



EPS Test Plan Guidelines

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February, 2024

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Revision Control:

Version	Author	Changes	Date
0.1	R.A. Borba	Document creation	2024/02/14



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List of Tables

5.1	Baseline test matrix	9
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Contents

List of Tables	v
1 Introduction	1
2 Documentation	3
2.1 Test Plan Structure	4
3 Test Objectives	5
3.1 Qualification Testing	5
3.2 Acceptance Testing	5
3.3 Proto-flight Testing	5
4 General Requirements	7
5 Baseline Test Matrix	9
5.1 Inspection	10
5.2 Functional	11
5.3 Performance	12
5.4 Mission	12
5.5 Environmental	13
References	15

CHAPTER 1

Introduction

This document contains a series of guidelines and recommendations regarding the preparation of test plans for CubeSat Electrical Power Systems.

This guidelines are based on the ECSS Standards ECSS-E-ST-10-02 [1] and ECSS-E-ST-10-03 [2] and are intended to be applicable to different EPS topologies and architectures.

An important consideration regarding the ECSS standards is that they were designed with for large scale missions and satellites of large sizes, and many of the requirements defined are not feasible for small scale CubeSat missions, with limited resources and development time, and especially when applying for a single module. The guidelines in this documents are an adaptation of the requirements defined in the standards, considering the scenario of a CubeSat mission.

Testing is considered part of the verification process outlined in the standards, this means that many of the concepts and considerations presented in this guidelines are derived from concepts related to this process. With this in mind, a basic review of the verification process main concepts is advised before implementing the test plan.

This document will cover: test plan structure, test objectives, associated documentation, general requirements and provide a baseline test matrix.

CHAPTER 2

Documentation

Regarding the documentation associated with testing, the standards define four types of documents: AIT (Assembly, Integration and Test) Plan, Test Specification, Test Procedure and Test Report. The expected content for each of these documents are defined in the appendices of the ECSS-E-ST-10-02 [1] and ECSS-E-ST-10-03 [2] documents. A description of the main purpose of these documents, as defined in the standards, is presented in the following paragraphs.

The AIT Plan document, which may also be named Test Plan, describes the entire testing process, linking each test with the requirement it verifies. It contains a planning and description of test activities, description of the selected models, test matrices linking tests with the corresponding test specification, procedure, report and model to be used, description of required equipment and facilities, documentation to be produced and schedule.

The Test Specification document describes the detailed specifications and requirements for the test. It contains a description of the purpose of the test, test approach, the item under test, the requirements being verified, required equipment, instrumentation and uncertainties, test conditions and tolerances, pass/fail criteria, related documentation and schedule.

The Test Procedure document describes the detailed procedures for execution of the test. It contains the objective of the test, reference to corresponding TSPE document, description of the item under test configuration, required equipment and detailed step-by-step instructions for the test execution.

The Test Report document describes the execution of the test, the test results, data analysis and assessments, as well as considerations and conclusions regarding the requirements being verified.

Regarding the applicability of this documentation structure, it is worth reminding that these definitions are meant to encompass testing for large sized satellites and large scale missions, and that, by following this structure, a great quantity documents would be generated, especially test specifications and procedures documents, considering at least one of each for each and every test.

In CubeSat missions, with simpler designs and simpler tests when compared to large sized satellites, where lower cost and rapid development are a focus, and especially considering that this is currently being applied to a single module, it is proposed for these documents to be combined and adapted to the documentation style of each project.

2.1 Test Plan Structure

As the purpose of this document is to provide guidance regarding the elaboration of test plans, based on the ECSS standards definitions, the following structure for the Test Plan document is proposed as a stating point:

- Introduction:
 - containing a description of the main objective, purpose and content of the document;
- Product presentation:
 - containing a description of the selected models for testing and their built status;
- Test program:
 - containing the main test matrix, linking each test with the corresponding specification, procedures, physical model used and reference to the requirements they verify;
 - description of each test block and test activity;
 - test flow and sequencing when necessary;
- Test facilities:
 - containing a description of the test facilities to be used, or requirements for selecting a test facility;
- Documentation:
 - containing a description of the documents to be produced;
- Schedule:
 - when test are to be executed in a specific time frame;
 - a schedule may not be needed for test plans meant to be recurrent.

CHAPTER 3

Test Objectives

The ECSS standards [2] define three main objectives for the testing process, qualification testing, acceptance testing and proto-flight testing. These objectives are directly related to the verification stages and model philosophy concepts of the verification process.

For each of these objectives, different margins regarding test levels and durations are defined and, when applicable, should be adopted directly from the standards document [2].

Regarding the test margins and required environmental tests, the launch provider may have its specific requirements. These take priority over the requirements defined in the ECSS standards.

In addition to these main objectives, a test plan may fulfill other purposes, such as to provide data for comparing different modules, or evaluate performance in research scenarios, for example. These additional objectives are not covered in the ECSS standards and are mainly relevant when the test plan is prepared for different purposes, outside of the verification process.

3.1 Qualification Testing

Qualification testing has the objective of verifying that the design of the item under test meets its applicable requirements, providing evidence that it performs in accordance to its specifications, considering the intended environment and qualification margins.

The qualification test plan is executed on dedicated qualification model units, manufactured specifically for the qualification tests.

3.2 Acceptance Testing

Acceptance testing has the objective of verifying that the item under test is in conformance with the verified design and is free from manufacturing defects or flaws, providing evidence that it performs in accordance to its specifications, considering the intended environment and acceptance margins.

The acceptance test plan is executed on every flight model unit.

3.3 Proto-flight Testing

Proto-flight testing combines the objectives of both qualification and acceptance testing. The proto-flight test plan may be executed on the first flight model unit and usually

combines qualification test levels with acceptance test durations for its margins.

CHAPTER 4

General Requirements

The ECSS-E-ST-10-03 [2] also defines testing requirements regarding test conditions, test input tolerances and measurement uncertainties, which are independent of the product (the item for which the standards are being applied), and no specific considerations were deemed necessary considering the EPS module.

These requirement are mostly relevant to environmental tests and, may be referenced directly from the standards document [2] when applicable.

The standards also define a series of reviews to be held before and after each test. In the context of a CubeSat mission, holding this many reviews would greatly lengthen mission time, especially if applied at module level testing. So, at this time, those reviews were not considered applicable.

CHAPTER 5

Baseline Test Matrix

The test matrix is where all the selected test for the test plan are presented and organized, it should contain or reference all the relevant information regarding each test.

Regarding the test program, the test matrix, presented in Table 5.1 is proposed as a baseline. It is intended to be applicable to different EPS architectures and cover most of the necessary tests. When writing a specific test plan, the relevant test activities applicable to the architecture as well as to the requirements of the EPS being tested should be selected. Also, any additional tests, specific to a given architecture, not covered in the baseline matrix, may be added as necessary.

Test Block	Test Activity
Inspection	Manufacturing Inspection Electrical Inspection Mechanical Inspection Integration Inspection
Functional	Harvesting System Output Channels Regulators Battery Management Output Channels Control Protection Circuits Sensor Readings Communication Buses
Performance	Module Power Consumption Harvesting Regulator Efficiency Output Channels Regulators Efficiency Battery Charging Regulator Efficiency Overall/System Efficiency
Mission	Mission Cases
Environmental	Vibration Thermal Vacuum Thermal Cycling Bake-out

Table 5.1: Baseline test matrix

The baseline test matrix is organized in four test blocks: inspection, functional, performance and environmental. Each block is composed of related test activities, and each activity is composed of one or more individual tests. Each individual test should be referenced to its specifications, procedures, model used and requirement being verified.

At individual test level, the dependencies on the specifics of each EPS architecture and implementation are greatly increased, so proposing individual tests at this moment is unfeasible considering this matrix, and the entire guidelines document, is intended to be adaptable to different topologies and architectures.

In the specific test plan, this matrix would need additional columns to include all the necessary information, and, for better organization, may be divided into multiple tables, as long as the tests are properly referenced.

In the next sections, a description of each block and activity will be presented.

5.1 Inspection

The Inspection test block has the objective of verifying the integrity of the manufacturing process and conformance of the physical model with the design files, ensuring there are no workmanship defects or flaws in the model.

This block is composed of the following activities:

- Manufacturing Inspection:
 - has the purpose of verifying the integrity of the manufacturing and transportation processes;
 - consists of visual inspection of the packaging conditions and conformance to the fabrication standards requirements;
- Electrical Inspection:
 - has the purpose of verifying the electrical integrity of the module;
 - consists of verifying conformance with the electrical schematics, checking solder quality and integrity, checking for absence of short circuits and performing first power up of the module;
- Mechanical Inspection:
 - has the purpose of verifying the physical properties of the board in relation to the design files;
 - consists of measurements of board dimensions, mass, size and position of mounting holes;
- Integration Inspection:
 - has the purpose of verifying that the module can be physically integrated with the satellite;
 - consists of checking the connectors pinout and positioning in relation to the design files.

5.2 Functional

The Functional test block has the objective of verifying that the module is capable of executing all of its required functions according to its designed specifications.

This block is composed of the following activities:

- Harvesting System:
 - has the purpose of verifying the correct operation and functioning of the module's harvesting system
 - consists of testing the relevant power converters as well as associated MPPT systems and algorithms;
- Output Channel Regulators:
 - has the purpose of verifying the correct operation and functioning of the output channels regulators;
 - consists of applying varying loads to the voltage regulators, according to the expected limits during mission operation;
- Battery Management:
 - has the purpose of verifying the correct operation end functioning of the battery management system;
 - consists of testing the associated regulators, verifying the operation of the monitoring systems, testing of the heating systems and associated algorithms;
- Output Channels Control:
 - has the purpose of verifying the correct operation and functioning of the output channels control system;
 - consists of testing the operation of the channel's power switches and correct functioning of regulator's enable pins;
- Protection Circuits:
 - has the purpose of verifying the correct operation and functioning of the modules protection circuits;
 - consists of the current limiting capabilities of power switches, integrated protections of regulators, batteries charging and discharging protections and associated algorithms;
- Sensor Readings:
 - has the purpose of verifying the correct operation and functioning of the sensors and the correctness of the readings;
 - consists of testing and comparison of the module's sensor readings against external measurement instruments;
- Communication Buses:

- has the purpose of verifying the correct operation and functioning of the communication buses and integrity of information;
- consists of checking the communication buses' configuration and protocols, verifying the integrity of the messages, including both external (for other modules) and internal (for peripherals) communication buses.

5.3 Performance

The Performance test block has the objective of verifying and evaluating the performance aspects of the module in relation to its requirements. The main focus of this block, considering an EPS module, is on evaluating the efficiency of the multiple conversion stages present in the module, as well as of the module as a whole. This usually consists of applying varying loads to the regulators and measuring input and output power consumptions in order to calculate the efficiency, resulting in an efficiency curve, providing data for different points of operation.

This test block is composed of the following activities:

- Module Power Consumption:
 - has the purpose of evaluating the power consumption of the isolated module, in normal operating conditions, with no loads connected;
- Harvesting System Efficiency:
 - has the purpose of evaluating the efficiency of the converters associated with the harvesting system;
- Output Regulators Efficiency:
 - has the purpose of evaluating the efficiency of the converters associated with the output channels;
- Battery Charge Regulators Efficiency:
 - has the purpose of evaluating the efficiency of the converters associated with the batteries;
- System Efficiency:
 - has the purpose of evaluating the efficiency of the system as a whole, considering all conversion stages;

5.4 Mission

The Mission test block has the objective of verifying the correct operation of the module in relation to the mission concept of operations. The activities of this block will involve simulations of expected scenarios during mission operation, considering what is feasible to simulate on ground. These may include, for example, system initialization, payload activation schedule, eclipse situations and other relevant scenarios. It is also included simulations of contingency situations, and time critical scenarios. Due to the nature of

this block, the test activities will be highly dependent on the specifics of each mission, and so no specific activities or scenarios are proposed at this moment.

5.5 Environmental

The Environmental test block has the objective of verifying that the module is capable of surviving and operating on the conditions of the environment it is exposed to.

The activities involve vibration tests, which relates to the launch conditions, and thermal vacuum, thermal cycling and bake-out tests, which relate to the space and orbit conditions; Specific details for these tests, including test levels and durations, are defined directly in the ECSS-E-ST-10-03 standard [2]. The requirements of the launch provider, when known, must also be taken into account and take precedence over the standards.

Bibliography

- [1] ECSS Secretariat. ECSS-E-ST-10-02 - Verification. Technical Report Rev.1, ECSS-ESTEC, 2 2018.
- [2] ECSS Secretariat. ECSS-E-ST-10-03 - Testing. Technical Report Rev.1, ECSS-ESTEC, 5 2022.