TubeSat Attitude Determination and Control System

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***Abstract* — Attitude Determination and Control Systems (ADCS) are a crucial component in satellites since this system aids in outer space navigation by allowing them to maneuver and orient themselves in a desired path once in orbit. This paper will focus on the design and development of the first ADCS for a TubeSat2.0 nanosatellite. Our design will consist of choosing an appropriate microcontroller, motors, motor controllers, reaction wheels, PCB, integration of sponsor mandated parts, and other key components used in the ADCS, while adhering to several engineering constraints and specifications. Our ADCS primary objective is the stabilization of the nanosatellite in all axes after a deployment into space.**

***Index Terms* — Attitude control, control design, control equipment, low earth orbit satellites, microcontrollers.**

I. INTRODUCTION

UCF Senior Design Group 21 will be prototyping and developing an Attitude Determination and Control System (ADCS) for a TubeSat (CubeSat-type) using reaction wheels. This technology is used to stabilize and orient satellites in space. The design components of our project will consist of the optimization of the reaction wheels' parameters and material, motors' power and torque, printed circuit board's format, hardware and software integration, overall power budget, and communications link budget.

Since the payload space of the TubeSat 2.0 is small and is constrained by a weight limit, we cannot implement a thrust device, such as a rocket engine. Also, this option would be very expensive and would require more resources to develop. We want to develop a better option by using reaction wheels along with the concept of angular momentum to orient our satellite in space. A motor is needed to spin the reaction wheels at different speed settings, as required by the ADCS system. The control system itself will be designed in the software that will be uploaded to the microcontroller. This program, along with the microcontroller, will take inputs from the equipped sensors and decide a plan of action to take by sending signals to the motors that spin the reaction wheels. Once the desired orientation is reached, the wheels will come to a stop. This process will be implemented on a continuous loop, so that if an external force acts on the nanosatellite, the program will execute again to control the system.

The major impacts of this project are to develop the first working ADCS for a TubeSat and to be able to use this information to better detail future space-bound projects that would be using this technology modularly. The differences between our system and what is readily available are first that this technology is using a completely different layout of satellite, which changes the charging rate and moment of inertia that serve as major inputs for the total system. Second, we are maximizing our efficiency and power with pure lead reaction wheels, most systems use a lighter alloy (which is both more expensive and less dense).

This project is sponsored by both Interorbital Systems and NASA's Florida Space Grant Consortium.

II. PROJECT GOALS

This project is intended to lay the groundwork for future missions conducted by The Collegiate Space Foundation at UCF. The Collegiate Space Foundation at UCF is a student organization committed to the design and development of space-based projects. In today's world, many educational organizations are participating in designing and building what is known as CubeSat projects. CubeSats are small scale satellites that are constrained to a volume of 10 cm^3. These satellites make it possible for organizations to develop a project at a fraction of the cost of a regular satellite seen in orbit. Not only is it cost effective to develop but it is also cost effective to launch. Since the size of the satellite is relatively small, most of the time a ride is hitched on a larger payload at a fraction of the cost. In some instances, the National Aeronautics and Space Administration will cover the cost of launch if your project has any kind of research that can be beneficial to science. With that said, we live in a world where it is possible now to work on space-based projects and send them to orbit at a reasonable cost. Instead of the CubeSat, The Collegiate Space Foundation at UCF decided to work on a kit known as a TubeSat. The TubeSat is relatively similar to the CubeSat, but they differ in geometry. A change in geometry affects some specifications of the mission but they are negligible for the discussion of this project's goal. Every member of this senior design project is a member of The Collegiate Space Foundation at UCF, and we want nothing more than to leave a long-lasting legacy at the University. We intend to do that by designing and developing a subsystem that will serve critical purposes in the future whether the organization utilizes the TubeSat or CubeSat Design.

Depending on the experiment being conducted, usually every satellite requires an Attitude Determination and Control System for stabilization in orbit. This is also taken into consideration when communicating with a ground station. Some satellites are equipped with directional antennas and pointing accuracy is extremely important. The only way to achieve high pointing accuracy is by using an ADCS. This group intends on designing and developing a subsystem of high portability. Even though the system is being retrofitted into a TubeSat and held to many design constraints, the team hopes to reuse this design in successive missions. All one would have to do is manipulate the size of a few components to meet the constraints of the given project. This Attitude Determination and Control System will be launched to orbit to prove out its functionality and its efficiency to stabilize an object in space.

III. ENGINEERING SPECIFICATIONS

Our requirement for this experiment is to create a three-axis attitude determination control system, where it reacts to its current movement to stabilize itself into a non-moving state. Specifically for this project, we will focus on the z-axis, since we are not able to easily simulate a no-gravity area for testing all three axes at the same time. This will be repeated for each of the axes without moving any of the wheels as each wheel should work independently in space. The results obtained should give us a very close demonstration of how all three wheels would work simultaneously, when launched into space.

The main three specifications are represented in the following table:

TABLE 1: ENGINEERING SPECIFICATION

Specification	Requirement	Units
Max. Current Draw	1912.5	mA
Motor RPM Range	990 - 15,054	RPM
Axial Stability (System)	0.0 ± 0.1	degrees/ second

The electrical components in our ADCS system consist of a microcontroller, inertial measurement unit, three motors, three motor controllers, and a voltage regulator. All in all, we expect a maximum current draw of 1912.5 mA, which was calculated assuming all of the components will be on at the same time, and also using the manufacturers' datasheets.

The motors chosen in our ADCS system have a range of 990 to 15,054 revolutions per minute, determined from the following equation provided by the manufacturer:

$$RPM = 60 * FG \quad (1)$$

The variable FG is the frequency input pin on the motor controller and it can take any value from 0 to 255 Hz. These frequencies directly correlate to the speed of the motor since they are the PWM frequencies output by our Arduino microcontroller.

The last specification refers to the stability of the satellite system. Because our ADCS is physically attached to the inside of the TubeSat nanosatellite, when the reaction wheels spin to counteract the forces due to the spin on the whole system, we will know the system is stable when it is no longer spinning. This is achieved when the system has a spin of 0.0 ± 0.1 °/sec. The tolerance of ±0.1 °/sec is to account for any factors that may cause a very slight spin on the system.

IV. SELECTION OF COMPONENTS

This section will focus on the selection of components for our ADCS system. Our sponsor, Interorbital Systems, will be providing a board with a microcontroller unit and inertial measurement unit. Although these components are required for our project, we have identified other alternatives with similar features.

A. Microcontroller

The ATmega2560 is a high performance, low power AVR 8-bit microcontroller with an advanced RISC architecture capable of 16 MIPS throughput at 16MHz. The version that will be used in the TubeSat 2.0 nanosatellite uses 3.3-volt logic. The Arduino Mega 2560 comes with many useful features that will improve the performance of our ADCS system, such as PWM outputs and a wide variety of Digital Input/Output pins. Some of the more notable features are 256K bytes of In-System Programmable Flash with Read-While-Write capabilities, 8Kbytes of SRAM, 32 general purpose working registers, six flexible Timer/Counters with compare modes and PWM support, and a 16-channel, 10-bit ADC.

The Arduino Mega 2560 was already included in the package we chose for this project. Fortunately, that is what we would have chosen if we had the option. It not only meets our space and voltage needs, but it also expands our possibilities because of the extra analog inputs, serial connections, and PWM outputs. This simplifies connection testing, provides for programming redundancy, and protects us if a pin is damaged. Furthermore, open-source coding is extremely useful for debugging code or testing pin functioning.

B. Inertial Measurement Unit

An inertial measurement unit is an electronic device that measures and reports a body's specific force, angular rate, and orientation. They use a combination of accelerometers, gyroscopes, and geomagnetic sensors. An accelerometer is a tool that measures proper acceleration, which is an instantaneous measurement in its own resting frame. Accelerometers use the force that is emitted on the wall of a certain axis to estimate the acceleration on the object. This method is capable of a 3-axis measurement due to the force capable of being emitted on 3 walls at a time. For this project we will only be using an accelerometer, which is available on the Bosch BMX160 IMU.

The BMX160 is part of Interorbital Systems' satellite kit and has a specific method of sensing axis orientation. If the IMU is accelerated and/or rotated triaxially, each of the corresponding channels of the device will send a positive acceleration and/or yaw rate referred to as dynamic acceleration. If the IMU is at rest without any rotation and the only force acting on the device is gravity, the IMU will send a positive acceleration (equal to gravity) on the corresponding channel and the gyroscope channel will read zero and this is referred to as static acceleration.

Although this IMU was part of the kit, we considered another possible candidate that could perform this function. We compared it to STMicroelectronics' IMU and found out that the BMX160 is more power efficient with a lower supply range voltage. This is especially important since this unit will have to be constantly running for the reaction wheels to counteract the movement recorded by the IMU. In theory, the IMU and the reaction wheel setup would be the highest power-drawing equipment on the satellite. The rest of the features are roughly the same between both IMU devices, so due to a lower power-draw on the Bosch BMX160 we would have selected the one included in the Interorbital Systems' kit.

C. Motor Controller

The motor controller chosen for our ADCS is the Texas Instruments DRV19064, which comes with useful features. This three-phase brushless DC motor controller requires a power supply range from 2.1 V to 5 V, and also contains a TLC555, which is a timing circuit constructed with several logic gates and amplifiers to create frequencies up to 2 MHz. The timing circuit is manufactured with a small timing capacitor because it can be supplied by high input impedance. A smaller timing capacitor helps in improving oscillation and time delays. TLC55 provides PWM signals which control the speed of the motor. The higher the width of the pulses, the faster spinning for the motor, thus the PWM signal can be optimized from 5% duty cycle to 95%.

The FR is the motor direction selector which can be controlled by setting a high input value from the Arduino IDE code to spin the motor clockwise or low value to make a turn counterclockwise. Also, the FR pin controls the three phases; U, W, and V each phase is shifted by an angle of 120 to make a complete rotation of 360 degrees.

FG pin output motor speed indicator and the FGS pin is used to read the frequency of FG pin to calculate the RPM of the motor, given by equation (1).

The TI Motor Driver provided us with functionalities that we needed for this project. Another motor controller manufactured by MikroE was considered as a potential candidate, which was also significantly cheaper than the TI product. Unbeknownst to us, the MikroE product runs on libraries that are proprietary, and to program into the Motor Driver, we would need to purchase a particular software to operate the motor, after which we would be able to begin testing. Purchasing the software alone would cost us almost five times the cost of the TI motor driver. In retrospect, the TI motor driver was the best choice because it not only contained everything we required, but it was also easily compatible with all other components that we are using. Overall, this is a higher quality product, and is extremely reliable. In addition, the resources provided by TI are above and beyond what we were provided when troubleshooting the MikroE motor driver. This was one of our biggest lessons learned in our project, as we were not aware that companies would use proprietary software that we would then need to purchase to be able to program the motor driver.

D. Motor

A brushless DC motor (BLDC) was chosen for our project because they are more reliable than other options, such as brushed motors. BLDC's offer better performance, a longer operating life, lower heat dissipation, and a higher torque.

The motor from Precision Microdrive with a model number of 712-100.001 is a sensor-less motor, having 3 poles with a ball bearing and permanent magnets. It has a shaft diameter of 15mm and a weight of 7.8 grams, while the length of the shaft spans 21mm. It is rated for a load of 0.5mN-m and 14000rpm at load speed. Its maximum operating voltage is 6V and has a load current rating of 300mA and a starting current rating of 1250mA. This motor has an efficiency of 50% and outputs a maximum power of 900mW. The maximum winding resistance is 6.75 ohms, and the maximum winding inductance is 50uH. According to its temperature specifications, it operates in a temperature range of −15°C to 45°C.

Another motor that was considered was the Maxon Group BLDC motor, whose specs can be seen in Table 2.

TABLE 2: MOTOR FEATURES COMPARISON

Feature	**Precision Microdrive**	**Maxon Group**
Body Diameter	15 mm	20 mm
Rated Speed	14,000 RPM	3,030 RPM

Rated Load	0.50 mN-m	3.22 mN-m
No. of Poles	3	4
Nominal Voltage	5 V	6 V
Load Current	300 mA	560 mA
Max. Efficiency	50%	56%

When comparing the BLDC of Precision Microdrives with Maxon Group we took into consideration (by order of priority) maximum RPM, efficiency, and energy consumption. In terms of maximum RPM, at first glance the Maxon Group's motor had a greater RPM, but that was at no load. If we planned to increase the load to maximum, the RPM would drop to around 9000 RPM 21% less than the Precision Microdrives' motor. In reference to the objectives we are trying to accomplish with the reaction wheels driving the momentum force, this was a huge deciding factor in choosing the Precision Microdrives' motor. The Maxon Group motor decreased by 10-12% of the efficiency when the motor was at max load. It is also our intention in this project to fully load the motor because we want to maximize the angular momentum produced by the reaction wheel. Once we could compare the efficiencies between the two motors at full load, we found that the Precision Microdrives motor was the better choice.

E. Structure and Reaction Wheels

The TubeSat is assembled by stacking PCBs on top of each other using standoffs. These standoffs are 20 mm long, resulting in a gap of that length between each of the PCB payloads. This length was used to determine the nominal diameter of each of our reaction wheels. Keeping the wheels to this size would guarantee that we were making the most of the space available between each PCB.

Pure lead was chosen to be the optimum material for the response wheel by the team because of its high density. Aside from density, pure lead was very cheap and also was machinable for our design.

The reaction wheel has been manufactured by the University Of Central Florida at the CECS machine lab. For the distributor, it was decided that the pure lead material would be obtained from McMaster Carr. Because McMaster Carr did not have 4.5 mm thick sheets of pure lead, the design's thickness was lowered to 3.175 mm or 1/8 in. This ultimately leads to a tradeoff between readily available material and momentum.

IV. SYSTEM DESIGN

The TubeSat is a pre-designed kit ready for development, and in this section we will touch upon hardware that was designed specifically by the team and affiliates for this project. Some hardware in this section was collaborated on with fellow members of The Collegiate Space Foundation at UCF as well as members of the Interorbital Systems team.

Figure 1: Satellite kit showing mounting structure and components attached to PCB

A. Mounting Structure

The ADCS Mounting Structure is utilized by fixing the BLDC motors and Reaction Wheels to the ADCS PCB in each of the three axes. This design will be placed at the bottom of the PCB while ensuring that the motor will be stable and not lose any momentum.

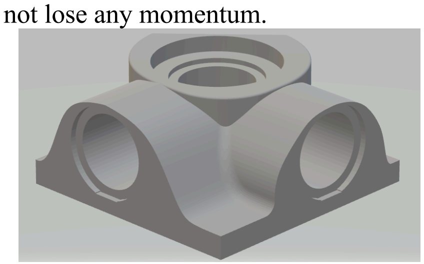

Figure 2: Mounting structure

The ADCS Mounting Structure was manufactured by University Of Central Florida at the Texas instruments innovation lab.

B. PCB Design

The PCB design started with building a detailed schematic that incorporated all the different functionalities from the working prototype and tied them into one system. Before getting started on the schematic, certain libraries are needed in order to develop a PCB that will seamlessly integrate into the TubeSat upon completion. The voltage regulator was the starting point for the schematic design, and we chose TI's TPS61232DRCR. Since the PCB needs to house three

BLDC motors that all operate at a nominal voltage of 5V, it was decided to add three voltage regulators that would be dedicated to each motor.

The motor controller utilized in the PCB design is the TI DRV10964FFDSNT. Each BLDC will have its own motor controller. With a few exceptions, the schematic is almost entirely reproduced in the PCB design. Because we will be generating our own PWM duty cycles from the TubeSat MCU, the PWM timer side of the circuit will be left out of our PCB design. The DRV10964FFDSNT's input PWM ports are linked to accessible PWM pins on the TubeSat bus. The first motor controller is linked to Bus A pin 21, the second to Bus A pin 22, and the third to Bus A pin 23.

The DRV10964FFDSNT's input FR (direction) pins are linked to accessible digital pins on the TubeSat bus. The direction is decided by either a 0 or a 1, necessitating the use of a digital interface. The first motor controller is linked to Bus B pin 31, the second to Bus A pin 32, and the third to Bus A pin 33.

The DRV10964FFDSNT's output FG (motor speed) pins are linked to accessible analog pins on the TubeSat bus. The speed is calculated by summing the high and low durations, necessitating the use of an analog interface. The frequency is then divided by the number of poles to calculate RPM (speed). The first motor controller is linked to Bus B pin 11, while the second motor controller is attached to Bus A pin 12, and third motor controller to Bus A pin 13.

Bus A		
(Digital 35) PC2	36 - 35	PC1 (Digital 36)
(Digital 37) PC0	34 - 33	PG1 (Digital 40)
(Digital 41) PG0	32 - 31	PD7 (Digital 38)
(N.C.) PD6	30 - 29	PD5 (N.C.)
(N.C.) PD4	28 - 27	PD3 (Digital 18)
(Digital 19) PD2	26 - 25	PL7 (Digital 42)
(Digital 43) PL6	24 - 23	PL5 (Digital 44)
(Digital 45) PL4	22 - 21	PL3 (Digital 46)
(Digital 47) PL2	20 - 19	PL1 (Digital 48)
(Digital 49) PL0	18 - 17	PG4 (N.C.)
(N.C.) PG3	16 - 15	N.C.
Reset	14 - 13	SDA (Digital 20)
(Digital 21) SCL	12 - 11	MISO (Digital 50)
(Digital 51) MOSI	10 - 09	CLK (Digital 52)
RBL	08 - 07	GND
VCC - 4.4 reg	06 - 05	VCC - 4.4V reg
GND	04 - 03	GND
3.3V	02 - 01	3.3V

Figure 3: Bus A pinout

Bus B		
(Digital 34) PC3	36 - 35	PC4 (Digital 33)
(Digital 32) PC5	34 - 33	PC6 (Digital 31)
(Digital 30) PC7	32 - 31	PJ0 (Digital 15)
(Digital 14) PJ1	30 - 29	PJ2 (N.C)
(N.C) PJ3	28 - 27	PJ4 (N.C)
(N.C) PJ5	26 - 25	PJ6 (N.C)
(Digital 39) PG2	24 - 23	PA7 (Digital 29)
(Digital 28) PA6	22 - 21	PA5 (Digital 27)
(Digital 26) PA4	20 - 19	PA3 (Digital 25)
(Digital 24) PA2	18 - 17	PA1 (Digital 23)
(Digital 22) PA0	16 - 15	PJ7 (N.C.)
(Analog 15) PK7	14 - 13	PK6 (Analog 14)
(Analog 13) PK5	12 - 11	PK4 (Analog 12)
(Analog 11) PK3	10 - 09	PK2 (Analog 10)
(Analog 9) PK1	08 - 07	PK0 (Analog 8)
(Analog 7) PF7	06 - 05	PF6 (Analog 6)
GND	04 - 03	GND
3.3V	02 - 01	3.3V

Figure 4: Bus B pinout

The voltage on the CONFIG test point or the biasing resistors R2 and R3 can be adjusted to modify the open to close loop handoff. Because our motor's maximum speed is between 200 and 250 Hz, we concluded that our handoff frequency should be 50 Hz. A voltage of 1.41V is required to produce a handoff frequency. This was accomplished by selecting values for the biasing resistors R2 to be 12 kΩ and R3 to be 4.7 kΩ.

It is critical to remember that bypass capacitors should be located as near to the voltage regulator as feasible. This was taken into account when arranging the components. All of the components will be put on the board's top layer. The ADCS mounting structure, which will house the BLDC motors and lead response wheels, will be kept for the bottom layer.

The last thing on the schematic is connecting the three different phases U,V, and W to test points so that they can be soldered to the corresponding BLDC motor. Before concluding the design of the schematic, we must confirm that the correct symbols and footprints have been used.

Because the board has two levels, routing of the traces was done on both layers to make the procedure easier. Vias are copper-filled holes that link two or more layers of a net and can be used to route data between layers.

Our last design stages were to pass a DRC, create Gerber files, and drill files, which will allow the board house to manufacture the exact board that was designed in KiCad. JLCPCB was chosen by the team to build our board because of the low prices given for prototype boards.

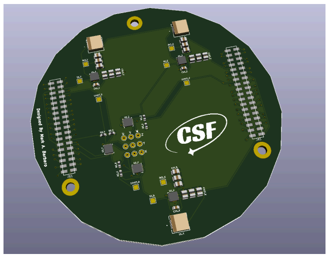

Figure 5: PCB design

V. SOFTWARE DESIGN

In this section we will share the software implementation in our ADCS. We have chosen Arduino IDE to write our program, since we are using an Arduino based microcontroller. The software will be executed on the Arduino ATmega 2560, which will take input measurements from the IMU and control the system according to the spin on the overall system. The software is one of the most crucial aspects of our project, because without a proper microcontroller that can handle tasks efficiently, and proper code to implement our desired control, the nanosatellite would not be able to orient itself in space and would tumble indefinitely.

When coding in Arduino, the main program gets split into two parts: the setup and the loop. The setup portion only gets executed once, at the start of the program. The loop portion behaves like a while() loop, except that in Arduino, this loop will execute whatever code is inside for as long as the device is turned on.

The setup() contains the following algorithm:

- Start
- Declare Baud rate for serial communication
- Declare output pins
- Write a digital HIGH to these pins
- Initialize bmx160 module
- Proceed to loop()

Once the above code is done, the loop() function will execute for the remainder of the time. Here is the algorithm for the loop():

- Start
- Declare magnetic, acceleration, and gyroscope variables.
- Obtain data from bmx160.
- Update motor
    - If angular velocity less than zero:
        - Increase speed in the opposite direction.
    - Else:
        - Decrease speed.
    - Verify that speed is within acceptable range.
- Wait a short delay.
- Repeat from the beginning.

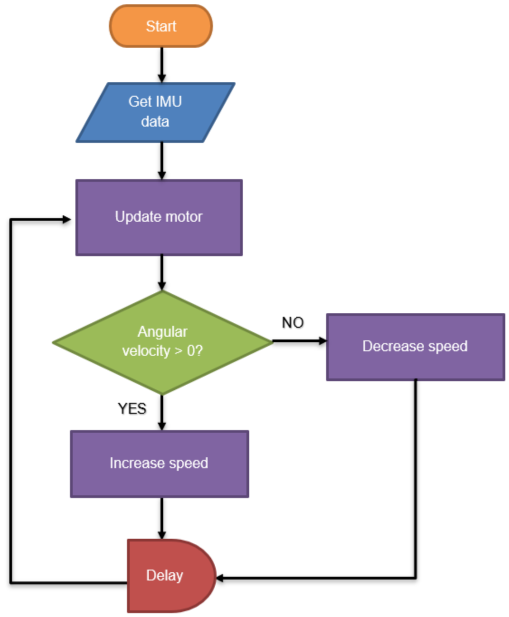

Figure 6: Program flowchart

VI. INTEGRATION AND TESTING

In our project, we use TubeSat 2.0, a single board controller, antenna, charger, and power management, which are all included in the kit. The TubeSat also has an ATmega 2560 microcontroller with 2560kB Flash memory, 8Kb SRAM, and 4kB EEPROM-compatible with the Arduino IDE. The system consists of a radio transceiver that can transmit and receive signals with a frequency of up to 433 MHz, as well as an amplifier that can boost the signal to 1.5 W.

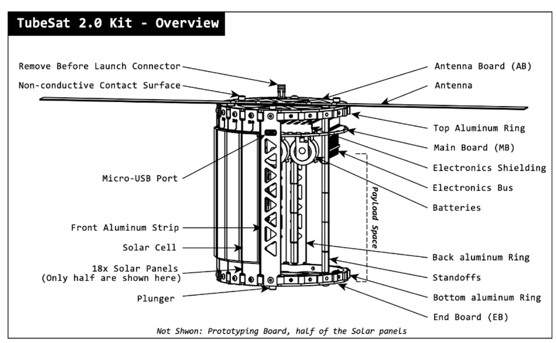

Figure 7: TubeSat 2.0 Kit Overview

The Main Board is the satellite's fundamental hub, since it contains many of the tasks used to keep the satellite operational. These are divided into three categories: power, radio, and controller. The justification for utilizing the microcontroller mentioned above is to keep the kit convenient, usable, and simple for all to use. To conserve power, the controller operates on 3.3V at 8MHz, as opposed to 5V at 16MHz for an Arduino Mega. It may, however, be implemented due on a standard 5V USB port using a USB-to-UART converter. TubeSat's radio is built on Silicon Labs' Si4464 high performance, low-current transceiver. It is programmable and interacts with the microcontroller through an SPI communication. There are different options for modulation from (G)FSK, 4(G)FSK, (G)MSK, OOK modulation, and data speeds varying from 100bps to 1Mbps. It is linked to the 1.5W Qorvo RFFM6406 power amplifier. Taking into account the working frequencies of the transceiver and the amplifier, the radio has been engineered and configured to operate in the 433MHz band, making it ideal for experimental satellite radio or research purposes.

Following the installation of the main board on the satellite, we will connect our PCB, which will be placed under the main board. Under the main board will be three Lithium cells, which are batteries that are used to power the main board and charge the solar panels. Our PCB will be connected to the main board through the Bus A and Bus B connectors, which are situated on top and bottom sides of the main board, respectively. The pitch of the two bus connectors is 2mm, which is considered non-standard. As a consequence, each bus pin has been routed to a pad on the 2.54mm pitch grid. The white rectangles printed on both sides of the board show these pads. These pads are set out in the same way as the buses.

We have split the testing phase of our project into two categories: software testing and system testing.

A. Software Testing

The program that we wrote for the microcontroller needs to be tested and checked on the ATmega 2560 before we build our satellite. What we are focused on here is code functionality; we want to see if the motors are able to spin smoothly as we have in the program. We have devised a series of steps and plan of action to take when testing our program on the controller board. This will allow us to see where our program fails and where it is successful. Before starting the test, the program must be uploaded from a computer to the Arduino via its USB port connector.

The following is a short summary of the software testing:

- Ensure that the MCU has power.
- Measure PWM frequency on the output pins.
- Simulate an angular acceleration by manually spinning the board around an axis.
- Verify that the motors are spinning.

We are able to verify that the PWM frequency directly corresponds to the motor speed (RPM) by using an oscilloscope connected to the FG pin on the motor controller that is on our PCB. The following chart was compiled from the measurements obtained:

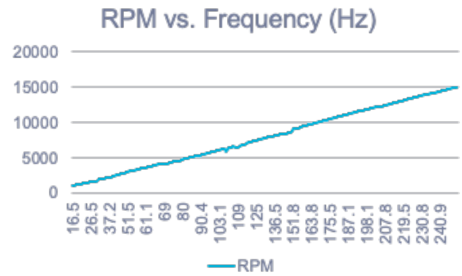

Figure 8: RPM Correlation with PWM Frequency

B. System Testing

This phase of the project is arguably one of the most important. During system testing, all aspects of the project must come together and work properly. For system testing, the team will first test each motor individually. After verifying that they work properly, we will test all of the motors and eventually the whole system.

In order to perform the stabilization function in orbit, the motors must be tested before launch. Unfortunately, testing all three axes simultaneously in a frictionless environment is just not feasible for this project, so the team will only be testing the Z-axis motor in the Senior Design demonstration. The Z-axis is the only axis that allows for close to zero friction when it's suspended off the ground. For the Z-axis test, the satellite will be suspended by a lightweight nylon wire. Once suspended, the TubeSat will be uploaded with testing software. The system will be tested by adding angular momentum to the static body. The IMU will sense and record this change in angular velocity and tell the program that it needs to react in such a way to stabilize. A successful stabilization of the Z-axis Reaction Wheel after angular momentum has been added to the system will confirm checkout.

The following power data was collected from running all components simultaneously:

TABLE 3: POWER BUDGET DATA

Data Type	**Data**
Motor Voltage	5V
Speed	7500 RPM
Current Draw	320 mA
Hours Recorded	7.5 Hours
Energy Capacity	7200 mAh
Power Capacity	36,000 mWh

VII. CONCLUSION

In conclusion, this project was a very fun and challenging experience. Our design proved to be successful in the testing phase and the developed ADCS system could be scaled to work on any size satellite or space vehicle. The experience gained on this project will mark our careers as electrical engineers, and we hope to establish ourselves as the first student-run space organization at UCF.

VIII. AUTHOR BIOGRAPHY

Mark Barbaro is a senior at the University of Central Florida studying Electrical Engineering. He will be receiving his BSEE in August of 2021 as well as completing the Pathways Program with the National Aeronautics and Space Administration at Kennedy Space Center. He intends to join NASA full time as an Engineer working on Artemis Program Moon to Mars missions.

Daniel Cadena will be receiving his degree in Electrical Engineering. He has been working at Siemens Energy since November of 2018 and was contracted as a Project Engineer since August 2019 and has received his PMP Certification at 24. He will be joining the GE Gas Power Commercial Leadership Program in August 2021 and pursuing his MBA.

Islam Aly is a senior at the University of Central Florida, where he will get a Bachelor of Science in Electrical Engineering and a minor in Computer Science in August 2021. He will begin his internship at TouchPoint Medical in Odessa, FL, before the end of August.

Andy Garcia is a senior at the University of Central Florida and will be receiving his Bachelor of Science degree in August of 2021. He is currently completing his internship with Gas Turbine Efficiency in Orlando and plans to obtain a UL 508A certification later this year. His interests lie in the power generation sector as well as power electronics.

IX. ACKNOWLEDGEMENT

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