Sensorless Brushless DC Motor Driver Module in a Power Flatpack 600V/70A, 1200V/60A

DESCRIPTION:

The SMCS6GXXX-XXX-1 is an, integrated three-phase brushless DC motor controller/driver subsystems housed in a compact power package. The SMCS6GXXX-XXX-1 is used in two quadrant modes of operation. Two-quadrant mode is recommended for steady operation because of the reduced switching losses. The controller is best used as a speed controller for controlling/driving fans, pumps, and motors in applications which require small size. Many integral control features provide the user much flexibility in adapting the SMCS6GXXX-XXX-1 to specific system requirements.
The small size of this subsystem is ideal for aerospace, military, industrial, and medical applications.

FEATURES:

- Fully integrated 3-phase brushless DC motor control subsystem includes power stage, non-isolated driver stage, and controller stage
- Up to 60A average DC bus current with up to 300VDC bus voltage, or 40A with up to 600VDC 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.
- Adjustable over-temperature shutdown set-point.
- Under-voltage shutdown for the 15V VCC.
- Case temperature sense output.
- Over-temperature shutdown with auto recovery and soft re-start.
- Duty-cycle is limited to 99% .
- Current limit reference for programmable over-current limit.
- DC bus current sense amplifier with absolute value output.
- Desaturation protection for all six IGBTs.
- Shoot-through protection
- Package size - 3.59" x 1.55" x 0.80"
- Total Weight 5.0 OZ.

APPLICATIONS:

- Fans and Pumps
- Hoists

ABSOLUTE MAXIMUM RATINGS (T_C=25 ^{o}C)

Characteristic	Maximum
Motor DC Bus Supply Voltage SMCS6G070-060-1 SMCS6G060-120-1	 400V 800V
Motor Peak Voltage SMCS6G070-060-1 SMCS6G060-120-1	 600V 1200V
Average Output Current SMCS6G070-060-1 SMCS6G060-120-1	 70 A 60A
Peak Output Current SMCS6G070-060-1 SMCS6G060-120-1	 80 A 70A
Control Supply Voltage VCC	18 V
Logic Input Voltage	-0.3 V to +5 V
Reference Source Current	-30 mA
Speed Command Input Voltage	- 0.3 V to +5 V
Operating and storage Junction Temperature	-55 ^{o}C to +150 ^{o}C
IGBT Thermal Resistance R_{thjC} **Diode Thermal Resistance R_{thjC}**	0.45 ^{o}C/W 0.80 ^{o}C/W
Pin-to-Case Voltage Isolation, at room conditions	1500V 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
Motor DC Bus Supply Voltage SMCS6G070-060-1 SMCS6G060-120-1	 300V 600V
Average Output Current, T_C=80 ^{o}C SMCS6G070-060-1 SMCS6G060-120-1	 60 A 40A
Control Supply Voltage VCC	15 V +/-10%

PARAMETER SYMBOL CONDITIONS (NOTE 1)	MIN.	TYP.	MAX.	UNITS
Power Output Section				
Collector-Emitter Leakage Current ICES SMCS6G070-060-1 at VCE=480V SMCS6G060-120-1 at VCE=960V			400	uA
Collector-to-Emitter Saturation Voltage VCEsat, at VCC=15V SMCS6G070-060-1 IC=30A IC=70A IC=90A SMCS6G060-120-1 IC=40A		1.15 1.50 1.70 1.9	1.30 1.80 2.00 2.3	V
Diode Forward Voltage SMCS6G070-060-1 IC=30A IC=70A IC=90A SMCS6G060-120-1 IC=40A		1.18 1.50 1.62 1.8	1.35 1.80 1.95 2.3	V
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 Output Current Io	4.7 -	5.0 -	5.3 30	V mA
Current-Sense Amplifier Section				
Amplifier Voltage Gain Over-current detection voltage	9 0.45	10 0.5	11 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				
Tachometer Output High Level Voh Tachometer Output Low Level Vol	4.5 -	- -	5.0 0.50	V V
PWM Section				
PWM Frequency Fs	13	15	17	kHz
Over-Temperature Shutdown				
Over-Temperature Shutdown	106	111	116	°C
Over-Temperature Shutdown Hysteresis		30		°C

SPECIFICATION NOTES:

1- All parameters specified for Ta = 25C, Vcc = 15Vdc, and all Phase Outputs unloaded. All negative currents shown are sourced by (flow from) the pin under test

Package Drawing Top View
(All dimensions are in inches, tolerance is +/- 0.010")

Base Plate Flatness   0.010" Concave

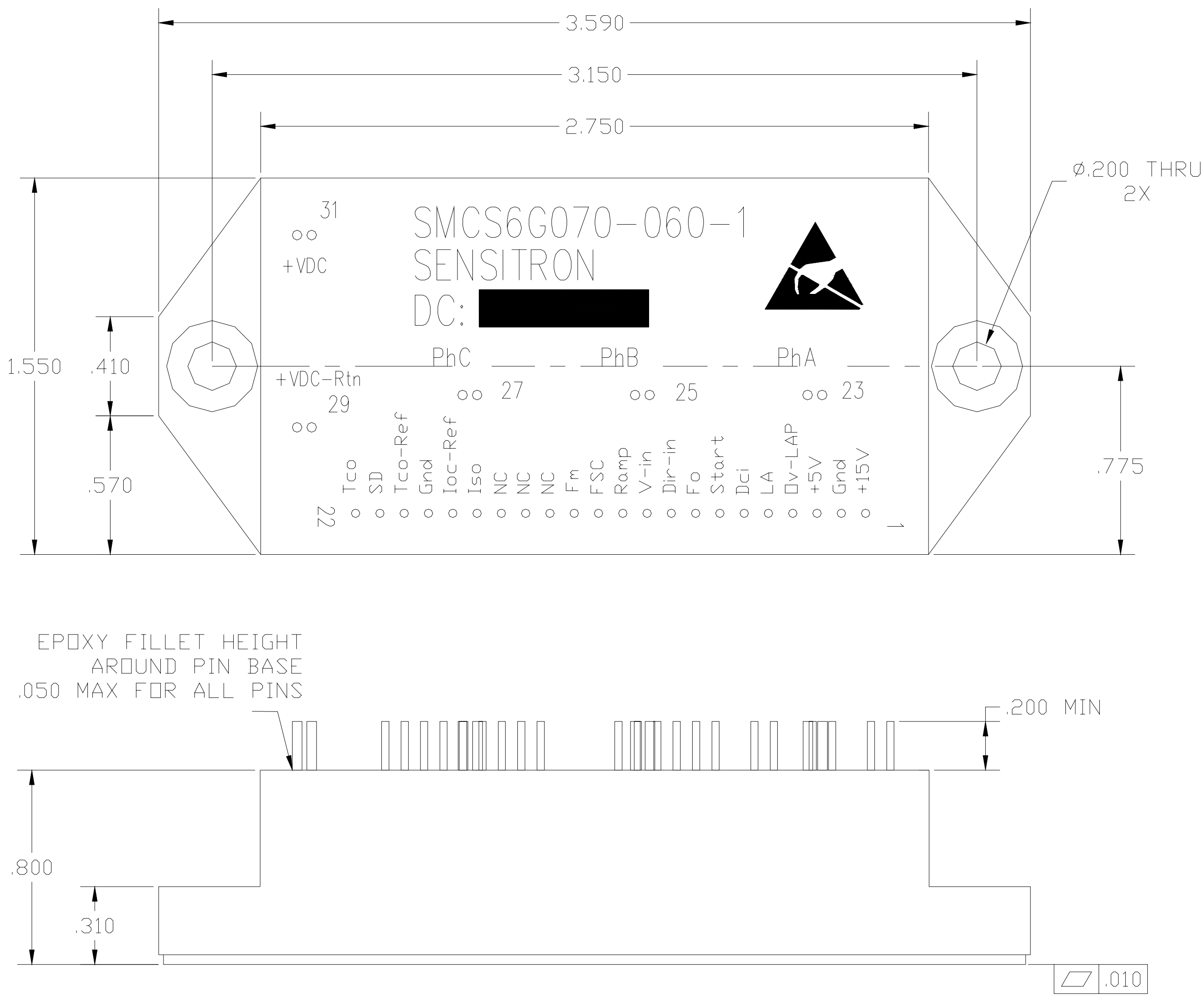

Fig. 2: Package Outline

Package Pin Locations
(All dimensions are in inches; tolerance is +/- 0.005" except otherwise specified)

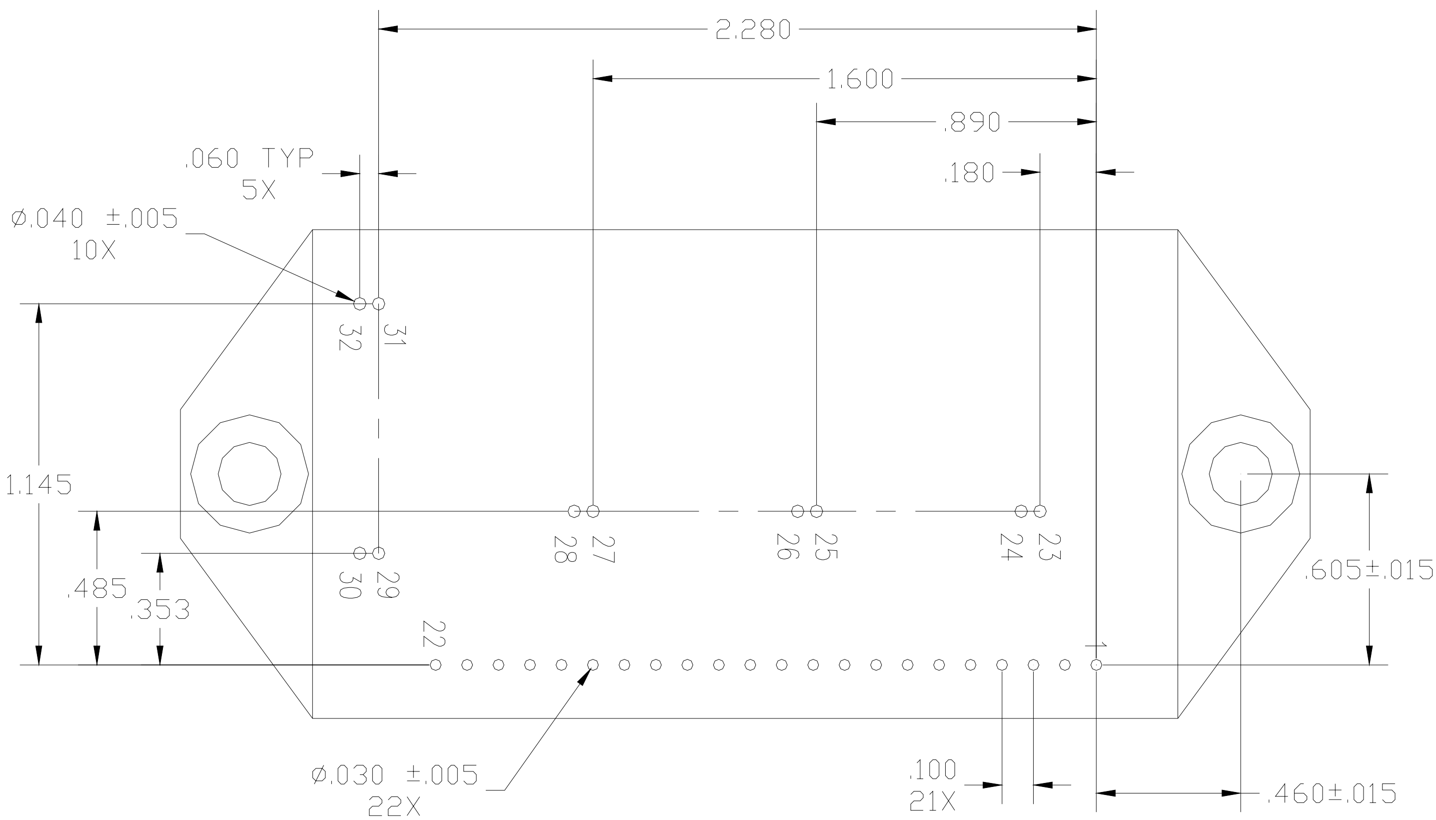

Fig. 3: Package Outline

PIN OUT

PIN NUMBER	NAME	DESCRIPTION
1	+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 2. The input current requirement is 50mA without any external loads on Pin 3. Recommended input range is 14V min, 15.5V max. +15V supply should be an isolated power supply.
2, 19	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 Pins 2 and 19. 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 29 and 30.
3	VDD (+5V Output)	+5V Output. . The maximum output current is 30mA. The return of +5V is Pin 2. This Pin should be bypassed to Gnd with 3-5µF capacitor. The range of this output is 4.7V to 5.3V.
4	Ov-Lap	Overlap Commutation Angle Select Low: Overlap commutation High: 120° commutation This pin has a pull-up resistor of 100K.
5	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.
6	Dci	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.
7	Start	

8	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.
9	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.**
10	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.
11	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 1uF. The ramp-up time duration, is given by $tr = \frac{Vin.C2}{3.8} \sec$ Hz where C2 is the total capacitance connected to Pin 11, in uF, and Vin is the speed command voltage applied at Pin 10 in volts. The ram-up time duration depends on the motor and its load. It should be optimized experimentally.
12	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.

PIN OUT (continued)

13	Fm	This Pin together with Pin 12, 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.
14	NC	Not connected
15	NC	Not connected
16	NC	Not connected
17	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 0.010 V/A.
18	Ioc-Ref -	Over-current Limit Adjustment. Connect a resistor Rg KOhms between Pins 18 and 19 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 17 will be 0.01*K_C V/A. The internal over-current shutdown threshold is 0.5V
20	Tco-Ref	Over-Temperature Shutdown Reference. It is internally set to 1.11V using a resistor divider of 50K pull-up to +5V, 10K pull-down, and 400K feedback.

21	SD	It is an active low, dual function input/output pin. It is internally pulled high to +15V by 15K Ω. As a low input it shuts down all IGBTs regardless of the Hin and Lin signals. SD is internally activated by the over-temperature shutdown, or desaturation protection SD can be used to shutdown all IGBTs by an external command. An open collector switch shall be used to pull down SD externally. SD can be used as a fault condition output. Low output at SD indicates a latching fault situation. SD is automatically cleared during more startup.
22	Tco	Analog output of case temperature sensor. The sensor output gain is 0.010 V/°C, with zero DC offset. This sensor can measure only positive °C. The internal impedance of this output is 4.99KΩ. The internal block diagram of the temperature sensor is shown in Fig. 12.

PIN OUT (continued)

23, 24	Phase A Output	Phase A terminals. Both terminals shall be used.
25, 26	Phase B Output	Phase B terminals. Both terminals shall be used.
27, 28	Phase C Output	Phase C terminals. Both terminals shall be used.
29, 30	+VDC Return	Motor supply DC bus return. Both terminals shall be used.
31, 32	+VDC	DC Bus Positive Input. Both 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

SMCS6GXXX-XXX 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.

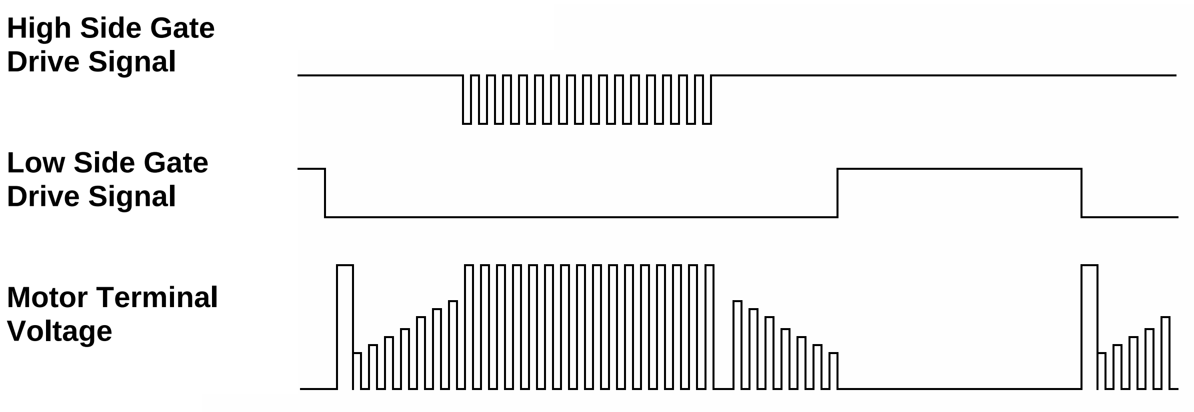

Fig. 4. High side Gate drive, Low Side Gate drive, and Motor Terminal Voltage

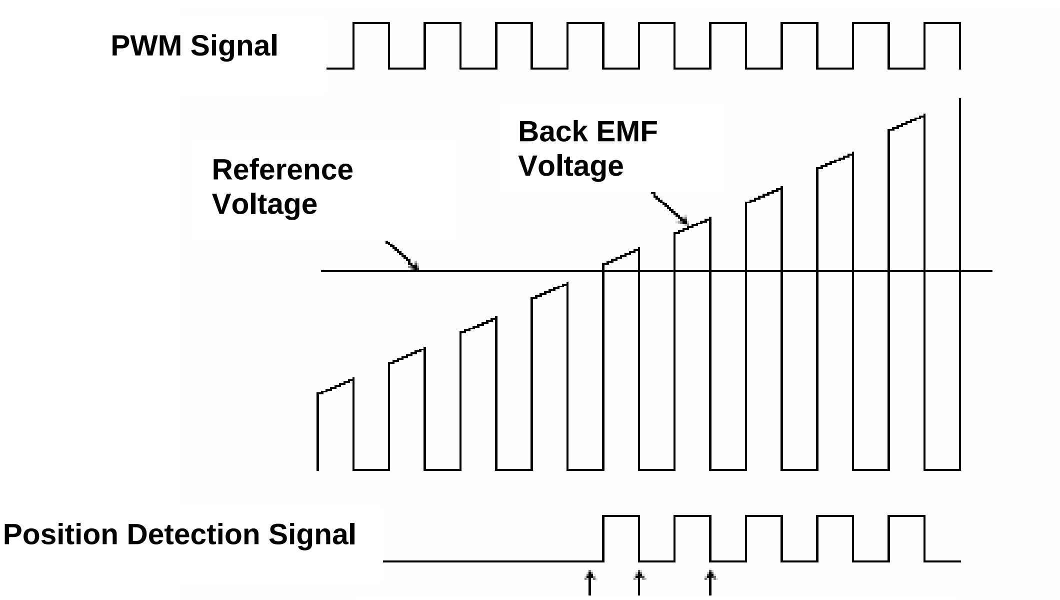

Fig. 5. Back EMF and Rotor Position Detection

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.

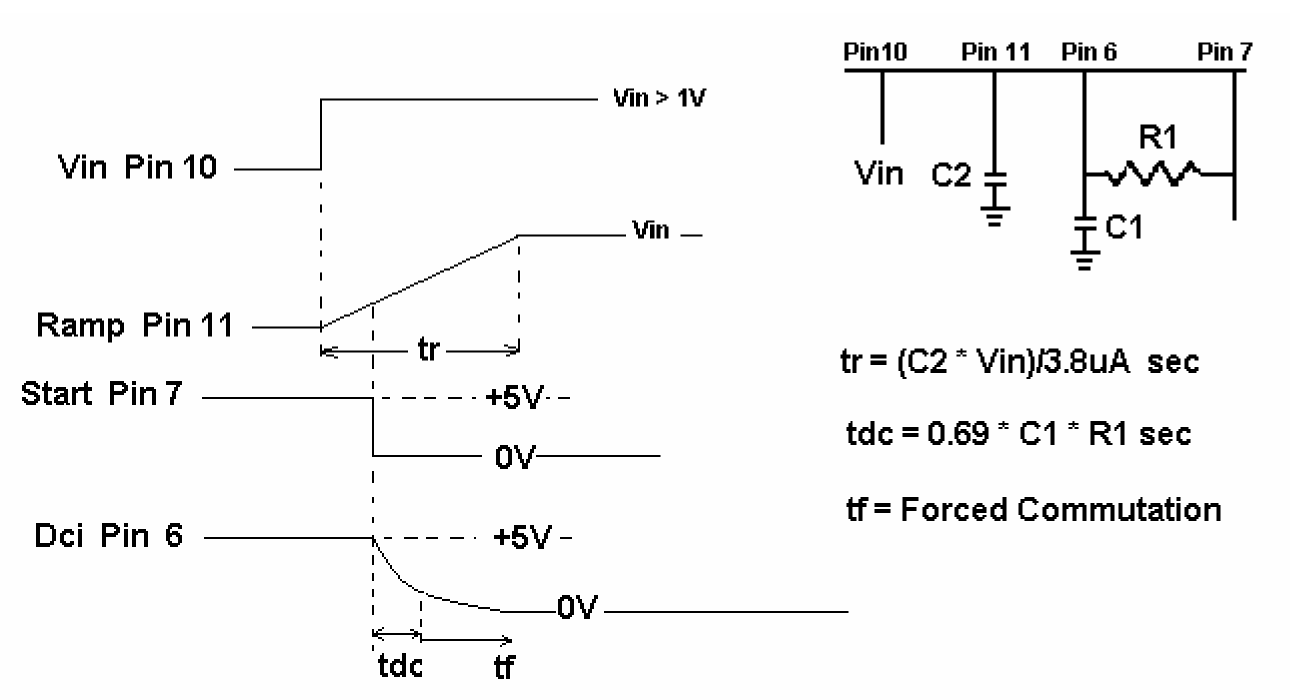

Fig. 6: Controller Startup Timing

Speed Control Input

An analog voltage applied to the Vin, Pin 10, 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)

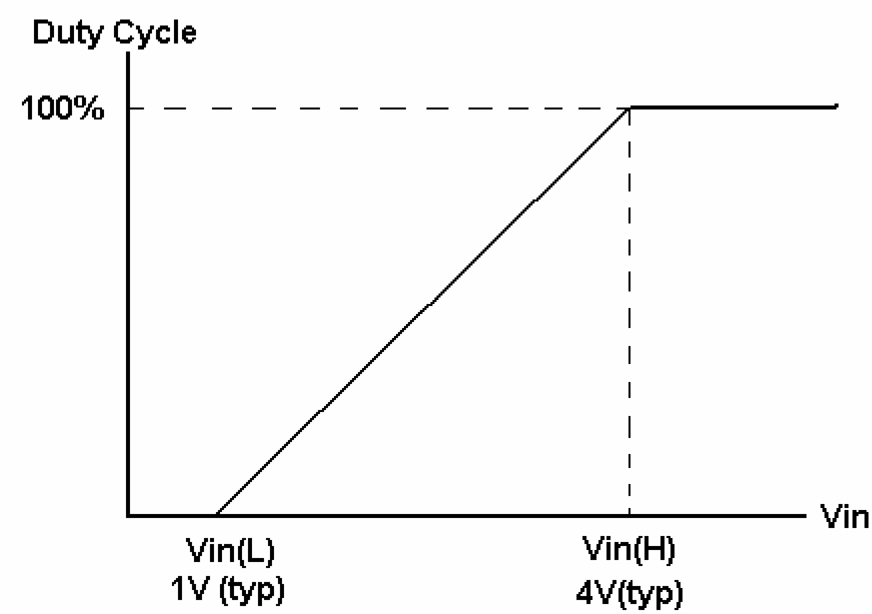

Fig. 7: PWM Duty Cycle vs Input Command

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.

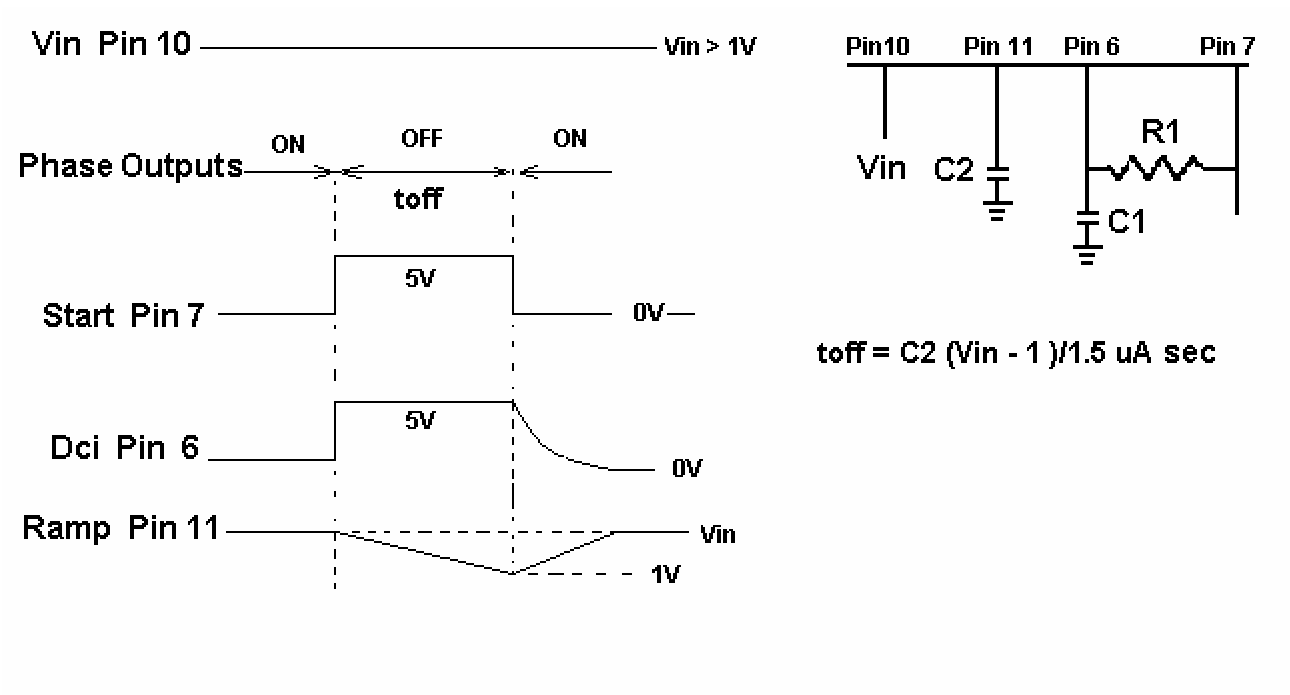

Fig. 8: Fault Detection & Re-Start

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.

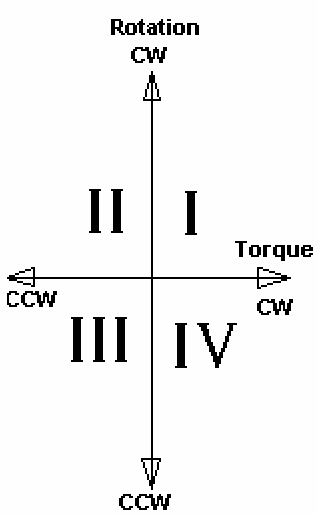

Fig. 9 . Four Quadrants of Operation

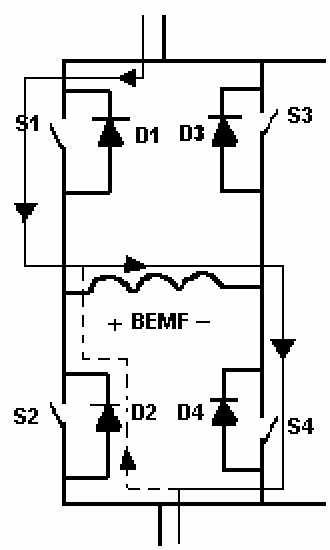

Fig. 10. Two-Quadrant Forward

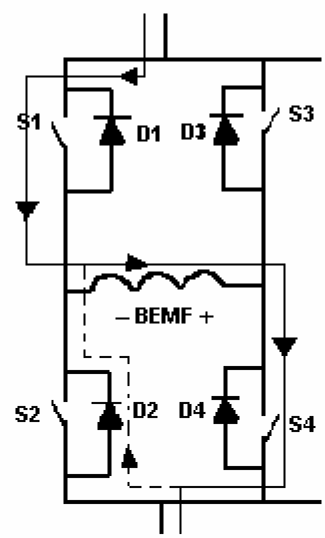

Fig. 11. Two-Quadrant Reverse

Temperature Sensor Output:

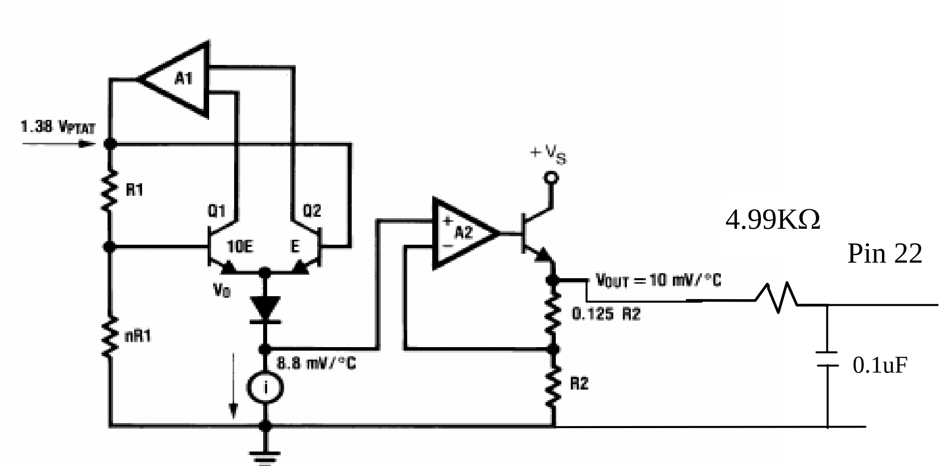

Fig. 12 Temperature Sensor Internal Block Diagram

For both negative and positive temperature measurement capability, Contact the Factory.

Cycle-by-cycle

Current limiting is provided internally by an over-current comparator.
A current monitoring output is provided at Pin 17.
A user adjustable over-current limit reference input is provided at Pin 18.
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 10. 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. 13.
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.

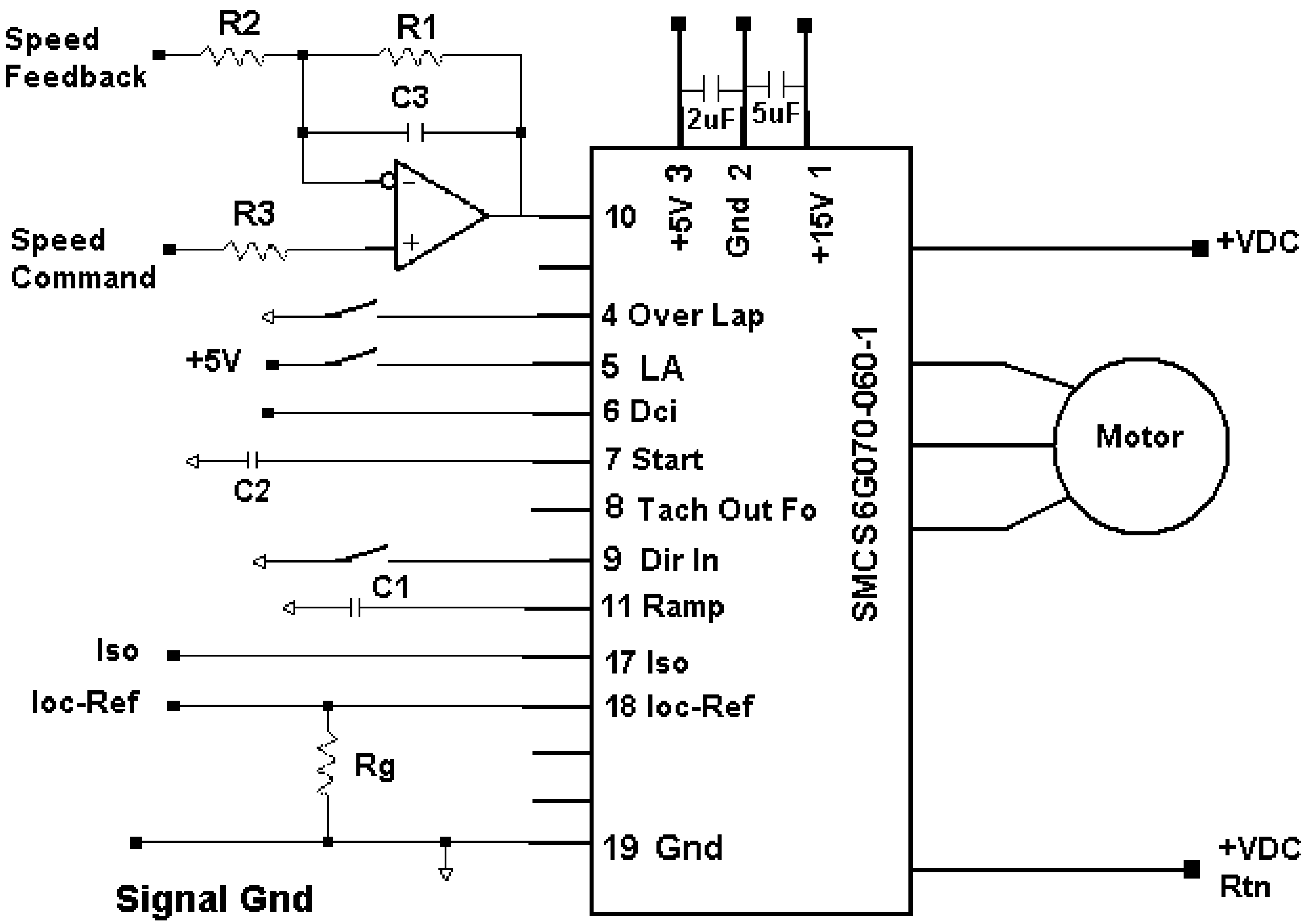

Fig. 13. Closed Loop Speed Control

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.

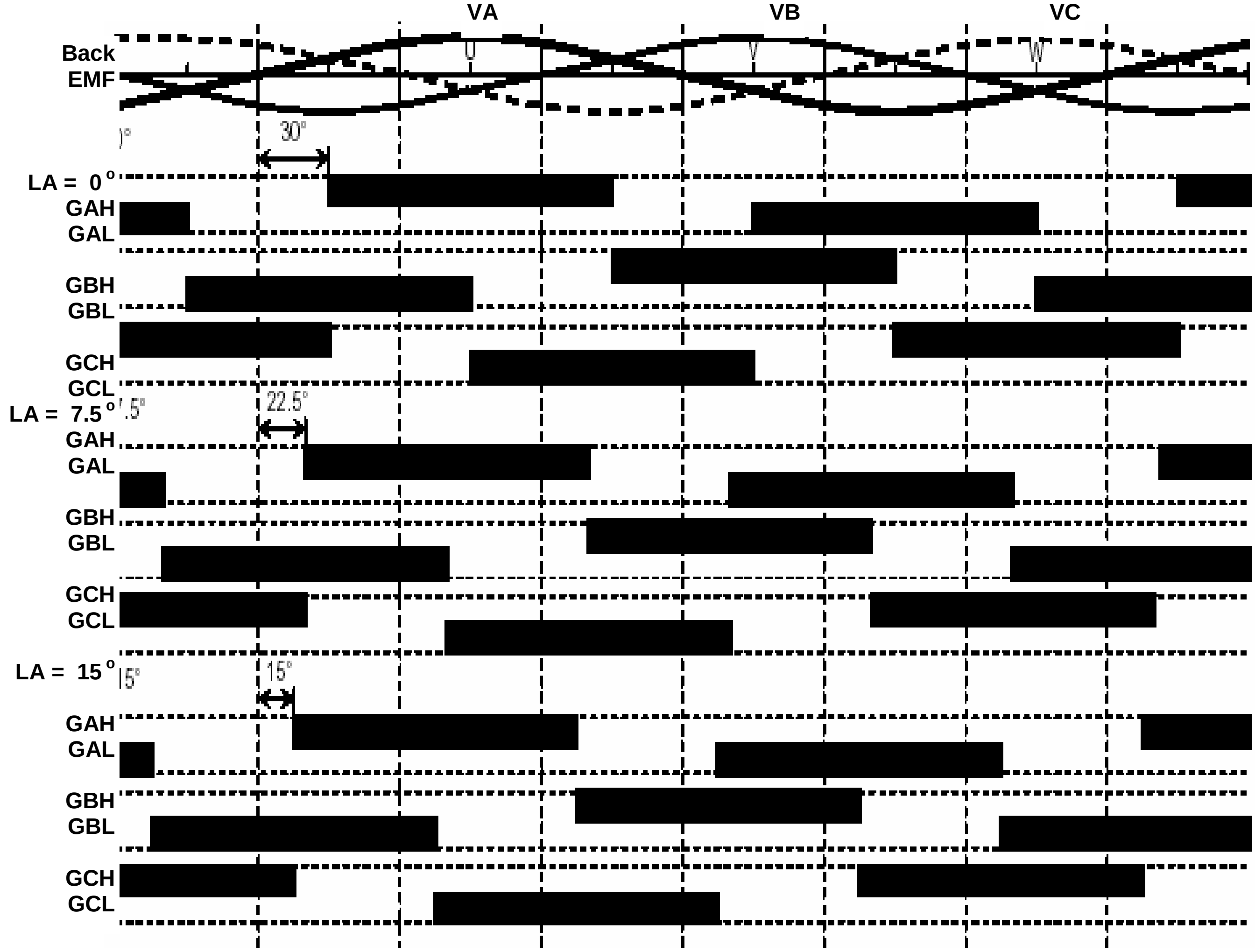

Fig. 14: Lead angle control

Overlap commutation

When Over-Lap (Pin 4) = high, the controller is configured to allow for 120° commutation. When Over-Lap (Pin 4)= 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.

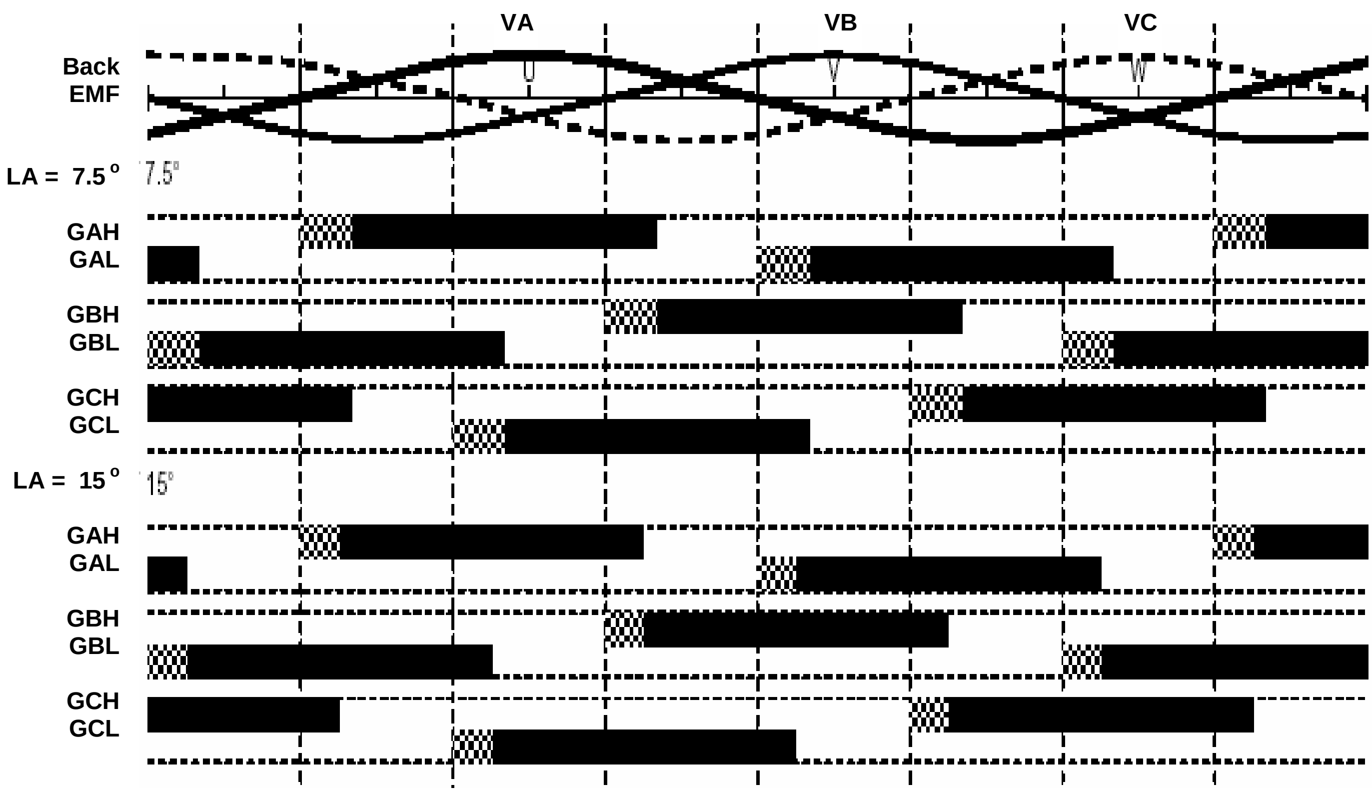

Fig. 15: Overlap commutation

DC Bus Filtering

To minimize the circuit parasitic inductance effect on the power stage, the layout of Fig. 14 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.

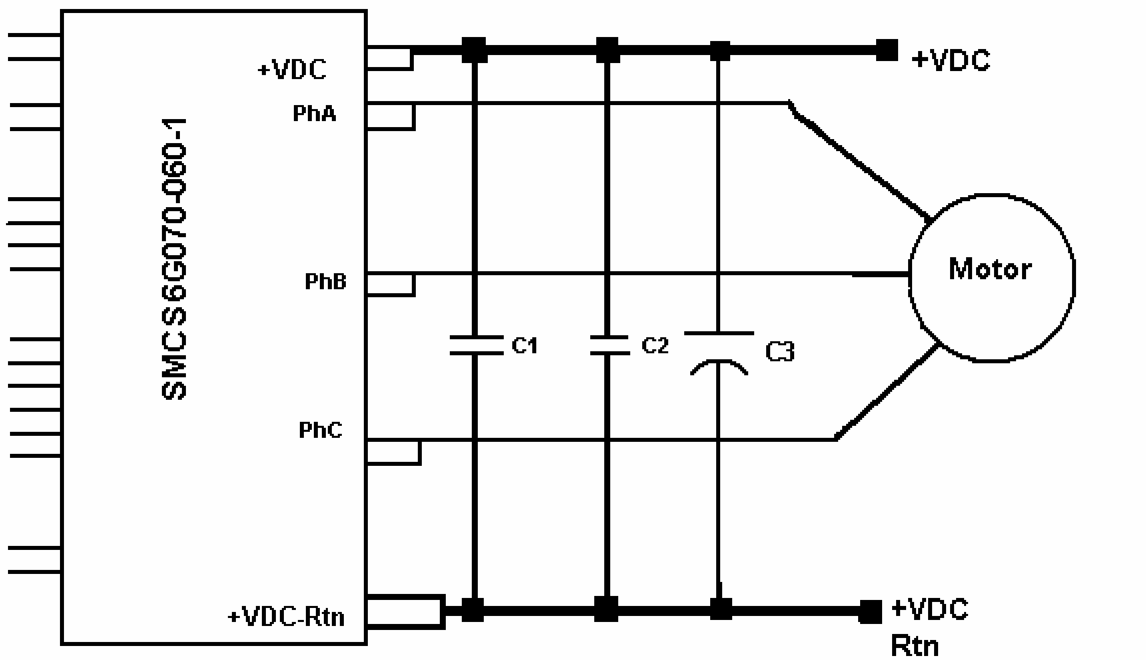

Fig. 16: DC Bus Bypass Capacitors

IGBT and Diode Switching Characteristics and Waveforms (for SMCS6G070-060-1)

1- Test Conditions: VCE=280V, IC= 25A

Test Results: Rise time tr= 66 nsec, Fall time tf= 52 nsec
Current Scale is 20A/div, **Voltage Scale** is 50V/div, **Power Loss Scale** is 2000Watt/div
Turn On Switching Loss = 0.47 mJ, **Turn Off Switching Loss** = 0.8 mJ

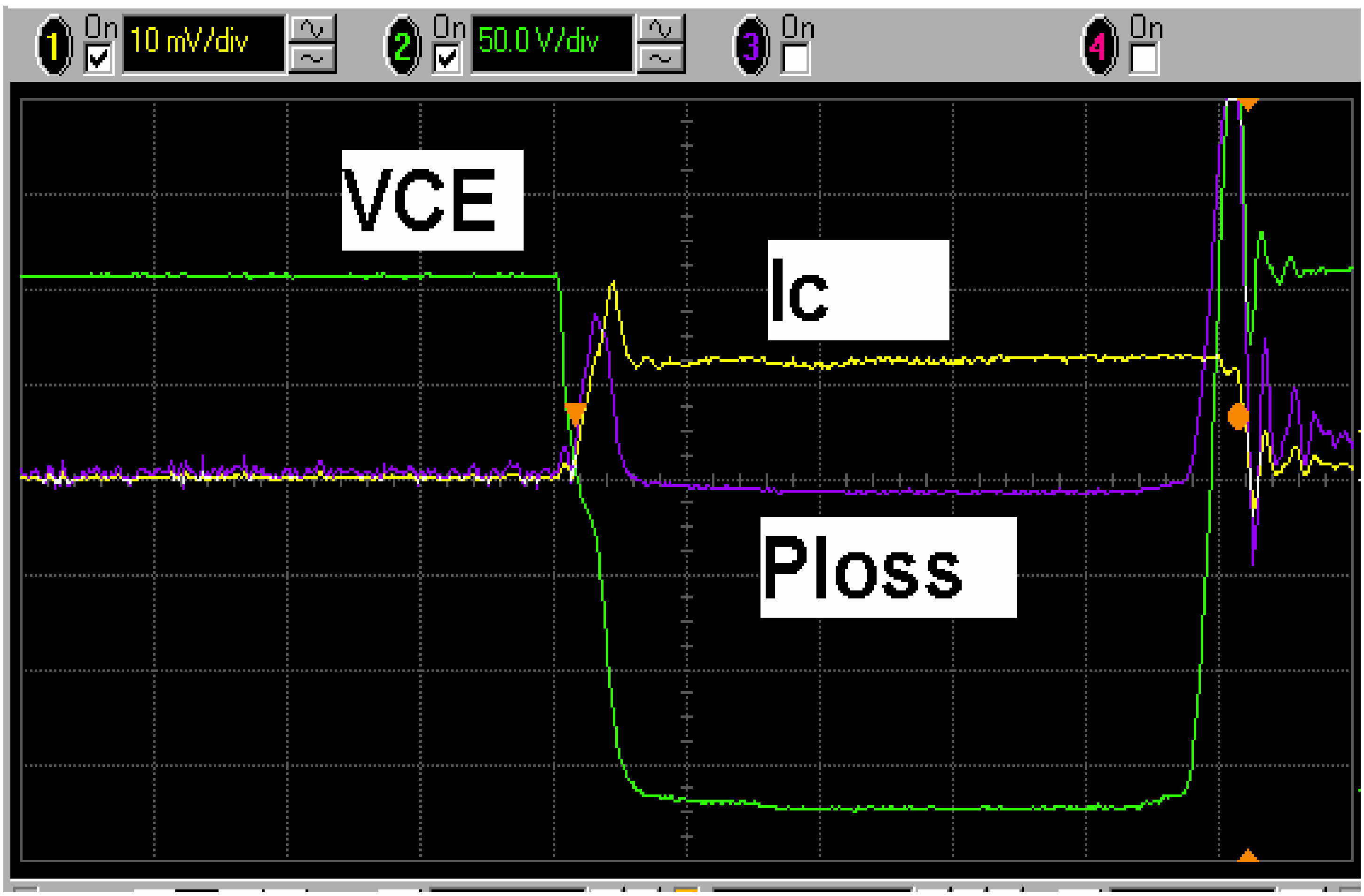

Fig. 17: IGBT Switching Performance

2- Test Conditions: VCE=280V, IC= 35A

Test Results: Rise time tr= 102 nsec, Fall time tf= 45 nsec
Current Scale = 20A/div, **Voltage Scale** = 50V/div, **Power Loss Scale** = 4000Watt/div
Turn On Switching Loss = 0.7 mJ, **Turn Off Switching Loss** = 1.4 mJ

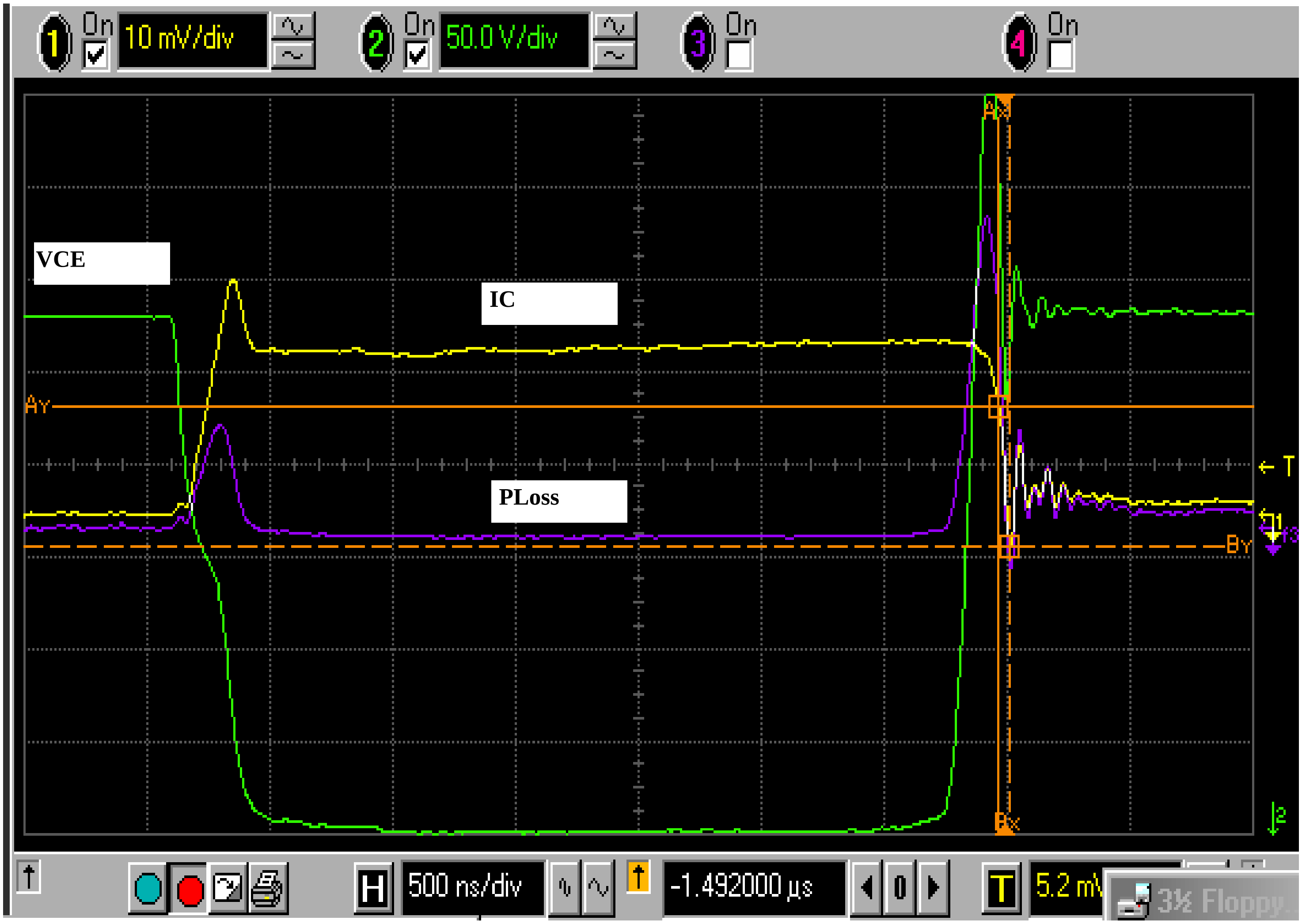

Fig. 18: IGBT Switching Performance

IGBT and Diode Conduction Characteristics:
(for SMCS6G070-060-1)

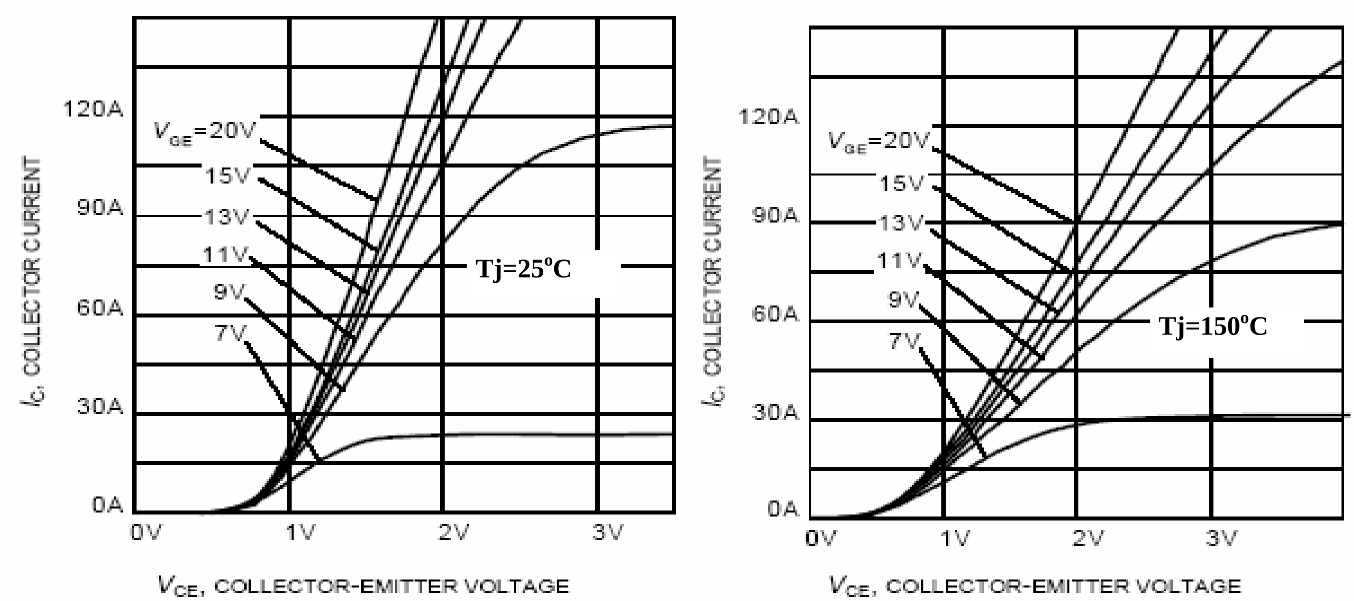

Figure 19. IGBT Conduction Characteristics

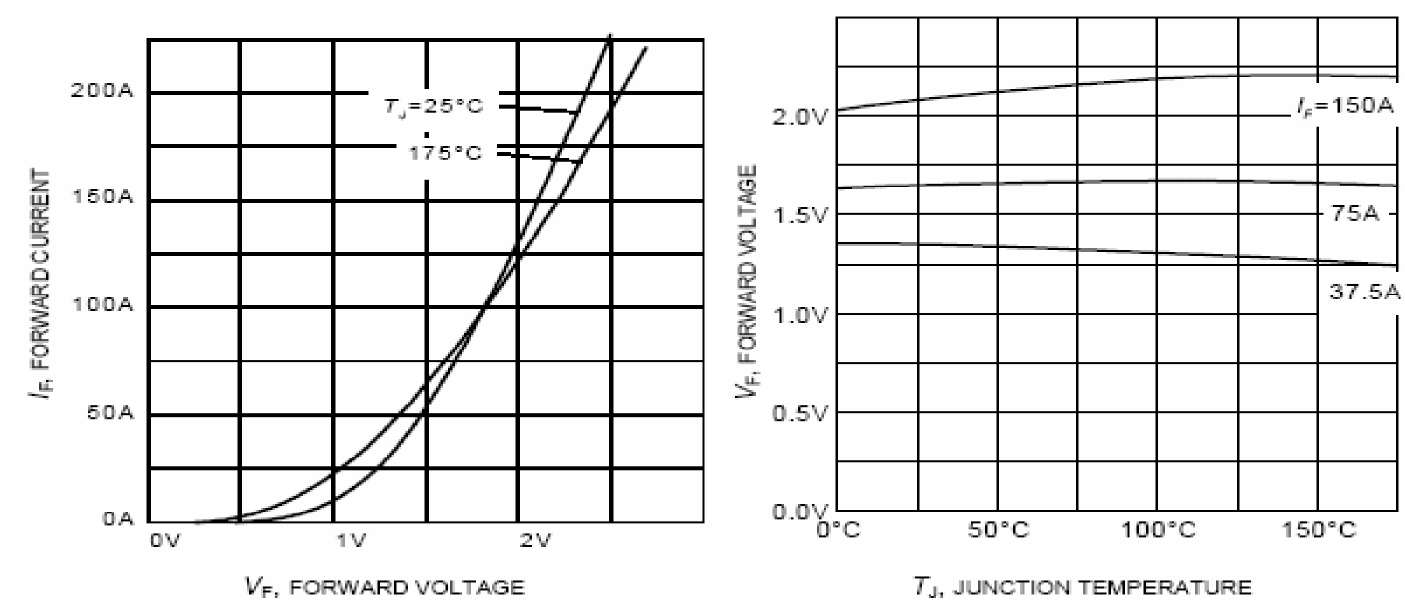

Figure 20. Diode Conduction Characteristics

Cleaning Process:

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 22: 210C for 10 seconds max
Power pins 23 to 32: 260C for 10 seconds max. Pre-warm module to 125C to aid in power pins soldering.