The Company

Broad Reach Engineering was founded in 1997 by a group of experienced aerospace engineers with the intent to provide innovative and cost effective high-end products and services to the aerospace industry. Broad Reach believes in a no-nonsense engineering approach to providing the solution that best fits the mission requirements.

Location & Facilities

Broad Reach Engineering maintains offices in Golden, Colorado, and Tempe, Arizona.

The Tempe site serves as the design center for Broad Reach avionics and software. This facility, located in the heart of the Phoenix Metro Area, has over 1500 square meters of office and laboratory space.

The facility includes a laminar flow clean room, electronics assembly lab, two dedicated avionics labs, and numerous assembly and test tools, including a NASA certified thermal vacuum chamber, solder reflow machine, and component X-Ray facility.

Products & Services

Broad Reach Engineering develops hardware and software for spaceflight missions and ground systems. Products include spacecraft avionics, science payload electronics, spacecraft flight software, ground and spaceborne GPS receivers for precision orbit determination (POD) and occultation science, ground support hardware and software, and mission design and analysis services.

Broad Reach has developed a variety of products in the past - many of which are shown in this document. While these designs exist and have been proven, it is assumed that new missions will require some minor or major variation of the existing design or completely new ones.

Broad Reach Engineering customers include both domestic and international space organizations. We have experience exporting our products in compliance with United States export regulations through the use of DSP-5 licenses, Technical Assistance Agreements (TAA), and Technology Transfer Control Plans (TTCP).
Company Heritage

Broad Reach Engineering has assembled a team of experts in the field of avionics, space flight hardware, and spacecraft and ground software design. More than 80% of Broad Reach Engineering employees are engineers by trade with direct, hands-on experience in designing, building, testing and flying space flight hardware and software.

Broad Reach Engineering has successfully delivered flight hardware and software for a number of national and international customers ranging from companies such as Lockheed, Boeing, EADS, and Ball Aerospace to international institutions such as UCAR, JPL, and DLR - to government agencies including AFRL, NASA, and DARPA. To date (2009), Broad Reach Engineering hardware and software has been deployed on at least thirteen spacecraft at LEO, GEO, and the Moon.

Selection of Customers & Projects

AFRL - TACSAT2/Roadrunner
Integrated Avionics, Flight Software, EGSE

JPL/AFRL - PIE
Propulsion Instrument Electronics

UCAR - COSMIC
COSMIC GPS Occultation Science & Precision Orbit Determination Receiver

Ball Aerospace - STP-SIV 1 & 2
Integrated C&DH & EPS Avionics for STP-SIV

DARPA/Alliance Space Inc. - SUMO
Robotic Arm Drivers and Controller

EADS - TerraSAR-X & Tandem-X
Precision Orbit Determination and Occultation Science GPS Receiver

Space Systems Loral
Integrated Avionics & Flight Software

Ball Aerospace - Digital Globe WorldView 1 & 2
High Speed Payload Data Processing Unit

AFRL/Lockheed - XSS11
Integrated C&DH & EPS Avionics

Lockheed - AMS/AMS-4/AMS-6
Integrated C&DH & EPS Avionics

Stanford/JPL - ST-7
Disturbance Reduction System Avionics

NASA/GSFC - Lunar Reconnaissance Orbiter
Redundant Gimbal Control Electronics

AFRL/Orbital - Angels
Integrated C&DH & EPS Avionics, GPS Receiver

Quality Engineering

Broad Reach Engineering adheres to the highest standards in the design and implementation of space flight hardware and software.

The Broad Reach AS9100 aligned Quality Assurance System backs this commitment with a comprehensive and efficient set of processes and protocols that address all critical epochs in the production life cycle.

Our approach has been scrutinized and approved by numerous customers including Lockheed Martin, NASA/JPL, NASA/AMES, AFRL, and Ball Aerospace Corporation.
Spacecraft Avionics

Broad Reach Engineering Advanced Avionics Systems are based on 3U boards designed specifically for spacecraft & payload applications. Systems are available for C&DH, EPS, integrated C&DH & EPS, or payload applications. Design options include single string and redundant systems.

All avionics are tailored to meet the mission requirements. Existing designs are drawn on where advantageous and new designs are created where significant benefits may result.

All Avionics designs adhere to the highest standards in space flight hardware design. Space qualified parts are used throughout unless special requirements dictate otherwise and all design methods are tailored specifically with space flight environmental and functional requirements in mind.

Typical Integrated Avionics Unit

- <5 kg
- <32 W @ 28V
- 750 W Solar Array Input
- 90 Power Switches
- 32-Ch RS-422
- MIL-STD-1553 BC/RT
- High-Speed LVDS I/O
- 12-Bit A/D
- 112 Analog Inputs
- 16 MB NVRAM
- 512 MB SDRAM
- 512 MB DDR RAM
- >266 MIPS/266 MFLOPS CPU
- CCSDS Cmd/Tlm Support

Sample System 1 - Single String C&DH

- BRE440 Based Processor Board (266+ MIPS)
- MOAB Board + Power Supply Board
- 2 Spare cPCI Slots
- <3 kg, <20 W Typical, 28 V
- OSE or VxWorks

Sample System 2 - Integrated C&DH & EPS

- BRE440 Based Processor Board (266+ MIPS)
- MOAB Board + CAPI Board + CASI Board
- Solar Array Interface & Battery Charge Controller Board
- LASI & Power Distribution Board
- <5 kg, <30 W Typical, 28 V, >90% Efficiency
- OSE or VxWorks

Sample System 3 - Redundant C&DH

- 2x BRE440 Based Processor Board (266+ MIPS)
- 2x MOAB Board + 2x PIB Board
- 2x Power Supply
- Redundancy Management Board
- Dual String Design with Cold or Hot Spare Capability
- <5 kg, <40 W Typical, 28 V
- OSE or VxWorks

Key Capabilities

- BRE440 Based Processor Board
- CPU Board has 512 Mbytes DDRRAM, 512 kB EEPROM
- Solid State Recorder Boards with 6 GBytes of Shared SDRAM
- 16 MBytes Flash Memory with TMR
- 3U Form Factor, 33/66 MHz, 32/64bit PCI Bus I/F
- 24 RS-422 Receiver – Transmitter I/Fs
- 2x 640 Mbps LVDS I/F
- 32 Digital, 8 High Voltage Discrete Inputs
- 24 Digital Discrete Outputs
- Autonomous SOH Data Acquisition 64 Analog Channels
- 12-Bit A/D Converter
- Uplink H/W Command Decode
- Variable Downlink Rates, CCSDS, SGLS & Other Formats
- EPS Supports 48x 5 Amp and 9x 25A 28V Switches
- Battery Charge Management, Current Set Points, VT Option
- Solar Array Interface for 8 Segments ~300 W
- All Parts SEL Immune
- SEU Mitigated Design
- Al, Magnesium, or Composite Chassis
- 100 kRad Option
### Modular Avionics Configurations

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<td>Pyxis-POD GPS Board</td>
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</tbody>
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### Software Development Unit

Engineering unit versions with flight like commercial CPUs are available as software development units (SDU) for customers who would like to evaluate the architecture and/or would like an early start on software development tasks. SDU Boards are form, fit, and function compatible to the actual flight hardware but are not subjected to flight like testing and utilize some commercial part equivalents, such as FPGAs, memory, and commercial chassis. SDUs provide an effective development platform that is available at a reduced schedule compared to full engineering or flight units.

SDUs are available with various CPU versions, ethernet support, full EPS subsystem, and various interface boards. Software support, including drivers is available for VxWorks and other operating systems.

### C&DH Avionics Unit

- **<3 kg**
- **<25 W @ 28 V**
- 24-Ch RS-422
- CCSDS or SGLS Support
- MIL-STD-1553 BC & RT Support
- 12-Bit A/D
- 64 Analog Inputs
- 16 MB TMR FLASH
- 512 MB DDR RAM
- >266 MIPS BRE440 SoC
- 30 kRad (100 kRad Option) - SEL Immune

**TOP VIEW**

**FRONT VIEW**
The Broad Reach Engineering BRE440 CPU is designed to meet the requirements of a wide variety of current and future space and high reliability applications. The BRE440 CPU is a fully radiation hardened implementation of the PowerPC 440 processor core in a true System-On-a-Chip design, including floating point unit.

Broad Reach Engineering has licensed the PPC440 core from IBM and has integrated it into the in-house developed chip design. Broad Reach Engineering has contracted with Synopsys and Honeywell for the final implementation and manufacture of the devices.

The BRE440 Chip presents the culmination of several years of internal development effort aimed at producing the highest level of space based processing capabilities.

### Features
- High Performance IBM PPC440 Core, 2 MIPS/MHz
- ANSI/IEEE 754-1985 compliant FPU
- Manufactured on Honeywell 150nm HX5000 Radiation Hardened ASIC Line
- Superscalar, Dual Issue, 32-bit RISC, Book E Compliant

### Memory
- 32 kByte L1 Instruction & Data Caches
- 256 kByte unified L2 Cache (can be configured as general purpose SRAM)
- On-Chip 8 kByte SRAM
- High Bandwidth Main Memory Access with Error Detection and Correction

### Interfaces
- PCI Interface for Peripheral Communication
- PCI Arbitration for up to 6 External Peripherals (Clock Distribution)
- 4 Channel DMA with Scatter/Gather Capability
- 32-Bit Peripheral Bus with EDAC
- 32-Bit DDR DRAM Bus with EDAC
- External Expansion Bus
- 2 Ethernet Media Access Controllers
- 2 UART Ports (16750 Compatible)
- JTAG

### Radiation Capability
- Honeywell HX5000, 150 nm Radiation Hardened SOI Technology
- TID >1 Mrad; Latch-up immune
- SEU >40 Years/Upset (Adams 90% worst case environment)

### Core Clock Frequency
- 83 MHz @ -55°C to 125°C
- 133 MHz @ -10°C to 80°C

### Availability
- Available in Many of Broad Reach Next Generation Avionics and Board Products Only
- Engineering Units Available as of Q1/2009 / Flight Units Available Q1/2010

The PowerPC name and logo are registered trademarks of IBM Corp. and used under license therefrom.
CPU Boards

**Mirideon Rad Hard CPU Board Series**

**Mirideon CPU Board Features**

- **High Performance BYU440 CPU**
  - w/ IBM PowerPC440 Core & FPU
- **Processor Speeds**
  - 83 MHz @ -55°C to 125°C
  - 133 MHz @ -10°C to 80°C
- **Memory**
  - 512 MB Double Data Rate (DDR) Synchronous DRAM with single error correct / double error detect EDAC
  - 256 kB EEPROM with hardware majority voting (TMR)
  - Up to 512 MB FLASH with software majority voting
- **Input/Output**
  - PCI V2.2, 32/64-bit, 33/66 MHz
  - 10/100 Mbps RMII Ethernet with LVDS buffers
  - Two (2) UART ports, configurable baud rates
  - Configurable for cPCI system slot or peripheral slot operation; Initiator and target operation
  - JTAG Interface with RS422 Buffers to CPU
  - Front panel provides 1 General Purpose Input and 1 General Purpose Output via RS422
- **Mechanical**
  - 3U CompactPCI Form Factor
  - 250 grams
- **Power**
  - Single 3.3V Supply
  - 8 W Peak
  - 5 W Typical
- **Environmental**
  - Conduction cooled board design
  - Temperature range -40°C to 71°C (at wedgelocks)
- **TID Levels**
  - Processor >1 MRad
  - DRAM > 50 kRad
  - Other > 100 kRad
- **Latch-up**
  - All parts >80 MeV/mg/cm^2
- **SEU Performance**
  - Processor >40 Years/upset (Adams 90%)
  - All memory has SEU mitigation
  - 2 M Hours MTBF @ 30°C predicted
- **Test & Development**
  - Compatible with multiple operating systems including VxWorks, Linux, OSE, Integrity

The development of the Broad Reach Engineering BRE440 Rad-Hard CPU enables a new generation of spacecraft processing solutions. Broad Reach is offering a number of products that are based on the BRE440 CPU to provide a higher level of processing power for on-orbit applications ranging from CPU boards to BRE440 based GPS Receivers.

The primary product is a series of CPU boards based on the BRE440 CPU intended for use in an Integrated Avionics Units or standalone C&DH systems. The first product in this lineup is the Mirideon CPU Board. A commercial version CPU board intended to allow early system and software development at low cost is available via the Starter 440 Board.

The EM and flight boards are very similar in functionality and performance to the Starter 440 Board in order to enable quick drop-in replacement.

Contact us for custom processor board solutions.

**Starter 440 Board**

The Starter 440 Board is a commercial CPU board implementation based on an AMCC 440GP CPU that is code compatible with the BRE440. The Starter 440 is compatible with our Avionics architecture and may be used for code development.

**Test & Development**

The Mirideon board provides 2 UART, JTAG, and an Ethernet interface for rapid code development and debug. All interfaces are available simultaneously. Alternatively, the UARTs may be used to communicate with external devices during flight.
The MOAB Series of Boards are designed as a single 3U cPCI card solution for interfacing to a large number and variety of commonly found subsystems, payloads, and sensors.

A typical MOAB board provides 20 full-duplex RS-422 or LVDS serial interfaces intended for use with devices such as uplink receivers, downlink transmitters, asynchronous interfaces, cross-link devices, ADCS components, and payload electronics. LVDS and 422 can be configured in any combination in increments of 4 channels. For example, a design may have 12 LVDS channels and 8 RS-422 channels, or 4 LVDS channels and 16 RS-422 channels, etc...

The MOAB boards provide a MIL-STD-1553B interface and can be setup as either Bus Controller (BC) or Remote Terminal (RT).

To interface to common telecommand components, the a MOAB board may be configured to be compatible with CCSDS, SGLS and other command decoding & telemetry encoding formats. Using these formats, the MOAB board may autonomously decode hardware commands, without the need for a system processor. The large amount of FPGA resource available may be used for mission/customer specific processing functions.

The 24 configurable discrete inputs and 24 outputs are provided for control and sensing of digital devices such as deployment indicators and thruster valves. The MOAB board also supplies 12 special purpose sun sensor inputs, 47 AD590 temperature sensor inputs and 24 general purpose analog input channels.

The memory on the MOAB board contains a total of 768 MBytes of Flash memory which can be used as-is or configured as 256 MBytes of Triple-Modular-Redundant Flash with voting logic implemented in the MOAB FPGA.

The board provides 2 MBytes of shared SRAM for general purpose use by the MOAB board or any devices on the cPCI bus.

For custom implementations using the MOAB architecture, 2 million gates of FPGA resources are available in a rad-tolerant, space flight qualified Actel FPGA.

For many missions the MOAB together with a CPU board can make a complete spacecraft C&DH System.

**Typical Features**
- 2 Million Gate FPGA (Actel Axcelerator)
- 2 Mbytes SRAM with EDAC
- 768 MBytes Flash / 256 MBytes Flash with TMR
- 47 AD590 Temperature Sensor Channels
- 8 AD590 Excitations
- 12 Sun Sensor Channels
- 3 Sun Sensor Excitations
- 24 General Purpose Analog Channels
- 20 Differential RS422/LVDS Transmitters
- 20 Differential RS422/LVDS Receivers
- 24 Discrete Outputs (Configurable to 3.3 V or 5 V)
- 24 Discrete Inputs (Configurable to 3.3 V to 28 V)
- MIL-STD-1553B Interface using BAE Summit Chip

**Reliability Features**
- All Parts SEL Immune
- SEU Mitigated Design
- 30 kRad Standard (100 kRad Option)
- Conduction Cooled Design
- All Parts MIL-883B

**Mass, Power, Dimensions**
- < 0.4 kg
- < 6.0 Watts Peak
- 100 mm x 175 mm x 30 mm (3U cPCI)

**Program Heritage**
- STP-SIV, Aquila, Angels, AMS-4, LADEE
**CASI™ Board Series**

The Camera and Storage Interface Boards (CASI) are designed as a single 3U cPCI card solution to interface to spacecraft communication subsystems and payloads, such as cameras or radar payloads where high data rates and data storage volume are required.

The CASI board provides an integrated camera/payload and mass storage interface. The board delivers 512Mbytes of SDRAM for mass storage, 3 LVDS Multiplexed Deserializers for high-speed LVDS interfaces, 12 LVDS or RS422 differential inputs and 12 LVDS or RS422 differential outputs (can be utilized for SpaceWire applications), 8 Bi-level outputs, and 7 Bi-level inputs.

The components chosen are radiation hardened and fault tolerant making the CASI a robust I/O connection. The board utilizes the radiation hardened Actel RTAX2000 FPGA for its 32-bit 33MHz PCI target and PCI DMA controller interface, SDRAM controller, and all customer defined camera/payload interface functions.

- **Typical Features**
  - 33 MHz, 32bit cPCI v2.1 Bus Interface with DMA Controller
  - 3 LVDS 3-to-21 Deserializers for Camera and Payload Input
  - 12 LVDS or RS-422 Receiver Interfaces
  - 12 LVDS or RS-422 Transmitter Interfaces
  - Differential interfaces can be configured as LVDS or RS422 in sets of 4
  - SpaceWire via LVDS Option
  - 512 MBytes to 2 GBytes SDRAM
  - 7 Bi-Level Discrete Inputs
  - 8 Bi-Level Discrete Outputs
  - Actel RTAX2000 FPGA
  - Conduction Cooled
  - 128-Pin Micro-D Front Panel Connector

- **Mass, Power, Dimensions**
  - <0.28 kg
  - <4.5 Watts Peak
  - 100 mm x 175 mm x 30 mm (3U cPCI)

- **Reliability Features**
  - All Parts SEL Immune
  - SEU Mitigated Design
  - 30 kRad Standard (100 kRad Option)

- **Program Heritage**
  - TacSat-2, XSS-11, AMS (Gen 1 CASI)
  - Angels, LADEE (Gen 2 CASI)

- **CASI & PIB Availability**
  - Engineering Boards 3-6 Months ARO (depending on NRE required)
  - Flight Boards 6 Months after EM

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**PIB™ Board Series**

The Payload Interface Board is designed as a single 3U cPCI card solution to interface to spacecraft payload subsystems, with configurable real-time and high-rate interfaces and 1GByte of mass memory SDRAM.

The PIB boards are derived from the CASI series to provide an integrated payload and mass storage interface board. A typical board delivers 1GByte of EDAC SDRAM for mass storage, 4 configurable high-rate synchronous/asynchronous payload receive interfaces, 4 configurable real-time asynchronous receive interfaces, 4 configurable asynchronous command interfaces, 32 Bi-level inputs, 32 Bi-level outputs, 16 open-collector outputs, and 32 differential analog channel inputs.

The components chosen are radiation hardened and fault tolerant making the PIB a robust I/O connection. The board utilizes the radiation hardened Actel RTAX2000 FPGA for its 32-bit 33MHz PCI target, SDRAM controller, and all customer-defined payload interface functions.

- **Typical Features**
  - 33 MHz, 32bit cPCI v2.1 Bus Interface with DMA Controller
  - 4 Synchronous Receive Interfaces
  - 100 kbps to 2 Mbps (Note: These four interfaces can each alternatively be configured as asynchronous interfaces for high-rate data input)
  - 4 Asynchronous Receive Interfaces
  - 4 Asynchronous Transmit Interfaces
  - 32 Differential Analog Voltage Inputs (+/-10 Volt)
  - 4 Discrete (SV) Inputs
  - 4 Discrete (SV) Outputs
  - 16 Open-collector Outputs
  - 4 Differential 1PPS Outputs
  - 1 GBytes SDRAM with EDAC
  - Actel RTAX FPGA with Bus Interface, Customer & Mission Specific Logic
  - Conduction Cooled
  - 256-Pin Micro-D Front Panel Connector

- **Mass, Power, Dimensions**
  - <0.28 kg
  - <4.5 Watts Peak
  - 100 mm x 175 mm x 30 mm (3U cPCI)

- **Reliability Features**
  - All Parts SEL Immune
  - SEU Mitigated Design
  - 30 kRad Standard (100kRad Option)

- **Program Heritage**
  - Ball / STP-SIV
The SACI, PAPI, and LASI boards provide a complete spacecraft power distribution system solution. The SACI Board provides a solar array and battery interface complete with battery charge control and telemetry feedback capability. The PAPI/LASI and McLASI boards are general purpose switching cards which are controlled via the SACI. Multiple PAPI/LASI/McLASI boards may be combined to increase the system capabilities.

The SACI, McLASI, and PAPI/LASI are designed to be compatible with a 3U form factor and provide interfaces for a 3U cPCI backplane. In such a setup, the SACI and PAPI/LASI may be used as part of an Integrated Avionics Unit - combining C&DH and EPS functions in one compact assembly.

### SACI™ Boards

- **Typical SACI Features**
  - Charge Control & Solar Array Interface Card
  - 14 Solar Array String Inputs @ 6.9 A (derated)
  - 12/14 Array Strings Switched
  - Software Battery Charging with HW Backup
  - Autonomous Charging of Dead Battery
  - Switch Command & Telemetry Interface
  - Controls up to 3 LASI Cards
  - Solar Array / Battery / Load Current Telemetry
  - Battery Voltage Telemetry
  - 8 PRT Sensor Interfaces
  - 3 Low Voltage Switched Outputs @ 5 V, +/-15 V
  - 20 A Total Throughput Current
  - RS-422 Interface

  Dimensions: 112 mm x 218 mm x 36 mm
  Mass: <0.32 kg

- **Program Heritage**
  - TacSat-2, XSS-11, AMS (Gen 1 SACI)
  - STP-SIV, Angels, Aquila, LADEE (Gen 2 SACI)

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### PAPI™ / LASI™ Boards

- **Typical PAPI/LASI Features**
  - 5 Arm/On/Off Outputs @ 6.9 A each (derated)
  - 10 On/Off Outputs @ 6.9 A each (derated)
  - 2 Arm/On/Off Outputs @ 1.2 A each (derated)
  - 6 On/Off Outputs @ 1.2 A each (derated)
  - 15 A Throughput Current
  - Bus Voltage Telemetry
  - Total Card Current Telemetry
  - Switch Status Telemetry

  Dimensions: 3U Form Factor
  Mass: <0.22 kg

- **Program Heritage**
  - TacSat-2, XSS-11, AMS, STP-SIV, Angels, Aquila, LADEE

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### McLASI™ Boards

- **Typical McLASI Features**
  - 4 On/Off Outputs @ 15 A each (derated)
  - 3 Torque Rod Power Outputs (H-Bridge)
  - Valve and/or Motor Driver Circuitry
  - 20 A Throughput Current
  - Bus Voltage Telemetry
  - Total Card Current Telemetry
  - Switch Status Telemetry

  Dimensions: 3U Form Factor
  Mass: <0.20 kg

- **Program Heritage**
  - TacSat-2, Aquila, STP-SIV
**Modular Avionics Test Interface Boards**

**RS422 - LVDS - Discretes - TTL - Analog - FPGA Logic - SRAM**

The McMOATI Boards (Digital & Analog McMOATI) are general purpose 3U cPCI test boards to used emulate a wide variety of payload or unique subsystem interfaces. Its intended use is for engineering and flight unit ground testing of critical space flight hardware. The board uses devices similar to those used on space flight hardware to ensure that functional and hardware compatibility are tested, even when actual subsystems are unavailable.

The McMOATI boards are a 3U cPCI compatible board designed as a general purpose test and interface boards. The designs provides a multitude of commonly found interfaces such as RS-422, LVDS, and digital and analog inputs and outputs. In addition to these interfaces, the Digital McMOATI provides more than 1 GB of RAM and both have up to 8 MB of SRAM. At the heart of these resources is a 3M Gate fully reprogrammable XILINX Virtex-II FPGA with full access to all I/O, memory, and PCI bus.

With its large number and selection of resources, the McMOATI board can be used in many configurations. Example solutions based on the McMOATI range from a simple PCI based RS-422 interface board to a complete spacecraft subsystem hardware-in-the-loop testset, all implemented on a single or multiple McMOATI boards.

The McMOATI may be used as a standalone board with fixed logic or in more complex arrangements used along side other McMOATI and PCI boards in a cPCI system with a host CPU.

Broad Reach Engineering provides the McMOATI board in many configurations to best meet a particular need. Some applications may only require certain interfaces, in which case Broad Reach will ship an appropriately populated board. Others may require an 'out-of-the-box' solution including a fully programmed FPGA and CPU based RTOS and test software.

Various versions of the McMOATI are in use at Broad Reach Engineering and customer locations for testing and simulation purposes. Let us put our testing and simulation experience to work in your project with this highly versatile and cost effective hardware & software solution.

**McMOATI Application Examples**

- Command Uplink / Telemetry Downlink Board
- Data Encryption / Decryption Board
- High-Speed LVDS Interface Board
- Solid State Recorder Board
- Image Processing Board
- 12-Ch RS-422 Interface Board
- “All of the above” Board
- Custom uC Core Board with differential I/O
- Subsystem Simulator Board
- Complete Digital Hardware-In-The-Loop System
- and many more designs.

**McMOATI System & Software Support**

The McMOATI Board may be used in an industry standard cPCI Chassis together with a cPCI based CPU board. Broad Reach Engineering can provide drivers for VxWorks or OSE, C based routines, or entire solutions.

**McMOATI - Complete Test & Simulation Capability**
Gimbal Control Electronics
Dual Redundant - Micro Stepping Drivers - MIL-STD-1553B

The Gimbal Control Electronics System is designed as a high reliability motor driver system to control the motion of two or more motors, such as used in solar array drives and antenna gimbals.

The function of the Gimbal Control Electronics (GCE) system is to control and drive two types of dual axis redundant actuators. Such as used for typical solar array drives and antenna gimbals. The system contains two primary and two redundant motor drive outputs. These motor drive outputs control and drive small, three phase Wye, six state, and permanent-magnet actuators. The GCE contains two primary and redundant incremental encoder interface circuits.

The GCE communicates with the spacecraft via a dual redundant MIL-STD-1553B bus. The spacecraft provides the 31VDC nominal voltage and the side enable pulsed discretes. The GCE assembly consists of two identical Controllers circuit boards, two identical Motor Driver circuit boards, two identical DC to DC converters boards, two Backplane boards and the chassis.

Features
- Use pulsed discretes to turn on active side.
- Spacecraft Interface via dual redundant MIL-STD-1553B buses
- Uses +5 V and ±15 V DC/DC Converters with separate EMI Filter
- Motor drive has micro-stepping capabilities
- Motor uses half Bridge driver and Quad Power Mosfet to drive the motor
- Provides 8 Isist power points for each motor
- Provides Encoder LED bias current selectable 20 mA or 35 mA
- Provides SOH Monitoring circuit, 12 bit ADC (internal voltages and motor current)
- Provides 1 mA constant current for PRTs and Thermistors (8)

Options
- Single String Version
- RS-422, RD-485, or LVDS interface
- Custom Command & Telemetry ICD
- >2 Motor Versions
- Custom Form Factor

Originally designed for a lunar orbit (NASA Lunar Reconnaissance Orbiter) this design can be tailored to your LEO, GEO or interplanetary mission needs.

Contact Broad Reach Engineering for additional information and a customized quote.

- Mass, Power, Dimensions
  - 3.8 kg
  - 24 to 35V Input
  - 12 W Nominal per active side (excluding motor current)
  - 190 mm x 158 mm x 118 mm
  - -10°C to +40°C Operational Temperature
  - -20°C to +50°C Qualification Temperature

- Reliability Features
  - All Parts SEL Immune
  - 100% Dual Redundant
  - The GCE contains primary and redundant incremental encoder interface circuits
  - The GCE contains two primary and two redundant 3 phase motor drive outputs.
  - >15 kRad Standard (100 kRad Option)
  - Conduction Cooled Design
  - All Parts MIL-883B

- Dimensions in mm

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</tbody>
</table>

- 1113 Washington Ave. - Suite 200
  Golden, CO 80401
  303.216.9777

- 2141 E. Broadway Rd. - Suite 211
  Tempe, AZ 85282
  480.377.0400

- Broad Reach Engineering Company
  www.broadreachengineering.com
The Rikishi Electronics Unit (REU) is a Robotic Arm Controller designed to drive up to nine separate servo motors (joints), such as found on robotic arms or articulated structures.

The Rikishi Electronics Unit (REU) provides a platform for command and telemetry processing, execution of motor control commands and algorithms, execution of general purpose commands, and storage for volatile and nonvolatile data.

The REU is composed of (1) communication board (COMM) and (9) motor controller boards (MCBs) integrated into a 10 slot 3U chassis. Spacecraft bus power (28 VDC) is applied directly to the REU backplane via its rear 8-pin power connector. There are chassis mounted DC/DC converters that provide regulated power from the 28 VDC spacecraft bus.

The spacecraft communicates to the REU via RS-422. An ‘emergency disable’ and ‘emergency hold’ discrete input is provided via the COMM board. The REU is designed as a single-string system without explicit redundancy. The (1) COMM board and the (9) MCBs are all on the primary side of the 28 VDC spacecraft bus. The COMM board provides isolated 5 V power required to power the COMM devices that are on the secondary side.

To move the Robotic Arm, joint level commands are sent to the COMM board from the S/C at a 500Hz rate. Each command contains the position, velocity, gravity compensation, and inertial load compensation values for each of the motors. If the command is accepted by the COMM board, it will forward the command to the appropriate MCB board for execution by the low level PID controller.

Position/velocity telemetry data is returned at a 500Hz rate from the COMM board to the S/C. Telemetry contains raw R/D position/velocity data and status from each of the MCB boards.

Commands can also be sent on the secondary command link to control such things as setting PID controller parameters, setting/clearing fault masks, clearing failures, writing/dumping SRAM, writing/dumping EEPROM, dumping debug parameters, etc. This secondary command link is setup for a command & acknowledge interface. All required telemetry not returned in 500Hz telemetry is returned using this interface.

Servo Motor Controller Board Features
- BRE ‘SNAP’ DSP Controller in FPGA (20 MFLOPS)
- Command and telemetry interface
- Resolver drive (differential sine wave)
- Motor drive (10 A 3-phase servo motor outputs)
- Motor commutation
- Motor brake drive and control (Opto-Isolated)
- Actuator output position determination
- Actuator output position closed loop control
- Analog data measurement
- Non-volatile code storage
- Volatile SRAM storage for micro-controller code
- PRT current source and measurement
- Pre-amp +/-15 V supply (Opto-Isolated)
- EMI filtered power for 28 VDC 3-phase outputs (10 A)

Typical Mass, Power, Dimensions

| REU Testing with 9 Servo Arm Simulator / EGSE |
| Servo Controller Board Features |
| BRE ’SNAP’ DSP Controller in FPGA (20 MFLOPS) |
| Command and telemetry interface |
| Resolver drive (differential sine wave) |
| Motor drive (10 A 3-phase servo motor outputs) |
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Motor Controller Board
- <500 grams
- 3U Form Factor
- 10 A Motor Driver Capability
Spaceborne GPS Receivers

Features
- GPS Internally Redundant (Digital Processors and DC-DC Converters)
- Based on PowerPC 603e CPU
- Dual-Frequency L-Band
- Dual POD Antennas
- Dual Occultation Antennas
- Solid State Recorder - 128 MBytes
- Integrated Payload Controller
- 4 RS-422 Inputs, Cmd/Tlm rates from 57.6 Kbps to 2 Mbps
- 3 Meter Accuracies Real-Time

Design & Heritage
The IGOR design is based on the NASA/JPL Black Jack space-borne GPS Receiver. The Black Jack receiver is a revolutionary spaceflight Global Positioning System (GPS) receiver developed by NASA/JPL to fill future needs for orbit-based GPS science.

The IGOR design continues the evolution of the Black Jack receiver and previous units and incorporates several improvements based on the experiences made with the Black Jack on previous NASA/JPL missions including CHAMP, SAC-C, Jason-1, and GRACE. To date 9 IGOR receivers have been deployed as primary science payload on the COSMIC mission, TerraSAR-X, Tandem-X and the TACSAT-2 missions. Additional receivers are due to be launched soon.

GPS Occultation Science
A technique relying on the simple fact that a planet’s atmosphere acts much like a variable density lens, bending and slowing the propagation of microwave signals passing through it from the Ionosphere down to the surface. The lens effect results from decreasing atmospheric density with altitude. If the positions of transmitting and receiving satellites are precisely known, the “atmosphere delay” can be measured precisely, the time derivative of which (Doppler) can be inverted to give atmospheric density vs. altitude information.

The IGOR Occultation GPS Receiver is designed to meet all the requirements of such occultation science experiments. In addition, the IGOR also provides the functionality of a POD GPS receiver with a payload controller, and a solid state recorder.

<table>
<thead>
<tr>
<th>IGOR Specifications</th>
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<tbody>
<tr>
<td>Dimensions</td>
</tr>
<tr>
<td>200 mm x 240 mm x 105 mm</td>
</tr>
<tr>
<td>Processor</td>
</tr>
<tr>
<td>2 Redundant Motorola PowerPC 603e</td>
</tr>
<tr>
<td>Mass</td>
</tr>
<tr>
<td>4.6 kg</td>
</tr>
<tr>
<td>Power</td>
</tr>
<tr>
<td>23 W Peak, 16 W Nominal [28 VDC +/- 6 V]</td>
</tr>
<tr>
<td>Radiation</td>
</tr>
<tr>
<td>TID - Estimated 12Krad at Low Dose Rates (Satellite Shielding not Included).</td>
</tr>
<tr>
<td>SEL - No Destructive Latch at 40 MeV</td>
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<tr>
<td>SEU - Designed for Tolerance &amp; Recovery</td>
</tr>
<tr>
<td>Availability</td>
</tr>
<tr>
<td>Now</td>
</tr>
<tr>
<td>(Product is slowly being phased out and replaced by Pyxis Receiver)</td>
</tr>
<tr>
<td>Flight Units 6-8 ARO</td>
</tr>
<tr>
<td>(depending on requirements)</td>
</tr>
</tbody>
</table>

Illustration of GPS Occultation Concept

Occulting GPS Sat
Occulting LEO Sat
IONOSPHERE
NEUTRAL ATMOSPHERE
EARTH

Broad Reach Engineering Company
www.broadreachengineering.com
**PYXIS NAUTICA**

**Next Generation Precision Orbit Determination + Occultation GNSS Receivers**

The Pyxis Line of spaceborne GNSS receivers is the next generation of GNSS receivers based on the highly successful IGOR receiver. The Pyxis incorporates the lessons learned from the IGOR design and implements a number of improvements and upgrades made possible by recent technology developments.

The Pyxis line is based on the BRE440 CPU and a new BRE developed GNSS ASIC/FPGA. Logic miniaturization and processing improvements allow reduction of the receiver size by at least a factor of 2 while increasing radiation and electrical performance. A new RF front-end and digital section improve signal-to-noise ratio as well as sampling resolution. The addition of L2C and L5 frequencies and eventually Galileo frequencies provide increased Occultation Data and improved PVT resolution. Software improvements include the addition of a customer API for custom code development and the addition of GNSS Attitude determination ability.

The Pyxis receiver is available as a stand-alone receiver or 3U cPCI board LEO Precision Orbit Determination receiver (Pyxis-POD), as a Radio Occultation and POD GNSS Receiver (Pyxis-RO), and as a GEO Precision Orbit Determination receiver (Pyxis-GEO).

**Pyxis-POD**
- BRE440 Processor
- <2.0 kg
- <20 W Peak, 16 W Nominal [28 VDC +/-6 V]
- SEL Immune & SEU Mitigated Design
- Attitude Determination via GNSS (Option)
- 1 or 2 Antenna Inputs (Option 4 for AD)
- 16 to 64 Channel GNSS Receiver
- Position Accuracy Sub cm
- Position Velocity Sub mm

**Pyxis-RO**
- BRE440 Processor
- <4.5 kg
- <30 W Peak, 25 W Nominal [28 VDC +/-6 V]
- SEL Immune & SEU Mitigated Design
- 4 to 6 Antenna Inputs
- 48 to 128 Channel GNSS Receiver
- Software for Open/Closed Loop Occultation Tracking

**Pyxis-GEO**
- BRE440 Processor
- <2.0 kg
- <20 W Peak, 16 W Nominal [28 VDC +/-6 V]
- SEL Immune & SEU Mitigated Design
- 1 or 2 Antenna Inputs
- Software Algorithms for POD at GEO

**Pyxis-POD / PYXIS-GEO**

**Dimensions in mm**

**Typical PYXIS-POD / PYXIS-GEO Dimensions in mm**

**PYXIS-RO to IGOR Comparison**
Specialized Payload & Instrument Electronics

Broad Reach Engineering designs specialized payload and instrument electronics to accomplish specific mission goals. Examples range from high voltage and very low current monitoring systems to high-speed payload data processing electronics. Broad Reach Engineering can deliver complex instrument electronics for your specialized science mission - in space, on earth, or any other planet.

Key Capabilities
- Custom Processor Solutions
- FPGA or CPU Based Designs
- PowerPC Designs
- Actel FPGAs & XILINX Virtex Reconfigurable FPGAs
- DC to RF Designs
- Ultra Low-CURRENT to High Voltage Designs
- Low to High-Volume Non-Volatile/Volatile Data Storage
- In-Situ Data Processing via FPGA or CPU
- Redundant or Single String Systems
- 3U, 6U cPCI or Custom Form Factor
- 422, 485, 1553, 1773, LVDS, SCSI, SpaceWire
- and Proprietary Data I/O
- All Parts SEL Immune
- SEU Mitigated Design
- 30 kRad to >1 MRad Designs

Example Developments
- Data Processing & Encryption Board
- Ball / Digitalglobe Worldview-1/2
- Vibration Isolation System Data Acquisition Board
- Honeywell / Tacsat-2
- Ion Probe Data Acquisition System
- AFRL / Tacsat-2
- Instrument Interface Electronics
- NASA ST-7 / LISA Pathfinder
- RF Amplifiers & Diplexers
- IGOR / IGOR+ Receivers

Contact Broad Reach Engineering today to discuss your Science Payload & Instrument Electronics needs.
The Swift-Broadband Terminal for Spacecraft (SB-SAT) is a communications terminal designed for LEO applications that provides a bi-directional communications link to the LEO from the ground via the Inmarsat 4th Generation GEO Communications Satellite Constellation and the Inmarsat BGAN Network. SB-SAT provides near real-time communication access to the LEO satellite globally and without the need for dedicated groundstations or spectrum licenses.

The Broad Reach Engineering SB-SAT terminal together with the Inmarsat SB-SAT data service provides communications access to the SB-SAT equipped LEO satellite similar to the way in which the NASA TDRSS satellites do.

Using the constellation of existing Inmarsat GEO satellites as a relay, a spacecraft equipped with an SB-SAT terminal is accessible globally and in near-real time through Inmarsat’s BGAN network. Based on 3G technology, Inmarsat’s BGAN network provides IP connectivity to the SB-SAT terminal allowing the user to treat the SB-SAT equipped satellites as just another node on an IP network, either a closed one or the Internet.

**Key System Features**
- Uses Existing Inmarsat Communications Infrastructure
- Global Coverage
- Near Real-Time Access
- Near Continuous Data Link
- On-Demand Service Use
- No Requirement for Frequency License
- No Provisioning Delay - Stand-By Possible
- Multiple Geographically Co-Located Links (Formation Flying)
- Access from Anywhere On Earth via Internet/Inmarsat
- Competitive Equipment Cost
- Competitive Service Pricing
- Equipment Designed Specifically for Spacecraft Application
- Optional Data Encryption (AES Internal or MCU-110 External)

**High Rate System Example**
- Dual Channel up to 984 kbps (Best Case)
- Full Duplex
- Multiple Antenna Options @ >14 dBi
- 2-Axis Articulated High Gain Antenna
- Electrically Steered Antenna Array
- Host Pointed High Gain Antenna
- Built-In Antenna Motor Controller Option
- Built-In L1 GPS Receiver
- <50 W Max. Power (Transmit)
- <20 W Nominal (Standby)
- <10 kg Including Antenna

**Low Rate System Example**
- Single Channel up to 48 kbps
- Full Duplex
- Fixed Medium Gain Patch Antenna(s) @ 6 dBi
- External GPS
- <25 W Max. Power (Transmit)
- <10 W Nominal (Standby)
- <3.5 kg

... and many more variations in between!

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**Global Coverage - Near Real Time - On Demand - IP Based Communications**

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**Dual Channel System with Articulated High Gain Antenna**

**Low Rate System with Patch Antenna(s)**

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**Equipment Designed Specifically for Spacecraft Application**

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**Optional Data Encryption (AES Internal or MCU-110 External)**

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**Competitive Equipment Cost**

---

**Competitive Service Pricing**

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**Equipment Designed Specifically for Spacecraft Application**

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**Optional Data Encryption (AES Internal or MCU-110 External)**

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**Competitive Equipment Cost**

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**Competitive Service Pricing**

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Broad Reach Engineering provides systems engineering and design services for space vehicle subsystems and space missions. Our employees are experienced in the development, management, and delivery of a variety of spacecraft hardware and software.

We specialize in supporting the mission with our knowledge, technology, and no-nonsense approach to mission and systems engineering. We strive to support the principal investigator in achieving the primary science goals by working as the technical facilitator between the spacecraft developer, mission operators, and the science team. Broad Reach can help you at all stages of a mission, starting in the proposal phase and extending all the way through testing, launch, and on-orbit operations.

About to embark on a space mission? Already on your way? Contact us to find out how we can help you achieve your goals.

**Capabilities & Approach**
- Combined over 350 Years Space Experience
- In-Depth Knowledge of Launch Vehicle Options
- Network of Partners in Industry and Academia
- No-Nonsense Approach
- Hands-On Experience in Design, Management, and Test
- Not Constrained by “Heritage” Systems Approach

**Services**
- Systems Engineering Support at All Project Stages
- Component, System, Vehicle, and Mission Design
- National & International Mission Support
- System & Subsystem Trade Studies
- Architecture Development
- Consulting & Review Support
- Due Diligence Support
Broad Reach Engineering has assembled a team of seasoned software architects and engineers with decades of hands-on experience developing software for space, aviation, telecommunications, and other high-reliability products, for real-time embedded and desktop environments.

Broad Reach expertise in software design includes object-oriented techniques (e.g., Unified Modeling Language) and structural approaches (e.g., Data Flow Diagrams) for applications that range from very small, embedded, OS-less applications to multi-processor, distributed, networked, client-server systems.

Broad Reach engineers are well versed in many programming languages including C, C++, Java, VB, as well as many scripting languages such as Perl, VB Script, Tcl, and Python.

Our software development process is custom tailored to the needs of each individual project. While some projects might require a process that embraces both RTCA/DO-178B and post MIL-STD-498 techniques, others might benefit from using a software ‘Craftsmanship’ approach. At the start of each project, we will establish the most fitting approach together with our client to best meet the project goals.

Regardless of the approach taken, quality is enforced throughout the entire software development lifecycle through the use of peer reviews, formal inspections, configuration control, and a controlled change management process.

In addition to general software design services, Broad Reach offers Spaceflight software covering Command & Control, Payload, Housekeeping, and Orbit Determination functions. Using a modular architecture, generic core spacecraft software services are combined with hardware specific interface code and mission specific algorithms, such as ADCS algorithms and payload software.

Broad Reach has developed an extensive set of core spacecraft software services that can quickly be tailored to the customer’s needs through easy integration of additional software functions. Broad Reach has successfully provided this approach on TACSAT-2, where software modules from 4 external parties have been integrated by Broad Reach with the Broad Reach Spacecraft Flight Software.

Operating Systems Supported
- Wind River VxWorks
- OSE, Nucleus, ThreadX
- Windows
- Solaris, Linux, OS-X
- uCOS

Target Platforms
- PowerPC
- ARM
- Intel
- Various DSPs
- Various other uC

Broad Reach Engineering has assembled a team of seasoned software architects and engineers with decades of hands-on experience developing software for space, aviation, telecommunications, and other high-reliability products, for real-time embedded and desktop environments.

Software Development System

Spacecraft EGSE

Broad Reach or 3rd Party Hardware