CUBESPACE

CubeSense Earth Gen 2

Product Description

DOCUMENT NUMBER	CS-DEV.PD.CI-01
VERSION	1.01
DATE	14/09/2023
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DISTRIBUTION LIST	External

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Revision History

VERSION	AUTHORS	DATE	DESCRIPTION
A	C. Leibbrandt	14/06/2023	First draft release
B	R. van Wyk	13/07/2023	Review and additions
1.00	C. Leibbrandt	24/07/2023	First published version
1.01	R. van Wyk	14/09/2023	Fixed erroneous value for vertical detection FoV

Reference Documents

The following documents are referenced in this document.

[1] CS-DEV.PD.CA-01 CubeADCS Product Description Ver.1.01 or later

[2] CS-DEV.ICD.CS-01 CubeSense Earth ICD Ver.1.00 or later

[3] CS-DEV.UM.CS-01 CubeSense Earth User Manual Ver.1.00 or later

List of Acronyms/Abbreviations

ACP	ADCS Control Program
ADCS	Attitude Determination and Control System
CAN	Controller Area Network
COTS	Commercial Off The Shelf
CSS	Coarse Sun Sensor
CVCM	Collected Volatile Condensable Materials
DUT	Device Under Test
EDAC	Error Detection and Correction
EHS	Earth Horizon Sensor
EM	Engineering Model
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
FDIR	Fault Detection, Isolation, and Recovery
FM	Flight Model
FSS	Fine Sun Sensor
GID	Global Identification
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GYR	Gyroscope
I2C	Inter-Integrated Circuit
ID	Identification
LTDN	Local Time of Descending Node
LEO	Low Earth Orbit
MCU	Microcontroller Unit
MEMS	Microelectromechanical System
MTM	Magnetometer
MTQ	Magnetorquer
NDA	Non-Disclosure Agreement
OBC	On-board Computer
PCB	Printed Circuit Board
RTC	Real-Time Clock
RWA	Reaction Wheel Assembly

RW	Reaction Wheel
SBC	Satellite Body Coordinate
SOFIA	Software Framework for Integrated ADCS
SPI	Serial Peripheral Interface
SRAM	Static Random-Access Memory
SSP	Sub-Satellite Point
STR	Star Tracker
TC	Telecommand
TCTLM	Telecommand and Telemetry (protocol)
TID	Total Ionizing Dose
TLM	Telemetry
TML	Total Mass Loss
UART	Universal Asynchronous Receiver/Transmitter

Table of Contents

Table of Tables

Table of Figures

1 Introduction

This document presents and describes the CubeSense Earth as a standalone product which may be integrated with a client satellite system.

This document is a prelude to the CubeSense Earth ICD (see [2]) and standard CubeSense Earth User manual (see [3]) providing further detail.

This CubeSense Earth product description henceforth documents all its features, characteristics and capabilities to serve as an introduction to the product.

Different client scenarios are catered for, namely:

1. Purchasing of a standard CubeSense Earth offering by a knowledgeable client who requires no further assistance,
2. Purchasing of a CubeSense Earth where the client initially requires CubeSpace consultation and suggestions to be able to make an informed decision on which CubeSense Earth variant to choose to optimally fulfil the client's requirements.

2 CubeSense Earth Context

An integrated CubeADCS is made up of several sub-systems, also referred to as CubeProducts. The standard CubeADCS offering is described in the CubeADCS Product Description document (see [1]).

CubeADCS, and therefore also the CubeSense Earth as a subsystem of the CubeADCS, is designed with modularity in mind. CubeProducts are typically mass manufactured, resulting in short production times and increased reliability through repeatability.

The integrated CubeADCS consists of an ADCS computer (the CubeComputer subsystem) and various other subsystems -sensors and -actuators, also referred to as nodes, connected via harnesses. The CubeSense Earth is defined as a subsystem of type Sensor.

In such an integrated CubeADCS, the satellite OBC will interface with the CubeComputer, which will, in turn, interface with the CubeSense Earth described in this document. However, each CubeProduct is also offered as a standalone product and allows for direct interfacing to a client system / client ADCS / OBC, utilising the electrical-, electronic- and mechanical interfacing normally utilized for interfacing to the CubeADCS.

All electrical and mechanical interfacing details for the CubeSense Earth are presented in [2].

A software library is available for inclusion in OBC source code, to facilitate communication with the CubeProduct and to ensure messages are formatted correctly. API and protocol details are also provided, should the client wish to develop their interfacing code.

The CubeSense Earth User Manual (see [3]), is also provided, both typically post-order placement, to guide the client user to be able to conduct a health check test after receipt of the physical item and to enable the user to set the CubeSense Earth to work within the client system/environment.

3 CubeSense Earth detailed description

3.1 Overview

The CubeSense Earth is an infrared horizon sensor that provides high-accuracy pitch and roll determination throughout the entire orbit, which allows for accurate satellite control in eclipse without the need for a star tracker. It is the perfect sensor for satellites requiring nadir pointing or station tracking throughout the orbit.

The main features of CubeSense Earth include:

- Infrared sensor
- Aluminium case with EMI filters
- Shared electronic design across the Gen2 family
- Compact form factor

An overview of CubeSense Earth is presented in Table 1.

Table 1: CubeSense Earth description

ITEM	DESCRIPTION	
CubeSense Earth (Sub-System) 	Description	Infrared earth horizon sensor
	Details	• Provides measurements in sunlight and eclipse, • Hermetically sealed lens, • Tolerates typical off-nadir angles
	Generic Term	Earth Horizon Sensor (EHS)
	CS Name and acronym	CubeIR (CI)

3.2 Subsystem diagram

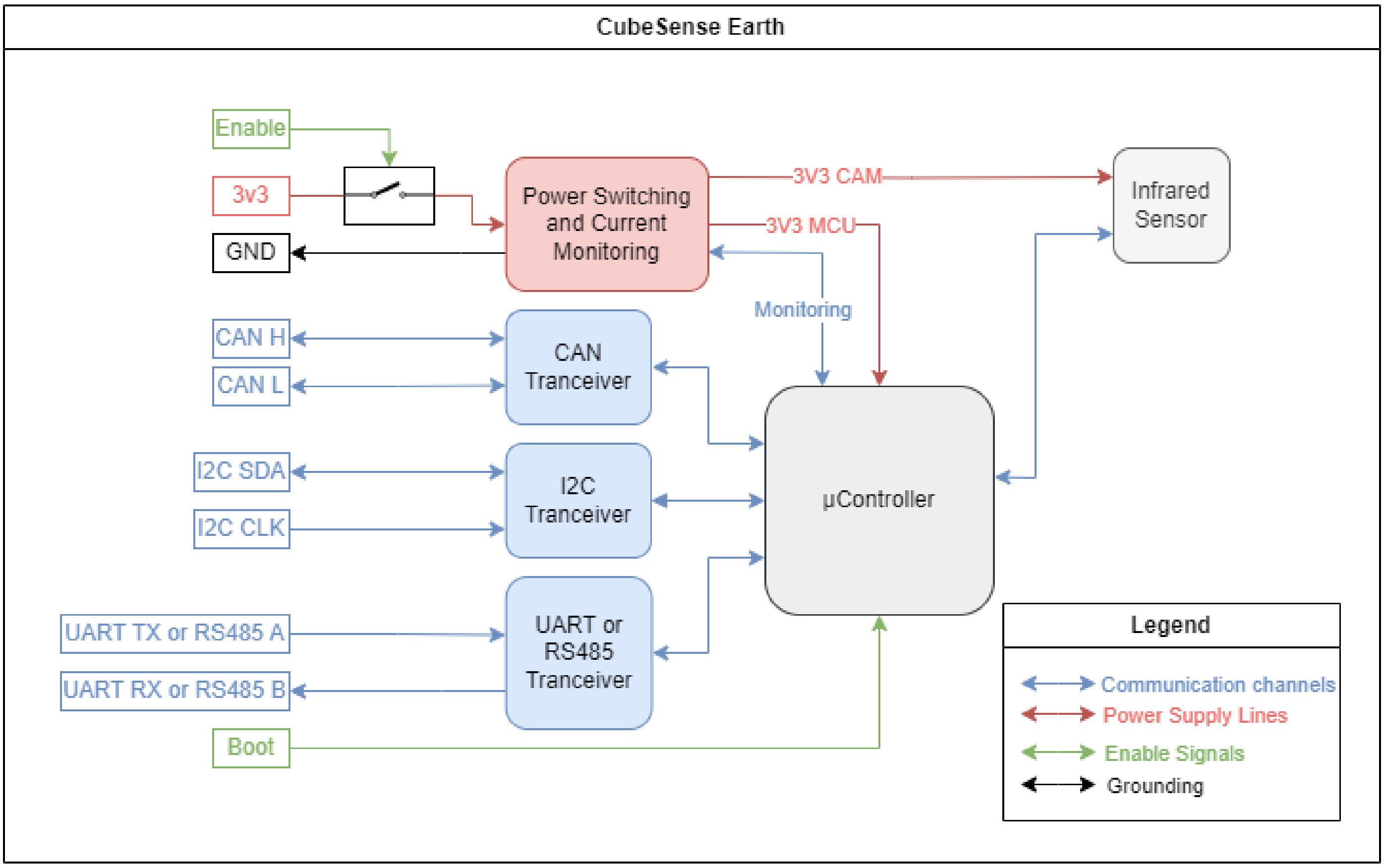


Figure 1: CubeSense Earth block diagram

3.3 CubeSense Earth Operation

This section provides a brief description of the available measurement outputs, configurations, and for which purposes they should be used.

Full details are available in the CubeSense Earth User Manual (see [3]) which is available post order placement.

3.3.1 Measurement Outputs

The main measurement outputs of interest that will be used in the client ADCS algorithms are the orientation relative to the horizon (rotation and elevation angle), the diagnostics related to the image capture (pass, fail and error messages) as well as the results of the horizon detection (detected or none found). The captured image that was used for the detection can also be downloaded as raw or processed and in .xml or .bmp formats each.

3.3.2 Configuration and Reference Values

The CubeSense Earth is calibrated and verified on an inhouse developed testing rig[1]. The image distortion effects caused by the fish-eye lens is characterised during the calibration process and saved to each device.

[1] For the verification process, the rig was designed to emulate aspects of the final orbit characteristic such as orbit height and the perspective of what the image sensor sees. This is used as a reference to exercise the detection algorithm as well as quantifying the accuracy of each device. The orientation of the CubeSense

The characteristics of the detection algorithm can be tweaked using TCTLM commands or through a dedicated CubeSupport application, typically supplied post order placement.

3.4 Performance characteristics

Table 2: CubeSense Earth performance characteristics

	CUBESENSE EARTH
PERFORMANCE	
Accuracy (Dependent on slew)	1° (roll and elevation) 3-sigma
Max slew rate [°/s]	14
PHYSICAL	
Mass [g]	18
Dimensions [WxHxL] [mm]	35x24x20
Detection field of view [°] (Horizontal/Vertical)	90/80
Detection field of view [°] (Diagonal)	90
POWER AND DATA	
Data bus*	CAN/UART/RS-485 * I2C available for custom solutions
Connector	Molex Micro-Lock Plus
Update rate [Hz]	Up to 2
Supply voltage [V]	3.3
Peak power [mW]	280
Average power [mW]	200
QUALIFICATION LEVELS	
Radiation	24 kRad
Random vibration	14.16 g RMS (NASA GEVS)
Thermal vacuum [°C]	-20 to 80
Thermal cold and hot start [°C]	-35 to 70

3.5 CubeSense Earth Sensor Selection

The CubeSense Earth is suited for nanosatellites and smaller microsatellites.

Earth device relative to the Earth horizon emulator is carefully varied and the orientation results are compared to known and expected values.

3.6 Interconnect

The CubeSense Earth sensor is designed to be connected to the CubeADCS CubeComputer or the client system using harnesses. These harnesses are based on the Molex Micro-Lock Plus family of wire-to-board connectors. These harnesses are made using wires with low-outgassing insulation.

Note that the black wires available as off-the-shelf cable assemblies from some other vendors are made from PVC and do not have low outgassing properties.

All CubeSense Earth interface-related information is detailed in the CubeSense Earth Interface Control Document (ICD) (see [1]).

3.7 Pre-loaded firmware applications

The CubeSense Earth is supplied with two pre-loaded applications on the unit. The first is a Bootloader and the other is the Control Program.

3.7.1 Bootloader

The Bootloader is the first application to run when the CubeSense Earth is powered on. It has the following features:

- Allows for quick identification through communications messages and protocol that is common across all CubeProducts,
- Allows CubeSense Earth Control Program and configuration to be (remotely) updated,
- Supports FDIR,
- Exposes Bootloader API to Host Device over communication channels.

3.7.2 Control Program

The control program is the main program of the CubeSense Earth. Some of the main functions are in support of the CubeComputer or client master node:

- Supports FDIR,
- Supports CubeSense Earth management (e.g. power, status, setup, and configuration),
- Supports CubeSense Earth sensor sampling,
- Reports CubeSense Earth measurement telemetry (elevation angle and rotation angle relative to the horizon as well as the capture and detection results),
- Exposes Control Program API to host device.

3.8 CubeSense Earth coordinate systems

The CubeSense Earth sensor implements its own Local Coordinate Frame (LCF). The CubeSense Earth LCF is defined in [2]. Sensor measurements are typically defined in the Measurement Coordinate Frame (MCF) as alpha and beta angles relative to the CubeProduct sensor boresight. Further details and formulas to translate from the MCF and LCF are defined in [3]

3.9 CubeSense Earth Sensor Placement

In general, all CubeSpace's attitude sensors, including the CubeSense Earth, must be mounted in optimal locations and orientated correctly to maximize their ability to take valid measurements and to minimize possible disturbances that will compromise their measurement accuracy.

Details are discussed in the following sub-section.

3.9.1 CubeSense Earth – Earth Horizon Sensor

The CubeSense Earth sensor operates in the thermal infrared (IR) spectrum and must be mounted with its boresight pointing towards the earth's horizon, i.e., at a horizon angle from the nadir direction (see Eq.3.1) depending on the orbit altitude. For example, for a 500 km circular orbit, the earth's horizon is found when pointing 68° from nadir. This is also then the required tilt angle that should be used for the CubeSense Earth sensor mounting, for this orbit.

The earth's horizon angle at the equator, depending on the orbit altitude *h*:

$$\theta_{hor} = asin\left({}^{R_E}/_{(R_E + h)}\right) \quad \text{Eq. 3.1}$$

with,

R_E = Equatorial radius of 6378 km

h = Orbit altitude in km

The detection FoV of CubeSense Earth is 90° x 80°. It measures the earth's horizon curvature to determine the roll and pitch angles. It is best to mount the sensor with the widest part of its FoV horizontally. The latter mounting orientation will give a measurement range of ±36° to the vertical boresight angle and allow at least ±45° for rotations of the horizon curvature around the boresight.

Ensure that CubeSense Earth has an unobstructed FoV to the Earth's horizon.

3.10 Harness lengths

Harness lengths are typically not known until a detailed satellite layout has been decided on. CubeSpace will supply a detailed wiring/harness list documenting all aspects of harnesses to the CubeSense Earth. CubeSpace will request the client to indicate harness lengths based on the final placement of the CubeSense Earth subsystems within the client satellite/system and the client's harness routing scheme.

3.11 Documentation

The CubeSense Earth is provided with a set of standard documents which are listed in Table 3:

Table 3: CubeSense Earth standard documentation

DOCUMENT	DESCRIPTION
Standalone Product Description (PD) - (This Document)	Provides an overview of the standard CubeSpace CubeSense Earth offering. It is typically supplied to prospective clients to allow a better understanding of the CubeSpace CubeSense Earth offering.
Standalone Interface Control Document (ICD)	Detailed information about the physical aspects of the standard CubeSense Earth offering addressing technical aspects of all interfaces. It is typically supplied to prospective clients to allow a better understanding of the CubeSpace CubeSense Earth offering and how to interface with it; electrically, mechanically and electronically.
API definition	Describes the communication messages that the CubeComputer or client host will use to interface with the CubeSense Earth in detail. It is typically only supplied to actual clients.
Standalone User Manual	Describes all functions and features in more detail (than provided in the Product Description). It also allows the user to conduct a Health Check to confirm the CubeSense Earth is "alive and well" after receipt of the shipment at the client.

DOCUMENT	DESCRIPTION
	It is typically only supplied to actual clients.
Software Guide	Describes how to make use of provided software packages. It is typically only supplied to actual clients.
CubeSense Earth Firmware Reference Manual	Provides a complete description of protocols used by communication transport layers. It is typically only supplied to actual clients.
Bootloader Application Note	Describes how to use the Bootloader and make use of all features. It is typically only supplied to actual clients.
Delivery Report	Report to indicate that QA took place on the delivered unit and that a Complete health check was performed at CubeSpace before shipment.

4 Ground Support Equipment

4.1 Support software (CubeSupport application)

The user is provided with ground support software called CubeSupport. This allows the user to directly connect to the CubeSense Earth and to gain access to all telemetry values and all commands. The CubeSupport application also has convenient HMI elements for uploading- and upgrading firmware, and downloading event, image, and telemetry logs (as applicable for the connected CubeProduct).

4.2 Support hardware (CubeSupport PCB)

CubeSpace provides ground support equipment to allow the user to power and interface with the CubeSense Earth out of the box. All required cables, interfaces and documentation are provided to allow the user to perform a health check of the CubeSense Earth upon delivery to the client.

5 Appendix: CubeADCS Coordinates definition

The CubeADCS defines the satellite body coordinate (**SBC**) frame, which is “fixed” to the satellite body. When the satellite has a nominal attitude (zero pitch, -roll and -yaw) the **SBC** will coincide with the orbit reference coordinate system (**ORC**).

5.1 Orbit reference coordinate (ORC)

The **orbit reference coordinate (ORC)** frame, notated as $\mathbf{X}_{ORC}$, $\mathbf{Y}_{ORC}$, and $\mathbf{Z}_{ORC}$, is defined throughout the CubeADCS literature as per Table 4 and Figure 2 below.

Table 4: CubeADCS Orbit reference frame notation

AXIS	POINTING DIRECTION
X_{ORC}	Flight Direction
Y_{ORC}	Orbit anti-normal direction
Z_{ORC}	Nadir direction

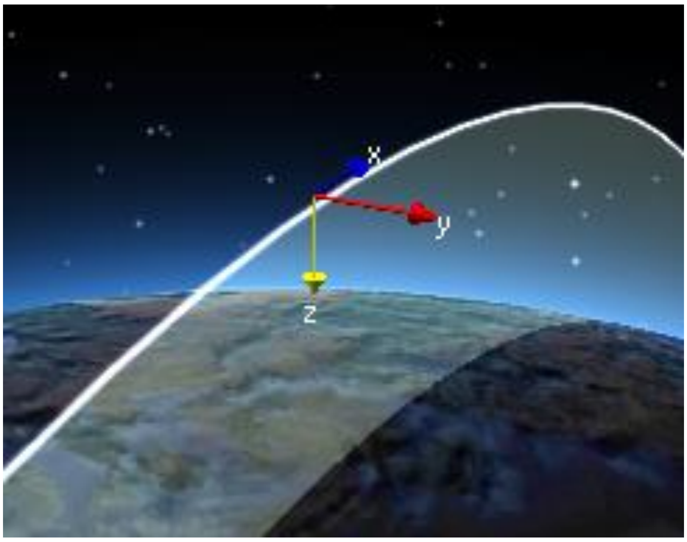
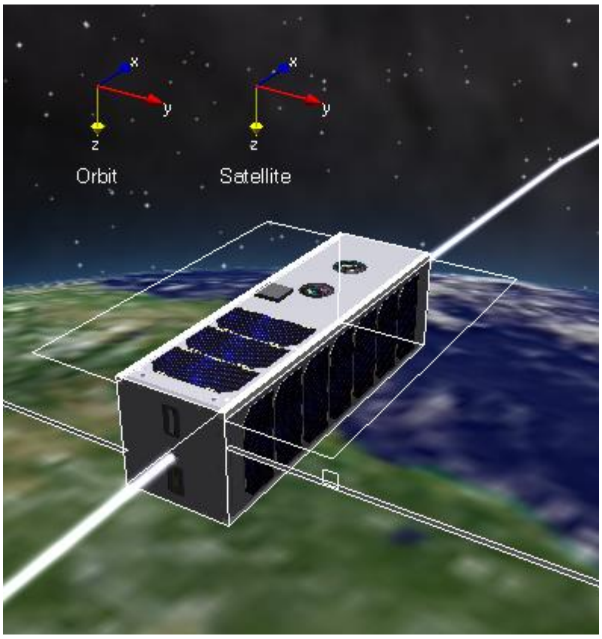


Figure 2: Orbit Reference Coordinate (ORC) frame

5.2 Spacecraft body coordinates (SBC)

The **spacecraft body coordinates (SBC)** frame is notated as $\mathbf{X}_{SBC}$, $\mathbf{Y}_{SBC}$, and $\mathbf{Z}_{SBC}$, and must be “fixed” to the satellite such that when roll-, pitch- and yaw angles are zero, the X_{SBC} axis points along the velocity direction, Y_{SBC} points in the orbit anti-normal direction and Z_{SBC} points towards nadir. For non-zero attitude angles, the **SBC** will rotate with respect to the **ORC**, as depicted in Figure 3.



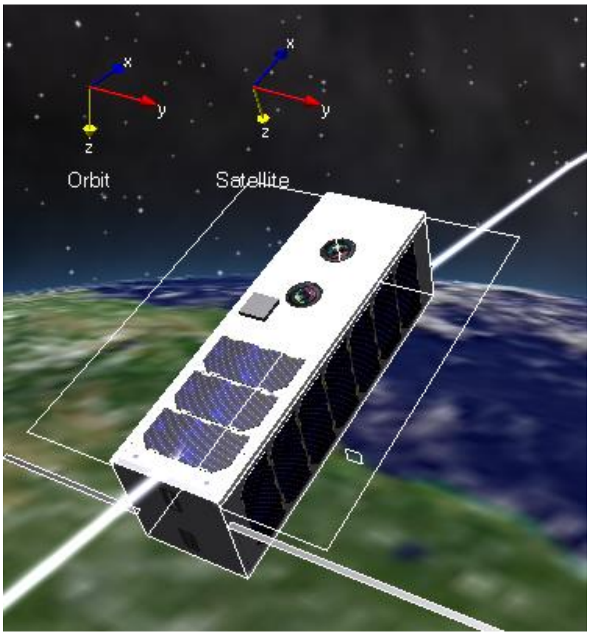


Figure 3: Satellite (spacecraft) Body Coordinate frame, relative to the Orbit Reference Coordinate frame for zero rolls, pitch and yaw (left image) and a 20° pitch angle (right image)

5.3 CubeADCS defined SBC versus mechanical and CAD reference frames.

It is often the case that satellite designers use a spacecraft's axes definition for CAD or mechanical ICD purposes that may be different from the CubeADCS-defined **SBC**. It is important to note that the ADCS does not attempt to translate or transform between a customer's CAD coordinate frame and the ADCS-defined SBC. Instead, the ADCS-defined SBC must be the only coordinate frame that is considered when specifying sensor or actuator mounting configurations, and when interpreting attitude angles.

5.4 Attitude angles convention

The CubeADCS follows an Euler 2-1-3 convention for roll, pitch and yaw angles.

5.5 Sensor/actuator mounting configuration

All actuators and sensors each have their local coordinate systems. Each sensor and actuator mounting must be defined relative to the SBC through a transformation matrix. This means that the transformation matrix for each actuator or sensor should be known.