

AMSAT CubeSatSim

A Functional Satellite Model for Education



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Topics

- About Me
- What is a CubeSat?
- About AMSAT
- What is a CubeSatSim?
- CubeSatSim Technical Details and Telemetry
- New Activity Guides and Educators Guide
- Get Involved
- Q & A
- Acknowledgements

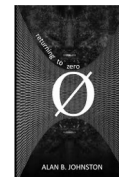
AMSAT CubeSatSim

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About Alan Johnston

- B.E. (First Class Honors), Electrical and Electronic Engineering, University of Melbourne, Australia
- Ph.D., Lehigh University, Bethlehem, PA, Electrical Engineering
- 25 years industry experience in telecom/VoIP industry
- 20 US patents in Voice over IP, internet communications
- 24 IETF RFC standards documents including RFC 3261 on Session Initiation Protocol
- 5 technical books on SIP, internet communications
- 2 techthrillers "Counting from Zero", "Returning to Zero"
- Associate Teaching Professor at Villanova University
- Vice President, Educational Relations, The Radio Amateur Satellite Corporation (AMSAT)



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CUBESAT

IT'S HIP TO BE SQUARE!

A CUBESAT is a MINIATURE CUBE-SHAPED SATELLITE.

DIMENSIONS

USED ALONE (1 unit) OR CAN BE STACKED Maximum of **24** units

ADVANTAGES

- ⚡ BUILT RAPIDLY (within 24 months)
- AxByC SIMPLE TECHNOLOGY purchased off-the-shelf
- ✂ SIMPLE TO DESIGN
- 🚀 NO SPACE DEBRIS they burn up in the atmosphere upon reentry
- 💰 LOW COST

4 TYPES OF MISSIONS

- 🔧 Technology demonstration
- 🔬 Scientific research
- 🎓 Educational project
- 🏢 Commercial

ORBIT

© Canadian Space Agency

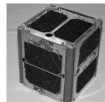
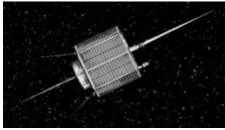
<https://www.asc-csa.gc.ca/eng/satellites/cubesat/what-is-a-cubesat.asp>

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About AMSAT

- The Radio Amateur Satellite Corporation, or AMSAT, is a worldwide group of Amateur Radio Operators (Hams). It was formed in the United States of America in 1969 as an educational organization.
- For over 50 years AMSAT groups in North America and elsewhere have played a key role in significantly advancing the state of the art in space science, space education, and space technology. The work now being done by AMSAT volunteers throughout the world will continue to have far-reaching, positive effects on the future of both Amateur Radio, as well as other governmental, scientific and commercial activities in space.



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What is a CubeSatSim?

- It is the core of an education program to evangelize the science and technology used in radio satellites.
 - University engineering programs
 - Amateur radio community
 - STEM (Science Technology Engineering Math) programs
 - Libraries, Museums, Maker Faires, etc.

Fully open source hardware and software!

AMSAT CubeSatSim



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What is a CubeSatSim?

- A low-cost satellite emulator that runs on solar panels, batteries, and transmits UHF radio telemetry



AMSAT CubeSatSim

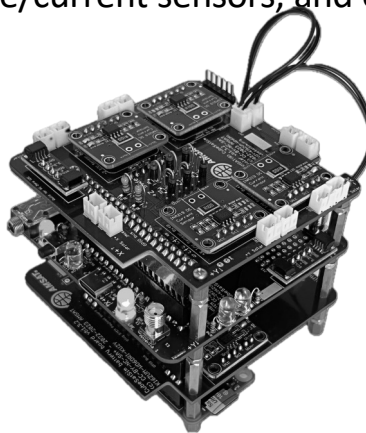
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What is a CubeSatSim?

- Uses a custom 3-board stack plus Raspberry Pi Zero 2 and a Raspberry Pi Pico microcontroller, rechargeable batteries, voltage/current sensors, and environment sensors.



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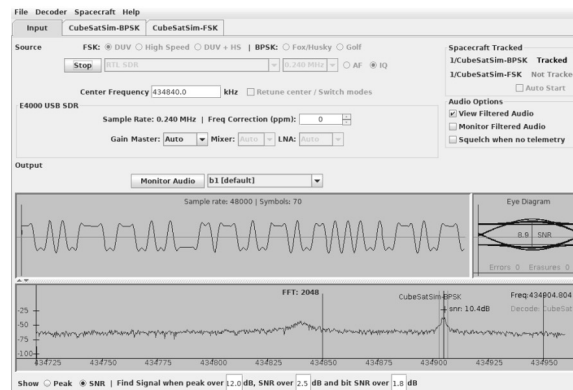
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What is a CubeSatSim?

- Transmits 70cm amateur band UHF radio housekeeping telemetry to a ground station in multiple formats - describing the operational location/health of the satellite.



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What is a CubeSatSim NOT?

- The CubeSatSim is NOT:
 - Hardware designed for space flight
 - Software designed for space flight
- The CubeSatSim is an educational model designed to be:
 - Low cost (a few hundred \$USD)
 - Easy to build (2 layer PCB, simple soldering and 3D printing)

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Technical Details

■ Raspberry Pi Zero 2

- Linux Single Board Computer runs housekeeping software: C, Python
- Has Pi Camera and USB Sound Card



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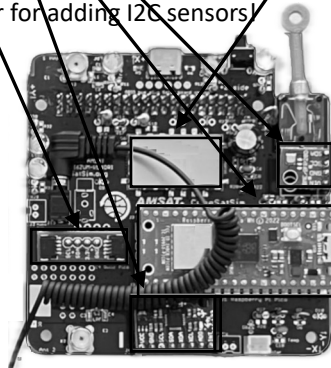


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Technical Details

■ Main Board

- Raspberry Pi Pico W microcontroller and **FM transceiver**
- **Temperature/Pressure/Humidity Sensor BME280**
- 3-Axis Accelerometer/Gyroscope MPU6050
- Qwiic connector for adding I2C sensors!



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Technical Details

■ Solar Board

- 6 INA219 Voltage/Current Sensors – one for each side Solar Panels
- Solar panels plug into JST 2.0 connectors
- Uses low cost solar panels (\$1.50/panel)



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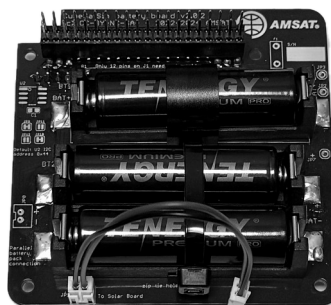


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Technical Details

■ Battery Board

- 3 AA Nickel Metal Hydride (NiMH) Batteries for safety
 - New improved 2800 mAh PRO batteries
- Includes INA219 current and voltage sensor
- Charged with solar panels or USB-C cable



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Technical Details

■ Ground Station

- Pre-built Software Stack (Fox-in-a-Box v4 Beta)
 - Now works on Pi 4 or 5 Bookworm
- Or, install on your own PC



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■ Software:

- FoxTelem
- Direwolf
- QSSTV
- OpenWebRX
- SDR++ (new!)
- CubicSDR
- RTL-TCP
- Gpredict
- KLaTracker

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Technical Details

Blinks	Mode	Description	Decoding	Command	Audio	Waterfall(WebSDR)
1	APRS	Automatic Packet Reporting System. This digital mode sends a packet of data with AFSK or Audio Frequency Shift Keying modulation.	Windows: SoundModem or Direwolf Raspberry Pi/Linux: OpenWebRX or Direwolf	a	CubeSatSim.org/a	
2	FSK	Frequency Shift Keying. This mode transmits a continuous signal that emulates the AMSAT Fox CubeSats such as Fox-1C or AO-55. Also known as DUV or Data Under Voice.	Windows/Raspberry Pi/Linux: FoxTelem	f	CubeSatSim.org/f	
3	BPSK	Binary Phase Shift Keying. This mode transmits a continuous signal that sounds like noise that emulates the AMSAT Fox-1E CubeSat. You demodulate using USB.	Windows/Raspberry Pi/Linux: FoxTelem	b	CubeSatSim.org/b	
4	SSTV	Slow Scan TeleVision. This mode transmits stored images in Scottie 2 format which sounds like a series of tones.	Windows: MMSSTV Raspberry Pi/Linux: QSSTV	s	CubeSatSim.org/s	
5	CW	Continuous Wave or Morse Code. This mode transmits a FM modulated tone at 20 words per minute Morse Code telemetry.	Windows/Raspberry Pi/Linux: ftdigi with spreadsheet http://cubesatsim.org/tdigm	m	CubeSatSim.org/m	
6	Cross Band Repeater	Simulates a U/V (UHF uplink, VHF downlink) FM satellite repeater. Default uplink is 435 MHz and downlink is 144.9 MHz.	OpenWebRX	e	CubeSatSim.org/e	
7	Fun Cube	FUNcube simulates the BPSK telemetry of the FUNcube series of CubeSats such as AO-73.	Raspberry Pi: FUNcube Telem	j	CubeSatSim.org/j	

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■ Telemetry Modes

- APRS (Automatic Packet Reporting System)
- FSK (Frequency Shift Keying DUV (Data Under Voice))
- BPSK (Binary Phase Shift Keying)
- SSTV (Slow Scan TV)
- CW (Continuous Wave aka Morse Code)
- Cross Band Repeater (New!)
 - U/V FM
- FunCube mode (New!)

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Recent CubeSatSim Improvements

- CubeSatSim v2 hardware and software released in 2024
- Software v2.1 released in 2025 adding:
 - New FunCube telemetry mode
 - New Cross Band Repeater mode
 - Improved Command and Control (C2C)
- Software v2.2 released in 2026 adding:
 - Improved simulated telemetry
 - Support for BME and MPU sensors attached to Pi Zero
 - Simulated failures

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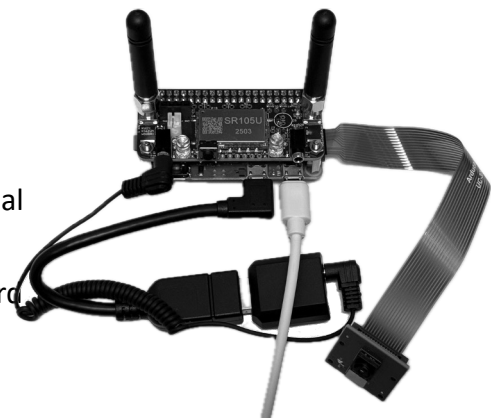
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New CubeSatSim Lite

- Single board, size of a Pi Zero
- Plug into a Pi Zero 2 and it generates simulated telemetry in all 7 modes
- Can add sensors without soldering via Qwiic connector
- Can add GPS (Global Positioning System) with serial interface
- Can do Command and Control with USB sound card
- Can plug a 3-cell battery with JST connector including full Battery Board
- Can remove attenuator for 0.5 W FM transmission for balloon payload



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CubeSatSim Telemetry

■ Telemetry Definition

- "Automatic measurement and wireless transmission of data from remote sources."

■ CubeSatSim transmits telemetry in all modes

■ AMSAT FoxTelem software automatically decodes telemetry

- APRS and CW modes use a spreadsheet to decode telemetry

■ Housekeeping Telemetry

■ Basic status of the spacecraft

■ Temperature

■ Voltages

■ Currents

■ Spin and acceleration

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Simulated CubeSat Telemetry

■ The CubeSatSim can generate real telemetry

■ The CubeSatSim can be placed on a turntable in front of an LED lamp



■ Simulated telemetry doesn't require any setup

■ CubeSatSim can be configured to send simulated telemetry

■ Simulated telemetry switches between illumination (daylight) and eclipse (darkness)

■ Parameters are randomly generated on boot

■ Software can also generate simulated failures in telemetry data!

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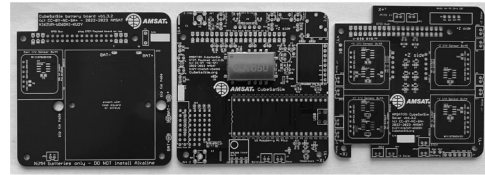
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You Can Build a CubeSatSim

- 3D print the Frame parts
 - <https://CubeSatSim.org/frame>
- Fabricate PCBs using Gerber files
 - <https://CubeSatSim.org/hardware>
- Order Parts using BOM
 - <https://CubeSatSim.org/bom>
 - Octapart BOM Tool can generate shopping cart of components
 - Other parts such as solar panels and antennas available on Amazon
- Solder and Assemble
 - Step-by-step instructions and videos on Wiki
 - <https://CubeSatSim.org/wiki>



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CubeSatSim Kits Available in USA

- We now have no-solder CubeSatSim kits available at Hamvention and on the AMSAT Store
 - 1-2 hours of assembly, no soldering!
- Over 120 produced so far!
 - 40 in 2024
 - 60 in 2026
 - 20 so far in 2026
 - <https://CubeSatSim.org/kit>



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Project Partnerships

- NASA
 - F Prime
- American Radop Relay League (ARRL)
 - USA Ham Radio Organization
 - Teachers Institute Program
- Science Centers
 - Example: CubeSatSim on display at Cox Science Center and Aquarium in West Palm Beach, FL by Jim Nagle, KF4OD
- **Look for more in 2026!**



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NASA F Prime and CubeSatSim



- “F Prime: A software ecosystem enabling the rapid development and deployment of embedded systems for spaceflight applications.”
 - <https://fprime.jpl.nasa.gov>
- Open source!
 - <https://github.com/nasa/fprime>
- JPL Interns are porting it to run on the Raspberry Pi Zero 2 and work with the CubeSatSim Hardware:
 - <https://github.com/fprime-community/fprime-amsat-reference>
- F Prime is for spacecraft, but porting it to run on the inexpensive CubeSatSim hardware is a useful teaching tool.

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ARRL Teachers Institute on Wireless Technology

- ARRL Teachers Institute on Wireless Technology
 - ‘Teaching the teachers’
 - Space Communications and Radio Astronomy course
 - Used 20 kits
 - They soldered the BME and MPU sensors
 - Each teacher built a CubeSatSim and took it home!
 - Very positive feedback from instructors and teachers



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CubeSatSim Documentation

Wiki instructions

Quick Start Guides

Activity Guides

Educator's Guide

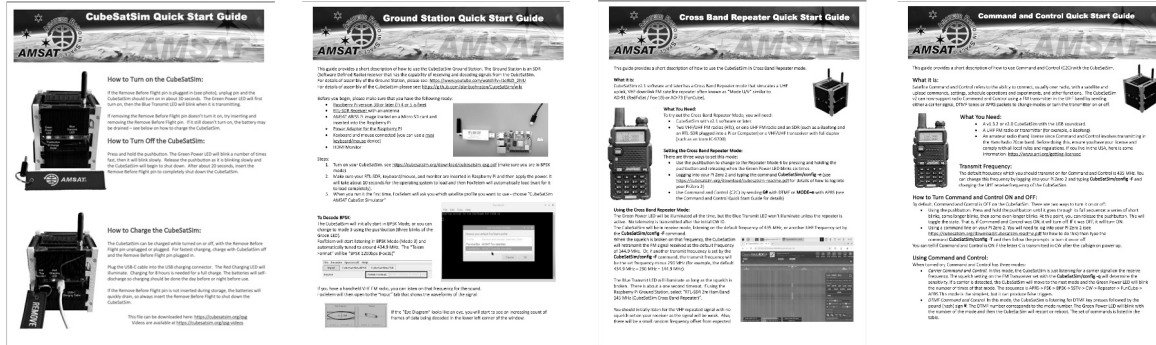
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New CubeSatSim Quick Start Guides



<https://CubeSatSim.org/qsg>

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CubeSatSim Activity Guides

Problem Statement

I just built (or borrowed) a CubeSatSim!

What can I do with it?

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What are Activity Guides?

- Step by step instructions for how to do a STEM (Science, Technology, Engineering, Math) educational activity using a CubeSatSim
- Most work with just a CubeSatSim or Lite
- Some are very easy
 - Listening to the sounds of the different modes on a HT and/or looking at modes on an SDR waterfall
- Some are more challenging
 - Telemetry analysis using FoxTelem

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What are Activity Guides?

- Activity Guides include questions
- Instructors Guide has example data and answers to questions
- Released under Creative Commons with Attribution license
 - Teachers can edit and include in their lesson plans
 - <https://CubeSatSim.org/ActivityGuides>
- 10 available now – more in future
- Videos available soon!

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List of CubeSatSim Activity Guides

AMSAT CubeSatSim – MPU Sensor Activity

Version 1 – July 2025

Alan Johnston KUZ2Y ku2y@arrl.net

Group: _____ Date: _____

Introduction:

In this activity, you will learn about the MPU6050 Rotation/Acceleration sensor on the CubeSatSim Main board, and rotation and acceleration readings.

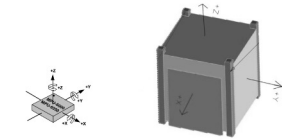
This online [Glossary](#) can help with any terms or acronyms you may not know.

A. MPU Rotation/Acceleration Sensor Readings

The MPU6050 sensor is the blue sensor board U2 on the Main board.



The [datasheet](#) for the IC shows the X, Y, and Z axes, which is also printed on the board. The MPU6050 sensor is mounted horizontally on the Main board, which is mounted horizontally in the CubeSatSim frame so that the axes align:



A device that measures rotation rate is known as a gyroscope, or simply a gyro. A device that measures acceleration is known as an accelerometer. The MPU6050

- Listening Activity Guide
- Telemetry Activity Guide
- Advanced Telemetry Activity Guide
- BME Sensor Activity Guide
- MPU Sensor Activity Guide
- Solar Panel Activity Guide
- Battery Activity Guide
- Troubleshooting Activity Guide
- Group Building Activity Guide
- MQTT Adafruit IO Activity Guide

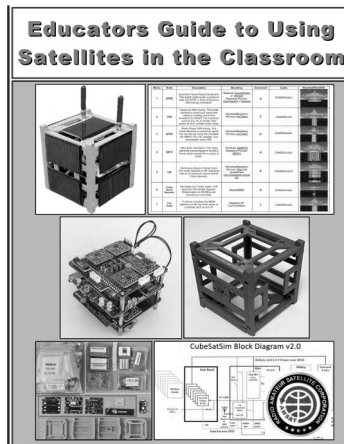
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AMSAT Educator's Guide to Using Satellites in the Classroom



<https://CubeSatSim.org/EducatorsGuide>

- Preface
- Introduction by David Vine, WA1EAW
- AMSAT® CubeSatSim Project Wiki
- CubeSatSim Quick Start Guide
- Ground Station Quick Start Guide
- Cross Band Repeater Quick Start Guide
- Command and Control Quick Start Guide
- CubeSatSim Activity Guides
- AMSAT Youth Initiative Update
- AMSAT Education and CubeSat Simulator Update
- Bridging Orbit and Classroom: SatNOGS and CubeSatSim
- New CubeSatSim Features and Capabilities
- Building AMSAT CubeSatSims in the Classroom
- CubeSatSim YouTube Playlist Links
- AMSAT CubeSatSim Glossary
- Radio Amateur Satellite Corp. Strategic Plan - 2021-2031
- Join AMSAT

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CubeSatSim...

in the Classroom

- *Villanova University, PA* Electrical and Computer Engineering Freshman Projects by Alan Johnston, KU2Y and Xun Jao, 6 CubeSatSims built
- *Johns Hopkins University, MD*, Drew Knuth is using CubeSatSims and Lites in a Small Satellite Development and Experimentation capstone graduate class
- *University of Texas at Dallas, TX*, Kangkook Jee, Tanner Raley, Fred Enriquez organized a satellite workshop at University of Texas at Dallas
 - 2025 and 2026
- *Iowa State University, IA* building CubeSatSims in Make to Innovate (M2I) and Cy Sat program, organized by Matthew Nelson

at Events

- *DEFCON Aerospace Village, NV*
 - Henry Danielson and Tim Fowler, KF0MLF
 - Workshop by RC Jones "How to Corrupt Youth to Cyber Focused Space Science"
- *Aerospace Village Sandbox at the RSA Conference*
- *Thomas Jefferson High School for Science and Technology* in Alexandria by Kristen Kucko, KQ4ECP
- *University of Colorado, Colorado Springs, Mechanical and Aerospace Engineering Department* by Dr Lynnane George, Senior Instructor

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CubeSatSim Can Be Upgraded to 2U

<https://github.com/alanbjohnston/CubeSatSim/wiki/Upgrading-to-2U>



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Questions?

Contact Alan at ku2y@arrl.net

<https://CubeSatSim.org>

<https://www.amsat.org>

<https://github.com/alanbjohnston/CubeSatSim/wiki>

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Acknowledgements

- Thanks to Mark Spencer, WA8SME, for his trailblazing work on CubeSat simulators for the ARRL and to Bob Bruninga, WB4APR (SK), for ideas and inspiration from his undergrad “LabSat” developments.
- Pat Kilroy, N8PK, was instrumental in getting the CubeSat Simulator project going again.
- We would also like to acknowledge all the open source hardware and software that is a part of the AMSAT CubeSatSim.
- Finally, we would like to acknowledge the support of the AMSAT Board of Directors and the members of AMSAT for their support and encouragement of this project.

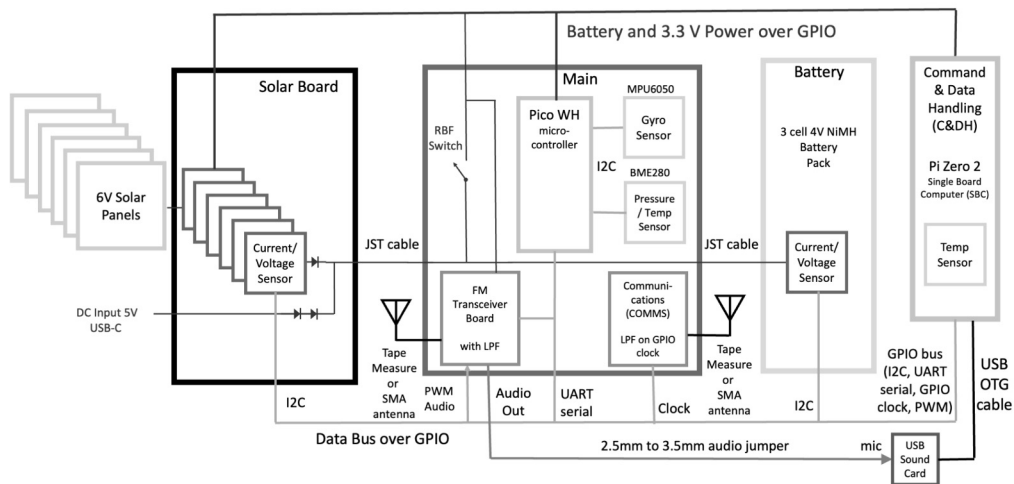
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CubeSatSim Block Diagram v2.0



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