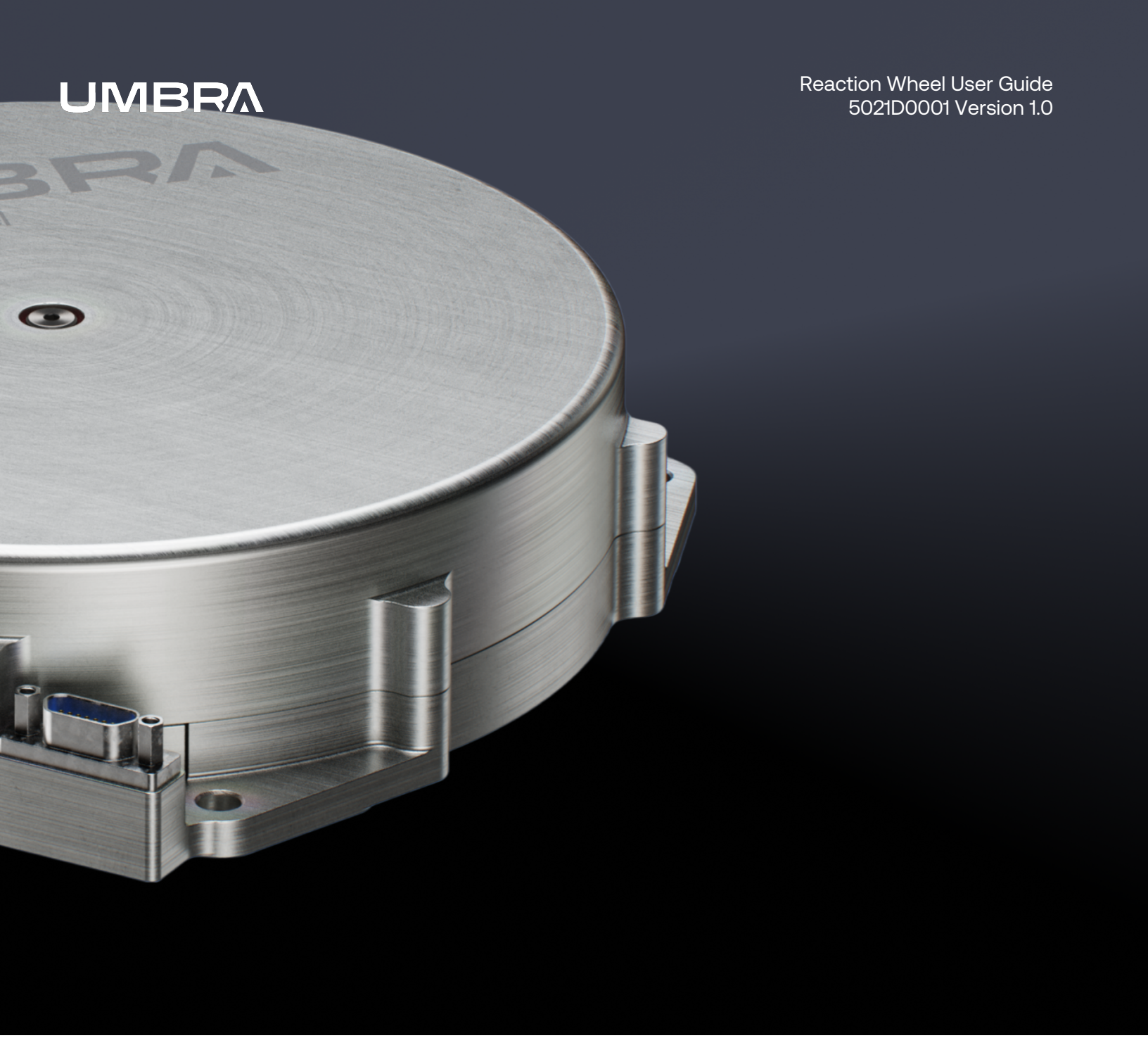


Reaction Wheel User Guide

Distribution Statement

No Restrictions

Export Control

No US Export Control Information

Table of Contents

Figures

Tables

1.0 Objective

This document provides user guidance for the integration of the Umbra Reaction Wheel.

The Umbra Reaction Wheel is a precision-controlled motorized flywheel used to control a spacecraft's attitude by accelerating or decelerating the flywheel's spin, which induces a reaction torque that rotates the spacecraft through conservation of angular momentum.

2.0 Document References

This section contains the document number and description for documents that are referenced herein.

2.1 Umbra Documents

5021H60000	2 NMS REACTION WHEEL MICD

2.2 Standard Documents

ANSI/ESD S20.20-2021	PROTECTION OF ELECTRICAL AND ELECTRONIC PARTS, ASSEMBLIES, AND EQUIPMENT
49 CFR 172	CODE OF FEDERAL REGULATIONS HAZARDOUS MATERIALS TABLE
GSFC-STD-7000	GENERAL ENVIRONMENTAL VERIFICATION STANDARD (GEVS)
IEEE-754	IEEE STANDARD FOR FLOATING-POINT ARITHMETIC
MIL-STD-461	MILITARY STANDARD: ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS REQUIREMENTS FOR EQUIPMENT
SAE-AS22759	WIRE, ELECTRICAL, FLUOROPOLYMER-INSULATED, COPPER OR COPPER ALLOY
SAE-AS50881	WIRING, AEROSPACE VEHICLE

3.0 Document Authority

In the case of a conflict between any dimensional, mounting pattern, or pinout information defined within this document and other information sources, the released mechanical and electrical drawings in Appendix B shall supersede this document.

3.1 Revision Notes

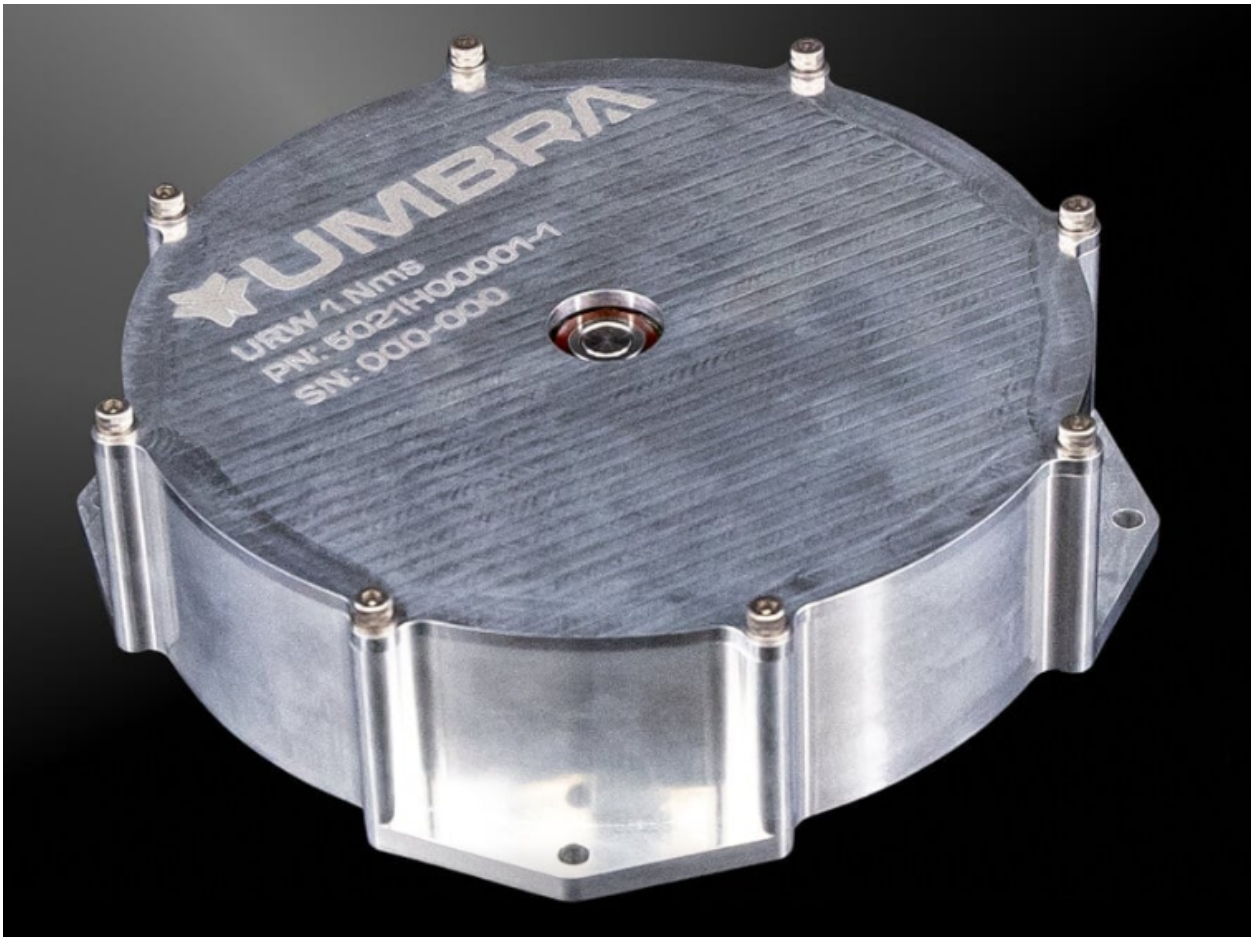
This document is Version 1.0.

3.2 Document Disclaimer

DISCLAIMER: This User Guide is intended to provide a brief summary of our knowledge and guidance regarding the use of this item. The information contained herein has been compiled from sources considered by Umbra to be dependable and is accurate to the best of Umbra's knowledge. It is not meant to be an all-inclusive document on worldwide hazard communication regulations. This information is offered in good faith. Each user of this material needs to evaluate the conditions of use and design the appropriate protective mechanisms to prevent employee exposure, personal injury, property damage or release to the environment of any hazardous substances. Umbra assumes no responsibility for injury, damage, or loss sustained by the recipient or third persons or for any damage to any property resulting from misuse of the product. Purchase and use of the product(s) identified herein are governed by the terms of sale under which you purchase the product(s) from Umbra.

4.0 Hardware Handling

Figure 1. Umbra Reaction Wheel



4.1 Mechanical Handling

Contact Umbra if any Umbra Reaction Wheel fails any procedure as described in this document. Do not continue use of any Umbra Reaction Wheel with a suspected failure.
Ensure that any transportation of the Umbra Reaction Wheel occurs in an environment described in Section 4.5 Storage and Transport Environment.

Do not drop the Umbra Reaction Wheel.

Only lift Umbra Reaction Wheel by the chassis.

Do not lift the Umbra Reaction Wheel by any attached harness.

Do not disassemble the Umbra Reaction Wheel.

Do not transport the Umbra Reaction Wheel while it is powered on. Only power on the Umbra Reaction Wheel while it is securely mounted to avoid damage to personnel and property.

4.1.1 Hazards

The Umbra Reaction Wheel does not contain any hazardous materials as defined by 49 CFR 172.

4.1.2 ESD Sensitivity

The Umbra Reaction Wheel is electrostatic discharge (ESD) sensitive.

Failure to follow ESD requirements and recommendations may result in damage to components and/or personnel injury.

Follow ANSI/ESD S20.20 while handling ESD sensitive components.

4.1.3 Unpacking

- Check shock detection stickers
- Remove from protective case
- Perform visual inspection for damage
- Take pictures as received
- There are no cleanliness requirements or contamination risks

4.2 RBF/ Red Tag GSE

Item(s) listed in Table 1 must be removed before flight.

Table 1. RBF Items

Item	Critical/Optional
J1 Connector Dust Cap	Critical

See Appendix B for more information.

4.3 Electrical Mate/Demate

Table 2. Electrical Connectors

Connector Designator	Assembly Connector	Mating Flight Connector
J1	MMDS-015	MMDP-015

See Section 5.1 Connector Pinouts for more information.

4.4 Connector Strain

It is recommended to secure all harnessing interfacing to the Umbra Reaction Wheel per the guidance found in SAE-AS50881 which describes guidance on the installation of wiring harnesses.

4.5 Storage and Transport Environment

Do not store the Umbra Reaction Wheel in direct sunlight.

Do not store the Umbra Reaction Wheel in such a way that damages part markings.

Ensure that critical RBF components are in place during all transport of the Umbra Reaction Wheel.

Table 3. Storage Environment

Parameter	Value
Storage Temperature	5°C to 30°C
Storage Humidity	< 50% Relative Humidity

4.6 Operating Environment

Table 4. Operating Environment

Parameter	Value
Operating Temperature	-34°C to 70°C

4.7 Survival Environment

Table 5. Survival Environment

Parameter	Value
Survival Temperature:	-34°C to 80°C
Random Vibration	Qualified to 14.16 Grms profile enveloping GEVS, Falcon 9, SpaceX Rideshare, and Electron levels
Shock	Qualified to 1000g peak profile enveloping GEVS, Falcon 9, SpaceX Rideshare, and Electron levels
Minimum Survivable Total Ionizing Dose	Designed to withstand at least 30 krad TID

4.8 Mounting Information

See Appendix B for information on mounting the Umbra Reaction Wheel.

Pay careful attention to orientation of the reaction wheels during integration.

Three or more Umbra Reaction Wheels are required for three-axis spacecraft control. Umbra recommends the use of reaction control systems such as the Umbra Magnetorquer for Reaction Wheel desaturation.

5.0 Electrical Properties

Table 6. Electrical Properties

Property	Typical Value	Notes
Operating Voltage Range	28 ± 4 V	Nominal Voltage: 28 V
Steady State Power Draw	5 W	
Maximum Power Draw	100 W	At maximum torque

5.1 Connector Pinouts

See Section 6.0 Software Properties for more information on signal packet structure.

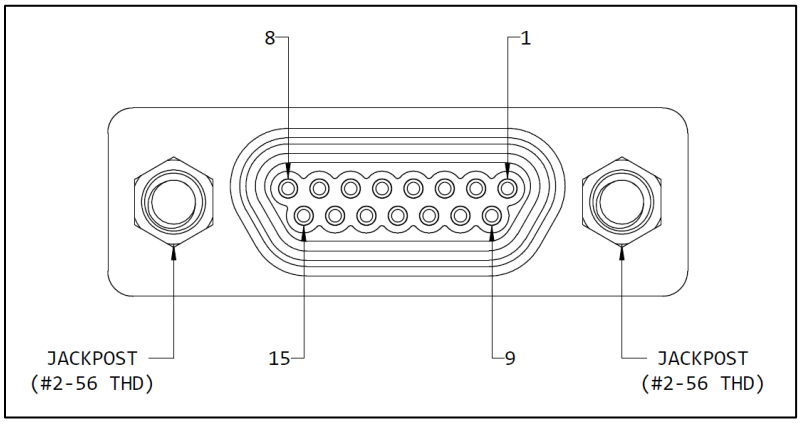
The Umbra Reaction Wheel J1 connector (MMDS-015) is shown in Appendix B. Refer to Table 7 for pinout and Figure 2 for the mating face view.

Table 7. J1 Connector Pinout

PIN	SIGNAL
1	ADDR1
2	ADDR2
3	CHASSIS
4	RS485_FC_TO_WHEEL_P
5	CHASSIS
6	GND
7	GND
8	28V_BOARD
9	ADDR0
10	RS485_WHEEL_TO_FC_N
11	RS485_WHEEL_TO_FC_P
12	RS485_FC_TO_WHEEL_N
13	GND
14	28V_BOARD
15	28V_BOARD

The assembly's connector body is electrically connected to CHASSIS ground and isolated from GND (power ground). The harness connector body and backshell should be isolated from GND as well – they will be electrically bonded to CHASSIS ground through the mating jackposts and jackscrews.

Figure 2. MMDS-015 Connector Mating Face View

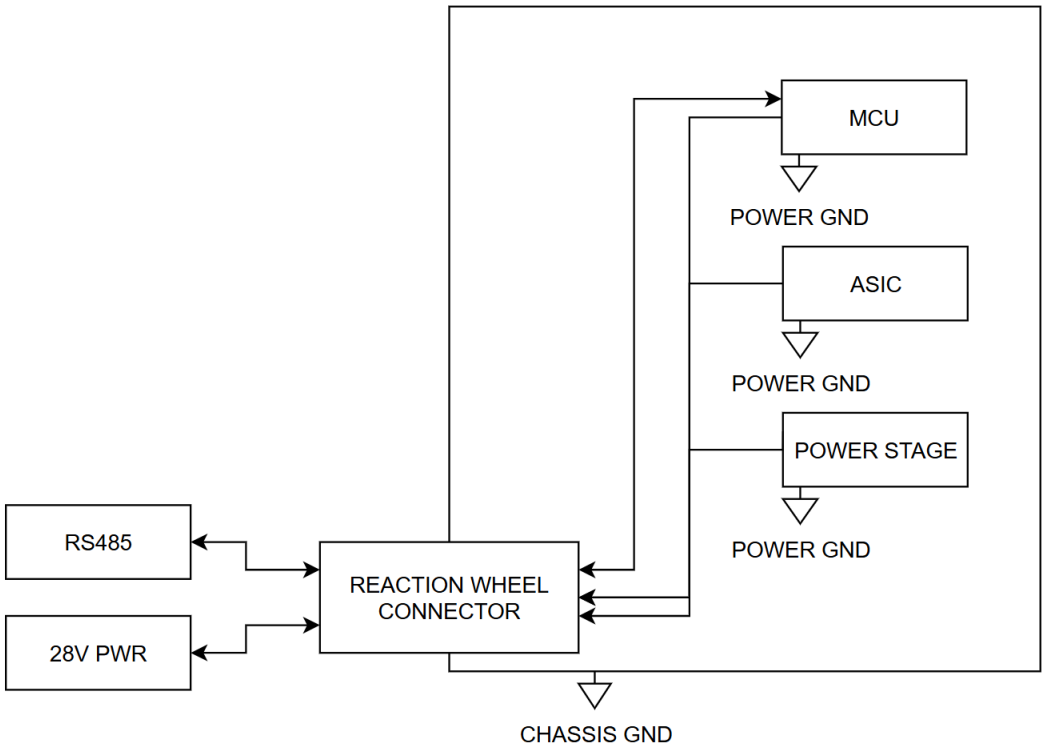


5.2 Harnessing Recommendations

Space-rated harnesses connecting to the Umbra Reaction Wheel should use wire following SAE AS22759. Umbra recommends the use of 24AWG wire.

5.3 Grounding Block Diagram

Figure 3. Reaction Wheel Grounding Diagram



5.4 EMI/EMC Properties

The Umbra Reaction Wheel contains an electromagnetic brushless DC motor, hence it does emit electromagnetic fields. The Umbra Reaction Wheel has not been tested for Electromagnetic Interference (EMI) / Electromagnetic Compatibility (EMC) per MIL-STD-461. It has been successfully tested for self compatibility with X-Band, S-Band, and L-Band radios. Contact Umbra for more information.

5.5 Material Properties

All Umbra products are manufactured from materials deemed space-rated based on low outgassing. See Appendix B for more information on material properties of the Umbra Reaction Wheel.

6.0 Software Properties

The Umbra Reaction Wheel must be connected to a GNC computer for spacecraft control. The Umbra Reaction Wheel may be commanded to achieve user-defined speed or torque values as described in this section.

6.1 Communication Parameters

6.1.1 Physical Layer

Umbra Reaction Wheel communication uses RS-485.

6.1.2 Communication Protocols

Datagrams are slip encoded with CCIT16 CRC error detection.

6.2 Telemetry

Umbra recommends using the **PING** and **READ_FILE** commands to acquire state of health and performance information about the Umbra Reaction Wheel as described in 6.3.2 Commands.

In Table 8. DRW Memory Map, R/W indicates the “Read/Write” access of the base address while R indicates “Read” only access. In this table, Y indicates Yes and N indicates No.

Table 8. DRW Memory Map

Base Address (hex)	Description	Length (bytes)	Format	R/W	Non-Volatile
0x0	Bootloader retries count (from most recent reset)	4	32-bit unsigned integer	R	N
0x4	Serial number	4	32-bit unsigned integer	R	Y
0x8	RS485-0 NSP Framing error count	4	32-bit unsigned integer	R	N
0xC	RS485-0 Runt count	4	32-bit unsigned integer	R	N
0x10	RS485-0 Oversize count	4	32-bit unsigned integer	R	N

Base Address (hex)	Description	Length (bytes)	Format	R/W	Non-Volatile
0x14	RS485-0 Bad CRC count	4	32-bit unsigned integer	R	N
0x18	RS485-0 FIFO overflow count	4	32-bit unsigned integer	R	N
0x1C	Uptime counter	4	Centi-sec (32-bit unsigned integer)	R	N
0x20	RS485-0 Incoming count	4	32-bit unsigned integer	R	N
0x24	RS485-0 Outgoing count	4	32-bit unsigned integer	R	N
0x28	V_BUS	4	Volts (IEEE-754)	R	N
0x2C	V_MOTOR	4	Volts (IEEE-754)	R	N
0x30	V_VCC	4	Volts (IEEE-754)	R	N
0x34	TEMP0	4	°C (IEEE-754)	R	N
0x38	TEMP1	4	°C (IEEE-754)	R	N
0x3C	TEMP2	4	°C (IEEE-754)	R	N
0x40	TEMP3	4	°C (IEEE-754)	R	N
0x44	SPEED	4	Rad/sec (IEEE-754)	R	N
0x48	PHASE_CURRENT	2	mA Signed 16 bit integer	R	N
0x4C	COMMANDED_PHASE_CURRENT	4	Amps (IEEE-754)	R	N
0x4E	COMMANDED_SPEED	4	RPM Float	R/W	N
0x52	COMMANDED_TORQUE	4	Nm Float	R/W	N
0x56	CONTROL_TYPE	2	Control Mode, 0x0-idle, 0x1-speed, 0x2-torque See 6.5 Modes	R/W	N
0x5A	LIMIT_SPEED	4	Rad/sec 32 bit unsigned integer	R/W	Y
0x5C	LIMIT_PHASE_CURRENT	4	mA Signed 32 bit integer	R/W	Y
0x60	SPEED_P_GAIN	2	Signed 16 bit integer	R/W	Y
0x64	SPEED_I_GAIN	2	Signed 16 bit integer	R/W	Y
0x66	SPEED_D_GAIN	2	Signed 16 bit integer	R/W	Y
0x68	TORQUE_P_GAIN	2	Signed 16 bit integer	R/W	Y
0x6A	TORQUE_I_GAIN	2	Signed 16 bit integer	R/W	Y
0x6C	FLUX_P_GAIN	2	Signed 16 bit integer	R/W	Y
0x6E	FLUX_I_GAIN	2	Signed 16 bit integer	R/W	Y
0x70	FAULT_OVERTEMP_THRESH	4	°C (IEEE-754)	R/W	Y
0x72	FAULT_UNDERTEMP_THRESH	4	°C (IEEE-754)	R/W	Y
0x76	FAULT_OVERCURRENT_THRESH	4	Amps (IEEE-74)	R/W	Y
0x7A	RESET_ENABLE	2	16-bit bitmap	R/W	Y
0x7E	STARTUP DELAY	2	ms 16-bit integer	R/W	Y

6.3 Commanding

6.3.1 Commanding Packet Format

The commanding packet format is to be defined.

6.3.2 Commands

Table 9. Reaction Wheel Commands

Name	Command Code	Description
PING	0x00	Returns device type and manufacturer, compile time, bootloader date, and compile time of application
PEEK	0x02	Reads device memory at provided address, returning the requested number of bytes
POKE	0x03	Writes device memory at provided address
CRC	0x06	Calculates checksum on requested area of memory
READ_FILE	0x07	Returns one or more 4 byte "files" from wheel at the requested address
WRITE_FILE	0x08	Writes one or more 4 byte "files" to wheel at the requested address

The commands **POKE** and **WRITE_FILE** are limited to writing only to memory addresses with read/write access as indicated in Table 8. DRW Memory Map.

6.4 Error Mitigation

Umbra recommends monitoring telemetry listed in Table 8. DRW Memory Map.

The Umbra Reaction Wheel can be rebooted for error recovery. RESET_ENABLE values determine which faults lead to automatic reboots for error recovery. The STARTUP_DELAY value determines how much time remains until the Umbra Reaction Wheel is actuated. This value will reset to the recommended delay upon startup of the Umbra Reaction Wheel to allow the Umbra Reaction Wheel to despin before new commanding if the Umbra Reaction Wheel reboots while saturated. The Umbra Reaction Wheel performs a self-test on boot to check for faults as described in this section.

Following any fault or boot, the Umbra Reaction Wheel will enter “idle” mode.

FAULT_OVERTEMP_THRESH and FAULT_UNDERTEMP_THRESH will activate if any temperature sensed of TEMP0, TEMP1, TEMP2, and TEMP3 are outside nominal range. Umbra recommends users enter “idle” mode on the Umbra Reaction Wheel while either fault is active. Umbra recommends customers retain default temperature fault thresholds.

FAULT_OVERCURRENT_THRESH checks the absolute value of PHASE_CURRENT. Umbra recommends users reboot the system if a fault is detected. Umbra recommends customers retain default current fault thresholds.

6.5 Modes

The value CONTROL_TYPE as described in Table 8. DRW Memory Map is used to determine what control mode is used to command the Umbra Reaction Wheel. The Umbra Reaction Wheel will report faults in all modes.

6.5.1 Idle Mode

In “idle” mode, the Umbra Reaction Wheel deactivates motor commutation and will not react to COMMANDED_SPEED or COMMANDED_TORQUE values. When the wheel enters an active mode (Speed or Torque control mode) the value of COMMANDED_SPEED or COMMANDED_TORQUE will take effect immediately. The Umbra Reaction Wheel will be free to desaturate momentum. It is safe to enter idle mode in any Umbra Reaction Wheel saturation state. When the Umbra Reaction Wheel reboots, it will enter this mode.

6.5.2 Speed Mode

In “speed” mode, the Umbra Reaction Wheel will spin up to the COMMANDED_SPEED value as described in Table 8. DRW Memory Map with maximum available torque. SPEED_P_GAIN, SPEED_I_GAIN, and SPEED_D_GAIN will be used internally for motor commutation. Umbra provides default values tuned to each motor.

6.5.3 Torque Mode

In “torque” mode, the Umbra Reaction Wheel will accelerate to achieve the COMMANDED_TORQUE value as described in Table 8. DRW Memory Map. If maximum wheel speed is achieved, Umbra Reaction Wheel will automatically return to “idle” mode. TORQUE_P_GAIN and TORQUE _I_GAIN will be used internally for motor commutation. Umbra provides default values tuned to each motor.

7.0 Performance Specifications

Table 10. Reaction Wheel Performance Specifications

Property	Value
Momentum Storage	±2 Nms
Torque	±0.1 Nm
Imbalance	Static: < 5 gmm Dynamic: < 100 gmm

7.1 Performance Validation

Customer recommended checkout is described in this document in Section

8.0 Operational Procedures.

8.0 Operational Procedures

Follow all requirements and recommendations in Section 4.1 Mechanical Handling while carrying out any and all procedures in this section. The Umbra Reaction Wheel may be damaged by carrying out any procedure listed in this section if mechanical handling requirements and recommendations are not followed.

8.1 Ground Support Equipment

Umbra does not provide GSE for the Umbra Reaction Wheel. However, if customers plan to carry out ground testing as described in this section, Umbra recommends that customers use a support panel to secure the Umbra Reaction Wheel during all testing.

8.2 First Use Procedure

See Section 4.1.3 Unpacking for additional information. The Umbra Reaction Wheel is ready for customer configuration upon boot up. Umbra recommends users record all default memory values at first bootup through use of the **PEEK** and **READ_FILE** commands.

8.3 Reaction Wheel Functional Test Procedure

The objective of this procedure is to demonstrate the Umbra Reaction Wheel can spin up in both directions and respond properly to commands.

8.3.1 Success Criteria

Umbra Reaction Wheel successfully responds to commands and reaches positive and negative speeds.

Umbra Reaction Wheel successfully responds to an "idle" command and comes to rest.

8.3.2 Test Procedure

1. Secure the Umbra Reaction Wheel to a support panel to ensure it remains in a fixed location during all testing.
2. Connect to the Umbra Reaction Wheel as described in 5.2 Harnessing Recommendations.
3. Use **READ_FILE** to read the software configuration of the Umbra Reaction Wheel. Record read values.
4. Note the **CONTROL_TYPE** of the Umbra Reaction Wheel should be "idle." This procedure describes commanding of the Umbra Reaction Wheel with "torque" CONTROL_TYPE.
5. Use one **WRITE_FILE** command to set the CONTROL_TYPE of the Umbra Reaction Wheel to "torque" and the value of COMMANDED_TORQUE to +0.1 Nm.
6. Monitor telemetry as the Umbra Reaction Wheel spins up at the commanded acceleration.
7. Use the **WRITE_FILE** command to set the value of COMMANDED_TORQUE to 0 Nm.

8. Monitor telemetry as the Umbra Reaction Wheel maintains speed.
9. Use the **WRITE_FILE** command to set the value of COMMANDED_TORQUE to -0.1 Nm.
10. Monitor telemetry as the Umbra Reaction Wheel spins up at the commanded torque value in the opposite direction.
11. Use **WRITE_FILE** to set the CONTROL_TYPE of the Umbra Reaction Wheel to “idle.”
12. Monitor telemetry as the Umbra Reaction Wheel spins down to 0 RPM.
13. Power off the Umbra Reaction Wheel.

8.4 Integration and Test

Pay careful attention to the installation location and unit coordinate frame to spacecraft coordinate frame orientation of the Umbra Reaction Wheels during integration.

Maintain test records of the orientation relative to the vehicle body axes to address any questions that may arise related to software commanded unit designation/identification or polarity of spin axis.

8.5 On-Orbit Checkout

The Umbra Reaction Wheel should be powered off during spacecraft launch. Users should read telemetry as described in Section Telemetry before commanding the Umbra Reaction Wheel.

Appendix A

Acronyms and Abbreviations

A.1 Acronyms and Abbreviations

EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
GEVS	General Environmental Verification Standard
GNC	Guidance, Navigation, and Control
GND	Ground
LEO	Low Earth Orbit
N	No
R	Read
R/W	Read/Write
RBF	Remove Before Flight
TBD	To Be Determined
Y	Yes

A.2 Units

°C	Degrees Celsius
gmm	Gram-Millimeters
Grms	root mean square acceleration
krad	Kilorads
mA	Milliamps
ms	Milliseconds
Nm	Newton meters
Nms	Newton meter seconds
Rad/sec	Radians per second
RPM	Rotations per Minute
V	Volts
W	Watts

Appendix B

Mechanical Interface Control Documentation