CUBESPACE

CubeStar Gen 1

CubeSpace Star Camera

Interface Control Document

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Ver 1.00	AS	ALL	17/11/2022	First release of document.

List of Acronyms/Abbreviations

DE	Declination
ESD	Electrostatic Discharge
FoV	Field of View
FPGA	Field-Programmable Gate Array
GUI	Graphical User Interface
GND	Ground
IC	Integrated Circuit
ICD	Interface Control Document
I^2C	Inter-Integrated Circuit
MCU	Microcontroller Unit
MEMS	Microelectromechanical System
OBC	Onboard Computer
PCB	Printed Circuit Board
RA	Right Ascension
SPI	Serial Peripheral Interface
TCMD	Telecommand
TLM	Telemetry
UART	Universal Asynchronous Receiver/Transmitter
ms	milliseconds
µs	microseconds
s	seconds
V	Volt

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1. Introduction

1.1 Purpose of the Document

CubeStar is a miniature star tracker specifically intended for, but not limited to low-power, performance-critical CubeSat applications.

This Interface Control Document (ICD) describes the electrical, mechanical, thermal and performance characteristics of CubeStar, as well as the main interfaces as required in the system design process.

1.2 Scope of the Document

This version of the ICD applies to the CubeStar hardware and software version as stated in Table 1.

Table 1 – CubeStar Subject Version

Element	Version
Hardware Version	V4.4
Firmware Version	3.9
Interface Version	5

The document consists of 30 pages divided into 9 sections of which this section is the first. Section 2 discusses the electrical interface along with the power requirements. The mass, mechanical dimensions, mounting options, and exclusion angles are discussed in Section 3 after which a summary of the available commands and telemetry requests appear in Section 4. Relevant coordinate systems are then described in Section 5, followed by a short description of CubeStar's star catalogue in Section 6. Section 7 describes some limitations regarding operating conditions and Section 8 then briefly describes the star tracker production process. Finally, Section 9 provides a summary of the essential characteristics of CubeStar.

Always take the necessary precautions for ESD protection when working with CubeStar. Always handle CubeStar in a clean area or cleanroom. Extra care must be taken to keep the lens clean.
Before handling, please note that CubeStar is highly sensitive. If the lens is moved or turned in the holder, the pre-programmed calibration values will no longer be valid, and CubeStar will no longer function correctly. Even a slight shift in lens position will affect the performance of CubeStar. It is also essential to design mounting supports for the lens in the satellite to prevent the lens from shifting due to launch vibrations.

2. Electrical interface

This section describes the required electrical connections and power requirements of the CubeStar hardware.

The CubeStar hardware features three headers, two of which are used to update subsystem firmware and one that is required to interface with CubeStar.

2.1 Interface Header

Power and communication lines are connected through the *HARWIN M80-8760722 L-Tek* single inline male interface header. More information regarding this header, as well as possible mating options, can be obtained from the manufacturer website[1].

The position of the CubeStar interface header is shown in Figure 1.

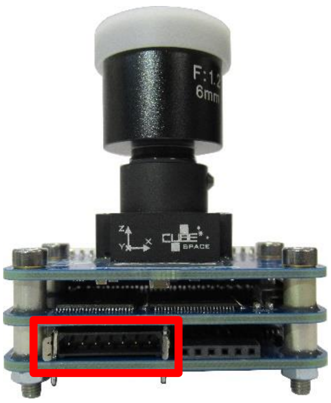

Figure 1 – CubeStar Interface Header Location

Figure 2 shows a drawing of the interface header with pin one, the first pin on the left, indicated with a designator. On CubeStar, pin one of the interface header can be identified as the closest pin to the stand-off post on the edge of the PCB. Pin seven is the pin closest to the centre of the PCB.

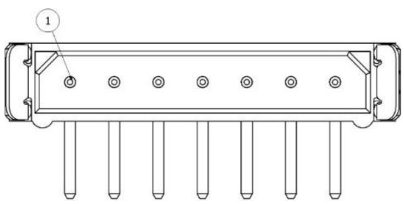

Figure 2 – CubeStar Interface Header

The pin descriptions of the interface header are listed in Table 2.

[1] Link to Harwin Webpage: https://www.harwin.com/products/M80-8760722/

Table 2 – CubeStar Connector Pin Descriptions

Pin #	Description
1	3.3 V regulated power input
2	I^2C Data (No pull-up) (Buffered input/output)
3	I^2C Clock (No pull-up) (Buffered input)
4	Ground
5	UART RX (Buffered input and connected to UART module RX pin in MCU)
6	UART TX (Buffered output and connected to UART module TX pin in MCU)
7	Enable. Requires a 3.3 V logic high input to turn on CubeStar. (Enable line has a 10 kΩ pull-down resistor)

2.1.1 Power and Enable Pins

Power must be provided using pin one (regulated 3.3 V) and pin four (*GND*). This power input is connected to an internal power switch that must be enabled for CubeStar to function. Pin seven *(Enable)* is used to enable this power switch with a 3.3 V logic high. It should be noted that the *Enable* pin is connected to a 10 kΩ internal pull-down resistor. This pull-down ensures that CubeStar is disabled when the controlling circuitry is turned off.

2.1.2 Communication Pins

CubeStar comes standard with both UART and I^2C capabilities. Both communication interface options are implemented with 3.3 V logic levels and can be used to control CubeStar.

2.1.3 Communication Bus Buffer Specifications

Both UART and I^2C connections are buffered to prevent the back powering of internal components and serve as input protection. There are no pull-up resistors on the client-side of the I^2C buffer.

2.1.3.1 UART

The UART transmit (Tx) and receive (Rx) lines are buffered with the SN74LVC2G17 IC by Texas Instruments.

CubeStar's MCU is connected to the B-side of the buffer, and the satellite bus is connected to the A-side.

For more information on the buffer and compatibility, please refer to the datasheet on the Texas Instruments web page[2].

[2] Link to datasheet: https://www.ti.com/lit/ds/symlink/sn74lvc2g17.pdf

2.1.3.2 I²C

The I²C data and clock lines are buffered with the PCA9512ADP IC from NXP. For more information on buffer compatibility, please refer to the datasheet on the NXP web page[3].

There are known compatibility issues with this buffer when the master device is connected incorrectly. It is also important to note that only a limited number of these buffers can be placed in series as each buffer stage introduces a static voltage offset into the signal path. Not adhering to these specifications can influence communication with the sensor, leading to unreliable data exchanges and unexpected behaviour.

2.2 Power Requirements

This section describes the power requirements that should be considered when interfacing with CubeStar.

2.2.1 Power Connection Inrush Current

CubeStar requires a regulated 3.3 V power supply with a current limit of 500 mA. As described in Section 2.1.1, CubeStar has a power switch on-board that is controlled by the user. A 10uF capacitor is located on the satellite bus-side of this switch, as illustrated in Figure 3.

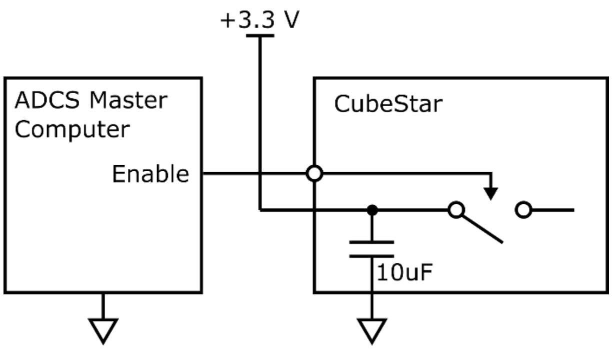

Figure 3 – CubeStar Power Switch

When the regulated 3.3 V power source is switched on, the capacitor is charged, thereby causing an inrush current to flow. The characteristics of this inrush current are shown in Figure 4. During the first inrush period, the peak current sunk is in the order of 156 mA. This current transient lasts roughly 28 µs.

[3] Link to datasheet: http://www.nxp.com/documents/data_sheet/PCA9512A_PCA9512B.pdf

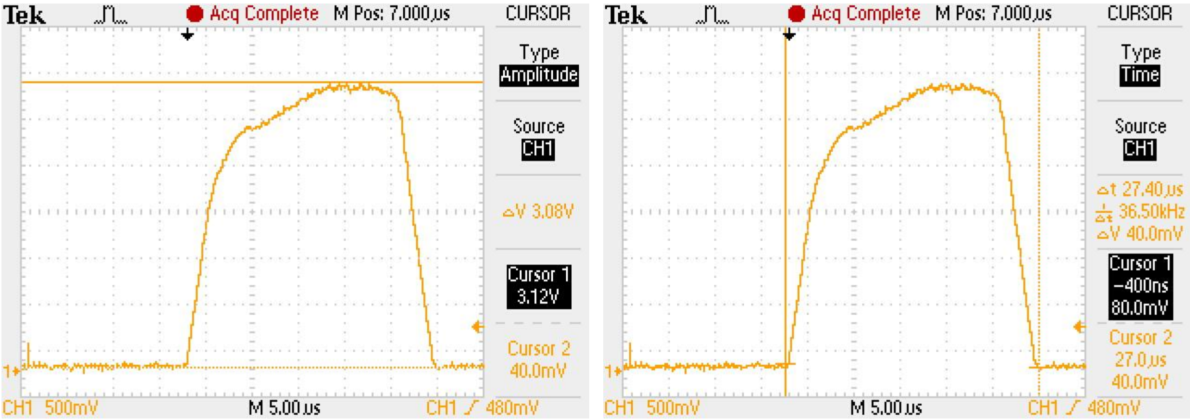

Figure 4 – In-Rush Current Profile of Capacitor

2.2.2 Enable and Setup Current

Once 3.3 V is supplied, and CubeStar is enabled, all star tracker sub-systems are initialised. During the image sensor setup procedure, an image is captured and read into internal SRAM. The entire setup process takes one second to complete. Figure 5 shows the current transients experienced during this setup period.

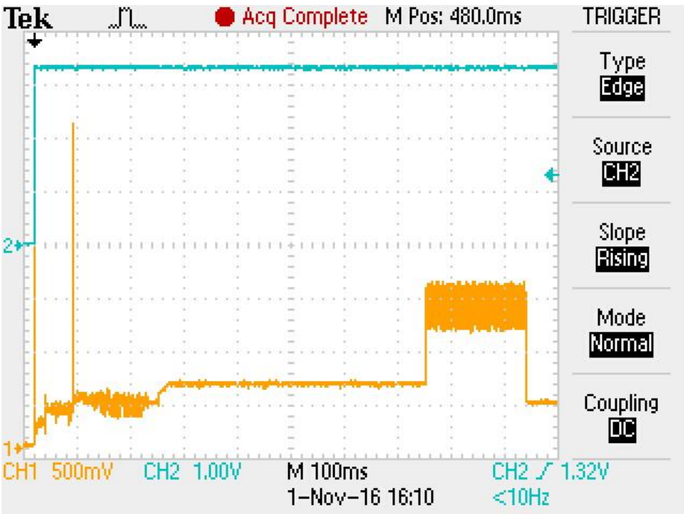

Figure 5 – Start-up Sequence

The blue (top) signal shows the power switch enable line. The yellow shows the voltage output from the CubeStar current sensor. There are two current spikes at the beginning of the start-up sequence. Both current spikes have an amplitude of about 156 mA and a period of 1 millisecond. After the second spike, the measured current stabilizes before showing a slight increase. This increase in the current drawn is as a result of the image sensor integration and pixel read-out. After image capture completes, the start-up sequence is completed and CubeStar is ready for use.

2.2.3 Nominal Power Usage

CubeStar operation consists of three distinct current usage phases. The typical current profile of these three phases, namely *Integration, Image Readout,* and *Processing and Idle,* is shown in Figure 6. Each phase is briefly discussed in this subsection.

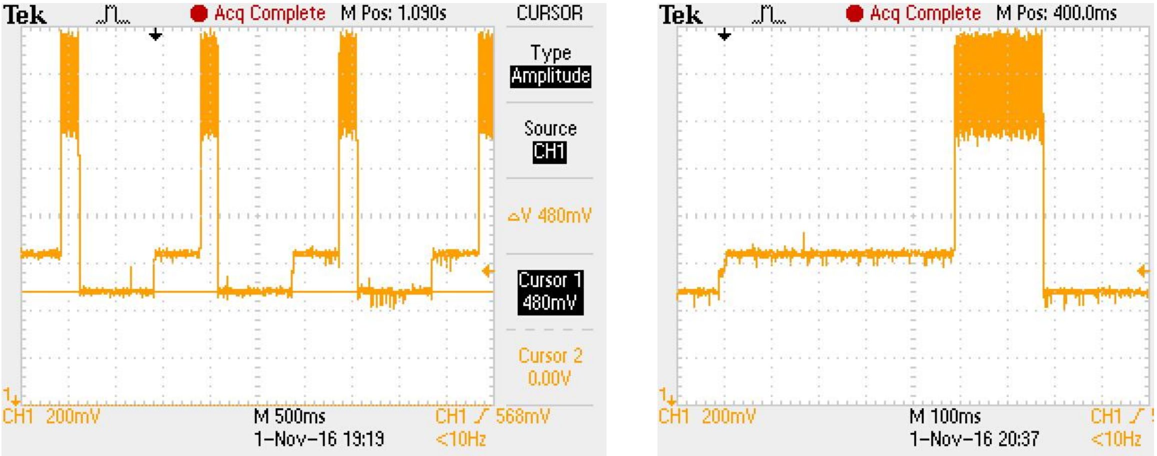

Figure 6 – Typical Current Profile

2.2.3.1 Integration

Each one-second CubeStar processing iteration starts with a user-settable integration period during which the imager pixels are exposed. By default, this period lasts roughly 500 ms. During this period the current profile reaches a maximum of 34 mA.

2.2.3.2 Image Readout

Once the image sensor pixels have been exposed for the appropriate amount of time, the image is read into SRAM. During this readout phase, the maximum current usage will be observed. Typically, a maximum current usage of about 80 mA is expected during the *Image Readout* procedure.

2.2.3.3 Processing and Idle

The last phase in the CubeStar operation cycle is the *Processing and Idle* phase. During the *Processing and Idle* phase, stars are detected and identified, and attitude estimates are determined. This phase comprises of both processing and idle time as the overall current consumption stays stable at about 24 mA, regardless of MCU activity.

2.2.4 Maximum Nominal Power Usage

Although all three operational phases will always be executed during nominal sensor behaviour, some tasks might overlap. It is, therefore, possible that the *Processing and Idle* phase will not be visible on the output current measurements. During this condition, CubeStar is being triggered so that the processing and image sensor integration periods overlap. This triggering scheme will lead to maximum power usage per iteration. A summary of the maximum and nominal current usage waveforms over one second is shown in Figure 7 and Figure 8.

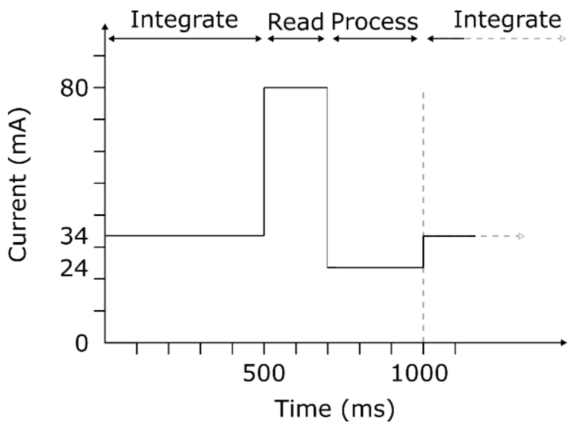

Figure 7 – Nominal Current Usage

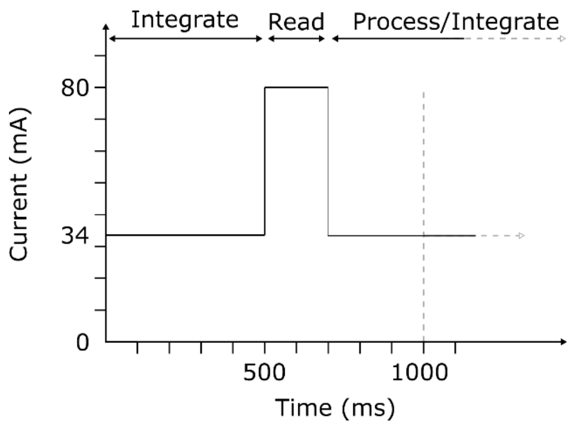

Figure 8 – Maximum Nominal Current Usage

From Figure 7 it can be determined that the average nominal power consumption during a single iteration is estimated as 120 mW, with a peak power consumption of 264 mW.

Figure 8 shows the worst-case power usage scenario, observed when the *Integration* and *Processing and Idle* phases overlap. In this case, the average power consumption during one second will be approximately 142 mW.

2.2.5 Power Summary

Table 3 shows a summary of the current usage of CubeStar in one iteration.

Table 3 – Current Drawn by CubeStar

CubeStar Operating State	Current Drawn (@ 3.3V)	Duration	Power
Disabled	0 mA	-	0 W
Power connection in-rush	156 mA	280 us	-
CubeStar Enable in-rush	Two spikes of 156 mA	Two 1 ms peaks	-
Integration	34 mA	500 ms	112.2 mW
Processing and Idle	24 mA	-	79.2 mW
Image Readout	80 mA	196 ms	264 mW
Worst case average power in 1 second loop	43 mA	1 s	142 mW
Peak power in the one-second loop	80 mA	196 ms	264 mW

3. Mechanical Interface

This section describes the mechanical interface of the CubeStar star tracker. The key points that will be discussed are the physical specifications, mounting considerations and mounting restrictions.

3.1 Physical Specifications

3.1.1 Volume and Size

The total volume of CubeStar is 50 mm x 35 mm x 56.1 mm excluding the mounting screws, with a tolerance of ±1mm added on the CubeStar height to account for the calibrated lens position.

The outer dimensions of the CubeStar hardware are shown in Figure 9. Each circuit board in the PCB stack has dimensions of 50 mm x 35 mm x 1.6 mm. In this figure, the total height of CubeStar, measured from the highest component on the bottom of the first PCB to the end of the lens is 56.1 mm. Note that this measurement excludes the mounting screws.

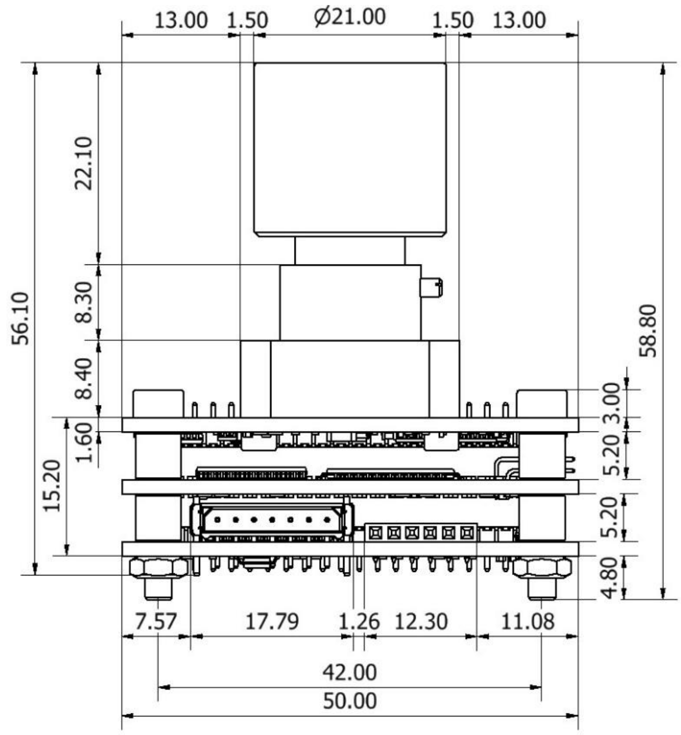

Figure 9 – CubeStar Bottom View with Dimensions

It should be noted that the interface header on CubeStar has latches that hold the mating connector in place. These latches protrude over the PCB by 1.61 mm. A front view of the CubeStar hardware, illustrating this latch overhang, is shown in Figure 10. The size of the mating connector and wires must be taken into consideration when planning the placement of CubeStar in the satellite.

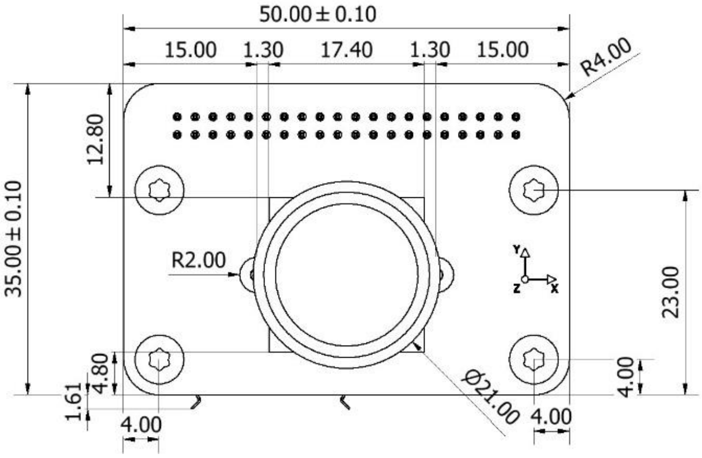

Figure 10 – CubeStar Front View with Dimensions

Another important note is the 1.6 mm height that the pins from the 40-pin headers connecting the 3 PCBs as a stack protrudes, as shown in Figure 11. When planning the placement of the CubeStar in the satellite it is important that these pins do not make contact with any other components or mechanics.

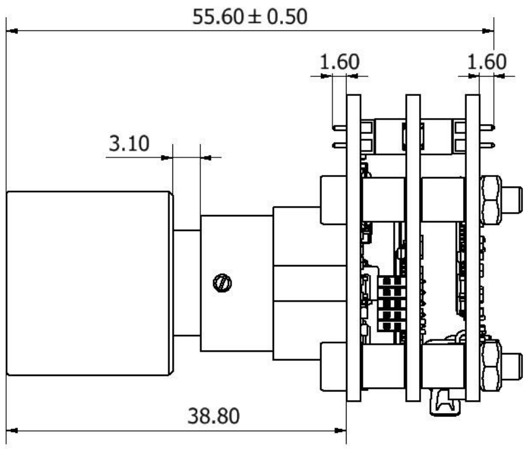

Figure 11 – CubeStar Side View with Dimensions

3.1.2 Field of View

The lens used on CubeStar has a horizontal Field of View (FoV) of 58° and vertical FoV of 47°. With this large field of view, care should be taken to ensure that there are no obstructions in, or near, the lens view-cone. Internally the FoV is limited to a 42° square by using a reduced region of interest. An illustration of this reduced region of interest is given in Figure 12. As illustrated by the shaded square, only stars in this 42° square will be used in the attitude estimation process.

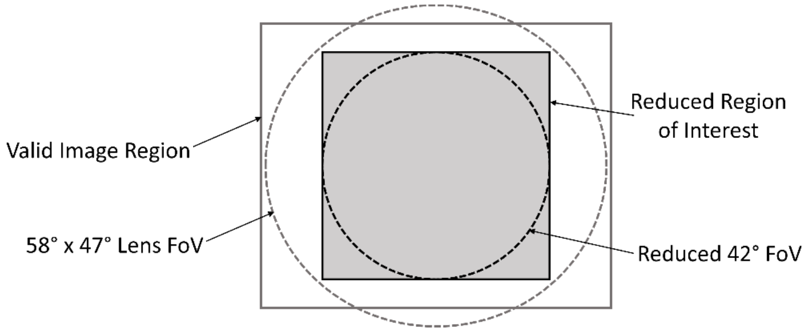

Figure 12 – CubeStar Reduced Region of Interest

The view-cone of the lens is shown in Figure 13. The successful operation of the star tracker cannot be guaranteed if this view-cone is obstructed by deployable satellite members.

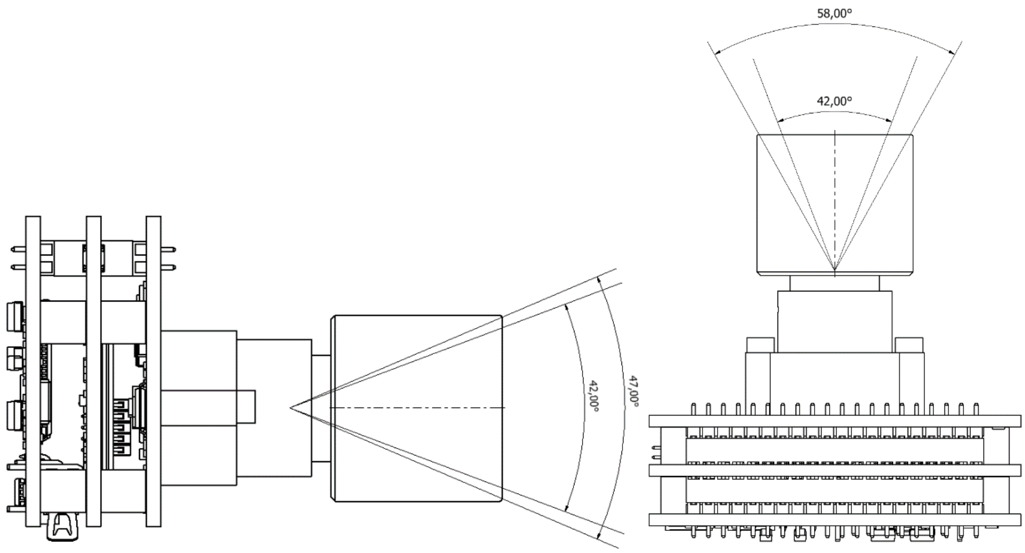

Figure 13 – CubeStar Field of View

3.1.3 Mass

The CubeStar assembly without mounting screws has a mass of 56.3 grams. Table 4 shows the mass breakdown of the main components.

Table 4 – CubeStar Mass Break Down

Item	Mass (grams)
First PCB	10.60
Second PCB	10.30
Third PCB	10.40
Lens holder	3.70
Lens	20
8 A4 Steel Spacers (each 0.16g)	1.28
Total Mass:	56.28

3.2 Mounting Considerations

3.2.1 Mounting Holes

The four mounting holes each have a 3.2 mm diameter to accommodate M3 sized bolts. Figure 14 shows the spacing of the mounting holes. CubeStar is supplied with four A4 grade stainless steel bolts, however these bolts can be removed and replaced with the required bolts to mount CubeStar to the satellite. It is important to ensure that spacing of at least 3 mm is left between the bottom PCB and the rest of the satellite when mounting CubeStar. This spacing is required to prevent electrical shorts.

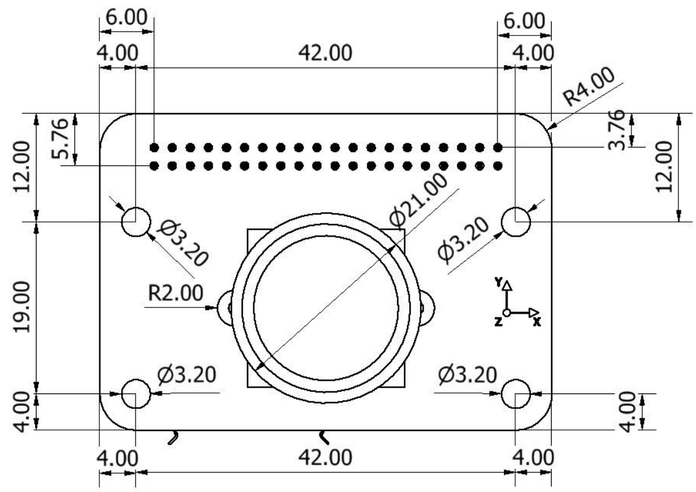

Figure 14 – CubeStar Mounting Holes

3.2.2 Lens Position

The lens is made up of multiple glass elements that can be damaged if not adequately supported. The lens holder and lens position are shown in Figure 15. The dimensions given in this figure have a tolerance of ±0.5 mm. An appropriately sized margin must therefore be left when designing the mounting and side panels.

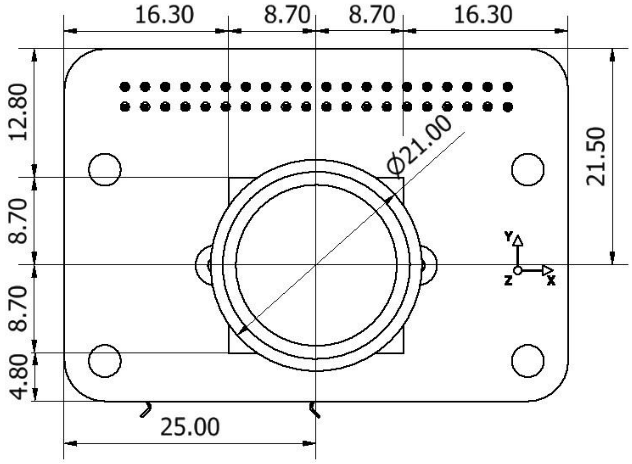

Figure 15 – CubeStar Lens Position

3.2.3 Mounting Restrictions

There are several important factors to consider before choosing a location to mount CubeStar. Although these mounting suggestions are only given as guidelines, they are advised for consideration to ensure optimal star tracker operation.

To ensure optimal performance, no panels, deployable structures, or objects should be mounted in, or close to the star tracker's FoV (58° x 47°). It is further crucial that no reflections are cast onto CubeStar's lens as this might degrade the overall star detection performance.

Although active thermal regulation is not required, it is recommended that CubeStar is mounted away from any solar rays. This will prevent performance degradation caused by excessive thermal conditions.

3.2.3.1 CubeStar Exclusion Angles

CubeStar should be mounted so that it is pointing away from the Sun, Earth, and Moon during the nominal flight orientation. If these celestial bodies enter the FoV, images will over saturate thereby impeding star detection. To demonstrate the effect of bright objects in the FoV, ground-based observations of the sun and moon are discussed in section 7.2.

The Earth exclusion angle for successful operation of CubeStar is the artificially limited 42° FoV. This is the absolute minimum, and it includes Earth's atmosphere up to at least the stratosphere. An example of Earth in CubeStar's FoV is shown in Figure 16, where the effect of Earth's atmosphere can also be observed. The exposure of this image was increased to make the objects more visible for the purpose of this document.

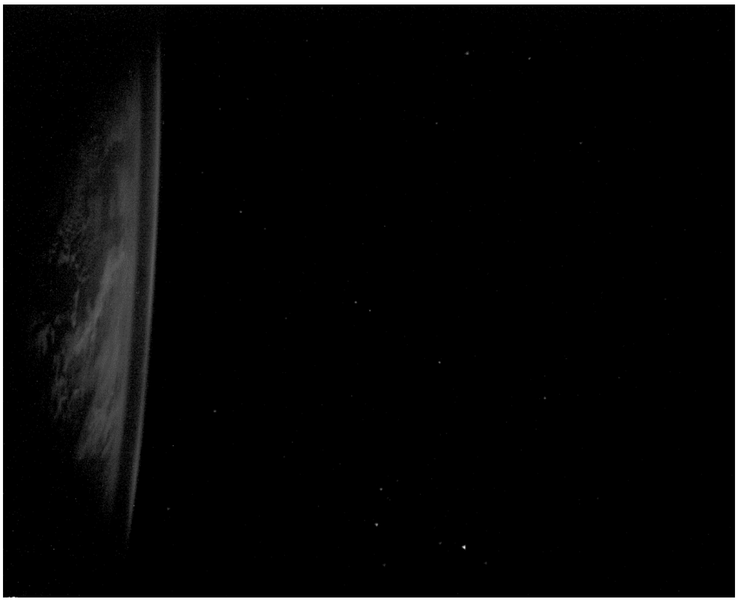

Figure 16 – CubeStar Image with Earth in FoV

The Sun and Moon exclusion angle for successful operation of CubeStar is 180°, i.e., 90° from CubeStar's boresight to the edge of the Sun and Moon. Since they are very bright objects, any light from within the exclusion angle can reflect onto the image sensor and degrade the performance. If the 180° exclusion angle cannot be achieved during the nominal flight orientation, CubeStar can be supplied with a baffle. The standard baffle decreases the Sun and Moon exclusion angle to 120°, however the addition of the baffle will increase the overall size and mass.

The recommendation of CubeSpace is to consider placing multiple CubeStars on the satellite, rather than opting for a baffle. The design of CubeStar in terms of cost, size and power consumption allows for placing multiple units on a single satellite pointing at different locations. This will ensure attitude estimates at various flight orientations during the entire orbit path, assuming at least one of the units points away from the Sun, Earth and Moon at any given location in the orbit.

3.2.3.2 Lens Baffle

The standard baffle design is shown in Figure 17 where the dimensions are also indicated. With the baffle and its required enclosure, the mass increases to 172 grams.

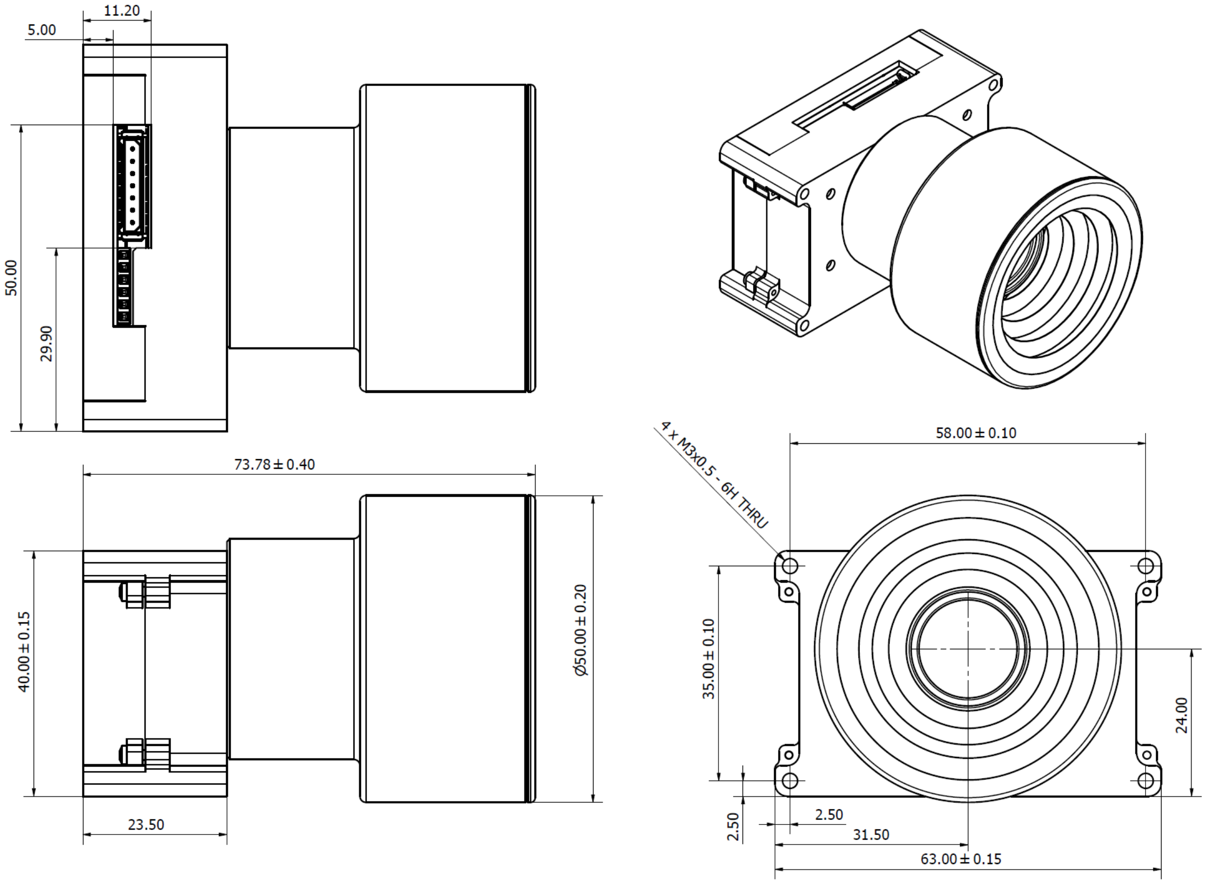

Figure 17 – CubeStar with Baffle

4. Software

The CubeStar star tracker is programmed with star tracker firmware used to perform detection, identification, matching, and attitude determination. To command action or request data from the star tracker, the firmware interface can be used.

4.1 Firmware Interface

The firmware interface is based on a telemetry request/telecommand structure. The user should transmit a telecommand with the necessary data if an action is required. Once the command has been serviced, the necessary action will be scheduled for execution.

Data can then be requested from the sensor by transmitting the corresponding telemetry request. CubeStar, in turn, will respond with the requested data. Care should be taken to schedule commands and requests appropriately so that normal operation is not interrupted. The following two sub-sections show the available telecommand and telemetry IDs.

4.1.1 Telecommands

Table 5 lists the available telecommands.

Table 5 – Telecommands Summary

ID	Name	Description	Length (bytes)
General			
2	Reset	Performs a soft reset	0
3	Clear WDG reset counter	Clears watchdog reset counter	0
4	Watchdog timer enable/disable	Enable or disable the watchdog timer	1
5	Clear error flags	Clears all active error flags	0
6	Exposure	Set image sensor exposure register value	2
25	Capture test pattern	Capture a test image to internal SRAM	1
26	Capture image	Manual image capture command	0
27	Lens focal length	Set lens focal length value	4
29	Lens principal point	Set Principal point	8
30	Lens distortion coefficients	Set lens distortion coefficients	16
33	Set image block for download	Set image block for download	3
36	Detection search region	Set star detection step size and region of interest bounds	9
37	Detection threshold values	Set pixel intensity threshold used during detection	2
38	Detection min and max pixels for a star	Set minimum and maximum star size limits used in star detection	2
39	Detection maximum values	Set detection maximum values	3

41	Identification distance margin	Set identification distance margin	1
43	Tracking configuration	Set configuration parameters used in tracking mode	5
47	Read config	Read the configuration from internal flash memory	0
48	Save current config	Save current configuration to internal flash memory	0
49	Clear stored config	Clear configuration stored in internal flash memory	0
50	Test SRAM	Test SRAM	0
52	Test WDG	Test the watchdog timer	0
54	Trigger one-second loop	Trigger CubeStar to capture and process an image	0
55	Trigger delay time	Set delay between when the trigger is received and performed	2
58	Rate estimation control	Set control register of rate estimation module	3
59	Image Sensor Median Filter Control	Set control register of Image sensor median filter	1
60	Image Sensor Analog Gain	Set image Sensor Analog Gain control	1
61	Image Sensor Shutter Mode	Set image Sensor Shutter Mode control	1
62	Imager Self-Test	Test Datapath between Imager and SRAM	0

4.1.2 Telemetry

Table 6 lists the telemetry requests available.

Table 6 – Telemetry Summary

ID	Name	Description	Length (bytes)
General			
128	Identification	Sensor status information for component identification	8
129	Start-up status	Start-up status	4
130	Temperature	MCU temperature	2
131	Error flags	Star tracker error status flags	11
134	Watchdog status	Status of the watchdog	1
135	Watchdog reset counter	Indicates how many WDG resets occurred	2
136	Self-Test Results	Self-Test results	1
137	Power status	Power switch and current consumption status	9
138	Exposure	Image sensor exposure register value	2

156	Lens focal length	Lens focal length value	4
158	Lens principal point	Principal point	8
159	Lens distortion coefficients	Lens distortion coefficients	16
160	Download image block	Download image block	256
163	Detection threshold values	Pixel intensity thresholds used during detection	2
164	Detection star size	Minimum and maximum star size limits used in star detection	2
165	Detection maximum values	Maximum number of detected stars and detection timeout time	3
169	Identification distance margin	Identification distance margin	1
172	Star Details	Details of identified and detected stars	28
173	Tracking configuration	Configuration parameters used in tracking mode	5
175	Star 1 vectors	Best star 1 information	21
176	Star 2 vectors	Best star 2 information	21
177	Star 3 vectors	Best star 3 information	21
179	Attitude quaternion	The estimated attitude expressed as a unit quaternion	8
181	Performance parameters	Performance parameters	8
182	Timing summary	Summary of main algorithm execution duration during the previous iteration	6
183	Estimated body rates	Estimated body rates	6
184	Sample period	Time elapsed between trigger requests	2
186	Rate estimation control	Control register of rate estimation	3
187	Trigger delay time	The delay between when the trigger is received and performed	2
197	Image Sensor Median Filter Control	Control register of Image sensor median filter	1
198	Image Sensor Analog Gain	Image sensor analog gain control	1
199	Image Sensor Shutter Mode	Image sensor shutter mode control	1

5. Coordinate Systems

Star vector measurements are given as matched vector pairs. Vector pair measurements are given in the CubeStar body frame and International Celestial Reference System (ICRS) inertial frame. This section aims to explain these two reference frames, along with the image sensor coordinate system from which the body reference frame is derived.

5.1 Image Sensor

The image sensor coordinate system is illustrated in Figure 18. As shown, when viewing CubeStar from the front the image sensor's origin pixel (0, 0) is in the top right corner. The image sensor produces an image with a resolution of 1280 x 1038 pixels. The X-axis of the image sensor is defined as the direction in which the pixel column number increases from 0-1279, which in this case is from right to left. The Y-axis is defined as the direction in which the row value increases from 0-1037, which in this case is from top to bottom. All star positions are referenced according to this image sensor coordinate system.

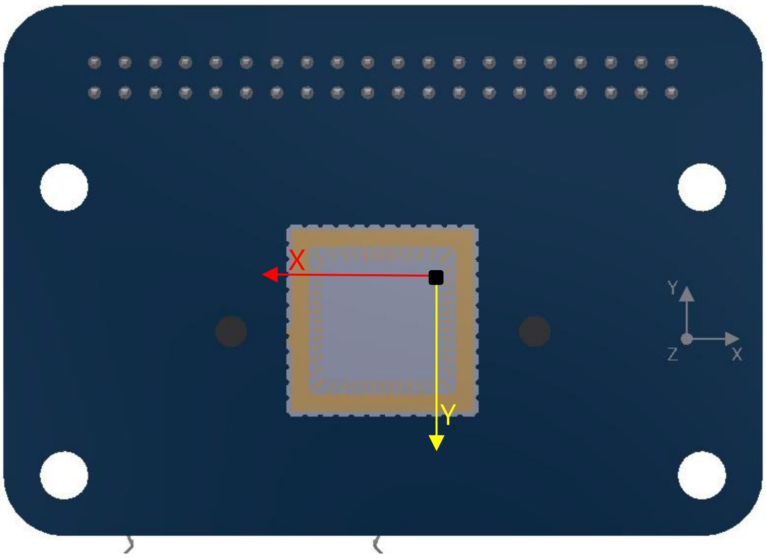

Figure 18 – CubeStar's Image Sensor

When an image is captured, pixels are stored left to right, top to bottom, as described in Table 7. Therefore, the top left corner pixel of the resulting image corresponds to pixel (0, 0) of the image sensor, while the bottom right corner pixel corresponds to pixel (1279, 1037). Please note that, due to the optical nature of the lens, images captured by CubeStar will be mirrored around both the X- and Y-axis.

Table 7 – CubeStar Image pixel map

	Columns X (0 to 1279) ->					
<- Y Rows (0 to 1037)	0,0	1,0	2,0	…	1278,0	1279,0
	0,0	1,0	2,0	…	1278,0	1279,0
	0,1					1279,1
	0,2					1279,2
	…					…
	0,1035					1279,1035
	0,1036					1279,1036
	0,1037	1,1037	2,1037	…	1278,1037	1279,1037

5.2 CubeStar Body Coordinate System

The CubeStar body axes are defined relative to the principal point of the lens. The axes of the body coordinate system with the origin at the principal point are given in Figure 19. All body vector measurements are referenced relative to this origin.

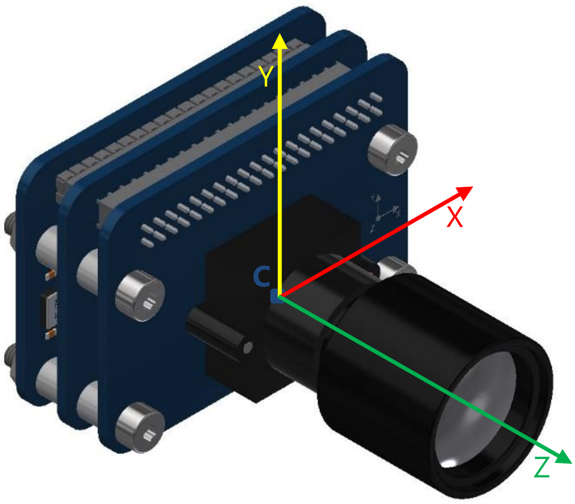

Figure 19 – CubeStar's Body Axis Coordinate System

The axes differ from the image plane axes in that the origin is moved to the principal point of the image plane. The axes are further flipped to take into account the effect of the lens.

In this figure, the principal point is indicated by the ***C*** symbol. According to this body axes definition, all unit vectors pointing towards the stars have positive Z-axis components.

5.3 Star Catalogue Inertial Coordinate System

Once detected stars are identified, the corresponding inertial vectors are obtained from a subset of the Hipparcos catalogue. The Hipparcos catalogue uses the ICRS inertial frame with an epoch of J1991.25. The ICRS origin is at the barycentre of the solar system, with axes that are intended to be “fixed” to inertial space. ICRS coordinates are approximately equivalent to equatorial coordinates.

To ensure improved accuracy, the star catalogue epoch is updated to 1 Jan 2018 12h (TT).

The estimated attitude is given as ICRS quaternions. The quaternion convention followed throughout the attitude determination process is the JPL convention. With this convention, the first three quaternion elements represent the vector component and the fourth component of the quaternion the scalar component.

6. Star Catalogue

The onboard star catalogue consists of a reduced list of the Hipparcos catalogue. This reduced star list contains 410 stars, each with a visible magnitude brighter than 3.8. This section explains the expected performance of CubeStar using this catalogue. The on-board star catalogue as a Right Ascension – Declination plot is shown in Figure 20.

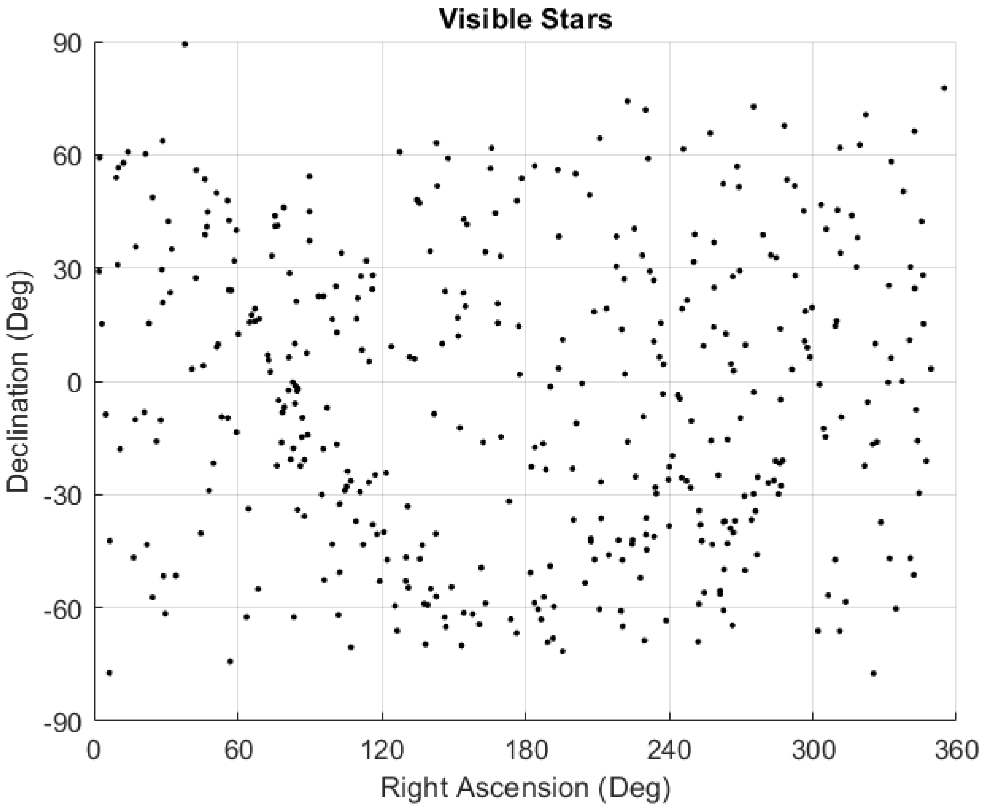

Figure 20 – CubeStar Star Catalogue

With this catalogue, it is estimated that CubeStar will observe a maximum of 38 and a minimum of two stars across the entire celestial sphere. As at least three stars are required to perform successful identification, it is estimated that 99.71% of pointing directions will lead to successful attitude identification.

7. Operational Limits

Although the CubeStar sky coverage has been verified theoretically, the overall sensor performance is greatly affected by various environmental conditions. Of these environmental conditions, the most frequently observed issues are caused by sensor rotational rate, and light leakage from celestial bodies.

This section describes these limitations and operational restrictions.

7.1 Rate Restrictions

CubeStar operates with a relatively long exposure time to ensure that enough stars are detectable. The long exposure places a limit on the maximum rotational rate at which the sensor can still function effectively. During high rate conditions, starlight is spread over more pixels, thereby lowering the overall star intensity and distorting the natural star shape.

During ground-based testing, sensor operation was verified up to a maximum rate of 0.3°/s. It is suggested that the nominal satellite rate is kept below this threshold to ensure that enough stars are visible. CubeSpace cannot guarantee successful attitude solutions at rate conditions higher than 0.3°/s.

7.2 Pointing Restrictions

A bright object that reflects light into the lens might lead to false readings or cause oversaturation of the pixels. To demonstrate the effects of a bright object on the images, several sample images are shown in this section. These images were captured on the ground.

Figure 21 shows an image taken with the sun in the FoV. The entire image is saturated with the sun appearing as a black circle in the image where the pixels are completely oversaturated.

Figure 21 – CubeStar Image of Sun

To investigate the damage that sunlight might have on CubeStar, a ground test was performed. In this test, CubeStar was pointed at the sun for 40 minutes while powered off. After the 40 minutes, CubeStar was powered and determined to function nominally.

It is advised to never let CubeStar point at the Sun for an extended amount of time. When the Sun is in CubeStar's FoV, CubeStar must be powered off.

Figure 22 shows an image captured by CubeStar with the Moon just outside the lens FoV. This image shows a lot of light leakage into the lens with severe internal reflections on the lens edge. Although some stars are still visible, the detection algorithm will discard the image because of the observed ring.

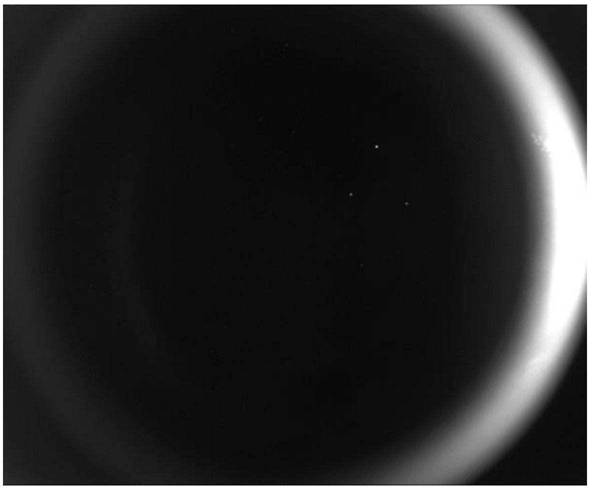

Figure 22 – Moon just outside the FoV

Figure 23 shows two images where the moon is inside the FoV. In these images, stars are barely visible and stray light will cause a detection error.

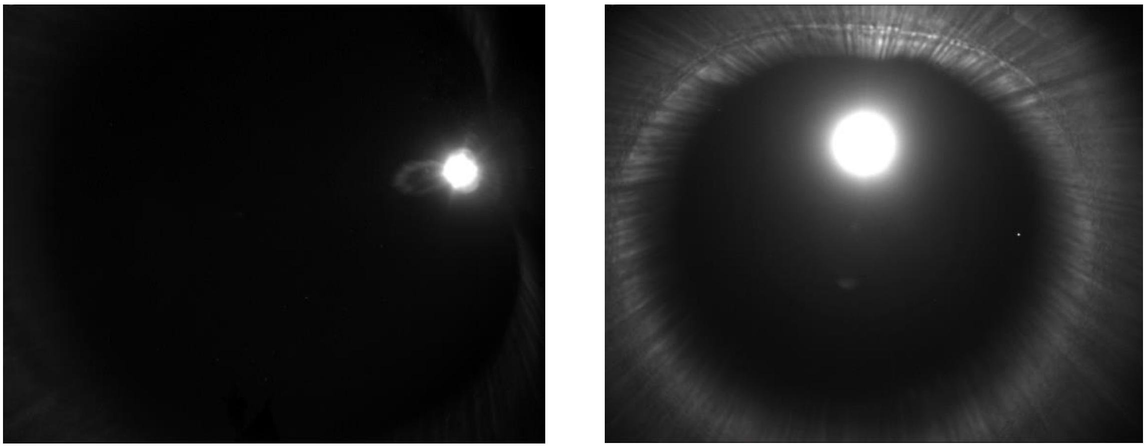

Figure 23 – CubeStar Image with Moon in FoV

8. Assembly and Testing

Before a CubeStar sensor is delivered, it undergoes an extensive production phase in our world-class facilities. During production, various tests are performed to ensure that each CubeStar passes our quality assurance procedures.

8.1 Calibration

Each CubeStar unit comes pre-calibrated. During calibration, the sensor is used for ground-based star observation from which a lens distortion model can be determined. Each CubeStar module is placed in a protective case to prevent damage during the calibration procedure. Once a CubeStar star tracker has been calibrated an extensive testing procedure is followed to confirm that the sensor performs as expected under night-time conditions.

8.2 Health Check Test

Every CubeStar is supplied with a document showing outgoing quality compliance. **Once the user receives a CubeStar, a user health check must be performed. The incoming inspection document must then be completed and returned to CubeSpace.** Following this procedure will allow early detection and correction of potential damage experienced during shipping.

9. Summary

The general specifications of CubeStar are summarised in Table 8.

Table 8 – CubeStar General Specifications Summary

Specification	Value	Notes
Mass	56.28 g	Without mounting screws
Dimensions	50 x 35 x 56.1 mm	The length of about 56.1mm can change by ±1mm.
Operational temperature range	-10°C to 60°C	
Storage temperature range	-40°C to 85°C	
Vibration	8.03 g RMS random	With lens fitted.
Radiation	24 kRad	Total Ionizing Dose
Power	142 mW average	
	264 mW peak	
Operating voltage	3.3 V	
In-rush current peak	156 mA	Maximum of the three peaks at power-on.
In-rush current time	1 ms	Maximum time of any one of the three peaks
Data Interface	I^2C and UART	
Field of View	58° x 47°	Horizontal (X-axis) x Vertical (Y-axis)
Star catalogue Size	410	
Sensitivity range	< 3.8	Star Magnitude
Sky coverage	99.71%	
Accuracy (3-sigma)	0.0154° - Right Ascension (Cross Axis)	
	0.0215° - Declination (Cross Axis)	
	0.061° - Roll	
Update rate	1 Hz	
Max tracking rate	0.3°/s	
Max acquisition time	3 s	