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BROADCOM®

Data Sheet

ACPL-351J

5.0 Amp Output Current IGBT and SiC/GaN MOSFET Gate Drive Optocoupler with Overcurrent Sensing and FAULT Signal

Description

The Broadcom® ACPL-351J is a 5A intelligent gate drive optocoupler. The high peak output current and wide operating voltage range make it ideal for driving IGBT or SiC/GaN MOSFET directly in motor control and inverter applications.

The device features fast propagation delay with excellent timing skew performance. It provides IGBT/MOSFET with overcurrent protection and FAULT signal for external isolated feedback. This gate drive optocoupler comes in a compact, surface-mountable SO-16 package. It provides reinforced insulation certified for safety regulatory IEC/EN/DIN, UL, and CSA.

CAUTION! Take normal static precautions in handling and assembly of this component to prevent damage, degradation, or both that may be induced by ESD. The components featured in this data sheet are not to be used in military or aerospace applications or environments.

Features

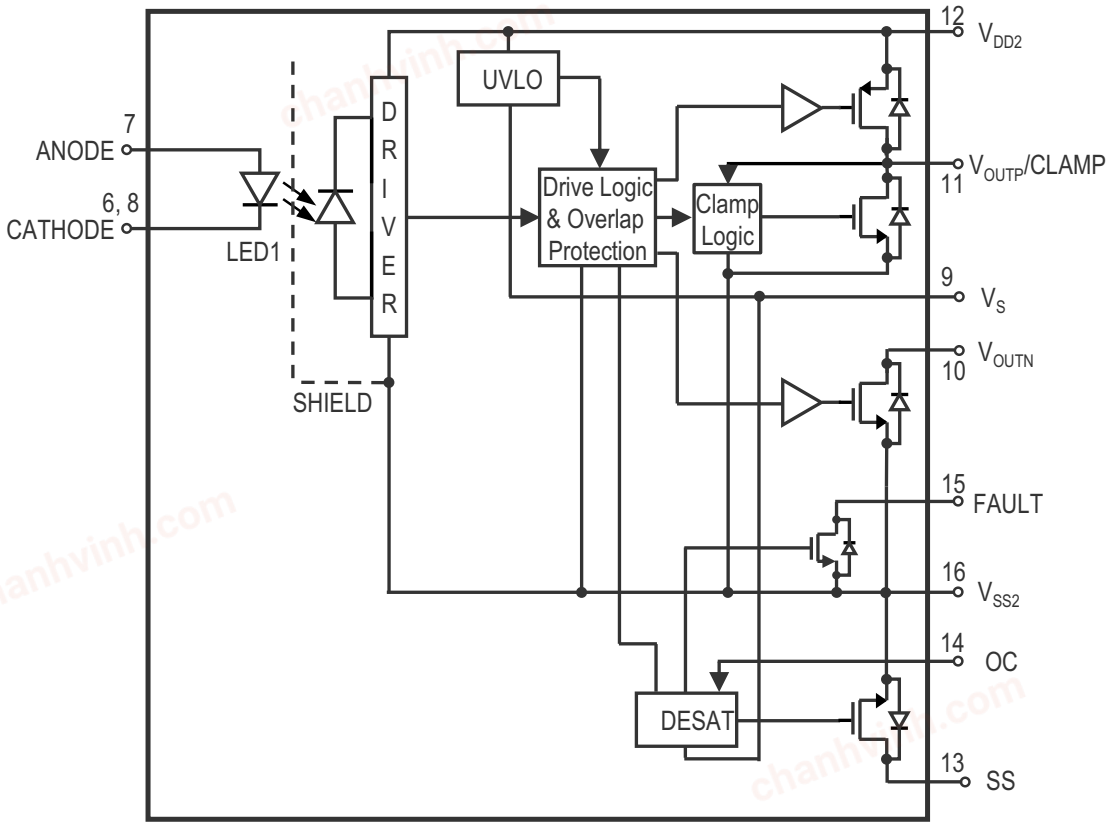
- ACPL-351J – 5.0 A maximum peak output current
- 150-ns maximum propagation delay
- Dual output drive to control turning on and off time
- Overcurrent detection with configurable "soft" shutdown
- FAULT signal for external isolated feedback
- Under voltage lockout (UVLO) with hysteresis
- 100 kV/µs minimum common mode rejection (CMR) at V_{CM} = 1500V
- 15V to 30V wide operating V_{DD2} range
- –40°C to 105°C industrial temperature range
- 8.3-mm creepage and clearance
- Safety approval:
  - UL Recognized 5000 V_{RMS} for 1 minute
  - CSA
  - IEC/EN/DIN EN 60747-5-5 V_{IORM} = 1414 V_{PEAK}

Applications

- IGBT and SiC/GaN MOSFET gate drives
- Industrial drives and inverters
- Renewable energy inverters
- Switching power supplies

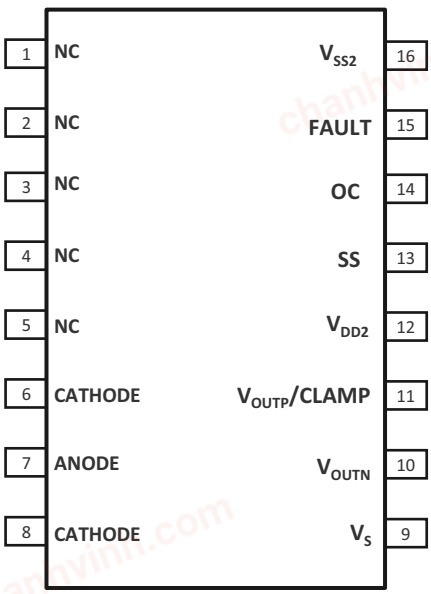
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Functional Diagram



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Pin Description



Pin	Symbol	Description
1	NC	No connection
2	NC	No connection
3	NC	No connection
4	NC	No connection
5	NC	No connection
6	CATHODE	Input LED cathode
7	ANODE	Input LED anode
8	CATHODE	Input LED Cathode
9	V_S	Common (IGBT emitter or MOSFET source) output supply voltage.
10	V_{OUTN}	Driver output to turn off IGBT or MOSFET gate
11	V_{OUTP}/CLAMP	Driver output to turn on IGBT or MOSFET gate/Miller clamp
12	V_{DD2}	Positive output power supply
13	SS	Soft shutdown
14	OC	Overcurrent (OC) input pin. When the voltage on the OC pin exceeds an internal reference voltage of 9V while the IGBT/MOSFET is on, the FAULT output is changed from logic high to low state.
15	FAULT	OC fault signal for external isolated feedback
16	V_{SS2}	Negative output power supply

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Ordering Information

ACPL-351J is UL Recognized with 5000 Vrms for 1 minute per UL1577.

Part Number	Option	Package	Surface Mount	Tape and Reel	IEC/EN/DIN EN 60747-5-5	Quantity
	RoHS Compliant					
ACPL-351J	-000E	SO-16	X		X	45 per tube
	-500E		X	X	X	850 per reel

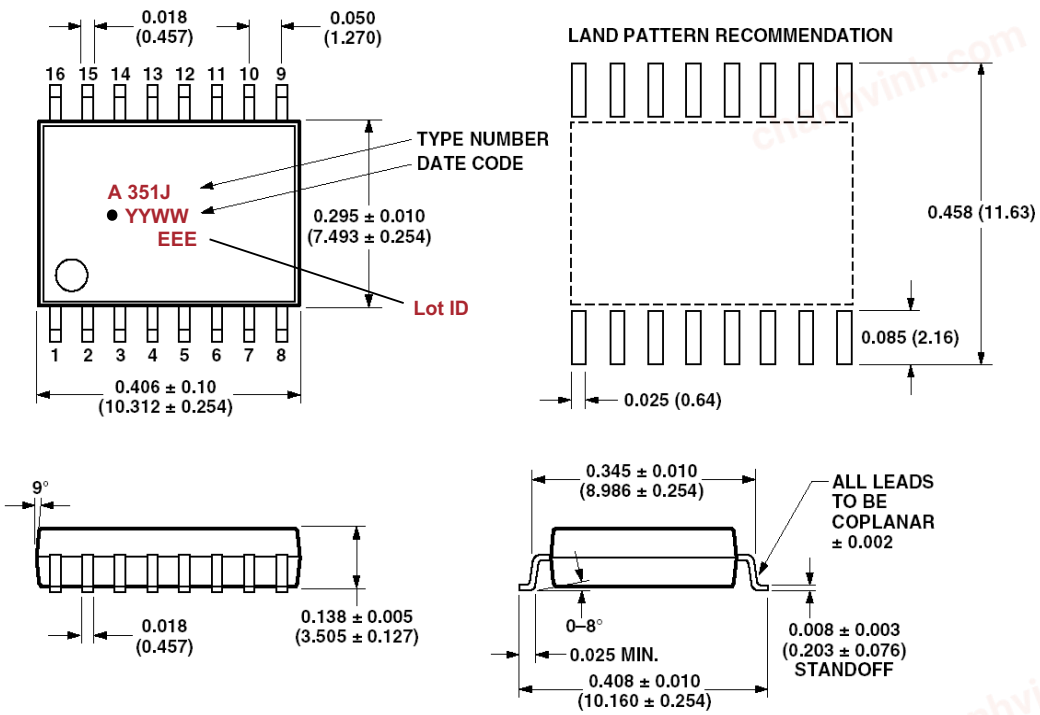
To order, choose a part number from the part number column and combine with the desired option from the option column to form an order entry.

Example:

ACPL-351J-500E to order a product of SO-16 surface mount package in tape and reel packaging with IEC/EN/DIN EN 60747-5-5 Safety Approval in RoHS compliant.

Option data sheets are available. Contact your Broadcom sales representative or authorized distributor for information.

ACPL-351J 16-Lead Surface Mount Package



NOTE:

1. Dimensions are in inches (millimeters).
2. Floating lead protrusion is 0.25 mm (10 mils) maximum.
3. Initial and continued variation in the color of the ACPL-351J's white mold compound is normal and does not affect device performance or reliability.

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Recommended Pb-Free IR Profile

Recommended reflow condition as per JEDEC Standard, J-STD-020 (latest revision). Use non-halide flux.

Regulatory Information

The ACPL-351J is approved by the following organizations.

IEC/EN/DIN EN 60747-5-5	Maximum working insulation voltage V_{IORM} = 1414 V_{PEAK}.
UL	Approval under UL 1577, component recognition program up to V_{ISO} = 5000 V_{RMS}. File E55361.
CSA	Approval under CSA Component Acceptance Notice #5, File CA 88324.

Table 1: IEC/EN/DIN EN 60747-5-5 Insulation Characteristics[a]

Description	Symbol	Characteristic	Units
Installation Classification per DIN VDE 0110/39, Table 1			
For rated mains voltage ≤ 150 V_{rms}		I - IV	
For rated mains voltage ≤ 300 V_{rms}		I - IV	
For rated mains voltage ≤ 600 V_{rms}		I - IV	
For rated mains voltage ≤ 1000 V_{rms}		I - III	
Climatic Classification		40/105/21	
Pollution Degree (DIN VDE 0110/1.89)		2	
Maximum Working Insulation Voltage	V_{IORM}	1414	V_{PEAK}
Input to Output Test Voltage, Method b[b] V_{IORM} × 1.875 = V_{PR}, 100% Production Test with t_m = 1 second, Partial Discharge < 5 pC	V_{PR}	2652	V_{PEAK}
Input to Output Test Voltage, Method a*D V_{IORM} × 1.6 = V_{PR}, Type and Sample Test, t_m = 10 seconds, Partial Discharge < 5 pC	V_{PR}	2262	V_{PEAK}
Highest Allowable Overvoltage (Transient Overvoltage t_{ini} = 60 seconds)	V_{IOTM}	8000	V_{PEAK}
Safety-Limiting Values – maximum values allowed in the event of a failure			
Case Temperature	T_S	175	°C
Input Current	$I_{S, INPUT}$	400	mA
Output Power	$P_{S, OUTPUT}$	1200	mW
Insulation Resistance at T_S, V_{IO} = 500V	R_S	$>10^9$	Ω

a. Isolation characteristics are guaranteed only within the safety maximum ratings that must be ensured by protective circuits in application. Surface mount classification is class A in accordance with CECCOO802.

b. Refer to IEC/EN/DIN EN 60747-5-5 Optoisolator Safety Standard section of the *Broadcom Regulatory Guide to Isolation Circuits*, AV02-2041EN for a detailed description of Method a and Method b partial discharge test profiles.

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Table 2: Insulation and Safety Related Specifications

Parameter	Symbol	ACPL-351J	Units	Conditions
Minimum External Air Gap (Clearance)	L(101)	8.3	mm	Measured from input terminals to output terminals, shortest distance through air.
Minimum External Tracking (Creepage)	L(102)	8.3	mm	Measured from input terminals to output terminals, shortest distance path along body.
Minimum Internal Plastic Gap (Internal Clearance)		0.5	mm	Through insulation distance conductor to conductor, usually the straight line distance thickness between the emitter and the detector.
Tracking Resistance (Comparative Tracking Index)	CTI	>175	V	DIN IEC 112/VDE 0303 Part 1.
Isolation Group		IIIa		Material Group (DIN VDE 0110, 1/89, Table 1).

NOTE: All Broadcom data sheets report the creepage and clearance inherent to the optocoupler component itself. These dimensions are needed as a starting point for the equipment designer when determining the circuit insulation requirements. However, when mounted on a printed circuit board, minimum creepage and clearance requirements must be met as specified for individual equipment standards. For creepage, the shortest distance path along the surface of a printed circuit board between the solder fillets of the input and output leads must be considered (the recommended land pattern does not necessarily meet the minimum creepage of the device). There are recommended techniques, such as grooves and ribs, that may be used on a printed circuit board to achieve the desired creepage and clearances. The creepage and clearance distances will also change depending on factors. such as pollution degree and insulation level.

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Table 3: Absolute Maximum Ratings

Parameter	Symbol	Min.	Max.	Units	Notes
Storage Temperature	T_S	–55	125	°C	
Operating Temperature	T_A	–40	105	°C	
Output IC Junction Temperature	T_J	—	125	°C	
Average Input Current	$I_{F(AVG)}$	—	25	mA	a
Peak Transient Input Current (<1 µs pulse width, 300 pps)	$I_{F(TRAN)}$	—	1.0	A	
Reverse Input Voltage	V_R	—	5	V	
"High" Peak Output Current	$I_{OH(PEAK)}$	—	5	A	b
"Low" Peak Output Current	$I_{OL(PEAK)}$	—	5	A	b
Total Output Supply Voltage	$(V_{DD2} – V_{SS2})$	–0.5	35	V	
Negative Output Supply Voltage	$(V_S – V_{SS2})$	–0.5	17	V	
Positive Output Supply Voltage	$(V_{DD2} – V_S)$	–0.5	$35 – (V_S – V_{SS2})$	V	
Input Current (Rise/Fall Time)	$t_{r(IN)}/t_{f(IN)}$	—	500	ns	
High Side Pull Up Voltage	V_{OUTP}	$V_{SS2} – 0.5$	$V_{DD2} + 0.5$	V	
Low Side Pull Down Voltage	V_{OUTN}	$V_{SS2} – 0.5$	$V_{DD2} + 0.5$	V	
Overcurrent Pin Voltage	V_{OC}	$V_S – 0.5$	$V_{DD2} + 0.5$	V	
Peak Clamp Sinking Current	I_{CLAMP}	—	3	A	
Miller Clamp Pin Voltage	V_{CLAMP}	$V_{SS2} – 0.5$	$V_{DD2} + 0.5$	V	
FAULT Pin Voltage	V_{FAULT}	—	$V_{DD2} + 0.5$	V	
Output IC Power Dissipation	P_O	—	600	mW	c
Input LED Power Dissipation	P_I	—	110	mW	d

a. Derate linearly above 70°C free-air temperature at a rate of 0.3 mA/ °C.

b. Maximum pulse width = 10 µs.The output must be limited to –5.0A/5.0A of the peak current by external resistors. See Supply and Ground Planes Layout and Loading Conditions to prevent output noise at 5A rated current.

c. Derate linearly above 95°C free-air temperature at a rate of 20 mW/ °C.

d. Derate linearly above 95°C free-air temperature at a rate of 3.7 mW/ °C. The maximum LED junction temperature should not exceed 125°C.

Table 4: Recommended Operating Conditions

Parameter	Symbol	Min.	Max.	Units	Notes
Operating Temperature	T_A	–40	105	°C	
Total Output Supply Voltage	$(V_{DD2} – V_{SS2})$	15	30	V	
Negative Output Supply Voltage	$(V_S – V_{SS2})$	0	15	V	
Positive Output Supply Voltage	$(V_{DD2} – V_S)$	15	$30 – (V_S – V_{SS2})$	V	
Input Current (ON)	$I_{F(ON)}$	8	12	mA	
Input Voltage (OFF)	$V_{F(OFF)}$	–3.6	0.8	V	
FAULT Pin Voltage	V_{FAULT}	—	30	V	

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In Table 5, all typical values at T_A = 25°C, $V_{DD2} – V_S$ = 15V, $V_S – V_{SS2}$ = 15V; all minimum and maximum specifications are at recommended operating conditions, unless otherwise noted.

Table 5: Electrical Specifications (DC)

Parameter	Symbol	Min.	Typ.	Max.	Units	Test Conditions	Figure	Notes
V_{OUTP} High Level Peak Output Current	I_{OH}	–4.5	9.0	—	A	$V_{DD2} – V_{OUTP}$ = 15V	3	a
V_{OUTN} Low Level Peak Output Current	I_{OL}	4.5	7.0	—	A	$V_{OUTN} – V_{SS2}$ = 15V	4	a
V_{OUTP} Output PMOS $R_{DS(ON)}$	R_{OUTP}	0.4	0.7	1.5	Ω	I_{OP} = –4.5A, I_F = 8 mA	5	a
V_{OUTN} Output NMOS $R_{DS(ON)}$	R_{OUTN}	0.3	0.6	1.2	Ω	I_{ON} = 4.5A, V_F = 0V	6	a
V_{OUTP} Output Voltage	V_{OH}	V_{DD2} – 0.60	V_{DD2} – 0.06	—	V	I_{OP} = –100 mA, I_F = 8 mA	1	b, c
V_{OUTN} Output Voltage	V_{OL}	—	V_{SS2} + 0.04	V_{SS2} + 0.60	V	I_{ON} = 100 mA, V_F = 0V	2	
Clamp Threshold Voltage	V_{TH_CLAMP}	—	2	3	V			
Clamp Low Level Sinking Current	I_{CLAMP}	2	2.5	—	A	V_{CLAMP} = V_{SS2} + 2.5V	7	
Clamp Output Transistor $R_{DS(ON)}$	$R_{DS,CLAMP}$	—	0.9	2	Ω	I_{CLAMP} = 2.5A		
SS Pull Down Current	I_{OSS}	70	140	—	mA	SS – V_{SS2} ≥15V, I_F = 8 mA, OC = Open	8	
SS R_{DSON}	R_{OUTSS}	—	16	40	Ω	I_{SS} = 70 mA, I_F =8 mA, OC = Open		
High Level Output Supply Current (V_{DD2})	I_{DD2H}	—	4.6	7.5	mA	I_F = 8 mA, No Load	9	
Low Level Output Supply Current (V_{DD2})	I_{DD2L}	—	3.7	6.5	mA	V_F = 0V, No Load,	9	
High Level Output Supply Current (V_{SS2})	I_{SS2H}	–2.2	–1.7	—	mA	I_F = 8 mA, No Load,	10	
Low Level Output Supply Current (V_{SS2})	I_{SS2L}	–1.2	–0.8	—	mA	V_F = 0V, No Load,	10	
Input Threshold Current Low to High	I_{FLH}	0.5	2	6.5	mA		11, 12	
Input Threshold Voltage High to Low	V_{FHL}	0.8	—	—	V			
Input Forward Voltage	V_F	1.2	1.55	1.95	V	I_F = 8 mA		
Temperature Coefficient of Input Forward Voltage	$\Delta V_F/\Delta T_A$	—	–1.7	—	mV/°C	I_F = 8 mA		
Input Reverse Breakdown Voltage	BV_R	5	—	—	V	I_R = 100 µA		
Input Capacitance	C_{IN}	—	70	—	pF	f = 1 MHz, V_F = 0V		

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Table 5: Electrical Specifications (DC) (Continued)

Parameter	Symbol	Min.	Typ.	Max.	Units	Test Conditions	Figure	Notes
UVLO Threshold, $V_{DD2} - V_S$	V_{UVLO+}	12	12.9	13.5	V	I_F = 8 mA, $V_{OUTP} - V_E > 5V$		b, c, d
	V_{UVLO-}	11	11.8	12.5	V	I_F = 8 mA, $V_{OUTP} - V_E < 5V$		b, c, e
UVLO Hysteresis, $V_{DD2} - V_S$	$V_{UVLO+} - V_{UVLO-}$	0.5	1	—	V			
OC Sensing Voltage Threshold	V_{OC}	8.5	9	9.5	V	$V_{DD2} - V_S > V_{UVLO+}$	13	c
Blanking Capacitor Charging Current	I_{CHG}	0.85	1	1.15	mA	V_{OC} = 2V	14	c, f
OC Low Voltage when Blanking Capacitor Discharge	V_{DSCHG}	—	1.1	2	V	I_{DSCHG} = 20 mA		c, f
Low Level FAULT Output Voltage	V_{FAULTL}	—	0.7	1.5	V	I_{FAULT} = 10 mA		
High Level FAULT Leakage Current	I_{FAULTH}	—	2	20	µA	V_{FAULT} = 30V		

a. Output is sourced at –4.5A /4.5A with a maximum pulse width = 10 µs.

b. 15V is the recommended minimum operating positive supply voltage ($V_{DD2} - V_S$) to ensure adequate margin in excess of the maximum V_{UVLO+} threshold of 13.5V. For high level output voltage testing, V_{OUTP} is measured with a 50-µs pulse load current. When driving capacitive loads, V_{OUTP} will approach V_{DD2} as I_{OUTP} approaches zero units.

c. When the system is out of UVLO ($V_{DD2} - V_S > V_{UVLO+}$), the OC detection feature of the ACPL-351J will be the primary source of IGBT/MOSFET protection. UVLO must be unlocked to ensure that OC is functional. When V_{DD2} exceeds V_{UVLO+} threshold, OC will remain functional until V_{DD2} is below the V_{UVLO-} threshold. The OC detection and UVLO features of the ACPL-351J work in conjunction to ensure constant IGBT / MOSFET protection.

d. This is the "increasing" (that is, turn-on or "positive going" direction) of $V_{DD2} - V_S$.

e. This is the "decreasing" (that is, turn-off or "negative going" direction) of $V_{DD2} - V_S$.

f. See OC Fault Detection Blanking Time for further details.

In Table 6, all typical values at T_A = 25°C, $V_{DD2} - V_S$ = 15V, $V_S - V_{SS2}$ = 15V; all minimum and maximum specifications are at recommended operating conditions, unless otherwise noted.

Table 6: Switching Specifications (AC)

Parameter	Symbol	Min.	Typ.	Max.	Units	Test Conditions	Figure	Notes
Propagation Delay Time to High V_{OUTP} Output Level	t_{PLH}	40	100	150	ns	R_{GP} = 5Ω, R_{GN} = 5Ω , C_G = 5 nF, f = 20 kHz, Duty Cycle = 50%, I_F = 8 mA	15, 16, 21	a
Propagation Delay Time to Low V_{OUTN} Output Level	t_{PHL}	40	90	150	ns			b
Pulse Width Distortion	PWD	–50	10	50	ns			c
Propagation Delay Difference Between Any Two Parts	PDD ($t_{PLH} - t_{PHL}$)	–75	—	75	ns			d
Propagation Delay Skew	t_{PSK}	—	—	60	ns			e

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Table 6: Switching Specifications (AC) (Continued)

Parameter	Symbol	Min.	Typ.	Max.	Units	Test Conditions	Figure	Notes
10% to 90% Rise Time on V_{OUTP}	t_R	—	37	—	ns	R_{GP} = 5Ω, R_{GN} = 5Ω, C_G = 2 nF, f = 20 kHz, Duty Cycle = 50%, I_F = 8 mA		
90% to 10% Fall Time on V_{OUTN}	t_F	—	30	—	ns			
OC Blanking Time	$t_{OC(BLANKING)}$	—	0.75	1	µs	R_{GP} = 5Ω, R_{GN} = 5Ω, C_G = 5 nF, f = 100 Hz, Duty Cycle = 50%, I_F = 8 mA, R_{SS} = 133Ω, R_{FS} = 1 kΩ, C_{FS} = 470 pF	20	f
OC Detection to 90% V_{GATE} Delay	$t_{OC(90\%)}$	—	0.13	—	µs		20	g
OC Detection to V_{GATE} = 2V Delay	$t_{OC(2V)}$	—	2.5	—	µs		20	h
OC Detection to OC Pull Low Propagation Delay	$t_{OC(LOW)}$	—	0.25	—	µs		20	i
OC Detection to SS Pull Low Propagation Delay	$t_{SS(LOW)}$	—	0.15	0.8	µs		17, 20	j
OC Detection to Low Level FAULT Signal Delay	$t_{OC(FAULT)}$	—	180	200	ns		20	k
Output Mute Time Due to Overcurrent	$t_{OC(MUTE)}$	2	3	4	ms		18, 20	l
Time Input Kept Low Before Fault Reset to High	$t_{OC(RESET)}$	2	3	4	ms		18, 20	m
V_{DD2} UVLO to V_{OUTP} High Delay	t_{UVLO_ON}	—	3	—	µs		22	n
VDD2 UVLO to V_{OUTN} Low Delay	t_{UVLO_OFF}	—	1.5	—	µs		22	o
Output High Level Common Mode Transient Immunity	$\|CM_H\|$	100	—	—	kV/µs	T_A = 25°C, I_F = 8 mA, V_{CM} = 1500 V,		p, q
Output Low Level Common Mode Transient Immunity	$\|CM_L\|$	100	—	—	kV/µs	T_A = 25°C, V_F = 0V, V_{CM} = 1500 V		q, r

a. t_{PLH} is defined as propagation delay from 50% of LED input I_F, to 50% of V_{OUTP} high level output.

b. t_{PHL} is defined as propagation delay from 50% of LED input I_F, to 50% of V_{OUTN} low level output.

c. Pulse width distortion (PWD) is defined as $|t_{PHL} - t_{PLH}|$ for any given unit.

d. Propagation delay difference (PDD) is the difference between t_{PHL} and t_{PLH} between any two units under the same test condition.

e. Propagation delay skew (t_{PSK}) is the difference in t_{PHL} or t_{PLH} between any two units under the same test condition.

f. The internal delay time to respond to an OC fault condition without any external blanking capacitor.

g. The amount of time from when the OC threshold is exceeded to 90% of V_{GATE} at the mentioned test conditions.

h. The amount of time from when the OC threshold is exceeded to V_{GATE} at 2V at the mentioned test conditions.

i. The amount of time from when the OC threshold is exceeded to 10% of OC low voltage.

j. The amount of time from when the OC threshold is exceeded to 10% of SS (Soft Shut) low voltage.

k. The amount of time from when the OC threshold is exceeded to FAULT output low.

l. The amount of time when the OC threshold is exceeded, output is muted to LED input.

m. The amount of time when the OC mute time is expired, the LED input must be kept low for FAULT status to return to high.

n. The delay time when V_{DD2} exceeds the UVLO+ threshold to 50% of the V_{OUTP} high level output.

o. The delay time when V_{DD2} exceeds the UVLO- threshold to 50% of the V_{OUTN} low level output.

p. Common mode transient immunity in the high state is the maximum tolerable dV_{CM}/dt of the common mode pulse, V_{CM}, to assure that the output will remain in the high state (that is, $V_{DD2} - V_{OUTP} < 1.0V$ or FAULT > 2V). V_{DD2} must be higher than V_{UVLO+}.

q. Split resistor network in the ratio 3:1 with 324Ω at the anode and 107Ω at the cathode.

r. Common mode transient immunity in the low state is the maximum tolerable dV_{CM}/dt of the common mode pulse, V_{CM}, to assure that the output will remain in a low state (that is, $V_{OUTN} - V_{SS2} < 1.0V$ or FAULT > 2 V). V_{DD2} must be higher than V_{UVLO+}.

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Table 7: Package Characteristics

Parameter	Symbol	Min.	Typ.	Max.	Units	Test Conditions	Fig.	Note
Input-Output Momentary Withstand Voltage	V_{ISO}	5000		—	V_{RMS}	RH < 50%, t = 1 min.ute, T_A = 25°C		a, b, c
Input-Output Resistance	R_{I-O}	—	> 10^9	—	Ω	V_{I-O} = 500V		c
Input-Output Capacitance	C_{I-O}	—	1.3	—	pF	freq = 1 MHz		
Thermal Coefficient Between:		—			°C/W			d
LED and Output IC	A_{EO}	33.1	—	—				
LED and Ambient	A_{EA}	176.1	—	—				
Output IC and Ambient	A_{OA}	76.7	—	—				

a. In accordance with UL1577, each optocoupler is proof tested by applying an insulation test voltage ≥ 6000 Vrms for 1 second. This test is performed before the 100% production test for partial discharge (method b) shown in IEC/EN/DIN EN 60747-5-5 Insulation Characteristic Table, if applicable.

b. The input-output momentary withstand voltage is a dielectric voltage rating that should not be interpreted as an input-output continuous voltage rating. For the continuous voltage rating, refer to your equipment level safety specification or the IEC/EN/DIN EN 60747-5-5 Insulation Characteristics Table.

c. The device is considered a two-terminal device: Pins 1 to 8 are shorted together and pins 9 to 16 are shorted together.

d. For further details, see Thermal Calculation.

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Figure 1: V_{OH} vs. Temperature

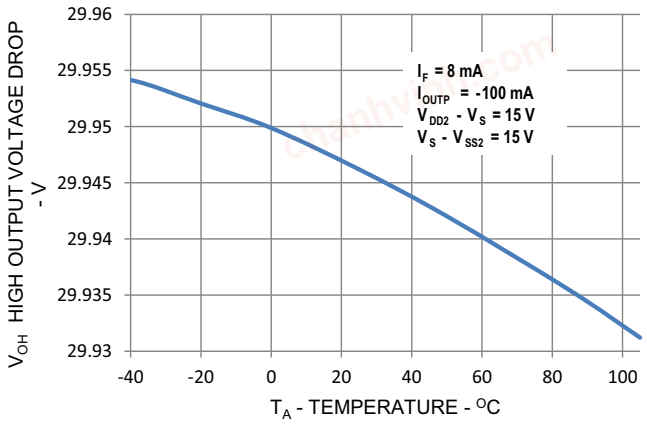


Figure 2: V_{OL} vs. Temperature

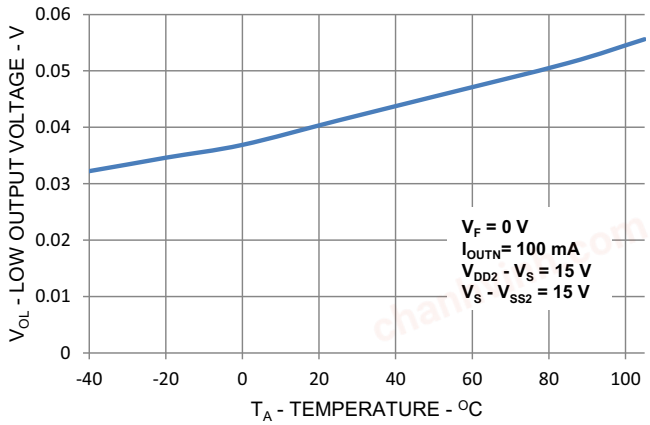


Figure 3: I_{OH} vs. V_{OH}

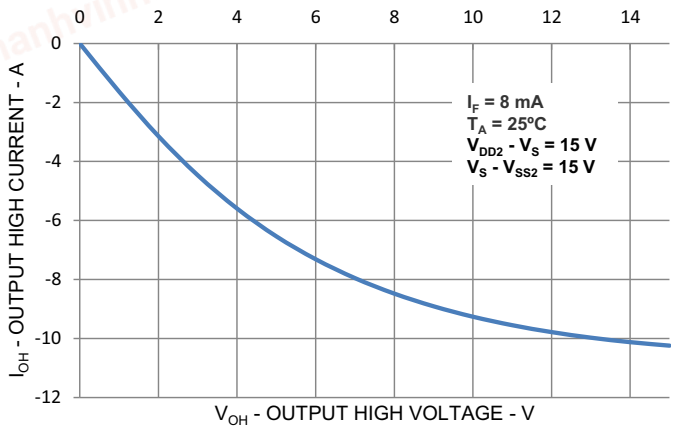


Figure 4: I_{OL} vs. V_{OL}

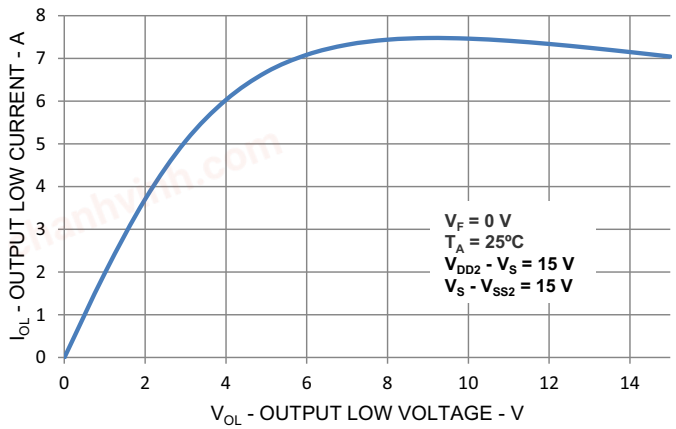


Figure 5: R_{OUTP} vs. Temperature

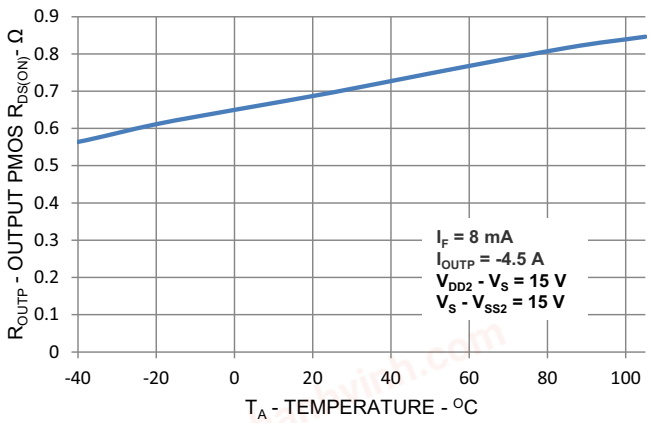
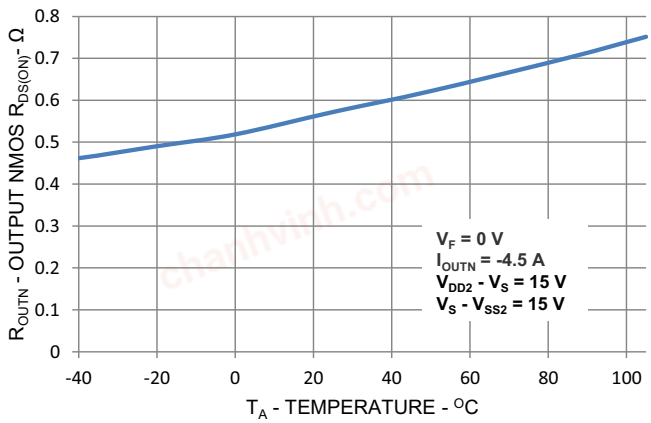


Figure 6: R_{OUTN} vs. Temperature



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Figure 7: I_{CLAMP} vs. Temperature

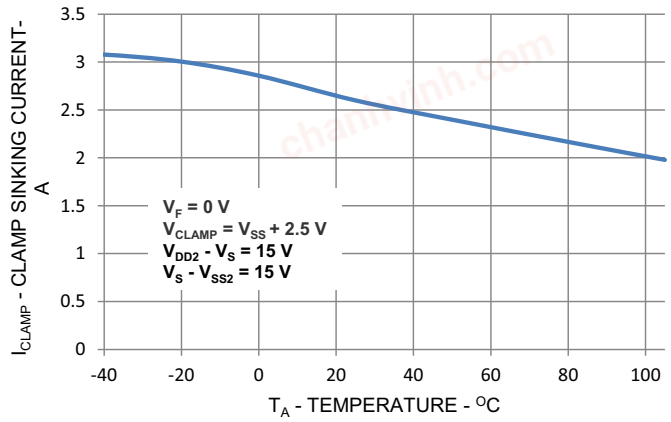


Figure 8: I_{OSS} vs. V_{OSS}

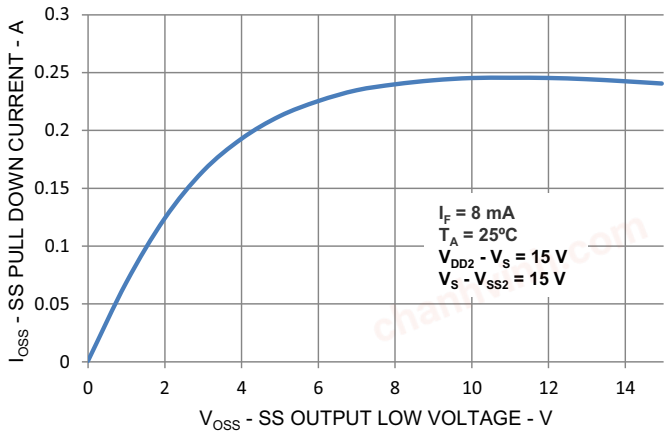


Figure 9: I_{DD2H}/I_{DD2L} vs. Temperature

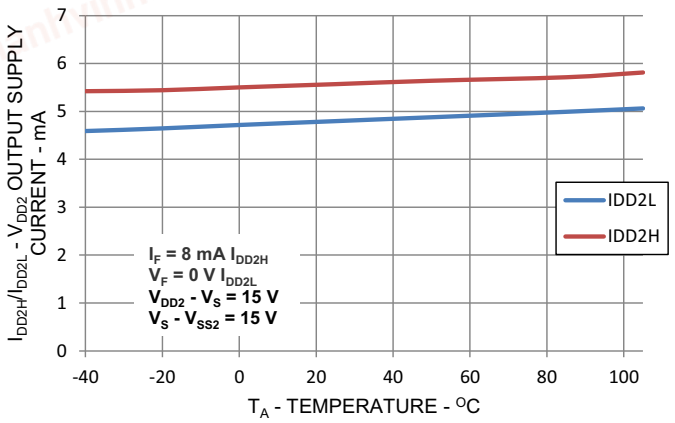


Figure 10: I_{SS2H}/I_{SS2L} vs. Temperature

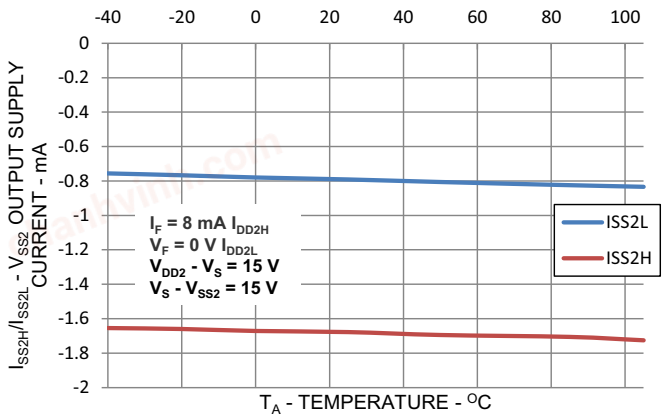


Figure 11: V_{OUTP}/V_{OUTN} vs. I_{FLH}

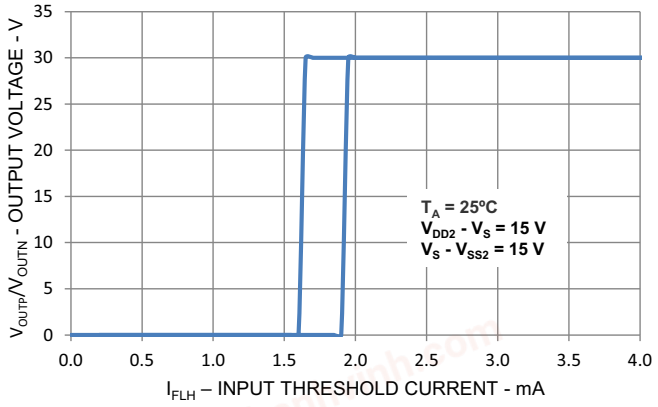
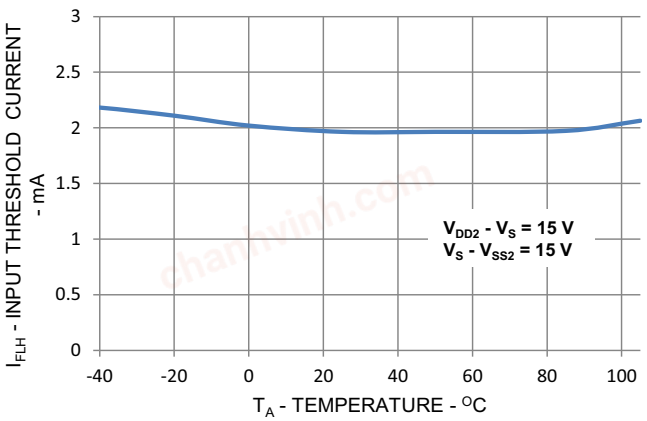


Figure 12: I_{FLH} vs. Temperature



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Figure 13: V_{OC} vs. Temperature

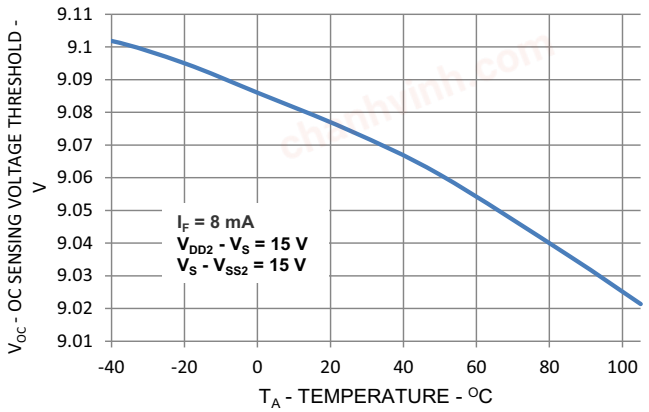


Figure 14: I_{CHG} vs. Temperature

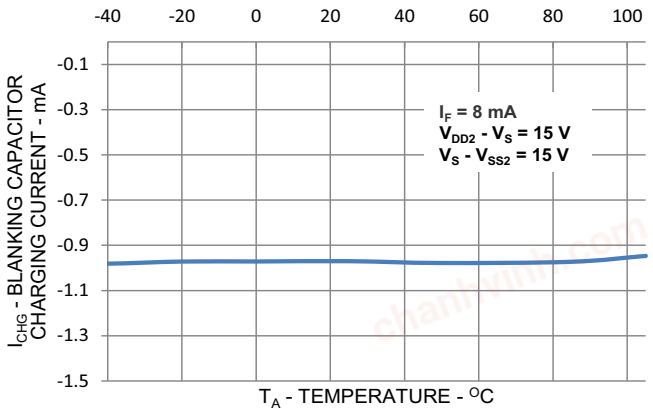


Figure 15: t_{PLH}/t_{PHL} vs. Temperature

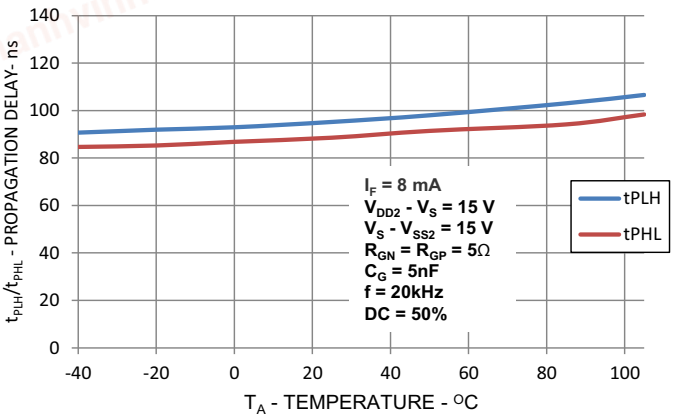


Figure 16: t_{PLH}/t_{PHL} vs. I_F

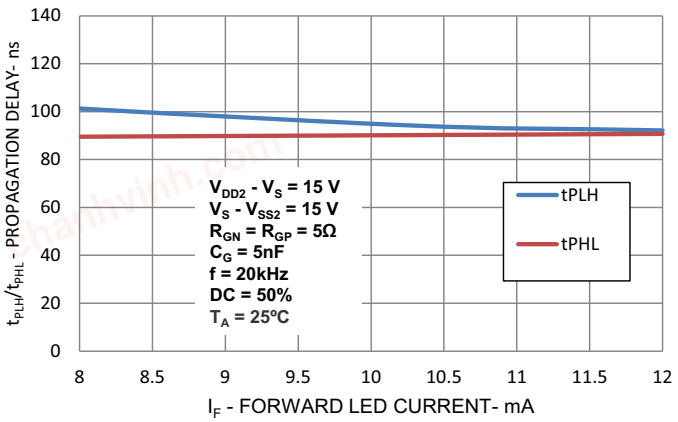


Figure 17: t_{PLH}/t_{PHL} vs. Temperature

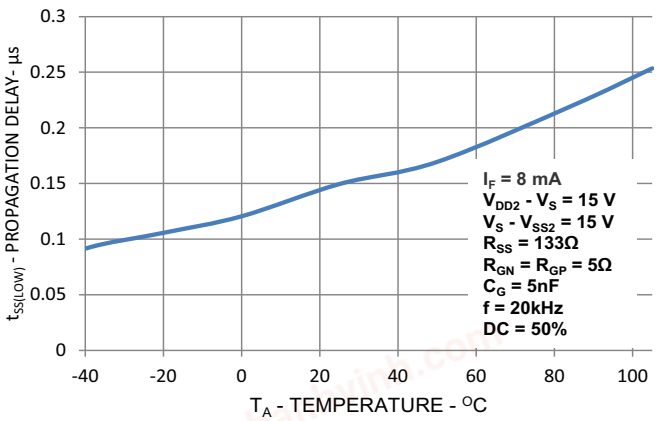
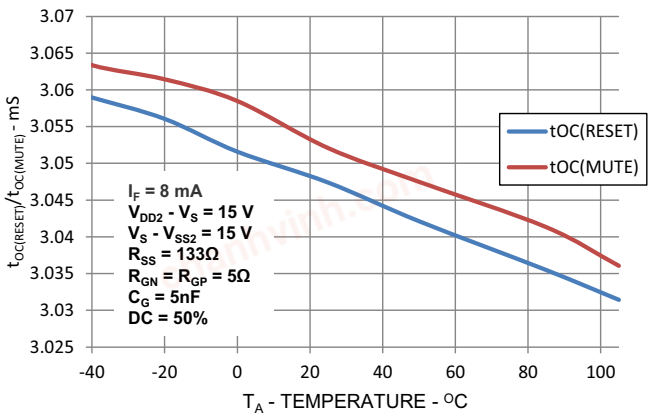


Figure 18: $t_{OC(RESET)}/t_{OC(MUTE)}$ vs. Temperature

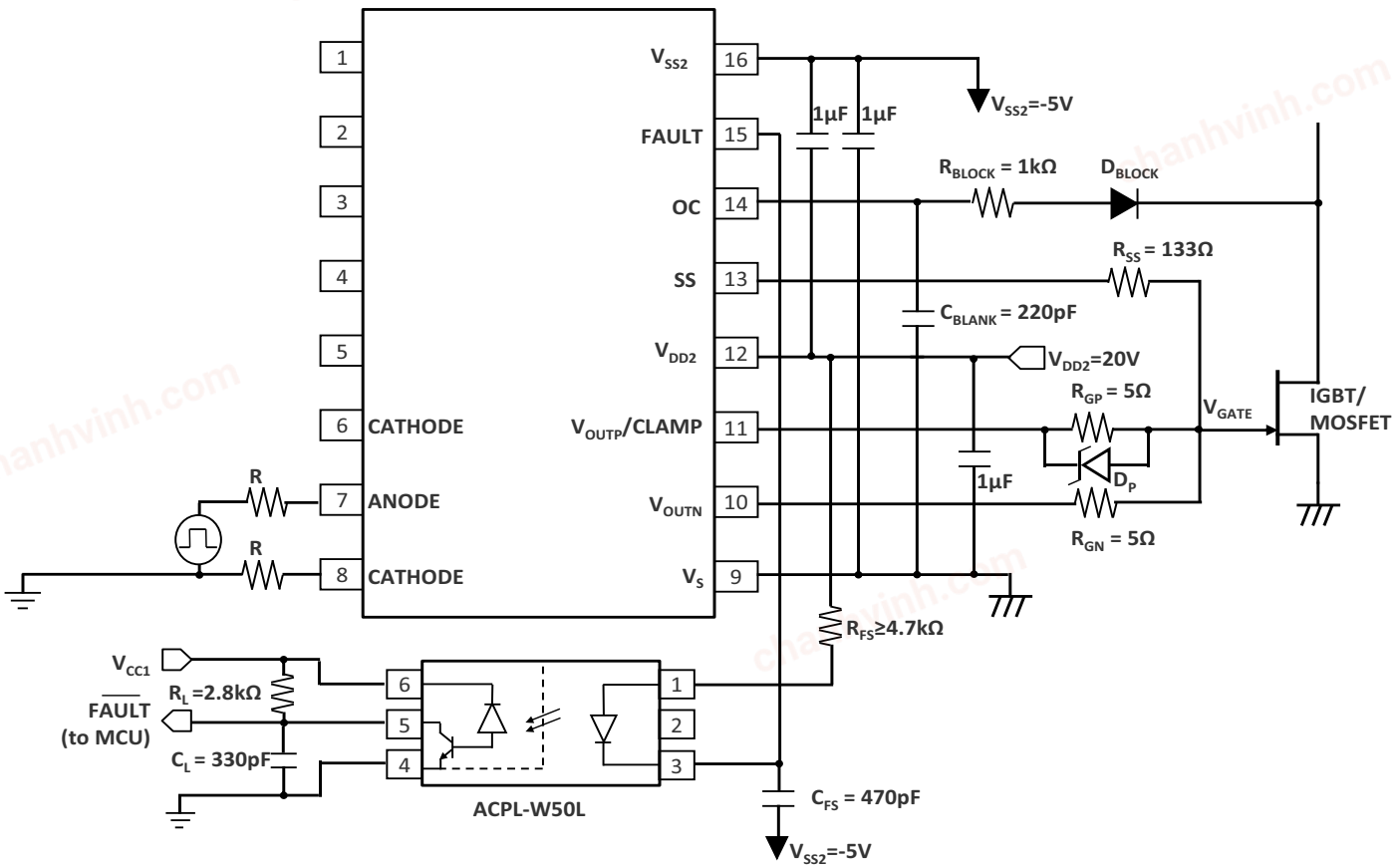


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Applications Information

Recommended Application Circuit

Figure 19: Recommended Application Circuit for the ACPL-351J



The ACPL-351J has an LED input control and overcurrent fault reporting mechanisms through the external feedback optocoupler. The supply V_{DD2} is connected to four 1-µF bypass decoupling capacitors to provide the large transient currents necessary during a switching transition.

The two resistors (R) connected to the input LED's anode and cathode are recommended to be split in the ratio of 3:1. They help to balance the common mode impedances at the LED's anode and cathode, which equalizes the common mode voltage changes at the anode and cathode to give high CMR performance.

The HV blocking diode, D_{BLOCK}, R_{BLOCK}, and 220-pF blanking capacitors are used to protect the OC pin and prevent false fault detection. During overcurrent fault conditions, the IGBT/MOSFET is soft shut down through the SS pin and the rate of shut down can be adjusted by R_{SS}.

The gate resistor (R_{GP} and R_{GN}) serves to limit the gate current and indirectly control the IGBT/MOSFET switching times. The Schottky diode, D_P, is used together with the CLAMP function to shunt parasitic IGBT/MOSFET Miller current during the off cycle.

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C_{FS} filters noise from turning on the external feedback LED during normal operation. During an overcurrent fault condition, the FAULT pin pulls to V_{SS2} to turn on the external LED to feedback to the MCU.

Output Control

The secondary output stage (V_{OUT}, CLAMP, OC, and SS) is controlled by the combination of V_{DD2}, LED current (I_F) and overcurrent (OC) conditions. The following table shows the logic truth table for these outputs. The logic level is defined by the respective threshold of each function pin.

Condition	Inputs			Secondary Outputs			Fault Reporting Output
	V_{DD2}	I_F	OC	V_{OUTN}	V_{OUTP}/CLAMP	SS	FAULT
V_{DD2} UVLO	Low	X	Not Active	Low	Low(CLAMP)	High-Z	High
Overcurrent	High	Low	Not Active	Low	Low(CLAMP)	High-Z	High
	High	High	Active(OC)	High-Z	Low(CLAMP)	Low	Low
Normal Switching	High	Low	Not Active	Low	Low(CLAMP)	High-Z	High
	High	High	Active(no OC)	High-Z	High(V_{OUTP})	High-Z	High

Introduction to Overcurrent (or DESAT) Detection and Protection

The power stage of a typical three-phase inverter is susceptible to several types of failures, most of which are potentially destructive to the power IGBT/MOSFET. These failure modes can be grouped into four basic categories: phase, rail supply short circuits, or both due to user misconnect or bad wiring; control signal failures due to noise or computational errors; overload conditions induced by the load; and component failures in the gate drive circuitry. Under any of these fault conditions, the current through the IGBT/MOSFET can increase rapidly, causing excessive power dissipation and heating. The IGBT/MOSFET becomes damaged when the current load approaches the saturation current of the device, and the collector/drain to emitter/source voltage rises above the saturation voltage level. The drastically increased power dissipation quickly overheats the power device and destroys it. To prevent damage to the drive, fault protection must be implemented to reduce or turn off the IGBT/MOSFET during a fault condition.

The ACPL-351J OC pin monitors the drain/source voltages of the MOSFET or the collector/emitter voltages of the IGBT. When the MOSFET goes into overcurrent or IGBT into desaturation, these voltages exceed the predetermined threshold, V_{OC}. The ACPL-351J triggers a local fault shutdown sequence and slowly reduces the high overcurrent to prevent damaging voltage spikes. The fault is reported to the controller through the external feedback optocoupler.

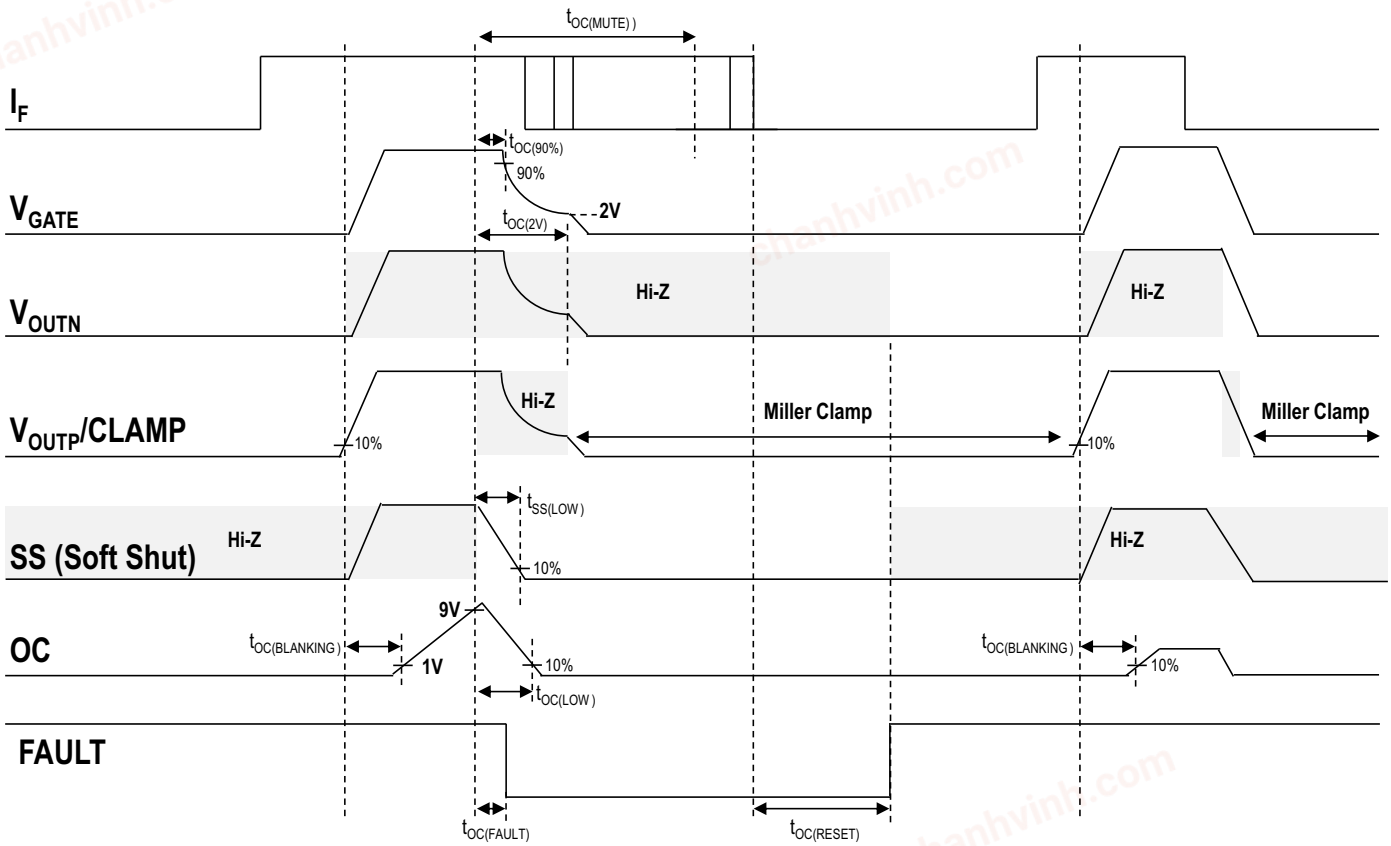
During the off state (no LED input) of the IGBT, the fault detect circuitry is disabled to prevent false “fault” signals.

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Description of Operation During an Overcurrent Condition

1. The OC terminal monitors IGBT's V_{CE} or MOSFET V_{DS} voltage.
2. When the voltage on the OC terminal exceeds 9V, the output voltages (V_{OUTP} and V_{OUTN}) go to Hi-Z state, and the SS pulls down the V_{GATE} at a slow rate adjustable using resistor R_{SS}.
3. The FAULT pin pulls to V_{SS2} to turn on the external feedback optocoupler and notifies the microcontroller of the fault condition.
4. The microcontroller takes the appropriate action.
5. When $t_{OC(MUTES)}$ expires, the LED input must be kept low for $t_{OC(RESET)}$ before the fault condition is cleared. FAULT status will return to high, and SS output will return to Hi-Z state.
6. In the event that the LED goes high during $t_{OC(RESET)}$, the $t_{OC(RESET)}$ timing will reset, and the LED input will need to be kept low for another $t_{OC(RESET)}$ before the fault condition is cleared.
7. V_{GATE} starts to respond to the LED input after the fault condition is cleared.

Figure 20: Circuit Behaviors During an Overcurrent Event



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OC Fault Detection Blanking Time

The OC fault detection circuitry must remain disabled for a short time period following the turn-on of the IGBT to allow the collector voltage to fall below the OC threshold. This time period, called the total OC blanking time, is controlled by the both internal OC blanking time $t_{OC(BLANKING)}$ (Figure 20) and external blanking time, determined by internal charge current, the OC voltage threshold, and the external blanking capacitor.

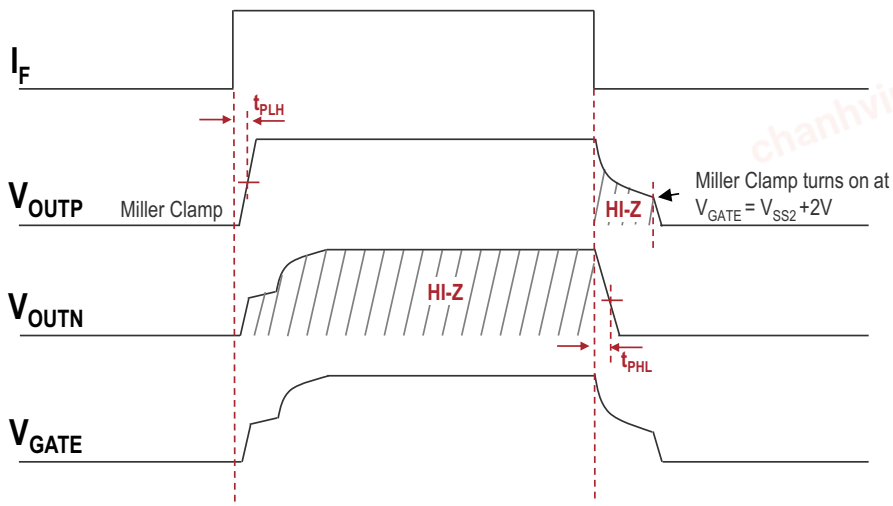
The total blanking time is calculated in terms of internal blanking time ($t_{OC(BLANKING)}$), external capacitance (C_{BLANK}), FAULT threshold voltage (V_{OC}), and blanking capacitor charge current (I_{CHG}) as follows.

$$t_{BLANK} = t_{OC(BLANKING)} + C_{BLANK} \times (V_{OC} / I_{CHG})$$

Description of Gate Driver and Miller Clamping

The gate driver is directly controlled by the LED current. When LED current is driven high, the output of the ACPL-351J is capable of delivering 5A maximum sourcing current to drive the IGBT's/MOSFET's gate. While the LED is switched off, the gate driver can provide 5A maximum sinking current to switch the gate off fast. An additional Miller clamping pull-down transistor is activated when the output voltage reaches about 2V with respect to V_{SS2} to provide low impedance path to the Miller current as shown in Figure 21.

Figure 21: Gate Drive Signal Behavior

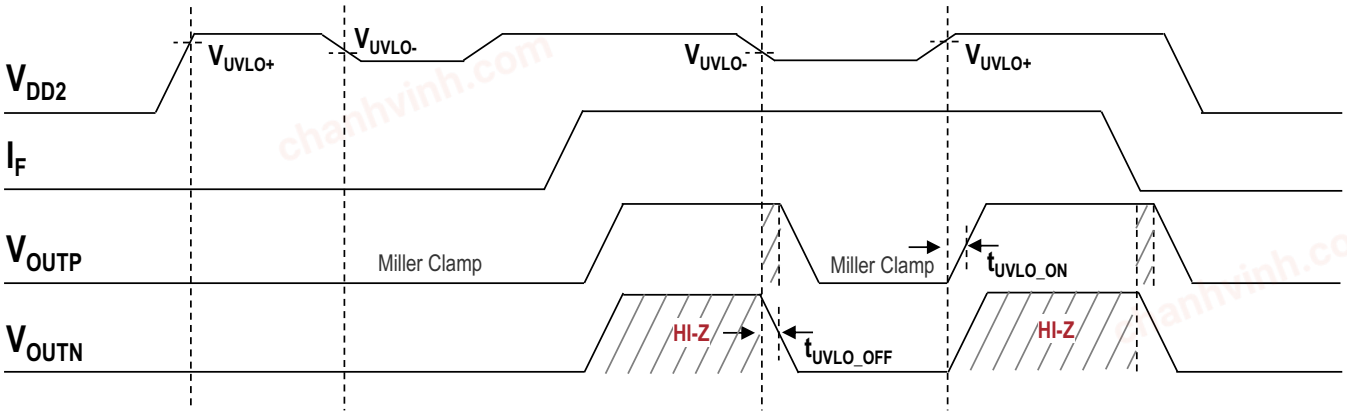


Description of Under Voltage Lockout

Insufficient gate voltage to IGBT/MOSFET can increase turn-on resistance of IGBT/MOSFET, resulting a large power loss and IGBT/MOSFET damage due to high heat dissipation. The ACPL-351J monitors the output power supply, V_{DD2}, constantly. When the output power supply is lower than the under voltage lockout (UVLO) threshold, the gate driver output shuts off to protect IGBT/MOSFET from low voltage bias. During power up, the UVLO feature locks the gate driver output low to prevent unwanted turn on at the lower supply voltage.

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Figure 22: Circuit Behaviors at Power Up and Power Down



Selecting the Gate Resistor (Rg)

Step 1: Calculate R_G minimum from the $I_{O(PEAK)}$ specification. The IGBT/MOSFET and R_G in Figure 19 can be analyzed as a simple RC circuit with a voltage supplied by the ACPL-351J.

$$R_G \geq \frac{V_{DD2}-V_{SS2}}{I_{OPEAK}} - R_{OUTP(MIN)}$$
$$= \frac{20-(-5)V}{5A} - 0.4\Omega$$
$$= 4.6\Omega$$

or

$$R_G \geq \frac{V_{DD2}-V_{SS2}}{I_{OPEAK}} - R_{OUTN(MIN)}$$
$$= \frac{20-(-5)V}{5A} = 0.3\Omega$$
$$= 4.7\Omega$$

The external gate resistor, R_G, and internal minimum turn-on resistance, R_{DSON}, ensure that the output current does not exceed the device absolute maximum rating of 5A. In this case, use as the worst case, $R_G \geq 4.8\Omega$.

Step 2: Check the ACPL-351J power dissipation and increase R_G if necessary. The ACPL-351J total power dissipation (P_T) is equal to the sum of the LED power (P_E) and the output IC power (P_O).

$P_T = P_E + P_O$

Assuming operation conditions of I_F = 8 mA, R_G = 4.8Ω, maximum duty cycle = 80%, Q_G = 0.5 µC, f = 100 kHz, and T_A = 80°C.

Calculation of LED Power Dissipation

$P_E = I_F \times V_F \times$ Duty Cycle
$= 8\text{ mA} \times 1.95\text{V} \times 0.8 = 12.5\text{ mW}$

Calculation of Output IC Power Dissipation

$P_O = P_{O(BIAS)} + P_{O(SWITCHING)}$
$= I_{DD2} \times (V_{DD2} - V_{SS2}) + P_{HS} + P_{LS}$
$P_{HS} = (V_{DD2} \times Q_G \times f) \times R_{OUTP(MAX)} / (R_{OUTP(MAX)} + R_G) / 2$
$P_{LS} = (V_{DD2} \times Q_G \times f) \times R_{OUTN(MAX)} / (R_{OUTN(MAX)} + R_G) / 2$

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P_{HS} = (25V × 0.5 µC × 100 kHz) × 1.5Ω / (1.5Ω + 4.8Ω) / 2 = 148.81 mW
P_{LS} = (25V × 0.5 µC × 100 kHz) × 1.2Ω / (1.2Ω + 4.8Ω) / 2 = 125.0 mW
P_O = 7.5 mA × 25V + 148.81 mW + 125.0 mW
= 461.3 mW < 600 mW ($_{PO(MAX)}$ at 95°C)

The value of 7.5 mA for I_{DD2} in the previous equation is the maximum I_{CC2} over the entire operating temperature range.

Because P_O is less than $P_{O(MAX)}$, Rg = 4.8Ω is correct for the power dissipation.

Thermal Calculation

The application and environmental design for the ACPL-351J must ensure that the junction temperature of the internal IC and LED within the gate driver optocoupler does not exceed 125°C. The following equations calculate the maximum power dissipation effect on junction temperatures.

LED Junction Temperature, $T_E = (A_{EA} \times P_E) + (A_{EO} \times P_O) + T_A$
$= (176.1°C/W \times 12.5\ mW) + (33.1°C/W \times 461.3\ mW) + 80°C$
$= 97.5°C$

Output IC Junction Temperature, $T_O = (A_{EO} \times P_E) + (A_{OA} \times P_O) + T_A$
$= (33.1°C/W \times 12.5\ mW) + (76.7°C/W \times 461.3\ mW) + 80°C$
$= 115.8°C$

Overcurrent Blocking Diodes and Threshold

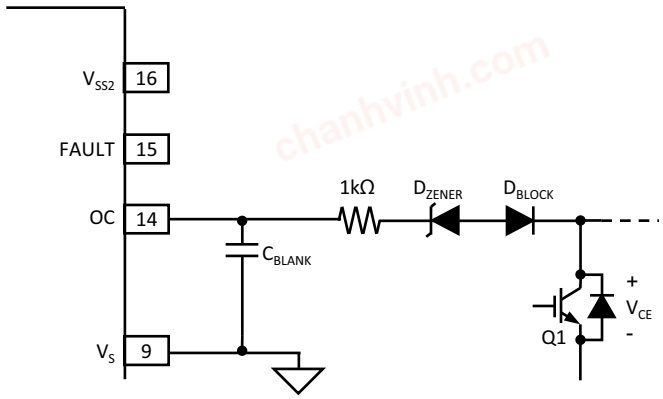
The D_{BLOCK} diode's function is to conduct forward current, allowing sensing of the IGBT's V_{CE} or MOSFET's V_{DS} when it is "on" and to block high voltages when it is "off".

During IGBT/MOSFET switching off and towards the end of the forward conduction of the D_{BLOCK} diode, a reverse current flows for a short time. This reverse recovery effect causes the diode to not be able to achieve its blocking capability until the mobile charge in the junction is depleted. During this time, there is commonly a very high dV/dt voltage ramp rate across the IGBT/MOSFET. This results in $I_{CHARGE} = C_{D\text{-}BLOCK} \times dV/dt$ charging current, which will charge the blanking capacitor, C_{BLANK}. To minimize this charging current and avoid false overcurrent triggering, it is best to use fast response diodes.

In the recommended application circuit shown in Figure 23, the voltage on pin 14 (OC) is $V_{OC} = V_F + V_{CE}$ (where V_F is the forward ON voltage of D_{BLOCK}, and V_{CE} is for example, the IGBT collector-to-emitter voltage). The value of $V_{OC,FAULT(TH)}$, which triggers OC to signal a FAULT condition, is nominally 9V – V_F. If desired, this threshold voltage can be decreased by using multiple D_{BLOCK} diodes or low voltage Zener diode in series. If n is the number of D_{BLOCK} diodes, the nominal threshold value becomes $V_{OC,FAULT(TH)} = 9V - n \times V_F$. If a Zener diode is used, the nominal threshold value becomes $V_{OC,FAULT(TH)} = 7V - V_F - V_Z$. In the case of using two diodes instead of one, diodes with half of the total required maximum reverse-voltage rating may be chosen.

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Figure 23: OC Blocking Diodes and Threshold



OC Pin Protection Resistor

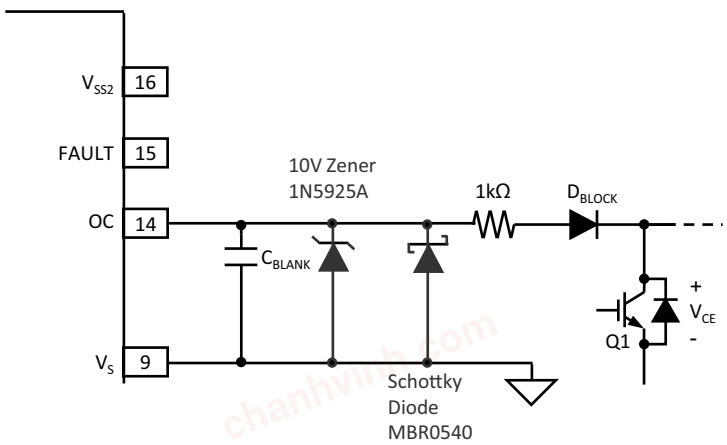
The freewheeling of flyback diodes connected across the IGBT/MOSFET can have large instantaneous forward voltage transients that greatly exceed the nominal forward voltage of the diode. This may result in a large negative voltage spike on the OC pin, which will draw substantial current out of the driver if protection is not used. To limit this current to levels that will not damage the driver IC, insert a 1-kΩ resistor in series with the D_{BLOCK} diode.

False Fault Prevention Diodes

One of the situations that may cause the driver to generate a false fault signal is if the substrate diode of the driver becomes forward biased. This can happen if the reverse recovery spikes coming from the IGBT/MOSFET freewheeling diodes bring the OC pin below ground. Hence, the OC pin voltage will be “brought” above the threshold voltage. This negative going voltage spikes are typically generated by inductive loads or reverse recovery spikes of the IGBT/MOSFETs free-wheeling diodes. To prevent a false fault signal, connect a Zener diode and Schottky diode across the OC pin and V_S pin

This circuit solution is shown in Figure 24. The Schottky diode prevents the substrate diode of the gate driver optocoupler from being forward biased while the Zener diode (value around 10V) is used to prevent any positive high transient voltage to affect the OC pin.

Figure 24: False Fault Prevention Diodes

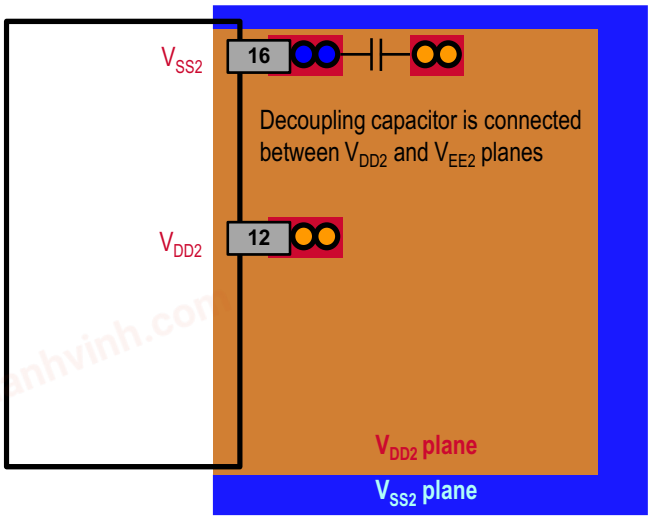


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Supply and Ground Planes Layout and Loading Conditions

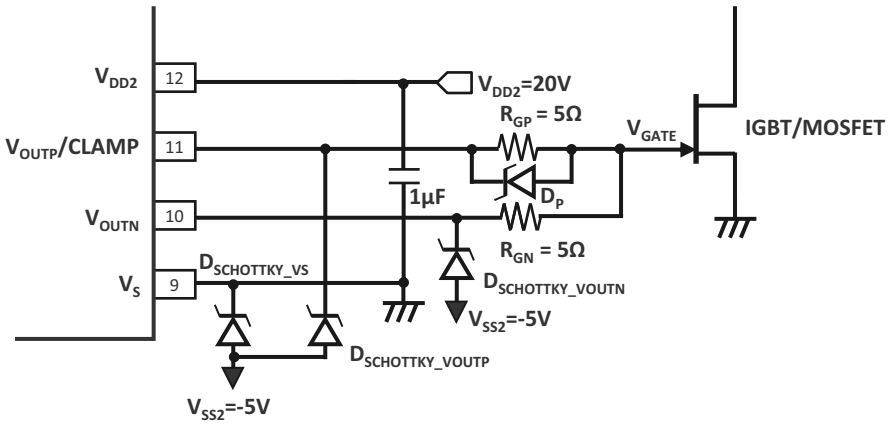
At 5A rated high current switching, the decoupling capacitor must be close to the V_{DD} and V_{SS} pins. Due to the fast switching, large V_{DD} and V_{SS} planes are recommended to prevent noise by lowering the parasitic inductance. Without the V_{DD} and V_{SS} planes, it is recommended to connect total load bigger than 2 nF during all applications or board testing to prevent output noise.

Figure 25: Recommended V_{DD2} and V_{SS2}, Supply and Ground Planes Layout.



Output Noise Prevention Diodes

Figure 26: Recommended Schottky Diodes to Prevent Output Noise



The output, V_{GATE} can be disturbed due to negative transient caused by parasitic inductance. This might cause noise at the V_{GATE} if voltage at V_{OUT} or V_S goes below the most negative potential of V_{SS}. Schottky diodes, $D_{SCHOTTKY_VOUTP}$, $D_{SCHOTTKY_VOUTN}$, or $D_{SCHOTTKY_VS}$ can be used to prevent the noise if any of these nodes experience negative transient caused by parasitic inductance.

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