# Piezo LEGS® Controller PMD301

## Technical Manual

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# Overview

This document is a guide to the technical aspects of installing and using ***Piezo LEGS® Controller PMD301***. Detailed information about the different Piezo LEGS motors can be found on our website:
**www.piezomotor.com**

# Content

# 1 - General Information

The PMD301 is a 1-axis controller/driver for use with Piezo LEGS motors from PiezoMotor. The two motor connectors provide identical output signals. Several units may be chained together to form multi-axis systems for use in various OEM applications. For linear motors it provides resolution down to sub-nanometer range.

PMD301 is the ideal choice for system designs where one or several Piezo LEGS motors are used. The unit controls the Piezo LEGS motor by feeding waveform signals to each of the piezoelectric actuator legs. The waveforms are designed specifically to make the drive legs perform a precise walking motion. The motion of the drive legs is transferred via friction contact to a linear rod or a rotary disc.

Communication with the unit is via USB or via 2-wire RS485. Multi-axis chain is possible using the RS485 interface. The PMD301can operate in closed loop using quadrature or serial encoders, or act as a Piezo LEGS amplifier for use with standard motion controllers (Servo Mode via analog or SPI interface).

Running 8192 microsteps produces 1 full waveform cycle (wfm-step), which gives around 5 µm movement with a Piezo LEGS linear motor. Microstep resolution is better than 1 nanometer. The waveform update rate is 65 kHz and maximum cycle frequency (wfm-step rate) is 2500 Hz. Maximum cycle frequency will be set lower for motors with capacitance >1.2 µF.

The motor can be parked (powered down) to minimize position disruption at power off. Still, the position may change somewhat during the parking procedure. The Piezo LEGS motors are capacitive and do not consume any power standing still, so there is normally no reason to park while holding a position. Do however park when connecting and disconnecting motors.

PMD301 is not intended for critical applications such as life support. The user is responsible to prevent any unacceptable damage that may be caused by system malfunction.

PMD301 has been tested to comply with EN and FCC standards for radio emission.

# 2 - Quick Start

## 2.1 Connecting and Running Motor by Serial Commands

1. Connect the PMD301 to your computer with an USB cable (not included).
2. Connect a 48V DC power supply (±5% and minimum 20W).
3. Virtual COM port drivers should install automatically, otherwise download drivers from the website of the manufacturer of the USB chip (**http://www.ftdichip.com**). A virtual COM port is mounted once connected and installed properly.
4. Download and install a data terminal software of preference. A simple freeware Windows program is *Terminal* (**https://sites.google.com/site/terminalbpp**). Connect with the PMD301 at 115200n81 to send ASCII commands.
5. Send the following commands to check the communication and disable servo mode.

| *Send:* | *Receive:* | *Comment:* |
|---|---|---|
| **X?<CR>** | **X?:PMD301 V20<CR>** | Check communication by reading the identification string. |
| **XY13,1<CR>** | **XY13,1<CR>** | Disable servo mode and select quadrature encoder as default even if you have SSI. |
| **XY32<CR>** | **XY32:0, Flash OK<CR>** | Save the setting to flash memory. |

6. Power off and connect motor and encoder. Connect your Piezo LEGS motor to the 5-pole connector. If you are using a Piezo LEGS Linear Twin motor, it needs to be connected with two cables in parallel (use both 5-pole connectors). Connect an encoder to the I/O sensor connector. Power on again.
7. The motor must be unparked (energized) in order to run. Selecting waveform with **M** command will unpark the motor. Open loop run command **J** can be used to test motor function. Be careful not to let the drive rod (the shaft) escape the motor. See below examples of a few commands to start out testing (more commands and command syntax in chapter 4).

| *Send:* | *Receive:* | *Comment:* |
|---|---|---|
| **XM2<CR>** | **XM2<CR>** | Command given to unpark motor with waveform Delta (**M2**). |
| **XE<CR>** | **XE:0<CR>** | If you have a quadrature encoder connected, you may read the position with **E**. Encoder reports position 0 counts. Serial encoder types need to be set at each power on using **Y13** command. |
| **XJ200,0,100<CR>** | **XJ200,0,100<CR>** | Open loop run command of 200 wfm-steps forward. Speed 100 wfm-steps/second. |
| **XJ-200,0,500<CR>** | **XJ-200,0,500<CR>** | Open loop run command of 200 wfm-steps reverse. Speed 500 wfm-steps/second. |
| **XE<CR>** | **XE:63** | Encoder reports position 63 counts. Due to variation of step-length, driving the same number of steps in two directions will not take you back to the original position. |

8. If you want to run closed loop, make sure to first check the Y-settings (chapter 4.2.2, page 9). Most importantly, make the correct settings of encoder type (**Y13**), target limits (**Y3** and **Y4**), encoder counting direction (**Y6**), and the SPC variable (**Y11**). Note that both **Y11** and **Y6** can be auto-configured using **Y25,1** (if encoder type is correctly set).

9. Closed loop run commands are **T**, **R** and **C**, as described in chapter 4.2.1, page 8. For example:

| *Send:* | *Receive:* | *Comment:* |
|---|---|---|
| **XE<CR>** | **XE:63<CR>** | Encoder reports position 63 counts. |
| **XT20<CR>** | **XT20<CR>** | Enter target mode and move to position 20. |
| **XY23<CR>** | **XY23:83,1<CR>** | Target timer indicates target was reached (**1**) in 83 milliseconds (**83**). |
| **XE<CR>** | **XE:21<CR>** | Encoder reports position 21 counts, and and is now actively controlling around that position. Stop range setting (**Y5**) may be altered to improve the positioning, but should be set equal to the encoder jitter. |
| **XS<CR>** | **XS<CR>** | Stop command (**S**) will stop motor and exit target mode. |
| **XM4<CR>** | **XM4<CR>** | Park motor (power down). |

10. When closed loop has been tuned, for example encoder limits and acceleration, don't forget to save to flash using **Y32** command.

## 2.2 Setting up Multiple Axes (Chained Units)

1. When you have one axis up and running via RS485 interface, you can introduce multiple other axes on the same RS485 line (not possible via USB interface). Start by only having one unit connected and change the axis address of that first unit. Every PMD301 delivered from factory will have default address **0**. Change the address to **1** using the **Y40** command. See below the sequence of commands to send and the expected responses from the PMD301:

| *Send:* | *Receive:* | *Comment:* |
|---|---|---|
| **X0Y40<CR>** | **X0Y40:0<CR>** | To read the current address, which according to response is indeed **0**. |
| **X0Y40,1<CR>** | **X0Y40,1<CR>** | To set address to **1**. The next commun-ication will have to be with the newly assigned address. |
| **X1<CR>** | **X1<CR>** | As seen the unit is now responding on its new address **1**. Note that address is still not stored in flash memory. |
| **X1Y32<CR>** | **X1Y32:0, Flash OK<CR>** | The save command **Y32** is used to store the axis address (and other settings) into flash memory. The new address will stick after power cycle. |

2. Now when the first unit has been assigned a new address, you can add a second unit to the chain. Remember to remove power from all units before connecting them together.

3. The newly added second unit will have its default address **0**. Change the unit address to **2** using the same procedure as before:

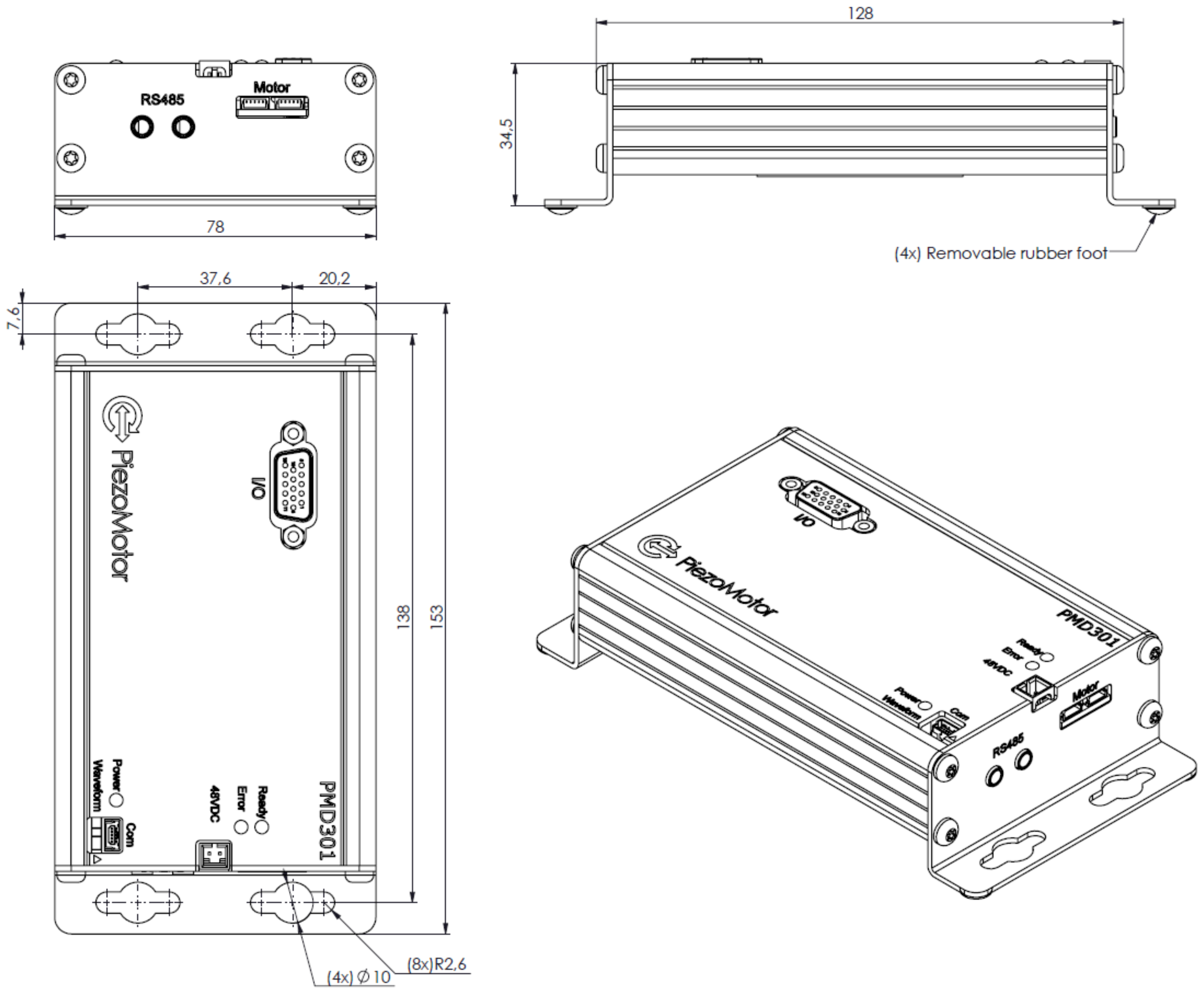
| *Send:* | *Receive:* | *Comment:* |
|---|---|---|
| **X0Y40,2<CR>** | **X0Y40,2<CR>** | To set address to **2**. Next command will need to address axis **2**. |
| **X2Y32<CR>** | **X2Y32:0, Flash OK<CR>** | Store address into flash memory. |

4. Now there are two units connected with addresses **1** and **2**. More units can be added with the same procedure. Always setup units with consecutive numbering **1**, **2**, **3**,…,**n**. Address range goes from **0**…**126**, but it may be beneficial to number from axis **1** if more than one unit is connected (especially when using chain command, see chapter 4.2, page 7).

# 3 - Installation

## 3.1 Mechanical

The PMD301 is possible to mount firmly if needed. Make sure the unit has sufficient air flow to allow for cooling by convection.



## 3.2 Electrical

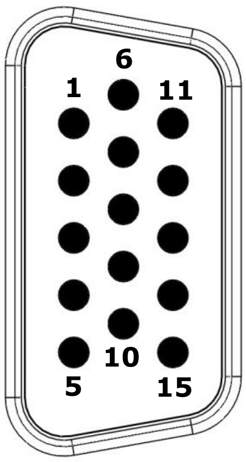
The board is powered with 48V DC power supply (±5%). Current consumption at 48V is 0.02A when motor is stopped and maximum 0.4A when motor is running at maximum speed. For pinouts and connectors, see chapter 3.4 on page 5.

## 3.3 Host Communication

The PMD301 connects to host via USB (virtual COM port) or via 2-wire RS485. Use data terminal software of choice and send commands in ASCII format

| Serial Communication | | | | | |
|---|---|---|---|---|---|
| **Baud Rate** | **Start Bit** | **Data Bits** | **Parity** | **Stop Bits** | **Handshaking** |
| 115200 bits/s | 1 | 8 | None | 1 | None |

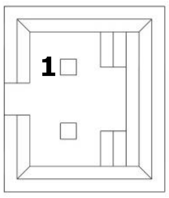
## 3.4 Connections



### Sensor and I/O

| Pin | Function | Alt. Function | I/O | Notes |
|---|---|---|---|---|
| Pin 1 | Limit Forward | in2 | In | External limit forward; ~30kΩ pull-up/down |
| Pin 2 | out1 | - | Out | 1kΩ output resistor |
| Pin 3 | GND | - | Out | Signal ground |
| Pin 4 | I+ | SSI Data+ | In+ | Index+ or SSI data in+ |
| Pin 5 | A− | SSI CK− | In/Out− | Input A− or output SSI clock− (idle high) |
| Pin 6 | Limit Reverse | in3 | In | External limit reverse; ~30kΩ pull-up/down |
| Pin 7 | in0+ | - | In+ | Differential input in0+ |
| Pin 8 | in0− | - | In− | Differential input in0− |
| Pin 9 | I− | SSI Data− | In− | Index− or SSI data in− |
| Pin 10 | B+ | - | In+ | Input B+ |
| Pin 11 | Analog in | in1 | In | ±10V input (12-bit); ~30kΩ input resistance |
| Pin 12 | out0 | - | Out | 1k output resistor |
| Pin 13 | 5V Out | - | Out | Max 0.5A |
| Pin 14 | B− | - | In− | Input B− |
| Pin 15 | A+ | SSI CK+ | In/Out+ | Input A+ or output SSI clock+ (idle high) |

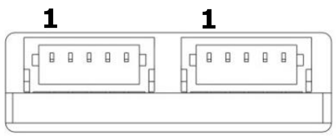
- 3.3 to 5V signal levels.
- Differential signals are terminated with 120Ω via 1nF. Negative inputs have 11kΩ to 2.5V whereas positive inputs have 22kΩ to 5V.
- Connector is d-subminiature DE15 (high density) female.



### Power

| Pin | Function | I/O | Notes |
|---|---|---|---|
| Pin 1 | +48V | In | 48 VDC ±5%, 20W |
| Pin 2 | GND | GND | Signal ground |

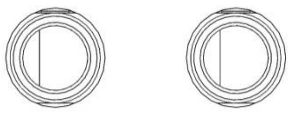
- Connector is from manufacturer Molex, part number 70543.



### Motor

| Pin | Function | I/O | Notes |
|---|---|---|---|
| Pin 1 | GND | GND | Signal ground |
| Pin 2 | Motor Phase 4 | Out | - |
| Pin 3 | Motor Phase 3 | Out | - |
| Pin 4 | Motor Phase 2 | Out | - |
| Pin 5 | Motor Phase 1 | Out | - |

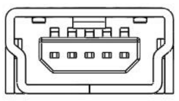
- The two motor connectors are connected in parallel.
- Connectors are from manufacturer JST, part number SM05B-SRSS-TB. Mates with connectors from JST series *SH* (crimp style) or *SR* (IDC style).



### RS485

| TRS | Function | I/O | Notes |
|---|---|---|---|
| Tip | Data+ | In/Out | Idle high; 47k to 5V |
| Ring | Data− | In/Out | Idle low; 23k to 2.5V |
| Sleeve | GND485 | GND485 | 100Ω to GND |

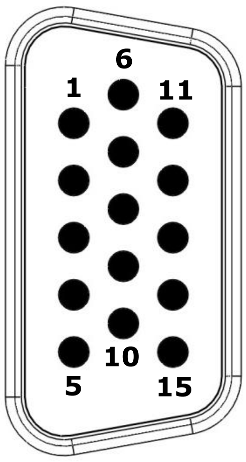
- Terminated with 120Ω via 1nF. If unit is on a chain of connected PMD301's (i.e. both connectors are in use), then the internal termination becomes disconnected.
- The RS485 transceiver is robust regarding EMC and may be used with long cables. For implementing EMC surge protection, refer to Texas Instruments datasheet SN65HVD82.
- Use standard 3.5 mm stereo plug (TRS).



### USB (virtual COM)

- Standard USB mini B connector for connection to PC. Upon driver installation an FTDI virtual COM port will open up for serial communication.

## 3.5 Connections in Servo Mode



### Servo and Status

| Pin | Function | I/O | Notes |
|---|---|---|---|
| Pin 1 | Analog Enable | In | 1=Analog enable, 0=SPI enable; 1kΩ input R, ~30kΩ pull-down |
| Pin 2 | Ready | Out | 1=Overheat or motor powered off, 0=Ready to run; 1kΩ output R |
| Pin 3 | GND | Out | Signal ground |
| Pin 4 | SPI_MOSI+ | In+ | SPI 16-bit signed speed data+ |
| Pin 5 | Fault− | Out− | 0=Error |
| Pin 6 | AEN (Amp. Enable) | In | 1=Amplifier enable, 0=Motor power off; 1kΩ input, ~30kΩ pull-dn. |
| Pin 7 | SPI_SS+ | In+ | SPI Slave Select+; set low during transmit |
| Pin 8 | SPI_SS− | In− | SPI Slave Select−; set high during transmit |
| Pin 9 | SPI_MOSI− | In− | SPI 16-bit signed speed data+ |
| Pin 10 | SPI_SCLK+ | In+ | SPI Serial Clock+; data sampled on positive edge |
| Pin 11 | Analog In | In | ±10V, 12-bit resolution, 5 kHz sample rate |
| Pin 12 | Reserved | Out | |
| Pin 13 | 5V Out | Out | Max 0.5A |
| Pin 14 | SPI_SCLK− | In− | SPI Serial Clock−; data sampled on negative edge |
| Pin 15 | Fault+ | Out+ | 1=Error |

- 3.3 to 5V signal levels.
- Differential signals are terminated with 120Ω via 1nF. Negative inputs have 11kΩ to 2.5V whereas positive inputs have 22kΩ to 5V.
- Connector is d-subminiature DE15 (high density) female.

# 4 - Operation

## 4.1 Introduction

The PMD301 is a versatile controller, designed to work in closed loop with encoder feedback. In this chapter, the command structure and commands are described so that a programmer can build software to control one or several controllers via the serial communication interface.

## 4.2 Command Syntax and Controller Functionality

- The serial communication interface is USB (virtual COM port) or 2-wire RS485, with addressed commands. Communication protocol is 115200n81. The host must allow responses to complete before sending next command.
- The protocol is plain text (ASCII), starting with **X** and axis number **0**...**126**, followed by the command and terminated with one of the command delimiters listed below.

**Command Delimiters**

| Delimiter | Hex ASCII | Name | Description |
|---|---|---|---|
| **<CR>** | 0D | Carriage Return | Terminates a command, response will follow from controller |
| **<LF>** | 0A | Line Feed | Terminates a command, response will follow from controller |
| **;** | 3B | Semicolon | Terminates a command, suppress response from controller, useful for sending several commands together without reply |

- The axis number can be excluded for axis **0**, e.g. **X0E<CR>** or **XE<CR>** are both valid for checking encoder position on axis **0**.
- Set-commands will be echoed back by default.
- Axis **127** is broadcast address with no responses except for “the empty command” **X127<CR>**, in which case each axis responds with its axis number at 2 ms delay per axis, useful to detect all present units. Host should wait 300 ms before sending a new command.
- Command timeout is 300 ms. Host must disable the transmitter within 20 µs after transmission (default) and allow responses to complete before sending the next command.
- Data is in decimal format except when interpreted on a bit level in some status reports.
- Tilde (**~**) after the axis number will instead address the next higher axis number. For instance, **X0~U<CR>** will ask status from axis **1**. The response will trigger yet the next axis to give a chain response. If the axes are consecutive and a chain command is given to address **0~**, all axes will respond except axis **0**. For example, with three controllers connected (**1**, **2** and **3**) a command **X0~U<CR>** will give the response **X1~U:aaaa<CR>X2~U:bbbb<CR>X3~U:cccc<CR>** If a syntax error is detected for a chain command, then the **~** is omitted to prevent errors from consecutive axes.
- A syntax error is indicated by inserting **_??_** in the response, e.g. **X1_??_Q5**. Any syntax error in the stop command (**S**) is ignored.
- If the command was correct but could not be executed, then the command is echoed with a trailing ‘**!**’, e.g. trying to run when motor was parked (will instead unpark).
- A target command (**T**, **R** or **C**) will enter Target Mode (closed loop) and a stop command (**S**) will end Target Mode. An open loop run command (**J** or **I**) will end Target Mode as well. The closed loop normally runs every 1 ms, except for some slow SSI encoders where the target loop iterates every 2 ms. There is no error checking for 32-bit encoder position rollover, but there are position limits (**Y3** and **Y4**) that can be used to prevent this situation in closed loop.

## 4.2.1 Commands

| Commands | |
|---|---|
| **Command** | **Description** |
| **?** | ***Read identification string***<br>Read controller type and firmware revision. Example response: **X0?:PMD301 V21** |
| **U**{StatusType} | ***Read status***<br>Read controller status. See details in chapter 4.2.3, page 11.<br>{StatusType}: **0**,**1**,**2**,**3**,**4** |
| **S** | ***Stop***<br>Stop motor and exit target mode. |
| **M**{Waveform}<br>**M** | ***Waveform and parking state***<br>Set-command to select waveform will also unpark the motor. Read-command gives both waveform and parking state (**M:5** if parked with *Rhomb* and **M:6** if parked with *Delta*).<br>{Waveform}: **1** Waveform *Rhomb*<br>**2** Waveform *Delta*<br>**4** Park (power-off) |
| **T**{TargetPos}**,**{Speed}<br>**T**{TargetPos}<br>**T** | ***Target***<br>Closed loop move to new target position. Motor should not be parked. Response to read-command is **T:100** if last active target was encoder position 100.<br>{TargetPos}: New target position [*encoder counts*]<br>{Speed}: Stepping rate; will set **Y8** [*wfm-steps/second*; *Hz*] |
| **R**{RelActive}**,**{Speed}<br>**R**{RelActive}<br>**R** | ***Target relative to latest active target***<br>Closed loop move to new position relative to latest active target. Beware of i32 overflow. Read-command reports the current target position.<br>{RelActive}: Distance relative to latest active target [*encoder counts*]<br>{Speed}: Stepping rate; will set **Y8** [*wfm-steps/second*; *Hz*] |
| **C**{RelCurrent}**,**{Speed}<br>**C**{RelCurrent}<br>**C** | ***Target relative to current encoder position***<br>Closed loop move to new position relative current position. **C0** to hold current encoder position. Beware of i32 overflow. Read-command reports the current target position.<br>{RelCurrent}: Distance relative to current encoder position [*encoder counts*]<br>{Speed}: Stepping rate; will set **Y8** [*wfm-steps/second*; *Hz*] |
| **E**{Position}<br>**E** | ***Encoder position***<br>Read or set encoder position. Beware that setting position in target mode will move motor.<br>{Position}: Position to set [*encoder counts*] |
| …**b** | ***Predefine command***<br>Any command with a trailing **b** can be predefined in memory and later executed with **B**. For example **X1T100b&lt;CR&gt;** and **X2T200b&lt;CR&gt;** to predefine targets for axis 1 and 2. |
| **B**{Parameter}<br>**B** | ***Execute a predefined command***<br>To execute a command which has been predefined in memory. Useful for simultaneous execution of all axes using broadcast command: **X127B1&lt;CR&gt;**. Read more in chapter 4.8.<br>{Parameter}: **0** To clear a predefined command<br>**1** To begin execution of a predefined command. |
| **D**{outX}**,**{State}<br>**D** | ***Digital I/O***<br>To set output pins or read their status. See chapter 4.7 on page 15 for more details. |
| **J**{wfmStep}**,**{µStep}**,**{Speed}<br>**J**{wfmStep}**,**{µStep}<br>**J**{wfmStep}<br>**J** | ***Run motor (Jog)***<br>Open loop stepping. Read more in chapter 4.6.<br>{wfmStep}: Number of waveform-steps [1 wfm-step = 8192 µsteps]<br>{µStep}: Number of microsteps<br>{Speed} : Stepping rate [*wfm-steps/second*; *Hz*] |
| **H**{Speed}<br>**H** | ***Speed for open loop***<br>Speed setting for open loop run commands **J** and **I**.<br>{Speed}: Stepping rate [*wfm-steps/second*; *Hz*] |
| **N**{Mode}<br>**N** | ***Index mode***<br>When enabled, use open loop jogging (**I**) to search for quadrature index. Read more in ch. 4.5.<br>{Mode}: **0** Disabled **1** Position was reset at index (read only)<br>**2** Stop at index<br>**4** Stop and reset position at index |
| **I**{wfmStep}**,**{µStep}**,**{Speed}<br>**I**{wfmStep}**,**{µStep}<br>**I**{wfmStep}<br>**I** | ***Run motor (Index Jog)***<br>Same as **J** command, but will only run if index mode is activated and index has not been detected. Read more in chapter 4.6. |

| **Commands** | |
|---|---|
| **Command** | **Description** |
| **L**{SampleDelay}<br>**L-**{SampleDelay} | ***Position logging***<br>Logging of 100 encoder positions.<br>{SampleDelay}: Delay time between samples [millisecond]<br>Example: **L5** starts logging directly after command is given (with 5 ms delay between samples), whereas **L-5** arms logging to start when receiving next command (for example a run command). |
| **L0**<br>**L** | ***Read stored log data or status***<br>Response is: **L0:**{StartTime}**,**{SampleDelay}**,**{StopTime}**,**{samples}**,** {pos0}**,**…**,**{pos99}<br>Response is: **L:**{StartTime}**,**{SampleDelay}**,**{StopTime}**,**{samples}**,** {pos0} |
| **Y**{#}**,**{Setting}<br>**Y**{#} | ***Settings command***<br>See chapter 4.2.2 below. |
| …**<esc>** | Escape cancels the command line (command delimiter still required). No response. |
| **<empty>** | Empty command is just echoed back (useful as a ping), e.g. **X1<CR>** will echo axis 1.<br>Empty command to broadcast address, **X127<CR>**, will trigger each axis to respond with its axis number at 2 ms delay per axis (useful to detect all present units). |

## 4.2.2 Settings and Miscellaneous (Y-commands)

- Set using **Y**{#}**,**{x} or alternatively **Y**{#}**=**{x}
- Read using **Y**{#} or alternatively **Y**{#}**?**
- Command **Y**{#} will most often only report the parameter whereas **Y**{#}**?** also adds a short description.
- Undocumented **Y**{#} are reserved for future use. A trailing '**!**' indicates unimplemented **Y**{#}, for example **Y99:!**

| **Settings and Miscellaneous** | | |
|---|---|---|
| **Command** | **Description** | **Notes** |
| **Y0** | ***Read microstep counter***<br>Reads back the microstep within the waveform (8192 microsteps per cycle).<br>Example response: **Y0:0,4096** first digit is not used, second is 0…8191. | 0,U16 |
| **Y1,**{Initiate} | ***Initiate from flash***<br>{Initiate}: **2** Initiate from flash (Y3…12, Y38…40)<br>**3** Initiate factory default values (Y3…12) | **Y32** saves to flash |
| **Y1** | ***Compare current flash settings***<br>Responses: **Y1:0, Flash equal** Y3…12, Y38…40<br>**Y1:1, Flash differ** Y3…12, Y38…39<br>**Y1:2, Axis differ** Y40 | |
| **Y2,**{xLimitEn}<br>**Y2** | ***External limit enable***<br>{xLimitEn}: **0** Disabled<br>**1** Enabled, active high (pull-up)<br>**2** Enabled, active low (pull-up) | *Default*<br>**0** U2 |
| **Y3,**{LimitA}<br>**Y3** | ***Target mode position limit A***<br>Target mode will stop when encoder count <A | *Default*<br>**-10000** I32 |
| **Y4,**{LimitB}<br>**Y4** | ***Target mode position limit B***<br>Target mode will stop when encoder count >B | *Default*<br>**10000** I32 |
| **Y5,**{StopRange}<br>**Y5** | ***Target mode stop range***<br>Number of encoder counts from target where it is optimal to stop the motor.<br>This dead band should be set equal to the encoder jitter. | *Default*<br>**1** U16 |
| **Y6,**{EncDir}<br>**Y6** | ***Encoder counting direction***<br>{EncDir}: **0** for positive counting in forward direction<br>**1** for negative counting in forward direction | *Default*<br>**0** U1 |
| **Y7,**{MinSpeed}<br>**Y7** | ***Target mode minimum speed***<br>Stepping rate [*wfm-steps per second*; *Hz*] | *Default*<br>**1** U16 |
| **Y8,**{TargetSpeed}<br>**Y8** | ***Target mode speed***<br>Stepping rate [*wfm-steps per second*; *Hz*]<br>Measured capacitance limits actual maximum speed (see **U3** command) | *Default*<br>**2500** U16 |

## Settings and Miscellaneous

| Command | Description | Notes |
|---|---|---|
| **Y9,**{SpeedRampUp}<br>**Y9** | ***Target mode speed ramp up***<br>Acceleration in target loop. Max 800 [*Hz/ms*]. | *Default*<br>**20** U16 |
| **Y10,**{SpeedRampDown}<br>**Y10** | ***Target mode speed ramp down***<br>Deceleration in target loop. Max 800 [*Hz/ms*]. | *Default*<br>**20** U16 |
| **Y11,**{SPC}<br>**Y11** | ***Steps Per Count in target mode***<br>{SPC} can be calculated ≈ 50·{EncoderResolution}, where encoder resolution is given in nanometers. You may use script **Y25,1** to auto-configure this setting. Read more in chapter 4.3, page 13. | *Default*<br>**250** U32 |
| **Y12,**{Model}<br>**Y12** | ***Target mode model***<br>{Model}: **0** to reach target as fast as possible<br>**1** to avoid overshoot only in forward direction<br>**2** to avoid overshoot only in reverse direction<br>**3** to avoid overshoot in both directions | *Default*<br>**0** U8 |
| **Y13,**{EncType}<br>**Y13** | ***Encoder type***<br>{EncType}: **0** No encoder; Host may report positions (32-bit)<br>**1** Quadrature (32-bit, max 15 MHz counting)<br>**2** Analog ±10V, 12-bit (0…4095)<br>**3** Servo; Analog or SPI; slave to external motion controller<br>**4/5/6** BiSS 18/26/32 bit<br>**8**…**30** SSI 8…30-bit; 750 kbps; Position is extended to 32-bit by lap counter.<br>**38**…**60** SSI 8..30-bit; 130 kpbs; Position is extended to 32-bit by lap counter; Target loop runs at half speed (every 2 ms)<br>The quadrature input signal A is used as output to SSI encoders and also in servo mode. To avoid output to quadrature encoders, servo mode only enables output if the analog input voltage is zero. Furthermore, only encoder type 0…3 is saved to flash with Y32 whereas serial encoders will revert to 0 (none) at power on. | *Setting at delivery*<br>**3** U8 |
| **Y14,**{QuadOffset}<br>**Y14** | ***Quadrature offset***<br>For example: **Y14,1000** to set index position = 1000 | I32 |
| **Y19** | ***Read analog input***<br>0…4095 = −10…+10 V | U12 |
| **Y21** | ***Read time*** [*ms*]<br>Free running 32 second timer. Max value 32762 [*ms*] | U15 |
| **Y22** | ***Read xLimit time*** [*ms*]<br>Example: **Y22:3650,1** if stop detected at time 3650 ms | U15 |
| **Y23** | ***Read target timer*** [*ms*]<br>Examples: **Y23:650,1** if target reached in 650 ms<br>**Y23:20,0** if target not yet reached, running 20 ms | U15 |
| **Y25,**{RunScript}<br>**Y25** | ***Run Script***<br>{RunScript}: **0** Stop<br>**1** Script for auto-configuration of **Y6** and **Y11**<br>Read more in chapter 4.4 on page 13. | **Y25:1,1**<br>when executing<br>**Y25:1,0**<br>when finished |
| **Y30** | ***Read target mode parameters***<br>Y2…13 | csv<br>multiple data types |
| **Y32** | ***Save to flash***<br>Parameters Y2…13, Y38…40 are saved to flash. Will not store serial encoders for Y13, but instead reverts to no encoder at power on. Save takes ~60 ms. | **Y32:0 Flash OK**<br>when save is done |
| **Y38** | ***Analog servo stop voltage***<br>Value 0…4095 = −10…+10 V Value is calibrated for 0V at delivery. | *Setting at delivery*<br>**~2047** U12 |
| **Y39** | ***Analog servo stop range***<br>Motor stops at Y38 ±Y39<br>Also used for disabling analog servo by setting **Y39,65535** | *Setting at delivery*<br>**1** U12 |
| **Y40,**{Address}<br>**Y40** | ***Axis address***<br>{Address}: **0**…**126** | *Setting at delivery*<br>**0** U8 |
| **Y41** | ***Software reset***<br>Reboot takes about 2.5 seconds | **Y41:0, Reset**<br>When rebooted |
| **Y42** | ***Read unit serial number*** | U32 |
| **Y44,**{ResponseDelay}<br>**Y44** | ***Command response delay***<br>Delay time for RS-485 response [*μs*] | *Default at power on*<br>**20** U8 |

### 4.2.3 Controller Status (U-command)

**U0**

**U0:**{d1}{d2}d3}{d4}

This command will give status information for many different controller functions.

| **Bit Value** | {d1} | {d2} | {d3} | {d4} |
|---|---|---|---|---|
| **8** | comError | reset | servoMode | parked |
| **4** | encError | xLimit | targetLimit | overheat |
| **2** | voltageError | script | targetMode | reverse |
| **1** | cmdError | index | targetReached | running |

| | |
|---|---|
| Underlined | Means the specific flag will stay active until reported. |
| *comError* | Error in communication has occurred; wrong baudrate, data collision, or buffer overflow. |
| *encError* | Encoder error (serial communication or reported error from serial encoder). |
| *voltageError* | Supply voltage or motor fault was detected. |
| *cmdError* | Command timeout occurred or a syntax error was detected when response was not allowed. |
| *reset* | Power-on/reset has occurred. |
| *xLimit* | Is set if the last motor movement was stopped by external limit switch. |
| *script* | Flag indicates that the SPC test or some other script is running. |
| *index* | Indicates that index signal was detected since last report. |
| *servoMode* | If servo mode is selected. |
| *targetLimit* | Is set if the position limit is reached. |
| *targetMode* | If target mode is active (closed loop). |
| *targetReached* | If target was reached; may still be regulating in closed loop. |
| *parked* | Motor is powered down. |
| *overheat* | Controller board output stage is overheated. |
| *reverse* | Last motion was in reverse direction. |
| *running* | Motor is running. |

| **Send** | **Example Response** | **Comment** |
|---|---|---|
| **U0** | **U0:0808** | {d2}: **8** Reset (8) has occurred; normal at power on.<br>{d4}: **8** Motor is parked (8). |
| **U0** | **U0:0162** | {d2}: **1** Index was detected since last report (1).<br>{d3}: **6** Target mode (2) stopped by encoder limit (4).<br>{d4}: **2** Last motion was in reverse direction (2). |

**U1**

**U1:**{out}{in}

This command will give status of output and input pins (I/O). It also gives a fan request status when PMD301 is close to overheat and could use some cooling. Note that bit response is hexadecimal.

| **Bit Value** | {out} | {in} |
|---|---|---|
| **8** | fanRequest | in3 |
| **4** | - | in2 |
| **2** | out1 | in1 |
| **1** | out0 | in0 |

| **Send** | **Example Response** | **Comment** |
|---|---|---|
| **U1** | **U1:9c** | {out}: **9** **out0** high (1) and **fanRequest** (8).<br>{in}: **c** **in3** is high (8) and **in2** is high (4). |

## U2

**U2:**{5V}**,**{3.3V}**,**{48V}**,**{M23}**,**{Temp}**,**{s5V}

This command will give status information for board voltages. Errors previously detected are indicated with an asterisk (*****). Motor will stop on voltage error or overheat.

| Parameter | Description | Nominal Value | Unit | Error Limit |
|---|---|---|---|---|
| {5V} | Internal 5V | **5.00** | V | ±10% |
| {3.3V} | Internal 3.3V | **3.30** | V | ±5% |
| {48V} | Internal 48V | **48.0** | V | ±5% |
| {M23} | Test signal motor failure | **~23** | - | *≤14* |
| {Temp} | Temperature on PCB | - | °C | *≥74°C* |
| {s5V} | 5V out to sensor | **5** | V | ~0.6A |

| Send | Example Response | Comment | | |
|---|---|---|---|---|
| **U2** | **U2:5.05,3.32,47.2*,23,56C,5** | {5V}: | **5.05** | Measured 5V level. |
| | | {3.3V}: | **3.32** | Measured 3.3V level. |
| | | {48V}: | **47.2*** | Measured 48V level. The star indicates that an error was detected, but may no longer be present. |
| | | {M23}: | **23** | Indicating test signal is okay. |
| | | {Temp}: | **56C** | Indicating 56°C on PCB board. |
| | | {s5V}: | **5** | Indicating 5V level is okay. Reports 0 if sensor is drawing too much current and voltage drops. |

## U3

**U3:**{cap}**,**{freq}

This command will give status regarding measured motor capacitance and maximum allowed drive frequency.

| Send | Example Response | Comment | | |
|---|---|---|---|---|
| **U3** | **U3:2064nF,1696Hz Delta** | {cap}: | **2064nF** | Indicating estimated motor capacitance of roughly 2064 nF. |
| | | {freq}: | **1696Hz Delta** | Calculated maximum drive frequency and information about the selected waveform (Delta or Rhomb). |

## U4

**U4:**{d1}{d2}{d3}{d4}**,**{out}{in}

This command will give status information same as U0 and U1 together.

Visual status information is also given by the "Error" and "Ready" LED's on the PMD301.

| **Error LED** | **Ready LED** | | |
|---|---|---|---|
| Off | Off | - | Motor powered off (parked) |
| Off | Green | - | Motor powered on (unparked) and ready to run |
| Red | Green | - | Overheat |
| Red | Off | - | Error |

The "Power" LED will give a green light when unit is powered on, and a short blink when executing a command.

## 4.3 Target Mode (Closed Loop)

A target run command (**T**, **R** or **C**) will enter Target Mode (closed loop) and a stop command (**S**) will end Target Mode. Giving an open loop run command (**J** or **I**) will also end Target Mode. The closed loop normally runs every 1 ms except for extra slow SSI encoders where the target loop iterates every 2 ms. There is no error checking for 32-bit encoder position rollover, but there are position limits (**Y3** and **Y4**) that can be used to prevent this situation in closed loop. Note that setting the encoder position while operating in Target Mode may have the effect that the motor starts to move if the position is no longer equal to target.

Target Mode requires that an encoder (position sensor) is connected. PMD301 supports quadrature encoders, serial encoders (SSI or BiSS) or analog input. Encoder type is selected with setting **Y13**. If an unsupported encoder is required, one may let host computer handle encoder and send position updates to PMD301 at regular intervals (for example every 10 ms) so that the controller can perform target loop.

There are a few Target Mode settings parameters (**Y3**…**Y12**) that specifically decide the closed loop behavior. Most importantly settings must be made for target limits (**Y3** and **Y4**), encoder counting direction (**Y6**), and the SPC variable (**Y11**). Note that both **Y11** and **Y6** can be auto-configured using **Y25,1**
(if encoder type is correctly set).

The **Y11** setting for Steps Per Count (SPC) tells the controller how to convert a distance (encoder counts) into microsteps. The motor step length is rather approximate, so the SPC parameter does not have to be very precise for obtaining a stable target loop. The SPC has a scaled integer representation, and needs to be calculated. SPC can often be approximated to 50·[encoder resolution in nanometers]. For instance, if the encoder resolution is 5 nm, we can enter **Y11**=250. One may also run a number of open loop steps and determine the change in encoder counts per wfm-step [*counts/wfm-step*]. For example, run 16 wfm-steps (**J16**) and note the change in encoder counts. Divide by 16 to get a value $X$ in unit *counts/wfm-step*. Now calculate **Y11**=65536·4/$X$.

If you do not want to calculate SPC manually, there is a script **Y25,1** which will auto-configure **Y11** described in the next section (4.4).

Target Mode will adjust to the acceleration and deceleration parameters set by **Y9** and **Y10**. For example, the ramp down deceleration parameter **Y10** defines the behavior when approaching target. Overshooting target can be prevented if deceleration is soft (a low value for **Y10**). There is also a parameter **Y12** to slow down target approach in one or both directions.

## 4.4 Script Command (Y25)

The only script implemented at this time is **Y25,1** which is a script to determine the relationship between encoder resolution and motor step length, and to set parameters **Y6** and **Y11** accordingly. The script will run the motor ±16 wfm-steps (roughly ±0.1 mm) and check encoder positions to do calculations. A read command will show **Y25:1,1** when executing and **Y25:1,0** when finished. An error gives a negative value (for example **Y25:1,-1**) and **Y11** is set very low.

## 4.5 Index Mode Command (N)

The alternatives are **N2** (to stop at index), **N4** (to stop and reset position at index), or **N0** (deactivate Index Mode). **N4** enters index mode which will reset position when the index signal comes (when ABI=111).

The read command **N** reports current index mode status and last detected index position with response **N:**{mode}**,**{position}. Mode **1** will be reported when position has been reset at index, for example **N:1,132**.
A question mark after the read command (**N?**) will add a short description, e.g. **N:1,132., indexed** (meaning position has been reset at index). A dot '**.**' after the logged index position indicates that the position was logged since the last report. The index position as given by read command is logged by index signal alone, so it may be logged before position reset and can deviate somewhat from the true index position where position reset occurs (ABI=111).

The open loop command **I** can be used when searching for index. The **I** command is similar to **J** command, with the difference that it only runs when Index Mode is active, i.e. when index has not been found.

Setting quadrature offset **Y14** is a way to alter the position while keeping the index position valid. Setting the quadrature position directly (e.g. **E0**) will introduce an uncertainty to the exact index position and the Index Mode will therefore revert to zero (unindexed) and furthermore reset the offset (**Y14**=0). A position reset at index will set the position equal to **Y14**. Setting **Y14** afterwards will simply redefine the index position without the need to go back and find it.

## 4.6 Jog Commands (J and I)

Open loop jog command **J** can move motor in full wfm-steps, by microsteps, or by a combination of wfm-steps and microsteps, as well as set the speed. 8192 microsteps constitutes 1 wfm-step.

All input values are signed integers. A negative value for any of the parameters will give reverse movement.

| | | |
|---|---|---|
| **J**{wfmStep}**,**{µStep}**,**{Speed} | Set command: | wfm-steps + microsteps at given speed |
| **J**{wfmStep}**,**{µStep} | Set command: | wfm-steps + microsteps, previous speed |
| **J**{wfmStep} | Set command: | wfm-steps, previous speed |
| **J** | Read command: | Returns **J:1** if motor is running<br>Returns **J:0** if motor is stopped. |

| *Send Examples:* | *Comment:* |
|---|---|
| **XJ-16,4096,256<CR>** | Run 16 wfm-steps and 4096 microsteps, reverse direction.<br>16 + 4096/8192 = 16.5 wfm-steps.<br>Speed is 256 wfm-steps/second.<br>Will complete in 16.5/256 seconds ≈ 64.5 ms |
| **XJ0,128,5<CR>** | Run 128 microsteps, forward direction.<br>0 + 128/8192 = 0.015625 wfm-steps.<br>Speed is 5 wfm-step/second.<br>Will complete in 0.015625/5 seconds ≈ 3.1 ms |
| **XJ-978<CR>** | Run 978 wfm-steps, reverse direction.<br>Speed will be depending latest open loop speed (stored in **H**) |

The **I** command works the same but will only run if index mode is activated and index has not been detected. Useful to avoid running if index is detected just before the run command is given.

## 4.7 Digital I/O Command (D)

There are some unused digital inputs and outputs available for general purpose. As can be seen in the pinout table (chapter 3.4, page 5), limit switch signals share pins with **in2** and **in3**. These pins have internal 30kΩ pull-up when the limit switch function is disabled.

Digital **in1** is derived from the analog input, using 1.4V digital level.

Digital **in0** is a differential input. A single ended signal may be connected to **in0+**.

Outputs **out0** and **out1** have 2kΩ output resistance when level is high and 1kΩ when level is low.

**D**

**D:**{out2}{out1}{out0}**,**{in3}{in2}{in1}{in0}

Read command will give status of input and output pins. Pin high indicated by **1**, and pin low indicated by **0**.

| Send | Example Response | Comment |
|---|---|---|
| **D** | **D:010,1100** | {out2}: **0** This output is not implemented for PMD301<br>{out1}: **1** Indicating out1 is high<br>{out0}: **0** Indicating out0 is low<br><br>{in3}: **1** Indicating in3 is high<br>{in2}: **1** Indicating in2 is high<br>{in1}: **0** Indicating in1 is low, i.e. analog in <1.4V<br>{in0}: **0** Indicating in0 is low |

Set command **D**{outX}**,**{State} will set output pins, where {outX} is **2**/**1**/**0** for **out2**/**out1**/**out0**, and {State} is **1** for pin high and **0** for pin low.

| Example Send | Comment |
|---|---|
| **D0,1** | out0 is set high (1) |

## 4.8 *Predefining a Command (B)*

Any command given that ends with a trailing **b** will be stored in the **B** command and can later be executed with **XB1**. For instance, **X1T100b<CR>** and **X2T200b<CR>** will store commands **T100** for axis 1 and **T200** for axis 2. Both commands can then be executed simultaneously by sending command **B1** to the broadcast address, **X127B1<CR>**. Sending **X0~B1<CR>** will also execute the predefined commands almost simultaneously (chain command for consecutively numbered axes).

| | |
|---|---|
| …**b** | Stores a command, for example **X1T200b<CR>** will store command **T100** for axis 1. |
| **B0** | Clears a stored command. |
| **B1** | Begins execution of stored command. The response from executed command is not returned. If however the executed command generates an alert, then the alert indicator '**!**' is returned, i.e. **XB1!** |
| **B** | Reports the stored command string.<br>Example response: **B:T100b** |

# 5 - Servo Mode

## 5.1 *Slave to an External Motion Controller*

PMD301 can act as a Piezo LEGS amplifier for an external servo motion controller with analog or serial SPI interface. Servo mode is enabled by default at delivery; otherwise it may be selected by connecting with the PMD301 by serial interface, setting **Y13** parameter to **3** and saving the setting to flash memory by **Y32** command. Note that the serial commands to run/stop the motor will disable servo mode until reboot or **Y13** parameter is set to **3** again.

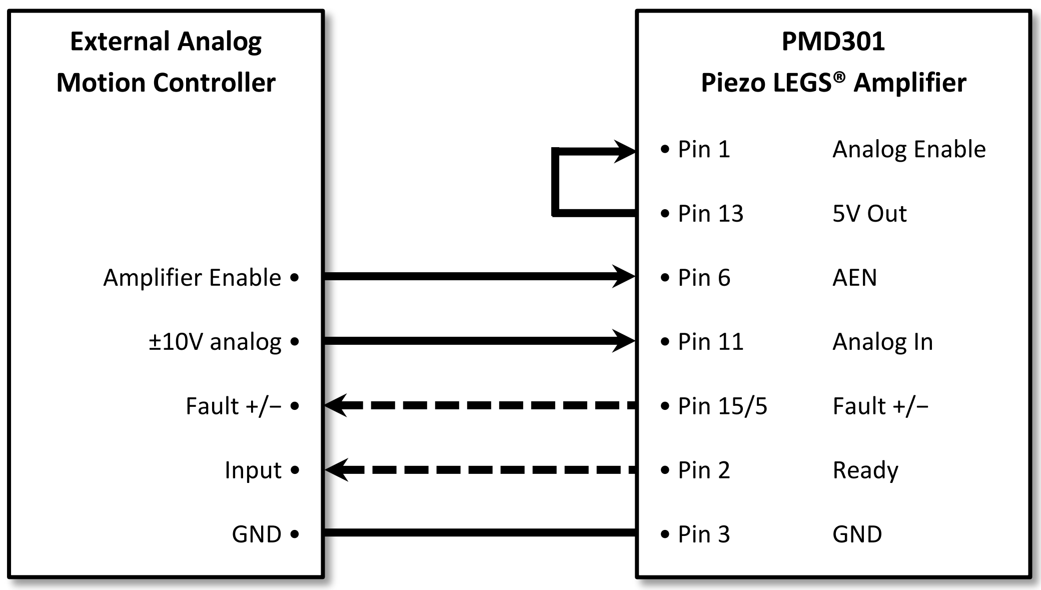
In servo amplifier mode, the waveform selection is done by the manual red switch near the USB connector. Slide the switch towards the edge to select the *Delta* waveform (▲). The *Delta* waveform gives much higher positioning accuracy and is normally preferred. The *Rhomb* waveform may give longer step length for light loads, i.e. faster max speed.

See chapter 3.5 on page 6 for connections in Servo Mode. A low level on **AEN** input signal (amplifier enable) will power down (park) the motor. It normally takes 250 ms to power down and at least 80 ms to power up the motor (longer with larger motors). “Error” LED lighting up when unparking motor indicates waveform *Rhomb*. The **Ready** signal will be low when PMD301 is ready to run (also indicated by green LED “Ready”). A high **Ready** signal indicates amplifier overheat or motor powered down (parked). Overheat will also be indicated by red LED “Error”.

A high level on **Fault+** indicates a critical error, e.g. motor or voltage failure (not overheat). Fault condition is also indicated by red LED “Error”. A fault will stay for at least 250 ms.

Maximum motor stepping rate is 2500 Hz. A capacitance check is done at the time of unpark and may select a lower speed limit for motors with capacitance >1.2 µF.

## 5.2 *Analog Interface*

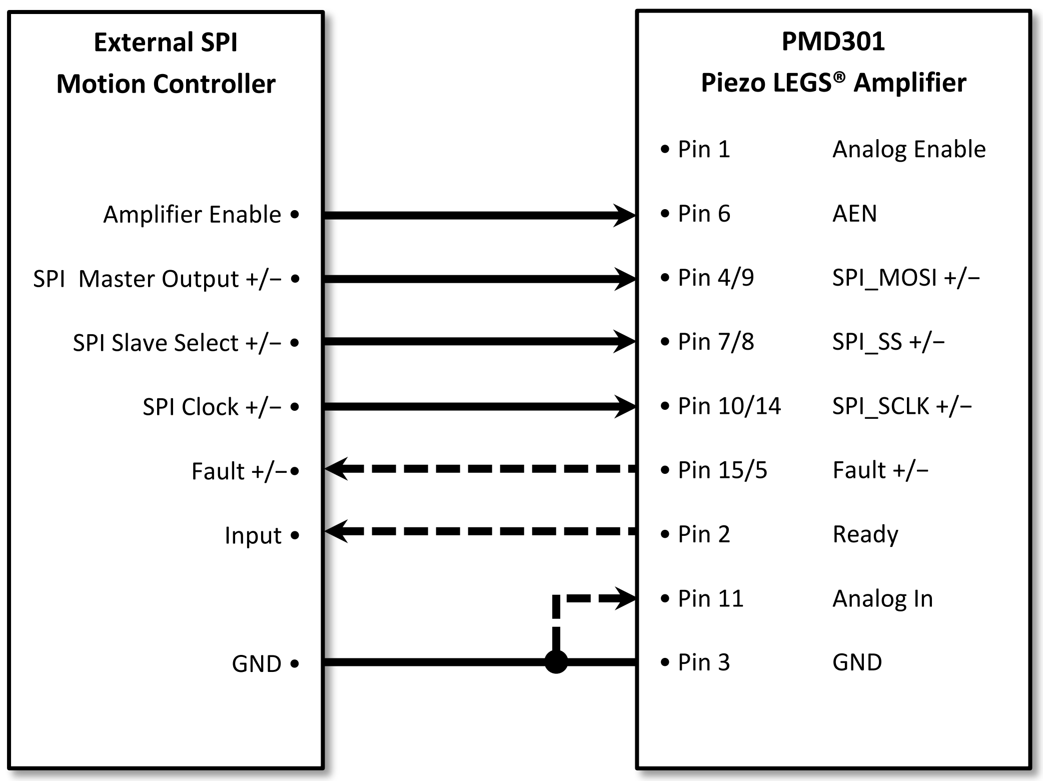


A high level on **Analog Enable** activates **Analog In**, easiest by connecting Pin 1 and 13 as shown in the figure above. Amplifier enable signal from the motion controller connects to **AEN** input and unparks motor on high level. Alternatively, connect the amplifier enable signal from the motion controller to **Analog Enable** and use a separate signal for park/unpark control to Pin 6.

Analog input is ±10V (12-bit resolution, 5 kHz update rate).

Note that the **Fault** output signal is disabled until **Analog In** has been detected close to 0V where after it will be enabled. It is optional to connect the status signals (dashed in figure).

## 5.3 SPI Interface



The SPI signals are AC-terminated with 120Ω in series with 1 nF capacitors. Single ended signals may be used if all inverted inputs are tied together and buffered with a 100nF capacitor.

Connect **Analog Enable** to **GND** or leave it unconnected. The amplifier enable signal from the motion controller connects to **AEN** input and unparks motor on high level. The **SPI_MOSI** input controls the motor speed. The motor will stop when input SPI data is =0. The PMD301 expects regular speed updates and will stop the motor if no SPI data has been received for about 10 ms. The 16-bit signed SPI data gives linear speed control (stepping rate). Note that motor step is not constant and a position sensor (encoder) is necessary for feedback to the motion controller.

**SPI_SCLK+** idle state is high and PMD301 samples data after positive edge (max 15 Mbps). Serial command **E** can be used to report the latest received SPI data (useful for debugging).

Note that the **Fault** output is disabled for a floating (1V) analog input – connect **Analog Input** to **GND** to enable the fault output signal. It is optional to connect the status signals (dashed in figure).

## 5.4 External Motion Controller PID Settings

The external motion controller should normally be setup for a brush-type DC servo amplifier. However, the motor command will alter the motor stepping rate (frequency) rather than the torque, so the PID settings will differ from a normal servo. It is recommended to have D=0 and I=0 and only use P. If there is a “velocity feed forward”, this may improve motion control.

A servo controller normally requires feedback from a position sensor (encoder). Using a motion controller without an encoder often results in continuous run at maximum speed unless a limit has been set on PID output. Limiting the PID output can be convenient when testing for example the encoder direction. Take away the PID limit when the system is functioning, and set the desired motion speed, acceleration, and deceleration.

For the analog interface, a tiny integrator limit can be useful to compensate for a small offset that may occur in the PMD301 analog interface. The motor frequency is slightly non-linear to the analog voltage to improve resolution at low speed.

# 6 - Safety Instructions

## Note!

The PMD301 driver is a high-end product intended for use with PiezoMotor's Piezo LEGS product line. In order to get best performance and reliability it is important the driver unit is handled according to the instructions given in this manual and other delivery documents.

## Caution!

The piezoceramic elements in a Piezo LEGS motor act as capacitors and can sometimes hold substantial electrical charge.

- ➢ Make sure motors are discharged through suitable discharge resistors.

## Caution!

Incorrect installation using improper mounting materials or methods can cause damage to the PMD301 driver unit.

## Caution!

Depending on its use the PMD301 unit can get very hot.

- ➢ The PMD301 should be installed in a clean and dry environment with access to proper ventilation. On installation, ensure that air can flow around the unit without obstruction.

## Caution!

Electrostatic discharges can cause irreparable damage to the electronics.

- ➢ Note and follow the ESD protective measures

## Caution!

Incorrect connection of motor leads may cause irreparable damage to both motor and PMD301.

- ➢ Connect in accordance with the specified pin assignment.

# 7 - Maintenance

## 7.1 General Maintenance Instructions

The PMD301 does not require any regular maintenance. Follow given safety instructions.

## 7.2 Trouble Shooting

If problem arise, the status command (**U**) should provide useful information. Check wirings to motor and encoder. Try running in open loop to see if you can get movement. Regarding closed loop operation, make sure the Target Mode settings are correct. If you get readings from the encoder you can see if you have the correct resolution by taking a number of open loop wfm-steps and checking how many encoder counts you have traveled. A wfm-step is typically 5±3 µm for a standard Piezo LEGS linear motor.

## 7.3 Firmware Updates

When new features are added, the user can update the firmware over the serial interface using bootloader software. PiezoMotor will make updates available on **www.piezomotor.com**.

When firmware is updated, you should also look for the latest revision of this manual to learn about the updates, or read the change log document.

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