CUBESPACE

CubeTorquer Gen 2

Product Description

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A	C. Leibbrandt	15/06/2023	First draft release
B.	C. Leibbrandt	28/07/2023	Updated after review
1.00	C. Leibbrandt	28/07/2023	First published version

Reference Documents

The following documents are referenced in this document.

[1] CS-DEV.ICD.CR-01 CubeTorquer ICD Ver.1.00 or later

[2] CS-DEV.UM.CR-01 CubeTorquer 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
COM	Centre of Mass
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
HMI	Human Machine Interface
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

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1 Introduction

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

This document is a prelude to the CubeTorquer ICD (see [1]) and standard CubeTorquer User manual (see [2]) providing further detail.

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

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2 CubeTorquer Context

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

CubeADCS, and therefore also the CubeTorquer 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 subsystem -sensors and -actuators, also referred to as nodes, connected via harnesses. The CubeTorquer is defined as a subsystem of type Actuator.

In such an integrated CubeADCS, the satellite OBC will interface with the CubeComputer, which will, in turn, interface with the CubeTorquer 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 CubeTorquer are presented in [1].

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 CubeTorquer User Manual (see [2]), is also provided, 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 CubeTorquer to work within the client system / environment.

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3 CubeTorquer detailed description

3.1 Overview

CubeTorquers are magnetic torquer rods, intended as actuators used for controlling the orientation of satellites in Low Earth orbit. These rods generate a magnetic field when current is passed through them, which generates a torque through interaction with the earth's magnetic field. Typically, three rods are used per satellite, placed in the three principal axes of the satellite.

The CubeTorquer product has been refined over eight years of use in orbit and offers excellent performance, is robust, user friendly, and comes in a range of sizes for satellites ranging in sizes from 2U to 27U. These rods are manufactured in a production facility that, through innovation and automation, is geared for mass manufacturing, and can be repeatably delivered in high quantities, on short lead-times, at affordable prices.

Handling Warning: Please handle all magnetic torquer rods with extreme caution and avoid hard, high-frequency mechanical shocks. Such impacts can in extreme cases notably influence the magnetic properties of the cores, which impacts the linearity and magnetic remanence of the rods. Examples of unwanted impacts include dropping the rod onto hard surfaces and bumping the rod against hard surfaces or objects. It is recommended that rods always be placed onto padded surfaces while on the bench. Note however that shocks and vibrations experienced during typical satellite qualification campaigns, and during launch, would not degrade the performance of the product at all.

The main features of CubeTorquer include:

- Heat treated core,
- Robust mounting,
- Molex Micro-lock family across all Gen2 devices,
- High magnetic gain,
- Large variant range suitable for Satellite sizes from 1 to 27U.

The CubeTorquers are built using automated machinery and goes through rigorous testing, which ensures absolute repeatability, and enables high volumes and low cost. With their compact design, and low-profile connector, they are perfectly suited for satellites where space and mass are of high priority.

An overview of the CubeTorquer is presented in Table 1.

Table 1: CubeTorquer description

ITEM	DESCRIPTION	
CubeTorquer (Component of CubeADCS core) 	Description	Magnetic torque rod
	Details	• Ultra-low remanence magnetic actuators, • Available in various sizes from 0.2 Am^2 [CR0002] to 2.0 Am^2 [CR0020]
	Generic Term	Magnetorquer (MTQ)
	CS Name and acronym	CubeTorquer (CR)

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3.2 Functions and Features

The main function of a CubeTorquer is to generate a magnetic moment when, and only when, current is passed through it. Electrically conductive wire is wound around a special ferrous core. The core is made from heat-treated ferrous material, which has a high saturation magnetic flux and ensures a low remnant magnetic moment after exciting the core.

Torquer rods are typically driven using PWM control and in some cases, through variable current drivers. CubeTorquer's special heat-treated ferrous core provides a highly linear relationship between coil-current and magnetic moment, with total linearity >98%. This significantly simplifies magnetic torquer controllers since linearity can be assumed.

A crucially important factor about torquer rods is their remnant magnetic moment. This is the magnetic moment left on the coil after it has been excited, and then switched off. Remnant magnetic moments remain in the core material of the rod after it has been magnetized when magnetic flux has flown through it. If this remnant magnetic field is too large once current to the rod is stopped, it may interfere with magnetometer measurements on satellites, causing undesired disturbance torques on the satellite, and may interfere with sensitive payloads. CubeTorquer, through the special heat-treated core, has a negligible remnant magnetic moment.

CubeTorquer can be mounted on three sides and features a compact connector which is polarized. Also, the CubeTorquer is offered with short lead-times and global availability. This makes it very simple to integrate CubeTorquer into any satellite mission.

3.3 Performance characteristics

Table 2: CubeTorquer performance characteristics

	CUBETORQUER VARIANTS							
	CR0002	CR0003	CR0004	CR0006	CR0008	CR0010	CR0012	CR0020
PERFORMANCE								
Minimum Magnetic Moment [Am²] @ 5V	0.2	0.3	0.4	0.6	0.8	1.0	1.2	2.0
Magnetic Gain [Am²/A]	2.3	4.3	3.3	5.8	7.0	7.8	8.6	13.2
Linearity [0-5V]	2.50 %							
Nominal Resistance [Ω]	51.0	66.5	39.5	45.0	44.5	37.5	36.5	32.5
Inductance [H]	0.26	0.45	0.26	0.34	0.32	0.38	0.31	0.37
Time Constant [ms]	5	6.7	6.5	7.6	7.2	10.1	8.4	11.4
PHYSICAL								
Mass [g]	16.5	23	23	31	28	37	45	54
Dimensions [WxHxL] [mm]	10.5 x 10.5 x 47	10.5 x 10.5 x 59	10.5 x 10.5 x 59	10.5 x 10.5 x 77	10.5 x 10.5 x 92	10.5 x 10.5 x 92	13 x 13 x 122	13 x 13 x 152
POWER & DATA								
Max Voltage [V]	5							

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	CUBETORQUER VARIANTS
Connector	Molex Pico-Lock
QUALIFICATION LEVELS	
Radiation [kRad]	24
Random Vibration [g RMS]	14.16 g RMS (NASA GEVS)
Thermal vacuum [°C]	-20 to 80
Thermal cold and hot start [°C]	-35 to 70

3.4 CubeTorquer selection

The CubeTorquer is suited for nanosatellites and smaller microsatellites.

3.5 CubeTorquer Actuator sizing

The CubeTorquer actuators must be scaled based on the satellite's size, deployable structures, and required manoeuvrability.

The CubeTorquer is available in a range of sizes and can be selected based on mission needs. For 6U and smaller satellites, up to 3 magnetorquers should be considered. The number of magnetorquers for use as standalone subsystems within a client satellite is however unlimited.

Table 3 provides a rough guideline for selecting between the various actuator sizes available for CubeTorquer depending on satellite size and desired performance.

Table 3: Actuator specifications

SATELLITE SIZE	CUBETORQUER	MOUNTING
Up to 6U	0.2 to 0.4 Am^2 [CR0002-CR0004]	CubeTorquers can be mounted externally or internally.
6U to 27U	0.4 to 2.0 Am^2 [CR0004-CR0020]	

3.6 Interconnect

The CubeTorquer actuator is designed to be connected 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.

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 CubeTorquer interface related information is detailed in the CubeTorquer Interface Control Document (ICD) (see [1]).

3.7 Pre-loaded firmware applications

The CubeTorquer has no firmware applications.

3.8 CubeTorquer coordinate systems.

The CubeTorquer actuators implements its own Local Coordinate Frame (LCF). The CubeTorquer LCF is defined in [1].

3.9 CubeTorquer actuator placement

In general, all CubeSpace's attitude actuators, and specifically the CubeTorquer must be placed in locations far enough from sensitive payloads or sensors that can be disturbed by their magnetic fields.

Details are discussed in the following sub-section.

3.9.1 CubeTorquers - Magnetorquers

CubeTorquers rods are heat treated to have very small residual moment, but care should still be taken to mount magnetically sensitive payloads and magnetometer sensors as far as possible from them. Although magnetometer measurements should only be taken during windows of magnetorquer inactivity, they can still be disturbed by the residual magnetic moments and within the magnetic decay time of these magnetorquers.

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 CubeTorquer. CubeSpace will request the client to indicate harness lengths based on the final placement of the CubeTorquer subsystems within the client satellite/system and the clients harness routing scheme.

3.11 Documentation

The CubeTorquer is provided with a set of standard documents which are listed in Table 4:

Table 4: CubeTorquer standard documentation

DOCUMENT	DESCRIPTION
Standalone Product Description (PD) - (This Document)	Provides and overview of the standard CubeSpace CubeTorquer offering. It is typically supplied to prospective clients to allow a better understanding of the CubeSpace CubeTorquer offering.
Standalone Interface Control Document (ICD)	Detailed information about the physical aspects of the standard CubeTorquer offering addressing technical aspects of all interfaces. It is typically supplied to prospective clients to allow a better understanding of the CubeSpace CubeTorquer offering and how to interface to it; electrically, mechanically and electronically.
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 CubeTorquer is "alive and well" after receipt of the shipment at the client. It is typically only supplied to actual clients.
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

In addition to the CubeTorquer itself, the package will contain some or all of the following Ground Support Equipment (GSE):

- CubeTorquer Interface harness (normally a single harness is supplied, branching from a single main connector to 3 separate CubeTorquer connectors)

No other dedicate GSE is provided due to the simplicity of the CubeTorquer design.

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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 5 and Figure 1 below.

Table 5: CubeADCS Orbit reference frame notation

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

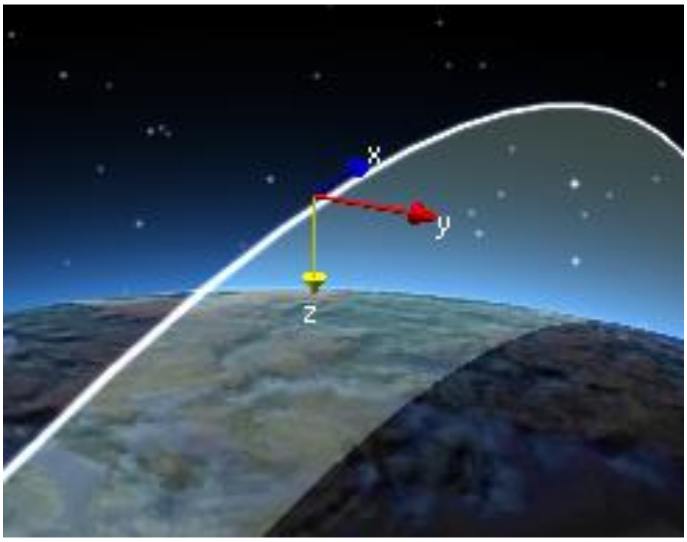

Figure 1: Orbit Reference Coordinate (ORC) frame

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 2.

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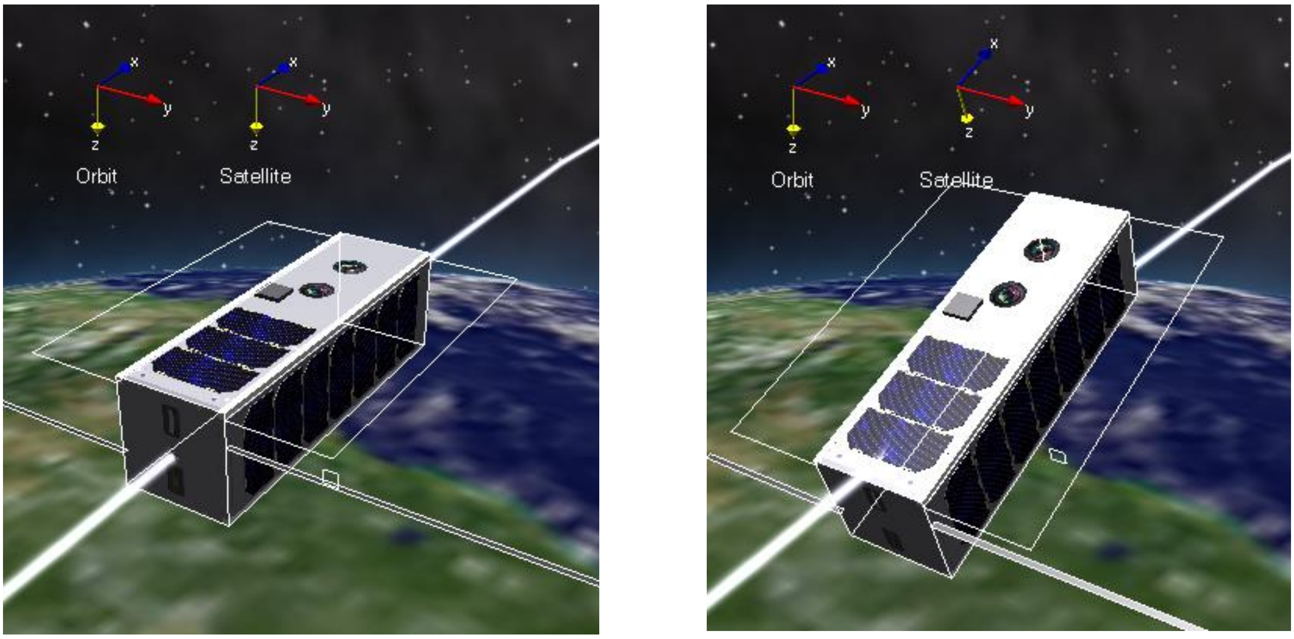

Figure 2: Satellite (spacecraft) Body Coordinate frame, relative to the Orbit Reference Coordinate frame for zero roll, pitch and yaw (left image) and a 20° pitch angle (right image)

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.

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