PLUTO EXPRESS POWER SYSTEM ARCHITECTURE

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ABSTRACT

The Pluto Express power system mast answer the challenge of the next generation spacecraft by reducing its power, mass and volume envelopes, Technology developed by the New Millennium Program will enable the power system to meet the stringent requirements for the Pluto Express mission without exceeding the spacecraft mass and volume budgets.

Traditionally, there bas bcca an increasing tread of the percentage of mass of the power system electronics with respect to the total spacecraft mass. With all of the previous technology focus on high density digital packaging, the power system electronics have not bcca keeping pace forcing the spacecraft to absorb a relative itlct-case in the power system mass. The increasing trend can be reversed by using mixed signal ASICs and high density multi-chip-module (MCM) packaging techniques validated by the New Millennium Program.

As the size of the spacecraft shrinks, the power system electronics must become tightly integrated with the spacecraft loads. The power system architecture needs the flexibility to accommodate the specific load requirements without sacrificing the capability for growth or reduction as the spacecraft requirements change throughout the development. Modularity is a key requirement that will reduce the overall power system cost.

Although the focus bas been on shrinking the power system volume and mass, the efficiency and functionality cannot be ignored. Increased efficiency and functionality will only enhance the power systems capability to reduce spacecraft power requirements.

The combination of the New Millennium packaging technologies with the Pluto Express power system architecture will produce a product with the capability to meet a wide. range of mission profiles white reducing system development costs.

PLUTO EXPRESS MISSION OVERVIEW

The Pluto Express offers all of the challenges of a faster, better cheaper mission without accepting the associated risk. The mission length is approximately 12 years with a target launch dale in 2001. The current trajectory utilizes a Venus-Venus-Venus-Jupiter gravity assist taking the spacecraft from minimum of distance. of 0.6 AU to a maximum distance of 30 AU from the sun. Pluto Express is a flyby of Pluto and its moon Charon with the encounter only lasting a few days.

The mission driven mass, volume and power allocations create the need for high density packaging. Unfortunately, analog technologies such as power electronics have not scca such advances in high density packaging, as in the digital technologies. High density analog packaging techniques available today, such as hybrids and mixed signal application specific integrated circuits (ASIC), have high non-recurring engineering (NRE) costs. In order to meet the cost constraints imposed by today's economical environment, these NRE costs must be spread over a larger production run which caa be shared by a number of projects.

Fortunately the New Millennium Program (NMP) recognizes the economic pressure for the individual projects and provides a avenue for the development and validation of the new technology. The goal of the NMP Microelectronics Integrated Product Development Team (IPDT) is to validate promising new packaging technologies, modular building block designs, and standard interfaces. The IPDT has a number of members from industry, universities, laboratories and NASA with a common goal of producing a roadmap of technologies which will bc needed for the next generation of spacecraft. Pluto Express is one of the maay customers for these technologies.

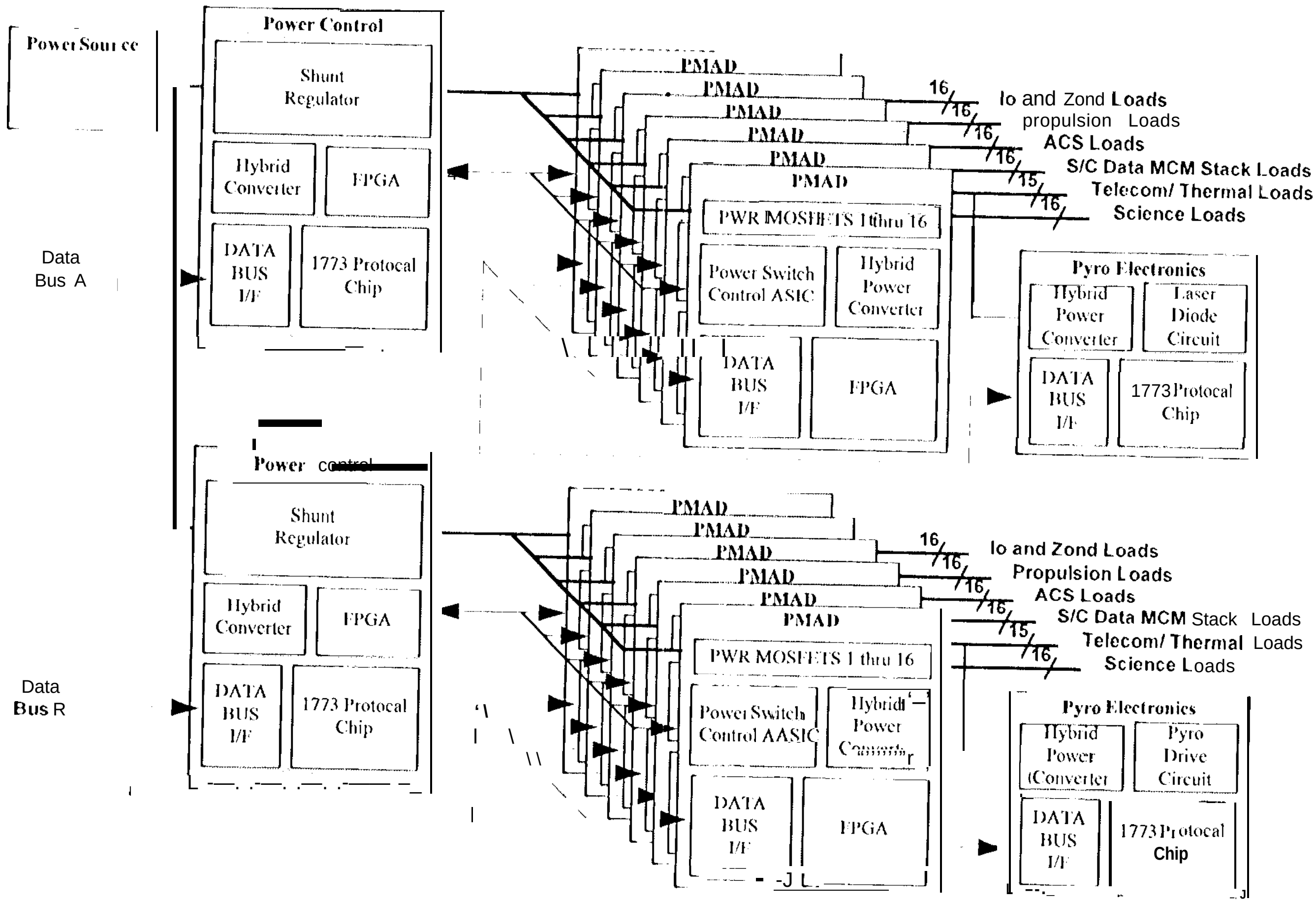

Figure 1: Pluto Power System Block Diagram

However new technology is only part of the solution to meet the system allocations and stay within the estimated funding profile. The Pluto design must be modular and flexible enough to attract partners for NRE cost sharing. Although this adds to the complexity of the design, the benefits spread across institutional boundaries. The ultimate goal is to have joint funding from a number of sources for the design of a common set of building blocks which can be reconfigured to build an optimum system for each mission

DESIGN APPROACH

The Pluto Express power system approach embraces the Microelectronics IPDT's philosophy for high density packaging, modular designs and standard interfaces.

The power system architecture must utilize this philosophy without sacrificing the capability for design optimization. This requires a combination of MCM packaging with accessible surface mount packaging. With intelligent partitioning of the power system functions. a modular design can evolve with the capability for late changes and minor optimization.

Functions which are common throughout the power system such as power switching, pulse width modulation, and the command interface, can be incorporated in mixed signal ASICs or MCMs without much concern for future modification. These functions are considered the core building blocks for the power system which can be combined for specific applications.

Certain functions are either load specific or mission specific and thus require accessible packaging on the surface of MCM modules, flex prints or standard circuit boards. Functions such as input filters, voltage regulation, and trip levels, can be adjusted to increase the overall power system efficiency.

POWER SYSTEM ARCHITECTURE

The Pluto power system (Figure 1) utilizes a power system architecture which is designed to be scaleable for different mission power levels. The architecture can be expanded for block redundancy or point redundancy.

The power system architecture consists of three unique functional modules which can be optimized for a specific power source or load requirement.

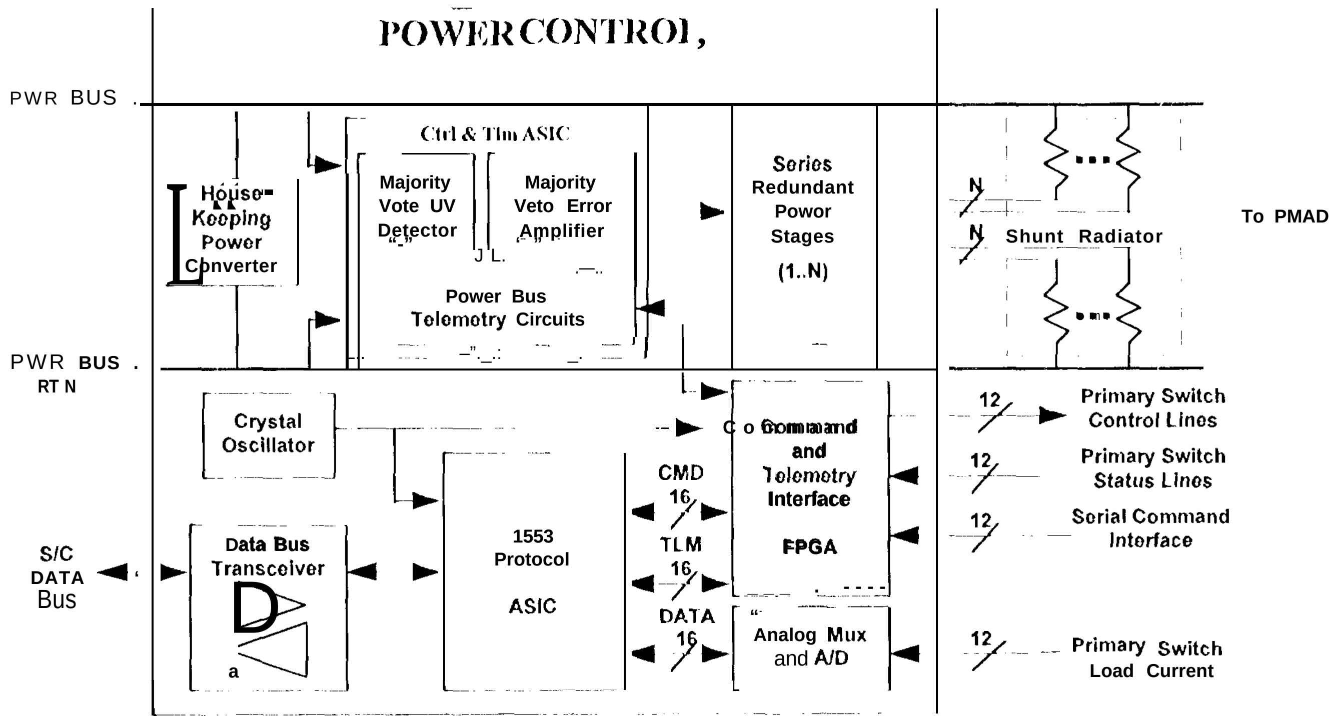

Figure 2 : Power Control Block Diagram

The Power Control module provides the main interface with the power source. The primary function is to regulate the power bus voltage at the peak power operating point of the source. Power Control also provides all of the fault protection and telemetry for the power bus. Although the power system is block redundant, only one shunt regulator will control the power bus and the other is a cold spare, The power bus must be protected from all possible shorts.

The Power Management and Distribution (PMAD) module provides the custom load interface. Each module can be configured with custom magnetics and discrete components to provide the load specified voltage. Each interface is protected by a power switch and is commandable via the data bus interface.

The Pyro Drive Electronics provides the interface to all of the pyro devices. The drive electronics can be changed depending on the type of initiator used for that mission,

Every module has the same standard data bus interface which enables the spacecraft computer direct access to each module. The test and integration costs decrease due to having a standard bus interface combined with increased visibility into each module for testing. The fault protection improves by removing, an internal power system command bus which can fail and disable the whole siring,. With the direct data bus interface, a single failure can disable only one module. Cross-strapping is another advantage of direct access to the data bus. The data system has a cross-string module enabling either flight computer to use both data buses.

SOURCE

The power source for Pluto Express has some extraordinary mission requirements. Since the spacecraft ranges from 06 AU to 30 AU, the number of possible sources which can be considered are limited. Several different sources and technologies are being investigated that can provide 90 W of power at 30 AU.

POWER CONTROL

Power control will provide the power bus regulation, fault protection and telemetry. It consists of a shunt regulator, power converter, command interface and undervoltage detector.

The shunt regulator can be optimized to provide bus regulation at the. peak output power of the power source. The shunt regulator is designed to be single fault tolerant with a majority voted control circuit and series redundant power stages. The number of power stages will depend on the maximum power dissipation capability for the MCM slice.

The shunt regulator control circuit can be implemented with multiple chips or a single partitioned mixed signal ASICs. The power stage mosfets can be packaged in the MCM with the compensation network in accessible discrete components.

Power Control also contains the bus fault protection which is a two level undervoltage detector. The first level of protection notifies the data system of the loss of power margin. A discrete signal option is available for autonomously loadshedding some non-critical loads.

The second level of protection is for a severe bus fault or deep undervoltage. The immediate response is to loadshed via the

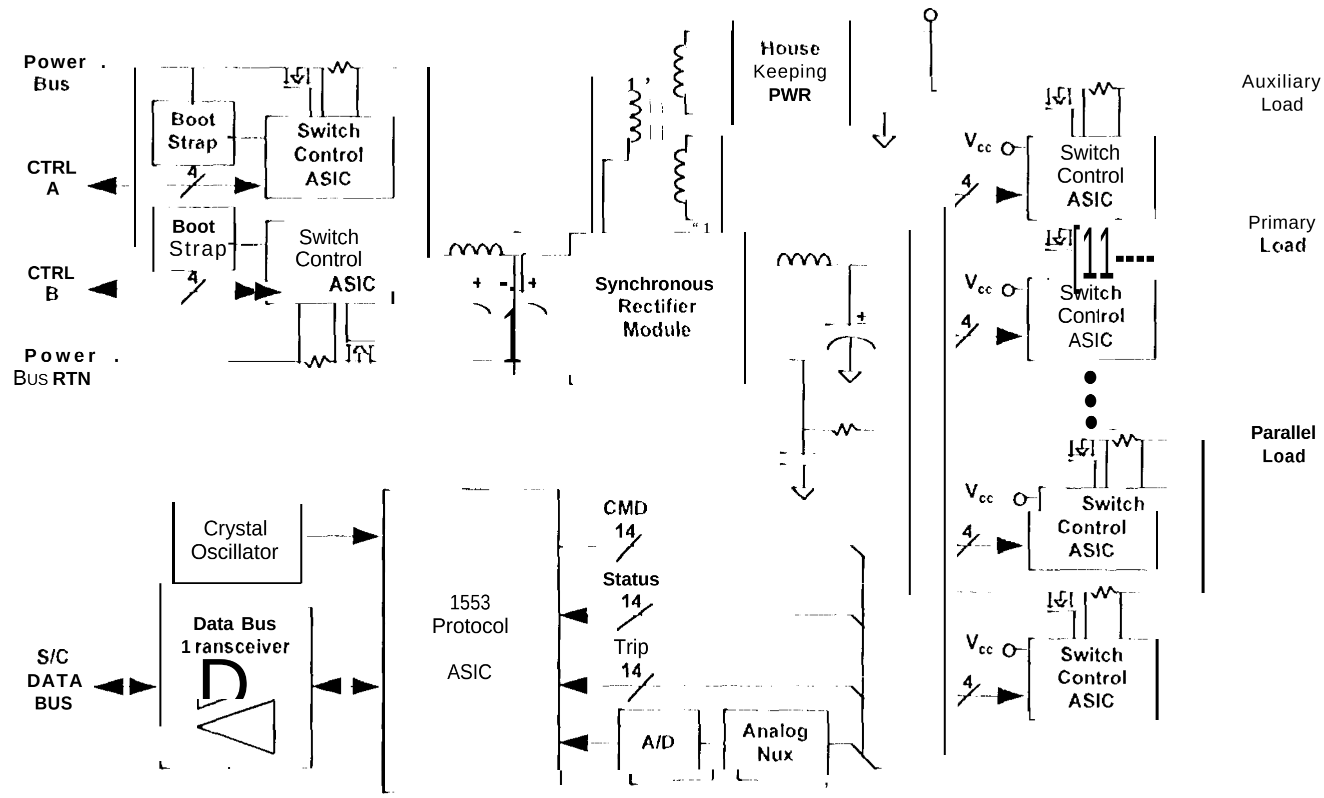

Figure 3 : PMAD Block Diagram

primary side of the power converters for the non-critical subsystems. The second response is to interrupt the data system and trigger a fault protection response.

Power control will provide the command interface between the spacecraft data bus and the primary side switches for all of the power converters.

A field programmable gate array (FPGA) will provide all of the logic for controlling the primary switches. The different fault responses can be programmed in the FPGA. The FPGA can also be used to distribute a power synchronization signal to each of the power converters if required by the mission.

PMAD

The PMAD function is to provide power conversion, load switching and fault protection. Each PMAD module is designed with a set of components accessible for customization to specific load requirements. The number of PMAD modules depends on the number of loads and the total power of the spacecraft.

The power converter converts the power bus voltage to the load specified voltages. The power converter consists of a hybrid control circuit with a discrete power transformer, control circuit, input filter and output filter. Access to the main transformer allows for design optimization to a specific line voltage determined by power control. This allows the system to achieve its maximum efficiency at the peak power operating voltage of the source.

The hybrid control circuit contains all of the switching functions of a DC to DC converter. Inside the hybrid is the PWM controller and a synchronous rectifier for the primary output. The power converter switching frequency can be synchronized from 50 to 200" KHz.

The primary output of the converter is the specified voltage with the highest load. This output has the advantage of a synchronous rectifier which provides higher efficiency at a high load current ((J to 10 A up to 50 W). The voltage range of the primary output is 2.5 to 1 ? Vdc. The output regulation is 1%. The overall efficiency of the power converter with a single output is greater than 9W% for an output power range of 8 to 30 W.

The primary output is part of the main control loop of the power converter. The control loop response can be modified to meet specific load requirements. The power converter compensation is reduced to a linear control problem similar to opamp stabilization.

Additional voltages are available as auxiliary windings on the main power transformer. The auxiliary outputs will require a post regulator. The house keeping power of the PMAD module is derived from an auxiliary output. Additional low power loads can be accommodated by other auxiliary outputs.

The input filter is designed to meet the power bus impedance and noise requirements. The filter design is determined by requirements imposed by the Power Control to ensure the power bus stability.

The output filters are designed to meet the output ripple requirements of each load. The filler design will change from module to module on the same spacecraft.

The load switching function provides a controlled intel face to the load with fault protection, commandability, and telemetry. Load switching is accomplished by 16 power switches of which two are used to protect the power bus from a converter fault. Each switch has a mixed signal ASIC, power mosfet and a current sense resistor.

The controlled interface allows multiple loads to be connected to the same power converter. The soft start function enables a load to be turned on without affecting the output voltage provided to the other loads from the same PMAD module.

The current limit function provides control during a load fault. Others loads on the same power converter arc not affected while PMAD clears a fault.

The tı ip level can be selected by an external resistor. The level can be configured to the response capability of the power system.

Each load is individually commandable. This allows for tighter power management in flight which is necessary when the power from the source is limited.

Load current telemetry is a available for each switch. The analog load current telemetry can be converted to digital telemetry by tbc command interface. Since telemetry is available on every switch, the power converter efficiencies can be calculated in flight as well as the identification of load variations.

The command interface and powei switches arc powered by an auxiliary winding on the power conver ter. The PMAD module is essentially self contained and can be added and removed with little impact on the system.

The power mosfet is an N-channel device with a typical on-state resistance of S() mohm. The internal charge pump and levelshiftei allows the switch to be used in different configurations. Switches can be connected in parallel to reduce the voltage drop for high current loads. It also can configured for a sctics/parallel or bi-directional connection to the load. Additionally, these switches can be configured in various ways to meet critical load requirements or to provide need cross-strapping between loads.

'1 he command interface is via the standard interface to tbc spaceci aft data bus, If the data bus is isolated, PMAD can maintain isolation between the power bus and a group of loads. This spaceci aft grounding can be optimized by providing a PMAD slice for each subsystem. However a system trade between grounding and the impact of an additional interface on the data bus needs to be done. The system can be optimized for a lowei number of converters to reduce the volume and mass.

PYRO ELECTRONICS

The power system traditionally provides the pyrotechnic command ing function on the spacecraft. The command interface ptok'ides a direct link to the engineering data bus for pyro enable and event comma ads as well as telemetry.

The pyro drivei interface design is determined by the technology of the squibs and actuators used on the spacecraft. It is envisioned that the switching technology from the PMAD function can be utilized here to initiate the pyro devices or valve drive electronics. With the capability for isolation, and custom powei conversion, the pyı o electronics module can accommo date either a NASA standard initiator or the addition of a laser pyro interface. Design of this module is greatly dependent cm the initiator technology chosen.

SUMMARY

The Pluto Express Power System architecture combines high density packag ing techniques and discrete components for a reduction in mass and volume without sacrificing functionality or efficiency.

The power system architecture maintains level of flexibility which can be customized to special source or load requirements. The flexibility will ultimately improve the overall efficiency of tbc.power system. By having a flexible design which is modular as well as adaptable, power systems on future spacecraft can save time, cost and mass with a minimum investment of dollars.

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