SENSORLESS BRUSHLESS DC MOTOR CONTROLLER MODULE IN A POWER FLATPACK (100V, 250V)/40A

FEATURES:

- Fully integrated 3-phase brushless DC motor control subsystem includes power stage, non-isolated driver stage, and controller stage
- Up to 40A average DC bus current with up to 60VDC bus voltage, or 30A with up to 150VDC bus voltage.
- sensorless commutation
- Internal precision current sense resistor.
- Cycle by cycle current limiting.
- Fixed frequency PWM from zero speed to full speed.
- Closed-loop speed control.
- Direction input for direction reversal of motor
- Tacho output with frequency output proportional to speed
- Soft start input with adjustable starting time.
- Under-voltage shutdown for the 15V VCC.
- Duty-cycle is limited to 99% .
- Current limit reference for programmable over-current limit.
- DC bus current sense amplifier.
- Two Quadrant Mode of Operation.
- MOSFET Output Stage, with lowest Rdson.
- Hermetic or non-hermetic device (3.10" x 2.10" x 0.385")
- **Hermetic Device Part # (SMCS6MXX-XX)**
- **Non-Hermetic Device Part # (SMCS6MXX-XX-1)**

APPLICATIONS:

- Fans and Pumps

DESCRIPTION:

SMCS6MXX-XX is an, integrated three-phase sensorless brushless DC motor controller/driver subsystems housed in a 43 Pin power flatpack. SMCS6MXX-XX is a completely self-contained motor controller that converts an analog input command signal into a motor speed. SMCS6MXX-XX is best used as a two quadrant speed controller for controlling/driving fans, pumps, and motors in applications which require small size.

SMCS6MXX-XX is available with MOSFET power stage for DC bus voltage from 28V to 160V, and with IGBT power stage for DC 300V DC bus systems

The small size of the complete subsystem is ideal for aerospace, military, high-end industrial, and medical applications.

ABSOLUTE MAXIMUM RATINGS

Characteristic	Maximum
Operating DC Bus Supply Voltage SMCS6M40-10-1 SMCS6M40-25-1	 60 V 150 V
Maximum Peak DC Bus Supply Voltage SMCS6M40-10-1, SMCS6M40-25-1	 100 V 250 V
RMS Output Motor Current for SMCS6M40-10-1 SMCS6M40-25-1	40 A 30 A
Instantaneous Peak Output Current for SMCS6M40-10-1 SMCS6M40-25-1	60 A 40 A
+15V Supply Voltage	+17 V
Logic Input Voltage	-0.3 V to +5.5 V
Operating & Storage Junction Temperature	-55 ^{o}C to +150 ^{o}C
Power Devices Thermal Resistance R_{thjC} for SMCS6M40-XX-1	0.60 ^{o}C/W
Pin-to-Case Voltage Isolation, at room conditions	600V DC
Lead Soldering Temperature, 10 seconds maximum, 0.125” from case * Tcase = 25° C	300°C

Recommended Operating Conditions (T_C=25 ^{o}C)

Characteristic	Maximum
Operating Supply Voltage SMCS6M40-10-1, SMCS6M40-25-1	 50 V 130 V
RMS Output Motor Current for SMCS6M40-10-1, T_C=80^{o}C for SMCS6M40-25-1, T_C=80^{o}C	30 A 25A
+15V Supply Voltage	+ 15 V +/-10%

PARAMETER SYMBOL CONDITIONS (NOTE 1)	MIN.	TYP.	MAX.	UNITS
Power Output Section				
Drain-Source Leakage Current IDss at 0.8VDss **Diode Forward Voltage V_F at** I_F = 40 A Diode Reverse Recovery Time trr I_F = 40A, di/dt = -100A/usec, SMCS6M40-10-1 SMCS6M40-25-1			250 1.0 100 200	uA V nSec
Drain-to-Source On-Resistance Rds(on) I_D =40A SMCS6M40-10-1 Device, SMCS6M40-25-1 V_{CC} =15V Note (2)			 5 60	 mΩ
Control Section				
Control Supply Current Icc at Vcc =15V Turn-On Threshold Vcc(+) Tc over operating range	 8.0	 10.0	40 11.5	mA V
5V Reference Section				
Output Voltage Vref, at 30mA load Output Current Io	4.7 -	5.0 -	5.3 30	V mA
Current-Sense Amplifier Section				
Amplifier Voltage Gain Over-current detection voltage Gain variation is +/- 5% over temperature range from –40°C to 125°C.	18 0.45	20 0.5	22 0.55	mV/A V
Logic Input Section				
Dir in, LA,Ov-Lap, Fm High-Level Input Voltage Threshold Dir in, LA, Ov-Lap, Fm Low-Level Input Voltage Threshold Fsc High-Level Input Voltage Threshold Fsc Low-Level Input Voltage Threshold Fsc Middle-Level Input Voltage Threshold	3.5 - 4 - 2	- - - - 2.5	- 1.5 - 1 3	V V V V V
Tachometer & Start Outputs				
Output High Level Voh , Io = -500uA Output Low Level Vol, Io = 500uA	4.5 -	- -	5.0 0.50	V V
PWM Section				
PWM Frequency Fs	13	15	17	kHz

SPECIFICATION NOTES:

1- All parameters specified for Ta = 2°C, Vcc = +15Vdc, and all Phase Outputs unloaded. All negative currents shown are sourced by (flow from) the Pin under test.
2- Pulse Test: Pulse Width < 300 μSec, Duty Cycle < 2%.

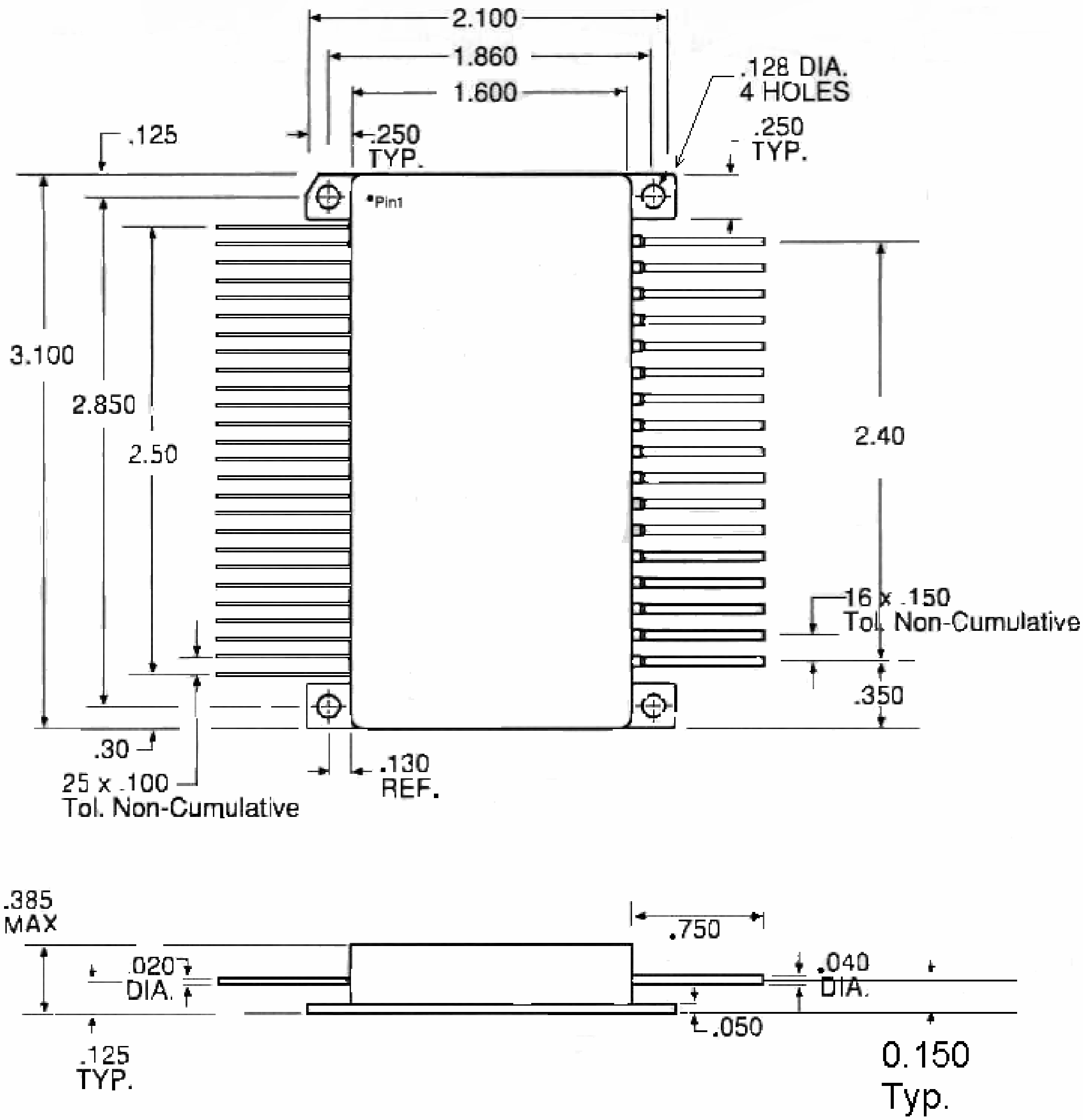
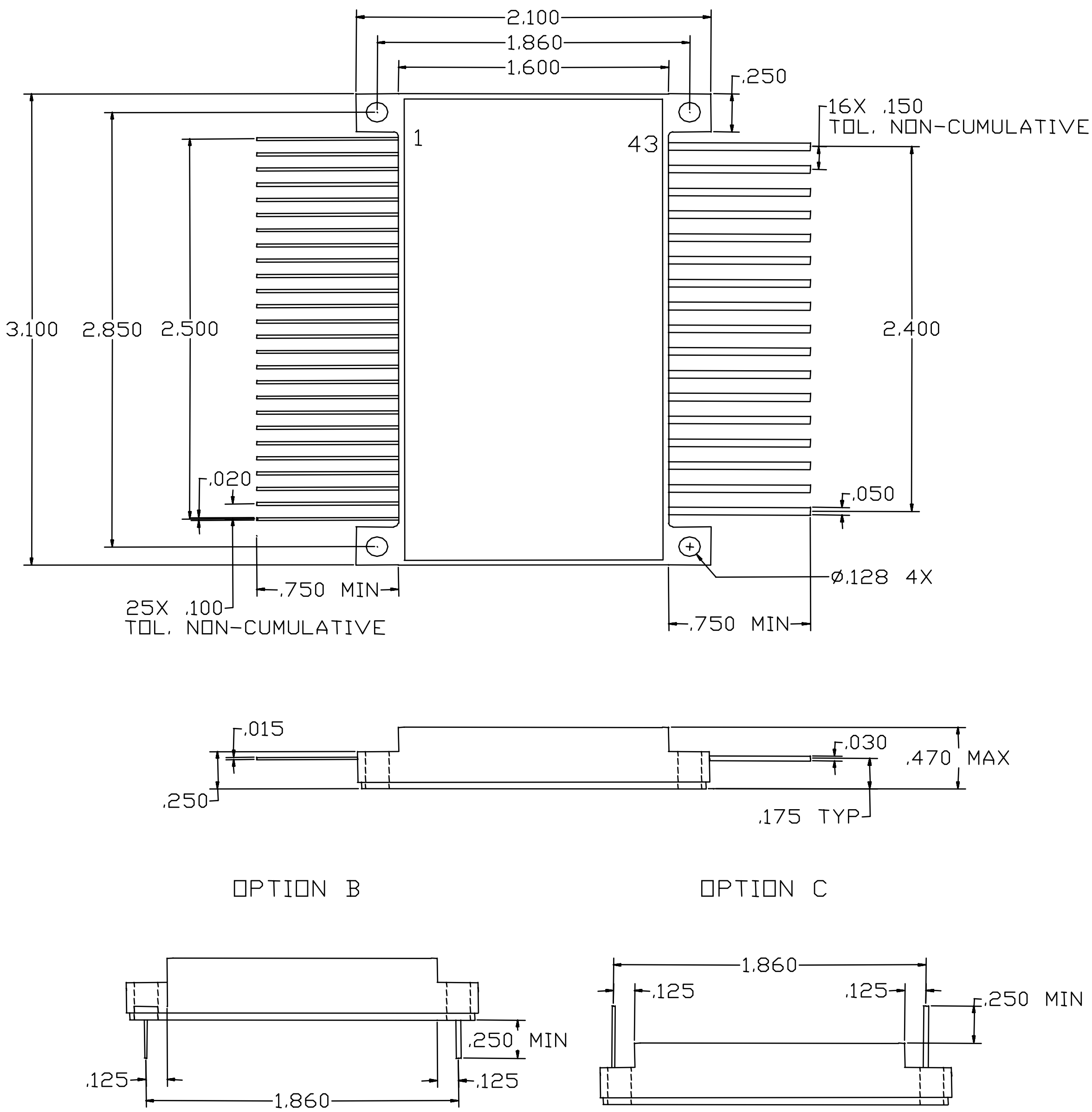


Fig. 2: Mechanical Outline For Hermetic Package, SMCS6MXX-XX



- For Option B part number is SMCS6MXX-XX-1B**,** for Option C part number is SMCS6MXX-XX-1**C.**
- Base plate flatness less than 0.010”.
- Screw and washer size #4.
- Mounting torque 4 in-lb
- It is recommended to use thermal grease but not thermal pads.

Fig. 3: Mechanical Outline For Plastic Case Package, SMCS6MXX-XX-1

PIN OUT

PIN NUMBER	NAME	DESCRIPTION
2	+15V Input	The +15V power supply connection for the controller. Under-voltage lockout keeps all outputs off for Vcc below 9 to 10.5V. The return of +15V is Pin 3. The input current requirement is 30mA without any external loads on Pin 6. Recommended input range is 14V min, 15.5V max. +15V supply should be an isolated power supply in high voltage applications above 28V DC bus.
3,4,21,22	Signal Gnd	Return for +15V supply, and +5V output Reference ground for all control signals of the device. All bypass capacitors and compensation components must be connected as close as possible to signal ground Pins. This ground is internally connected to the +VDC Rtn. It is preferred not to have external connection between Signal Gnd and +VDC Rtn at Pins 27 and 28.
6	VDD (+5V Output)	+5V Output. . The maximum output current is 30mA. The return of +5V is Pin 3. This Pin should be bypassed to Gnd with 3-5µF capacitor. The range of this output is 4.7V to 5.3V.
8	Fsc	Forced Commutation Frequency Select Input Low : Fsc = 2.5 Hz Middle : Fsc = 5 Hz High or open : Fsc = 10 Hz This pin has a pull-up resistor of 15K.
9	Vin	Speed Command Input (Duty Cycle Control Input) 0 ≤ Vin ≤ Vin (L): Output off Vin (L) ≤ Vin ≤ Vin (H): Set the PWM duty cycle according to the analog input. Vin (H) ≤ Vin ≤ VDD: Duty cycle = 100% (63/64) 0.8V < Vin (L) <1.2 V, 1.0V typical 3.8V < Vin (H) <4.2 V, 4.0V typical This pin has a pull-down resistor of 100K.

PIN OUT (continued)

10	Startup Ramp	Startup Ramp (Soft Start) Set a startup commutation time and duty cycle ramp-up. Connect this pin to a capacitor to set the ramp-up time. The capacitor charge current Isc is 2.6uA < Isc <5.0 uA, 3.8uA typical This pin is internally connected to C2 of 0.1uF. The ramp-up time duration, is given by $tr = \frac{Vin.C2}{3.8} \sec$ where C2 is the total capacitance connected to Pin 10, in uF, and Vin is the speed command voltage applied at Pin 9 in volts. The ram-up time duration depends on the motor and its load. It should be optimized experimentally.
11	Dir-in	Rotation direction input High : Reverse rotation (A → C → B) Low or open : Forward rotation (A → B → C) The pin has a pull-up resistor of 10K. **It is not safe to reverse the direction of rotation when the motor is running at high speed. First reduce the command input, then reverse direction when the motor speed is very low.**
12	Fm	This Pin together with Pin 8, set an upper limit of the maximum commutation frequency. **Fsc = Low** Fm = Low , Maximum commutation frequency Fm = 162 Fm = High or Open , Maximum commutation frequency Fm = 325 **Fsc = High or Middle** Fm =Low , Maximum commutation frequency Fm = 1302 Fm = High or Open , Maximum commutation frequency Fm = 2604 The pin has a pull-up resistor of 15K.
13	Tachometer Output	Tachometer Output Variable frequency output proportional to the motor speed. The pulse duty cycle is 50%. There are 3 pulses every 360 electrical degrees. The number of pulses per motor revolutions is P*3/2. The Tachometer output frequency is $ft = \frac{P.n}{40}$ Hz Where P is the number of poles, n is the motor speed in rpm.

PIN OUT (continued)

14	Start	DC excitation time setting pins When Vin ≥ 1 V (typ.), the START pin goes low to start DC excitation. The duration of the DC excitation mode is given by tdc Tdc = 0.69. R1. C1 sec After the Dci pin reaches VDD/2, the controller moves from DC excitation to forced commutation mode.
15	Dci	
16	LA	The lead angle control input. The lead angle settings are: LA (Low) Lead angle 7.5 degrees LA (High) Lead angle 15 degrees The pin has a pull-down resistor of 100K.
17	Ov-Lap	Overlap Commutation Angle Select Low: Overlap commutation High: 120° commutation This pin has a pull-up resistor of 100K.
18	Ph-FB	Motor back EMF feedback information. This input is used to optimize back EMF sensing together with the Ph-Ref input at **Pin 19** Keep This pin floating.
19	Ph-Ref	Motor back EMF reference input Keep This pin floating.
20	TP	This is for factory testing Keep This pin floating.

PIN OUT (continued)

23	Ioc-Ref	Over-current Limit Adjustment. Connect a resistor Rg Kohms between Pins 23 and 22 to decrease the current amplifier gain and increase peak current limit. The current amplifier gain attenuation due to Rg will be $Kc = \frac{Rg}{2Rg + 49.9}$ The output signal gain at Pin 25 will be 0.02*K_C V/A. The internal over-current shutdown threshold is 0.5V
25	Iso	Current Sense Amplifier Output for external monitoring. This pin is internally connected to the over-current comparator for **cycle-by-cycle** current limiting. It is recommended to have the over-current limit 20-30% higher than the target peak motor current. The gain of Iso is internally set to 0.020 V/A.
1,5,7,24,26	NC	Not Connected

PIN OUT (continued)

27, 28	+VDC Return	Motor supply DC bus return. Both terminals shall be used.
31, 32	Phase C Output	Phase C terminals. Both terminals shall be used.
36, 37	Phase B Output	Phase B terminals. Both terminals shall be used.
41, 42	Phase A Output	Phase A terminals. Both terminals shall be used.
29, 30, 34, 35, 39, 40	Source Terminal	These pins are the source terminals of the three arms of the three-phase bridge. These Pins shall be shorted together externally using a low impedance bus to minimize power loss, as shown in Fig. 15.
33, 38, 43	+VDC	DC Bus Positive Input. All terminals shall be used. +VDC bus should be bypassed to +VDC Rtn with adequately voltage-rated low ESR capacitor.
Case	NC	Not connected

Application Information

Operation

SMCS6MXX-XX uses back EMF sensing for rotor position detection. The position detection is done in synchronization with the PWM signal. Positional variation occurs in connection with the frequency of the PWM signal.
Fig. 5. illustrates the back EMF detection.

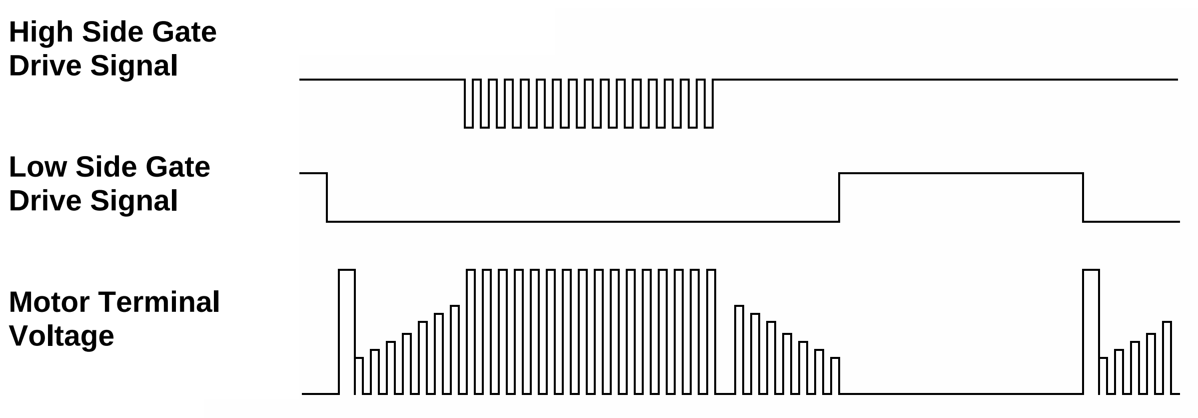


Fig. 4. High side Gate drive, Low Side Gate drive, and Motor Terminal Voltage

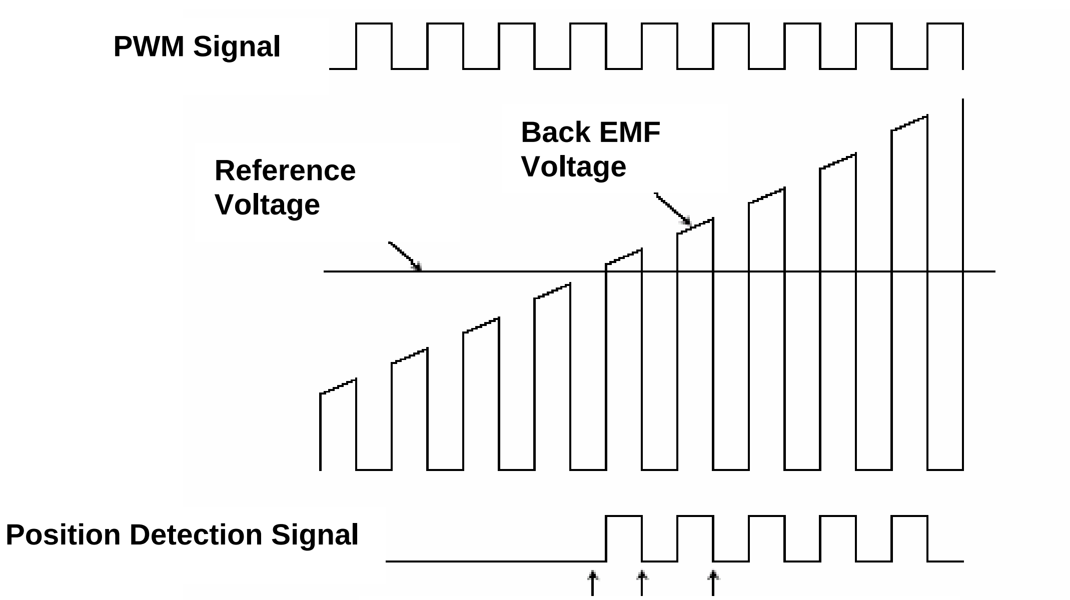


Fig. 5. Back EMF and Rotor Position Detection

Startup operation

When the motor is stationary, there is no back-EMF and the motor position is unknown. On receiving an analog voltage command input, the rotor is aligned to a known position in DC excitation mode for a period (tdc), during which the Dci pin voltage decreases to half VDD level. The time constant for the period is determined by C1 and R1. After that, switching occurs to forced commutation mode represented by (tf). The duty cycles for DC excitation and forced commutation modes are determined according to the ramp pin voltage. The ramp duration is determined by C2.

An external capacitor, in parallel with C1, sets the times that the controller stays in DC excitation and forced commutation modes. Those times vary depending on the motor type and motor loading. Thus, they must be adjusted experimentally.

When the number of turn of a motor is more than forced commutation frequency, the motor switches to sensorless mode. The PWM duty cycle for sensorless mode after the ramp-up time is determined by the Vin value.

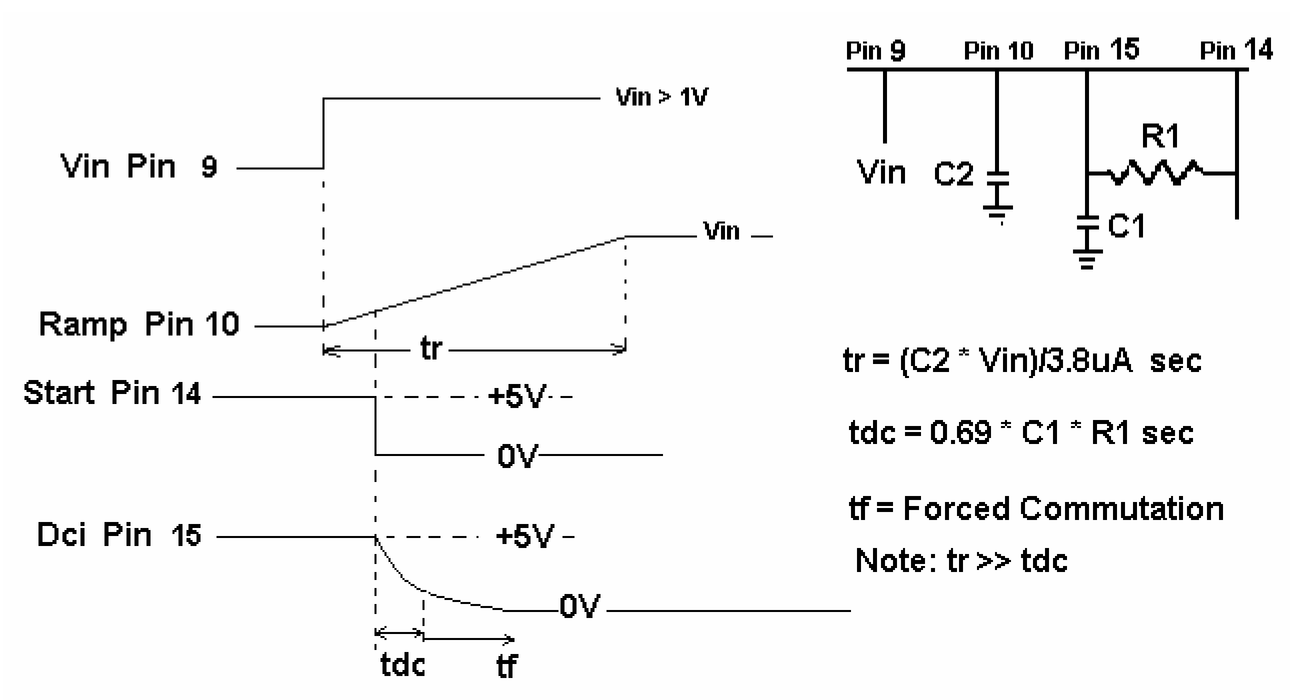


Fig. 6: Controller Startup Timing

Speed Control Input

An analog voltage applied to the Vin, Pin 9, is converted by the 6-bit AD converter to control the PWM duty cycle.
0 < Vin < Vin (L), PWM Duty cycle = 0%
Vin (L) < Vin < Vin (H), PWM Duty Cycle according to Fig. 7 (1/64 to 63/64)
Vin (H) < Vin < VDD, PWM Duty cycle = 100% (63/64)

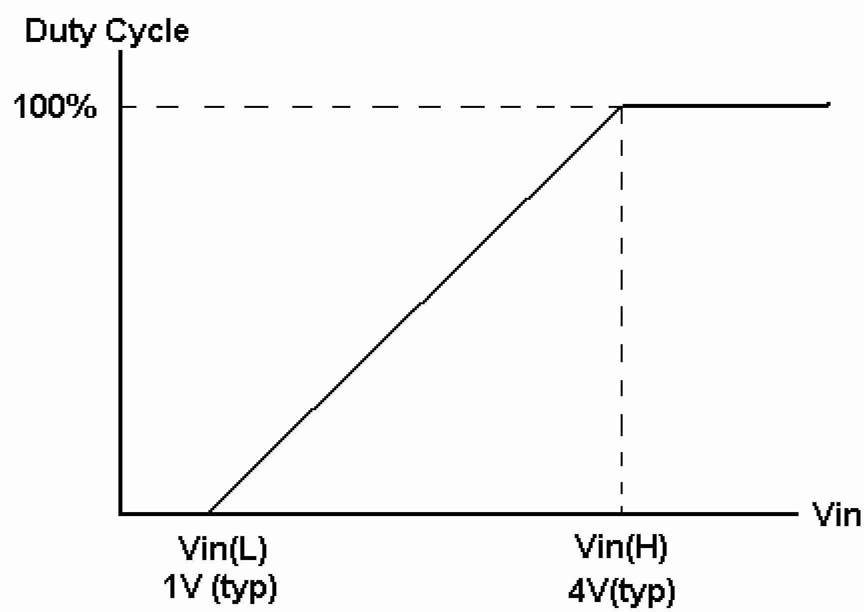


Fig. 7: PWM Duty Cycle vs Input Command

Fault protection

When a signal indicating the following faults is applied to the internal back EMF sensing, the output transistors are disabled. After time toff, about one second, the motor is restarted. This operation is repeated as long as a fault is detected.
• The maximum commutation frequency is exceeded.
• The rotation speed falls below the forced commutation frequency.

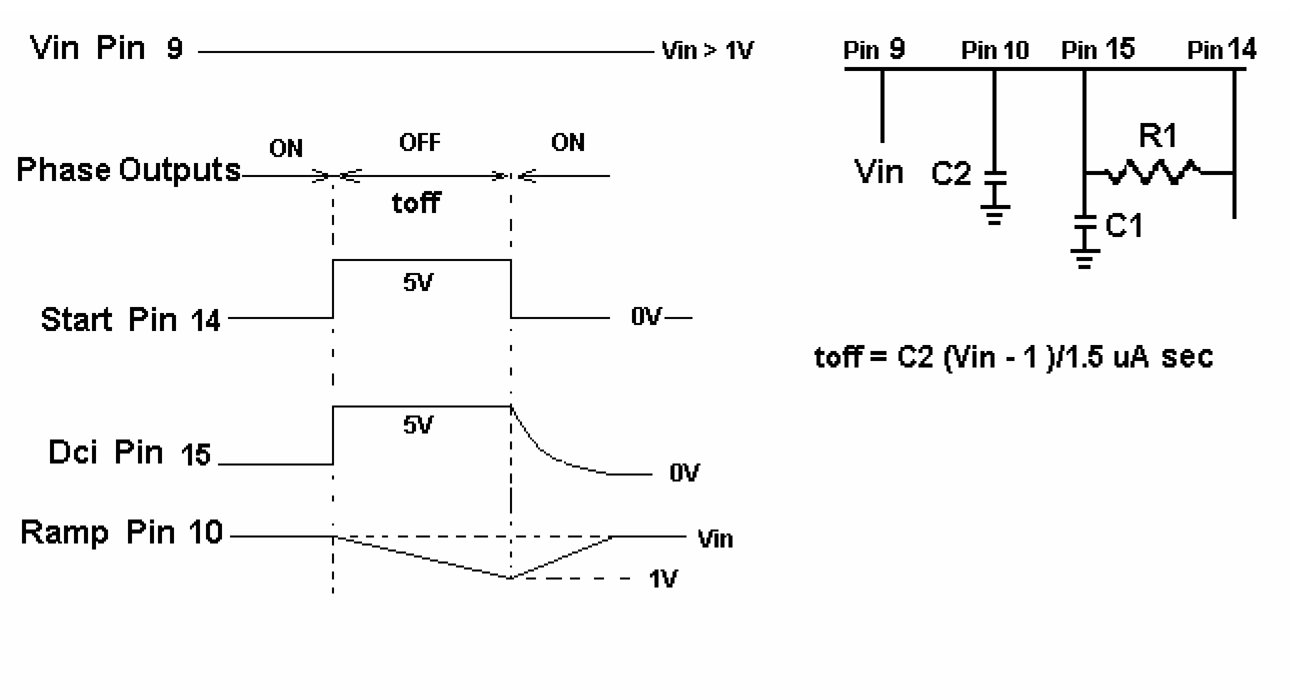


Fig. 8: Fault Detection & Re-Start

Two Quadrant Mode Of Operation Of BDC Motor

Fig. 9 illustrates the four possible quadrants of operation for a BDC motor. Two-quadrant mode refers to a motor operating in quadrants I and III. With a two-quadrant BDC motor, friction is the only force to decelerate the load.

Two-quadrant mode, modulates only the high-side devices of the output power stage, as shown in Fig. 4. The current paths within the output stage during the PWM on and off times are illustrated in Fig. 10. During the on time, both switches S1 and S4 are on, the current flows through both switches and the motor winding. During the PWM cycle off time, the upper switch S1 is shut off, and the motor current circulates through the lower switch S4 and D2. The motor is assumed to be operated in quadrants I or III. During direction reversal in quadrants II and IV, the motor current path is as shown in Fig. 11.

Two-quadrant mode of operation is the **most efficient mode**, because the controller and motor switching losses are minimized. Also, EMI emission is minimum with two-quadrant mode of operation.

The limitation of two-quadrant mode of operation is, it is not safe to reverse motor direction at high speed.

In four-quadrant mode, both upper and lower switches are modulated. Motor current always decays during off time, eliminating any uncontrolled circulating current. In addition, the current always flows through the current sense resistor. **For servo system applications**, refer to SMCT6MXX-XX, or SMCT6GXX-XX motor controllers.

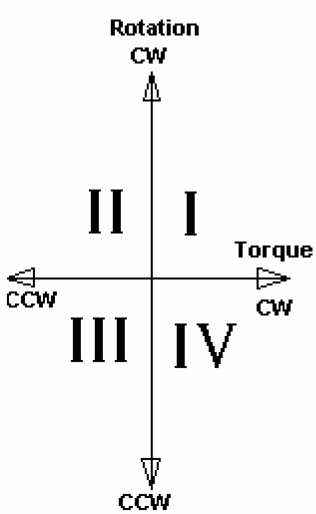


Fig. 9 . Four Quadrants of Operation

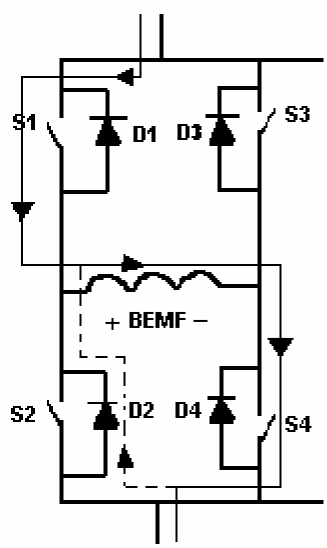


Fig. 10. Two-Quadrant Forward

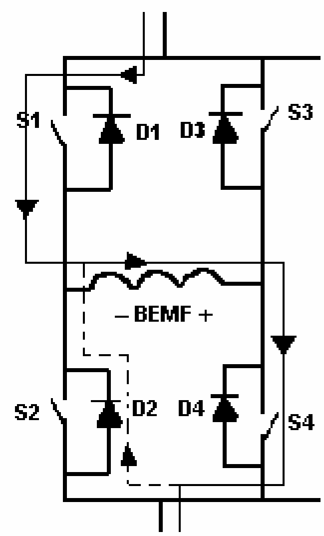


Fig. 11. Two-Quadrant Reverse

Cycle-by-cycle

Current limiting is provided internally by an over-current comparator.
A current monitoring output is provided at Pin 25.
A user adjustable over-current limit reference input is provided at Pin 23.
The over-current reference adjustment procedure is described in the Pin Description section.

Closed Loop Speed Control

The motor speed is directly proportional to the input analog command at Pin 9. However, speed regulation is poor in open loop systems. For tight speed regulation, a closed loop speed control can be implemented as shown in Fig. 12.
A tachometer can be used to provide speed feedback information, and an error amplifier to close the speed loop.

Motor Terminals Connection

Since the rotor position detection is done through the phases, the phase IDs are irrelevant. Any motor terminal connection to the controller with the sequence ABC, or BCA, or CAB will results in the same direction of rotation as long as the controller direction input is not changed. A motor terminal connection sequence of the opposite as CBA, or BAC, or ACB will result in a reversed rotation.

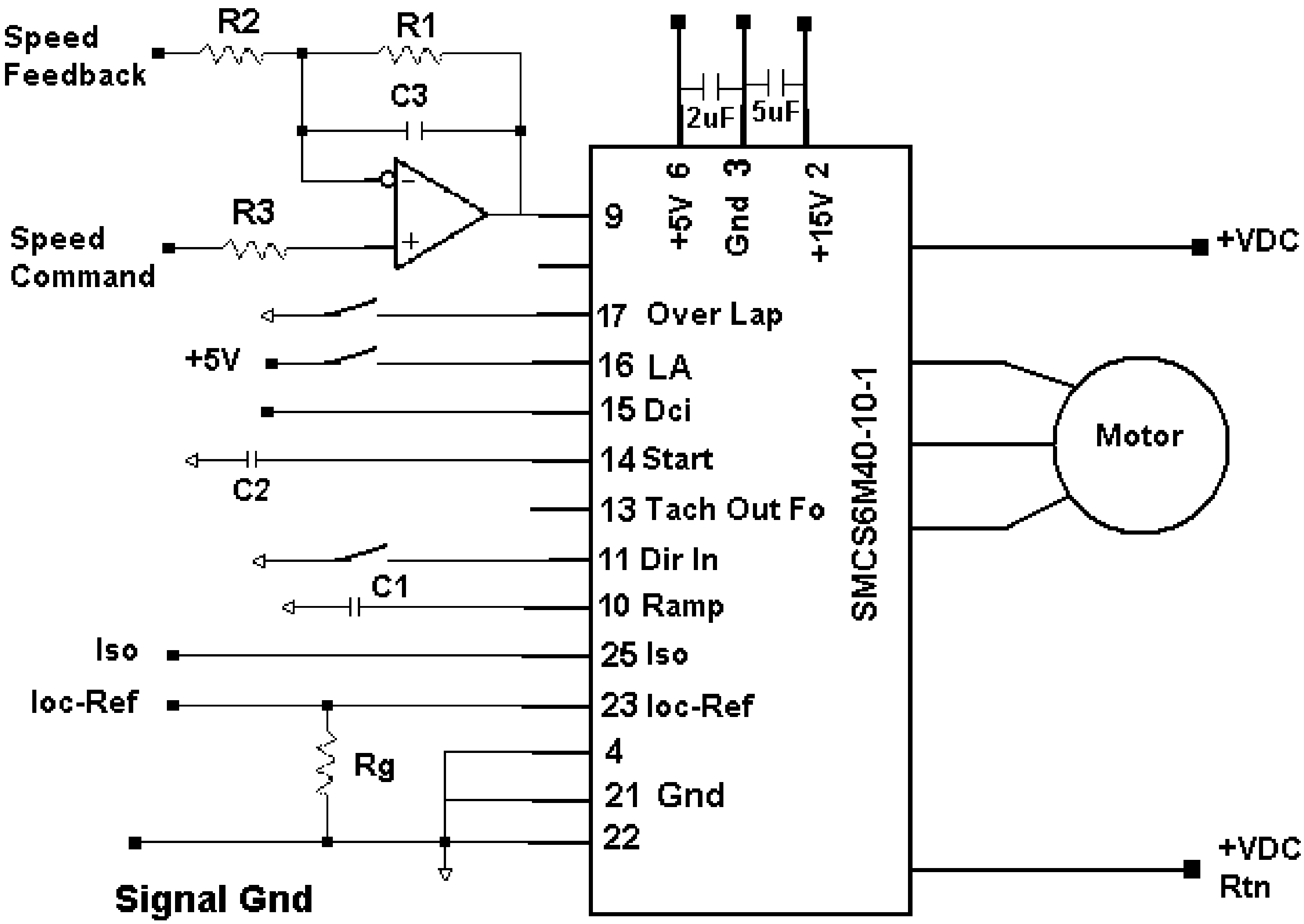


Fig. 12. Closed Loop Speed Control

Lead Angle Control

The motor runs with a lead angle of 0° in forced commutation mode at startup. After switching to natural commutation, the lead angle automatically changes to the value set by the LA pin.

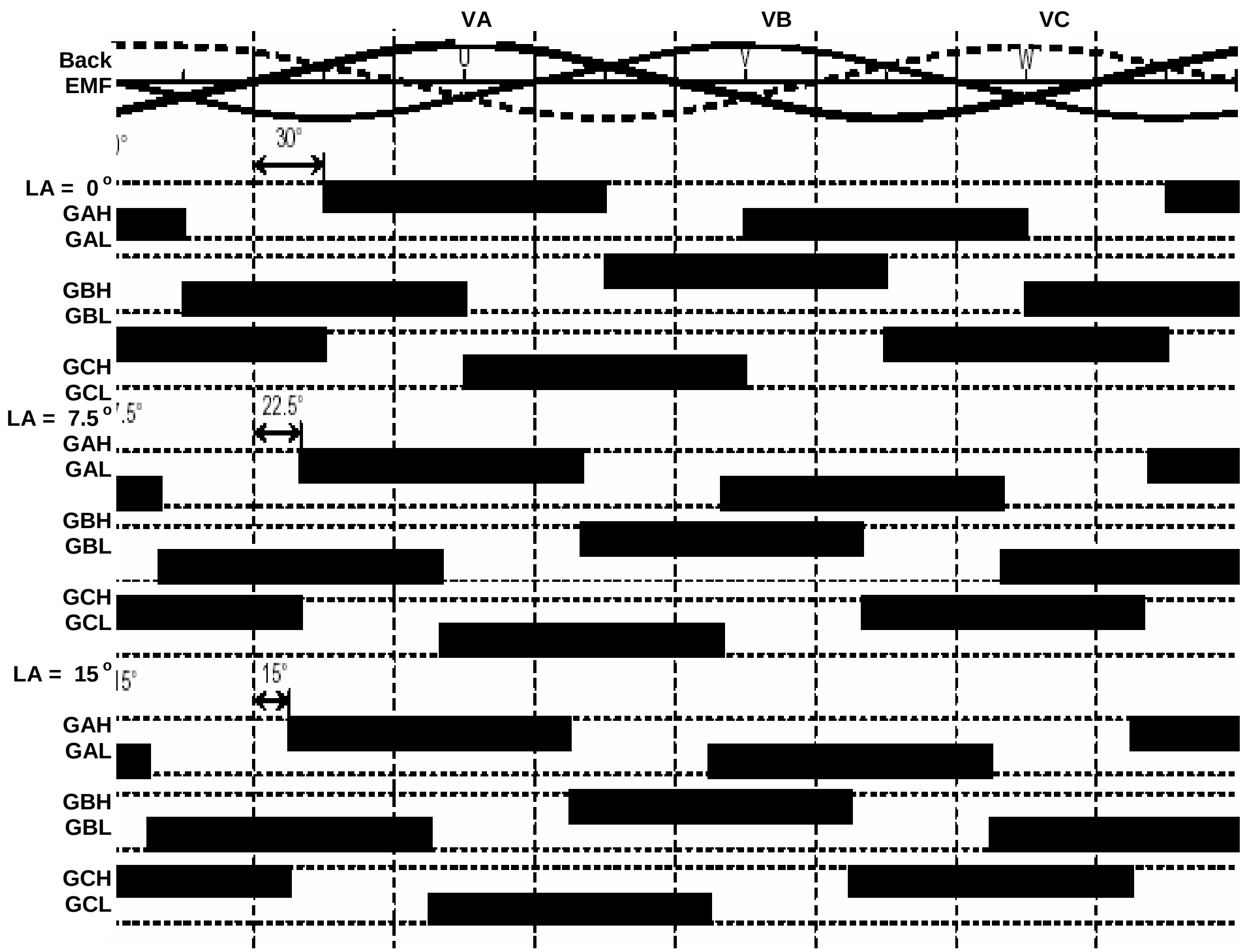


Fig. 13: Lead angle control

Overlap Commutation

When Over-Lap (Pin 17) = high, the controller is configured to allow for 120° commutation. When Over-Lap (Pin 17)= low, it is configured to allow for overlap commutation. In overlap commutation, there is an overlap period during which both the outgoing transistor and incoming transistor are conducting (as shown in the shaded areas). This period varies according to the lead angle.

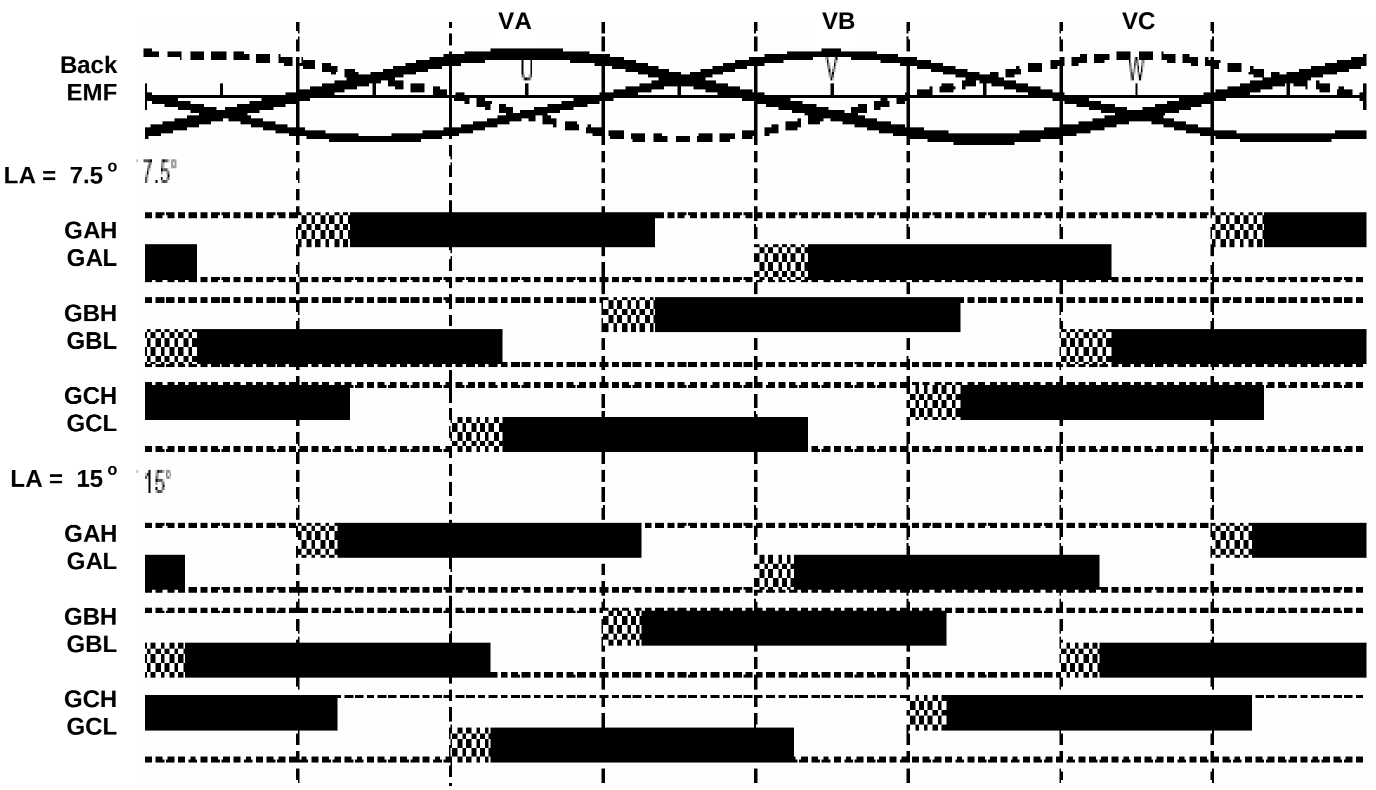


Fig. 14: Overlap commutation

DC Bus Filtering

To minimize the circuit parasitic inductance effect on the power stage, the layout of Fig. 15 is suggested. C1, and C2 are 0.5μF to 1μF ceramic capacitors, connected across the DC bus as close as possible to the controller. Also, a bulk low ESR capacitor C3 with adequately voltage-rating shall be used.

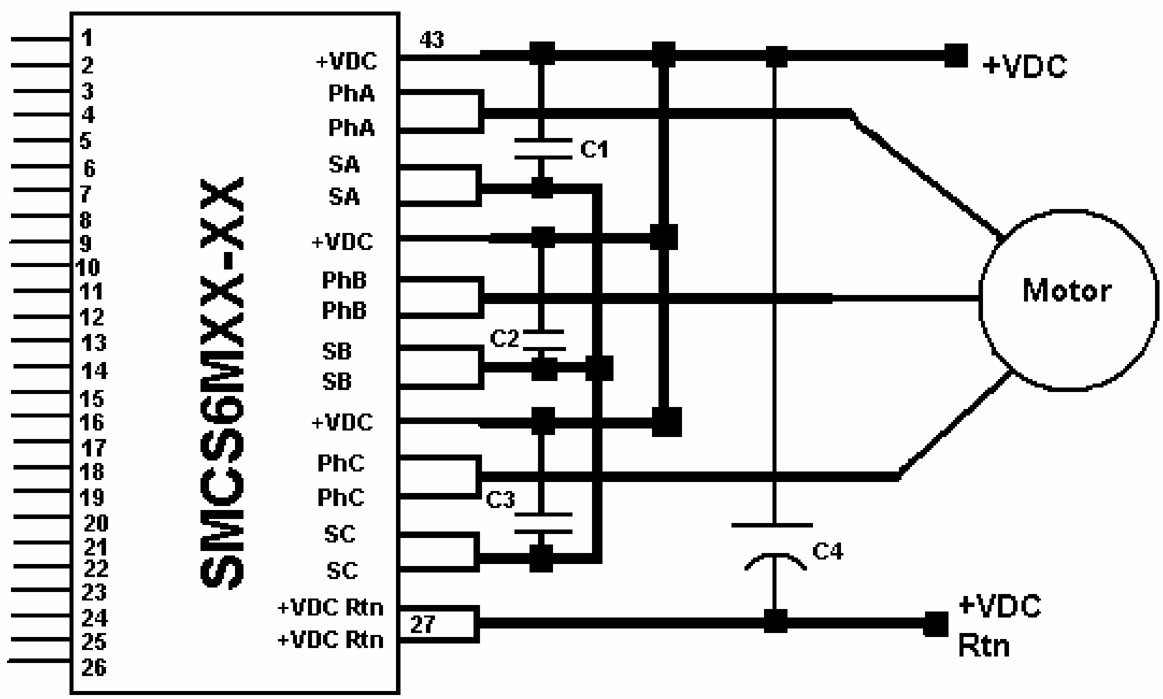


Fig. 15 . DC Bus Bypass Capacitors

PART NUMBER/SELECTOR GUIDE TABLE

Part Number	**Operating DC Bus Supply Voltage**	**Peak DC Bus Voltage**	**RMS Output Current**	**Instantaneous Peak Output Current**	**Rds(on)** I_D =40A	**Hermetic ?**
SMCS6M40-10-Z	60	100	40	60	5	Yes
SMCS6M40-10-1Z	60	100	40	60	5	No
SMCS6M40-25-Z	150	250	30	40	60	Yes
SMCS6M40-25-1Z	150	250	30	40	60	No

where **Z is the lead bend option**

Cleaning Process for (SMCS6M40-XX-1):

Suggested precaution following cleaning procedure:
If the parts are to be cleaned in an aqueous based cleaning solution, it is recommended that the parts be baked immediately after cleaning. This is to remove any moisture that may have permeated into the device during the cleaning process. For aqueous based solutions, the recommended process is to bake for at least 2 hours at 125^{o}C.
Do not use solvents based cleaners.

Soldering Procedure:

Recommended soldering procedure
Signal pins 1 to 26: 210C for 10 seconds max
Power pins 27 to 43: 260C for 10 seconds max.