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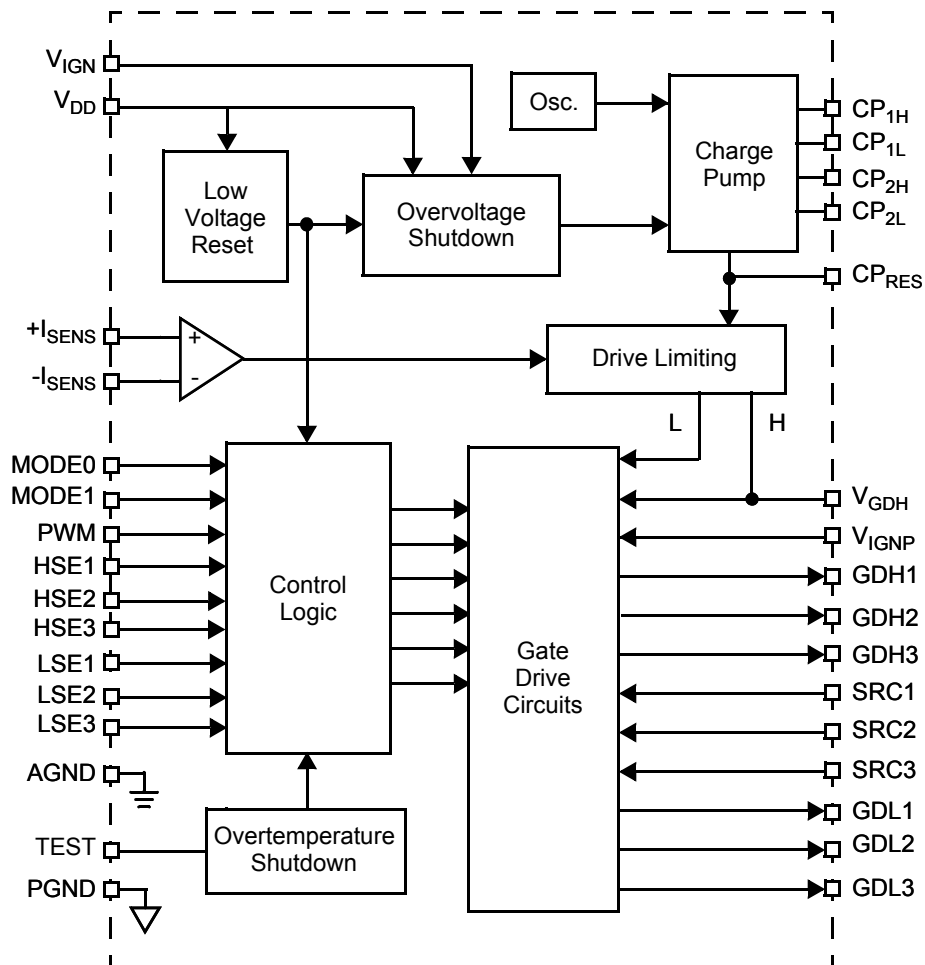
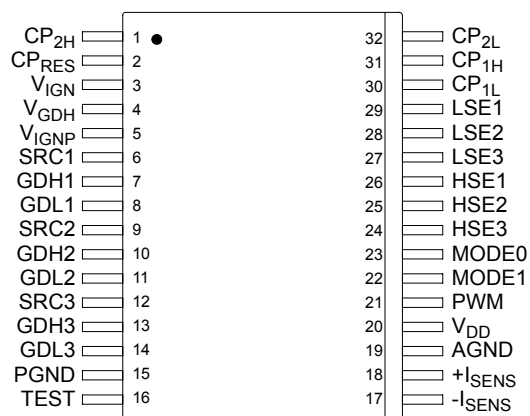


Figure 1. 33395 Simplified Internal Block Diagram

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TERMINAL FUNCTION DESCRIPTION

Terminal	Terminal Name	Formal Name	Definition
1	CP _{2H}	Charge Pump Cap	High potential terminal connection for secondary charge pump capacitor
2	CP _{RES}	Charge Pump Reserve Cap	Input from external reservoir capacitor for charge pump
3	V _{IGN}	Input Voltage	Input from ignition level supply voltage for power functions
4	V _{GDH}	High-Side Gate Voltage	Output full-time gate drive for auxiliary high-side power MOSFET switch
5	V _{IGNP}	Input Voltage Protected	Input from protected ignition level supply for power functions
6	SRC1	High-Side Sense	Sense for high-side source voltage, phase 1
7	GDH1	Gate Drive High	Output for gate high-side, phase 1
8	GDL1	Output for Gate	Output for gate drive low-side, phase 1
9	SRC2	High-Side Sense	Sense for high-side source voltage, phase 2
10	GDH2	Gate Drive High	Output for gate high-side, phase 2
11	GDL2	Output for Gate	Output for gate drive low-side, phase 2
12	SRC3	High-Side Sense	Sense for high-side source voltage, phase 3
13	GDH3	Gate Drive High	Output for gate drive high-side, phase 3
14	GDL3	Gate Drive Low	Output for gate drive low-side, phase 3
15	PGND	Power Ground	Ground terminals for power functions
16	Test	Test Terminal	This should be connected to ground or left open
17	-I _{SENS}	IS Minus	Inverting input for current limit comparator
18	+I _{SENS}	IS Plus	Non-inverting input for current limit comparator
19	AGND	Analog Ground	Ground terminal for logic functions
20	V _{DD}	Logic Supply Voltage	Supply voltage for logic functions
21	PWM	Pulse Width Modulator	Input for pulse width modulated driver duty cycle
22	MODE1	Mode Control Bit 1	Input for mode control selection
23	MODE0	Mode Control Bit 0	Input for mode control selection
24	HSE3	High-Side Enable	Input for high-side enable logic, phase 3

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TERMINAL FUNCTION DESCRIPTION (continued)

Terminal	Terminal Name	Formal Name	Definition
25	HSE2	High-Side Enable	Input for high-side enable logic, phase 2
26	HSE1	High-Side Enable	Input for high-side enable logic, phase 1
27	LSE3	Low-Side Enable	Input for low-side enable logic, phase 3
28	LSE2	Low-Side Enable	Input for low-side enable logic, phase 2
29	LSE1	Low-Side Enable	Input for low-side enable logic, phase 1
30	CP _{1L}	External Pump Capacitor	Input from external pump capacitor for charge pump and secondary terminals
31	CP _{1H}	External Pump Capacitor	Input from external pump capacitor for charge pump and secondary terminals
32	CP _{2L}	Charge Pump Capacitor	Input from external reservoir, external pump capacitors for charge pump, and secondary terminals

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MAXIMUM RATINGS

All voltages are with respect to ground unless otherwise noted

Rating	Symbol	Value	Unit
V _{IGN} Supply Voltage	V _{IGN}	-15.5 to 40	VDC
V _{IGNP} Load Dump Survival	V _{IGNP} LD	-0.3 to 65	VDC
V _{DD} Logic Supply Voltage (Fail Safe)	V _{DD}	-0.3 to 7.0	VDC
Logic Input Voltage (LSEn, HSEn, PWM, and MODEn)	V _{IN}	0.3 to 7.0	VDC
Start Up Current V _{IGNP}	I _{VIGNStartUp}	100	mA
ESD Voltage Human Body Model (Note 1) Machine Model (Note 2)	V _{ESD1} V _{ESD2}	±500 ±200	V
Storage Temperature	T _{STG}	-65 to 160	°C
Operating Ambient Temperature	T _A	-40 to 125	°C
Operating Case Temperature	T _C	-40 to 125	°C
Maximum Junction Temperature	T _J	150	°C
Power Dissipation (T _A = 25°C)	P _D	1.5	W
Terminal Soldering Temperature	T _{SOLDER}	240	°C
Thermal Resistance, Junction-to-Ambient	R _{θJA}	65	°C/W

Notes

- ESD1 testing is performed in accordance with the Human Body Model (C_{ZAP} = 100 pF, R_{ZAP} = 1500 Ω).
- ESD2 testing is performed in accordance with the Machine Model (C_{ZAP} = 200 pF, R_{ZAP} = 0 Ω).

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STATIC ELECTRICAL CHARACTERISTICS

Characteristics noted under conditions $-40^{\circ}\text{C} \leq T_A \leq 125^{\circ}\text{C}$, $5.5\text{ V} \leq V_{\text{IGNP}} \leq 24\text{ V}$ unless otherwise noted. Typical values reflect approximate parameter mean at $T_A = 25^{\circ}\text{C}$ under normal conditions unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
POWER INPUT					
V_{IGN} Current @ 5.5 V–24 V, $V_{\text{DD}} = 5.5\text{ V}$	I_{IGN}	–	0.2	1.0	mA
V_{IGNP} Current @ 5.5 V–24 V, $V_{\text{DD}} = 5.5\text{ V}$	I_{IGNP}	–	–	100	mA
V_{IGNP} Overvoltage Shutdown	$V_{\text{IGNP}_{\text{SD}}}$	25	33	36.5	V
V_{IGNP} Voltage	V_{IGNP}	5.5	–	24	V
V_{DD} Current @ 5.5 VDC, $5.5\text{ V} \leq V_{\text{IGNP}} \leq 24\text{ V}$	I_{VDD}	–	1.8	4.0	mA
V_{DD} Low-Voltage Reset Level	$V_{\text{DD}(\text{RESET})}$	2.5	3.2	4.0	V
V_{DD} One-Time Fuse (Logic Supply)	–	7.0	–	–	V
INPUT/OUTPUT					
Input Current at $V_{\text{DD}} = 5.5\text{ V}$ LSEn, HSEn, PWM, and MODEn = 3.0 V	I_{IN}	5.0	12	25	μA
Input Threshold at $V_{\text{DD}} = 5.5\text{ V}$ LSEn, HSEn, PWM, and MODEn (Note 3)	V_{TH}	1.0	2.0	3.0	V
V_{SCRn} Source Sense Voltage SRC1, SRC2, SRC3	V_{SCRn}	-0.3	V_{IGNP}	24	V
Comparator Input Offset Voltage	$V_{\text{INP}(\text{OFFSET})}$	5.0	14	20	mV
Comparator Input Bias Current	$V_{\text{INP}(\text{BIAS})}$	-500	-170	500	nA
Comparator Input Offset Current	$I_{\text{INP}(\text{OFFSET})}$	-300	-3.0	300	nA
Common Mode Voltage (Note 4)	V_{CMR}	0	–	$V_{\text{DD}}-2.0$	V_{DC}
Comparator Differential Input Voltage (Note 4)	V_{INPdiff}	$-V_{\text{DD}}$	–	$+V_{\text{DD}}$	V
Charge Pump Voltage V_{IGN} (Note 5) $V_{\text{IGNP}} = 5.5\text{ V}$, $I_{\text{CRES}} = 1.0\text{ mA}$ $V_{\text{IGNP}} = 9.0\text{ V}$, $I_{\text{CRES}} = 1.0\text{ mA}$ $V_{\text{IGNP}} = 12\text{ V}$, $I_{\text{CRES}} = 5.0\text{ mA}$ $V_{\text{IGNP}} = 24\text{ V}$, $I_{\text{CRES}} = 1.0\text{ mA}$ $V_{\text{IGNP}} = 24\text{ V}$, $I_{\text{CRES}} = 5.0\text{ mA}$	$V_{\text{CRES}}-V_{\text{IGNP}}$	4.0 4.0 4.5 8.0 4.5	6.0 7.5 10 16 12	18 18 18 18 18	V
V_{GDH} Output Voltage with GDHn in ON State $V_{\text{IGNP}} = 5.5\text{ V}$, $I_{\text{GDHn}} = 1.0\text{ mA}$ $V_{\text{IGNP}} = 12\text{ V}$, $I_{\text{GDHn}} = 5.0\text{ mA}$ $V_{\text{IGNP}} = 24\text{ V}$, $I_{\text{GDHn}} = 5.0\text{ mA}$	$V_{\text{GDHn}(\text{on})}-V_{\text{SRCn}}$	4.0 4.0 4.5	5.2 9.0 11	18 18 18	V
V_{GDH} Output Voltage with GDHn in OFF State $V_{\text{IGNP}} = \text{SRCn} = 14\text{ V}$, $I_{\text{GDHn}} = 1.0\text{ mA}$	$V_{\text{GDHn}(\text{off})}$	-1.0	0.6	1.0	V

Notes

- Logic inputs LSEn, HSEn, PWM, and MODEn have internal 20 μA internal sinks.
- Guaranteed by design and characterization. Not production tested.
- The Charge Pump has a positive temperature coefficient. Therefore the Min's occur at -40°C , Typ's at 25°C , and Max's at 125°C .

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STATIC ELECTRICAL CHARACTERISTICS

Characteristics noted under conditions $-40^{\circ}\text{C} \leq T_A \leq 125^{\circ}\text{C}$, $5.5\text{ V} \leq V_{\text{IGNP}} \leq 24\text{ V}$ unless otherwise noted. Typical values reflect approximate parameter mean at $T_A = 25^{\circ}\text{C}$ under normal conditions unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
INPUT/OUTPUT (continued)					
V_{GDL} Low-Side Output Voltage GDHn in ON State $V_{\text{IGNP}} = 5.5\text{ V}$, $I_{\text{GDLn}} = 1.0\text{ mA}$ $V_{\text{IGNP}} = 12\text{ V}$, $I_{\text{GDLn}} = 5.0\text{ mA}$ $V_{\text{IGNP}} = 24\text{ V}$, $I_{\text{GDLn}} = 0.0\text{ mA}$ $V_{\text{IGNP}} = 24\text{ V}$, $I_{\text{GDLn}} = 5.0\text{ mA}$	$V_{\text{GDL(on)}}$	5.0 8.0 8.0 8.0	8.0 14 17 16	18 18 19 19	V
V_{GDL} Output Voltage GDHn in OFF State $V_{\text{IGNP}} = 14\text{ V}$, $I_{\text{GDLn}} = 1.0\text{ mA}$	$V_{\text{GDL(off)}}$	-1.0	0.3	1.0	V
Thermal Shutdown (Note 6)	T_{LIM}	160	–	190	$^{\circ}\text{C}$

Notes

6. Guaranteed by design and characterization. Not production tested.

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DYNAMIC ELECTRICAL CHARACTERISTICS

Characteristics noted under conditions $-40^{\circ}\text{C} \leq T_A \leq 125^{\circ}\text{C}$, $5.5\text{ V} \leq V_{\text{IGNP}} \leq 24\text{ V}$ unless otherwise noted. Typical values reflect approximate parameter mean at $T_A = 25^{\circ}\text{C}$ under normal conditions unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
High-Side (GDHn) and Low-Side Drivers (GDHn) Rise Time (25% to 75%), C_{ISS} Value = 2000 pF (Note 7)	t_{RH}	–	0.35	1.5	μs
High-Side (GDHn) and Low-Side Drivers (GDHn) Fall Time (75% to 25%), C_{ISS} Value = 2000 pF (Note 7)	t_{FH}	–	0.25	1.5	μs
Shoot-Through Suppression Time Delay (33395) (Note 7), (Note 8)	$t_{\text{D1}}, t_{\text{D2}}$	1.0	3.0	5.5	μs
33395T		0.2	0.65	1.0	
Current Limit Time Delay (Note 9)	$t_{\text{ILIMDELAY}}$	1.5	2.8	5.0	μs

Notes

7. See [Figure 2](#), page 9.
8. Shoot-Through Suppression Time Delay is provided to prevent directly connected high- and low-side MOSFETs from being on simultaneously.
9. Current Limit Time Delay: The internal comparator places the device in the current limit mode when the comparator output goes LOW and sets an internal logic bit. This takes a finite amount of time and is stated as the Current Limit Time Delay.

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Timing Diagram

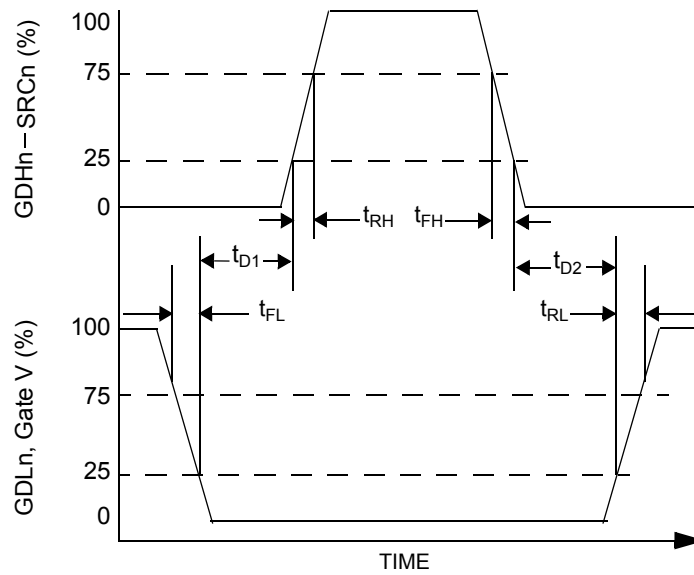


Figure 2. Shoot-Through Suppression

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SYSTEM/APPLICATION INFORMATION

INTRODUCTION

The 33395 and 33395T devices are designed to provide the necessary drive and control signal buffering and amplification to enable a DSP or MCU to control a three-phase array of power MOSFETs such as would be required to energize the windings of powerful brushless DC (BLDC) motors. It contains built-in

charge pump circuitry so that the MOSFET array may consist entirely of N-Channel MOSFETs. It also contains feedback sensing circuitry and control circuitry to provide a robust overall motor control design.

FUNCTIONAL DESCRIPTION

Gate Drive Circuits

The gate drive outputs (GDH1, GDH2, etc.) supply the peak currents required to turn ON and hold ON the MOSFETs, as well as turn OFF and hold OFF the MOSFETs.

Charge Pump

The current capability of the charge pump is sufficient to supply the gate drive circuit's demands when PWM'ing at up to 28 kHz. Two external charge pump capacitors and a reservoir capacitor are required to complete the charge pump's circuitry.

Charge reservoir capacitance is a function of the total MOSFET gate charge (Q_G) gate drive voltage level relative to the source (V_{GS}) and the allowable sag of the drive level during the turn-on interval (V_{SAG}). C_{RES} can be expressed by the following formula:

$$C_{RES} = \frac{Q_G \times V_{GS}}{2 \times V_{GS} \times V_{SAG} - V_{SAG}^2}$$

For example, for $Q_G = 60 \text{ nC}$, $V_{GS} = 14 \text{ V}$, $V_{SAG} = 0.2 \text{ V}$:

$$C_{RES} = \frac{(60 \text{ nC}) \times (14 \text{ V})}{2 \times (14 \text{ V}) \times (0.2 \text{ V}) - (0.2)^2} = 0.15 \text{ }\mu\text{F}$$

Proper charge pump capacitance is required to maintain, and provide for, adequate gate drive during high demand turn-ON intervals. Use the following formula to determine values for C_{P1} and C_{P2} :

For example, for the above determination of $C_{RES} = 0.15 \text{ }\mu\text{F}$:

$$\frac{C_{RES}}{20} \leq C_{P1} = C_{P2} \leq \frac{C_{RES}}{10}$$

By averaging these two values, the proper C_{Pn} value can be determined:

$$\frac{0.15 \text{ }\mu\text{F}}{20} = 0.0075 \text{ }\mu\text{F, lower limit; and } \frac{0.15 \text{ }\mu\text{F}}{10} = 0.015 \text{ }\mu\text{F, upper limit}$$

$$C_{P1} \text{ and } C_{P2} = (0.0075 \text{ }\mu\text{F} + 0.015 \text{ }\mu\text{F}) \div 2 = 0.01 \text{ }\mu\text{F}$$

Thermal Shutdown Function

The device has internal temperature sensing circuitry which activates a protective shutdown function should the die reach excessively elevated temperatures. This function effectively limits power dissipation and thus protects the device.

Overvoltage Shutdown Function

When the supply voltage (V_{IGN}) exceeds the specified over-voltage shutdown level, the part will automatically shut down to protect both internal circuits as well as the load. Operation will resume upon return of V_{IGN} to normal operating levels.

Low Voltage Reset Function

When the logic supply voltage (V_{DD}) drops below the minimum voltage level or when the part is initially powered up, this function will turn OFF and hold OFF the external MOSFETs until the voltage increases above the minimum voltage level required for normal operation.

Control Logic

The control logic block controls when the low-side and high-side drivers are enabled. The logic implements the Truth Table found in the specification and monitors the M0, M1, PWM, CL, OT, OV, LSE, and HSE terminals. Note that the drivers are enabled 3 μs after the PWM edge. During complimentary chop mode the high-side and low-side drives are alternatively enabled and disabled during the PWM cycle. To prevent shoot-through current, the high-side drive turn-on is delayed by t_{D1} , and the low-side drive turn on is delayed by t_{D2} (see [Figure 2](#), page 9).

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Note that the drivers are disabled during an overtemperature or overvoltage fault. A flip-flop keeps the drive off until the following PWM cycle. This prevents erratic operation during fault conditions. The current limit circuit also uses a flip-flop for latching the drive off until the following PWM cycle.

Note PWM must be toggled after POR, Thermal Limit, or overvoltage faults to re-enable the gate drivers.

V_{GDH}

The V_{GDH} terminal is used to provide a gate drive signal to a reverse battery protection MOSFET. If reverse battery protection is desired, V_{IGN} would be applied to the source of an external MOSFET, and the drain of the MOSFET would then deliver a "protected" supply voltage (V_{IGNP}) to the three phase array of external MOSFETs as well as the supply voltage to the V_{IGNP} terminal of the IC.

In a reverse polarity event (e.g., an erroneous installation of the system battery), the V_{GDH} signal will not be supplied to the external protection MOSFET, and the MOSFET will remain off and thus prevent reverse polarity from being applied to the load and the V_{IGNP} supply terminal of the IC.

High-Side Gate Drive Circuits

Outputs GDH1, GDH2, and GDH3 provide the elevated drive voltage to the high-side external MOSFETs (HS1, HS2, and HS3; see [Figure 3](#), page 13). These gate drive outputs supply the peak currents required to turn ON and hold ON the high-side MOSFETs, as well as turn OFF the MOSFETs. These gate drive circuits are powered from an internal charge pump, and therefore compensate for voltage dropped across the load that is reflected to the source-gate circuits of the high-side MOSFETs.

Low-Side Gate Drive Circuits

Outputs GDL1, GDL2, and GDL3 provide the drive voltage to the low-side external MOSFETs (LS1, LS2, and LS3; see [Figure 3](#)). These gate drive outputs supply the peak currents required to turn ON and hold ON the low-side MOSFETs, as well as turn OFF the MOSFETs.

V_{DD} Fuse

The V_{DD} supply of the 33395 IC has an internal fuse, which will blow and set all outputs of the device to OFF, if the V_{DD} voltage exceeds that stated in the maximum rating section of the data sheet. When this fuse blows, the device is permanently disabled.

I_{SENS} Inputs

The $+I_{sens}$ and $-I_{sens}$ terminals are inputs to the internal current sense comparator. In a typical application, these would receive a low-pass filtered voltage derived from a current

sense resistor placed in series with the ground return of the three-phase output bridge. When triggered by the comparator, the CL (current limit) bit of the internal error register is set, and the output gate drive pairs (i.e., GDH1 and GDL1, GDH2 and GDL2, GDH3 and GDL3), are controlled such that current will cease flowing through the load (refer to [Table 1](#), Truth Table, page 12).

Overtemperature and Overvoltage Shutdown Circuits

Internal monitoring is provided for both over temperature conditions and over voltage conditions. When any of these conditions presents itself to the IC, the corresponding internally set bits of the error register are set, and the output gate drive pairs (i.e., GDH1 and GDL1, GDH2 and GDL2, GDH3 and GDL3), are controlled such that current will cease flowing through the load (refer to [Table 1](#)).

LSE and HSE Input Circuits

The low-side enable input terminals (LSE1, LSE2, LSE3) and high-side enable input terminals (HSE1, HSE2, HSE3) form the input pairs (HSE1 and LSE1, HSE2 and LSE2, HSE3 and LSE3) which set the logic states of the output gate drive pairs (i.e., GDH1 and GDL1, GDH2 and GDL2, GDH3 and GDL3) in accordance with the logic set forth in the Truth Table ([page 12](#)). Typically these inputs are supplied from an MCU or DSP to provide the phasing of the currents applied to a brushless dc motor's stator coils via the output MOSFET pairs.

PWM Input

The pulse width modulation input provides a single input terminal to accomplish PWM modulation of the output pairs in accordance with the states of the Mode 0 and Mode 1 inputs as set forth in the Truth Table ([page 12](#)).

Mode Selection Inputs

The mode selection inputs (Mode 0 and Mode 1) determine the PWM implementation of the output pairs in accordance with the logic set forth in the Truth Table ([page 12](#)). PWM'ing can thus be set to occur either on the high-side MOSFETs or the low-side MOSFETs, or can be set to occur on both the high-side and low-side MOSFETs as "complementary chopping".

Test Terminal

This terminal should be grounded or left floating (i.e., do not connect it to the printed circuit board). It is used by the automated test equipment to verify proper operation of the internal overtemperature shut down circuitry. This terminal is susceptible to latch-up and therefore may cause erroneous operation or device failure if connected to external circuitry.

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Table 1. Truth Table

The logic state of each output pair, GDLn and GDHn (n = 1, 2, 3), is a function of its corresponding input pair, LSEn and HSEn (n = 1, 2, 3), along with the logic states of the MODEn and PWM inputs and the internally set overtemperature shutdown (OT), overvoltage (OV), and current limit (CL) bits provided in this table.

NORMAL OPERATION

Switching Modes		Internally Set Bits			Input Pairs (e.g., LSE2 and HSE2)		Output Pairs (e.g., GDL2 and GDH2)	
MODE1	MODE0	OT	OV	CL	LSEn	HSEn	GDLn	GDHn
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0	1
0	0	0	0	0	1	0	PWM	0
0	0	0	0	0	1	1	0	0
0	1	0	0	0	0	0	0	0
0	1	0	0	0	0	1	0	1
0	1	0	0	0	1	0	PWM	PWM
0	1	0	0	0	1	1	0	0
1	0	0	0	0	0	0	0	0
1	0	0	0	0	0	1	0	PWM
1	0	0	0	0	1	0	1	0
1	0	0	0	0	1	1	0	0
1	1	0	0	0	0	0	0	0
1	1	0	0	0	0	1	PWM	PWM
1	1	0	0	0	1	0	1	0
1	1	0	0	0	1	1	0	0

FAULT MODE OPERATION

Switching Modes		Internally Set Bits			Input Pairs (e.g., LSE2 and HSE2)		Output Pairs (e.g., GDL2 and GDH2)	
MODE1	MODE0	OT	OV	CL	LSEn	HSEn	GDLn	GDHn
0	0	0	0	1	0	0	0	0
0	0	0	0	1	0	1	0	1
0	0	0	0	1	1	0	0	0
0	0	0	0	1	1	1	0	0
0	1	0	0	1	0	0	0	0
0	1	0	0	1	0	1	0	1
0	1	0	0	1	1	0	0	1
0	1	0	0	1	1	1	0	0
1	0	0	0	1	0	0	0	0
1	0	0	0	1	0	1	0	0
1	0	0	0	1	1	0	1	0
1	0	0	0	1	1	1	0	0
1	1	0	0	1	0	0	0	0
1	1	0	0	1	0	1	1	0
1	1	0	0	1	1	0	1	0
1	1	0	0	1	1	1	0	0
x	x	x	1	x	x	x	0	0
x	x	1	x	x	x	x	0	0

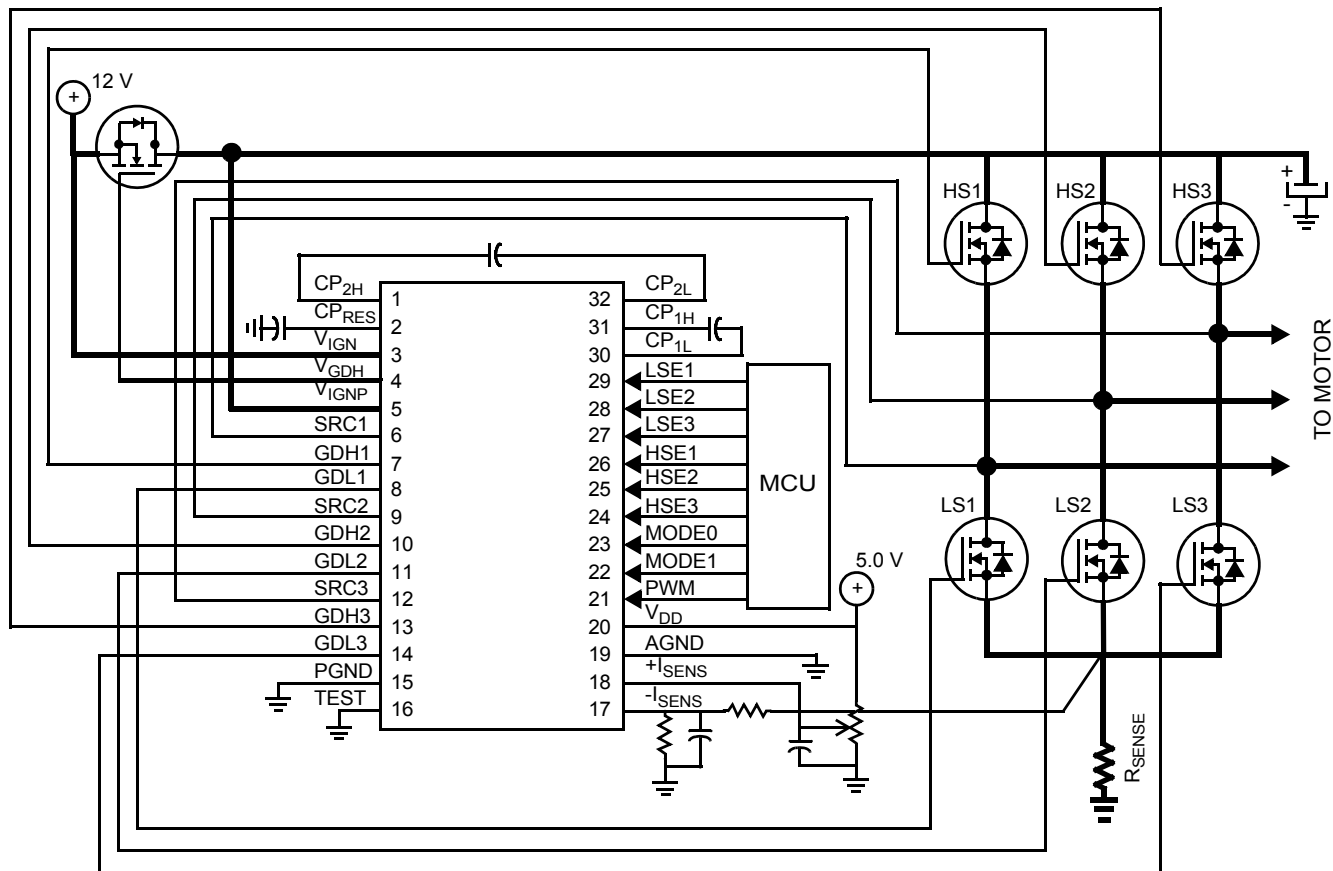


Figure 3. Typical Application Diagram

NOTES:

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- Figure 1 shows a cross-section of a part with a fillet. The dimensions are as follows:
- Fillet Radius: $R0.08 \text{ MIN}$
 - Gauge Plane: 0.25
 - Fillet Angle: 0° MIN
 - Base Angle: $8^\circ / 0^\circ$
 - Base Thickness: $0.29 / 0.13$
- The section is labeled **SECTION B-B**.

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NOTES

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