of isolating a current path in the event of a malfunction or if a repair is needed on the primary power system. The RBIs in both the DCSU and MBSU are fully commandable by on-board computers.

Each power channel contains one DCSU to perform power distribution on the Integrated Equipment Assembly (IEA). During insolation, the DCSU routes power from the arrays to an MBSU distribution bus, as well as to the BCDUs for battery charging. During eclipse, the DCSU routes battery power to the same MBSU distribution bus to satisfy power demands, and it also sends a small amount of power back to the SSU to keep the SSU firmware functioning in preparation for the next insolation cycle. In addition to primary power distribution, the DCSU has the additional responsibilities of routing secondary power to components on the PV modules (i.e., the Electronics Control Unit and other support components). This secondary power is provided by the DDCU located on the IEA. The DDCU receives primary power from the DCSU, converts it into secondary power, and sends it to Remote Power Controller Modules (RPCMs) for distribution. The PV module RPCMs are housed within the DCSU.

The MBSUs act as the distribution hub for the EPS system. The four MBSUs onboard the ISS are all located on the Starboard Zero (S0) truss. Each of MBSU receives primary power from two power channels and distributes it downstream to the DDCUs and other users including Service Module (SM) American to Russian Converter Units (ARCUs). In addition, the MBSUs can be used to crosstie power channels (i.e., feed one power channel loads with a different power channel source) to assist in failure recovery and assembly tasks.

The BGAs and SARJs on the ISS also play a role in primary power distribution. The BGA provides for the transmission of primary power from the solar array wings to the IEA and the SARJ provides for transmission of primary power from the DCSUs to the MBSUs. The BGAs and SARJs incorporate a roll-ring design to provide conduits for power (and data), while allowing a continuous 360° rotation.

Secondary Power Distribution



The workhorse of the secondary power distribution system is the RPCM, an Orbital Replacement Unit (ORU), which contains solid-state or electromechanical switches, known as Remote Power Controllers (RPCs). RPCs can be remotely commanded, by on-board computers, to control the flow of power through the distribution network and to the users. There are different types of RPCMs, containing varying numbers of RPCs and varying power ratings. As shown above, secondary power flows from a DDCU and is then distributed through a network of ORUs called Secondary Power Distribution Assemblies (SPDA) or Remote Power Distribution Assemblies (RPDA). Essentially, SPDAs and RPDAs are housings that contain one or more RPCMs. The only distinction between SPDAs and RPDAs is the location downstream of a DDCU. RPDAs are always fed from other RPCMs inside SPDAs. Note that RPCMs have only one power input; thus, if power is lost at any level of the Secondary Power System, all downstream user loads will be without power.

There is no redundancy in the Secondary Power System; rather, redundancy is a function of the user’s loads. For example, a critical user load may be able to select between two input power sources that use different power channels and thus different secondary power paths.

As with DDCUs, SPDAs and RPDAs may be located inside pressurized compartments or outside. Depending on their specific location, SPDAs or RPDAs may interface with the Lab Internal Thermal Control System (ITCS) or use heat pipes to dissipate heat. RPCMs are also located within the DCSU on the IEAs to provide secondary power-to-power channel components, as required.

Redundancy

Each of the power channels is preconfigured to supply power for particular ISS loads; however, to provide a backup source of power for critical equipment, the assembly complete design provides for rerouting (i.e., cross-tying) primary power between various power channels, as necessary. At assembly complete, the ISS will have four PV modules containing eight power channels with full cross-strapping capability. However, it is important to note that only primary power can be cross-strapped. Once power is converted into secondary power, power flow through the distribution network cannot be rerouted.

As a result, if there is a failure within the Secondary Power System, there is no redundancy, and the entire downstream path from the failure is unpowered. Instead, user loads generally determine redundancy. There are three types of user redundancy schemes as listed below:

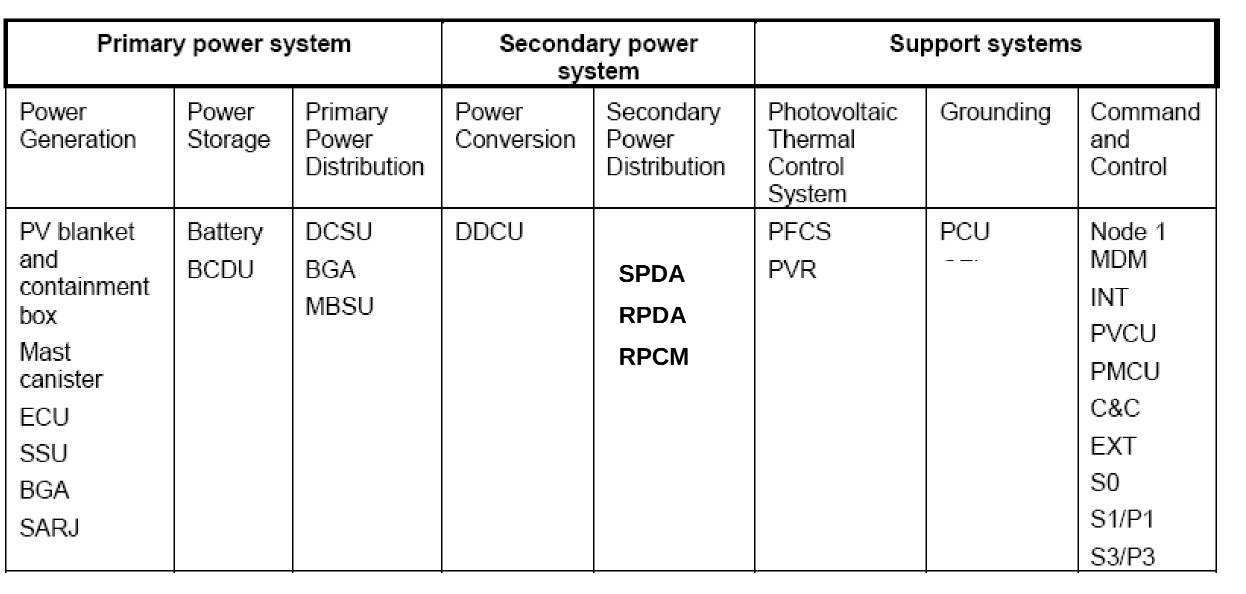
- Components may be wired with multiple power input sources, providing the capability of swapping among them.
- Two or more components that perform the same function can be fed by different power sources; thus, the responsibilities of one component can be assumed by another.
- Multiple components can work together to perform a function; with the loss of a single component, operational capabilities are degraded not lost.
- Set of available jumpers that can be used to temporarily regain power to a load until the secondary system can be fixed.

System Protection

The EPS is designed to protect equipment from power surges and overheating at several points along the power path from the source to the users. Current, voltage, and temperature sensors are located in nearly all the EPS equipment (ORUs) and are monitored by firmware located on the hardware or on-board computers, or both. If a voltage, current, or temperature is out of range, an appropriate safing action will be initiated either by the firmware or by computer software. The safing action is designed to limit the amount of time that the box is exposed to high power or high temperature. In case of power surges, it is also designed to limit the impact of that surge on other equipment along the power path.

The system protection function includes the architecture’s ability to detect that a fault condition has occurred, confine the fault to prevent damaging connecting components, and execute an appropriate recovery process to restore functionality, if possible. This process is usually referred to as Fault Detection, Isolation, and Recovery (FDIR). For example, upon detection of a fault, components can be isolated, thereby preventing propagation of faults. In response to overcurrent conditions, the architecture is designed such that each downstream circuit protection device is set to a lower current rating and responds more quickly than the protection device directly upstream. This ensures that electrical faults or shorts in the system do not propagate toward the power source. Another function of the architecture’s system protection shuts down the production of power when array output voltage drops below a specified lower-limit threshold. This prevents the PV cells from continuing to feed a downstream fault. In summary, all the various implementations of system protection work together to isolate faults or shorts at the lowest level. This approach minimizes impacts to the users of the EPS and protects the EPS from damage by low-level faults.

Key EPS Components



Primary power system			Secondary power system		Support systems		
Power Generation	Power Storage	Primary Power Distribution	Power Conversion	Secondary Power Distribution	Photovoltaic Thermal Control System	Grounding	Command and Control
PV blanket and containment box Mast canister ECU SSU BGA SARJ	Battery BCDU	DCSU BGA MBSU	DDCU	**SPDA** **RPDA** **RPCM**	PFCS PVR	PCU	Node 1 MDM INT PVCU PMCU C&C EXT S0 S1/P1 S3/P3

Solar Array Wing (SAW)

The principle function of the SAW is to produce electrical power from solar energy. The SAW contains 32,800 solar cells, 16,400 per blanket, which can produce approximately 31 kilowatts (kW) of electrical power at Beginning of Life (BOL), and about 26 kW after 15 years, at their designed End of Life (EOL). However, it is important to note that power availability is influenced by ISS attitude, operational mode (e.g., proximity operations), Sun alpha and beta angle, shadowing, etc.

Beta Gimbal Assembly (BGA)

The function of the BGA is to provide minor array pointing correction along the Beta Angle. The beta angle is the angle between the orbit plane and the solar direction (changes ~±4°/day)) to compensate for apparent solar motion induced by seasonal variations. There is one BGA associated with each SAW. The BGA provides one axis of rotation for a solar array wing. The BGA is capable of a full 360 degrees of rotation or may be commanded to a specific location via computer command. Electric power generated by the solar array wing is transferred through the BGA over the entire range of BGA axis rotation. The transfer of power is accomplished by a rotary coupling, the roll ring subassembly, which is mounted coaxially with the axis bearing and torque motor.

The BGA may be commanded to the following modes of operation:

- Angle Command Mode. BGA axis of rotation aligned to a commanded angle position.

- Latch Mode. The BGA axix of rotation is locked at specified location and prevented from further rotation.
- Manual Operating Mode. All non-essential functions are disabled and the drive motor is disabled. BGA axis may be rotated by manual action from the IEA side.
- Rate Mode. BGA may be commanded to rotate at a specified rate.

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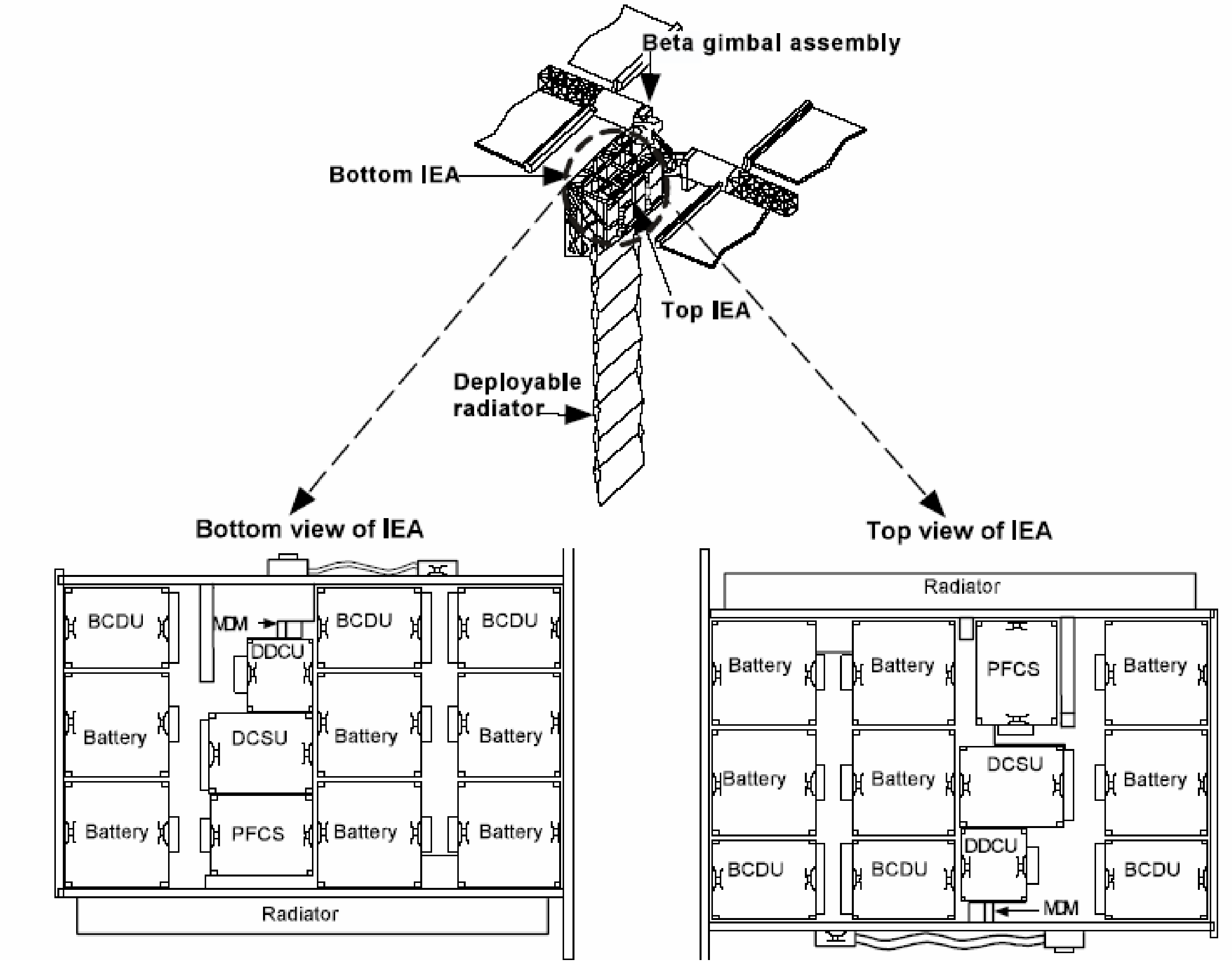
Electronics Control Unit (ECU)

The ECU is located on the BGA. It is the command and control link for the solar array wing and BGA. The ECU provides power and control for extension and retraction of the solar array mast, latching and unlatching of the blanket boxes, BGA rotation, and BGA latching.

Solar Alpha Rotary Joint

The purpose of the SARJ is to rotate the PVMs to provide alpha angle array pointing capability. The port SARJ and starboard SARJ are located at the outboard end of the P3 and S3 truss segments and provide 360° continuous rotational capability to the segments outboard of P3 and S3. The SARJ will normally complete one complete 360-degree revolution per orbit. The SARJ transfer electrical power through a set of roll rings, which provide a continuous rolling electrical connection while rotating.

Integrated Equipment Assembly (IEA)



Each IEA, located on P4, S4, P6 and S6, has many components: 12 Battery Subassembly orbital replacement units (ORUs), six Battery Charge/Discharge Units (BCDU) ORUs, two Direct Current Switching Units (DCSUs), two Direct Current-to-Direct Current Converter Units (DDCUs), two Photovoltaic Controller Units (PVCUs), and integrates the Thermal Control Subsystem which consists of one Photovoltaic Radiator (PVR) ORU and two Pump Flow Control Subassembly (PFCS) ORUs used to transfer and dissipate heat generated by the IEA ORU boxes. In addition, the IEA provides accommodation for ammonia servicing of the outboard PV modules as well as pass through of power, data to and from the outboard truss elements. The structural transition between the P3 and P4 (and S3 and S4 when launched next year) segments is provided by the Alpha Joint Interface Structure.

The IEA measures 16 feet (4.9 meters) by 16 feet (4.9 meters) by 16 feet ((4.9 meters), weighs nearly 17,000 pounds a (7,711.1 kilograms) and is designed to condition and store the electrical power collected by the photovoltaic arrays for use on board the Station.

The IEA integrates the energy storage subsystem, the electrical distribution equipment, the thermal control system, and structural framework. The IEA consists of three major elements:

1. The power system electronics consisting of the DCSU used for primary power distribution; the DDCU used to produce regulated secondary power; the BCDU used to control the charging and discharging of the storage batteries; and the batteries used to store power.

2. The Photovoltaic Thermal Control System (PVTCS) consisting of: the coldplate subassembly used to transfer heat from an electronic box to the coolant; the Pump Flow Control Subassembly (PFCS) used to pump and control the flow of ammonia coolant; and the Photovoltaic Radiator (PVR) used to dissipate the heat into deep space.

3. The computers used to control the P4 module ORUs consist of two Photovoltaic Controller Unit (PVCU) Multiplexer/Demultiplexers (MDMs).

The IEA power system is divided into two independent and identical channels. Each channel is capable of control (fine regulation), storage and distribution of power to the ISS. The two power modules are attached outboard of the AJIS.

Sequential Shut unit (SSU)

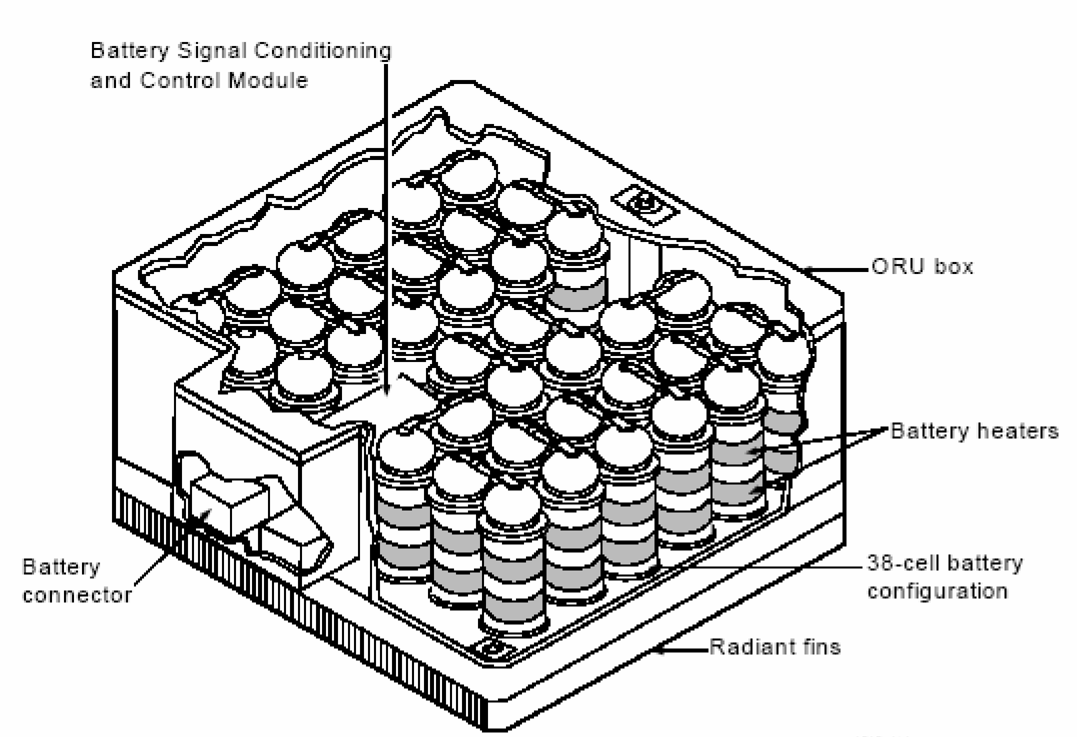
The SSU is the primary power regulation device that controls SAW output. By design, the SSU provides a consistent source of power (typically ~160 V-dc), based upon a programmable setpoint. Regulation of the array output voltage is required because array output current, when illuminated with sunlight, is often greater than the ISS demands. To accomplish this, the SSU receives power directly from the PV array and maintains output voltage to a setpoint, by shunting and un-shunting solar array strings. Each string can be individually connected or disconnected from the primary bus and the power output from the SSU is the sum of all connected strings at any time. When the SSU power output exceeds the power demand, then the bus voltage starts to rise and that triggers SSU to shunt strings to reduce SSU power output, and vice versa.


Sequential Shunt Unit (SSU)

The voltage setpoint is provided to the SSU by the on-board computer. The setpoint is designed to maximize array power capability (maximum power point) while ensuring control stability. As solar arrays age, the voltage setpoint is adjusted to ensure optimum performance.

There will be eight SSU’s on orbit when the station assembly is complete (two each per IEA, four IEAs when assembly complete). The SSU is located on the beta gimbal platform, at the bottom of the mast canister.

Battery Subassembly Orbital Replacement Unit

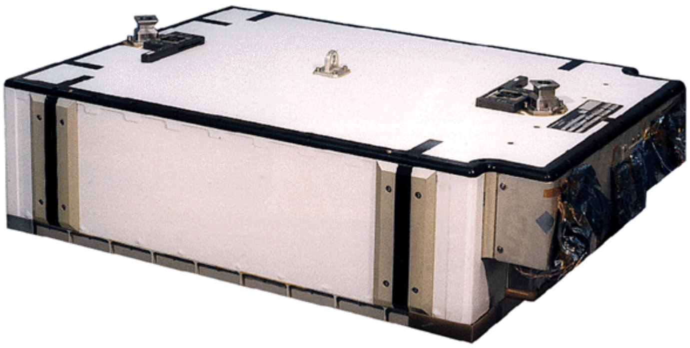


The battery subassembly consists of 38 lightweight nickel hydrogen cells and associated electrical and mechanical equipment, packaged in an ORU enclosure. When the sun is behind the Earth, all of the power is provided off the batteries, providing about a third of the station's power daily. The battery interfaces with a Battery Charge/Discharge Unit (BCDU), which provides charge and discharge control of electric energy. During isolation, solar electric energy, regulated by the SSU, will replenish energy stores in preparation for the next eclipse cycle. Two battery ORUs makes a battery set. There will be 24 battery sets on ISS at assembly complete.

The batteries have a design life of about seven years, but the actual life obtained on orbit is a function of how deeply the battery is discharged and the number of charge-discharge cycles (nominally 16 cycles per day).

The battery ORUs can be changed out robotically using a special purpose manipulator on the end of the station's robotic arm. Each battery measures 41 inches (104.1 cm) by 37 inches (94 cm) by 19 inches (48.3 cm) and weighs 372 pounds (168.7 kilograms).

Battery Charge/Discharge Unit (BCDU)

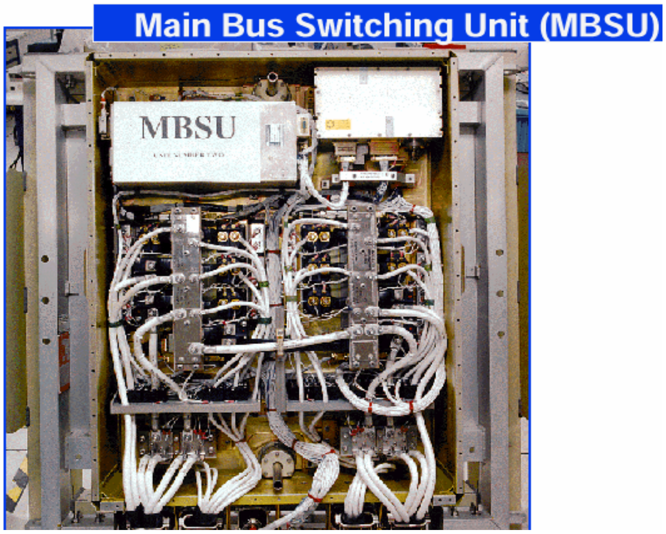


The BCDU serves a dual function of charging the batteries during isolation and providing conditioned battery power to the primary power busses during eclipse.

The Control Power Remote Bus Isolator (CPRBI) controls the flow of power to the DC control power output bus and also functions as a circuit breaker, limiting the load current during faults. The Fault Isolator (FI) limits the battery discharge current, in the event of a fault, to 85 to 127 amps. The BCDU also includes provisions for battery status monitoring and protection from power circuit faults.

Each BCDU measures 28 inches (71.1 cm) by 40 inches (101.6 cm) by 12 inches (30.5 cm) and weights 235 pounds (106.6 kilograms). The BCDU has an 8.4 kW battery charge capability with a 6.6 kW discharge capability. It provides 70 to 120 volts-dc control power output and can regulate power between 130 to 180 volts-dc. The power storage system consists of a BCDU and two Battery Subassembly ORUs.

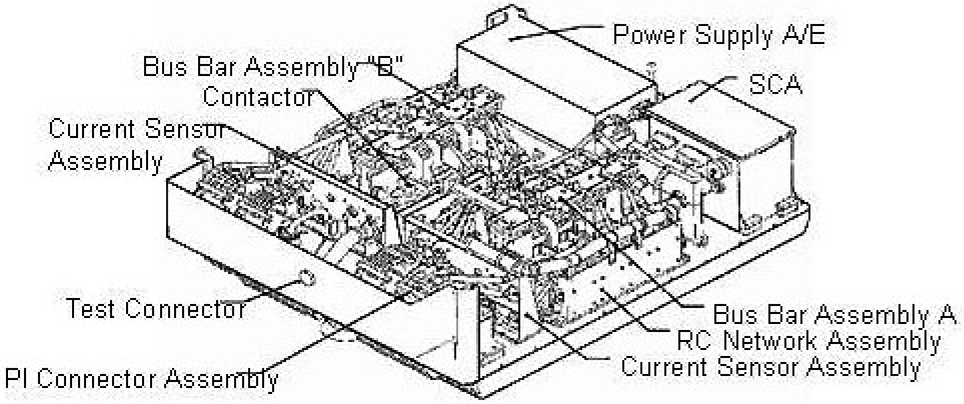
Main Bus Switching Unit (MBSU)



Located on the S0 truss,the four MBSUs distribute primary power from the power channels, downstream to the DDCUs, and other loads. They also provide the capability to cross tie Primary Power Channels to feed those DDCU loads in the event of a Primary Power Failure.

Command, communication, health monitoring, and RBI drive functions are provided by the Switchgear Controller Assembly (SCA). The MBSUs have a design life of approximately fifteen years. There is a spare MBSU located on orbit.

The system's design can accommodate the loss of PV modules and other problems by remotely accessing the MBSUs, by either the ground or on station, and internally redirecting power to by-pass faults or failures in the EPS. The four MBSUs themselves are not redundant. All MBSUs are required to power all station loads. However, MBSUs provide redundancy for power modules upstream. The MBSU output voltage range is from 133 to 177 V-dc.



The MBSU will be first used during STS-116/Assembly Mission 12A.1. All four MBSUs are activated during this mission. Each MBSU box is 28 inches by 40 inches by 12 inches and weighs 220 pounds.

DC Switching Unit (DCSU)

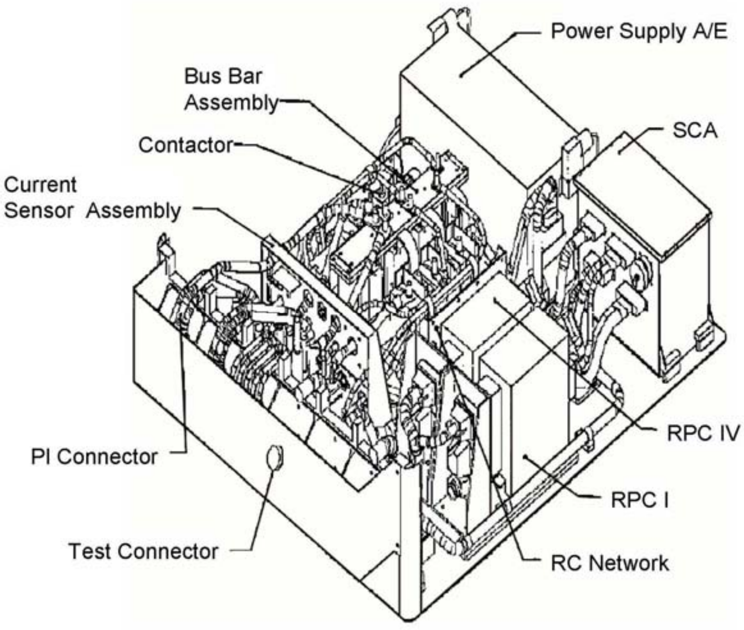
The DCSU is the electrical distribution box for a primary power channel. It provides fault protection for the many EPS ORUs, and numerous EPS support functions. The DCSUs primary function is to route power between the solar arrays, batteries, and downstream MBSUs and DDCUs.

The DCSU is used for power distribution, protection and fault isolation within the Integrated Equipment Assembly. The DCSU uses remote-controlled relays (RBIs) identical to those on the MBSU to route primary power to the BCDUs, MBSUs and DDCU. The DCSU also routes secondary power (124 V-dc plus or minus 1.5 V-dc) through solid state switches to the ECU, SSU, and PFCS ORUs.

There will be a total of eight DCSUs on the ISS once S5/S6 is delivered in June 2008. To date, DCSUs have performed very well, with no failures. They have a design life of 15 years. Each DCSU box is 28 inches by 40 inches by 12 inches and weighs 238 pounds.

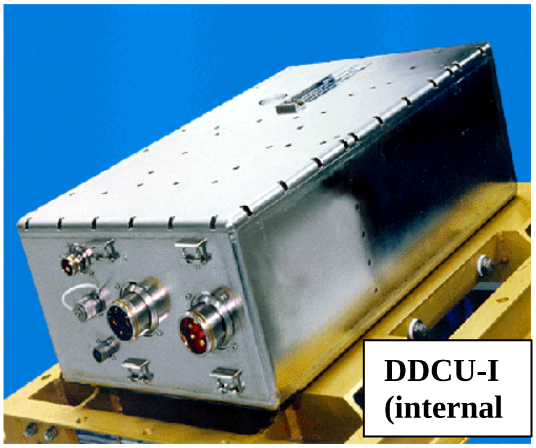
Direct Current-to-Direct Current Converter Unit (DDCU)

The secondary power conversion function uses one type of ORU, the DDCU. The DDCU provides electrical isolation between the primary and secondary EPS. As the name implies, the DDCU is responsible for dc power conversion, in this case primary power into secondary power, using a transformer. Each DDCU has one primary power input and one secondary power output. The DDCU converts the coarsely regulated primary power (115 V-dc to 173 V-dc) to a voltage-regulated secondary power (124.5 V-dc nominal plus or minus 1.5 V-dc). The primary power on the ISS is like the main transmission lines in a city with the DDCU serving like a transformer on a utility pole that converts the power so it can be used in your home. The primary power voltage is typically 160 V-dc; however, voltage can vary over a wide range although the output is specified to be 124 V-dc, which is the prescribed voltage for all users of the Secondary Power System. If any other voltage level is required by user loads (such as payloads or crew equipment), it is the user’s responsibility to perform the conversion from 124 V-dc to its required voltage.



DDCUs come in three versions:

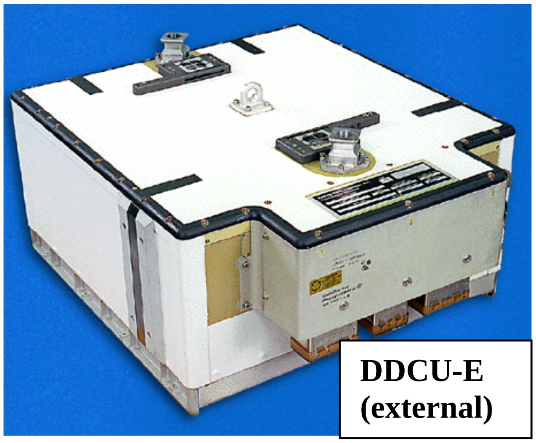
- DDCU-E (for external). These are used outside the habitable spaces on the station on the power module IEA, and Z1, S0, S1 and P1 trusses. There are four DDCU-Es on S0, and one each on S1 and P1.
- DDCU-I (for internal). These are used currently in the U.S. Laboratory and eventually in the Node 2 modules when those are delivered over the next several years. There are six DDCU-Is in the U.S. laboratory.
- DDCU-HP, The heat-pipe versions are currently located on the Zenith One (Z1) truss. There are two DDCU-HPs on Z1.



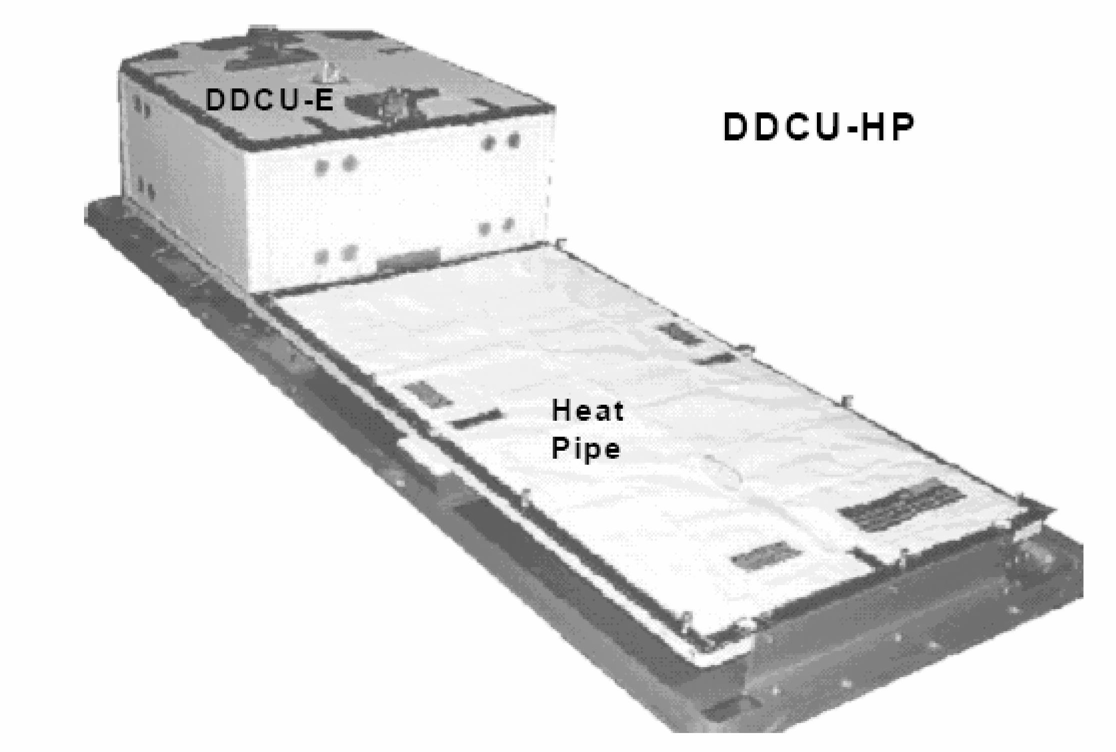
DDCU-I (internal

The only difference between the three types is the nature of the cooling system that transfers internal heat build up during operation to the surrounding space environment. The DDCU-Is are affixed to cold plates that transfer the heat to a water-cooled system inside the Lab and Node modules. This heat is then transferred by heat exchangers to the external ammonia cooling system where the heat is rejected into space via the large central radiators on the external S1 and P1 trusses (which will become active during this mission). The DDCU-Es are cooled via cold plates which interface directly to the external systems. The DDCU-HP are cooled directly by the radiator heat-pipe panel on which they are mounted.

To date, DDCUs have performed very well, with no failures. They have a design life of 15 years. There are already spare DDCUs (with the exception of DDCU-HP) on orbit. Each DDCU-E is 27 inches by 23 inches by 12 inches and weighs 129 pounds. Each DDCU-I is 27 inches by 18 inches by 10 inches and weighs 112 pounds. Each DDCU-HP is 68 inches by 25 inches by 14 inches and weighs 200 pounds.



DDCU-E (external)



Remote Power Controller Module (RPCM)

RPCMs are the interface between the EPS and all non-EPS equipment onboard the ISS. The RPCM is a multi-channel, high power circuit breaker. The RPCM is the workhorse of the secondary power system. The RPCM has the following two purposes:

- To control the distribution of secondary power to downstream loads by opening or closing RPCs
- To protect the EPS against downstream faults by opening RPCs when overcurrents are sensed

Six types of RPCMs facilitate system protection, fault isolation and power flow control in the ISS Electric Power Systems. There are approximately 119 RPCMs currently located on the station and there will be a total of 184 when assembly is complete. There are multiple spare RPCM located on orbit. Several failed RPCMs have been replaced on the ISS.

RPCMs are located in the following modules: Integrated Equipment Assembly (Two each in DCSU or a total of 16), P1 (12), P3 (8), S1 (12), S3 (8), S0 (24), Z1 (4), Node 1 (12), Node 2 (18), Node 3 (27), Quest Airlock (4) and U.S. Destiny Lab (39). Each RPCM is 6.8 inches by 8 inches by 3.5 inches and weigh 10.5 pounds.

Electrical Power System (EPS) Reconfiguration:

The space station will change from its early configuration to the beginning of the final assembly complete configuration. Since the P6 module has been on top of Z1, its power has been going directly to the DDCUs in the lab and Z1. Four MBSUs have been sitting on the S0 truss, but have not been getting any input power and are not feeding anything downstream. They have been sitting on a non-operating cooling loop. A series of bypass jumper cables and reconfigurable connections were initially installed that have allowed P6 to directly feed the DDCUs from the DCSUs. The initial configuration essentially bypassed the MBSUs. During STS-116, power will flow through the MBSUs for the first time since they have been on orbit, so that the main power from the trusses comes into the MBSUs first before going to the DDCUs. Each DCSU will feed one side of an MBSU.

To complete the reconfiguration, approximately 112 Extravehicular Activity (EVA) power connectors will be removed and reattached. Hundreds of commands from mission control will be issued to power up and down various components. This mission includes the largest number of EVA power connectors ever removed in a single assembly mission.

Two EVAs will be conducted to reconfigure the main power channels or paths. The purpose of the reconfigurations is to route power through the truss MBSUs and DDCUs. There are two channel domains over which electrical power travels across the truss and station elements called the 1 and 4, and 2 and 3 power domains, which comprises the basic numbering system for the power paths or domains. The four MBSUs are numbered 1 through 4. All the hardware downstream has a similar numbering system so you know which MBSU it came from. For example, when mission controllers refer to the 2/3 domain, they are referring to all the loads that go through MBSUs 2 and 3. In understanding the station power system, anything that receives a power feed from the 2/3 domain will have a "2/3" numbering scheme. Two separate thermal cooling loops on the ISS cool the 1/4 and 2/3 hardware. Each SAW on the IEA is labeled as A or B, so that each power channel has a power domain and a solar array designation. For example, the two power channels on the P6 module are 2B and 4B, and those on the P4 module are 2A and 4A. Similarly the channels on S4 are 1A and 3A and S6 are 1B and 3B.

During the first EVA during STS-116/Assembly Mission 12A.1, the P5 truss will be installed on the outboard side of P4. On the next day, NASA will remotely retract the 4B solar array, since there is a structural interference between the P6 4B array and the P4 arrays if rotated on the Solar Alpha Rotary Joint. Solar Array 4B on P6 will be retracted into its blanket boxes and the SARJ will be commanded into a solar tracking mode. P4 is not currently powering the rest of the space station, but will be brought on line during this mission.

During the second EVA during Flight Day 6, the entire 2/3 domain will be brought down for several hours while various power connectors are rewired. The remaining 1/4 path will support all the loads on the ISS, which means there will be no redundant power for the heaters and most of the equipment and systems (communications, guidance, navigation and control, etc.) throughout the station. They will power everything back up once the 2/3 domain is configured properly, and the MBSUs are brought on line. The MBSUs were checked on earlier spacewalks in 2002. NASA has provisions in place in case an MBSU fails when reconfigured. There will be an entire day, beginning when the crew begins their sleep shift following the first EVA, in which mission controllers will begin their procedures to transfer all the station systems from 1/4 to the 2/3 domain power path. Powering the DDCUs down, many of the systems that are being powered have been fed by DDCUs in the lab up to now, but after this reconfiguration, many of the DDCUs from the trusses will come alive for the first time. Two MBSUs and three truss DDCUs will be activated. On EVA 2, there are 15 umbilicals connected via EVA, and 6 Intra-Vehicular Activity (IVA). IVA activities consist of jumpers being connected inside the Lab, Node, and Airlock by the crew to provide backup power sources during the reconfigurations. There will be about 73 mates/demates of power connectors.

Two days later, a third EVA will be conducted on Flight Day 8 to reconfigure the 1/4 domain. For EVA 3, 20 umbilicals will be connected during the EVA and 9 IVAs, with a total of 81 mates/demates. Like on the earlier EVA, everything will run off the 2/3 domain power path while various connectors are removed and mission control powers items up and down. Two MBSUs and three truss DDCUs will be activated. Like the 2/3 domain reconfiguration, there will be limited power redundancy for several hours. The astronauts will do all of the reconfigurations on the 1/4 side while everything is powered down and then once all the connections are complete, then all four MBSUs will be on line and both cooling loops will be running and all the power is brought back up. Once NASA starts powering up after each 2/3 and 1/4 reconfiguration, they will know right away if any of the 2/3 or 1/4 hardware is not working. As each item is powered back up, the electronics will conduct an internal self-checking procedure. All of this data goes into mission control. There is a considerable amount of cleanup following an EVA to get all the systems back running and in a nominal configuration. It takes the entire night and next day following each EVA to verify those systems are operating nominally.

There will also be some minor reconfigurations on the Russian side when power converters are moved over to the U.S. primary side to where they are getting a higher voltage input. It is a seamless change and there are no changes in the major configurations on how the U.S. and Russians sides share power.

NASA conducted a large number of electrical power system simulations to prepare for this mission and is confident that electrical reconfiguration will go as planned. NASA has a number of contingency procedures since this reconfiguration operation is not without risks, especially if a problem should occur with the ammonia pumps for the cooling system that will brought on line for the first time. Boeing and other industry engineers will be assisting NASA in the ISS Mission Evaluation Room, one of the primary backroom support centers to mission control, should any issues or problems arise.

Equipment Reference:

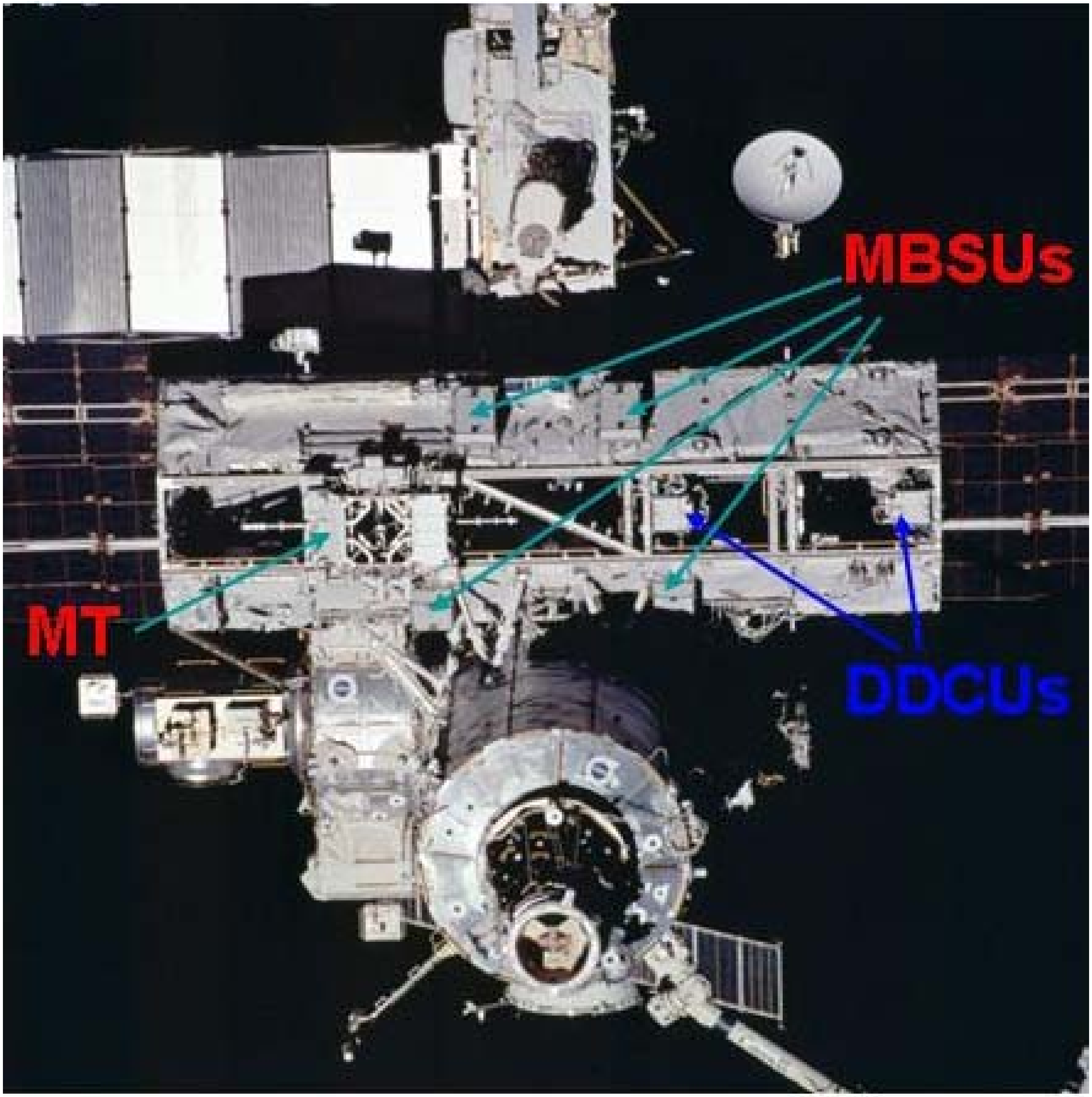


Image shows locations of the MBSUs and DDCUs on the SO truss element as part of the Electrical Power System

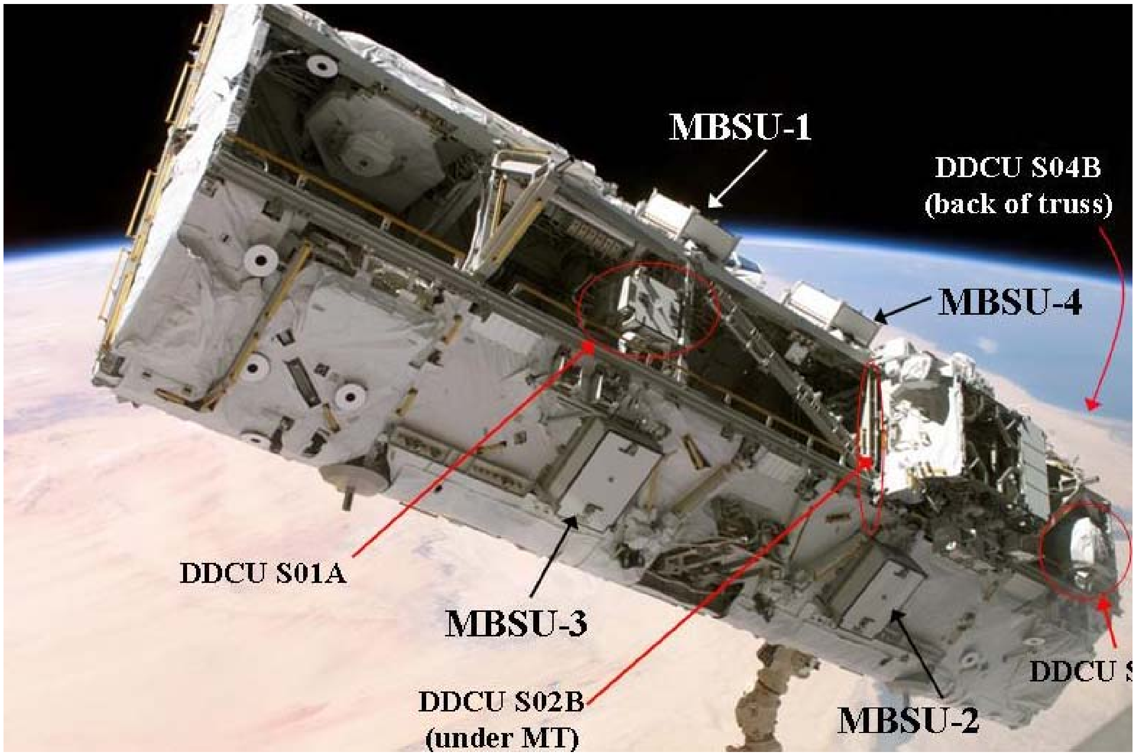
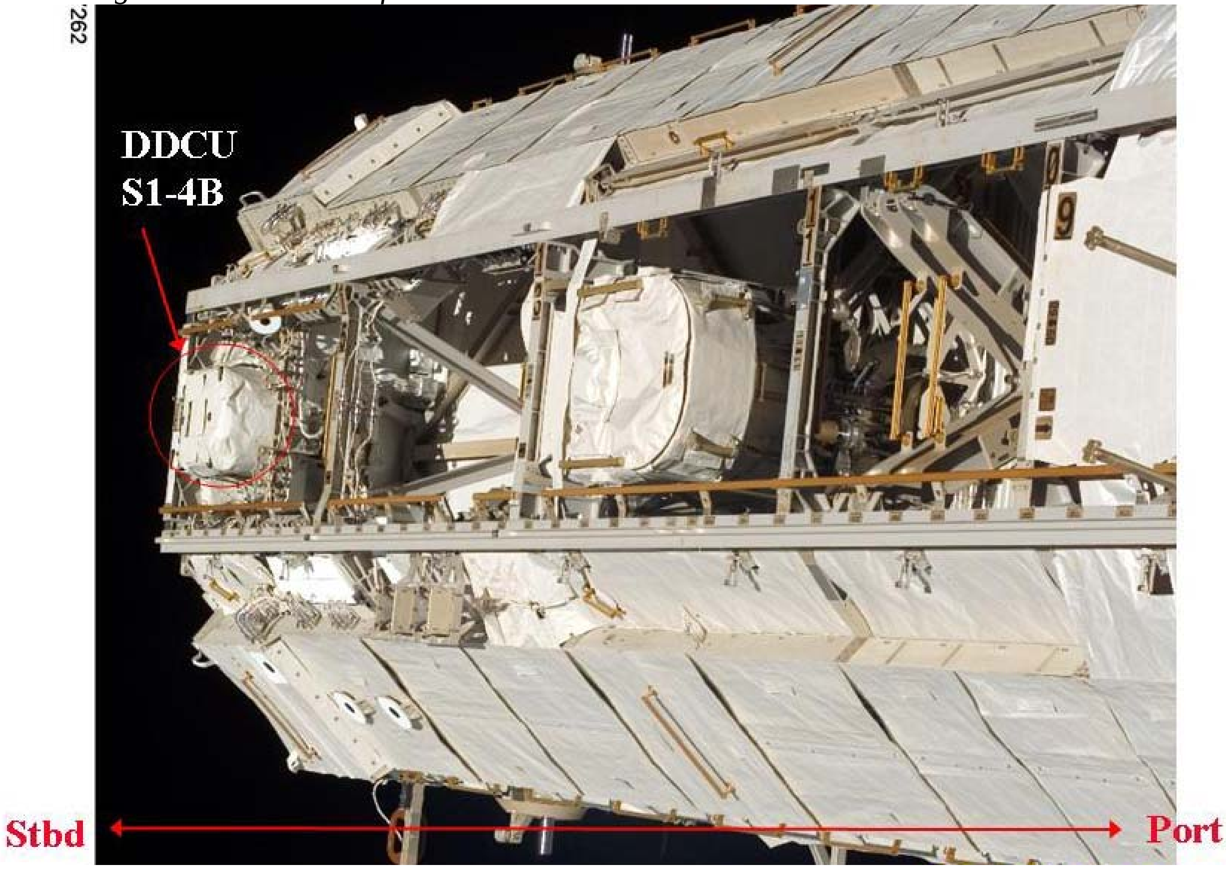
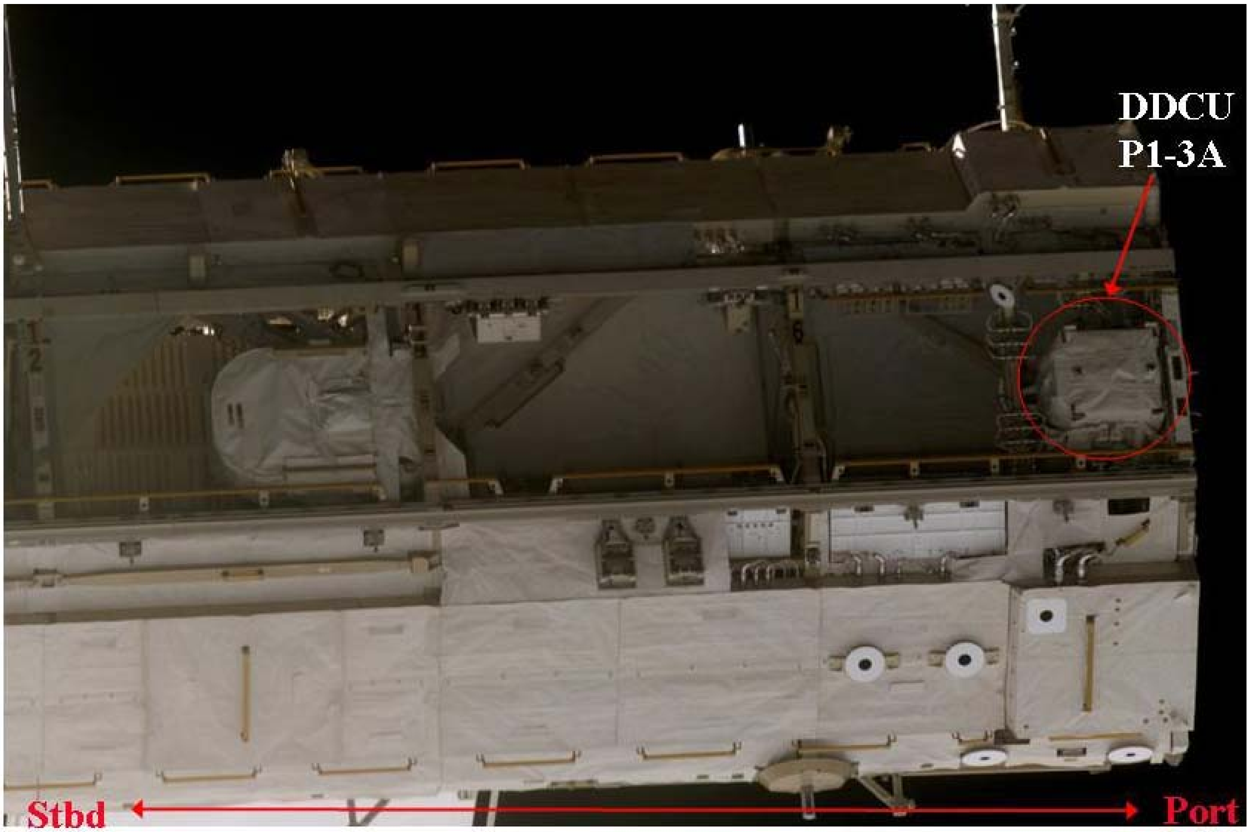


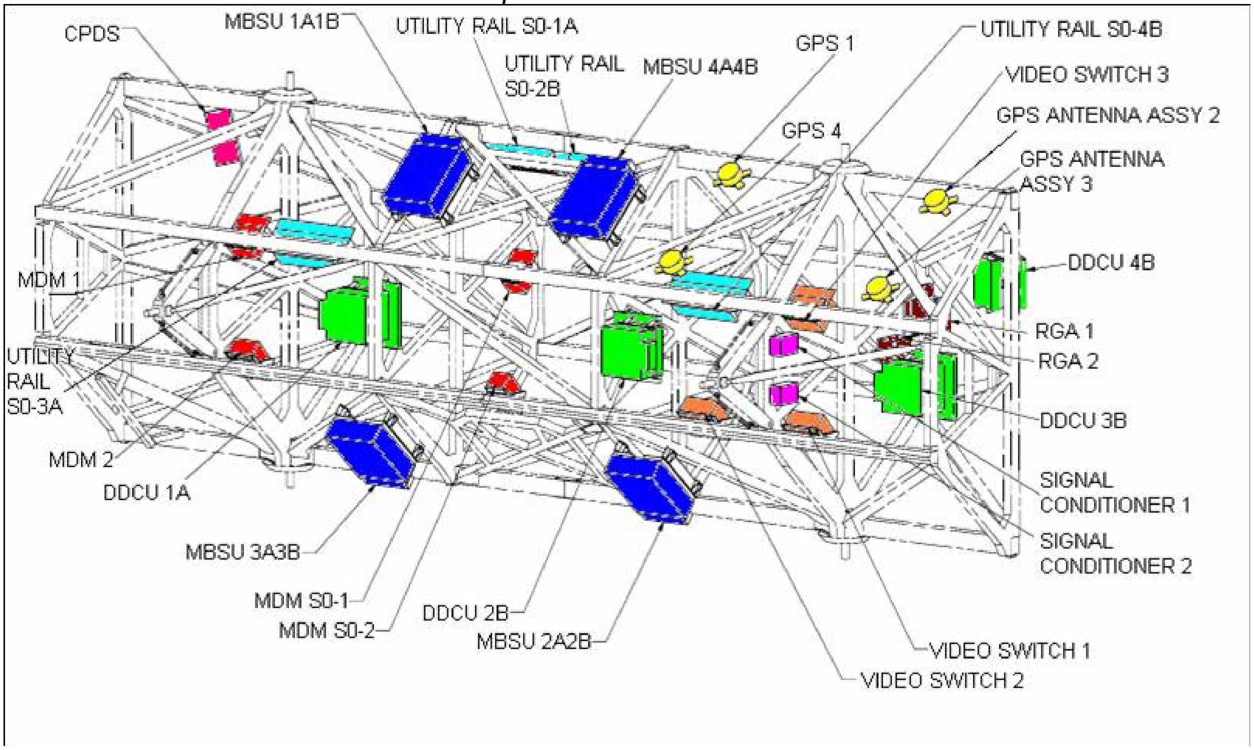
Image shows locations of DDCUs and MBSUs on the SO truss element to be activated



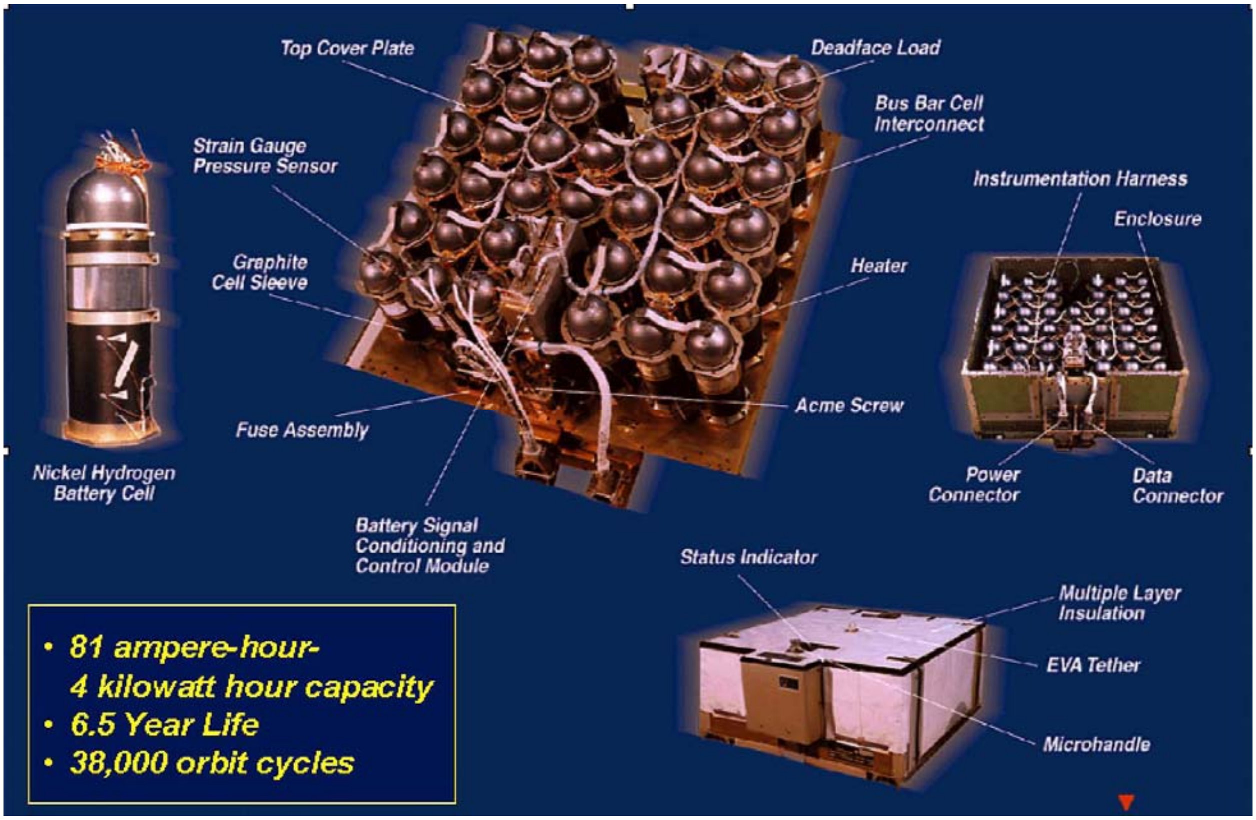
Location of DDCU to be activated on S1 truss



Location of DDCU to be activated on P1



EPS and other systems components on SO truss



- *81 ampere-hour-*
  4 kilowatt hour capacity
- *6.5 Year Life*
- *38,000 orbit cycles*