CUBESPACE

CubeMag Gen 2

Product Description

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PREPARED BY	C. LEIBBRANDT JM
REVIEWED BY	W. Morgan
APPROVED BY	External
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1.01	J. Miller	09/01/2024	Update to Table 2

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.CM-01 CubeMag ICD Ver.1.00 or later

[3] CS-DEV.UM.CM-01 CubeMag User Manual Ver.1.00 or later

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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

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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

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1 Introduction

This document presents and describes the standard CubeSpace Magnetometer variants namely the CubeMag Deployable (CM) and the CubeMag Compact (CMC) as standalone products which may be integrated with a client satellite system.

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

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

Different client scenarios are catered for, namely:

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

2 CubeMag Context

An integrated CubeADCS is made up of several sub-systems, also referred to as CubeProducts.

CubeADCS, and therefore also the CubeMag as a subsystem of the CubeADCS, is designed with modularity in mind. CubeProducts and 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 subsystem -sensors and -actuators, also referred to as nodes, connected via harnesses. The CubeMag 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 CubeMag described in this document. However, each CubeProduct can be offered as a standalone product and allows for direct interfacing to a client system / client ADCS, utilising the electrical-, -electronic and mechanical interfacing normally utilized for interfacing to the CubeADCS.

All electrical and mechanical interfacing details for the CubeMag 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 own interfacing code.

The CubeMag 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 CubeMag to work within the client system / environment.

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3 CubeMag detailed description

3.1 Overview

The CubeMag is a 3-axis magnetometer built for robustness and reliability. The CubeMag comes in a compact (non-deployable) or deployable version for satellites with larger magnetic disturbances.

The deployable form factor comes with a built-in redundant magnetometer. This sensor can be deployed to help minimize magnetic disturbances. Their form factors are compact and allows for easy integration into the client satellite.

The main features of CubeMag include:

- Deployment test – easy to deploy and stow using the provided deployment priming kits.
- In-orbit calibration,
- Pre-calibrated magnetometer,
- M2 mounting holes,
- Shared electronic design across the Gen2 family.

An overview of the CubeMag and its physical configuration options available is presented in Table 1.

Table 1: CubeMag description

ITEM	DESCRIPTION	
CubeMag Deployable (Sub-System) 	Description	Deployable magnetometer
	Details	Very low sensitivity to temperature change, Second (redundant) sensor included by default, Deployment mechanism can be re-armed/re-stowed
	Generic Term	Deployable Magnetometer (MTM)
	CS Name and acronym	CubeMag (CM)
CubeMag Compact (Sub-System) 	Description	Compact redundant magnetometer
	Details	Compact magnetometer to complement primary CubeMag Deployable
	Generic Term	Magnetometer (MTM)
	CS Name and acronym	CubeMag Compact (CMC)

3.2 Subsystem diagram

Figure 1 provides a high-level block diagram of the CubeMag deployable.

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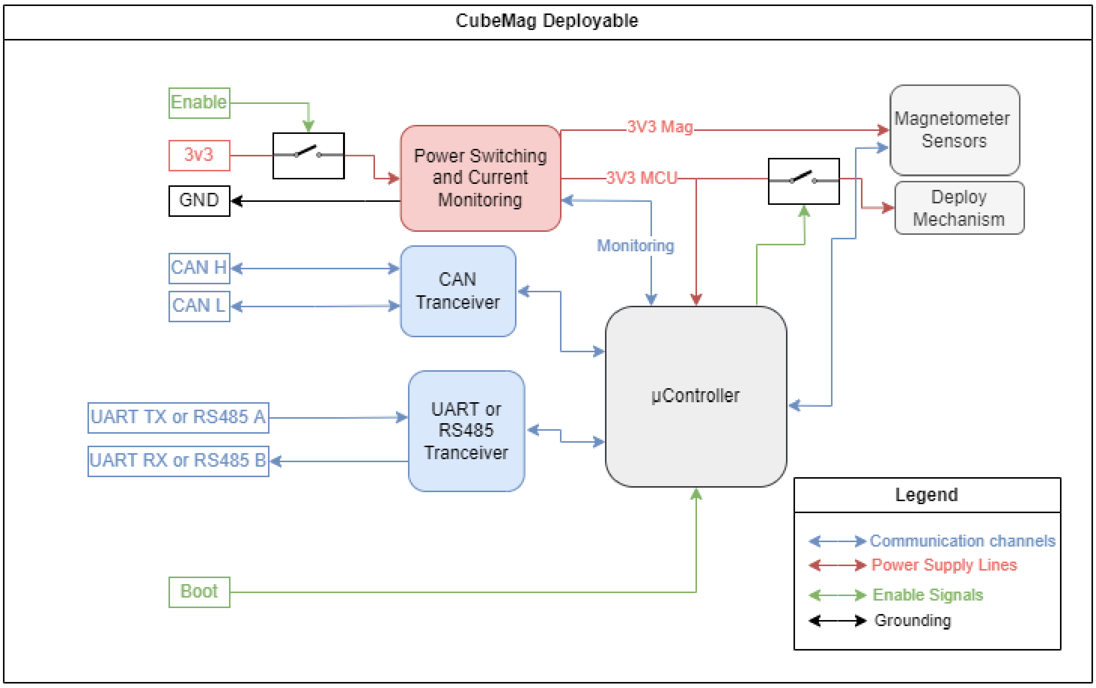

Figure 1: CubeMag deployable block diagram

Figure 2 provides a high-level block diagram of the CubeMag compact.

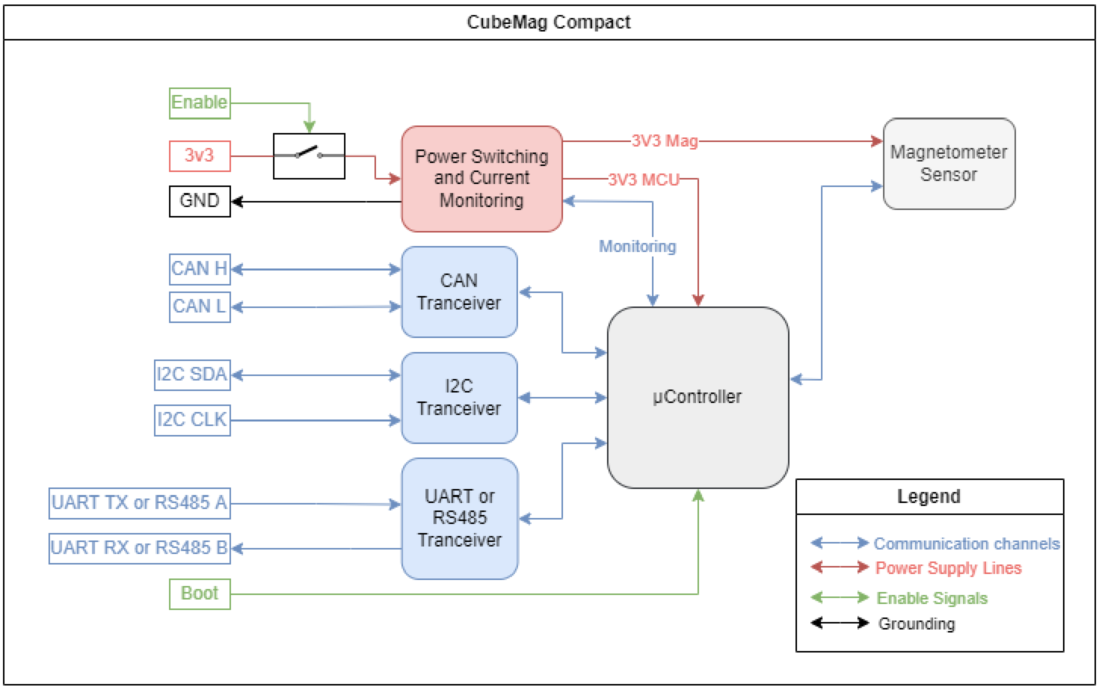

Figure 2: CubeMag compact block diagram

3.3 CubeMag Operation

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

Full details are available in the form of the CubeMag User Manual (see [3]) which is available after ordering a unit.

3.3.1 Measurement Outputs

The CubeMag has a vast range of TCTLM which are provided; for a complete documentation list, refer to Table 3. The measurement output from the magnetometers is what will be used in the client ADCS algorithms. The CubeMag deployable has main magnetometer readings and secondary magnetometer reading of which the field strength is output in the raw and calibrated values. The CubeMag compact has only one magnetometer of the raw and calibrated readings are available.

3.3.2 Configuration and Reference Values

The magnetometers are calibrated using a Helmholtz cage with a known field strength, from this sensitivity and bias values are calculated for each axis. These value values may be changed once the unit is in orbit to re-calibrate the magnetometer.

3.4 Performance characteristics

Table 2: CubeMag performance characteristics

	CUBEMAG VARIANTS	
	CubeMag Deployable	CubeMag Compact
PERFORMANCE		
Noise per channel [3-sigma] [nT]	50	120
Linearity [full scale]	0.6%	0.6%
Measurement Range [Gauss]	-8 to 8	
PHYSICAL		
Mass [g]	16	6
Dimensions [WxHxL] [mm] * Height with protrusion is 9.5	17x6.5*x82	24x7.8x24
POWER AND DATA		
Data bus**	CAN/UART/RS-485 ** I2C is not available	CAN/UART/RS-485 ** I2C is available for custom solutions
Connector	Molex Micro-Lock Plus	
Update rate [Hz]	5	
Supply voltage [V]	3.3	
Peak power [mW]	230	
Average power [mW]	50	50
Deployment power [mW]	2350	N/A
QUALIFICATION LEVELS		
Radiation	24 k Rad	
Random Vibration	14.16g RMS (NASA GEVS)	
Thermal vacuum [°C]	-20 to 80	
Thermal cold and hot start [°C]	-35 to 70	

3.5 CubeMag Sensor selection

Magnetometers are critical to the functioning of CubeADCS and should also be included as part of the client satellite / ADCS architecture.

CubeMag Deployable and CubeMag Compact are both suited for any nanosatellites and smaller microsatellites.

CubeMag Deployable is suggested as the main/primary satellite magnetometer due to the increased distance of the sensor from potential unwanted magnetic disturbances generated from within the satellite.

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CubeMag Compact is suggested for inclusion as a redundant magnetometer to provide redundancy if the primary CubeMag is contaminated with noise or in the (unlikely) case of primary CubeMag failure.

3.6 Interconnect

The CubeMag Deployable and CubeMag Compact are designed to connect to the CubeADCS CubeComputer or to the client system by means of 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. The CubeMag Deployable offers a loom with a latched connector to go through the satellite structure to ease with harness routing.

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 CubeMag interface related information is detailed in the CubeMag Interface Control Document (ICD) (see [2].

3.7 Pre-loaded firmware applications

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

3.7.1 Bootloader

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

- Allows for quick identification through communications messages and protocol that is common across all CubeProducts
- Allows CubeMag 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 CubeMag. Some of the main functions are in support of the CubeComputer or client master node:

- Supports FDIR,
- Supports CubeMag management (e.g. power, status, setup, and configuration),
- Reports CubeMag sensor measurement telemetry [e.g. field strength, temperature, current and MCU voltage],
- Exposes Control Program API to host device.

3.8 CubeMag coordinate systems

The CubeMag sensor implements its own Local Coordinate Frame (LCF). The CubeMag LCF is defined in [2]. Sensor measurements are typically defined in 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 CubeMag Sensor placement

In general, all CubeSpace's attitude sensors, and specifically the CubeMag must be mounted in optimal locations and orientated correctly to maximize their ability to take valid measurements and to minimize possible disturbances such as strong stray magnetic fields that will compromise their measurement accuracy.

In general, all CubeSpace's attitude actuators must be placed in locations far enough from sensitive payloads or sensors that can be disturbed by their magnetic fields or vibrations caused by the unbalance forces and torques of rotating discs.

Details are discussed in the following sub-section.

3.9.1 CubeMag deployable and compact - Magnetometers

3-Axis magnetometers are used to measure the small geomagnetic field vector direction to extract attitude information They are very sensitive devices that can easily be disturbed by any satellite bus generated magnetic fields. It is therefore important to ensure the following conditions are met when deciding on the optimal mounting location for the CubeMag(s):

- At least 10 cm from solar cells or panels,
- At least 10 cm from harnesses carrying varying large currents,
- As far away as possible from reaction wheels
    - If the client has also decided to utilise any of the CubeSpace CubeWheels, then at least 15 cm from CW0057 and CW0162 reaction/momentum wheels with rotating magnetic fields. For CW0017, a distance of 10 cm is allowable.
- As far as possible away from any permanent magnets.
- Far enough from any magnetic torque rods or torquer coils to prevent potential saturation or -bias disturbances from the remanent dipoles of torque rods.
- As far as possible from metals with magnetic properties (e.g., stainless steel fasteners) – metal that can be magnetised will bend the geomagnetic field lines and cause distorted measurements. Non-magnetic fasteners, e.g., brass, copper, titanium, or aluminium are preferred close to a magnetometer sensor.
- As far as possible from any magnetic shielding material (e.g., Mumetal), as this can block the local geomagnetic field.

3.10 Harness lengths

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

3.11 Documentation

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

Table 3: CubeMag standard documentation

DOCUMENT	DESCRIPTION
Standalone Product Description (PD) - (This Document)	Provides and overview of the standard CubeSpace CubeMag offering. It is typically supplied to prospective clients to allow a better understanding of the CubeSpace CubeMag offering.
Standalone Interface Control Document (ICD)	Detailed information about the physical aspects of the standard CubeMag offering addressing technical aspects of all interfaces. It is typically supplied to prospective clients to allow a better understanding of the CubeSpace CubeMag offering and how to interface to it; electrically, mechanically and electronically.
API definition	Describes the communication messages that the CubeComputer or client host will use to interface with the CubeMag in detail.

DOCUMENT	DESCRIPTION
	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 CubeMag is "alive and well" after receipt of the shipment at the client. 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.
CubeProduct 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.
Deployment Priming Manual	This manual guides the client through the stowing and re-priming the CubeMag deployable.
Delivery Report	Report to indicate that QA took place on 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 CubeMag 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 CubeMag out of the box. All required cables, interfaces and documentation is provided to allow the user to perform a health check of the CubeMag upon delivery to the client.

4.3 Deployment Test Equipment

CubeSpace provides additional deployment priming kits for the deployable magnetometer. These kits may be used to stow and re-prime the magnetometer after an initial ground deployment test has been conducted.

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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 3 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

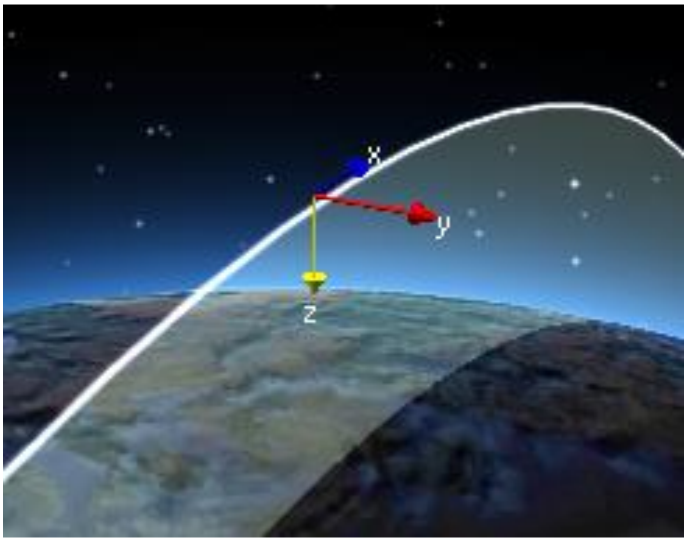

Figure 3: Orbit Reference Coordinate (ORC) frame

5.2 Spacecraft body coordinates (SBC)

The **spacecraft body coordinate (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 4.

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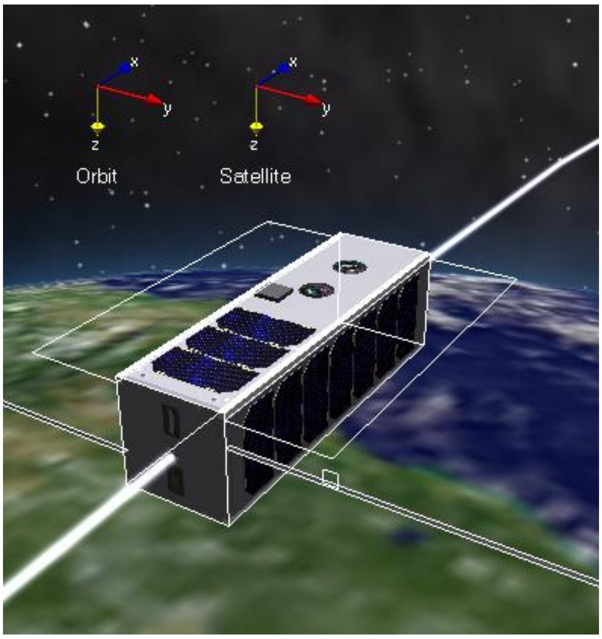

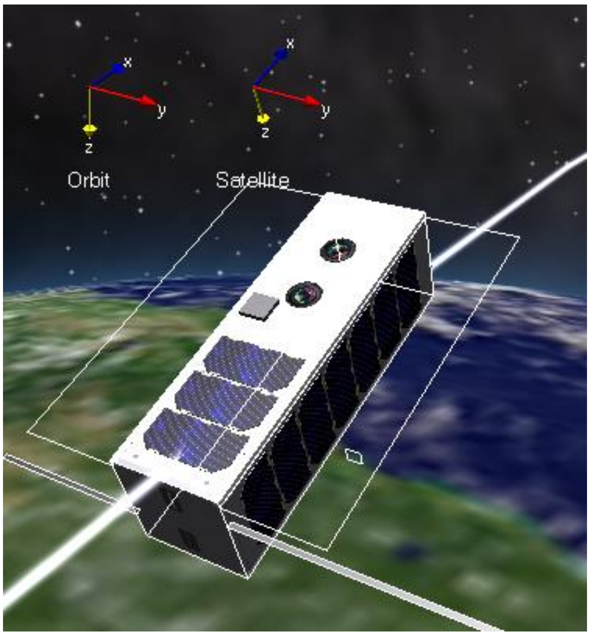

Figure 4: Satellite (spacecraft) Body Coordinate frame, relative to the Orbit Reference Coordinate frame for zero roll, pitch and yaw (left image) and a 20° pitch angle (right image)

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 own 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.

6 Appendix: Satellite Magnetic Cleanliness

The CubeMag measures the earth's geomagnetic field. The measurements are used by an ADCS system with active magnetic control (interaction with the geomagnetic field) to detumble the satellite and dump angular momentum built-up on the reaction/momentum wheels. The satellite designer must ensure that the satellite is magnetically as clean as possible without any large internal magnetic dipoles. These dipoles can be caused by:

- The configuration (connections) of the solar cells on the solar panels. This can be compensated for by back wiring loops on the solar panels or the use of paired solar panels on the same facet with a mirrored configuration to cancel possible current loops. An uncontrolled satellite can easily spin up to very high rates if left unattended over a period, due to these magnetic moments when the sun illuminates the solar panels. The applied principal here is like the working of an electric motor, i.e., a torque is produced by a rotating current loop (illuminated solar panel) in the geomagnetic field.
- Internal permanent magnets, e.g., thruster valve solenoids, scientific payloads, magnetised metal components, etc.
- Loop currents in harnesses, e.g., battery or regulated voltage bus supply currents from the EPS.

If a magnetic dipole is large enough and fixed in the satellite body frame, this dipole will track the geomagnetic field lines like a compass needle. It can specifically cause large attitude disturbances to a Y-Momentum stabilised satellite, preventing it from having small roll and yaw nutation angles. These dipoles can also cause significant disturbances to magnetometer measurements of the geomagnetic field. Magnetically sensitive satellites must preferably be degaussed before launch.

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