

## Cassini Power Management And Distribution

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The Cassini Power Subsystem provides power generation, management and distribution functions for the Saturn Orbiter Spacecraft. Power is derived from three parallel Radioisotope Thermoelectric Generators. The power is combined to form a single spacecraft power bus regulated to 30 Vdc within the Power Subsystem. Individual power lines are distributed to a maximum of 192 user loads through Solid State Power Switches. User loads are powered on and off via digital commands from the Information System which turn on and off the power switches. The power bus voltage is regulated by controlling the effective bus load in response to a bus voltage error signal. As load increases, the bus voltage decreases, and as loads decrease, the bus voltage increases. The bus error signal is used to adjust controllable shunt loads thereby managing the effective bus load and the user load power. User load power management and distribution are two major functions of the Cassini Power Subsystem.

### Mission Overview

Saturn is the second-largest and second-most-massive planet in the solar system -- and it has the most visible, impressive ring structure in the solar system. As a result of these attributes, it has been the subject of centuries of telescopic observations, as well as the focus of the Pioneer 11, Voyager 1, and Voyager 2 flyby missions. Yet many questions about Saturn and its moons remain that, if answered, could provide clues to how the solar system evolved and how life began on Earth. The Cassini mission will extensively study the Saturnian system's rich diversity, including the giant planet's atmosphere, rings and satellites; the surface and

atmosphere of its principal moon, Titan; and the nature of the fields and particles in Saturn's magnetosphere.

Cassini is a joint undertaking by NASA and the European Space Agency (ESA). NASA's Orbiter will study Saturn's rings and magnetosphere and measure the chemical structure of the planet's atmosphere. Several of its icy satellites will be studied including Titan's atmosphere and surface, in particular, the spacecraft's radar will peer through Titan's dense atmosphere and reveal its surface characteristics. The Orbiter will also perform repeated close flybys of Titan to make additional scientific observations. ESA will contribute the Huygens Probe, a major spacecraft component, which will descend into Titan's atmosphere and obtain detailed data of this moon's atmosphere and local surface.

### Spacecraft Overview

The Cassini Orbiter is a three-axis-stabilized spacecraft as depicted in Fig. 1. The main body of the Orbiter is formed by a stack consisting of a lower Equipment Module, the Propulsion Module, the Upper Equipment Module, and the High Gain Antenna. Attached to the stack are two science pallets, the Remote Sensing Pallet and the Fields and Particles Pallet. The Huygens Probe System, also attached to the stack, is supplied by ESA and will be deployed into Titan's atmosphere. Several instruments are attached to other points of the Upper Equipment Module.

The Orbiter stands 6.8 meters high with a maximum diameter (antenna diameter) of 4 meters.

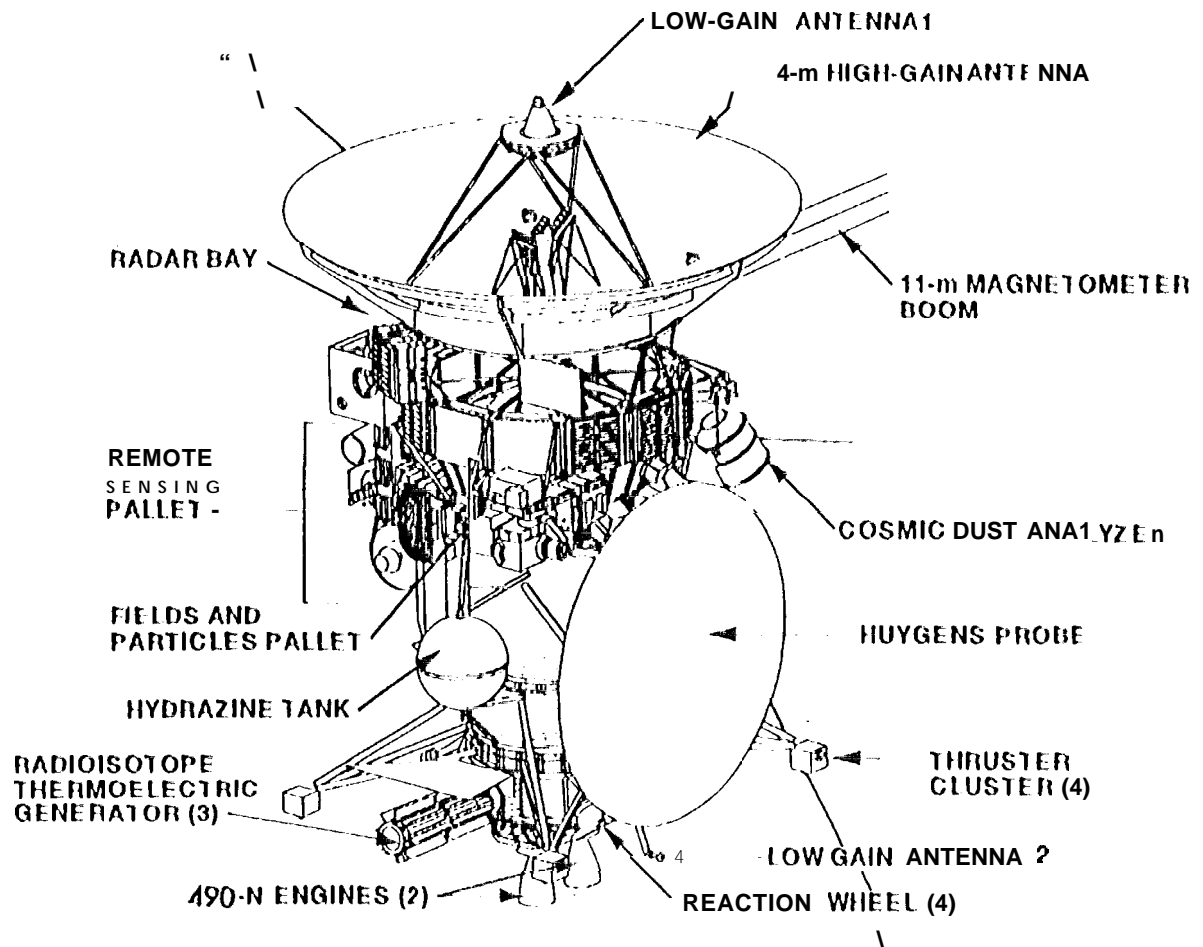


Fig. 1 Cassini Orbiter

The baseline Orbiter all-y mass at launch is 2150 kg, including 335 kg for the science payload and 332 kg for the Huygens Probe S system.

The information system of the Orbiter processes and distributes commands/data received from the ground and also collects science and engineering data on the (h-biter and processes them for transmission to the ground. It has the capability to store information on board for later use and transmission. On-board communications between the Command and Data Subsystem (CDS) and other subsystems are made via a standard 1553b data bus.

### Power/Pyro Subsystem

The Power/Pyro Subsystem (P/S) is the main power generation, regulation and (distribution subsystem for the spacecraft power bus. Power is generated in three Radioisotope Thermoelectric

Generators (1<'Gs), managed by the power electronics and distributed via Solid State Power Switches (SS'Ss). The pyrotechnic function of PPS provides redundant power conditioning, capacitive energy storage and power switching for pyro initiated devices on the spacecraft,

The RTGs provide as much as 900 watts at the beginning of the mission. The PPS is capable of managing and distributing all 900 watts. Power generated in the RTGs is routed to the Power Control electronics and through isolation circuitry capable of disconnecting each RTG from the power bus in the event of a RTG failure (Fig. 2.). The power is then split between the Shunt Regulator Assembly and the Power Distribution Assembly and thus the loads.

The Shunt Regulator Assembly senses the bus voltage and creates a control voltage signal proportional to the bus error voltage. The control

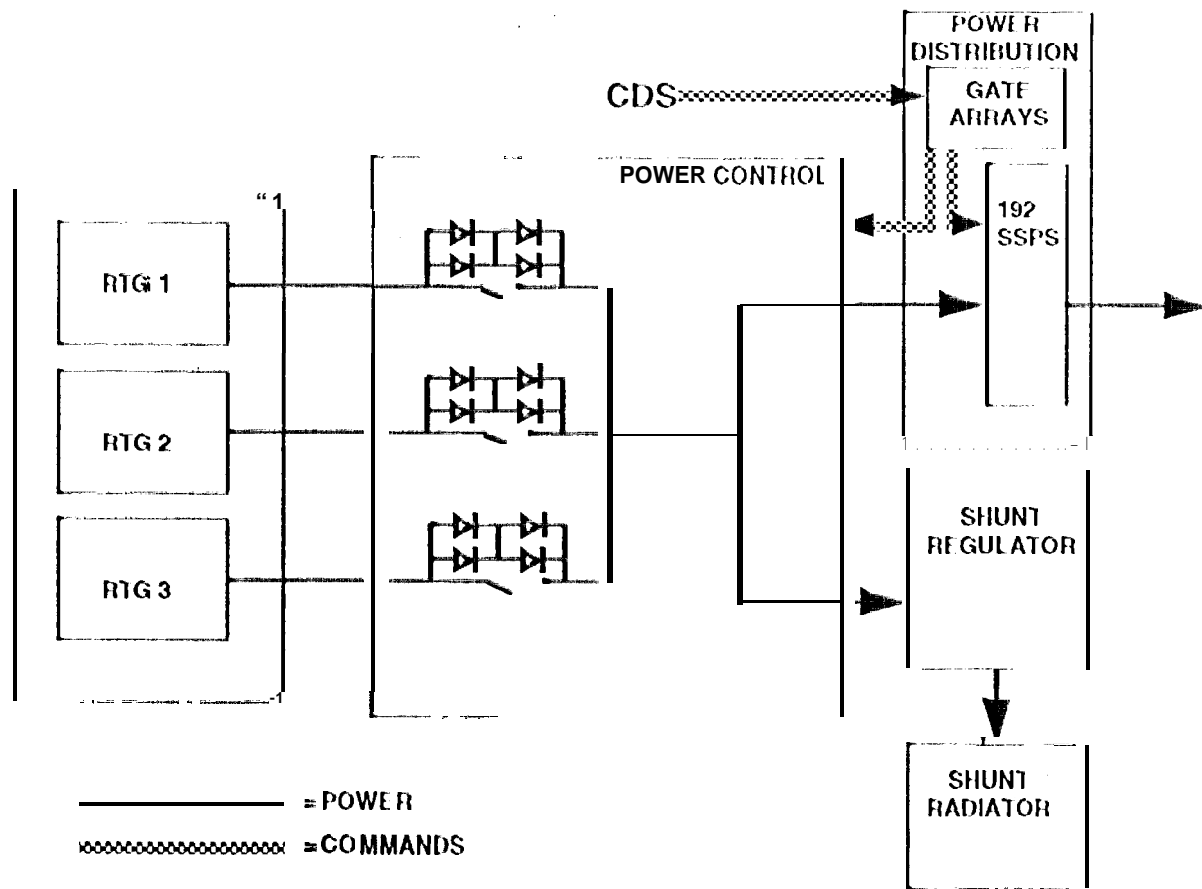


Fig. 2 PPS Power/Command Flow

loop uses the control voltage to adjust the distribution of current between the Shunt Radiator

and the power bus loads to maintain bus voltage regulation. The power bus is a 30 Vdc regulated bus with steady state and transient regulation as shown in Fig. 3.

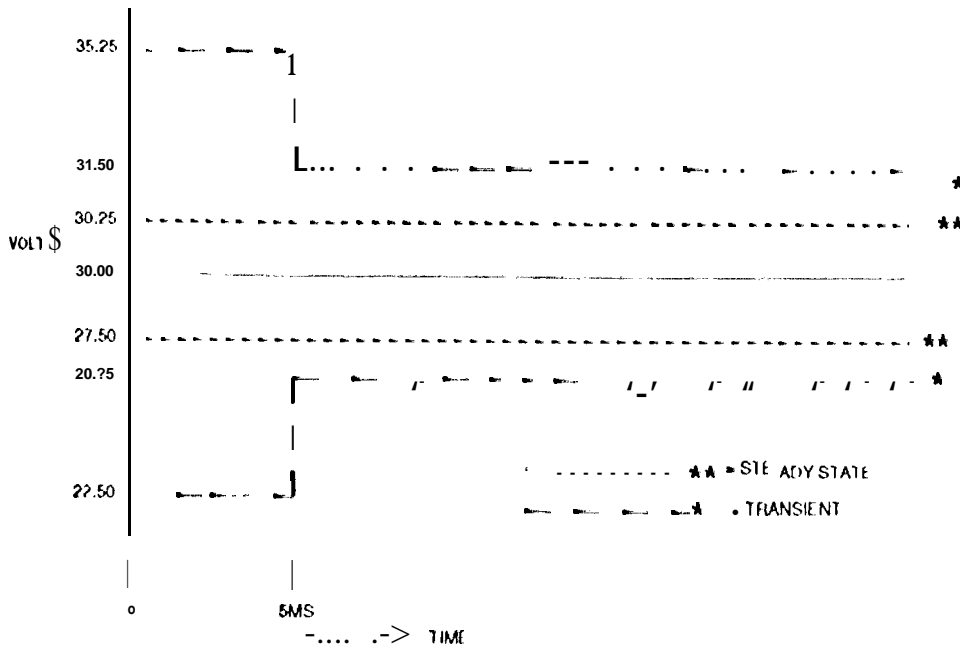


Fig. 3 Power Bus Regulation

The Power Distribution Assembly houses the Solid State Power Switches (SS)'Ss) which are the interface between the PPS and the power bus user loads. These switches provide: 1) controlled turn-on voltage, 2.) load fault isolation, and 3) fault current limiting. in addition, the SSPSs are configured within the Power Distribution

Assembly to provide additional features to the loads. These features are:

**auto-turn-on:** the capability to turn on both sides of a redundant load in the event that both sides have lost power,

**OFF Command Inhibited:** the capability to block OFF commands to the switch either permanently in hardware or by ground command,

**Parallel loads:** the capability to parallel two SSPSs to provide additional current to high power loads.

Coded commands are sent to PPS from the CDS via the 1553b communications bus. The coded commands are checked for errors and routed internal to PPS by the gate array in the Power Distribution Assembly. ON and OFF commands are sent to the SS1'Ss to turn on and off power bus loads.

The SSPS performs the function of connecting the 192 Cassini loads to the spacecraft power bus in response to commands from the CDS. Each SS1'S is capable of carrying and switching up to a 3 Amp (90 Watt) load. The SS1'S is a solid state device which utilizes semiconductors to connect (and disconnect) loads to the power bus. The semiconductors are configured to operate in either the low impedance "on" state or the high impedance "off" state. The power and return sides of the spacecraft loads are "switched" utilizing solid state components.

The SSPS uses two semiconductors for the actual switching of the power and return sides of the 30 Vdc power bus. The inter-llal circuitry resembles two independent switches cross-strapped for redundancy. There are block redundant elements for all commanding of the SS1'Ss. Telemetry for the state of each side of the SSPS is provided but the telemetry measurement itself is not redundant. A measurement of the current passing through the return leg of the circuit is also provided in telemetry. A block diagram of the SSPS is shown in Fig. 4.

### Solid State Power Switch

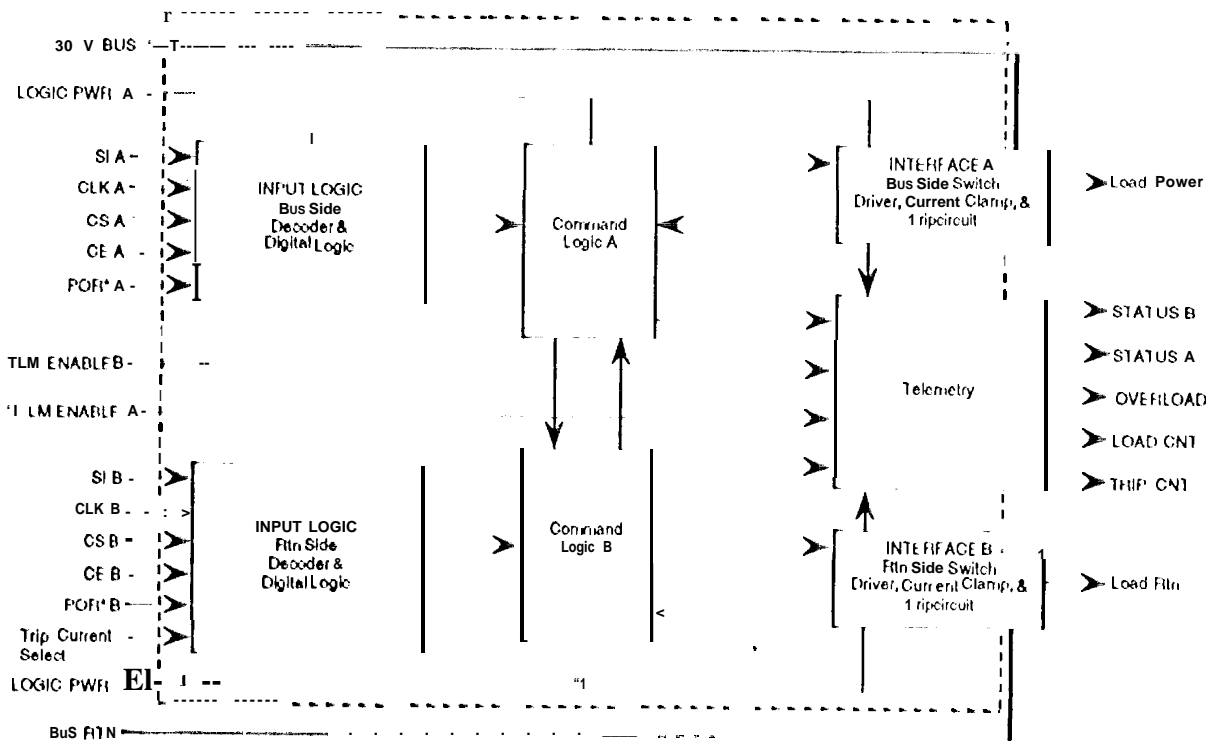


Fig. 4 SSPS Block Diagram

The SSPS responds to a sixteen bit digital command which includes its eight bit address, parity, five unused bits, a star-1 bit and an ON/OFF bit. It only responds to commands which have 1) the same address as a hardwired input, 2) the correct parity and 3) a start bit. The commands are sent to each side of the switch input and are internally cross-strapped. This cross-strapping is in response to a requirement that no single failure shall prevent a load from being disconnected from the power bus. Only one side of the SSPS needs to be turned OFF to disconnect the load.

The SS1'S controls the load voltage at turn-on in a linear fashion. The voltage will rise from 0 to 30 Volts in approximately 100 mS. This will cause a linear increase in current if the load is purely resistive. In-rush currents are controlled for resistive loads wherein capacitive and inductive loads will still experience some inrush current due to charging of input capacitors. Turn-off is controlled linearly but occurs much faster, in approximately 1 to 200  $\mu$ S.

The PPS is responsible for isolating loads which have faulted and are drawing excessive current. This function is performed by the SS1'S. The SS1'S monitors the current drawn by each load and continually compares that value to a settable trip level and an internal fail-safe trip level (fixed at approximately 4 A rms). Eight settable trip levels are available which are selected by a parallel digital input to the SSPS. If the load current exceeds either trip point for approximately 1 mS, then the SSPS will turn the load off. If the current exceeds the trip level but returns below it within the 1 mS, then the load will not be turned off (see Fig 5). A state diagram showing the allowable transitions between ON, OFF; and Tripped state of the SS1'S is shown in Fig. 6.

During a load fault, the SS1'S will limit the current drawn by the load to 6 Amps within 50  $\mu$ S. This current limiting capability allows PI'S to maintain the power bus voltage regulation within its transient specification. By limiting the current and (disconnecting, the load within the times specified, the Shunt Regulator can respond to alter the

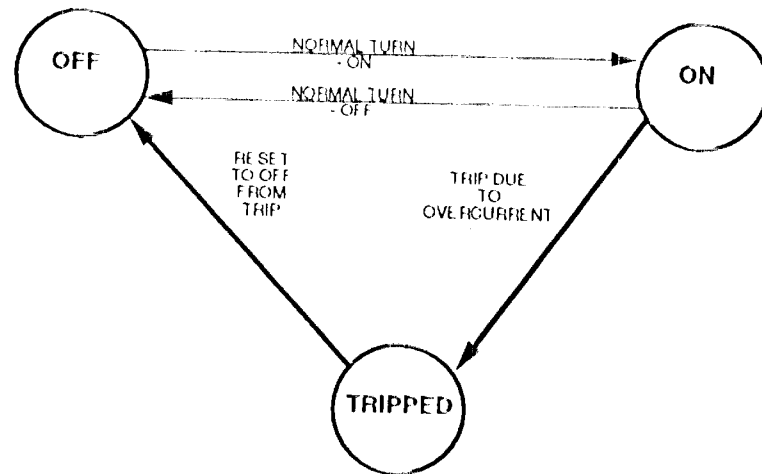


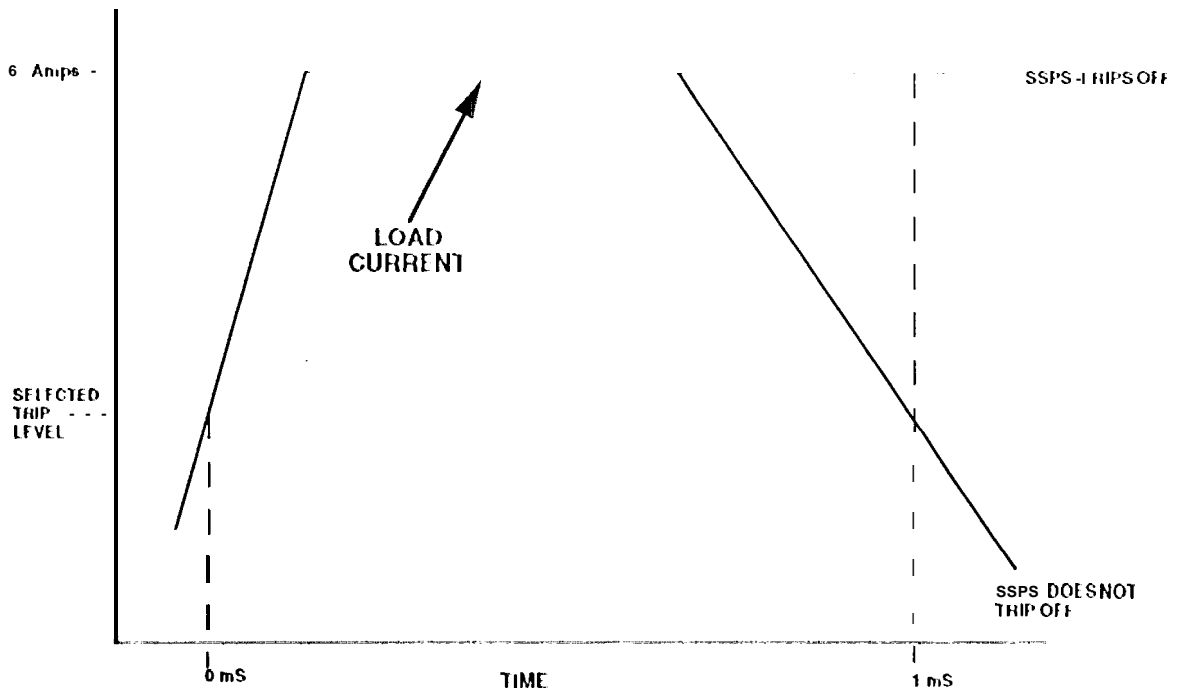
Fig. 5 SS1'S State Diagram

distribution of power between the Shunt Radiator and the loads to recover the bus to its specified steady state regulation limit within 5 mS.

### Fault Protection

The PPS provides fault protection for the spacecraft power bus for RTG shorts and for bus overloads. Load faults are protected using the load isolation function of the SSPS. Internal circuitry continually monitors the bus voltage, and compares it to preset reference voltage. In the event that the bus voltage is less than the preset reference voltage for a predetermined amount of time, then the PI'S takes three actions. These actions are: 1) turn off all except a small number of loads, 2) open the relays which bypass the isolation circuitry of the RTGs, and 3) send a signal to CDS that PI'S took actions 1 and 2.

These actions allow PI'S to recover the power bus to the steady state voltage range within 25 mS. Shedding of the loads decreases the load demand for power from the RTGs and allows the Shunt Regulator to adjust the distribution of current between the loads and the Shunt Radiator to restabilize voltage regulation. Closing the relays



**Fig. 6** SSPS Trip Condition

isolates the RTGs from the bus so that a faulted RTG cannot sink the current from the remaining RTGs. PPS sends a signal to CDS to indicate that a bus undervoltage has occurred and that PIS took the appropriate actions. It is then CDS responsibility to configure the spacecraft loads in order to continue a critical sequence or to wait for ground intervention,

**Summary**

The PPS performs the management and distribution of the RTG power for the Cassini mission. An integral part of this function is the SS1'S which provides both for the power switching interface between the PPS and the user and for the load fault isolation and control. This solid state hybrid device is a state of the art circuit breaker which provides functionality well beyond the traditional relay/fuse combination. The SS1'S operates in a more traditional circuit breaker mode (trip, reset and switching) plus incorporates the more specialized functions necessary to maintain power bus integrity (in-rush current limiting, selectable and fail-safe (fixed) trip levels, fault current limiting, telemetry

and redundancy). The SS1'S is responsible for load fault isolation while the PPS is responsible for the fault protection related to RTG shorts and power bus overloads.

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