

WARP2 SERIES IGBT WITH  
 ULTRAFAST SOFT RECOVERY DIODE

**Applications**

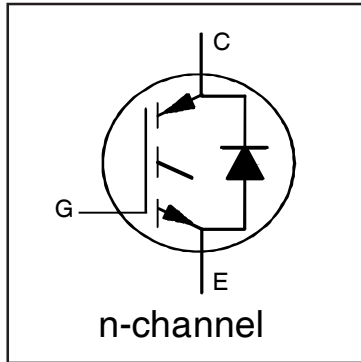
- Automotive HEV and EV
- PFC and ZVS SMPS Circuits

**Features**

- Low  $V_{CE(ON)}$  NPT Technology, Positive Temperature Coefficient
- Lower Parasitic Capacitances
- Minimal Tail Current
- HEXFRED Ultra Fast Soft-Recovery Co-Pack Diode
- Tighter Distribution of Parameters
- Lead-Free, RoHS Compliant
- Automotive Qualified \*

**Benefits**

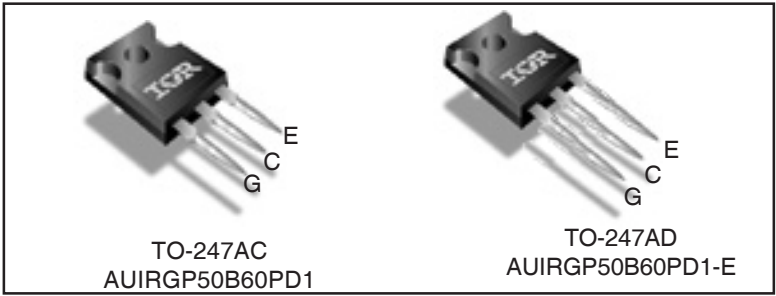
- Parallel Operation for Higher Current Applications
- Lower Conduction Losses and Switching Losses
- Higher Switching Frequency up to 150kHz



$V_{CES} = 600V$   
 $V_{CE(on)} \text{ typ.} = 2.00V$   
 @  $V_{GE} = 15V$   $I_C = 33A$

**Equivalent MOSFET Parameters**<sup>①</sup>

$R_{CE(on)} \text{ typ.} = 61m\Omega$   
 $I_D$  (FET equivalent) = 50A



<b>G</b>	<b>C</b>	<b>E</b>
Gate	Collector	Emitter

**Ordering Information**

Base part number	Package Type	Standard Pack		Complete Part Number
		Form	Quantity	
AUIRGP50B60PD1	TO-247AC	Tube	25	AUIRGP50B60PD1
AUIRGP50B60PD1E	TO-247AD	Tube	25	AUIRGP50B60PD1E

**Absolute Maximum Ratings**

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only; and functional operation of the device at these or any other condition beyond those indicated in the specifications is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability. The thermal resistance and power dissipation ratings are measured under board mounted and still air conditions. Ambient temperature ( $T_A$ ) is 25°C, unless otherwise specified.

	Parameter	Max.	Units
$V_{CES}$	Collector-to-Emitter Voltage	600	V
$I_C @ T_C = 25^\circ C$	Continuous Collector Current	75 <sup>②</sup>	A
$I_C @ T_C = 100^\circ C$	Continuous Collector Current	45	
$I_{CM}$	Pulse Collector Current (Ref. Fig. C.T.4)	150	
$I_{LM}$	Clamped Inductive Load Current <sup>②</sup>	150	
$I_F @ T_C = 25^\circ C$	Diode Continuous Forward Current	40	
$I_F @ T_C = 100^\circ C$	Diode Continuous Forward Current	15	
$I_{FRM}$	Maximum Repetitive Forward Current <sup>③</sup>	60	
$V_{GE}$	Gate-to-Emitter Voltage	$\pm 20$	V
$P_D @ T_C = 25^\circ C$	Maximum Power Dissipation	390	W
$P_D @ T_C = 100^\circ C$	Maximum Power Dissipation	156	
$T_J$	Operating Junction and	-55 to +150	°C
$T_{STG}$	Storage Temperature Range		
	Soldering Temperature for 10 sec.	300 (0.063 in. (1.6mm) from case)	
	Mounting Torque, 6-32 or M3 Screw	10 lbf-in (1.1 N·m)	

**Thermal Resistance**

	Parameter	Min.	Typ.	Max.	Units
$R_{\theta JC}$ (IGBT)	Thermal Resistance Junction-to-Case-(each IGBT)	—	—	0.32	°C/W
$R_{\theta JC}$ (Diode)	Thermal Resistance Junction-to-Case-(each Diode)	—	—	1.7	
$R_{\theta CS}$	Thermal Resistance, Case-to-Sink (flat, greased surface)	—	0.24	—	
$R_{\theta JA}$	Thermal Resistance, Junction-to-Ambient (typical socket mount)	—	—	40	
	Weight	—	6.0 (0.21)	—	g (oz)

\*Qualification standards can be found at <http://www.irf.com/>

## Dynamic Electrical Characteristics @ $T_J = 25^\circ\text{C}$ (unless otherwise specified)

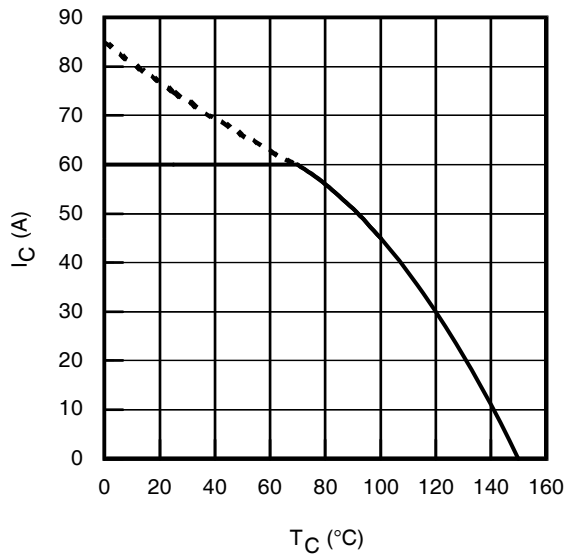
	Parameter	Min.	Typ.	Max.	Units	Conditions	Ref.Fig
$V_{(BR)CES}$	Collector-to-Emitter Breakdown Voltage	600	—	—	V	$V_{GE} = 0V, I_C = 500\mu A$	
$\Delta V_{(BR)CES}/\Delta T_J$	Temperature Coeff. of Breakdown Voltage	—	0.31	—	V/ $^\circ\text{C}$	$V_{GE} = 0V, I_C = 1mA (25^\circ\text{C}-125^\circ\text{C})$	
$R_G$	Internal Gate Resistance	—	1.7	—	$\Omega$	1MHz, Open Collector	
$V_{CE(on)}$	Collector-to-Emitter Saturation Voltage	—	2.00	2.35	V	$I_C = 33A, V_{GE} = 15V$	4, 5, 6, 8, 9
		—	2.45	2.85		$I_C = 50A, V_{GE} = 15V$	
		—	2.60	2.95		$I_C = 33A, V_{GE} = 15V, T_J = 125^\circ\text{C}$	
		—	3.20	3.60		$I_C = 50A, V_{GE} = 15V, T_J = 125^\circ\text{C}$	
$V_{GE(th)}$	Gate Threshold Voltage	3.0	4.0	5.0	V	$I_C = 250\mu A$	7, 8, 9
$\Delta V_{GE(th)}/\Delta T_J$	Threshold Voltage temp. coefficient	—	-10	—	mV/ $^\circ\text{C}$	$V_{CE} = V_{GE}, I_C = 1.0mA$	
$g_{fe}$	Forward Transconductance	—	41	—	S	$V_{CE} = 50V, I_C = 33A, PW = 80\mu s$	
$I_{CES}$	Collector-to-Emitter Leakage Current	—	5.0	500	$\mu A$	$V_{GE} = 0V, V_{CE} = 600V$	
		—	1.0	—	mA	$V_{GE} = 0V, V_{CE} = 600V, T_J = 125^\circ\text{C}$	
$V_{FM}$	Diode Forward Voltage Drop	—	1.30	1.70	V	$I_F = 15A, V_{GE} = 0V$	10
		—	1.20	1.60		$I_F = 15A, V_{GE} = 0V, T_J = 125^\circ\text{C}$	
$I_{GES}$	Gate-to-Emitter Leakage Current	—	—	$\pm 100$	nA	$V_{GE} = \pm 20V, V_{CE} = 0V$	

## Static or Switching Characteristics @ $T_J = 25^\circ\text{C}$ (unless otherwise specified)

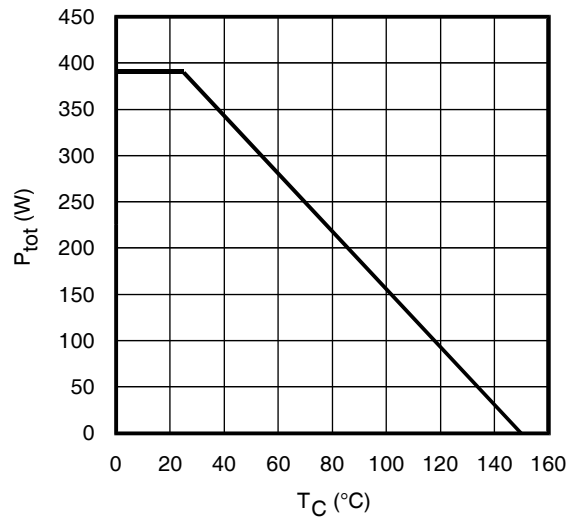
	Parameter	Min.	Typ.	Max.	Units	Conditions	Ref.Fig
$Q_g$	Total Gate Charge (turn-on)	—	205	308	nC	$I_C = 33A$	17
$Q_{gc}$	Gate-to-Collector Charge (turn-on)	—	70	105		$V_{CC} = 400V$	CT1
$Q_{ge}$	Gate-to-Emitter Charge (turn-on)	—	30	45		$V_{GE} = 15V$	
$E_{on}$	Turn-On Switching Loss	—	255	305	$\mu J$	$I_C = 33A, V_{CC} = 390V$	CT3
$E_{off}$	Turn-Off Switching Loss	—	375	445		$V_{GE} = +15V, R_G = 3.3\Omega, L = 200\mu H$	
$E_{total}$	Total Switching Loss	—	630	750		$T_J = 25^\circ\text{C} \text{ ④}$	
$t_{d(on)}$	Turn-On delay time	—	30	40	ns	$I_C = 33A, V_{CC} = 390V$	CT3
$t_r$	Rise time	—	10	15		$V_{GE} = +15V, R_G = 3.3\Omega, L = 200\mu H$	
$t_{d(off)}$	Turn-Off delay time	—	130	150		$T_J = 25^\circ\text{C} \text{ ④}$	
$t_f$	Fall time	—	11	15			
$E_{on}$	Turn-On Switching Loss	—	580	700	$\mu J$	$I_C = 33A, V_{CC} = 390V$	CT3
$E_{off}$	Turn-Off Switching Loss	—	480	550		$V_{GE} = +15V, R_G = 3.3\Omega, L = 200\mu H$	11, 13
$E_{total}$	Total Switching Loss	—	1060	1250		$T_J = 125^\circ\text{C} \text{ ④}$	WF1, WF2
$t_{d(on)}$	Turn-On delay time	—	26	35	ns	$I_C = 33A, V_{CC} = 390V$	CT3
$t_r$	Rise time	—	13	20		$V_{GE} = +15V, R_G = 3.3\Omega, L = 200\mu H$	12, 14
$t_{d(off)}$	Turn-Off delay time	—	146	165		$T_J = 125^\circ\text{C} \text{ ④}$	WF1, WF2
$t_f$	Fall time	—	15	20			
$C_{ies}$	Input Capacitance	—	3648	—	pF	$V_{GE} = 0V$	16
$C_{oes}$	Output Capacitance	—	322	—		$V_{CC} = 30V$	
$C_{res}$	Reverse Transfer Capacitance	—	56	—		$f = 1Mhz$	
$C_{oes\ eff.}$	Effective Output Capacitance (Time Related) ⑤	—	215	—		$V_{GE} = 0V, V_{CE} = 0V \text{ to } 480V$	15
$C_{oes\ eff. (ER)}$	Effective Output Capacitance (Energy Related) ⑤	—	163	—			
RBSOA	Reverse Bias Safe Operating Area	FULL SQUARE				$T_J = 150^\circ\text{C}, I_C = 150A$ $V_{CC} = 480V, V_p = 600V$ $R_g = 22\Omega, V_{GE} = +15V \text{ to } 0V$	3 CT2
$t_{rr}$	Diode Reverse Recovery Time	—	42	60	ns	$T_J = 25^\circ\text{C}$ $I_F = 15A, V_R = 200V,$	19
		—	74	120		$T_J = 125^\circ\text{C}$ $di/dt = 200A/\mu s$	
$Q_{rr}$	Diode Reverse Recovery Charge	—	80	180	nC	$T_J = 25^\circ\text{C}$ $I_F = 15A, V_R = 200V,$	21
		—	220	600		$T_J = 125^\circ\text{C}$ $di/dt = 200A/\mu s$	
$I_{rr}$	Peak Reverse Recovery Current	—	4.0	6.0	A	$T_J = 25^\circ\text{C}$ $I_F = 15A, V_R = 200V,$	19, 20, 21, 22
		—	6.5	10		$T_J = 125^\circ\text{C}$ $di/dt = 200A/\mu s$	

### Notes:

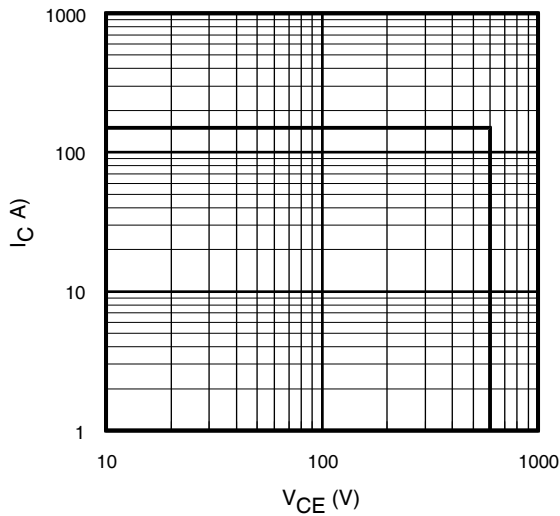
- $R_{CE(on)}$  typ. = equivalent on-resistance =  $V_{CE(on)} \text{ typ.} / I_C$ , where  $V_{CE(on)} \text{ typ.} = 2.00V$  and  $I_C = 33A$ .  $I_D$  (FET Equivalent) is the equivalent MOSFET  $I_D$  rating @  $25^\circ\text{C}$  for applications up to 150kHz. These are provided for comparison purposes (only) with equivalent MOSFET solutions.
- $V_{CC} = 80\% (V_{CES})$ ,  $V_{GE} = 15V$ ,  $L = 28 \mu H$ ,  $R_G = 22 \Omega$ .
- Pulse width limited by max. junction temperature.
- Energy losses include "tail" and diode reverse recovery, Data generated with use of Diode 30ETH06.
- $C_{oes\ eff.}$  is a fixed capacitance that gives the same charging time as  $C_{oes}$  while  $V_{CE}$  is rising from 0 to 80%  $V_{CES}$ .  $C_{oes\ eff. (ER)}$  is a fixed capacitance that stores the same energy as  $C_{oes}$  while  $V_{CE}$  is rising from 0 to 80%  $V_{CES}$ .
- Calculated continuous current based on maximum allowable junction temperature. Package current limit is 60A. Note that current limitations arising from heating of the device leads may occur with some lead mounting arrangements.



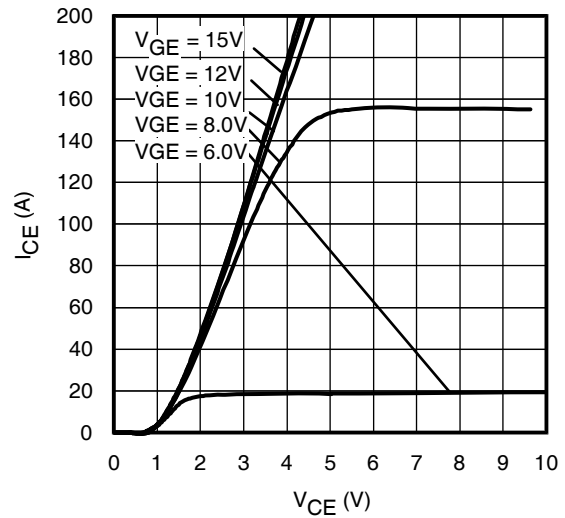
**Fig. 1 - Maximum DC Collector Current vs. Case Temperature**



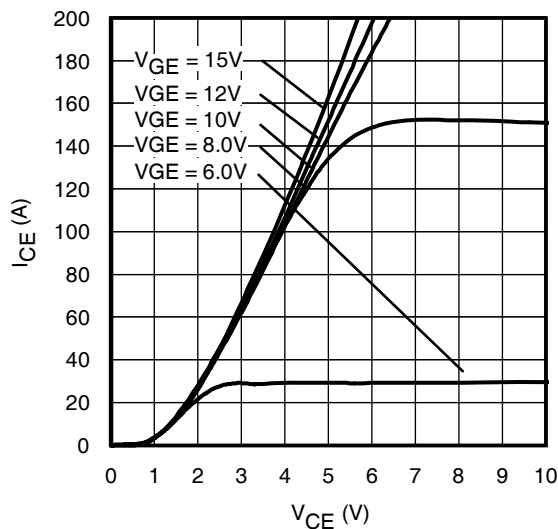
**Fig. 2 - Power Dissipation vs. Case Temperature**



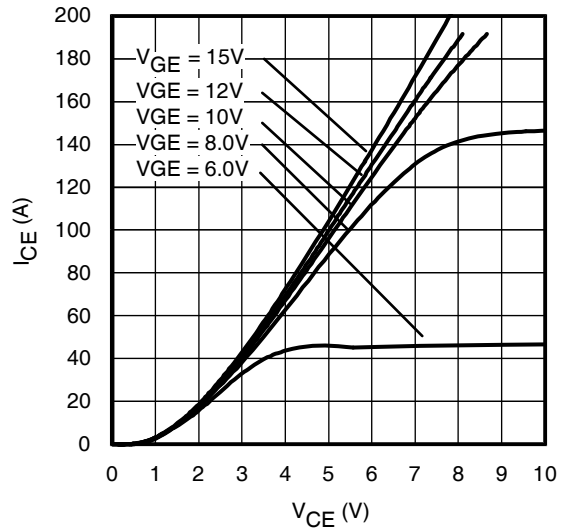
**Fig. 3 - Reverse Bias SOA**  
 $T_J = 150^\circ\text{C}; V_{GE} = 15\text{V}$



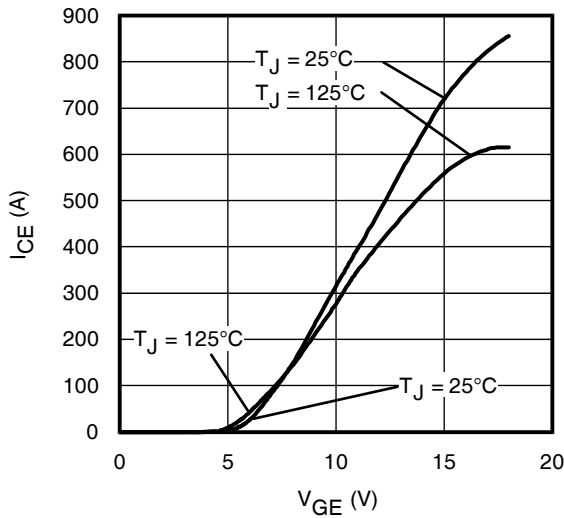
**Fig. 4 - Typ. IGBT Output Characteristics**  
 $T_J = -40^\circ\text{C}; t_p = 80\mu\text{s}$



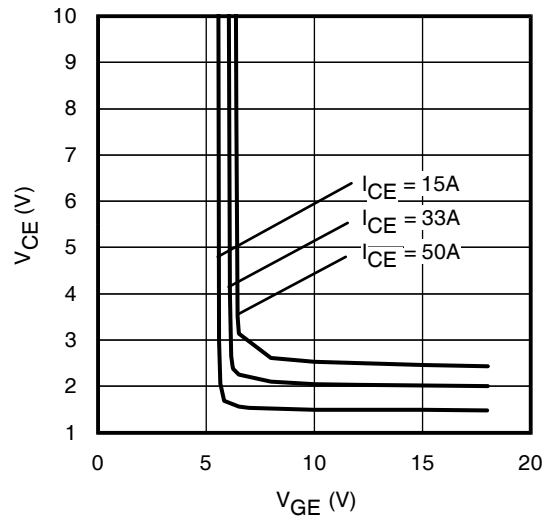
**Fig. 5 - Typ. IGBT Output Characteristics**  
 $T_J = 25^\circ\text{C}; t_p = 80\mu\text{s}$



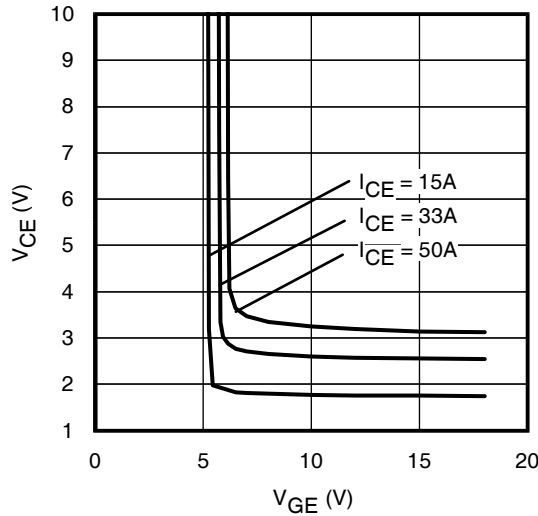
**Fig. 6 - Typ. IGBT Output Characteristics**  
 $T_J = 125^\circ\text{C}; t_p = 80\mu\text{s}$



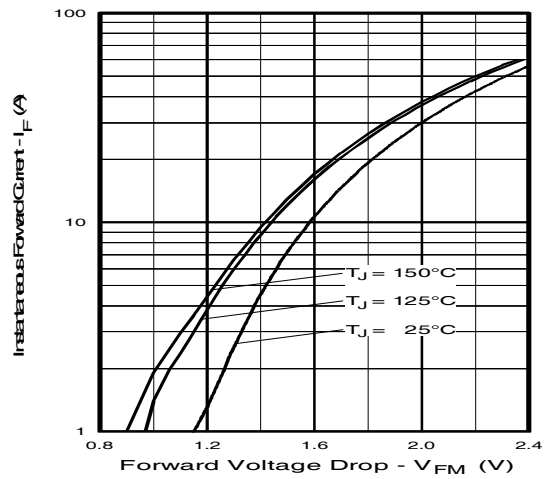
**Fig. 7 - Typ. Transfer Characteristics**  
 $V_{CE} = 50V$ ;  $t_p = 10\mu s$



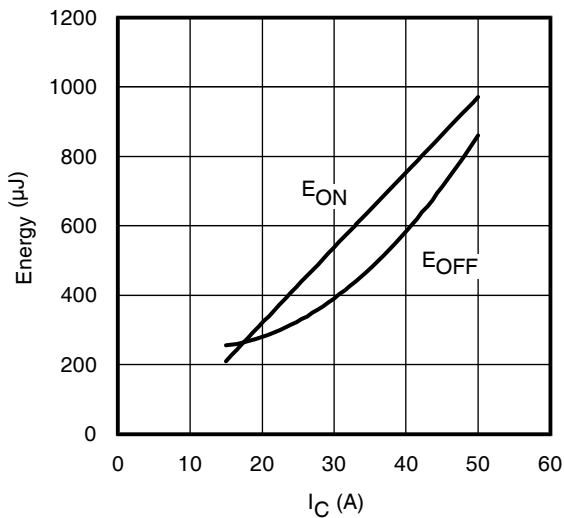
**Fig. 8 - Typical  $V_{CE}$  vs.  $V_{GE}$**   
 $T_J = 25^\circ C$



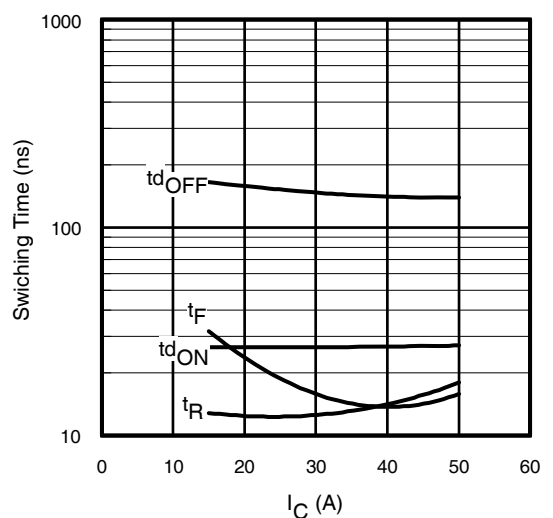
**Fig. 9 - Typical  $V_{CE}$  vs.  $V_{GE}$**   
 $T_J = 125^\circ C$



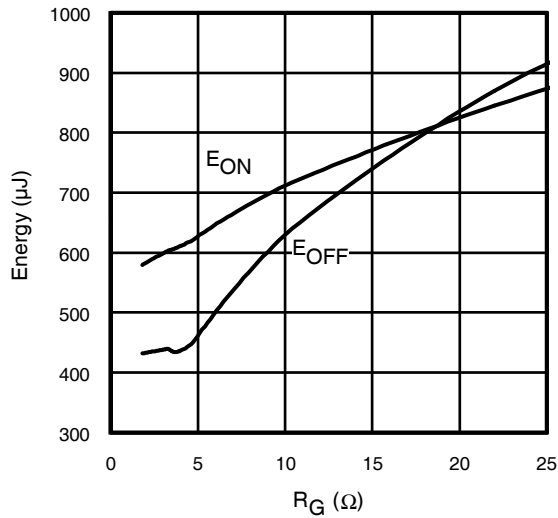
**Fig. 10 - Typ. Diode Forward Characteristics**  
 $t_p = 80\mu s$



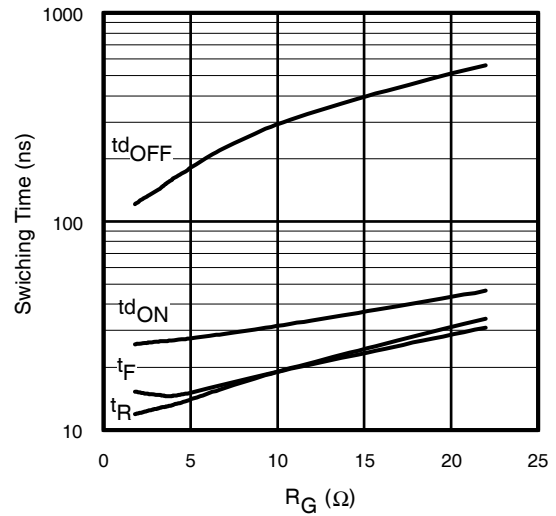
**Fig. 11 - Typ. Energy Loss vs.  $I_C$**   
 $T_J = 125^\circ C$ ;  $L = 200\mu H$ ;  $V_{CE} = 390V$ ;  $R_G = 3.3\Omega$ ;  $V_{GE} = 15V$ .  
 Diode clamp used: 30ETH06 (See C.T.3)



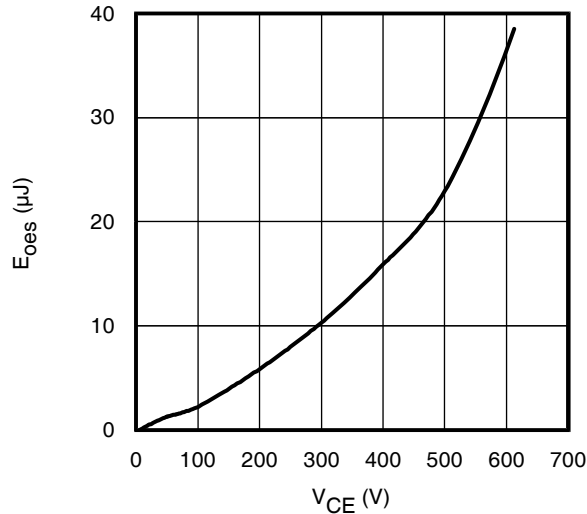
**Fig. 12 - Typ. Switching Time vs.  $I_C$**   
 $T_J = 125^\circ C$ ;  $L = 200\mu H$ ;  $V_{CE} = 390V$ ;  $R_G = 3.3\Omega$ ;  $V_{GE} = 15V$ .  
 Diode clamp used: 30ETH06 (See C.T.3)



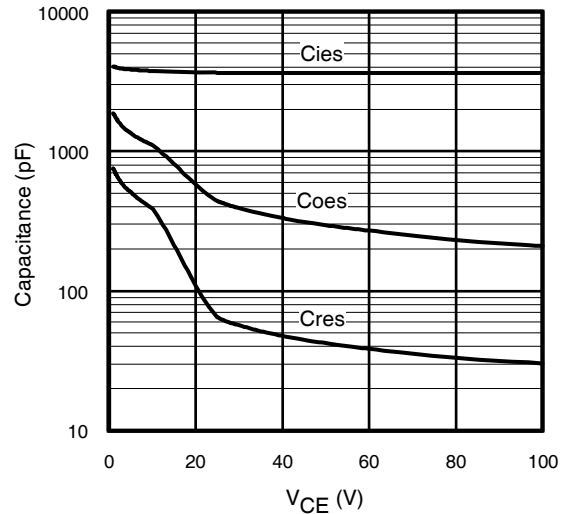
**Fig. 13 - Typ. Energy Loss vs.  $R_G$**   
 $T_J = 125^\circ\text{C}$ ;  $L = 200\mu\text{H}$ ;  $V_{CE} = 390\text{V}$ ;  $I_{CE} = 33\text{A}$ ;  $V_{GE} = 15\text{V}$   
 Diode clamp used: 30ETH06 (See C.T.3)



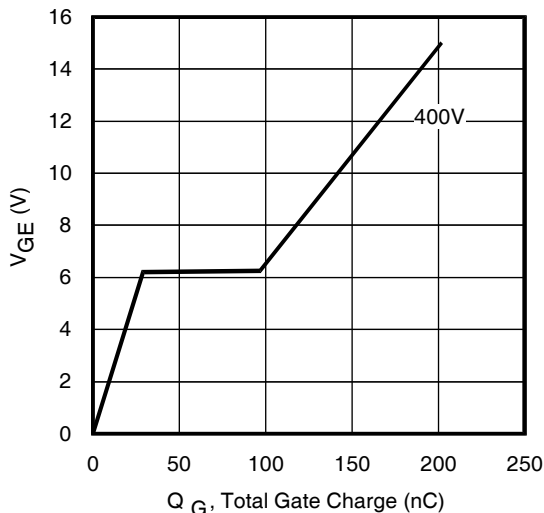
**Fig. 14 - Typ. Switching Time vs.  $R_G$**   
 $T_J = 125^\circ\text{C}$ ;  $L = 200\mu\text{H}$ ;  $V_{CE} = 390\text{V}$ ;  $I_{CE} = 33\text{A}$ ;  $V_{GE} = 15\text{V}$   
 Diode clamp used: 30ETH06 (See C.T.3)



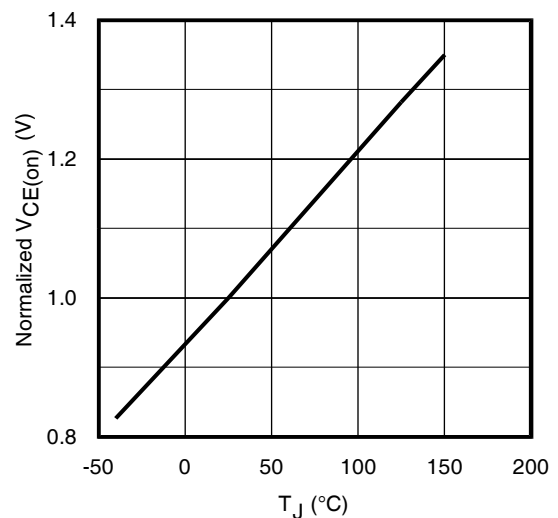
**Fig. 15- Typ. Output Capacitance Stored Energy vs.  $V_{CE}$**



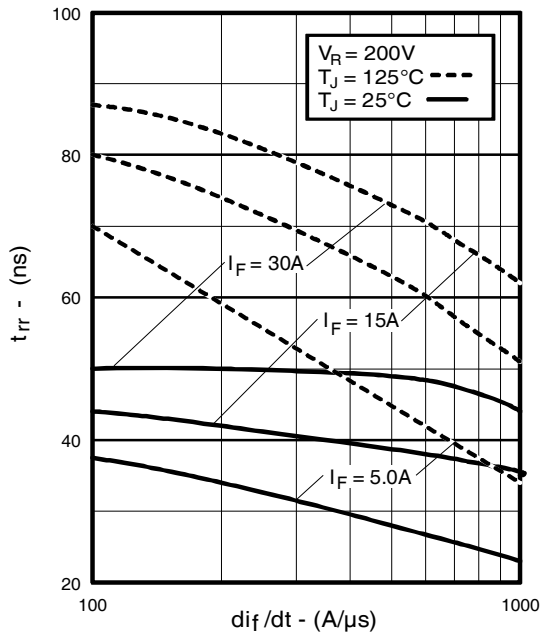
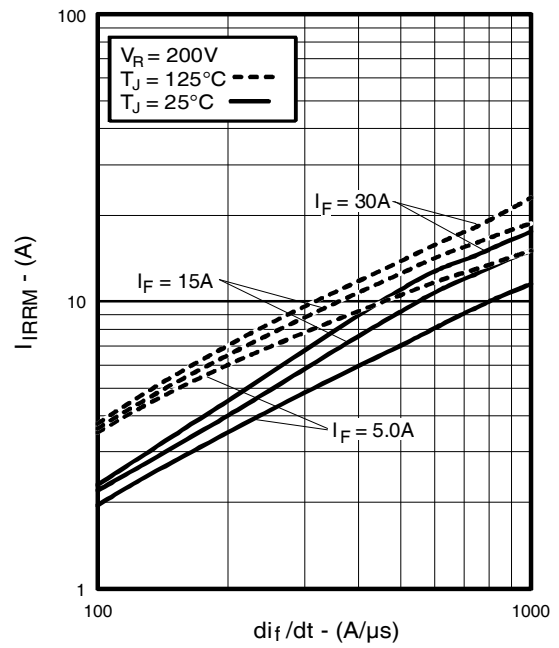
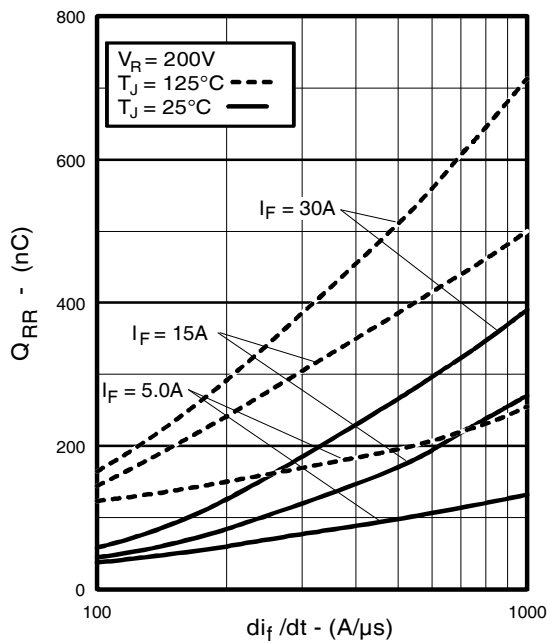
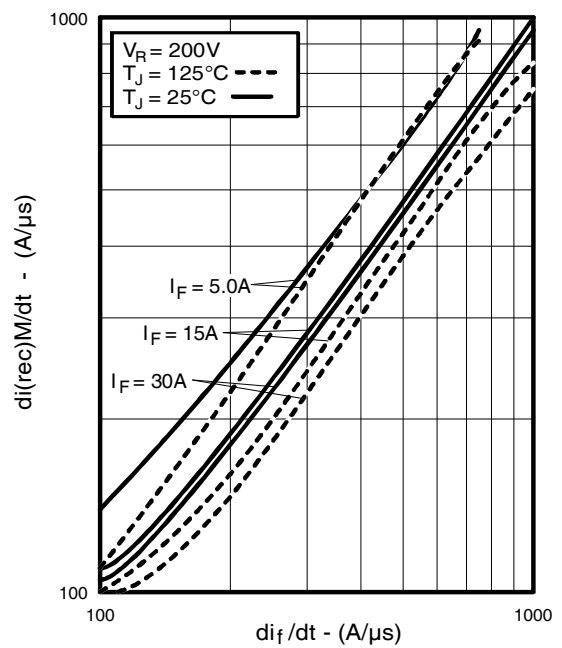
**Fig. 16- Typ. Capacitance vs.  $V_{CE}$**   
 $V_{GE} = 0\text{V}$ ;  $f = 1\text{MHz}$

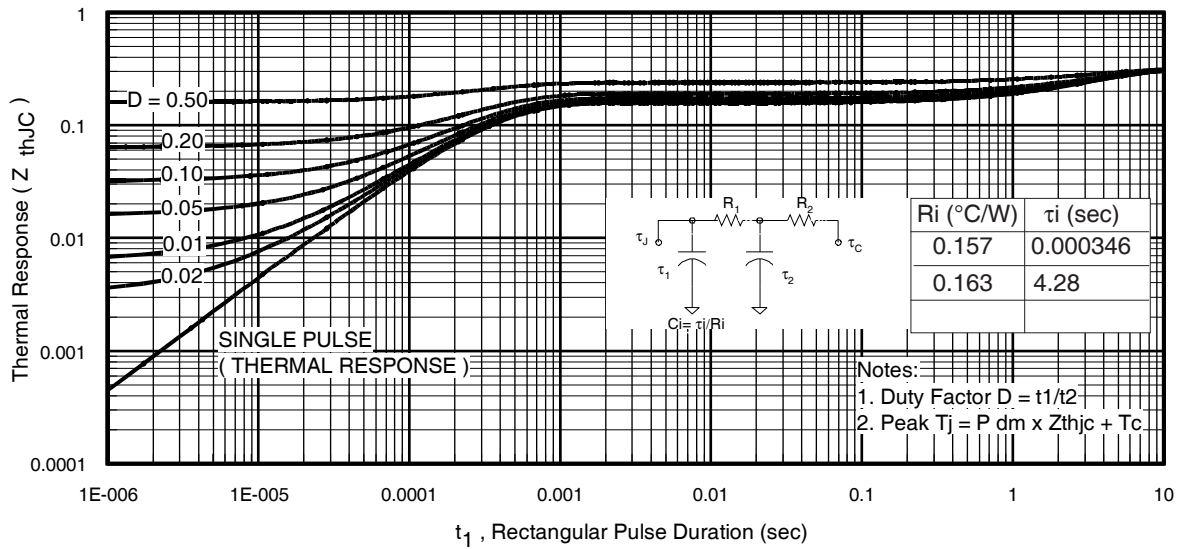
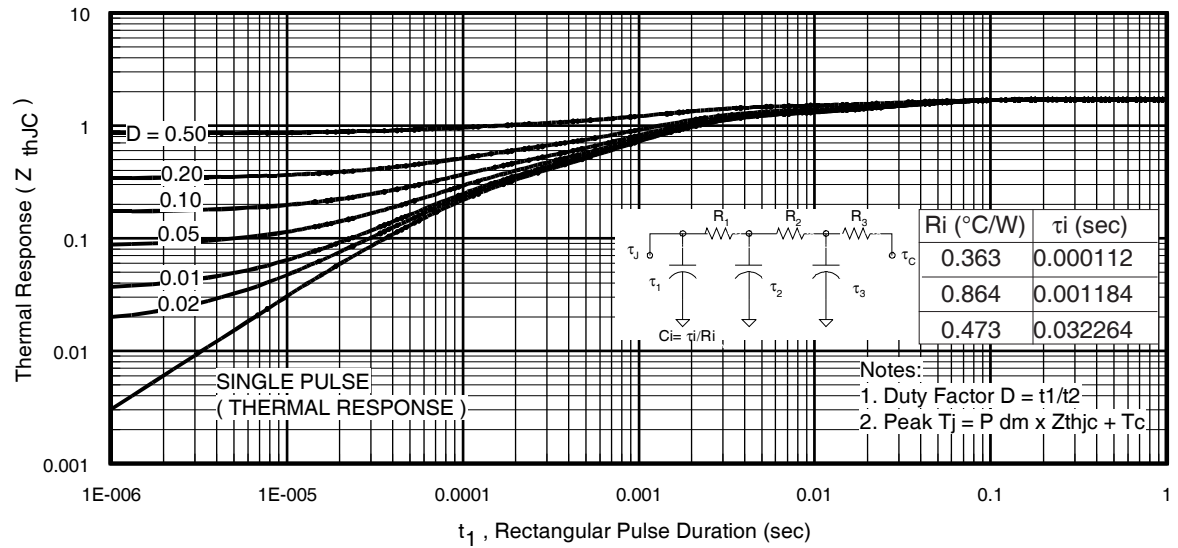


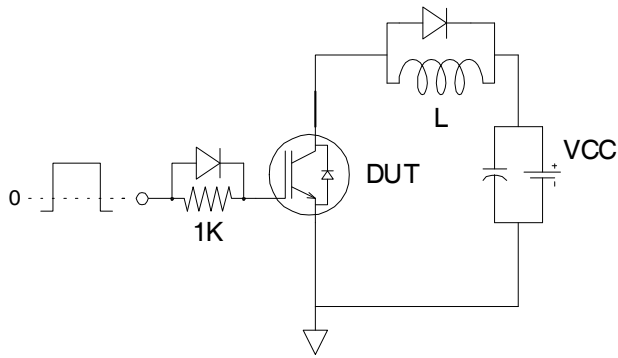
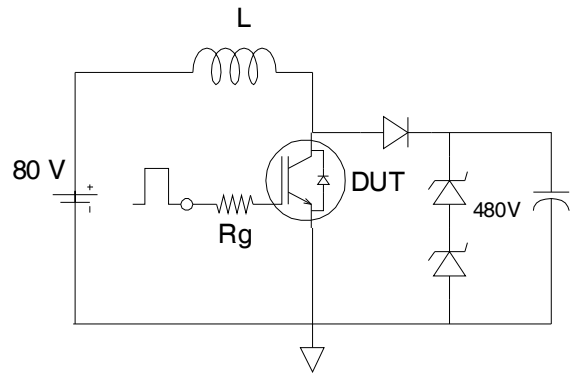
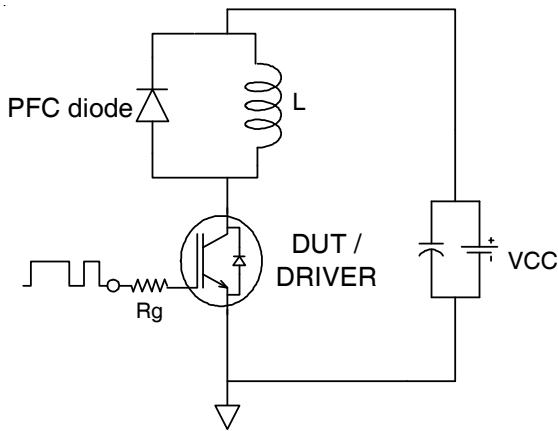
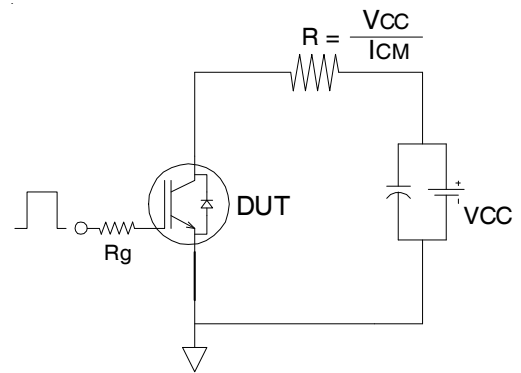
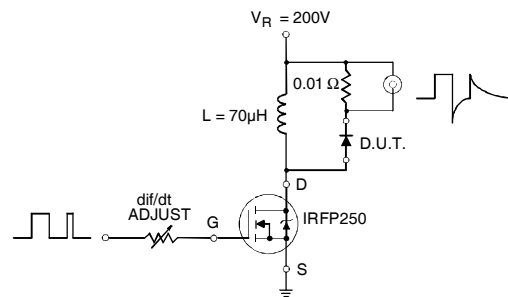
**Fig. 17 - Typical Gate Charge vs.  $V_{GE}$**   
 $I_{CE} = 33\text{A}$



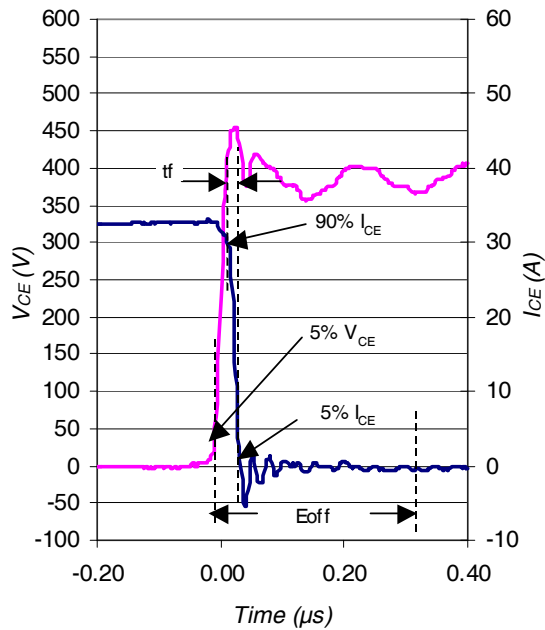
**Fig. 18 - Normalized Typ.  $V_{CE(on)}$  vs. Junction Temperature**  
 $I_C = 33\text{A}$ ,  $V_{GE} = 15\text{V}$


**Fig. 19 - Typical Reverse Recovery vs.  $di_f/dt$** 

**Fig. 20 - Typical Recovery Current vs.  $di_f/dt$** 

**Fig. 21 - Typical Stored Charge vs.  $di_f/dt$** 

**Fig. 22 - Typical  $di_{(rec)M}/dt$  vs.  $di_f/dt$**

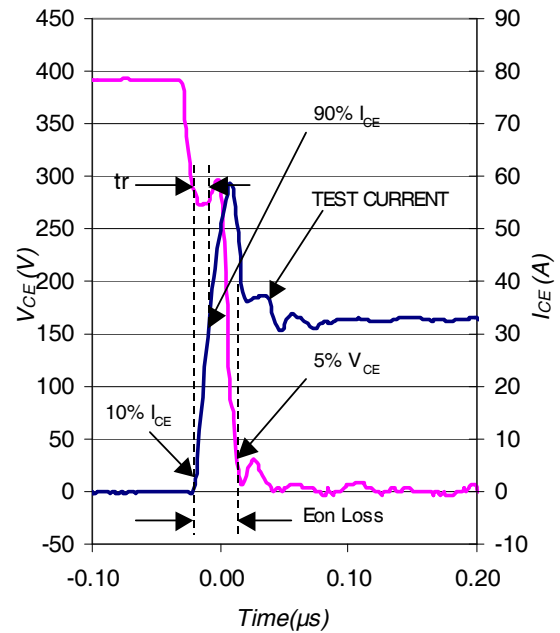

**Fig 23. Maximum Transient Thermal Impedance, Junction-to-Case (IGBT)**

**Fig. 24. Maximum Transient Thermal Impedance, Junction-to-Case (DIODE)**


**Fig.C.T.1 - Gate Charge Circuit (turn-off)**

**Fig.C.T.2 - RBSOA Circuit**

**Fig.C.T.3 - Switching Loss Circuit**

**Fig.C.T.4 - Resistive Load Circuit**
**REVERSE RECOVERY CIRCUIT**

**Fig. C.T.5 - Reverse Recovery Parameter Test Circuit**

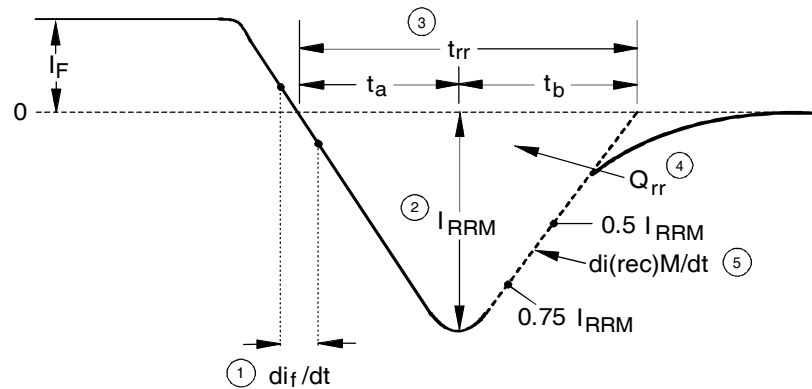




**Fig. WF1** - Typ. Turn-off Loss Waveform  
@  $T_J = 25^\circ\text{C}$  using Fig. CT.3



**Fig. WF2** - Typ. Turn-on Loss Waveform  
@  $T_J = 25^\circ\text{C}$  using Fig. CT.3



1.  $di_f/dt$  - Rate of change of current through zero crossing
2.  $I_{RRM}$  - Peak reverse recovery current
3.  $t_{rr}$  - Reverse recovery time measured from zero crossing point of negative going  $I_F$  to point where a line passing through  $0.75 I_{RRM}$  and  $0.50 I_{RRM}$  extrapolated to zero current

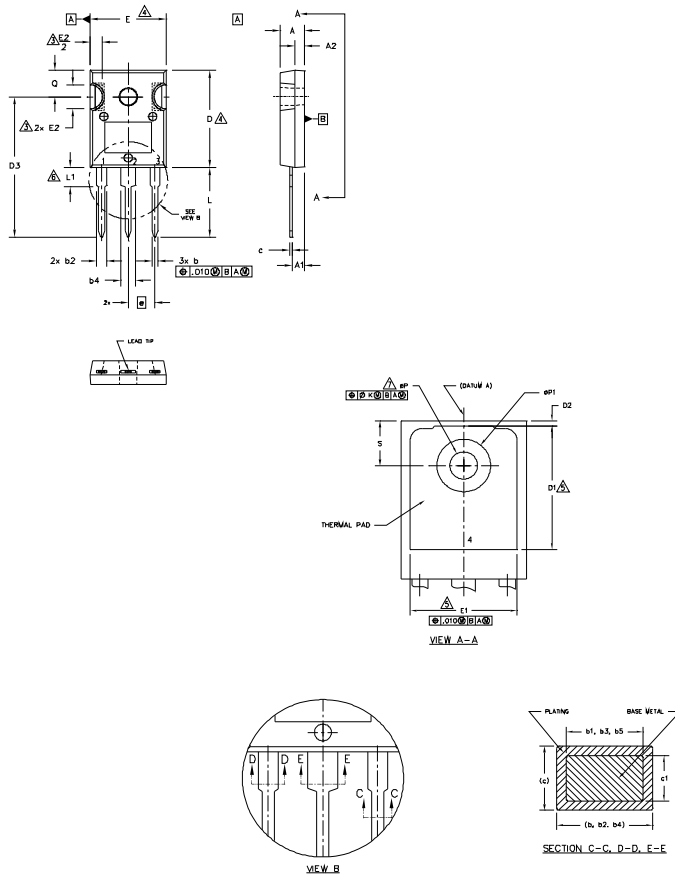
4.  $Q_{rr}$  - Area under curve defined by  $t_{rr}$  and  $I_{RRM}$   

$$Q_{rr} = \frac{t_{rr} \times I_{RRM}}{2}$$
5.  $di_{(rec)M}/dt$  - Peak rate of change of current during  $t_b$  portion of  $t_{rr}$

**Fig. WF3** - Reverse Recovery Waveform and Definitions

## TO-247AC Package Outline

Dimensions are shown in millimeters (inches)



**NOTES:**

1. DIMENSIONING AND TOLERANCING AS PER ASME Y14.5M 1994.
2. DIMENSIONS ARE SHOWN IN INCHES.
3. CONTOUR OF SLOT OPTIONAL.
4. DIMENSION D & E DO NOT INCLUDE MOLD FLASH. MOLD FLASH SHALL NOT EXCEED .005" (0.127) PER SIDE. THESE DIMENSIONS ARE MEASURED AT THE OUTERMOST EXTREMES OF THE PLASTIC BODY.
5. THERMAL PAD CONTOUR OPTIONAL WITHIN DIMENSIONS D1 & E1.
6. LEAD FINISH UNCONTROLLED IN L1.
7. ØP TO HAVE A MAXIMUM DRAFT ANGLE OF 1.5 ° TO THE TOP OF THE PART WITH A MAXIMUM HOLE DIAMETER OF .154 INCH.
8. OUTLINE CONFORMS TO JEDEC OUTLINE TO-247AC .

SYMBOL	DIMENSIONS				NOTES
	INCHES		MILLIMETERS		
	MIN.	MAX.	MIN.	MAX.	
A	.183	.209	4.65	5.31	
A1	.087	.102	2.21	2.59	
A2	.059	.098	1.50	2.49	
b	.039	.055	0.99	1.40	
b1	.039	.053	0.99	1.35	
b2	.065	.094	1.65	2.39	
b3	.065	.092	1.65	2.34	
b4	.102	.135	2.59	3.43	
b5	.102	.133	2.59	3.38	
c	.015	.035	0.38	0.89	
c1	.015	.033	0.38	0.84	
D	.776	.815	19.71	20.70	4
D1	.515	-	13.08	-	5
D2	.020	.053	0.51	1.35	
D3	1.122	1.161	28.50	29.50	4
E	.602	.625	15.29	15.87	
E1	.530	-	13.46	-	
E2	.178	.216	4.52	5.49	
e	.215 BSC		5.46 BSC		
Øk	.010		0.25		
L	.559	.634	14.20	16.10	
L1	.146	.169	3.71	4.29	
ØP1	.140	.144	3.56	3.66	
O	.209	.224	5.31	5.69	
S	.217 BSC		5.51 BSC		

**PART NUMBERS AFFECTED:**

- AUIRG4PH50S
- AUIRGP4066D1/E
- AUIRGP40630/E
- AUIRGP50B60PD1/E
- AUIRGP35B60PD/E
- AUIRGP4062D1/E
- AUIRGP65A20D0
- AUIRGP65G20D0
- AUIRGP/F66524D0
- AUIRGP/F76524D0
- AUIRGP/F66548D0
- AUIRGP/F76548D0

**LEAD ASSIGNMENTS**

**HEXFET**

- 1.- GATE
- 2.- DRAIN
- 3.- SOURCE
- 4.- DRAIN

**IGBTs, CoPACK**

- 1.- GATE
- 2.- COLLECTOR
- 3.- EMITTER
- 4.- COLLECTOR

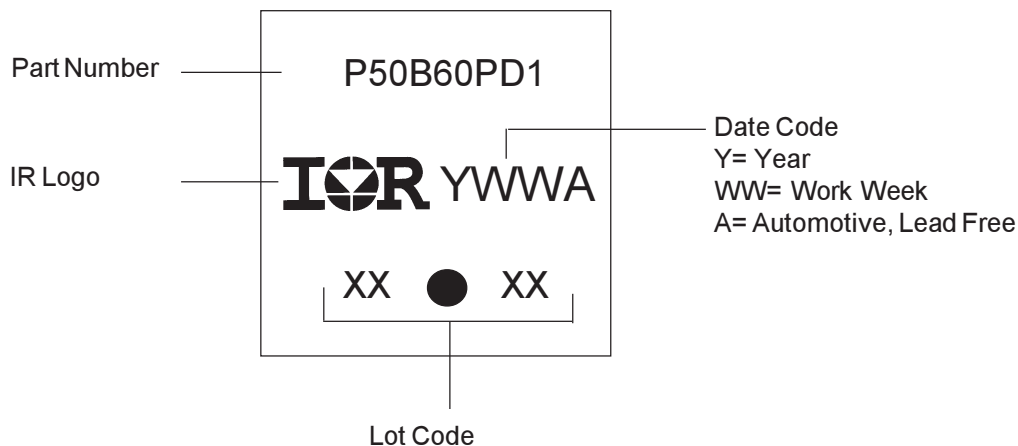
**DIODES**

- 1.- ANODE/OPEN
- 2.- CATHODE
- 3.- ANODE

**SPECIAL NOTE:**

- a) ADDED D3 FOR SPECIAL REQUIREMENT

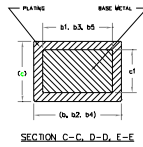
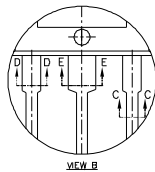
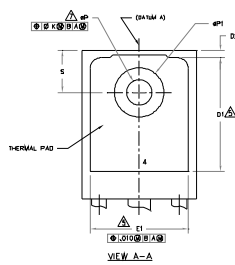
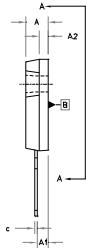
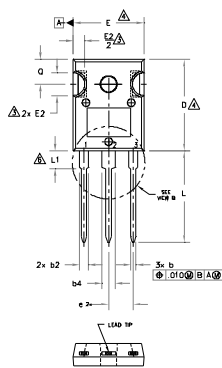
## TO-247AC Part Marking Information



Note: For the most current drawing please refer to IR website at <http://www.irf.com/package/>

## TO-247AD Package Outline

Dimensions are shown in millimeters (inches)



**NOTES:**

- DIMENSIONING AND TOLERANCING AS PER ASME Y14.5M 1994.
- DIMENSIONS ARE SHOWN IN INCHES.
- CONTOUR OF SLOT OPTIONAL.
- DIMENSION D & E DO NOT INCLUDE MOLD FLASH. MOLD FLASH SHALL NOT EXCEED .005" (0.127) PER SIDE. THESE DIMENSIONS ARE MEASURED AT THE OUTERMOST EXTREMES OF THE PLASTIC BODY.
- THERMAL PAD CONTOUR OPTIONAL WITHIN DIMENSIONS D1 & E1.
- LEAD FINISH UNCONTROLLED IN L1.
- ØP TO HAVE A MAXIMUM DRAFT ANGLE OF 1.5 ° TO THE TOP OF THE PART WITH A MAXIMUM HOLE DIAMETER OF .154 INCH.
- OUTLINE CONFORMS TO JEDEC OUTLINE TO-247AD.

SYMBOL	DIMENSIONS				NOTES
	INCHES		MILLIMETERS		
	MIN.	MAX.	MIN.	MAX.	
A	.190	.203	4.83	5.13	
A1	.087	.102	2.21	2.59	
A2	.059	.098	1.50	2.49	
b	.039	.055	0.99	1.40	
b1	.039	.053	0.99	1.35	
b2	.065	.094	1.65	2.39	
b3	.065	.092	1.65	2.34	
b4	.102	.135	2.59	3.43	
b5	.102	.133	2.59	3.38	
c	.015	.035	0.38	0.89	
c1	.015	.033	0.38	0.84	
D	.776	.815	19.71	20.70	4
D1	.515	-	13.08	-	5
D2	.020	.053	0.51	1.35	
E	.602	.625	15.29	15.87	4
E1	.530	-	13.46	-	
E2	.178	.216	4.52	5.49	
e	.215 BSC		5.46 BSC		
Øk	.010		0.25		
L	.780	.827	19.57	21.00	
L1	.146	.169	3.71	4.29	
ØP	.140	.144	3.56	3.66	
ØP1	-	.291	-	7.39	
Q	.209	.224	5.31	5.69	
S	.217 BSC		5.51 BSC		

**LEAD ASSIGNMENTS**

**HEXFET**

- GATE
- DRAIN
- SOURCE
- DRAIN

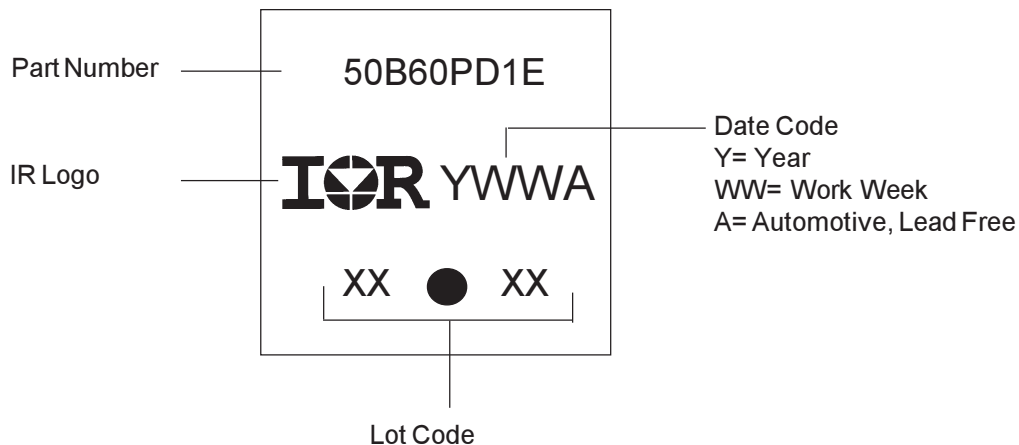
**IGBTs, CoPACK**

- GATE
- COLLECTOR
- EMITTER
- COLLECTOR

**DIODES**

- ANODE/OPEN
- CATHODE
- ANODE

## TO-247AD Part Marking Information



Note: For the most current drawing please refer to IR website at <http://www.irf.com/package/>

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