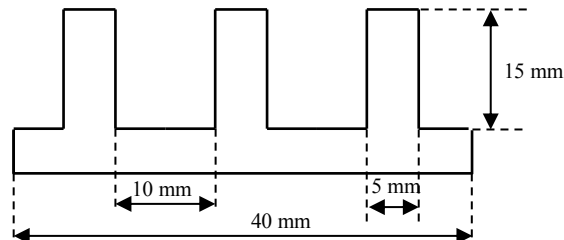


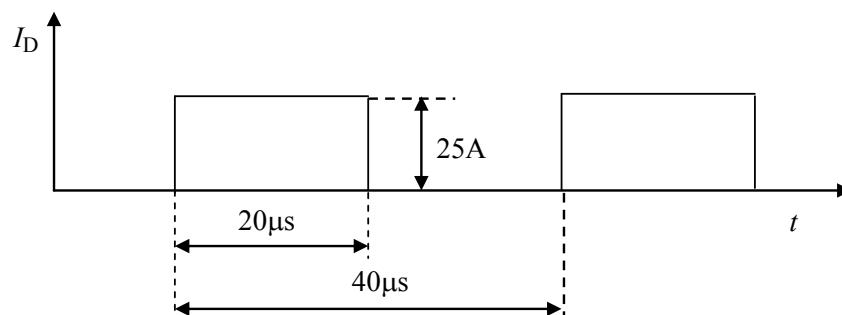
ELEC-E8421 Tehoelektroniikan komponentit

Tentti 14.12.2017, kello 13:00-16:00, sali AS1

- Selvitä lyhyesti (2...4 lausetta + mahdollinen kuva), mitä seuraavilla termeillä tarkoitetaan
 - ioni-istutus
 - takavirran varaus
 - SOA
 - prospektiivinen oikosulkuvirta
 - ESR.
- Esittele IGBT:n rakenne, toimintaperiaate ja ominaisuudet.
- Esittele johtuvien sähkömagneettisten häiriöiden suodattamiseen käytettyjä suodattimia, niiden toimintaperiaatteita ja niissä käytettyjä komponentteja.
- Erään laitteen hakkuriteholähteen tehopuolijohteiden jäädyttämiseksi luonnollisella tuuletuksella on aiottu muotoilla laitteen 60 mm korkea takaseinä oheisen kuvan poikkileikkauksen mukaiseksi rivoitukseksi (vain yhden komponentin osuus esitetty). Kuinka suuri saa komponentin häviöteho korkeintaan olla, kun takaseinän sisäpinnan lämpötila ei saa ylittää 80 °C lämpötilaa ulkolämpötilan ollessa 50 °C? Käytä kaavaa $R_{th} = 11,7 A^{-0,7} P_H^{-0,15}$ jossa R_{th} on lämpövastus, yksikkö K/W, A on pinta-ala neliödesimetreissä ja P_H häviöteho watteina. Tehtävässä oletetaan, että laitteen sisällä ei ilma kierrä.



- Määrä $SCT2080KE$ SiC mosfetin vaatiman jäähdtyselementin lämpövastus, kun fetin virta on oheisen kuvan mukainen. Jäähdytysilman lämpötila on 45 °C ja $V_{GS} = 18$ V. Fetin yli oleva jännite on päällekytkennän aikana 520 V ja katkaisun aikana 700 V.



V_{DSS}	1200V
$R_{DS(on)}$ (Typ.)	80mΩ
I_D	40A
P_D	262W

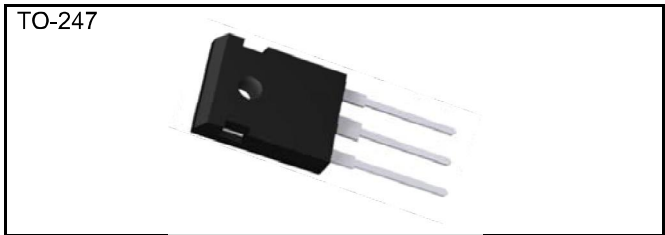
●Features

- 1) Low on-resistance
- 2) Fast switching speed
- 3) Fast reverse recovery
- 4) Easy to parallel
- 5) Simple to drive
- 6) Pb-free lead plating ; RoHS compliant

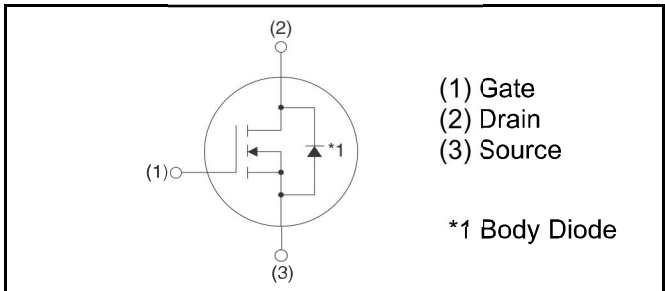
●Application

- Solar inverters
- DC/DC converters
- Induction heating
- Motor drives

●Outline



●Inner circuit



●Packaging specifications

Type	Packing	Tube
	Reel size (mm)	-
	Tape width (mm)	-
	Basic ordering unit (pcs)	30
	Packing code	C
	Marking	SCT2080KE

●Absolute maximum ratings ($T_a = 25^\circ\text{C}$)

Parameter	Symbol	Value	Unit	
Drain - Source voltage	V_{DSS}	1200	V	
Continuous drain current	$T_c = 25^\circ\text{C}$	I_D^{*1}	40	A
	$T_c = 100^\circ\text{C}$	I_D^{*1}	28	A
Pulsed drain current	$I_{D,pulse}^{*2}$	80	A	
Gate - Source voltage (DC)	V_{GSS}	-6 to 22	V	
Gate - Source surge voltage ($T_{surge} < 300\text{nsec}$)	$V_{GSS-surge}^{*3}$	-10 to 26	V	
Power dissipation ($T_c = 25^\circ\text{C}$)	P_D	262	W	
Junction temperature	T_j	175	$^\circ\text{C}$	
Range of storage temperature	T_{stg}	-55 to +175	$^\circ\text{C}$	

● Thermal resistance

Parameter	Symbol	Values			Unit
		Min.	Typ.	Max.	
Thermal resistance, junction - case	R_{thJC}	-	0.44	0.57	°C/W
Thermal resistance, junction - ambient	R_{thJA}	-	-	50	°C/W
Soldering temperature, wavesoldering for 10s	T_{sold}	-	-	265	°C

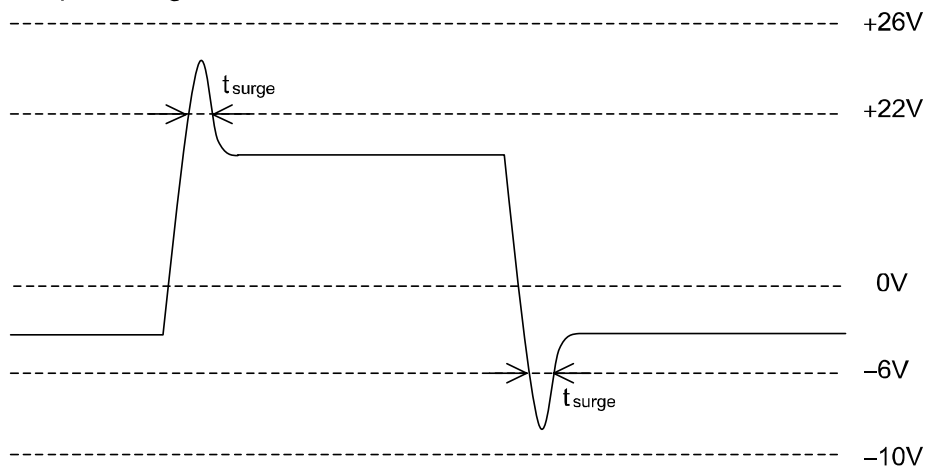
● Electrical characteristics ($T_a = 25^\circ\text{C}$)

Parameter	Symbol	Conditions	Values			Unit
			Min.	Typ.	Max.	
Drain - Source breakdown voltage	$V_{(BR)DSS}$	$V_{GS} = 0V, I_D = 1mA$	1200	-	-	V
Zero gate voltage drain current	I_{DSS}	$V_{DS} = 1200V, V_{GS} = 0V$	-	1	10	μA
		$T_j = 150^\circ\text{C}$	-	2	-	
Gate - Source leakage current	I_{GSS+}	$V_{GS} = +22V, V_{DS} = 0V$	-	-	100	nA
Gate - Source leakage current	I_{GSS-}	$V_{GS} = -6V, V_{DS} = 0V$	-	-	-100	nA
Gate threshold voltage	$V_{GS(th)}$	$V_{DS} = V_{GS}, I_D = 4.4mA$	1.6	2.8	4.0	V

*1 Limited only by maximum temperature allowed.

*2 $PW \leq 10\mu s$, Duty cycle $\leq 1\%$

*3 Example of acceptable Vgs waveform



*4 Pulsed

●Electrical characteristics (T_a = 25°C)

Parameter	Symbol	Conditions	Values			Unit
			Min.	Typ.	Max.	
Static drain - source on - state resistance	R _{DS(on)} ^{*4}	V _{GS} = 18V, I _D = 10A T _j = 25°C T _j = 125°C	- -	80 125	117 -	mΩ
Gate input resistance	R _G	f = 1MHz, open drain	-	6.3	-	Ω
Transconductance	g _{fs} ^{*4}	V _{DS} = 10V, I _D = 10A	-	3.7	-	S
Input capacitance	C _{iss}	V _{GS} = 0V	-	2080	-	pF
Output capacitance	C _{oss}	V _{DS} = 800V	-	77	-	
Reverse transfer capacitance	C _{rss}	f = 1MHz	-	16	-	
Effective output capacitance, energy related	C _{o(er)}	V _{GS} = 0V V _{DS} = 0V to 500V	-	116	-	pF
Turn - on delay time	t _{d(on)} ^{*4}	V _{DD} = 400V, V _{GS} = 18V	-	35	-	ns
Rise time	t _r ^{*4}	I _D = 10A	-	36	-	
Turn - off delay time	t _{d(off)} ^{*4}	R _L = 40Ω	-	76	-	
Fall time	t _f ^{*4}	R _G = 0Ω	-	22	-	
Turn - on switching loss	E _{on} ^{*4}	V _{DD} = 600V, I _D = 10A V _{GS} = 18V/0V	-	174	-	μJ
Turn - off switching loss	E _{off} ^{*4}	R _G = 0Ω, L = 500μH *E _{on} includes diode reverse recovery	-	51	-	

●Gate Charge characteristics (T_a = 25°C)

Parameter	Symbol	Conditions	Values			Unit
			Min.	Typ.	Max.	
Total gate charge	Q _g ^{*4}	V _{DD} = 400V	-	106	-	nC
Gate - Source charge	Q _{gs} ^{*4}	I _D = 10A	-	27	-	
Gate - Drain charge	Q _{gd} ^{*4}	V _{GS} = 18V	-	31	-	
Gate plateau voltage	V _(plateau)	V _{DD} = 400V, I _D = 10A	-	9.7	-	V

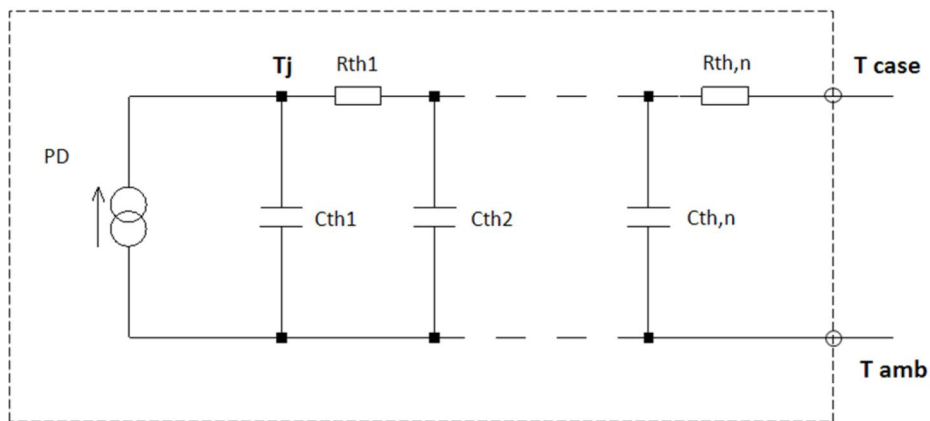
●Body diode electrical characteristics (Source-Drain) ($T_a = 25^\circ\text{C}$)

Parameter	Symbol	Conditions	Values			Unit
			Min.	Typ.	Max.	
Inverse diode continuous, forward current	I_S^{*1}	$T_C = 25^\circ\text{C}$	-	-	40	A
Inverse diode direct current, pulsed	I_{SM}^{*2}		-	-	80	A
Forward voltage	V_{SD}^{*4}	$V_{GS} = 0\text{V}, I_S = 10\text{A}$	-	4.6	-	V
Reverse recovery time	t_{rr}^{*4}	$I_F = 10\text{A}, V_R = 400\text{V}$ $di/dt = 150\text{A}/\mu\text{s}$	-	31	-	ns
Reverse recovery charge	Q_{rr}^{*4}		-	44	-	nC
Peak reverse recovery current	I_{rrm}^{*4}		-	2.3	-	A

●Typical Transient Thermal Characteristics

Symbol	Value	Unit
R_{th1}	0.078	K/W
R_{th2}	0.197	
R_{th3}	0.162	

Symbol	Value	Unit
C_{th1}	0.005	Ws/K
C_{th2}	0.018	
C_{th3}	0.249	



●Electrical characteristic curves

Fig.1 Power Dissipation Derating Curve

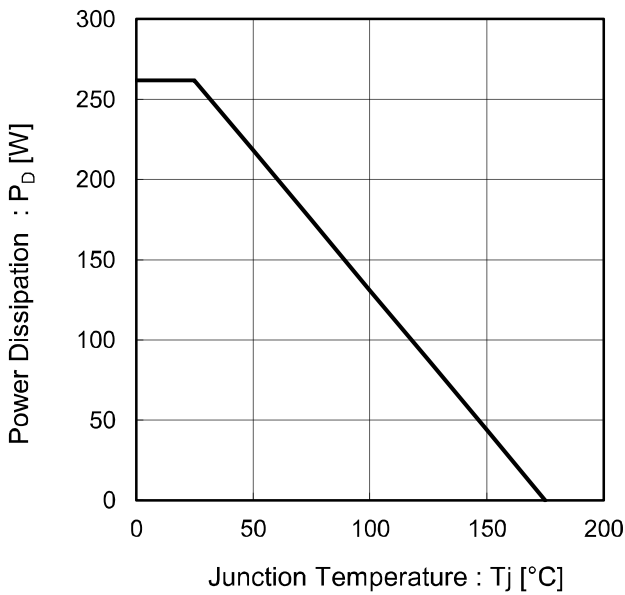


Fig.2 Maximum Safe Operating Area

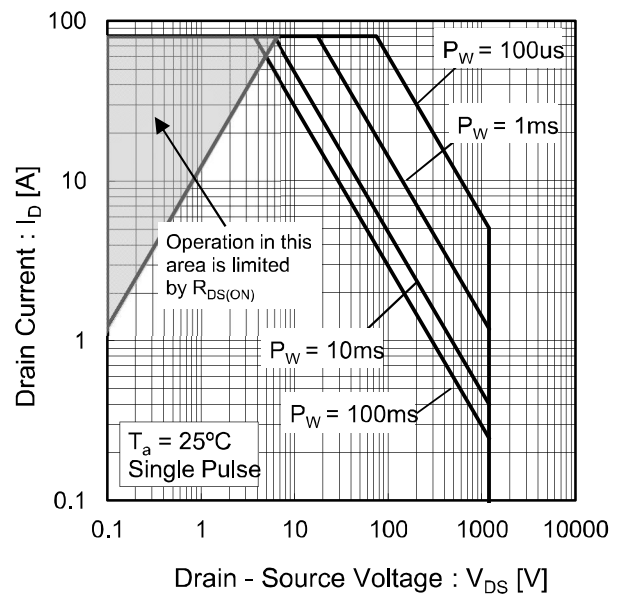
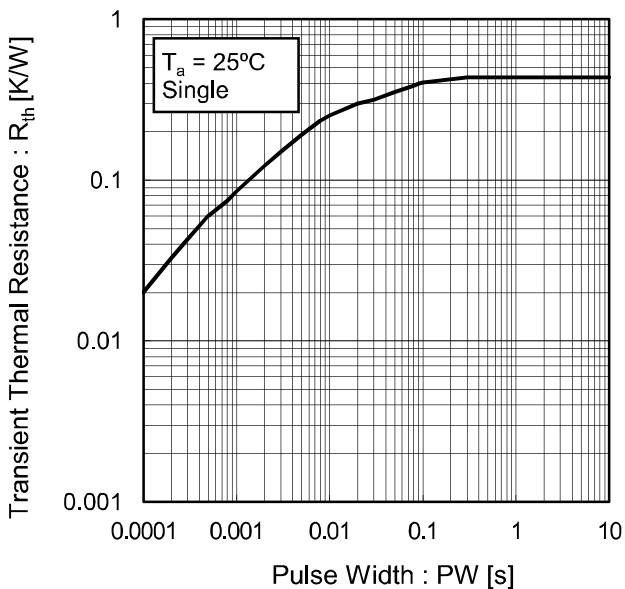


Fig.3 Typical Transient Thermal Resistance vs. Pulse Width



●Electrical characteristic curves

Fig.4 Typical Output Characteristics(I)

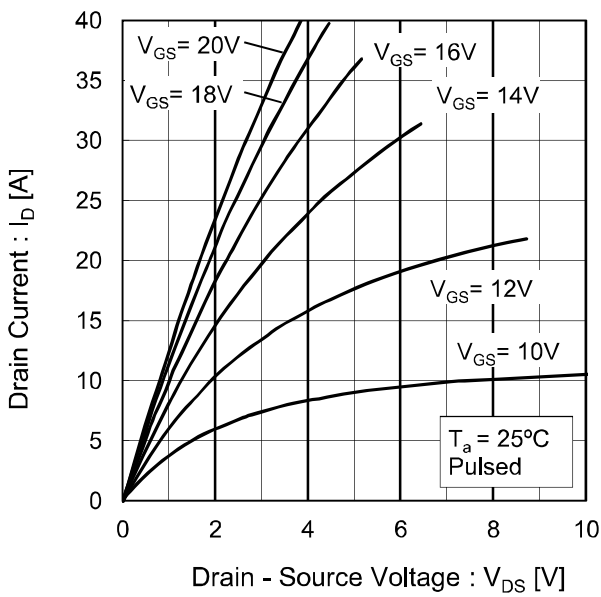


Fig.5 Typical Output Characteristics(II)

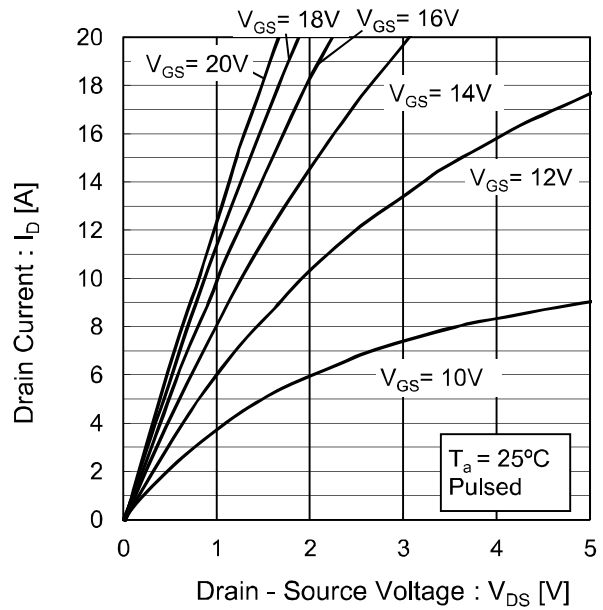


Fig.6 Typical Output Characteristics(I)

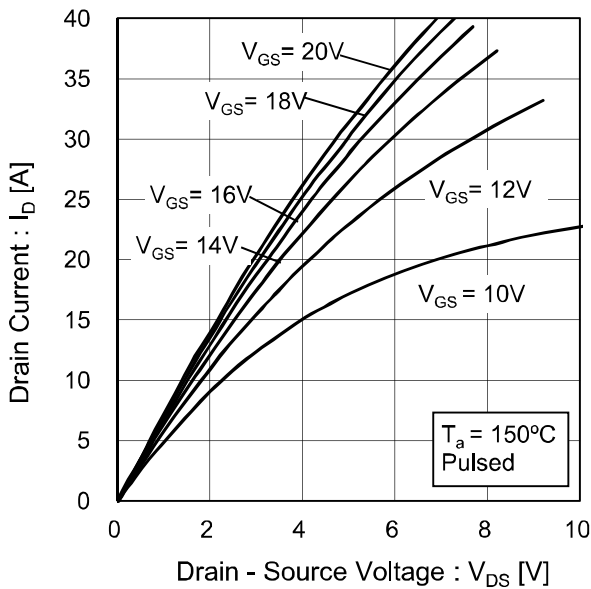
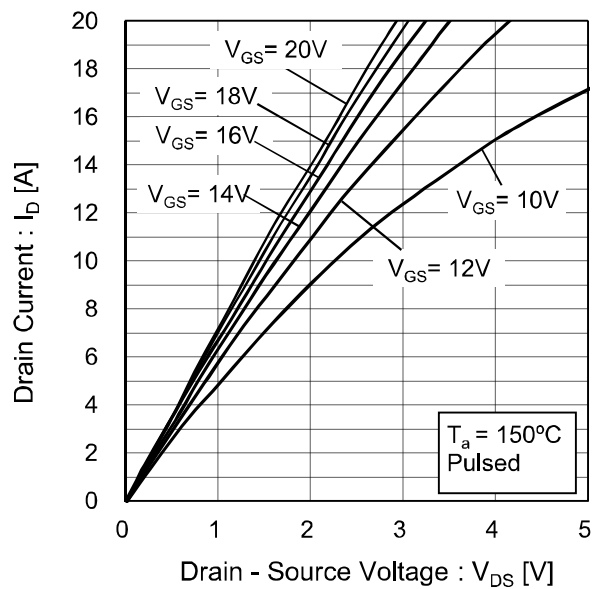


Fig.7 Typical Output Characteristics(II)



●Electrical characteristic curves

Fig.8 Typical Transfer Characteristics

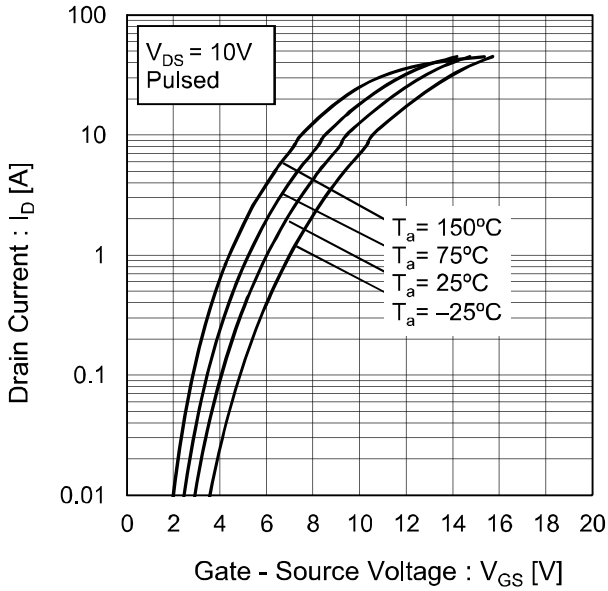


Fig.9 Typical Transfer Characteristics (II)

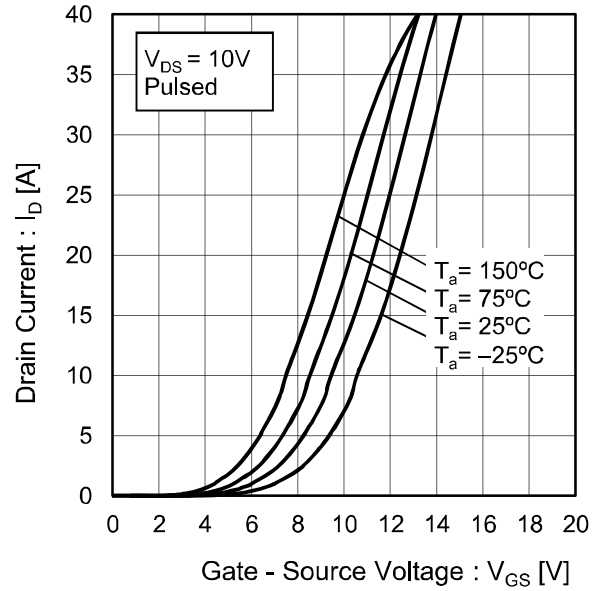


Fig.10 Gate Threshold Voltage vs. Junction Temperature

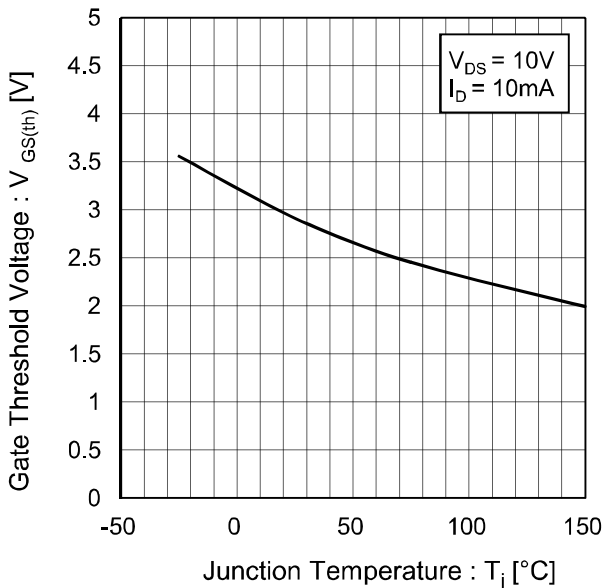
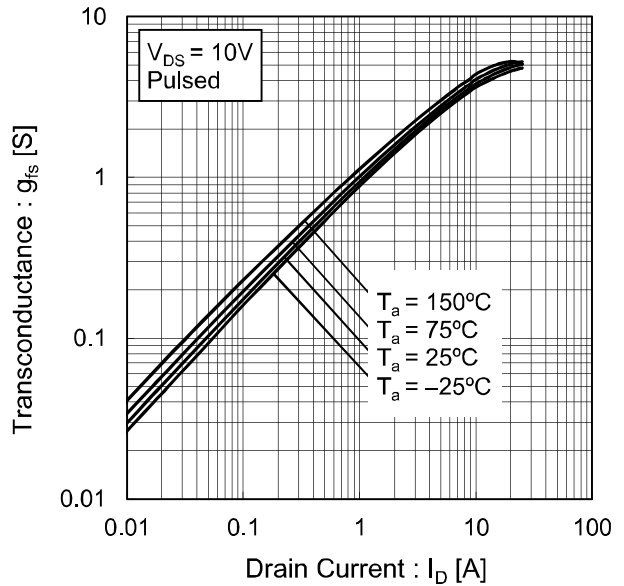


Fig.11 Transconductance vs. Drain Current



●Electrical characteristic curves

Fig.12 Static Drain - Source On - State Resistance vs. Gate - Source Voltage

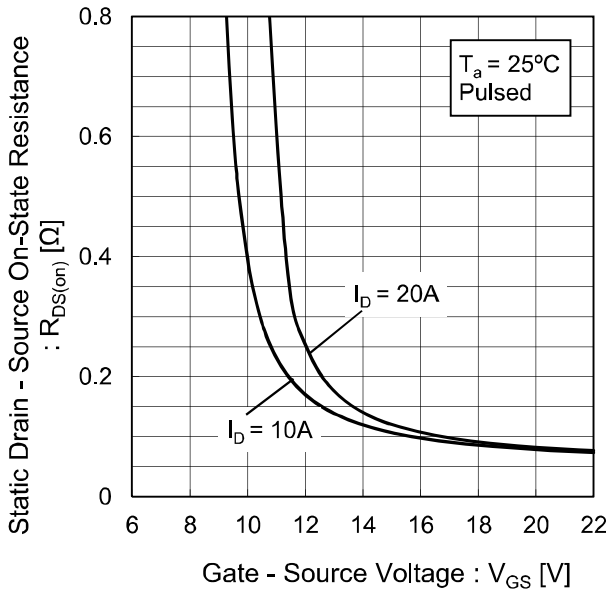


Fig.13 Static Drain - Source On - State Resistance vs. Junction Temperature

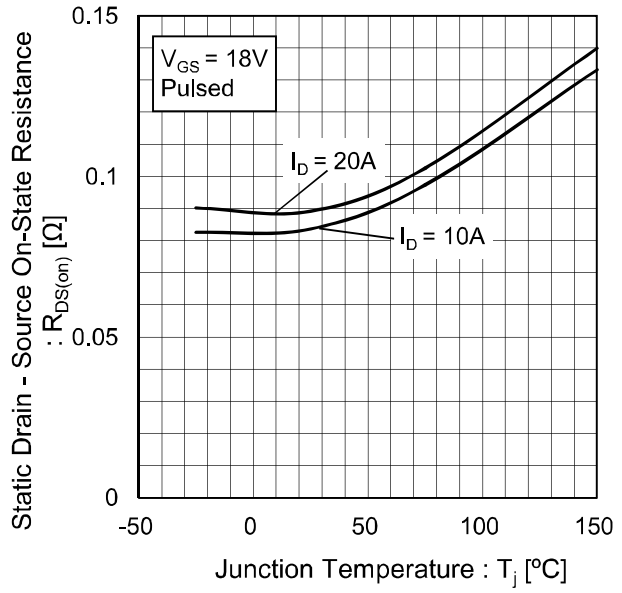
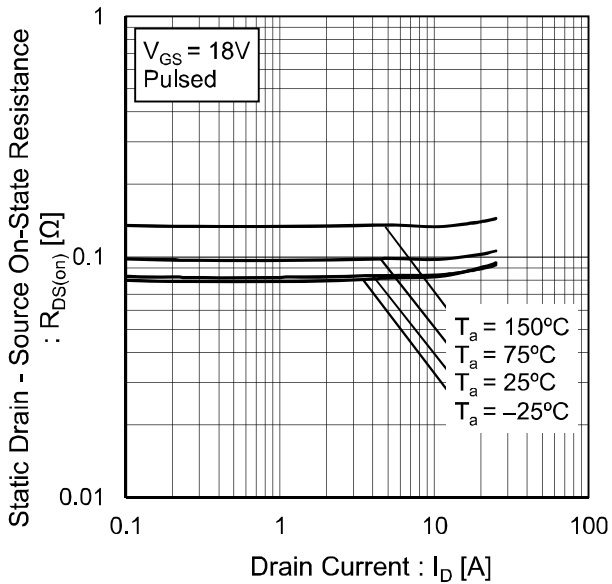


Fig.14 Static Drain - Source On - State Resistance vs. Drain Current



●Electrical characteristic curves

Fig.15 Typical Capacitance vs. Drain - Source Voltage

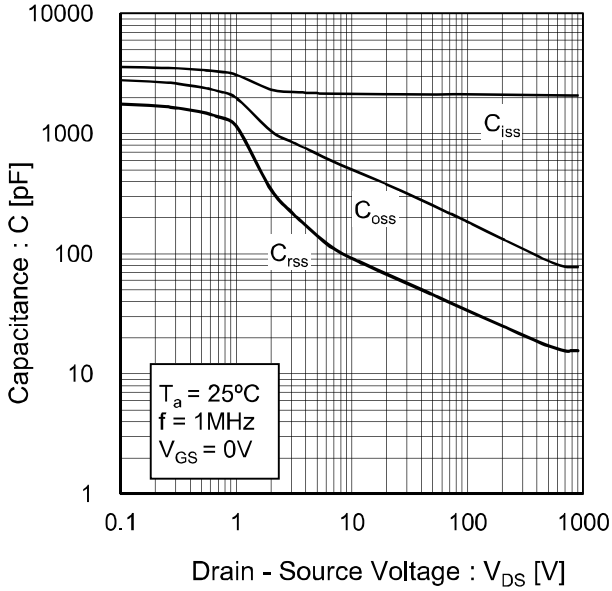


Fig.16 Coss Stored Energy

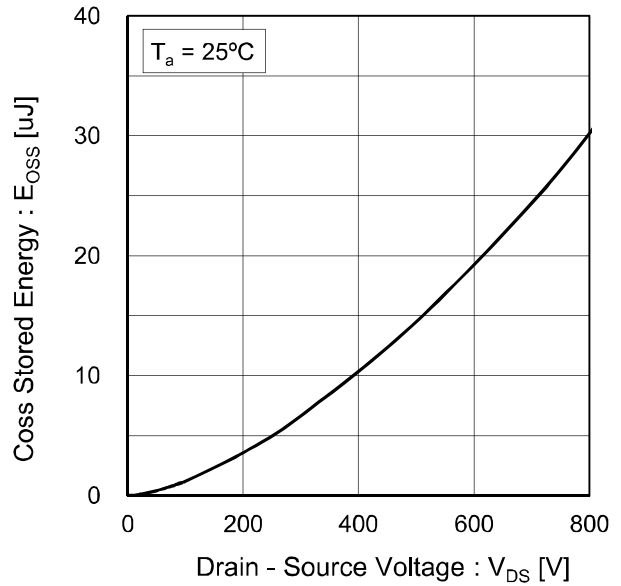


Fig.17 Switching Characteristics

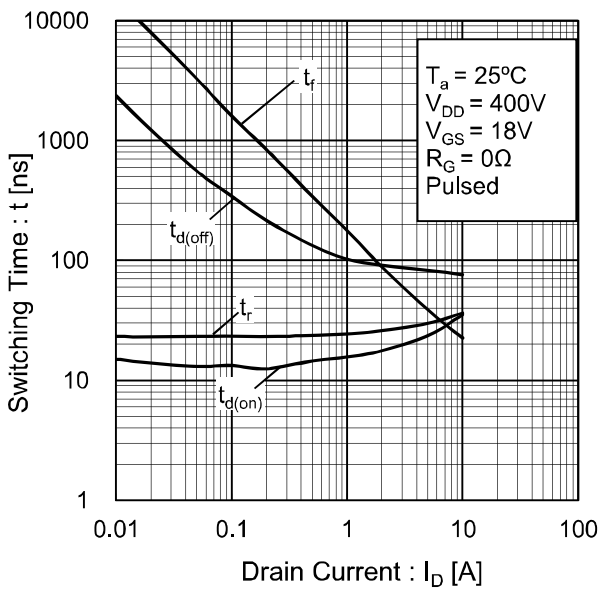
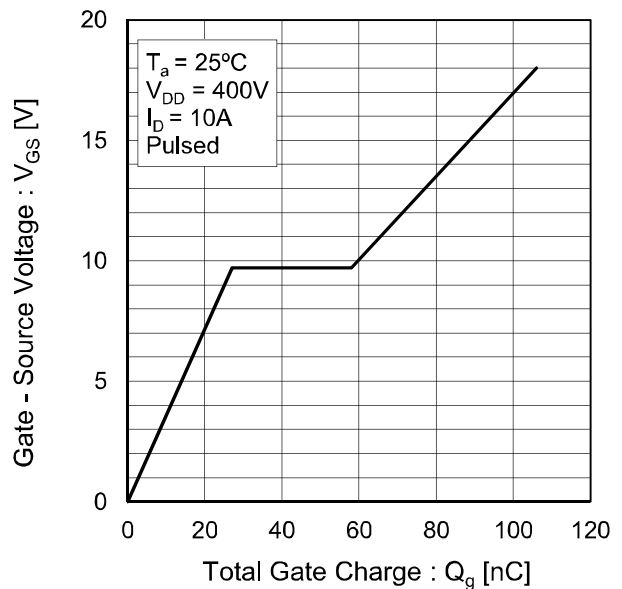


Fig.18 Dynamic Input Characteristics



●Electrical characteristic curves

Fig.19 Typical Switching Loss vs. Drain - Source Voltage

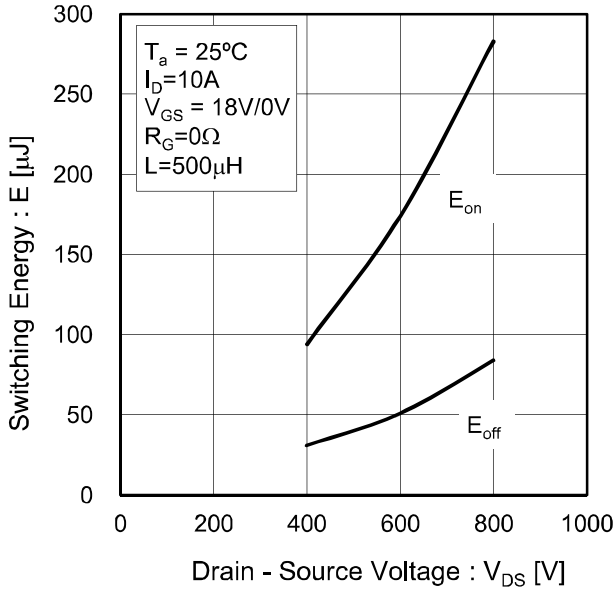


Fig.20 Typical Switching Loss vs. Drain Current

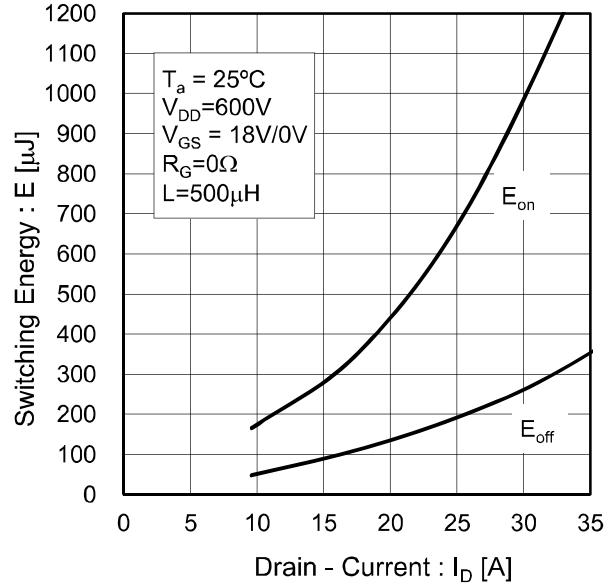
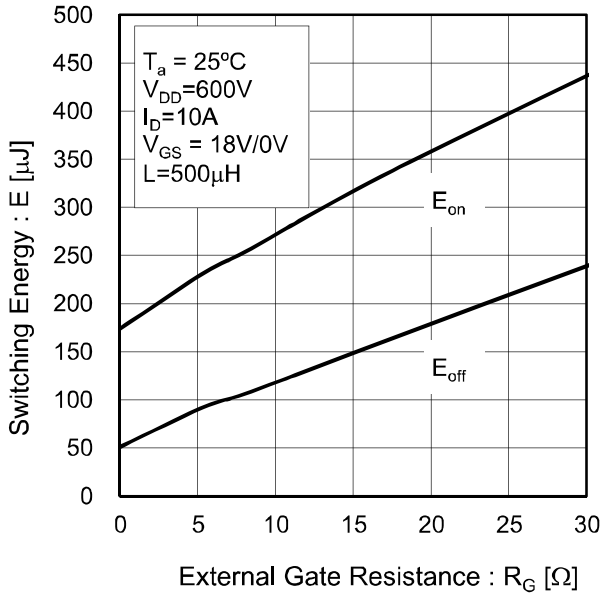


Fig.21 Typical Switching Loss vs. External Gate Resistance



●Electrical characteristic curves

Fig.22 Inverse Diode Forward Current vs. Source - Drain Voltage

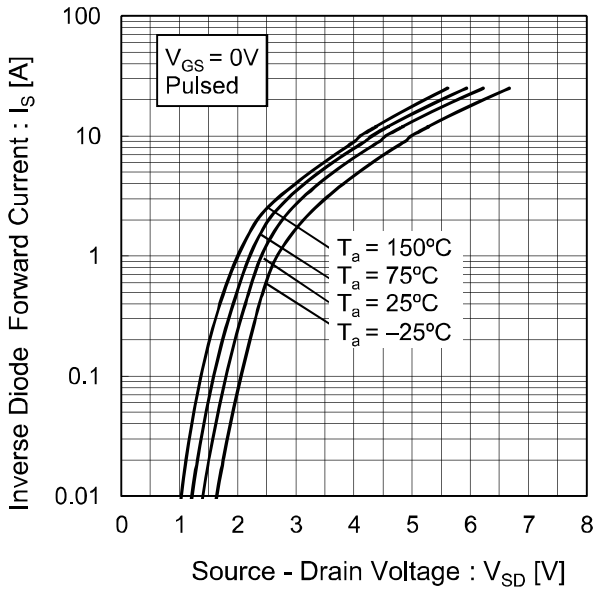
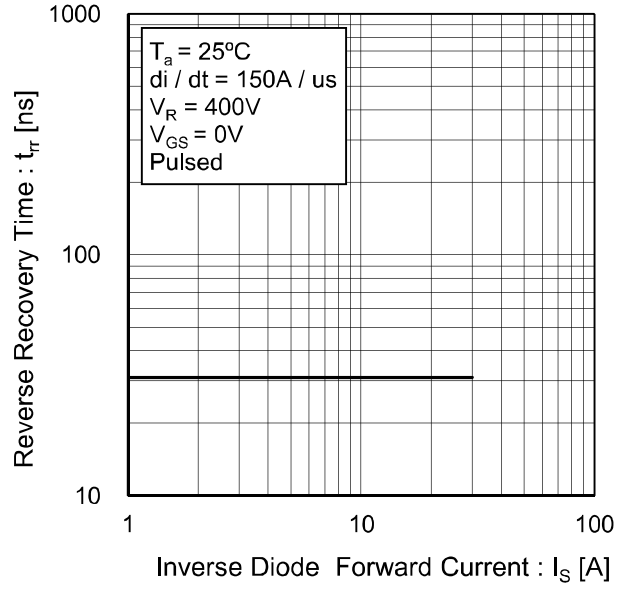


Fig.23 Reverse Recovery Time vs. Inverse Diode Forward Current



● Measurement circuits

Fig.1-1 Switching Time Measurement Circuit

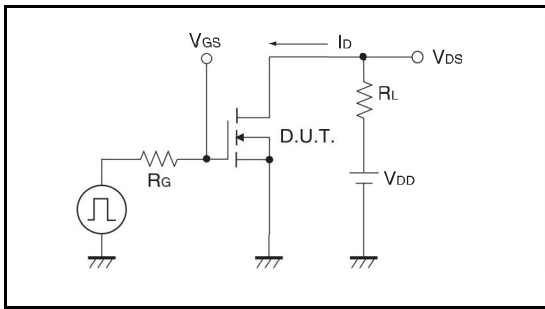


Fig.1-2 Switching Waveforms

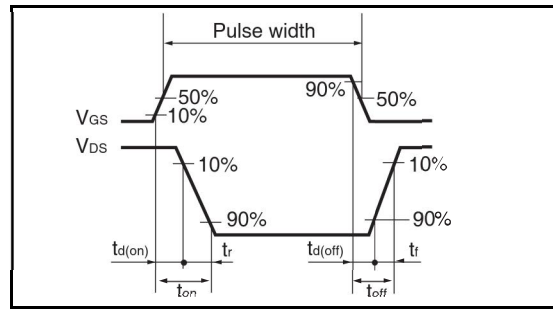


Fig.2-1 Gate Charge Measurement Circuit

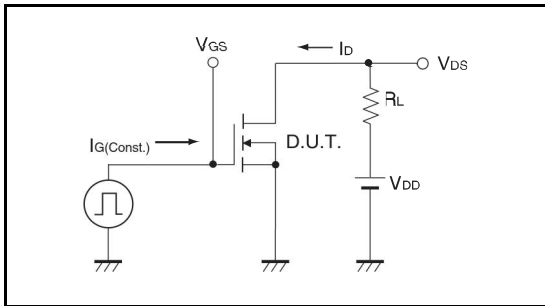


Fig.2-2 Gate Charge Waveform

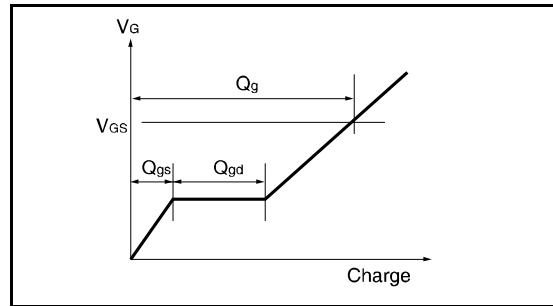


Fig.3-1 Switching Energy Measurement Circuit

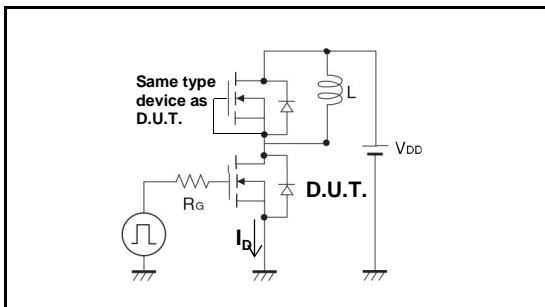


Fig.3-2 Switching Waveforms

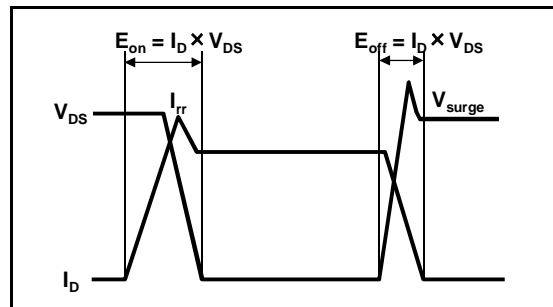


Fig.4-1 Reverse Recovery Time Measurement Circuit

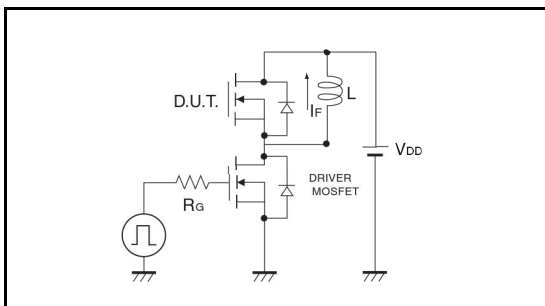
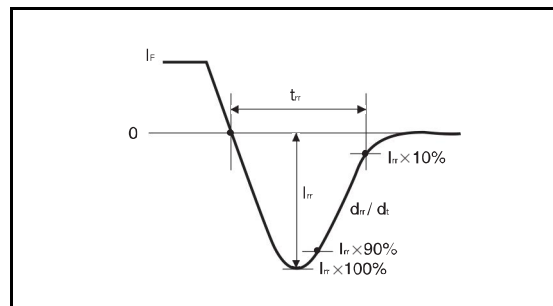


Fig.4-2 Reverse Recovery Waveform



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Tentti 14.12.2017 RATKAISUT

Tehtävät 1-2: Katso kirja,, tehtävä 3 katso lisämateriaali

Tehtävä 4

$$R_{\text{thSA}} = 11,7 A^{-0.7} P_{\text{H}}^{-0,15} = \frac{T_{\text{S}} - T_{\text{A}}}{P_{\text{H}}}$$

josta saadaan

$$P_{\text{H max}}^{0,85} = \frac{T_{\text{S}} - T_{\text{A}}}{11,7 A^{-0.7}}$$

ja edelleen

$$P_{\text{H max}} = \left(\frac{T_{\text{S}} - T_{\text{A}}}{11,7 A^{-0.7}} \right)^{\frac{1}{0,85}}$$

Kotelon sisällä oletettiin ilman kierron olevan mitättömän. Siten jäähdytys-elementin voi olettaa jäähtyvän vain ulkopinnaltaan.

Ulkopinnan pinta-alaksi saadaan

$$A = (40 \text{ mm} + 6 \cdot 15 \text{ mm}) \cdot 60 \text{ mm} = 7800 \text{ mm}^2 = 0,78 \text{ dm}^2$$

jos elementin ala ja yläpintoja ei huomioida (niiden pinta-ala on $6 \cdot 15 \text{ mm} \cdot 5 \text{ mm} = 450 \text{ mm}^2 = 0,045 \text{ dm}^2$ eli aika pieni. Lisäksi ilma ei niissä välttämättä liiku).

Sijoittamalla arvot kaavaan saadaan komponentin maksimihäviöksi

$$P_{\text{H max}} = \left(\frac{80^{\circ}\text{C} - 50^{\circ}\text{C}}{11,7 \cdot 0,78^{-0.7}} \right)^{\frac{1}{0,85}} = 2,47 \text{ W}$$

Tehtävä 5

Kun $V_{\text{GS}} = 18 \text{ V}$, $T_{\text{J}} = 150^{\circ}\text{C}$ ja $I_{\text{D}} = 25 \text{ A}$ saadaan kuvasta 13 arvioiden 25 A virralla

$$R_{\text{DS}} \approx 0,15 \Omega$$

Siten johtohäviöenergia per pulssi on

$$E_{\text{HON}} = R_{\text{DS}} I_{\text{D}}^2 t_{\text{ON}} \approx 0,15 \Omega (25 \text{ A})^2 20 \mu\text{s} \approx 1,9 \text{ mJ}$$

Vaihtoehtoisesti voi kuvasta 6 lukea jännitehäviöksi 25 A virralla kun $V_{\text{GS}} = 18 \text{ V}$ ja $T_{\text{J}} = 150^{\circ}\text{C}$ noin 3.9 V, josta laskemalla päätyy suunnilleen samaan tulokseen.

Kytkehäviöistä valmistaja antaa tietoja eri tavoin. Kuvassa 16 on annettu fetin kapasitansseihin varautuva energia, joka kuvaa transistorin sisäisiä häviöitä hyvin pienellä kuormavirralla. Nyt kuitenkin virtaa on 25 A.

Arvioidaan kytkentähäviöt yläkanttiin olettamalla virran muuttuvan nousu- ja laskuaikoina lineaarisesti ja jännitteen olevan tänä aikana vakio. Kuvasta 17 saadaan extrapoloimalla 25 A virralla nousuajaksi t_r noin 60 ns ja laskuajaksi t_f noin 11 ns.

Siten kytkentähäviöenergiat ovat

$$E_{H\text{TON}} < \frac{t_r U_{SD\text{TON}} I_D}{2} = \frac{60 \text{ ns} \cdot 520 \text{ V} \cdot 25 \text{ A}}{2} \approx 0,39 \text{ mJ}$$

$$E_{H\text{TOFF}} < \frac{t_f U_{SD\text{TOFF}} I_D}{2} = \frac{11 \text{ ns} \cdot 700 \text{ V} \cdot 25 \text{ A}}{2} \approx 0,10 \text{ mJ}$$

Toinen vaihtoehto on käyttää kuvaa 19, jossa vastaavat häviöt on annettu 10 A virralla. Kuvan tuloksia on skaalattava 25/10, jotta ne vastaavat tehtävän lukuarvoja. Siten kuvan perusteella $E_{H\text{TON}} = 2,5 \cdot 130 \mu\text{J} = 325 \mu\text{J}$ ja $E_{H\text{TOFF}} = 2,5 \cdot 70 \mu\text{J} = 175 \mu\text{J}$ eli kohtuu lähellä edellä laskettuja arvoja.

Myös kuvassa 20 annettuja arvoja voi käyttää, mutta nyt jännite on skaalattava kohdalleen $E_{H\text{TON}} = 520/600 \cdot 660 \mu\text{J} = 572 \mu\text{J}$ ja $E_{H\text{TOFF}} = 700/600 \cdot 200 \mu\text{J} = 233 \mu\text{J}$. Nämä lukuarvot ovat huomattavasti aiempia korkeampia. Yksi syy on se, että varsinkin syttymishäviö kasvaa kuvassa virran kasvaessa enemmän kuin lineaarisesti

Koska taajuus on huomattavasti yli 1 kHz, voidaan mitoitus tehdä keskimääräisen häviötehon ja pysyvän tilan lämpövastuksen perusteella.

Keskimääräiseksi häviötehoksi saadaan ensimmäiseksi laskettujen häviötehojen perusteella

$$P_{H\text{ave}} = \frac{E_{H\text{ON}} + E_{H\text{TON}} + E_{H\text{TOFF}}}{T} = \frac{1,9 \text{ mJ} + 0,39 \text{ mJ} + 0,1 \text{ mJ}}{40 \mu\text{s}} \approx 60 \text{ W}$$

Siten jäähdytyslementin lämpövastukseksi fetin ja elementin välinen lämpövastus mukaanlukien saadaan

$$R_{thCA} \leq \frac{T_J - R_{thJC} P_{H\text{ave}} - T_A}{P_{H\text{ave}}} = \frac{150 \text{ }^\circ\text{C} - 0,44 \frac{^\circ\text{C}}{\text{W}} \cdot 60 \text{ W} - 45 \text{ }^\circ\text{C}}{60 \text{ W}} \approx 1,31 \frac{^\circ\text{C}}{\text{W}}$$

Edellä on käytetty varovaisuuden vuoksi 150 °C liitoslämpötilaa, mutta datalehden mukaan nykyinen komponentin versio kestää myös 175 °C.