KONGR45GPEN

DESIGN OF FAULT DETECTION, ISOLATION AND RECOVERY IN THE ACUBESAT NANOSATELLITE

DRAFT SPACEDOT (THE TITLE PAGE WILL CHANGE)

PUBLISHED BY DRAFT SPACEDOT (THE TITLE PAGE WILL CHANGE)

TUFTE-LATEX.GITHUB.IO/TUFTE-LATEX/

The AcubeSAT project is carried out with the support of the Education Office of the European Space Agency, under the educational Fly Your Satellite! programme.

First printing, 2021

Contents

List of Figures

List of Tables

Acronyms

ADCS Attitude Determination and Control Subsystem 15, 16

CCSDS The Consultative Committee for Space Data Systems 15

CDR Critical Design Review 15

COMMS Communications 15, 16

COTS Commercial Off-The-Shelf 16

ECSS European Cooperation for Space Standardization 19

EMC Electromagnetic Compatibility 16

EPS Electrical Power Subsystem 16

FDIR Fault Detection, Isolation and Recovery 13, 15, 19, 21, 23

GS Ground Station 16

ISM Industrial, Scientific, Medical 16

MPPT Maximum Power Point Tracking 16

OBC On-Board Computer 16

OBDH On-Board Data Handling 16

OPS Operations 16

PCDU Power Conditioning & Distribution Unit 16

PUS Packet Utilisation Standard 19

RF RadioFrequency 15

SU Science Unit 16, 17

SYE Systems Engineering 17

TC Telecommands 15

TM Telemetry 15

Abstract

Space is not a welcoming environment; while the aerospace engineering community has managed to reliably operate thousands of satellites in orbit, CubeSats, the most popular class of nanosatellite, only have a 50% success rate. Low costs, lack of strict technical requirements and scarcity of publicly available documentation often drives up the risks for educational, scientific and commercial CubeSats. This thesis investigates a configurable and modular Fault Detection, Isolation and Recovery (FDIR) architecture that uses the ECSS Packet Utilisation Standard. This FDIR concept, along with the provided open-source software implementation, can be used by CubeSat missions to increase the reliability of their design and chances of mission success, by autonomously responding to on-board errors. The thesis also includes background information regarding CubeSat reliability, and explores the software and hardware used to implement the proposed FDIR design on the AcubeSAT mission, currently under design by students of the Aristotle University of Thessaloniki.

KAPOU EDW tha mpei kai to abstract sta ellhnika

1
Reliability Engineering in CubeSat Systems

1.1 Kalispera

space is very important[1] Fault Detection, Isolation and Recovery (FDIR)

[1] Durou, Godet, Mangane, Pérarnaud, and Roques, "Hierarchical Fault Detection, Isolation and Recovery Applied to Cof and Atv Avionics."

2
The AcubeSAT mission

2.1 CubeSat

2.2 Subsystems

The AcubeSAT nanosatellite is technically and programmatically split into N different subteams or **subsystems**, each responsible for a different se[1]ction of the satellite, and made up out of M dedicated members.

In the following sections, a brief introduction on the function and design of each subsystem is presented. For more detailed information, the reader is encouraged to refer to AcubeSAT's website[2], or to the publicly available Critical Design Review (CDR) documents[3].

[1] White, Shields, P. Papadeas, Zisimatos, Surligas, Papamatthaiou, D. Papadeas, and Kosmas, "Overview of the Satellite Networked Open Ground Stations (SatNOGS) Project."

[2] `https://acubesat.spacedot.gr/subsystems/`

[3] `https://gitlab.com/acubesat/documentation/cdr-public`

2.2.1 Attitude Determination and Control Subsystem (ADCS)

2.2.2 Communications (COMMS)

The communications subsystem is responsible for transmitting data between the Earth and the spacecraft in orbit. The transmitted data is split into 3 different categories:[4]

[4] Kapoglis and Chatziargyriou, *AcubeSAT TTC DDJF*.

- **Telecommands (TC)**: Commands from the Earth to the satellite. They can be used to request information, or to perform specific spacecraft actions.
- **Telemetry (TM)**: Information sent from the satellite towards Earth, typically including vital information such as sensor values, system status, timestamps and events.
- **Science data**: The scientific data generated by the payload. These are the highest-volume data and represent the main scientific output of the mission.

It is important to mention that the satellite orbit only allows for a very short visibility duration every day, increasing the needs for on-board autonomy and the importance of a correctly implemented FDIR method.

The main component of the COMMS subsystem is the **SatNOGS COMMS board**,[5] an open-source RF transceiver developed by the

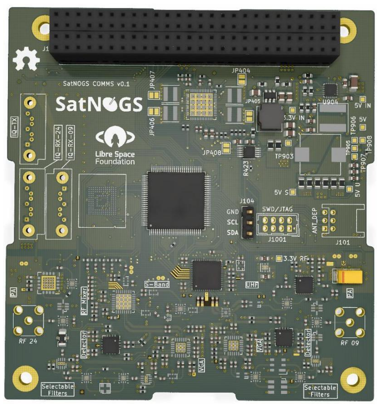

Figure 2.1: The SatNOGS COMMS board

[5] Surligas, "SatNOGS-COMMS."

LibreSpace Foundation, based on CCSDS telecommunications standards.

Communication will take place using 2 frequency bands on the ISM range, namely 436.5 MHz and 2.425 GHz, supported by a deployable turnstile and a directional patch antenna respectively. The use of ISM frequencies allows easy radio-amateur access to the satellite.

The communications subsystem is also responsible for the Electromagnetic Compatibility (EMC) analysis and interference mitigation, as well as the design and construction of the satellite Ground Station. The Ground Station will be part of **SatNOGS**,[6] a global network of satellite ground stations based on open technologies and open data.

[6] White, Shields, P. Papadeas, Zisimatos, Surligas, Papamatthaiou, D. Papadeas, and Kosmas, "Overview of the Satellite Networked Open Ground Stations (SatNOGS) Project."

2.2.3 *Electrical Power Subsystem (EPS)*

The EPS is the subsystem responsible for the generation, distribution and storage of electrical power of the spacecraft. It is a critical aspect of the spacecraft due to the direct dependence of all subsystems to the high power needs of many CubeSat subsystems, and is theorised to be the most common reason for CubeSat failure.[7]

[7] Langer and Bouwmeester, "Reliability of CubeSats – Statistical Data, Developers' Beliefs and the Way Forward."

AcubeSAT has opted for a Commercial Off-The-Shelf (COTS) subsystem approach for the EPS:[8]

[8] Anastasios-Faidon, Kanavouras, and Pavlakis, *AcubeSAT System DDJF*.

- **Solar panels** are procured from EnduroSat. Four 3U panels cover the X and Y faces of the satellite, and one 1U panel covers the $-Z$ face.
- The **Power Conditioning & Distribution Unit (PCDU)** is procured from NanoAvionics and offers 10 switched channels with overcurrent protection over 4 voltage rails, as well as 4 Maximum Power Point Tracking (MPPT) converters.
- The **battery pack**, also procured from NanoAvionics, contains 4 18650 Li-Ion cells in a 2S2P[9] configuration.

[9] 2 series, 2 parallel

A dynamic approach is taken with regards to power budget calculation:

1. The in-orbit power generation is calculated for the duration of the mission using the **STK** software, taking into account satellite orientation, pointing profiles and eclipse, with a 1 min resolution.
2. The power consumption of the system is calculated on average for each different operational mode.
3. MPPT efficiencies and battery charge level are calculated for each timepoint, assuming worst-case thermal and electrical conditions
4. A system-wide 10% margin is applied to the results

Table 2.1: AcubeSAT nominal mode power budget

Consumer	Power
ADCS	1.10 W
COMMS	0.85 W
EPS	0.99 W
OBC	0.12 W
SU	0.25 W
Total	3.30 W
Orbit Average Power	4.24 W

We have created a Python library consolidating the above steps[10] and producing the necessary outputs to prove the adequacy of the design.

[10] https://gitlab.com/acubesat/eps/power-budget

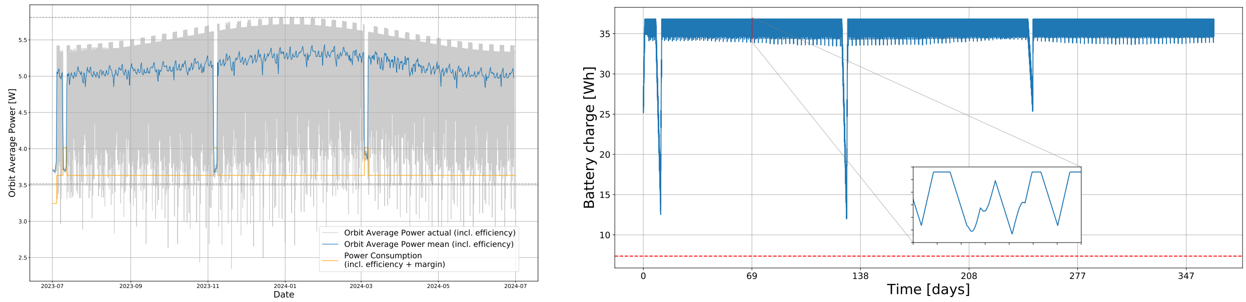

Figure 2.2: Dynamic power budget analysis. Left: Power consumption & generation for the orbit. Right: Battery discharge level throughout the mission

2.2.4 *On-Board Data Handling (OBDH)*

2.2.5 *Operations (OPS)*

The operations subsystem is responsible
the following system modes:[11]

- **Launch/Off mode**: During this mode, the satellite is turned completely off, and no subsystems are energised. This is used to represent the state of the spacecraft inside the deployer, where no electronics are allowed to be energised,[12] and the CubeSat is in a completely dormant state.

- **Commissioning mode**: This mode is initiated as soon as the CubeSat exits the deployer, meaning that launch is complete. It contains the initial startup actions of the spacecraft, including detumbling and antenna deployment. No science takes place during commissioning mode.

- **Nominal mode**: This mode represents the state where the CubeSat will spend most of the time on. Apart from the necessary autonomy functions and battery charging, the CubeSat will also downlink telemetry and science data. No science takes place during nominal mode, except for health checks commanded from the ground. Nominal mode is also the only mode where the satellite performs nadir or sun pointing (Section 2.2.1).

- **Science mode**: This is where the main experiment takes place and payload data are generated. This mode includes operation of the fluidic system, control of the microfluidic chip, reinvigoration of the cells, and periodic acquisition of pictures using the miniaturised microscope.

  AcubeSAT has split science mode into **3 distinct occurrences**, termed sub-experiments α, β and γ, lasting 72 hours each, and taking place at different points of the mission to investigate the time-dependence of the observed results.

- **Safe mode**: It is common for spacecraft systems to include a *safe mode*, where

[11] Zaras, Kapoglis, Georgousi, Papafotiou, Chadolias, Anthopoulos, Retselis, Arampatzis, Xenos, and Christidou, *AcubeSAT Mission Description & Operations Plan*.

[12] California Polytechnic State University, *CubeSat Design Specification Rev. 13*, req. 3.3.3.

2.2.6 Structural

2.2.7 Systems Engineering (SYE)

2.2.8 Science Unit (SU)

2.2.9 Thermal

2.2.10 Trajectory

2.3 Tools used

3
FDIR concept in AcubeSAT

3.1 The ECSS Packet Utilisation Standard

3.1.1 The ECSS services

- **`ST[01]`: Request verification**
  blablablab
- **`ST[02]`: Device management**
  blablablablba

3.2 The SAVOIR standard

4
Software implementation of FDIR

5
Hardware implementation of FDIR

Bibliography

[1] O. Durou, V. Godet, L. Mangane, D. Pérarnaud, and R. Roques, "Hierarchical fault detection, isolation and recovery applied to cof and atv avionics," *Acta Astronautica*, vol. 50, no. 9, pp. 547–556, May 1, 2002, ISSN: 0094-5765. DOI: 10.1016/S0094-5765(01)00212-0. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0094576501002120 (visited on 04/03/2021).

[2] D. White, C. Shields, P. Papadeas, A. Zisimatos, M. Surligas, M. Papamatthaiou, D. Papadeas, and E. Kosmas, "Overview of the Satellite Networked Open Ground Stations (SatNOGS) Project," *Small Satellite Conference*, Aug. 8, 2018. [Online]. Available: https://digitalcommons.usu.edu/smallsat/2018/all2018/313.

[3] K. Kapoglis and E. Chatziargyriou, *AcubeSAT TTC DDJF*, 2021. [Online]. Available: https://gitlab.com/acubesat/documentation/cdr-public/-/blob/master/DDJF/DDJF_TTC.pdf.

[4] M. Surligas, "SatNOGS-COMMS," presented at the CubeSat Developers Workshop, Apr. 12, 2021, p. 22.

[5] M. Langer and J. Bouwmeester, "Reliability of CubeSats – Statistical Data, Developers' Beliefs and the Way Forward," *Proceedings of the 30th Annual AIAA/USU Conference on Small Satellites*, 2016. [Online]. Available: https://repository.tudelft.nl/islandora/object/uuid%3A4c6668ff-c994-467f-a6de-6518f209962e (visited on 05/20/2021).

[6] R. Anastasios-Faidon, K. Kanavouras, and G. Pavlakis, *AcubeSAT System DDJF*, 2021. [Online]. Available: https://gitlab.com/acubesat/documentation/cdr-public/-/blob/master/DDJF/DDJF_SYS.pdf.

[7] A. Zaras, K. Kapoglis, M. Georgousi, T. Papafotiou, M. Chadolias, A. Anthopoulos, A.-F. Retselis, A. Arampatzis, K.-O. Xenos, and E. Christidou, *AcubeSAT Mission Description & Operations Plan*, 2021. [Online]. Available: https://gitlab.com/acubesat/documentation/cdr-public/-/blob/master/MDO%20file/MDO.pdf.

[8] California Polytechnic State University, "CubeSat Design Specification Rev. 13," Feb. 20, 2014. [Online]. Available: https://www.cubesat.org/s/cds_rev13_final2.pdf.