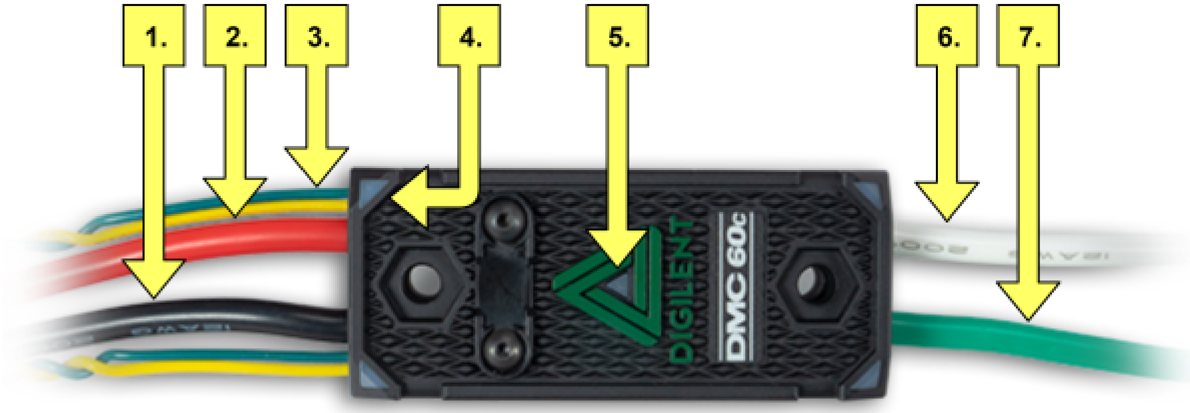
DMC60C Reference Manual

The DMC60C is the feature-packed, CAN-enabled successor to the DMC60. It is a powerful, compact, FIRST Robotics Competition (FRC) approved motor controller designed for use with any 12-24V brushed DC motor. The DMC60C features an open loop PWM control mode, two internal closed loop control modes (voltage compensation, current control), two external closed loop control modes (position, velocity), and a follower control mode. These features are made available in competition with an easy-to-use API, complete with examples, in C/C++, Java, and LabVIEW. The DMC60C also features a web configuration utility that can be installed on any FRC configured roboRIO. This configuration utility enables live configuration of several DMC60C parameters including closed loop PID constants. This makes the DMC60C an ideal component in any robotics application.

Features



Callout	Feature Description	Callout	Feature Description
1	Input Ground (GND)	5	Brake/Coast CAL Button
2	Positive Input (V+)	6	Positive Output (M+)
3	Input Signal Cables (x2)	7	Output Ground (M-)
4	Status LEDs (x4)		

Specifications

1 Electrical

PARAMETER	MIN	NOMINAL	MAX	UNIT
Input Voltage	6	12	28	V
Continuous Current			60	A
Surge Current (2 seconds)		100		A
PWM Input Signal Pulse Width	0.6	1-2	2.4	ms
PWM Input Signal Period	2.9		100	ms
PWM Input Signal Throttle Dead Band		4%		
PWM Input Signal Resolution		1		μs

PARAMETER	MIN	NOMINAL	MAX	UNIT
PWM Input Signal Logic High Threshold	1.0			V
PWM Input Signal Logic Low Threshold			0.4	V
PWM Output Signal Frequency		15625		Hz

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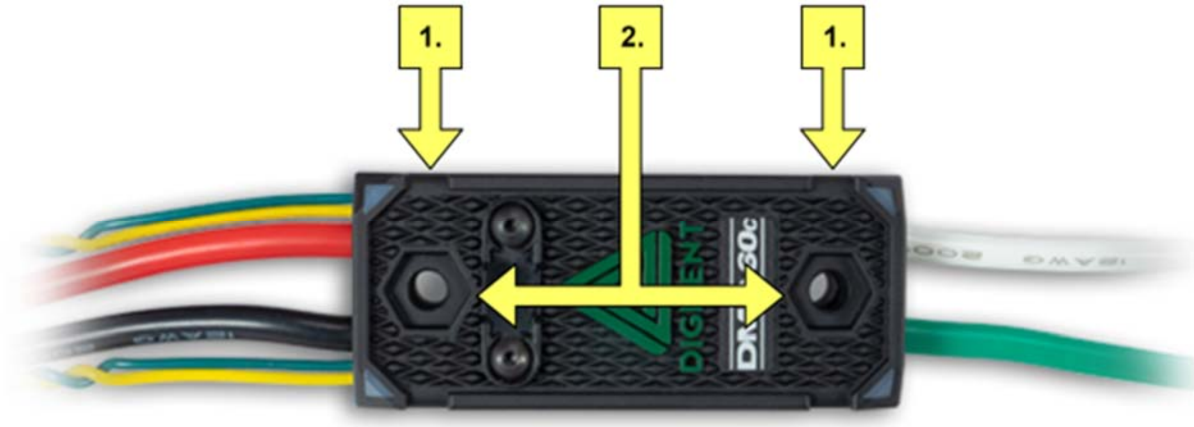
2 Mechanical

The DMC60C's aluminum case is electrically isolated and may be mounted directly to a robot using zip-ties or #8-32 screws. The case may become hot after pro-longed use in high current applications. For optimum performance it is recommended that the DMC60C be mounted in a location that allows airflow over the top of the case and around both sides of the case.



Callout	**Feature Description**
1	Zip Tie Grooves
2	Mounting Holes and #8 Bolt/Nut Pocket Clearance

Mechanical Specifications Table	
PARAMETER	**VALUE**
DMC60C Length	2.76 in (70.0 mm)
DMC60C Width	1.18 in (30.0 mm)
DMC60C Height	1.00 in (25.4 mm)
Mounting Hole Spacing	2.00 in (50.8 mm)

Functional Description

1 Power Input Connections

The DMC60C's black and red wires, labeled GND and V+ on the housing, respectively, are used to carry input power from a chosen power source to the DMC60C. The black wire is to be connected to the ground or negative terminal of the power source. The red wire is to be connected to the positive terminal of the power source. When powering the DMC60C via a Power Distribution Panel (PDP), this typically means that the DMC60C's red wire should be connected to the PDP's red terminal and the DMC60C's black wire should be connected to the PDP's black terminal.

The DMC60C does not feature output short protection, and as such, shorting the output leads can result in catastrophic failure. Therefore it is recommended that a 40 Amp breaker (or fuse) be placed in line with the DMC60C's positive input lead (red wire).

The DMC60C does NOT include input reverse polarity protection. Reversing the polarity of the inputs may result in permanent damage to the DMC60C.

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2 Motor Output Connections

The DMC60C's green and white wires, labeled M- and M+ on the housing, respectively, are used to carry a control signal from the DMC60C to a connected motor. The green wire is to be connected to the negative lead of the motor. The white wire is to be connected to the positive lead of the motor. The stall current associated with the motor may be very high. Therefore it is recommended that these connections be made through crimped connectors or by soldering the leads directly together.

If the DMC60C output leads are not long enough to reach the motor then they may be extended. It is recommended that 12 AWG (or thicker) stranded wire be used and that the wires be soldered directly together.

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3 Input Signal Cable Connections

The DMC60C can either be controlled by CAN signals applied on the input signal cables, or by PWM input signals applied via one of the two input signal cables. Usage of the CAN protocol to control the DMC60C is outside of the scope of this manual. Take a look at one of the guides on the DMC60C Resource Center for more information on how to use the CAN protocol to control the DMC60C.

The DMC60C continually measures the positive pulse width of the PWM Input Signal applied to the Input Signal Cable and maps it to an output voltage, or duty cycle. By default, a positive pulse width of 1.0 milliseconds corresponds to 100% duty cycle in the reverse direction (current flow from M- to M+), a positive pulse width of 2.0 milliseconds corresponds to 100% duty cycle in the forward direction (current flow from M+ to M-), and a positive pulse width of 1.5 milliseconds (+/- 4%)

corresponds to neutral. When a neutral pulse width is detected, the present Brake/Coast setting is applied to the output. The DMC60C expects the PWM Input Signal to have an input period between 2.9 and 100 milliseconds. The allows te update rate to be as high as 344 Hz or as low as 10 Hz.

The DMC60C's Input Signal Cable features a 0.1“ pitch 3-pin female header that is compatible with most RC / PWM Servo Controllers, allowing the DMC60C to be readily wired directly to those devices. The Input Signal Cable consists of two wires, the signal wire (yellow), and the ground wire (green).

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4 Motor Controller LEDs

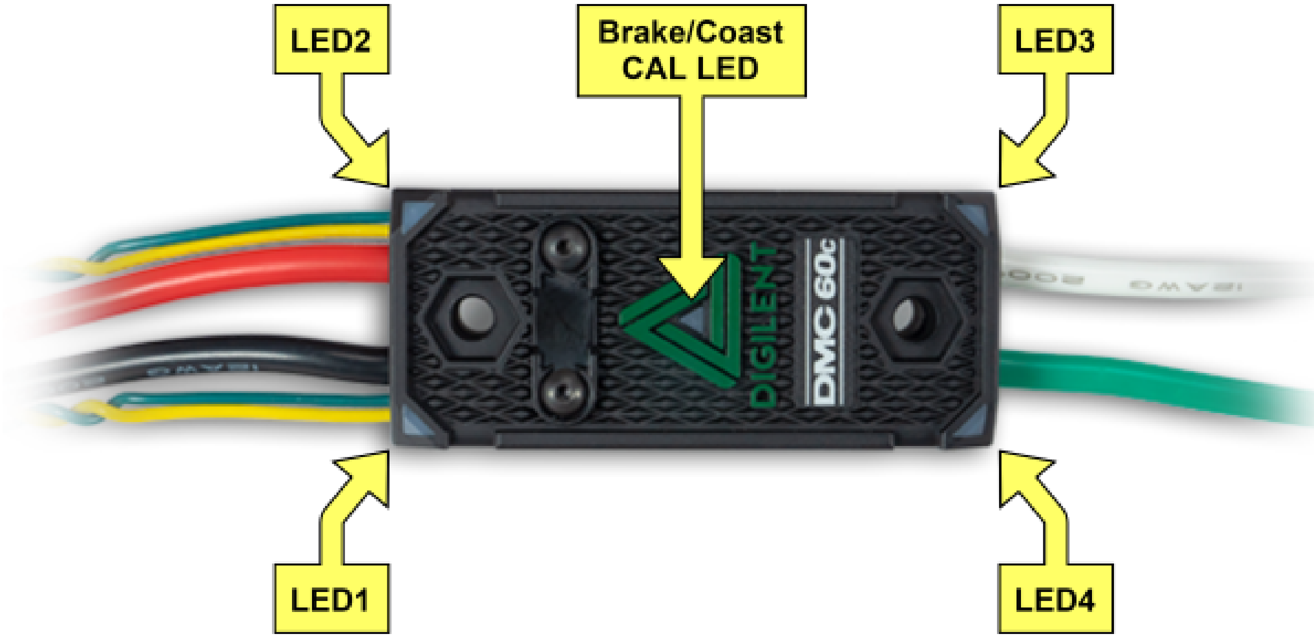

Figure 4.1 DMC60C LED Label Callout

The DMC60C contains four RGB (Red, Green, and Blue) LEDs and one Brake/Coast CAL LED. The four RGB LEDs are located in the corners and are used to indicate status during normal operation, as well as when a fault occurs. The Brake/Coast CAL LED is located in the center of the triangle, which is located at the center of the housing, and is used to indicate the current Brake/Coast setting. When the center LED is off, the device is operating in coast mode. When the center LED is illuminated, the device is operating in brake mode. The Brake/Coast mode can be toggled by pressing down on the center of the triangle, and then releasing the button.

At power-on, the RGB LEDs illuminate Blue, continually getting brighter. This lasts for approximately five seconds. During this time, the motor controller will not respond to an input signal, nor will the output drivers be enabled. After the initial power-on has completed, the device begins normal operation and what gets displayed on the RGB LEDs is a function of the input signal being applied, as well as the current fault state. Assuming that no faults have occurred, the RGB LEDs function as follows:

Table 4.1 LED Patterns in PWM Operating Mode	
Servo Input Signal Applied	**LED State**
No Input Signal or Invalid Input Pulse Width	Alternate between top (LED1 and LED2) and bottom (LED3 and LED4) LEDs being illuminated Red and Off.
Neutral Input Pulse Width	All 4 LEDs illuminated Orange.
Positive Input Pulse Width	LEDs blink Green in a clockwise circular pattern (LED1 → LED2 → LED3 → LED4 → LED1). The LED update rate is proportional to the duty cycle of the output and increases with increased duty cycle. At 100% duty cycle, all 4 LEDs are illuminated Green.
Negative Input Pulse Width	LEDs blink Red in a counter-clockwise circular pattern (LED1 → LED4 → LED3 → LED2 → LED1). The LED update rate is proportional to the duty cycle of the output and increases with increased duty cycle. At 100% duty cycle, all 4 LEDs are illuminated Red.

Table 4.2 LED Patterns in CAN Operating Mode	
CAN Bus Control State	**LED State**
No Input Signal or CAN bus error detected	Alternate between top (LED1 and LED2) and bottom (LED3 and LED4) LEDs being illuminated Red and Off.
No CAN Control Frame received within the last 100ms or the last control frame specified modeNoDrive (Output Disabled)	Alternate between top (LED1 and LED2) and bottom (LED3 and LED4) LEDs being illuminated Orange and Off.
Valid CAN Control Frame received within the last 100ms. The specified control mode resulted in a Neutral Duty Cycle being applied to Motor Output	All 4 LEDs illuminated solid Orange.

Valid CAN Control Frame received within the last 100ms. The specified control mode resulted in a Positive Duty Cycle being Motor Output	LEDs blink Green in a clockwise circular pattern (LED1 → LED2 → LED3 → LED4 → LED1). The LED update rate is proportional to the duty cycle of the output and increases with increased duty cycle. At 100% duty cycle, all 4 LEDs are illuminated Green.
Valid CAN Control Frame received within the last 100ms. The specified control mode resulted in a Negative Duty Cycle being Motor Output	LEDs blink Red in a counter-clockwise circular pattern (LED1 → LED4 → LED3 → LED2 → LED1). The LED update rate is proportional to the duty cycle of the output and increases with increased duty cycle. At 100% duty cycle, all 4 LEDs are illuminated Red.

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5 Brake / Coast Mode

The DMC60C's response when a neutral duty cycle is applied to the output depends on the Brake/Coast setting. When the DMC60C is configured for Brake Mode, the M+ and M- leads are internally shorted when a neutral duty cycle is applied to the output, which causes an attached motor to resist rotation. If an attached motor is spinning, then its speed decreases at a much quicker rate than it would if the M+ and M- leads were allowed to float. When configured for Coast Mode, the M+ and M- leads float when a neutral duty cycle is applied to the output.

The current Brake/Coast setting is displayed by the Brake/Coast CAL LED, which is in the center of the triangle located at the center of the housing. When the device is operating in Brake Mode, the LED is illuminated Red. When the device is operating in Coast Mode, the LED is off. The Brake/Coast setting can be toggled by pressing down on the center of the triangle, then releasing the button.

The Brake/Coast setting is stored in non-volatile memory and is re-stored automatically after power cycles.

When the DMC60C is connected to a CAN bus the Brake/Coast setting may be overridden by the CAN control frame. When the Brake/Coast override is active the Brake/Coast CAL LED is overridden to display the setting specified by the CAN control frame. During this time the DMC60C employs the Brake/Coast mode that is specified in the CAN frame when applying the neutral duty cycle to the output.

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6 Input Signal Calibration

The DMC60C accepts PWM input signals with a positive pulse width between 0.6 and 2.4 milliseconds. Due to variations in controllers, it may be necessary to adjust, or calibrate, the pulse widths that correspond to the maximum forward and reverse duty cycles, as well as the neutral input.

To perform calibration, follow these steps:

- 1. Press and hold the Brake/Coast CAL button. After approximately 5 seconds, the top and bottom LEDs will begin to alternate between Blue and Off. This indicates that calibration has started.
- 2. While continuing to hold the button, use the controller to move between full forward and full reverse (perhaps by moving a joystick), making sure to reach both extremes. This may be repeated more than once, but there is no required minimum.
- 3. Return the controller to neutral (return the joystick to the neutral position).
- 4. Release the Brake/Coast CAL button.
- 5. If calibration was successful, then the top and bottom LEDs will quickly alternate between Green and Off and the new calibration constants will be stored in non-volatile memory. If calibration failed, then the top and bottom LEDs will quickly alternate between Red and Off and the device will continue to operate using the existing calibration constants.

Note: *Calibration may only be performed while a servo input signal is present.*

To restore default calibration:

- 1. Disconnect the power source from the DMC60C.
- 2. Hold the Brake/Coast CAL button down.
- 3. While continuing to hold the button, apply power to the DMC60C.
- 4. Continue holding down the button until the top and bottom LEDs alternate quickly between Green and Off.
- 5. Release the Brake/Coast CAL button.

Note: *This will also restore all DMC60C settings to their factory default state.*

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7 Internal Temperature Monitoring and Over Temperature Protection

The DMC60C features an onboard thermistor, which allows the temperature of the circuit board to be continuously monitored. When the motor controller detects that the temperature of the circuit board has exceeded 70°C it will begin to decrease the duty cycle of the output. Additionally, the color of the LED indicators will be changed to Cyan (forward) or Fuchsia (reverse) to indicate that the device is operating in reduced duty cycle mode. As the temperature continues to rise, the duty cycle will be further reduced at a rate of approximately 2.85% per degree C until the temperature of the PCB exceeds 100°C, at which point the output duty cycle will be set to 0% and an over temperature fault is signaled. The motor controller will continue to operate with a decreased duty cycle until the temperature of the PCB falls below 70°C, at which point, it will resume outputting the duty cycle that corresponds to the input signal.

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8 Input Voltage Monitoring and Under Voltage Protection

The DMC60C continuously monitors the input voltage. If the input voltage falls below 5.75 Volts (+/-2%) for 5 or more seconds, then the output duty cycle will be set to 0% and an under voltage fault is signaled. The output will remain disabled until the fault is cleared (3 seconds), at which point it may be re-enabled if the under-voltage condition is no longer present.

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9 Fault Indicators

When a fault condition is detected, the output duty cycle is reduced to 0% and a fault is signaled. The output then remains disabled for 3 seconds. During this time the onboard LEDs (LED1-4) are used to indicate the fault condition. The fault condition is indicated by toggling between the top (LED1 and LED2) and bottom (LED3 and LED4) LEDs being illuminated Red and off. The color of the bottom LEDs depends on which faults are presently active. The table below describes how the color of the bottom LEDs maps to the presently active faults.

Table 9.1 Fault Indicator LED Colors

Color	Over Temperature	Under Voltage
Green	Present	Not Present
Blue	Not Present	Present
Cyan / Aqua	Present	Present

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10 Expansion Connector

The DMC60C includes a 10-pin (2 x 5, 0.050” pitch) expansion port that allows sensors to be directly attached to the controller. Presently it supports direct attachment of limit switches and quadrature encoders. The figure below shows the pinout. Please note that any sensor attached to the expansion port should be powered through pin 1 (+3.3V) and/or pin 2 (+5V) and should not be powered by an external voltage supply.

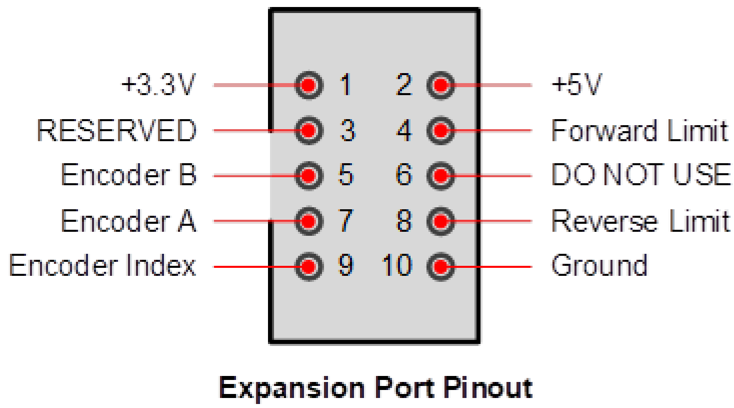

Figure 10.1 DMC60C Expansion Port Pinout

10.1 Expansion Port Electrical Specifications

Table 10.1.1 Expansion Port Electrical Specifications				
PARAMETER	**MIN**	**NOMINAL**	**MAX**	**UNIT**
+3.3V Supply Voltage	3.135	3.3	3.465	V
+3.3V Supply Current			0.050	A
+5V Supply Voltage	4.75	5.0	5.25	V
+5V Supply Current			0.100	A
Digital Input Signal Logic High Threshold[1] (Encoder A, B, Index, Fwd/Rev Limit)	2.64		5.5	V
Digital Input Signal Logic Low Threshold (Encoder A, B, Index, Fwd/Rev Limit)	0		0.66	V

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[1] All expansion port digital input pins tolerate input voltages up to 5.5V. Each of these pins is clamped to the 3.3V supply through a 200 ohm resistor and a Schottky diode

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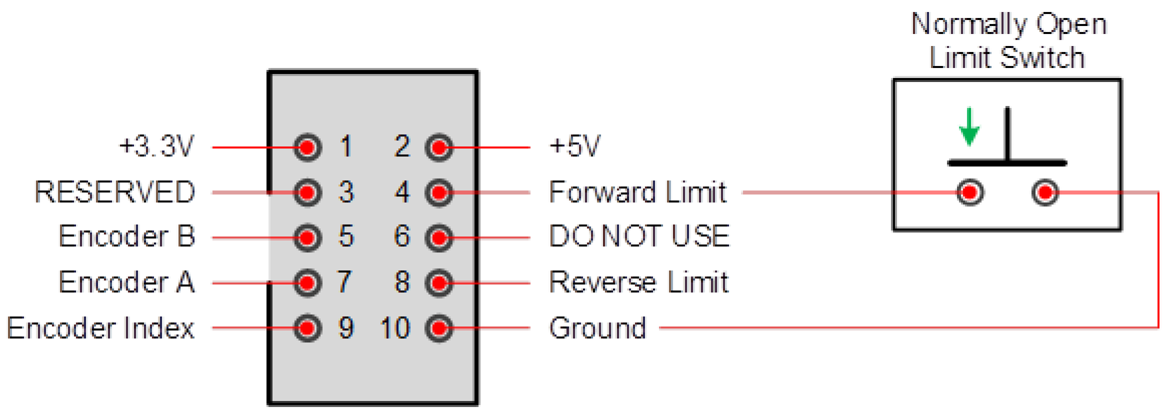
11 Limit Switches

The DMC60C expansion port includes pins for attaching both forward and reverse limit switches. These input pins can be individually configured to interface with a normally open or normally closed switch using Digilent's web-based configuration utility on the RoboRio or by sending the appropriate CAN frame on the CAN bus. Additionally, the enable/disable state of the limit switch inputs can be overridden by the CAN control frame.

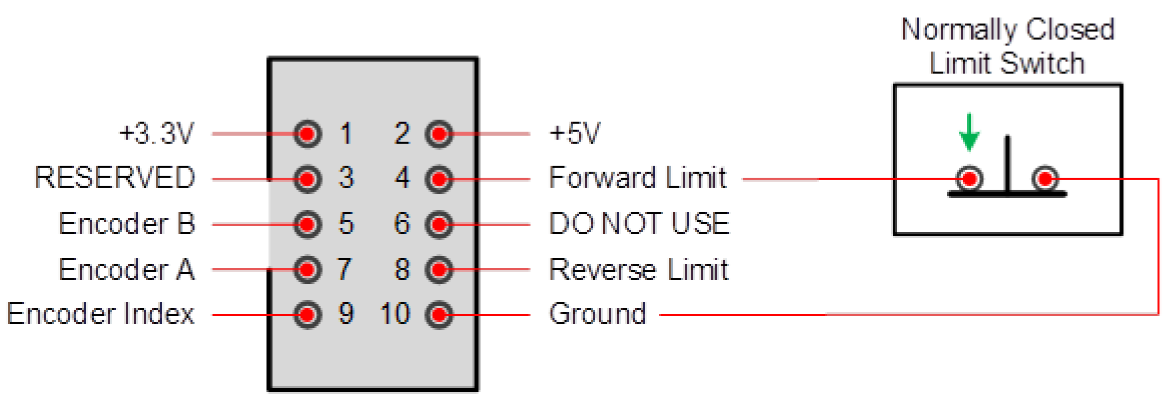
By default, both the forward and reverse limit switch inputs are enabled and configured to interface with normally open switches. When a limit switch is active the DMC60C will not allow the motor output to be driven in the associated direction. Any attempt to drive the output in the direction of an active limit switch will result in the neutral duty cycle being applied to the H-Bridge.

The onboard Microcontroller uses internal pull-ups on both pins, and as a result, no external pull-ups are required. The diagrams that follow show how to wire switches to the forward and reverse limit switch inputs.



Forward Limit Switch Connection – Normally Open

Figure 11.1



Forward Limit Switch Connection – Normally Closed

Figure 11.2

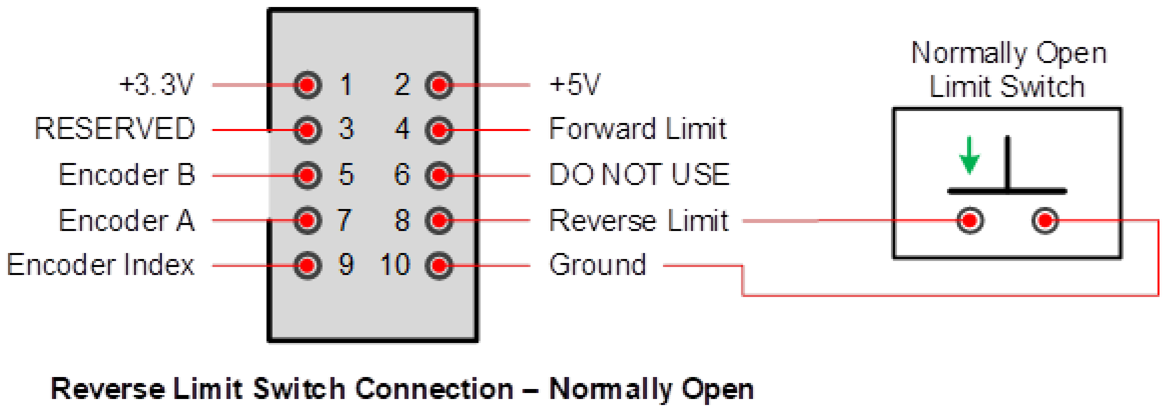


Figure 11.3

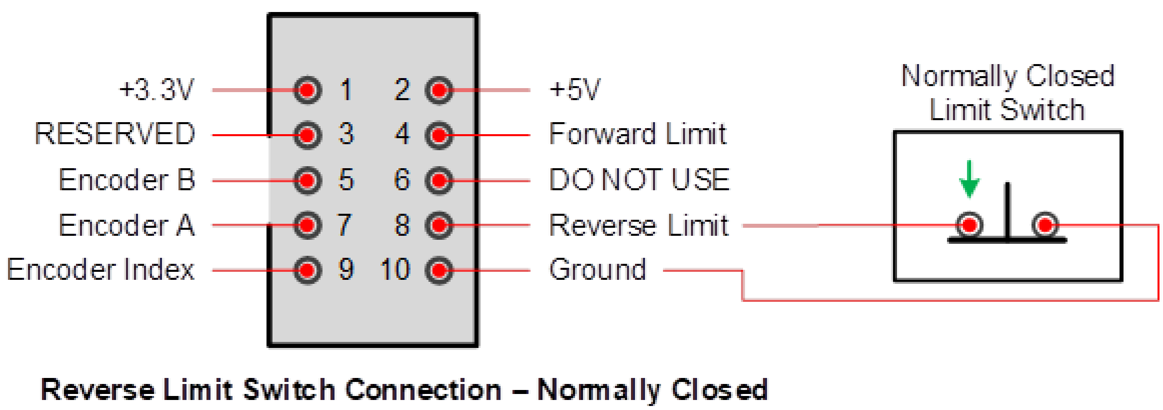


Figure 11.4

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12 Quadrature Encoder Input

The DMC60C can perform closed loop velocity and closed loop position control. Velocity and position measurements are made using a quadrature encoder. A quadrature encoder may be attached to the Encoder A, Encoder B, and Encoder Index (optional) pins of the DMC60C expansion port. Please note that the encoder should be powered by the +3.3V or +5V pins of the expansion port, and that these pins should **never** be connected to each other.

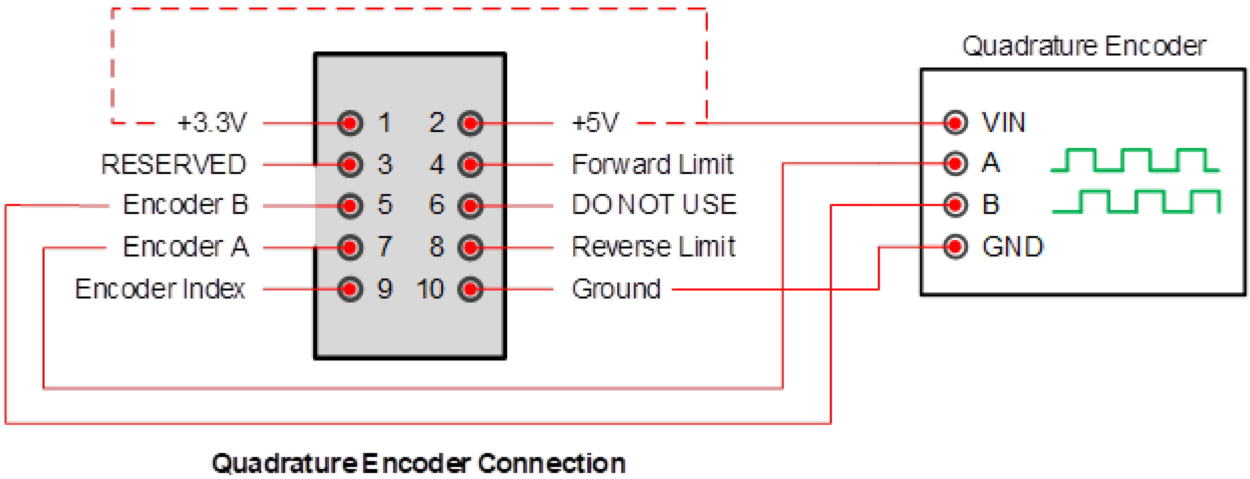

Figure 12.1 DMC60C Quadrature Encoder Connection

Table 12.1 Quadrature Encoder Input Specifications	
PARAMETER	**MAXIMUM**
Quadrature Encoder Counts per Revolution	78,643,200 / Max RPM
Quadrature Encoder RPM	78,643,200 / Max Counts Per Revolution

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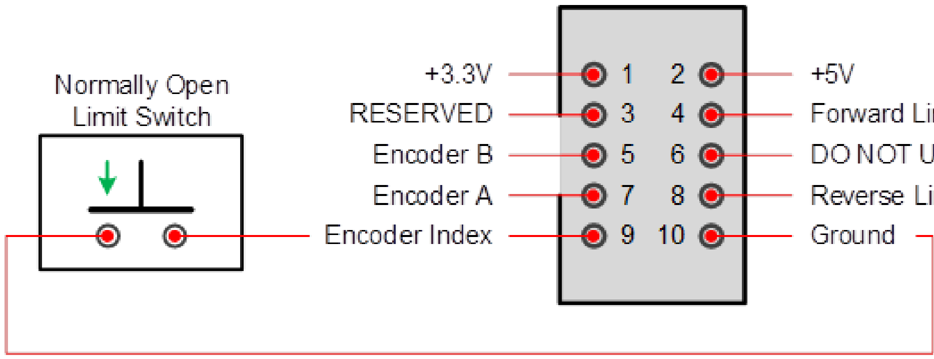
13 Quadrature Encoder Index

The DMC60C expansion port includes a pin (Encoder Index) for attaching a digital sensor or a switch to automatically clear the quadrature encoder's position count. The onboard Microcontroller uses an internal pull-up, which makes it possible to attach a switch directly without the need for an external pull-up.

The DMC60C can be configured to clear the position count in response to a rising or falling (default) edge on the Encoder Index pin. By default, this functionality is disabled, and any input applied to the Encoder Index pin is ignored by the DMC60C.

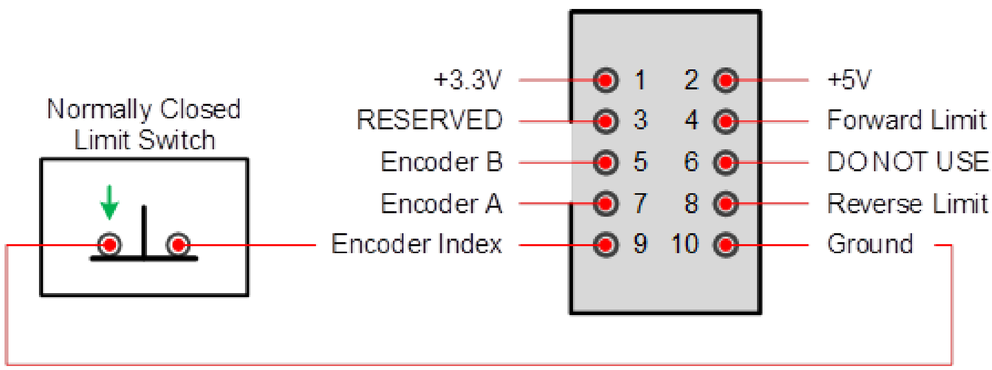
The DMC60C may also be configured to clear the position count based on the logic level of a signal applied to the Forward Limit or Reverse Limit pins of the expansion connector. By default, this functionality is disabled. The active state required to clear the position count is dependent on the configuration of the associated limit switch input. For example, if the Forward Limit switch is configured as a normally open switch then a logic '0' on the Forward Limit pin will cause the position count to be cleared when this functionality is enabled. If the Forward Limit switch is configured as a normally closed switch, then a logic '1' on the Forward Limit pin causes the position count to be cleared when this functionality enabled. Please note that the position count continues to be cleared for as long as the associated pin remains driven to the active state.

The figures below show how to attach a switch to the Encoder Index pin of the expansion port.



Index Switch Connection – Normally Open

Figure 13.1



Index Switch Connection – Normally Closed

Figure 13.2

14 Restoring Factory Default Connections

Perform the following steps to restore factory default settings:

- 1. Disconnect the power source from the DMC60C.
- 2. Hold the Brake / CAL button down.
- 3. While continuing to hold the button, apply power to the DMC60C.
- 4. Continue holding down the button until the top and bottom LEDs alternate quickly between Green and Off.
- 5. Release the Brake / CAL button.

The manufacture date string, hardware revision number string, and serial number string will be retained. All other non-volatile configuration variables, including the CAN bus device number, are reset to their factory default state.