

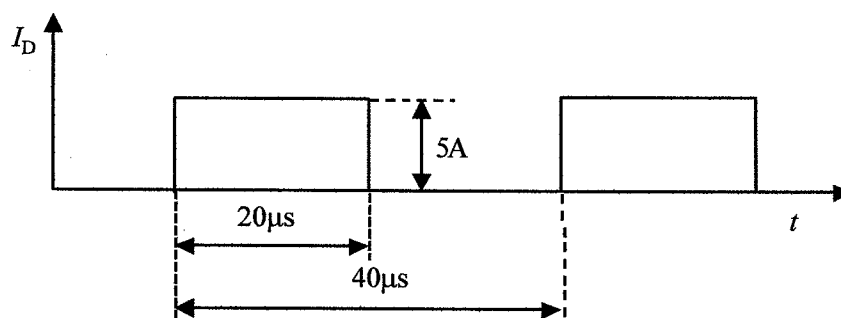
## Papereihin

- sukunimi ja etunimet
- opiskelijanumero
- koulutusohjelma.

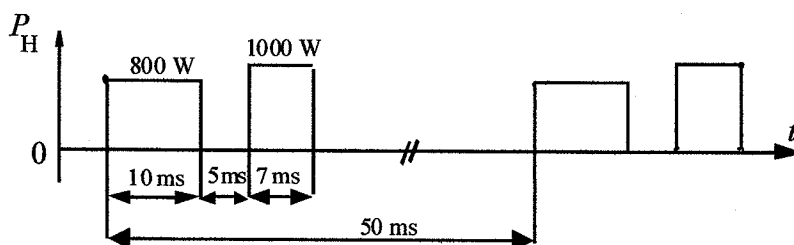
## Tentissä sallitut apuvälineet

- kynät, kumit jne.
- taskulaskin
- lukion kaavakokoelma tms. + Laplace taulut

1. Selvitä lyhyesti (max. 2...4 lausetta + mahdollinen kuva), mitä seuraavilla termeillä tarkoitetaan
  - SiC
  - IGCT
  - NPT rakenne
  - varistori
  - lähivaikutus.
2. Esittele eri diodityyppien rakenteet, toimintaperiaatteet ja ominaisuudet.
3. Esittele kirjassa esitetyt puolijohdtehokomponenttien jäähdytysmenetelmät ja -laitteet sekä niiden keskinäiset edut ja haitat.
4. Määrää IRG4BC20UPbF -IGBT:n vaatiman jäähdytysalustan lämpövastus, kun IGBT:n virta on oheisen kuvan mukainen. Jäähdytysilman lämpötila on  $45\text{ }^{\circ}\text{C}$ ,  $V_{GE} = 15\text{ V}$  ja  $R_G = 50\ \Omega$ . IGBT:n yli oleva jännite on päällekytkennän aikana  $360\text{ V}$  ja katkaisun aikana  $500\text{ V}$ .



5. Viimeisellä sivulla on esitetty IGBT-moduulin SKM 300 GB 123 D muutoslämpövastuskäyrästä. Laske kiihdytettyä superpositiomenetelmää käyttäen transistorin maksimilämpenemä koteloon nähden kun transistorin häviöteho on seuraavan kuvan mukainen:



International  
**IR** Rectifier

PD - 95445

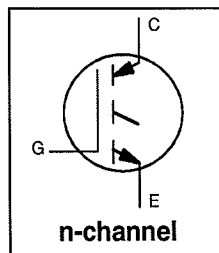
# IRG4BC20UPbF

INSULATED GATE BIPOLAR TRANSISTOR

UltraFast Speed IGBT

## Features

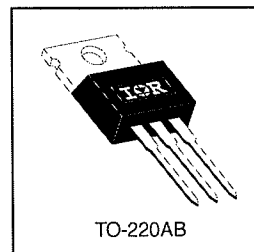
- UltraFast: optimized for high operating frequencies 8-40 kHz in hard switching, >200 kHz in resonant mode
- Generation 4 IGBT design provides tighter parameter distribution and higher efficiency than Generation 3
- Industry standard TO-220AB package
- Lead-Free



$V_{CES} = 600V$
$V_{CE(on) typ.} = 1.85V$
@ $V_{GE} = 15V, I_C = 6.5A$

## Benefits

- Generation 4 IGBTs offer highest efficiency available
- IGBTs optimized for specified application conditions
- Designed to be a "drop-in" replacement for equivalent industry-standard Generation 3 IR IGBTs



TO-220AB

## Absolute Maximum Ratings

	Parameter	Max.	Units
$V_{CES}$	Collector-to-Emitter Breakdown Voltage	600	V
$I_C @ T_C = 25^\circ C$	Continuous Collector Current	13	A
$I_C @ T_C = 100^\circ C$	Continuous Collector Current	6.5	
$I_{CM}$	Pulsed Collector Current ①	52	
$I_{LM}$	Clamped Inductive Load Current ②	52	
$V_{GE}$	Gate-to-Emitter Voltage	$\pm 20$	V
$E_{ARV}$	Reverse Voltage Avalanche Energy ③	5.0	mJ
$P_D @ T_C = 25^\circ C$	Maximum Power Dissipation	60	W
$P_D @ T_C = 100^\circ C$	Maximum Power Dissipation	24	
$T_J$	Operating Junction and	-55 to + 150	°C
$T_{STG}$	Storage Temperature Range		
	Soldering Temperature, for 10 seconds	300 (0.063 in. (1.6mm from case )	
	Mounting torque, 6-32 or M3 screw.	10 lbf•in (1.1N•m)	

## Thermal Resistance

	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	—	2.1	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.50	—	
$R_{\theta JA}$	Junction-to-Ambient, typical socket mount	—	80	
$Wt$	Weight	2.0 (0.07)	—	g (oz)

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## IRG4BC20UPbF

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IR RectifierElectrical Characteristics @  $T_J = 25^\circ\text{C}$  (unless otherwise specified)

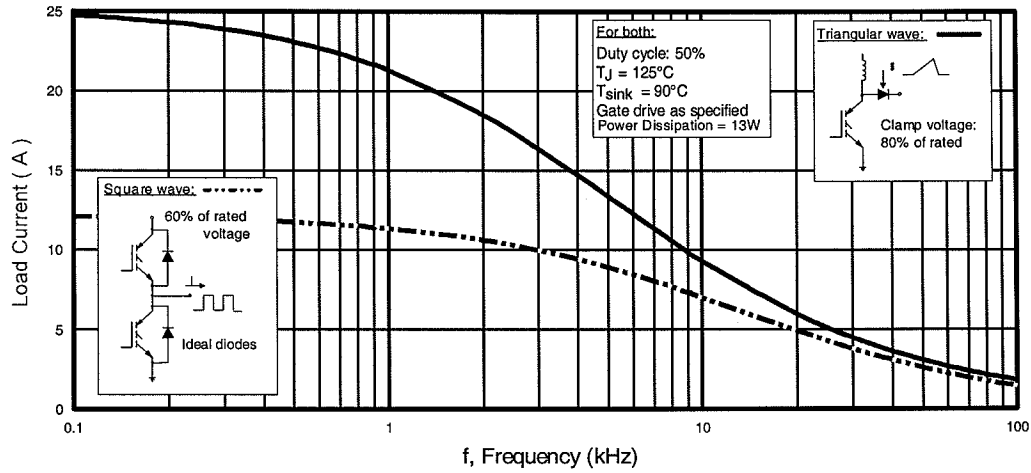
	Parameter	Min.	Typ.	Max.	Units	Conditions
$V_{(BR)CES}$	Collector-to-Emitter Breakdown Voltage	600	—	—	V	$V_{GE} = 0V, I_C = 250\mu A$
$V_{(BR)ECS}$	Emitter-to-Collector Breakdown Voltage ①	18	—	—	V	$V_{GE} = 0V, I_C = 1.0A$
$\Delta V_{(BR)CES}/\Delta T_J$	Temperature Coeff. of Breakdown Voltage	—	0.69	—	V/°C	$V_{GE} = 0V, I_C = 1.0mA$
$V_{CE(ON)}$	Collector-to-Emitter Saturation Voltage	—	1.85	2.1	V	$I_C = 6.5A, V_{GE} = 15V$ See Fig. 2, 5
		—	2.27	—		
		—	1.87	—		
$V_{GE(th)}$	Gate Threshold Voltage	3.0	—	6.0		$V_{CE} = V_{GE}, I_C = 250\mu A$
$\Delta V_{GE(th)}/\Delta T_J$	Temperature Coeff. of Threshold Voltage	—	-11	—	mV/°C	$V_{CE} = V_{GE}, I_C = 250\mu A$
$g_{fe}$	Forward Transconductance ②	1.4	4.3	—	S	$V_{CE} = 100V, I_C = 6.5A$
$I_{CES}$	Zero Gate Voltage Collector Current	—	—	250	$\mu A$	$V_{GE} = 0V, V_{CE} = 600V$
		—	—	2.0		$V_{GE} = 0V, V_{CE} = 10V, T_J = 25^\circ C$
		—	—	1000		$V_{GE} = 0V, V_{CE} = 600V, T_J = 150^\circ C$
$I_{GES}$	Gate-to-Emitter Leakage Current	—	—	$\pm 100$	nA	$V_{GE} = \pm 20V$

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

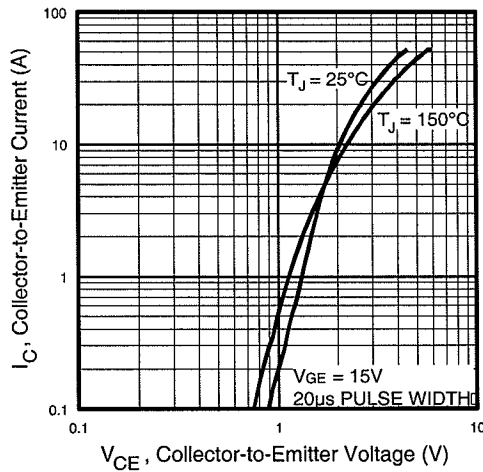
	Parameter	Min.	Typ.	Max.	Units	Conditions
$Q_g$	Total Gate Charge (turn-on)	—	27	41	nC	$I_C = 6.5A$ $V_{CC} = 400V$ See Fig. 8 $V_{GE} = 15V$
$Q_{ge}$	Gate - Emitter Charge (turn-on)	—	4.5	6.8		
$Q_{gc}$	Gate - Collector Charge (turn-on)	—	10	16		
$t_{d(on)}$	Turn-On Delay Time	—	21	—	ns	$T_J = 25^\circ C$ $I_C = 6.5A, V_{CC} = 480V$ $V_{GE} = 15V, R_G = 50\Omega$ Energy losses include "tail" See Fig. 10, 11, 13, 14
$t_r$	Rise Time	—	13	—		
$t_{d(off)}$	Turn-Off Delay Time	—	86	130		
$t_f$	Fall Time	—	120	180		
$E_{on}$	Turn-On Switching Loss	—	0.10	—	mJ	See Fig. 10, 11, 13, 14
$E_{off}$	Turn-Off Switching Loss	—	0.12	—		
$E_{\Sigma}$	Total Switching Loss	—	0.22	0.4		
$t_{d(on)}$	Turn-On Delay Time	—	20	—	ns	$T_J = 150^\circ C,$ $I_C = 6.5A, V_{CC} = 480V$ $V_{GE} = 15V, R_G = 50\Omega$ Energy losses include "tail" See Fig. 13, 14
$t_r$	Rise Time	—	14	—		
$t_{d(off)}$	Turn-Off Delay Time	—	190	—		
$t_f$	Fall Time	—	140	—		
$E_{\Sigma}$	Total Switching Loss	—	0.42	—	mJ	
$L_E$	Internal Emitter Inductance	—	7.5	—	nH	Measured 5mm from package
$C_{ies}$	Input Capacitance	—	530	—	pF	$V_{GE} = 0V$ $V_{CC} = 30V$ See Fig. 7 $f = 1.0MHz$
$C_{oes}$	Output Capacitance	—	39	—		
$C_{res}$	Reverse Transfer Capacitance	—	7.4	—		

## Notes:

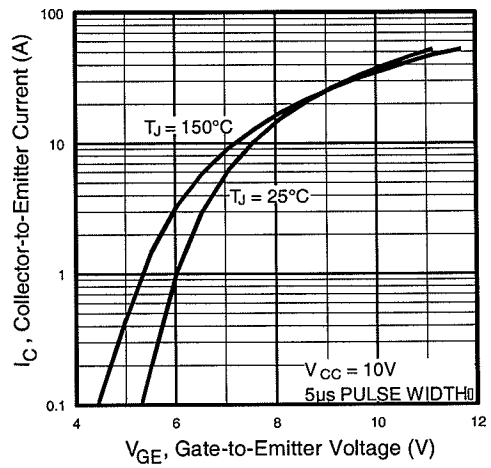
- ① Repetitive rating;  $V_{GE} = 20V$ , pulse width limited by max. junction temperature. ( See fig. 13b )
- ②  $V_{CC} = 80\%(V_{CES}), V_{GE} = 20V, L = 10\mu H, R_G = 50\Omega,$  (See fig. 13a)
- ③ Repetitive rating; pulse width limited by maximum junction temperature.
- ④ Pulse width  $\leq 80\mu s$ ; duty factor  $\leq 0.1\%$ .
- ⑤ Pulse width  $5.0\mu s$ , single shot.



**Fig. 1 - Typical Load Current vs. Frequency**  
(For square wave,  $I = I_{RMS}$  of fundamental; for triangular wave,  $I = I_{PK}$ )



**Fig. 2 - Typical Output Characteristics**



**Fig. 3 - Typical Transfer Characteristics**

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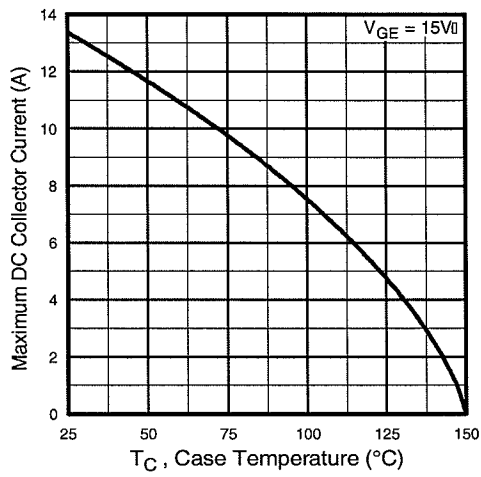


Fig. 4 - Maximum Collector Current vs. Case Temperature

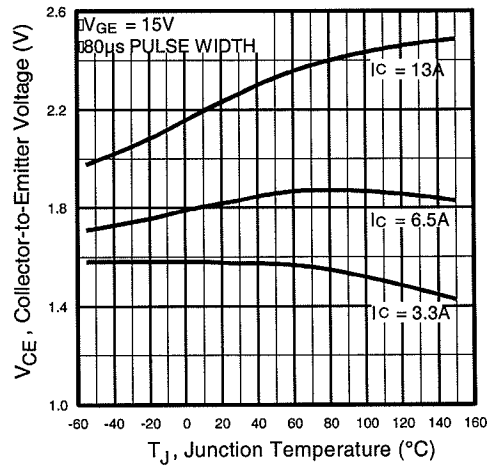


Fig. 5 - Collector-to-Emitter Voltage vs. Junction Temperature

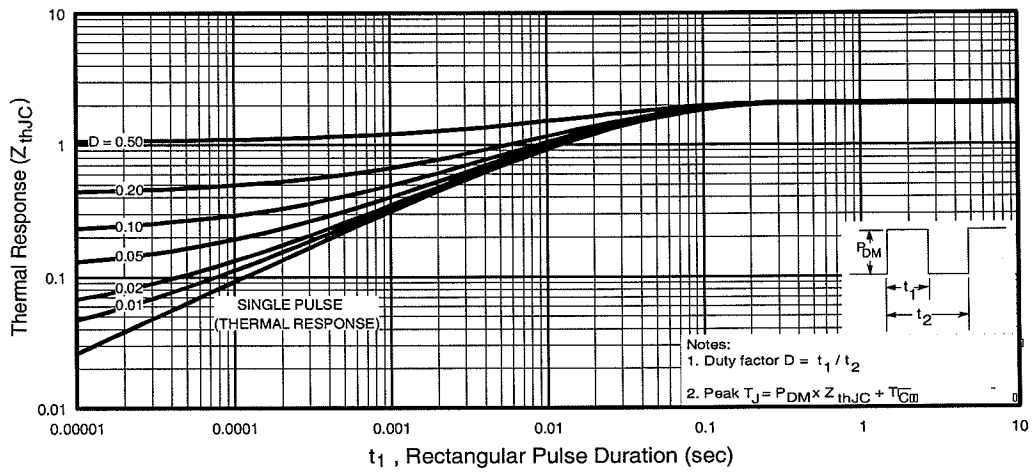


Fig. 6 - Maximum Effective Transient Thermal Impedance, Junction-to-Case

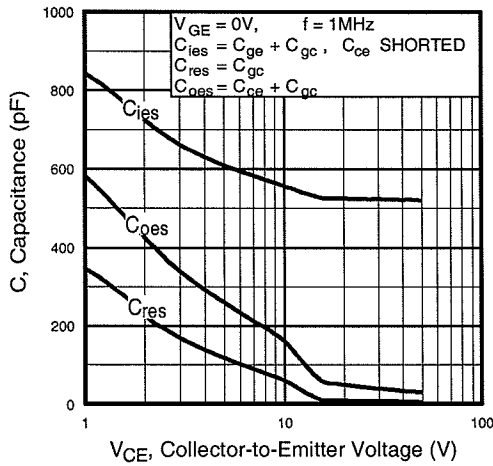


Fig. 7 - Typical Capacitance vs. Collector-to-Emitter Voltage

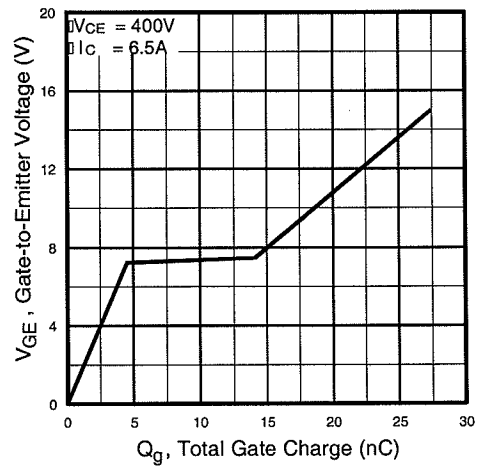


Fig. 8 - Typical Gate Charge vs. Gate-to-Emitter Voltage

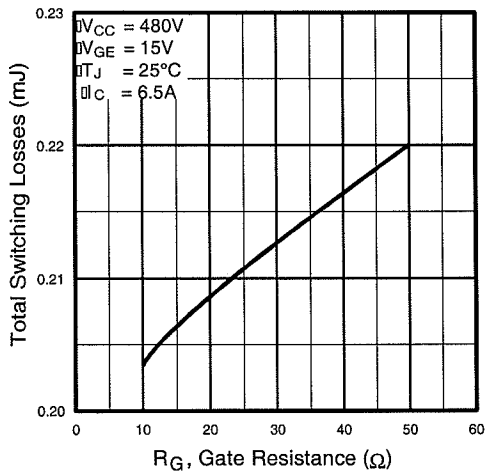


Fig. 9 - Typical Switching Losses vs. Gate Resistance

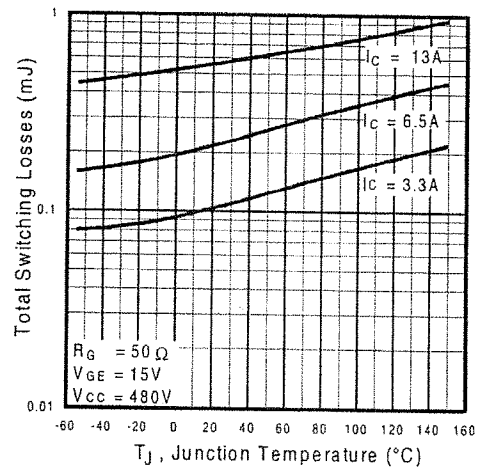


Fig. 10 - Typical Switching Losses vs. Junction Temperature

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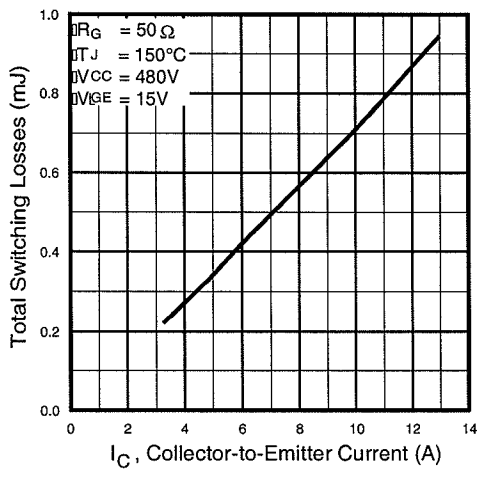


Fig. 11 - Typical Switching Losses vs. Collector-to-Emitter Current

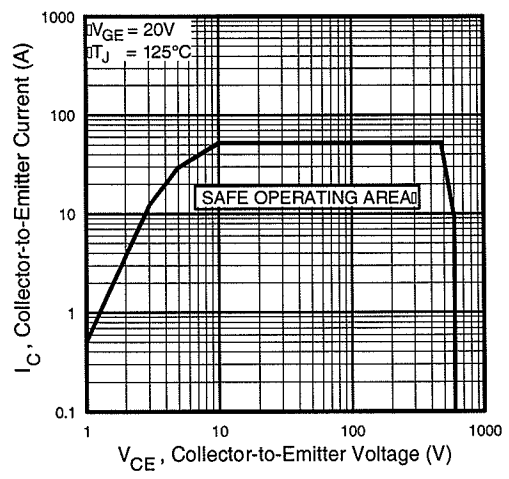
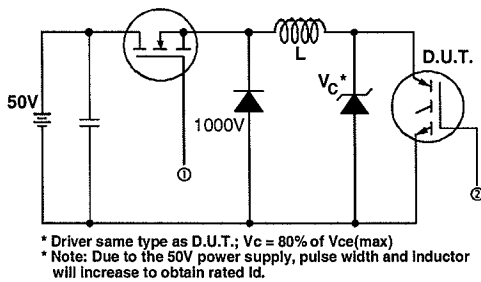


Fig. 12 - Turn-Off SOA



\* Driver same type as D.U.T.;  $V_C = 80\%$  of  $V_{ce(max)}$   
 \* Note: Due to the 50V power supply, pulse width and inductor will increase to obtain rated Id.

Fig. 13a - Clamped Inductive Load Test Circuit

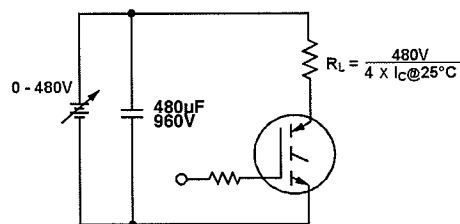


Fig. 13b - Pulsed Collector Current Test Circuit

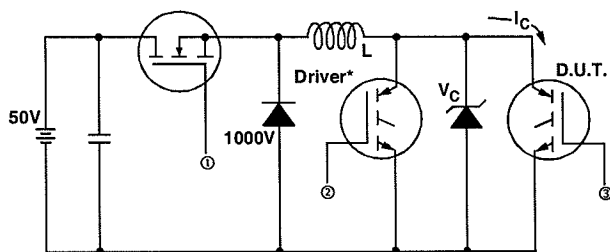


Fig. 14a - Switching Loss Test Circuit

\* Driver same type as D.U.T.,  $V_C = 480V$

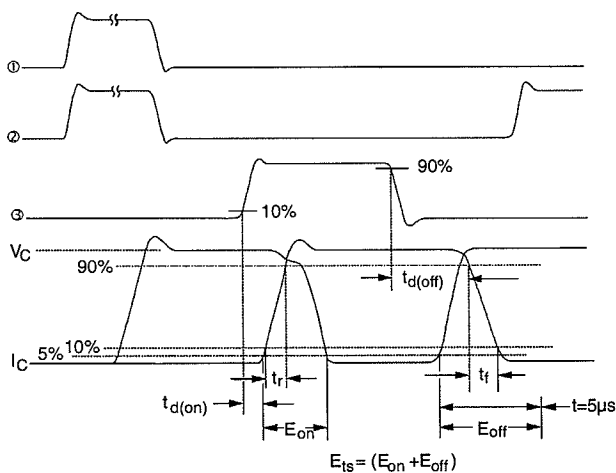


Fig. 14b - Switching Loss Waveforms

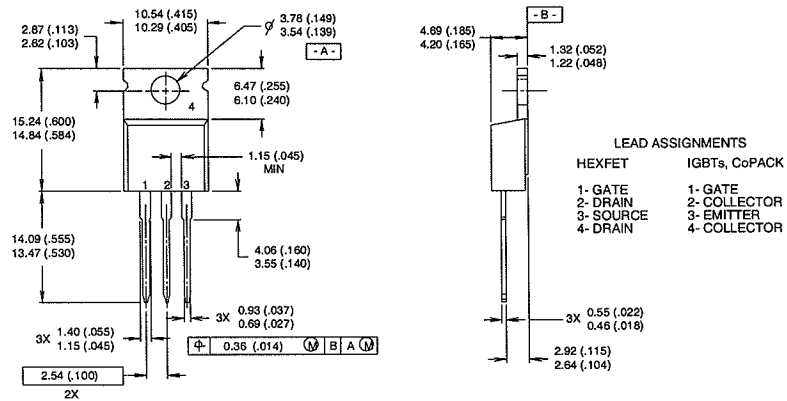


# IRG4BC20UPbF

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## TO-220AB Package Outline

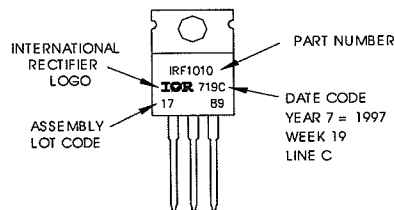
Dimensions are shown in millimeters (inches)



- NOTES:
- 1 DIMENSIONING & TOLERANCING PER ANSI Y14.5M, 1982.
  - 2 CONTROLLING DIMENSION : INCH
  - 3 OUTLINE CONFORMS TO JEDEC OUTLINE TO-220AB.
  - 4 HEATSINK & LEAD MEASUREMENTS DO NOT INCLUDE BURRS.

## TO-220AB Part Marking Information

EXAMPLE: THIS IS AN IRF1010  
 LOT CODE 1789  
 ASSEMBLED ON WW 19, 1997  
 IN THE ASSEMBLY LINE "C"  
**Note:** "P" in assembly line position indicates "Lead-Free"



Data and specifications subject to change without notice.

International  
**IR** Rectifier

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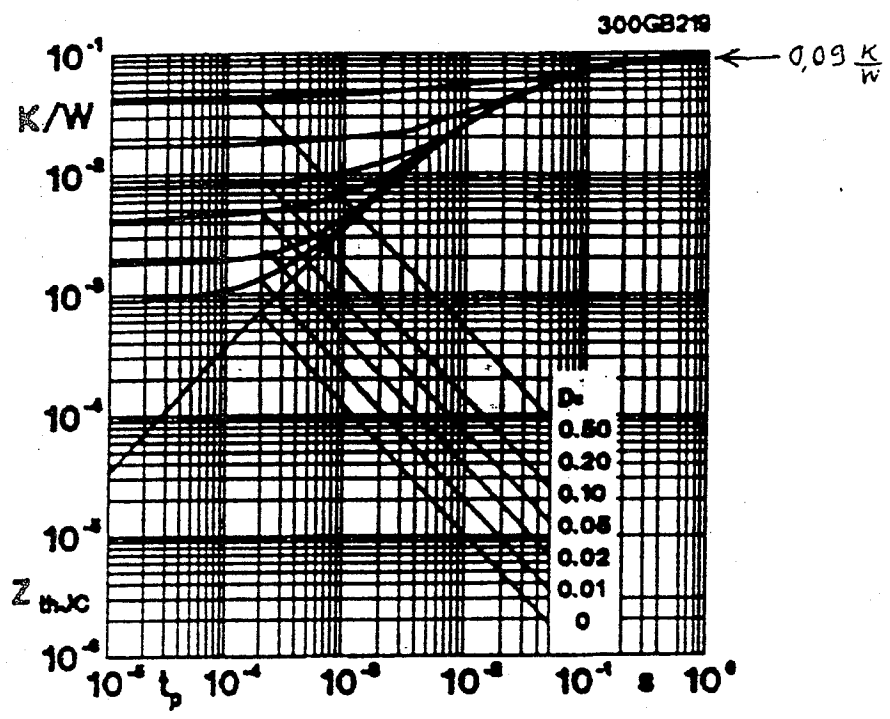


Fig. 19 Transient thermal impedance of IGBT  
 $Z_{thJC} = f(t_p)$ ;  $D = t_p / t_c = t_p \cdot f$

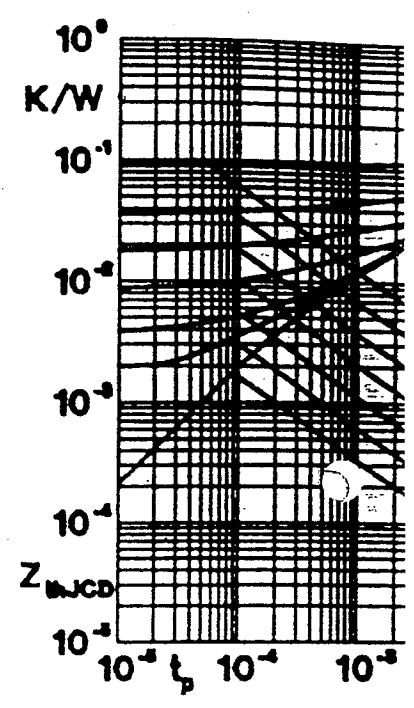


Fig. 20 Transient thermal impedance of inverse CAL diode

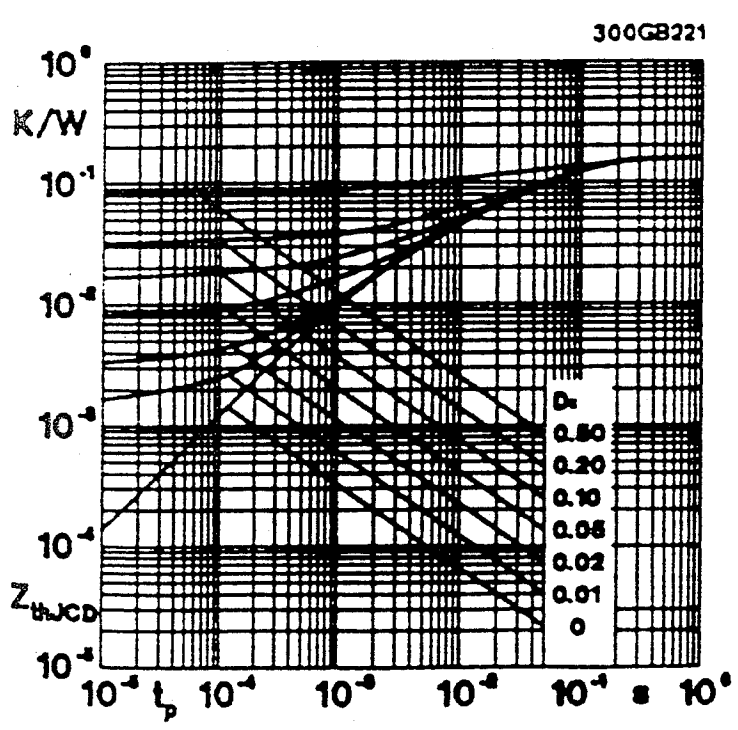


Fig. 21 Transient thermal impedance of the freewheeling diode  $Z_{thCD} \rightarrow B 6 - 95, \text{ rem. } 6)$

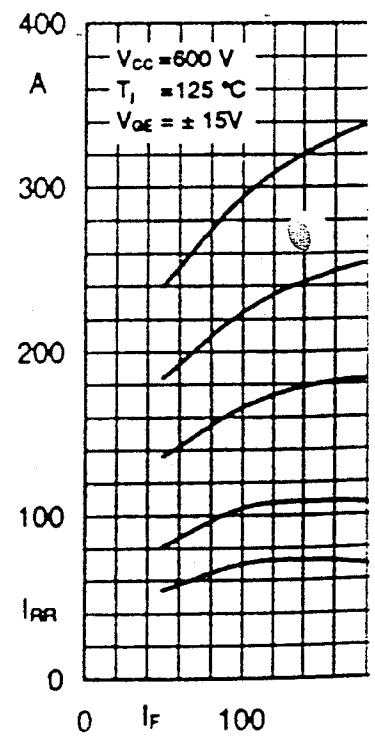
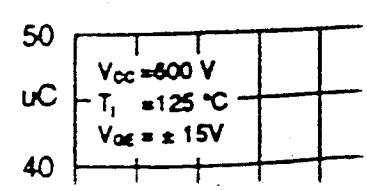
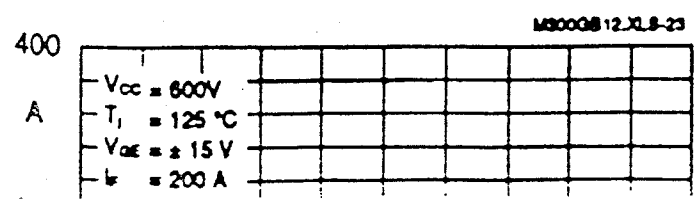


Fig. 22 Typ CAL diode reverse current  $I_{RR} = f(I_F)$

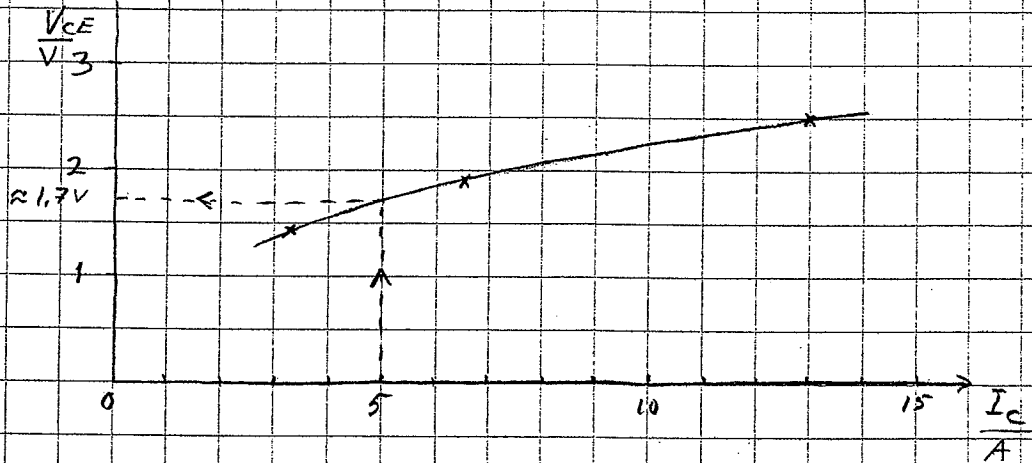


Teht. 1 - 3 : Katso kirja

Teht. 4

Johtohäviöt

Suoraan kuvasta 2:  $V_{CE} = 11 \cdot 10 \frac{6\text{mm}}{26\text{mm}} \approx 1,7\text{V}$  tai  
Kuva 5 aukkipiirrettynä; kun  $T_J = 150^\circ\text{C}$



Siksi  $V_{CE} \approx 1,7\text{V}$

$$E_{HON} = V_{CE} \cdot I_C \cdot t_{ON} = 1,7\text{V} \cdot 5\text{A} \cdot 20\mu\text{s} = 170\mu\text{J}$$

Kytkenhäviöt

Kaikkia kuvissa 9, 10 ja 11 on päällekytkentä ja katkaisuhäviöiden summa  $480\text{V}$  jännitteelle. Nyt päällekytkennän arkana jännite on  $360\text{V}$  ja katkaisussa  $500\text{V}$ . Numeroarvista nähdään (switching characteristics) että  $25^\circ\text{C}$  lämpötilassa suhde  $E_{on} / E_{off} = 0,1\text{mJ} / 0,12\text{mJ} \approx 0,833$ . Oletetaan, että sama suhde pätee myös isommissa lämpötiloissa.

Tent. 4 jatkoa

Kuvasta 11 saadaan 5 A virralla ja 480 V jännitteellä

$$E_{rs} \approx 340 \mu\text{J} \quad \text{joten} \quad E_{on} = \frac{0,1 \text{ ms}}{0,22 \text{ ms}} \cdot 340 \mu\text{J} \approx 155 \mu\text{J}$$

$$E_{off} = \frac{0,12 \text{ ms}}{0,22 \text{ ms}} \cdot 340 \mu\text{J} = 185 \mu\text{J}$$

Jos oletetaan häviön olevan verrannollinen jännitteeseen, ovat kytkentähäviöt

$$E_{on} \approx \frac{500\text{V}}{480\text{V}} \cdot 155 \mu\text{J} \approx 116 \mu\text{J}$$

$$E_{off} \approx \frac{360\text{V}}{480\text{V}} \cdot 185 \mu\text{J} = 193 \mu\text{J}$$

Siten

$$P_{H_{ave}} = \frac{1}{T} (E_{cond} + E_{on} + E_{off}) = \frac{1}{40 \mu\text{s}} (170 \mu\text{J} + 116 \mu\text{J} + 193 \mu\text{J})$$

$$= 12,0 \text{ W}$$

Määritetään kuoren lämpötila kuvan 6 perusteella

Keskimääräinen teho johtojalle laskettauna on

$$P_{DM} = \frac{T}{T_{on}} \cdot P_{H_{ave}} = \frac{40 \mu\text{s}}{20 \mu\text{s}} \cdot 12,0 \text{ W} = 24,0 \text{ W}$$

$$\text{Kuvasta 6 kun } D = \frac{t_{on}}{T} = \frac{20 \mu\text{s}}{40 \mu\text{s}} = 0,5 \quad \text{ja} \quad t_i = t_{on} = 20 \mu\text{s}$$

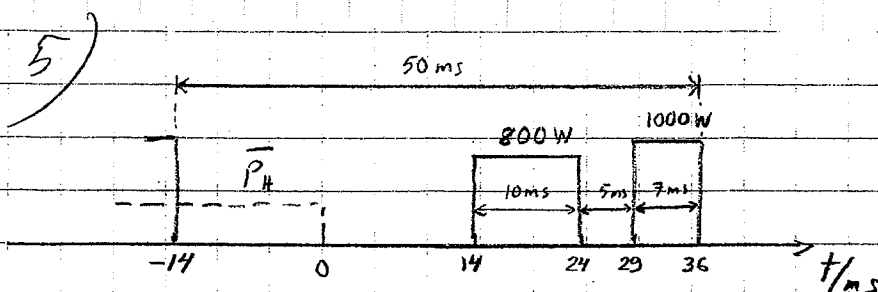
$$Z_{thjc} \approx 1,1 \text{ } ^\circ\text{C/W}$$

$$\Rightarrow T_c = T_j - P_{DM} \cdot Z_{thjc} = 150 \text{ } ^\circ\text{C} - 24,0 \text{ W} \cdot 1,1 \frac{^\circ\text{C}}{\text{W}} = 124 \text{ } ^\circ\text{C}$$

Jäähdytysalueen lämpövastuksen on siten oltava

$$R_{thSA} \leq \frac{T_c - T_A}{P_{H_{ave}}} - R_{thCS} = \frac{124 \text{ } ^\circ\text{C} - 45 \text{ } ^\circ\text{C}}{12,0 \text{ W}} - 0,5 \text{ } ^\circ\text{C/W}$$

$$\approx 6,1 \text{ } ^\circ\text{C/W}$$



Keskimääräinen teho:

$$\bar{P}_H = \frac{800 \text{ W} \cdot 10 \text{ ms} + 1000 \text{ W} \cdot 7 \text{ ms}}{50 \text{ ms}} = 300 \text{ W}$$

Keskimääräinen lämpenemä ( $\approx$  lämpenemä hetkellä  $t=0$ )

$$\bar{\Delta T}_{JC} = \bar{P}_H \cdot Z_{thJC}(\infty) = 300 \text{ W} \cdot 0,09 \frac{\text{K}}{\text{W}} = 27 \text{ K}$$

Lämpenemä 800 W pulssin lopussa ( $Z(t)$  luetaan käyrältä  $D=0$ !)

$$\begin{aligned} \Delta T_{JC}(24 \text{ ms}) &= \bar{\Delta T}_{JC} - Z_{thJC}(24 \text{ ms}) \cdot \bar{P}_H + Z_{th}(10 \text{ ms}) \cdot P_1 \\ &= 27 \text{ K} - 0,043 \frac{\text{K}}{\text{W}} \cdot 300 \text{ W} + 0,026 \frac{\text{K}}{\text{W}} \cdot 800 \text{ W} \\ &\approx \underline{35 \text{ K}} \end{aligned}$$

ja 1000 W pulssin lopussa:

$$\begin{aligned} \Delta T_{JC}(36 \text{ ms}) &= \bar{\Delta T}_{JC} - Z_{thJC}(36 \text{ ms}) \cdot \bar{P}_H + (Z_{th}(22 \text{ ms}) - Z_{th}(12 \text{ ms})) \cdot P_1 \\ &\quad + Z_{th}(7 \text{ ms}) \cdot P_2 \\ &= 27 \text{ K} - 0,05 \frac{\text{K}}{\text{W}} \cdot 300 \text{ W} + (0,04 \frac{\text{K}}{\text{W}} - 0,028 \frac{\text{K}}{\text{W}}) \cdot 800 \text{ W} \\ &\quad + 0,02 \frac{\text{K}}{\text{W}} \cdot 1000 \text{ W} \\ &\approx \underline{42 \text{ K}} \end{aligned}$$

Siis maksimilämpenemä on noin 42 K