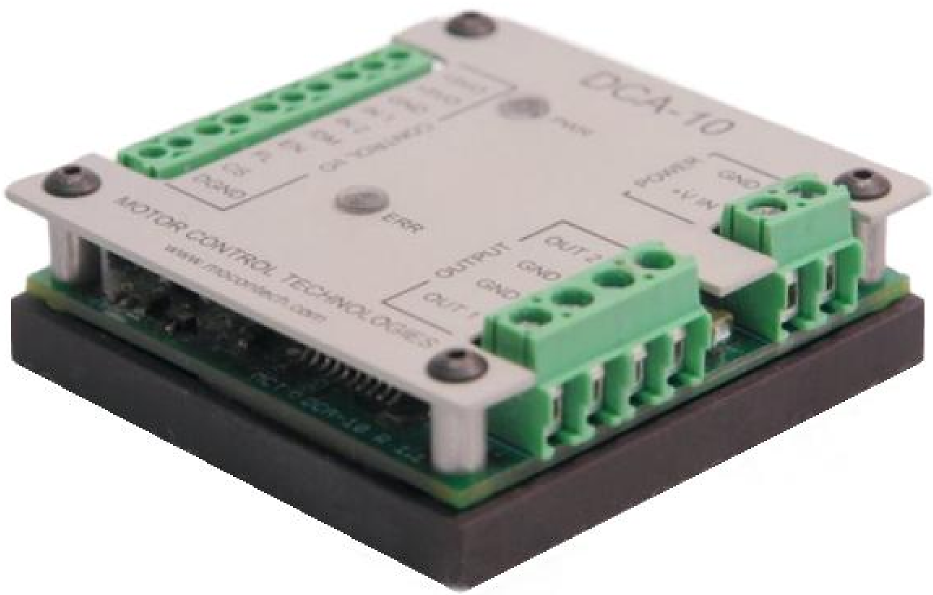
MOTOR CONTROL TECHNOLOGIES



DCA-10

DC Brushed Motor Drive

Motor Control Technologies; LLC
www.mocontech.com

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Revision History

- 12-2008 Rev 1.1
  - Initial release

- 4-2009 Rev 1.2
  - General editing
  - Updated Electrical Specifications section

- 2-2010 Rev 1.3
  - General editing

Product Description

The DCA-10 is a brushed D.C. motor drive capable of sourcing up to 5 Amps continuous current. Four-quadrant motor control is made easy with a simplified two-line control scheme. Motor velocity is controlled via a user-supplied pulse width modulated signal. The motor direction is controlled with standard digital control line. The DCA-10 is fully compatible with +3.3V and +5V logic levels, making it easy to integrate with standard data acquisition hardware and micro controller technologies.

Additional feedback and control options enhance DCA-10 control capabilities. An analog voltage feedback signal allows for real-time load current monitoring. A fault detection signal alerts the user of fault states detected at the drive. Other available features include short circuit detection, over temperature shutdown, and drive enable and disable capabilities. The DCA-10 also has an expanded operating mode to control up to two inductive or resistive loads. This feature allows the user to control power to loads such as solenoids, individual phases on a stepper motor, or resistive loads.

Every DCA-10 comes with sturdy anodized aluminum heat sink and enclosure. The integrated heat sink ensures that the unit will perform at optimal levels out-of-the-box and without costly additional hardware.

The DCA-10 also provides convenient +5V power supply output for peripheral electronics.

Operating Mode Description

The DCA-10 has two operating modes: 1) standard mode (default) and 2) half-bridge mode. Standard mode is used when driving a DC brushed motor. Half-bridge mode is an auxiliary mode useful for driving two loads such as solenoids. Switching between modes is made easy by setting the jumpers at JP1. Figure 1 depicts the correct jumper setting at JP1 for standard and half-bridge modes.

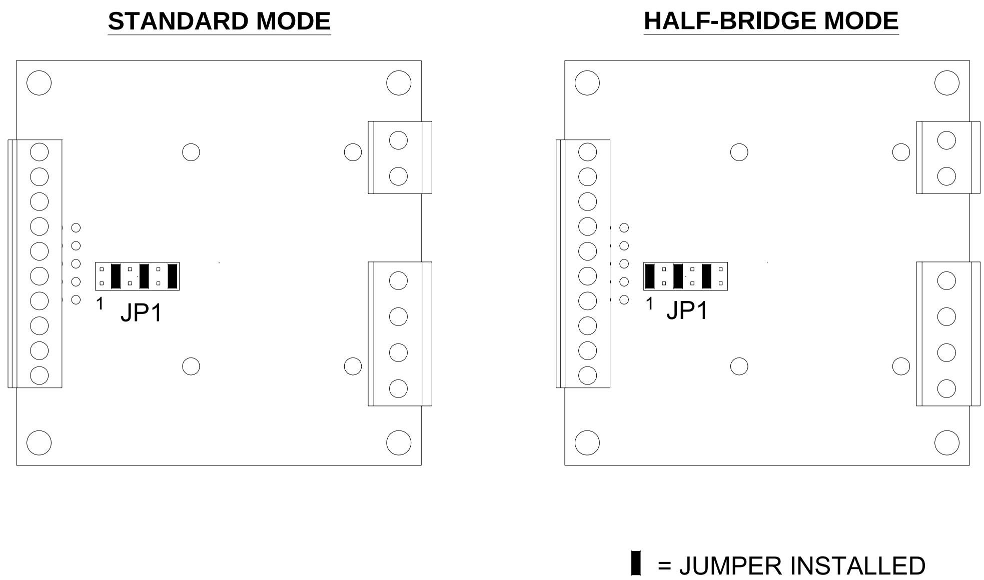


Figure 1. DCA-10 jumper settings at JP1 for Standard and Half-bridge modes.

The jumper settings at JP1 only affect the functionality and power-up states of IN 1 and IN 2. All other Control I/O lines behave the same in both modes.

Standard Mode (Default)

Standard Mode is the default mode for the DCA-10. Table 1 lists the truth table describing control I/O and output states for the DCA-10 in standard mode.

Table 1. Truth table for standard mode operation

EN	/DM	IN1 (Dir)	IN2 (PWM)	OUT 1	OUT 2	FL	Result
0	X	X	X	H.I.	H.I.	0	Bridge Disabled
1	0	X	X	H.I.	H.I.	1	Motor Disabled/Fault
1	1	0	0	+V	+V	0	Brake Mode
1	1	0	1	0	+V	0	Motor Rotates
1	1	1	0	+V	+V	0	Brake Mode
1	1	1	1	+V	0	0	Motor Rotates

Notes:

- **+V ≈ +VIN-0.5V**
- **H.I. = High impedance state**
- **x = Does not matter what state the line is in**

Motor Direction

The direction the motor rotates is dictated by the logic state at the IN 1 line, i.e. logic LOW or logic HIGH. The motor direction that corresponds to the IN 1 logic state will differ from motor to motor. Always verify motor rotation before placing a motor into service. An internal pull-down resistor will hold IN 1 LOW when nothing is connected to it.

Motor Speed

Motor speed is commanded using a Pulse Width Modulated (PWM) signal at the IN 2 pin. The speed of the motor is directly proportional to the PWM duty cycle. For example:

- 100% duty cycle = Motor at full speed
- 50% duty cycle = Motor at half speed
- 0% duty cycle = motor off

A PWM control signal possesses two basic characteristics: 1) frequency, and 2) duty cycle. The frequency determines the amount of time between the rising edges of the signal. The frequency is calculated by inverting the time between rising edges ($1/t_{PERIOD}$). The duty cycle is the percentage of time the PWM signal is HIGH. For example, a 30% duty cycle means the PWM signal is HIGH 30% of the time and LOW 70% of the time. The duty cycle is calculated by dividing the total time the pulse is high by the PWM waveform period (t_{ON} / t_{PERIOD}). Figure 2 depicts the characteristics of a 2 kHz PWM signal with a 30% duty cycle.

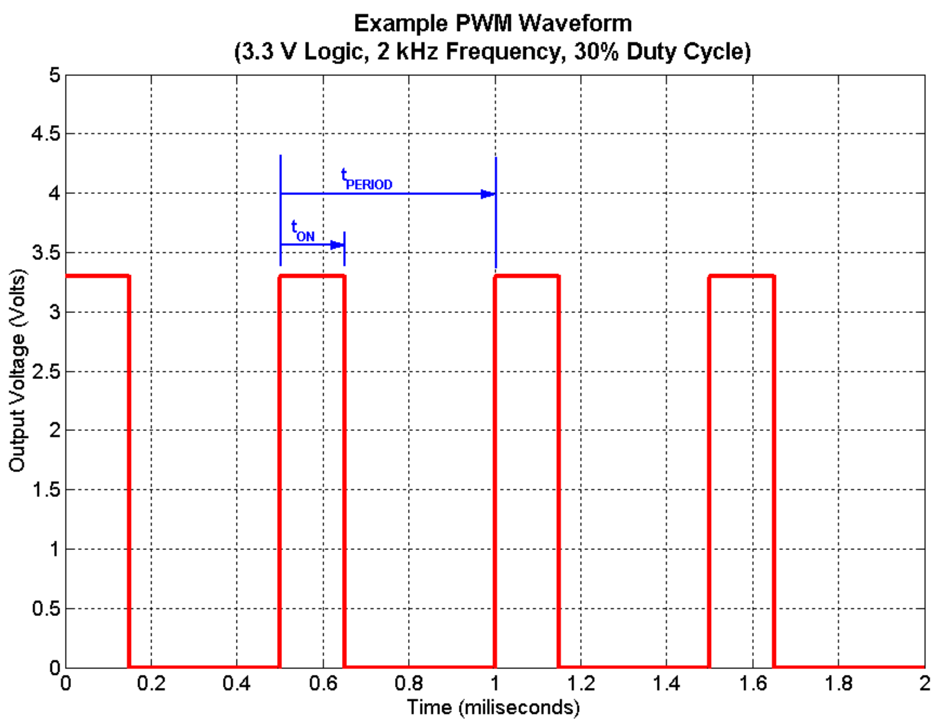


Figure 2. Example of a 2 kHz PWM signal with 30% duty cycle.

An internal pull-down resistor will hold IN 2 LOW (motor OFF) when nothing is connected to it. The DCA-10 will default to motor OFF at power up if nothing is connected, or if the IN 2 line becomes disconnected during use. Under these conditions the motor outputs are placed into a high impedance state. High impedance state at the outputs is the equivalent of physically disconnecting the power at the motor's power terminals.

Brushed DC Motor Connection

The motor terminals of a DC brushed motor are always connected between OUT 1 and OUT 2. The two GND terminals at the "Output" screw terminals are **not** used in standard mode. Figure 3 depicts the correct method for connecting a DC brushed motor to the DCA-10 in standard mode.

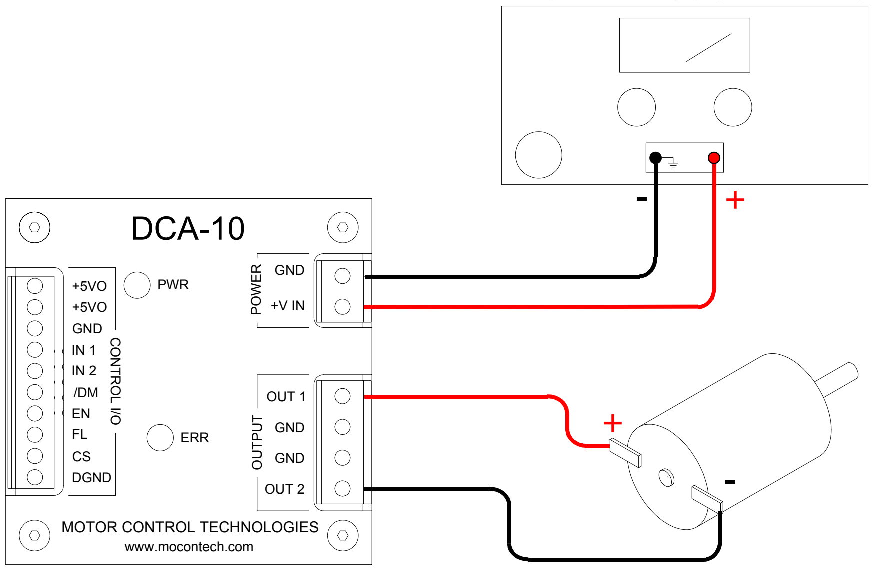


Figure 3. DC brushed motor connection to DCA-10 in standard mode.

Motor Deceleration

A motor may be decelerated in one of two ways: 1) active braking, and 2) free-wheeling. Active braking physically shorts the motor terminals together through the H-bridge and generates an opposing torque that decelerates the motor. Active braking is used whenever the motor is commanded to a slower speed.

Freewheeling is a passive mode of deceleration and allows the motor to decelerate without resistance. Freewheeling places the motor terminals into a high impedance state and allows the motor to decelerate at a natural rate. Freewheeling deceleration is achieved by disabling the motor (/DM = 0) or disabling the bridge (EN = 0). Freewheeling is recommended when decelerating high inertia loads.

NOTE:

Active braking can lead to excessive bridge currents and voltage spikes at the H-bridge. The motor's winding resistance determines the maximum current the bridge will see during a braking event. See Appendix B for the minimum recommended motor winding resistance to use with the DCA-10.

NOTE:

Care should be taken when using active braking on a motor driving high inertia loads. As a rule of thumb, do not decrease the duty cycle more than 40% at one time, and do not exceed a deceleration rate of 40% per 100 ms (DEC_{MAX}).

Half-Bridge Mode

Half-bridge mode is a special operating feature that expands the capabilities of the DCA-10. The user should read the following section carefully before using the DCA-10 in half-bridge mode.

Half-bridge mode is designed to power two independent loads. Solenoids, individual phases on a stepper motor, or small resistive loads are examples of such loads. Half-bridge mode bypasses internal control logic and exposes the low-level logic control on the H-bridge. The drive outputs, OUT 1 and OUT 2, are directly controlled through the IN 1 and IN 2 control I/O lines, producing two independent half-bridges for driving loads. OUT 1 and OUT 2 can be used as switches to turn loads ON and OFF, or they may incorporate a PWM scheme to precisely control power to a load.

It is important to note that the states of OUT 1 and OUT 2 are the inverse of the IN 1 and IN 2 states. This is a direct affect of bypassing the internal control logic. This is not the case when operating in standard mode and the user should account for logic inversion in their control scheme. Table 2 lists the truth table describing control I/O and output states for the DCA-10 in half-bridge mode.

Table 2. Truth table for DCA-10 outputs in half-bridge mode.

EN	/DM	IN1	IN2	OUT 1	OUT 2	FL	Result
0	X	X	X	H.I.	H.I.	0	Bridge disabled
1	0	X	X	H.I.	H.I.	1	Outputs disabled/Fault
1	1	1	X	0	X	0	OUT 1 OFF
1	1	0	X	+V	X	0	OUT 1 Conducting
1	1	X	1	X	0	0	OUT 2 OFF
1	1	X	0	X	+V	0	OUT 2 Conducting

Notes:
- **+V ≈ +VIN-0.5V**
- **H.I. = High impedance state**
- **x = Does not matter what state the line is in**

Load Connection

Electrical connections in half-bridge mode are different than in standard mode. Each load is connected from OUT 1 to GND or OUT 2 to GND. Figure 4 depicts how a solenoid or resistive load should be connected in half-bridge mode.

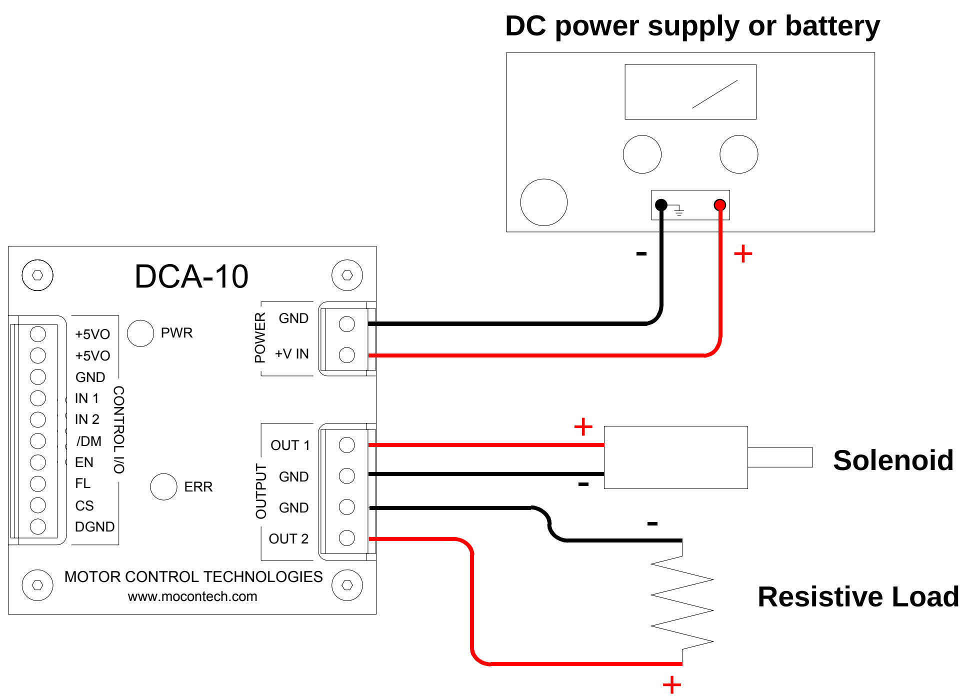


Figure 4. Example DCA-10 connection to solenoids or resistive loads.

A direct connection from OUT 1 or OUT 2 to GND should only be made on purely resistive or purely inductive loads as shown in Figure 4. **Do not connect the terminals of a DC brushed motor between OUT 1 and GND or OUT 2 and GND.** Doing so can cause serious damage to the unit. Always connect the terminals on a DC brushed motor to OUT 1 and OUT 2.

NOTE:

A DC brushed motor may be connected to the DCA-10 in half-bridge mode when specialized control schemes are required. In such specialized cases, the DC brushed motor should be connected between OUT 1 and OUT 2 as shown in Figure 3 (standard mode motor connection).

Pin Description

Power Supply Input (+VIN)

+VIN is the positive voltage supply terminal. Connect the +VIN terminal to the positive terminal on a +9 VDC to +24 VDC voltage supply. Verify cabling between the DCA-10 and power supply is adequately sized for the expected current loads. Power cables that are too small will lead to unexpected voltage drops.

Ground (GND)

The DCA-10 has four GND terminals: one at the “Power” screw terminals, two at the “Motor Output” screw terminals, and one at the “Control IO” screw terminals. The GND pin at the “Power” screw terminal should only be used as a current return to the DCA-10 power supply. This should be the only connection to the power supply ground to eliminate ground loop issues. The two GND pins at the “Motor Output” screw terminal are only used when operating in half-bridge mode. See the section entitled “Half-Bridge Mode” description for further details. The GND pin at the “Control IO” terminal is only used for grounding external electronics powered from the +5VO terminal.

All four GND terminals are connected internally on the DCA-10. Each terminal is intended for specific use and should be used accordingly. Incorrect ground connections can lead to spurious ground loop currents and erratic behavior by the DCA-10.

The DCA-10 may be powered from a floating or grounded power supply. The particular type of supply is left to the user to select. Pay special attention to ground loops when using grounded power supplies. Only use one GND terminal as the DCA-10 power return, and always use a single grounding point when connecting the DCA-10 with other grounded equipment.

Floating supplies may also be used to power the DCA-10. Only use floating supplies if the DCA-10 is not directly interfacing with other grounded electronics.

NOTE:

The DCA-10 heat sink is electrically isolated from +VIN and ground. Always use the GND pin at the power screw terminals to ground the DCA-10.

OUT 1 and OUT 2

Standard Mode Use

OUT 1 and OUT 2 are the power outputs of the DCA-10. The voltage between OUT 1 and OUT 2 is amplified version of the PWM signal supplied applied at IN 2. The peak-to-peak voltage is approximately equal to the supply voltage (~ +VIN – 0.5V). Always connect the positive and negative terminals on a brushed DC motor to OUT 1 and OUT 2. **Do not connect a brushed DC motor between OUT 1 and GND or OUT 2 and GND**. Doing so can lead to serious damage to the DCA-10.

Half-Bridge Mode Use

In half-bridge mode OUT 1 and OUT 2 may be used to power solenoids or resistive loads. See the description in the section entitled “Operating Mode Description” for jumper settings and further details about this special operating mode.

IN 1

Standard Mode Use

IN 1 is a digital input used to control motor direction in standard mode (logic LOW or logic HIGH). The motor direction that corresponds to the IN 1 logic state will differ from motor to motor. Always verify motor rotation before placing a motor into service. An internal pull-down resistor will hold IN 1 LOW when nothing is connected to it.

Half-Bridge Mode Use

IN 1 also provides a direct connection to OUT 1 when operating in half-bridge mode, where the state of OUT 1 is the inverse of the IN 1 state. An internal pull-up resistor keeps IN 1 at logic HIGH (OUT 1 = logic LOW) when nothing is connected to it. See the section entitled “Half-Bridge Mode” for further details about this special feature.

IN 2

Standard Mode Use

IN 2 is a digital input used to control motor speed via a pulse width modulated signal (PWM). The speed of the motor is directly proportional to the PWM duty cycle. For example:

100% Duty cycle – Motor at full speed
50% duty cycle – Motor is at half speed
0% duty cycle – Motor is off.

An internal pull-down holds IN 2 low if nothing is connected to it (motor off).

Half-bridge Mode Use

IN 2 also provides a direct connection to OUT 2 when operating in half-bridge mode, where the state of OUT 2 is the inverse of the IN 2 state. An internal pull-up resistor holds IN 2 at a logic HIGH (OUT 2 = logic LOW) when nothing is connected to it. See the section entitled “Half-Bridge Mode” for further details about this special feature.

/DM

/DM is a digital input that will place OUT 1 and OUT 2 into high impedance states when the line is held LOW (/DM = logic LOW). An internal pull-up resistor will keep the line HIGH when not connected. Use the /DM line with a limit switch for emergency stops or use it to decelerate the motor by freewheeling.

EN

EN is a digital input used to enable and disable the H-bridge power IC. When disabled (EN = 0), the bridge will go into sleep mode and will draw minimal power. OUT 1 and OUT 2 are placed into a high impedance state when the bridge is disabled. The bridge will function normally when the EN line is held HIGH. An internal pull-down resistor will hold EN LOW if nothing is connected (bridge disabled).

FL

FL is a digital output that reports the DCA-10's fault state. The FL line will always be LOW under normal operating conditions. The FL line is set (logic HIGH) if a fault condition is detected by the DCA-10. The following fault conditions will cause FL to transition to a logic HIGH state:

- Over temperature shutdown – Shutdown due to over temperature occurs when the internal temperature on the power I.C. exceeds T_{MAX} (Appendix B). Over temperature events should not exceed more than one event in a 24-hour period to prevent damage to the drive.

- Short circuit detection – A short circuit is detected when the current through the H-bridge exceeds I_{THS} or I_{TLS}. Inrush currents on inductive loads can trigger the short circuit protection. Ramp the PWM duty cycle in a constant rate when this condition occurs.

- Under voltage shutdown – The bridge will go into a fault state when the supply voltage drops below +9V. The DCA-10 will automatically recover form an under voltage condition when the supply voltage rises above +9V.

- /DM pulled LOW – See /DM pin description.

If a fault is detected the bridge will go into safe mode and place OUT1 and OUT2 in high impedance states. OUT 1 and OUT 2 will remain in a high impedance state until the fault is cleared. A fault state is cleared by cycling the EN or the /DM line from a LOW to HIGH state. All other bridge functionality will remain operational when a fault is detected.

CS

The CS line is an analog output that outputs a voltage proportional to the current flowing through the H-bridge. The voltage output from CS will range between 0 VDC and +2 VDC under normal operating conditions (0 – 5 Amps). Use the following equation for converting CS voltage to the equivalent motor current:

Equation 1.

$I_{motor} = V_{cs} \times 3.7596$

In Half-bridge mode CS reports the sum of the currents flowing through both half-bridges. The actual current flowing through each half bridge cannot be determined directly when two loads are powered simultaneously. The error associated with the CS is slightly higher in half-bridge mode and should only be used as a reference for monitoring current through the bridge.

+5VO

The +5VO terminal is a regulated +5V output that derives its power from +VIN. +5VO may be used to power external electronics such as encoders, limit switches, etc. The maximum continuous current sourced from +5VO should not exceed 100 milliamps.

DGND

DGND is a protected ground that should always be used when interfacing the DCA-10 with grounded external electronics. A small series resistance and internal fuse prevents current transients from using the connected electronic's ground as a current return for the motor.

Differences in ground potential between the DCA-10 and other electronics will show up across the small resistance at DGND. Ground offsets are typically only a few milivolts, but can lead to significant errors when monitoring bridge current via the CS line. Always verify if ground offsets exist. The majority of ground offsets can be corrected using standard grounding techniques. However, some cases may require direct compensation by the user. Account for any offsets by either correcting in current calculations, or by using a differential analog measurement between CS and GND.

Appendix A – Theory of Operation

H-bridge Operation

The DCA-10 is designed around an H-bridge topology. An H-bridge gets its name from the four power transistors configured in the shape of and H. Each leg of bridge is called a half-bridge and is comprised of two transistors in series between +Vs and ground. Each transistor is set up in a push-pull configuration such that only one transistor is capable of conducting at given time. The addition of a control logic layer allows the states of both transistors in a half-bridge to be controlled using a single logic line. A logic HIGH sent to a half-bridge will turn it ON and logic LOW will turn it OFF. When the half-bridge is ON the top transistor (high-side) is conducting and the bottom transistor (low-side) is in a high impedance state. The voltage seen at the output is equal to +Vs. When the half bridge is OFF the states of each transistor are reversed, and the output is dropped to ground potential. Figure 5 depicts a simplified representation of the H-bridge topology.

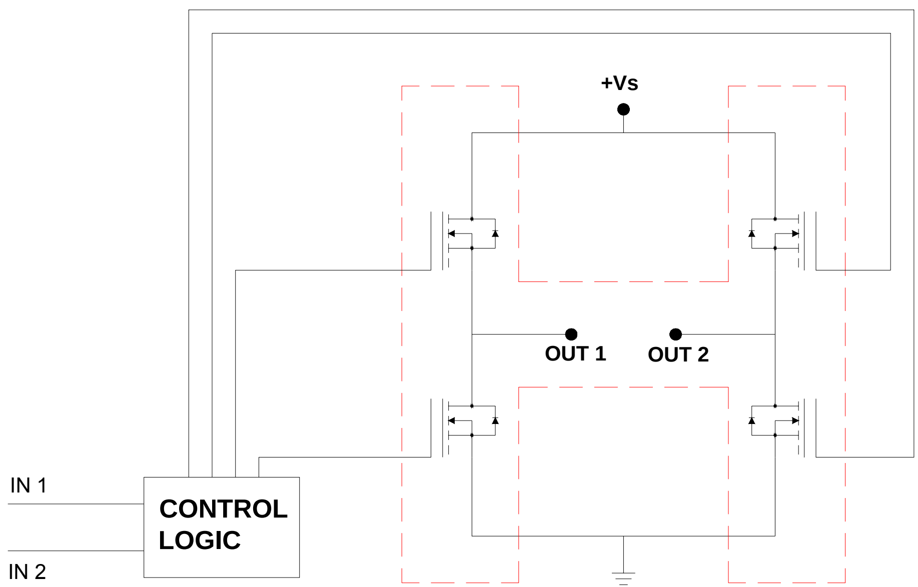


Figure 5. Simplified schematic of H-bridge topology.

H-bridges are particularly useful in when working with DC brushed motors because they provide a convenient way to control both power and direction. The terminals of a DC brushed motor are connected between the two half bridges, forming a full-bridge configuration. The motor will start rotating when one half-bridge is turned ON and the other is turned off. This effectively connects one motor terminal to +Vs and one terminal to ground. The direction of the motor may be reversed by simply commanding the respective half-bridges to their opposite states.

DC brushed motors offer one of the most convenient methods for varying motor speed. The speed of a DC brushed motor is proportional to the voltage applied to its terminals as compared to its rated voltage. The maximum motor speed is achieved by applying the maximum rated voltage to the motor. Applying a voltage that is one half the motor's rated voltage will result in the motor rotating at half the maximum speed under the same conditions. An H-bridge can only supply a voltage equal to +Vs. It cannot vary the voltage to the motor in a true analog sense. It can however, vary the power to the motor by modulating the voltage seen at the motor terminals. That is, the H-bridge can output a time varying pulsed voltage to the motor. Modulation of the output voltage in this manner is termed Pulse Width Modulation, or PWM for short.

A PWM signal has two essential characteristics: 1) frequency, and 2) duty cycle. The frequency determines the amount of time between the rising edges of the pulsed PWM signal. The frequency is calculated by inverting the time between rising edges (Equation 2). The duty cycle is the percentage of time the PWM signal is HIGH. For example, a 30% duty cycle means the PWM signal is HIGH 30% of the time and LOW 70% of the time. The duty cycle is calculated by dividing the time the pulse is HIGH by the PWM waveform period (Equation 3)

Equation 2

$$f_{PWM} = (t_{PERIOD})^{-1}$$

Equation 3

$$D.C. = t_{ON} \div t_{PERIOD} \times 100\% \quad \text{or } D.C. = t_{ON} \times f_{PWM} \times 100\%$$

The equivalent analog voltage is determined by multiplying +Vs by PWM duty cycle. A 30% PWM signal is equivalent to an analog voltage that is 30% of +Vs.

Equation 4

$$V_{EQ} = D.C. \times Vs$$

Motor Deceleration

H-bridges also provide a convenient method for decelerating a DC brushed motor. Every DC brushed motor will generate a back EMF when it is rotating. This back EMF is a voltage induced into the rotor coils as they rotate though the motor's magnetic field. The back EMF always opposes the voltage applied at the motor terminals by the user. .

Active braking occurs when the back EMF is greater than the voltage applied to the motor terminals. In this event the back EMF will cause current to flow in the opposite direction, which in turn generates a torque that opposes motor rotation. As a result the motor will decelerate until the back EMF is less than the voltage at the terminals, or the motor comes to a rest.

An H-bridge is particularly useful for active braking because the motor terminals are easily shorted at the H-bridge. This is accomplished by setting both half-bridges to the same state. If both half-bridges are turned on, current can flow through the two high-side transistors. This is termed high-side braking. If both half-bridges are turned off, the current will flow through the bottom transistors. This mode is termed low-side braking. A schematic of current flow through the h-bridge during high-side and low-side braking events is shown in Figure 6.

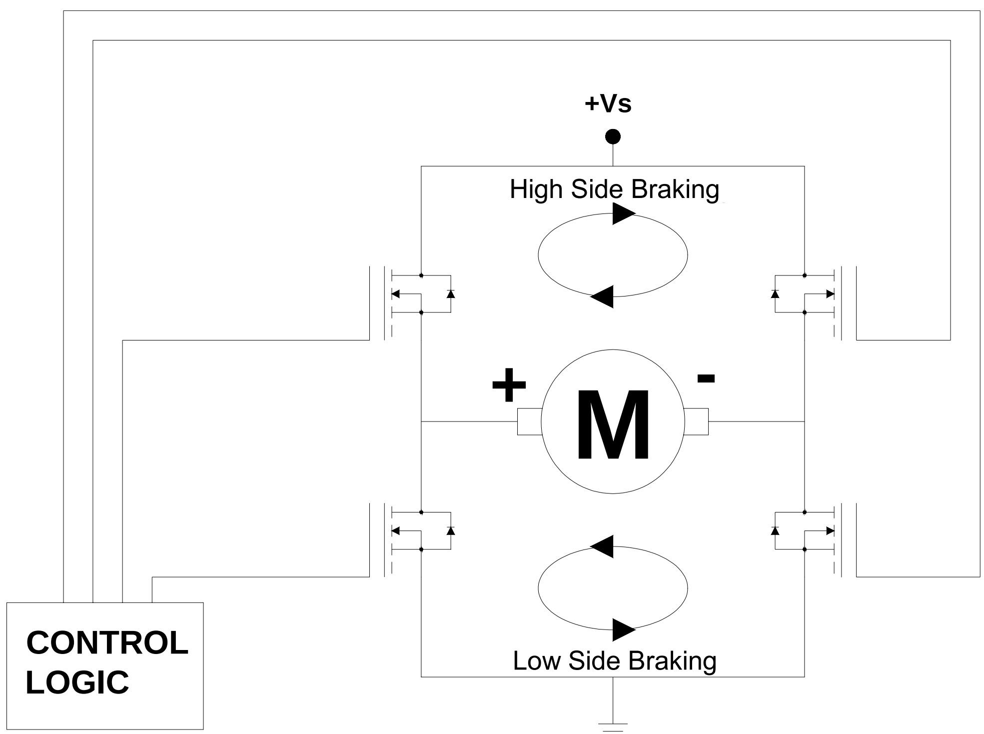


Figure 6. Current flow through an H-bridge during high-side and low-side braking events.

Appendix B – Electrical Characteristics

General

Characteristic	Symbol	Min	Typ	Max	Unit
Supply Voltage	$+V_S$	9	--	24	V
H-bridge Output Voltage	OUT_n	--	$+V_S$ – 0.5	--	V
Continuous Output Current [1]	I_{OUT}	0	--	5	A
Current Limiting Threshold	I_{LIM}	5.0	6.5	7.8	A
Over temperature Shutdown [2]	T_{MAX}	175	--	225	C
Peripheral Power (+5VO) [3]	+5V0				
I_{out} = 0 A		--	5.0	5.2	V
I_{out} = 50 mA		--	4.6	5.1	V
I_{out} = 100 mA		--	4.3	5.0	V
Quiescent Current	I_Q				
Drive Enabled (EN = 1)					
+Vs = 9V		--	15	--	mA
+Vs = 24V		--	17	--	mA
Drive Disabled (EN = 0)					
+Vs = 9V		--	7	--	mA
+Vs = 24V		--	8	--	mA
Operating Temperature Range	T_{OP}	-40	--	85	˚C

NOTES:
1) Inability to adequately dissipate heat from the drive unit will result in lower continuous current limit due to over temperature shutdown limits.
2) Power IC junction temperature.
3) Current sourcing above 100 mA from +5VO will result in excessive voltage drop and heat generation within the unit. Thermal shutdown of +5V output can result.

Control IO

Characteristic	Symbol	Min	Typ	Max	Unit
Control I/O voltage limits	V_I	-7	--	7	V
Control Input logic levels HIGH input voltage LOW input voltage	 V_{IH} V_{IL}	 2 --	 -- --	 -- 0.8	 V V
Control Output logic levels HIGH output voltage LOW output voltage	 V_{OH} V_{OL}	 -- --	 5 0.8	 -- --	 V V
Input Impedance	R_{IN}	--	10	--	kΩ
Output Impedance	R_{OUT}	--	10	--	kΩ

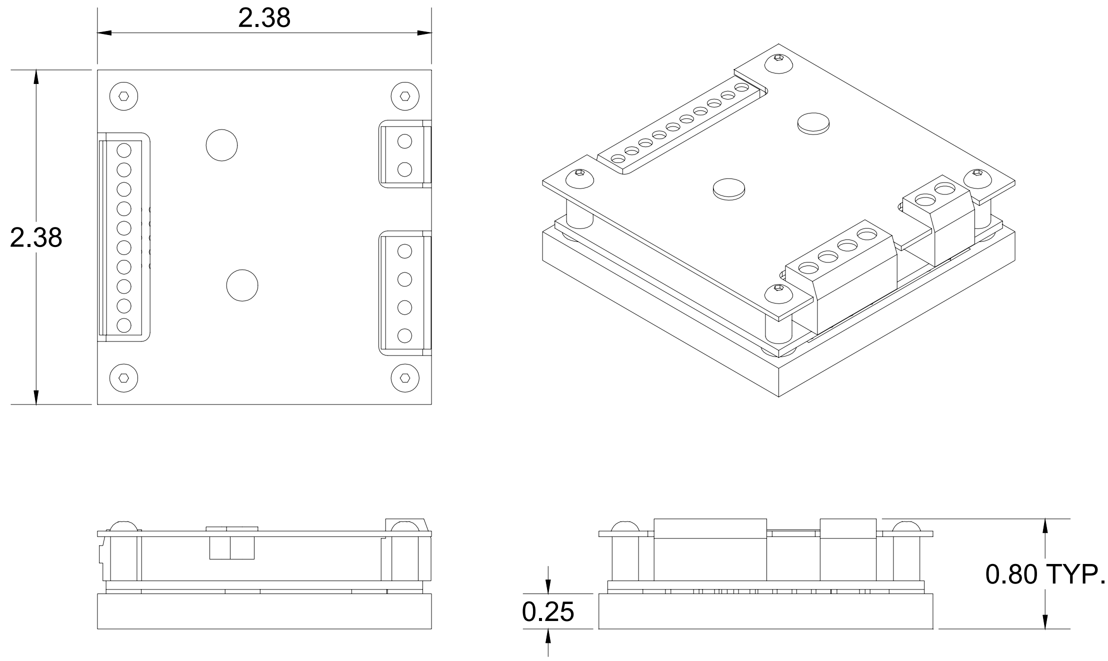
H-bridge

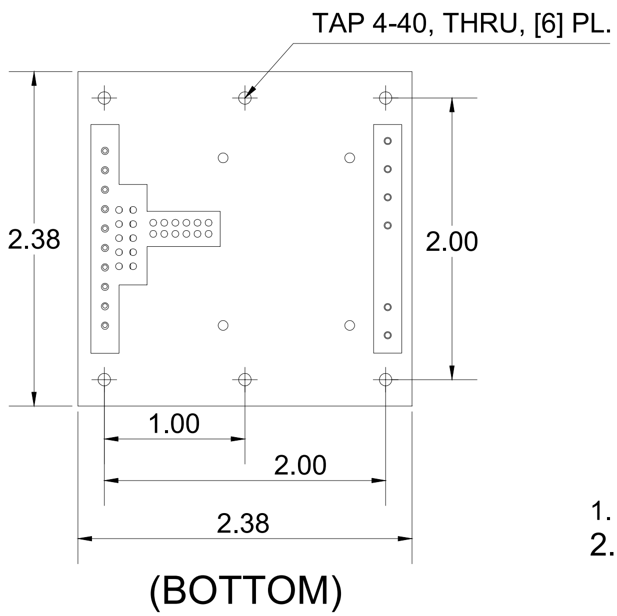
Characteristic	Symbol	Min	Typ	Max	Unit
PWM Frequency	f_{PWM}	0	--	10	KHz
Duty Cycle Change	DEC_{MAX}	-400	--	--	%/s
Bridge Resistance (1)	R_{BR}	--	0.240	--	Ω
Bridge Current Feedback Signal I_{BRIDGE} = 0 A I_{BRIDGE} = 0.5 A I_{BRIDGE} = 1.5 A I_{BRIDGE} = 3.0 A I_{BRIDGE} = 6.0 A	V_{FB}	-- 106 356 713 1.43	-- 133 400 800 1.60	61 170 467 933 1.87	mV mV mV mV V
Short Circuit Threshold (high-side)	I_{THS}	11	--	--	A
Short Circuit Threshold (low-side)	I_{TLS}	8	--	--	A
Recommended Motor Winding Resistance (2) +Vs = 24V +Vs = 18V +Vs = 12V +Vs = 9V	R_{MOT}	 2.5 2.0 1.1 1.0	 -- -- -- --	 -- -- -- --	Ω

NOTES:

1) R_{BR} value when the junction temperature at 25 C.
2) Motor winding resistances less than that noted for R_{MOT} can result in excessive bridge currents during braking, and can cause serious damage to the DCA-10.

Appendix C – Mechanical Drawings





1. Dimensions shown are in inches.
2. All dimensions ± 0.010”

NOTE:

The DCA-10 base and enclosure are electrically isolated from +VIN and GND.