

Tentti 12.12.2011, kello 13 ... 16, sali S3

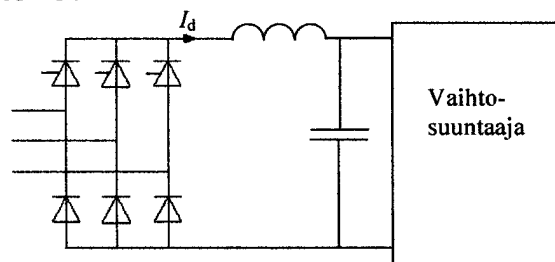
Papereihin

- sukunimi ja etunimet
- opiskelijanumero
- koulutusohjelma.

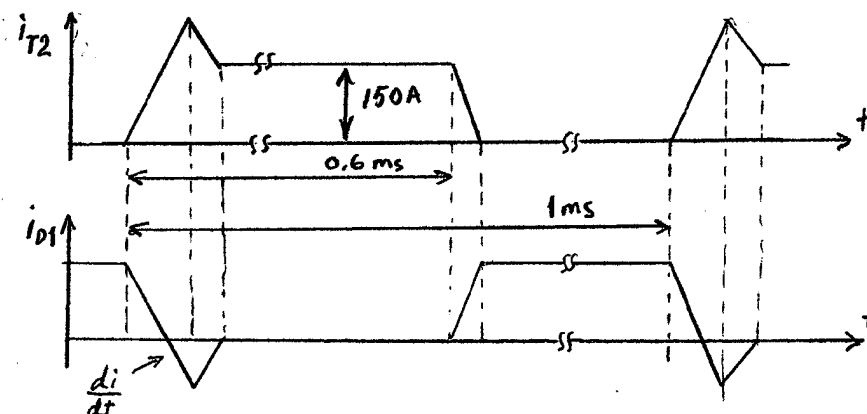
Tentissä sallitut apuvälineet

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

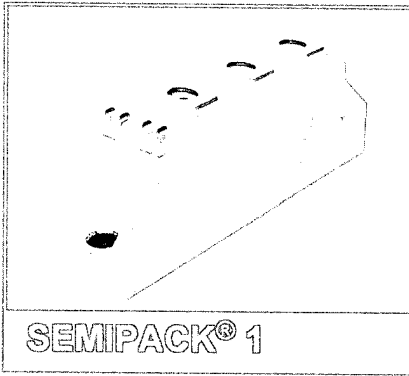
1. Selvitä lyhyesti (max. 2...4 lausetta + mahdollinen kuva), mitä seuraavilla termeillä tarkoitetaan
 - SiC
 - takavirran varaus
 - triak
 - varistori
 - Hall-anturi.
2. Esittele IGBT:n rakenne, toimintaperiaate ja ominaisuudet.
3. Esittele kirjassa esitetyt vastustyyppit, niiden ominaisuudet ja käyttötarkoitukset. Kerro myös mitä asioita on otettava huomioon vastuksen valinnassa ja mitoituksessa.
4. Kolmea tyristori/diodi -moduulia SKKH 57/16 E G6 (datalehti oheisena) käytetään allaolevassa kolmivaiheisessa tasasuuntaajasillassa. Mikä on moduulien yhteisen jäähdytuselementin lämpövastuksen $R_{th(s-a)}$ oltava, jotta silta kykenisi syöttämään 120 A tasavirran jäähdytysilman lämpötilan ollessa $65\text{ }^{\circ}\text{C}$?



5. IGBT moduuli SEMiX223GB12Vs (datalehti oheisena) sisältää kaksi IGBT transistoria vastadiodeineen. Yläpuolen diodi ja alapuolen IGBT johtavat alla olevan kuvan mukaisesti vuorotellen kuormaan menevää virtaa. Jäähdytuselementin lämpövastus $R_{th SA}$ on $0,08\text{ }^{\circ}\text{C/W}$ ja jäähdytysilman lämpötila on $45\text{ }^{\circ}\text{C}$. Mitkä ovat diodin ja IGB-transistorin liitoslämpötilat, kun IGB-transistorin hilasyötön resistanssi on $3,8\ \Omega$ ja jännite $\pm 15\text{ V}$? (Huom. datalehdessä s = sink = jäähdytuselementti). Tasasähkösyötön jännite on 560 V .



SKKH 57/16 E G6



Thyristor / Diode Modules

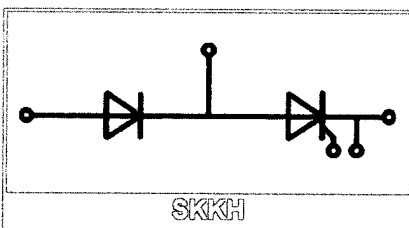
SKKH 57/16 E G6

Features

- Heat transfer through aluminium oxide ceramic isolated metal baseplate
- UL recognized, file no. E63532

Typical Applications

- DC motor control (e. g. for machine tools)
- AC motor soft starters
- Temperature control (e. g. for ovens, chemical processes)
- Professional light dimming (studios, theaters)



Absolute Maximum Ratings				
Symbol	Conditions	Values	Unit	
Chip				
$I_{T(AV)}$	sinus 180°	$T_c = 85\text{ °C}$	61	A
		$T_c = 100\text{ °C}$	45	A
I_{TSM}	10 ms	$T_j = 25\text{ °C}$	1500	A
		$T_j = 130\text{ °C}$	1200	A
i^2t	10 ms	$T_j = 25\text{ °C}$	11250	A ² s
		$T_j = 130\text{ °C}$	7200	A ² s
V_{RSM}		1700	V	
V_{RRM}		1600	V	
V_{DRM}		1600	V	
$(di/dt)_{cr}$	$T_j = 130\text{ °C}$	140	A/μs	
$(dv/dt)_{cr}$	$T_j = 130\text{ °C}$	1000	V/μs	
T_j		-40 ... 130	°C	
Module				
T_{stg}		-40 ... 125	°C	
V_{isol}	a.c.; 50 Hz; r.m.s.	1 min	3000	V
		1 s	3600	V

Characteristics						
Symbol	Conditions	min.	typ.	max.	Unit	
Chip						
V_T	$T_j = 25\text{ °C}, I_T = 180\text{ A}$		1.5	1.75	V	
$V_{T(TO)}$	$T_j = 130\text{ °C}$		0.85	1	V	
r_T	$T_j = 130\text{ °C}$		4.00	4.50	mΩ	
$I_{DD}; I_{RD}$	$T_j = 130\text{ °C}, V_{DD} = V_{DRM}; V_{RD} = V_{RRM}$			20	mA	
t_{gd}	$T_j = 25\text{ °C}, I_G = 1\text{ A}, di_G/dt = 1\text{ A}/\mu\text{s}$		1		μs	
t_{gr}	$V_D = 0.67 \cdot V_{DRM}$		2		μs	
t_q	$T_j = 130\text{ °C}$		170		μs	
I_H	$T_j = 25\text{ °C}$		150	250	mA	
I_L	$T_j = 25\text{ °C}, R_G = 33\ \Omega$		300	600	mA	
V_{GT}	$T_j = 25\text{ °C}, \text{d.c.}$	2.5			V	
I_{GT}	$T_j = 25\text{ °C}, \text{d.c.}$	100			mA	
V_{GD}	$T_j = 130\text{ °C}, \text{d.c.}$			0.25	V	
I_{GD}	$T_j = 130\text{ °C}, \text{d.c.}$			4	mA	
$R_{th(j-c)}$	cont.			per chip	0.420	K/W
				per module	0.210	K/W
$R_{th(l-c)}$	sin. 180°			per chip	0.440	K/W
				per module	0.220	K/W
$R_{th(j-c)}$	rec. 120°			per chip	0.460	K/W
				per module	0.230	K/W
Module						
$R_{th(c-s)}$	chip				0.22	K/W
					module	0.11
M_s	to heatsink M5	4.25		5.75	Nm	
M_t	to terminals M5	2.55		3.45	Nm	
a				5 * 9,81	m/s ²	
w			75		g	

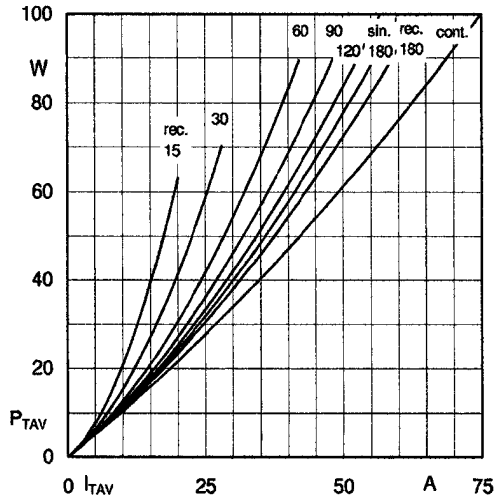


Fig. 1L: Power dissipation per thyristor/diode vs. on-state current

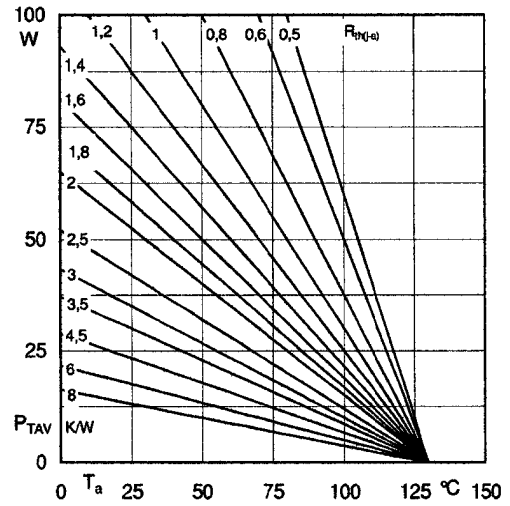


Fig. 1R: Max. power dissipation per chip vs. ambient temperature

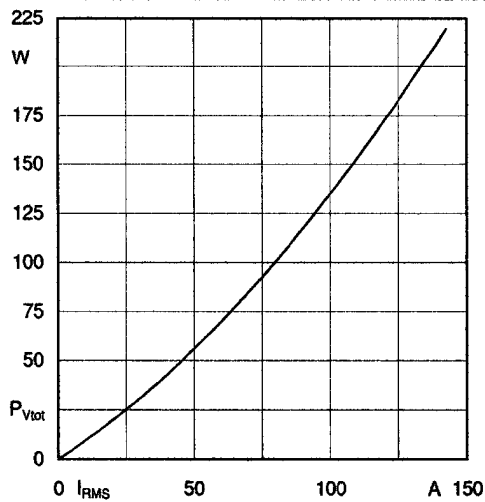


Fig. 2L: Max. power dissipation of one module vs. rms current

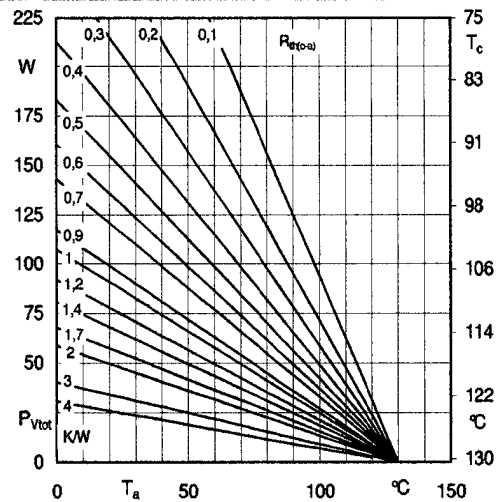


Fig. 2R: Max. power dissipation of one module vs. case temperature

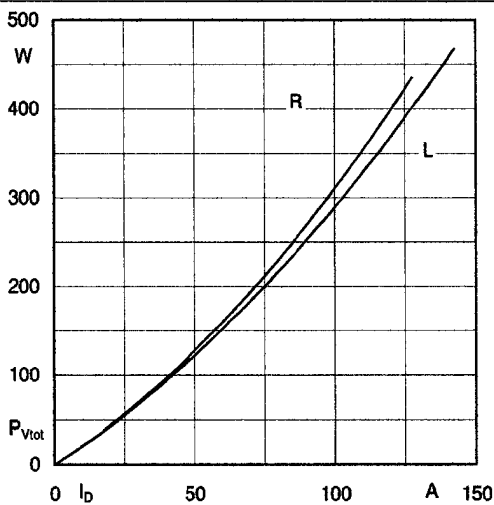


Fig. 3L: Max. power dissipation of two modules vs. direct current

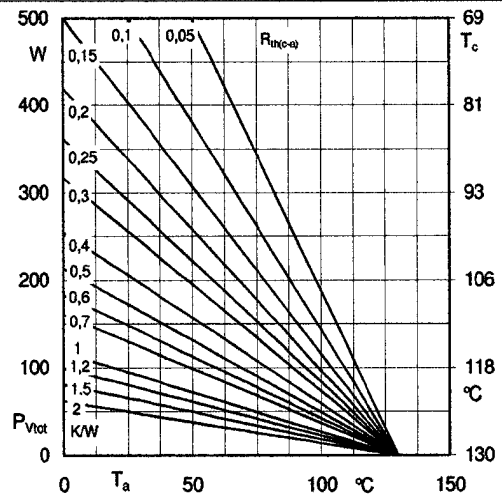
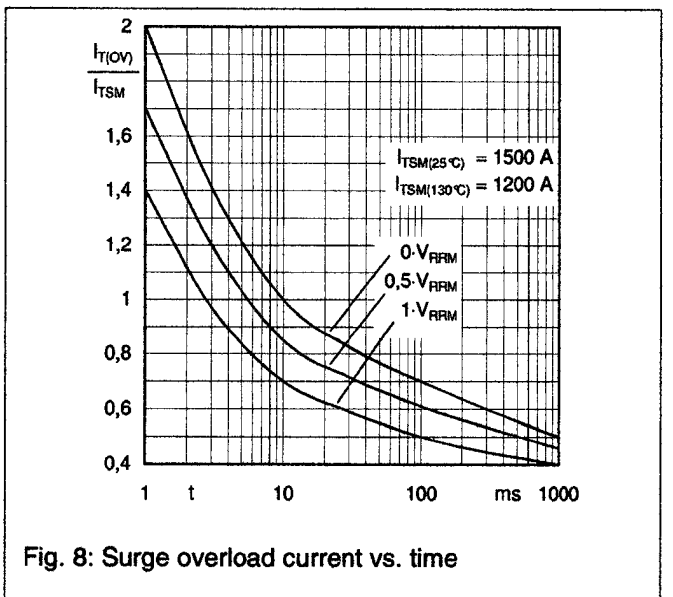
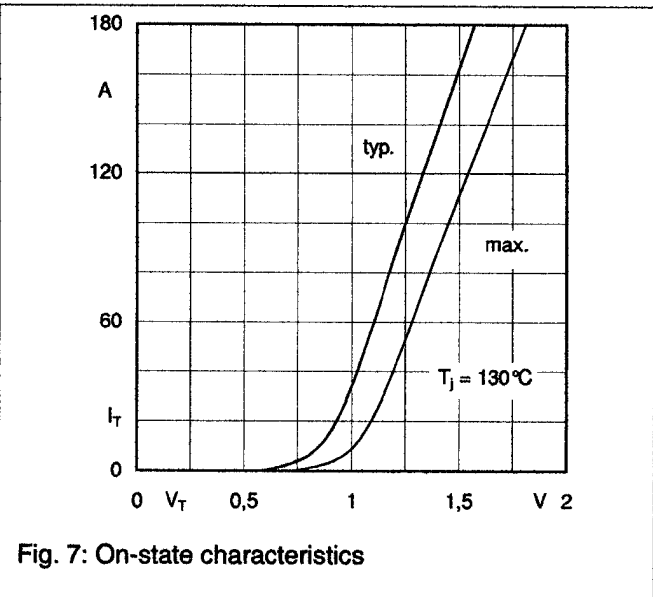
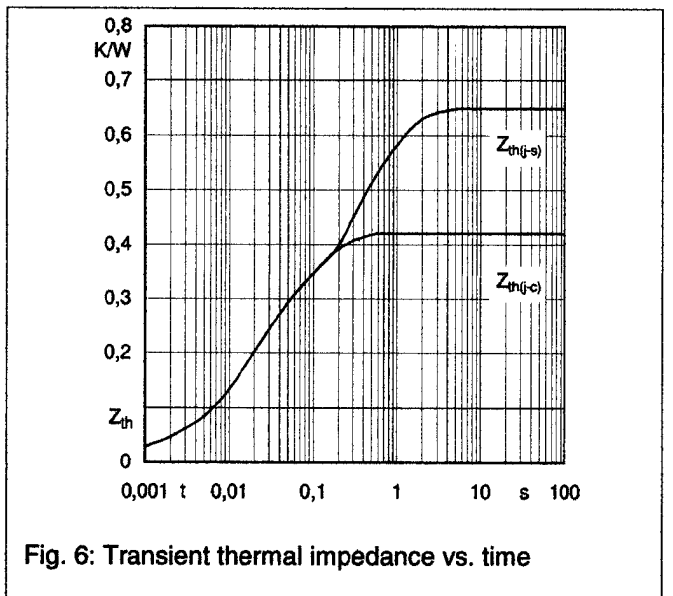
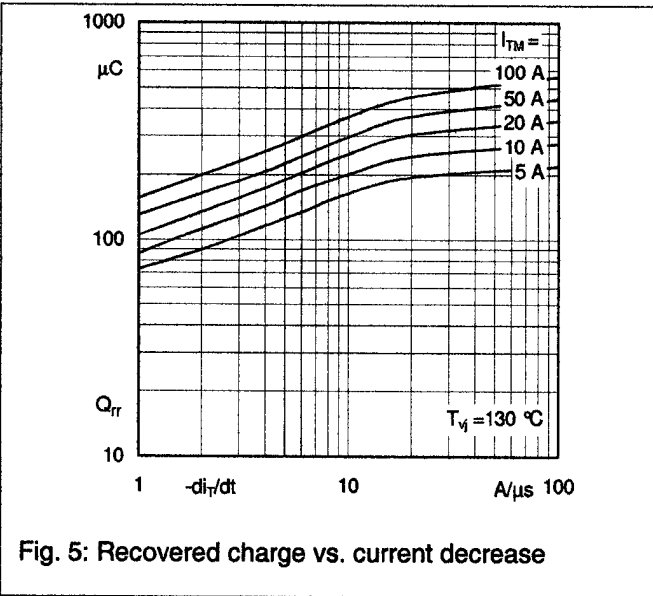
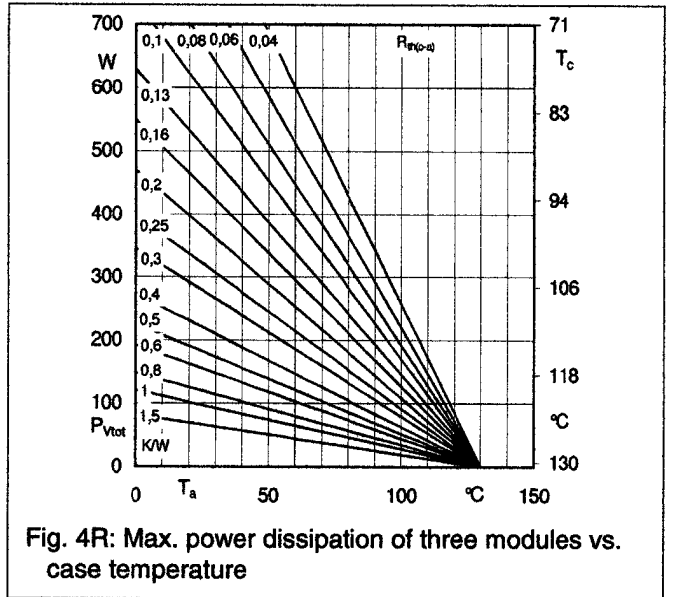
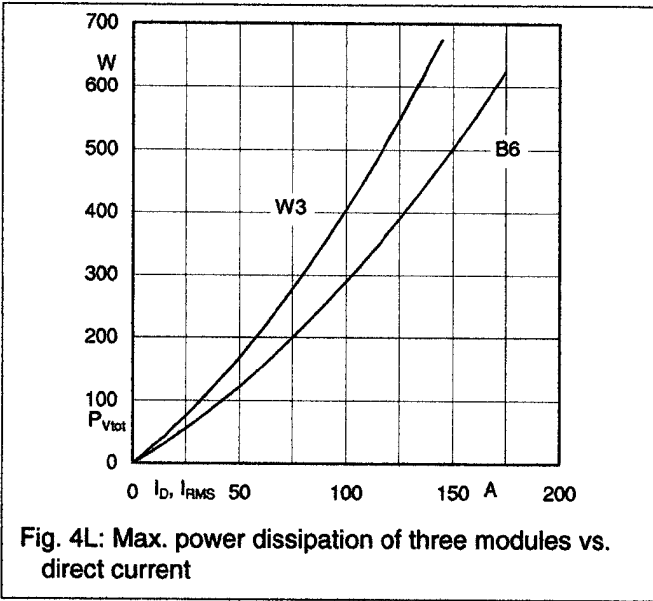
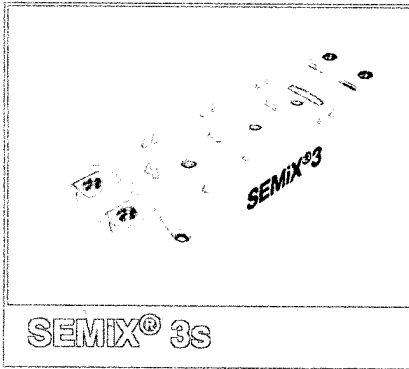


Fig. 3R: Max. power dissipation of two modules vs. case temperature



SEMIX223GB12Vs



SEMIX223GB12Vs

Features

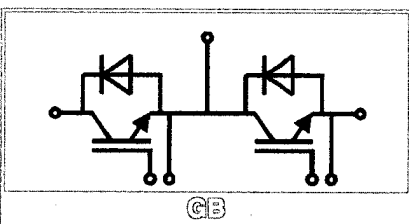
- Homogeneous Si
- $V_{CE(sat)}$ with positive temperature coefficient
- High short circuit capability
- UL recognised file no. E63532

Typical Applications*

- AC inverter drives
- UPS
- Electronic Welding

Remarks

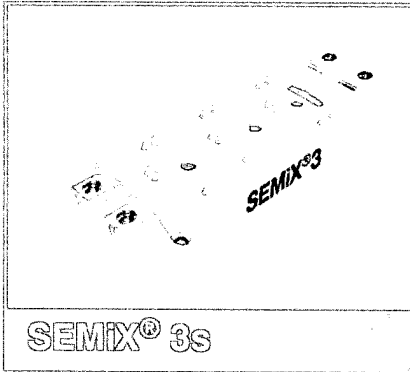
- Case temperature limited to $T_C=125^\circ\text{C}$ max.
- Product reliability results are valid for $T_J=150^\circ\text{C}$
- Dynamic values apply to the following combination of resistors:
 $R_{Gon,main} = 2,9 \Omega$
 $R_{Goff,main} = 2,9 \Omega$
 $R_{G,x} = 2,2 \Omega$
 $R_{E,x} = 0,5 \Omega$



Absolute Maximum Ratings			
Symbol	Conditions	Values	Unit
IGBT			
V_{CES}		1200	V
I_C	$T_J = 175^\circ\text{C}$	$T_C = 25^\circ\text{C}$ 323 $T_C = 80^\circ\text{C}$ 246	A
I_{Cnom}		225	A
I_{CRM}	$I_{CRM} = 3 \times I_{Cnom}$	675	A
V_{GES}		-20 ... 20	V
t_{psc}	$V_{CC} = 600\text{ V}$ $V_{GE} \leq 15\text{ V}$ $V_{CES} \leq 1200\text{ V}$	$T_J = 125^\circ\text{C}$ 10	μs
T_J		-40 ... 175	$^\circ\text{C}$
Inverse diode			
I_F	$T_J = 175^\circ\text{C}$	$T_C = 25^\circ\text{C}$ 263 $T_C = 80^\circ\text{C}$ 197	A
I_{Fnom}		225	A
I_{FRM}	$I_{FRM} = 3 \times I_{Fnom}$	675	A
I_{FSM}	$t_p = 10\text{ ms, sin } 180^\circ, T_J = 25^\circ\text{C}$	1161	A
T_J		-40 ... 175	$^\circ\text{C}$
Module			
$I_{I(RMS)}$	$T_{terminal} = 80^\circ\text{C}$	600	A
T_{stg}		-40 ... 125	$^\circ\text{C}$
V_{isol}	AC sinus 50Hz, $t = 1\text{ min}$	4000	V

Characteristics					
Symbol	Conditions	min.	typ.	max.	Unit
IGBT					
$V_{CE(sat)}$	$I_C = 225\text{ A}$ $V_{GE} = 15\text{ V}$ chipllevel		$T_J = 25^\circ\text{C}$ 1.85 $T_J = 150^\circ\text{C}$ 2.3	2.3 2.55	V
V_{CE0}			$T_J = 25^\circ\text{C}$ 0.94 $T_J = 150^\circ\text{C}$ 0.88	1.04 0.98	V
r_{CE}	$V_{GE} = 15\text{ V}$		$T_J = 25^\circ\text{C}$ 4.0 $T_J = 150^\circ\text{C}$ 6.1	5.6 7.0	$\text{m}\Omega$
$V_{GE(th)}$	$V_{GE} = V_{CE}, I_C = 9\text{ mA}$	5.5	6	6.5	V
I_{CES}	$V_{GE} = 0\text{ V}$ $V_{CE} = 1200\text{ V}$		$T_J = 25^\circ\text{C}$ 0.1 $T_J = 150^\circ\text{C}$ 0.3		mA
C_{ies}			$f = 1\text{ MHz}$ 13.5		nF
C_{oes}	$V_{CE} = 25\text{ V}$		$f = 1\text{ MHz}$ 1.33		nF
C_{res}	$V_{GE} = 0\text{ V}$		$f = 1\text{ MHz}$ 1.33		nF
Q_G	$V_{GE} = -8\text{ V...} + 15\text{ V}$		2460		nC
R_{Gint}	$T_J = 25^\circ\text{C}$		3.33		Ω
$t_{d(on)}$	$V_{CC} = 600\text{ V}$ $I_C = 225\text{ A}$		$T_J = 150^\circ\text{C}$ 470		ns
t_r	$V_{GE} = \pm 15\text{ V}$		$T_J = 150^\circ\text{C}$ 72		ns
E_{on}	$R_{Gon} = 3.8\ \Omega$		$T_J = 150^\circ\text{C}$ 19.9		mJ
$t_{d(off)}$	$R_{Goff} = 3.8\ \Omega$		$T_J = 150^\circ\text{C}$ 665		ns
t_f	$di/dt_{on} = 3200\text{ A}/\mu\text{s}$ $di/dt_{off} = 2000\text{ A}/\mu\text{s}$		$T_J = 150^\circ\text{C}$ 109		ns
E_{off}	$du/dt_{off} = 6600\text{ V}/\mu\text{s}$		$T_J = 150^\circ\text{C}$ 27.2		mJ
$R_{th(j-c)}$	per IGBT			0.14	K/W

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Characteristics						
Symbol	Conditions	min.	typ.	max.	Unit	
Inverse diode						
$V_F = V_{EC}$	$I_F = 225\text{ A}$ $V_{GE} = 0\text{ V}$ chip		$T_J = 25\text{ °C}$ $T_J = 150\text{ °C}$	2.2 2.1	2.49 2.4	V V
V_{F0}			$T_J = 25\text{ °C}$ $T_J = 150\text{ °C}$	1.1 0.7	1.3 0.9	V V
r_F			$T_J = 25\text{ °C}$ $T_J = 150\text{ °C}$	3.6 4.7	3.9 5.4	mΩ mΩ
I_{RRM}	$I_F = 225\text{ A}$		$T_J = 150\text{ °C}$	210		A
Q_{rr}	$di/dt_{off} = 3400\text{ A/}\mu\text{s}$ $V_{GE} = -15\text{ V}$		$T_J = 150\text{ °C}$	39.4		μC
E_{rr}	$V_{CC} = 600\text{ V}$		$T_J = 150\text{ °C}$	16.4		mJ
$R_{th(j-c)}$	per diode				0.23	K/W
Module						
L_{CE}				20		nH
R_{CC+EE}	res., terminal-chip	$T_C = 25\text{ °C}$ $T_C = 125\text{ °C}$		0.7 1		mΩ mΩ
$R_{th(c-s)}$	per module			0.04		K/W
M_s	to heat sink (M5)			3	5	Nm
M_t		to terminals (M6)		2.5	5	Nm
w					300	g
Temperatur Sensor						
R_{100}	$T_C = 100\text{ °C}$ ($R_{25} = 5\text{ k}\Omega$)			493 ± 5%		Ω
$B_{100/125}$	$R(T) = R_{100} \exp[B_{100/125}(1/T - 1/T_{100})]$; T[K];			3550 ± 2%		K

SEMIX223GB12Vs

Features

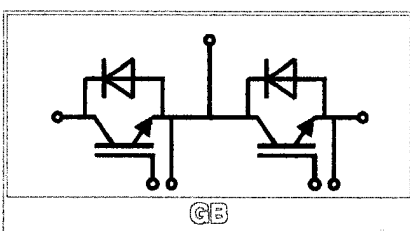
- Homogeneous Si
- $V_{CE(sat)}$ with positive temperature coefficient
- High short circuit capability
- UL recognised file no. E63532

Typical Applications*

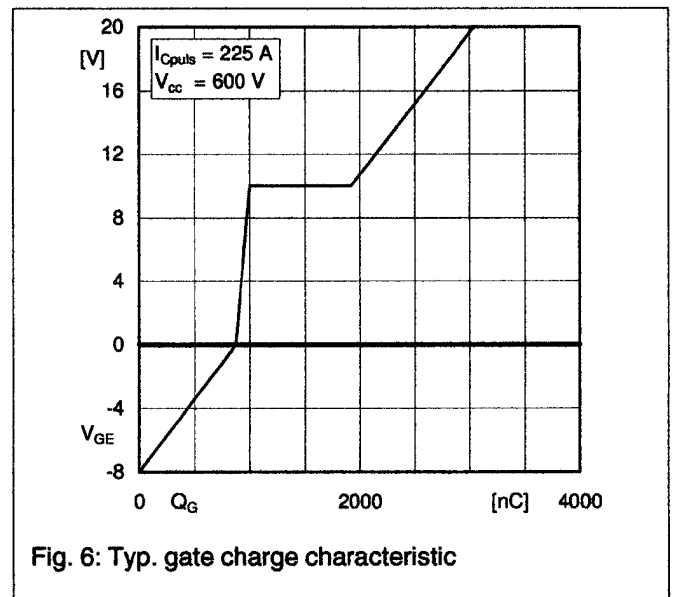
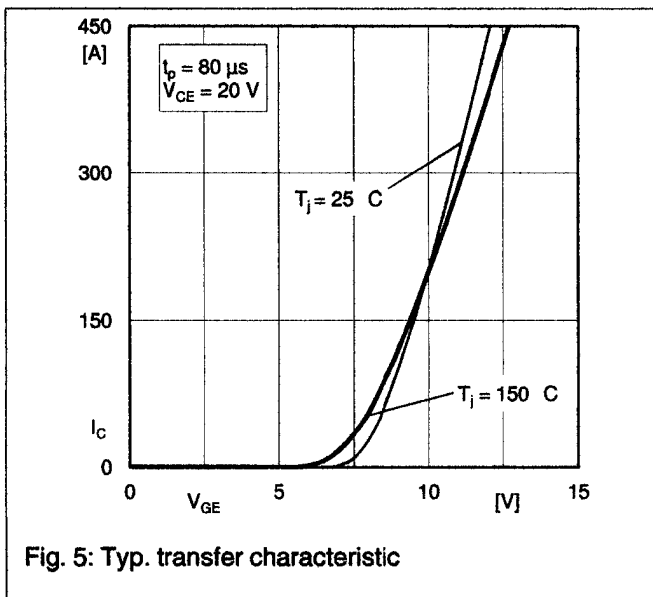
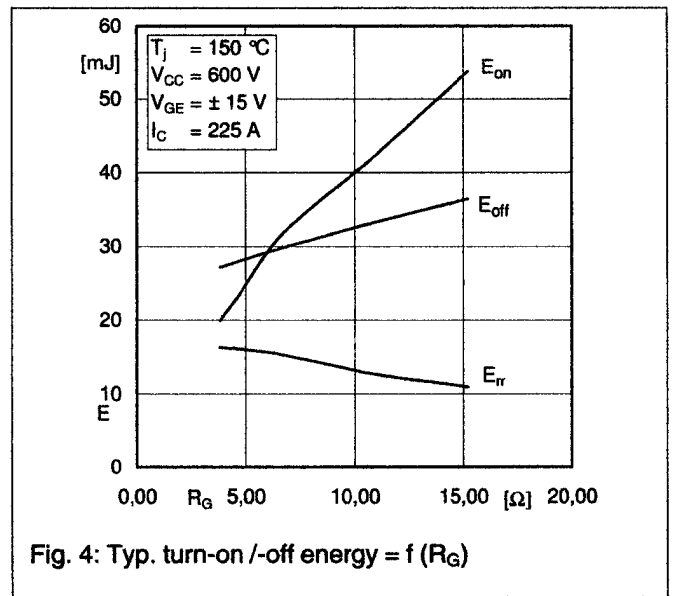
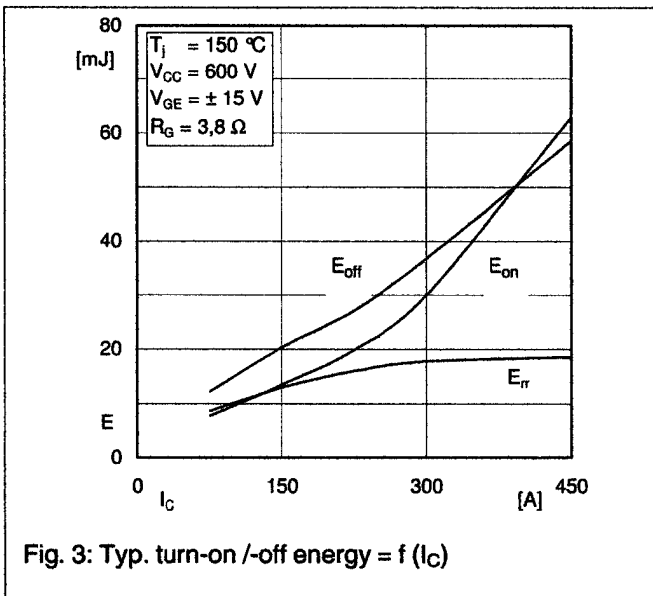
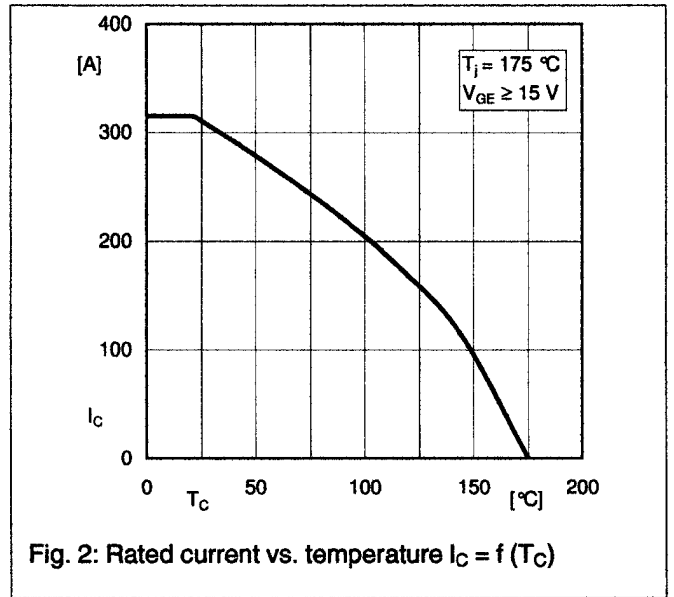
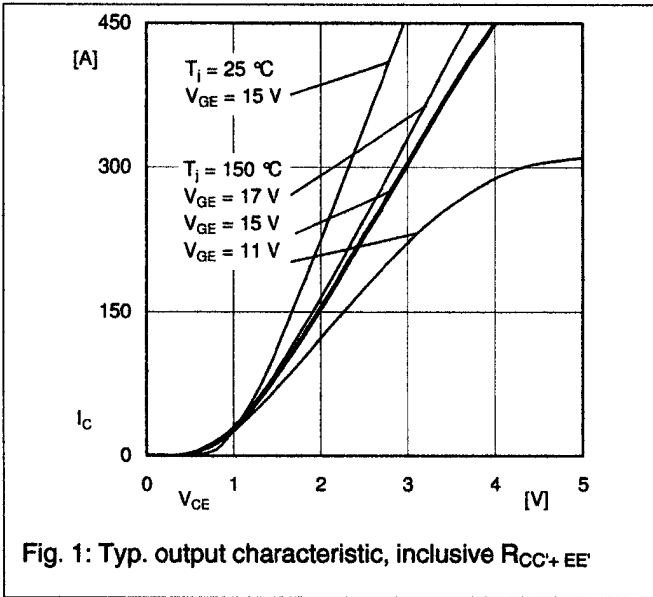
- AC inverter drives
- UPS
- Electronic Welding

Remarks

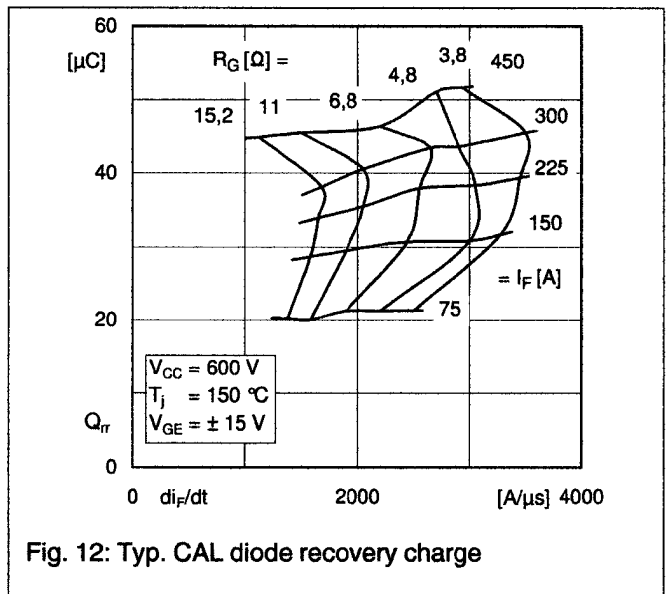
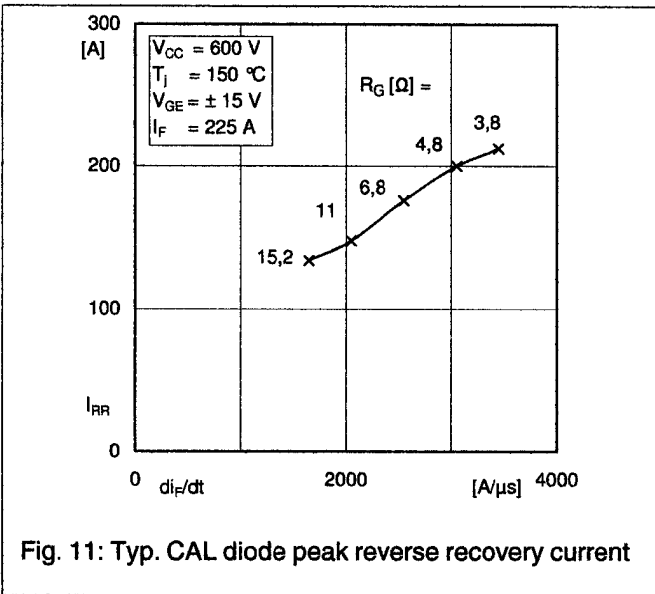
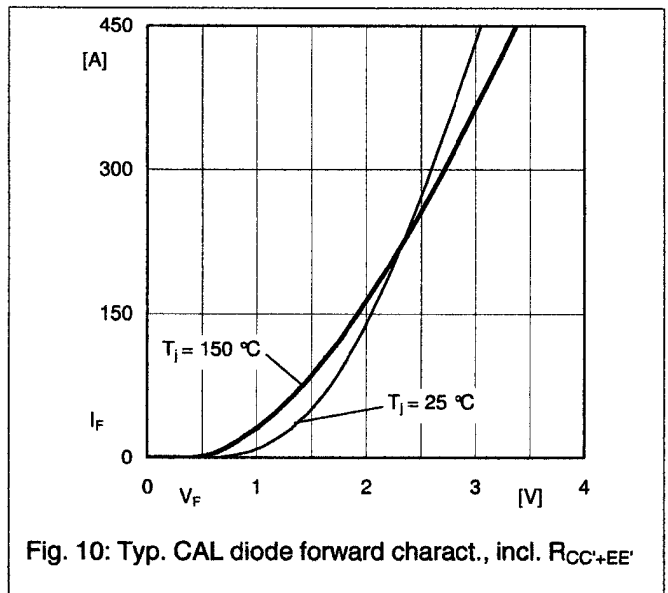
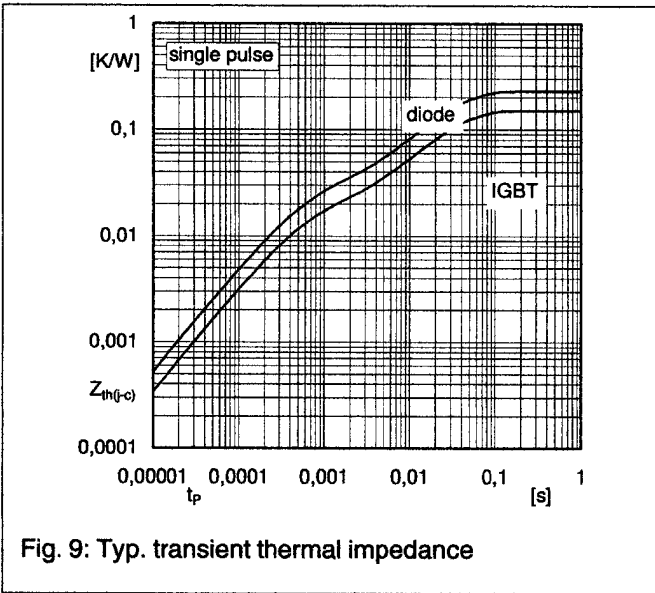
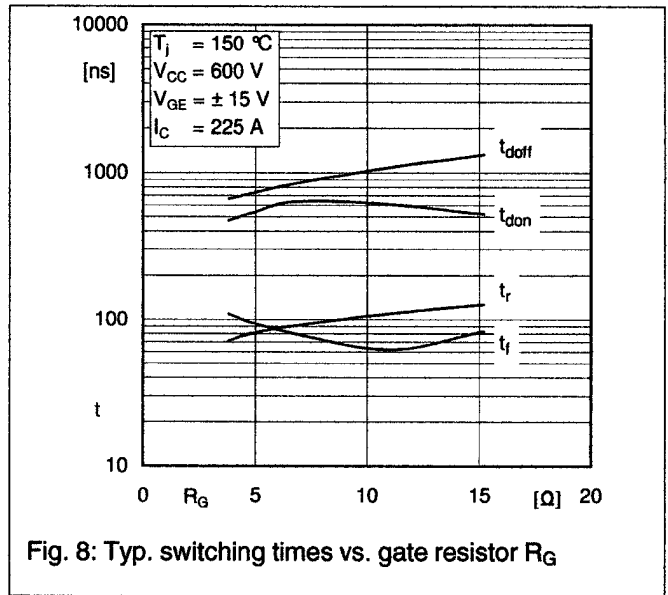
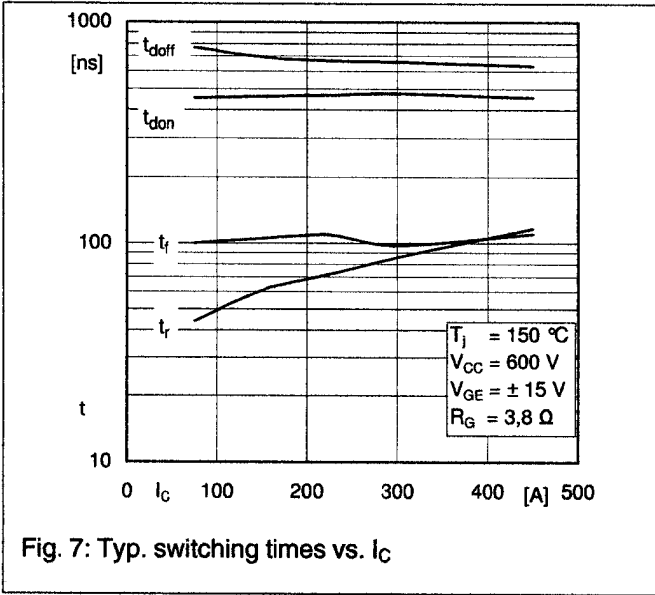
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 $R_{G,X} = 2,2\ \Omega$
 $R_{E,X} = 0,5\ \Omega$



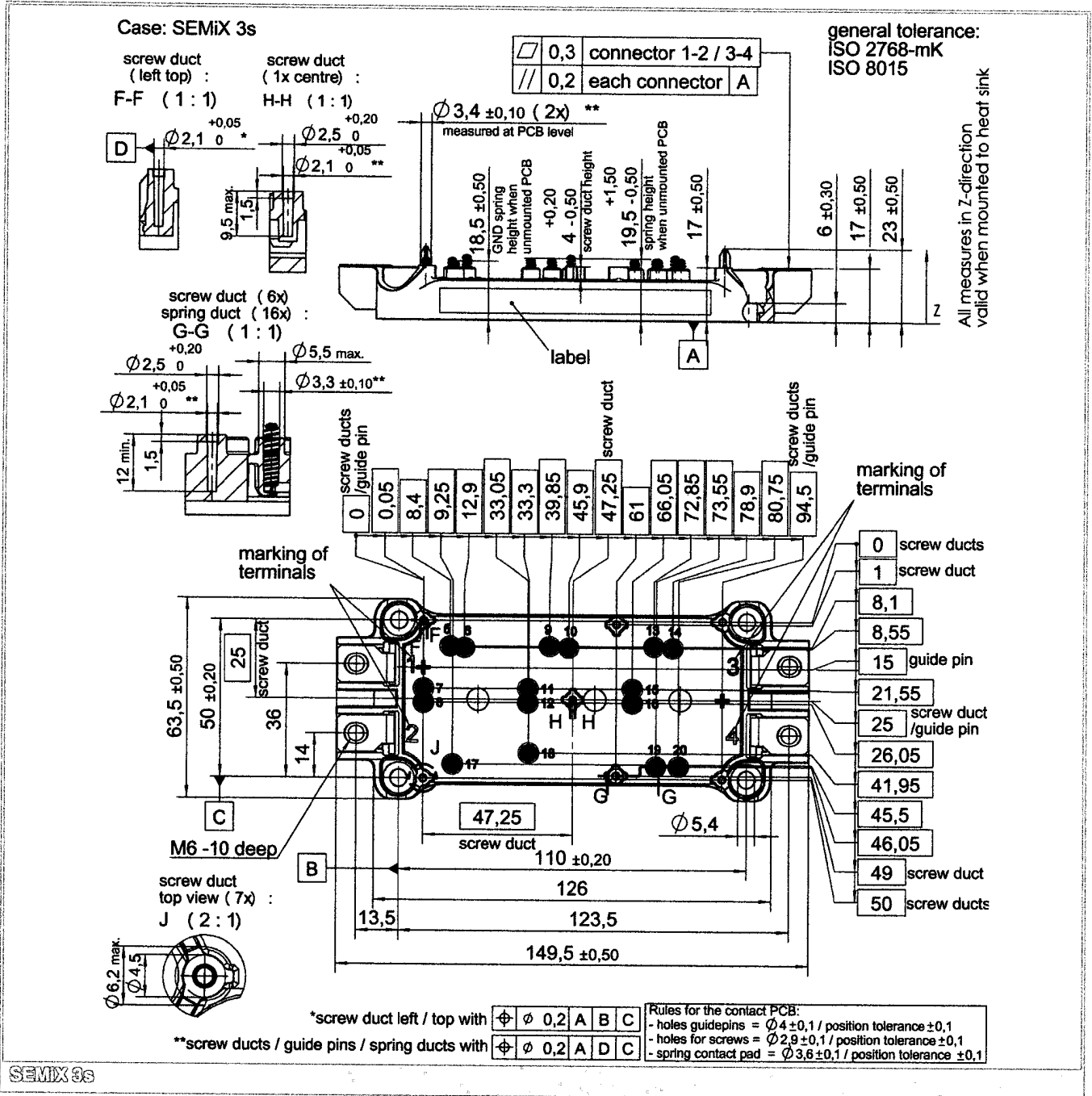
SEMIX223GB12Vs



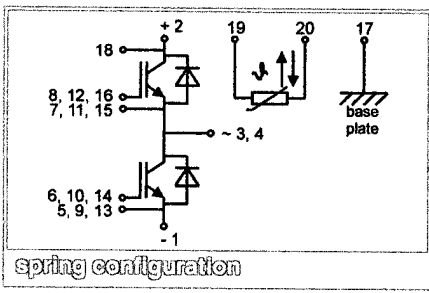
SEMIX223GB12Vs



SEMIX223GB12Vs



SEMIX 3s



This is an electrostatic discharge sensitive device (ESDS), international standard IEC 60747-1, Chapter IX

* The specifications of our components may not be considered as an assurance of component characteristics. Components have to be tested for the respective application. Adjustments may be necessary. The use of SEMIKRON products in life support appliances and systems is subject to prior specification and written approval by SEMIKRON. We therefore strongly recommend prior consultation of our staff.

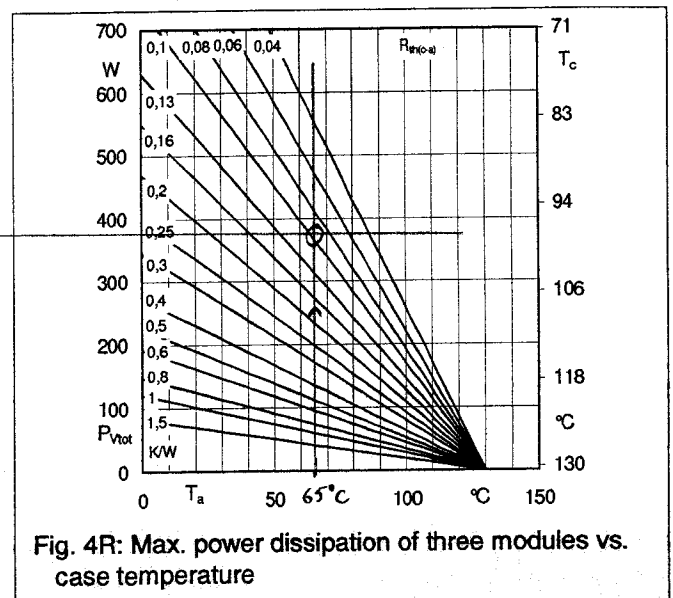
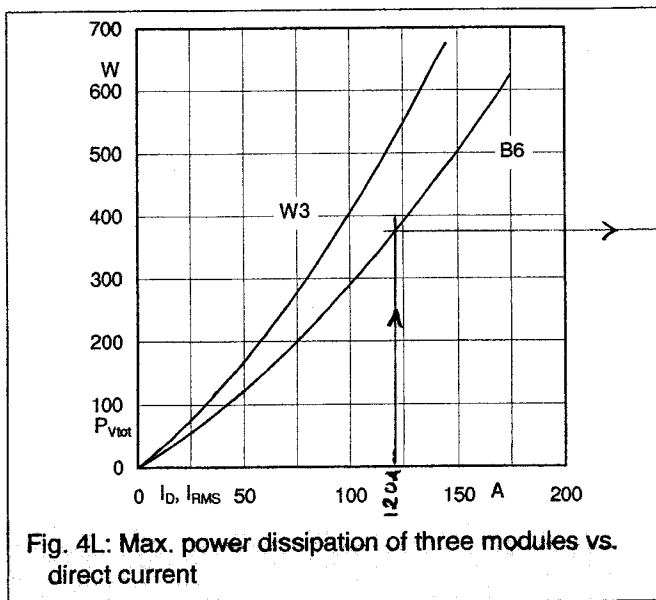
S-81,3120 Tehoelektronikan komponentit 1(4)
Tentti: 12.12.2012 Ratkaisut

Teht. 1-3: Katso kirja

Teht. 4

Datalehden kuvat 4L ja 4R pätevät kolmelle moduulille. Kuvan 4L käyrä B6 pätee näistä tehtyyn kuusipulssisilttaan. Vaaka-astelkolla on valmiiksi I_D eli tasavirta. Siten piirtämällä pystysuora viiva kohtaan 120 A ja käyrän B6 leikkauspisteestä vaakasuora viiva oikeanpuoleiseen käyrästään nähdään että sen ja 65°C kohtaan piirretyn suoran leikkauspisteessä on

$$R_{th(c-a)} \approx 0,095 \frac{\text{K}}{\text{W}}$$



Datalehden sivulla 1 annetaan $R_{th(c-s)} = 0,11 \frac{\text{K}}{\text{W}}$ per moduuli. Nyt kyseessä on kolme moduulia, joten

$$\underline{\underline{R_{th(s-a)} \approx 0,095 \frac{\text{K}}{\text{W}} - \frac{0,11 \frac{\text{K}}{\text{W}}}{3} \approx 0,058 \frac{\text{K}}{\text{W}}}}$$

Teht. 5

IGBT:n häviöenergiat pulssia kohden

Kuva 3 pätee kun $V_{GE} = \pm 15V$ ja $R_G = 3,8 \Omega$
kuten tehtävässä on, mutta jännite on 600V

Siten saadaan 150 A virralle ja 560V jännitteelle

$$E_{HTON} \approx 14 \text{ mJ} \cdot \frac{560V}{600V} \approx 13 \text{ mJ}$$
$$E_{HTOFF} \approx 21 \text{ mJ} \cdot \frac{560V}{600V} \approx \underline{\underline{20 \text{ mJ}}}$$

Johtohäviöenergia saadaan laskettua kuvan 1
jännitteellä.

$$V_{CE} \approx 2,0 \text{ V} \text{ kun } I_C = 150 \text{ A}, V_{GE} = 15V \text{ ja } T_J = 150^\circ\text{C}$$

(tai numeroarvoista (max.) $V_{CE} = V_{CE0} + r_{CE} I_C = 0,98V + 7\text{m}\Omega \cdot 150 \text{ A} = 2,03 \text{ V}$)

Siten

$$E_{HCOND} = V_{CE} \cdot I_C \cdot t_{ON} \approx 2,0 \text{ V} \cdot 150 \text{ A} \cdot 0,6 \text{ ms}$$
$$\approx \underline{\underline{180 \text{ mJ}}}$$

(Kytkeäajat $< 1 \mu\text{s} \ll 0,6 \text{ ms}$, joten ne voidaan unohtaa ilman suurta virhettä)

IGBT:n häviöteho on siten

$$P_{HIGBT} = f (E_{HTON} + E_{HTOFF} + E_{HCOND})$$
$$\approx 1000 \frac{1}{s} (13 \text{ mJ} + 20 \text{ mJ} + 180 \text{ mJ})$$
$$\approx \underline{\underline{213 \text{ W}}}$$

Teht. 5 jatkoa

Diodin häviöt

Myös diodin takavirran katkaisussa syntyvät häviöt saadaan kuvasta 3 16BT:n tapaan

$$E_{Hrr} \approx 13 \text{ mJ} \cdot \frac{560 \text{ V}}{600 \text{ V}} \approx \underline{\underline{12 \text{ mJ}}}$$

Jännite 150 A virralla saadaan kuvasta 10

$$U_F \approx 1,9 \text{ V} \quad \text{kun } T_J = 150^\circ \text{C}$$

$$\begin{aligned} \text{(tai sitten numeroarvoista (max.)) } U_F &\approx U_{F0} + r_F I_F \\ &\approx 1,1 \text{ V} + 5,9 \text{ m}\Omega \cdot 150 \text{ A} \\ &\approx 1,99 \text{ V} \end{aligned}$$

Siden johtohäviöenergia on

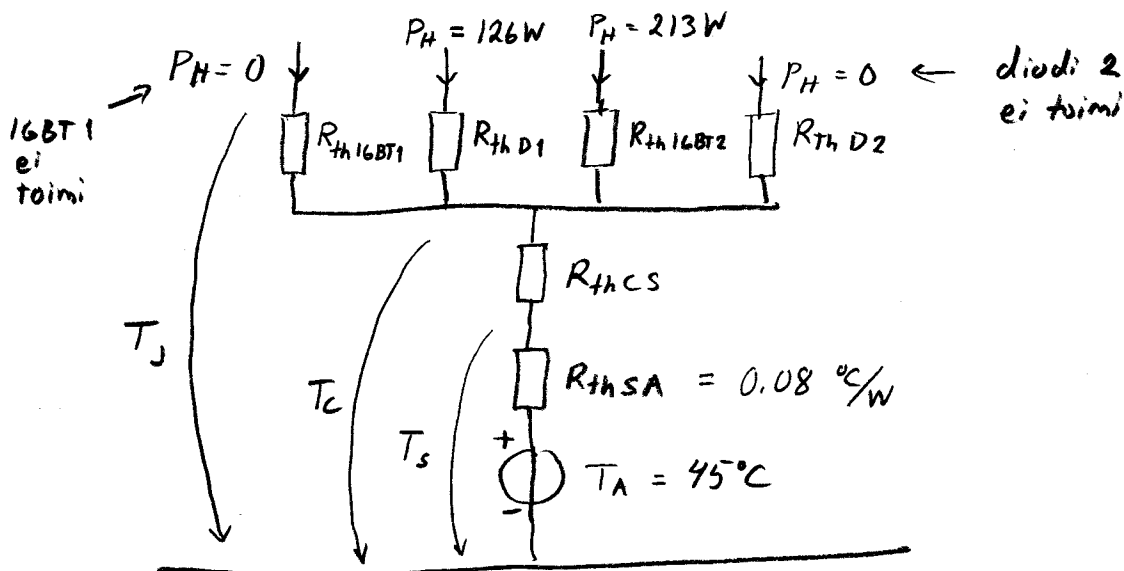
$$E_{H, \text{conv}, D} \approx 1,9 \text{ V} \cdot 150 \text{ A} \cdot 0,4 \text{ ms} \approx \underline{\underline{114 \text{ mJ}}}$$

Ja edelleen diodin keskimääräinen häviöteho

$$\begin{aligned} \underline{\underline{P_{H,D}}} &= f (E_{Hrr} + E_{H, \text{conv}, D}) \approx 1000 \frac{1}{s} (12 \text{ mJ} + 114 \text{ mJ}) \\ &\approx \underline{\underline{126 \text{ W}}} \end{aligned}$$

Tent. 5 jatkoa

Moduulin terminen sijaishytkenä, kun taajuus
 $f \approx 1 \text{ kHz}$ (\approx pysyvä tila)



Datalehden numeroarvoista löytyvät maksimiarvot:

$$R_{th\,JC, \text{IGBT}} = 0.14 \frac{\text{K}}{\text{W}}$$

$$R_{th\,JC, D} = 0.23 \frac{\text{K}}{\text{W}}$$

$$R_{th\,CS} = 0.04 \frac{\text{K}}{\text{W}}$$

Siispä

$$\begin{aligned} T_C &= (P_{H, \text{IGBT}} + P_{H, D}) (R_{th\,CS} + R_{th\,SA}) + T_A \\ &\approx (213 \text{ W} + 126 \text{ W}) (0.04 \frac{\text{K}}{\text{W}} + 0.08 \frac{\text{K}}{\text{W}}) + 45^\circ\text{C} \\ &\approx 86^\circ\text{C} \end{aligned}$$

Joten

$$\begin{aligned} \underline{\underline{T_{J, \text{IGBT}}}} &= T_C + P_{H, \text{IGBT}} \cdot R_{th\,JC, \text{IGBT}} = 86^\circ\text{C} + 213 \text{ W} \cdot 0.14 \frac{\text{K}}{\text{W}} \approx \underline{\underline{116^\circ\text{C}}} \\ \underline{\underline{T_{J, D}}} &= T_C + P_{H, D} \cdot R_{th\,JC, D} = 86^\circ\text{C} + 126 \text{ W} \cdot 0.23 \frac{\text{K}}{\text{W}} \approx \underline{\underline{115^\circ\text{C}}} \end{aligned}$$