Magnetorquer

ECE 445 Design Document
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1 Introduction

1.1 Objective

The CubeSat utilizes magnetorquers to change its flight attitude in space. Currently the magnetorquer device used has an integrated magnetic coil in its PCB, which limits its ability to provide a large magnetic field, therefore the satellite has a limited ability to maneuver in orbit. Our goal is to create an improved version of it satisfying the requirements as follows.

The Cubesat team requires additional features as well as a larger maximum torque induced by the coil. These features include the ability to sense both the magnetic moment and torque produced; We will use an onboard magnetometer to test the aliveness of our coil as a self-test procedure. This is because in space there is no way to know if the magnetorquer is providing torque, an on-board device that detects the magnetic field solves this problem. The module will be a master/slave on the I2C BUS capable of receiving power and strength information from another master, as well as writing capabilities to the power controller and reading and writing capabilities to the magnetometer. The satellite uses the I2C interface for its other modules so this makes most sense for our design.

1.2 Background

CubeSats often rely on magnetorquers to control attitude in space by producing a magnetic interaction. Researchers have designed a flat-coil designed printed on a PCB, however the current device's maximum output is a magnetic moment of 0.27Am^2 at 200mA which is too weak for testing purposes and its intended functionality of being able to rotate the host device at a desired rate.

The bus, IlliniSat-2, is intended for generality as currently five different missions are being flown with the bus. As such, when designing components for this project it is imperative to implement a common hardware design such that very little variation is required to meet the needs of multiple missions. The electrical system within the bus that we are interested in is the attitude determination and control system (ADCS), which can be viewed as the arms and legs of the satellite. It will determine the satellite's current attitude or orientation and point the satellite towards a desired position.

1.3 High-level requirements list

- The maximum magnetic moment capable must be at least twice the current value at 0.54Am^2
- The module must act as an I2C slave to receive operating status(on/off) and magnetic moment value from the master, and adjust its output correspondingly.
- The module has to provide information for its voltage, current, operating status, magnetic moment, and other relevant information upon requirement for debugging purposes.

2 Design

Block Diagram

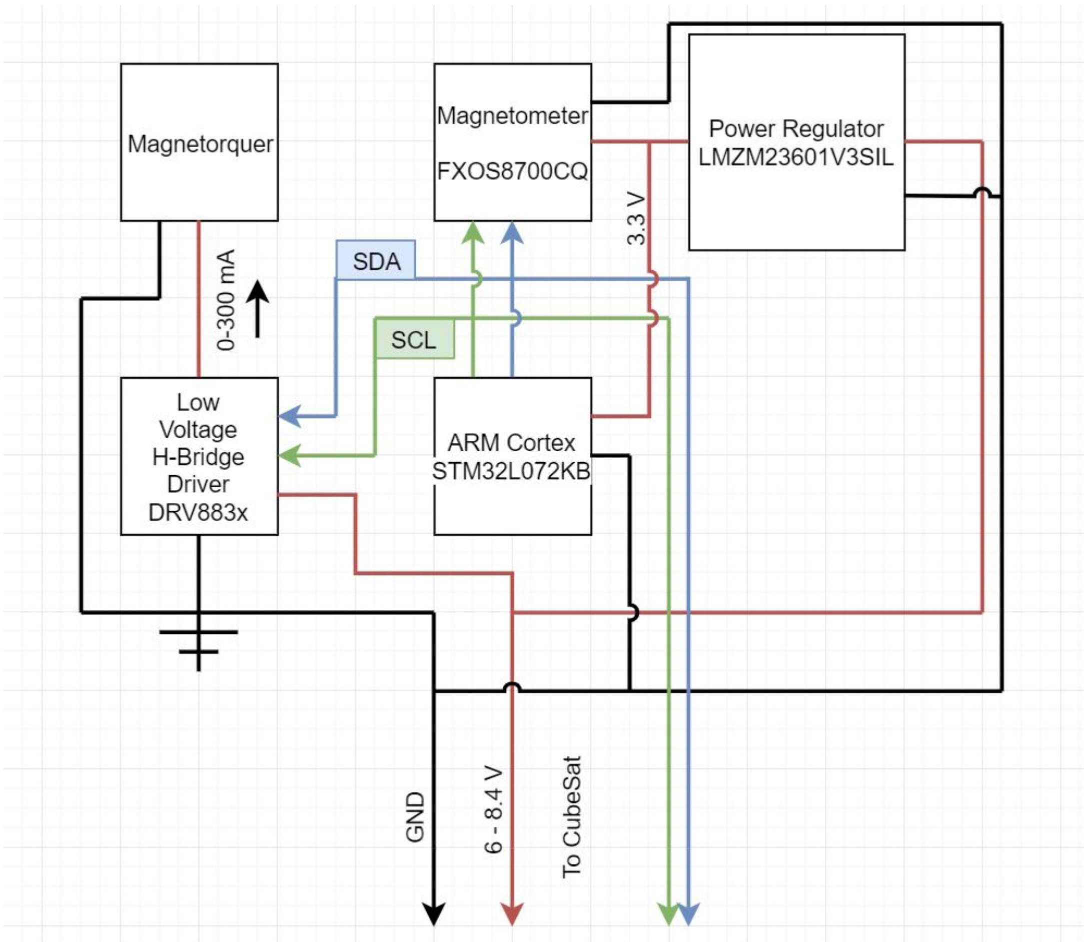

Figure 1. Block Diagram

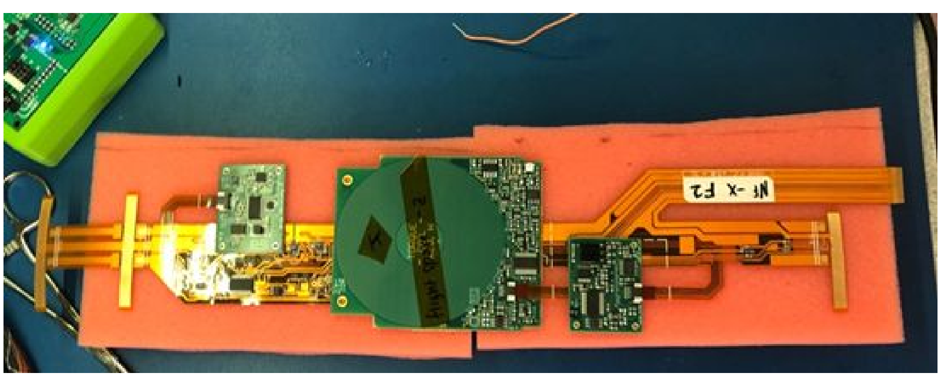

Figure 2. Physical picture of current design (PCB embedded flat coil)

2.1 Magnetorquer

Produces magnetic moment and subsequently torque. We have decided to abandon the current design of a copper coil embedded in a PCB i.e. a flat coil that goes through multiple layers of pcb which is the circular part shown on the picture above. This is because it is severely limited by the ability of the manufacturer of the pcb to incorporate enough loop of printed wire that can withstand a large current. We instead need to have a physical coil that is wrapped around a supporting frame with a designed number of loops, wire choice(which affects the maximum current rating) and physical size to achieve a good compromise between size and performance. The size is fixed to a maximum of 10cm x 10cm, and thickness has to be chosen by experiments. This is the key module that essentially completes the task of controlling flight attitude - the goal of this satellite module.

This function block takes analog power input from the power block. Because the magnetic field produced is directly related to the current, we will need to provide the corresponding current through the coil, which is controlled by the microprocessor under the instruction of the satellite and executed by the power block.

The tolerance of this unit is limited to the ability for a certain kind of wire to withstand a certain amount of current flowing through it. For example a 30 gauge wire can safely handle 0.5A. The accuracy of output depends on the accuracy of the current provided by the powering source for the wire. We will experimentally determine the amount of current for various magnitudes of magnetic field output and make sure the power unit is assigned with the correct input values for its power output.

Requirement	Verification
Must produce a field with a magnetic moment that is twice that current value (.27 Am^2) at maximum. *The error should be within 5%.*	We would give inputs to the microprocessor for different magnetic moment outputs and measure the produced magnetic field and see if corresponds to the correct value of magnetic moment. (5% error) It should be noted that in space the magnetic field is different from that on Earth, so we need to do the correct calculation to convert and see if the output is correct.

2.2 Magnetometer and accelerometer

Used as a method to sense magnetic moment activity and strength, to ensure the Magnetorquer is functioning properly. This serves as a check for how the magnetorquer is functioning and can additionally provide acceleration data so that the rotation rate can be monitored.

This subsystem will use a FXOS8700CQ chip which is a 6-axis sensor with integrated linear accelerometer and magnetometer. This chip has a supply voltage of 1.95 to 3.6V, which is different from the value from satellite power rail, so we need to step down the voltage and this is achieved in the power function block.

Requirement	Verification
Must be able to sense a magnetic field produced by the coil and send analog input into the microprocessor accordingly.	Will test with CubeSat team's helmholtz cage and a magnetic field that can be generated there without our magnetorquer.

2.3 Power Distribution

This part is responsible for providing power to all other parts. It provides the microprocessor and magnetometer/accelerometer with their fixed input voltages. It also receives instructions from Data Control and then provides a tunable amount of input to the magnetorquer.

This part will be composed several dc-dc down conversion chips that takes the unregulated 6-8.4V input from satellite battery rail into the corresponding voltage values for our different subsystems.

The following design converts the 6-8.4V input into a 3.3V output to be used for the microprocessor and magnetorquer.

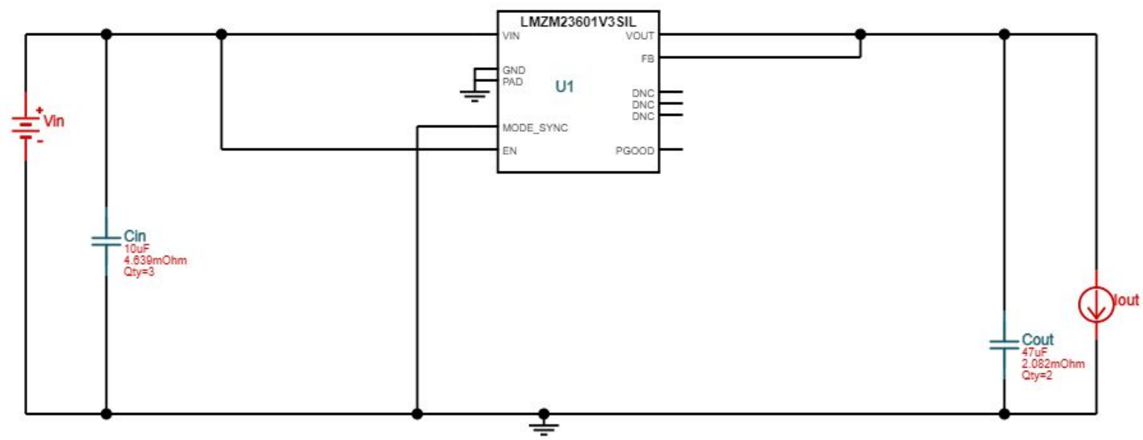

Figure 3. Proposed voltage supply for microprocessor and magnetometer

Requirement	Verification
Must be able to accept input ranged from 6 to 8.4V and convert it to a value in the corresponding Vdd ranges of the microprocessor and magnetometer/accelerometer. Must be able to give a steady current for desired output to the magnetorquer under the instructions of the microprocessor.	Test with similar load on breadboard in the lab and verify that we are seeing the correct output.

2.4 Microprocessor and external data interface

Will be sent desired torque, calculate the required voltage and send that to the power control. Will contain a microcontroller, I2C command and data interface. This part utilizes a ST-Microelectronics STM32L072KB ARM microcontroller. It gives current, voltage, magnetic moment, and operating status of the magnetorquer, possibly acceleration data upon requirement of end user.

Requirement	Verification
1. Must be able to communicate with external devices via I^2C protocols to accept operating status(on/off) and magnetic moment. *2. Must be able to return back voltage, current values, measured magnetic field and acceleration via the same interfaces; use a correct algorithm to give the power unit instructions on its output to the magnetorquer.*	1. Test with magnetorquer using helmholtz cage available in CubeSat team room checking moment using their magnetometer 2. Test with helmholtz cage and verify values with the team to verify algorithm and make sure it is outputting correctly

3 Risk Analysis

Producing a field with double the current magnetic moment at a maximum is a significant risk to the success of this project. The current design for the coil has it passing through a seven layer PCB with a loop at each layer. Simply adding loops to the coil poses a big challenge in manufacturing and as such will very likely call for the use of an outside vendor. It will be imperative to double check all work before sending anything to a manufacturer, as the cost and time to produce such a PCB could prove to be a detrimental risk to the project's completion. Adding more layers and loops to the design could prove to be cost inefficient and as such, finding and communicating with a manufacturer should be done as soon as possible to appropriately understand any limitations and constraints that may exist.

The magnetorquer will therefore need to be redesigned to achieve higher moment. A higher moment can be achieved by using physical magnet wire, thicker than that used in the PCB embedded flat coil such as 30AWG magnet wire to increase the coil density. Another idea is to loop the coil in a square shape as opposed to the current circular loop it follows. This would increase area by ~27% thus increasing moment. Different material wires and different loop designs all need to be tested and so getting a PCB early is imperative and as such we will be ordering independently. Space within the satellite is a constraint and as such we are trying to minimize depth and keep it around ~.16cm however, this can be increased if necessary as long as the increase in moment is significant. We are considering utilizing an optimization algorithm to assess different coil designs such as *fmincon* in Matlab to help us select an initial design to test and proceed from there. We are also currently wrapping up research on designs and have a few great resources (theses) currently pointing us to an air coil design.

4 Cost Analysis

We calculate our cost of development assuming a rate of $40/hour for 10 hours a week. Of the full semester we assume 12 weeks for our labor calculations.

3 * $40/hr * 10hr/week * 12 weeks * 2.5 = $36,000

Parts:

Part	Cost
Microcontroller (mouser; STM32L072KBU3)	$4.32
Magnetometer (digikey; FXOS8700CQ)	$1.83
Step-down DC/DC converter (mouser; LMZM23601V3SILR)	$2.40
TDK C3216X5R1E476M160AC Cout capacitor for LMZM23601V3SILR	$0.78x2
TDK C1608X5R1E106M080AC Cin capacitor for LMZM23601V3SILR	$0.60x3
PCB (PCBWay)	$4.86

5 Schedule

Time	**Riley**	**Reda**	**Jiayin**
10.4-10.10	Ordering parts and gather documentation for easy setup.	Work with machine shop on feasible design for new coil. Research different materials for coils.	Design PCB, hand over to CubeSat team for ordering.
10.11-10.17	Set up magnetometer and perform verifications.	Test different magnet wire for permeability and decide on coil choice.	Work on designing and creating power regulator and performing verifications.
10.18-10.24	I2C Control with ARM, read through documentation.	Characterize coil, begin constructing magnetorquer.	Begin constructing magnetorquer.

10.25-10.31	Connect magnetometer via I2C.	Characterize the magnetorquer to check for torque linearity +/- 5%	Component testing using helmholtz cage.
11.1-11.7	Ensure that the ARM is capable of reading and storing voltage and current values put through the magnetorquer.	Check magnetorquer for magnetic moment, verify that it is sufficient.	Soldering components onto PCB in preparation for assembly.
11.8-11.14	Verify correct output from ARM and ensure it can be read for debugging purposes.	Assemble full prototype and test in lab with helmholtz cage.	Test and fix errors with Reda. Document testing for turnover.
11.15-11.21	Plan and start putting together final demo.	Help Riley prepare for final demo. Reserve use of helmholtz cage and secure video camera.	Prepare turnover documentation for CubeSat team.
11.22-11.28	Fall Break	Fall Break	Fall Break
11.29-12.5	Finalize design, bug fixes.	Prepare final presentation.	Finalize design, bug fixes.
12.6-12.12	Work on final report.	Work on final presentation. Work on poster board if there's time.	Work on final report.

6 Safety and Ethics

Our project is a component of a much larger work and we are responsible for working with the team handling the entirety of the project in an ethical manner. This work relationship is an implementation of the IEEE Code of Ethics, #7: “to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others”[2]. We hope to absorb as much knowledge from the team who is much more familiar with the scope of the project than we are. At the same time, it is important that we credit the appropriate people for their ideas and help. It will be necessary to challenge the information and ideas being given to us in order to properly iterate the current design to a superior one. We will be challenging our main source of information on the project which may prove to be difficult, but it is crucial to still do so to achieve meaningful innovation.

Sources:

[1] Wang Z.P. DESIGN OF A SCALABLE NANO UNIVERSITY SATELLITE BUS (ILLINISAT-2 BUS) COMMAND AND DATA HANDLING SYSTEM AND POWER SYSTEMS, 2018. [Thesis]. University of Illinois.

[2] Ieee.org, "IEEE IEEE Code of Ethics", 2016. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 29- Feb- 2016].