Solar Energy Generator System Design

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1.0 Introduction

The solar energy generator has a buck boost topology DC-DC converter that can either step up or step down the output voltage from the input voltage, which allows the system to operate at the panels peak efficiency known as the maximum power point. The maximum power point is tracked using a current and voltage sensor by periodically changing the input to output voltage relationship of the DC-DC converter and measuring the corresponding changes in output power the sensors. In addition to implementing Maximum Power Point Tracking, the buck boost topology allows the battery operating voltage range to be either higher, lower, or both relative to the panel input voltage depending on the solar panels used. When configured properly it can be used to harness the energy of panels up to 500W in capacity. Batteries used can be anywhere from 100 watt hours to a few kilo-watt hours in capacity, and the initial target battery chemistry is lithium iron phosphate due to its high cycle life and increased safety over traditional lithium cells. Other chemistry such as lead acid will also be supported in the future. The generator is composed of the following circuit blocks: a buck boost DC-DC converter, a battery current sensor, a load current sensor, a battery voltage sensor, gate drivers for the converter, a C2000 micro controller, 12V, 5V, 3.3V and 1.8V rails, and a load switch.

A load switch is critical to protecting the battery from over discharge and short circuit. The load switch opens and disconnects the load if either of these conditions should occur. Currently, this portion of the system is not fully defined and may be implemented either with relays or MOSFETs as the switch. Each of the two load switches should be able to handle at least 10A, and more may be potentially be added externally.

A Texas Instruments C2000 TMS320F28035 has been selected for the final design of the project, but in the prototyping stage a TMS320F28027 is being used as it is available in a pre made "launchpad" platform from TI, which includes the necessary debugging and programming interface as well as 5V and 3.3V supplies. The C2000 microcontroller was selected because it has many features designed for digital power applications, and configuring it to drive the buck boost converter is not only easy, but powerful, allowing multiple converters to be driven in a phase relationship, and allowing for fast shut down of the converter stage in the event of a dangerous transient event. In the final single-PCB solution, a buck converter will be connected to both the panel input and the battery via a diode or, which will source power from the higher of the two voltages. This 5V rail will then supply power for a 12V rail (boost) for the FET gate drivers and the 3.3V and 1.8V rails for the micro, sensor circuits, display, and various other circuits.

Finally, the generator will include a simple character display, buttons and an encoder wheel to configures various system settings such as battery float voltage, power limiting, a shutdown load timer, display system power output, and allow for future information and configuration features. I selected an OLED display from Adafruit for its high contrast and bold appearance.

In the current stage of development the separate sensor board, power stage board and the C2000 development board are all connected to each other in a manner very similar to the configuration of the final completed PCB. Some features are not currently available such as the load switches and the supply rails. Much of the last two months of development has been teaching myself to code for the C2000 platforms. The next stages of development will include finalizing the proof of concept with separate interconnected PCBs, finishing work on the final

PCB, measuring the performance of the prototype with instruments and searching for possible improvements, and creating in depth documentation of the project.

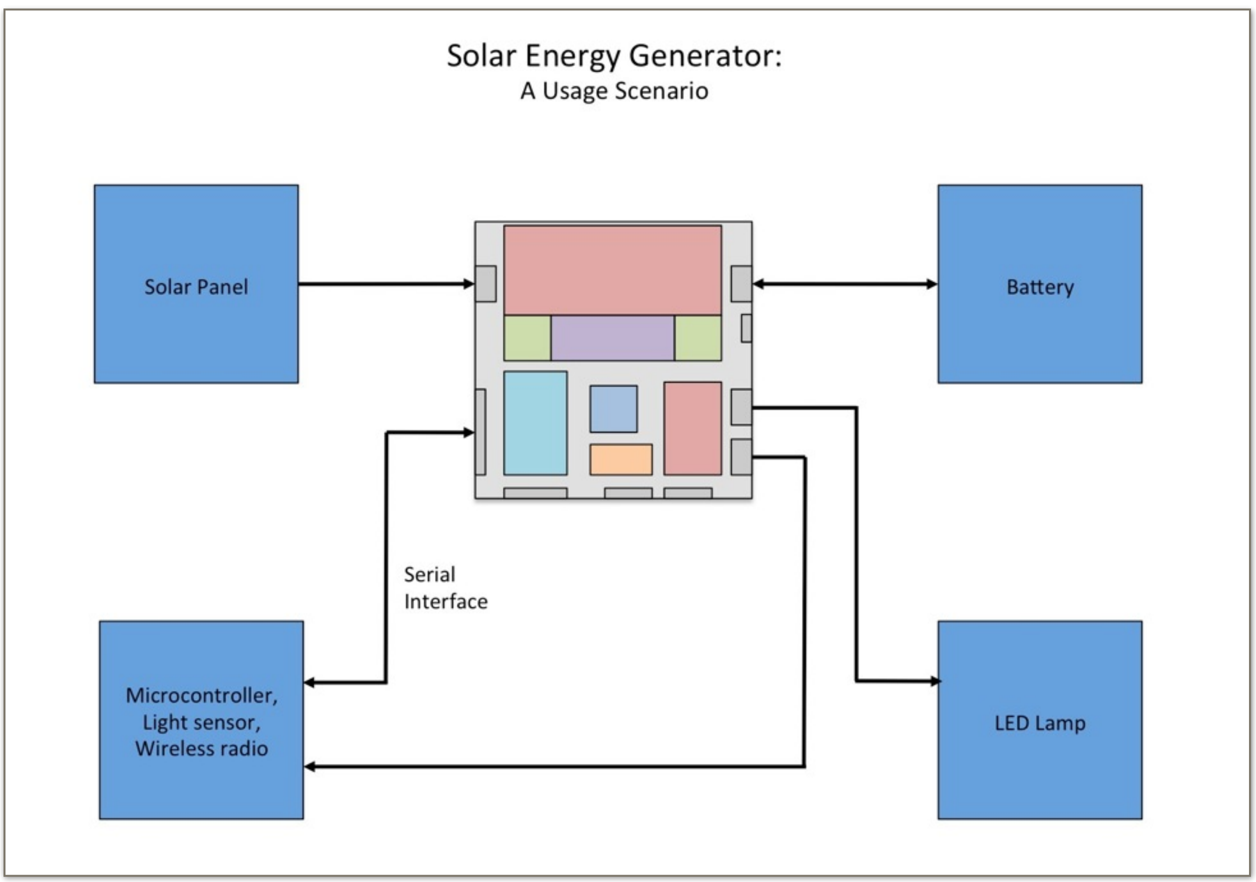
1.1 Table of Contents

1.2 List of target applications

- LED street lights and security lights
- Weather and sensor stations
- Radio relays and mesh network nodes
- Security cameras and sensors
- Power for sailboats and cabins and RVs

1.3 Example Application

The following diagram shows a usage scenario for the Solar Energy Generator. In this scenario, the generator is connected to a solar panel, a battery, and two loads. One of these loads is an LED lamp. The other is a microcontroller that senses the ambient light level, communicates with the generator over a serial bus, and communicates to a host controller over a wireless radio. The microcontroller can tell the generator to turn on or off the load over the serial interface. It could also be connected directly to the LED lamp so that the lamp can be dimmed depending on the remaining energy left in the battery, which is facilitated by the serial interface.



1.4 Device Features

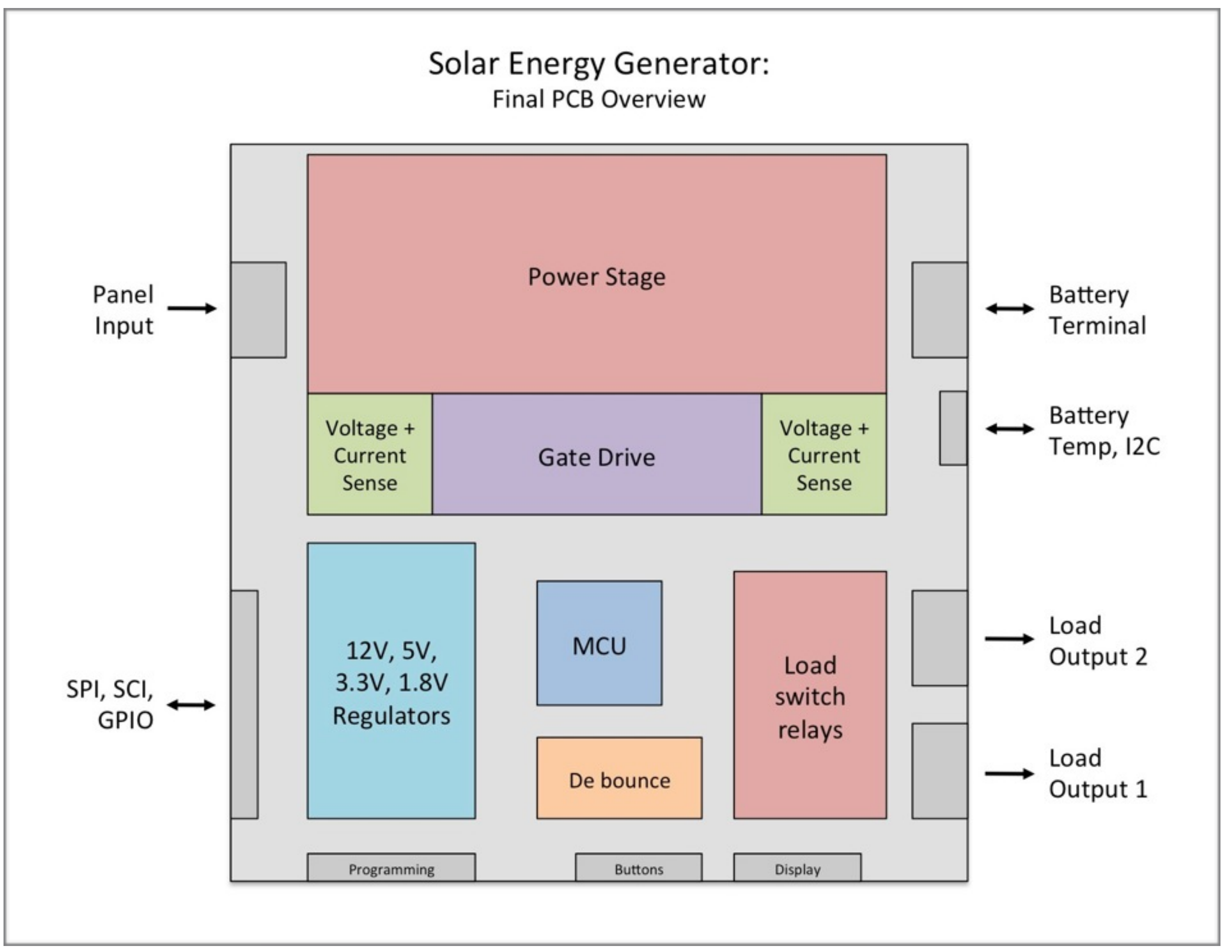
- Supports panels in series or parallel combinations up to 500W
- Interface allows for custom configuration of power limiting, battery float voltage and chemistry, monitoring of real time power output, and control of two different load switches
- Compact size of 120x120x45mm
- High efficiency of 95%
- A Dual phase (in final PCB design) converter allows for currents up to 16A, input FETs and internal rails tolerate input voltages up to 50V
- Maximum Power Point Tracking allows for increased efficiency under all insolation and temperature conditions.
- Load switches allow actuation of load and will prevent loads from damaging batteries by over depletion, short circuit and over current conditions.

2.0 System specifications

This section gives a detailed description of target design specifications for the solar energy generator. A block overview of the final PCB design is included as a guideline for the look at feel of the final board. Connections to and from the board and their various functions are described. A list of electrical specifications is given for both the external connections as well as some internal characteristics of the system. Finally, a list of planned commands that can be addressed to the generator either from an SPI or SCI interface is given. This list of commands is what will allow external load that use the generator as an energy source and to access information on the state of the battery, panel, load current, and other parameters. These features are not commonly found in other similar generator or chargers, and should set the solar energy generator apart from other system by allowing for tighter integration.

2.1 Final PCB general overview

The following diagram is intended to be a rough draft of each of the circuit blocks Present on the final PCB and their relative size and position. External connections are also shown here.



2.2 Connection Description List

A list of connections that can be made to and from the solar energy generator. These include power connections as wells as analog and digital data connections.

Connection	Description
Panel Input	These terminals accept down to a 12 gauge wire connection for a solar panel up to 500W. Connection to a panel under sunlight with at least 200mA of available current drive at at least 15V will allow the harvester to power up.
Battery	Positive and negative connection terminals for the battery. The solar energy generator accepts a lead acid or lithium iron phosphate battery connection with cell voltage configurations between 12 and 36V.
Load 1	Positive and negative connections for a load of up to 10A. This load switch is overcurrent and short circuit protected and can be turned off and on from the interface.
Load 2	Positive and negative connections for a load of up to 10A. This load switch is overcurrent and short circuit protected and can be turned off and on from the interface.
Temp Sensor	Battery temperature connections for an LM65 temperature sensor. This sensor determines if the battery is within the appropriate temperature range and shuts down charging and loads if the battery becomes overheated.
Display	SPI connection for the OLED display. This display allows the user to configure the system and monitor current, voltage and power during charge and discharge cycles
Interface	Debounced connections for 6 buttons, a rotary encoder and 4 LED indicators.
I2C	I2C interface used for future expansion options such as additional sensors or battery balance board.
SPI/SCI	SPI interface used for communicating with the generator and querying it for information.
GPIO	Used for future expansion options such as additional sensors or battery balance board.

2.3 Electrical Specifications

This is a list of electrical input and output specifications various external connections made to the generator as well as specs for some of the on board circuits. These specs are overall design goals that the system should meet when completed.

Charistic	Description and Conditions	Min	Typ.	Max	Units
V_IN	Panel Input voltage	10	36*	50	V
I_IN	Panel Input current	0.1	10*	16	A
P_IN	Panel Input power	5	360*	500	W
V_OUT	Battery terminal output voltage	8		50	V
I_OUT	Battery terminal output current	-20		16	A
I_LOAD	Load terminal output current	0		20	A
I_Supply_12V	On board 12V supply current			200	mA
I_Supply_5V	On board 5V supply current			1000	mA
I_Supply_3.3V	On board 3.3V supply current			600	mA
I_Supply_1.8V	On board 1.8V supply current			600	mA
T_MPPT	Time to finding maximum power point		1	2	S
Converter Eff.	Converter efficiency	90	96	99	%
Converter Frequency	Power coverer switching frequency		120		kHz
Output ripple voltage	Peak to Peak output ripple voltage		20	100	mV
Operating Temperature	Board operating temperature	0		85	C

2.4 Serial Communication Functions

A list of planned functions for the generator to interface with external systems.

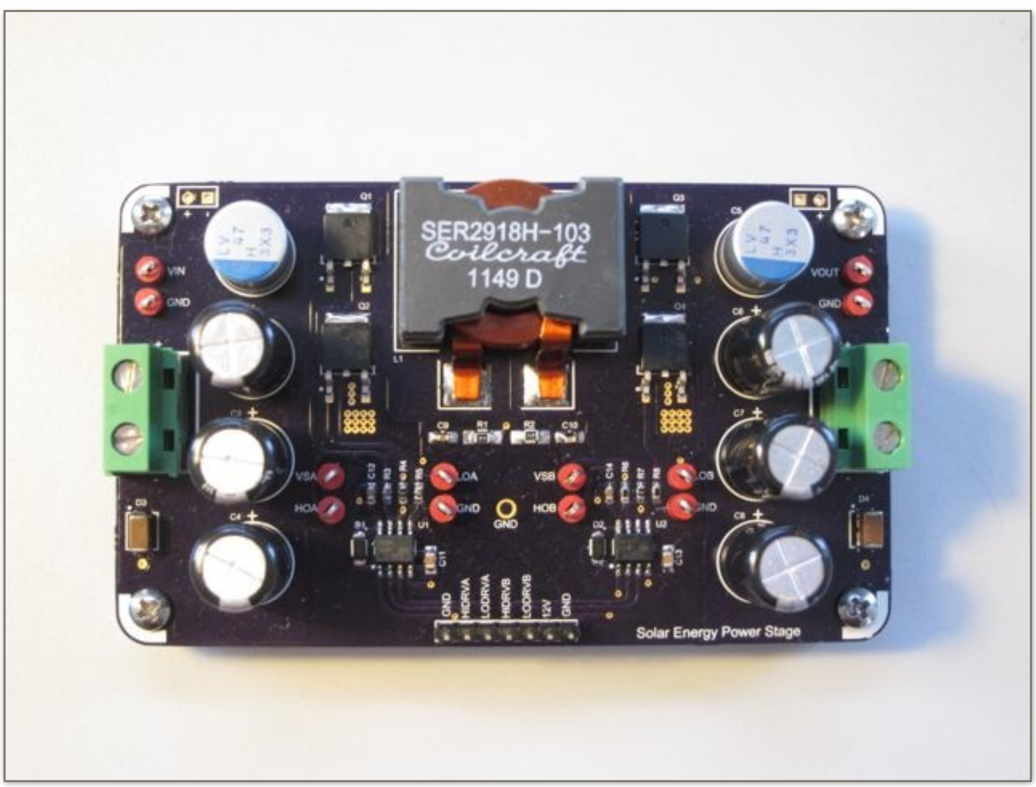
Function	Read/Write	Description
Get Status	Read	Returns status of the system, ex "charging", "discharging", "fault"
Set Load	Write	Enables or disables connected loads
Get Load Stat	Read	Returns vales to indicate which loads are enabled and which are disabled
Enable	Write	Enables or disables battery charging. System must be disabled in order to configure battery chemistry, float voltage, charge current, etc.
Get PV	Read	Returns average panel voltage over the last second
Get PI	Read	Returns average panel current over the last second
Get PP	Read	Returns average panel power over the last second
Get BV	Read	Returns average battery voltage over the last second
Get BI	Read	Returns average battery current over the last second
Get BP	Read	Returns average batter power of the last second
Get SOC	Read	Returns the state of charge of the battery as an integer between 0 and 100 symbolic of battery percentage estimate
Set Chem	Write	Sets the type of battery chemistry
Set Float	Write	Sets the battery float volage
Set Current	Write	Sets the maximum battery charge current

3.0 Prototype Hardware

The solar energy harvester is comprised of several main circuit elements: Input voltage and current measurement, A buck-boost converter stage, Output voltage and current measurement, a C2000 piccolo microcontroller with various peripheral circuitry interfacing with buttons, and serial and other IO. In the prototype phase these circuits have been designed as separate boards that are connected together by 22 gauge jumper wires and thicker 14 gauge wires for high current connections. The boards include a differential voltage sensor, Hall effect current sensor, and power stage boards. Additionally, a C2000 launchpad is used as the development board for the microcontroller, and separate analog and digital supply voltages are set up by linear regulators on a breadboard. A 12V switching power supply deli pavers power to the gate drive ICs on the power stage board.

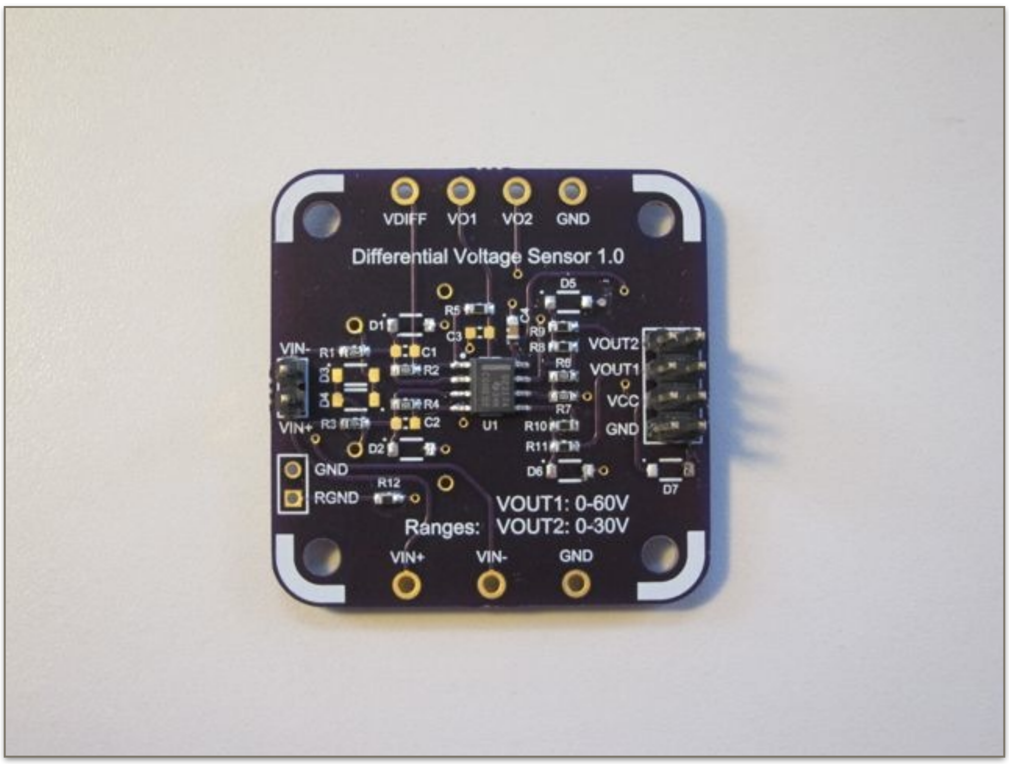
3.1 Buck-Boost power stage

The power stage allows the converter to change the panel input voltage to battery voltage relationship by stepping the voltage up or down. This ability is critical to controlling the battery charging process as well as finding a point on the solar panel known as the Maximum power point, where the panel will deliver the most energy it is capable of given current sunlight and temperature conditions to the battery load. The prototype power stage has the power circuitry which includes input and output capacitors, switching FETs and an inductor as well as gate driver ICs to drive the FETs. The board takes an input from the input current sensor board and sends converter power out to the battery current sense board.



3.2 Voltage Measurement

Voltage measurement is accomplished by a differential voltage circuit that allows for high impedance sense lines to both the high voltage and ground point that is being measured. When high currents are present in the power stage, the voltage drop associated with this high current would cause errors in the voltage measurement if the voltage sensor was not differential. After going through a low pass filter, the output of the difference amplifier, which has a 1/20 gain, may be multiplied by a second amplifier with a gain of 2. This allows the board to have two effective ranges with a 3.3V supply of either 30V or 60V.

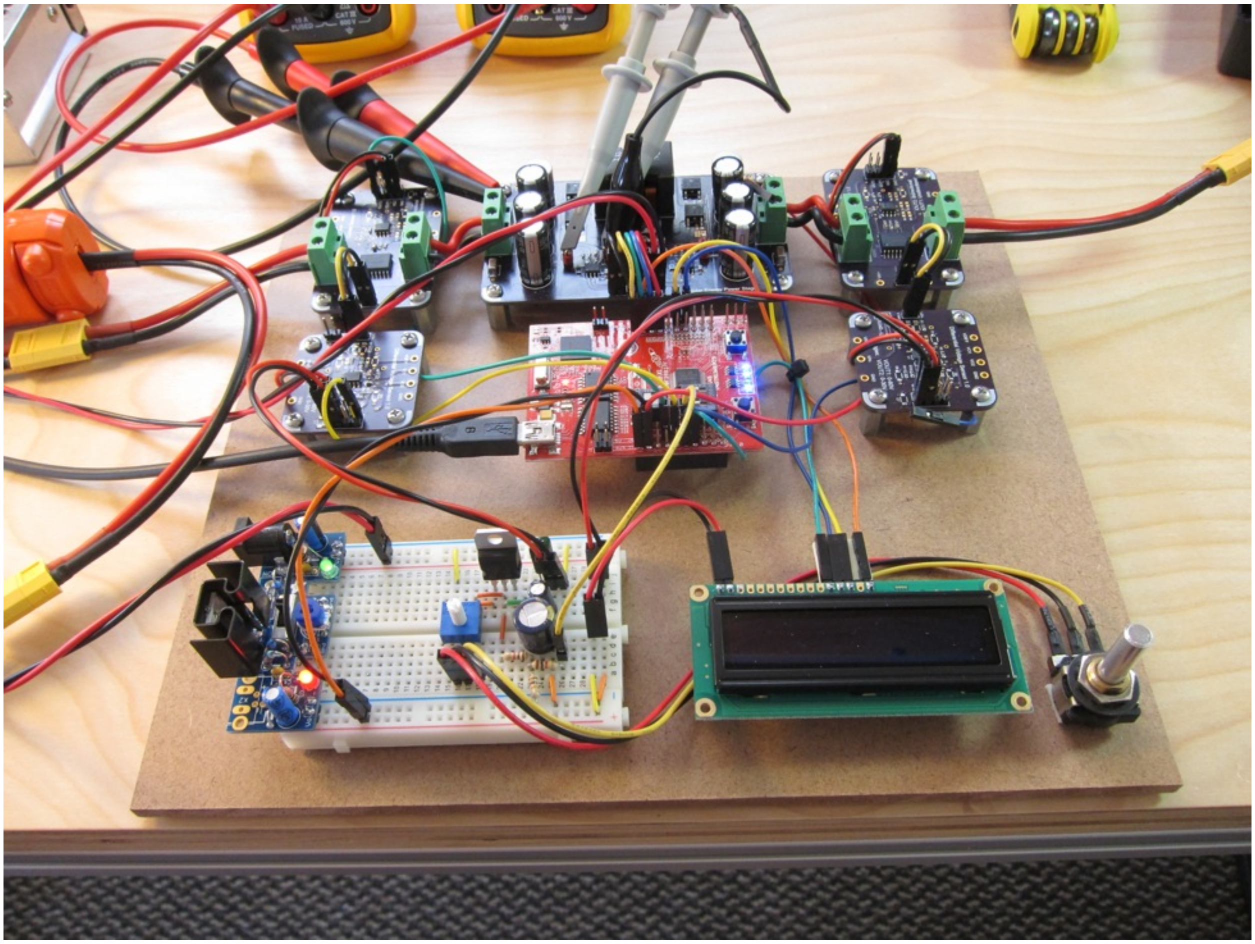


3.3 Current Measurement

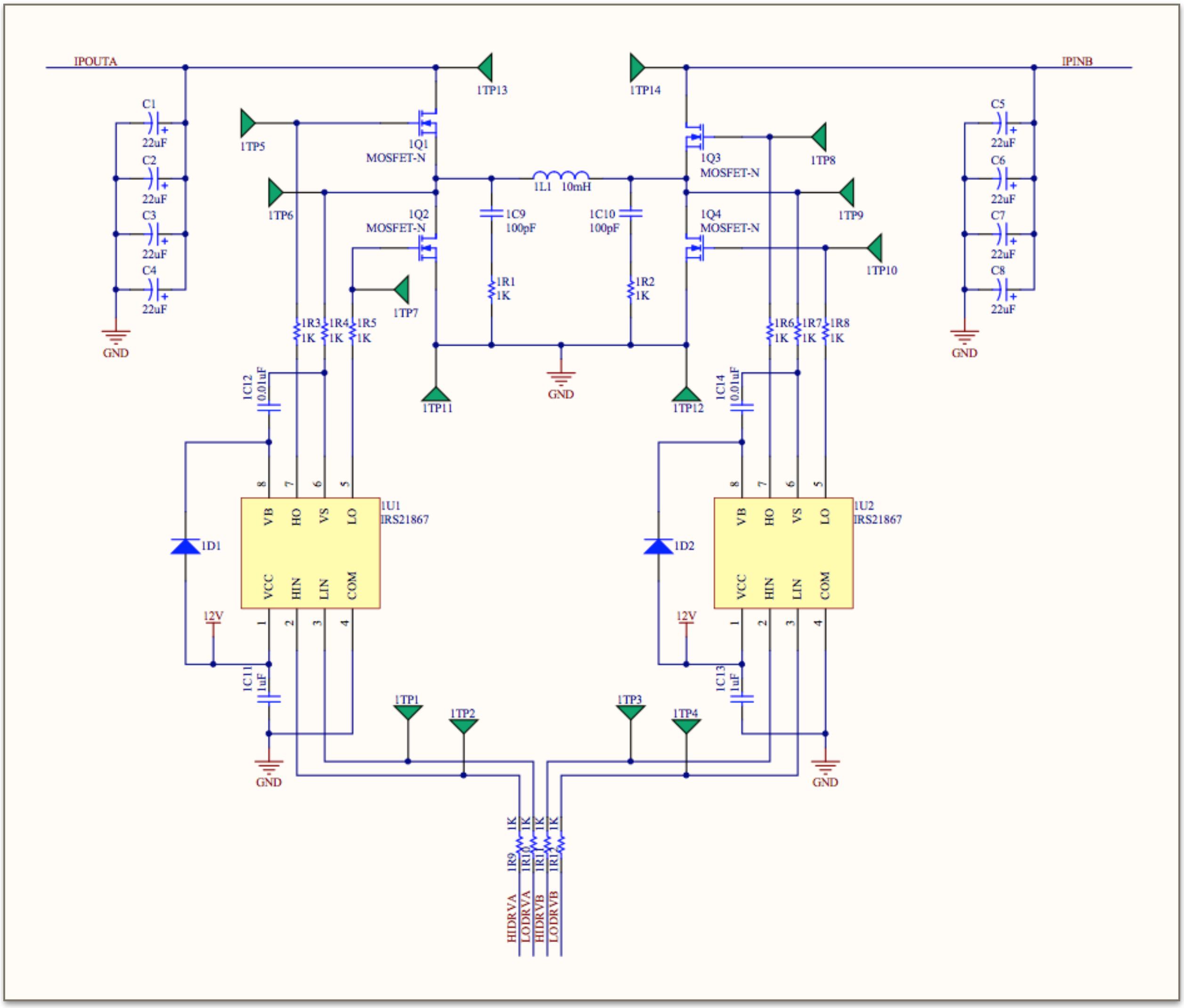
Current measurement is performed by an Allegro Hall effect sensor. The output of the sensor goes through a low pass filter and a buffer. The sensor has a range of +/-20A.

3.4 Prototype hardware setup

All of these boards are mounted on an MDF board so that connections can be neatly made between them. The current prototype is a work in progress and will change as more experiments and improvements are made to the system.



4.0 Buck-Boost Power Stage Schematic



4.1 Differential Voltage Sensor Schematic