

## ACFJ-3530T

### Automotive Gate Drive Optocoupler with Integrated Flyback DC-DC Controller, IGBT Desat Sensing, Active Miller Clamping, UVLO Feedback and Negative Bias

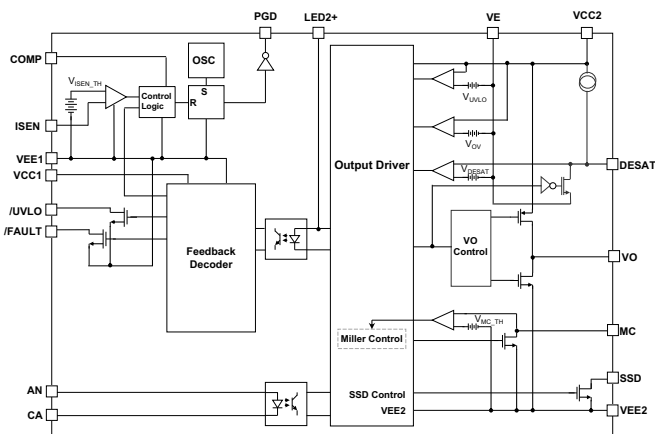
#### Description

The Broadcom® Automotive Optocoupler Smart Gate Driver features integrated flyback controller for isolated DC-DC converter, IGBT desaturation sensing with soft-shutdown protection and fault feedback, under voltage lockout with feedback, and active Miller current clamping. The fast propagation delay with excellent timing skew performance enables excellent timing control and efficiency. This full feature optocoupler comes in a compact, surface-mountable SO-24 package with 0.8-mm pitch for space-savings, is suitable for HEV and EV applications.

Broadcom R<sup>2</sup>Coupler™ isolation products provide reinforced insulation and reliability that deliver safe signal isolation critical in automotive and high-temperature industrial applications.

#### Functional Diagram

Figure 1: ACFJ-3530T Functional Diagram



#### Features

- Qualified to AEC-Q100 Grade 1 Test Guidelines
- Automotive temperature range:  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$
- Integrated flyback controller for isolated DC-DC converter for power supply control and diagnostic
  - Regulated output supply voltage:  $16\text{V} \pm 5\%$
  - Programmable negative supply
  - Supply output over load protection
  - Supply output short circuit protection
  - External primary switch good for Load Dump test conditions and high power scaling
- Minimum peak output current:  $-1.5\text{A}/+1.5\text{A}$
- Minimum Miller clamp sinking current: 2A
- Maximum propagation delay: 200 ns
- Integrated fail-safe IGBT protection
  - IGBT Desat over-current sensing, "Soft" IGBT turnoff and fault feedback
  - Under Voltage Lock-Out protection (UVLO) with feedback
- High noise immunity
  - Common Mode Rejection (CMR):  $50\text{kV}/\mu\text{s}$  at  $\text{VCM} = 1500\text{V}$
  - Miller current clamping
  - Direct LED input with low input impedance and low noise sensitivity
  - Negative gate bias
- SO-24 package with 8-mm creepage and clearance
- Regulatory approvals:
  - UL1577, CSA
  - IEC 60747-5-5

#### Applications

IGBT/SiC MOSFET gate driver for traction inverter, charger, and HVAC

# Ordering Information

Part Number	Option (RoHS Compliant)	Package	Surface Mount	Tape and Reel	IEC/EN/DIN EN 60747-5-5	Quantity
ACFJ-3530T	-000E	SO-24	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.

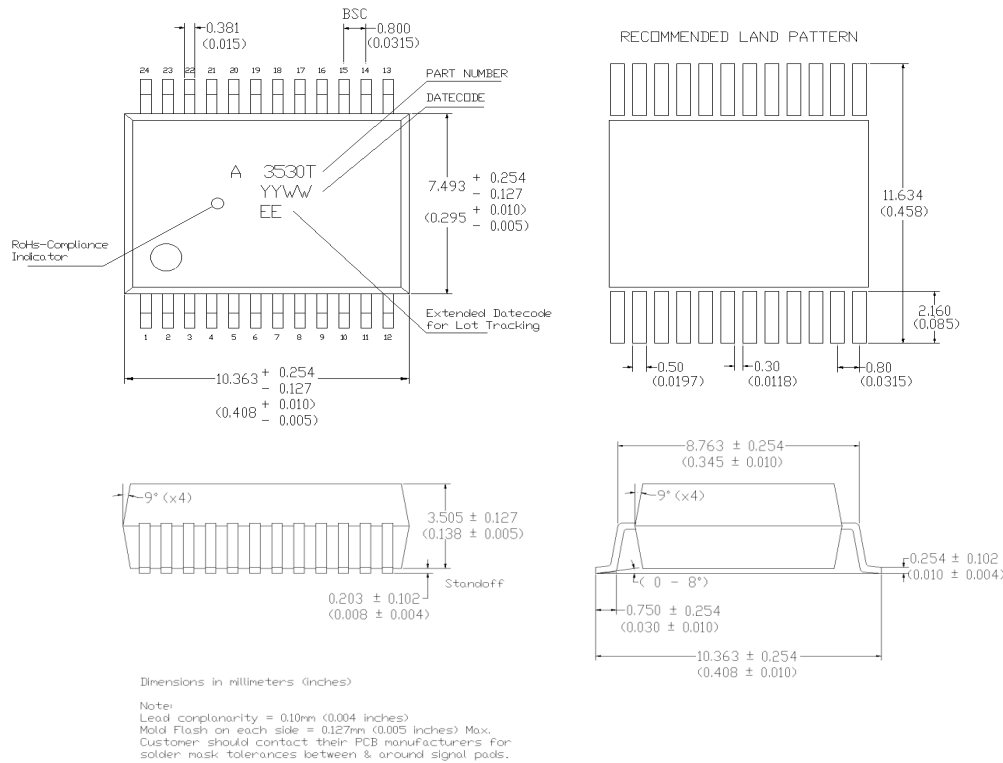
Example 1:

ACFJ-3530T-500E to order product of SO-24 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.

# Package Outline Drawing

Figure 2: Package Outline Drawing (24-Lead Surface Mount)



# Recommended PB-Free IR Profile

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

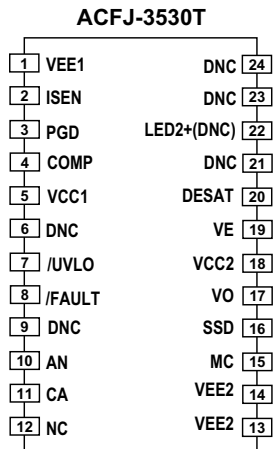
**NOTE:** Non-halide flux should be used.

## Product Overview Description

The ACFJ-3530T (shown in [Figure 1](#)) is a highly integrated power control device that incorporates all the necessary components for a complete, isolated IGBT gate drive circuit. It features flyback controller for isolated DC-DC converter, a high-current gate driver, Miller current clamping, IGBT desaturation over-current protection, supply under voltage lock-out protection and feedback in a SO-24 package. Direct LED input allows flexible logic configuration and differential current mode driving with low input impedance, greatly increased its noise immunity.

## Package Pin Out

Figure 3: ACFJ-3530T Pin Configuration



## Pin Description

Pin Number	Pin Name	Description
1	VEE1	Input ground
2	ISEN	Current sense for flyback controller
3	PGD	Primary gate driver for external MOSFET
4	COMP	Compensation network for flyback controller
5	VCC1	Input power supply
6	DNC	Do not connect (internally connected to VEE1 lead frame)
7	/UVLO	Under-voltage feedback for VCC1; under-voltage lock out feedback for VCC2; over-voltage feedback for VCC2
8	/FAULT	Desaturation fault feedback
9	DNC	Do not connect (internally connected to input LED cathode lead frame)
10	AN	Input LED anode
11	CA	Input LED cathode
12	NC	No connection
13	VEE2	Output ground (connect decoupling capacitor to VCC2 and VEE2 planes through vias locally)
14	VEE2	Output ground (connect decoupling capacitor to VCC2 and VEE2 planes through vias locally)
15	MC	Miller current clamping output
16	SSD	Soft shutdown driver
17	VO	Output driver for IGBT/MOSFET gate
18	VCC2	Output power supply (connect decoupling capacitor to VCC2 and VEE2 planes through vias locally)
19	VE	IGBT emitter/MOSFET source reference
20	DESAT	Desaturation over-current sensing
21	DNC	Do not connect (internally connected to LED2+ lead frame)
22	LED2+(DNC)	Do not connect, for testing only
23	DNC	Do not connect (internally connected to VEE2 lead frame)
24	DNC	Do not connect (internally connected to VEE2 lead frame)

## Approvals

The ACFJ-3530T is approved by the following organizations.

UL	CSA	IEC/EN/DIN EN 60747-5-5
Approved under UL 1577, component recognition program up to $V_{ISO} = 5000 V_{RMS}$	Approved under CSA Component Acceptance Notice #5, File CA 88324	Approved under: IEC 60747-5-5, EN 60747-5-5, DIN EN 60747-5-5

## IEC/EN/DIN EN60747-5-5 Insulation Characteristics

Description	Symbol	Characteristic	Units
Insulation Classification per DIN VDE 0110/1.89, Table 1 for rated mains voltage $\leq 150 V_{rms}$ for rated mains voltage $\leq 300 V_{rms}$ for rated mains voltage $\leq 600 V_{rms}$ for rated mains voltage $\leq 1000 V_{rms}$		I - IV I - IV I - IV I - III	
Climatic Classification		40/125/21	
Pollution Degree (DIN VDE 0110/1.89)		2	
Maximum Working Insulation Voltage	$V_{IORM}$	1230	$V_{PEAK}$
Input to Output Test Voltage, Method b $V_{IORM} \times 1.875 = V_{PR}$ , 100% Production Test with $t_m = 1s$ , Partial Discharge $< 5 pC$	$V_{PR}$	2306	$V_{PEAK}$
Input to Output Test Voltage, Method a $V_{IORM} \times 1.6 = V_{PR}$ , Type and Sample Test, $t_m = 10s$ , Partial Discharge $< 5 pC$	$V_{PR}$	1968	$V_{PEAK}$
Highest Allowable Overvoltage (Transient Overvoltage $t_{ini} = 60s$ )	$V_{IOTM}$	8000	$V_{PEAK}$
Safety-Limiting Values – maximum values allowed in the event of a failure			
Case Temperature	$T_S$	175	$^{\circ}C$
Input Power	$P_{S,INPUT}$	400	mW
Output Power	$P_{S,OUTPUT}$	1200	mW
Insulation Resistance at $T_S$ , $V_{IO} = 500V$	$R_S$	$> 10^9$	$\Omega$

### NOTE:

1. Isolation characteristics are guaranteed only within the safety maximum ratings which must be ensured by protective circuits in application. Surface mount classification is class A in accordance with CECC00802.
2. Refer to the optocoupler section of the Isolation and Control Components Designer's Catalog, under Product Safety Regulation section IEC/EN/DIN EN 60747-5-5, for a detailed description of Method a and Method b partial discharge test profiles.

## Insulation and Safety Related Specifications

Parameter	Symbol	Value	Units	Conditions
Minimum External Air Gap (Clearance)	L(101)	8.3	mm	Measured from the input terminals to the output terminals, shortest distance through the air.
Minimum External Tracking (Creepage)	L(102)	8.3	mm	Measured from the input terminals to the output terminals, shortest distance path along the 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)

## ESD Ratings

Parameter	Classification	Note
Human Body Model	H2	Per AEC Q100-002
Charge Device Model	C4B	Per AEC Q100-011

## Absolute Maximum Ratings

Unless otherwise specified, all voltages at input IC reference to  $V_{EE1}$ , all voltages at output IC reference to  $V_{EE2}$ .

Parameter	Symbol	Min.	Max.	Units	Note
Storage Temperature	$T_S$	-55	150	°C	
Operating Temperature	$T_A$	-40	125	°C	
IC Junction Temperature	$T_J$	—	150	°C	
Average LED Input Current	$I_{F(AVG)}$	—	20	mA	
Peak Transient LED Input Current (< 1- $\mu$ s pulse width, 300 pps)	$I_{F(TRAN)}$	—	1	A	
LED Reverse Input Voltage ( $V_R$ )	$V_{CA} - V_{AN}$	—	6	V	
ISEN Pin Voltage	$V_{ISEN}$	-0.5	6	V	a
Primary Gate Driver Voltage	$V_{PGD}$	-0.5	6	V	a
COMP Pin Voltage	$V_{COMP}$	-0.5	6	V	a
Input Supply Voltage	$V_{CC1}$	-0.5	6	V	a
/UVLO Pin Voltage	$V_{/UVLO}$	-0.5	6	V	a
/FAULT Pin Voltage	$V_{/FAULT}$	-0.5	6	V	a
/UVLO Output Sinking Current	$I_{/UVLO}$	—	5	mA	
/FAULT Output Sinking Current	$I_{/FAULT}$	—	5	mA	
Total Output Supply Voltage	$V_{CC2}$	-0.5	30	V	b
Positive Output Supply Voltage	$V_{CC2} - V_E$	-0.5	22	V	
Negative Output Supply Voltage	$V_{EE2} - V_E$	-12	0.5	V	
DESAT Pin Voltage	$V_{DESAT} - V_E$	-0.5	$V_{CC2} + 0.5$	V	
Gate Driver Output Voltage, VO	$V_O$	-0.5	$V_{CC2} + 0.5$	V	b
Gate Driver Output Voltage, SSD	$V_{SSD}$	-0.5	$V_{CC2} + 0.5$	V	b
Gate Driver Output Voltage, MC	$V_{MC}$	-0.5	$V_{CC2} + 0.5$	V	b
Peak Output Current, VO	$ I_{O(PEAK)} $	—	2.5	A	c
Output IC Power Dissipation	$P_O$	—	600	mW	d
Input IC Power Dissipation	$P_I$	—	150	mW	e

a. Reference to  $V_{EE1}$ .

b. Reference to  $V_{EE2}$ .

c. Maximum pulse width=1  $\mu$ s, maximum duty cycle=1%.

d. Output IC power dissipation is derated linearly above 105°C from 600 mW to 550 mW at 125°C for high effective thermal conductivity board. For low effective thermal conductivity board, output IC power dissipation is derated linearly above 105°C from 600 mW to 400 mW at 125°C. PCB thermal resistance characteristic has to be considered so as not to exceed absolute maximum rating. See [Thermal Resistance Model for ACFJ-3530T](#) for details.

e. Input IC power dissipation is derated linearly above 105°C from 150 mW to 125 mW at 125°C for high effective thermal conductivity board. For low effective thermal conductivity board, input IC power dissipation is derated linearly above 105°C from 150 mW to 100 mW at 125°C. See [Thermal Resistance Model for ACFJ-3530T](#) for details.

## Recommended Operating Conditions

Unless otherwise specified, all voltages at input IC reference to  $V_{EE1}$ , all voltages at output IC reference to  $V_{EE2}$ .

Parameter	Symbol	Min.	Max.	Units	Note
Operating Temperature	$T_A$	-40	125	°C	
Input IC Supply Voltage	$V_{CC1}$	4.5	5.5	V	a
Positive Output IC Supply Voltage	$V_{CC2} - V_E$	15.2	16.8	V	
Negative Output IC Supply Voltage	$V_{EE2} - V_E$	-10	0	V	b
Input LED Turn On Current	$I_{F(ON)}$	10	16	mA	
Input LED Turn Off Voltage ( $V_{AN} - V_{CA}$ )	$V_{F(OFF)}$	-5.5	0.8	V	
DC-DC Flyback Controller PWM Duty Cycle	$D_{MAX}$	—	50	%	c

- Power-up sequence: Battery supply ( $V_{BAT+}$ ) to the DC-DC flyback transformer must be ready before  $V_{CC1}$  power up. When  $V_{CC1}$  is powered up from 0V to  $V_{UVLO1\_TH+}$ , DC-DC soft start current will start to charge the compensation network which is connected to COMP pin. Subsequently,  $V_{CC2}$  supply will be regulated to 16V. See [Soft Start Operation](#) for details.
- This supply is optional. It is required only when negative gate drive is implemented. Negative gate drive voltage can be programmed easily by connecting a Zener diode from  $V_E$  to  $V_{EE2}$ . Connect  $V_E$  to  $V_{EE2}$  if negative gate drive bias is not required.
- See [Operation of Integrated DC-DC Flyback Controller](#) for details.

## Electrical and Switching Specifications

Unless otherwise specified, all minimum/maximum specifications are at recommended operating conditions; all voltages at input IC reference to  $V_{EE1}$ , all voltages at output IC reference to  $V_{EE2}$ . All typical values at  $T_A = 25^\circ\text{C}$ ,  $V_{CC1} = 5\text{V}$ ,  $V_{CC2} - V_E = 16\text{V}$ ,  $V_E = V_{EE2} = 0\text{V}$ .

Parameter	Symbol	Min.	Typ.	Max.	Units	Test Conditions	Figure	Note
<b>DC-DC Flyback Converter</b>								
$V_{CC1}$ MOS Threshold	$V_{CC1\_MOS\_TH}$	0.5	1.3	1.5	V	$I_{UVLO} = 2\text{ mA}$	29	
$V_{CC1}$ UVLO ON Threshold	$V_{UVLO1\_TH+}$	3.7	4.0	4.3	V		29	
$V_{CC1}$ UVLO Threshold Hysteresis	$V_{UVLO1\_HYS}$	0.08	0.3	0.5	V			
PWM Switching Frequency	$f_{PWM}$	100	135	170	kHz			a
Primary Gate Drive Output High Level	$V_{PGD\_H}$	$V_{CC1} - 0.5$	$V_{CC1} - 0.25$	$V_{CC1} - 0.01$	V	$I_{PGD} = -50\text{ mA}$		
Primary Gate Drive Output Low Level	$V_{PGD\_L}$	0.01	0.2	0.4	V	$I_{PGD} = 50\text{ mA}$		
Primary Gate Drive Rise Time	$t_{r\_PGD}$	10	22	40	ns	$C_{PGD} = 1\text{ nF}$		
Primary Gate Drive Fall Time	$t_{f\_PGD}$	10	19	40	ns	$C_{PGD} = 1\text{ nF}$		
Maximum PWM Duty Cycle	$D_{MAX}$	55	62	69	%		7	b
$I_{SEN}$ Threshold	$V_{ISEN\_TH} - V_{EE1}$	0.16	0.2	0.24	V			
Regulated $V_{CC2}$ Voltage	$V_{CC2} - V_E$	15.2	16	16.8	V	$I_{COMP} = 0\text{ A}$	8	



Parameter	Symbol	Min.	Typ.	Max.	Units	Test Conditions	Figure	Note
<b>IC Supply Current</b>								
Input Supply Current	$I_{CC1}$	3	4.5	6.7	mA	$V_{COMP} = 2.3V$	9	
Output High Supply Current	$I_{CC2H}$	9	13	17	mA	$V_{CC2} - V_E = 16.8V$ $I_F = 10\text{ mA}$ , $V_E - V_{EE2} = 0V$	10	
Output Low Supply Current	$I_{CC2L}$	8	12.5	16	mA	$V_{CC2} - V_E = 16.8V$ $I_F = 0\text{ mA}$ , $V_E - V_{EE2} = 0V$	10	
Output High $V_E$ Supply Current	$I_{EH}$	-1	-1.6	-2.5	mA	$V_{CC2} - V_E = 16.8V$ $I_F = 10\text{ mA}$ , $V_E - V_{EE2} = 8V$	11	
Output Low $V_E$ Supply Current	$I_{EL}$	-1	-1.6	-2.5	mA	$V_{CC2} - V_E = 16.8V$ $I_F = 0\text{ mA}$ , $V_E - V_{EE2} = 8V$	11	
<b>Logic Input and Output</b>								
LED Forward Voltage ( $V_{AN} - V_{CA}$ )	$V_F$	1.25	1.55	1.85	V	$I_F = 10\text{ mA}$	12	
LED Reverse Breakdown Voltage ( $V_{CA} - V_{AN}$ )	$V_{BR}$	6	—	—	V	$I_F = -10\text{ }\mu\text{A}$		
LED Input Capacitance	$C_{IN}$	—	90	—	pF			
LED Turn On Current Threshold, Low to High	$I_{TH+}$	—	3.1	7.5	mA	$V_O > 5V$	13	
LED Turn On Current Threshold, High to Low	$I_{TH-}$	0.3	2.4	—	mA	$V_O < 5V$	13	
LED Turn On Current Hysteresis	$I_{TH\_HYS}$	—	0.6	—	mA			
/UVLO Logic Low Output Voltage	$V_{UVLO\_L}$	—	—	0.4	V	$I_{UVLO} = 3\text{ mA}$		
/UVLO Logic High Output Current	$I_{UVLO\_H}$	—	0.015	1	$\mu\text{A}$	$V_{UVLO} = 5V$		
/FAULT Logic Low Output Voltage	$V_{FAULT\_L}$	—	—	0.4	V	$I_{FAULT} = 3\text{ mA}$		
/FAULT Logic High Output Current	$I_{FAULT\_H}$	—	0.015	1	$\mu\text{A}$	$V_{FAULT} = 5V$		
<b>Gate Driver</b>								
High Level VO Voltage	$V_{OH}$	$V_{CC2} - 0.25$	$V_{CC2} - 0.05$	$V_{CC2} - 0.01$	V	$I_O = -50\text{ mA}$	14	c, d, e
Low Level VO Voltage	$V_{OL}$	0.01	0.05	0.25	V	$I_O = 50\text{ mA}$	15	
Low Level SSD Voltage	$V_{SSD\_L}$	0.01	0.05	0.25	V	$I_{SSD} = 40\text{ mA}$		
High Level VO Current	$I_{OH}$	—	—	-1.5	A	$V_O = V_{CC2} - 5V$		f
Low Level VO Current	$I_{OL}$	1.5	—	—	A	$V_O = 5V$		f
Low Level SSD Current	$I_{SSD\_L}$	2	—	—	A	$V_{SSD} = 7V$	16	f
$V_{IN}$ to High Level VO Propagation Delay Time	$t_{PLH}$	—	110	200	ns	$V_{Source} = 5V$ , $R_{LED} = 260\Omega$ , $R_g = 10\Omega$ , $C_{load} = 1\text{ nF}$ , $f = 10\text{ kHz}$ , Duty cycle = 50%	17, 22	g
$V_{IN}$ to Low Level VO Propagation Delay Time	$t_{PHL}$	—	128	200	ns		17, 22	h
Pulse Width Distortion	PWD	-50	18	100	ns		i, j	
Dead Time Distortion ( $t_{PLH} - t_{PHL}$ )	DTD	-100	-18	50	ns		k	
VO 10% to 90% Rise Time	$t_R$	—	15	—	ns		22	
VO 90% to 10% Fall Time	$t_F$	—	15	—	ns		22	

Parameter	Symbol	Min.	Typ.	Max.	Units	Test Conditions	Figure	Note
Output High Level Common Mode Transient Immunity	$ CM_H $	50	—	—	kV/ $\mu$ s	$T_A = 25^\circ\text{C}$ , $I_F = 10\text{ mA}$ , $V_{CM} = 1500\text{V}$	23	l
Output Low Level Common Mode Transient Immunity	$ CM_L $	50	—	—	kV/ $\mu$ s	$T_A = 25^\circ\text{C}$ , $I_F = 0\text{ mA}$ , $V_{CM} = 1500\text{V}$	24	m
<b>Active Miller Clamp</b>								
Clamp Threshold Voltage	$V_{TH\_CLAMP}$	1.5	2	2.5				
Clamp Low Level Sinking Current	$I_{CLAMP}$	2	3.5	—	A	$V_{CLAMP} =$ $V_{EE2} + 3.5\text{V}$	18	
<b>VCC2 UVLO Protection (UVLO Voltage <math>V_{UVLO}</math> reference to <math>V_E</math>)</b>								
$V_{CC2}$ UVLO Threshold Low to High	$V_{UVLO2\_TH+}$	11.25	12.5	13.75	V	$V_O > 5\text{V}$		e, n
$V_{CC2}$ UVLO Threshold High to Low	$V_{UVLO2\_TH-}$	10.35	11.5	12.65	V	$V_O < 5\text{V}$		e, o
$V_{CC2}$ UVLO Hysteresis	$V_{UVLO2\_HYS}$	0.8	1	1.2	V			
$V_{CC2}$ to /UVLO High Delay	$t_{PLH\_UVLO2}$	—	15	35	$\mu$ s			p
$V_{CC2}$ to /UVLO Low Delay	$t_{PHL\_UVLO2}$	—	38	100	$\mu$ s			q
$V_{CC2}$ UVLO to VO High Delay	$t_{UVLO2\_ON}$	—	2.8	6	$\mu$ s			r
$V_{CC2}$ UVLO to VO Low Delay	$t_{UVLO2\_OFF}$	—	1.9	6	$\mu$ s			s
<b>VCC2 Over-Voltage Protection (OV Voltage <math>V_{OV}</math> reference to <math>V_E</math>)</b>								
$V_{CC2}$ Over Voltage Protection Threshold, Low to High Reference to $V_E$	$V_{OV2\_TH+} - V_E$	18	19.5	21	V			
$V_{CC2}$ Over Voltage Protection Threshold, High to Low Reference to $V_E$	$V_{OV2\_TH-} - V_E$	17	18.5	20	V			
$V_{CC2}$ Over Voltage to /ULVO Flag High Delay	$t_{PLH\_OV2}$	—	8	20	$\mu$ s			t
$V_{CC2}$ Over Voltage to /ULVO Flag Low Delay	$t_{PHL\_OV2}$	—	14	35	$\mu$ s			u
<b>Short Circuit Protection (reference to <math>V_E</math>)</b>								
Desat Sensing Threshold	$V_{DESAT\_TH} - V_E$	8.55	9.1	9.45	V		19	v
Desat Charging Current	$I_{CHG}$	0.925	1.0	1.075	mA	$V_{DESAT} - V_E = 2\text{V}$	20	
Desat Discharging Current	$I_{DSCHG}$	19	60	—		$V_{DESAT} - V_E = 2\text{V}$	21	
VCC2 during Short Circuit Fault Condition	$V_{CC2(Fault)}$	—	16	—	V			
ICC2 during Short Circuit Fault Condition	$I_{CC2(Fault)}$	—	14	—	mA			
Desat Blanking Time	$t_{DESAT(BLANKING)}$	0.1	0.3	0.5	$\mu$ s			w
Desat Sense to 90% $V_{GATE}$ Delay	$t_{DESAT(90\%)}$	0.05	0.10	0.20	$\mu$ s	$R_g = 15\Omega$ , $C_{load} = 1\text{ nF}$		x
Desat Sense to $V_{GATE} = (V_{EE2} + 2\text{V})$ Delay	$t_{DESAT(2V)}$	0.1	0.17	0.3	$\mu$ s			y
Desat Sense to /FAULT Low Signal Delay	$t_{DESAT(/FAULT)}$	2.1	4.2	8	$\mu$ s			z
Output Mute Time Due to Desaturation Sense	$t_{DESAT(MUTE)}$	1.6	3	6	ms			aa
Time Input Kept Low Before /FAULT Reset to High	$t_{DESAT(RESET)}$	1.6	3	6	ms			ab

a. PWM switching frequency of PGD is dithered in a range of  $\pm 6\%$  typically over 3.3 ms.

- b. Maximum PWM duty cycle,  $D_{MAX}$  is the hard limit set by IC for protection purpose. For discontinuous mode (DCM) operation, the maximum duty cycle for transformer design should be limited to 50% under system full load conditions.
- c. For High Level Output Voltage testing,  $V_{O\_H}$  is measured with a dc load current. When driving capacitive loads,  $V_{O\_H}$  will approach  $V_{CC2}$  as  $I_{O\_H}$  approaches zero.
- d. Maximum pulse width = 1.0 ms, maximum duty cycle = 20%.
- e. After  $V_O$  of the ACFJ-3530T is allowed to go high ( $V_{CC2} - V_E > V_{UVLO2\_TH+}$ ), the DESAT detection feature of the ACFJ-3530T will be the primary source of IGBT protection.  $V_{CC2}$  must be greater than  $V_{UVLO2\_TH+}$  threshold to ensure Desat is functional. Desat detection feature will remain functional until  $V_{CC2}$  is below  $V_{UVLO2\_TH-}$  threshold. Thus, the Desat detection and UVLO features of the ACFJ-3530T work in conjunction to ensure constant IGBT protection.
- f. Maximum pulse width = 1  $\mu$ s, maximum duty cycle = 1%.
- g.  $t_{PLH}$  is defined as propagation delay from 50% of input source voltage,  $V_{Source}$  to 50% of High level output.
- h.  $t_{PHL}$  is defined as propagation delay from 50% of input source voltage,  $V_{Source}$  to 50% of Low level output.
- i. Pulse Width Distortion (PWD) is defined as ( $t_{PHL} - t_{PLH}$ ) of any given unit.
- j. As measured from  $I_F$  to output ( $V_O$ ).
- k. Dead Time Distortion (DTD) is defined as ( $t_{PLH} - t_{PHL}$ ) between any two parts under the same test conditions.
- l. Common Mode Transient Immunity (CMTI) 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, Output > 13V). A 330 pF and a 10-k $\Omega$  pull-up resistor are needed in UVLO and Desat faults detection mode.
- m. Common Mode Transient Immunity (CMTI) 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, Output < 1.0V). A 330 pF and a 10-k $\Omega$  pull-up resistor are needed in UVLO and Desat faults detection mode.
- n. This is the "increasing" (that is, turn-on or "positive going" direction) of  $V_{CC2} - V_E$ .
- o. This is the "decreasing" (that is, turn-off or "negative going" direction) of  $V_{CC2} - V_E$ .
- p. The delay time when  $V_{CC2}$  exceeded  $V_{UVLO2\_TH+}$  to 50% of /UVLO positive going edge.
- q. The delay time when  $V_{CC2}$  exceeded  $V_{UVLO2\_TH-}$  threshold to 50% of /UVLO negative going edge.
- r. The delay time when  $V_{CC2}$  exceeded  $V_{UVLO2\_TH+}$  to 50% of  $V_O$  positive going edge (that is,  $V_O$  turn-on).
- s. The delay time when  $V_{CC2}$  exceeded  $V_{UVLO2\_TH-}$  threshold to 50% of  $V_O$  negative going edge (that is,  $V_O$  turn-off).
- t. The delay time when  $V_{CC2}$  exceeded  $V_{OV2\_TH-}$  to 50% of /UVLO positive going edge.
- u. The delay time when  $V_{CC2}$  exceeded  $V_{OV2\_TH+}$  to 50% of /UVLO negative going edge.
- v. See [During IGBT Short Circuit Event](#) for further details.
- w. The delay time for ACFJ-3530T to respond to an over-current/short circuit fault condition without any external blanking capacitor at the DESAT pin.
- x. The amount of time from when Desat threshold is exceeded to 90% of  $V_{GATE}$  negative going edge as mentioned test conditions.
- y. The amount of time from when Desat threshold is exceeded to ( $V_{EE2} + 2V$ ) of  $V_{GATE}$  negative going edge as mentioned test conditions.
- z. The amount of time from when Desat threshold is exceeded to 50% of /FAULT negative going edge.
- aa. The amount of time when Desat threshold is exceeded, driver output  $V_O$  is mute to LED input.
- ab. The amount of time when Desat Mute time is expired, LED input must be kept Low for /FAULT status to return to High.

## Package Characteristics

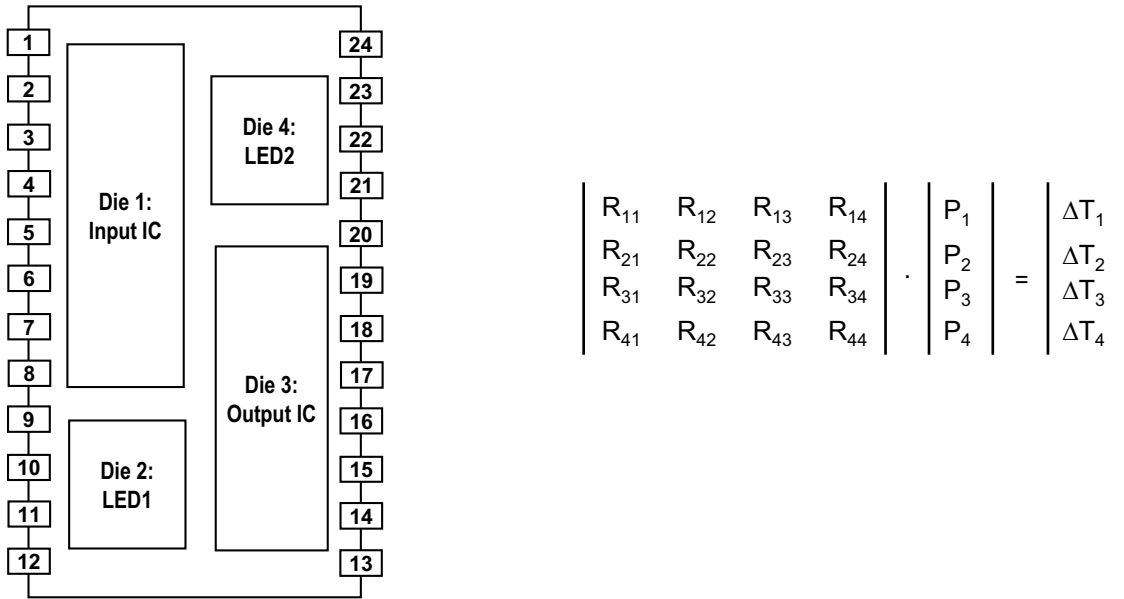
Parameter	Symbol	Min.	Typ.	Max.	Units	Test Conditions	Note
Input-Output Momentary Withstand Voltage	$V_{ISO}$	5000	—	—	$V_{RMS}$	RH < 50%, t = 1 minute, $T_A = 25^\circ C$	a, b, c
Resistance (Input – Output)	$R_{I-O}$	—	$10^{14}$	—	$\Omega$	$V_{I-O} = 500$ Vdc	c
Capacitance (Input – Output)	$C_{I-O}$	—	1.3	—	pF	f = 1 MHz	

- a. In accordance with UL1577, each optocoupler is proof tested by applying an insulation test voltage  $\geq 6000$  VRMS for 1 second.
- 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 IEC/EN/DIN EN 60747-5-5 Insulation Characteristics Table.
- c. The device is considered as a two-terminal device: pins 1 to 12 are shorted together and pins 13 to 24 are shorted together.

## Thermal Resistance Model for ACFJ-3530T

The diagram for measurement is shown in Figure 4. This is a multi-chip package with four heat sources, the effect of heating of one die due to the adjacent dice are considered by applying the theory of linear superposition. Here, one die is heated first and the temperatures of all the dice are recorded after thermal equilibrium is reached. Then, the second die is heated, and all the dice temperatures are recorded and so on until the fourth die is heated. With the known ambient temperature, the die junction temperature and power dissipation, the thermal resistance can be calculated. The thermal resistance calculation can be cast in matrix form. This yields a 4 by 4 matrix for this case of four heat sources.

Figure 4: Diagram of ACFJ-3530T for Thermal Resistance Model



### Definitions

$R_{11}$ : Thermal Resistance of Die1 due to heating of Die1 ( $^{\circ}\text{C}/\text{W}$ )

$R_{12}$ : Thermal Resistance of Die1 due to heating of Die2 ( $^{\circ}\text{C}/\text{W}$ )

$R_{13}$ : Thermal Resistance of Die1 due to heating of Die3 ( $^{\circ}\text{C}/\text{W}$ )

$R_{14}$ : Thermal Resistance of Die1 due to heating of Die4 ( $^{\circ}\text{C}/\text{W}$ )

$R_{21}$ : Thermal Resistance of Die2 due to heating of Die1 ( $^{\circ}\text{C}/\text{W}$ )

$R_{22}$ : Thermal Resistance of Die2 due to heating of Die2 ( $^{\circ}\text{C}/\text{W}$ )

$R_{23}$ : Thermal Resistance of Die2 due to heating of Die3 ( $^{\circ}\text{C}/\text{W}$ )

$R_{24}$ : Thermal Resistance of Die2 due to heating of Die4 ( $^{\circ}\text{C}/\text{W}$ )

$R_{31}$ : Thermal Resistance of Die3 due to heating of Die1 ( $^{\circ}\text{C}/\text{W}$ )

$R_{32}$ : Thermal Resistance of Die3 due to heating of Die2 ( $^{\circ}\text{C}/\text{W}$ )

$R_{33}$ : Thermal Resistance of Die3 due to heating of Die3 ( $^{\circ}\text{C}/\text{W}$ )

$R_{34}$ : Thermal Resistance of Die3 due to heating of Die4 ( $^{\circ}\text{C}/\text{W}$ )

$R_{41}$ : Thermal Resistance of Die4 due to heating of Die1 ( $^{\circ}\text{C}/\text{W}$ )

$R_{42}$ : Thermal Resistance of Die4 due to heating of Die2 ( $^{\circ}\text{C}/\text{W}$ )

$R_{43}$ : Thermal Resistance of Die4 due to heating of Die3 ( $^{\circ}\text{C}/\text{W}$ )

$R_{44}$ : Thermal Resistance of Die4 due to heating of Die4 ( $^{\circ}\text{C}/\text{W}$ )

$P_1$ : Power dissipation of Die1 (W)

$P_2$ : Power dissipation of Die2 (W)

$P_3$ : Power dissipation of Die3 (W)

$P_4$ : Power dissipation of Die4 (W)

$T_1$ : Junction temperature of Die1 due to heat from all dice ( $^{\circ}\text{C}$ )

$T_2$ : Junction temperature of Die2 due to heat from all dice ( $^{\circ}\text{C}$ )

$T_3$ : Junction temperature of Die3 due to heat from all dice ( $^{\circ}\text{C}$ )

$T_4$ : Junction temperature of Die4 due to heat from all dice ( $^{\circ}\text{C}$ )

$T_a$ : Ambient temperature ( $^{\circ}\text{C}$ )

$\Delta T_1$ : Temperature difference between Die1 junction and ambient ( $^{\circ}\text{C}$ )

$\Delta T_2$ : Temperature difference between Die2 junction and ambient ( $^{\circ}\text{C}$ )

$\Delta T_3$ : Temperature difference between Die3 junction and ambient ( $^{\circ}\text{C}$ )

$\Delta T_4$ : Temperature difference between Die4 junction and ambient ( $^{\circ}\text{C}$ )

$$T_1 = (R_{11} \times P_1 + R_{12} \times P_2 + R_{13} \times P_3 + R_{14} \times P_4) + T_a \text{ ----- (1)}$$

$$T_2 = (R_{21} \times P_1 + R_{22} \times P_2 + R_{23} \times P_3 + R_{24} \times P_4) + T_a \text{ ----- (2)}$$

$$T_3 = (R_{31} \times P_1 + R_{32} \times P_2 + R_{33} \times P_3 + R_{34} \times P_4) + T_a \text{ ----- (3)}$$

$$T_4 = (R_{41} \times P_1 + R_{42} \times P_2 + R_{43} \times P_3 + R_{44} \times P_4) + T_a \text{ ----- (4)}$$

Measurement is done on both low effective thermal conductivity test board (according to JESD51-3) and on high effective thermal conductivity test board (according to JESD51-7).

Test Board Type	Test Board Conditions	Thermal Resistance	Power Dissipation Derating Chart
Low effective thermal conductivity board	<ul style="list-style-type: none"> <li>Single layer board for signal.</li> <li>Outer layer copper thickness: 2 oz.</li> <li>Board size: 76.2 mm × 76.2 mm.</li> </ul>	<p>R<sub>11</sub>: 59.5°C/W                      R<sub>12</sub>: 44.1°C/W                      R<sub>13</sub>: 29.6°C/W                      R<sub>14</sub>: 49.3°C/W                      R<sub>21</sub>: 31.1°C/W                      R<sub>22</sub>: 153.5°C/W                      R<sub>23</sub>: 33.2°C/W                      R<sub>24</sub>: 46.4°C/W                      R<sub>31</sub>: 30.3°C/W                      R<sub>32</sub>: 50.9°C/W                      R<sub>33</sub>: 50.4°C/W                      R<sub>34</sub>: 62.9°C/W                      R<sub>41</sub>: 33.2°C/W                      R<sub>42</sub>: 47°C/W                      R<sub>43</sub>: 42°C/W                      R<sub>44</sub>: 118.6°C/W</p>	<p><b>Figure 5: Power Dissipation Derating Chart Using Low Effective Thermal Conductivity Board</b></p> <p><b>NOTE:</b></p> <ul style="list-style-type: none"> <li>Input IC power dissipation is derated linearly above 105°C from 150mW to 100mW at 125°C.</li> <li>Output IC power dissipation is derated linearly above 105°C from 600mW to 400mW at 125°C.</li> </ul>
High effective thermal conductivity board	<ul style="list-style-type: none"> <li>Four-layer board that embodies two signal layers, a power plane, and a ground plane.</li> <li>Outer layer copper thickness: 2 oz.</li> <li>Inner layers copper thickness: 1 oz.</li> <li>Board size: 76.2 mm × 76.2 mm.</li> </ul>	<p>R<sub>11</sub>: 37°C/W                      R<sub>12</sub>: 18.8°C/W                      R<sub>13</sub>: 12.4°C/W                      R<sub>14</sub>: 22.9°C/W                      R<sub>21</sub>: 15.5°C/W                      R<sub>22</sub>: 129.2°C/W                      R<sub>23</sub>: 16.1°C/W                      R<sub>24</sub>: 21.5°C/W                      R<sub>31</sub>: 14.6°C/W                      R<sub>32</sub>: 23.9°C/W                      R<sub>33</sub>: 28.6°C/W                      R<sub>34</sub>: 31.8°C/W                      R<sub>41</sub>: 18.4°C/W                      R<sub>42</sub>: 22.8°C/W                      R<sub>43</sub>: 22.8°C/W                      R<sub>44</sub>: 90.5°C/W</p>	<p><b>Figure 6: Power Dissipation Derating Chart Using High Effective Thermal Conductivity Board</b></p> <p><b>NOTE:</b></p> <ul style="list-style-type: none"> <li>Input IC power dissipation is derated linearly above 105°C from 150 mW to 125 mW at 125°C.</li> <li>Output IC power dissipation is derated linearly above 105°C from 600 mW to 550 mW at 125°C.</li> </ul>

Application and environmental design for ACFJ-3530T needs to ensure that the junction temperature of the internal ICs and LED within the gate driver optocoupler do not exceed 150°C. The following examples are based on typical circuit shown in [Figure 25](#) for estimation of maximum power dissipation and corresponding effect on junction temperatures. This thermal calculation can only be used as a reference for thermal comparison between actual application board layout and PCB board according to JESD51-7. The actual power dissipation achievable will depend on the application environment (PCB layout, air flow, part placement, and so on).

### Calculation of Input IC Power Dissipation, $P_1$

$$\text{Input IC Power Dissipation } (P_1) = P_{I(\text{Static})} + P_{IH(\text{PGD})} + P_{IL(\text{PGD})}$$

where:

$$P_{I(\text{Static})} - \text{Static power dissipated by the input IC} = V_{CC1(\text{MAX})} \times I_{CC1(\text{MAX})}$$

$$P_{IH(\text{PGD})} - \text{High side switching power dissipation at PGD pin}$$

$$= (V_{CC1(\text{MAX})} \times Q_{G\_ExtMOS} \times f_{PWM\_DCDC}) \times R_{OH\_PGD(\text{MAX})} / (R_{OH\_PGD(\text{MAX})} + R_{G\_PGD}) / 2$$

$$P_{IL(\text{PGD})} - \text{Low side switching power dissipated at PGD pin}$$

$$= (V_{CC1(\text{MAX})} \times Q_{G\_ExtMOS} \times f_{PWM\_DCDC}) \times R_{OL\_PGD(\text{MAX})} / (R_{OL\_PGD(\text{MAX})} + R_{G\_PGD}) / 2$$

$$Q_{G\_ExtMOS} - \text{Gate charge of external MOSFET connected to PGD pin at supply voltage}$$

$$f_{PWM\_DCDC} - \text{DC-DC switching frequency}$$

$$R_{OH\_PGD(\text{MAX})} - \text{Maximum high side PGD pin output impedance} = 0.5V / 50 \text{ mA} = 10\Omega$$

$$R_{OL\_PGD(\text{MAX})} - \text{Maximum low side PGD pin output impedance} = 0.4V / 50 \text{ mA} = 8\Omega$$

$$R_{G\_PGD} - \text{Gate resistance connected to PGD pin}$$

Example:

$$P_{I(\text{Static})} = 5.5V \times 6.7 \text{ mA} = 36.85 \text{ mW}$$

$$P_{IH(\text{PGD})} = (5.5V \times 5 \text{ nC} \times 160 \text{ kHz}) \times 10\Omega / (10\Omega + 20\Omega) / 2 = 0.73 \text{ mW}$$

$$P_{IL(\text{PGD})} = (5.5V \times 5 \text{ nC} \times 160 \text{ kHz}) \times 8\Omega / (8\Omega + 20\Omega) / 2 = 0.63 \text{ mW}$$

$$P_1 = 36.85 \text{ mW} + 0.73 \text{ mW} + 0.63 \text{ mW} = 38.21 \text{ mW}$$

### Calculation of Input LED Power Dissipation, $P_2$

$$\text{Input LED Power Dissipation } (P_2) = I_{F(\text{LED})} (\text{Recommended Max}) \times V_{F(\text{LED})} (\text{at } 125^\circ\text{C}) \times \text{Duty Cycle}$$

Example:

$$P_2 = 16 \text{ mA} \times 1.25V \times 50\% = 10 \text{ mW}$$

**Calculation of Output IC Power Dissipation, P<sub>3</sub>**

$$\text{Output IC Power Dissipation (P}_3\text{)} = P_{O(\text{Static})} + P_{OH} + P_{OL}$$

where:

$$P_{O(\text{Static})} - \text{Static power dissipated by the output IC} = (V_{CC2} - V_{EE2}) \times I_{CC2(\text{MAX})}$$

$$(V_{CC2} - V_{EE2}) - \text{Total output power supply} = \text{Regulated } V_{CC2(\text{MAX})} + V_z \text{ (} V_z \text{ can be } 0V \text{ if negative supply is not used)}$$

$$P_{OH} - \text{High side switching power dissipation at } V_O \text{ pin}$$

$$= (V_{CC2} - V_{EE2}) \times Q_G \times f_{PWM} \times R_{OH(\text{MAX})} / (R_{OH(\text{MAX})} + R_{GH}) / 2$$

$$P_{OL} - \text{Low side switching power dissipation at } V_O \text{ pin}$$

$$= (V_{CC2} - V_{EE2}) \times Q_G \times f_{PWM} \times R_{OL(\text{MAX})} / (R_{OL(\text{MAX})} + R_{GL}) / 2$$

$$Q_G - \text{External buffer gate charge at supply voltage}$$

$$f_{PWM} - \text{Input LED switching frequency}$$

$$R_{OH(\text{MAX})} - \text{Maximum high side } V_O \text{ pin output impedance at } I_{OH(\text{MIN})} = 3.33\Omega$$

$$R_{GH} - \text{Gate charging resistance}$$

$$R_{OL(\text{MAX})} - \text{Maximum low side } V_O \text{ pin output impedance } I_{OL(\text{MIN})} = 3.33\Omega$$

$$R_{GL} - \text{Gate discharging resistance}$$

Example:

$$(V_{CC2} - V_{EE2}) = 16.8V + 5.5V = 22.3V$$

$$P_{O(\text{Static})} = 22.3V \times 17 \text{ mA} = 379.1 \text{ mW}$$

$$P_{OH} = (22.3V \times 200 \text{ nC} \times 10 \text{ kHz}) \times 3.33\Omega / (3.33\Omega + 10\Omega) / 2 = 5.57 \text{ mW}$$

$$P_{OL} = (22.3V \times 200 \text{ nC} \times 10 \text{ kHz}) \times 3.33\Omega / (3.33\Omega + 10\Omega) / 2 = 5.57 \text{ mW}$$

$$P_3 = 379.1 \text{ mW} + 5.57 \text{ mW} + 5.57 \text{ mW} = 390.24 \text{ mW}$$

**Calculation of LED2 Power Dissipation, P<sub>4</sub>**

$$\text{LED2 Power Dissipation (P}_4\text{)} = I_{F(\text{LED2})} (\text{Design Max}) \times V_{F(\text{LED2})} (\text{at } 125^\circ\text{C}) \times \text{Duty Cycle}$$

Example:

$$P_4 = 16 \text{ mA} \times 1.25V \times 50\% = 10 \text{ mW}$$

**Calculation of Junction Temperature using High Effective Thermal Conductivity Board:**

$$\text{Input IC Junction Temperature} = (37^\circ\text{C/W} \times P_1 + 18.8^\circ\text{C/W} \times P_2 + 12.4^\circ\text{C/W} \times P_3 + 22.9^\circ\text{C/W} \times P_4) + T_a$$

$$\text{Input LED Junction Temperature} = (15.5^\circ\text{C/W} \times P_1 + 129.2^\circ\text{C/W} \times P_2 + 16.1^\circ\text{C/W} \times P_3 + 21.5^\circ\text{C/W} \times P_4) + T_a$$

$$\text{Output IC Junction Temperature} = (14.6^\circ\text{C/W} \times P_1 + 23.9^\circ\text{C/W} \times P_2 + 28.6^\circ\text{C/W} \times P_3 + 31.8^\circ\text{C/W} \times P_4) + T_a$$

$$\text{LED2 Junction Temperature} = (18.4^\circ\text{C/W} \times P_1 + 22.8^\circ\text{C/W} \times P_2 + 22.8^\circ\text{C/W} \times P_3 + 90.5^\circ\text{C/W} \times P_4) + T_a$$

**Junction temperatures of the internal ICs and LEDs must not exceed 150°C.**



# Typical Performance Plots

Figure 7: PWM Duty Cycle vs.  $V_{COMP}$

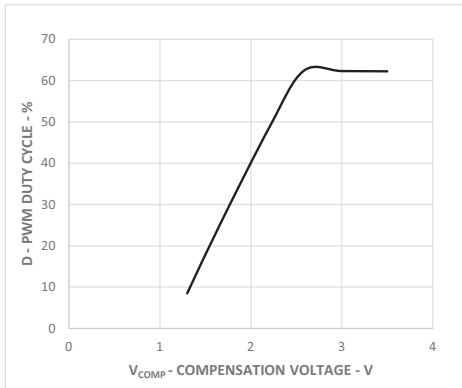


Figure 8:  $I_{COMP}$  vs. Supply Voltage

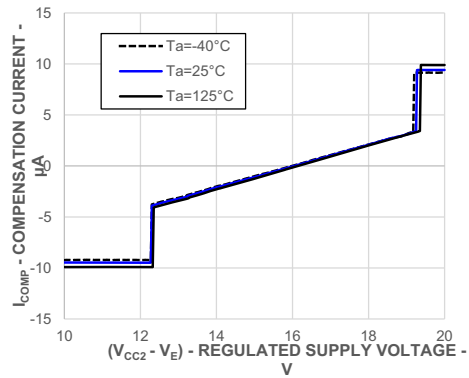


Figure 9:  $I_{CC1}$  vs. Temperature

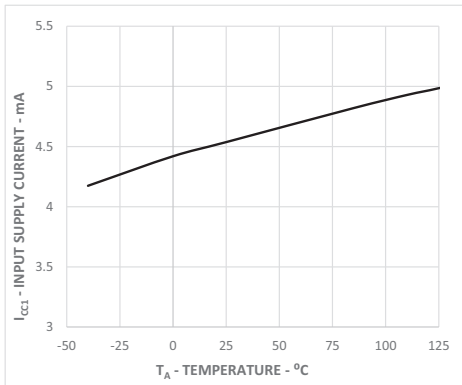


Figure 10:  $I_{CC2}$  vs. Temperature

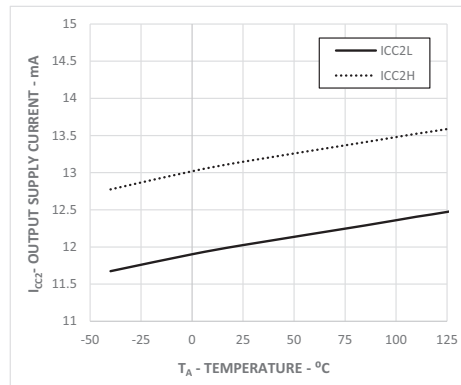


Figure 11:  $I_E$  vs. Temperature

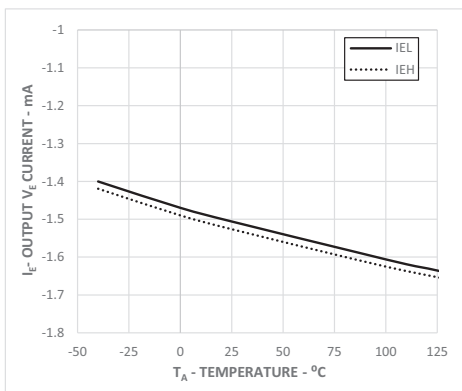


Figure 12:  $I_F$  vs.  $V_F$

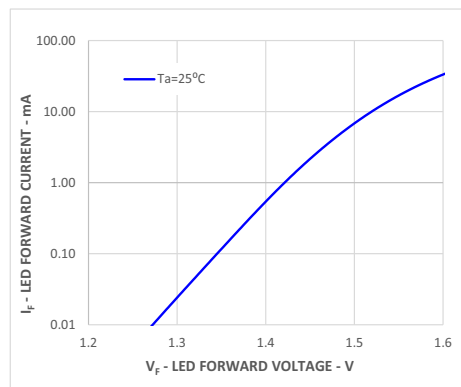


Figure 13:  $I_{TH}$  vs. Temperature

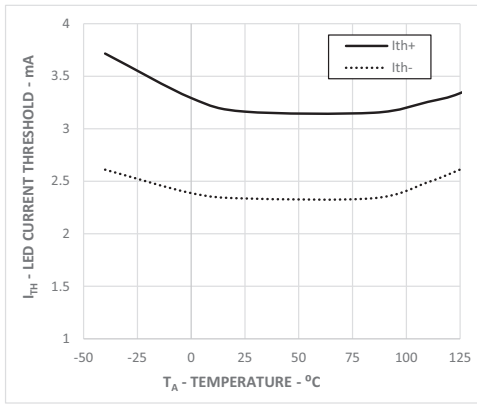


Figure 14:  $V_{OH}$  vs.  $I_{OH}$

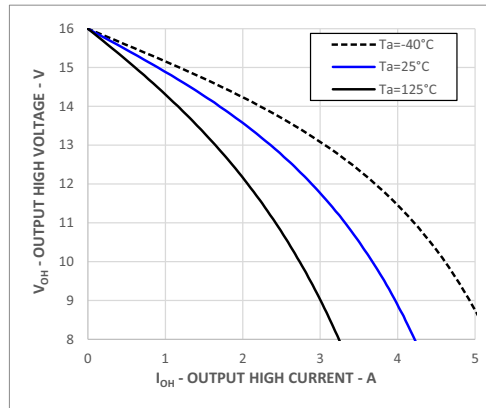


Figure 15:  $V_{OL}$  vs.  $I_{OL}$

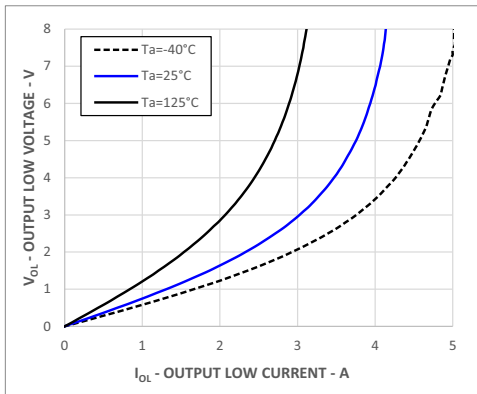


Figure 16:  $I_{SSD}$  vs.  $V_{SSD}$

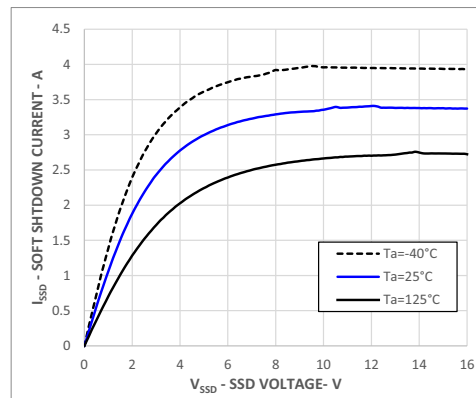


Figure 17:  $T_p$  vs. Temperature

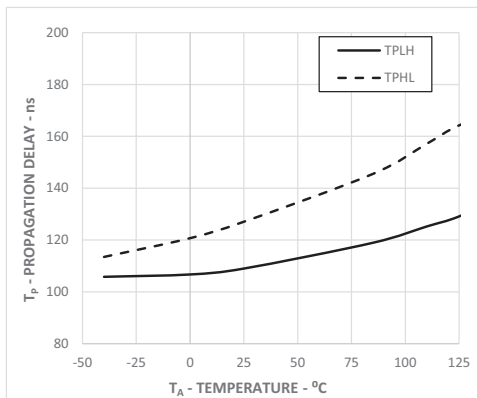


Figure 18:  $I_{CLAMP}$  vs.  $V_{CLAMP}$

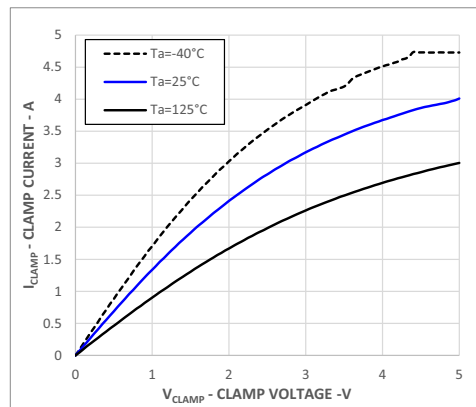




Figure 23: CMR VO High Test Circuit

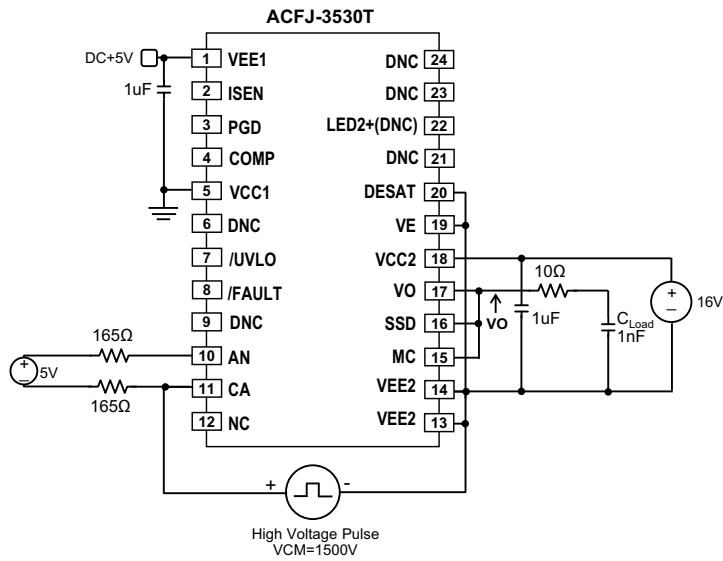
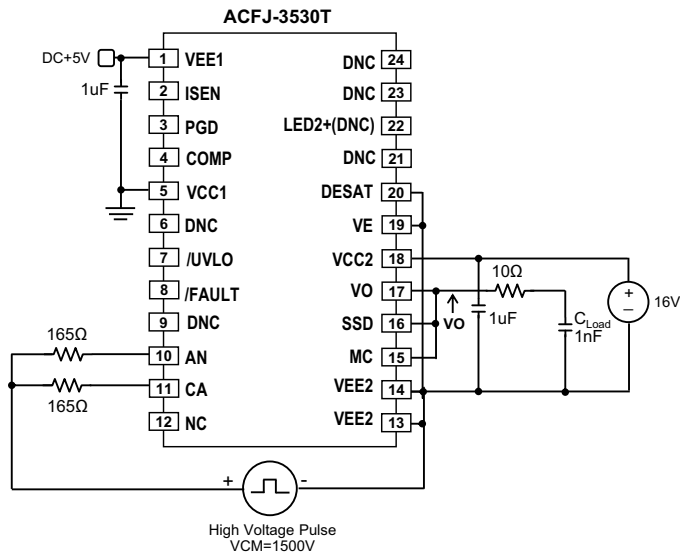
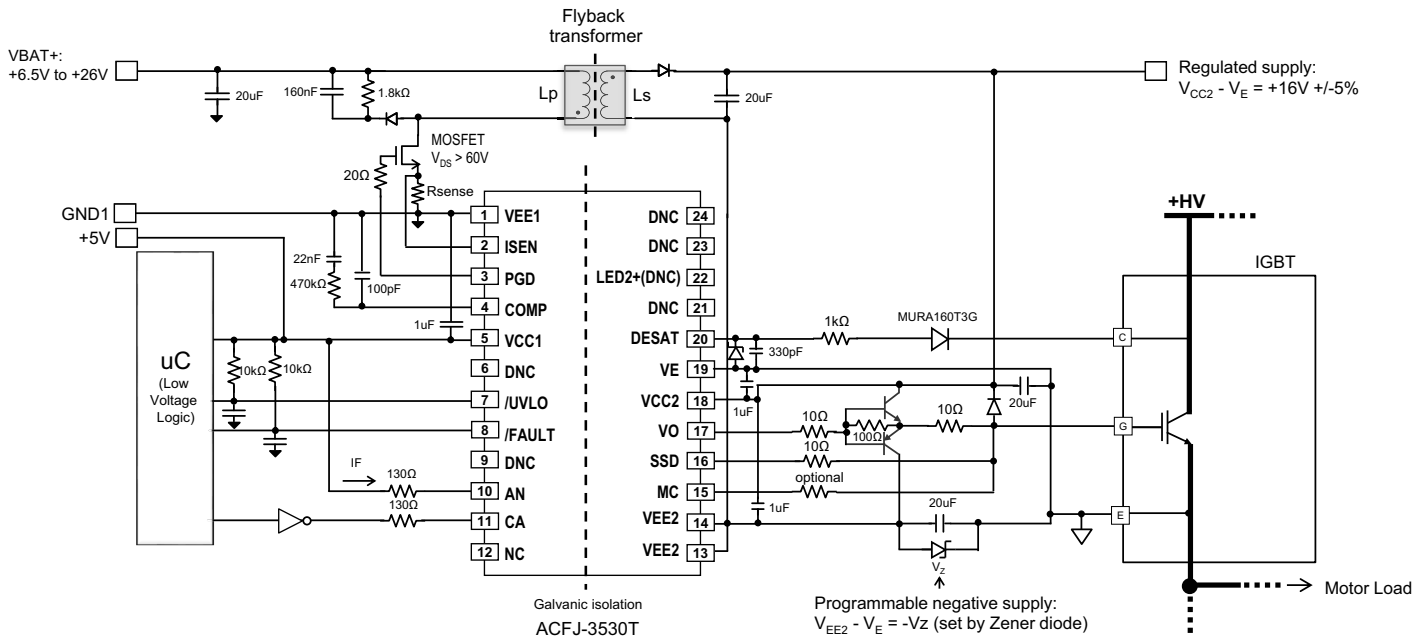


Figure 24: CMR VO Low Test Circuit



## Typical Gate Drive Circuit with IGBT Desaturation Detection

Figure 25: ACFJ-3530T Typical Gate Drive Circuit with IGBT Desaturation Over-Current Sensing and Negative Bias Set by Vz



**NOTE:** Component values are subjected to change with various application requirements.

## Description of Operations and Functions

### Operation of Integrated DC-DC Flyback Controller

The ACFJ-3530T integrated DC-DC flyback controller operates in a discontinuous conduction mode (DCM) at a fixed average switching frequency of 135 kHz. It converts a wide 6.5V to 26V input range to 16V fixed positive output and programmable negative voltage of 0V to 10V. These voltage ranges are well suited for various automotive and industrial applications.

The primary control block implements direct duty cycle control logics for line and load regulation. Primary winding current is sensed and limited to  $V_{ISEN\_TH}$  to prevent transformer short circuit failure from damaging the primary switch. The sense resistor ( $R_{sense}$ ) is selected based on the maximum primary winding current limit and maximum power dissipation requirement. Secondary output voltage  $V_{CC2}$  is sensed and feedback to the primary control circuits. The closed loop control circuits always regulates  $V_{CC2}$  to 16V with respect to  $V_E$ . When  $V_{CC2}$  is greater than the specified  $V_{CC2}$  threshold ( $V_{OV2\_TH+}$ ),  $V_{CC2}$  over voltage protection is triggered. The PGD pin on the primary side of gate driver is shut down to protect secondary over voltage failure. When  $V_{CC2}$  reduces to  $V_{OV2\_TH-}$ , the PGD pin is released and DC-DC regulation resumes its normal operations.

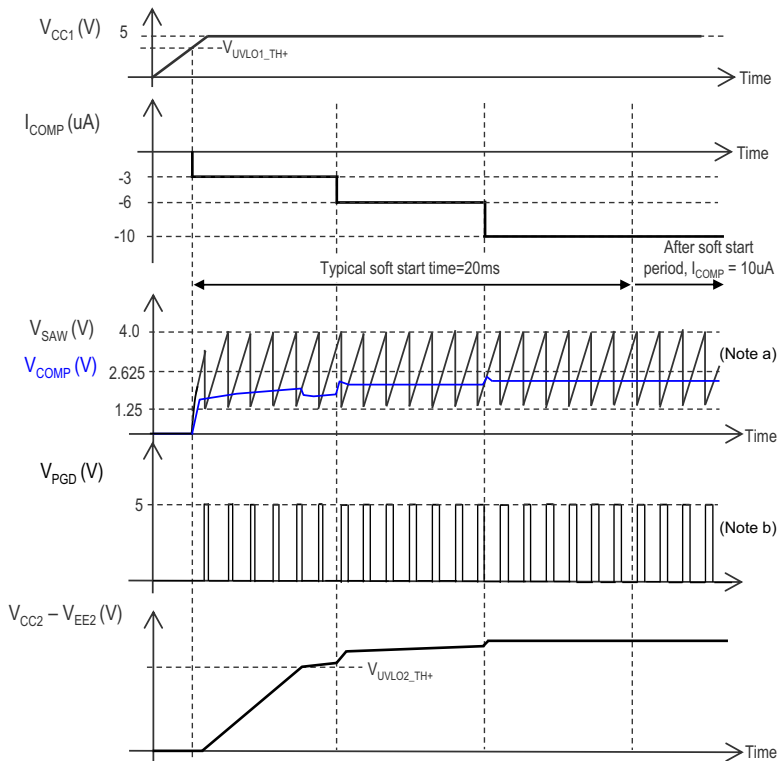
While designing the flyback transformer for DCM controller, the maximum PWM duty cycle must be limited to 50% or less at the minimum input voltage (for example,  $V_{BAT+} = 6.5V$ ) under full load conditions. A flyback transformer should be connected to ACFJ-3530T according to [Figure 25](#) for complete isolated DC-DC converter. The input LED should be kept off while powering up the  $V_{CC1}$ . To ensure proper operation of the DC-DC converter, fast  $V_{CC1}$  rise time ( $\leq 5$  ms) is preferred for soft start function to control the inrush current. If  $V_{CC2}$  fails to rise above 6V at the end of the soft start period (about 20 ms), the primary switch is turned off to prevent a possible  $V_{CC2}$  short circuit event during start-up. The DC-DC controller can be restart by power reset  $V_{CC1}$ .

The average PWM switching frequency of primary gate drive (PGD) is dithered  $\pm 6\%$  typically from center frequency of 135 kHz. Frequency dithering feature helps to achieve better EMI performance by spreading the switching and its harmonics over wider band.

## Soft Start Operation

ACFJ-3530T is designed with built-in soft start feature. When  $V_{CC1}$  is higher than  $V_{UVLO1\_TH+}$ , the built-in soft start circuit starts to function. Typical soft start timing is 20 ms. Soft start current ( $I_{COMP}$ ) charges up the compensation network through the  $V_{COMP}$  pin and gradually increases the  $V_{COMP}$  voltage to the correct working level. [Figure 26](#) shows the typical DC-DC start up waveforms.

**Figure 26: Typical DC-DC Start Up Waveforms**



### NOTE:

- $V_{SAW}$  is IC internal saw waveform and cannot be measured externally.  $V_{SAW}$  frequency is not drawn to scale.
- Typical DC-DC switching frequency at PGD pin is 135 kHz.  $V_{PGD}$  frequency is not drawn to scale.

## Status Flags

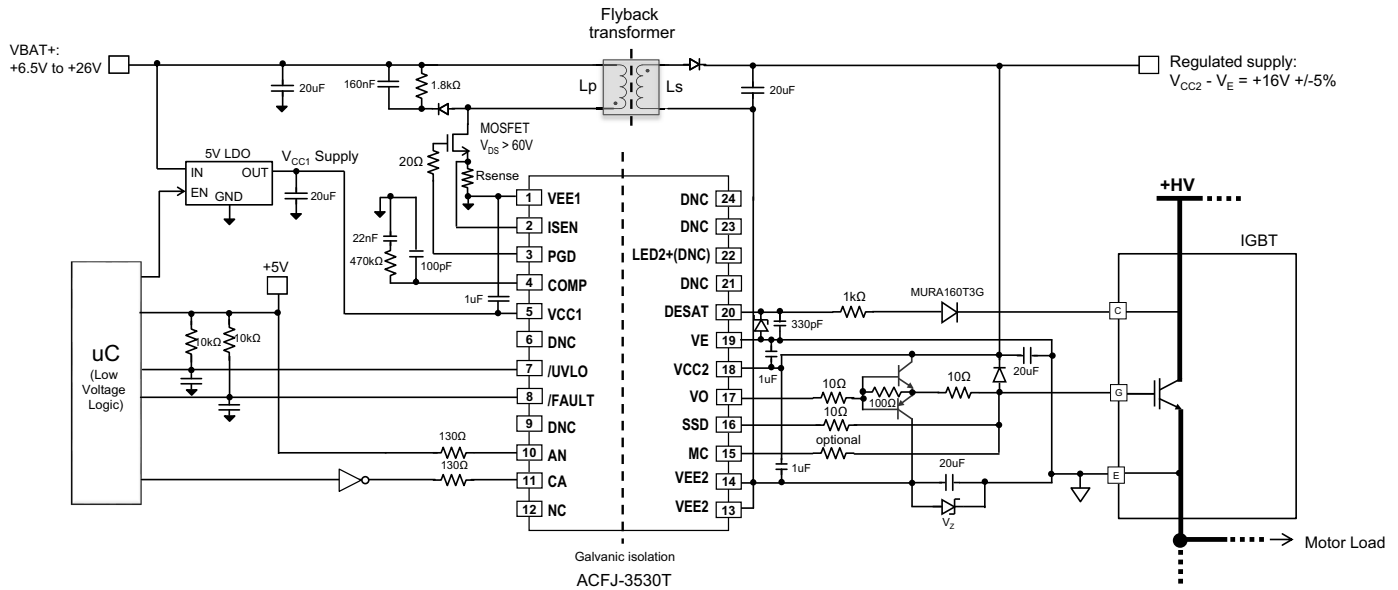
The status flags at the primary side reflect the state of the circuit operation. [Figure 29](#) exemplifies how the status flags react when  $V_{CC2}$  ramps up and down when  $V_{CC1}$  is ready.

- Normal operation: All the status flags (/UVLO and /FAULT) are in Hi-Z state. These pins are pulled high through the external resistors.
- Under voltage lock out (UVLO) fault: During operation, if  $V_{CC1}$  falls below the  $V_{CC1}$  threshold ( $V_{UVLO1\_TH-}$ ) or  $V_{CC2}$  falls below the UVLO threshold ( $V_{UVLO2\_TH-}$ ), /UVLO flags will be pulled low.
- $V_{CC2}$  over voltage (OV) fault: When  $V_{CC2}$  is over  $V_{CC2}$  over voltage protection threshold ( $V_{OV2\_TH+}$ ), /UVLO flags will be pulled low.
- IGBT short circuit (SC) fault: If a short circuit fault occurs, the IGBT gate will be soft shutdown (pulled low by the SSD pin action). /FAULT pin will be pulled low.
- LED2 Fault: When  $V_{CC2} - V_{EE2}$  supply voltage is greater than typical 6V, secondary side LED2 starts to pulse to inform the primary IC that the feedback channel is working normally. If the primary IC detects no signal from LED2, it is diagnosed as LED2 is faulty. Primary IC will stop the DC-DC regulation by pulling the PGD pin and COMP pin low. Both status flags (/ULVO and /FAULT) will be pulled low to inform the microcontroller. The primary IC's power ( $V_{CC1}$ ) is then needed to be rebooted for IC reset. [Figure 27](#) shows a typical gate driver circuit with low-dropout linear regulator (LDO) for primary IC ( $V_{CC1}$ ) reboot during LED2 fault condition.

**Table 1: Status Flags**

Conditions	Status Flags	
	/UVLO	/FAULT
Normal operation	Hi-Z	Hi-Z
VCC1 UVLO fault	Low	Hi-Z
VCC2 UVLO fault	Low	Hi-Z
VCC2 OV fault	Low	Hi-Z
Short circuit (SC) fault	Hi-Z	Low
LED2 fault	Low	Low

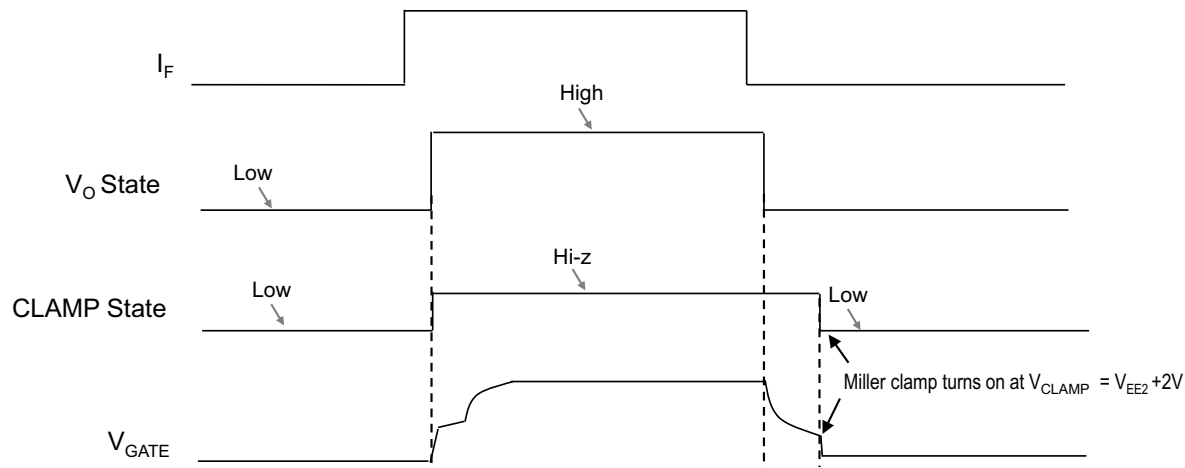
Figure 27: Typical Gate Driver Circuit with Low-Dropout Linear Regulator (LDO) for  $V_{CC1}$  Reboot



### Description of Gate Driver and Miller Clamping

The gate driver is directly controlled by the input LED current ( $I_F$ ). When input LED current is driven high, the main output of ACFJ-3530T can then deliver a 1.5A sourcing current to drive the external buffer that drives the IGBT's gate. While the input LED is switched off,  $V_O$  provides 1.5A sinking current to external buffer to switch the gate off fast. The Miller clamping pull-down MOSFET (MC pin) is activated when gate voltage drops below  $V_{TH\_CLAMP}$  voltage to provide low impedance path to Miller current.

Figure 28: Gate Drive Signal Behavior

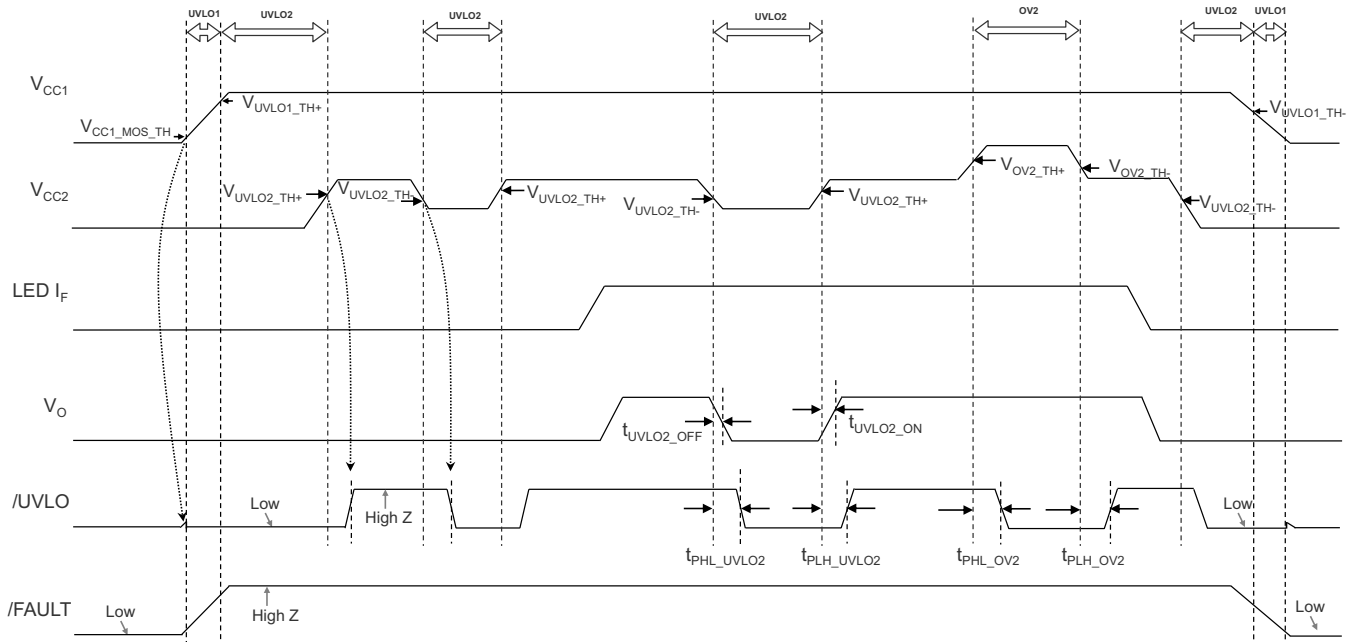




## Description of Under Voltage Lock Out

Insufficient gate voltage to IGBT can increase turn on resistance of IGBT, resulting in large power loss and IGBT damage due to high heat dissipation. ACFJ-3530T monitors the output power supply ( $V_{CC2}$ ) constantly. When output power supply is lower than under voltage lock out (UVLO) threshold, gate driver output will shut off to protect IGBT from low voltage bias. During power up, the UVLO feature forces the ACFJ-3530T's output low to prevent unwanted turn-on at lower voltage. When power supply ( $V_{CC2}$ ) voltage increases more than  $V_{UVLO2\_TH+}$  threshold, the /UVLO fault status will be cleared and the gate driver resumes its normal function automatically.

Figure 29: Circuit Behaviors during Power Up and Power Down



## Description of Over Voltage Protection

When  $V_{CC2}$  is greater than the specified  $V_{CC2}$  over voltage protection threshold, the PGD pin on the primary side of gate driver is shut down to protect secondary over voltage failure. When  $V_{CC2}$  goes below the  $V_{CC2}$  over voltage protection threshold, PGD starts to regulate again. The  $V_{CC2}$  over voltage condition is feedback to microcontroller by pulling the /UVLO pin low. Output driver ( $V_O$ ), Miller clamp, Desat protection and soft shutdown functions are not locked out by over voltage protection. See [Status Flags](#) for /UVLO and /FAULT feedback truth table.

## DESAT Fault Detection Blanking Time

After the IGBT is turned on, the DESAT fault detection circuitry must remain disabled for a short period of time to allow the IGBT collector voltage to fall below the DESAT threshold. This time period, called the total DESAT blanking time, is the sum of both internal DESAT blanking time,  $t_{\text{DESAT(BLANKING)}}$  and external blanking time. While the internal DESAT blanking time is preset within the device, the external blanking time is flexibly determined by selecting the blanking capacitor ( $C_{\text{BLANK}}$ ) with preset DESAT sensing voltage ( $V_{\text{DESAT\_TH}}$ ) and Desat charge current ( $I_{\text{CHG}}$ ).

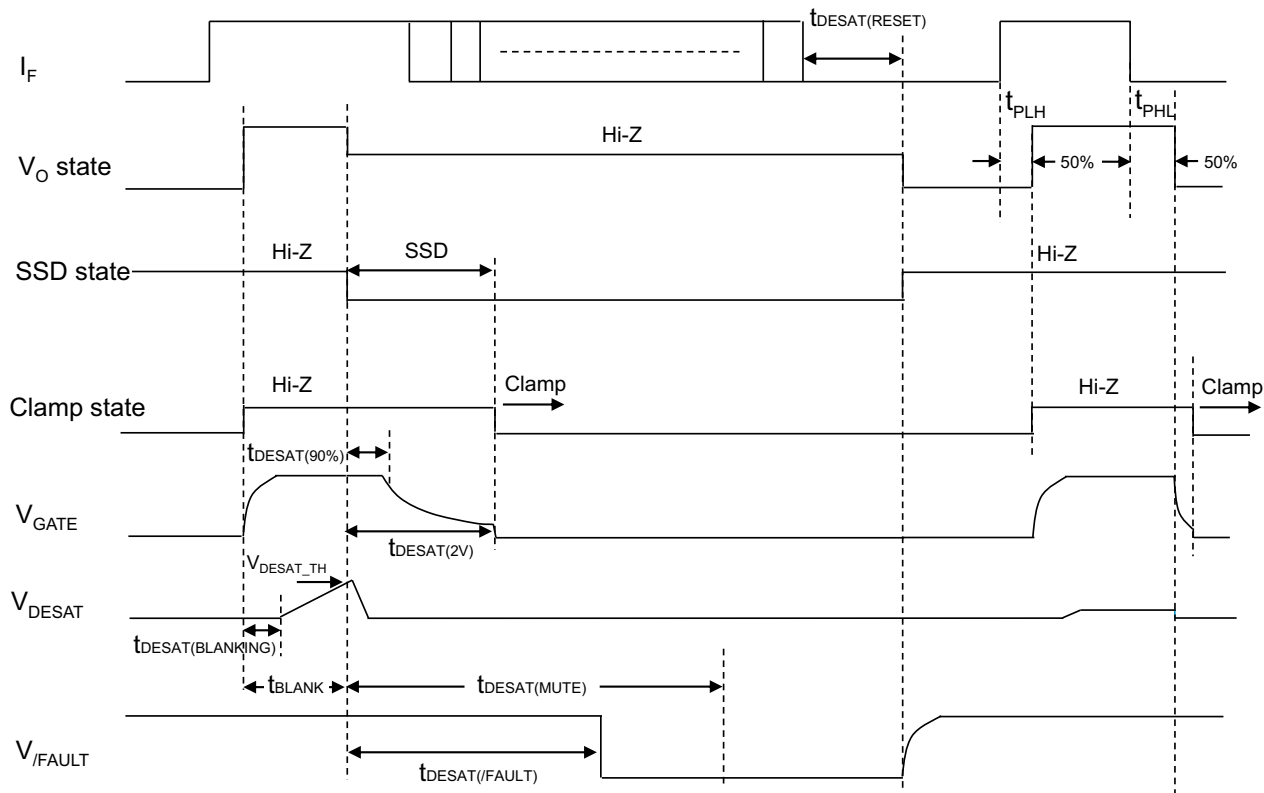
The total blanking time is calculated in terms of internal blanking time ( $t_{\text{DESAT(BLANKING)}}$ ), external capacitance ( $C_{\text{BLANK}}$ ), DESAT sensing voltage ( $V_{\text{DESAT\_TH}}$ ), and DESAT charge current ( $I_{\text{CHG}}$ ) as follows:

Total DESAT blanking time,  $t_{\text{BLANK}} = t_{\text{DESAT(BLANKING)}} + C_{\text{BLANK}} \times V_{\text{DESAT\_TH}} / I_{\text{CHG}}$

## During IGBT Short Circuit Event

1. DESAT terminal monitors IGBT's VCE voltage.
2. When the voltage on the DESAT terminal exceeds 9.1V, the IGBT gate voltage ( $V_{GATE}$ ) is slowly lowered by soft shutdown (SSD) pin. Output driver, VO enters into high impedance state.
3. Output driver VO ignores all PWM commands during mute time ( $t_{DESAT(MUTE)}$ ) and remains in high impedance state.
4. /FAULT output goes low, notifying the microcontroller of the fault condition.
5. Microcontroller takes appropriate action.
6. When ( $t_{DESAT(MUTE)}$ ) expires, the LED input must be kept low for  $t_{DESAT(RESET)}$  before the fault condition can be cleared. /FAULT status will return to high, and SSD output will return to high impedance state.
7. Output (VO) starts to respond to LED input after fault condition is cleared.

Figure 30: Circuit Behaviors during IGBT Short Circuit Event



## Printed Circuit Board Layout Considerations

Care must be taken while designing the layout of printed circuit board (PCB) for optimum performance.

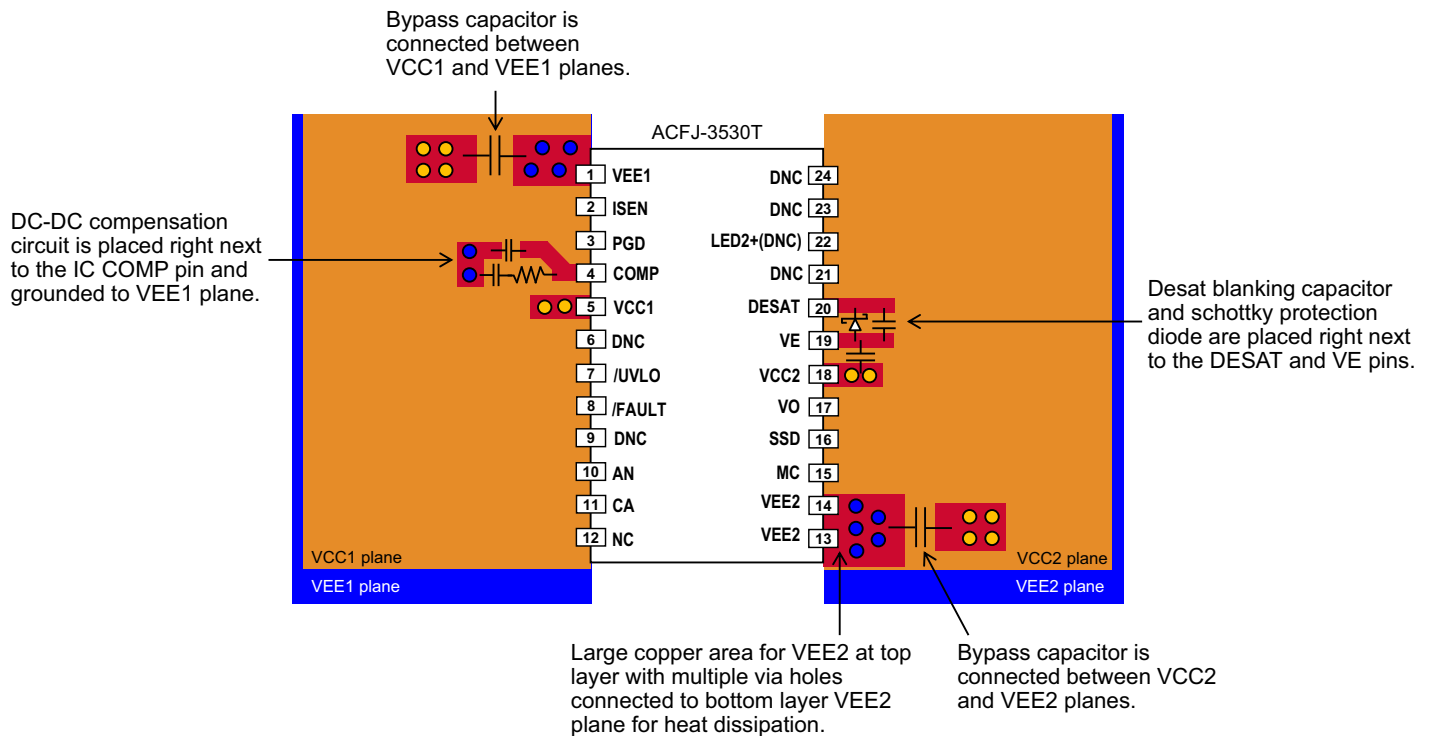
Adequate spacing should always be maintained between the high voltage isolated circuitry and any input referenced circuitry. The same minimum spacing between two adjacent high-side isolated regions of the printed circuit board must be maintained as well. Insufficient spacing will reduce the effective isolation and increase parasitic coupling that will effect CMR performance.

The placement and routing of supply bypass capacitors requires special attention. During switching transients, the majority of the gate charge is supplied by the bypass capacitors. Maintaining short charging and discharging paths between capacitors and gate can help to achieve clean switching waveforms and low supply ripples. It is recommended to have supply and ground planes for  $V_{CC2}$  and  $V_{EE2}$ . It is also recommended to connect IC power pins, such as  $V_{CC2}$  (pin 18) and  $V_{EE2}$  (pins 13 and 14) and external output buffer directly to these planes using multiple via holes locally. Similar layout guidelines are applicable to input side circuitry, such as power supply  $V_{CC1}$  (pin 5), input side ground  $V_{EE1}$  (pin 1) and supply decoupling capacitors.

For thermal dissipation purposes, it is recommended to place large copper area for top layer  $V_{EE2}$  (pins 13 and 14) and connect the copper area with multiple via holes to  $V_{EE2}$  plane at the bottom layer of PCB as illustrated in Figure 31.

The compensation network circuitry which connected to COMP (pin 4) is to be placed next to IC with short traces.

**Figure 31: Example of Recommended Layout**



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