ECE 445: Senior Design

Main Power Converter for IlliniSat-2 Project

Project Proposal

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1. INTRODUCTION

1.1 Statement of Purpose

The IlliniSat-2 is a multidisciplinary project with the goal of designing and building a fully functional satellite to be deployed into low Earth orbit. The purpose of our project is to design and build the main power converter, which will take power from Solar Photovoltaic Panels and will charge Li ion batteries. The project is, thus, oriented to the design and control of power systems, which is an area of main interest for all the members of the team. Also, it requires the integration of our project within a larger one. This allows our project to be part of a great accomplishment: deploying a satellite into orbit. Our design will take extra considerations to prepare our product to endure the space environment.

1.1 Objectives

1.2.1 Goals

- Highly efficient power converter
- Prepare it to endure the space environment
- Minimize the size of the product
- Set up a main battery and a backup battery

1.2.1 Functions

- Maximum power point tracking for the Photovoltaic (PV) panels
- Convert voltage from the PV panels to either a higher or lower voltage
- Select which one of the batteries is charging

1.2.1 Benefits

- The backup battery guarantees power supply in case of main battery failure
- GaN fets allow very high switching frequencies
- The smaller the converter, the more room is available in the satellite

1.2.1 Features

- The circuit should sustain large the temperature gradients
- The backup battery will only be charging if the main battery is full
- Efficiency is a priority, and should be at least 90.0% at all times
- Prevent heat dissipation issues in the space environment

2. DESIGN

2.1 Block Diagram

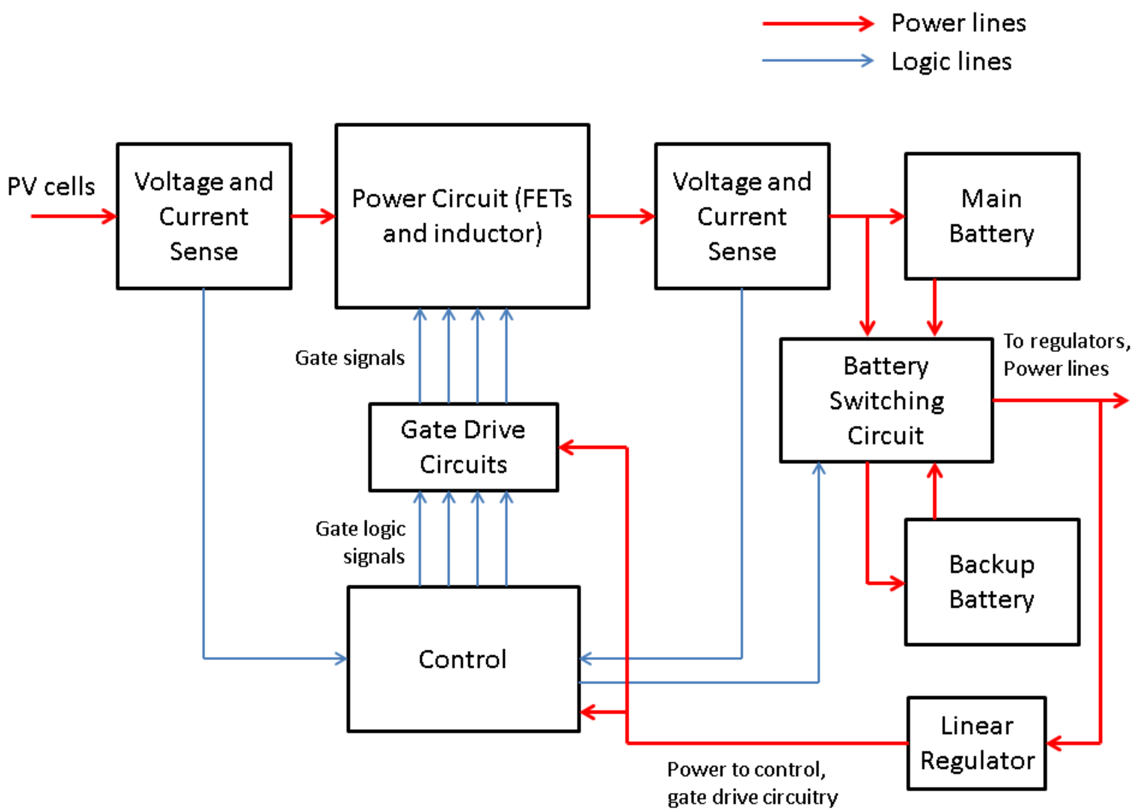

Fig. 1: Block diagram for the power converter, showing power and control circuits.

2.2 Block Descriptions

<u>Power Circuit</u>

The power circuit block refers to the DC-DC switching converter that forms the interface between the PV cells and the battery. The power circuit will be a four switch buck-boost topology with EPC GaN FETs as the switching devices.

<u>Voltage and Current Sense</u>

The voltage and current sense blocks will convert voltage and current levels both before and after the power circuit to logic signals to be read by the control circuitry. The current sense circuitry will probably consist of an off-the-shelf current sensing IC, and the voltage sense will consist of a voltage divider.

Control
The control block is a microcontroller with a maximum power point tracking algorithm on it. The maximum power point tracker uses information about the voltage and current from the PV cells and adjusts the conversion ratio of the power circuit to keep the power coming from the PV cells at a maximum. It also monitors the battery voltage and stops charging if it reaches the safe upper limit for the battery. In the case of a prolonged battery undervoltage, overcurrent or disconnection, the controller will use the battery switching circuit to switch to the backup battery.

Gate Drive Circuits
The gate drive circuits provide the power necessary to switch the GaN FETs at a high frequency without drawing current from the microcontroller. They will consist of off-the-shelf gate drive ICs.

Main/Backup Battery
Rose Electronics 7.4V 2.2Ah Li-Ion batteries.

Battery Switching Circuit
The battery switching circuit chooses which battery is charged by the power converter, and which battery supplies power to the rest of the satellite subsystems and payloads. The backup battery will be charged if the main battery is full; if both batteries are full, charging will be temporarily halted. The main battery will be connected to the subsystems and payload unless a battery switch signal is received from the controller, at which point the backup battery will be connected and charging will be switched to the backup battery.

Linear Regulator
Regulates the 7.4V output from the batteries to the voltage levels required by the gate drive circuits and microcontroller in order to power them.

2.3 Performance Requirements

Power Circuit

1. The power circuit shall convert a DC input voltage to an output voltage either higher or lower than the input with little change in efficiency.
2. The power circuit shall operate with an efficiency greater than 90.0% at all times.

Voltage and Current Sense

1. The voltage and current sense blocks shall convert voltage and current values at their locations into a logic level that can be read by the microcontroller.
2. The voltage and current sense blocks shall be together responsible for no more than a 1% loss in converter efficiency.

Control

1 While in steady-state operation, the converter's input voltage and current shall correspond to the maximum power point of the Photovoltaic cells under any level of illumination
2 The controller shall monitor output voltage and current to ensure the safe operation of the Lithium-Ion batteries.
    a The converter's output voltage shall not exceed the safe voltage range of the Lithium-Ion batteries, 6.0 to 8.2 V.
    b The converter's output current shall not exceed the safe charging current of the Lithium-Ion batteries, 2.2 A.
4 The controller shall switch automatically between charging the main battery and the backup battery as needed.

Gate Drive Circuits

1 The gate drive circuits will tolerate a switching frequency of up to 100kHz while drawing negligible current from the microcontroller.

Main/Backup Battery

1 The batteries shall operate as specified in their datasheets.

Battery Switching Circuit

1 The battery switching circuit shall fully disconnect the battery currently not in use from the satellite subsystems and from the charging circuit.
2 The battery switching circuit shall automatically detect a main battery fault, and shall connect the charging circuit and satellite subsystems to the backup battery even under minimal power conditions.

Linear Regulator

1 The linear regulator shall regulate the 7.4V battery voltage to the voltage level required by the microcontroller. The linear regulator shall have a drop-out voltage less than or equal to 2.4 V.

3. VERIFICATION

3.1 Testing Procedures

Power Circuit

The power circuit will be tested with a battery load and a DC voltage source to determine the efficiency under full load. The power circuit will be tested at a range of switching frequencies to determine the best trade-off between voltage ripple and device stresses.

Voltage and Current Sense
The voltage and current sense blocks will be calibrated with known voltage and current sources to determine their accuracy.

Control
The microcontroller will be tested with the power circuit to determine its ability to successfully track the maximum power point of the solar cells. The Spectrolab UTJ solar cells and Rose Electronics batteries are available in the Cubesat lab, and another group within the Illinisat-2 project is developing a sun simulator which can be used with the solar cells to simulate different levels of illumination. Assuming this project is finished in time for our testing schedule, it will be used to determine the maximum power point tracking ability of the controller. The controller's battery switching function will also be tested, as will its ability to maintain the safe voltage range of the battery, by monitoring battery voltages during testing procedures.

Gate Drive Circuits
Gate Driver Circuit will be tested using the input form a power supply and varying input to get the desired output. It should produce the desired duty ratio.

Main/Backup Battery

The battery could be tested by observing the output from it and it should meet all the requirements.

Battery Switching Circuit
The battery will be charged using the output from the power converter. The voltage of the battery would be observed using the multimeter as soon as it reaches its maximum level the the current should start going into the the reserve battery and start charging it. Once both the batteries are fully charged at that time the circuit should shut down. This whole procedure can also be done using the external input to test the circuit separately without the power converter.

Linear Regulator
The linear regulator will be tested using a DC supply of 7.4V to replace the main battery. The linear regulator should then output the specified voltage (2.4V). The output voltage should be a stable signal.

3.2 Tolerance Analysis
Gallium Nitride (GaN) FETs is a relatively new technology. It was chosen for this project because they offer a much higher power handling capacity than other switching devices. GaN FETs allow high switching frequencies. However, this also means that we need to remove a significant amount of heat from a small area. GaN FETs will be tested so that they do not exceed

a certain temperature gradient when in continuous operation. Heat removal is an important issue of the board because of the conditions where it is designed to work in.

4. COST AND SCHEDULE

4.1 Cost Analysis

4.1.1 Labor

Name	Hourly Rate	Total hours invested	Total =Hourly Rate x 2.5 x Total Hours Invested
Sam Kearney	$ 35	150	$ 13,125
Roberto Suarez	$ 35	150	$ 13,125
Rachit Goel	$ 35	150	$ 13,125
Total		450	**$ 39,375**

4.1.2 Parts

Part	Part Number	Unit Cost	Quantity	Total
PCB's		$ 35	2	$ 70
Capacitor	B0017KFZJ8	$ 0.35	10	$ 3.5
BJT's	MMBT3904 NXP SOT23	$ 1.25	6	$ 7.5
MOSFETS	EPC2014	$ 2.50	4	$ 10
Resistors		$ 0.20	25	$ 5
Battery	LI-2S1P-2200	$ 10.0	2	$ 20

Microcontroller	PIC18F8722	$ 13.32	1	$ 13.32
Switches		$ 3.00	8	$ 24
				$ 153.32

4.1.3 Grand Total

Section	**Total**
Labor	$ 39,372
Part	$ 153.32
Total	**$ 39,525.32**

4.2 Schedule

Week	**Task**	**Responsibility**
2/4	Finalize and hand in proposal	All
	Research gate drive circuits/GaN FETs/inductors and design	Sam Kearney
	Research microcontrollers, come up with MPPT tracking algorithms and current sensing techniques	Roberto Suarez
	Research Li-Ion battery failure and design preliminary battery switching circuit	Rachit Goel
2/11	Mock Design Review	All
	Select capacitors, inductors, resistors	Rachit Goel
	Select appropriate microcontrollers, FET's and BJTs	Sam Kearney
	Select appropriate design and components for battery switching circuit	Roberto Suarez
2/18	Order parts and review initial design	Roberto Suarez
	Design the power converter circuit	Rachit Goel

	Design feedback circuit	Sam Kearney
2/25	Design Review	All
	Build prototype for power converter circuit	Rachit Goel
	Build prototype for Feedback and Linear regulator circuit	Sam Kearney
	Build prototype for gate driver circuit, voltage and current sensor	Roberto Suarez
3/4	Layout PCB for gate driver and feedback circuit	Rachit Goel
	Layout PCB for controller and power circuit	Roberto Suarez
	Layout PCB for battery switching circuit and review all designs	Sam Kearney
3/11	Individual Progress Report	Sam Kearney
	Individual Progress Report	Rachit Goel
	Individual Progress Report	Roberto Suarez
3/18	Debugging the circuit	All
3/25	Mock up demo	Rachit Goel
	Test the efficiency of the circuit and try to improve it	Sam Kearney
	Debug remaining issues	Roberto Suarez
4/1	Mock up presentation	Roberto Suarez
	Completion of modules	Rachit Goel
	Tolerance analysis	Sam Kearney
4/8	Ensure completion	Rachit Goel
	Verification of requirements	Roberto Suarez
	Fix remaining issues	Sam Kearney
4/15	Prepare Demo	Roberto Suarez
	Prepare Presentation	Rachit Goel
	Prepare Paper	Sam Kearney

4/22	Demo	All
4/29	Presentation	Rachit Goel
	Final Paper	Sam Kearney
	Check In Supplies	Roberto Suarez