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INTERFACE CONTROL DOC

HONEYWELL COMMERCIAL (HC) SERIES

REACTION WHEEL ASSEMBLY (RWA)

HC11 INTERFACE CONTROL DOCUMENT

ICD64020011

Rev -

March 2025

DISCLAIMER

Export Classification:

ECCN 9E515.a

(5504.2.c)

Table of contents

Revision History

Revision	Date	Description
Rev -	03/24/2025	Initial Release per ECN-6208631

1 HC11 Interface Control Drawing – ICD64020011

1.1 Overview/Scope

Honeywell's Commercial (HC) Series Reaction Wheel Assembly (RWA), also referred to as the New Space RWA, is a low-cost, high performance, fully self-contained 'smart' wheel consisting of the Housing, Inertia Rotor, Bearings, Brushless DC Motor, Electronics, and interfaces to the spacecraft via a single 31-Pin Connector. The RWA is intended to serve high-volume, low-cost, low-mass, small-sat LEO constellation market.

This document is intended to serve as both a detailed user guide and as a top-level Interface Control Document (ICD). As such, this document describes; storage constraints, pre-installation procedure, operational constraints, overall architecture, block diagrams as appropriate, mechanical interface, electrical interface, communication signals/protocol and defines general terminology used in attitude control systems.

This ICD is the controlling document and supersedes all other references should a discrepancy exist. The intended audiences are: Project Management, Design Engineering, Design Verification, Systems Design, and other support disciplines as needed. It details the electro-mechanical interface to the Honeywell HC RWA and Honeywell's API customers and/or 3rd party vendors will need to interface to the RWA.

Note that values in this document are subject to change, pending completion of PN 64020011 HC11 Qualification Test campaign.

2 General Overview

2.1 Assumptions

None at this time.

2.2 Constraints

None at this time

2.3 Definitions

Throughout this document, the following italicized terms have the following meanings and/or definitions:

- The term ***operating temperature*** means the baseplate temperature range the unit can be operated at and maintain full performance and/or functionality.
- The ***operating voltages*** are assumed to be maintained at the RWA J1 connector under all operating conditions

2.4 Acronyms

ACS	Attitude Control System
ATP	Acceptance Test Procedure
BLDC	Brushless Direct Current
BEMF	Back Electro-Motive Force
CAN	Controller Area Network
CG	Center of Gravity
CRC	Cyclical Redundancy Check
DC	Direct Current
EOL	End of Life
FOC	Field Oriented Control
FPGA	Field Programmable Gate Array
HC	Honeywell Commercial
ICD	Interface Control Drawing
NS	New Space
PBA	Printed Board Assembly
PWM	Pulse Width Modulation
RPM	Revolutions Per Minute
RWA	Reaction Wheel Assembly
UART	Universal Asynchronous Receiver-Transmitter

2.5 References

The table below illustrates the orderable HC11 part numbers.

Table 1 – Orderable Part Numbers

Part Number	Description	Comm. Protocol	Deliverable Torque	Mounting Interface	Test Procedure
64020011-901	RWA – HC11 (RS422)	RS422	300 mNm	10-32	TP64020011
64020011-903	RWA – HC11 (RS485)	RS485	300 mNm	10-32	TP64020011
64020011-913	RWA – HC11 (RS485)	RS485	200 mNm	M5	TPR-92519546-1000

The table below lists applicable reference documents.

Table 2 – Reference Documents

Type	Number	Description
O&I Drawing	64012781	Outline & Installation, HC11 RWA

3 Theory of Operation

This section describes, in high-level terms, the overall operation of the reaction wheel assembly.

3.1 Background

The RWA is a self-contained assembly that forms part of the attitude control sub-system of the spacecraft. It receives either torque, speed or telemetry commands from the spacecraft and adjusts, as necessary, the new operational speed or torque. Upon request, the RWA sends telemetry information back to the spacecraft. The RWA converts electrical energy to stored mechanical energy later to be exchanged between itself and the spacecraft.

3.2 Overview

The RWA is comprised of the following functional groups as diagramed in Figure 1. The diagram is intended to be a high-level overview only and not an exhaustive accounting of the RWA.

Power to the RWA enters and exits via the AXON 31-pin connector. Exact pin location among other details will be described in more detail later in the document. Communication is achieved via a redundant pair of serial channels. Communication protocol, format etc. are fully described in a subsequent section. Refer to Section 7.2 for a full connector pinout listing.

Commutation is achieved by FOC methods using an FPGA, drivers, and half-bridge inverters. FOC commutation uses rotor position information which is achieved via a proprietary encoding scheme. Firmware image and RWA identification information is redundantly stored in MRAM.

Input power is protected from EMI by a common mode choke and low pass filtering.

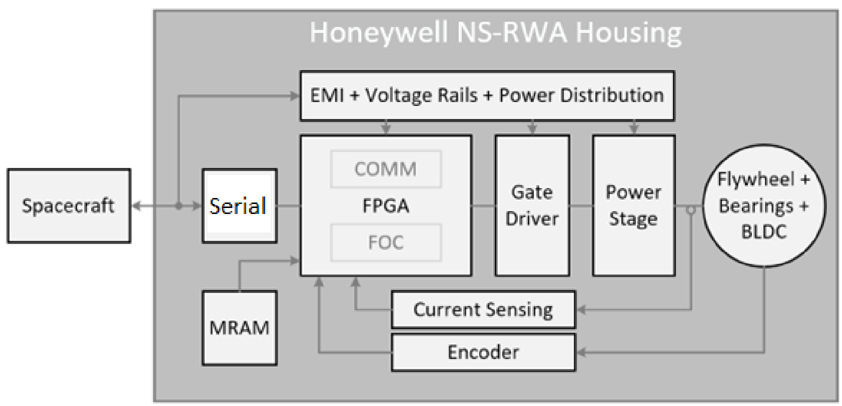


Figure 1 – Simplified RWA Block Diagram

3.3 Reserved

3.4 Reserved

3.5 Reserved

4 Specifications

This section defines the HC11 specifications applicable to the products related to this ICD.

Table 3 – HC11 Specifications

Description	Limit		Unit
	-901, -903	-913	
Rated torque imparted at mounting plate(3)	0.3	0.2	Nm
Rated angular momentum (at 3600 RPM) (1)	25		Nms
Standby Power (max)	≤6		Watt
Peak Power (max)	≤185	≤125	Watt
Steady State Power (max)	≤25		Watt
Rated RWA Mission Life, LEO (typical)	7	13	year
Minimum RWA Reliability for above mission life (P_s)	7 yrs, 25°C , 1800 rpm P_s=0.975	13 yrs, P_s=TBC	
Rated transition time from "standby" to "operational" mode	≤10		sec
Rated torque percent over/under shoot from commanded value	TBC	TBC	%
Rated dynamic torque ripple (max-min) as a % of commanded value	TBC	TBC	%
Bus Voltage Range (2)(3)	24 – 38		VDC
Static Imbalance (BOL)	≤1 (TBC)		g-cm
Dynamic Imbalance (BOL)	≤10 (TBC)		g-cm^2

Notes:

(1) Angular Momentum (H) at a given speed (x) for this RWA is determined by:

$$H(x) = 25Nms * \frac{x\ RPM}{3600\ RPM}$$

(2) Bus voltage is measured at the RWA J1 connector. The RWA will sink & source bus current in the range of +/- 0.1A-6.5A based on bus voltage & motor operations. The power bus source impedance must be << 0.150 ohms to limit voltage variations at the RWA connector. (6.5A is worst case for operation at lowest do-not-exceed voltage, with maximum acceleration/deceleration, at/near maximum speed.)

(3) Torque performance may be reduced under certain conditions (below 27V, min/max temp), pending analysis/test

5 Operation and Handling Guidelines

This section describes the general operating and handling guidelines for the Honeywell Commercial Series (HC) RWAs.

The RWA is intended for use in the attitude control system of an unmanned satellite. The wheel provides reaction torque and momentum storage about a given spacecraft axis. The unit is designed to operate in space and will be subjected to the environments normally associated with space borne products (temperature extremes, random vibration, vacuum, radiation, etc.).

5.1 System Operations

The RWA interfaces electrically to an attitude control subsystem. RWA power, control, and telemetry signals are interfaced through a single electrical connector. Reaction torque is net torque transferred to the spacecraft through the unit mounting surface. Generated heat is transferred by conduction through the unit mounting surface and radiation to the surroundings. Operation of the RWA requires a secure mounting of the unit on its intended support structure and application of torque to the inertia wheel by powering the RWA and providing commands through an appropriate control system.

In addition to the space environment, a small portion of the unit's operating life will occur during component and spacecraft testing. It is during this time that the greatest potential for safety hazards exists. The operating procedure is essentially the same as described above, except that the unit may be mounted to a test support fixture and the control system may be a component test console.

5.2 Identification

The RWA contains a label with identification data as shown in Figure 2 below:

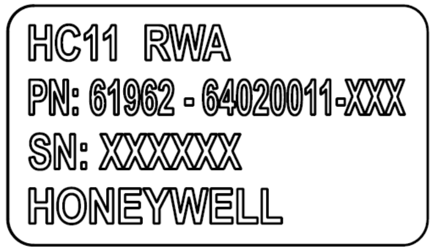


Figure 2 – RWA Identification Label

The RWA also contains two electronic copies of the label information. These tables are available to the user via the serial interface. The memory locations, field descriptions, and examples of ASCII text content is shown in the table below.

Table 4 – Memory Identification Table

Address Range	Field Name	Description
TBC	RWA Description	Describes what HW RWA item this is e.g. HC11-GEN2
TBC	Honeywell RWA ID	RWA Identifier defined by Honeywell e.g. 61962 PN: 64020011-901
TBC	RWA Serial Number	Serial number of the specific RWA e.g. 99000101
TBC	Honeywell Reserved Item #1	Reserved 32-byte ASCII string #1
TBC	Honeywell Reserved Item #2	Reserved 32-byte ASCII string #2
TBC	Honeywell Reserved Item #3	Reserved 32-byte ASCII string #3

5.3 ESD Precautions

Design measures have been taken to protect the Honeywell RWA from ESD. However, some ESD events may cause damage that could lead to immediate and/or latent failures. To prevent possible ESD damage, the RWA should always be stored within an ESD-safe bag or ESD-safe container. The RWA should only be handled with appropriate ESD protection. All packaging will be clearly marked with an “ESD Sensitive” label. Regardless of labeling, all RWA devices are susceptible to damage from an ESD event and must be packaged and handled accordingly.

5.4 Operational Constraints

Normal operating speed is ±3600 RPM. Nominal performance can be expected over the operational temperature range. This operational temperature range is for ground testing and short-term operation on mission; otherwise, the average baseplate temperature must be maintained within the Mission Long-Term temperature min/max.

Table 5 – Thermal Environment Constraints

Thermal	Min	Max
Operational	-15 °C	60 °C
Non-Operational	-30 °C	70 °C
Mission Long-Term Average Baseplate Temperature	10 °C	40 °C

5.5 Electrical Constraints

The recommended operational bus voltage range is 24 – 38 VDC. For bus voltages outside this range an internal under/over voltage protection will disable the drive circuitry within the RWA. The under voltage trip point is 19V and the over voltage trip point is 42V. The under voltage or over voltage fault must be cleared to reenable the drive circuitry.

Table 6 – RWA Bus Voltage Limit Summary

Do Not Exceed Lower Limit	Safe to Operate Lower Limit	Nominal	Safe to Operate Upper Limit	Do Not Exceed Upper Limit
21V	24V	28V	38V	40V

The RWA will meet published specs if operated within the safe to operate limits above. It is not recommended the RWA operate between the safe-to-operate limits and do-not-exceed limits. No immediate damage will occur however long-term operation in this region may reduce the RWA mission life and result in excessive RWA component heating.

If the overvoltage condition persists for longer than 252µs, an overvoltage fault will be asserted, and the motor will be disabled. Continued exposure to high voltage may result in damage to the hardware.

5.6 Health and Safety Fault Thresholds

The RWA continuously monitors critical operational parameters to aid in detecting potential damaging conditions that may impact normal operation. Monitoring is done in real time and does not require spacecraft intervention. Upon detecting potentially harmful conditions, the RWA disables the motor drivers and flags the offending fault condition in the Health and Status telemetry frame. Over current is monitored on Phase B and Phase C only. Below are the fault thresholds for each monitored fault condition.

Table 7 – RWA Fault Thresholds

Fault Condition	Fault Threshold	H&S Word	H&S Bit
Over Current	9.76A Pk	DAT[5]	b[0]
Bus Over Voltage	42V **[±3.3%]**	DAT[5]	b[1]
Bus Under Voltage	19V **[±5.0%]**	DAT[5]	b[2]
Angular Position	>5.6 deg step	DAT[5]	b[5]
Wheel Over Speed	4200RPM	DAT[5]	b[7]

[EOL tolerance]

5.7 Mechanical

The RWA was designed to withstand exposure to the environments specified below. **To prevent injury to test personnel and/or damage to the RWA, RWA should be securely bolted to a stationary fixture or the satellite whenever the rotor is spinning.** Only high strength bolts of grade 5 or higher should be used to bolt the RWA down. The engagement length of the bolt should be adequate to ensure a minimum thread engagement of 1.5x the diameter.

5.8 Bearing Drag Telemetry Constraints

The RWA provides the reaction torque that was commanded. It accomplishes this by adjusting the real angular acceleration against an internal profile to achieve the commanded torque. The bearing drag telemetry has shared input parameters but is otherwise independent from the internal control loop. The bearing drag telemetry is only provided as a method for qualitative performance monitoring over different operational conditions as well as mission lifetime. It should only be used to compare values reported from the same RW under the same conditions (speed, temperature) over time. It should never be used to adjust the commanded torque.

The bearing drag telemetry is based on the nominal value of the motor torque constant. When operating the motor at a constant speed, it represents the torque (motor current * motor torque constant) required to maintain that speed. However, this drag telemetry will include all drag parameters that influence maintaining a constant motor speed. These include variations in motor torque constant, actual bearing drag, and any parasitic/eddy currents in the motor driver circuit that do not produce torque. The bearing drag telemetry is not valid during acceleration or when operating outside controller design limits (low voltage, etc.).

5.9 Handling and Storage

The RWA is flight grade hardware and should be treated as such and stored/handled in a class 100 (ISO 5) or better cleanroom environment until such time it is commissioned for use

For long term storage, it is recommended that the RWA be stored with the spin axis horizontal with protective covers over the external connector. The recommended storage length is no more than two years. Re-evacuation may be necessary after extended period of storage and can be quoted by Honeywell.

Over time, run-in channeling tracks are established within the spin bearings, which provide a continuous oil supply during operation. These established grease channels are effectively settled during operation but can be disrupted due to short term and long-term environmental influences. Short term influences include unit handling or vibration in which the induced forces deform the channel walls. Long term influences include storage at 1g-force for periods of as little as a few weeks or longer, which will deform or slump the grease structure. The increased drag resulting from this short term and long-term environmental exposures will require additional run-in time to reestablish the grease channels and reduce the wheel drag.

Although run-in may be required to lower the RW drag torque, this benign condition should be temporary, and the user may continue to use the RW as normal.

Honeywell recommends run-in for RWs following delivery, vibration, or extended storage periods. During the run-in period, bearing channeling is slowly reestablished and the RWA will show a steady progression of torque loss (bearing drag) improvement with time and is considered complete when normal torque loss levels and power consumption levels are reestablished. The recommended run-in is at ambient temperature, +/- 3600 RPM’s, for 12 hours in each direction. After each run-in cycle, the RWA should be checked for acceptable power consumption and bearing drag levels. If the desired levels have not been achieved, the run-in procedure should be repeated. If the desired levels cannot be reestablished after 120 run-in hours, contact Honeywell.

5.10 Packaging

The following packaging process will be utilized prior to shipment:

1. Securely install dust cover and Kapton tape over the connector
2. Place RWA in an ESD shielding, water vapor proof MIL-B-81705 bag
3. Backfill with dry nitrogen to remove moisture and heat seal the bag
4. Place the RWA into another ESD shielding, water-vapor proof bag with three, eight-unit desiccants (MIL-D-3464, type II) and a humidity indicator (MIL-I-8835)
5. Backfill with dry nitrogen to remove moisture and heat seal the bag

Following this procedure, the bagged RWA can be inserted into an appropriately padded shipping container, with legible labels and warning stickers.

6 Mechanical

6.1 Overall Form Factor

When initially at rest and commanded with a positive torque command or a positive speed command, the RW's internal inertia rotor will start spinning in the counterclockwise direction, as viewed from the top of the RWA.

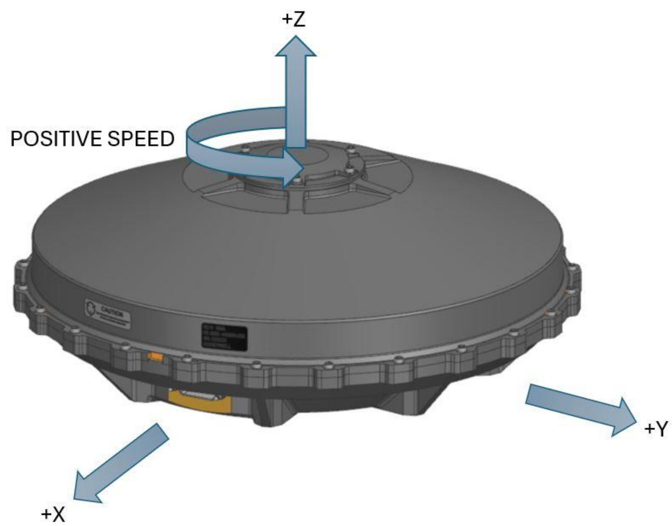


Figure 3 – Frame of Reference Definition

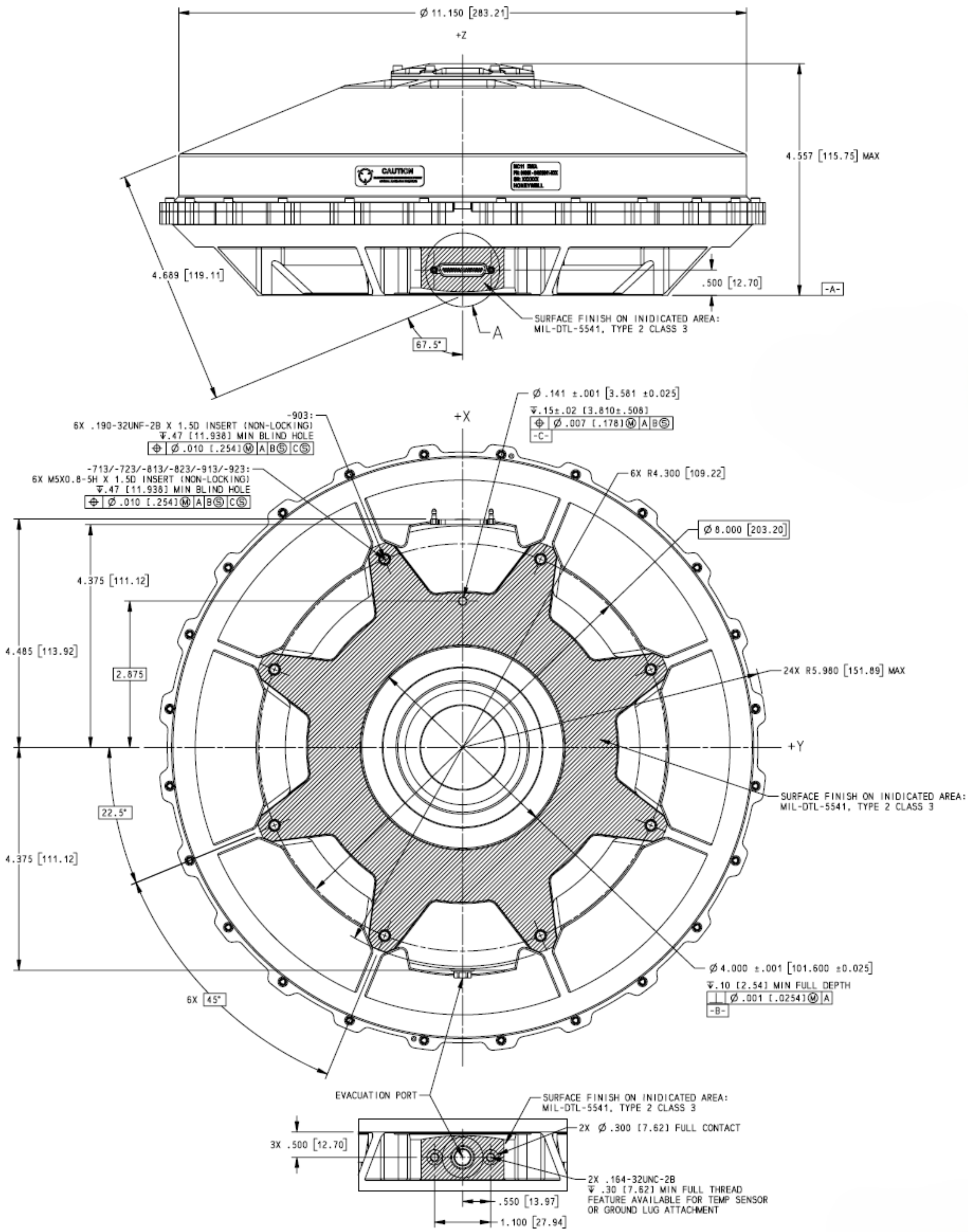


Figure 4 – HC11 Form Factor

6.2 Characteristics

The mechanical characteristics of the RWA are show in the table below.

Table 8 – RWA Mechanical Characteristics

RWA Envelope Dimensions	304 mm D x 116 mm H
Housing Material	Aluminum 6061
Mounting Locations	8
Number of Contact Areas	1
Contact Area (cm^2)	158
Roughness of Contact Area (microns RMS)	63 max
Eigen frequency (1^{st} Natural Frequency, Hz)	140

6.3 Center of Gravity Location

The nominal location of the center of gravity is shown below.

Table 9 – RWA Mechanical Characteristics

CG location about center of mounting plane (+/- 1mm)		
X	Y	Z
-0.194 mm	**0** mm	**52.146** mm

6.4 Mass and Inertia properties

The nominal mass of the unit is 7.58 kg. The maximum mass is 7.79 kg.

The nominal inertia values about the center of gravity.

Table 10 – Inertia Locations

Inertia about center of gravity ± 10%		
X	Y	Z
0.048 Nms^2	**0.048** Nms^2	**0.088** Nms^2

6.5 Thermal properties

The RWA measures PBA temperature by way of a precision platinum RTD sensor mounted on the PBA surface. The sensor is sampled every 15.8µs at 12bit resolution, has a rated temperature range of -55 to +175 DegC with a tolerance rating of +/- 0.55 K @ 50 DegC. The temperature is reported via telemetry as a 32bit single precision floating point value in DegC.

7 Connector Detail

The satellite connects to the RWA via the downstream 31-conductor receptacle. The RWA connector type is socket; therefore, the upstream connector type must be plug. Connector technical design information is described below.

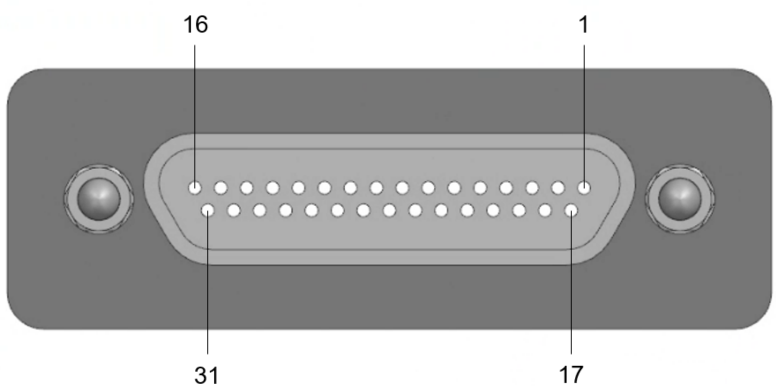
To the greatest extent possible, digital signals have been separated from power signals by a minimum of one conductor position. Power and ground signals are located on adjacent pins and separated by a minimum of one conductor position.

The Axon D-click connector mating force is 82 N; during mating, and audible click indicates when the latch springs are properly engaged.

7.1 31-Pin Receptacle

Electrical signals interface to the spacecraft via a single 31-pin, two row, D-click, Micro-D connector manufactured by AXON; part number **MDH231S*x*L*xxx*G5**. There are numerous mating options that are compatible with this connector; contact Honeywell or AXON for the appropriate connector PN based on specific end use requirements and/or configuration.

Figure 5 below diagrams the connector pin-out looking into the connector from outside the case.



Note: Orientation is looking into the face of the RWA connector

Figure 5 – 31-Pin Receptacle Pin-Out

7.2 Connector Pin-Out

Table 11 – 31-Pin Conductor designations for RS422

Pin	Signal Name	Type	Description
1	**VBUS**	**Power**	**Bus Input**
2	**VBUS**	**Power**	**Bus Input**
3	**VBUS**	**Power**	**Bus Input**
4	*REMOVED*	-	*Contact removed*
5	**VBUS-RTN**	**Ground**	**Bus Return**
6	**VBUS-RTN**	**Ground**	**Bus Return**
7	**VBUS-RTN**	**Ground**	**Bus Return**
8	*REMOVED*	-	*Contact removed*
9	**PGND**	**Ground**	**Power Ground (for DTI interface, test use only)**
10	**ISO-GND**	**Signal**	**Isolated Ground (for comm interfaces)**
11	**COMM-PRI-2L**	**Signal**	**RS422: Primary Inverted Output**
12	**COMM-PRI-1L**	**Signal**	**RS422: Primary Inverted Input**
13	**DTI-TLM-DAT**	**Signal**	**DTI Telemetry Data (Test use only)**
14	**DTI-CMD-DAT**	**Signal**	**DTI Command Data (Test use only)**
15	**COMM-SEC-2L**	**Signal**	**RS422: Secondary Inverted Output**
16	**COMM-SEC-1L**	**Signal**	**RS422: Secondary Inverted Input**
17	**VBUS**	**Power**	**Bus Input**
18	**VBUS**	**Power**	**Bus Input**
19	**VBUS**	**Power**	**Bus Input**
20	*REMOVED*	-	*Contact removed*
21	**VBUS-RTN**	**Ground**	**Bus Return**
22	**VBUS-RTN**	**Ground**	**Bus Return**
23	**VBUS-RTN**	**Ground**	**Bus Return**
24	*REMOVED*	-	*Contact removed*
25	*REMOVED*	-	*Contact removed*
26	**COMM-PRI-2H**	**Signal**	**RS422: Primary Noninverted Output**
27	**COMM-PRI-1H**	**Signal**	**RS422: Primary Noninverted Input**
28	**DTI-TLM-CLK**	**Signal**	**DTI Telemetry Clock (Test use only)**
29	**DTI-CMD-CLK**	**Signal**	**DTI Command Clock (Test use only)**
30	**COMM-SEC-2H**	**Signal**	**RS422: Secondary Noninverted Output**
31	**COMM-SEC-1H**	**Signal**	**RS422: Secondary Noninverted Input**

Table 12 – 31-Pin Conductor designations for RS485

Pin	Signal Name	Type	Description
1	**VBUS**	**Power**	**Bus Input**
2	**VBUS**	**Power**	**Bus Input**
3	**VBUS**	**Power**	**Bus Input**
4	*REMOVED*	-	*Contact removed*
5	**VBUS-RTN**	**Ground**	**Bus Return**
6	**VBUS-RTN**	**Ground**	**Bus Return**
7	**VBUS-RTN**	**Ground**	**Bus Return**
8	*REMOVED*	-	*Contact removed*
9	**PGND**	**Ground**	**Power Ground (for DTI interface, test use only)**
10	**ISO-GND**	**Signal**	**Isolated Ground (for comm interfaces)**
11	**COMM-PRI-2L**	**Signal**	**RS485: Primary Inverted I/O (internally tied to Pin 12)**
12	**COMM-PRI-1L**	**Signal**	**RS485: Primary Inverted I/O (internally tied to Pin 11)**
13	**DTI-TLM-DAT**	**Signal**	**DTI Telemetry Data (Test use only)**
14	**DTI-CMD-DAT**	**Signal**	**DTI Command Data (Test use only)**
15	**COMM-SEC-2L**	**Signal**	**RS485: Secondary Inverted I/O (internally tied to Pin 16)**
16	**COMM-SEC-1L**	**Signal**	**RS485: Secondary Inverted I/O (internally tied to Pin 15)**
17	**VBUS**	**Power**	**Bus Input**
18	**VBUS**	**Power**	**Bus Input**
19	**VBUS**	**Power**	**Bus Input**
20	*REMOVED*	-	*Contact removed*
21	**VBUS-RTN**	**Ground**	**Bus Return**
22	**VBUS-RTN**	**Ground**	**Bus Return**
23	**VBUS-RTN**	**Ground**	**Bus Return**
24	*REMOVED*	-	*Contact removed*
25	*REMOVED*	-	*Contact removed*
26	**COMM-PRI-2H**	**Signal**	**RS485: Primary Noninverted I/O (internally tied to Pin 27)**
27	**COMM-PRI-1H**	**Signal**	**RS485: Primary Noninverted I/O (internally tied to Pin 26)**
28	**DTI-TLM-CLK**	**Signal**	**DTI Telemetry Clock (Test use only)**
29	**DTI-CMD-CLK**	**Signal**	**DTI Command Clock (Test use only)**
30	**COMM-SEC-2H**	**Signal**	**RS485: Secondary Noninverted I/O (internally tied to Pin 31)**
31	**COMM-SEC-1H**	**Signal**	**RS485: Secondary Noninverted I/O (internally tied to Pin 30)**

8 Electrical

The RWA electronics are fully contained within the RWA housing and reside adjacent to the BLDC motor and inertia flywheel. The RWA interfaces to the spacecraft via a single 31-pin AXON connector which contains both power and communication signals. The communication interface has been designed to be flexible, fully redundant, and support reliable high bandwidth digital IO. The RWA motor is driven using Field Oriented Control (FOC) and Pulse Width Modulation (PWM) techniques.

8.1 Simplified Block Diagram

A high level block diagram of the electronics and motor assembly are shown in the figure below

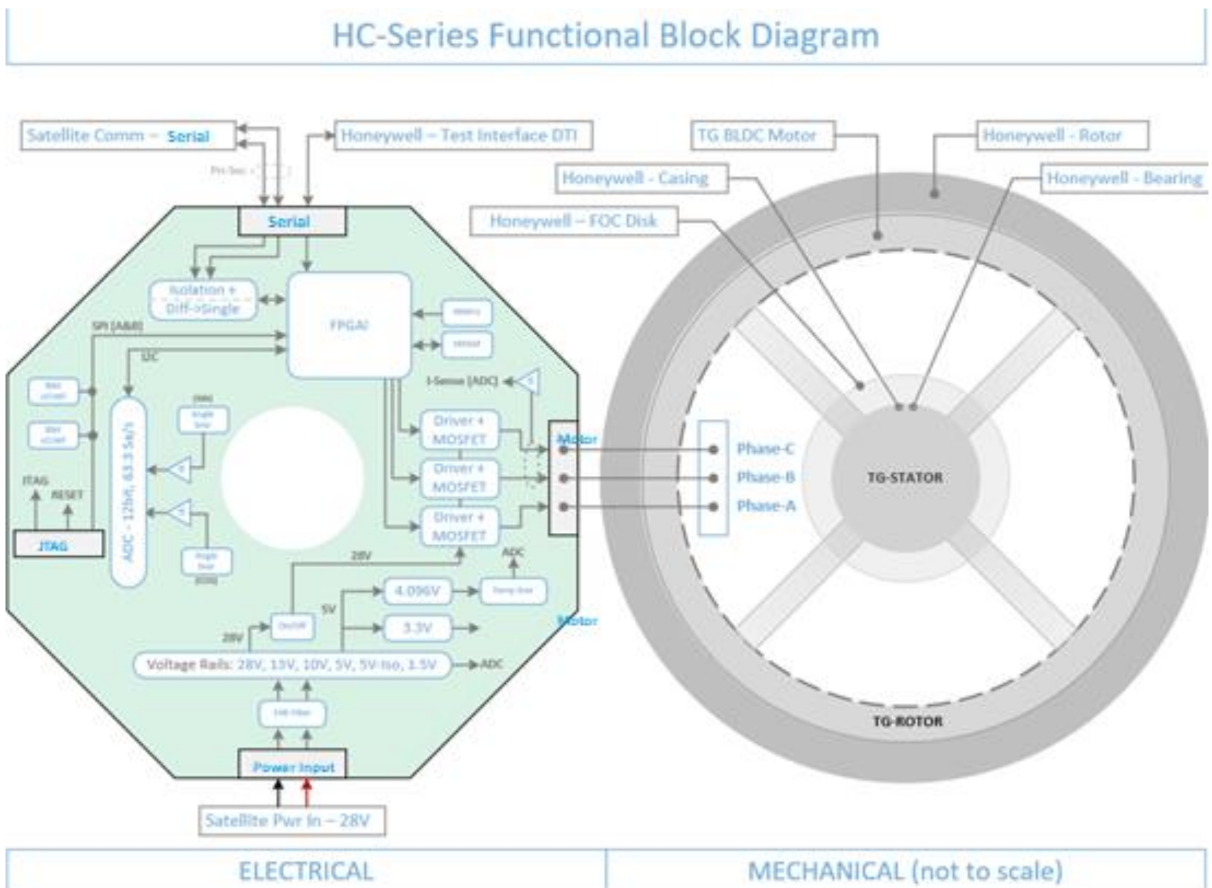


Figure 6 – Simplified Block Diagram

8.2 Simplified Motor Control Loop

The HC RWA controller is designed to produce a reaction torque on the vehicle. Refer to the figure below for the diagram. The user commands a reaction torque, which is limited to 300 mNm. The controller directly routes the commanded torque to the torque/current loop which reacts as a first order system with a bandwidth (f) of 200Hz. A friction compensation loop provides additional torque to overcome drag and other losses up to 50 mNm for a maximum motor torque of 350 mNm.

Note that commanded torque is equal to net reaction torque at the unit mounting surface due to the internal friction compensation loop (e.g., 150 mNm torque command results in 150 mNm net reaction torque on the vehicle).

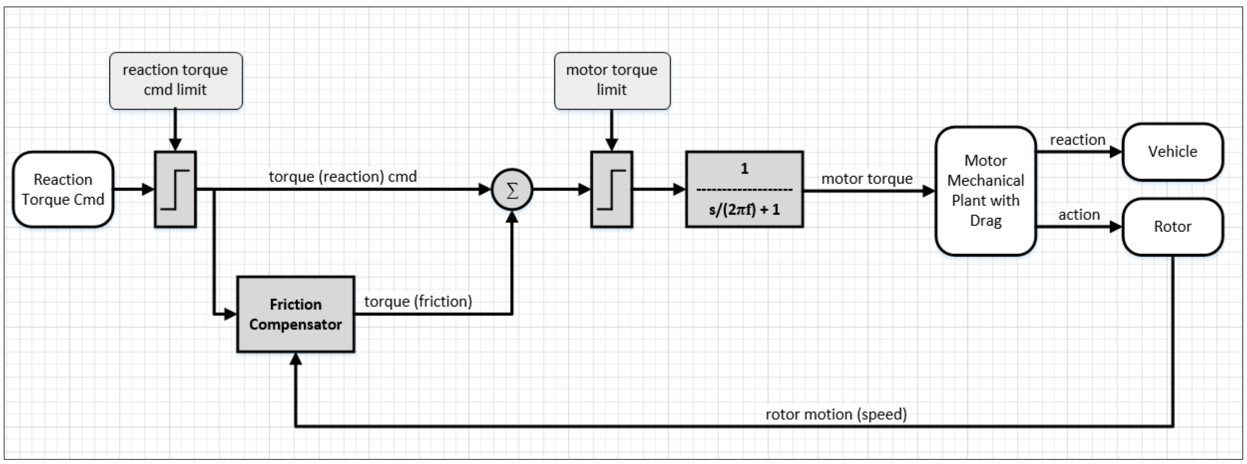


Figure 7 – Simplified Motor Control Loop Diagram

8.3 RS422/RS485 Interface Diagram

The RWA has two RS422/RS485 interfaces for external communication (primary and secondary). Each pair is DC-Coupled and AC-Filtered with shunt capacitors as shown in the diagram below. All communication signals are referenced to ISO-GND which is internally connected at a single point to chassis ground. Not shown is the digital isolation IC located between the FPGA and driver/receiver IC's.

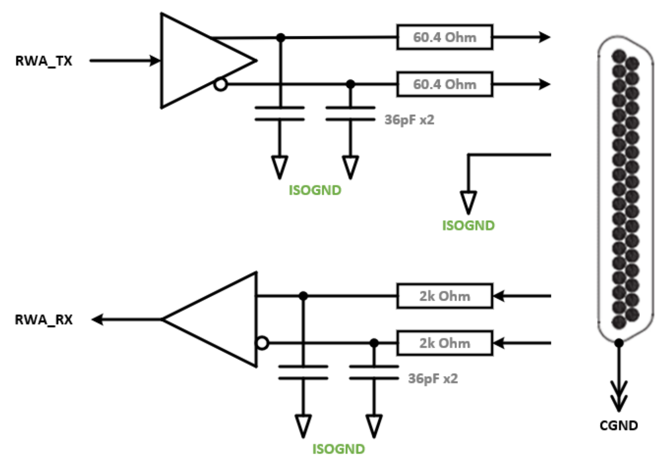


Figure 8 – RS422 Electrical Interface Diagram

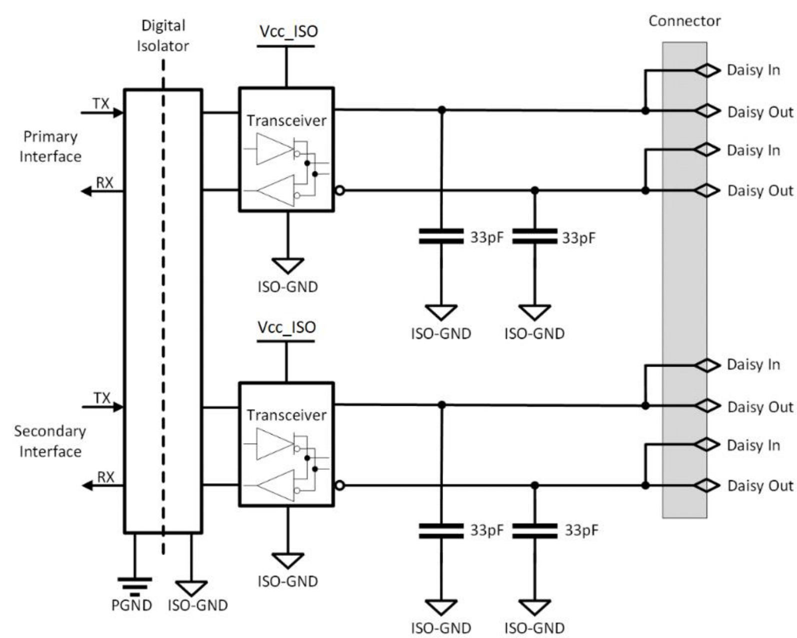


Figure 9 – RS485 Electrical Interface Diagram

8.4 Power Overview

Power flows between the spacecraft and RWA via the 31pin connector. The table below lists expected power consumption (and generation) over the speed range for various torque commands. Power consumption is represented by positive values while power returned to the spacecraft bus is represented by negative values.

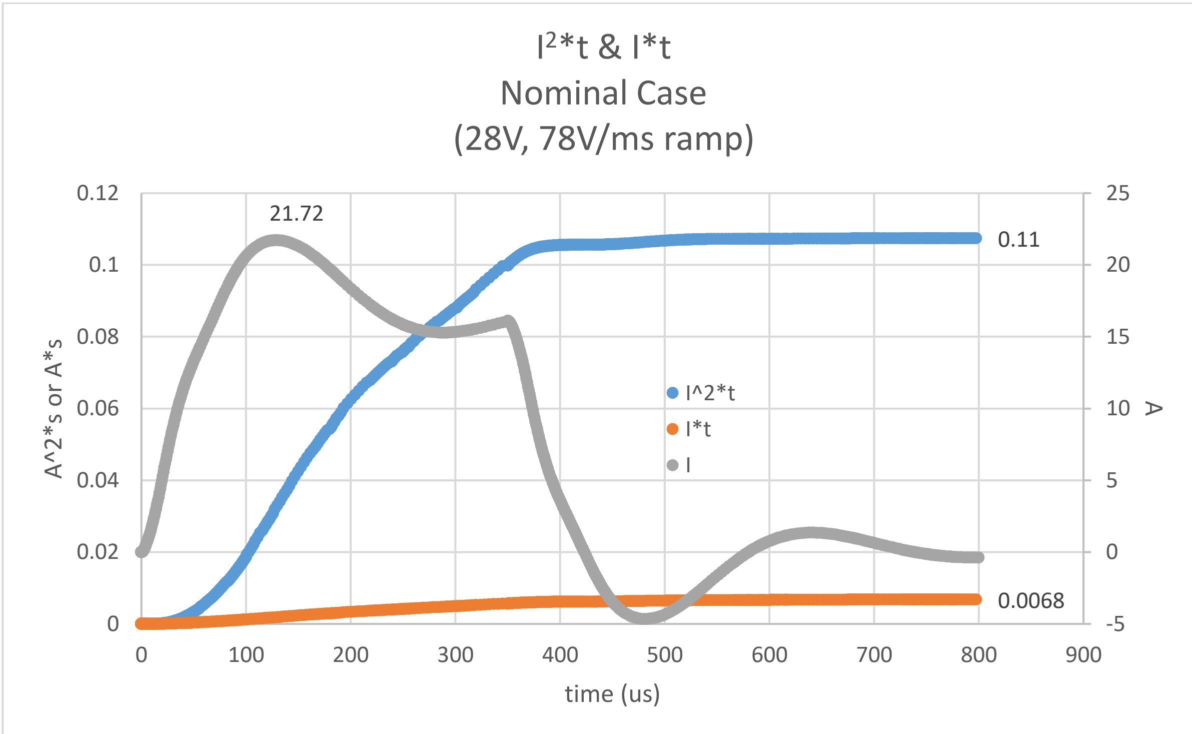
Note: There is no built-in command to power cycle the RWA. Power cycling can only be achieved by toggling the power input bus voltage off/on.

Table 13 – Power Consumption Table

[Table Pending Update]

8.5 In-Rush Current

See figures below for nominal and worst case in-rush. Honeywell recommends the bus ramp rate stay below 117V/ms with around 78V/ms being the nominal target in operation.



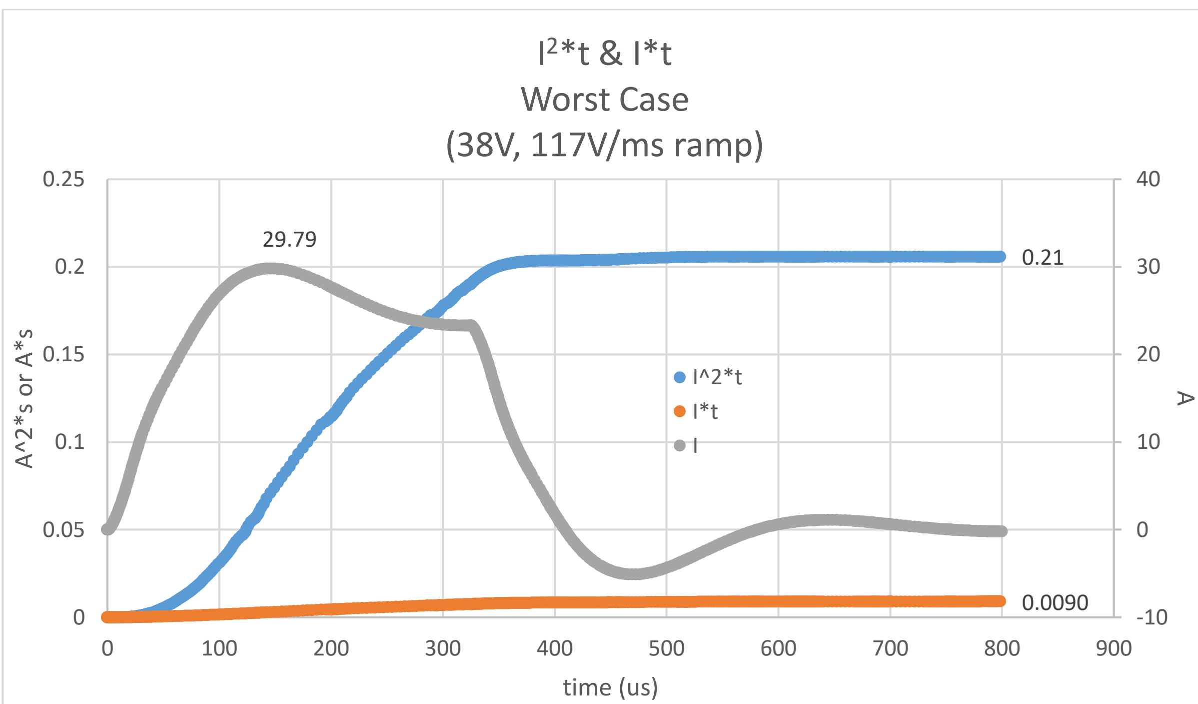


Figure 10 – Nominal and Worst Case In-Rush

8.6 Grounding Scheme

There are three grounds in the system: Power ground, chassis ground, and isolated ground (ISO-GND). Power and all motor circuitry are referenced to power ground. Communication signals are referenced to ISO-GND which is available at the external J1 connector. ISO-GND and chassis ground have a single point connection internal to the RWA. Refer to Figure 11 below for a diagram of the HC-series grounding scheme.

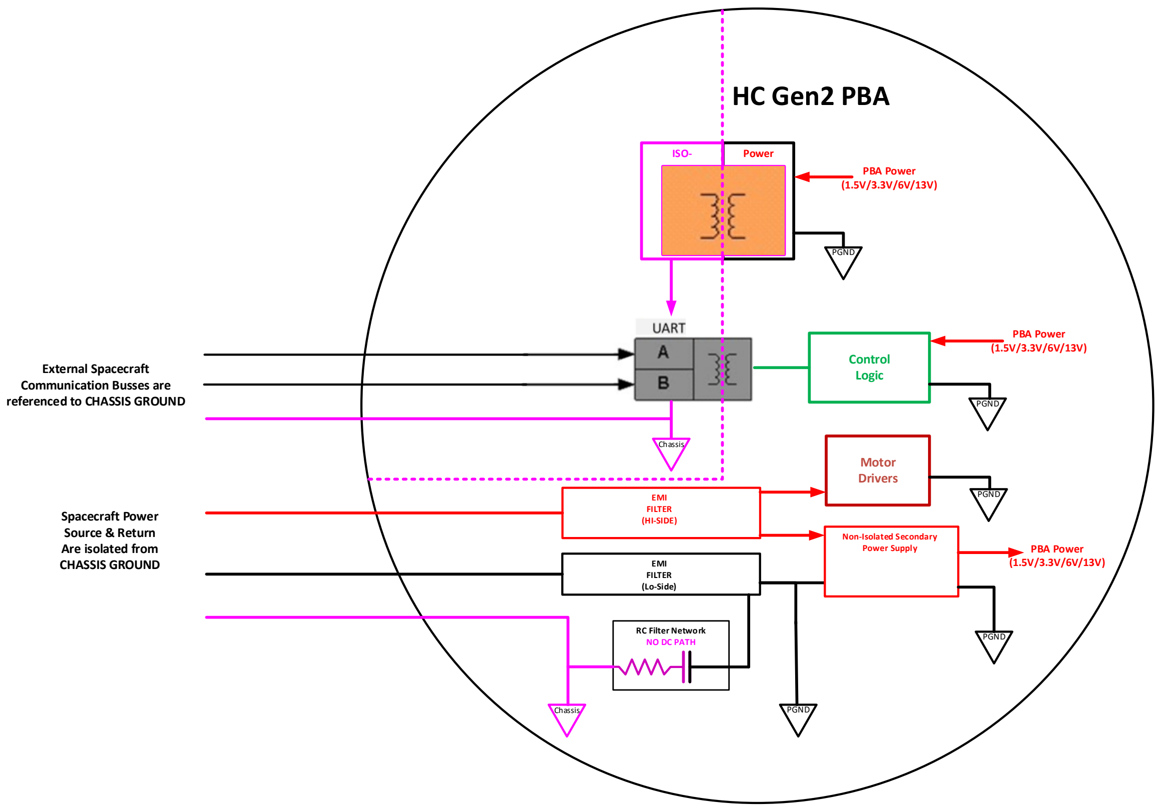


Figure 11 – Grounding Scheme Diagram

8.7 Reserved

8.8 Return Current

The RWA can and will act as both a generator and motor. Depending on the state of operation, the RWA will consume or source current to the spacecraft power bus.

The following operational modes must be considered

- The input bus must not be shorted (low impedance) while the wheel is spinning
    - High current may flow due to BEMF
    - Possible damage to RWA
- The RWA electronics may remain energized even when external power is removed (open) due to BEMF generated by the wheel
    - The wheel speed should be zero when cycling RWA power
    - If wheel speed is not zero, reset of electronics will be delayed
- Deceleration of the wheel may raise the bus voltage if the source impedance is too high
    - Overvoltage trip may occur
- Acceleration of the wheel may lower the bus voltage if the source impedance is too high
    - Undervoltage trip may occur

9 Communications API

The RWA communication interface to the spacecraft is through a single 31pin connector (refer to Section 7.2). In addition to serving as the communication interface, the connector also provides the input power and return path to/from the RWA/Spacecraft.

The communication scheme is based on a serial standard. The serial interface is a balanced data transmission scheme which offers a robust, high speed solution optimized for long distance transmission in a point-to-point noisy environment.

The RWA consists of two physically independent communication channels for each data transmission direction; receive and transmit (Rx/Tx). The primary is defined as "A" while the secondary "B". The spacecraft can switch between the primary and secondary channels at any time. Refer to Figure 12 below for a general overview of the signal chain.

Note: All digital ICs involved in the communication chain are powered via an isolated supply and are referenced to ISO-GND which is available as a dedicated pin on the 31-pin connector (preferred) or can be referenced to chassis ground.

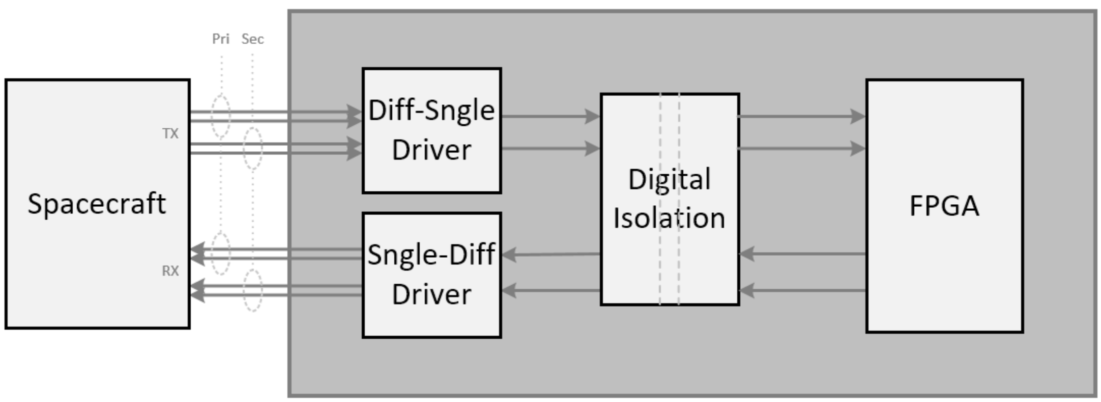


Figure 12 – Communication Signal Flow Diagram

It is important to note that the RWA strictly adheres to a Master-Slave arrangement where the Master is defined as the Spacecraft and the slave as the RWA. Therefore, all communication must be initiated by the spacecraft without exception. All messaging will follow the same general flow as shown in Figure 13 below.

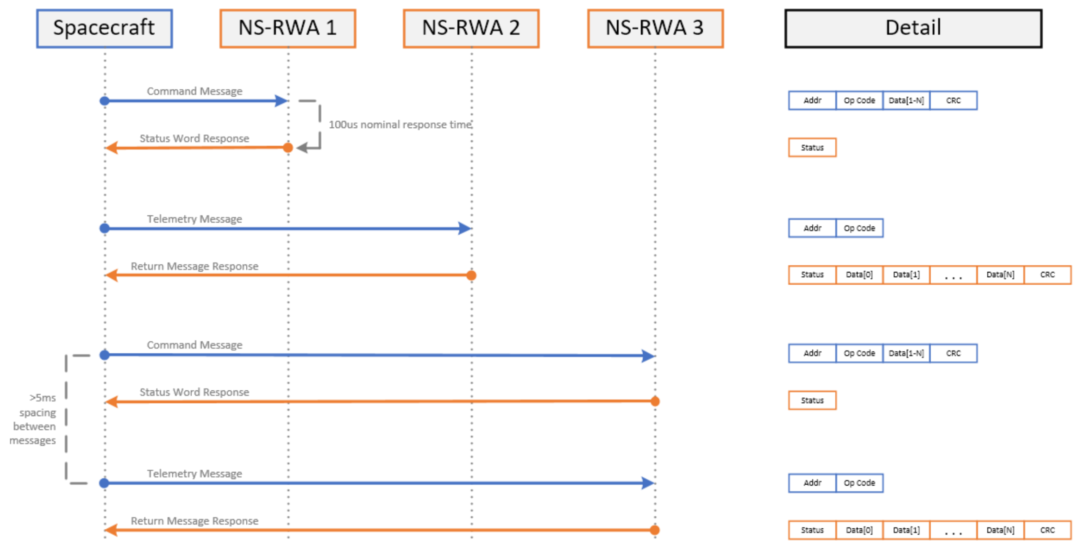


Figure 13 – Message Flow Diagram

The physical layer is realized by several discrete components as diagramed in Figure 13 above. As noted earlier, the physical layer ICs are all powered by an isolated voltage rail. The digital IO signals are isolated by a high-speed digital IC. The protocol layer is handled by the FPGA which is partitioned into two separate cores; the primary core is dedicated to motor control while the secondary core is reserved for communication.

The communication protocol commonly referred to as the link-layer is defined in this context as the electrical connection between the Spacecraft and each RWA that is mounted to and electrically connected with the Spacecraft. The messaging format, timing and constraints are detailed below.

9.1 Message Types

The RWA messages are grouped into two main categories: Commands and Telemetry. The command messages are further split into sub-categories; primary, secondary, memory, and engineering.

Note: All engineering commands are included in the flight release but are disabled before flight.

As shown above, the message content, format and return value are different between commands and telemetry. The exact format for each will be detailed below along with timing, constraints, addresses etc.

An overview of all messages currently supported are shown in Figure 14 below.

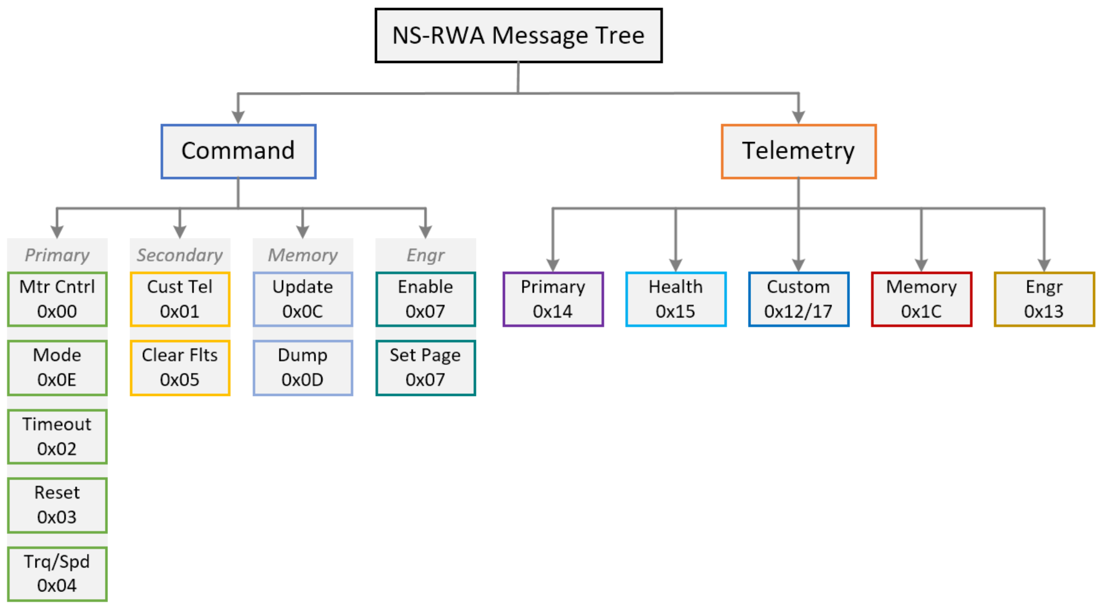


Figure 14 – Message Tree

9.2 Message Format, Timing and Addressing

This section provides information on format, timing, and other relevant parameters that are necessary and preliminary to more detailed information to follow.

Format

In this context, a word is defined as one start bit, 8 data bits, one parity bit, and one stop bit as shown below in Figure 15. Where the start bit is defined as active low, stop bit active high, and the parity bit is even. The standard bit rate is customer specific between 9600 bit/s to 125k bit/s.

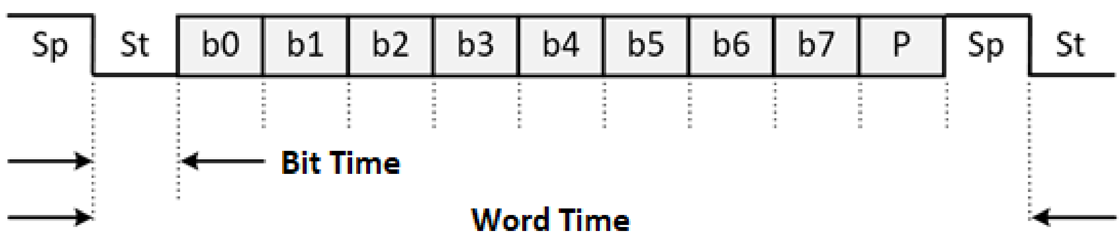


Figure 15 – Word Definition

Both the command and telemetry message frames are constructed using the above word definition as follows.

The command message consists of an address word, OpCode word, payload word(s) (may be zero length) always ending in a CRC word. The CRC is calculated as a bitwise XOR of each bit contained in the message. Upon receipt of any command from the spacecraft, a status word is returned by the RWA that serves as an acknowledgement.

The command message follows the format detailed below:

Note: Bit positions within the tables as bx, where bo is the lsb.

Words are transmitted Word[0], Word[1] … Word[n-1], Word[n].

32bit FP values are transmitted big-endian and have been noted in the frame definitions.

All other multi-byte values are transmitted little-endian.

Word 0										
b0	b1	b2	b3	b4	b5	b6	b7	b8	b9	b11
Start	ADR0	ADR1	ADR2	ADR3	ADR4	ADR5	ADR6	ADR7	Parity	Stop

Word 1										
Start	OC0	OC1	OC2	OC3	OC4	OC5	OC6	OC7	Parity	Stop

Word [2-N]										
Start	DAT0	DAT1	DAT2	DAT3	DAT4	DAT5	DAT6	DAT7	Parity	Stop

Word [N+3]										
Start	CRC0	CRC1	CRC2	CRC3	CRC4	CRC5	CRC6	CRC7	Parity	Stop

NS-RWA Response Time

Word 0										
b0	b1	b2	b3	b4	b5	b6	b7	b8	b9	b11
Start	STS0	STS1	STS2	STS3	STS4	STS5	STS6	STS7	Parity	Stop

Figure 16 – Command Message Format

Where:

ADR[0-7] 8bit address of the RWA

OC[0-7] Command OpCode

DAT[0-7] Payload data. May be multiple words. May be zero words. Message dependent

CRC[0-7] 8bit CRC value

STS[0-7] 8bit status word returned by the RWA

In the context of RWA comm messaging, a frame shall be defined as the contiguous collection of one or more words that comprise a command or telemetry message.

The telemetry message follows the format detailed below:

Word 0										
b0	b1	b2	b3	b4	b5	b6	b7	b8	b9	b11
Start	ADR0	ADR1	ADR2	ADR3	ADR4	ADR5	ADR6	ADR7	Parity	Stop

Word 1										
Start	OC0	OC1	OC2	OC3	OC4	OC5	OC6	OC7	Parity	Stop

NS-RWA Response Time

Word 0										
b0	b1	b2	b3	b4	b5	b6	b7	b8	b9	b11
Start	STS0	STS1	STS2	STS3	STS4	STS5	STS6	STS7	Parity	Stop

Word [1-N]										
Start	DAT0	DAT1	DAT2	DAT3	DAT4	DAT5	DAT6	DAT7	Parity	Stop

Word [N+2]										
Start	CRC0	CRC1	CRC2	CRC3	CRC4	CRC5	CRC6	CRC7	Parity	Stop

Figure 17 – Telemetry Message Format

Where:

ADR[0-7] 8bit address of the RWA

OC[0-7] Telemetry OpCode

DAT[0-7] Payload data. May be multiple words. May be zero words. Message dependent

CRC[0-7] 8bit CRC value

STS[0-7] 8bit status word returned buy the RWA (see below)

The status word will be the first word returned by the RWA after receipt of a command or telemetry message. In the case of a command message, it will be the ONLY response. In the case of a telemetry message, the RWA will likely respond with status and payload data depending on the exact telemetry frame.

The status word content and format are shown below:

Word 0										
b0	b1	b2	b3	b4	b5	b6	b7	b8	b9	b10
Start	STS0	STS1	STS2	STS3	STS4	STS5	STS6	STS7	Parity	Stop

Figure 18 – Status Word Content

Where:

b[0]	Start bit
b[1]	Reserved
b[2-6]	Last command OpCode echo back
b[7]	Fault status
	0 = No Fault
	1 = Fault status has been flagged. Details about fault contained in the Health & Status message
b[8]	Current operation mode
	0 = operate mode
	1 = standby mode
b[9]	Parity bit - even
b[10]	Stop bit

Timing

Back-to-back command messages, to the same RWA, must be spaced at least 5ms apart. Similarly, back-to-back telemetry messages, must be spaced such that the preceding telemetry message must have been processed and payload data sent before the next telemetry request is issued.

For multi-word messages, no time gaps are allowed between the stop bit of the previous word and the start bit of the following word.

Addressing

The RWA is shipped from the factory with default address 0x04. The RWA address is configurable at any time by the spacecraft or manufacturing software.

9.3 Command Messages

This section provides a detailed explanation of each command message supported by the RWA.

It is intended to serve as the RWA programmers guide.

Motor Control

Summary This command enables/disables the motor

OpCode 0x00

Applicability While in operate mode only

Frame Length 11 words

Message Frame

Word 0	Word 1	Word 2	Word 3	...	Word 9	Word 10
ADR0	OC0	DAT0	DAT1	...	DAT7	CRC0

Where:

ADR0	RWA Address	
OC0	Command OpCode	
DAT[0]	b[0]	0=disable, 1=enable
	b[1-7]	Unused - reserved
DAT[1-7]	Unused - reserved	
CRC0	Checksum per definition above	

Return Word(s) 1 status word per definition above

Example

Mode Control

Summary This command transitions the RWA from Standby to Operate mode.

Note: Motor will be enabled upon entering operate mode

OpCode 0x0E

Applicability While in standby mode only

Frame Length 3 words

Message Frame

Word 0	Word 1	Word 2
ADR0	OC0	CRC0

Where:

ADR0	RWA Address
OC0	Command OpCode No Payload for this command
CRC0	Checksum per definition above

Return Word(s) 1 status word per definition above

Example

Speed/Torque Timeout Monitor

Summary This command enables/disables the speed/torque timeout monitor feature. If enabled, the timeout routine monitors the elapsed time between successive speed/torque commands. If the elapsed time exceeds 110ms the timeout flag will be asserted, and the current speed will be maintained until the next speed/torque command. The flag will remain asserted until explicitly cleared by the spacecraft.

OpCode 0x02

Applicability While in operate mode only

Frame Length 4 words

Message Frame

Word 0	Word 1	Word 2	Word 3
ADR0	OC0	DAT0	CRC0

Where:

ADR0	RWA Address	
OC0	Command OpCode	
DAT0	b[0]	0=timeout disabled, 1=timeout enabled
	b[1-7]	Unused - reserved
CRC0	Checksum per definition above	

Return Word(s) 1 status word per definition above

Example

Reset Control

Summary

This command resets the RWA, disables the motor, and places the RWA in standby mode. After reset, it can take up to 1s to complete a reboot before communications can resume.

Note: If the motor is spinning it will coast down until the mode is again set to operate. Once in operate mode, the current speed will be held.

OpCode

0x03

Applicability

While in operate mode only

Frame Length

4 words

Message Frame

Word 0	Word 1	Word 2	Word 3
ADR0	OC0	DAT0	CRC0

Where:

ADR0	RWA Address
OC0	Command OpCode
DAT0	Must be 0x5D. Otherwise command is ignored
CRC0	Checksum per definition above

Return Word(s)

1 status word per definition above

Example

Torque and Speed Control

Summary This command sets the operating speed or torque depending on command type specified in word DAT0.

Note: Either speed or torque can be commanded -not both.

OpCode 0x04

Applicability While in operate mode only

Frame Length 8 words

Message Frame

Word 0	Word 1	Word 2	Word 3	...	Word 6	Word 7
ADR0	OC0	DAT0	DAT1	...	DAT4	CRC0

Where:

ADR0	RWA Address	
OC0	Command OpCode	
DAT[0]	b[0]	0=torque mode, 1=speed mode
	b[1-7]	Unused, reserved
DAT[1-4]	32bit FP value Torque/Speed value. Big endian. Units: Nm/RPM	
CRC0	Checksum per definition above	

Return Word(s) 1 status word per definition above

Example

Clear Faults

Summary This command clears the fault flags in the Health & Status message. This is the only command that will clear a fault that resulted in disabling the motor. Faults must be cleared before the motor can be re-enabled. An example of faults that must be cleared are; overcurrent, overvoltage, undervoltage etc.

OpCode 0x05

Applicability While in operate mode only

Frame Length 5 words

Message Frame

Word 0	Word 1	Word 2	Word 3	Word 4
ADR0	OC0	DAT0	DAT1	CRC0

Where:

ADR0 RWA Address

OC0 Command OpCode

DAT[0-1] 16bit Int value. Writing 65535 clears all bits. Writing a ‘1’ to any bit position clears the flag associated with that position

CRC0 Checksum per definition above

Return Word(s) 1 status word per definition above

Example

Change RWA Address

Summary This command writes the specified address to RWA MRAM. Note that this command will only be accepted while RWA is in "standby" mode. After issuing a new address, the RWA must be reset for the new address to take effect. Resetting the RWA can be accomplished in one of two ways: 1) cycling power to the RWA or 2) put the RWA in "normal" mode (must issue command using the previous address) and then sending the reset command (0x03) also using the previous address. Once the RWA returns from reset, the new address will be in effect and will remain unchanged unless and until a new RWA change address command is issued.

OpCode 0x0C

Applicability While in standby mode only

Frame Length 35 words

Message Frame

Word 0	Word 1	Words[2-33]	Word 34
ADR0	OC0	DAT[0-31]	CRC0

Where:

ADR0 RWA Address (previous address)
OC0 Command OpCode
DAT[0] 0xFC. MRAM address LSB
DAT[1] 0xFF MRAM address
DAT[2] 0xFF MRAM address MSB
DAT[3] 0x04 Num of Bytes. Must be 0x04
DAT[4] 8bit Int value representing the new RWA address. Only the lower 5 bits are used allowing for 32 possible addresses.
DAT[5-31] 8bit Int values. Should be 0x00.
CRC0 Checksum per definition above

Return Word(s) 1 status word per definition above

Example

9.4 Telemetry Messages

This section provides a detailed explanation of each telemetry message returned by the RWA. It is intended to serve as the RWA programmers guide.

Primary Telemetry

Summary This telemetry type returns key operational parameters of the RWA.

OpCode 0x14

Applicability While in operate mode only

Frame Length 2 words

Message Frame

Word 0	Word 1
ADR0	OC0

Where:

ADR0 RWA Address

OC0 Command OpCode

Return Frame 11 words

Telemetry Frame

Word 0	Word 1	Word 2	...	Word 9	Word 10
STS0	DAT0	DAT1	...	DAT8	CRC0

Where:

STS0	Status word per definition above	
DAT[0]	b[0]	Motor State: 0=disabled. 1=enabled
	b[1-2]	Control mode: 0=Torque. 1=Speed
	b[3]	Fault Flag. Cleared after every read
	b[4]	Timeout Flag. Refer to Section 9.3 above
	b[5]	Timeout State. 0=disabled. 1=enabled
	b[6-7]	Unused - reserved

DAT[1-4] 32bit FP value for drag torque in Nm. Big endian

Difference between spacecraft commanded torque and torque value required to meet commanded torque

DAT[5-8] 32bit FP value for speed in RPM. Big endian

CRC0 Checksum per definition above

Health and Status Telemetry

Summary

The RWA continuously monitors critical operational parameters to aid in detecting potential damaging conditions that may impact normal operation. Monitoring is done in real time and does not require spacecraft intervention. Upon detecting potentially harmful conditions, the RWA shuts down various hardware elements (motor for example) as appropriate and flags the offending fault condition in the Health and Status telemetry frame.

Note: These fault conditions are not self-clearing and require the spacecraft to clear the flag and cycle the motor-enable command to re-enable the motor.

The spacecraft can retrieve the H&S telemetry frame at any time. The fault thresholds can be found in Section 5.6.

OpCode

0x15

Applicability

While in operate mode only

Frame Length

2 words

Message Frame

Word 0	Word 1
ADR0	OC0

Where:

ADR0	RWA Address
OC0	Command OpCode

Return Frame

21 words

Telemetry Frame

Word 0	Word 1	Word 2	...	Word 19	Word 20
STS0	DAT0	DAT1	...	DAT18	CRC0

Where:

STS0	Status word per definition above	
DAT[0]	Last command processed by the RWA	
DAT[1-3]	Unused - reserved	
DAT[4]	b[0]	MRAM State. 0=disabled. 1=enabled
	b[1-7]	Unused - reserved
DAT[5]	b[0]	Over-current error flag
	b[1]	Bus over-voltage error flag
	b[2]	Bus under-voltage error flag
	b[3]	Unused - reserved
	b[4]	Unused - reserved
	b[5]	Angular Position
	b[6]	Unused - reserved
	b[7]	Wheel over-speed error flag
DAT[6]	b[0]	Unused - reserved
	b[1]	Unused - reserved
	b[2]	Unused - reserved
	b[3-7]	Unused - reserved
DAT[7-10]	32bit FP value for bus voltage in V. Big endian	
DAT[11-14]	32bit FP value for bus current in A. Big endian	
DAT[15-18]	32bit FP value for board temperature in DegC. Big endian	
CRC0	Checksum per definition above	

10 Security Manual

Honeywell Product Security: We take security concerns seriously and work to quickly evaluate and address them. Once reported, we commit the appropriate resources to analyze, validate and provide corrective actions to address the issue. Honeywell Security Policy Reference: https://www.honeywell.com/us/en/product-security

Incident Reporting: To report a suspected security vulnerability or device behavior suspected to be related to device security please notify Honeywell by following instructions at the following website: https://www.honeywell.com/us/en/product-security#vulnerability-reporting

End of Document