

**WARP2 SERIES IGBT WITH  
ULTRAFAST SOFT RECOVERY DIODE**

**Features**

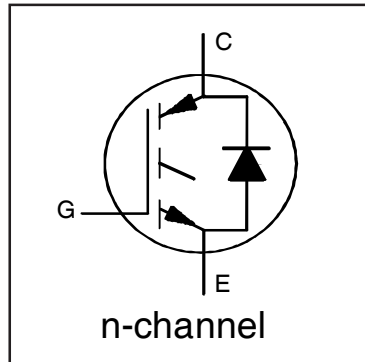
- NPT Technology, Positive Temperature Coefficient
- Lower  $V_{CE(SAT)}$
- Lower Parasitic Capacitances
- Minimal Tail Current
- HEXFRED Ultra Fast Soft-Recovery Co-Pack Diode
- Tighter Distribution of Parameters
- Higher Reliability
- Lead-Free, RoHS Compliant
- Automotive Qualified\*

**Applications**

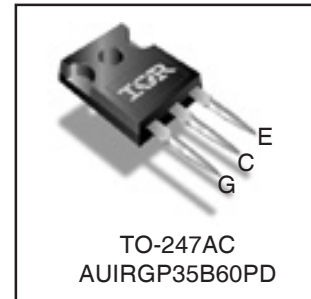
- PFC and ZVS SMPS Circuits
- DC/DC Converter Charger

**Benefits**

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



$V_{CES} = 600V$ $V_{CE(on)} \text{ typ.} = 1.85V$ @ $V_{GE} = 15V$ $I_C = 22A$
<b>Equivalent MOSFET Parameters<sup>①</sup></b>
$R_{CE(on)} \text{ typ.} = 84m\Omega$ $I_D \text{ (FET equivalent)} = 35A$



G	C	E
Gate	Collector	Emitter

**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	60	A
$I_C @ T_C = 100^\circ C$	Continuous Collector Current	34	
$I_{CM}$	Pulse Collector Current (Ref. Fig. C.T.4)	120	
$I_{LM}$	Clamped Inductive Load Current <sup>②</sup>	120	
$I_F @ T_C = 25^\circ C$	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	±20	V
$P_D @ T_C = 25^\circ C$	Maximum Power Dissipation	308	W
$P_D @ T_C = 100^\circ C$	Maximum Power Dissipation	123	
$T_J$	Operating Junction and Storage Temperature Range	-55 to +150	°C
$T_{STG}$			
	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)	—	—	0.41	°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)	—	0.50	—	
$R_{\theta JA}$	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/>

## 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	—	0.78	—	V/°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	—	1.85	2.15	V	$I_C = 22A, V_{GE} = 15V$	4, 5, 6, 8, 9
		—	2.25	2.55		$I_C = 35A, V_{GE} = 15V$	
		—	2.37	2.80		$I_C = 22A, V_{GE} = 15V, T_J = 125^\circ\text{C}$	
		—	3.00	3.45		$I_C = 35A, V_{GE} = 15V, T_J = 125^\circ\text{C}$	
$V_{GE(th)}$	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/°C	$V_{CE} = V_{GE}, I_C = 1.0mA$	
$g_{fe}$	Forward Transconductance	—	36	—	S	$V_{CE} = 50V, I_C = 22A, PW = 80\mu s$	
$I_{CES}$	Collector-to-Emitter Leakage Current	—	3.0	375	$\mu A$	$V_{GE} = 0V, V_{CE} = 600V$	
		—	0.35	—	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	$V_{GE} = \pm 20V, V_{CE} = 0V$	

## 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)	—	160	240	nC	$I_C = 22A$	17
$Q_{gc}$	Gate-to-Collector Charge (turn-on)	—	55	83		$V_{CC} = 400V$	CT1
$Q_{ge}$	Gate-to-Emitter Charge (turn-on)	—	21	32		$V_{GE} = 15V$	
$E_{on}$	Turn-On Switching Loss	—	220	270	$\mu J$	$I_C = 22A, V_{CC} = 390V$	CT3
$E_{off}$	Turn-Off Switching Loss	—	215	265		$V_{GE} = +15V, R_G = 3.3\Omega, L = 200\mu H$	
$E_{total}$	Total Switching Loss	—	435	535		$T_J = 25^\circ\text{C} \text{ (4)}$	
$t_{d(on)}$	Turn-On delay time	—	26	34	ns	$I_C = 22A, V_{CC} = 390V$	CT3
$t_r$	Rise time	—	6.0	8.0		$V_{GE} = +15V, R_G = 3.3\Omega, L = 200\mu H$	
$t_{d(off)}$	Turn-Off delay time	—	110	122		$T_J = 25^\circ\text{C} \text{ (4)}$	
$t_f$	Fall time	—	8.0	10			
$E_{on}$	Turn-On Switching Loss	—	410	465		$I_C = 22A, V_{CC} = 390V$	CT3
$E_{off}$	Turn-Off Switching Loss	—	330	405	$V_{GE} = +15V, R_G = 3.3\Omega, L = 200\mu H$	11, 13	
$E_{total}$	Total Switching Loss	—	740	870	$T_J = 125^\circ\text{C} \text{ (4)}$	WF1, WF2	
$t_{d(on)}$	Turn-On delay time	—	26	34	ns	$I_C = 22A, V_{CC} = 390V$	CT3
$t_r$	Rise time	—	8.0	11		$V_{GE} = +15V, R_G = 3.3\Omega, L = 200\mu H$	12, 14
$t_{d(off)}$	Turn-Off delay time	—	130	150		$T_J = 125^\circ\text{C} \text{ (4)}$	WF1, WF2
$t_f$	Fall time	—	12	16			
$C_{ies}$	Input Capacitance	—	3715	—		pF	$V_{GE} = 0V$
$C_{oes}$	Output Capacitance	—	265	—	$V_{CC} = 30V$		
$C_{res}$	Reverse Transfer Capacitance	—	47	—	$f = 1MHz$		
$C_{oes\ eff.}$	Effective Output Capacitance (Time Related) (5)	—	135	—	$V_{GE} = 0V, V_{CE} = 0V \text{ to } 480V$		15
$C_{oes\ eff. (ER)}$	Effective Output Capacitance (Energy Related) (5)	—	179	—			
RBSOA	Reverse Bias Safe Operating Area	FULL SQUARE				$T_J = 150^\circ\text{C}, I_C = 120A$ $V_{CC} = 480V, V_p = 600V$ $R_g = 22\Omega, V_{GE} = +15V \text{ to } 0V$	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:

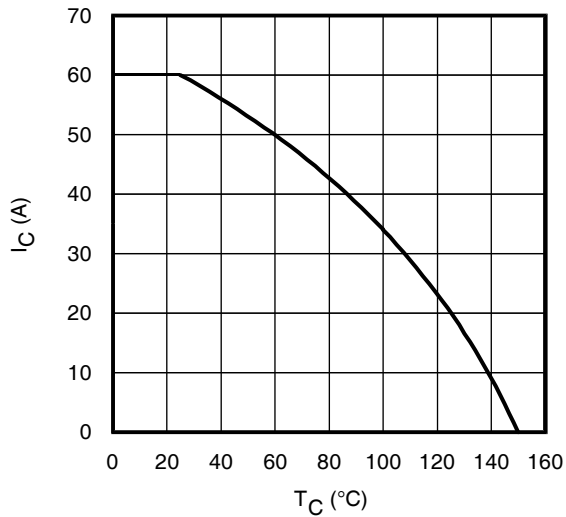
- $R_{CE(on)}$  typ. = equivalent on-resistance =  $V_{CE(on)}$  typ. /  $I_C$ , where  $V_{CE(on)}$  typ. = 1.85V and  $I_C = 22A$ .  $I_D$  (FET Equivalent) is the equivalent MOSFET  $I_D$  rating @  $25^\circ\text{C}$  for applications up to 150kHz. These are provided for comparison purposes (only) with equivalent MOSFET solutions.
- $V_{CC} = 80\% (V_{CES}), V_{GE} = 20V, L = 28\mu H, R_G = 22\Omega$ .
- 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%  $V_{CES}$ .

**Qualification Information†**

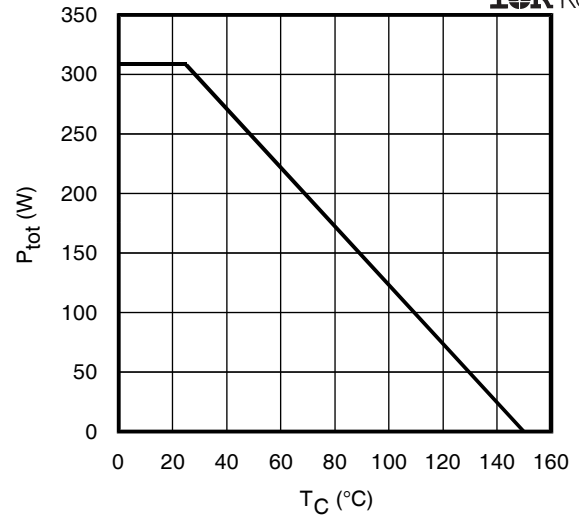
<b>Qualification Level</b>		Automotive (per AEC-Q101) ††	
		Comments: This part number(s) passed Automotive qualification. IR's Industrial and Consumer qualification level is granted by extension of the higher Automotive level.	
<b>Moisture Sensitivity Level</b>		TO-247	MSL1
<b>ESD</b>	Machine Model	Class M4 (425V) AEC-Q101-002	
	Human Body Model	Class H2 (4000V) AEC-Q101-001	
	Charged Device Model	Class C5 (1125V) AEC-Q101-005	
<b>RoHS Compliant</b>		Yes	

† Qualification standards can be found at International Rectifier's web site: <http://www.irf.com/>

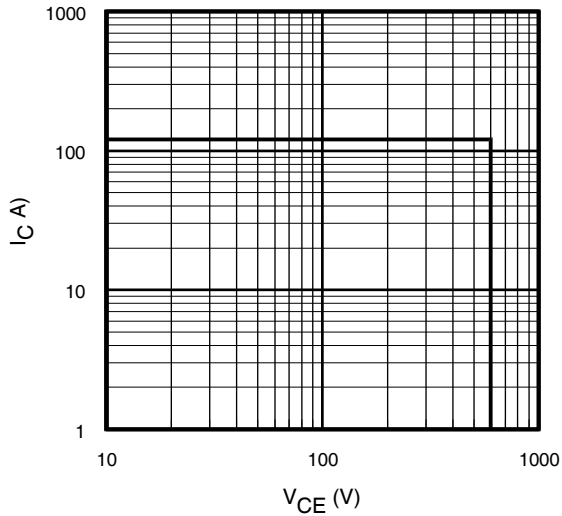
†† Exceptions to AEC-Q101 requirements are noted in the qualification report.



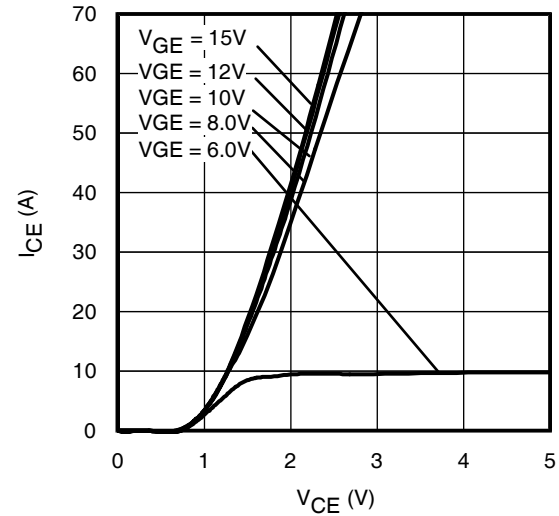
**Fig. 1** - Maximum DC Collector Current vs. Case Temperature



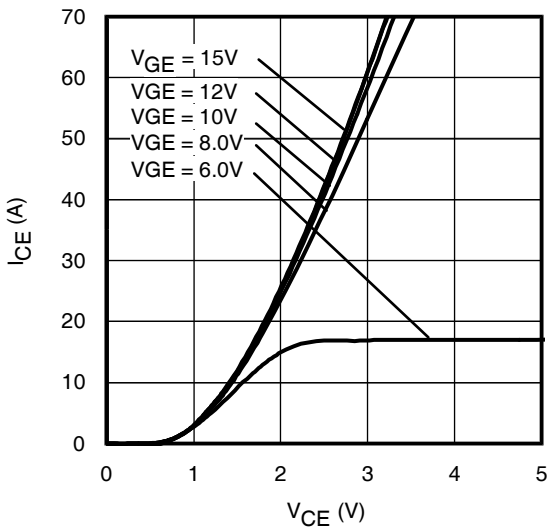
**Fig. 2** - Power Dissipation vs. Case Temperature



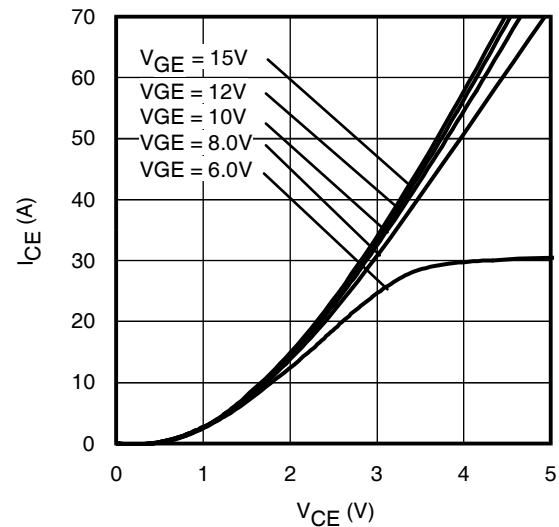
**Fig. 3** - Reverse Bias SOA  
 $T_J = 150^{\circ}C$ ;  $V_{GE} = 15V$



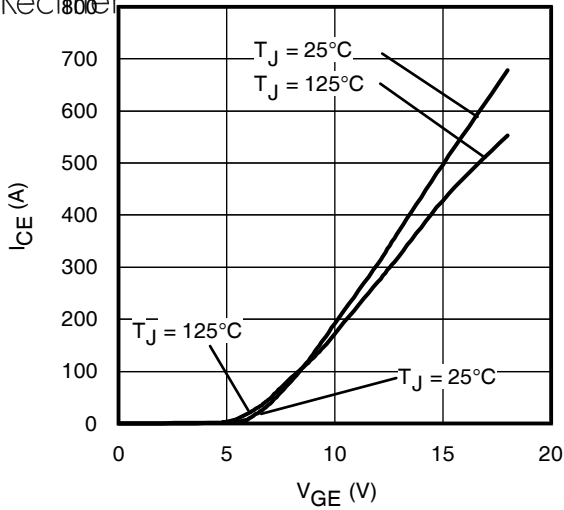
**Fig. 4** - Typ. IGBT Output Characteristics  
 $T_J = -40^{\circ}C$ ;  $t_p = 80\mu s$



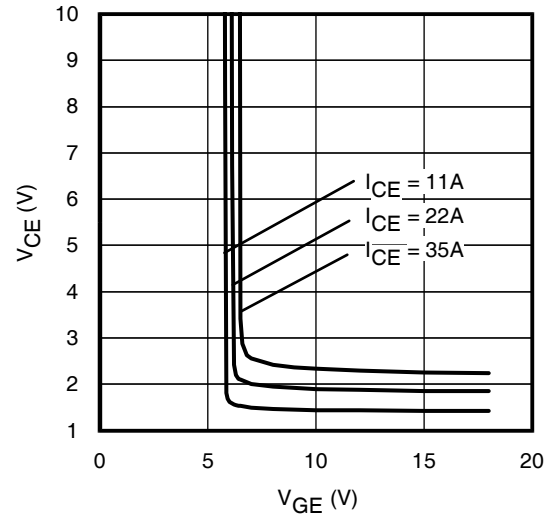
**Fig. 5** - Typ. IGBT Output Characteristics  
 $T_J = 25^{\circ}C$ ;  $t_p = 80\mu s$



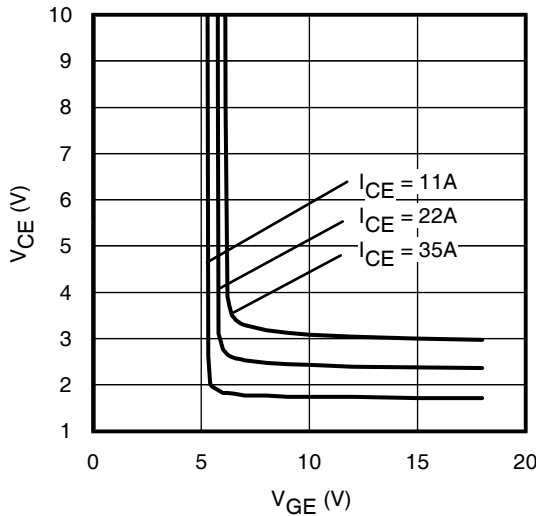
**Fig. 6** - Typ. IGBT Output Characteristics  
 $T_J = 125^{\circ}C$ ;  $t_p = 80\mu s$



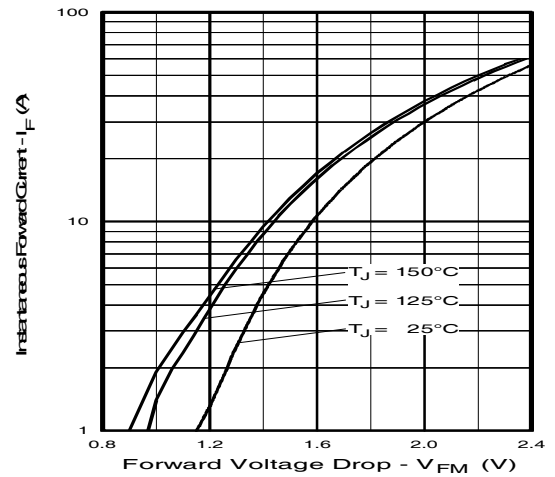
**Fig. 7 - Typ. Transfer Characteristics**  
 $V_{CE} = 50V$ ;  $t_p = 10\mu s$



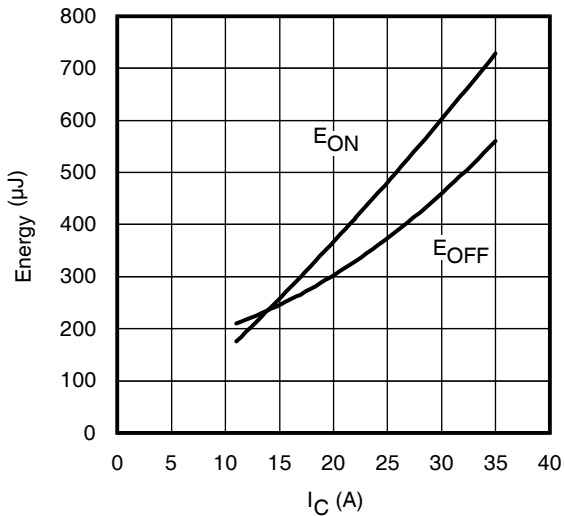
**Fig. 8 - Typical  $V_{CE}$  vs.  $V_{GE}$**   
 $T_J = 25^\circ C$



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

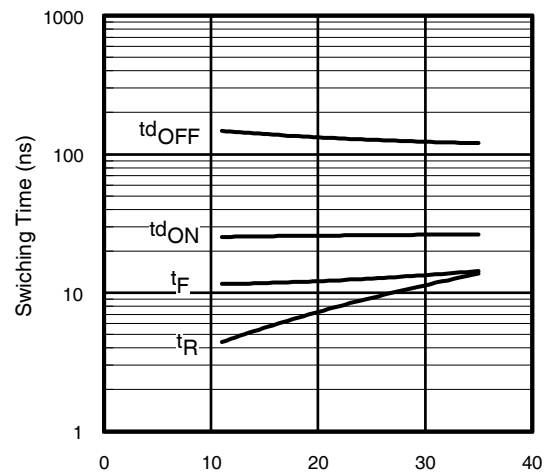


**Fig. 10 - Typ. Diode Forward Characteristics**  
 $t_p = 80\mu s$



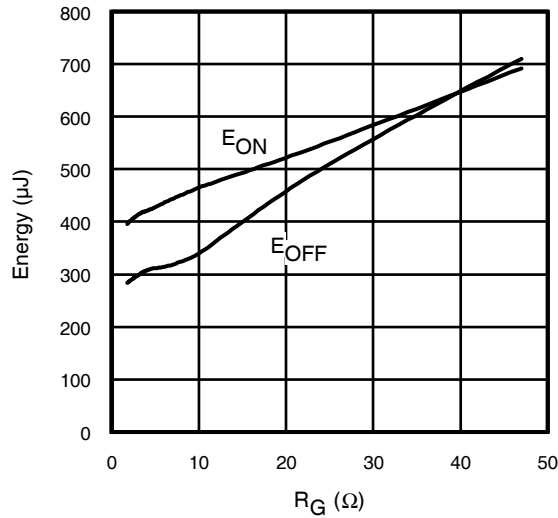
**Fig. 11 - Typ. Energy Loss vs.  $I_C$**

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

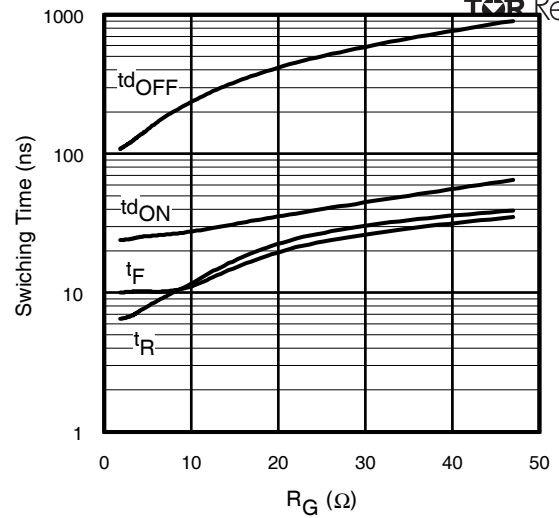


**Fig. 12 - Typ. Switching Time vs.  $I_C$**   
 $T_J = 125^\circ C$ ;  $L = 200\mu H$ ;  $V_{CE} = 390V$ ;  $R_G = 3.3\Omega$ ;  $V_{GE} = 15V$ .  
 Diode clamp used: 30ETH06 (See C.T.3)

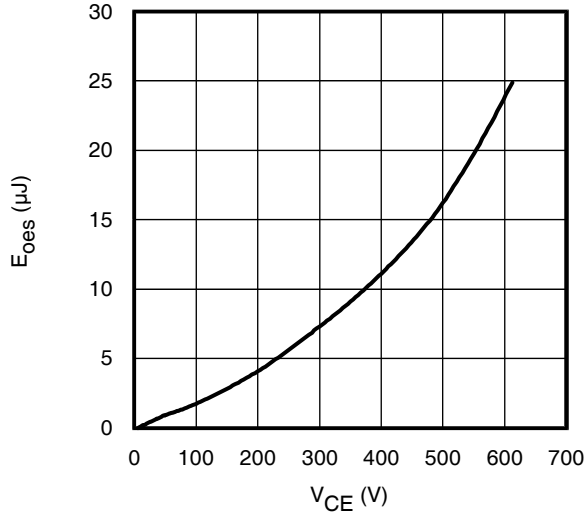
# AUIRGP35B60PD



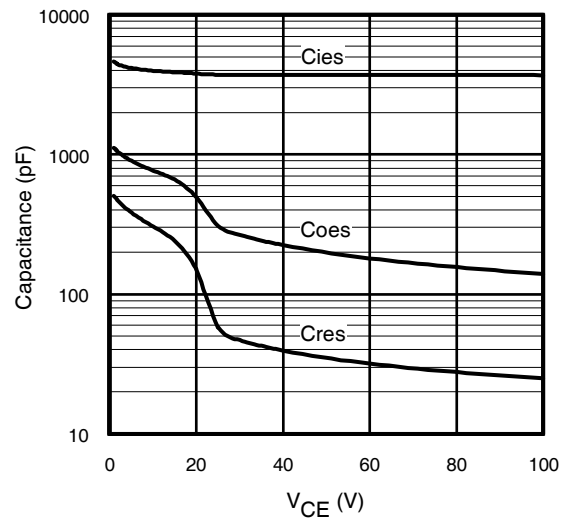
**Fig. 13 - Typ. Energy Loss vs.  $R_G$**   
 $T_J = 125^\circ\text{C}$ ;  $L = 200\mu\text{H}$ ;  $V_{CE} = 390\text{V}$ ;  $I_{CE} = 22\text{A}$ ;  $V_{GE} = 15\text{V}$   
 Diode clamp used: 30ETH06 (See C.T.3)



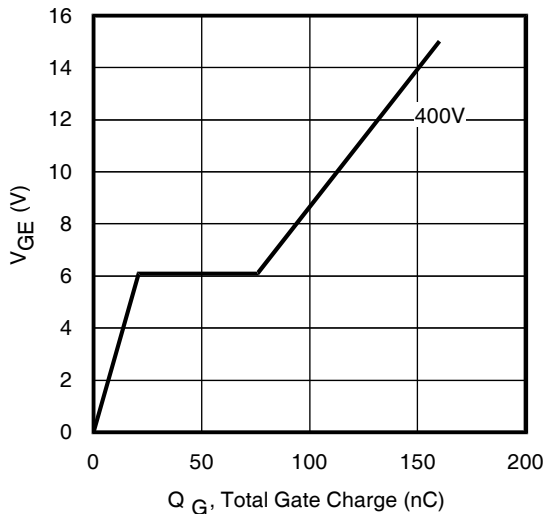
**Fig. 14 - Typ. Switching Time vs.  $R_G$**   
 $T_J = 125^\circ\text{C}$ ;  $L = 200\mu\text{H}$ ;  $V_{CE} = 390\text{V}$ ;  $I_{CE} = 22\text{A}$ ;  $V_{GE} = 15\text{V}$   
 Diode clamp used: 30ETH06 (See C.T.3)



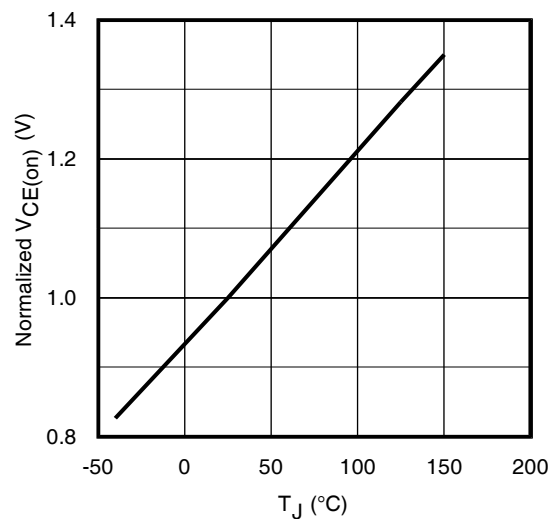
**Fig. 15- Typ. Output Capacitance  
 Stored Energy vs.  $V_{CE}$**



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



**Fig. 17 - Typical Gate Charge vs.  $V_{GE}$**   
 $I_{CE} = 22\text{A}$



**Fig. 18 - Normalized Typ.  $V_{CE(on)}$   
 vs. Junction Temperature**  
 $I_C = 22\text{A}$ ,  $V_{GE} = 15\text{V}$

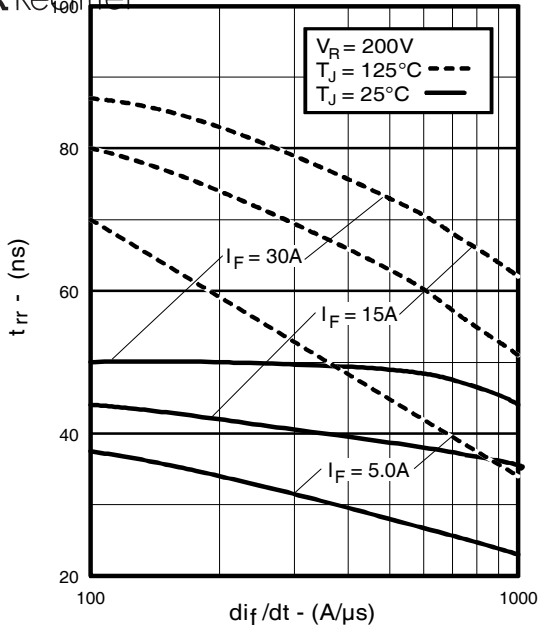


Fig. 19 - Typical Reverse Recovery vs.  $di_f/dt$

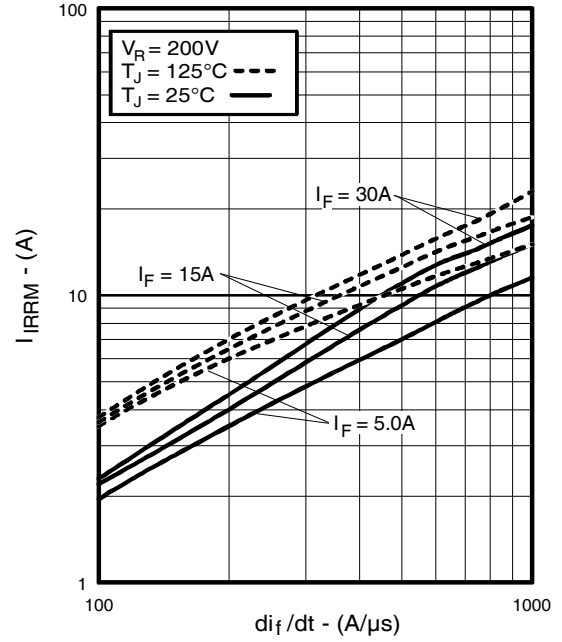


Fig. 20 - Typical Recovery Current vs.  $di_f/dt$

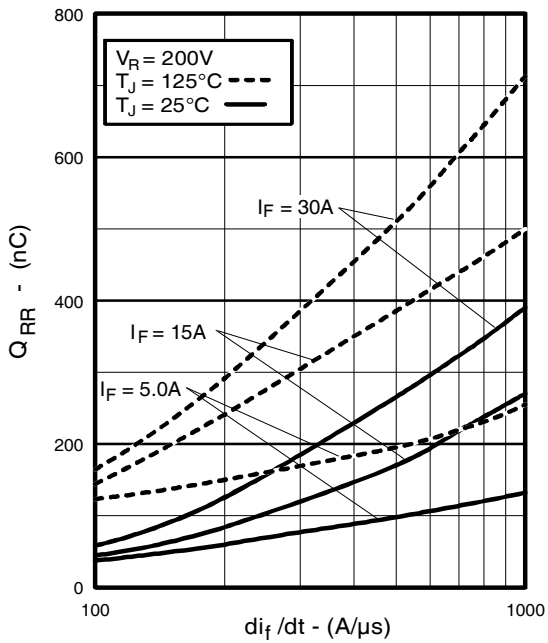


Fig. 21 - Typical Stored Charge vs.  $di_f/dt$

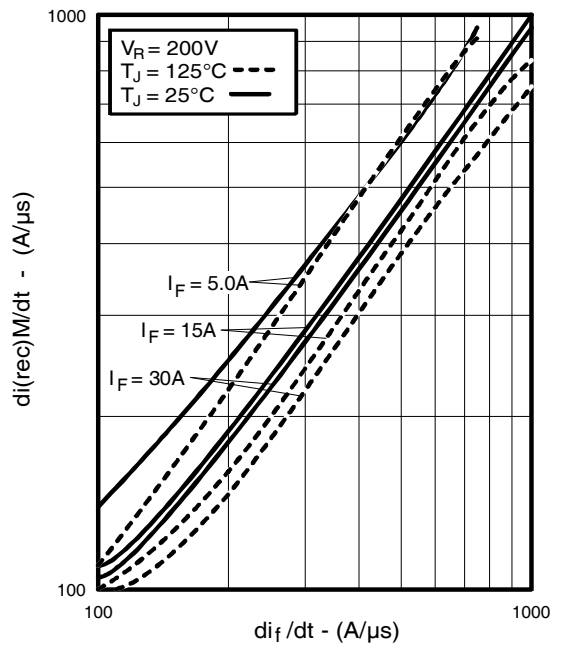


Fig. 22 - Typical  $di_{(rec)M}/dt$  vs.  $di_f/dt$

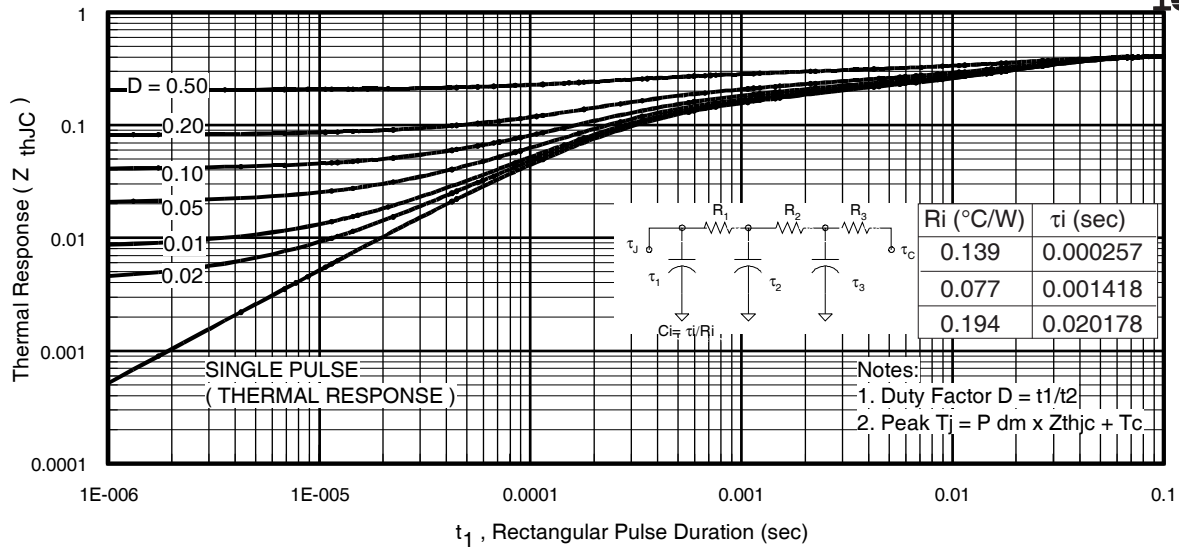


Fig 23. Maximum Transient Thermal Impedance, Junction-to-Case (IGBT)

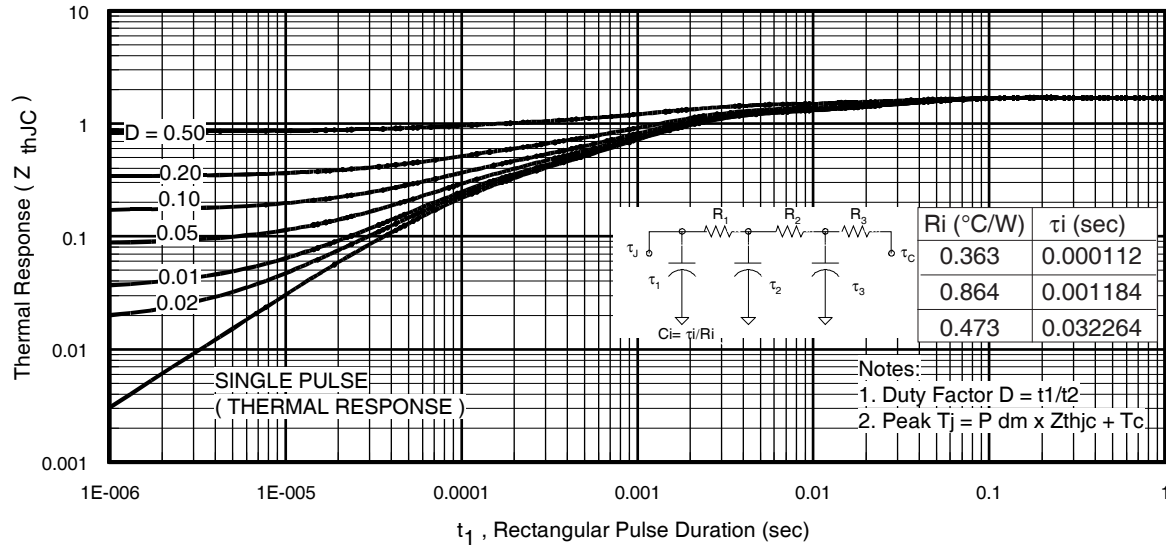
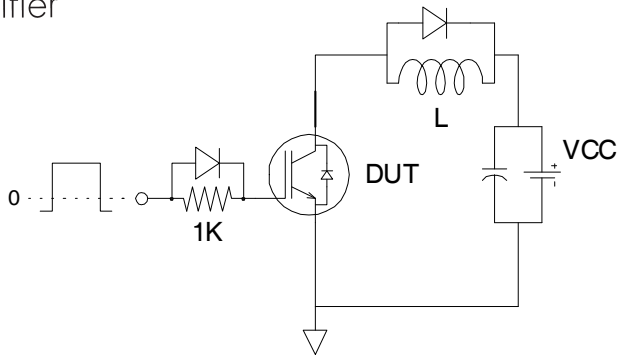
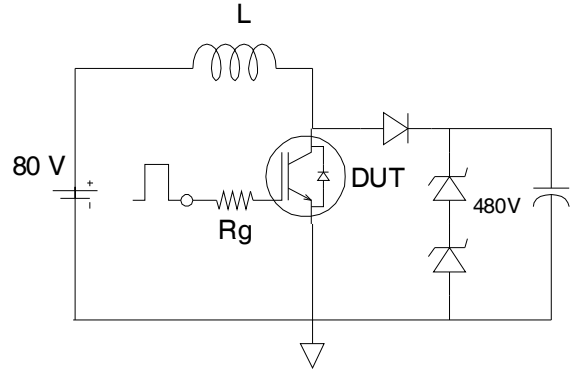


Fig. 24. Maximum Transient Thermal Impedance, Junction-to-Case (DIODE)

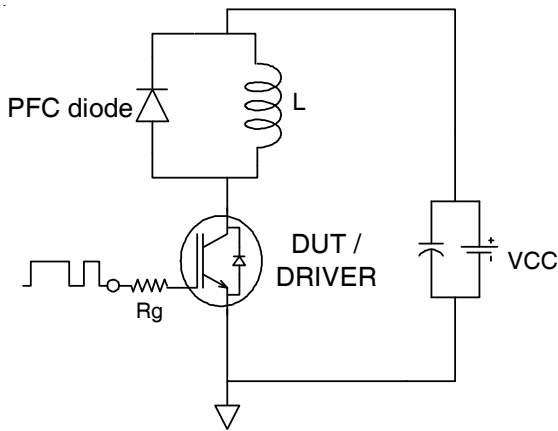




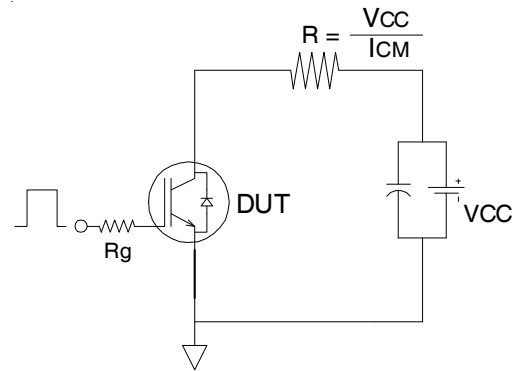
**Fig.C.T.1** - Gate Charge Circuit (turn-off)



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

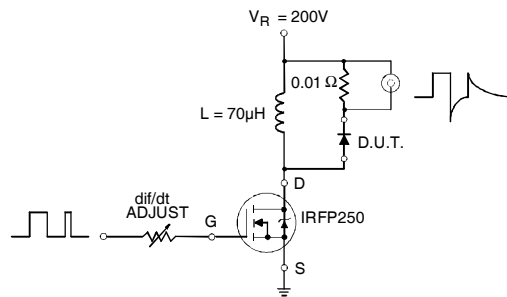


**Fig.C.T.3** - Switching Loss Circuit

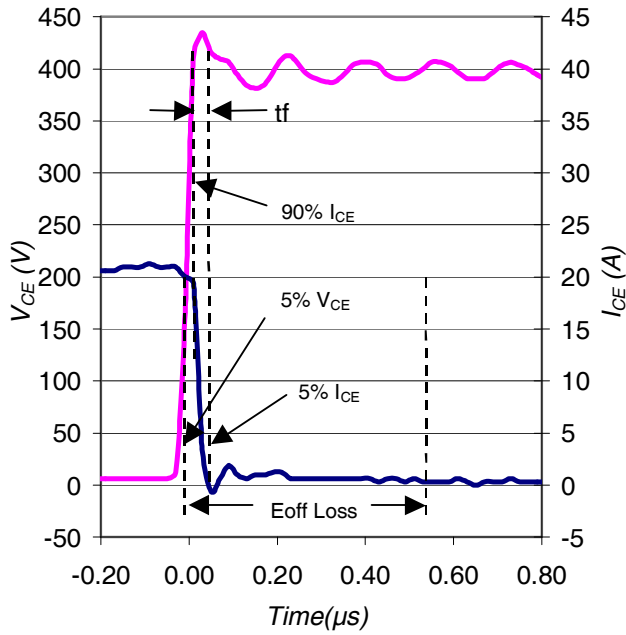


**Fig.C.T.4** - Resistive Load Circuit

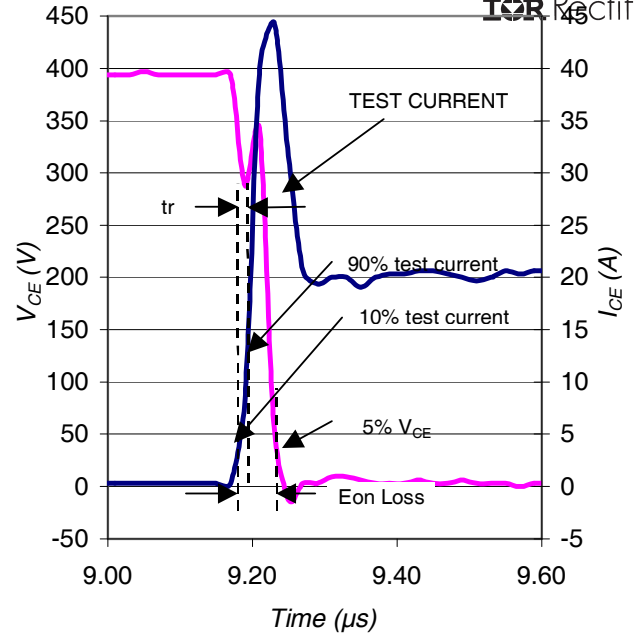
### REVERSE RECOVERY CIRCUIT



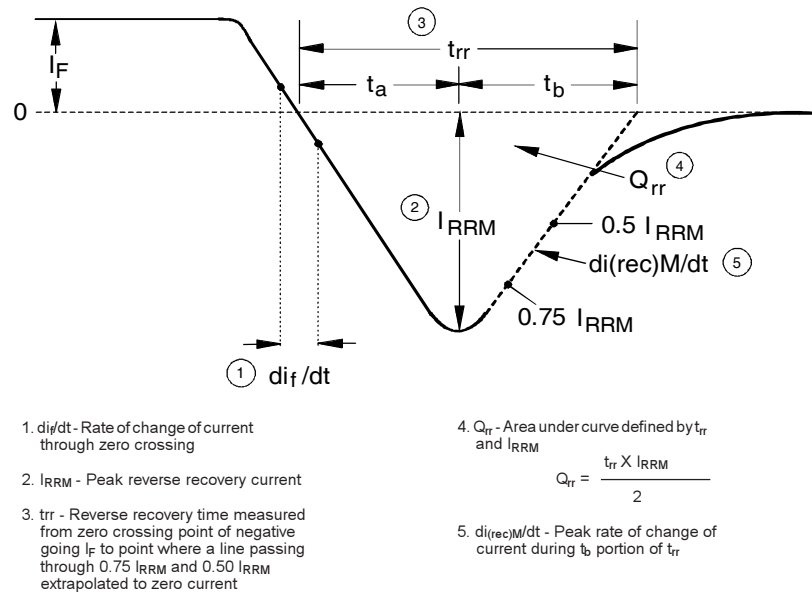
**Fig. C.T.5** - Reverse Recovery Parameter Test Circuit



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



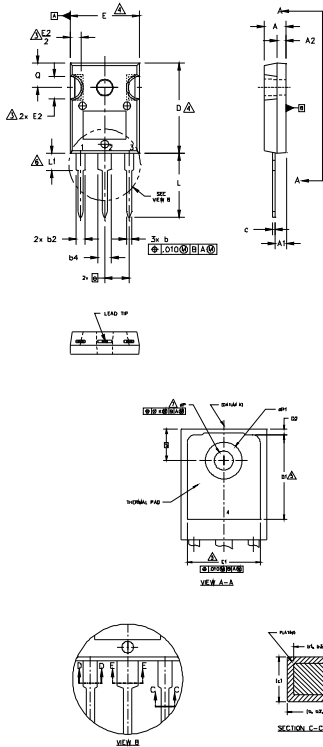
**Fig. WF2** - Typ. Turn-on Loss Waveform  
 @  $T_J = 25^\circ\text{C}$  using Fig. CT.3



**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	
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		
ek	Ø10		Ø25		
L	.559	.634	14.20	16.10	
L1	.146	.169	3.71	4.29	
ØP1	.140	.144	3.56	3.66	
Q	.209	.224	5.31	5.69	
S	.217 BSC		5.51 BSC		

**LEAD ASSIGNMENTS**

**HEXFET**

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

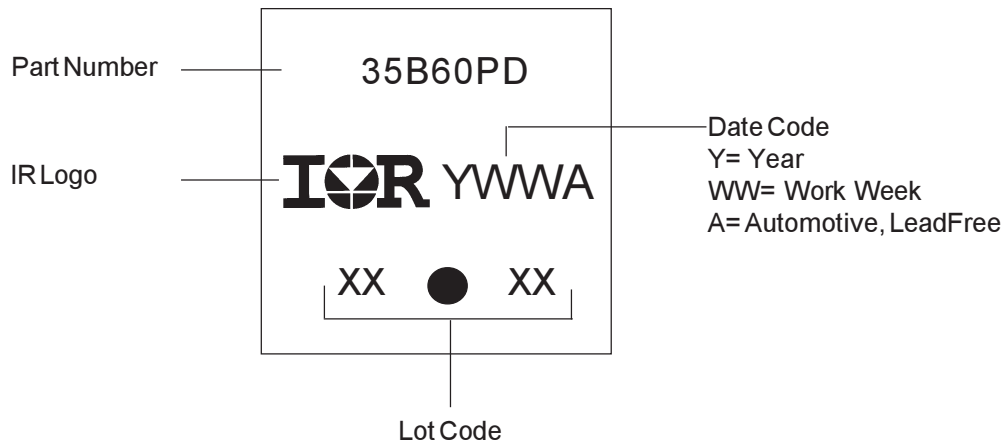
**IGBTs\_CoPACK**

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

**DIODES**

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

## TO-247AC Part Marking Information



TO-247AC package is not recommended for Surface Mount Application.

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

## Ordering Information

Base part number	Package Type	Standard Pack		Complete Part Number
		Form	Quantity	
AUIRGP35B60PD	TO-247	Tube	25	AUIRGP35B60PD

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**WORLD HEADQUARTERS:**  
101 N. Sepulveda Blvd., El Segundo, California 90245  
Tel: (310) 252-7105