Technical Report: CubeSAT

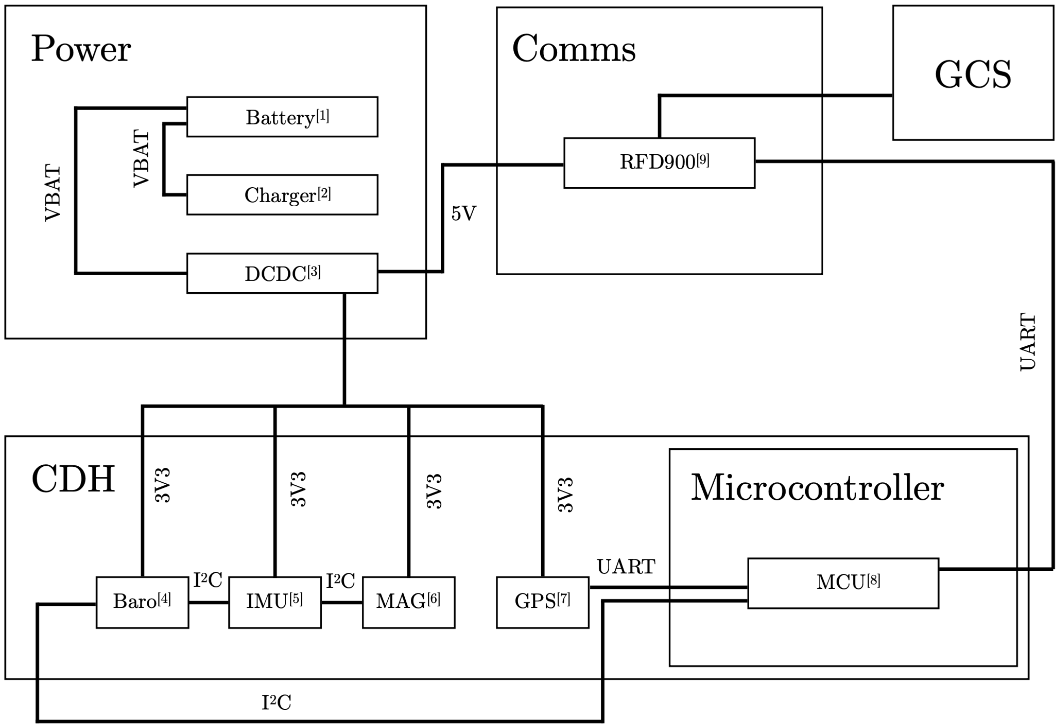
QUT Aerospace Society

September 24, 2024

Contents

CubeSAT Overview

1.1 Technical Breakdown



[1] Voltage Source: 3.3V / 5V 18650 Protected Lithium Ion Battery
[2] TP4057 Battery Charger
[3] DCDC: Buck Boost Converter (TPS63060)
[4] Barometric Pressure and Temperature Sensor (BMP388)
[5] Inertial Measurement Unit (Accelerometer and Gyro BMI270)
[6] Magnetometer: QMC5883L Hall Sensor
[7] Ultra-low-power GNSS antenna: SAM-M10Q
[8] MCU: ESP32-S3-MINI-1 Microcontroller Chip
[9] RFD900 Radio Modem

Figure 1.1: Block Diagram of the Payload Subsystem

The payload subsystem of the CubeSAT project is essential for the success of the project and for the collection of data. The system is powered via a 18650 LiPo battery which is regulated to 3.3V to power the barometer, IMU, Magnetometer, GPS, and microncontroller (ESP32-S3-Mini-1). The CubeSAT project consists of 5 PCBs with a 3D printed structure to house the components.

- Batteries
- Power Regulation
- Communication and Data Handling
  - Microcontroller PCB
  - Sensor PCB
    - QMC5883L Magnetometer
    - BMI270 IMU
    - BMP388 Barometer
    - SAM-M10Q GPS
    - ESP32-S3-Mini-1
- Communications
  - RFD900
  - Antennas
- Communication Transmission (Antennae)

1.1.1 Communication and Data Handling

Microcontroller Selection

The microcontroller serves as the central processing unit for the CDH system, interfacing with sensors and managing data flow. The selection process shall consider the following requirements

- Support for I2C, and SPI communication protocols
- Dual-core architecture for efficient multitasking
- UART/Serial support for programming and communication
- USB bootloader availability for easy firmware updates
- Integrated flash memory for code storage (optional)
- Arduino IDE compatibility for ease of development

By factoring the above requirements, the following options were considered

- ESP32-S3-Mini-1
- RP2040
- STM32-F103

Given the similarity in functionality, and development support between all three options, the ESP32-S3-Mini-1 has been chosen for its reliability, prior experience with the team, and lack of impedance issues present in options such as the RP2040. Furthermore, its superior performance and efficiency compared to other options make it a viable candidate for future improvements, and enhancements to the project.

Figure 1.2: Image of the ESP32-S3-Mini-1 Microcontroller

GPS Selection

The GPS module serves as the primary source of location data for the CubeSAT, providing accurate positioning information for the payload. The selection process shall consider the following requirements

- Accuracy
  - Support for multi-band GNSS (L1/E1), with a ¡ 1.5m horizontal accuracy
  - Position updates at a minimum rate of 10Hz for real-time tracking and navigation
- Communication
  - UART communication upto 115200 baud for interfacing with the microcontroller
  - Power efficient serial communication operation
- Operating power
  - 3.3 or 5V operating voltage for optimal compatibility with existing power systems
  - Consumption of < 25mA during continuous tracking to remain within limited power budgets

Taking into account the above requirements, the SAM-M10Q GPS module was chosen for its high accuracy, low power consumption, and compatibility with the ESP32-S3-Mini. The module provides a high update rate of 10Hz, and supports multi-band GNSS for improved accuracy and reliability. Furthermore, its low power consumption of 21mA at 3.3V makes it an ideal candidate for the CubeSAT project [**sammdatasheet**]

Figure 1.3: Image of the SAM-M10Q GPS Module

IMU Selection

A low power, high accuracy IMU is essential for the CubeSAT project, providing accurate orientation and motion data for the payload. The selection process shall consider the following requirements

- Low cost (less than $10 per unit)
- Low power and high precision (up to ± 16g accelerometer, ± 2000 degree/s gyroscope)
- Flexibility in communication (I2C, SPI)

By factoring the above requirements, the BMI270 IMU was chosen for its high accuracy, low power consumption, and compatibility with the ESP32-S3-Mini. The module provides a wide range of motion sensing capabilities, with a ± 16g accelerometer, and ± 2000 ◦/s gyroscope. Furthermore, its low power consumption of 700μA during operation, i2C (up to 3.4MHz) and SPI (up to 10MHz) communication interfaces, dual core architecture with a 16KB FIFO buffer for configuration and buffering, Arduino libraries for easy integration, and low cost of $7 to $10 per unit make it an ideal candidate for the CubeSAT project [**bmidatasheet**]

Magnetometer Selection

A space, cost, and energy efficient magnetometer is essential for the CubeSAT project, providing accurate magnetic field data for the payload. The selection process shall consider the following requirements

- Low cost (less than $5 per unit)
- Low power and high precision (up to ± 8 gauss)
- Flexibility in communication (I2C, SPI)
- Small form factor for easy integration
- Wide operating temperature range (-40 to 85 °C)
- Low power consumption (less than 100μA)

By factoring the above requirements, the QMC5883L magnetometer was chosen for its high accuracy, low power consumption, and compatibility with the ESP32-S3-Mini. The module provides a wide range of magnetic field sensing capabilities, with a ± 8 gauss range, and 0.2 gauss resolution. Furthermore, its low power consumption of 100μA during operation, I2C (up to 400kHz) communication interface, while it lacks SPI support, its small form factor, wide operating temperature range, and low cost of $2 to $5 per unit make it an ideal candidate for the CubeSAT project [**qmcdatasheet**]

Figure 1.4: Image of the QMC5883L Magnetometer Module

Barometer Selection

A space, cost, and energy efficient barometer is essential for the CubeSAT project, providing accurate pressure data for the payload. The selection process shall consider the following requirements

- Low cost (less than $5 per unit)
- Wide operating temperature range (-40 to 85 °C)
- Wide operating pressure range (30 to 125 kPa)
- High absolute accuracy ($\pm$ 50 Pa)

Three barometers were considered for the CubeSAT project, the ICP10101, S-THP-01A, and the BMP388. However, the BMP388's superior accuracy (50Pa vs 100Pa for the ICP10101), support for a wider range of communication protocols (i2C and SPI vs i2C only for the ICP10101, and RS485 for the S-THP-01A), and lower cost ($1.65 for the BMP388 vs $6.08 for the ICP10101, and $55.09 for the S-THP-01A) make it an ideal candidate for the CubeSAT project [**bmpdatasheet**]

Figure 1.5: Image of the BMP388 Barometer Module

1.1.2 Power

Power is supplied to the payload system via two 18650 LiPo batteries in parallel. The batteries are regulated to 3.3V via a pair of TPS63060DSCR buck-boost converters, regulating voltage to 5V and 3.3V for the payload system, with an STC3100IQT battery monitor to monitor battery voltage and current.

Battery Monitor

1.1.3 Radio Modem

The RFD900 radio modem is used for communication between the CubeSAT and the ground station. The modem operates on the 915MHz frequency band, with a maximum output power of 1W, and a range of up to 40km. The modem supports serial communication at up to 115200 baud, with a power consumption of 1.5W during transmission, and 0.5W during reception. Simple integration using the MAVLink Protocol, and support for AES-128 encryption allows for easy integration and secure communication between the CubeSAT and the ground station.

1.1.4 Antenna

The antenna system consists of a pair of dipole antennas, one for the CubeSAT, and one for the ground station. The antennas are tuned to the 915MHz frequency band, with a gain of 2.15dBi, and a VSWR of 1.5:1. The antennas are connected to the RFD900 radio modem via SMA connectors, providing a reliable and efficient communication link between the CubeSAT and the ground station.

Design Implementation

2.1 Power PCB Design

The power PCB is designed to regulate power from the batteries to the system of PCBs in the CubeSAT. The PCB consists of two TPS63060DSCR buck-boost converters, an STC3100IQT battery monitor, and a pair of 18650 LiPo batteries. The TPS63060DSCR buck-boost converters regulate voltage to 5V and 3.3V for the payload system, with the STC3100IQT battery monitor monitoring battery voltage and current. The batteries are connected in parallel to provide redundancy and increase capacity. The PCBs were designed using Altium Designer, and each component was integrated using the recommended configuration in the datasheets. The resultant schematic and PCB layout is provided below.

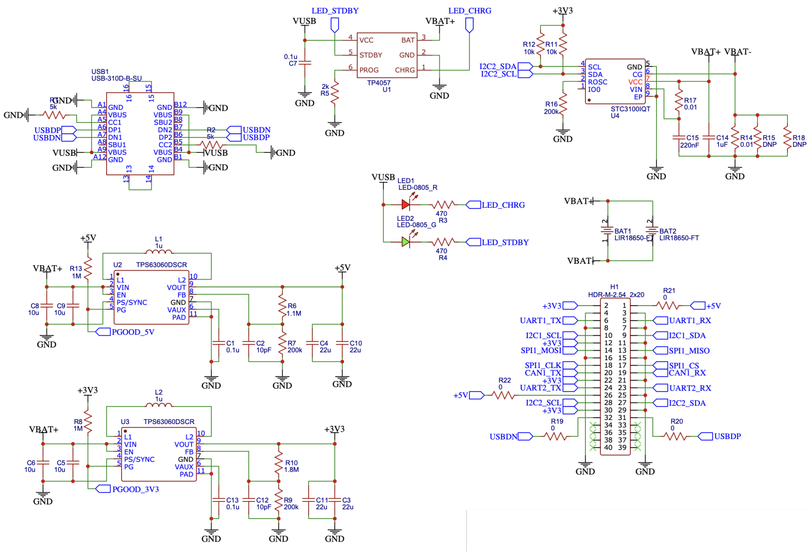


Figure 2.1: Power Regulation Schematic

2.2 CDH PCB Design

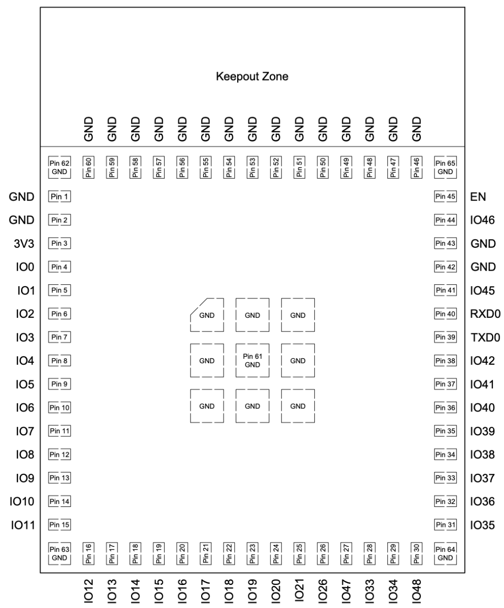


Figure 2.2: ESP32S3 Microcontroller Pin Configuration

Using the sample configuration specified in the datasheet 2.3 [**esp32s3mini**], the ESP32-S3-Mini-1 was integrated into the CDH PCB in order to interact with the sensors and radio through the I2C and SPI communication protocols. It must be noted that the ESP32-S3-MINI-1 was utilized for cost efficiency and had the keepout zone cut off to accomodate the specification. However, redesigns were not necessary as the pin configuration is identical to the ESP32-S3-MINI-1U.

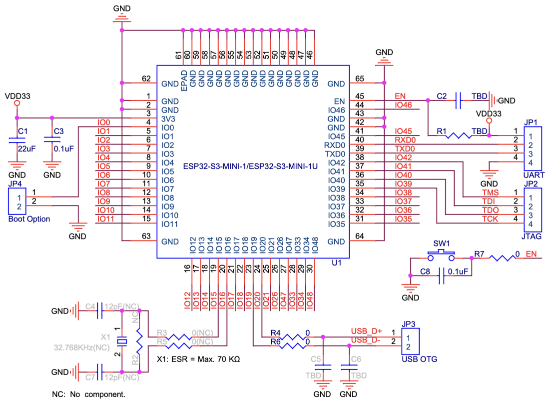


Figure 2.3: ESP32S3 Microcontroller Example Configuration

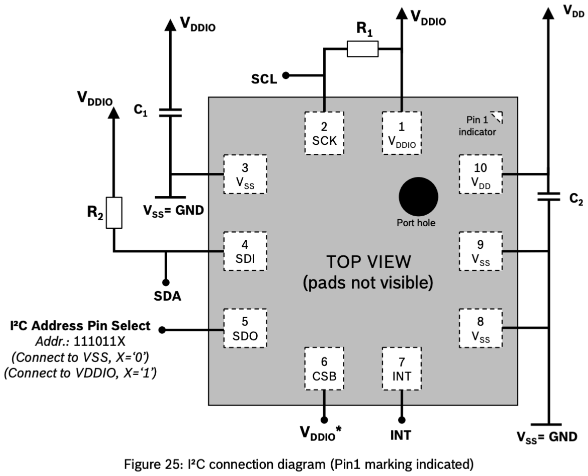


Figure 2.4: Barometer Datasheet Configuration

words

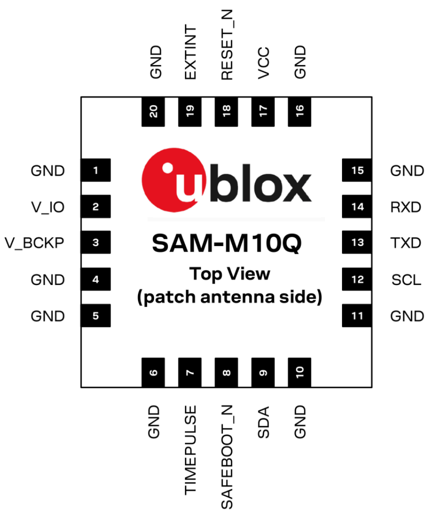


Figure 2.5: GPS Datasheet Configuration

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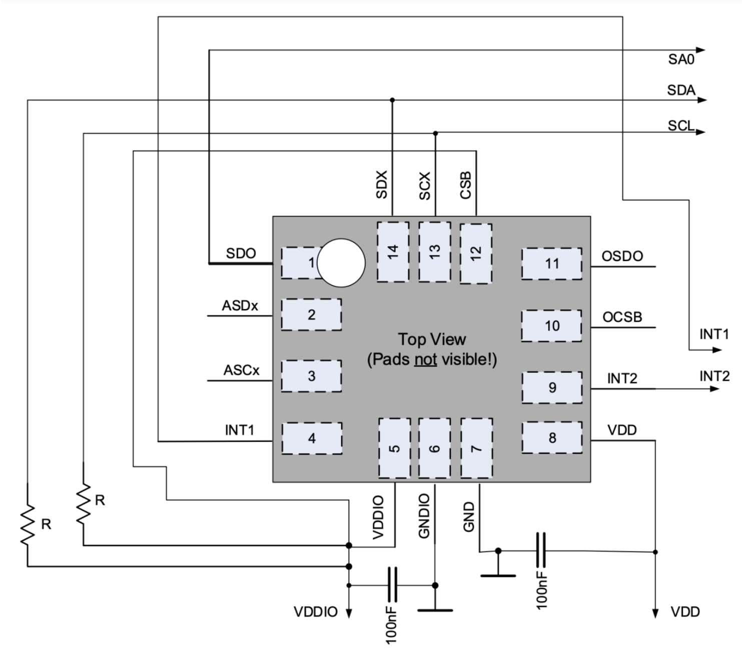

Figure 2.6: IMU Datasheet Configuration

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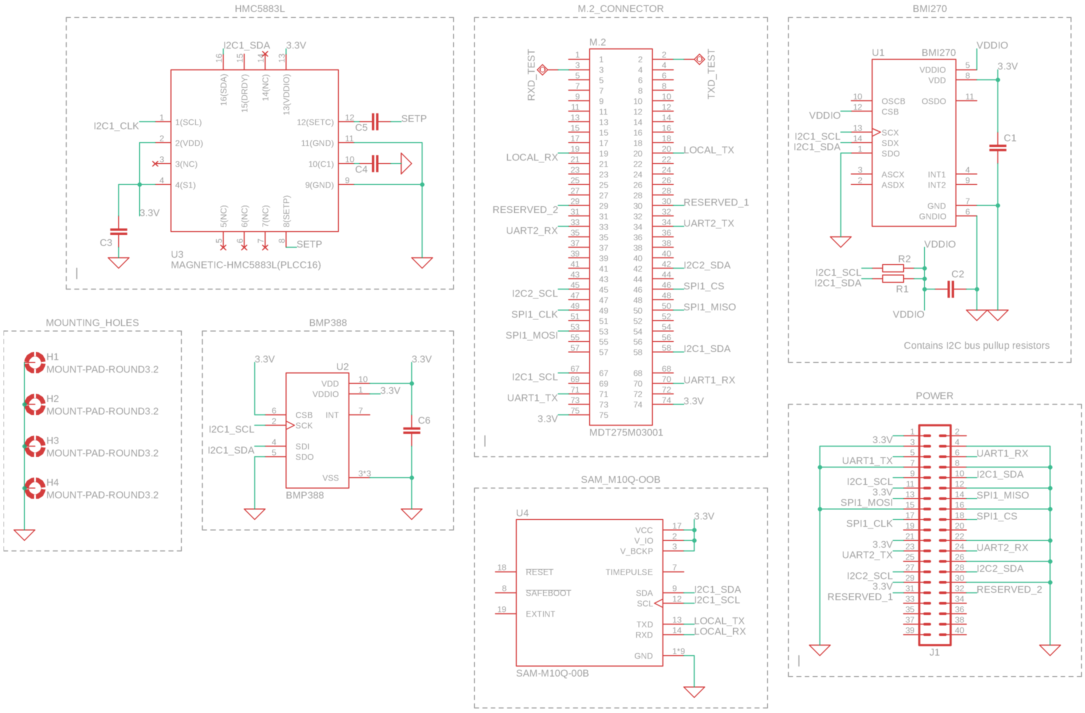

Figure 2.7: Final CDH Schematic

2.3 Data Handling

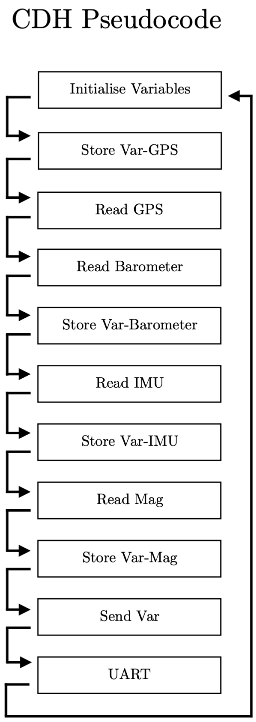

Figure 2.8: Data Handling Program Flowchart

Design Verification and Validation

3.1 Payload Subsystem

3.1.1 Microcontroller

The data handling code was first tested for functionality on a development board before being ported to the ESP32-S3-Mini-1. The code was tested for functionality and performance, with the microcontroller interfacing with the sensors.

System Requirements Compliance