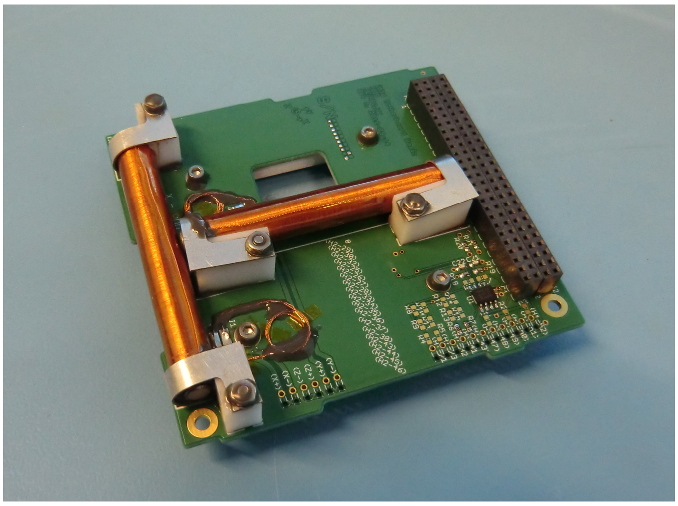
Magnetotorquer Board User Manual

ISIS.IMTQ.UM.001



Issue 1.1

Release information

Written by:	R. Fernandez	2011-11-30
Checked by:	A. Overlack	2011-12-01
Approved by:	A. Bonnema	2011-12-01

Distribution List:

Change log

Date	Issue	Modified by	Section / Pages Affected	Reason for Change
2011-11-11	1.0	R. Fernandez	All	First Release
2011-12-01	1.1	R. Fernandez	§2	Safety Manuals (ISIS.iMTQ_EM.SM.001 and ISIS.iMTQ_FM.SM.001) integrated into the User Manual
2012-04-06	1.2	A.E. Overlack	various	Post project close adjustments

Applicable Documents

AD01	ISIS.iMTQ.HS.001	iMTQ Handling and Storage Sheet	
AD02			
AD03			
AD04			
AD05			

Reference Documents

RD01			
RD02			
RD03			
RD04			
RD05			

TBD/TBC/TBW

TBD/TBC/TBW	Responsible	Action	Page

Disclaimer

The contents of this document are subject to the relevant provisions in the contract concluded between the parties. ISIS – Innovative Solutions In Space B.V. ("ISIS") shall not be liable, in full or in part, for any damage arising out from the application or use of any product or circuit described herein, in case such application or use are carried out in a manner not in line with the instructions and warranties provided in the User Manual, Safety Manual, product information sheets or any other document provided by ISIS upon the delivery of the product ("Documents"). Further, ISIS shall not be liable for any damage caused by any use which exceeds the function(s) of the product, or does not conform to such function(s) as described in the Documents. ISIS shall not be liable for any damage arising from a use which is not carried out in a manner conforming to acceptable practices in the aerospace industry.

ISIS warrants that the product is supplied after relevant tests had shown the product is in good order and functioning, as far as these tests may indicate and predict product functionality.

List of Acronyms

1/2/3U	1-Unit, 2-Unit, 3-Unit; commonly referring to the singles and multiples of the commercially available CubeSat sizes
AIV	Assembly, integration, verification
COTS	Commercial off the shelf
COM	Centre of Mass
EMC	Electro-Magnetic Compatibility
EMI	Electro-Magnetic Interference
ESD	Electrostatic discharge
I^2C	Inter integrated circuit communication bus.
iMTQ	ISIS Magnetorquer Board
ISIS	Innovative Solutions In Space BV.
RH	Relative Humidity
N/A	Not Applicable
PWM	Pulse Width Modulation
TBC	To Be Confirmed
TBD	To Be Determined
TBW	To Be Written
UM	User Manual

Table of Contents

Table of Figures

Table of Tables

1 Introduction

The ISIS magnetorquer board – iMTQ – is a 3-axis magnetorquer system for a wide range of applications. The design is focussed on providing flexibility in stack- or structural integration. By combining a set of torque rods with a flat air core torquer the system requires less volume, while still providing equal magnetic moments in all three dimensions. The actuation level of the iMTQ system is much higher than magnetorquers which are for instance embedded in solar panel substrates.

The iMTQ system can be used for magnetic attitude control for a wide range of cubesats (up to 12U) and nano satellites.

The iMTQ is relies on external power, and it's actuators are controlled through an external interface. The iMTQ system does not come with attitude control software, nor with interfacing software.

1.1 Purpose and Scope of Document

This document provides all information required to use and handle the ISIS Magnetorquer Board properly. Whenever specific information applies to a certain configuration of this system it will be noted explicitly.

This document is valid until it is declared obsolete or replaced with a succeeding version. Changes with respect to the previous version will be clear from the revision. As this document may be updated without prior notice, it is advised to check the ISIS website "http://www.isispace.nl" or ask us for the latest version at "support@isispace.nl" before using this document as reference.

1.2 Shipment contents

Please check the contents of the shipment case for completeness and damage during shipment. The shipment contains the following items:

Item	Quantity	Check
iMTQ – Magnetorquer Board	1	
Printed User Manual	1	
iMTQ Calibration Report*	1*	
Copy of torque rod check-out report (included as annex in calibration report)	2	
iMTQ Handling & Storage sheet	1	
Reference copy of configuration options sheet**	1**	

Table 1-1 Shipment Content Check-list

** Please note that engineering models of the iMTQ are shipped without calibration report, unless stated otherwise.*

*** If the iMTQ is shipped as a part of a satellite kit, ISIS will define the iMTQ configuration to suit the complete system. In this case the option sheet does not apply.*

1.3 Specification

1.3.1 Technical specification

Parameter	**Typical Value**	**Comments**
Environmental Characteristics		
Qualified operational temperature range	-40 to +70°C	
Storage temperature range	-50 to +85°C (RH<60%)	
Electrical Characteristics		
Torquer supply voltage (design)	5V	
Nominal magnetic dipole (per actuator)	0.2 Am^2	
Actuation power (rods)	0.2 W	5V, 20 C, 0.2 Am^2
Actuation power (air core)	0.57 W	5V, 20 C, 0.2 Am^2
Temperature sensor current consumption	<150 uA	
Physical Characteristics		
Dimensions (Main)	95.9 x 90.1 mm	
External height	15 mm	
Weight	194 grams	

Table 1-2 iMTQ Overall Specification

1.3.2 Serial number specification

Each iMTQ product is given its unique serial number. The following table defines the serial number representation:

Serial number format: **iMTQ.[###].[EM/FM]**	
iMTQ	ISIS product line identifier
[###]	Production number
[EM/FM]	Flight- / Engineering model indicator

Table 1-3 iMTQ serial numbering specification

2 Handling and Storage

2.1 Handling

Note that the iMTQ is sensitive to Electro Static Discharge (ESD).

Whenever handling the iMTQ, make sure to follow the following directives:

- Handle the iMTQ in an ESD protected environment (bench mat, wrist strap)
- Handling with active power supply connection is not recommended
- Ensure over-current protection are present when connecting to external power supplies
- The iMTQ is supplied after final functional test results have been performed. Operating it outside its prescribed operating conditions may impede functionality.
- This system is intended for INDOOR use only and should not be operated outdoors as the board electronics might be damaged.
- Ensure that the system is always operated within its qualification temperature range: -40 to +70°C [RD01]

2.2 Storage

- Store the iMTQ in an ESD bag.
- Storage temperature: -50 to +85°C (RH<60%)

2.2.1 Disposal

WARNING

This product contains materials that can be harmful for the Environment and as such it should not be disposed of with conventional waste but treated according to WEEE regulations (UE Directives 2002/96/EC and further amendments) and brought to an appropriate recycling facility.

3 Functional Description

3.1 General Description

3.1.1 Actuation

The iMTQ board provides three magnetic actuators for attitude control operations. The board incorporates two torque rods with a metallic core and one air core torquer. The two torque rods are manufactured by Satellite Services (SSBV UK). The air core actuator has been designed to equal the actuation level of the torque rods at equal voltages. The actuators must be driven individually by applying a constant voltage, or a PWM signal. The iMTQ does not have the capability to actuate automatically, and relies on the provision of analog actuation signals through the actuation interfaces. The application of control signals / voltages must be done from an external system through these three interfaces on the board. These and other interfaces of the board are specified in chapter 4 of this document.

3.1.2 Telemetry

The iMTQ is equipped with a Texas Instruments TMP100 temperature sensor, which provides data over I^2C. The temperature data can be used for compensation of changes in magnetic actuation levels due to changes in temperature. Please note that only for flight models (-FM) this behaviour is characterized in the calibration report. Engineering models are only shipped with calibration reports upon request.

3.2 Power Conditioning and Distribution

The torquers place no requirements on the power fed to them. Please note that deviations in actuation power will result in deviations of control torques. While the iMTQ does not perform any power conditioning it does supply the I2C temperature sensor and I2C bus interface directly from the 3V3 supply lines of the CSKB connectors.

The Temperature sensors power requirements are stated in its respective datasheet:

http://www.ti.com/lit/ds/symlink/tmp100.pdf

3.3 Grounding Scheme

In addition to the grounding scheme of the I^2C bus which can be found in paragraph 4.2.1, the system is grounded through its four mounting holes / mechanical interface.

The iMTQ is supplied with a common grounding scheme involving a solid ground plane which may be connected directly to the structural ground of the satellite via 4 x 0 Ohm resistors if required. The 3 magnetic coils and associated connections are supplied isolated from ground

3.4 Electrical Description

The iMTQ system has three connection interfaces; one for each torquer. The board is fitted with a CubeSat Kit Bus CSKB connector. The I^2C bus can also be accessed from the break-out functionality on the board. The temperature sensor is accessible through the I^2C bus. The details regarding I^2C communication are specified in paragraph 4.1.2 of this document.

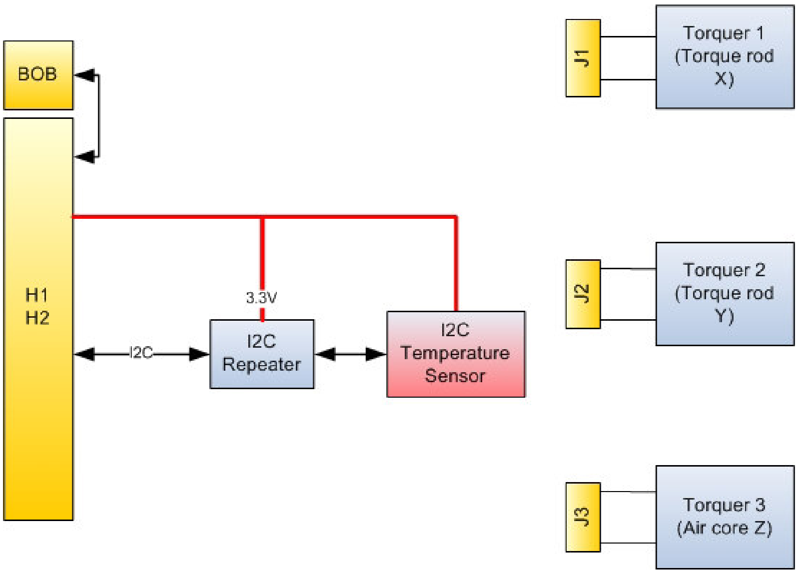


Figure 3-1 iMTQ electrical block diagram

3.5 System overview

The iMTQ overview is given in the next figures. The main components are marked. Please note that a cut out is incorporated in the design to allow for the throughput of wiring and harnessing should that be necessary inside the satellite.

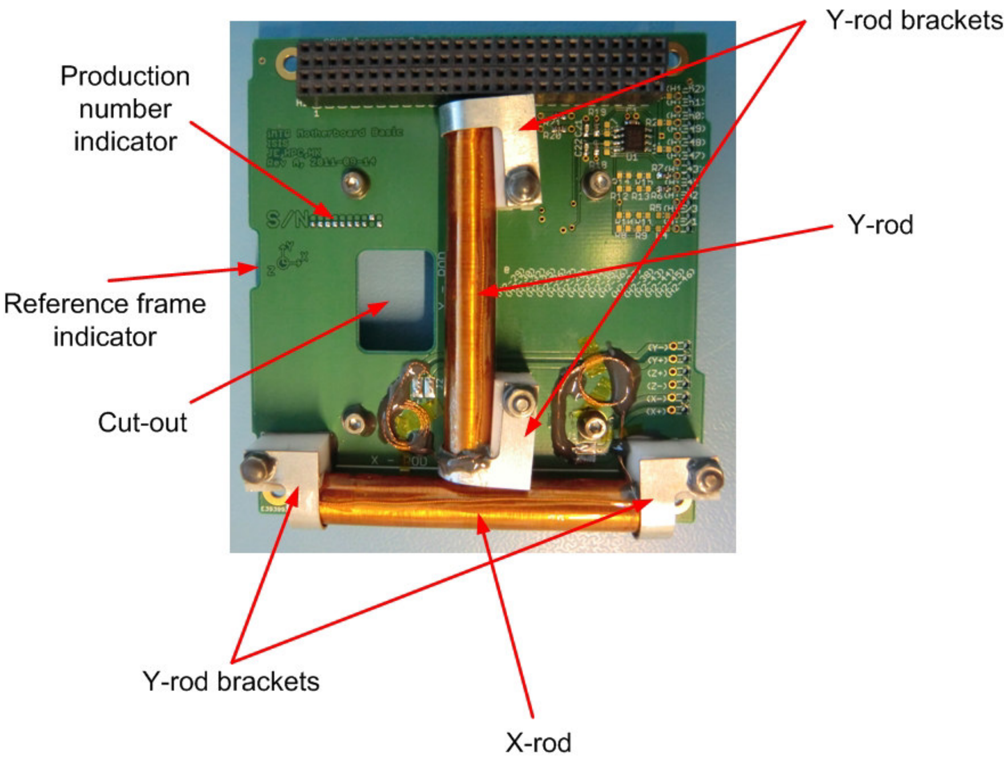


Figure 3-2 iMTQ overview – top

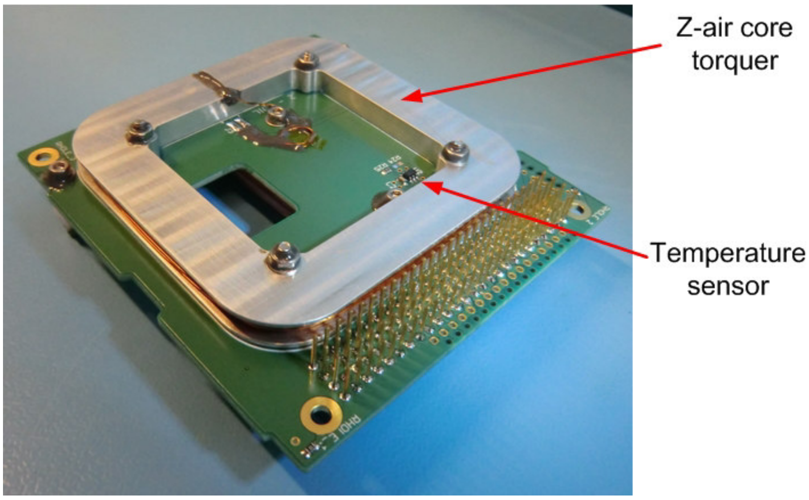


Figure 3-3 iMTQ overview - bottom

4 Interfaces

4.1 Electrical interfaces

4.1.1 Torquer interface

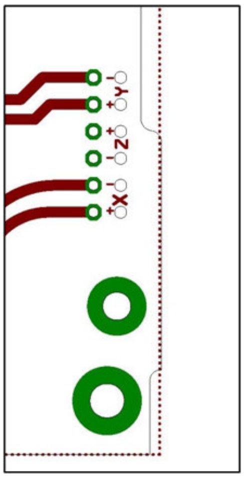


Figure 4-1 Torquer interface

In the lower right corner of the iMTQ PCB you will find the direct interface to the torquers. The polarities are marked. Please note that applying power to the respective torquers in the marked polarities will generate a magnetic dipole in the positive direction of the torquer reference frame, which is indicated on the board. Please also note that for design reasons, the z-torquer (air core) interface is inverted on the board with respect to the x- and y-torquer interfaces.

4.1.2 Temperature sensor interface

The temperature sensor can be accessed through both the normal (H1-41 & H1-43) I^2C two wire interface and the alternate two wire interface (H1-21 & H1-23). The sensor is powered through the 3v3 pins of the bus. The sensor can be supplied with power from both the H2-27 & H2-28 pins.

The data interface’s hardware characteristics are listed in Table 4-1 below.

Parameter	**Typical Value**
Bus logic low-level input voltage	0 - 1 V DC
Bus logic low-level output voltage	0.47 – 0.6V DC
Bus logic high-level voltage	2.3 - 3.3 V DC
Supported I^2C modes	Standard-mode (up to 100 kbits/sec) Fast-mode (up to 400 kbits/sec)
Supported address types	7 bits (10 bits on request)
I^2C node type	Slave only
I^2C general call supported	Yes

Table 4-1 I2C specifications

Note: Because of the use of I^{2}C repeaters to provide bus isolation, the low-level output voltage cannot have a value of 0V, but typically a value of 0.5V.

For more details on the I^{2}C bus timings and operations, please refer to the *I2C-bus specification and user manual* from Phillips – NXP (UM10204, Rev. 03, 19 June 2007, http://www.nxp.com/documents/user_manual/UM10204.pdf).

4.2 Data Interface

4.2.1 I^{2}C interface & break-out functionality

The iMTQ is fitted with the CSKB stack connector, which makes it possible to place the system anywhere in the stack. The temperature sensor on board the iMTQ is connected through this connector to the I^{2}C bus. It could be possible that other systems in the satellite need to be connected to the bus, but cannot be (mechanically) connected to the stack of systems. Therefore the iMTQ provides break-out functionality, which enables the user to connect other subsystems to the bus by wire connection. Please note that this is an architectural feature, and does not relate to the ADCS functionality of the iMTQ itself.

The pin-out of the stack connector and the definition of the channels are explained in the following figures and tables:

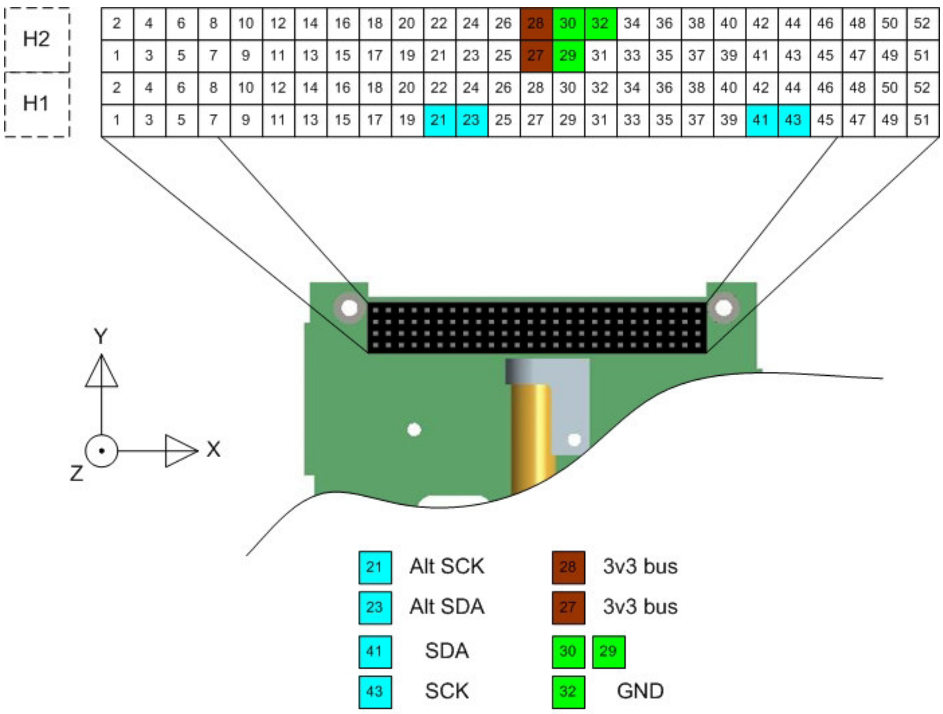


Figure 4-1 CSKB connector pin-out

CSKB Pin	Function	Remarks
H1-21	ALT SCK	Alternative I2C bus serial clock
H1-23	SDA ALT	Alternative I2C bus serial data
H1-32	5V Battery Charge	External Charge pin to charge integrated battery
H1-41	SDA	I2C bus serial data
H1-43	SCK	I2C bus serial clock
H1-47	5V Out #1	Switched supply 5V supply nr 1 (On by default and allocated to OBC)
H1-48	3V3 Out #1	Switched supply 3V3 supply nr 1 (On by default and allocated to OBC)
H1-49	5V Out #2	Switched supply 5V supply nr 2 (On by default and available to payload)
H1-50	3V3 Out #2	Switched supply 3V3 supply nr 2 (On by default and available to payload)
H1-51	5V Out #3	Switched supply 5V supply nr 3 (Off by default and available to payload)
H1-52	3V3 Out #3	Switched supply 3V3 supply nr 3 (Off by default and available to payload)
H2-25	5V Satellite bus	Always on 5V supply line
H2-26	5V Satellite bus	Always on 5V supply line
H2-27	3V3 satellite bus	Always on 3V3 supply line
H2-28	3V3 satellite bus	Always on 3V3 supply line
H2-29	GND	Satellite signal ground connection
H2-30	GND	Satellite signal ground connection
H2-32	GND	Satellite signal ground connection
H2-45	EPS Battery Bus	Always on Battery voltage supply line
H2-46	EPS Battery Bus	Always on Battery voltage supply line

Table 4-2 CSKB typical connections

The break-out pin-out is indicated on the iMTQ board. The break out interface can be found on the right corner of the board. This is also indicated in the next figure.

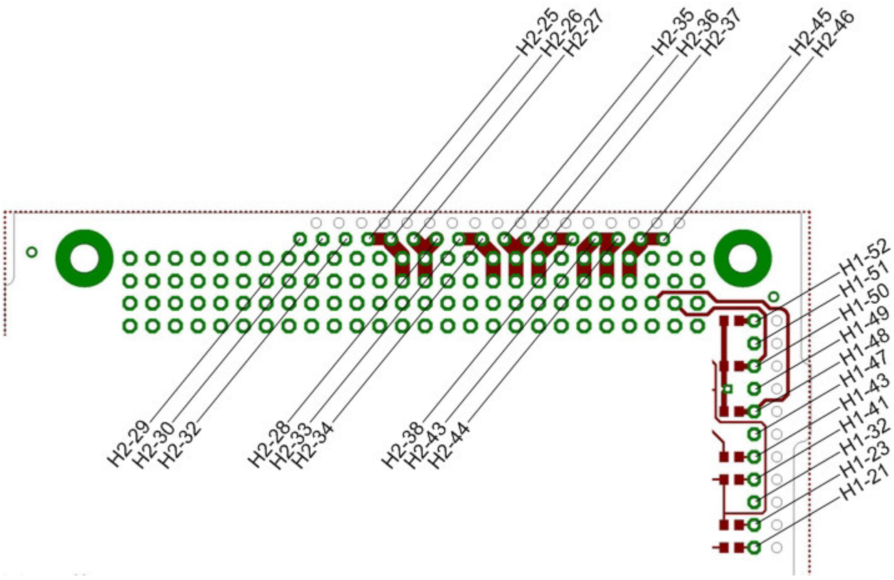


Figure 4-2 Break-out pin-out definition

4.3 Mechanical interfaces

The iMTQ should be mounted in the satellite structure by means of the four 3.2 mm mounting holes on the PCB. This interface is compatible with ISIS structures, and the PCB also conforms to the standard ISIS from factor, which is specified in Annex A. It is not recommended to mount the iMTQ system by any other means than the said mounting interface.

The mass of the complete system, without additional wiring is 194 grams. The centre of gravity is defined by the following picture.

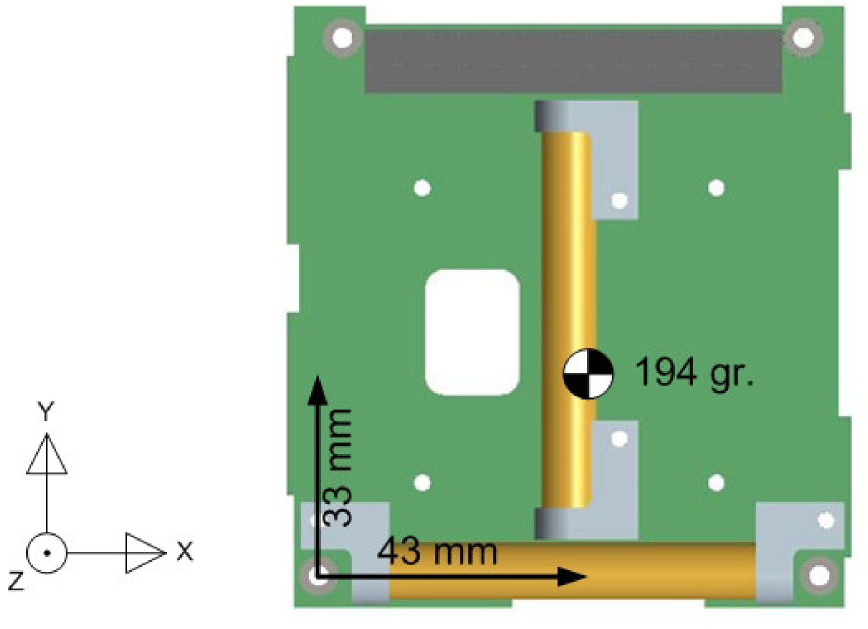


Figure 4-2 Centre of gravity location

5 Detailed Description of Operations

5.1 Assembly & integration instructions

5.1.1 Placement considerations

The iMTQ board is a relatively heavy board compared to CubeSat subsystems of similar shape and envelope. It is recommended to keep that in mind while designing the satellite architecture, as to prevent undesired asymmetric mass distributions.

5.1.2 Soldering and strain relief

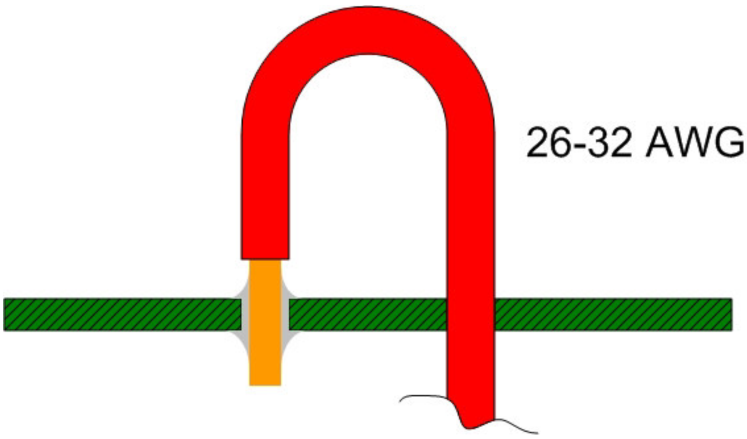


Figure 5-1 Schematic of recommended strain relief soldering method

The iMTQ can be shipped in a pigtail configuration where the leads to the actuators are provided. If this is not the case, and/or use is made of the iMTQ's break-out functionality, ISIS recommends that leads/wires are soldered in the manner indicated in Figure 5-1. This strain relief method provides a more durable and resilient soldered connection. The break-out ports on the PCB are accompanied by holes for this purpose. The recommended wire gauge is between 26 and 32 AWG.

5.2 Attitude Control Instructions

5.2.1 Magnetic control quick start

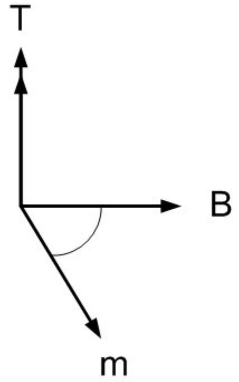


Figure 5-2 Magnetic control

The iMTQ system can generate a magnetic moment vector '**m**' in the spacecraft body reference frame. By means of a measurement of the local (geo) magnetic field '**B**' (measurement not provided by iMTQ) a torque '**T**' on the spacecraft can be established. The following relation applies:

$$\overline{T} = \overline{m} \times \overline{B}$$

From the user's control law for the satellites attitude control (either for attitude manoeuvring or for reaction wheel desaturation) a required control torque should be established '$\mathbf{T}_{req}$'. This can be translated to a magnetic moment vector that will expedite this torque in the available torque space.

Note: The torque-space of magnetic control under the influence of a linear B-field is always two dimensional. Please keep in mind that magnetic control cannot always provide the desired control torque in the satellite body reference frame. The torque that can be produced in the satellite body reference frame is dependent on the orientation of the B-field.

The magnetic control dipole vector for actuation is given by:

$$\overline{m} = \frac{\overline{B} \times \overline{T}_{req}}{\left\| \overline{B} \right\|^2}$$

Note: The magnitude of the required torque input will determine the magnitude of the commanded control dipole. It is advised to incorporate a dipole vector limiter/normalization algorithm in the users' flight software to prevent saturation of actuators and subsequent control misalignment.

6 Temperature Sensor Interface Description

The iMTQ is equipped with an TMP100 temperature sensor, which can be accessed through the I^2C interface. This interface is described in this chapter.

6.1 Description

Please find the format specification for all the commands below

Command Name	Command Code
Name of the command	Command code in binary

Description

Extended description of the command.

Parameters

[000 – 000] format

Specification of the parameters required after the command.

Response

[000 – 000] format

Specification of the response that the antenna system will generate for this command.

The parameter and response descriptions contain specifications per byte or sequence of bytes. There can be several parameters or responses associated with a command and each have its own specification. Please note that parameters always start at byte 001, as byte 000 contains the command code. These specifications contain the following items:

6.1.1 Parameter / response length

This specifies the length and the location in the byte sequence of the parameter or response of the command. Several examples are provided below to explain the possible options.

[001 - 001]

Parameter / response has a fixed length of 1 byte and is located in byte 001

[001 - 020]

Parameter / response has a fixed length of 20 bytes and is located in bytes 001 through 020

[001 - 020*]

Parameter / response has an arbitrary length between 1 byte and 20 bytes and is located in the corresponding number of bytes starting at byte 001

6.1.2 Format specification

This specifies the format of the byte(s) of the parameter or response. Several examples are provided below to explain the possible options.

0000xxxx	The four most significant bits contain zeroes, while the four least significant ones contain the relevant bits
xxxxxxxx 000000xx	All bits of the first (and least significant) byte are relevant, while of the second byte only the two least significant bits are relevant
n/a, binary	All bits in all the bytes are relevant and are interpreted as binary content, i.e. no interpretation will take place
n/a, ASCII	All bits in all the bytes are relevant and are interpreted as ASCII content, specific interpretation depends on the command
_ _ _ _ _ _01	The two least significant bits have the specific value of '01', while the other bits can be either a 1 or a 0 (don't care)

6.2 Telemetry and Command Definition

6.2.1 Measure Temperature

Command Name	Command Code
Measure Temperature	00000000

Description

Obtaining the temperature value from the TMP100 temperature sensor register.

Parameters

None

Response

[000 – 001] xxxxxxxx _ _ _ _ xxxx

Raw 12 bits measurement of the temperature.

001	T3	T2	T1	T0	-	-	-	-
000	T11	T10	T9	T8	T7	T6	T5	T4

The temperature value is encoded with two's complement and the most significant byte is sent first. To return the value in degree Celsius, multiply the raw value with 0.0625 (1/16).

Example readout:

Temperature Raw byte 0 = 0x64
Temperature Raw byte 1 = 0x00
Temperature Raw 12 bit complete raw value = 0x0640
Temperature Readout in Celsius = 100°C

Temperature Raw byte 0 = 0xE7
Temperature Raw byte 1 = 0x80
Temperature Raw 12 bit complete raw value = 0x0E78
Temperature Readout in Celsius = 50°C

Temperature Raw byte 0 = 0x15
Temperature Raw byte 1 = 0x80
Temperature Raw 12 bit complete raw value = 0x0158
Temperature Readout in Celsius = 21°C

6.2.2 Set Configuration

Command Name	Command Code
Set Configuration	00000001

Description

Set the TMP100 Configuration Register that controls the operational mode of the temperature sensor.

Parameters

[001 – 001] xxxxxxxx

001	OS	R1	R0	-	-	-	-	SD

SD

1 – Shut the device down after the current conversion has been completed.

0 – Device operates in normal mode.

R1 and R0

Control the resolution of the measurement. The measurement's resolution is controllable in maximizing efficiency for higher resolution or faster conversion time.

R1	R0	Resolution	Typical Conversion Time
0	0	8LSB (0.5°C)	40 ms
0	1	4LSB (0.25°C)	80 ms
1	0	2LSB (0.125°C)	160 ms
1	1	1LSB (0.0625°C)	320 ms

OS

1 – One-Shot Temperature measurement mode (when the device is in shutdown mode).

0 – Device operates in normal mode.

Response

None

6.2.3 Obtain Configuration

Command Name	Command Code
Obtain Configuration	00000001

Description

Obtain the TMP100 Configuration Register that controls the operational mode of the temperature sensor.

Parameters

None

Response

[000 – 000] xxxxxxxx

001		OS	R1	R0	-	-	-	-	SD

SD

1 – Shut the device down after the current conversion has been completed.

0 – Device operates in normal mode.

R1 and R0

Control the resolution of the measurement. The measurement's resolution is controllable in maximizing efficiency for higher resolution or faster conversion time.

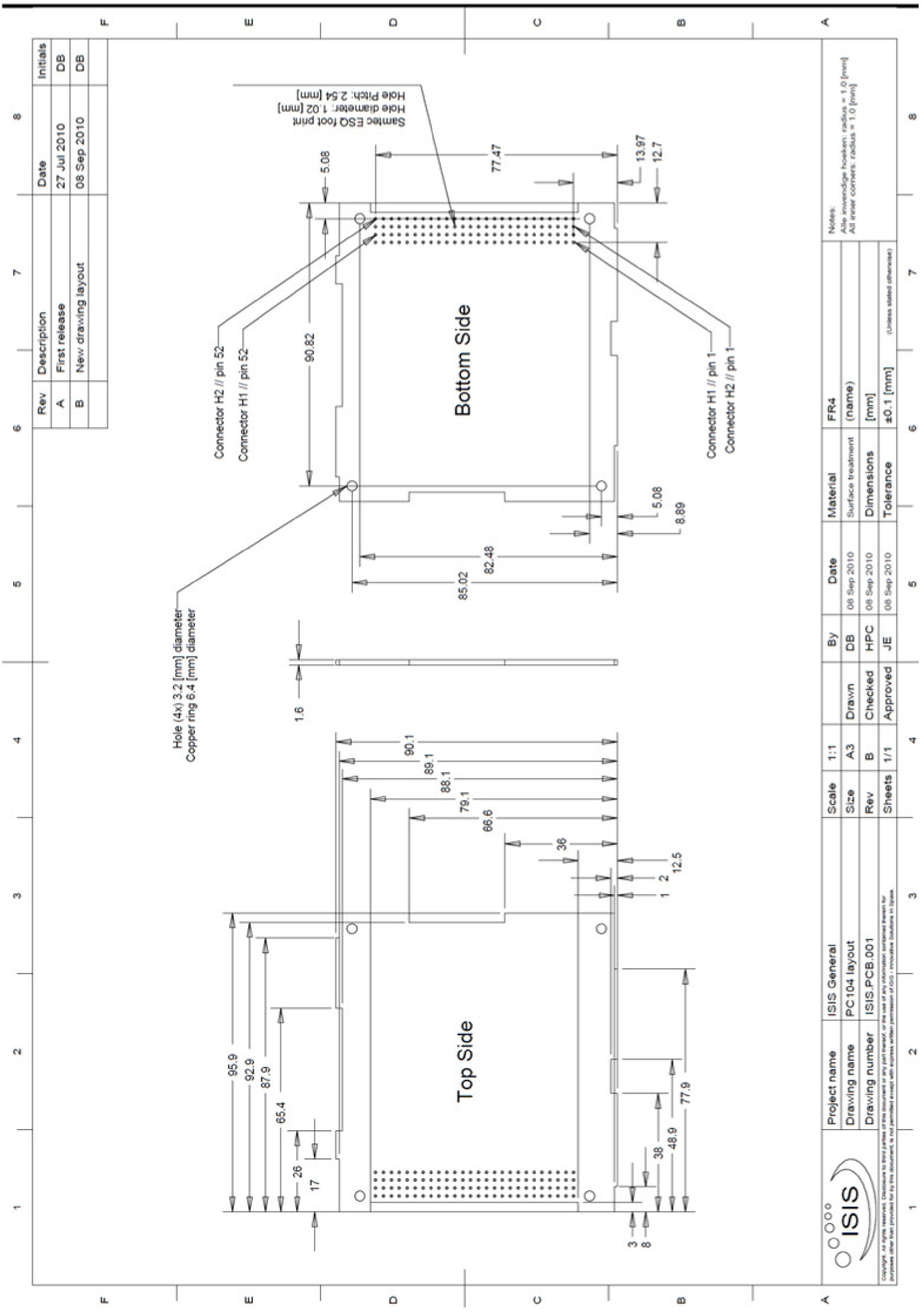
R1	R0	Resolution	Typical Conversion Time
0	0	8LSB (0.5°C)	40 ms
0	1	4LSB (0.25°C)	80 ms
1	0	2LSB (0.125°C)	160 ms
1	1	1LSB (0.0625°C)	320 ms

OS

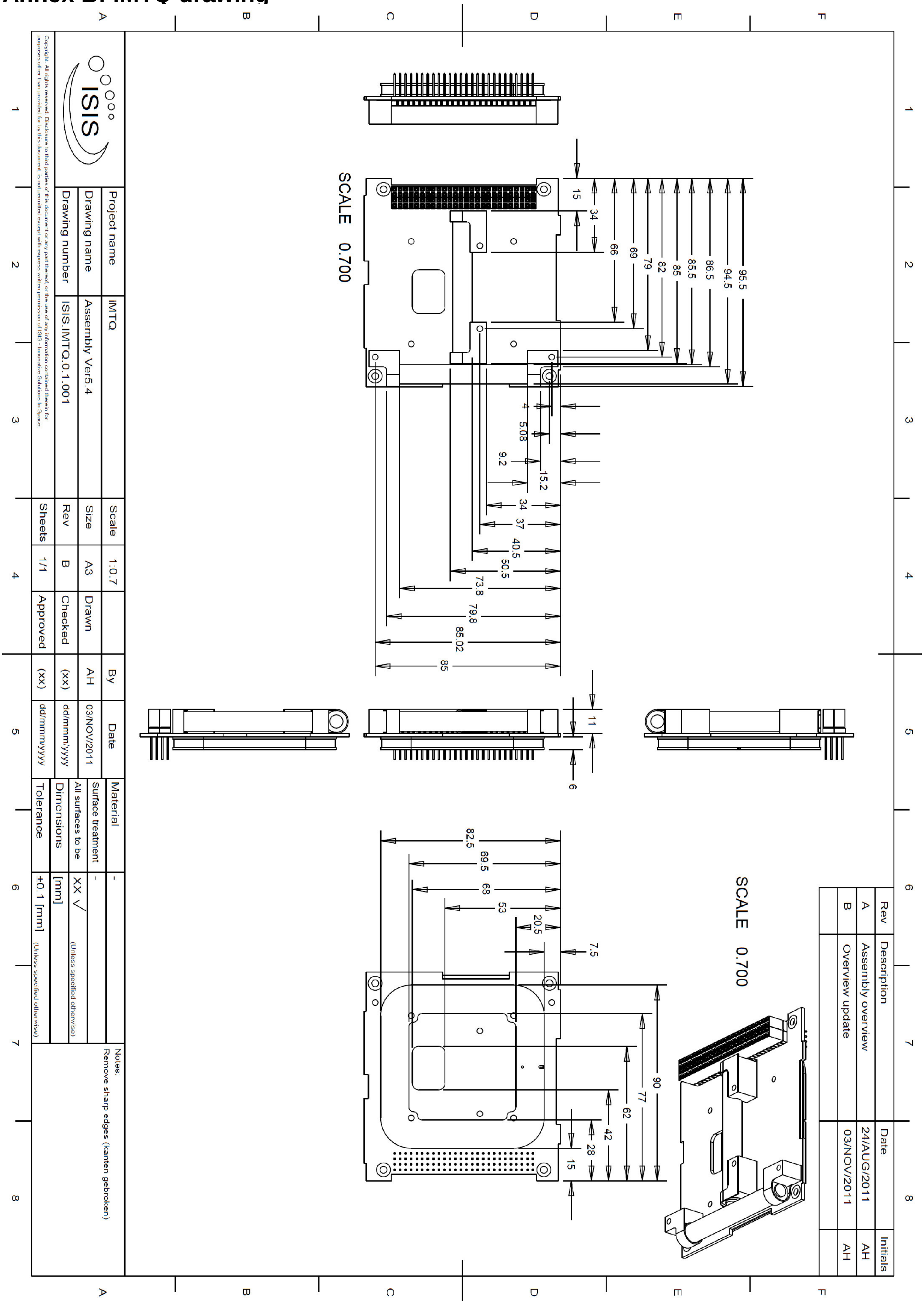
1 – One-Shot Temperature measurement mode (when the device is in shutdown mode).

0 – Device operates in normal mode.

Annex A: ISIS PCB form factor



Annex B: iMTQ drawing



Annex C. Configuration Overview

Parameter	Value	
I2C Data Connection	H1-23	
	H1-41	
I2C Clock Connection	H1-21	
	H1-43	
Temperature sensor 3V3 power connection	H2-26,27	
	H1-48	
	H1-50	
	H1-52	
Type of CSKB connector mounted		