EIRFLAT-1: A FlatSat platform for the development and testing of the 2U CubeSat EIRSAT-1

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Abstract

The Educational Irish Research Satellite (EIRSAT-1) is a 2U CubeSat being designed, built and tested at University College Dublin. A FlatSat platform known as EIRFLAT-1 has been constructed to enable the testing and development of the CubeSat. EIRFLAT-1 facilitates the electrical connections between CubeSat components while leaving key interfaces accessible for test equipment and allowing for the hot swapping of components. Commercial Off The Shelf and in-house developed hardware has been tested using EIRFLAT-1 at component, subsystem and full system level. In addition, the FlatSat has been used for flight software development. This paper describes the design of EIRFLAT-1 including electrical and mechanical components and additional ground support equipment developed to assist in the testing and development activities. EIRFLAT-1 has proven to be an invaluable tool for testing and has led to the discovery of issues and unexpected behaviour with flight hardware which would have contributed to schedule delays if undiscovered until after the satellite was assembled. Moreover, EIRFLAT-1 facilitated early and incremental testing of both software and operations procedures. The schematics for the electrical design of EIRFLAT-1, which is compatible with all CubeSat Kit PC/104 components, has been made publicly available for use by other educational CubeSat teams.

Keywords
EIRSAT-1, CubeSat, FlatSat, Ground Support Equipment

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1. Introduction

The Educational Irish Research Satellite (EIRSAT-1) is a 2U CubeSat currently being developed under the second edition of the European Space Agency's educational "Fly Your Satellite!" programme. The satellite contains three novel payloads and a custom antenna deployment module that are supported by an AAC Clyde Space Commercial Off The Shelf (COTS) platform which has been adapted to interface with these novel hardware components [1]. Combining COTS components with in-house developed hardware, software and firmware results in a complex system which requires extensive testing [2, 3].

To ensure compatibility between all the spacecraft components and to allow for pre-assembly system level testing, a FlatSat called EIRFLAT-1 has been constructed (Figure 1). A FlatSat is a test bed into which satellite components can be integrated to represent the final spacecraft configuration, while allowing for access to individual components which you may not have in the flight configuration. FlatSats allow for power transmission and communication between all or some spacecraft components, hot swapping of development model payloads and access to the spacecraft interfaces for testing and verification purposes. FlatSats are used in the development of multiple classes of satellite from large spacecraft such as Solar Orbiter [4] and Emirates Mars Mission [5] to CubeSats such as ISTSAT-1 [6] and Aalto-1 [7].

Since the CubeSat standard was first proposed in the 1990s, university teams developing new technologies have utilised them as a quick and cost-effective path to space. Companies such as GOMSpace, AAC Clyde Space and ISI Space produce COTS platforms which allow CubeSat teams to focus on their payload development without the overheads involved in producing their own power systems, on-board computers, structures, communication systems or attitude control systems, providing both time and cost savings. EIRFLAT-1 has been designed in a manner which allows it to be compatible with a wide array of COTS components to allow for a focus on rapid iterative payload development. A full description of the design and manufacture of EIRFLAT-1 is provided in Section 2.

EIRFLAT-1 has been used extensively for the acceptance and functional testing of EIRSAT-1's Engineering Qualification Model (EQM) components at both subsystem and system levels prior to satellite integration [8]. Additionally, the FlatSat has been used by the team for flight software development and the development and testing of operational procedures in simulated mission scenarios. The FlatSat is also being used for the testing of Flight Model (FM) components. Further information on the testing conducted using EIRFLAT-1 can be found in Section 3.

The importance of the FlatSat was demonstrated by the discovery of a number of issues and unexpected system behaviours prior to the flight configuration assembly of the EQM. These could then be solved or noted without the need to disassemble the entire satellite. One such example was the discovery of a fault with one of the On-Board Computer's (OBC) I^2C buses for payload communications which required the OBC to be returned to the supplier for repair.

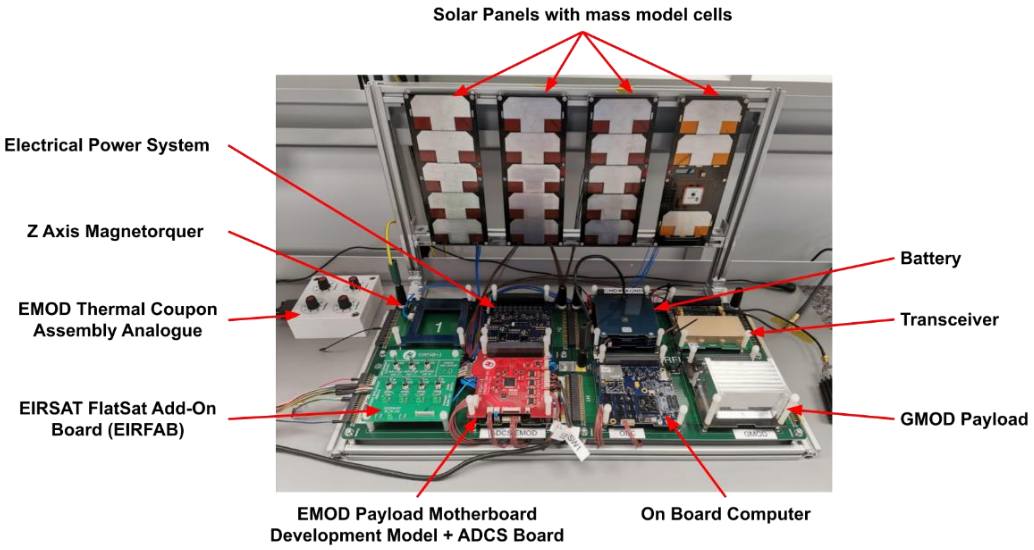

Figure 1. Labelled photograph of EIRFLAT-1 with Engineering Qualification Model components taken during a system level test campaign.

EIRFLAT-1, as the first integration of the EIRSAT-1 system, provided an excellent learning experience for the team in the handling of flight hardware, space systems engineering and flight software development. Lessons learned during the development of EIRFLAT-1 and the testing conducted to date will be taken into consideration during the design phase of an updated FlatSat. When EIRSAT-1 is in orbit, the EQM hardware will be integrated in this updated FlatSat configuration for software validation and debugging. These lessons are discussed in more detail in Section 4.

2. Design and Construction of EIRFLAT-1

EIRFLAT-1 consists of several key mechanical and electrical components which allow the FlatSat to function as a whole system which can interface with test equipment such as multimeters and oscilloscopes. A description of these components and how they are integrated with one another is provided in this section.

2.1. EIRFLAT-1 Electrical Interface Board

Printed circuit boards (PCBs) called Electrical Interface Boards (Figure 2) enable the electrical connections between spacecraft components which follow the CubeSat Kit's modified PC/104 standard [10]. This standard is used by many in the CubeSat industry, including manufacturers like GOMSpace and AAC Clyde Space. The electrical interface boards consist of four slots, each with their own 104 pin header through which most of the power and data is transmitted. The spacecraft buses are broken out into headers at the sides of the boards for access with test equipment or to expand the FlatSat by linking two interface boards together.

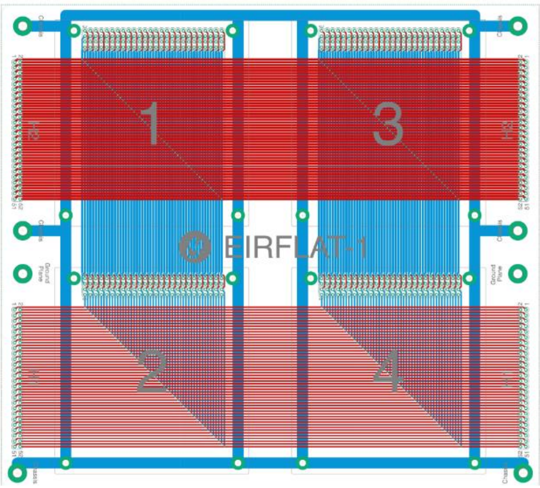

Figure 2. Schematic of an Electrical Interface Board which electrically connects subsystems.

The four slots all share a common ground plane, to which the subsystems are connected via conductive M3 spacers located at the corners of the slots. These spacers are also used to secure the components in place on the FlatSat. Banana sockets allow for the ground plane of the interface board to be referenced to a piece of test equipment or to one of the spacecraft's subsystems to match the grounding scheme of the fully assembled system.

The schematic of the electrical interface boards has been made available at www.github.com/ucd-eirsat-1/FlatSat for use by university CubeSat teams making use of the CubeSat Kit standard.

2.2. Structure

EIRFLAT-1's electrical interface boards are mounted on an aluminium structure which provides mechanical support. A schematic of the structure is shown in Figure 3. The structure consists of lengths of 20mm x 20mm aluminium profile secured using M5 hardware including T slot nuts, angle brackets and bolts. In addition to the main base of the structure which supports the electrical interface boards, a detachable stand can be used to support solar panels in a vertical orientation. The solar array stand reduces the surface area required on a bench when solar panels are added to the FlatSat assembly, allows test operators to illuminate the panels directly without holding torches above the panels, minimises the surface area upon which dust can fall, and allows for a protective screen to be placed around the cells, protecting one of the more fragile and expensive components of the CubeSat from damage.

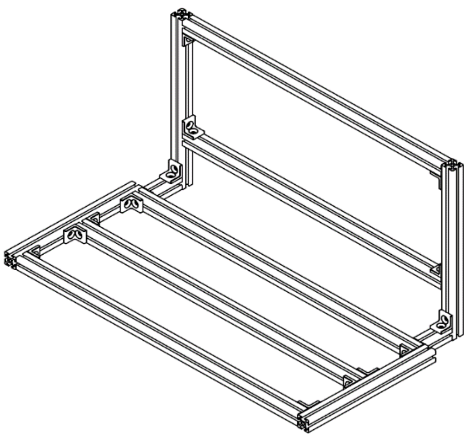

Figure 3. EIRFLAT-1 Aluminium Structure including the flat base and the solar array stand.

Aluminium tape running along the lengths of profile allows the structure to act in the same manner as the conductive elements of the CubeSat structure from an electrical grounding perspective. The ground plane of each interface board is connected to the structure through the mounting holes. The aluminium then connects this to the solar panels through the panel mounting holes. The conductive tape was added to EIRFLAT-1 after the structure had been assembled, when it was noted that the aluminium profile was anodised and was therefore not conductive as originally assumed.

2.3. Additional Ground Support Equipment (GSE)

It is possible to connect all the subsystems of EIRSAT-1 together for system level testing using just the structure and electrical interface boards, however, several additional pieces of GSE have been designed to improve EIRFLAT-1 for development purposes and for testing individual subsystems.

2.3.1. Fake Electrical Power Subsystem (EPS)

In order to supply power to the spacecraft, EIRSAT-1 uses a COTS electrical power subsystem consisting of solar panels, a battery and a motherboard which handles battery management, power conditioning and power distribution. For testing and development, it is preferable to supply power to components on the FlatSat without using the flight EPS hardware in several situations. This saves the EPS from the risk associated with over-cycling the battery, or with connections to previously untested components of the spacecraft. In order to supply power to the FlatSat the Fake EPS (Figure 4) is positioned in one of the electrical interface board slots and connected to a bench power supply unit using 4mm banana cables. The Fake EPS has a banana socket for each of the spacecraft power buses, plus two grounding connectors. The Fake EPS PCB distributes the power from these banana sockets to the main header, supplying power to the other subsystems on the interface board just as the EPS would during a full system level FlatSat test.

2.3.2. EMOD Thermal Coupon Assembly (TCA) Analogue

One of EIRSAT-1's payloads is the Enbio Module (EMOD), an experiment designed to monitor the performance of thermal surface treatments on orbit [1]. This is achieved by using PT100 resistance temperature devices to measure the temperature of four coupons located in an assembly on EIRSAT-1's exterior. To verify the functionality of the supporting electronics and software for this experiment, the EMOD TCA Analogue (Figure 4) was designed to allow test operators to provide the EMOD electronics with a resistance to measure which corresponds to the temperatures expected on orbit using potentiometers. This way, testing and development activities can ensure that the experiment is working over the full expected temperature range while at ambient conditions and without having the sensitive coatings of the thermal coupons exposed to the environment.

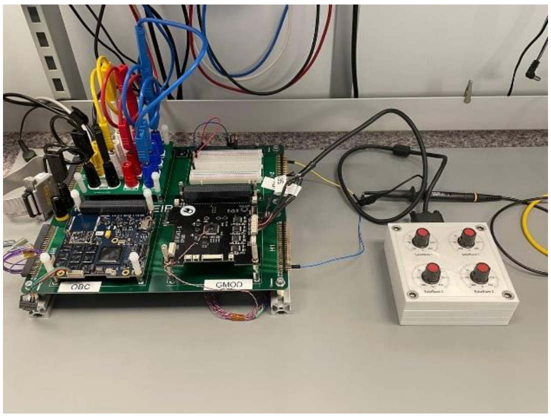

Figure 4. Photograph of an electrical interface board being used for software development of the EMOD payload using the Fake EPS and the EMOD TCA Analogue.

2.3.3. EIRFLAT-1 Add-On Board (EIRFAB)

EIRFAB, a PCB which connects to EIRFLAT-1, has been designed to functionally test several components of the spacecraft which are electrical in nature but are parts of mechanical components of the spacecraft.

CubeSats have deployment switches mounted on the exterior of the structure. These micro-switches ensure that the spacecraft remains powered off until it has successfully been ejected from the deployer. These switches are not ideal for testing purposes, as they can easily be damaged and are open by default. Instead of using these micro-switches, EIRFAB has three toggle switches which replace the deployment switches during FlatSat testing. These switches are robust and allow for the spacecraft to be left in a stowed or deployed configuration.

One of the other major mechanical components of EIRSAT-1 is the Antenna Deployment Module (ADM) [9]. The ADM has large tape spring antennas which are deployed when the satellite is in its separation sequence. During FlatSat testing it is not practical to use the ADM. The deployed elements take up a lot of space on the workbench and as they deploy quickly, they could potentially damage other components of the FlatSat. It is also time consuming to re-stow the antenna elements which reduces the time available for testing. The EIRFAB-1 PCB contains the same electronics as the ADM which allows the testing to be conducted without deploying antenna elements. Since the elements will not deploy, LEDs have been added to the circuitry to provide a visual indicator that the deployment mechanism is active. The ADM also uses micro-switches to tell the on-board computer when the doors have opened, and the elements have been deployed. On EIRFAB these have been replaced with toggle switches which allow operators to test how the system responds on deployment failure.

The third and final piece of electronics on EIRFAB is a coarse sun sensor circuit. EIRSAT-1 uses five of these sensors in its attitude determination and control system. Four of them are located on the solar panels, however, the fifth is attached to the exterior of the ADM. The circuit on EIRFAB has one sun sensor and a connector which allows it to interface with the attitude control subsystem.

2.4. Layout and Harnessing

Many of the electrical connections between EIRSAT-1 components and the required GSE cannot be made through the main spacecraft header. Within the main stack assembly there are some connections which do not rely on the PC/104 header, but on a harnessing system or other board to board connectors. Components on the spacecraft exterior (e.g. ADM, EMOD TCA, solar panels and sun sensors) are also connected to the main stack assembly via a harnessing system. For EIRFLAT-1 a harnessing system using the same materials as the system on the spacecraft has been built to replicate the spacecraft configuration as much as possible, despite the extended distances between components. This choice ensured that the connections between the components were in a worst-case scenario, and if all of the integration tests passed on the FlatSat then the team would have high confidence in the harnessing system fulfilling its requirements in the flight configuration. The addition of this harnessing system, and the board-to-board connections placed restrictions on the layout of EIRFLAT-1. Ensuring that the harnesses could be neatly arranged allowed for better access to testing interfaces and reduced the risk of connection errors. The layout of EIRFLAT-1 is shown in Figure 1. The EMOD board is located directly on top of the ADCS board to facilitate a board-to-board connection between these subsystems. These PCBs are located towards the left side of the FlatSat as the main spacecraft umbilical cable is connected to the left side of the EMOD board and runs to GSE located out of shot to the left of EIRFLAT-1. The EPS board is located at the back of the FlatSat to shorten the routes between the solar panels and the EPS. The transceiver is located towards the right of the satellite to allow it to be connected to the ADM, or GSE which requires coaxial cable connections.

3. Testing and Development

EIRFLAT-1 is used in three test campaigns prior to system assembly. The first of these is acceptance testing, during which components are installed on the FlatSat in isolation from other flight hardware and are tested using GSE to ensure that the components are operating according to their specifications. Once the components have been accepted, they are integrated with other components of their subsystem and tested at subsystem level. Some components are included in multiple subsystem test campaigns. For example, the solar panels are installed on the FlatSat for both the EPS tests (charging test, maximum power point tracking test) and the ADCS tests (magnetorquer and sun sensor tests). EIRSAT-1's OBC is installed on the FlatSat for many of these tests to test subsystem telemetry and telecommand. Following the subsystem functional testing, all of the components are added to EIRFLAT-1 and a system level functional test is conducted. This test verifies the functionality and requirements of the system and ensures that no unexpected errors arise due to the integration of the whole system.

This full cycle of testing has already been conducted for EIRSAT-1's EQM hardware, culminating in the flight configuration assembly of the EQM in November 2020 [8]. Currently, EIRFLAT-1 is being used for subsystem level testing of FM components of the satellite following a successful acceptance test campaign. In addition to these test activities, EIRFLAT-1 is used to assist in the development of flight software. During development periods, the OBC is installed on the FlatSat either on its own or with development models of the satellite's payloads for testing new software images. Moreover, software bugs are investigated and fixed using an OBC on EIRFLAT-1 while testing continues using the fully assembled satellite. This is to continue through-out EIRSAT-1's mission lifetime as EIRFLAT-1 is used to test new software images, new operations and for debugging of problems while EIRSAT-1 operates in space.

4. Discussion

EIRFLAT-1 has proven to be a vital resource during the development of the EIRSAT-1 CubeSat. The platform served as an excellent base to students working with flight hardware for the first time. The design has allowed for successful iterative payload development and robust testing which highlighted several issues which may have caused delays if they had gone unnoticed until the satellite had been assembled. Some of these issues included:

- Damaged I^2C bus on the EQM OBC which had to be repaired. This issue was discovered during the OBC acceptance test campaign.
- Reversed polarity of the sun sensor on EIRSAT-1's custom solar panel when compared to the COTS panel. This issue was solved by a redesign of the flight harnessing system. This issue was discovered during the ADCS subsystem test.

The initial design of the EIRFLAT-1 platform, while useful, was not perfect. Improvements have been made to the system. One of the improvements is the addition of aluminium tape to the EIRFLAT-1 structure to ensure the solar panels and the other subsystems share an electrical ground as they would in flight configuration. Another is a change in the location of grounding points on the electrical interface boards. The importance of proper grounding procedures was highlighted during the acceptance test of the EQM transceiver on EIRFLAT-1 when an improperly grounded radio caused an overvoltage event on the transceiver which had to be sent for repairs. Systems to ensure that all satellite components and GSE are correctly grounded have been implemented to reduce the risk of a similar incident occurring in the future.

5. Conclusions

EIRFLAT-1, a FlatSat for the development and testing of the EIRSAT-1 satellite or other CubeSats which make use of the CubeSat kit standard, has proved to be an invaluable tool. The design of the FlatSat allows for the components of the satellite to be tested in isolation, at subsystem level and at system level, all while keeping the satellite interfaces accessible to test equipment. EIRFLAT-1 has uncovered several issues with the system which could have been costly had they not been discovered until the satellite was assembled in its flight configuration.

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