User Manual
for the Arduino Uno
PWM Motor Controller

version 1.10 R. Waters

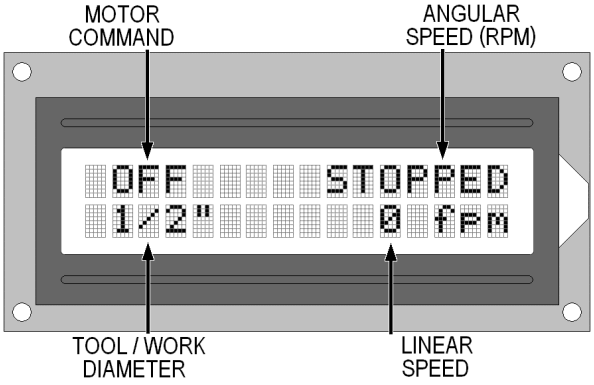
This manual is a companion document to the DM article “What’s an Arduino and what can I do with it?” and provides some detail on usage of the software features. The minimum hardware required to exercise this sketch is an Arduino Uno and a standard LCD/keypad shield. The full project also uses a prototype shield implementing the schematic at the end of this document.

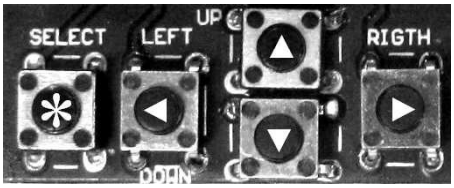
Several field-configurable hardware options exist:

1. A Tachometer sensor that produces a stream of pulses may be connected.
   Three separate scale factors are applied, each designed to address a particular factor:
   a. Fine tuning for small errors in CPU clock frequency
   b. Number of tachometer pulses per revolution
   c. A general scale factor for mechanical drive ratio compensation
2. Several optional off-board command inputs complement the keypad functions:
   a. A potentiometer speed control
   b. A fixed-threshold input for a secondary keypad or a single run/stop command button
   c. A programmable-threshold input for run/stop commands (1 or 2 switches, or speed pot)

The system supports 2 modes. **Operation** mode runs the motor, and **Configuration** mode accesses various settings. User settings will persist through a power cycle when saved.

After power-on initialization, the system enters normal operating mode, where motor commands are enabled. The display is divided into quadrants, each one showing the current value of its parameter. The motor command (Off or XX%) is always displayed in the upper left corner. If the tachometer is enabled, RPM will be shown in the upper right corner, and when a tool diameter is also specified, linear cutting speed is on the lower right.





Commands are entered via the 5-button keypad on the LCD / keypad shield, which contains 4 directional arrows and a SELECT key.

Keypad functions vary depending on the current system mode, generally as in this table:

MODE	Available When	▲ ▼ Arrows	◄ ► Arrows	Select Button
Configuration	Motor Command is OFF	Select a configuration parameter	Change parameter value	Saves all configuration parameters
Operation	Motor Command is XX%	Change tool diameter	Change max motor command	Toggles motor On / Off

The arrow keys repeat when held down. For numeric parameters with a wide range, the incremental step size will gradually increase during repetition to perform large changes.

When the motor command is OFF, the UP and DOWN arrows select configurable parameters in the following sequence that "wraps around" in a loop. Functions lacking the prerequisite setting will be skipped.

Configuration Parameter or Function	Prerequisite
1. **Operation** Display, as described above	
2. **Tool Diameter**	5. Tachometer
3. **Max Motor Power** (PWM command in %)	
4. **Motor Accel Rate**	
5. **Tachometer Input** in Pulses/Rev Nonzero value enables tachometer (& func 2, 6, 7, 8)	
6. Tachometer Calibration (fine tune)	5. Tachometer
7. Tachometer Scale Factor (drive ratio)	5. Tachometer
8. **Units of Measure** (SAE or SI)	5. Tachometer
9. **Run/Stop Command** ADC Channel for off-board switch(es) or pot (and funct 10, 11)	
10. Run Command threshold voltage	9. Run/Stop Cmd
11. Stop Command threshold voltage	9. Run/Stop Cmd
12. **Speed Control Potentiometer** ADC Channel for analog speed control (and func 13, 14)	
13. Max Speed Pot threshold voltage	12. Speed Pot
14. Min Speed Pot threshold voltage	12. Speed Pot
15. **Auxiliary Keypad or Select Switch** ADC channel	
16. Restore all parameters to default values	
17. **Diagnostic Tests** (Tachometer & ADC voltmeter)	
18. Sketch **version** info (display only)	
19. LCD backlight **brightness**	

ADVISORY: Selecting a disconnected or improperly connected ADC channel for either the **Run/Stop Command** or **Auxiliary Keypad/Switch** input (#9 or #15 above) may render the system unusable due to rapid processing of invalid commands. Recovery from this condition may be achieved by holding down the SELECT button on the LCD keypad during power-on or reset. This will erase all user settings from the on-board EEPROM.

Overview of Configuration Functions

Display	Engrg. Units	Range	Description
Tool Diameter	in (SAE units) or mm (SI units)	Unspecified, or 1/16" to 12", 1 mm to 300 mm	Diameter of cutting tool or work, used to compute cutting speed if tachometer is available
Max Motor Power	% of full power	1 to 100%	Sets the PWM command when no speed pot is present; else sets the command limit when pot is at max.
Motor Accel Rate	% (of full power) per sec	10 to 100%	Sets how fast the controller will ramp the PWM command up or down. ex: 40% rate takes 2.5 sec
Tachometer Input	Pulses / Rev	Disabled, or 1 – 4	Specifies the number of tachometer pulses received per revolution.
Tach Calibration	% of Reading	± 1.0000%	Tachometer correction for Arduino crystal time base error; specified to be less than 0.5%.
Tach Scale Factor	Unitless (ratio)	0.0100 to 6.5535	Tachometer scale factor; the mechanical drive ratio between the tachometer source and shaft of interest (default is 1.0000)
Units of Measure	-	SAE (in, sfpm) SI (mm, m/min)	Sets units of measure for tool diameter & cutting speed, if avail.
Run/Stop Cmd	-	SELECT toggle, AUTORUN, Pot/Sw on ADC#1-5	Sets the source of RUN/STOP commands based on a voltage correlating directly to a command. e.g. foot sw, run/stop switches, etc
Speed Ctrl Pot	-	NONE, Or ADC #1-5	Defines the ADC channel connected to the speed potentiometer wiper.
MAX Speed, MIN Speed	ADC counts, VDC	0-1023 counts, 0-5.000V	Defines the active range of the speed control pot. Handy when mechanical issues limit full travel, or when using a foot pot for both speed & run cmd.
Aux Keypad/Sw	NONE, Select Btn ADC	NONE, SELECT Btn or Keypad ADC	Defines the ADC channel for either an auxiliary keypad (like the LCD shield) or a single pushbutton switch duplicating the SELECT button (to toggle RUN/STOP mode).
Restore Defaults	-	-	Restore default configuration settings: No tach or external controls.
Diagnostic Tests	varies	Tach Diag, Peak CPU load, ADC input	Selects various diagnostic tests: Tach input state and pulse count, Peak CPU loading in %, ADC input voltage from 0-5 VDC
Version Display	Major.Minor	1.09	Displays the firmware version, same as power-on "splash" screen
LCD Backlight	%	OFF – 100%	LCD backlight illumination via LED.

Detailed descriptions of the Configuration mode functions:

Function Name: **Tool (or Work) Diameter**
N/A When: Tachometer Input = Disabled
Units of Measure: inches when Units of Measure = SAE. or
millimeters when Units of Measure = SI
Range: Unspecified (when set to 0), or
1/16" to 12" (when Units of Measure = SAE), or
1 mm to 300 mm (when Units of Measure = SI)
Commands: LEFT key decreases diameter, RIGHT key increases it
Pressing SELECT will save the current diameter as the power-on default.
Description: This setting specifies the diameter of the cutting tool (when milling/drilling) or work (when turning). This value is used to compute linear cutting speed when the tachometer function is enabled. If this value is set to 0 (shown as "unspecified") the RPM will still be displayed but linear cutting speed will not.

Function Name: **Maximum Motor Power**
Units of Measure: % of full power (e.g. PWM Output Duty Cycle)
Range: 1 to 100%
Default: 50%
Commands: LEFT key decreases max motor command, RIGHT key increases it
Pressing SELECT will save the current max command as the power-on default.
Description: This setting assigns the PWM motor command (motor speed) when no analog speed control pot is present. If a speed control pot is enabled, this sets the motor command used when the speed pot is at its maximum setting (e.g. fully clockwise).

Function Name: **Motor Acceleration Rate**
Units of Measure: % (of full power) per second
Range: 10 to 100% in 2% steps
Default: 32%
Commands: LEFT key decrements rate by 2%, RIGHT key increments it
Pressing SELECT will save the current rate as the power-on default.
Description: This setting determines how fast the controller will ramp the PWM command up or down. The rate of acceleration is a ratio, expressed as a fraction of 100% power per second. A setting of 40% will therefore transition from 0 to 100% in 2.5 seconds. The accel / decel rate is independent of the "Max Motor Power" setting, so reduced motor speeds will be achieved in proportionately less time.
Note: During operation, the motor command displayed in the upper left corner reflects the actual PWM signal being generated at that instant. Additional delays in motor speed change may be introduced by external factors including power supply response and mechanical inertia or load.

Function Name:	**Tachometer Input**
Units of Measure:	Pulses per Shaft Revolution
Range:	Disabled (when set to 0), or 1 to 4
Default:	Disabled
Commands:	LEFT key decrements tachometer pulses/rev, RIGHT key increments it Pressing SELECT will save the current value as the power-on default.
Description:	This setting specifies the number of tachometer pulses received per revolution of the tachometer sensor shaft. Setting this value to "disabled" (0) will disable all tachometer and cutting speed functions.
Note:	In almost every case, the best design for tachometer use will be 1 pulse/rev. Only at extremely low speeds is there any advantage in having more than 1 pulse/revolution. In such cases, precisely even spacing of the pulses throughout each revolution is required. Any differences here will reduce accuracy and increase display jitter.

Function Name:	**Tachometer Calibration**
N/A When:	Tachometer Input = Disabled
Units of Measure:	% of measured value
Range:	± 1.0000%
Default:	0.0000%
Commands:	LEFT key decreases the correction factor, RIGHT key increases it. Hold the LEFT / RIGHT key down to accelerate the rate of change. Pressing SELECT will save the current value as the power-on default.
Description:	This is the Tachometer correction factor for slight errors in the Arduino on-board crystal time base.
Example:	If the tachometer reads 3606 RPM for a 60-Hz input, set this parameter to -0.1666% to correct it.
Note:	The specification for the crystal resonator on the Uno R3 is ±0.5%, but actual values seem to run within 0.2%. Calibration of this value requires an accurate time base such as a power line frequency. Since the correction is so small, it can generally be left at 0.

Function Name:	**Tachometer Scale Factor**
N/A When:	Tachometer Input = Disabled
Units of Measure:	Unitless (ratio)
Range:	0.0100 to 6.5535
Default:	1.0000
Commands:	LEFT key decreases scale factor, RIGHT key increases it. Hold the LEFT / RIGHT key down to accelerate the rate of change. Pressing SELECT will save the current value as the power-on default.
Description:	This setting specifies a multiplier applied to the measured tach sensor speed before the value is displayed. It provides a simple way to compensate for a mechanical drive ratio between the tachometer source and the shaft of interest. If the tach sensor is mounted on the shaft of interest, leave this value at 1.0000.
Example:	If you have a belt drive reduction with the tachometer mounted on the motor, the mechanical drive ratio is entered. If the motor shaft (tachometer pickoff) turns 2.67 times for each revolution of the quill shaft, the tach scale factor is therefore the reciprocal of this, or 0.375. The motor spinning at 2,667 RPM will display a quill speed of 1000 RPM.

Function Name: **Units of Measure**

N/A When: Tachometer Input = Disabled

Selections: SAE (diameter = inches, speed = surface feet/minute) or
SI (diameter = mm, speed = meters/minute)

Command: Left / Right keys toggle the selection
Pressing SELECT will save the current value as the power-on default.

Default: SAE (in, sfpm)

Description: This setting determines the engineering units used for the display of tool diameter & cutting speed.

Function Name: **Run / Stop Command**

N/A When: Aux Keypad/Sw = NONE

Command: Left / Right keys step through the available selections.
Pressing SELECT will save the current value as the power-on default.

Description: This parameter selects the ADC source for off-board commands to run or stop the motor.

Option 1: SELECT key toggle (default value)
This setting essentially means that NO off-board switches are connected, and the system should initialize to a motor OFF condition. The SELECT key ALWAYS provides a way to command the motor to start or stop, regardless of any other command sources.

Option 2: AUTORUN
This setting essentially means that no off-board switches are connected, and the system should initialize to a motor ON condition. This configuration would be appropriate for the case when the motor is started and stopped by applying line power to the entire system. The SELECT key still provides a way to command the motor to stop, thereby allowing configuration of the various parameters.

Option 3: Pot / Switch on ADC 1 to 5
This setting specifies the ADC channel to receive an input voltage mapped to RUN/STOP commands by user-defined threshold voltages. These are assigned via the **RUN/STOP command threshold** settings function, below.
This concept will support several input configurations, some of which are
(a) a “dead-man” foot switch as described in the article,
(b) a pair of pushbuttons in a latching run/stop configuration, or
(c) a speed control potentiometer, as in a sewing machine or TIG welder.

Function Names: **RUN command threshold**
STOP command threshold

N/A When: Run/Stop Cmd = SELECT toggle or AUTORUN

Command: Left & Right keys decrement and increment the threshold voltage.
Hold the key down to auto-repeat in an accelerating step for larger changes.
Pressing SELECT will save current values as power-on defaults.

Units of Measure: ADC counts and VDC

Range: 0-1023 ADC counts, 0-5.000V

Default: RUN command above 800 counts (about 4 VDC)
STOP command below 200 counts (about 1 VDC)

Description: These two settings define operation of an external Run/Stop command switch or pot when one is present and assigned to an ADC channel by the "Run/Stop Cmd" function above. The input (0 to 5V) is broken into 3 logical ranges at the two specified thresholds. An input voltage between the two thresholds produces no command, thereby supporting separate RUN and STOP buttons.

Note: A minimum of 100 counts (about 0.5V) is required between the two thresholds. Failure to meet this requirement is indicated by the phrase "span err" on the display.

Note: Setting the RUN command lower than the STOP command will accommodate a reversed potentiometer.

Function Name: **Speed Control Potentiometer**

Selections: NONE, or ADC #1-5

Default: NONE

Command: Left & Right keys step through the available ADC channels.
Pressing SELECT will save the current value as the power-on default.

Description: Defines the ADC channel connected to the speed potentiometer wiper.

Note: The active range of the pot defaults to about 0.1 V to 5.0 V,

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Function Name: **MAX / MIN Speed above / below** (Pot Command Limits)

N/A When: Speed Ctrl Pot = NONE

Units of Measure: ADC counts and VDC

Range: 0-1023 ADC counts, 0-5.000V

Default: MIN speed at or below 20 counts (0.1 VDC)
MAX speed at or above 1020 counts (5.0 VDC)

Command: Left & Right keys decrement and increment the threshold voltage. Hold the key down to auto-repeat in an accelerating step for larger changes.
Pressing SELECT will save current values as power-on defaults.

Description: Defines the active range of the speed control pot when one is present and assigned to an ADC channel by the Speed Control Pot function above. While the default values should work in most cases, other limits are appropriate in certain cases such as:

- When mechanical constraints limit full travel of the pot,
- When the pot is wired backwards,
- When using a foot pot for both speed & run/stop commands. This allows a portion of the pot's span to issue run/stop commands before the speed actually increases from 0.

Note: A minimum of 100 counts (about 0.5V) is required between the two thresholds. This condition is indicated by the phrase "span err" on the display.
A reversed potentiometer may be accommodated by setting the RUN command lower than the STOP command.

Function Name:	**Auxiliary Keypad / Switch**
Selections:	NONE, SELECT Btn ADC, or Keypad ADC
Default:	NONE
Command:	Left & Right keys step through the available selections. Pressing SELECT will save the current value as the power-on default.
Description:	Defines the ADC channel for either of two possible off-board command sources:
(1)	An auxiliary keypad electrically identical to the LCD/keypad shield. This configuration allows all 5 key commands to be generated from an off-board source. The keypad provides 5V input when no keys are pressed.
(2)	A momentary switch duplicating only the SELECT keypad button function. This provides another command source for the common function of toggling RUN / STOP mode. The switch must provide a quiescent (inactive) voltage of 5V normally, and GND when depressed.
Note:	This function may render the system unusable due to commands received on the specified ADC. See the note under "Restore Defaults" below to fix the problem.
Note:	Command threshold voltages are hard-coded in the sketch and cannot be modified through system configuration.
Note:	When this function is enabled, the input voltage must be greater than 4.9V (indicating switch or keypad inactive), or the system power-on test will disable it. This test prevents programming an unused ADC channel and thereby flooding the system with random key commands. *Don't ask how I learned this…*

Function Name:	**Restore Defaults**
Command:	Pressing SELECT will restore the "factory" default configuration settings.
Description:	Restores the initial configuration settings: Tachometer functions disabled, no off-board controls (e.g. run switch, speed pot, aux keypad).

Configuration errors may render the system unusable.
This function may be invoked by depressing and holding
the LCD keypad SELECT key at power-on.

Function Name: **Diagnostic Tests**
Selections: Tach Diagnostic, Peak CPU loading, and ADC input monitor
Command: Left & Right keys step through the available tests.
Description: Selects various diagnostic tests:

Test Name: **D2 Tach Pulses**
Units of Measure: Boolean as LO/HI, and integer pulse count (see below)
Description: Monitors the tachometer input on Digital Pin 2. Displays the Boolean state as HI or LO and displays the accumulated pulse count processed by the interrupt service routine. For static testing of the raw tachometer sensor signal, you can also use the Analog Input Monitor (below) on ADC channel 3.

Test Name: **Peak CPU Load**
Units of Measure: % of the PWM cycle time
Description: This function is a check on how busy the CPU is, and evaluates whether the sketch is viable or not. It displays the amount of time the CPU is busy running the user interface, expressed as a percentage of the available time. If peak loading ever approaches 100%, a system malfunction may be expected.
In this application, the PWM output frequency is 20 Hz, so the total PWM cycle time is 50 milliseconds. Since the UI is managed during the longer period (when output is either HI or LO), the worst case occurs when the PWM command is at 50%. This makes the available time less than 25 msec. If the peak CPU load is reported as 55%, then processing is taking 55% of 25 msec = 14 msec in each iteration of the loop() function to run.

Test Name: **Analog Input Monitor, Ch. 0 to 5**
Units of Measure: Volts DC
Command: Pressing SELECT will lock the channel selection for 10 seconds to enable reading the actual keypad voltages.
Description: This function displays the ADC input voltage (from 0-5 VDC) on the selected channel (set by Left/Right arrows). Refer to the ADC assignment list on page 2 for the channel assignments used in this project.

Function Name: **Version Display**
Units of Measure: Major.Minor
Displays: X.xx
Description: Displays the firmware version, identical to the power-on “splash” screen

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Function Name: **LCD Backlight**
Units of Measure: % of full brightness
Selections: OFF – 100%
Default: 20%
Description: Sets the LCD backlight illumination via hardware PWM control of the LED. LCD contrast is set using the trim pot on the upper left corner of the LCD/keypad shield.
Note: This parameter is placed last in the list so that it is easily accessible by pressing the UP arrow from the command mode. The wrap-around feature makes it first in the reversed order.

Configuration Notes:

Connections to the Arduino **Digital** Pins use these fixed assignments:

- Digital Pin 2 = Tachometer input (triggered on rising edge)
- Digital Pin 3 = PWM output (20 Hz, Active HIGH)

Connections to the Arduino **Analog** Input Pins 1-5 are field-configurable. The following ADC channels were used for the stated purpose in this project. Your project could be configured differently.

ADC 1 input is labeled "CMD SWITCH" on schematic, last page. A momentary contact SPDT microswitch (activated by depressing the speed Pot) duplicates the function of the keypad SELECT button, thereby commanding motor START / STOP.
It presents +5V when inactive (either directly or via a pullup resistor), and GND when depressed. Schematic C below was used because the microswitch offered an SPDT configuration. Schematic B would also work for an SPST switch.
This configuration was enabled by setting "**Aux Keypad/Sw**" to "**SLCT btn on ADC1**"

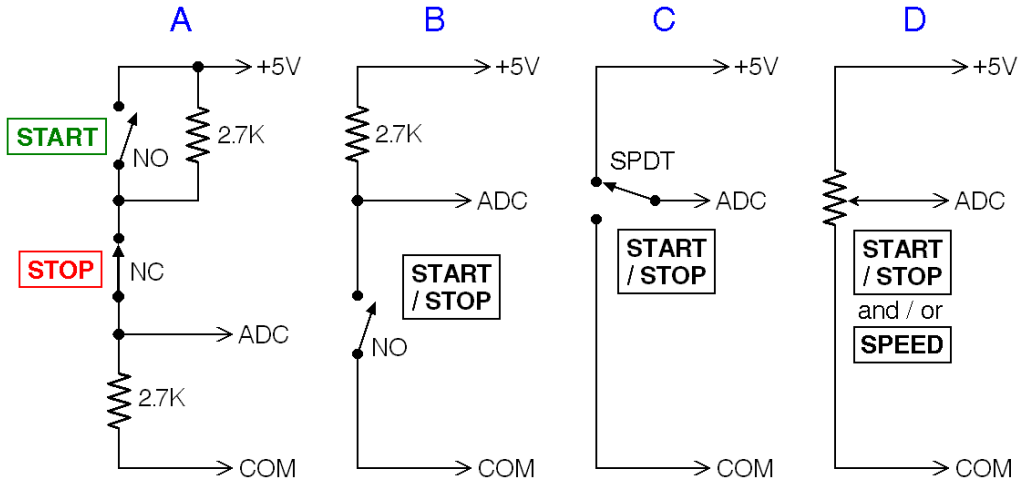
ADC 2 input is labeled "SPEED POT" on schematic, last page. The front panel analog Speed Control Potentiometer was connected as shown in schematic D below, with the wiper to Analog pin 2. It presents 0 VDC when fully CCW, and +5 VDC when fully CW. A foot control could also be used for this function.
The speed control pot function was enabled by setting
"**Speed Ctrl Pot**" to "**ADC Channel 2**"
"**MAX Speed above**" = "**1020** (counts), **4.985 V**"
"**MIN Speed below**" = "**20** (counts), **0.098 V**"

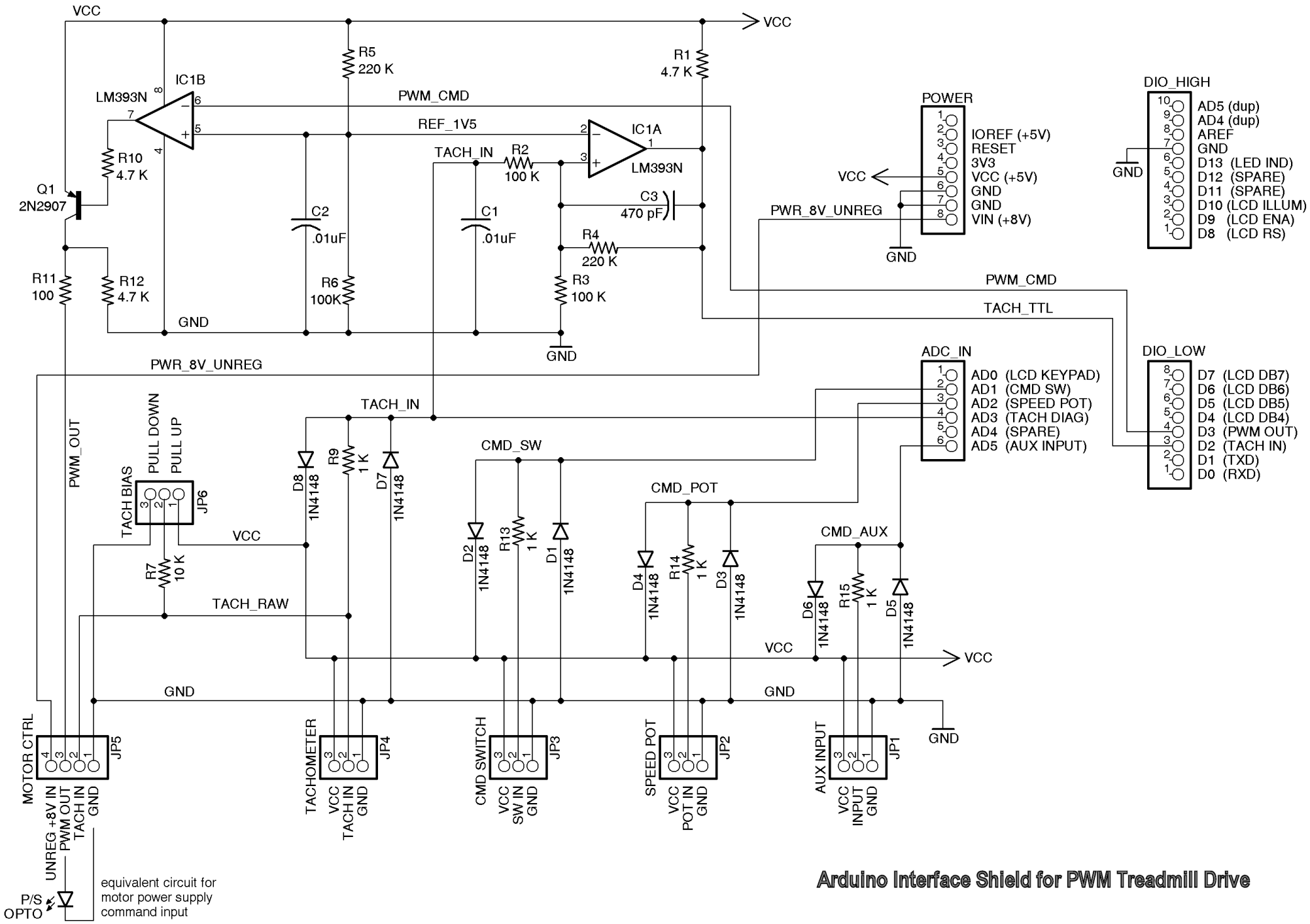
ADC 3 input is labeled "TACH DIAG" on schematic, last page. The raw tachometer signal is presented to Analog Pin 3 as a field diagnostic aid. This allows monitoring of the signal produced by the tachometer sensor at low speed by using the voltmeter function in the Diagnostic Test suite. The quill may be rotated by hand and the tachometer sensor voltage observed as it changes.

ADC 4 Spare

ADC 5 input is labeled "AUX INPUT" on schematic, last page. The momentary contact Foot Switch was connected to the "Auxiliary" input on ADC 5, and wired as shown in schematic C below, to generate 0 VDC when inactive, or 5 VDC when depressed.
This switch will command the motor to run when held depressed, and was configured by:
"**Run/Stop Cmd**" to "**Pot/Sw on ADC 5**"
"**RUN cmd above**" = "**800** (counts), **3.910 V**"
"**STOP cmd below**" = "**200** (counts), **0.978 V**"

Note: ADC5 could also support ANY of the other schematics below for run/stop commands by setting the appropriate values for the threshold voltages.





Arduino Interface Shield for PWM Treadmill Drive