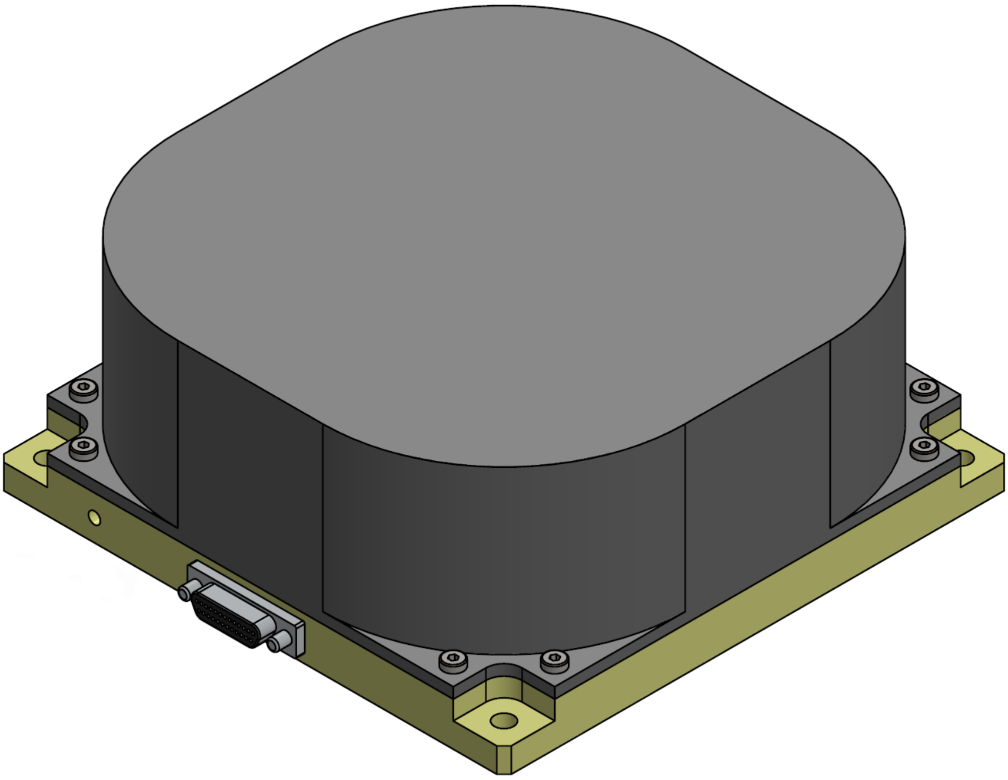
Description / Manual
Interface Control Document
Reaction Wheel
VRW-2

Project: SPACETY



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1 Introduction

VECTRONIC Aerospace has developed the VRW reaction wheel series especially for small satellite applications. Reaction wheels are actuators used to influence the rotational motion of a spacecraft. According to the principle of angular momentum conservation, a torque is exerted onto the spacecraft if the wheel speed is changed. The ratio between acceleration of the wheel and the spacecraft is equal to the ratio of their moments of inertia.

The reaction wheels VRW-2 comprise the following components:

- brushless DC Motor,
- rotor,
- wheel drive electronics,
- housing.

The wheel speed is controlled with a model supported PI-loop running inside the 32 Bit micro processor which is using a low noise high efficiency four quadrant operating power stage. The wheel drive electronic includes thermal and over voltage protection circuits. The signal interface is a CAN bus communication interface.

2 Mechanical Interface

2.1 Overview

Table 1: Overview of mechanical design

Items	Description
Connector	MDM25, male
Mounting	Via 4 M5 mounting lugs 126 mm x 126 mm – hole diameter 5.3 mm
Grounding	Via 1 fixation lug
Length x Width x Height	140 mm x 140 mm x 60 mm
Mass	<1.9 kg
Center of Mass	(dimensions see mechanical interface drawing in ICD)
Moment of Inertia (Rotor)	> 0.00318 kgm² Total matrix: (see mechanical interface drawing in ICD)
Material	Hood: EN-AW-6082 Baseplate: EN AW-7075 (housing)
Surface Treatment	Cover: Anox 10µ black Baseplate: Alodine 1200
Emissivity	Cover: 0.88 Baseplate: 0.10
Absorptivity	Cover: 0.88 Baseplate:0.35
Flatness of mechanical interface surface	Better than 0.1 mm
Roughness of mechanical interface surface	typical values for Rz: 1.5µm to 4.5µm
Area of mechanical interface surface	19058 mm²
Thermal capacity	TBD J/K

2.2 Mounting Interface

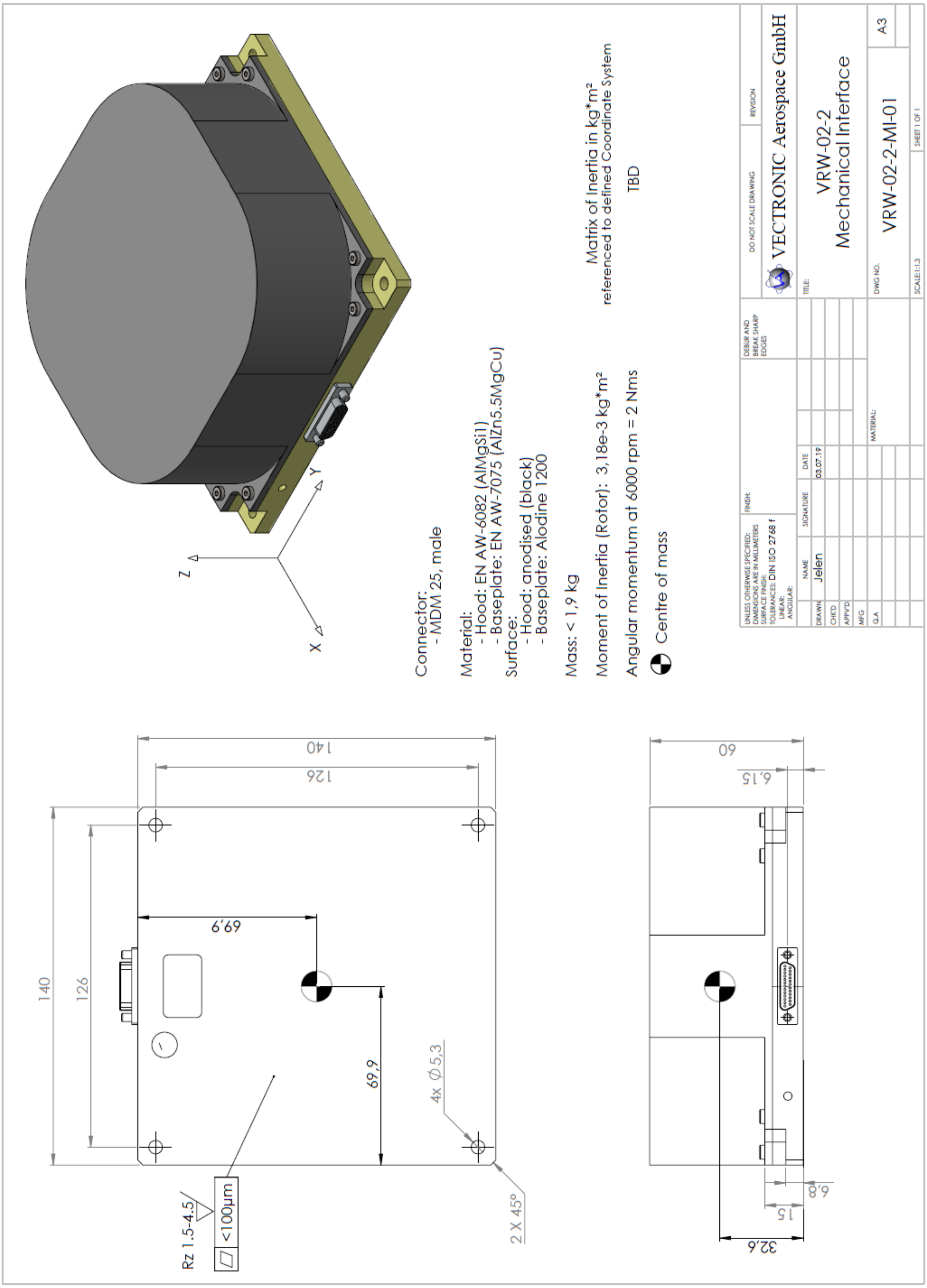

Figure 1: Wheel Mounting interface

2.3 Axis Definition

The coordinate system of the wheel is defined as follows:

- X-Axis: Inside the mounting plane in direction of the connector
- Y-Axis: Inside the mounting plane, perpendicular to X and Z axis, building an orthogonal right handed system with $\vec{X} \times \vec{Y} = \vec{Z}$
- Z-Axis: From the wheel center towards the top.

The mounting plate represents the –Z side of the wheel.

2.4 Sign of Rotation

A positive rotation is defined in the direction of a mathematical positive angle around the Z-Axis.
In a top view, a positive rotation of the rotor is counter-clockwise (CCW).

3 Electrical Interface

Interfaces for power and data are both available on a MDM25 male connector. The pin assignment of the VRW-2 electrical interface is described in the following table.

3.1 Connector Pin Assignment

Table 2: Pin assignment (colors of standard Cinch connector with cable)

PIN	Description	Remark
1	Power Supply Input	(20 VDC .. 47 VDC)
2	Power Supply Input	(20 VDC .. 47 VDC)
3	--	Not Connected
4	Power Supply Return	Signal Ground (GND). Internally connected to pins 6 and 8.
5	--	Not Connected
6	Power Supply Return	Signal Ground (GND). Internally connected to pins 4 and 8.
7	--	Not Connected
8	Power Supply Return	Signal Ground (GND). Internally connected to pins 4 and 6.
9	CANA_H (main interface)	CAN bus channel A High Signal
10	Case Ground	Internally connected to pin 12.
11	CANB_L (main interface)	CAN bus channel B Low Signal
12	Case Ground	Internally connected to pin 10.
13	--	Do not connect. Reserved for internal use
14	Line A Transmit (auxiliary interface)	Output (RS422 signal)
15	--	Not Connected
16	Line B Transmit (auxiliary interface)	Output (RS422 signal)
17	Line B Receive (auxiliary interface)	Input (RS422 signal)
18	Line A Receive (auxiliary interface)	Input (RS422 signal)
19	CANA_L (main interface)	CAN bus channel A Low Signal
20	CANA_L (main interface)	CAN bus channel A Low Signal
21	CANA_H (main interface)	CAN bus channel A High Signal
22	CANB_H (main interface)	CAN bus channel B High Signal
23	CANB_H (main interface)	CAN bus channel B High Signal
24	CANB_L (main interface)	CAN bus channel B Low Signal
25	--	Not Connected

3.2 Power Interface

The VRW-2 in has a non-isolated unregulated power input interface. The minimum and the maximum input voltages are 20 VDC and 47 VDC respectively, with maximum 800 mVpp ripple between 0 and 100 MHz.

The different voltages necessary for the correct operation of the device are provided internally.
The in-rush current is less than of 3 A for 100 µs.

Operating at lower voltages will not cause damage but performance is not guaranteed.

Operating at higher voltages will cause damage.

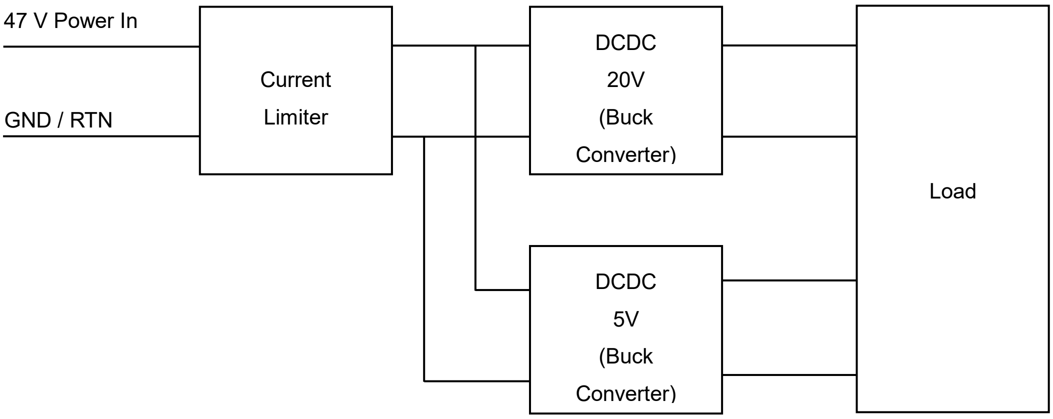

Figure 2: Power Interface

3.3 Grounding

Case Ground is isolated from Power Ground.

3.4 Data Interfaces

Two redundant main serial data interfaces with identical properties (CAN version 20B NRZ at 500 kbit/s with standard or extended frame) with optional terminal resistor (terminal resistor not soldered by default) and one RS422 auxiliary serial data interface (Serial, asynchronous, 1 start bit, 1 stop bit, no parity bit, (8,N,1), LSBit is sent first, MSByte first (Big Endian)) at 115200 bit/s are provided.

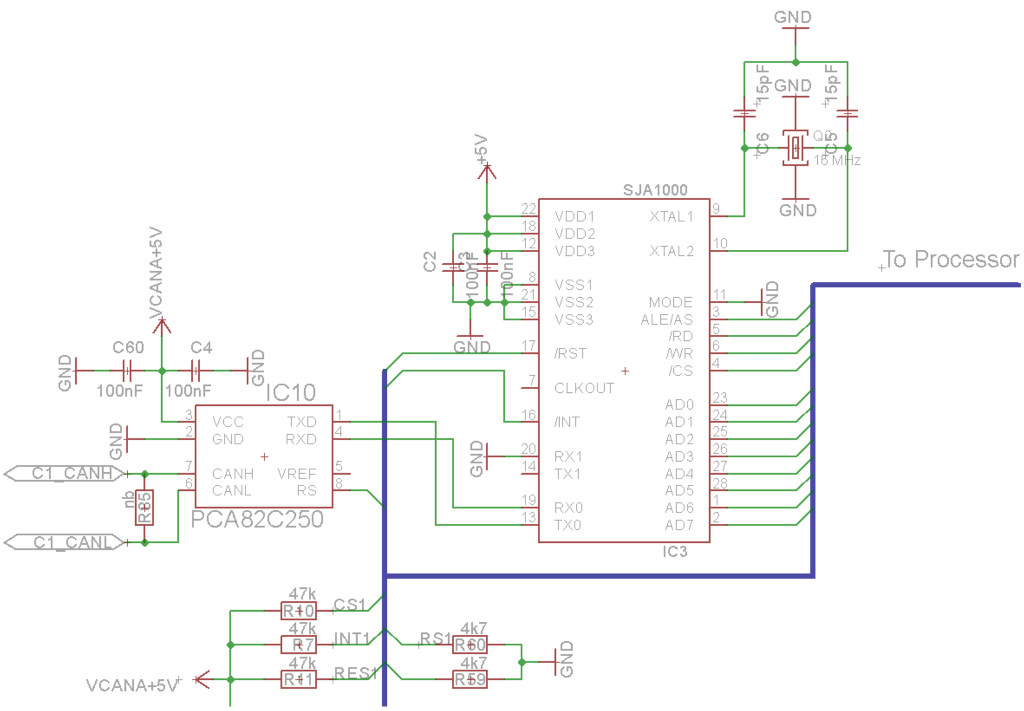

Figure 3: CAN Communication Interface

The principle of the RS422 communication interface is shown in the following schematics.

The value of the resistors R11, R21, and R22 (on the receive lines) are respectively 4.7 kΩ, 30 kΩ and 30 kΩ. The both pull-up resistors (on the CPU side) have each 100 kΩ.

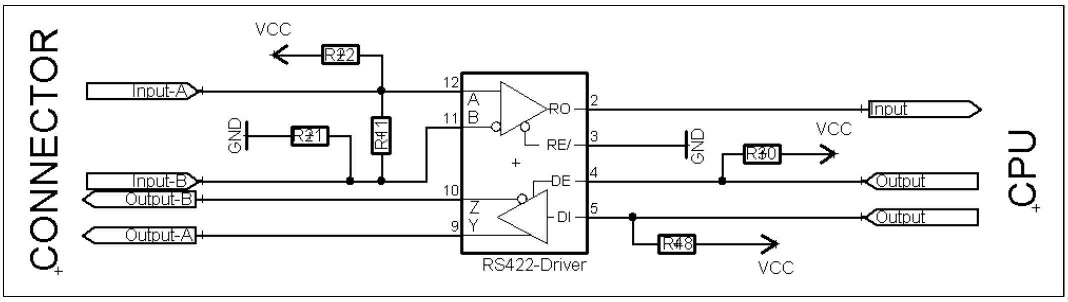

Figure 4: RS422 Communication Interface

Impedance matching is not critical, therefore as default a relative high value of 4k7 has been selected. Depending on project, the RS422 lines can provide other values and additional in-series resistors.

4 Software Interface

4.1 Overview

After the power-on-reset and initialization sequence the VRW-2 device enters the steady state and waits for commands. Steady state means that the control loops are not active and the motor current is adjusted to zero, the default target speed of the wheel is also zero.
If the device receives a command, it will be processed and eventually requested data will be sent back to the host. The data transfer between the host and the VRW-2 on the RS422 interface has to be performed within a 10ms time interval. The timeout timer is started at the reception of the first command byte by the internal CPU. All command bytes must have been received within this period, otherwise communication is cancelled without further reaction on wheel side.

4.2 Communication Protocol

The protocol used for communication with the sensor is the CAN protocol version 2.0B. The communication is usually initiated by the host computer.
The communication rate on both CAN busses is 500 kbit/s

4.3 Extended Data Frame Format

The extended data frame, defined in the CAN protocol, starts with one Start-Of-Frame (SOF) bit, followed by the Arbitration Field, 0 up to 8 user data byte, an 18-bit CRC and acknowledge (ACK) field and ends with a 7-bit End-Of-Frame (EOF).

4.4 General Timing on CAN Bus

After Power On, the communication ready time is less than 300 ms
After CAN Reset, the communication ready time is less than 10 ms
The maximum response time from end of command reception to start of response frame is less than 3 ms
The maximum time interval between multiple transmission frames (e.g. Telemetry) is less than 1 ms.
The host command frequency should not be higher than 10 Hz

4.5 Reception Message Filter Configuration

Both the VRW CAN controller uses the following filter to check the received commands:

- Source Address should be 0x00 for OBC
- Target Address should be the own ID (e.g. 0x08 for wheel A)
- Frame Info shall be 'Single Frame'
- DLC shall be 8 (0b1000)

After command reception, the 8 byte command data are checked on consistency

4.6 Arbitration Field Format

Table 3: Arbitration Field Format

	Arbitration Field																																Control Field						Data Field		
	11 Bit Identifier													18 Bit Identifier																											
SOF	28	27	26	25	24	23	22	21	20	19	18	SRR	IDE	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	RTR	r1	r0	DLC3	DLC2	DLC1	DLC0	b7	b6	…
0												1	1										0									0	0	0							
	Source Address								Target Address										Frame Info					Command Counter											DLC				Data		

Source Address Definition:

Direction OBC to VRW: 0x00

Direction VRW to OBC

Wheel A: 0x08

Wheel B: 0x09

Wheel C: 0x0A

Wheel D: 0x0B

Target Address Definition

Direction VRW to OBC: 0x00

Direction OBC to VRW

Wheel A: 0x08

Wheel B: 0x09

Wheel C: 0x0A

Wheel D: 0x0B

Frame Info Definition

Direction OBC to VRW:

Single Frame: 0b0001

Direction VRW to OBC

Single Frame: 0b0001

Start Frame: 0b0010

Interm.Frame: 0b0011

Command Counter

Direction OBC to VRW

incremented by OBC

Direction VRW to OBC

incremented by VRW

DLC Definition (always 8 Byte)

Direction OBC to VRW

DLC: 0b1000

Direction VRW to OBC

DLC: 0b1000

Example: Wheel A sends Start Frame of Telemetry Cmd. No. 100

	Example for Wheel A:								Example for OBC										Example for Start Frame																						
SOF	28	27	26	25	24	23	22	21	20	19	18	SRR	IDE	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	RTR	r1	r0	DLC3	DLC2	DLC1	DLC0	b7	b6	…
0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	1	0	0	0	0	0	1	0	0	0	..	..	..
	Source Address								Target Address										Frame Info					Command Counter											DLC				Data		

4.7 List of Command Frames (OBC to VRW)

Table 4: List of Command Frames

Command Name	Source Addr	Target Addr	Frame Info	DLC	D0	D1	D2	D3	D4	D5	D6	D7
Request Telemetry	**00**	WID	**01**	**08**	**20**	dc	dc	dc	dc	dc	dc	dc
Send Version Info	**00**	WID	**01**	**08**	**D2**	dc	dc	dc	dc	dc	dc	dc
Set Max Torque	**00**	WID	**01**	**08**	**21**	MT3	MT2	MT1	MT0	dc	dc	dc
Set Wheel Speed	**00**	WID	**01**	**08**	**22**	WS3	WS2	WS1	WS0	dc	dc	dc
Set Current Value	**00**	WID	**01**	**08**	**23**	CV1	CV0	dc	dc	dc	dc	dc
Set Net Torque	**00**	WID	**01**	**08**	**24**	NT3	NT2	NT1	NT0	dc	dc	dc
En/Dis RS422 TM Stream	**00**	WID	**01**	**08**	**FE**	TMS	dc	dc	dc	dc	dc	dc
CAN HW Reset	**00**	WID	**01**	**08**	**2C**	CHx	dc	dc	dc	dc	dc	dc

Notes:
Bold values in hexadecimal

dc:	don't care
WID:	Wheel ID
MTx:	Maximum Torque in [Nm], format IEEE32, MT3 as MSB
WSx:	Target Wheel Speed in [rad/s], format IEEE32, WS3 as MSB
CVx:	Current Value in 16 Bit as digits, signed short +/-32767, CV1 as MSB
NTx:	Target Net Torque in [Nm], format IEEE32, NT3 as MSB
TMS:	0x00 for off, 0xFF for on
CHx:	0x01: Reset CAN A, 0x02: Reset CAN B, 0x03: Reset CAN A and CAN B

The command counter received by OBC is not relevant

4.8 List of Response Frames (VRW to OBC)

Table 5: List of Response Frames

Response Name	Source Addr	Target Addr	Frame Info	DLC	D0	D1	D2	D3	D4	D5	D6	D7
Request Telemetry Start	WID	**00**	**02**	**08**	LEN (H)	LEN (L)	TM0	TM1	TM2	TM3	TM4	TM5
Request Telemetry Inter.	WID	**00**	**03**	**08**	TMi	TMi	TMi	TMi	TMi	TMi	TMi	TMi
Request Telemetry (End)	WID	**00**	**03**	**08**	TMi	TMi	TMi	TMi	TMi	TMi	TMi	CKS
Send Version Info	WID	**00**	**01**	**08**	SN1	SN0	SW1	SW0	dc	dc	dc	dc

Notes:

LEN:	Length of following Telemetry data in Bytes as 16 Bit unsigned int, (typ. 37, 0x0025)
SNx	Serial Number of the unit
SWx	Software Version Number
CKS	sum of the preceding 39 Byte, ignoring carry bits

The transmitted command counter inside the Arbitration Field is incremented for each successfully received command on the corresponding CAN Bus. The increment is done before transmission. It is the same value as given inside the Telemetry data.
The response frames will be transmitted on the same bus (A/B) where the command has been received.
The counter is set to zero at Power Up

4.9 Description of Commands

4.9.1 Set Max Torque

This command is used to set the maximum used torque of the wheel in the speed control mode. The value is coded as 4 bytes float value in the unit Nm. The default value at power up is set internally to the nominal maximum torque of 0.050 Nm.
The valid range for the parameter is from 0.005 to 0.060 Nm
If the commanded value is higher than 0.060 Nm, then the max torque is internally set to 0.060 Nm
If the commanded value is lower than 0.005 Nm, then the max torque is internally set to 0.005 Nm.

Remarks:
- The maximum allowed torque will be reduced automatically in case of high speed or high temperature
- This torque limitation is not active in Current Control Mode

Example:
OBC sets a maximum torque for speed control mode of 0.030 Nm in Wheel B.

Command Name	Source Addr	Target Addr	Frame Info	DLC	D0	D1	D2	D3	D4	D5	D6	D7
Set Max Torque	**00**	**09**	**01**	**08**	**21**	**3C**	**F5**	**C2**	**8F**	dc	dc	dc

4.9.2 Set Wheel Speed

This command is used to activate/control the speed of the wheel. It sets the target speed of the wheel. The speed value is coded as 4 bytes float value in the unit [rad/s]. This command activates automatically the speed control loop. The default value at power up is set internally to zero.
The maximum value of target speed is 6000 rpm (628.3185 rad/s); all higher values will be set back to this value.
If the commanded target speed is +630.0 rad/s, it will be reduced to +628.3185 rad/s.
If the commanded target speed is -630.0 rad/s, it will be reduced to -628.3185 rad/s.
Example:
OBC sets a speed value of -5000 rpm or -523.59878 rad/s in Wheel C.

Command Name	Source Addr	Target Addr	Frame Info	DLC	D0	D1	D2	D3	D4	D5	D6	D7
Set Wheel Speed	**00**	**0A**	**01**	**08**	**22**	**C4**	**02**	**E6**	**52**	dc	dc	dc

4.9.3 Set Current Value

This command is used to control directly the motor current of the VRW. It disables automatically the speed /torque control loop and sets motor current and direction according to the value. The parameter is a 16 Bit signed integer, the scale is linear as long as the motor voltage is less than the input voltage and is about 90.5 µA per Digit (from max +-32767).
The motor constant is 0.025 Nm/A +/- 10%, therefore the resolution in torque is about 2.26 µNm per Digit
The maximum allowed value for the motor current is checked and limited automatically. It is a function of actual speed and target torque direction and limited internally to ensure safe operation of the wheel. This behavior is shown in principle in the diagrams in chapter 4.xx and 4.yy.

Example:
OBC sets a current value of -200 in Wheel C which corresponds to a motor torque of about 0.45 mNm

Command Name	Source Addr	Target Addr	Frame Info	DLC	D0	D1	D2	D3	D4	D5	D6	D7
Set Current Value	**00**	**0A**	**01**	**08**	**23**	**FF**	**38**	dc	dc	dc	dc	dc

4.9.4 Set Net Torque

This command is used to control directly the net torque of the wheel. The value is coded as 4 bytes float in the unit [Nm]. This command activates automatically the torque control mode and disables speed and current control mode. The maximum torque value is limited at this point to +/- 60 mNm, all higher values will be set back to the corresponding value. In further processing, this maximum may be reduced by three additional features:

- Automatic torque reduction according speed limit
- Automatic torque reduction according temperature limit

As main difference to the direct current control mode, this command provides a unity gain with respect to net torque independent of wheel speed and torque direction. The value is proportional to the acceleration/deceleration of the rotor.

Example:

OBC sets a Net Torque of 0.005 Nm in Wheel C

Command Name	Source Addr	Target Addr	Frame Info	DLC	D0	D1	D2	D3	D4	D5	D6	D7
Set Net Torque	**00**	**0A**	**01**	**08**	**24**	**3B**	**A3**	**D7**	**0A**	dc	dc	dc

4.9.5 En/Dis RS422 TM Stream

(not active in this project, TBC)

4.9.6 CAN HW Reset

As described in the List of Command Frames.

4.10 Format of Telemetry Data

After receiving the command 'Request Telemetry' the VRW sends in total 5 CAN frames with 40 Byte of telemetry. First a start frame followed by 4 intermediate frames. The data section starts with the length of the data which is always 40 and ends with the checksum of the 39 preceding data bytes disregarding carry bits. The telemetry data format is described in the following table:

Table 6: Description of Telemetry

Frame	ByteNo.	Description	Format	Remark
1	0	Length of Data, Header	2 byte unsigned integer	Always 0x0025
1	2	CAN A Command Counter	1 byte unsigned integer	
1	3	CAN B Command Counter	1 byte unsigned integer	
1	4	CAN A Invalid Cmd Counter	1 byte unsigned integer	
1	5	CAN B Invalid Cmd Counter	1 byte unsigned integer	
1	6	Status Register	2 byte unsigned integer	
2	8	CAN A Tx Error Counter	1 byte unsigned integer	
2	9	CAN A Rx Error Counter	1 byte unsigned integer	
2	10	CAN B Tx Error Counter	1 byte unsigned integer	
2	11	CAN B Rx Error Counter	1 byte unsigned integer	
2	12	CAN A Restart Counter	1 byte unsigned integer	
2	13	CAN B Restart Counter	1 byte unsigned integer	
2	14	Unit Power	2 byte unsigned integer	Unit Power [mW]
3	16	Wheel speed	4 byte float value	actual speed in [rad/sec]
3	20	Torque	4 byte float value	Net Torque in [Nm]
4	24	Current	2 byte signed integer	Motor current [Digit]
4	26	Motor Temperature	2 byte unsigned integer	T[°K] = 0.4883 * value
4	28	PCB Temperature	2 byte unsigned integer	T[°K] = -0.1842 * value + 392.19
4	30	Max. Torque	2 byte unsigned integer	[µNm]
5	32	Max. Current value	2 byte unsigned integer	(abs value in Digits)
5	34	Internal system time	4 byte unsigned integer	Frq = 1125/4 Hz
5	38	reserved	1 byte unsigned integer	
5	39	Checksum	1 byte unsigned integer	

All counters are set to zero at Power Up
The Status Register consists of 16 Bit and is located in the telemetry block on byte position 6 to 7. Bit 0 is LSB, Bit 15 is MSB and located in byte position 6 at MSB.

Table 7: Description of Status Register

BitNo	Bit Description	Set (1) condition
0	Current Control Loop	Current Control Loop is active
1	Speed Control Loop	Speed Control Loop is active
2	Torque Control Loop	Torque Control Loop is active
3	Temperature Limit	Torque Limiter due to high temperature is active
4	Speed Limit	Torque Limiter due to high speed is active
5-15	reserved	

4.11 System Communication Error Procedures

The following additional error handling is implemented:
The VRW checks commands which include float values before executing. If the data block of a command corresponds to a NaN value, the received command will be treated as illegal command and ignored. The invalid command counter will be incremented. A NaN value is detected according the following condition:
Value & 0x7F80 0000 = 0x7F80 0000

As soon as there is no new command for 10 seconds neither on CAN Bus A nor on CAN Bus B, the VRW initiates a Hardware Reset of both CAN controller A,B

As soon as the Net Torque Control Mode is active and there is no new command for 2 seconds neither on A nor on B, the VRW target torque is automatically set to zero (hold speed)

Table 8: Communication Error Description

Com Error Type	Inv. Cmd. Cnt.	VRW reaction
unknown cmd	increment	no
parameter out of range	no change	parameter auto adjustment
parameter is NaN	increment	no

4.12 Torque Limitation on High Speed

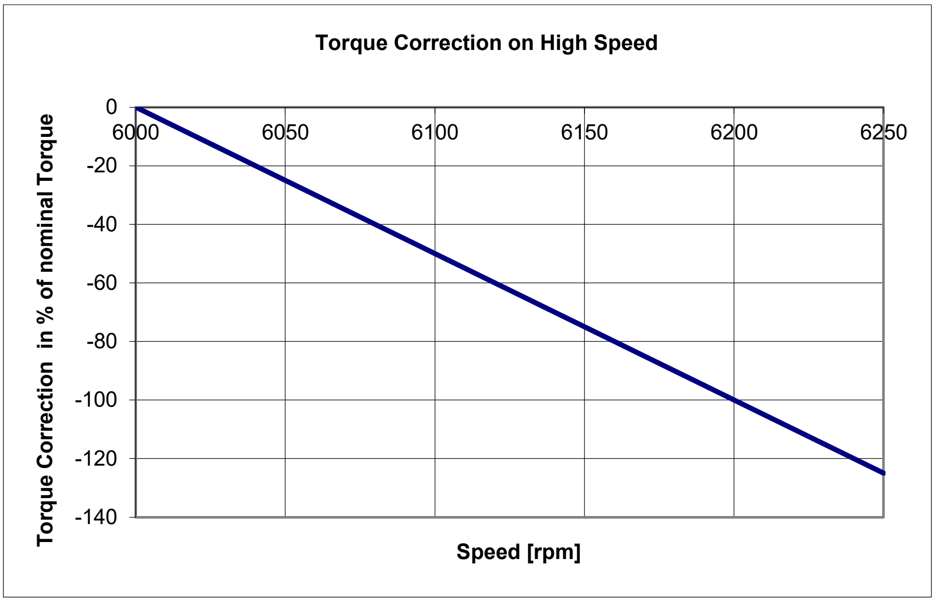

Figure 5: Torque Correction on high Speed

Example: For a VRW with a nominal Torque of 50 mNm at a rotor speed of 6160 rpm, the maximum allowed torque is automatically reduced by 80% resulting in a new maximum value of 10 mNm

4.13 Torque Limitation on High Motor Temperature

The automatic torque limitation on high motor temperatures begins at 80 °C. The torque correction term is calculated and added to the maximum allowed torque building a new lower maximum value. The higher output of the both temperature sensors is taken into account.

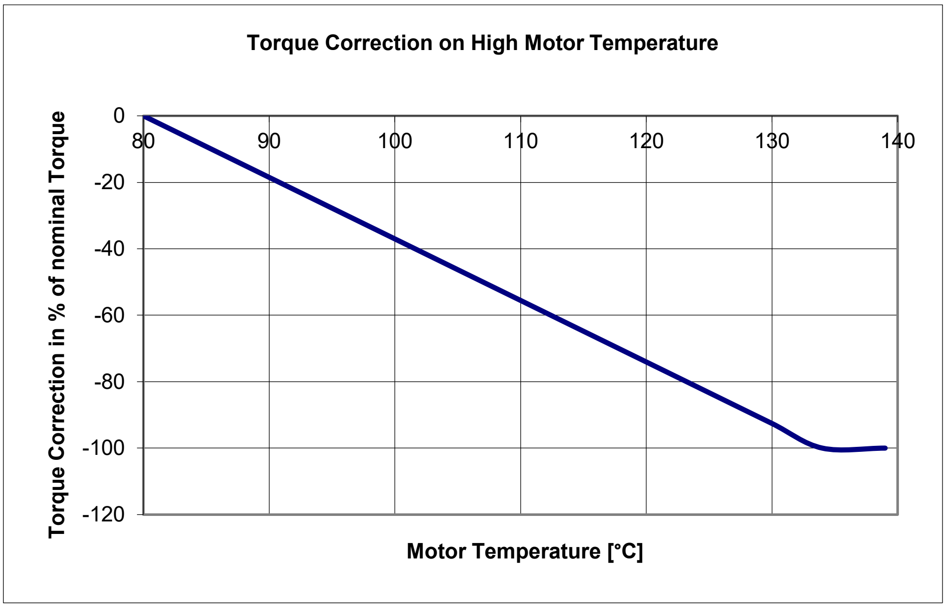

Figure 6: Torque Correction on high Motor Temperature

Example: For a VRW with a nominal Torque of 50 mNm at a motor temperature of 100°C, the maximum allowed torque is automatically reduced by 37% resulting in a new maximum value of 31.5 mNm