



## ABILITY HAND™ Interface Control Document

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### Introduction:

The PSYONIC Ability Hand has a number of communication interfaces allowing information to be sent to the hand from outside sources. These are used for settings changes, relaying sensor information, and various modes of motion control. The purpose of this document is to provide documentation on each interface as available in Ability Hand firmware v2.0+.

The interfaces are:

1. Standard Mode (I2C)
2. Extended Mode (UART/RS485/I2C)
3. Bluetooth Low Energy
4. Analog Inputs

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# 0 Configuration Options

The Ability Hand is available in two wrist configurations: the Bolt Pattern-Research Wrist and Clinical Wrist. An overview of each configuration's features are shown below in Table 1.

*Table 1: Ability Hand Wrist Configuration Options*

<b>Option</b>	<b>Bolt mount</b>	<b>Quick disconnect mount</b>	<b>Half moon connectors</b>	<b>Breakout header connector</b>	<b>Wrist rotator compatible</b>
Bolt Pattern-Research Wrist	✓			✓	
Clinical Wrist		✓	✓		✓

# 1 Electrical Specification

*Table 2: Electrical Characteristics*

Symbol	Ratings	Min	Typ	Max	Unit
+V	Standard Operating Voltage	6.0		8.4	V
$I_q$	Quiescent Current Consumption	-	120	-	mA
$I_{max}$	Peak Current Consumption	-	-	14	A
AN1, AN2	Analog Input Voltage	0	-	5	V

## Wiring for physical interfaces

A 6-wire interface to the hand is provided through a Molex 0874380643 connector for Research Wrists and through a slip ring electronic quick disconnect (EQD) for Clinical Wrists. The EQD allows industry standard half moon connectors to be used for all signals. Research wrists have these connections also available on a 0.1" breakout header.

*Table 3: Signal pinouts*

Name	Clinical wrist half moons	Research wrist Molex 0874380643	Breakout 0.1" header
+V	3 pin PWR (red)	Pin 1	Pin 2, 4
GND	3 pin PWR (black)	Pin 2	Pin 1, 6, 8, 10
AN1	3 pin electrode	Pin 3	Pin 3
AN2	3 pin electrode	Pin 4	Pin 5
SDA	2 pin COM (green)	Pin 5	Pin 7
SCL	2 pin COM (yellow)	Pin 6	Pin 9

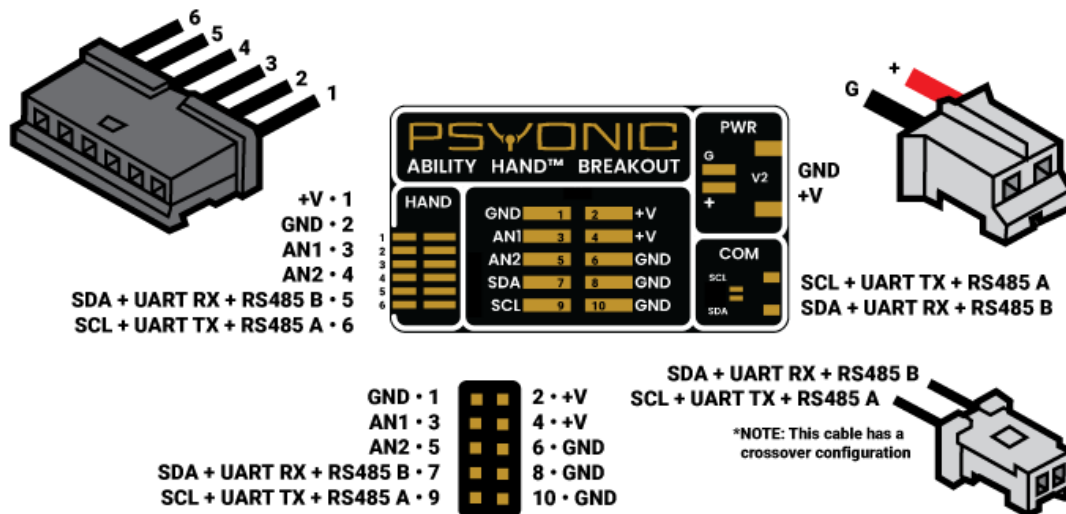
*Table 4: Functional description*

Name	Signal	Function
+V	Power	System power
GND	Ground	System ground
AN1	Analog Input 1	Analog control of the hand
AN2	Analog Input 2	Analog control of the hand

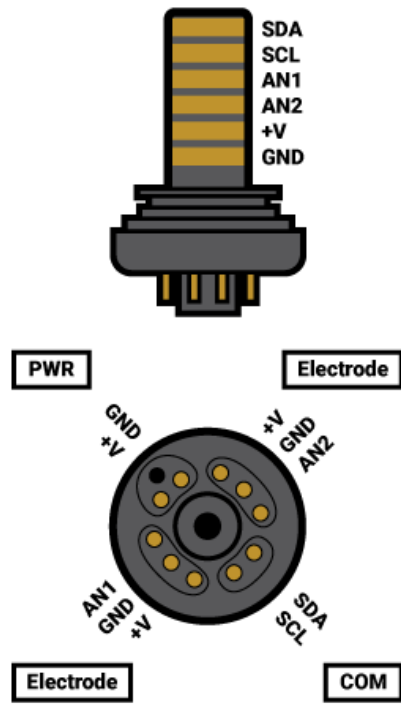
SDA	SDA/UART RX/RS485 B	Digital control of the hand*
SCL	SCL/UART TX/RS485 A	Digital control of the hand*

\*Can support both 3.3V I2C and UART. Newer hardware revisions of the hand also support 5V level RS485 on those connections. The communication mode for these signals is stored in flash memory, and must be selected and configured using bluetooth command options.

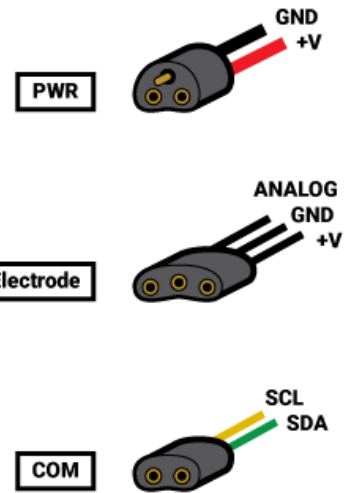
### Pinout for Research Wrist Option:



### Pinout for Clinical Wrist Option (Electronic Quick Disconnect):



### Mating Half Moons



## 2 Standard Communication Interface

### Introduction

This communication interface is intended for use of the Ability Hand in clinical applications. The hand has 2 different packet structures and 4 different control modes. The first covers the 'industry standard' *Grip Control Mode* interface, consisting of a 3-byte transmission and 7-byte reception, which allows the master device to select a grip index and speed, and read back some basic status information. The second packet structure covers the *Finger Control Mode* interface, which allows for individual control of the fingers and direct touch sensor readings. This has a 25-byte transmission packet and a reception packet ranging from 24-64 bytes in length.

**Important Note:** I2C is accessed through pins 5 and 6 of the cable harness for the hand. I2C mode must be enabled using the relevant bluetooth flash setting.

### 2.1 I2C Specification

The hand supports both standard (100kHz) and fast (400kHz) I2C modes. When operating in 'fast mode', the cable length of the hand should be limited to preserve packet integrity. In general, it is recommended to keep the I2C cable length as short as possible between the master and slave devices. The slave address of the hand is always 0x50. The hand has built in 10k pullup resistors, so external I2C pullup resistors are not necessary for a functional interface.



## 2.2 Grip Control Mode

*Packet Structure:*

**Transmissions: (From Master to Hand)**

S	Addr (0x50) - R/W bit low	A	command type	command	speed	P
---	---------------------------	---	--------------	---------	-------	---

1. *Hand slave address:*

0x50

2. *Command type:*

Value	Command	Description
0x1D	HAND_SET_GRASP	Normal control mode. Hand will parse data bytes for grip control
0x48	HAND_STATUS	Handshaking. Hand will reply with 0xDEADBEEF

3. *Grip Commands: (Valid for packets starting with 0x1D)*

Value	Command	Description
0x00	Open	Opens the hand. Open configuration will vary depending on the last grip.
0x01	Power	All digits flexed with the thumb rotated internally.
0x02	Key	Also known as lateral grasp. When key grasp is opened, only the thumb flexor extends and all other digits remain flexed.
0x03	Pinch	Precision pinch with index finger and thumb.
0x04	Tripod Opened	3-jaw chuck where the pinky and ring fingers are extended.
0x05	Sign of the Horns	\m/
0x06	Cylinder	Thumb will touch the middle and ring fingers
0x07	Mouse Grasp	Grip which allows the use of a computer mouse
0x08	Power/Key Switch	When the thumb is rotated internally, the hand will close into a power grasp. When the thumb is rotated externally, the hand will close into a key grasp
0x09	Point	Index finger point with the thumb rotated internally and flexed.

0x0A	Rude Point	Middle finger point
0x0B	Hook Grasp	Static finger hooked configuration
0x0C	Relax Grip	Puts the hand in a 'relaxed' configuration.
0x0D	Sleeve Grip	Puts the thumb out of the way so the hand can be guided through the sleeve of a shirt or jacket
0x0E	Peace Grip	Makes an approximation of a 'peace' hand sign
0x0F	Tripod Closed	3-jaw chuck where the ring and pinky are flexed
0x10	Hangloose Grip	Makes the 'hangloose' hand gesture
0x11	Handshake Grip	Halfway between a key grip and a power grip
0x12	Fixed Pinch Grip	Pinch where the thumb doesn't move while opening
0x13	User Grip 7	User defined grip
0x14	User Grip 8	User defined grip
0x15	User Grip 9	User defined grip
0x16	User Grip 10	User defined grip
0x17	User Grip 11	User defined grip
0x18	Trigger Grip	For grabbing/pulling trigger on spray bottles
0x19	User Grip 12	User defined grip
0x1A	User Grip 13	User defined grip
0x1B	User Grip 14	User defined grip
0x1C	User Grip 15	User defined grip
0x1D	User Grip 16	User defined grip
0x1E	User Grip 17	User defined grip
0x1F	User Grip 18	User defined grip
0x20	Finger Wave	If enabled (enabled by default) this grip will make the fingers move periodically and out of phase in a 'waggle' pattern. If disabled, this is a slot for another user defined grip.

\*Note: all 'User defined grips' will result in no motion if selected, until modified using the PSYONIC mobile app or otherwise through the BLE interface

#### 4. Speed:

- 4.1 When this byte is 0, the hand will stop.
- 4.2 When this byte is between 1 and 254, the **finger period** will vary linearly between 2 seconds and .29 seconds. A value of 1 will set the finger period to 2 seconds, and a value of 254 will set the finger period to .29 seconds. Finger period is defined as the allotted time for a finger to move through its motion path, and multiple periods can elapse over the course of a given grip.
- 4.3 When this byte is 255, the finger period will be set to .2 seconds.

### Receptions: (From Hand to Master)

1. HAND\_SET\_GRASP mode (byte 0 of last transmission was 0x1D):

S	Addr (0x50) – R/W bit low	A	S	Addr (0x50) – R/W bit high	A	Bytes 0–1: vibration motor intensity	Bytes 2–3: 0xBEEF (for handshaking)	Bytes 4–6 grip color (r,g,b)	Byte 7: grip status	Byte 8: grip percent	Byte 9: checksum	P
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Bytes 0–1 comprise a 16-bit integer that maps to the maximum touch sensor value, for use in controlling our vibration motor.

Byte 7 will return 0xFF when the grip is in progress, and for closed grips, the grip command of the last requested grip from the master when the grip is completed. For opened grips, due to legacy support of an old COAPT protocol, Byte 7 may sometimes be zero, and sometimes be a non-zero value not equal to the current grasp command. A value not equal to 0xFF will indicate that the hand has completed its motion.

Byte 8 will contain a concatenation of a grip percentage, and a motor driver power status bit.

Bit 7: if all 6 motor drivers are disabled (hand in idle state), will have value 1. If any one motor driver is active, will have value 0

Bits 6–0: Grip completion percentage (7bit; i.e. 127 corresponds to 100%)

Byte 9 will contain a checksum of the entire packet. The 8-bit signed sum of bytes 0–9 will be equal to 0 if there were no communication errors.

## 2.3 Tap Notification

*Packet Structure:*

### **Transmissions: (From Master to Hand)**

Tap messages are to be sent by a valid PSYONIC IO board. The full 4 byte message is sent once per tap, and each 4 byte word corresponds to a different tap type.

*Single Tap:*

S	Addr (0x50) - R/W bit low	A	Header Word: 0x5A	0x55	0x59	0xA6	P
---	---------------------------	---	-------------------	------	------	------	---

Default action: no action

*Double Tap:*

S	Addr (0x50) - R/W bit low	A	Header Word: 0x5A	0xA5	0x7B	0x36	P
---	---------------------------	---	-------------------	------	------	------	---

Default action: the hand will switch to the next grip in the direct control grip set (4 grips, circular buffer).

*Triple Tap:*

S	Addr (0x50) - R/W bit low	A	Header Word: 0x5A	0x55	0xDA	0x55	P
---	---------------------------	---	-------------------	------	------	------	---

Default action: the hand will enter 'freeze mode'. Direct control inputs are temporarily ignored while in freeze mode, and the hand will indicate freeze mode by blinking the requested RGB led color.

## 3 Extended Mode API Interface<sup>1</sup>

This interface is intended for use by researchers for control of the hand with high levels of access to the hardware resources on the hand. It is supported in 3.3V level I2C, UART, and 5V level RS485<sup>2</sup>. Communication modes (I2C, UART, RS485) must be selected with a flash setting, configurable over BLE. By default, the hand is configured for I2C.

The Extended Mode API interface is entered when the hand receives a valid transmission with a correct address, format header, and checksum<sup>3</sup> in the protocol current selected by the flash setting. The hand will leave 'normal' mode and be controlled via the parsed data in one of the formats described in following sections<sup>4</sup>. The hand will operate based on the API command for a maximum of 300ms, if no new command is received within 300ms it will automatically exit API mode. The time to enter API mode is negligible, but care should be taken to ensure turnaround time between valid transmissions does not exceed 300ms in order to prevent the hand from re-entering normal mode which may be accompanied by undesired finger movements.

### 3.1 Communication Protocol Specifications

#### 3.1.1 I2C Specification

I2C API Mode is available over the SCL/SDA pins from the hand (see Table 3). The Extended API supports I2C in 100kHz (normal) and 400kHz (fast) modes. In fast mode, cable length must be considered to ensure data integrity. The hand has internal 10kΩ pull-up resistors on the I2C lines, external resistors are not required. In I2C mode the ability hand is always at address 0x50.

Following are sample I2C Transmission Packets, full details of the API are in section 3.2.

Table 5: Sample I2C Transmission Packet Format (Master to Hand)

-			Byte 0	Bytes 1 - 12	Byte 13	-
S	Addr (0x50) - R/W bit low	A	Format header	Payload. One value per motor (6x total values), either voltage, position, velocity, or current (i.e. torque) request.	Checksum	P

Table 6: Sample I2C Reception Packet Format (Hand to Master)

<sup>1</sup> Extended Mode API available from software version 2.0 and higher

<sup>2</sup> RS485 is only available on hardware version 10.0 and newer

<sup>3</sup> In fast mode for UART & RS485 the checksum is not checked prior to entering API mode

<sup>4</sup> Special Read Only API Commands described in section 3.3.2 do not enter API control mode

-					Byte 0	Bytes 1 to n - 2	Byte n - 1	Byte n	-
S	Addr (0x50) - R/W bit low	A	S	Addr (0x50) - R/W bit high	A	Format Header	Payload. Hand data in format specified by header. Length will be 36 or 69 bytes for a total length ( <b>n</b> ) of 39 or 72 bytes.	Bitmask indicating finger enable/disable status	P

### 3.1.2 UART/RS485 Specification

The ability hand supports UART, and hardware versions 10.0 and greater support 5V level RS485 on pins 5-6 (SCL/SDA) of the main cable harness. The design of the protocol is for a multi-drop RS485 network, but it is compatible with direct UART (at appropriately reduced baud rates).

The extended interface for UART or RS485 can be entered by first configuring the hand for either extended mode 3.3V level UART or 5V level RS485 using the appropriate bluetooth controlled flash setting, then sending a properly formatted data frame using the selected protocol.

#### 3.1.2.1 Configuration

The settings used for UART and RS485 are configurable using flash settings. The following parameters can be modified and saved to the hands flash memory:

1. Slave address (default: 0x50)
2. Baud rate<sup>5</sup> (default: 460800)
3. Reply behavior<sup>6</sup> (default: standard mode)

When the hand is configured in UART API extended mode it will listen for transmission packets from a UART/RS485 master addressed to its slave address at the specified baud rate. The Ability Hand supports any 8-bit slave address except 0x00 and the following enumerated baud rates.

Table 7: UART/RS485 Enumerated Baud Rates

Enum Value	1	2	3	4	5	6	7	8	9
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<sup>5</sup> Baud Rates above 460800 are only available for RS485, not UART.

<sup>6</sup> Multiple Reply Behaviors only available over UART. RS485 always uses standard behavior.

<b>Baud Rate</b>	1200	2400	4800	9600	14400	19200	28800	31250	38400
<b>Actual Baud<sup>7</sup></b>	1205	2396	4808	9598	14414	19208	28829	31250	38462
<b>Enum Value</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>	<b>17</b>	<b>18</b>
<b>Baud Rate</b>	56000	57600	76800	115200	230400	250000	460800	921600	1000000
<b>Actual Baud</b>	55944	57762	76923	115942	230400	250000	470588	941176	1000000

The baud rate and slave address can be modified via the Bluetooth Word Setting API\_CONFIG0 (section 4.4.2). The transmission behavior can also be modified for increased bandwidth with Bluetooth Binary Setting 33 (section 4.4.3).

### 3.1.2.2 Transmission Behavior and Format

The following table describes the general format of each UART transmission packet. The 0th byte is the hand address, the 1st byte is the format header. The next sequence of bytes corresponds to a unique command for each of the 6 motors in the hand, which are used based on the format header. The final byte is a checksum of all preceding bytes, including the address.

*Table 8: General format for transmissions (to the hand)*

Byte 0	Byte 1	Bytes 2-13	Byte 14
Hand slave address (default 0x50)	Format header	Payload. One value per motor (6x total values), either voltage, position, velocity, or current (i.e. torque) request.	Checksum

The general behavior of the hand in UART/RS485 mode is that it waits to receive a transmission frame addressed to it and then issues a response. The hand uses idle-line detection to group sequences of bytes. If the hand's UART RX line is left idle (high level) for 15 bits at the current baud rate, the frame is considered completed, and the hand will begin issuing its response. The next byte received after an idle event is considered to be the start (byte 0) of the next data frame. The UART on the hand is fully asynchronous; bytes can be received and transmitted at the same time.

### 3.1.2.3 Standard Response Behavior and Format

<sup>7</sup> The Actual Baud Rate produced by the MCU on the Ability Hand.

The standard response behavior for UART and RS485 is that the hand will reply with a response frame immediately after a data frame with a matching slave address and checksum is received. In this mode, transmission messages can be a minimum of 3 bytes long (address, format header, and checksum). Any truncation of the message is allowed as long as the last byte in the frame has a properly computed checksum.

*Table 9: General format for receptions (from the hand)*

Byte 0	Bytes 1 to n - 2	Byte n - 1	Byte n
Format Header	Payload. Hand data in format specified by header. Length will be 36 or 69 bytes for a total length (n) of 39 or 72 bytes.	Bitmask indicating finger enable/disable status	Checksum

### 3.1.2.4 UART Fast Response Mode

Over UART, an additional fast mode is available. This mode can be enabled over bluetooth via a Binary Setting (see section 4.6.3). Fast Mode the hand will issue a reply<sup>8</sup> immediately after a matching address byte and valid format header is sent by the master<sup>9</sup>. This mode provides a simple way of increasing the bandwidth. Achieving the same bandwidth in standard mode is possible with precise timing, but more difficult to implement. Fast mode also decreases the probability that the hand will not issue a reply due to single event errors during the transmission of a large master data frame as a valid checksum is not required.

## 3.2 Temperature Protection

The API has built-in motor overtemperature protection that limits the torque available to the motors. A temperature heuristic is calculated which builds with motor usage and reduces with motor inactivity. A threshold with hysteresis is enforced; if the temperature heuristic climbs above a fixed level, the motors will have reduced power available until the estimated temperature falls below a (lower) threshold. The status of this overtemperature protection is available in each reply format in the form of a bitmap. The overtemperature heuristic can be reset via the API. However, repeated use of this command can cause permanent damage to the hand. See Table 11 for command information.

<sup>8</sup> In fast mode the format of the response will lag by one data frame. When the hand is initialized in fast mode the first response will always be in the default format (format 1).

<sup>9</sup> Only a matching address and format header are required to generate a response. However, the hand will still reject transmissions with an invalid data frame.



## 3.3 Extended Mode Data Format Overview

### 3.3.1 Control Modes

There are four motor control modes available:

1. Position
2. Velocity
3. Torque ( $I_q$ )<sup>10</sup>
4. Voltage ( $V_q$ )

There are three response variants available that include different data combinations:

1. Finger position, current, touch sensors
2. Finger position, rotor velocity, touch sensor
3. Finger position, current, rotor velocity

Additionally, a read only mode is available to receive data over UART/I2C. In this mode the hand is not controlled by UART/I2C and will respond to other control inputs such as Bluetooth or Analog Inputs. See section 3.3.3 for more details on read only mode.

Control modes are selected with a 'format header' in the transmit message, which is the first non-address byte. This byte determines both the format the hand will use to parse the data, and the content of the response it will issue. In the event that the hand is in API mode and receives a valid message (address & checksum) with a format header that does not specify a response mode<sup>11</sup>, the hand will generate a response message with the last format header received. The default response format is variant 1. In addition to the control modes, there are miscellaneous options which can be enabled or disabled using the format header.

*Table 10: Extended API Control Mode Format Headers*

Control Mode	Reply Mode	Format Header (Hexadecimal)
Position mode	Variant 1	0x10

<sup>10</sup> Torque Control Mode available from firmware version 2.3.

<sup>11</sup> This includes messages with format headers for miscellaneous commands, with unknown format headers, or with no format header. If this is the first API message sent the default response mode will be used

	Variant 2	0x11
	Variant 3	0x12
Velocity mode	Variant 1	0x20
	Variant 2	0x21
	Variant 3	0x22
Torque mode	Variant 1	0x30
	Variant 2	0x31
	Variant 3	0x32
Voltage mode	Variant 1	0x40
	Variant 2	0x41
	Variant 3	0x42

### 3.3.2 Read Only Mode

Read Only mode is available to get data from the hand without affecting the hand. Read Only commands do not trigger the hand to enter API control mode<sup>12</sup>. This allows data to be streamed from hand while it is controlled by another method, such as over Bluetooth or Analog Inputs.

Mode	Format Header Value (Hexadecimal)
Read Only mode, reply variant 1	0xA0
Read Only mode, reply variant 2	0xA1
Read Only mode, reply variant 3	0xA2

### 3.3.3 Miscellaneous Format Header Commands

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<sup>12</sup> Note that a message with a Read Only format header also does not trigger the hand to exit API control mode. Read Only messages will sustain the hand in API control mode by resetting the 300ms timeout upon reception.

A number of miscellaneous commands are available to either trigger a one-time action or change volatile settings which reset on each power cycle. These commands trigger the hand to enter API mode and will sustain the hand in API control mode by resetting the 300ms timeout.

Miscellaneous messages can be sent without the data payload of command messages. For convenience, a data payload of up to 12 bytes can be included – this data will be ignored by the hand. The payload must have a valid checksum in the last byte.

*Table 11: Miscellaneous Payload Format Headers*

Description	Format Header Value (Hexadecimal)
Reset Over Temperature Safety Threshold <sup>13</sup>	0xB0
Upsample Thumb Rotator <sup>14</sup> Enable	0xC2
Upsample Thumb Rotator Disable	0xC3
Exit API Control Mode <sup>15</sup>	0x7C

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<sup>13</sup> Use with Caution, repeated use may damage the hand. The hand should be allowed to cool down if it is in over temperature condition. See Section 3.2.

<sup>14</sup> Upsampling acts on incoming position requests for the thumb rotator. This feature is to be used if new positions are being requested infrequently (on the order of 30Hz) which can cause jerky motion due to the high link inertia and lower gear ratio of the thumb rotator joint.

<sup>15</sup> Immediately exit API mode, skipping the 300 millisecond timeout. This can be safely called when not in API mode without causing any unexpected movements

## 3.4 Extended API Data Format

### 3.4.1 Position Data

Position is sent and received as a signed 16-bit integer (`int16_t`) in little endian format. The conversion ratio to represent finger positions (in degrees, with 0 degrees representing the fully extended position) is as follows:

$$P_{\text{digital}} = \Theta_{\text{degrees}} * 32767 / 150$$

Positive finger angles cause all joints but the thumb rotator to flex inwards towards the palm. The thumb rotator direction is reversed; negative angles from 0 cause it to flex away from its fully extended position. This relationship holds for velocity, voltage, and torque requests as well.

### 3.4.2 Finger Velocity Data To Hand

Velocity is sent as a signed 16-bit integer (`int16_t`) in little endian format. Velocities are represented in fixed point format with the following format:

$$\omega_{\text{digital}} = \omega_{\text{degrees/sec}} * 32767 / 3000$$

Positive velocities cause the fingers and thumb flexor to flex inwards toward the palm and negative voltages cause them to flex outwards toward the fully open positions. This is reversed for the thumb rotator.

In velocity control mode, the hand will track the requested velocity in finger degrees per second. Note that this differs from the velocity reported by the hand, which is the rotor velocity in radians per second. Therefore, the motor rotor velocity will differ by the gear ratio, units, and fixed point-conversion factor.

### 3.4.3 Rotor Velocity Data From Hand

Velocity data from the hand represents the motor rotor velocity in radians per second: The conversion is given below:

$$\omega_{\text{digital}} = \omega_{\text{rad/sec}} * 4$$

Note that the gear ratio of the finger must be used to convert this number into the rotational speed of the actual finger joint.

The gear ratios for each finger are provided in the table below:

Finger	Gear Ratio
Index	649:1
Middle	649:1
Ring	649:1
Pinky	649:1
Thumb Flexor	649:1
Thumb Rotator	162.45:1

### 3.4.4 Voltage Data

Voltage is only available as a control mode, the hand does not report voltage data. Voltage is sent as a signed 16-bit integer (`int16_t`) in little endian format. The requested 'voltage' is interpreted as a percentage of the power supply voltage, and can be thought of as a PWM duty cycle. The range of input values is  $(-3546, 3546)$ , where 3546 is 100% duty in the forward direction of the motor, and -3546 is 100% duty in the negative direction of the motor. Voltage/duties are enforced using the 'sinusoidal control' commutation method.

Note that, as with the other control modes, the thumb rotator will flex inwards when given a *negative* input, whereas the remaining joints will flex inwards when given a *positive* valued input.

### 3.4.5 Current (Torque) Data

Current values are sent as a signed 16-bit integer (`int16_t`) in little endian format. The requested value is interpreted as a motor rotor current request, in a fixed-point representation based on the current measurements taken with the analog instrumentation

on the hand board. When this mode is active, the hand performs field-oriented control on each motor to track the requested rotor current. The rotor current returned in reply variants 1 and 3 is expressed in the same units.

The equation that relates fixed-point rotor currents to currents in amps is given below:

$$I_{\text{digital}} = I_{\text{amps}} * 7000 / 0.540$$

The motor torque constant is provided below:

$$k_t = 1.49 \text{ mNm/A}$$

The fingertip forces can be calculated using the above equations, the kinematic information provided in the universal robot description format (URDF) file included with the API, and the description of the 4 bar linkage parameters included elsewhere in this document.

Due to the extremely high bandwidth of FOC (30-40kHz) there will be effectively no difference between the requested motor current and measured rotor current, so it is recommended to use reply variant 2 or 3 when in this mode.

It is also important to note that there is passive, electromagnetic damping that occurs as a consequence of the motor dynamics when using voltage as a control input. This damping effect is removed as a consequence of active torque tracking, and as a result explicit damping is required in most cases to close a stable control loop on position when using torque as an input.

It is strongly recommended to use the rotor velocity term in variants 2 and 3 for damping, as this measurement will provide a substantially lower noise velocity estimate than a velocity measurement computed from the finger angles.

### 3.4.6 Touch Sensor Data

Touch Data is packed into 45 total bytes as 12 bit unsigned integers. For hands that do not have all touch sensors installed, a value of 0 will be sent in their place. Note that each word is broken up and packed with little-endianness. The endianness of the receiving system should be considered when unpacking this range of bytes.

The following C code will decode this range of bytes when run on a little-endian system.

```

/*
 * Load packed 12 bit values located in an 8 bit array
 * into an unpacked (zero padded) 16 bit array
 */
void unpack_8bit_into_12bit(uint8_t* arr, uint16_t* vals, int valsize)
{
    for(int i = 0; i < valsize; i++)
        vals[i] = 0; //Clear the buffer before loading with |=

    for(int bidx = valsize * 12 - 4; bidx >= 0; bidx -= 4)
    {
        int validx = bidx / 12;
        int arridx = bidx / 8;
        int shift_val = (bidx % 8);
        vals[validx] |= ((arr[arridx] >> shift_val) &0x0F) << (bidx % 12);
    }
}

```

### 3.4.7 Overtemperature Torque Limit Status

The status of the torque limiting safety function is exposed through the api in the form of a bitmask, which indicates whether a motor is 'hot' or 'cold'. This is always the second to last byte, regardless of format. If the temperature has exceeded an internally defined threshold, the finger is deemed 'hot', and if it dips below a different internally defined threshold, it is deemed 'cold'. The maximum torque of hot fingers is reduced which will result in slower or less powerful movements.

Table 12: Torque Limit Status Bitmap Indices

Bit 0	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7
Index	Middle	Ring	Pinky	Thumb Flexor	Thumb Rotator	(Ignored)	(Ignored)

### 3.4.8 Checksums

All transmissions to the hand must have a valid checksum in the final byte to be processed. All transmissions from the hand will include a checksum in the final byte which can be used to check data integrity. The checksum is the 2s complement negation of the (8 bit, 2s complement) sum of the preceding bytes. The 8 bit 2s complement sum all bytes will be equal to 0 for an uncompromised data frame.

## 3.5 Example Extended API Data Frames

### 3.5.1 Control Commands to the Hand

All command transmissions to the hand follow the same format regardless of control mode. Note that the Read Only commands may be sent in the format of a Control Command or a Miscellaneous Command.

*Table 13: I2C Control Command to Hand*

Byte 0	Bytes 1-2	Bytes 3-4	Bytes 5-6
Command Header	Index Finger Data	Middle Finger Data	Ring Finger Data
Bytes 7-8	Bytes 9-10	Bytes 11-12	Byte 13
Pinky Finger Data	Thumb Flexor Data	Thumb Rotator Data	Checksum

*Table 14: UART/RS485 Control Command to Hand*

Byte 0	Byte 1	Bytes 2-3		Bytes 4-5	Bytes 6-7
Hand Slave Address	Command Header	Index Finger Data		Middle Finger Data	Ring Finger Data
Bytes 8-9	Bytes 10-11		Bytes 12-13		Byte 14
Pinky Finger Data	Thumb Flexor Data		Thumb Rotator Data		Checksum

### 3.5.2 Miscellaneous Commands to Hand

Miscellaneous Commands are sent with just the command header and checksum.

*Table 15: I2C Miscellaneous Command to Hand*

Byte 0	Byte 1
Command Header	Checksum



*Table 16: UART/RS485 Miscellaneous Command to Hand*

Byte 0	Byte 1	Byte 2
Hand Slave Address	Command Header	Checksum

### 3.5.3 Hand Reply Variants 1 & 2

Reply Variants 1 and 2 are identical except for the second piece of data. Variant 1 includes the Motor Current while variant 2 includes the Motor Rotor Velocity.

*Table 17: I2C, UART, RS485 Reply Variants 1 & 2*

Byte 0	Bytes 1-2	Byte 3-4		Bytes 5-6	Bytes 7-8
Format Header	Index Position	Index Current / Rotor Velocity		Middle Position	Middle Current / Rotor Velocity
Bytes 9-10	Bytes 11-12	Bytes 13-14		Bytes 15-16	Bytes 17-18
Ring Position	Ring Current / Rotor Velocity	Pinky Position		Pinky Current / Rotor Velocity	Thumb Flexor Position
Byte 19-20	Bytes 21-22	Bytes 23-24		Byte 25	Byte 26
Thumb Flexor Current / Rotor Velocity	Thumb Rotator Position	Thumb Rotator Current / Rotor Velocity		bits 11-4 of index site 0 touch sensor data	bits 3-0 of index site 0 & bits 11-8 of the index site 1
Byte 27	Byte 28	...	Byte 69	Byte 70	Byte 71
bits 7-0 of index site 1	bits 11-4 of index site 2	...	bits 7-0 of thumb site 5	Hot/Cold status of each finger	Checksum

### 3.5.4 Hand Reply Variant 3

Reply Variant 3 includes the finger position, motor current, and rotor velocity omitting the touch sensor data.

Table 18: I2C, UART, RS485 Reply Variant 3

Byte 0	Bytes 1-2	Byte 3-4	Bytes 5-6	Bytes 7-8	Bytes 9-10	Bytes 11-12	Bytes 13-14
Format Header	Index Position	Index Current	Middle Position	Middle Current	Ring Position	Ring Current	Pinky Position
Bytes 15-16	Bytes 17-18		Byte 19-20	Bytes 21-22		Bytes 23-24	Bytes 25-26
Pinky Current	Thumb Flexor Position		Thumb Flexor Current	Thumb Rotator Position		Thumb Rotator Current	Index Rotor Velocity
Byte 27-28	Byte 27-28	Bytes 31-32	Bytes 33-34		Bytes 35-36	Byte 37	Byte 38
Middle Rotor Velocity	Middle Rotor Velocity	Pinky Rotor Velocity	Thumb Flexor Rotor Velocity		Thumb Rotator Rotor Velocity	Hot/Cold status	Checksum

## 4 Bluetooth Low Energy

### 4.1 Introduction

The Ability Hand has bluetooth low-energy connectivity which can be used to obtain various diagnostic information, control motion, and change important settings in the flash memory of the hand. Bluetooth connections use a GATT profile. Commands are generally sent from the BLE client (i.e. a phone or PC) to the BLE server (the Ability Hand) with write operations in the form of short ASCII encoded strings. The Ability hand sends data back to the BLE client in the form of notifications.

General message structure (for sending data to the Ability Hand) consists of a header byte, followed by a unique message structure. There are 10 different header bytes which subdivide the categories of operation for the Ability Hand bluetooth interface.

Grip Command Header (Legacy)	G
Grip Configuration Header	g
(Flash Data Storage/FDS) Write Command Header	W
Read Command Header	R
Read Status Header	S
Data Plotting Header	P
Firmware Update Header	O
Miscellaneous Command Header	C
Grip Customization Header	m
Individual Finger Control Header	M

### 4.2 General Connection Information

The GATT profile UUIDs are listed as follows:

Service UUID	"6E400001-B5A3-F393-E0A9-E50E24DCCA9E"
RX Characteristic UUID	"6E400002-B5A3-F393-E0A9-E50E24DCCA9E"
TX Characteristic UUID	"6E400003-B5A3-F393-E0A9-E50E24DCCA9E"

Write data to the RX characteristic to send it to the Ability Hand.

Notifications must be enabled for the TX characteristic to receive data from the Ability Hand. The Ability Hand transmits all data as notifications.

## 4.3 Grip Commands

### 4.3.1 Grip Commands (Legacy) ('G')

This section describes how the app can move the hand to a limited number of grip configurations with a predefined speed. This command format is used by the demo mode screen in the PSYONIC App.

Set a grip: '**G--**'

- Byte 0: '**G**'. Prefix for this mode
- Byte 1: The grip index. ASCII format. List defined below:
  - '**0**': Open the hand
  - '**1**': Power
  - '**2**': Key
  - '**3**': Pinch
  - '**4**': Chuck
  - '**5**': \m/
  - '**6**': Cylinder Grip
  - '**7**': Mouse Grip
  - '**Z**': Power/Key Mode switch
  - '**9**': Point
  - '**A**': Rude Point
  - '**8**': Hook grasp
  - '**C**': Relax
  - '**D**': Sleeve Grasp
  - '**B**': Peace Grasp
  - '**F**': Chuck Grasp
  - '**E**': Hang Loose Grasp
  - '**G**': Handshake Grasp
  - '**H**': Pinch (fixed thumb flexor location)
  - '**I**': Unassigned
  - '**J**': Unassigned
  - '**K**': Unassigned
  - '**L**': Unassigned
  - '**M**': Unassigned
  - '**N**': Trigger grip
  - '**O**': Unassigned
  - '**P**': Unassigned

- **'Q'**: Unassigned
- **'R'**: Unassigned
- **'S'**: Unassigned
- **'T'**: Unassigned
- **'U'**: Unassigned
- **'V'**: If enabled with binary setting, does 'waggle grip'. If not, loads an unassigned grip (no motion)
- Any other value: Open the hand
- Byte 2: The speed. RAW BINARY FORMAT. Can use ASCII commands; a value of **'A'** will move the hand with a calm, slow speed. Fastest human typable speed will use the character **'~'**. (It may be possible, depending on platform, to use extended ascii. ALT+254 is the second fastest, ALT+255 is the fastest).
- For the PSYONIC App:
  - 0: stop the hand mid grasp
  - 1-254: proportional speed (maximum .3s)
  - 255: max speed (.2s)
- Example command: **'G3A'**. The hand will make a pinch grasp with low speed.

### 4.3.2 Grip Commands ('g')

Grips can also be requested using a command-line friendly/typable format. This command set indexes directly into the Ability Hand's grip configuration list (section 4.3.3) with a typed, user requested grip period. The structure of this command set is as follows:

- **gxx:xx.xx**

Where g is the header, bytes 1-2 are for the grip index, byte 3 is a colon separation character, and the remaining (arbitrary length) bytes are a typed floating point format number corresponding to the desired *period* in seconds that should elapse for each sub-motion of the selected grip.

Note that the index **-1** can be used as a shorthand to access the open configuration of whichever grip is currently active.

Examples:

- **g03:0.20** - execute a power grasp with a 0.2 second motion period
- **g-1:5.1234** - open the hand with a 5.1234 seconds motion period

### 4.3.3 Grip Configuration List

<b>0</b>		<b>8</b>		<b>16</b>		<b>24</b>	
<b>1</b>		<b>9</b>		<b>17</b>		<b>25</b>	
<b>2</b>		<b>10</b>		<b>18</b>		<b>26</b>	
<b>3</b>		<b>11</b>		<b>19</b>		<b>27</b>	
<b>4</b>		<b>12</b>		<b>20</b>		<b>28</b>	
<b>5</b>		<b>13</b>		<b>21</b>		<b>29</b>	
<b>6</b>		<b>14</b>		<b>22</b>		<b>30</b>	
<b>7</b>		<b>15</b>		<b>23</b>		<b>31</b>	

- 0 chuck grasp
- 1 chuck ok grasp
- 2 pinch grasp
- 3 power grasp
- 4 key grasp
- 5 handshake grasp
- 6 three finger trigger grasp
- 7 point grasp
- 8 relax grasp
- 9 sign of the horns grasp
- 10 rude point grasp
- 11 mode switch close grasp (*note: special grip which gets written to by application*)
- 12 Utility/Cylinder
- 13 Mouse
- 14 Hook
- 15 Sleeve
- 16 Peace
- 17 Hangloose
- 18 Pinch, thumb does not move
- 19 Free
- 20 Free
- 21 Free

- 22 Free
- 23 Free
- 24 Free
- 25 Free
- 26 Free
- 27 Free
- 28 Free
- 29 Free
- 30 Free
- 31 Waggle Grip, IF waggle is not disabled (We28 disables it)
- 32 - 63: **open configurations. Add 32 to the grip index below for the open config**

#### 4.3.4 Grip Change CLI Specification ('m')

Before entering, select the grip you want to change using demo mode. You can modify both the grip and the open configuration of that grip.

- **'m'** : enter grip modification mode.

Once in grip modification mode, you will see a status message that tells you you're changing a configuration index. Indices 0-31 are close configurations and indices 32-63 are open configurations.

Select grip configuration idx:

- **'mg--'** where '--' is a typed, base 10 integer. Only integers between 0 and 63 are valid. This will load the grip configuration index to be modified. The grip configuration list is the same as for the non-legacy grip commands, detailed in section 3.3.2

Select finger:

- **'mf0'** : select index finger
- **'mf1'** : select middle finger
- **'mf2'** : select ring finger
- **'mf3'** : select pinky finger
- **'mf4'** : select thumb flexor
- **'mf5'** : select thumb rotator



Set selected finger setpoint:

- **'mq----**': where ---- is a typed, base 10 floating point number. Negative signs are interpreted and valid. Decimal points are interpreted and valid, although they are *not* required.
  - Example uses of this command:
    - **'mq30'** : sets the current finger to 30.000 degrees
    - **'mq-55'** : sets the current finger to -55.000 degrees
    - **'mq15.123'** : sets the current finger to 15.123 degrees
    - **'mq-1.234'** : sets the current finger to -1.234 degrees
  - Out of bounds value will be truncated to finger limits, the hand will return the value of the final position.
  - The thumb rotator can only move to negative values; all other fingers move only to positive values. All fingers can move to "0".

Set the selected finger priority:

- **'mp--'** : where -- is a *signed* (i.e. **'mp-1'** is parsed as -1) base 10 integer which sets the priority of the given setpoint of the selected grip configuration. Priority determines the order in which the finger will come in. Priority 0 comes in first, until all priority 0 finger motions have finished, then priority 1, then priority 2, etc. Negative priority setpoints will never be loaded (i.e.that finger will not move or be changed).

View current finger position:

- **'mr'** : print the current selected finger position to console in ascii-string format

View the current finger priority:

- **'mR'** : print the current selected finger priority to console in ascii-string format

Save the current configuration:

- **'ms'** : the selected grip configuration will be saved (all setpoint and priority changes for the whole grip)

Exit grip modification mode:

- **'me'**: return to normal mode

## 4.4 Write Configuration CLI Specification ('W')

All commands in this section (prefix **'W'**) change filesystem data and save it. When using the CLI, a successful save will return with the string "success". An unsuccessful save will return with "error: fs write".

Electrode Flip Bit: **'WKO' / 'WK1'**

- Changes which electrode corresponds to what electrode connection on the coax plug. Software equivalent of swapping electrodes on the coaxial plug.

Key on Power Off Bit: **'WGO' / 'WG1'**

- When '0' is written, the hand will move to a key grasp, initiated by power off. When '1' is written, the hand will do nothing before power is lost. Legacy alias for MC\_ENABLE\_POWEROFF\_GRIP\_BIT

Write Hand Type: **'WH-'**

- Write the hand type. Not checked; if an out of bounds type is written, the ENTIRE filesystem will be restored to system default settings on the next power cycle.
  - **'WHO'**: Long left hand
  - **'WHI'**: Long right hand
  - **'WH2'**: Short left hand
  - **'WH3'**: Short right hand

Write Control Mode: **'W0-'**

- Change and save the new control mode.
  - **'W00'**: Bluetooth control mode
  - **'W01'**: Direct control mode
  - **'W02'**: Linear Transducer control mode
  - **'W03'**: I2C Top Rings control mode (aka Coapt Top Rings)
  - **'W04'**: Single site control mode
  - **'W08'**: I2C Mid Rings (aka Coapt Mid Rings)

Vibration Enable/Disable Bit **'W30' / 'W31'**

- **'W30'** Enable vibration feedback
- **'W31'** Disable vibration feedback

Vibration Intensity Bit **'WK--'**

- **'WK'** header followed by raw binary value between 0-87. 87 is the maximum value parsed; it is internally thresholded by the hand.

Contact Reflex Enable/Disable Bit **'W50' / 'W51'**

- **'W50'** Enable vibration feedback
- **'W51'** Disable vibration feedback

Write Max Mappable Grip Period **'WM[typed floating point number]'**

- Direct control (dual and single site) will proportionally map the grip period (in seconds) using this number. Grip period = time for the hand to transition between open and close configurations. Setting this number will determine the minimum amount of time the hand can possibly take to close using one of these modes. Numbers smaller than .2 will automatically be capped at .2 Numbers larger than about 5 seconds will seemingly result in direct control ceasing to function properly; use this feature carefully!
- Examples of valid commands:
  - **'WM1.0'**
  - **'WM.33'**
  - **'WM0.4'**

Write Electrode 1 threshold **'W6-----'**

Write Electrode 2 threshold **'W7-----'**

Write Electrode 1 gain **'W8-----'**

Write Electrode 2 gain **'W9-----'**

- Prefix followed by a 4 byte floating point number. These 4 bytes are raw binary data<sup>16</sup> in 32-bit ieee-754 floating point number (single precision) format. Sets the corresponding threshold or gain.

Write Hand Name : **'WJ-----'**

- Writes the variable portion of the bluetooth advertising name to the filesystem. Typed string format
- Example of use: **'WJ20ABH025'**

Write Mode Switch Toggles: **'WSxxxxxxx'**

- **'WS'** header followed by 7 digit data. Each can take **'0'**, **'1'**, or **'x'** (any character OTHER than **'0'** or **'1'** is equivalent to **'x'**). As with other binary toggle settings, **'0'** is ENABLE and **'1'** is DISABLE.
- Data order:
  - Position 0: Open on Open (**'WS0xxxxxx'** / **'WS1xxxxxx'**)
  - Position 1: Double Impulse Close (**'WSx0xxxxx'** / **'WSx1xxxxx'**)
  - Position 2: Double Impulse Open (**'WSxx0xxxx'** / **'WSxx1xxxx'**)
  - Position 3: Co Contract (**'WSxxx0xxx'** / **'WSxxx1xxx'**)
  - Position 4: Long Co Contract (**'WSxxxx0xx'** / **'WSxxxx1xx'**)
  - Position 4: Long Open (**'WSxxxxx0x'** / **'WSxxxxx1x'**)
  - Position 4: Long Close (**'WSxxxxxxx0'** / **'WSxxxxxxx1'**)

Write Mode Switch Grips: **'WTxxxxxxx'**

---

<sup>16</sup> These bytes are not typable. They are raw binary data, not an interpreted string.

- **'WT'** header followed by a 6 character data field. Data is the exact same format as the **'W2'** command.
- Data Format (**x** = data, **-** = placeholder character. Example to show position, NOT valid commands):
  - Position 0: Double Close Grip **'WSx-----'**
  - Position 1: Double Open Grip **'WS-x-----'**
  - Position 2: Co-Contract Grip **'WS--x----**
  - Position 3: Long Co-Contract Grip **'WS----x--'**
  - Position 4: Long Open Grip **'WS-----x-'**
  - Position 5: Long Close Grip **'WS-----x'**

Enable Binary Setting **'We[ARG]'**

Disable Binary Setting **'Wd[ARG]'**

- **[ARG]** is a typed integer string between 0 and 63 corresponding to the index of a binary setting to change
- The enable command will set the binary setting to **'0'**, enabling that setting.
- The disable command will set the binary setting to **'1'**, disabling that setting.
- The complementary read setting for this command is **'RZ'**. See the command spec for **'RZ'** for the complete list of binary settings
- Example command: **'We16'** will enable UART/RS485 communication. **'Wd16'** will disable UART/RS485 (returning to I2C)
- See section 4.6.3 for full list of Binary Settings

Write Direct Control Timing Information **'WU[0-3][0-255]'**

- This command writes timing settings for double impulse pulse time, rest time, long hold hold time, and long co contract hold time.
- The first argument **[0-3]** is a single digit character (**'0'**, **'1'**, **'2'**, or **'3'**).
  - **'0'**: writes the double impulse pulse time
  - **'1'**: writes the long hold time
  - **'2'**: writes the long co contract time
  - **'3'**: writes the rest interval time
- The second argument **[0-255]** is a typed string integer ranging from 0 to 255. Each value corresponds to an increment of 15mS, starting at 50mS.
- Once written, the hand will automatically follow up with one of the following responses.
  - Double Impulse = [pulse time in ms]
  - Long Hold = [pulse time in ms]
  - Co Contract = [pulse time in ms]
  - Rest Interval = [pulse time in ms]

- Example command: **'WU040'** will set the double impulse pulse time to 650mS. The follow up string will read 'Double Impulse = 650'.
- The complementary read command is **'RX[0-3]'**

Factory Reset Settings: **'WL'**

- Special command (no data field) which restores factory default settings<sup>17</sup> to the hand.

Factory Reset Non-Grip Settings: **'Wo'**

- Special command (no data field) which restores non-grip settings to factory default.

Write contact reflex grip period: **'WWx.xxx'**

- String format to write the contact reflex period setting. The value written will be the period in seconds the hand will take to achieve its grip when the contact reflex is active. A period of 1000 will stop the hand. A period of .2 is the maximum possible speed for that grip.

Write Miscellaneous 32 bit word: **'Wmxxx:xxxx'/'Wnxxx:xxxx'**

- General command format: Header (**Wm/Wn**), *exactly* 3 characters worth of address (valid inputs are 000-215), colon argument separator, followed by the typed numerical argument (which will be loaded into the specified word).
- **'Wmxxx:xxxx'** takes an argument string (after the colon) as a floating point string. An example: **'Wm001:1.234'** will set miscellaneous memory index 1 to 1.234f.
- **'Wnxxx:xxxx'** takes an argument string (after the colon) as a *hexadecimal* string. An example: **'Wn002:0xDEADBEEF'** will load the value 0xDEADBEEF into memory index 2.
- This feature is not intended to be used as general storage. Each word is potentially used to change the behavior of various features on the hand, changing currently unused words may result in undesired behavior when a future update utilizes this word. This command is created to be a 'general purpose' command which reduces the scope of individual command strings and thus overall developer effort. The list of words for this command can be found in section 4.6.

---

<sup>17</sup> Resets all data including important fields such as hand name and gearbox ratio. Prior to a reset, the data of such fields should be recorded.

## 4.5 Read Configuration CLI Specification ('R')

Commands in this section (with the prefix '**R**') read various filesystem data and send them using the nRF BLE UART service.

Read Power Off Option Bit '**RO**'

- 0 : hand will move to the key when powered off.
- 1: hand will do nothing when powered off

Read Electrode Flip Bit '**RL**'

- 0: electrodes are flipped.
- 1: electrodes are not flipped

Read Hand Type '**RO**'

- 0 : Long left hand
- 1 : Long right hand
- 2 : Short left hand
- 3 : Short right hand

Read Hand Type (Human Readable Format) '**RM**'

- Printed string describing the hand type in human readable format.

Read Control Mode '**RI**'

- 0 : Bluetooth control mode
- 1 : Direct control mode
- 2 : Linear Transducer control mode
- 3 : I2C Top Rings control mode (aka Coapt Top Rings)
- 4 : Single site control mode
- 5 : Direct control mode (flipped electrodes)
- 6 : Linear Transducer Control mode (flipped electrodes)
- 7 : Single site control mode (flipped electrodes)
- 8 : I2C Mid Rings (aka Coapt Mid Rings)

Read Vibration Enable Bit '**R4**'

- 0: vibration is enabled.
- 1: vibration is disabled

Read Hand Name '**RC**'

- Human readable hand name (string).
- Postamble portion of the bluetooth advertising name.

Read Electrode 1 threshold '**RD**'

Read Electrode 2 threshold '**RE**'

Read Electrode 1 gain '**RF**'

Read Electrode 2 gain '**RG**'

- 32 bit ieee 754 single-precision floating point format electrode threshold/gain.
- Not human readable.

Read Contact Reflex Period '**Ra**'

- Returns human readable contact reflex grip period (period the hand has when reflex is activated)

Read Max Mappable Grip Period '**RS**':

- Sends the header '**PER**' followed by an ASCII floating point string indicating the value of the mappable grip speed. Example: '**PER1.234**'.

Read mode switch grips '**RW**':

- Sends the bytes written to the mode switch grip fields. Does not contain a header. Byte order is as follows:
  - Byte 0: Double Impulse Close Byte
  - Byte 1: Double Impulse Open Grip
  - Byte 2: Co Contract Grip
  - Byte 3: Long Co Contract Grip
  - Byte 4: Long Open Grip
  - Byte 5: Long Close Grip

Read Mode Switch Toggles '**RV**':

- Sends the header '**MOD:**' followed by a 7 character string corresponding to the '**0**' or '**1**' ascii toggle settings sent with the complementary write command. The order is the same, stated as follows:
  - Position 0: Open on Open
  - Position 1: Double Impulse Close
  - Position 2: Double Impulse Open
  - Position 3: Co Contract
  - Position 4: Long Co Contract
  - Position 5: Long Open
  - Position 6: Long Close

Read Binary Configuration Setting: '**RZ[ARG]**'

- The **[ARG]** field is a typed integer string between 0-63, corresponding to the binary setting to be read.
- The hand will reply with the string: **BIN[ARG]=[VAL]**, where **[ARG]** is the setting number and **[VAL]** is the value of that setting ('**0**' for enable and '**1**' for disable).
- Example: '**RZ14**'. The hand will reply with '**BIN16=0**' if UART/RS485 mode is enabled.

- The complementary write commands for this command are '**We[ARG]**' and '**Wd[ARG]**', which enable or disable the setting of index **[ARG]**, respectively.
- See section 4.6.3 for list of binary settings.

Read Miscellaneous 32 bit word: '**Rmxxx/Rnxxx**'

- General command format: Header (**Wm/Wn**), *exactly* 3 characters worth of address (valid inputs are 000-215).
- The hand will reply with the string: **mem[xxx]=val** where xxx is the word address and val is the value of that word in the specified format
- '**Rmxxx**' returns the word as a floating point number
- '**Rnxxx**' returns the word as a hexadecimal number

Read Timing Information '**RX[0-3]**'

- Hand will reply with TIM[number] where the number is the time in ms. Will range from 50 to 3875.
- The argument (0-3) corresponds to the timing parameter index, as specified in the complementary write command, '**WU[0-3][0-255]**'.



## 4.6 List of Configurable Settings

### 4.6.1 List of Word Settings: Floating point format

The table below shows all memory indices that are interpreted by the hand firmware as floating point values. Only these settings should be written to using the floating point variant of the write command.

Table 19: Floating Point Format Bluetooth Word Settings

Memory Index:	Label:	Description:
000	WORD_IDLE_TIMEOUT	Amount of time in seconds that must elapse with no EMG activity while the hand is open for the hand to enter a relaxed configuration

### 4.6.2 List of Word Settings: Hexadecimal format

The table below shows all memory indices that are interpreted by the hand firmware as floating point values. Only these settings should be written to using the hexadecimal variant of the write command.

Table 20: Hexadecimal Format Bluetooth Word Settings

Index:	Label:	Description:
001	WORD_API_CONFIG0	Uses byte-wise values to set baud rate, transmission frame format, and slave node ID for the UART/RS485 API protocol.  <b>Byte 0:</b> Unused <b>Byte 1:</b> Slave Address <b>Byte 2:</b> Enumerated Baud Rate (see Section 2.2) <b>Byte 3:</b> Unused
003	WORD_HARDWARE_PROFILE	ENUM for Hand Hardware Version <b>0:</b> v10.x <b>1:</b> Pre-v10.x  <i>*Requires Power Cycle to Take Effect</i>

### 4.6.3 List of Binary Settings

Table 21: Binary Bluetooth Settings

Setting Name	Index	Default	Description
MC_VIBRATION_EN_BIT	0	1	Enable/disable vibration when touch sensors are pressed
MC_CONTACT_REFLEX_EN_BIT	1	0	Enable/disable contact reflex, triggered by touch sensors.
MC_NO_ADAPTER_ENCODER	2	0	Enable/disable check for adapter encoder. If enabled and an adapter encoder is detected, the adapter encoder is used to control that finger position.
MC_ENABLE_POWEROFF_GRIP_BIT	3	0	When enabled, the hand performs a power off grip upon reception of a signal to power off
<i>Reserved</i>	4	X	<i>Reserved</i>
MC_ELECTRODE_FLIP_BIT	5	0	When enabled, the open and close electrode input roles are swapped.
MC_IS_32_TO_1_BIT	6	0	Enable to flag the motor planetary gearboxes as 32.45:1. Default to 0 for safety, must be manually enabled for most hands
MC_ENABLE_OPEN_ON_OPEN_MS	7	1	Enable the open on open mode switch strategy for direct control.
MC_ENABLE_DI_CLOSE_MS	8	0	Enable the 'double impulse close' direct control mode switching strategy.
MC_ENABLE_DI_OPEN_MS	9	0	Enable the 'double impulse open' mode switching strategy
MC_ENABLE_CC_SHORT_MS	10	0	Enable the short co-contract signal for mode switching
MC_ENABLE_CC_LONG_MS	11	0	Enable the long co-contract mode switch signal
MC_ENABLE_LONG_OPEN	12	0	Enable long open mode switch strategy
MC_ENABLE_LONG_CLOSE	13	0	Long close mode switch strategy
MC_NO_FS_LOADING	14	0	If enabled, finger positions are not loaded from the filesystem on startup, even if saved positions are available
MC_DISABLE_AUTO_LP_MODE	15	0	If enabled, the I2C signal to bring the hand out of the low power state is

			ignored, thus placing the hand in a permanent low power state (unless overruled by the MC_FORCE_HIGH_POWER_MODE toggle)
MC_COMM_IS_UART	16	0	Enables the UART/RS485 peripheral on the COMM lines. I2C will no longer function.
MC_SLIP_DETECTION_EN	17	0	Enable slip detection feature on the hand.
MC_ENABLE_TAP_FREEZE	18	0	Enable IMU triple tapping for 'freeze' grip
MC_FIRST_OVER_CTL_ENABLE	19	1	Enables 'first over' strategy for direct control.
MC_ENABLE_TAP_MODESWITCH	20	0	Enable IMU double tapping to change grips (in control modes that use the griplist)
<i>Reserved</i>	21	X	<i>Reserved</i>
MC_DISABLE_DC_FILTER	22	0	When enabled, the low pass filter on direct control electrode signals is not used.
<i>Reserved</i>	23	X	<i>Reserved</i>
<i>Reserved</i>	24	X	<i>Reserved.</i>
MC_NO_TAP_MODESWITCH_WHILE_CLOSED	25	0	When enabled, mode switching via IMU tapping is disabled when the hand is in a closed configuration.
MC_COAPT_FORCE_2INPUT_OC	26	0	When enabled, the hand attempts to prevent coapt from recognizing it by overloading the handshaking message on startup with 0 for 15 seconds.
MC_FORCE_HIGH_POWER_MODE	27	0	When enabled, all power related messaging is ignored and the hand will constantly be in the highest power state.
MC_DISABLE_FINGER_WAGGLE	28	0	When enabled, the 'finger waggle' grip behavior reverts to just another user-configurable, empty grip.
<i>Reserved</i>	29	0	<i>Reserved</i>
MC_ENABLE_ULTRAFAST	30	0	Experimental feature to allow increased

			max finger speed for smaller ranges of motion.
MC_ENABLE_PULLSTRING_LOCKOUT	31	0	Enables the lockout feature of pullstring/linear transducer control mode.
MC_ENABLE_IDLE_RELAX	32	0	When enabled, the hand will move to a relaxed configuration when open with no electrode activity for a specifiable amount of elapsed time.
MC_FAST_UART	33	0	Enable Fast Mode for UART, see section 3.
<i>Reserved</i>	34-63	X	<i>Reserved</i>

**\*Note:** Do not change reserved settings. These may be used internally for hand functionality.

**\*Note:** there are 64 settings total. Settings not in this table can be modified with '**We**'/'**Wd**'. Settings that are changed which are not in this table will have no effect at the time being, but may cause deviations from default behavior for future features.

## 4.7 Plotting Commands BLE Specification ('P')

The BLE Plotting Commands allow for high frequency data reporting over BLE. These commands are used by the plotting functionality of the Psyonic app. Due to the high rate of data being sent, these commands are not “command line friendly” and may overwhelm your terminal environment. These commands should be parsed by software.

**'P0'**: Enable Touch Sensor Plotting. IEEE 754 single precision (32 bit) floating point format.

**'P1'**: Disable Touch Sensor Plotting

**'P2'**: Enable Direct Control Plotting. IEEE 754 single precision (32 bit) floating point format.

**'P3'**: Disable Direct Control Plotting

**'P4'**: Enable FSR plotting

FSR plotting data format:

The data is sent in a 45 byte array. This 45 byte array is divided into five 9 byte chunks. Each 9 byte chunk corresponds to a finger. The finger order is: ***index, middle, ring, pinky, thumb***. Each 9 byte chunk is divided into six individual values, which are 12 bits in length. Each of these values corresponds to an individual sensor site on that finger. This means that the 0th touch sensor index data is split into the 0th and part of the 1st byte index.

See Section 3.4.6 for more details on unpacking this data.

## 4.8 Over The Air Updates (OTA) CLI Specification ('O')

The following section details how to OTA update the hand. All of these commands are blocking, the hand will not do anything else while they are running, and require a reboot upon completion regardless of outcome.

**'00'**: OTA updates the central controller with a DFU .zip package.

1. The hand will play a song to indicate entry into OTA DFU mode.
2. The BLE advertising name will change to DFU targ.
3. Once entered, you can navigate to the DFU menu in the nRF Toolbox App
  - a. Connect to the device named DFUTarg
  - b. Select the DFU .zip file to update the hand with
  - c. Tap 'upload'
4. The hand restarts upon successful completion of OTA DFU.

**'01'**: Bootload the motor drivers with the firmware saved in Central Controller Memory.

- The binary data of the motor driver application code is saved in the application memory of the central motor controller. Sending this command will enter bootloading mode. The behavior of bootloading mode is detailed below, the bootloading procedure incorporates automatic retries on each step.
  - The hand will indicate the start of the bootloading procedure with the GATT notification: 'Start Driver Bootloading...'
  - For each driver the hand will provide the following GATT notifications:
    - 'starting driver #' when the bootloading for that driver begins
    - 'ch # responsive' if the driver has successfully responded to bootloader commands
    - 'driver # ok' if the driver bootloading is successful
    - 'driver # ERROR' if the driver bootloading has failed
  - When all 6 motor drivers have been flashed successfully, the notification "Bootload done OK" will be sent. The hand will then restart.
  - If any motor driver fails to bootload it can be reattempted after a power cycle. Drivers that are responsive but then fail are likely to succeed on a retry. If a driver repeatedly fails to bootload this indicates a hardware failure on the hand. The hand must be returned to PSYONIC for repair.
- If you receive the GATT notification 'Cannot Bootload: Unknown Hardware' verify that the value in the hexadecimal word setting 003 is correct (see section 4.6.2)

**'02'**: Verify Driver Firmware

- This command is not available on hardware older than v10 due to hardware limitations

- This command verifies the driver firmware by comparing the checksum of the memory on the driver with the known checksum from memory on the central controller.
- On the reception of this command the hand will indicate that verification is starting with the GATT Notification: "Verifying Drivers..."
- For each driver the hand will send one of the following GATT Notifications:
  - 'driver # ok' if the verification is successful
  - 'driver # error' if the verification is unsuccessful
- If all drivers are successfully verified the hand will send the following GATT Notification and automatically restart: 'All Drivers Verified OK'
- Checksum verification may be unsuccessful for any of the following reasons:
  - Communication Failure
  - Memory Corruption
  - Driver is on a different firmware version than expected by the central controller

### **'O3': Cherrypick Bootload Motor Drivers**

- This command is not available on hardware older than v10 due to hardware limitations
- This command is a combination of O1 and O2 commands above. The central controller will attempt to verify the firmware on each driver, if the verification fails for a driver it will then bootload that driver.
- On the reception of this command the hand will indicate that verification is starting with the GATT Notification: "Cherrypick Bootload..."
- For each driver the hand will send the following notification if the verification has been successful:
  - 'driver # ok, not bootloading'
- If the verification is not successful, the central controller will attempt to bootload that driver. The hand will send the same "responsive", "ok", or "ERROR" GATT notifications as specified in command O1.
- If all drivers are successfully verified or successfully bootloaded the hand will send the GATT Notification and automatically restart.
  - 'All Drivers OK'

## 4.9 Miscellaneous/Custom Commands CLI Specification ('C')

**"C0"**: Play the 'DOOM' theme song. \m/

**"CAxx"** (BLE\_SET\_VIB): Override vibration motor intensity to input argument. Command expires after 10s and normal vibration control resumes. Input argument parsed as a base ten string number: example **CA55**

**"CB"** (BLE\_CLEAR\_VIB): Clear the vibration motor intensity. Will only affect one program loop of vibration commands mapped to touch sensor. Used to clear BLE\_SET\_VIB before the 10s expiry

**"CDUMP"** (BLE\_DUMP\_FS): Dump the entire filesystem raw in multiple multi-byte chunks over Bluetooth. Format subject to change based on coded implementation of filesystem.

**"CR"** (BLE\_RESET\_HAND): Calls NVIC\_SystemReset() ARM function. **Not safe** due to STM32 SPI slave peripheral hardware implementation.

**"CNxxxxxx"** (BLE\_SHOW\_RGB): Display an RGB value on both the hand board RGB led and the IO board RGB led. Used to preview different colors. Input format is a 32bit/4 character, base-16/hexadecimal string. Meant to make it simple to preview 'html' color codes: i.e. first byte is red, second byte is green, third is blue. Example: **"CN00FE45"** will display the io board's best attempt at creating 0x00FE45, a light green color.

**"Crxx"** (BLE\_READ\_EEPROM): Request a read of IO board EEPROM address. There are only 100 single byte eeprom addresses accessible through this command and its complement, BLE\_WRITE\_EEPROM. The post-header argument is a base-10 string from 0-99. Only 2 characters of the input string are used and the rest are discarded. Hand will reply with a notification containing the value in the argument address when the operation is complete, in the format **"%.2X%.2X"** (the requested address as a 2 character hex string followed by the requested data as a 2 character hex string). Example: **"Cr31"**

**"CExx:xx"** (BLE\_WRITE\_EEPROM): Request a write to IO board EEPROM address. The address field is a 2 character base-10 string (i.e. only accessible EEPROM space are addresses 0-99). The data field is parsed as a base-10 string but does not have a character limit: however it is loaded into a uin8\_t, so values over 255 WILL overflow. There is no input guarding on the hand side, so software must ensure that only values between "0" and "255" are sent. Example **CE31:207**



## 4.10 BLE Individual Finger Control ('M')

The fingers positions can be updated individually using the following command structure:

Byte 0: Command Header	Bytes 1-2: Index position (little endian)	Bytes 3-4: Index period (little endian)	Bytes 5-24: Positions and periods for all
'M' (0x4D)	int16 representation of the requested finger position.	uint16 representation of finger travel period	...

Finger order is the same as in all other instances of ordered per-finger data (index,middle,ring,pinky,thumb flexor, thumb rotator).

The fixed point representations of positions and periods can be computed with the following scaling factors and castings, depicted in c code:

```
int16_t pos_16 = (int16_t)((position * (float)0x7FFF)/(150.f));
uint16_t per_16 = (uint16_t)((period * (float)0xFFFF)/(300.f));
```

## 4.11 IO board EEPROM Map

### Button Functionality:

This section describes the options that can be assigned to single, double and triple tapping the io board button using the commands "**Crxx**" and "**CExx:xx**", which are described in the previous section.

Addresses:

Address (hex):	Address (decimal):	Function
0x0A	10	Single tap function definition
0x0B	11	Double tap function definition
0x0C	12	Triple tap function definition

Button Function Value:	Mapped behavior
1	Displays battery level
2	Sends the 'freeze' signal to the hand
3	Sends the 'mode switch' signal to the hand

Example commands which restore default behavior map of the button taps:

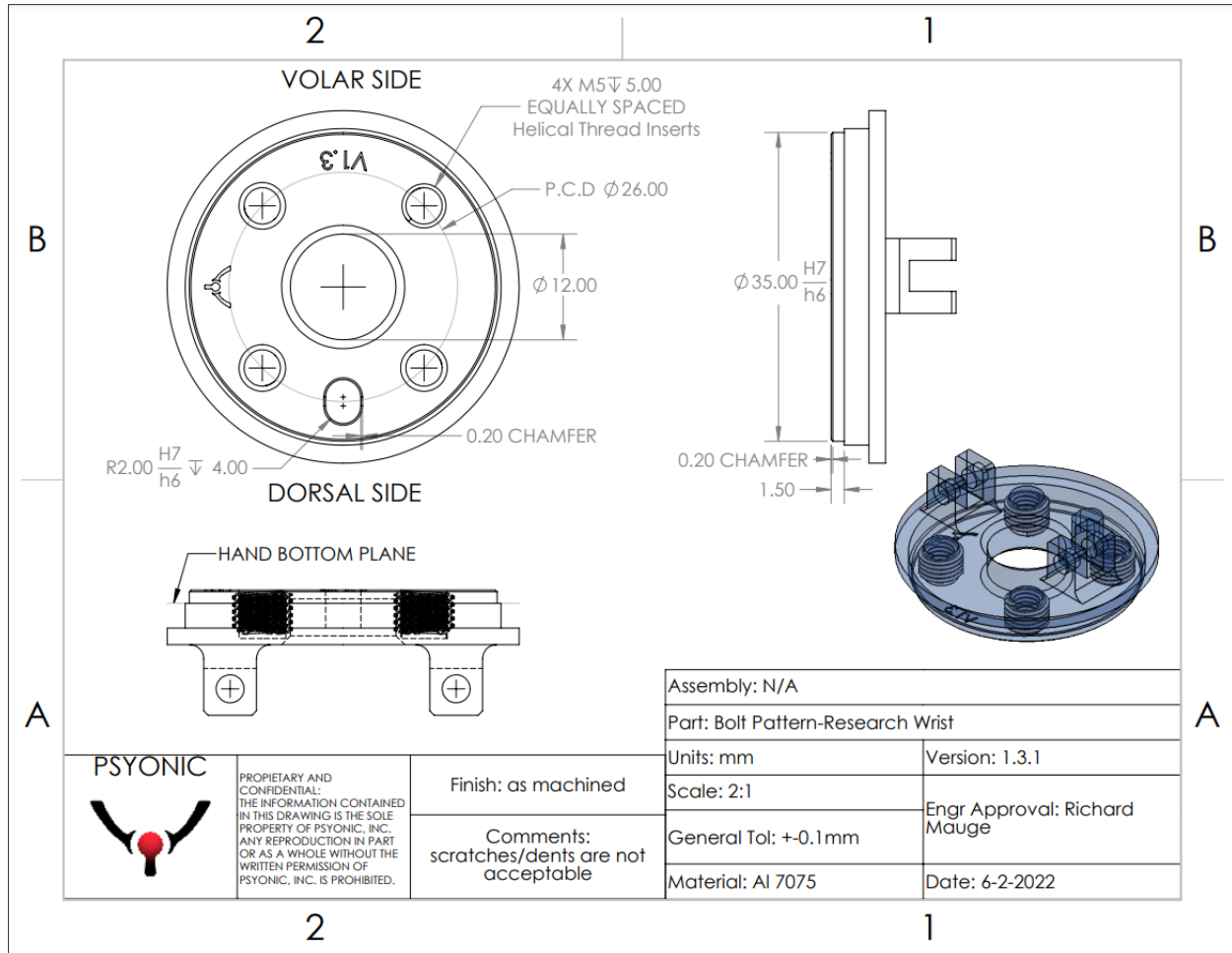
**CE10:01**

**CE11:03**

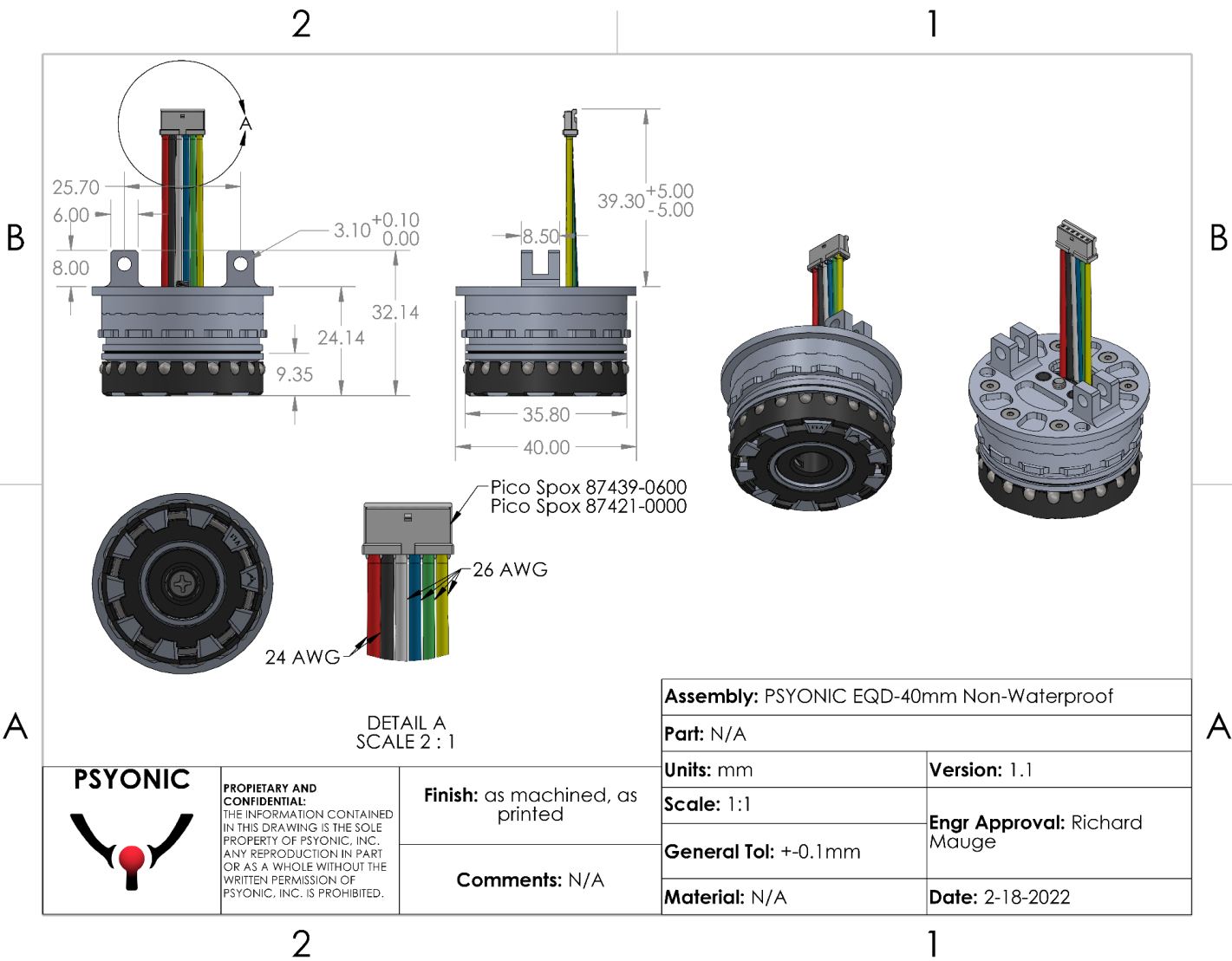
**CE12:02**

## 5 Mechanical Information

### 5.1 Bolt Pattern-Research Wrist



5.2 Psyonic 40mm-Non WP Electronic Quick Disconnect-Clinical Wrist



## 6 Document Control

Please contact PSYONIC for the latest version of this document.

Version	Date	Changes
1.0	3/25/2022	Initial Release
1.1	4/26/2022	<ul style="list-style-type: none"><li>- Font/Structure change</li><li>- In Section 4, the hexadecimal write example erroneously used the “Wm” command instead of the correct “Wn” command</li><li>- New BLE OTA Commands: O2 (Verify) and O3 (Cherrypick)</li><li>- Updated BLE OTA Command O1 with new notification info</li><li>- Document the need for a power cycle on word 003 in section 4.6.2</li></ul>
1.2	6/06/2022	<ul style="list-style-type: none"><li>- UART List Actual Baud Rates</li><li>- Fix Table of Contents Page Number Discrepancies</li><li>- Torque Control Availability Update</li><li>- Updated drawings and information for research wrist options</li></ul>
1.3	6/07/2022	<ul style="list-style-type: none"><li>- Correct Section 0 Configuration options to reflect research wrist options as changed in v1.2</li><li>- Minor wording fixes and clarifications</li></ul>

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