PowerBuoy Power Converter Review

May 12, 2015

Introduction

The MBARI PowerBuoy is a point-absorber time wave-energy converter that consists of a surface buoy connected to a submerged anti-heave plate by an electro-hydraulic power take-off device. Wave excitation causes the two bodies to move relative to one another and the power take-off device converts the energy in this relative motion from mechanical energy to electrical energy. Inside the power take-off device the piston forces oil through a hydraulic motor, this turns an electrical generator. A challenging aspect of this design is that the energy to be converted occurs across a wide range of power levels, for average powers of 300W in the system, the range of instantaneous power is from 0 to 8000W. Because the generator is a permanent magnet type, the voltage range that this power is delivered out of the generator is also wide, zero to hundreds of volts. This document and review outlines the electrical conversion system being developed to convert this wide range of voltage and power to a constant voltage suitable for storage in batteries. Figure 1 illustrates the basic components of the system.

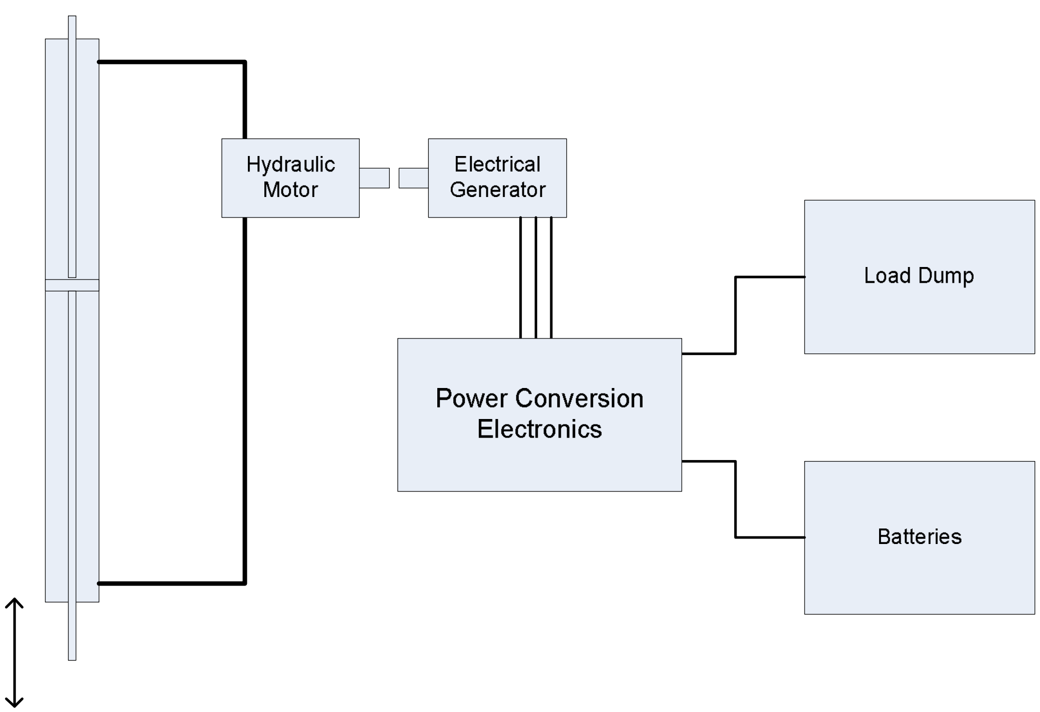


Figure 1 Block diagram of power flow through wave-energy buoy. Mechanical power is translated by the hydraulic system (piston and motor) to rotational power, which is converted to electricity by the generator. Depending on the state of the batteries, this electrical energy is then used to charge the batteries, or is dumped into a load to maintain a target loading on the system.

The previous iteration of this power converter system utilized commercially available DC to DC converters to convert the generator output to 28 Volts, suitable for charging a 24V lead-acid battery bank. Although this system has been used in several deployments, it suffered from several drawbacks.

- The system had limited capacity and was not able to convert more than ~1000W, at powers above this level current was directed to a load dump at the generator output voltage. It would be possible to increase this capacity by adding more converters. In addition to being cost prohibitive, without complicated switching, this makes the system less efficient at lower powers by running several DC-DC converters in parallel at low loadings compared to their capacity.
- No DC-DC converters were available to cover the entire input voltage range, so the system switched between converters as the generator output voltage changed (Two converters were used, 35-150V, and 150V-425V). Because the output voltage of the generator sags when it is loaded, the current that each converter was allowed to draw at the bottom end of its voltage range had to be limited, or the generator voltage would drop below the converter range and they would turn off again.

Although limited by these features, that system powered several deployments and a wealth of data has been collected, this has been very useful in designing the power converter scheme described here.

The goal of the current design effort is to create the necessary power electronics to overcome the previous limitations and develop a system that has sufficient capacity to convert all (or almost all) of the available energy to a voltage suitable for storage. For reasons to be described in the next section, the resulting system utilizes a higher voltage battery bus that is at or above the maximum voltage the generator produces when it is spinning at top speed. In this way the capacity of the system to provide useful voltages (i.e. 24 Volts) only needs to be large enough to satisfy the peak system loads of a few hundred watts, not the peak generation power levels. As described below, the power conversion system therefore consists of a boost-only system that raises the generator voltage up to the battery system voltage. Should the batteries be full, this system redirects the energy to a load dump to keep the power take-off system loaded.

Converter Operating Points

Data from previous deployments provides a good estimation of the power levels and required operating points of the power conversion system. Figure 2 illustrates the distribution of energy captured over three deployments (6 months total) as a function of generator RPM for three deployments. As is clear, the bulk of the total energy is captured when the generator is spinning at between 1000 and 3000 RPM, so this is the speed band the power conversion system should operate best at. Although the peak speeds observed are close to 8000RPM, these events occur rarely so the system needs to survive these events, but does not necessarily need to capture energy efficiently at those extremes. Similarly, zero or very low speeds occur often, but there is little total energy in these occurrences. This means that the total efficiency of the converter can be increased significantly if it has a low quiescent current and doesn't use a lot of power when the generator isn't spinning.

Figure 3 shows the range of expected power/rpm points the system needs to work effectively at. The loading depends upon sea-state, so there is a range of loads that are encountered. The upper edge is approximated by the $0.027*N^{1.5}$ curve, and the lower edge is approximately 0.5 W per RPM. At very low speed (< 1000RPM), the typical loading is below the 0.5W/RPM line and is approximated by the $0.011*N^{1.5}$ curve. The hydraulic system includes a pressure relief valve that opens at a set pressure (below 3000psi) and acts as a power limiter into the generator. As long as the power converter system increases the current flowing through the generator at higher speeds, this limiter also acts as a peak voltage limiter. e.g. as the piston moves faster, the RPMS and the pressure increase together until the pressure relief valve opens, effectively limiting the peak rotational speeds observed. The few data points above 6000 RPM are from a single storm in which the pressure relief valve was set too high to effectively limit the generator speed.

Figure 4 and Figure 5 provides some information about the duration of high power levels, this is important for sizing the current carrying capacity of the electrical elements throughout the system. The data shows the instantaneous power captured throughout the three deployments, filtered by a variety of moving average window lengths. It is clear that high power events don't last very long. From this data a power handling specification for all elements of the system has been set at 1000W continuously, with 4 second long 8000W pulses.

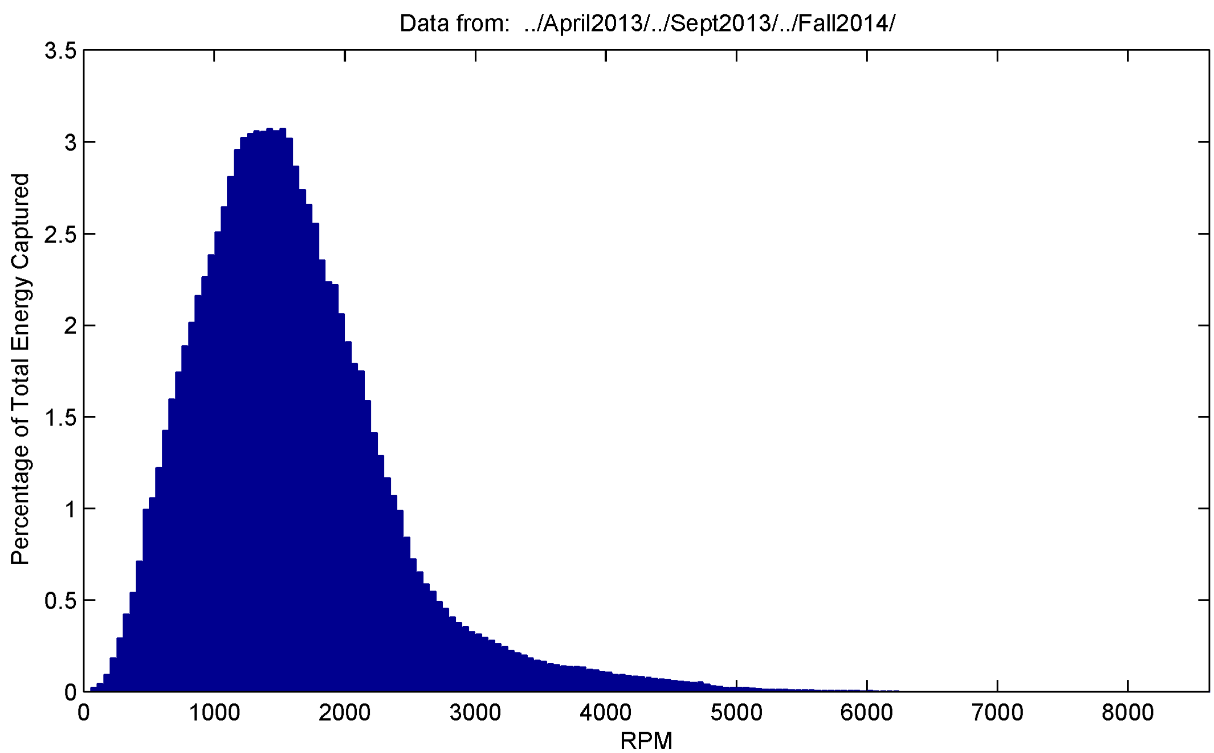


Figure 2 Histogram of energy capture versus generator RPM. The bulk of the energy captured by the system occurs between 1000 and 3000 RPM, so the systems efficiency should be optimized in this range.

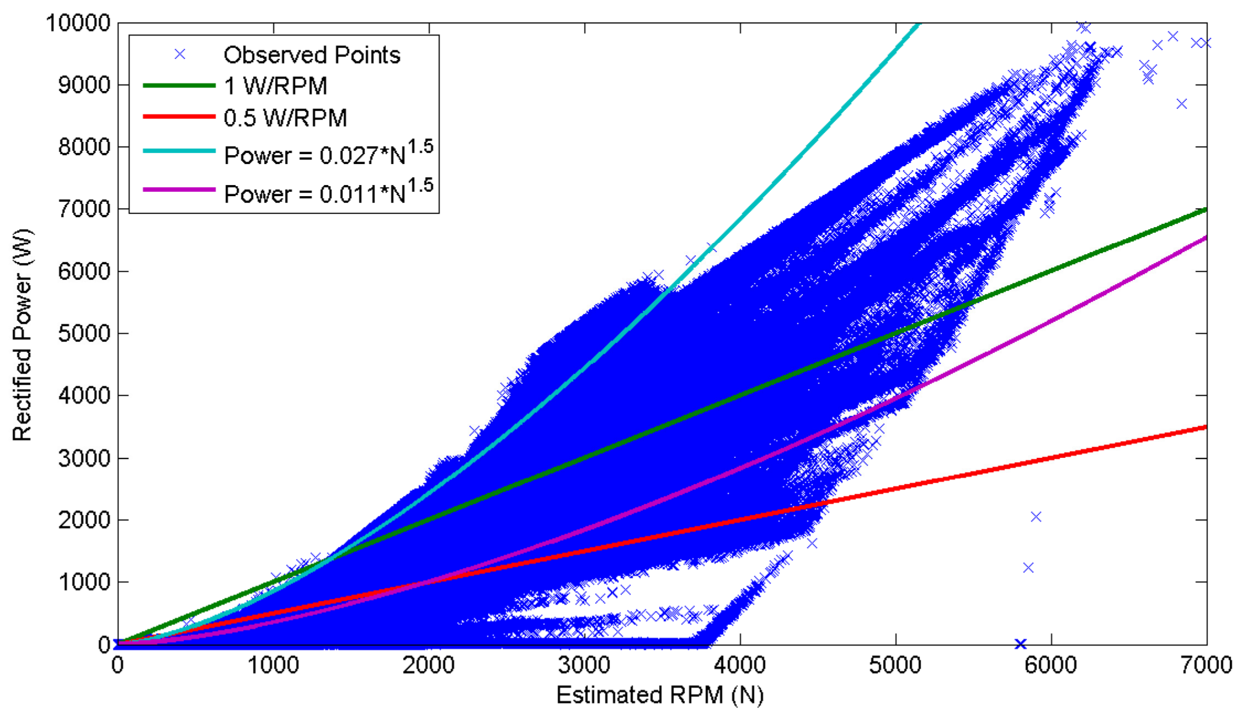


Figure 3 Output power versus generator speed operating points.

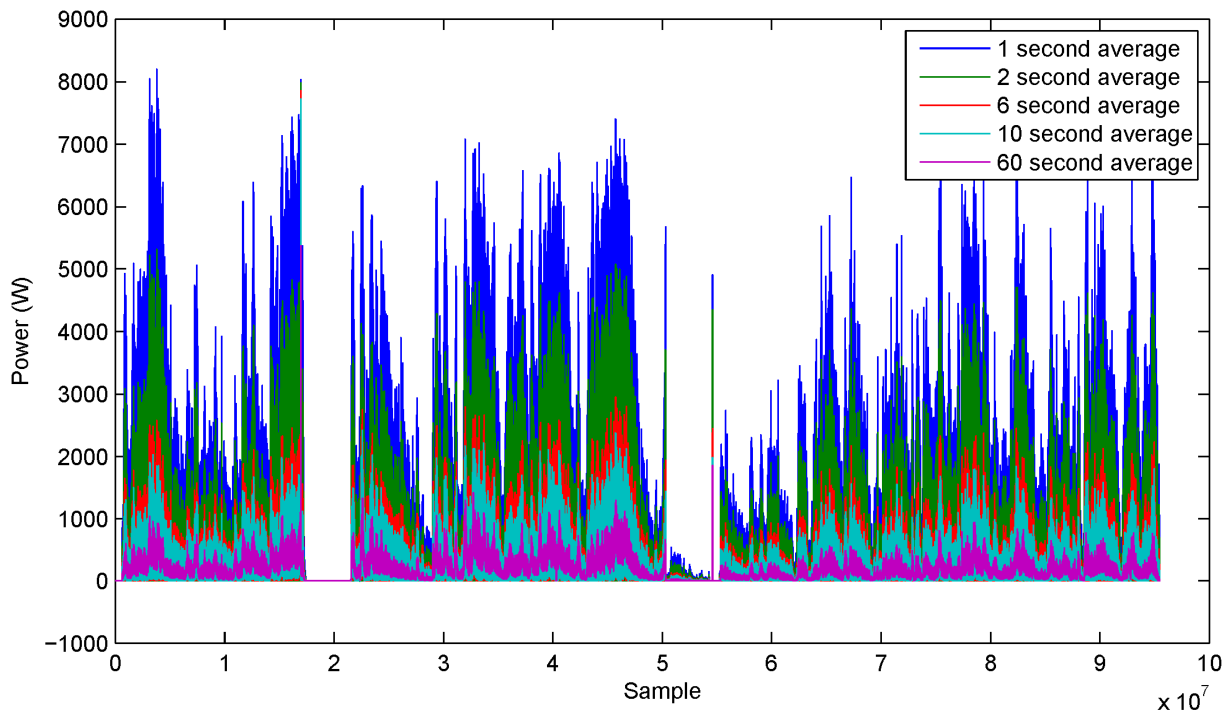


Figure 4 Time histories of power captured, filtered by various length moving average windows.

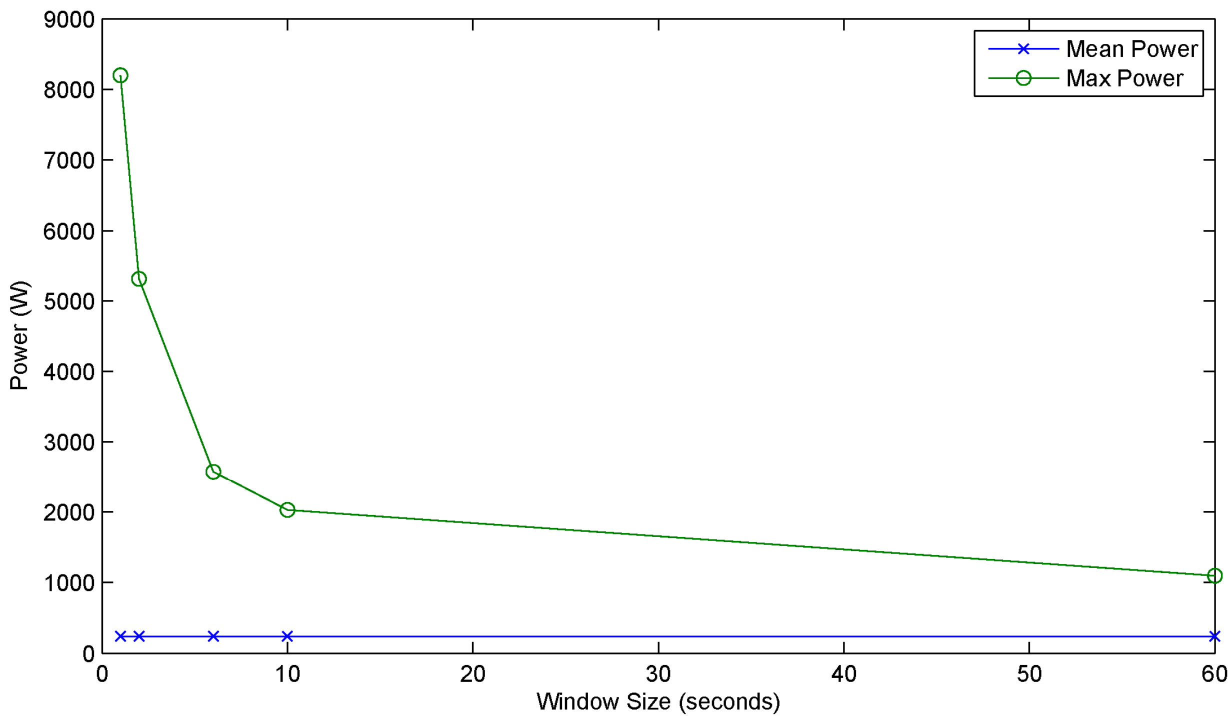


Figure 5 Max observed power for each window size.

Requirements

In addition to being able to handle the power levels described above, and being optimized for efficiency between 1000RPM and 3000RPM, additional requirements for the system include:

- An ability to act as a battery charger that delivers more power when the battery bank is discharged, and less (zero) power when the batteries are fully charged. Additionally, the power converter should limit electricity flowing to the batteries to a peak voltage and current. These targets depend on the size/type of battery pack installed.
- An ability to maintain a target load on the hydraulic motor that is a function of motor speed and direction. This target needs to be adjustable during operation as the wave-energy platform performs best when lightly loaded in calm sea-states, and heavily loaded in rough sea-states.
- An ability to dump excess power safely to maintain the loading targets if the batteries are full and cannot accept additional charge.
- An ability to operate independently, with or without a battery connected (in case of a failed cable or batteries),
- An ability to provide a low-voltage (i.e. 24V) connection for independent buoy equipment to draw power from. In the case of depleted batteries, the system shall turn this voltage off to preclude external equipment from discharging the battery pack below safe levels. Some hysteresis in this low-voltage disconnect is required to keep the disconnect from cycling.
- The power converter shall collect instantaneous voltage and current data during operation and make that available for logging by an external buoy controller, no long-term storage of performance data within the power system is required.

Other Desirable Features

In addition to providing the capabilities described above, there are a handful of other features that are desirable, but are not absolutely required for upcoming test deployments.

- Bi-directional operation. In some applications, it may be desirable to run the generator in reverse and use the power system to move the hydraulic ram in and out. To accomplish this the system needs to be able to transfer energy from the batteries to the generator to run it as a motor. Typical applications would require at a minimum a torque mode, and possibly the ability to close a loop to maintain a measured value at a target (such as a pressure sensor indicating the depth of the submerged anti-heave plate).
- The ability to adjust the operating point of the converter (load versus RPM) based on recent (10’s of minutes) history of the generator behavior (RPM) which represents the current sea-state.

Proposed Design Overview

In order to meet the requirements and goals described above, the design that has been pursued is a boost-only power converter that boosts the output of a permanent magnet generator (whose output voltage depends on RPM) to a higher voltage battery bus. This design uses the inductance of the motor windings as the inductive element, uses MOSFETs for the rectifier bridge, and includes a large (1mF) capacitor to smooth the output. By turning on the lower three FETs in the bridge for part of a high frequency cycle (20kHz), the output voltage of the bridge is boosted above the generator voltage depending on the ratio of on-time to off-time of the lower three FETs in the bridge. Typical of a boost converter, the effect is that when the leads of the motor are shorted together, energy accumulates in the windings of the motor and the inductance insists that the resulting current keeps flowing when the lower FETs are turned off. The resulting energy flowing onto the bus is at a voltage higher than it would otherwise be in a simple rectifier. By adjusting the pulse width of the signal driving the lower part of the bridge, the output voltage can be controlled. The capacitor on the bus filters the resulting ripple and relatively constant current flows up to the batteries.

The control system is relying on the fact that the batteries draw higher current when a higher voltage is applied, this allows the control system to adjust the total power (increasing voltage increases current) and hence can follow a target power which is a function of motor RPM as desired. In the case that the batteries are full, and therefore can't draw power without exceeding their peak voltage, the control system must dump the excess power through a power resistor. This is done by pulse-width-modulating a single transistor which is on the low side of a resistor that is well heat-sunk by the sub-sea housing itself. The control system to achieve this functionality is described in more detail below.

The battery system is nominally selected to be 24 lead-acid batteries in series, fully discharged these have a voltage of 250V, and the float voltage for the system is 330V. This provides the range of voltages the system must produce current at. Different battery chemistries would change this requirement somewhat.

Although not required, there are some performance enhancements possible by commutating the transistor bridge.

<u>Design Particulars</u>

- Generator: AKM64S Permanent Magnet motor, Kv = 40V/kRPM, Rw = 0.15 Ohms, Lw = 0. 87 mH. Peak continuous current = 24A.
- MOSFETs: Cree SiCarbide FETs, RDSon = 0.025 Ohms
- Capacitor: 600V, 1.03mF
- Load Dump Resistor. 2X1kW 10 Ohm Ohmite TAP resistor
- Current measurements. Resistive shunts (immune to magnetic fields near to motor/generator)
- Control micro-controller: dsPIC33FJ
- Bus Voltage (250V->330V), corresponds to 24 Lead-Acid 12V cells in series.

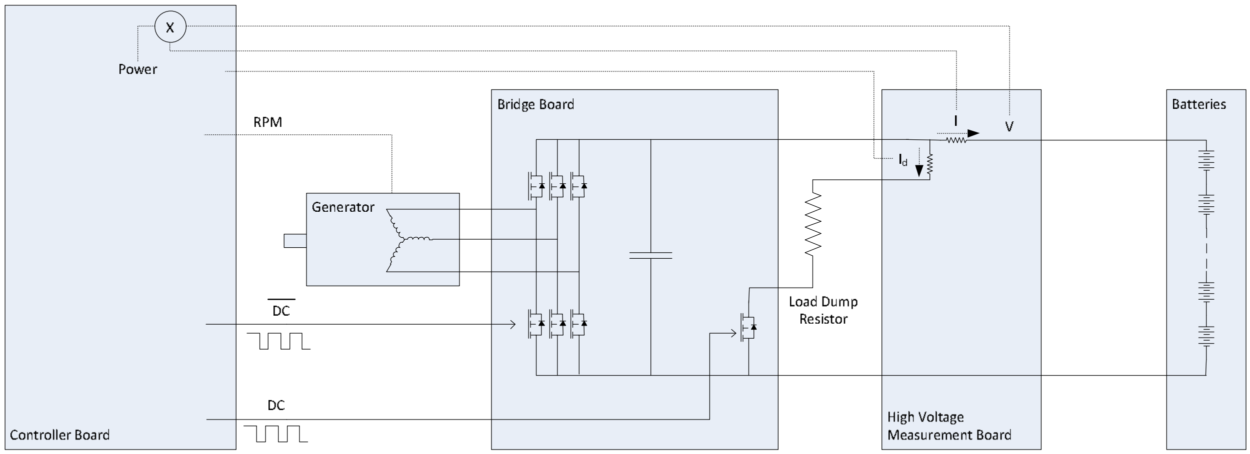


Figure 6 Block diagram of major power system components. Everything in this drawing except for the batteries will be in a single housing sub-sea. The control system is microprocessor based (dsPic) and is responsible for monitoring the output voltage and current and adjusting the bridge and load dump PWM signals. Not shown is a fourth circuit board that provides 15V from the high voltage bus to power the controller board, measurement board, and bridge board.

Prototype Performance

Most of this system has been prototyped in the lab, performance measurements have been made by spinning the generator with a second motor that allows the entire operating range to be exercised. Figure 7 shows the test setup.

Estimates of the boost converter behavior can be made by making some small-ripple assumptions about the current flow, and equating the energy stored in the windings during the charge part of the cycle with the energy accepted by the capacitor in the discharge part [Ref: Erickson & Maksimovic]. Since the time spent in each is a function of the duty cycle, the analysis results in an estimate of output voltage as a function of duty cycle for various loadings. Figure 8 presents some of the test data collected at two loadings, 0.5W/RPM, and 1W/RPM. As can be seen the measured results consistently underperform the expected results. This is most likely because although the model includes the generator winding resistance and the FET on resistance as loss terms, it does not include losses that occur during transistor switching, the diode voltage drops, or a myriad of other small losses.

As can be seen there is a duty cycle above which the boost effect diminishes, meaning that there is a peak output voltage achievable. As can be seen, at the speeds illustrated, the 330V peak target necessary for charging the batteries can be achieved in all cases.

The maximum power levels tested so far have been limited by failures that occur at higher power levels. These failures are under investigation and are likely related to ringing seen on the FET gate drive lines. To control these oscillations resistance has been included in the gate drive signal which slows the transition time, and increases switching losses.   An improved prototype board is under development.

In spite of the failures, this test set-up has allowed us to prototype nearly the entire system, include the current and high voltage measurements, data acquisition, control system, and CAN communications.

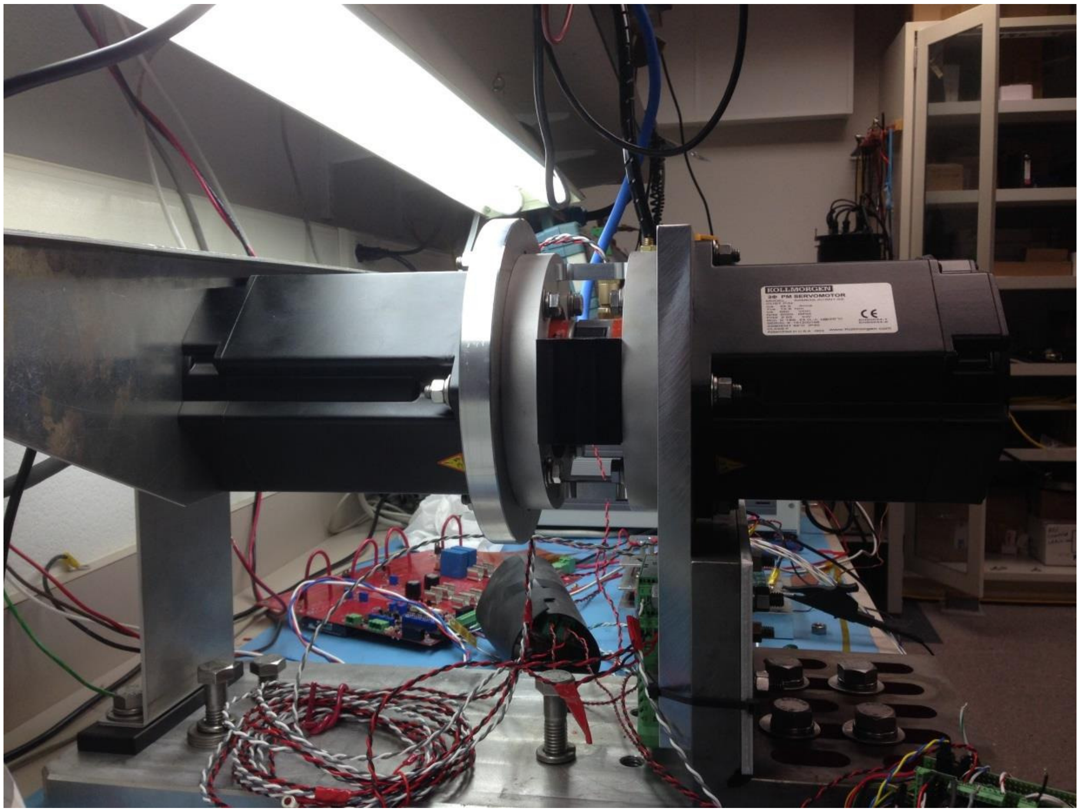
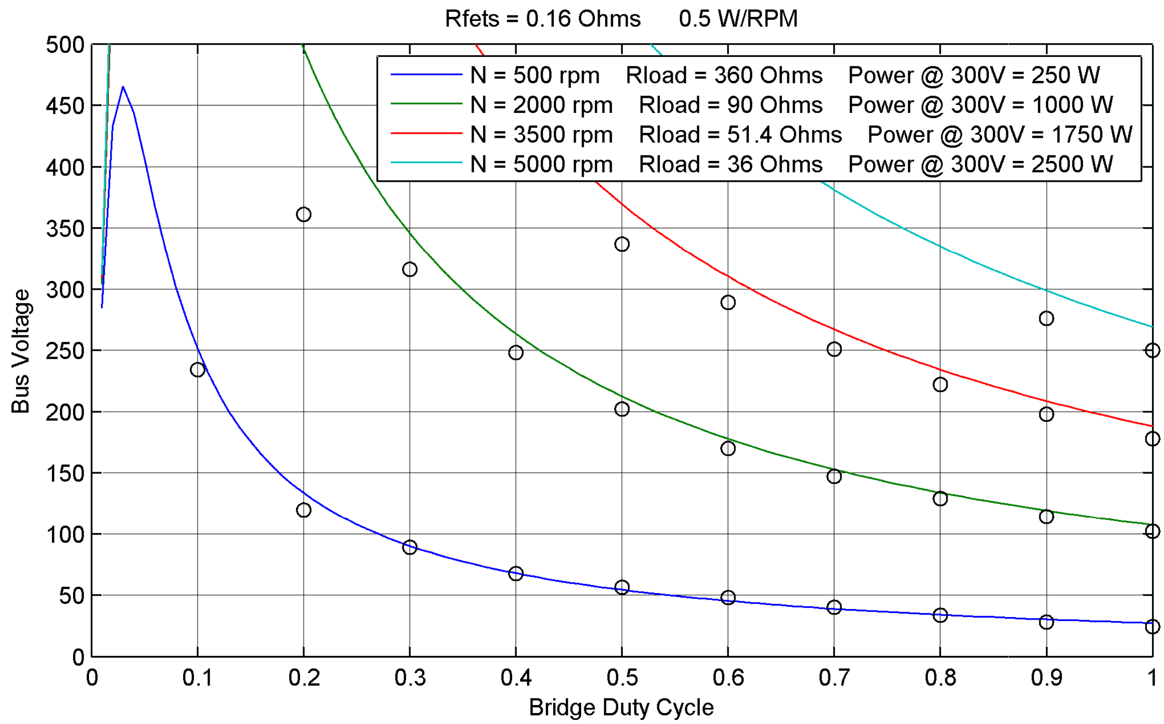


Figure 7 Lab test setup, the motor on the right is the driving motor, and the generator under test is on the left. Between the two is a torque sensor for measuring mechanical input power. The sheet-metal wings on the left are to support calibrating weights for the torque sensor, and the sheet metal angle behind that hold the power conductors and encoder wires at the axis of the motor so they contribute as small a torque as possible.



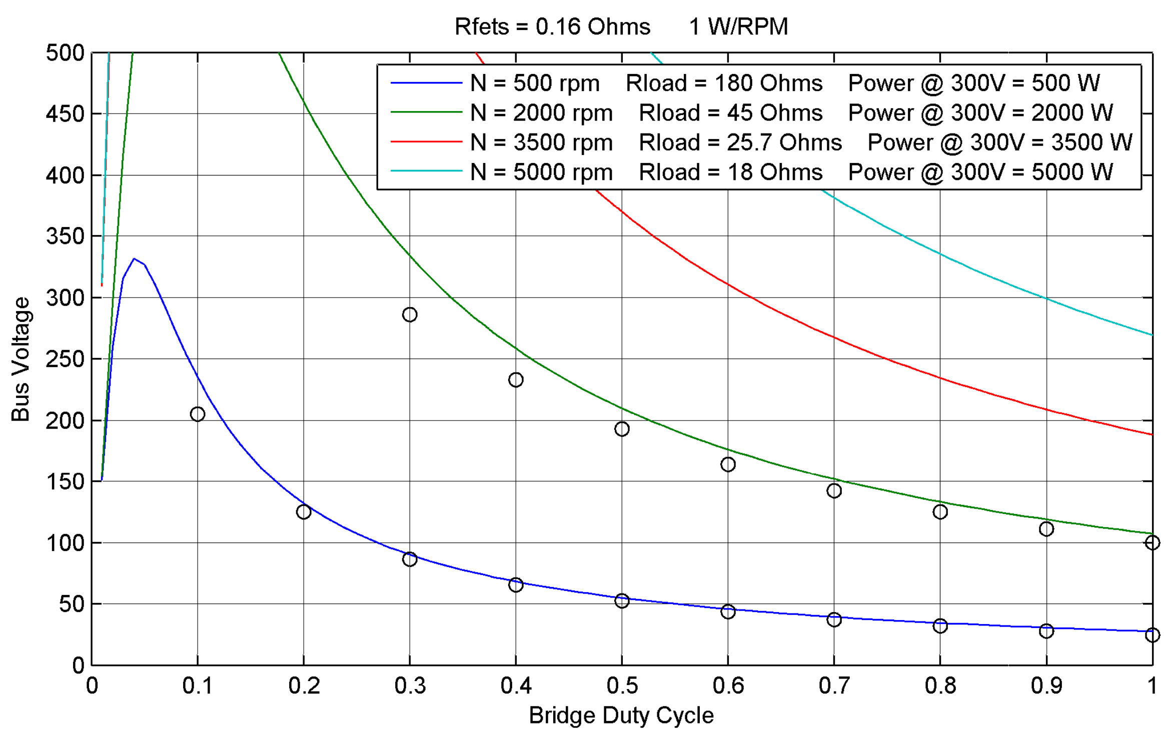


Figure 8 Test results for output voltage at different boost duty cycles, motor speeds, and loadings. The colored lines are predictions that include the winding resistance and FET on resistance as loss items, the black circles are measured results.

Reference Materials

- System Block Diagram and Overall Wiring Diagram
- Power Converter Housing Mechanical Arrangement
- Bridge Board Schematic and Specifications
- High Voltage Measurement Board Schematic
- BootStrap Power Supply Schematic
- Controller Board Schematic
- Battery System Schematic
- Firmware Overview
- Electrical Safety

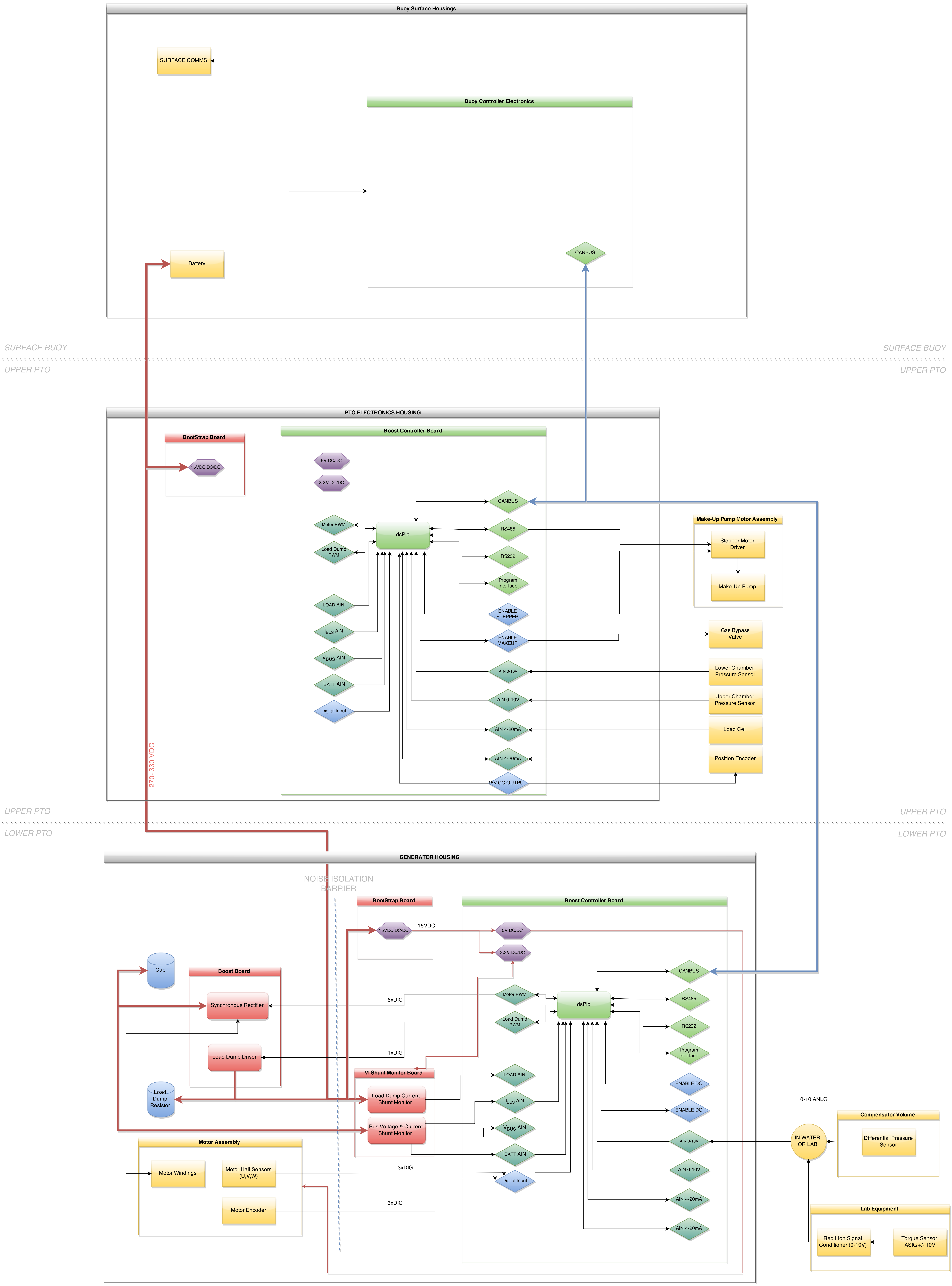
System Block Diagram and Overall Wiring Diagram

This section shows how the power converter reviewed here fits into the overall system. The power converter system supplies 24V to the buoy electronics (controller, GPS, radio, etc) and provides telemetry data over CAN bus. Also streaming data on the same CAN bus is a controller in the pneumatic spring that monitors piston position and gas pressures. Those electronics are variants of the controller and power supply boards developed for the power converter.

Documentation Included:

- System Block Diagram
- Overall Wiring Diagram

POWER BUOY FUNCTIONAL ELECTRONICS DIAGRAM



Power Converter Housing: Mechanical Design

The bulk of the power converter is to be housed sub-sea in the same housing as the electrical generator. This includes the left four boxes of Figure 6, this allows the potentially electrically noisy components to be kept away from other buoy electronics, and allows the load-dump resistor to be easily cooled by seawater without routing those high-voltage connections outside of the can. With all the components housed together in this manner the system can run without a battery connection and will continue to load the system properly should the batteries become dis-connected. The mechanical design is shown in the included drawings, notable features are an effort to keep the noisy power electronics in a separate compartment from the control electronics. Only a modest amount of EMI shielding between these compartments is planned at the moment, but this could increase if noise issues become an issue.

Documentation Included:

- Solid-models
- Load-dump heat transfer estimates

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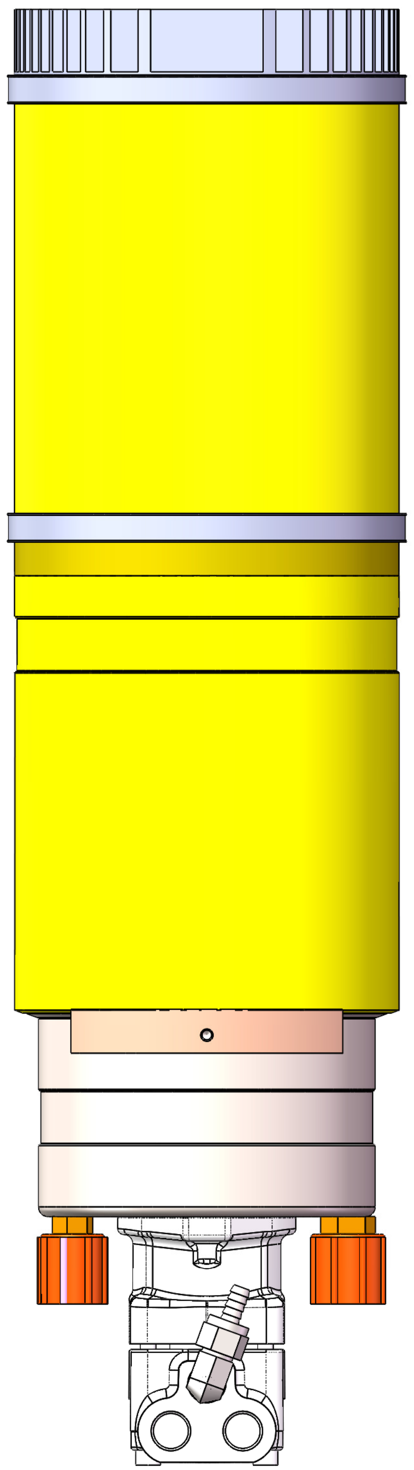

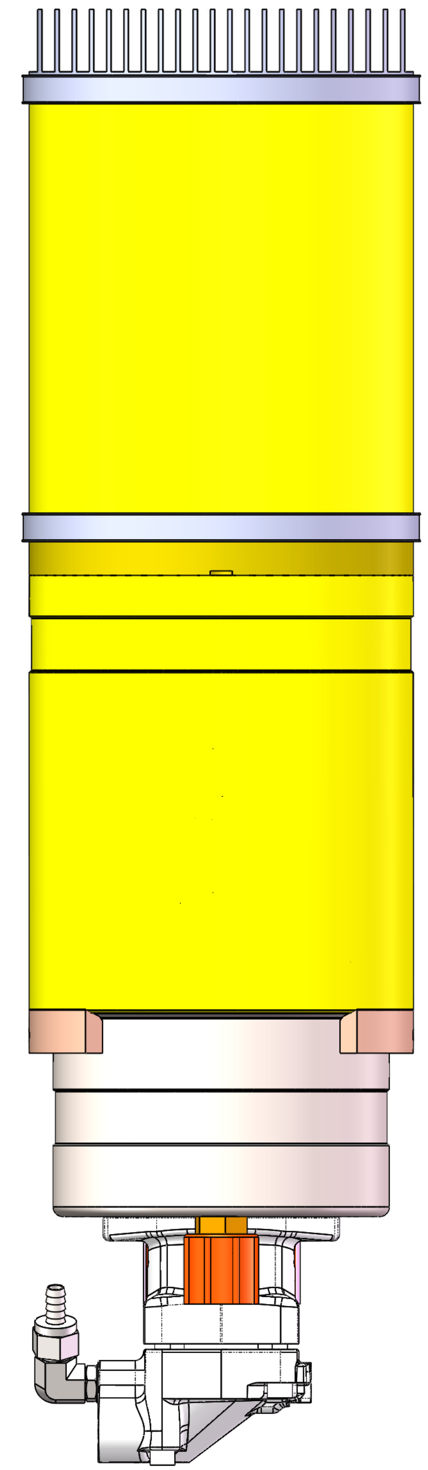

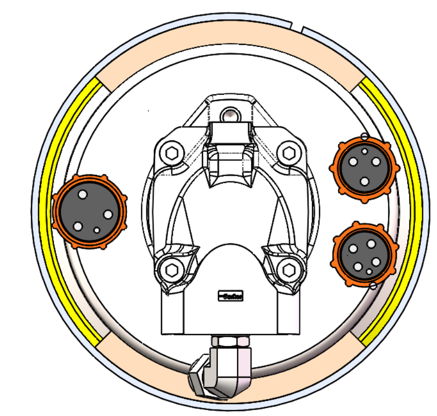

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2. DIMENSION LIMITS HELD AFTER PLATING.
3. REMOVE BURRS AND SHARP EDGES .015 MAX.
4. MACHINED FILLET RADII .0150-.030.
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6. PERPENDICULARITY & PARALLELISM OF MACHINED SURFACES .002 PER INCH. MAX .012 INCHES FOR SINGLE SURFACE.

DO NOT SCALE DRAWING

APPROVALS	DATE
DRAWN J. ERICKSON	
ENGINEER J. ERICKSON	
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PROJECT NO. 707976	
PROJECT ZZZZZZZZ	
WEIGHT	

Monterey Bay Aquarium Research Institute
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7700 Sandholdt RD.
Moss Landing, CA 95039
PH: (831) 775-1700

PROJECT NAME
Gen. Hsg. Clamp

SIZE B | DWG. NO. .DWG | REV.

SCALE 1:8 | CAD FILE: MECH ENG ON TORNADO | SHEET 1 OF 3

REVISIONS			
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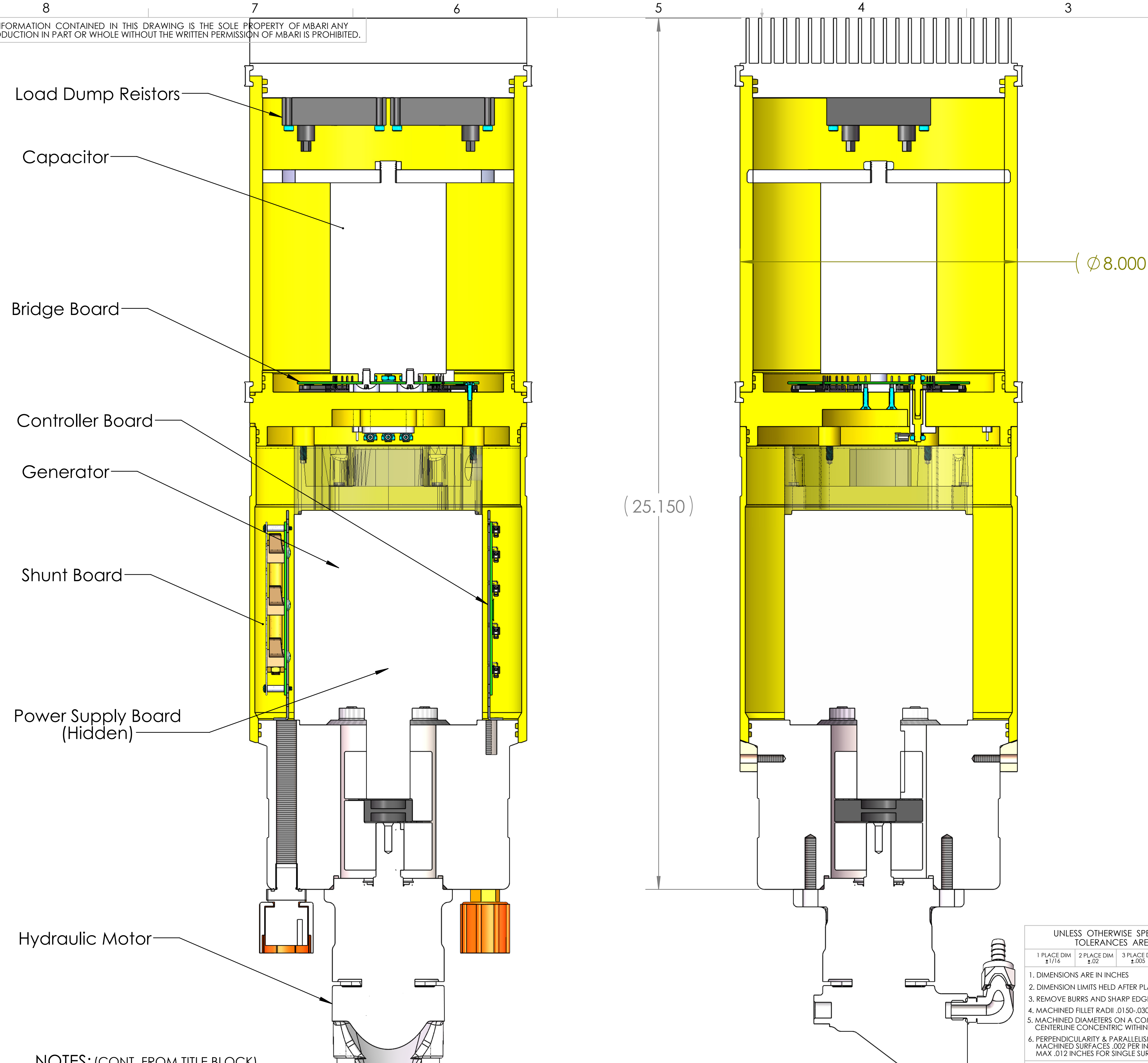
	INITIAL RELEASE	X/XX/00	J.E.



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ENGINEER J. ERICKSON	
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SIZE	DWG. NO.	REV.
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SCALE 1:8 | CAD FILE: MECH ENG ON TORNADO | SHEET 2 OF 3

REVISIONS

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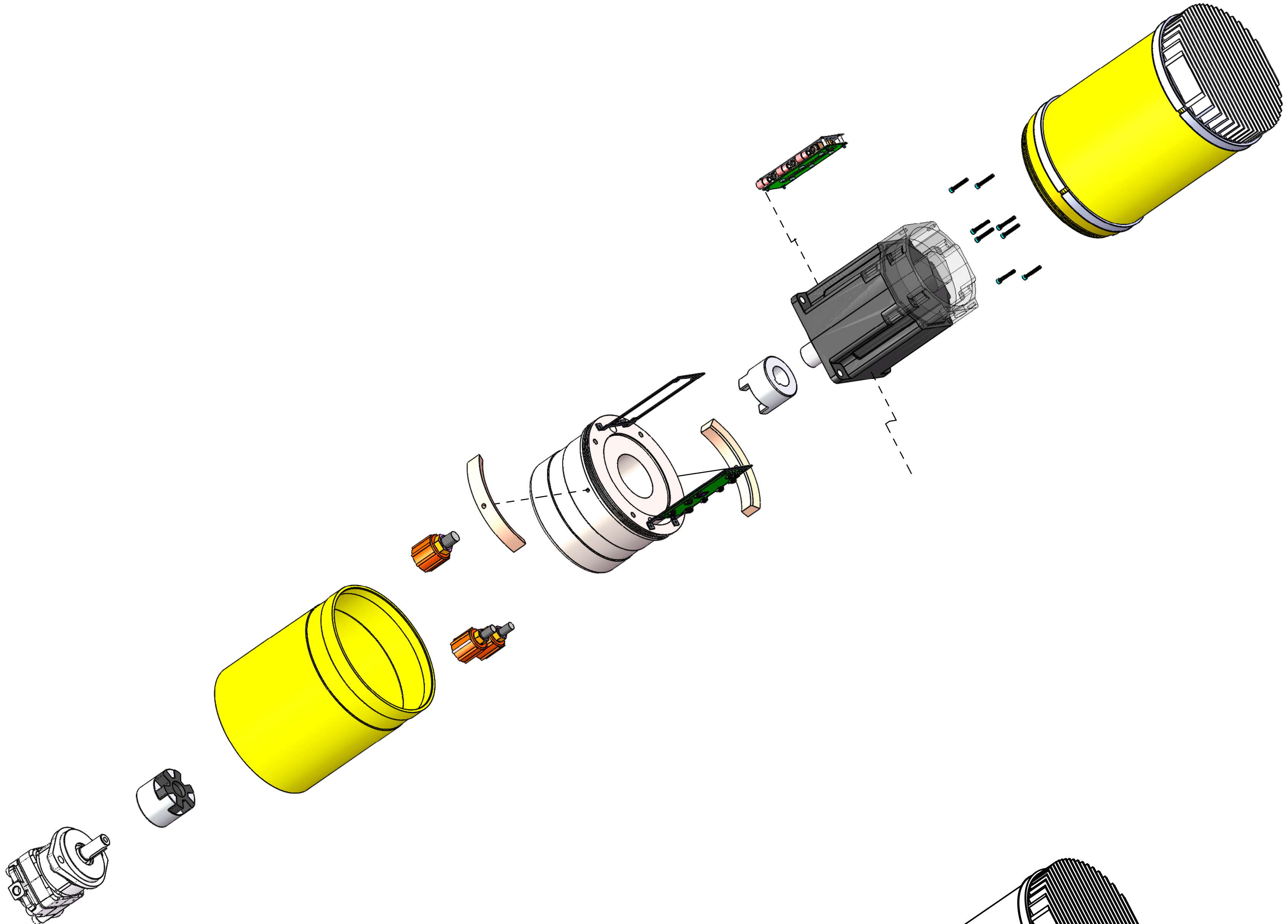

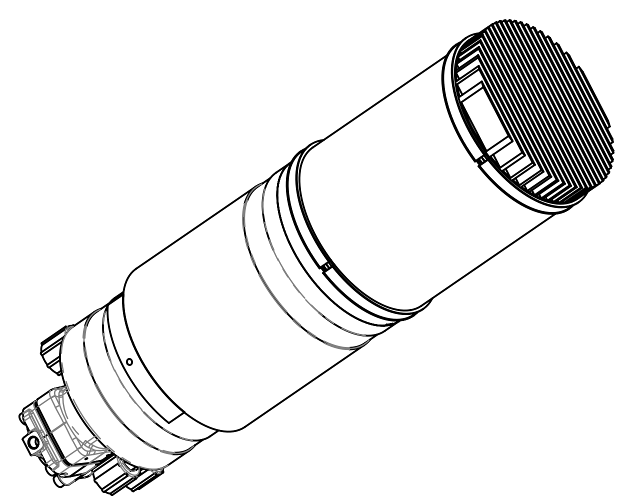

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15	1	A-201xxx-15	boost Converter V2		MBARI	
14	1					
13	1	A-201xxx-15	Shunt Assembly		MBARI	
12	1	BH3F	Subconn Circular Conn 3 contacts		Subconn	Brass UNS-C36000
11	1	BHB3F	Subconn Circular Conn #8 High Volt contacts		Subconn	Brass UNS-C36000
10	1	BH4F	Subconn Circular Conn 4 contacts		Subconn	Brass UNS-C36000
9	1					
8	1	AKM64S-ACCNR-00	Servo-Motor		Danaher	
7	1	L099\L100 SOX	Coupling Spider		Love-Joy	
6	1	AL100x32mm-10	Motor Coupling		Love-Joy	
5	1	AL100x18-6	Motor Coupling		Love-Joy	
4	1	P-201727-15	Shaft Aligner / Motor Mount		MBARI	AISI 316 Annealed Stainless Steel Bar (SS)
3	1		Female SAE straight barb fitting for 3/8" hose			
2	1		Male o-ring boss X Male JIC 90 degree adapter			
1	1	F11-005	Parker Hydraulic MOtor		Parker Hydraulics	

BILL OF MATERIALS

Shop / Q.C.

Inspector

Shop Foreman

Engineer

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APPROVALS		DATE
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ENGINEER	J. ERICKSON	
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PROJECT NO.	XXX	
PROJECT	ZZZZZZZZ	
WEIGHT	lb.	

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SIZE B | DWG. NO. .DWG | REV.

SCALE 1:8 | CAD FILE: MECH ENG ON TORNADO | SHEET 3 OF 3

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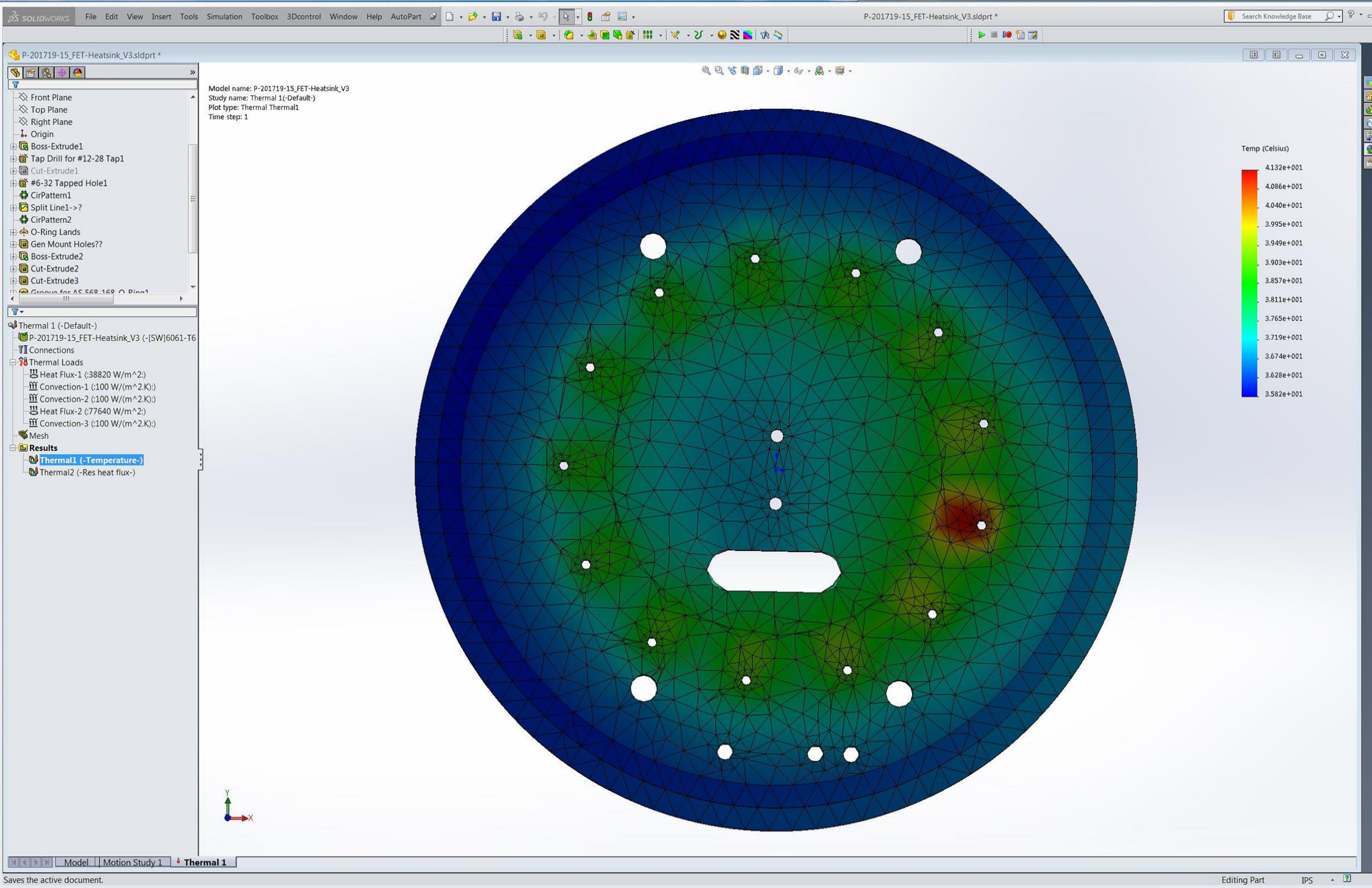
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Split Line1->?
CirPattern2
O-Ring Lands
Gen Mount Holes??
Boss-Extrude2
Cut-Extrude2
Cut-Extrude3
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Convection-3 (:100 W/(m^2.K):)
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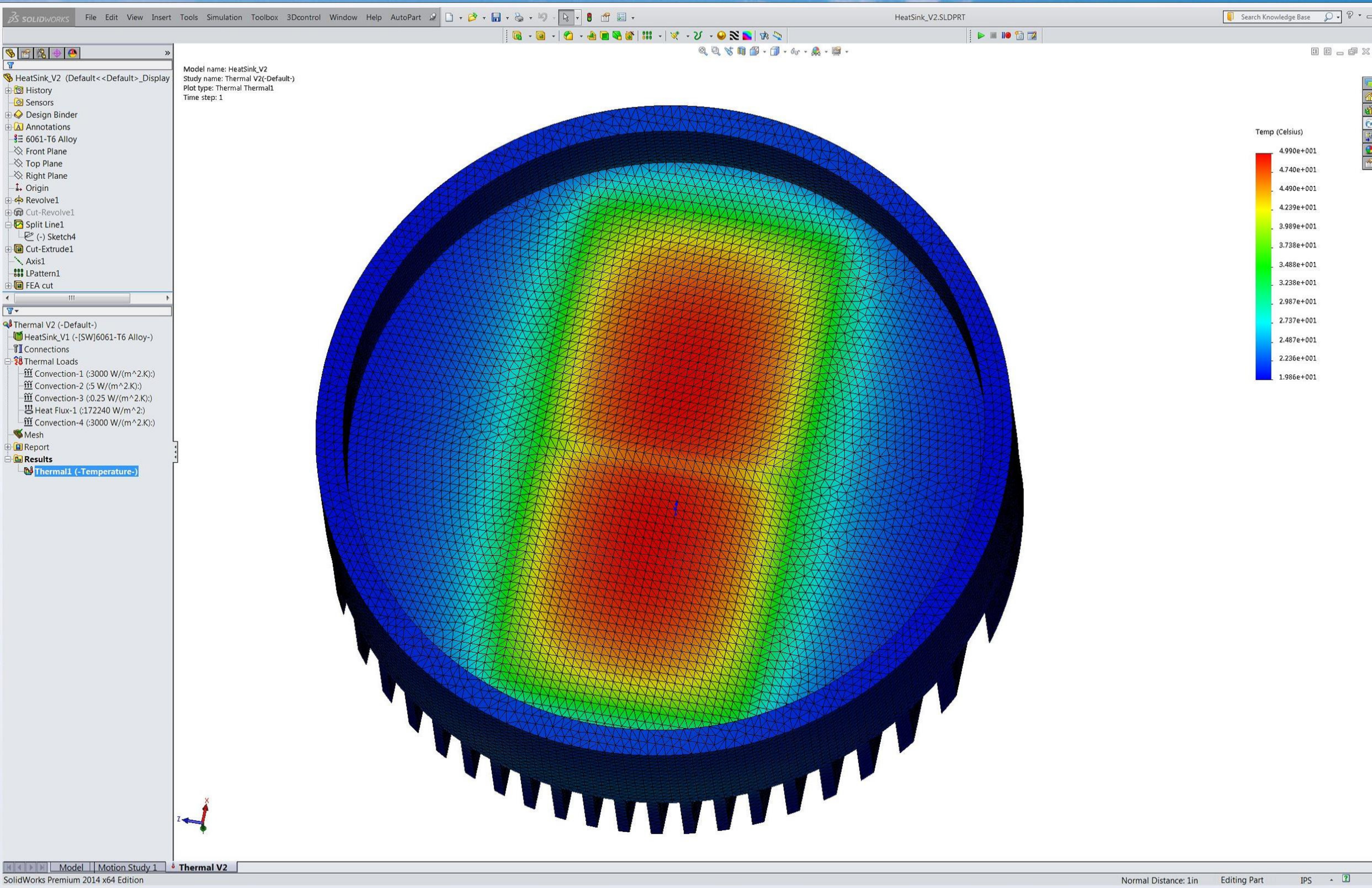
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Temp (Celsius)
4.990e+001
4.740e+001
4.490e+001
4.239e+001
3.989e+001
3.738e+001
3.488e+001
3.238e+001
2.987e+001
2.737e+001
2.487e+001
2.236e+001
1.986e+001
Model
Motion Study 1
Thermal V2
SolidWorks Premium 2014 x64 Edition
Normal Distance: 1in
Editing Part
IPS

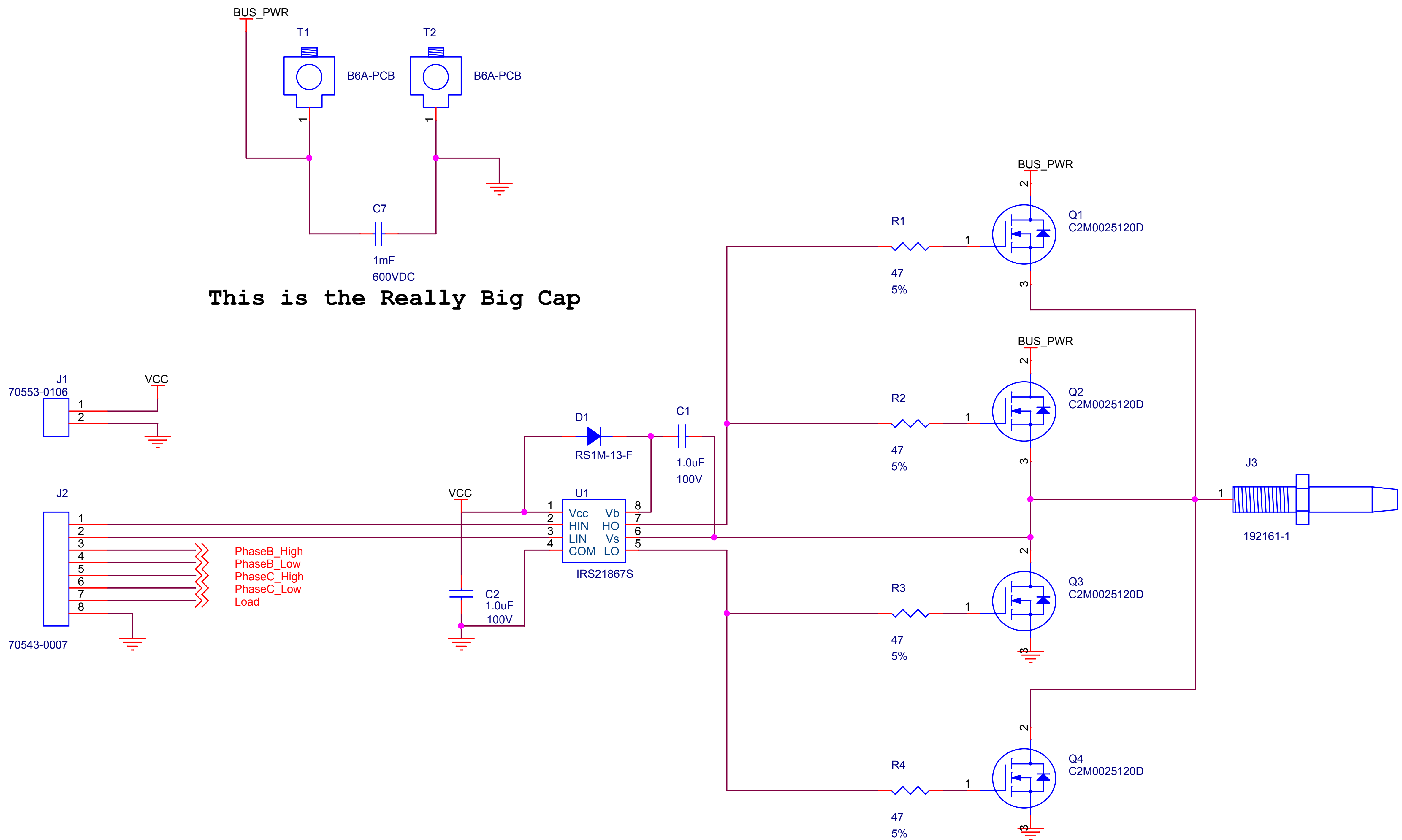
Circuit Board: Bridge Board

This board houses the FETs that accomplish the high-voltage switching to achieve the boost feature. Although simple in concept, there are challenges here to design and lay this out in a manner that controls EMI and has the transistors only switching when they are commanded. In addition to the bridge FETs, this board includes the large boost capacitor, the load dump transistor and connections to the load dump resistor (off-board).

This circuit has been prototyped and is operational, although the layout can be improved significantly to better control the FET switching.

Documentation Included:

- Schematic
- Datasheet for FETS/Diodes/Capacitor/Load-Dump Resistor



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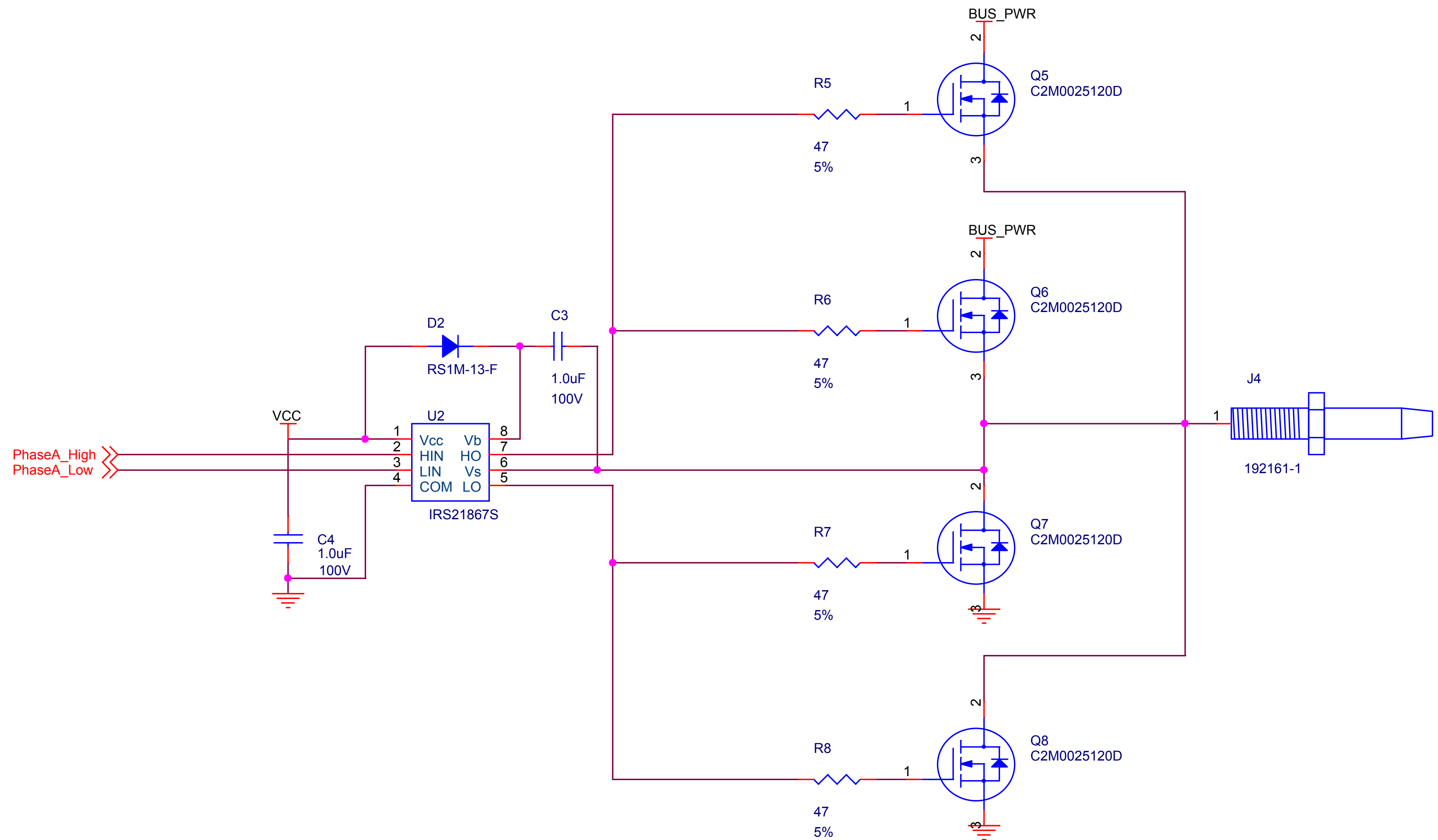
Title Power Buoy Boost Bridge PhaseA /			Number <Doc>	
Size B	Engineer SJensen	Layout <Layout Eng.>	Filename boostbridge.opj	Rev 0
	Date: Thursday, April 30, 2015		Sheet 1 of 4	



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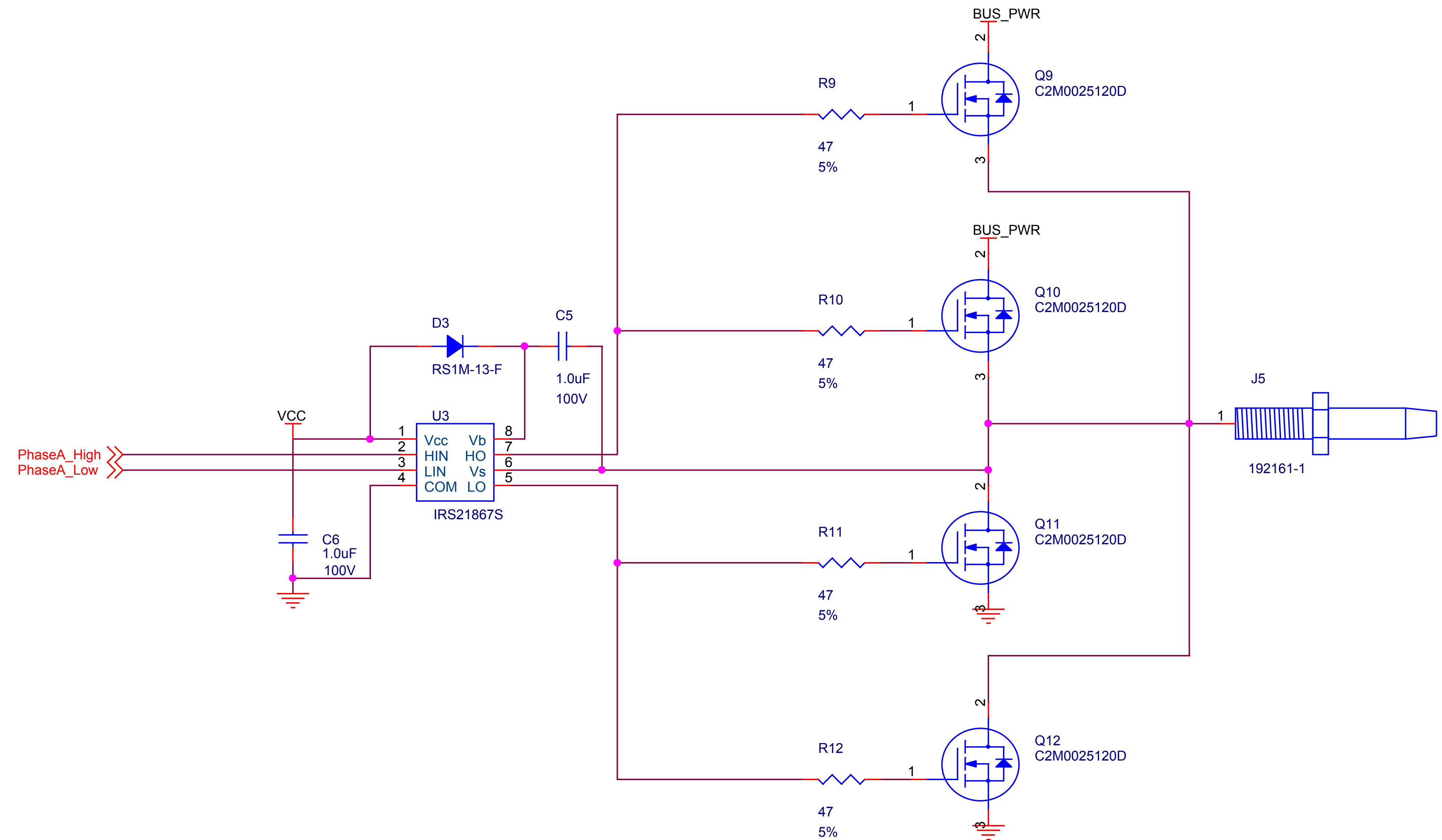
Size B	Engineer SJensen	Layout <Layout Eng.>	Filename boostbridge.opj	Rev 0
Date: Thursday, April 30, 2015		Sheet 2 of 4	



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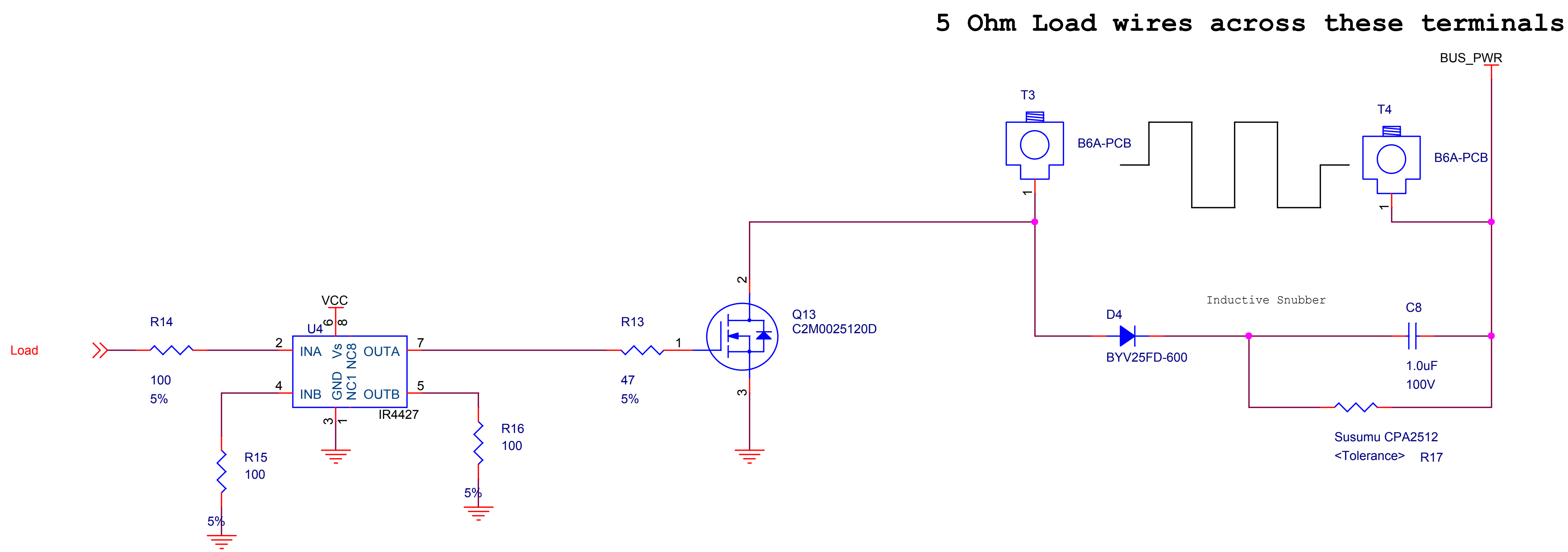
Title: Power Buoy Boost Bridge PhaseC /			Number: <Doc>
Size: B	Engineer: SJensen	Layout: <Layout Eng.>	Filename: boostbridge.opj · Rev: 0
Date: Thursday, April 30, 2015		Sheet 3 of 4	



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Title **Power Buoy Boost Bridge Load** /		Number **<Doc>**	
Size **B**	Engineer **SJensen**	Layout **<Layout Eng.>**	Filename **boostbridge.opj** Rev **0**
	Date: Thursday, April 30, 2015	Sheet 4 of 4	

CREE

C2M0025120D

Silicon Carbide Power MOSFET
C2M™ MOSFET Technology

N-Channel Enhancement Mode

V_{DS}	1200 V
I_D @ 25˚C	90 A
$R_{DS(on)}$	25 mΩ

Features

- New C2M SiC MOSFET technlogy
- High Blocking Voltage with Low On-Resistance
- High Speed Switching with Low Capacitances
- Easy to Parallel and Simple to Drive
- Avalanche Ruggedness
- Resistant to Latch-Up
- Halogen Free, RoHS Compliant

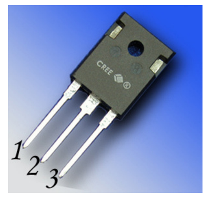
Benefits

- Higher System Efficiency
- Reduced Cooling Requirements
- Increased Power Density
- Increased System Switching Frequency

Applications

- Solar Inverters
- Switch Mode Power Supplies
- High Voltage DC/DC converters
- Battery Chargers
- Motor Drive
- Pulsed Power Applications

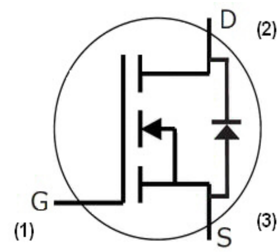
Package



TO-247-3

Halogen-Free

RoHS



Part Number	Package
C2M0025120D	TO-247-3

Maximum Ratings (T_C = 25 ˚C unless otherwise specified)

Symbol	Parameter	Value	Unit	Test Conditions	Note
V_{DSmax}	Drain - Source Voltage	1200	V	V_{GS} = 0 V, I_D = 100 μA	
V_{GSmax}	Gate - Source Voltage	-10/+25	V	Absolute maximum values	
V_{GSop}	Gate - Source Voltage	-5/+20	V	Recommended operational values	
I_D	Continuous Drain Current	90	A	V_{GS} =20 V, T_C = 25˚C	Fig. 19
		60		V_{GS} =20 V, T_C = 100˚C	
$I_{D(pulse)}$	Pulsed Drain Current	250	A	Pulse width t_P limited by T_{jmax}	Fig. 22
P_D	Power Dissipation	463	W	T_C=25˚C, T_J = 150 ˚C	Fig. 20
T_J , T_{stg}	Operating Junction and Storage Temperature	-55 to +150	˚C		
T_L	Solder Temperature	260	˚C	1.6mm (0.063”) from case for 10s	
M_d	Mounting Torque	1 8.8	Nm lbf-in	M3 or 6-32 screw	

IRS21867S

HIGH AND LOW SIDE DRIVER

Features

- Floating channel designed for bootstrap operation
- Fully operational to +600V
- Tolerant to negative transient voltage, dV/dt immune
- Low VCC operation
- Gate drive supply range from 5V to 20V
- Undervoltage lockout for both channels
- 3.3V and 5V input logic compatible
- Matched propagation delay for both channels
- Logic and power ground +/- 5V offset
- Lower di/dt gate driver for better noise immunity
- Output source/sink current capability 4.0A (Typ.)
- Leadfree, RoHS compliant

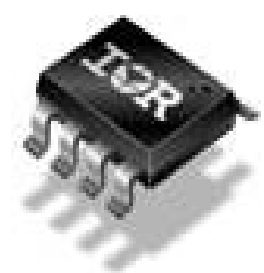
Applications

- Battery powered equipment
- Hand-tools
- Fork-lifts
- Golf-carts
- RC Hobby Equipment
- E-bike

Product Summary

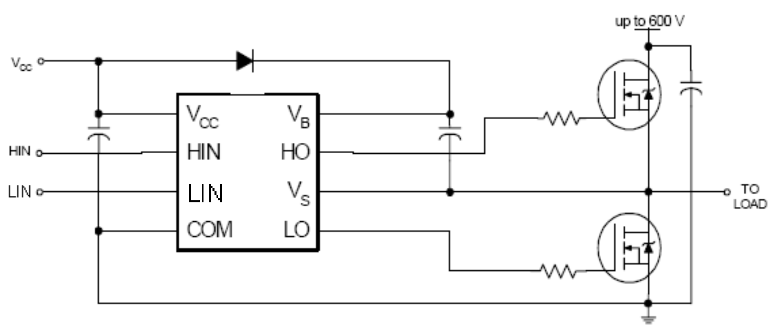
Topology	Single-Phase
V_{OFFSET}	≤ 600V
V_{OUT}	10V – 20V
I_{o+} & I_{o-} (typical)	4.0A & 4.0A
t_{on} & t_{off} (typical)	170ns & 170ns

Package Options



SOIC-8

Typical Connection Diagram



IRS21867S

Refer to Lead Assignment for correct pin Configuration. This diagrams show electrical Connections only. Please refer to our Application Notes and Design Tips for proper circuit board layout

TAP1000 & 2000

1000 & 2000 Watt Heat Sinkable Planar

The TAP series delivers 1000W or 2000W of continuous power when properly mounted to a liquid cooled heat sink (based on 85°C mounting plate temperature)

Applications include power conditioning, power distribution, power conversion, and power control.

FEATURES

- High Energy Rating
- Low Inductance
- Resistor Element Electrically Isolated
- High Dielectric Strength
- Small Footprint

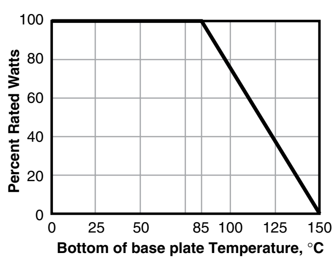
APPLICATIONS

- Power semiconductor balancing
- Motor control
- Inrush Current Limiting

CHARACTERISTICS

Resistor Element	Thick Film on Alumina Substrate
Power Rating	1000W or 2000W at 85°C mounting plate
Resistance Values	0.5Ω to 1000Ω
Resistance Tolerance	+10% std.
Max Operating Voltage	2000VDC
Temperature Coefficient	± 250 PPM/°C
Dielectric Strength	6KV standard
Operating Temperature Range	-55°C to 85°C
Terminal Screws	#10-32
Max Contacts Torque	10 in-lb
Mounting Screws	#8-32
Max Mounting Torque	15 in-lb
Creepage Distance	50mm ± 1mm (min)

Derating



Test	Rating Continuous	Pulse
Rated Power, max. current and heat sink plate temperature limited	(TA1K0) 1000W (TA2K0) 2000W	
Operating Voltage	√P*R	N/A
Max. Applied Voltage, ohms law limited	223V	2000VDC
Max. Current	10A	53.33A
Critical Resistance; below this resistance max power has to be de-rated due to exceeding max current	(TA1K0) 10Ω (TA2K0) 20Ω	

Test	Method	Maximum ΔR
Short Time Overload	1.14 x √P*R / 10 sec @ 70°C	Max % ΔRsto = ±(2% + 0.05Ω)
Moisture Resistance	(TA1K0) 1000 hrs @ 40°C, 90-95% RH (TA2K0) 1750 hrs @ 40°C, 90-95% RH	≤1% ≤1%
Thermal Shock	MIL-STD-202, Method 107	MIL-STD-202, Method 107
Vibration, elec.	MIL-STD-202, Method 201	±2% Resistance
Vibration, mech.	MIL-STD-202, Method 201	No Loose Terminal Screws
Load Life	(TA1K0) 1000 Hrs 90 min ON / 30 min OFF (TA2K0) 1750 Hrs 90 min ON / 30 min OFF	≤1% ≤1%
Pulse Tolerance	52µF @ 2KV / 60 sec intervals, 104J, 20,000 Pulses	≤1%
Dielectric Strength	6KVDC for 1 minute	≤1%

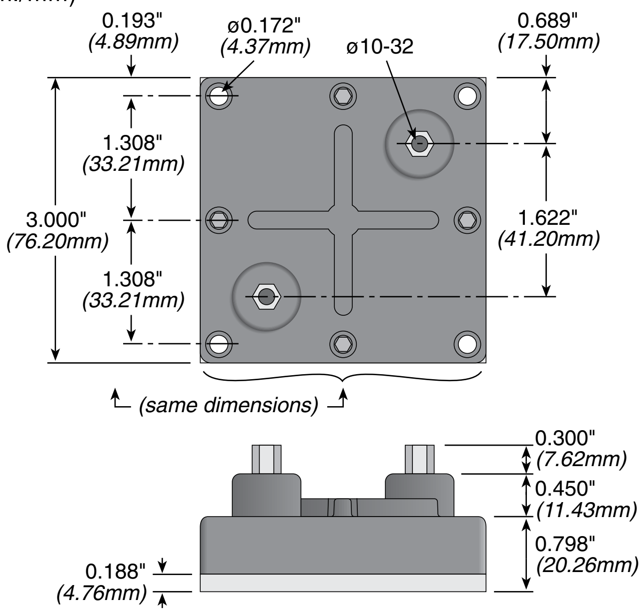
(continued)

TAP1000 & 2000

1000 & 2000 Watt Heat Sinkable Planar

DIMENSIONS

(in./mm)



APPLICATION NOTES

Proper heat sinking techniques are essential to performance of a TAP resistor. Pleased follow these guidelines when designing TAP system:

- Heats sink plate (base plate of the resistor) temperature must be monitored to establish proper de-rating. Best technique is to attach a thermocouple to the side of the base plate of the resistor. Temperature of plastic housing or heat sink cannot be used to establish rating of the resistor. Usage of laser thermometers should be avoided.
- To obtain a power rating of 1000W or 2000W, the bottom case temp must not exceed 85°C. This can only be achieved if the thermal conduction to the heatsink Rth-cs<0.025°K/W. This value can be reached by using thermal transfer compound with a heat conductivity of 1W/mK. The flatness of the cooling plate must be better than 0.05mm overall. The roughness of the surface should not exceed 6.4µm.
- Due to very high power density, only liquid cooled heat sinks are recommended for applications when >300W power rating is desired.
- Properly designed heat sink should have more than 2 cooling pipes under the surface of the TAP resistor. The Hydroblok, a 4 pass aluminum heat sink (http://www.ohmite.com/ta1k0-sink.html) is an example of properly designed heat sink.

ORDERING INFORMATION

RoHS Compliant

TA 1K0 PH 2R50 K E

Style	Wattage	Package Type	Resistance	Tolerance
TA	1K0	PH	2R50	K
			2.5Ω = 2R50	K = 10% (standard)
			50Ω = 50R0	L = 20%

Standard Part Numbers

Ohms	1000 Watt 10% Tolerance	Ohms	2000 Watt 10% Tolerance
0.5	TA1K0PHR500KE	0.5	TA2K0PHR500KE
1	TA1K0PH1R00KE	1	TA2K0PH1R00KE
2.5	TA1K0PH2R50KE	2.5	TA2K0PH2R50KE
5	TA1K0PH5R00KE	5	TA2K0PH5R00KE
7.5	TA1K0PH7R50KE	7.5	TA2K0PH7R50KE
10	TA1K0PH10R0KE	10	TA2K0PH10R0KE
15	TA1K0PH15R0KE	15	TA2K0PH15R0KE
25	TA1K0PH25R0KE	25	TA2K0PH25R0KE
50	TA1K0PH50R0KE	50	TA2K0PH50R0KE
100	TA1K0PH100RKE	100	TA2K0PH100RKE
250	TA1K0PH250RKE	250	TA2K0PH250RKE
500	TA1K0PH500RKE	500	TA2K0PH500RKE
750	TA1K0PH750RKE	750	TA2K0PH750RKE
1000	TA1K0PH1K00KE	1000	TA2K0PH1K00KE

WIMA DC-LINK MKP 6

Metallized Polypropylene (PP) - Capacitors in Cylindrical Case
MKP 6 with High Volume/Capacitance Ratio
MKP 6 HP with Higher Current Carrying Capability

Special Features

- **Very high volume/capacitance ratio**
- **Self-healing properties**
- **With cylindrical aluminium case for bus bar mounting**
- **Dry construction without electrolyte or oil**
- **No internal fuse required**
- **Negative capacitance change versus temperature**
- **Very low dielectric absorption**
- **According to RoHS 2011/65/EU**
- **Customer-specific capacitances or voltages on request**

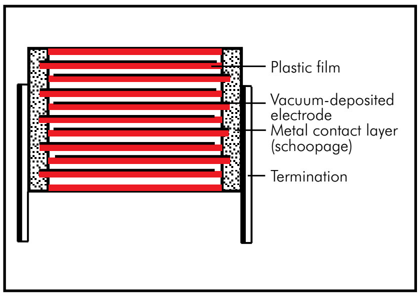
Typical Applications

DC capacitors with high capacitances for applications in power electronics also at non-sinusoidal voltages and currents e.g. in

- **Wind power systems**
- **Inverters**

Construction

Dielectric:
Polypropylene (PP) film
Capacitor electrodes:
Vacuum-deposited
Internal construction:



Encapsulation:
Aluminium case with PU-sealing, UL 94 V-0
Terminations:
Screw connection (male or female), screw bolt M12 x 16.
Marking:
Colour: Metallic. Marking: Black on silver label.

Electrical Data

Capacitance range: 75 µF to 4920 µF
Rated voltages: 600 VDC, 700 VDC, 900 VDC,1100 VDC, 1300 VDC, 1500 VDC
Capacitance tolerances: ±20%, ±10% (±5% available subject to special enquiry)
Operating temperature range:
–40° C to +85° C
Insulation resistance at +20° C:
⩾ 5000 sec (MΩ x µF)
(mean value: 20000 sec)
Measuring voltage: 100 V/1 min.

Dielectric loss factor
tan δ_0: 2 x 10^{-4}
Test voltage between terminals
at +25° C: 1.5 $U_{r\ DC}$, 10sec
Test voltage between terminals and case
at +25° C and 50 Hz: 3 kV_{AC} , 1 min.
Dielectric absorption:
0.05 %
Reliability:
Operational life > 100000 hours
Failure rate < 50 fit (hot spot ⩽ 70° C)

Mounting Recommendation

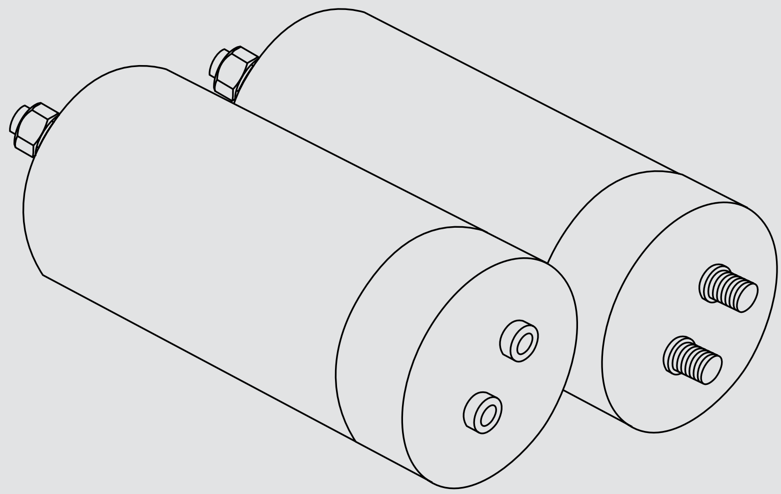
Excessive mechanical strain, e.g. pressure or shock onto the capacitor body, is to be avoided during mounting and usage of the capacitors.

Packing

Transportation-safe packing in cardboard boxes.

For further details and graphs please refer to Technical Information.

The capacitors are non-polarized and are optionally available with „male" and „female" terminations. The earth bolt is electrically inactive and serves for fixing and/or earthing of the metal case.



11.14

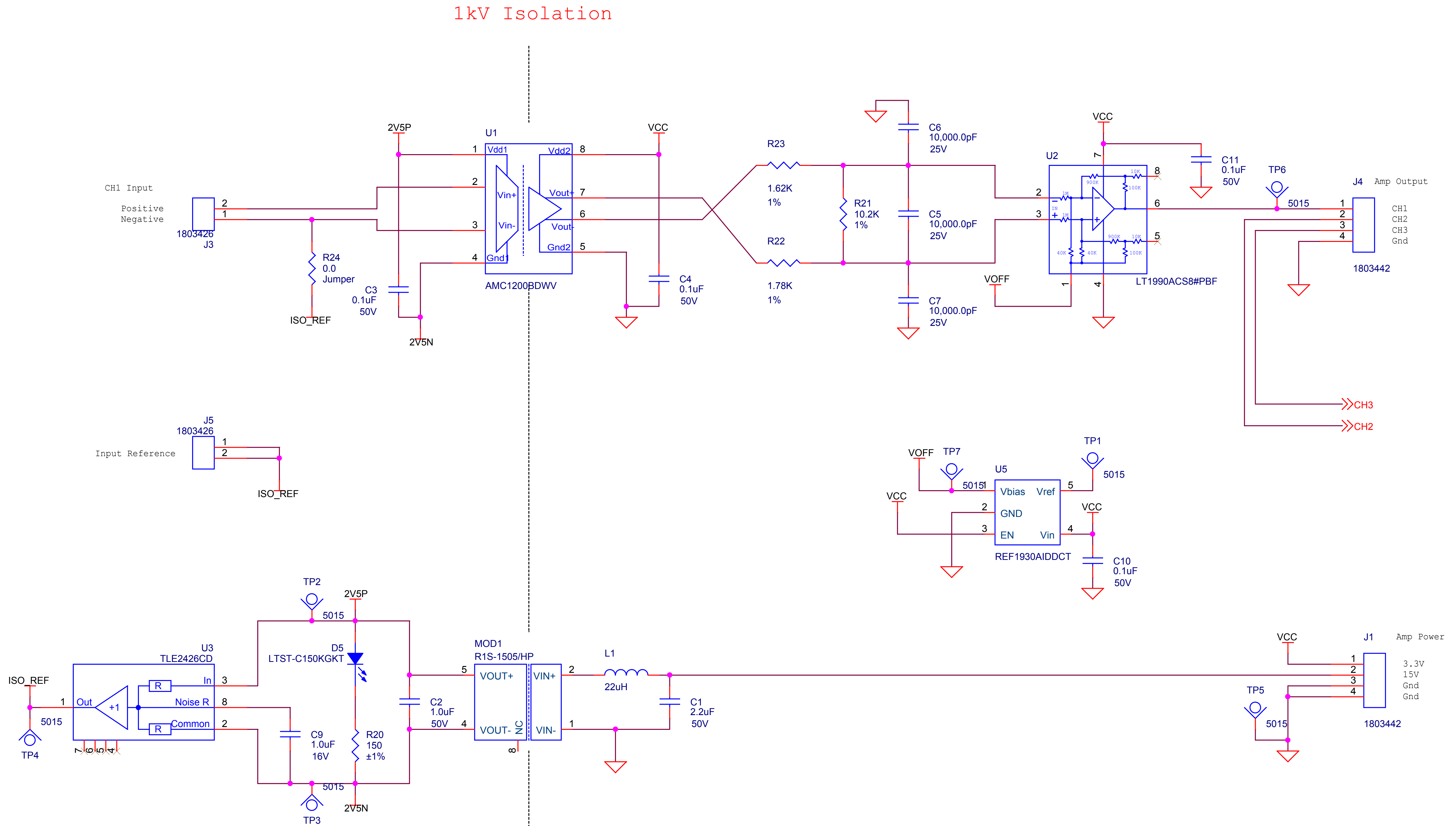
Circuit Board: High-Voltage Measurement Board

This board measures the current and voltage of the high voltage bus. It contains three resistive shunts and amplifiers to measure the current flowing from the bridge-board, the current flowing to the load-dump resistor, and optionally the current flowing to the batteries (these three signals aren't independent, so in fact there is a spare). A voltage divider provides a means to measure the high-voltage bus. In all cases these measurements are converted to differential signals for transmission to the controller board, where they are converted back to single-ended and connected to the ADC in the microprocessor.

This circuit has been prototyped and is operational.

Documentation Included:

- Schematic of prototype board.
- Schematic of circuit board in system that holds the shunts themselves, in this case the differential signals that this board creates are converted back to single-ended on the controller board.



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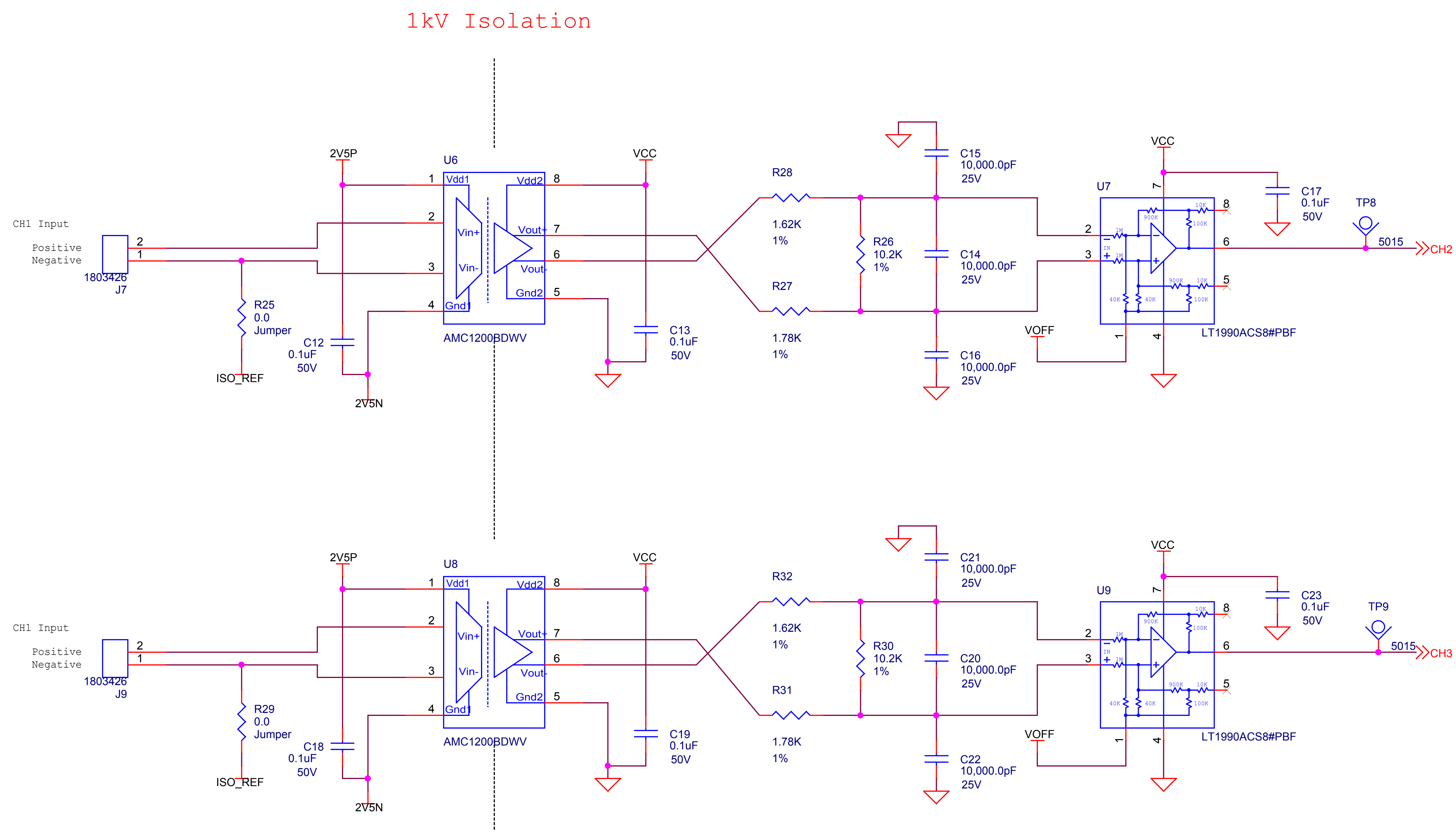
Title: PowerBuoy Current Sense Amplifier /			Number: <Doc>
Size: B	Engineer: SJensen	Layout: <Layout Eng.>	Filename: <Filename>
Date: Thursday, March 26, 2015		Sheet 1 of 2	Rev 0



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Title	PowerBuoy Current Sense Amplifier	<Path>	Number	<Doc>
Size B	Engineer SJensen	Layout <Layout Eng.>	Filename <Filename>	Rev 0
	Date: Thursday, March 26, 2015	Sheet 2 of 2		

Fully-Differential Isolation Amplifier

Check for Samples: AMC1200, AMC1200B

FEATURES

- ±250-mV Input Voltage Range Optimized for Shunt Resistors
- Very Low Nonlinearity: 0.075% max at 5 V
- Low Offset Error: 1.5 mV max
- Low Noise: 3.1 mV_{RMS} typ
- Low High-Side Supply Current: 8 mA max at 5 V
- Input Bandwidth: 60 kHz min
- Fixed Gain: 8 (0.5% accuracy)
- High Common-Mode Rejection Ratio: 108 dB
- 3.3-V Operation on Low-Side
- Certified Galvanic Isolation:
  - UL1577 and IEC60747-5-2 Approved
  - Isolation Voltage: 4250 V_{PEAK} (AMC1200B)
  - Working Voltage: 1200 V_{PEAK}
  - Transient Immunity: 10 kV/µs min
- Typical 10-Year Lifespan at Rated Working Voltage (see Application Report SLLA197)
- Fully Specified Over the Extended Industrial Temperature Range

APPLICATIONS

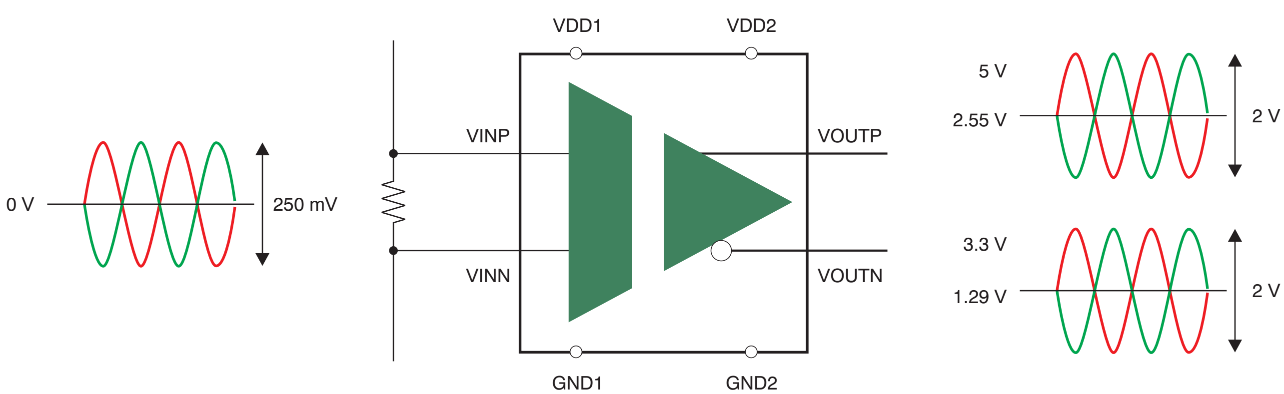
- Shunt Resistor Based Current Sensing in:
  - Motor Control
  - Green Energy
  - Frequency Inverters
  - Uninterruptible Power Supplies

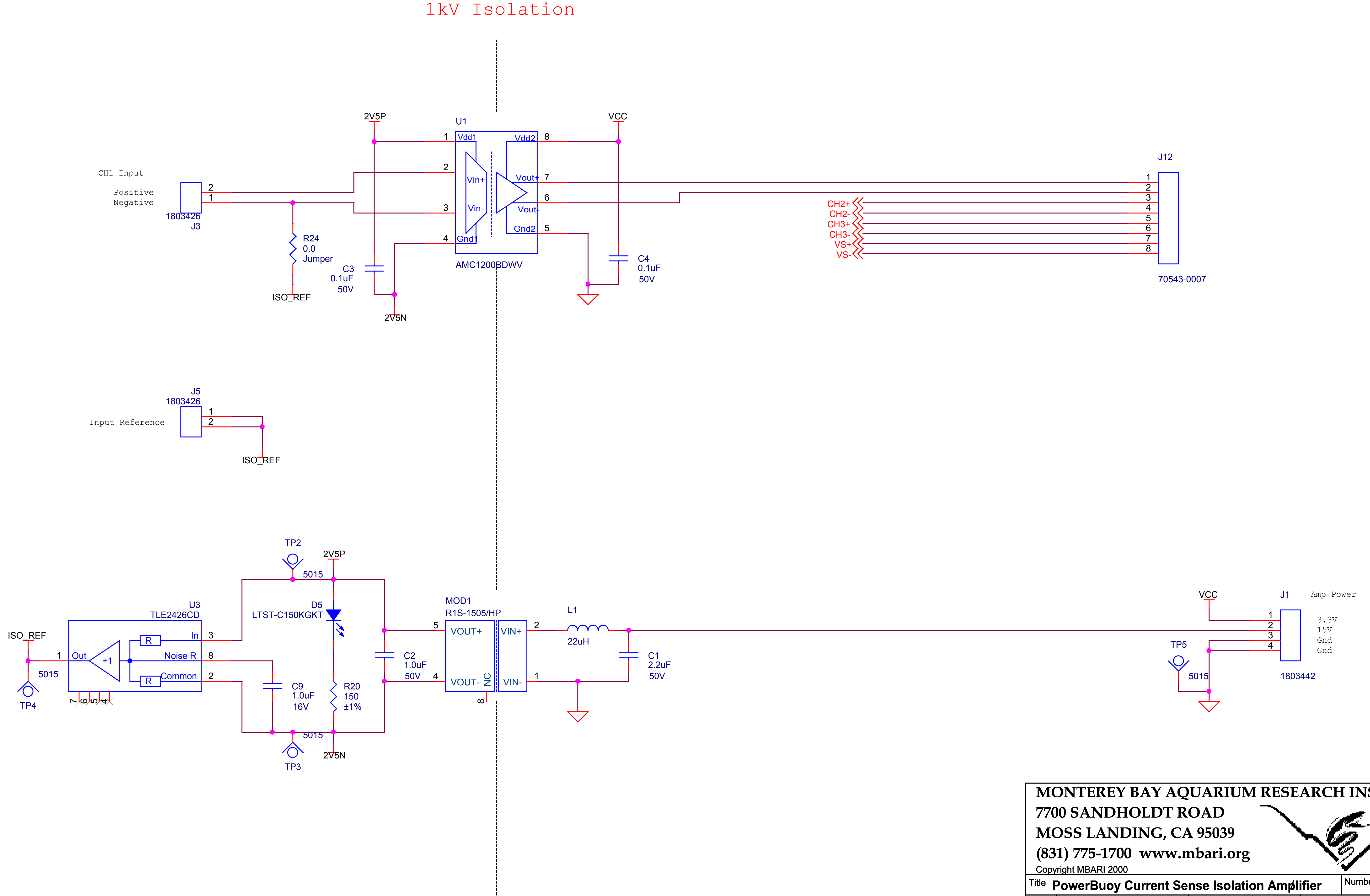
DESCRIPTION

The AMC1200 and AMC1200B are precision isolation amplifiers with an output separated from the input circuitry by a silicon dioxide (SiO_2) barrier that is highly resistant to magnetic interference. This barrier has been certified to provide galvanic isolation of up to 4250 V_{PEAK} (AMC1200B) or 4000 V_{PEAK} (AMC1200) according to UL1577 and IEC60747-5-2. Used in conjunction with isolated power supplies, these devices prevent noise currents on a high common-mode voltage line from entering the local ground and interfering with or damaging sensitive circuitry.

The input of the AMC1200 or AMC1200B is optimized for direct connection to shunt resistors or other low voltage level signal sources. The excellent performance of the device supports accurate current control resulting in system-level power saving and, especially in motor-control applications, lower torque ripple. The common-mode voltage of the output signal is automatically adjusted to either the 3-V or 5-V low-side supply.

The AMC1200 and AMC1200B are fully specified over the extended industrial temperature range of –40°C to +105°C and are available in a wide-body SOIC-8 package (DWV) and a gullwing-8 package (DUB).





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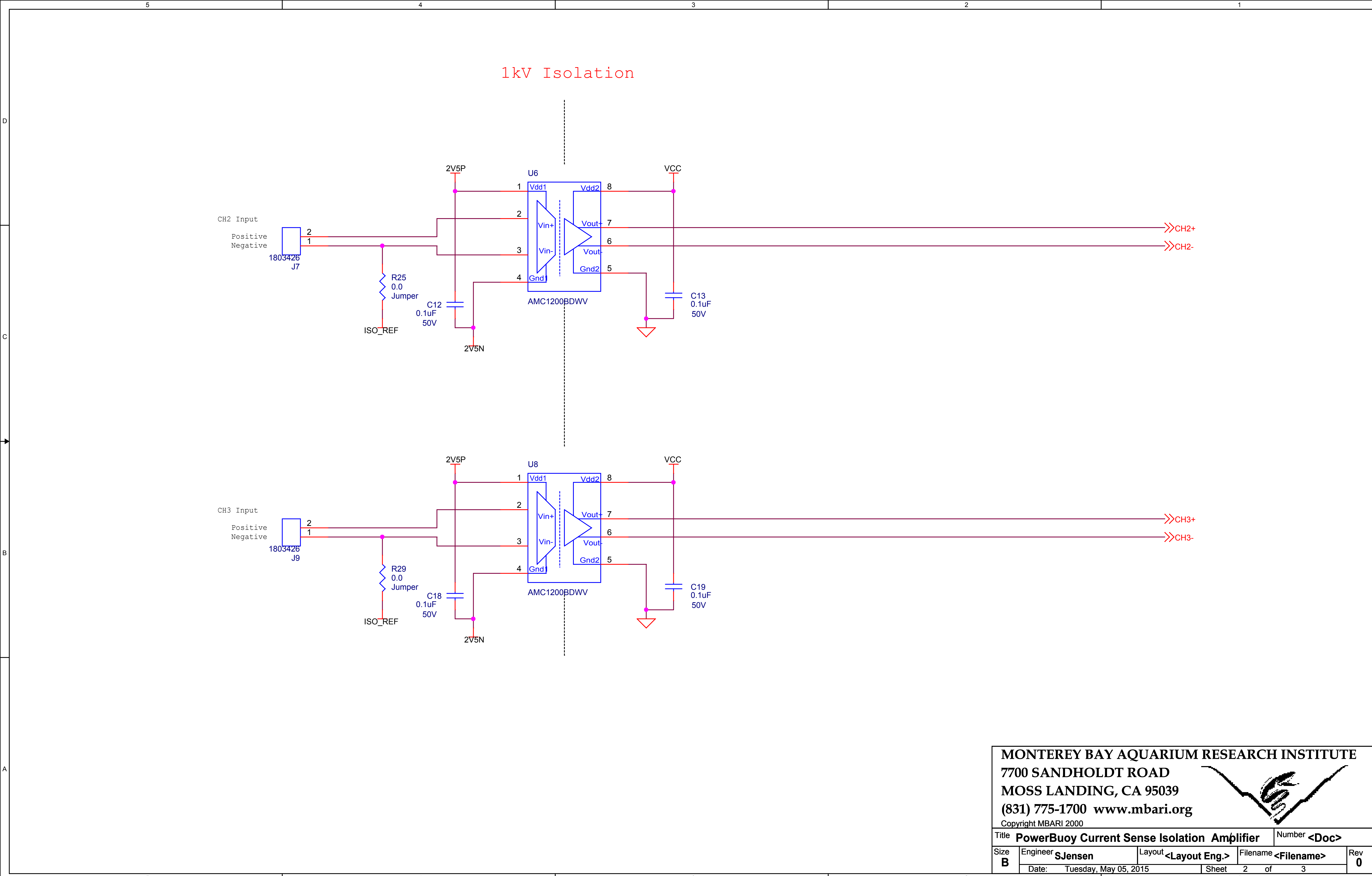
Title: PowerBuoy Current Sense Isolation Amplifier		Number: <Doc>	
Size: B	Engineer: SJensen	Layout: <Layout Eng.>	Filename: <Filename> / Rev: 0
Date: Tuesday, May 05, 2015		Sheet 1 of 3	



1kV Isolation
2V5P
U6
VCC
Vdd1
Vdd2
CH2 Input
Positive
Negative
1803426
J7
Vin+
Vin-
Vout+
Vout-
Gnd1
Gnd2
CH2+
CH2-
R25
0.0
Jumper
C12
0.1uF
50V
ISO_REF
2V5N
AMC1200BDWV
C13
0.1uF
50V
2V5P
U8
VCC
CH3 Input
Positive
Negative
1803426
J9
CH3+
CH3-
R29
0.0
Jumper
C18
0.1uF
50V
ISO_REF
2V5N
AMC1200BDWV
C19
0.1uF
50V
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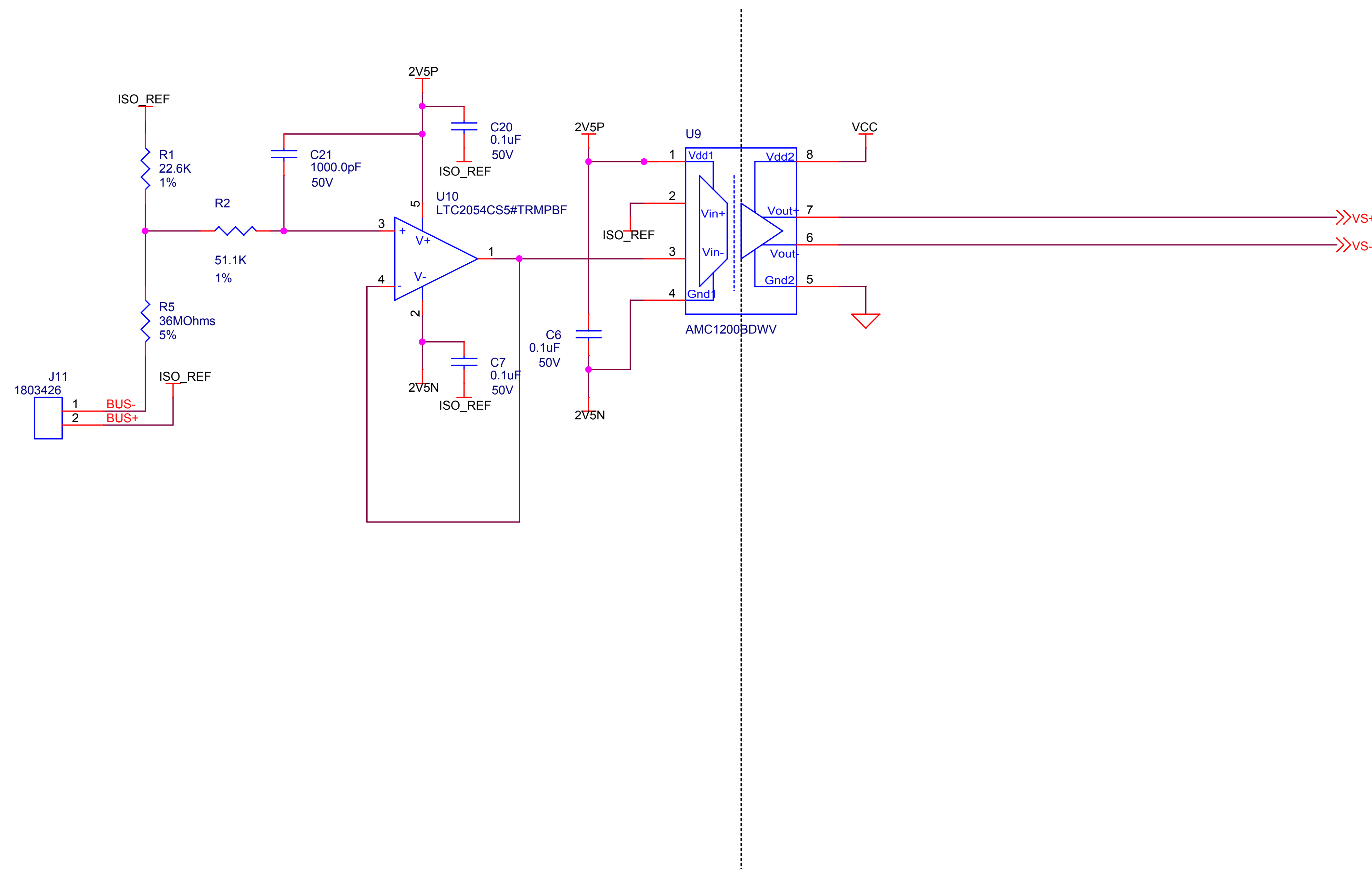
Number <Doc>
Size B
Engineer SJensen
Layout <Layout Eng.>
Filename <Filename>
Rev 0
Date: Tuesday, May 05, 2015
Sheet 2 of 3



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Title **PowerBuoy Current Sense Isolation Amplifier**			Number **<Doc>**	
Size **B**	Engineer **SJensen**	Layout **<Layout Eng.>**	Filename **<Filename>**	Rev **0**
	Date: Tuesday, May 05, 2015		Sheet 3 of 3	

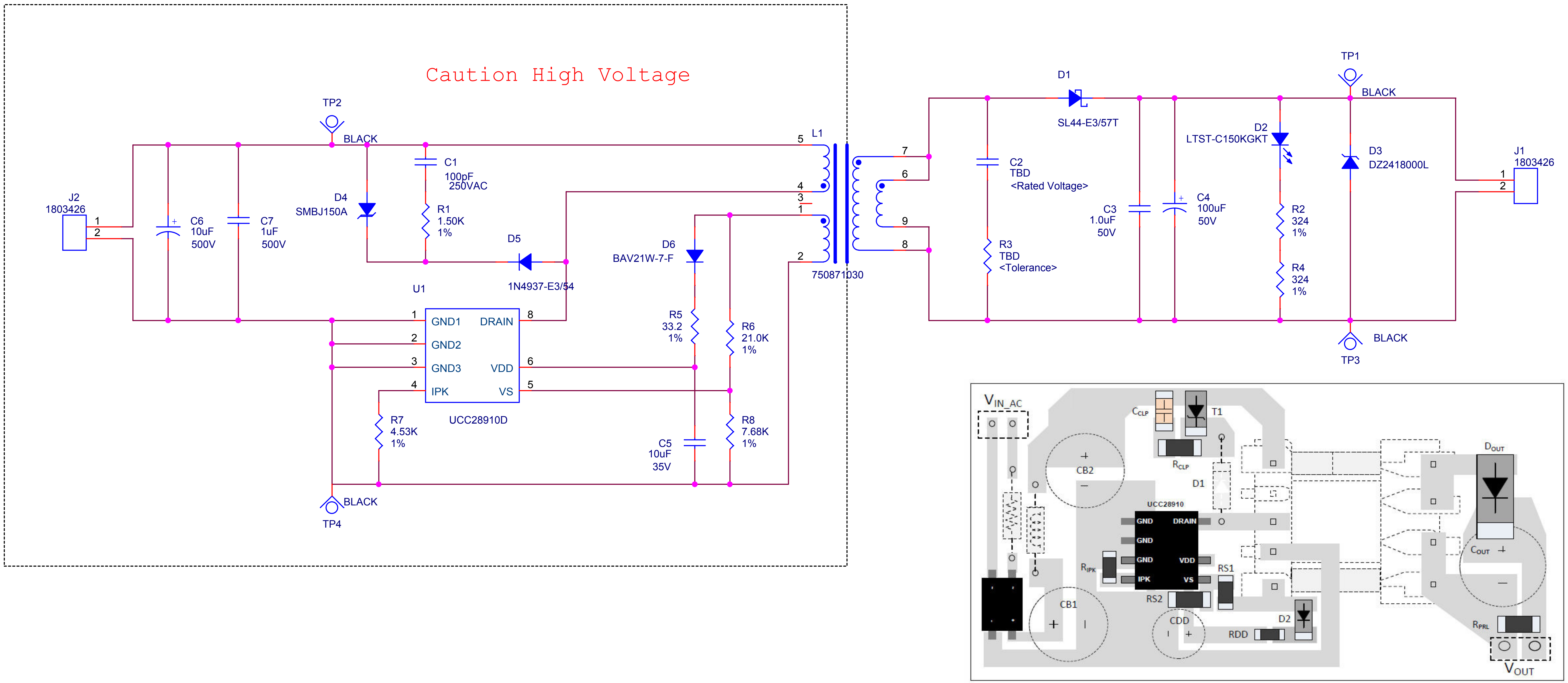
Circuit Board: Bootstrap Power Supply Board

Because it is necessary to power the processor, motor encoder, bridge board drivers, and current shunt amplifiers sub-sea, a power supply is required to convert the bus voltage to 15V, 5V, and 3V. This board is a 15V 2W supply designed with a wide input range (40-400V) for this. The 15V supply is further converted to 3.3V and 5V on-board the Controller board for powering the processor and the motor encoder. The 15V also goes directly to the bridge board and High-voltage measurement board. Because this supply turns on at 40V, the processor will power up at about 1000RPM in the case the batteries are disconnected and control the load on the system appropriately before the generator spins too fast.

This circuit has been prototyped and is operational.

Documentation Included:

- Schematic



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Title **PBbootstrap**			Number **<Doc>**
Size **B**	Engineer **SJensen**	Layout **<Layout Eng.>**	Filename **PBbootstrap** — Rev **0**
Date: Wednesday, February 04, 2015			Sheet 1 of 1

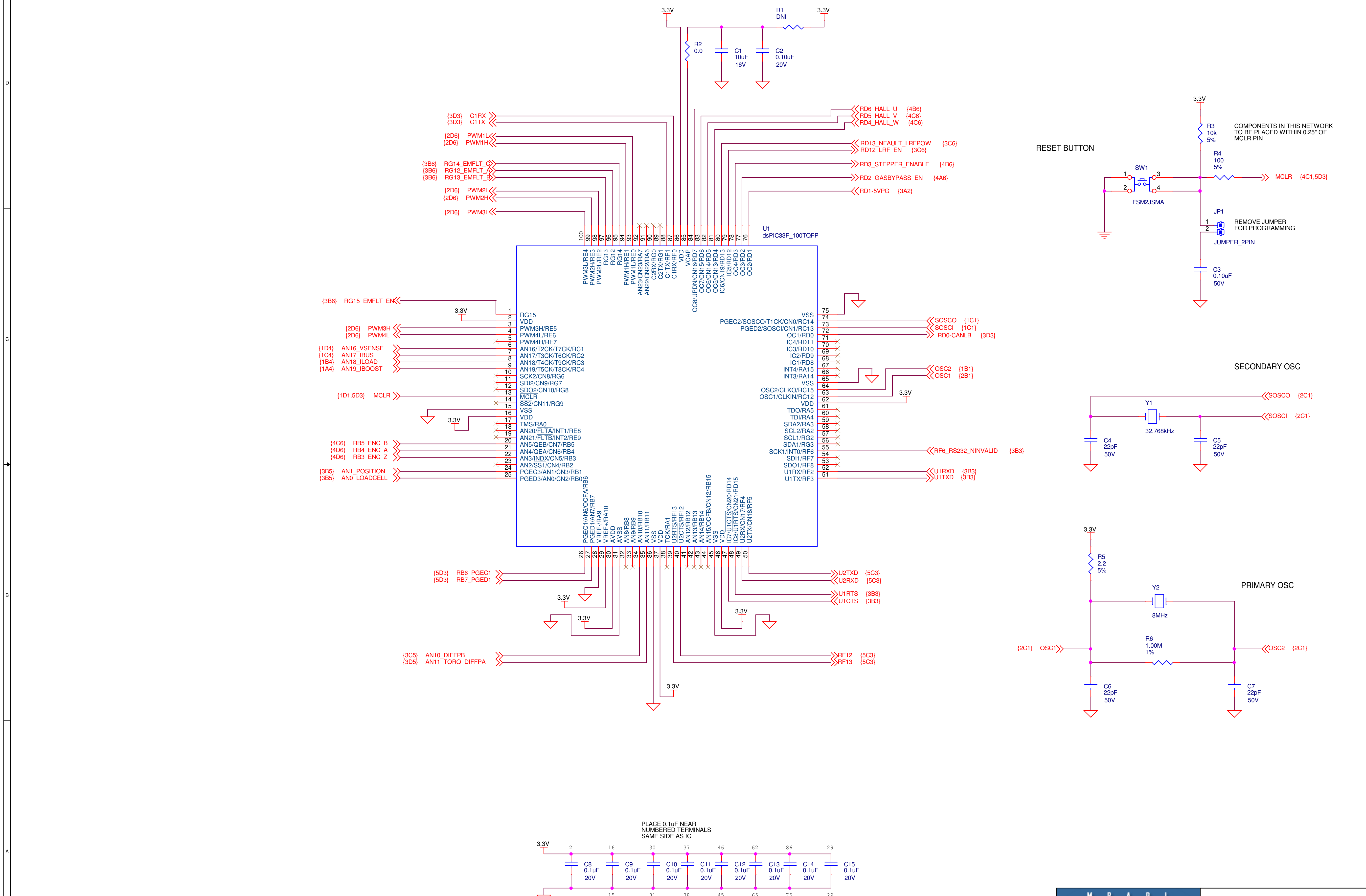
Circuit Board: Controller Board

This board houses the dsPIC microprocessor and contains power supplies (3.3V and 5.5V), and the necessary input filtering on the analog inputs.   This board is also to be used elsewhere in the system for piston and pneumatic spring monitoring, inputs for the gas pressures, laser range-finder, load cell, and EM tether integrity are included but aren't used for the power converter control.

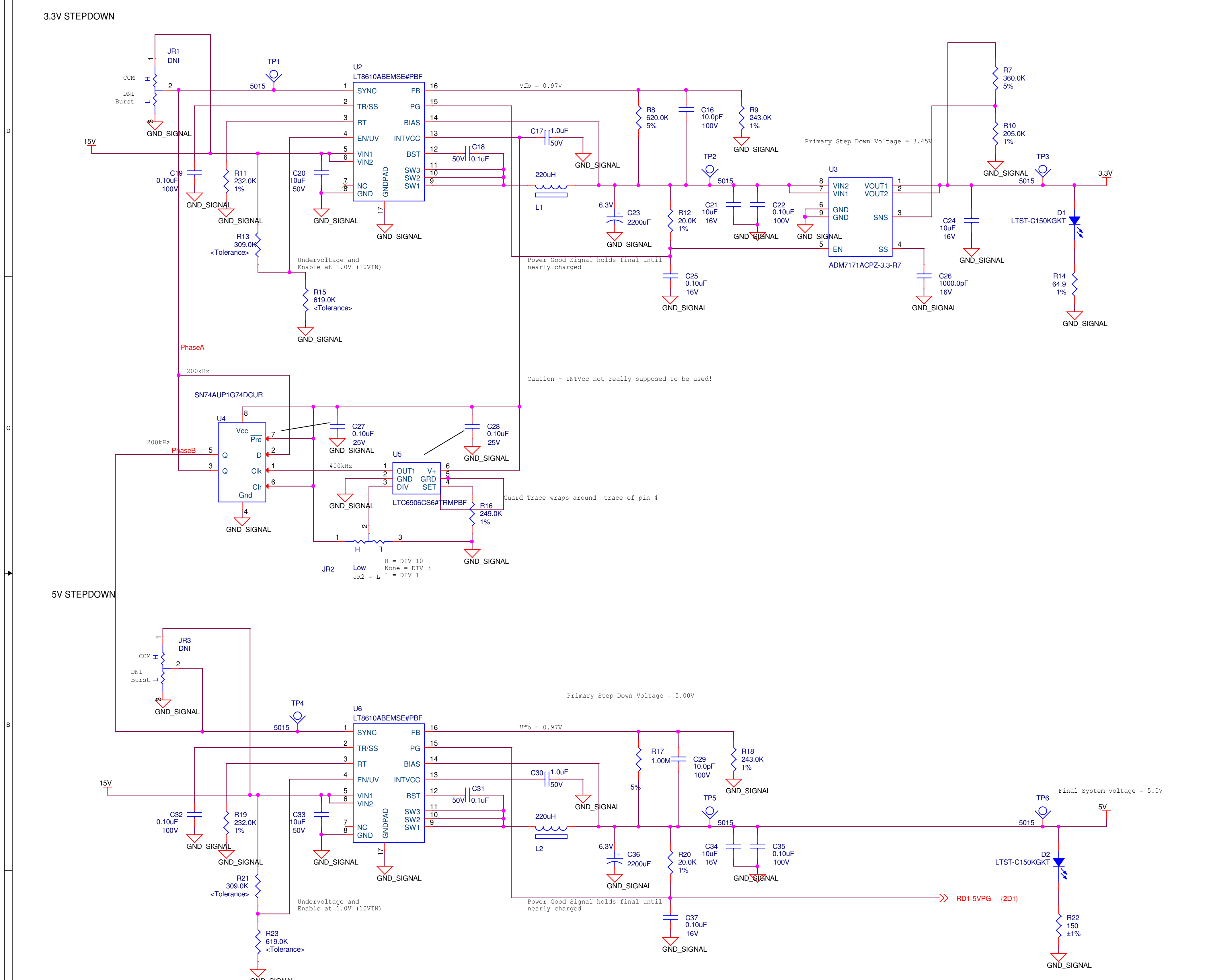
Many parts of this circuit (with simpler filtering) have been prototyped and are operational.

Documentation Included:

- Schematic



MBARI	**Monterey Bay Aquarium Research Institute** 7700 Sandhold Road, Moss Landing, CA 95039			
	Title: Boost Controller Board - Microcontroller			
Engineer: E. MARTIN	Size: C	Document Number: 10021168	Layout File: <Layout File>	Rev: 0.1.1
Layout: <Layout>	Date: Sunday, May 03, 2015		Sheet 1 of 6	



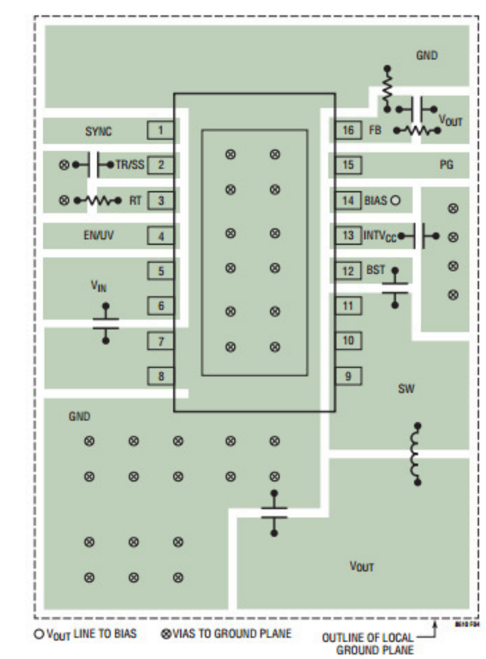


Figure 4. Recommended PCB Layout for the LT8610

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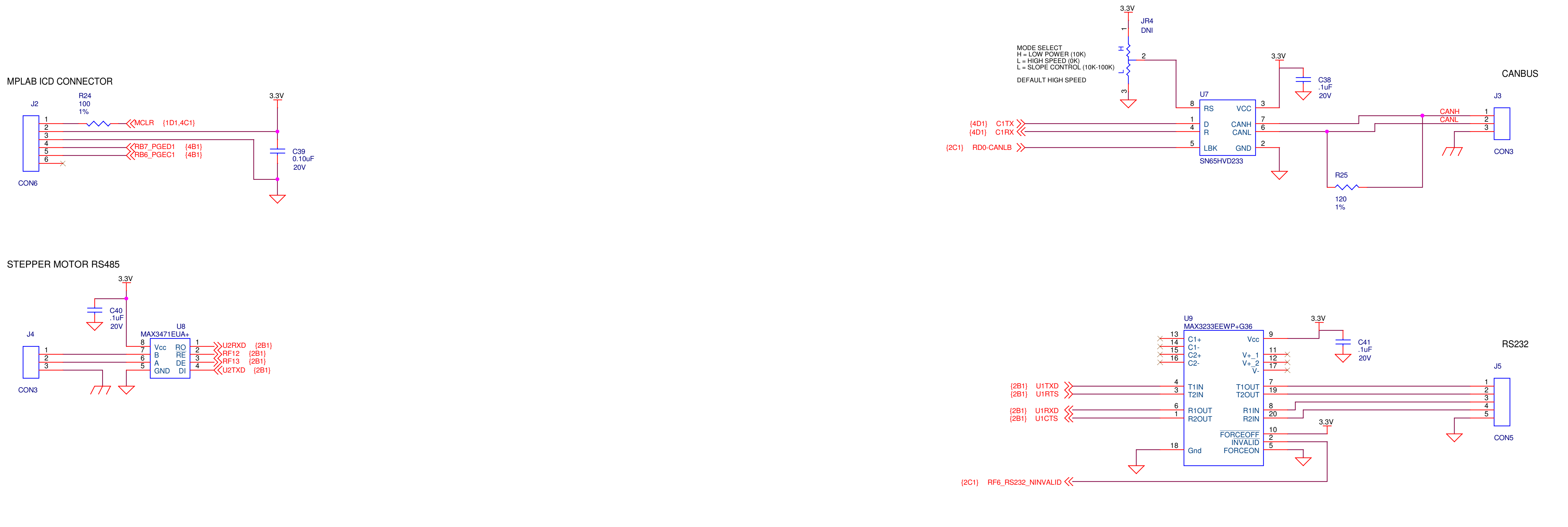
Title			
Boost Controller Board - Power Supply			
Engineer: E. MARTIN	Size: C	Document Number: 10021168	Layout File: <Layout File>
Layout: <Layout>	Date: Sunday, May 03, 2015	Sheet 2 of 6	Rev 0.1.0



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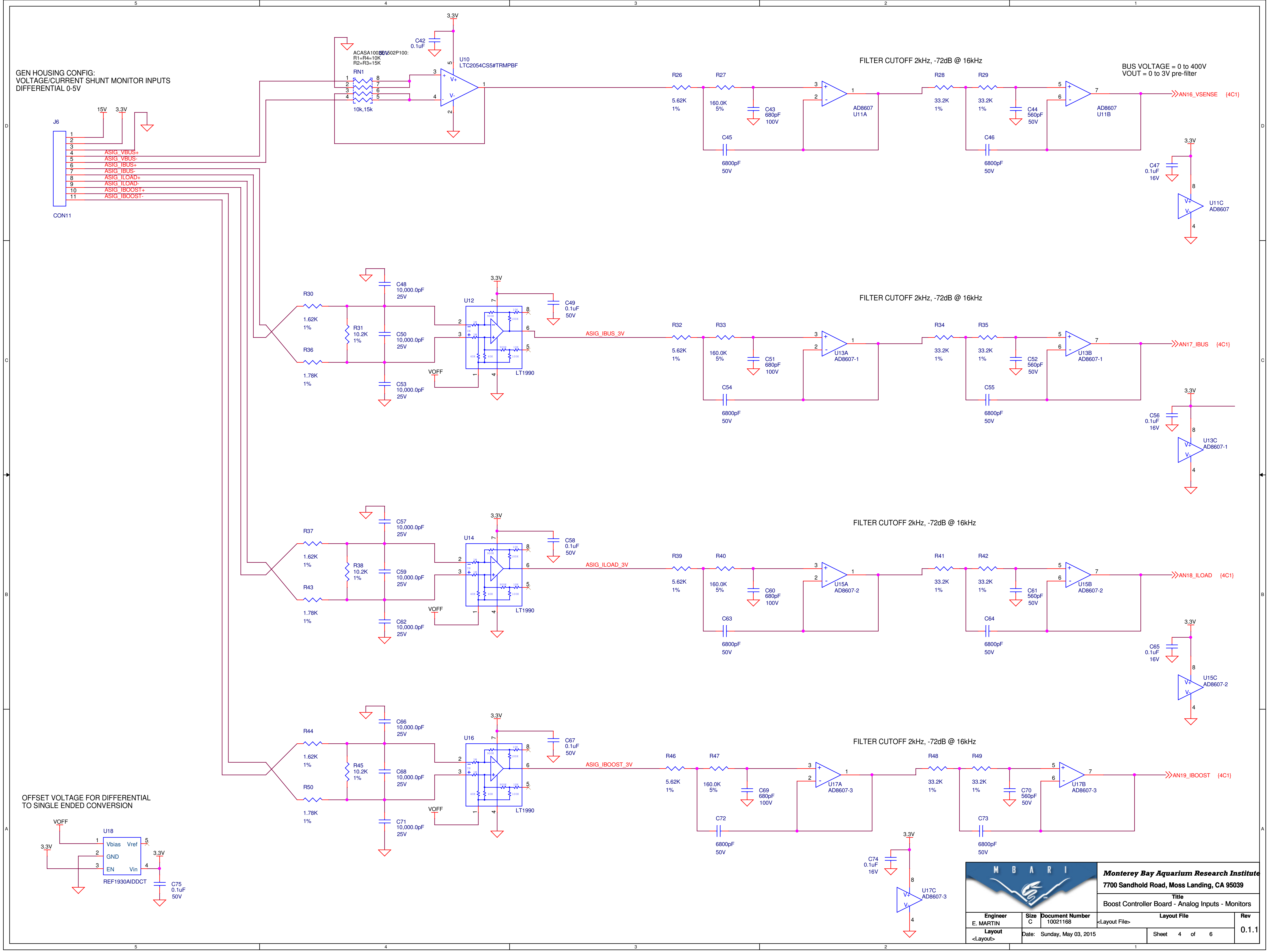
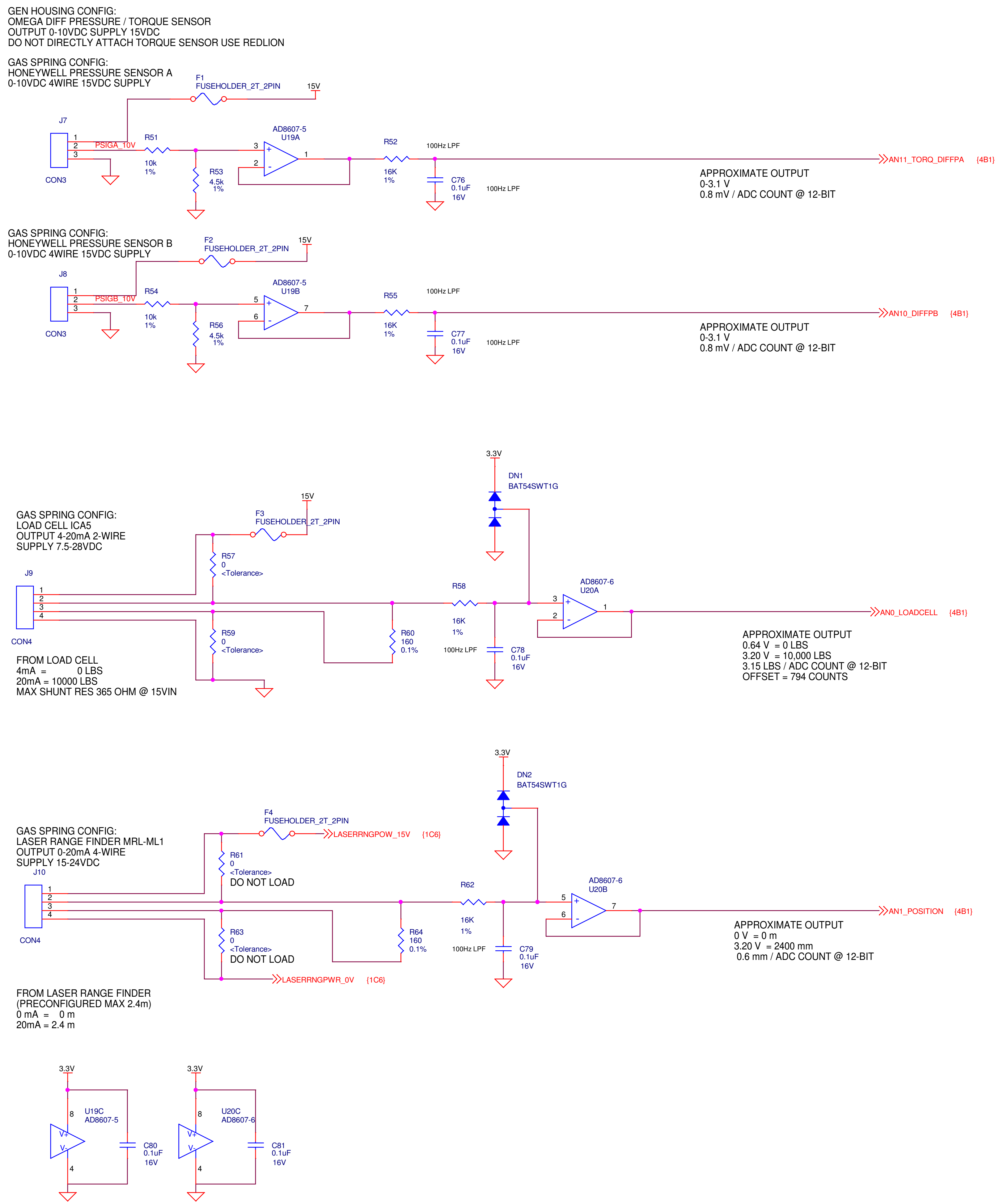
Engineer	Size	Document Number	Layout File	Rev
E. MARTIN	C	10021168	<Layout File>	0.1.1
Layout: <Layout>	Date:	Sunday, May 03, 2015	Sheet 3 of 6	

Title: Boost Controller Board - Telemetry


GEN HOUSING CONFIG:
VOLTAGE/CURRENT SHUNT MONITOR INPUTS
DIFFERENTIAL 0-5V
J6
CON11
15V
3.3V
ASIG_VBUS+
ASIG_VBUS-
ASIG_IBUS+
ASIG_IBUS-
ASIG_ILOAD+
ASIG_ILOAD-
ASIG_IBOOST+
ASIG_IBOOST-
RN1
10k,15k
R1=R4=10K
R2=R3=15K
U10
LTC2054CS5#TRMPBF
C42
0.1uF
FILTER CUTOFF 2kHz, -72dB @ 16kHz
BUS VOLTAGE = 0 to 400V
VOUT = 0 to 3V pre-filter
R26
5.62K
1%
R27
160.0K
5%
C43
680pF
100V
C45
6800pF
50V
U11A
AD8607
R28
33.2K
1%
R29
33.2K
1%
C44
560pF
50V
C46
6800pF
50V
U11B
AN16_VSENSE
{4C1}
C47
0.1uF
16V
U11C
AD8607
R30
1.62K
1%
R31
10.2K
1%
R36
1.78K
1%
C48
10,000.0pF
25V
C50
10,000.0pF
25V
C53
10,000.0pF
25V
U12
LT1990
C49
0.1uF
50V
VOFF
ASIG_IBUS_3V
R32
R33
C51
C54
U13A
AD8607-1
R34
R35
C52
C55
U13B
AD8607-1
AN17_IBUS
{4C1}
C56
U13C
AD8607-1
R37
R38
R43
C57
C59
C62
U14
LT1990
C58
ASIG_ILOAD_3V
R39
R40
C60
C63
U15A
AD8607-2
R41
R42
C61
C64
U15B
AD8607-2
AN18_ILOAD
{4C1}
C65
U15C
AD8607-2
R44
R45
R50
C66
C68
C71
U16
LT1990
C67
ASIG_IBOOST_3V
R46
R47
C69
C72
U17A
AD8607-3
R48
R49
C70
C73
U17B
AD8607-3
AN19_IBOOST
{4C1}
C74
0.1uF
16V
U17C
AD8607-3
OFFSET VOLTAGE FOR DIFFERENTIAL
TO SINGLE ENDED CONVERSION
U18
Vbias
Vref
GND
EN
Vin
REF1930AIDDCT
C75
0.1uF
50V
M B A R I
Monterey Bay Aquarium Research Institute
7700 Sandhold Road, Moss Landing, CA 95039
Title
Boost Controller Board - Analog Inputs - Monitors
Engineer
E. MARTIN
Size
C
Document Number
10021168
Layout File
<Layout File>
Rev
0.1.1
Layout
<Layout>
Date: Sunday, May 03, 2015
Sheet 4 of 6



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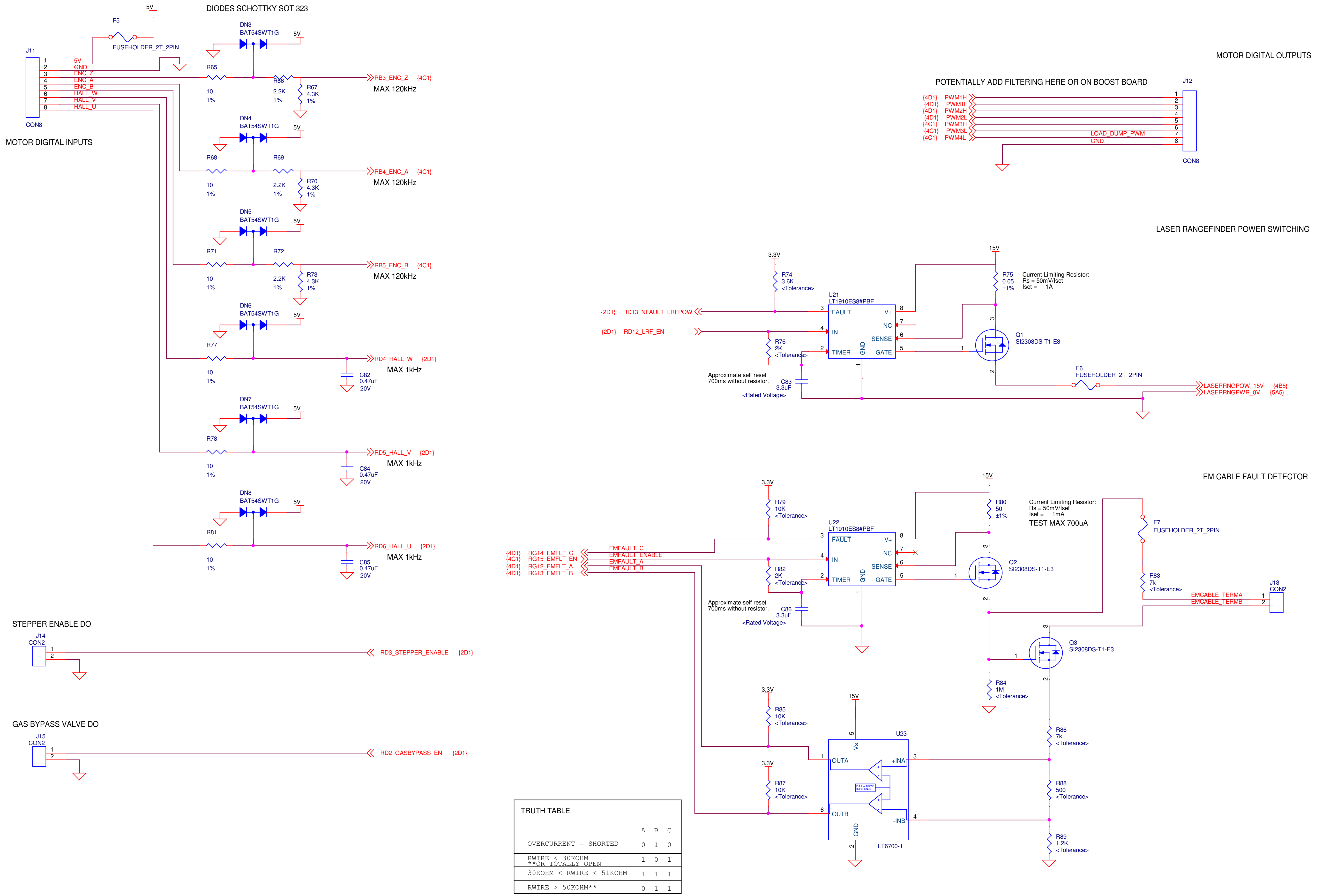
Title				
Boost Controller Board - Analog Inputs - Sensors				
Engineer: E. MARTIN	Size: C	Document Number: 10021168	Layout File: <Layout File>	Rev: 0.1.1
Layout: <Layout>	Date: Sunday, May 03, 2015		Sheet 5 of 6	



TRUTH TABLE

	A	B	C
OVERCURRENT = SHORTED	0	1	0
RWIRE < 30KOHM **OR TOTALLY OPEN	1	0	1
30KOHM < RWIRE < 51KOHM	1	1	1
RWIRE > 50KOHM**	0	1	1

M B A R I

Monterey Bay Aquarium Research Institute
7700 Sandhold Road, Moss Landing, CA 95039

Title			
Boost Controller Board - Digital I/O			
Engineer: E. MARTIN	Size: C	Document Number: 10021168	Layout File: <Layout File>
Layout: <Layout>	Date: Sunday, May 03, 2015	Sheet 6 of 6	Rev 0.1.1

Battery System

In addition to batteries, the battery system contains converters to provide a low-voltage supply to other buoy equipment, a low voltage disconnect circuit to turn off the low-voltage supply if the batteries become discharged, and switches to turn the system on and off for connection.

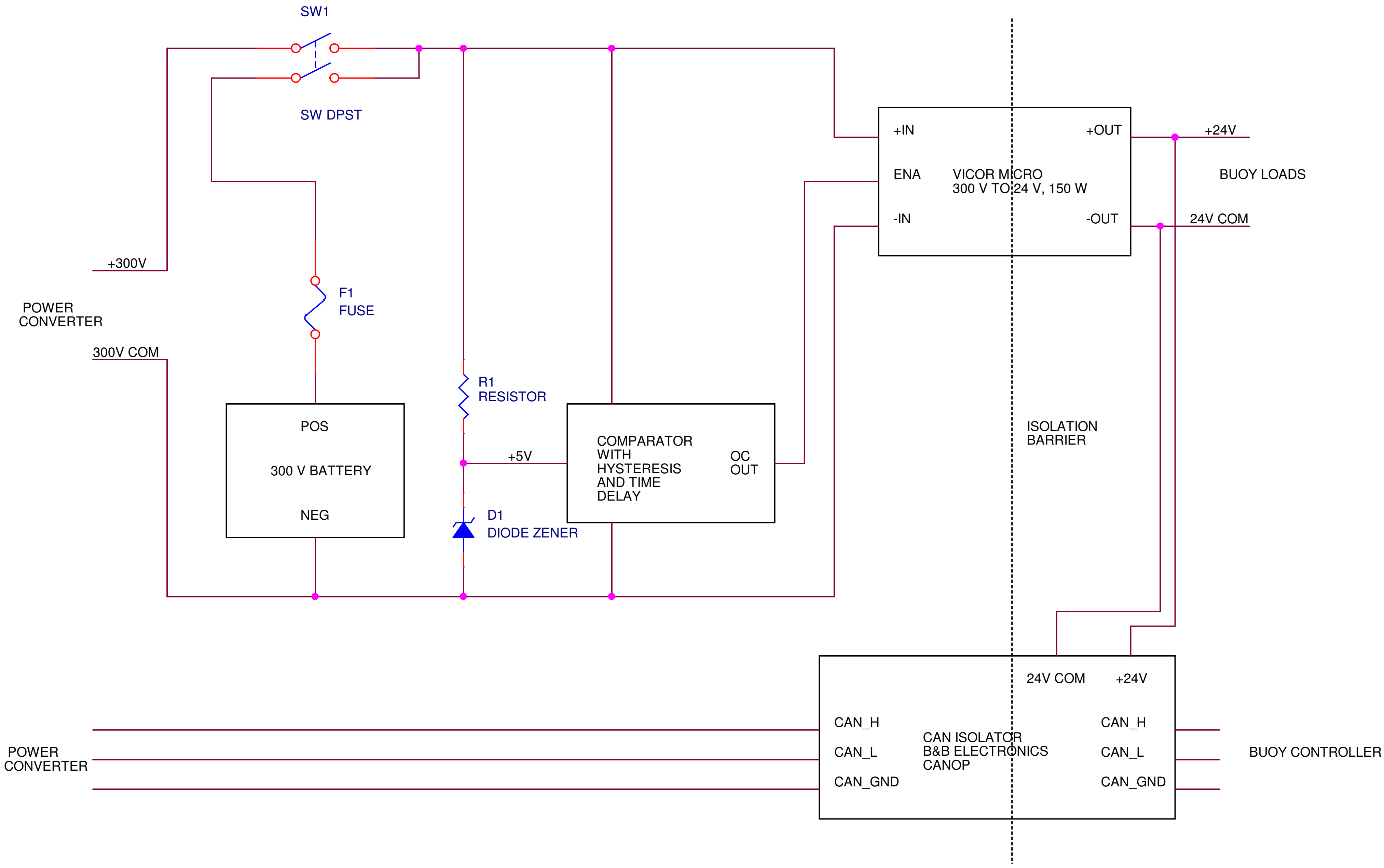
A preliminary design for housing 24 14A-Hr lead acid batteries has been developed. The design of this housing uses a stainless box we've used successfully on the buoy in past deployments, and includes features to keep access to hazardous voltages to a minimum during assembly. The intention is that a plastic guard will fit down over the batteries and have covers over each terminal such that only one terminal can be exposed at a time for connection.

We have performed testing on these lead-acid batteries to determine the effect of pulse charging. We found that charging continuously at C/4, and charging at C with a 25% duty cycle (10 second period) is not equivalent. The pulse charged battery decayed in capacity considerably faster than the constantly charged battery. Nevertheless, the current design still allows battery charging at pulses of C or greater, but it is estimated that these events occur rarely enough that we won't significantly degrade the batteries. It is possible to have the control system limit battery charging to a certain current and to direct the rest to the load-dump resistor during peak events, this is under investigation.

We are also concerned about hydrogen build-up in the housing and are planning a test to quantify this effect at both continuous C/4 charging, and during pulse charging.

Documentation Included:

- Schematic
- Lab Battery Test Results
- Concept SolidModel of housing



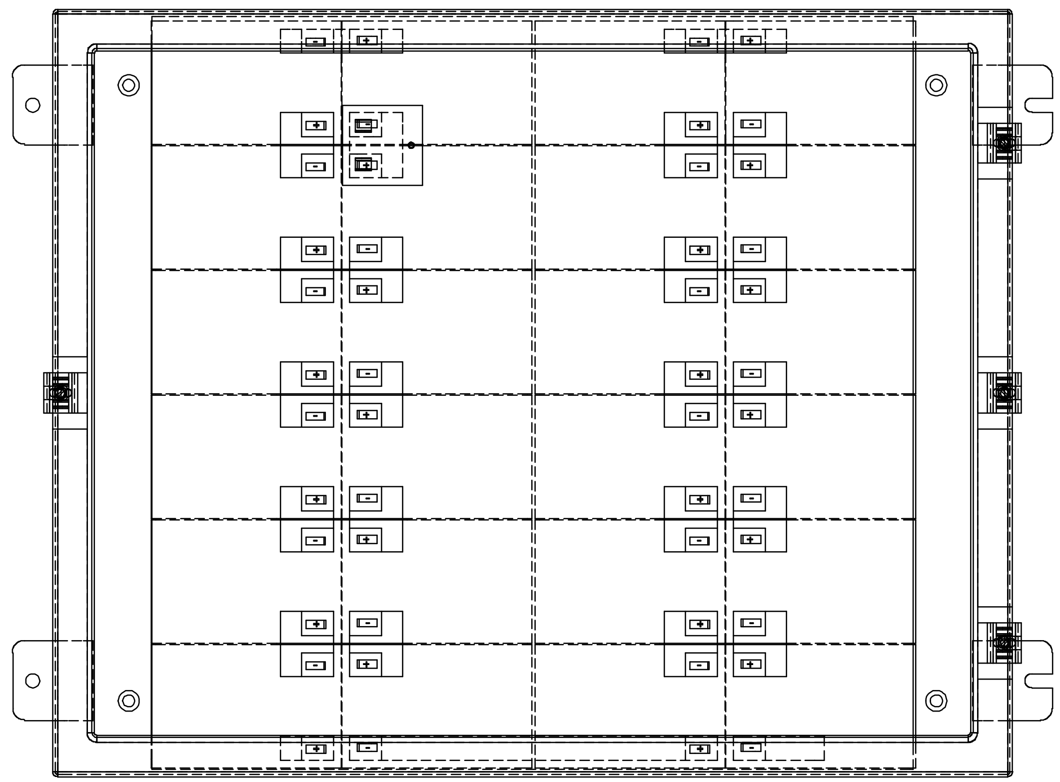
Engineer: P. McGill

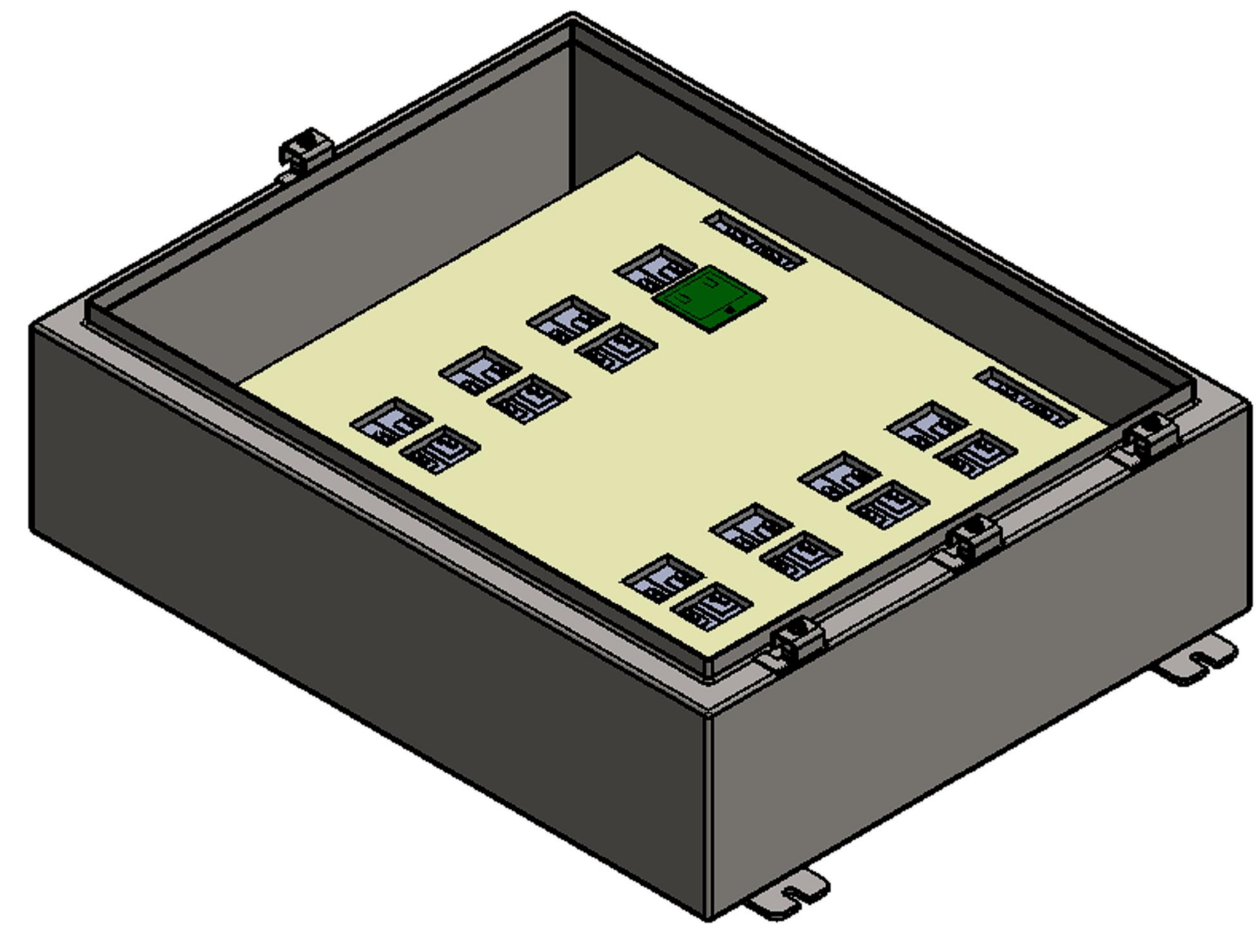
Title: Power Buoy: Battery Box Concept

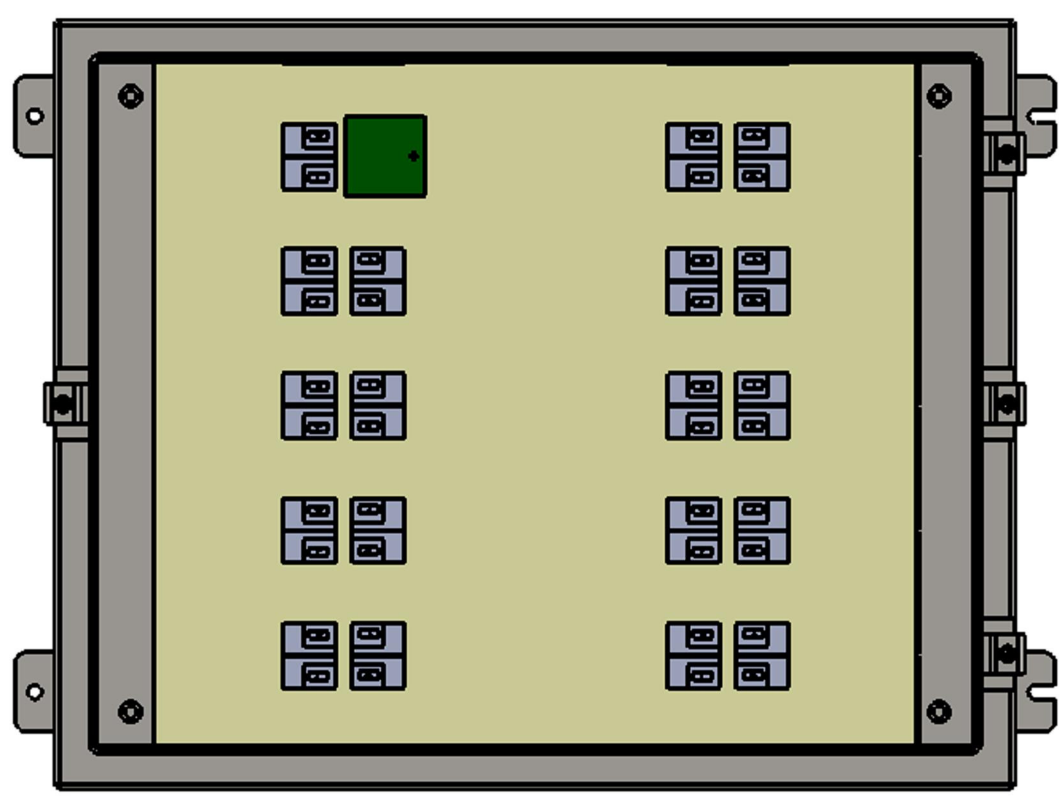
Size	Document Number	Rev
A	<Doc>	1.1.0

Date: Monday, May 04, 2015 Sheet 1 of 1

REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
	INITIAL RELEASE		







BILL OF MATERIALS

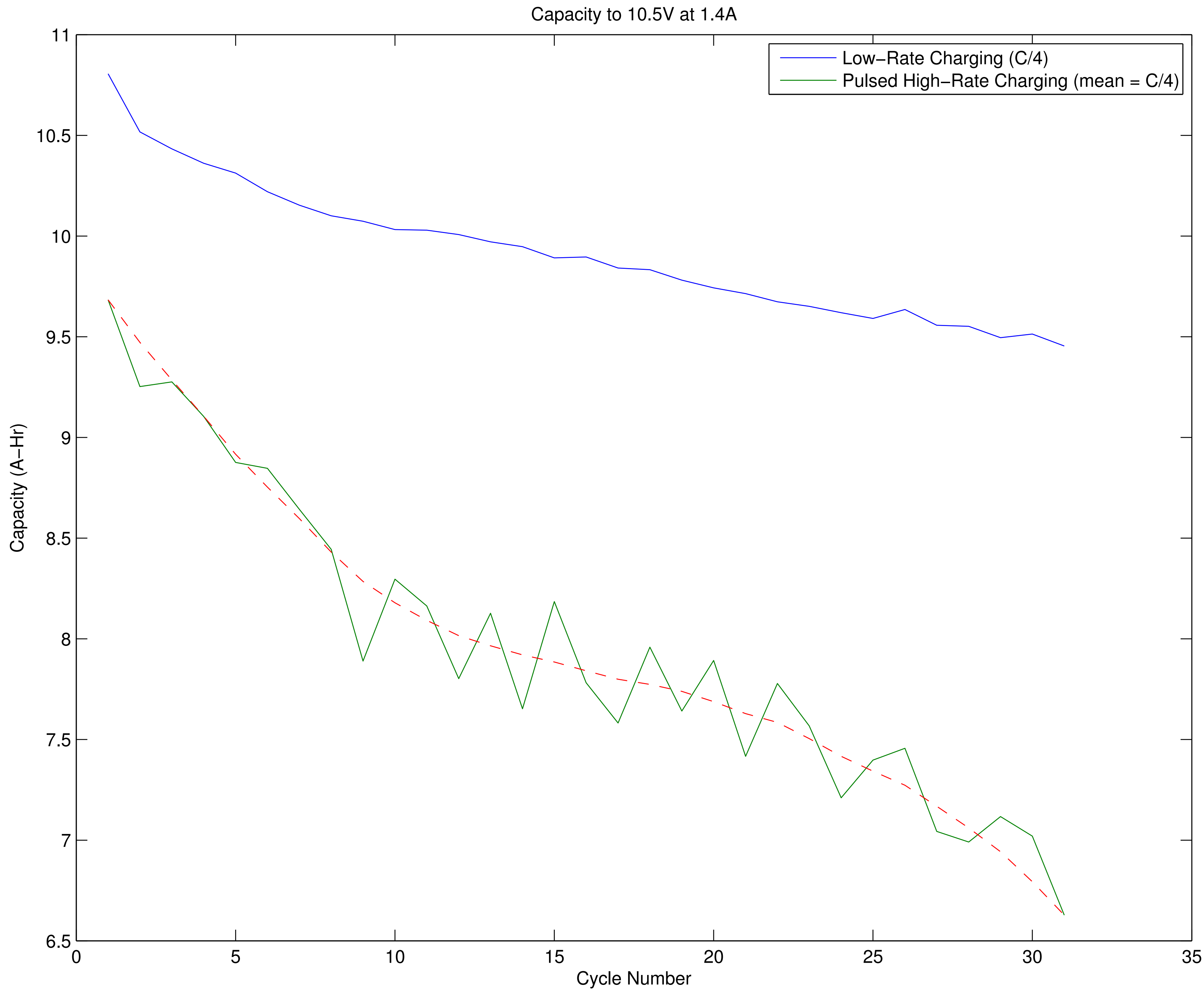
Shop / Q.C.		UNLESS OTHERWISE SPECIFIED TOLERANCES ARE:	APPROVALS	DATE
Inspector		1 PLACE DIM ±1/16 · 2 PLACE DIM ±.02 · 3 PLACE DIM ±.005 · ANGLES ±1°	DRAWN NAME	9/27/00
Shop Foreman		1. DIMENSIONS ARE IN INCHES 2. DIMENSION LIMITS HELD AFTER PLATING.	ENGINEER NAME	9/27/00
Engineer		3. REMOVE BURRS AND SHARP EDGES .015 MAX. 4. MACHINED FILLET RADII .0150-.030.	CHECKED	
NEXT ASSY Description	NEXT ASSY Number	5. MACHINED DIAMETERS ON A COMMON CENTERLINE CONCENTRIC WITHIN .OO5 6. PERPENDICULARITY & PARALLELISM OF MACHINED SURFACES .002 PER INCH. MAX .012 INCHES FOR SINGLE SURFACE.	PROJECT NO. XXX PROJECT ZZZZZZZZ	
Application		DO NOT SCALE DRAWING	WEIGHT	

Monterey Bay Aquarium Research Institute
MBARI
7700 Sandholdt RD.
Moss Landing, CA 95039
PH: (831) 775-1700

24-14A-HrBattBox

SIZE	DWG. NO.	REV.
B	100XXXDWG	

SCALE 1:6 | CAD FILE: MECH ENG ON TORNADO | SHEET 1 OF 1



Capacity to 10.5V at 1.4A
Low−Rate Charging (C/4)
Pulsed High−Rate Charging (mean = C/4)
Capacity (A−Hr)
Cycle Number
11
10.5
10
9.5
9
8.5
8
7.5
7
6.5
0
5
10
15
20
25
30
35

Firmware and Control System

The control system for the power converter runs on a dsPIC33f microprocessor, which includes 12-bit ADC's, a 16bit fixed point DSP for filtering and PID loops, and a range of peripherals useful in this application such as a motor control PWM generator that generates complementary PWM signals with a programmable dead-time to limit shoot-through, a CAN controller for communications, and an DMA controller that frees the CPU/DSP from spending time doing data transfer to/from the various peripherals.

The firmware for this project is entirely interrupt driven, with nothing happening in "main()". Three asynchronous but periodic interrupts run continuously, and a variety of interrupts occur due to various events.

Periodic Interrupts:

- ADC conversions are initiated at 128kHz, scanning through four channels such that every channel is sampled at 32kHz (with some skew between channels). The DMA is set up to collect 32 samples on each channel before initiating a DMA interrupt. Therefore, at 1kHz a ISR is called and presented with the 32 samples on each channel taken over the past 1 ms. This ISR filters these using a FIR running on the DSP, resulting in a filtered signal at 1kHz. This same ISR then calls the control code which generates control signals (PWM signals for the bridge and load-dump transistor). The processor can run considerably faster than this update rate, but so far this bandwidth has been sufficient.
- A 604Hz interrupt occurs for computing RPM of the generator. This ISR looks at the change in encoder position and computes RPM based upon the interrupt period. The frequency of this interrupt is a tradeoff between maximum rotor speed and resolution, and has been selected to be able to measure speed up to 10000RPM, with a resolution of 1RPM.
- A 25Hz interrupt also occurs, this ISR further filters some of the ADC channels, packages the data into CANbus frames, and initiates the appropriate CAN transfers

Asynchronous Interrupts:

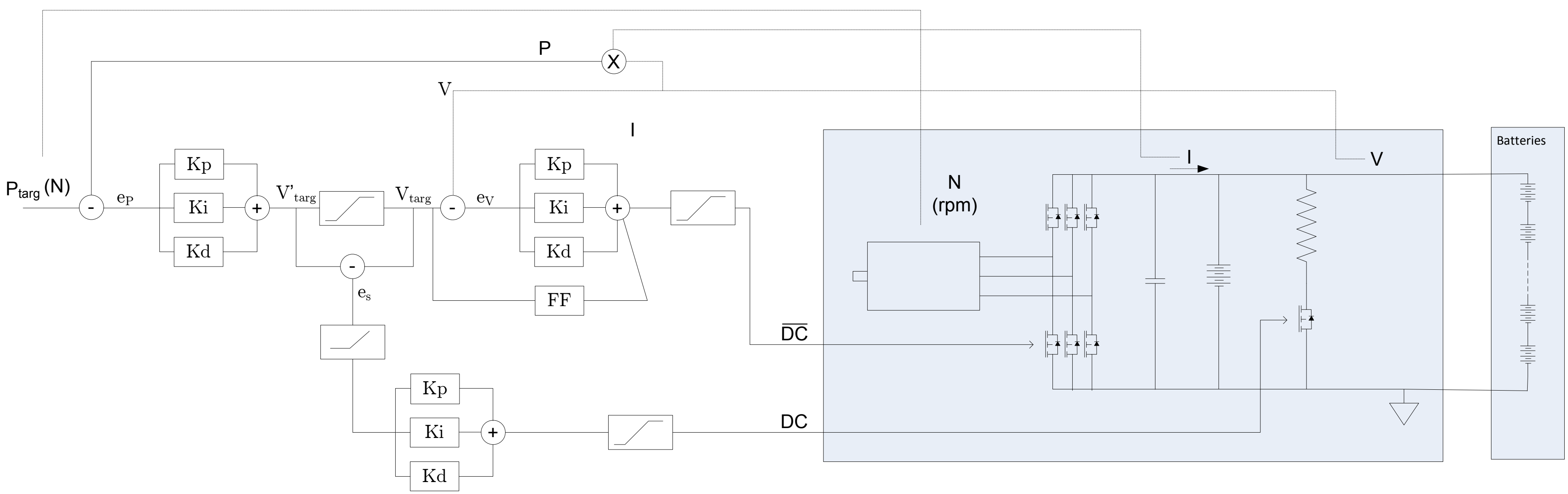
- Encoder position change. An interrupt occurs at every encoder transition, and when the index pulse is seen. If the phases that the PWM signal is applied to depends upon rotor position (such as in motor mode), the PWM setting is overridden for the appropriate phases in this interrupt.
- CAN data available, this interrupt occurs when a CAN packet arrives that has passed the CAN ID mask.

The control loops for battery charging are shown in the attached figures, control of power as a function of RPM is achieved with an inner and outer loop, the outer loop sets a target voltage based on the power error, under the assumption that raising the voltage raises the power. A threshold is applied to this target voltage to constrain it to an allowable range and the amount of thresholding provides an error signal for the load dump control. In this way the load dump is only active when the power control loop is not able to raise the bus voltage high enough to achieve the power target. e.g. If the bus voltage has been raised to the battery system float voltage, and the batteries are still not drawing enough current, the load dump becomes active. Anti-windup is included in every case where a control signal can saturate. There is potential for interaction between the control loops but in testing so far these interactions have been stable.

Documentation Included:

- Control Loop Diagrams
- Firmware Documentation
- CANbus packet structure

Mode 00: Battery Charger w/ specified power target as a function of rotor speed.



Description

Communication between the Boost Controller, the Pneumatic Spring controller, and the Buoy Controller is done via CAN Bus. Custom fields within the 29bit packet ID are used for data and command ID, as described here. Encoded in the CAN ID are three values, a controller ID that specifies either the origin of streamed data, or the destination of commands, a Data/Cmd ID that specifies the data or command packet contents, and a sequence number that groups data from one instant in time across packets, this counts up for streamed data and rolls over. It is intended that the Data/Cmd ID's are unique to each controller.

Request and response is avoided, instead each controller streams appropriate data repetitively at relatively low rates (10's of Hz). Packets can be sent to controllers change modes and state, but are not acknowledged, instead the complete controller state is represented in the streamed packets so the sender can verify that a change was accepted.

Packet ID Structure

Extended Packet ID: xxxxxxxxxxx xxxx xxxxx xxxxxxxxx

11 bits unused | Controller ID | Data/Cmd ID | Seq. Num.

Sequence Number = 9 bits
Data/Cmd ID = 5 bits
Controller ID = 4 bits

Higher ID values have higher priority

Boost Controller (ID = 02)

Data Packets Streamed Out

DataID = 00: Time (float) | Voltage (float)
DataID = 01: P1DC (int) | Pmeas (int) | DBarMin (int) | lag (int)
DataID = 02: iTemp1 (int) | iTemp2 (int) | iTemp3 (int) | iTemp4 (int)
DataID = 03: VoltageTarget (float) | Current Target (float)
DataID = 04: IBridge (float) | ILoad (float)
DataID = 05: BridgeDC (float) | LoadDC (float)
DataID = 06: RPMs (float) | Torque (float)

Cmd Packets Acceped

CmdID = 10: Scale Fact | Retract Fact
CmdID = 11: Bridge DC | Load DC
CmdID = 12:
CmdID = 13:

PneumaticSpring Controller (ID = 01)

Data Packets Streamed Out

DataID = 00:
DataID = 01:
DataID = 02:

Cmd Packets Acceped

CmdID = 10:
CmdID = 11:
CmdID = 12:

Buoy Controller (ID = 00)

Data Packets Streamed Out

DataID = 00:
DataID = 01:
DataID = 02:

Cmd Packets Acceped

CmdID = 10:
CmdID = 11:
CmdID = 12:

CAN Bus @ 500kbit/sec

Oscillator Setup
- Fosc = 79.2275MHz
- Fcy = 39.61375

TMR1
- Based on Fosc and rolls over at approximately 25Hz
- T1CON = 0x8020 (1:64 prescaler)
- PR1 =2X12378-1

- _T1Interrupt is executed when this rolls over.

TMR2
- Based on Fosc and rolls over at 604.467Hz
- T1CON = 0x8000 (1:1 prescaler)
- PR1 =65535

- _T2Interrupt is executed when this rolls over.

TMR3
- Based on Fosc and rolls over at 128.616 kHz
- T1CON = 0x8000 (1:1 prescaler)
- PR1 =308

- _T3Interrupt is executed when this rolls over.

CN
- Set up to cause interrupt on any change of CN6 or CN7 which are the A and B channels of the encoder. Calls _CNInterrupt which adjusts the FET commutation based upon rotor position.
- This is enabled if commutation is needed (e.g. motor mode) and disabled in cases where the FET pwm signals don't depend on rotor position.

QEI
- Encoder module is set up to set the counter to 0 if rotating clockwise at the index pulse, and 4096 if rotating counterclockwise.
- Calls _QEI_Interrupt on index pulse.

CAN1
- Set to 500kb/s
- Uses 6 buffers in DMA ram
    - 4 Tx buffers
    - 2 Rx buffers
- The TMR1 Interrupt loads the Tx buffers and initiates CAN transfers which proceed w/o CPU involvement.
- An interrupt occurs when packets that match the specified mask arrive.

UART2
- Set to 115200 baud 8N1
- Interrupts enabled for characters in Rx Buffer
- This UART is currently only used for debugging and will be disabled for deployment.

ADC1
- 12 bit mode
- Set up to scan through specified inputs repeatedly and transfer resulting data to buffers via DMA
- DMA system is set up to cause interrupt when one half of the buffer is full.
- Example. The ADC scans 4 inputs at 128kHz and uses DMA to place the results in a big buffer, sequentially. When the set of four inputs has been sampled the specified number of times (32 for example), the DMA initiates an interrupt (_DMA0Interrupt). This resulting interrupt occurs at about 1kHz (128/(4*32)) and 32 samples of each channel are available then. The samples aren't simultaneous, the maximum skew across the channels is 4/20000 = 31.25 microseconds.

DMA
Three DMA channels are set-up.
- DMA0 transfers data from ADC to buffer
- DMA1 transfers CAN data from buffer to CAN1 when CAN1 is able to send.
- DMA2 transfers CAN data from CAN1 to buffer when packet is received and passes filters.

MCPWM
- PWM Timebase = Tcy
- PWM Freq approximately 20kHz
- MC channels 1-3 drive FET pairs and the low side of channel 4 drives the load-dump FET.
- Deadtime on channel 1-3 set to: 1 microsecond
- Initial values are 100% for channel 1-3 and 0% for channel 4.
- PWM values are set by boost voltage PID controller (initiated by ADC sample set complete interrupt (_DMA0Interrupt).
- Override values are set by _CNInterrupt based upon rotor position via table look-up when appropriate (motor mode).

_T1Interrupt
- Updates “time” variable.
- Assembles and ships CAN packets over to CAN controller via DMA.

_T2Interrupt
- Computes rotor speed based on encoder.
- Interrupt is called at TMR2 rollover frequency (~600Hz), speed updates down slower based on postscaler defined for this purpose.

_T3Interrupt
- Initiates ADC scanning which happens in one-shot mode.

_CNInterrupt
- This is called every time one of the encoder inputs (A or B) changes state.
- This interrupt performs the needed commutation by setting the MCPWM over-ride bits appropriate to the rotor position.

_QEI_Interrupt
- This occurs on index pulse and is used to count revolutions in a signed 16bit counter.

DMA0Interrupt
- After N channels are read M times, the DMA system notices and causes this interrupt which performs filtering and subsequent processing (PID loops) based on the samples collected. This all needs to complete fast enough to be done before next set of samples is available. However, the ADC/DMA is working in “ping-pong” mode so the ADC is filling the second buffer while this interrupt is processing the first buffer.
- This interrupt
    1) Performs filtering of most recent set of ADC samples
    2) Executes PID loops
    3) Sets Boost and Load-Dump PWM values based on PID results.

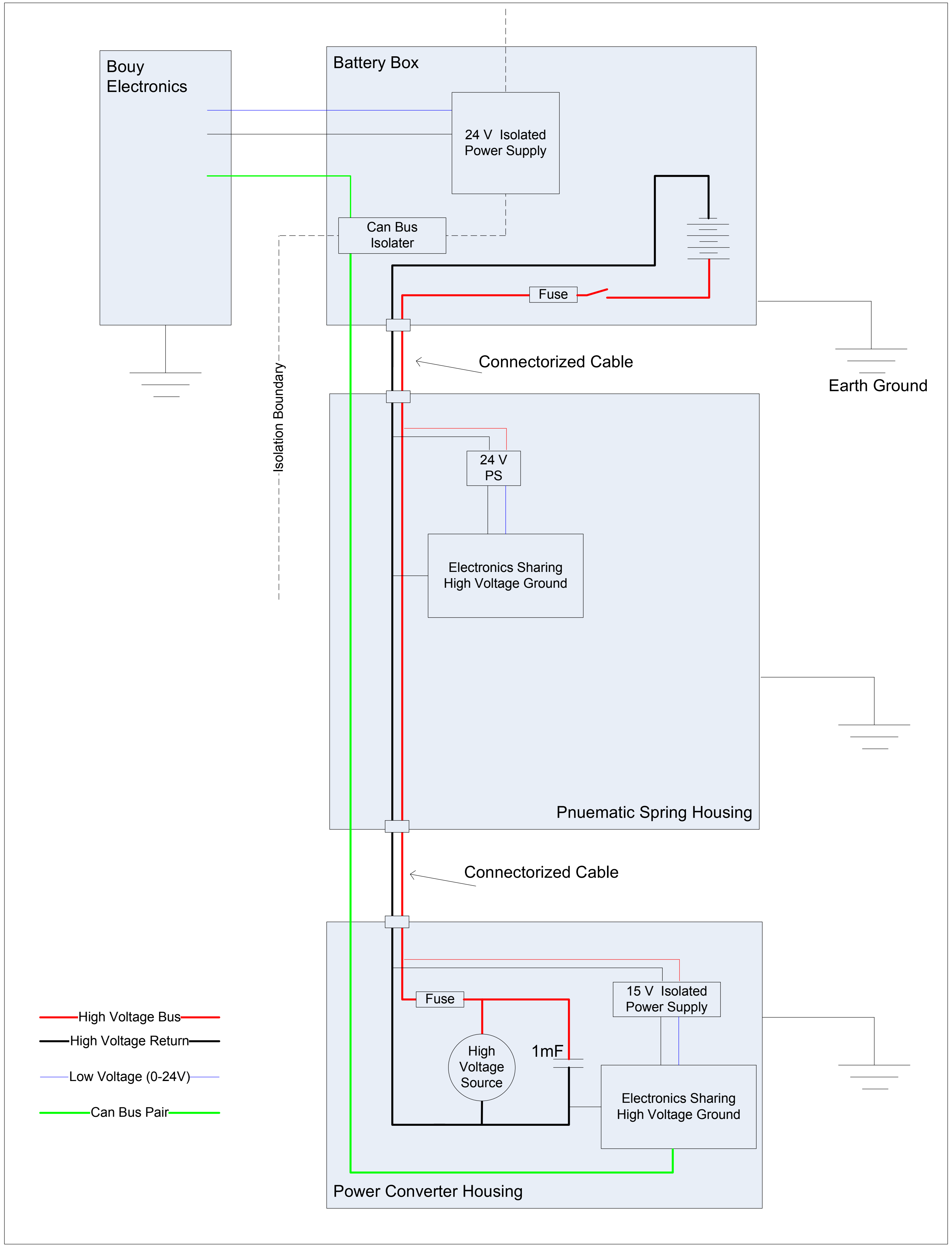
_U2RxInterrupt
- This occurs on UART2 character received and responds to single character inputs that affect settings and modes.

Electrical Safety

Because of the potentially dangerous voltages in this system, electrical safety is extremely important. The generator makes dangerous voltages whenever it spins, so cannot be turned off while the system is at sea. The other source of high voltage is the battery system, which can be turned off to contain the voltages to a single housing. However, the battery voltages are always present even if the system is ashore and disabled, so there are safety issues to be considered in assembly and handling of this component. Finally, the power converter contains a capacitor that can quietly contain high voltages after the main battery system is turned off or removed.

Three areas of electrical safety under consideration are:

- Battery box assembly and maintenance safety.
- Safety of the system at sea and hazards to divers and uninvited visitors to the buoy.
- Capacitor safety



Fault	**Effect**
HV or HV-Retrun connects to housing or seawater	In this case nothing much happens, the potential of the HV system will shift but no current will flow abnormally.
HV hard shorts to HV-Return	In this case fuses will blow, any fuse on the battery side of the short the short will blow immediately, and any fuse on the generator side of the short will blow when the power converter tries to charge the batteries. With the fuses blown the battery will continue to power the buoy electronics for a time, and the power converter will continue to load the generator and dump power through the load-dump resistor in boot-strap mode (i.e. above ~1000RPM). Load on the PTO will be maintained.
HV and HV-Return short independently to seawater.	This is the most likely fault, resulting from a simple severing of the cable between the PTO and Buoy by fishing activity. If this does not blow the fuses, current will flow through the seawater and burn the wires. The batteries will discharge in this case and the power converter will deliver what power it can to the short, and direct the rest to the load dump in bootstrap mode. Load on the PTO will be maintained.
HV shorts to HV-Return with some resistance.	In the case that the fuses do not blow, the battery will discharge through the short, and the power converter will deliver what power it can into the short up to 330V, at which point the load dump circuit will take over. Load on the PTO will be maintained.
HV or HV-Return becomes an open circuit	In this case no current flows and the power converter will direct all power through the load dump in bootstrap mode. Load on the PTO will be maintained.
HV becomes open circuit and connects to system housings in two different locations, i.e on the buoy, and on the PTO.	This degenerates to fault three or four if the PTO housing and the Buoy housing are bonded together. If they are insulated (due to a plastic bushing as we've been using at the connection), a voltage that is potentially hazerdous to divers could exist between the PTO and the buoy structure, depending upon the resistance of seawater.