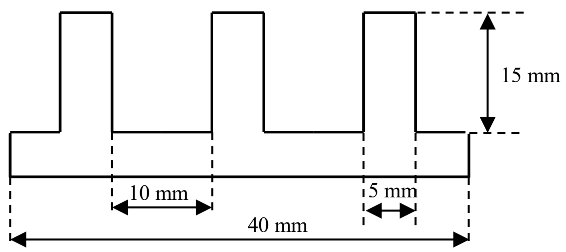
ELEC-E8421 Tehoelektroniikan komponentit
Exam 13.1.2020 (translation for Finnish)

1. Explain shortly (2...4 sentences + possible drawing), what the following terms mean
   - ion-injection
   - reverse recovery charge
   - SOA
   - prospective short circuit current
   - ESR.

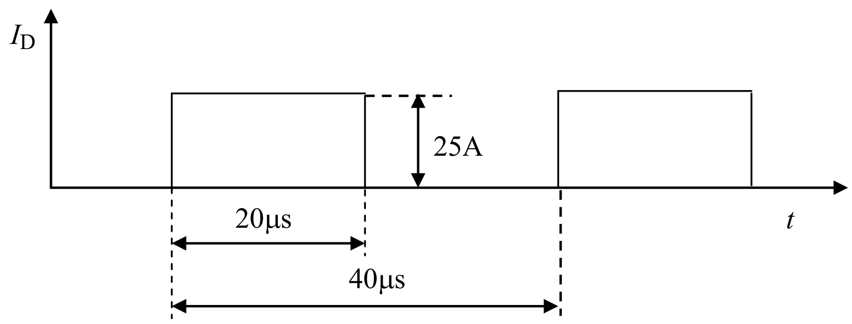
2. Describe the construction, functioning principle and properties of IGBT.

3. Discuss filters used for the EMC, their operating principles and components used.

4. Cooling element of a switched mode power supply is as shown below and it works with natural convection. Element will cover the backside of the supply, height is 60 mm. What is the allowed power loss when the temperature of the backside cannot be higher than 80 ˚C when ambient temperature is 50 ˚C. Use the equation $R_{th} = 11{,}7\ A^{-0{,}7}\ P_H^{-0{,}15}$ where R_{th} is the thermal resistance K/W, A is surface area in dm^2 and P_H loss power. It is assumed that air is not circulating inside the power supply.



5. Calculate the needed thermal resistance of the cooling element for SCT2080KE SiC Mosfet, when the current through it is as shown below. Ambient temperature is 45 ˚C and V_{GS} = 18 V. During turn-on voltage over the device is 520 V and turn-off 700 V.



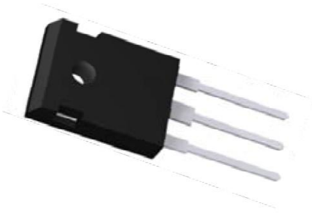
SCT2080KE

N-channel SiC power MOSFET Datasheet

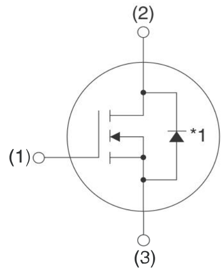
V_{DSS}	1200V
$R_{DS(on)}$ (Typ.)	80mΩ
I_D	40A
P_D	262W

●Outline

TO-247



●Inner circuit



(1) Gate
(2) Drain
(3) Source

*1 Body Diode

●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

●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°C)

Parameter		Symbol	Value	Unit
Drain - Source voltage		V_{DSS}	1200	V
Continuous drain current	T_c = 25°C	I_D *1	40	A
	T_c = 100°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} < 300nsec)		$V_{GSS\text{-}surge}$ *3	–10 to 26	V
Power dissipation (T_c = 25°C)		P_D	262	W
Junction temperature		T_j	175	°C
Range of storage temperature		T_{stg}	–55 to +175	°C

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●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

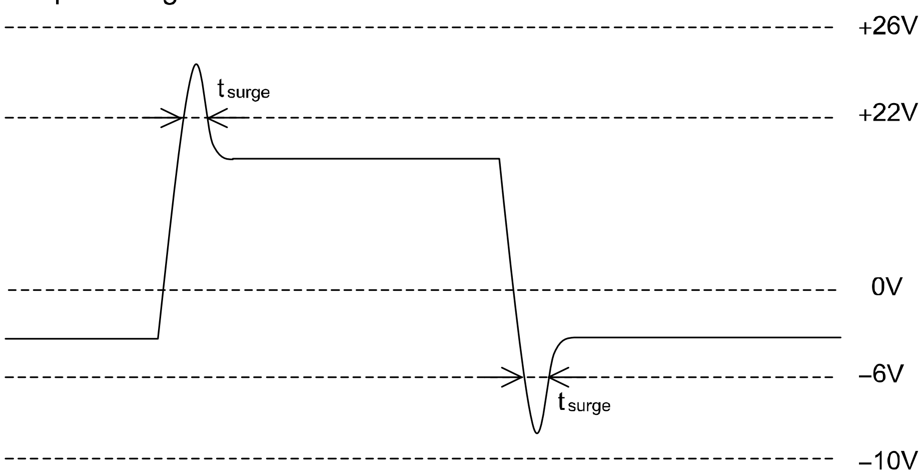
●Electrical characteristics (T_a = 25°C)

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				μA
		T_j = 25°C	-	1	10	
		T_j = 150°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 ≤ 10μs, Duty cycle ≤ 1%

*3 Example of acceptable Vgs waveform



*4 Pulsed

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● 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	-	80	117	mΩ
		T_j = 125°C	-	125	-	
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 R_G = 0Ω, L=500μH *E_{on} includes diode reverse recovery	-	174	-	μJ
Turn - off switching loss	E_{off} *4		-	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

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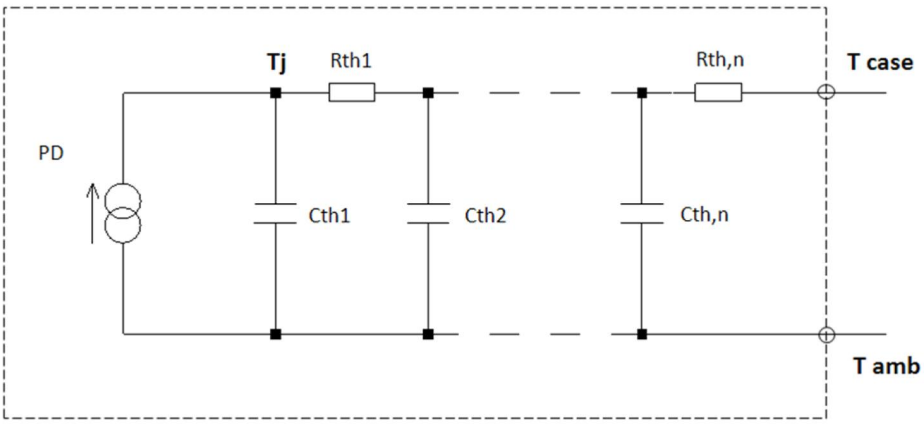
●Body diode electrical characteristics (Source-Drain) (T_a = 25°C)

Parameter	Symbol	Conditions	Values			Unit
			Min.	Typ.	Max.	
Inverse diode continuous, forward current	I_S *1	T_c = 25°C	-	-	40	A
Inverse diode direct current, pulsed	I_{SM} *2		-	-	80	A
Forward voltage	V_{SD} *4	V_{GS} = 0V, I_S = 10A	-	4.6	-	V
Reverse recovery time	t_{rr} *4	I_F = 10A, V_R = 400V di/dt = 150A/μs	-	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	



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●Electrical characteristic curves

Fig.1 Power Dissipation Derating Curve

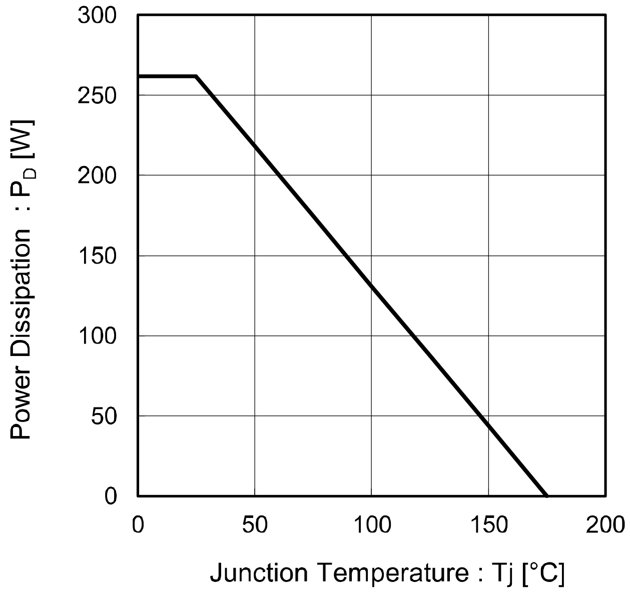


Fig.2 Maximum Safe Operating Area

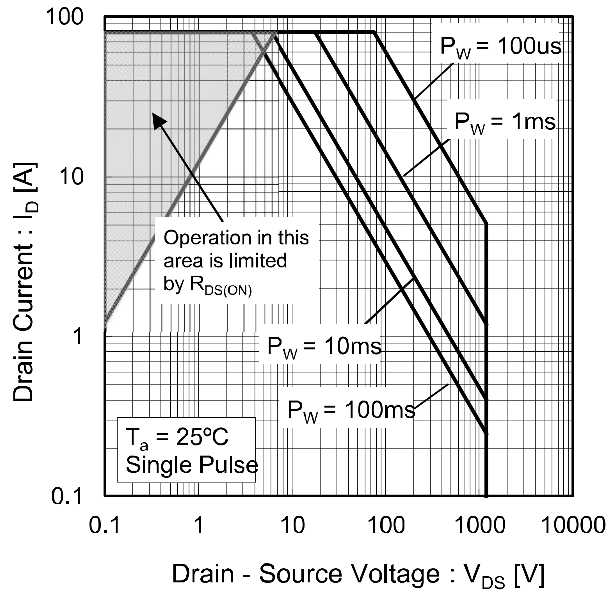
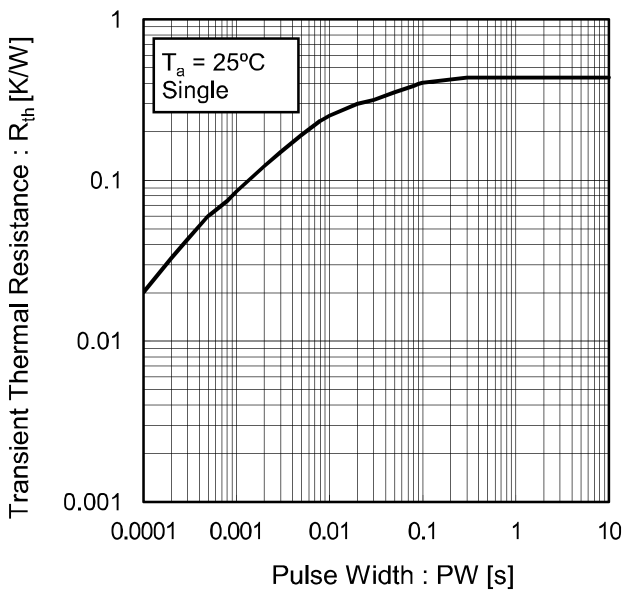


Fig.3 Typical Transient Thermal Resistance vs. Pulse Width



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●Electrical characteristic curves

Fig.4 Typical Output Characteristics(I)

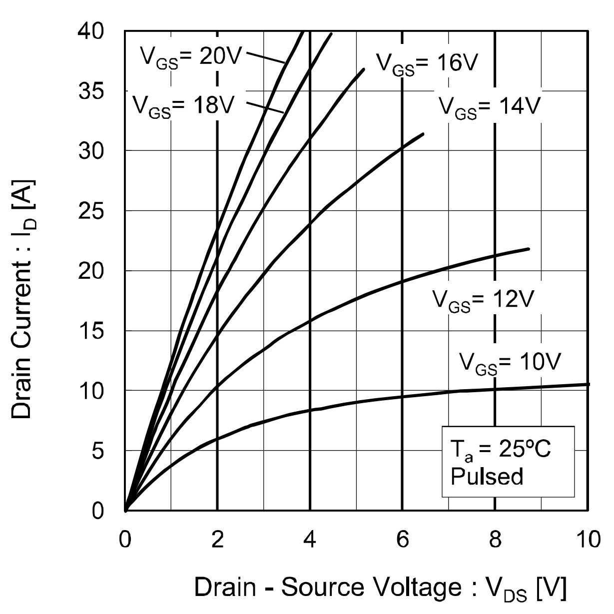


Fig.5 Typical Output Characteristics(II)

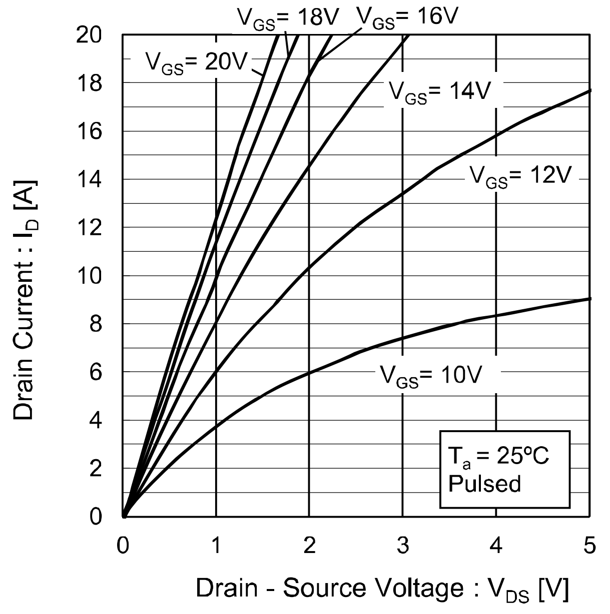


Fig.6 Typical Output Characteristics(I)

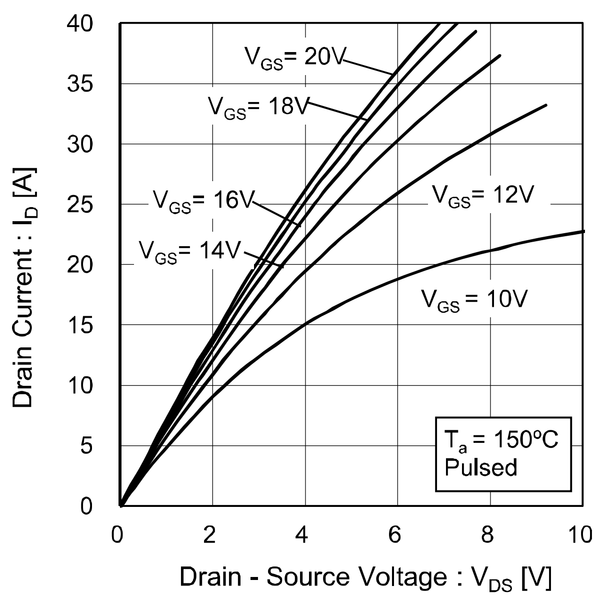
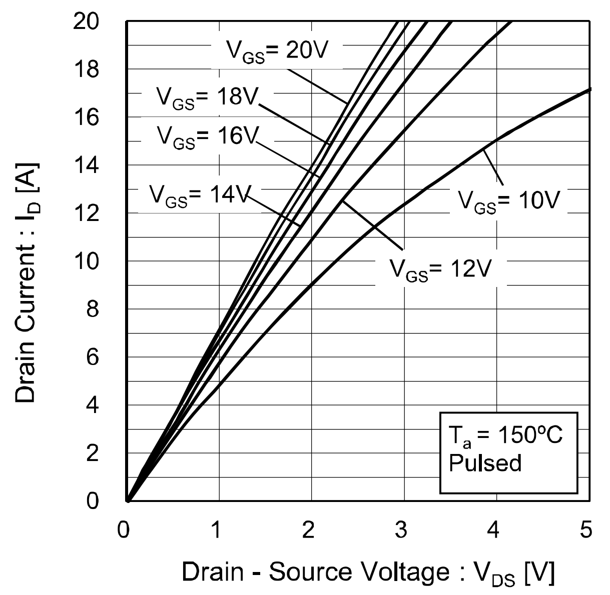


Fig.7 Typical Output Characteristics(II)



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● **Electrical characteristic curves**

Fig.8 Typical Transfer Characteristics

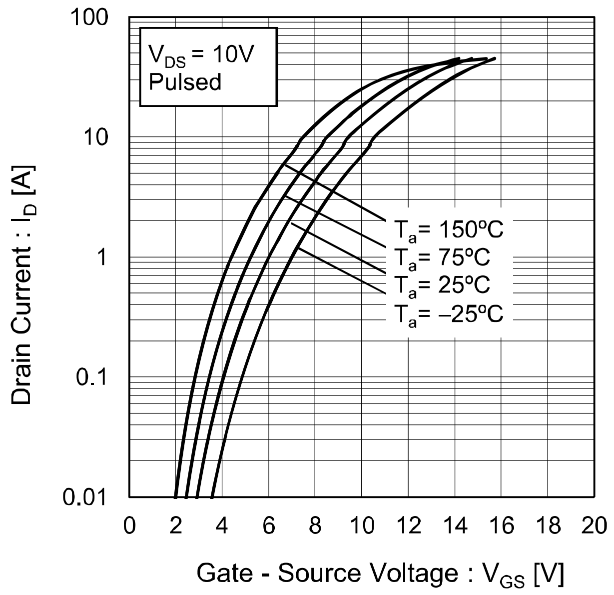


Fig.9 Typical Transfer Characteristics (II)

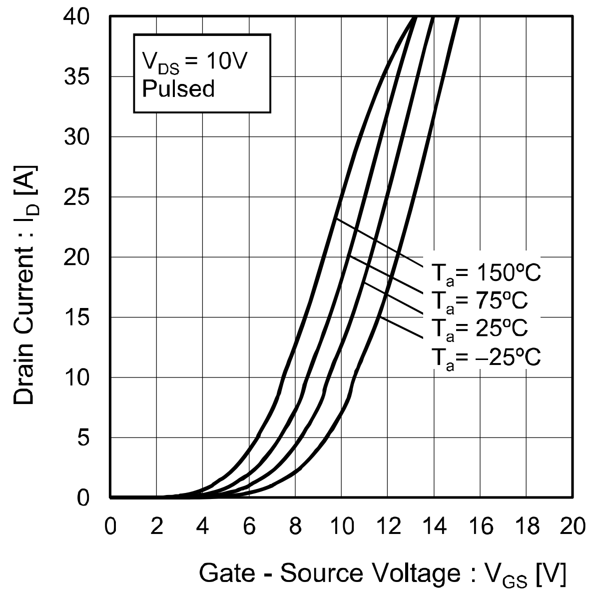


Fig.10 Gate Threshold Voltage vs. Junction Temperature

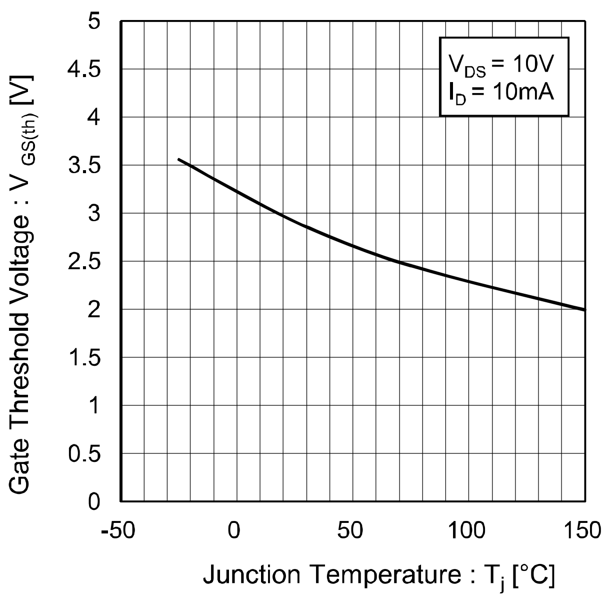
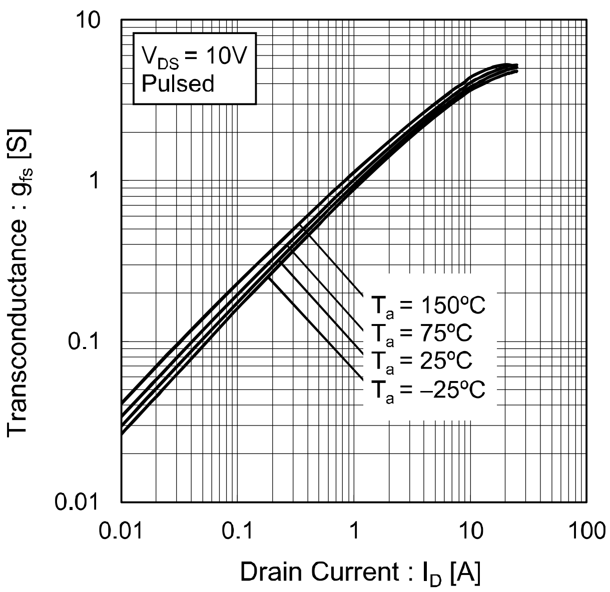


Fig.11 Transconductance vs. Drain Current



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●Electrical characteristic curves

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

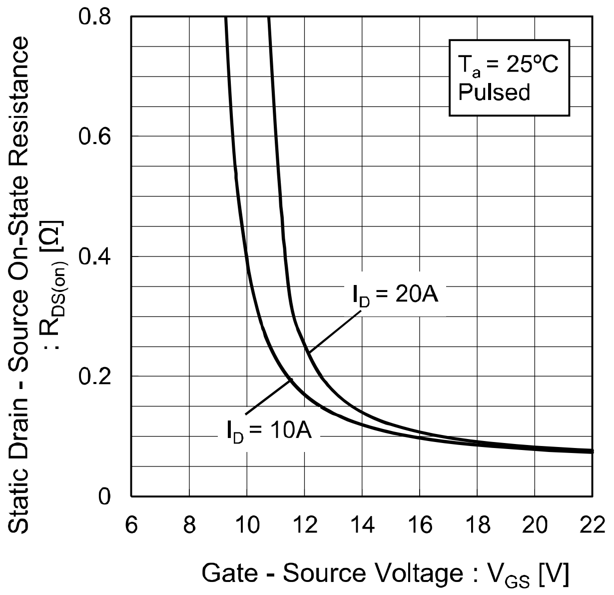


Fig.13 Static Drain - Source On - State Resistance vs. Junction Temperature

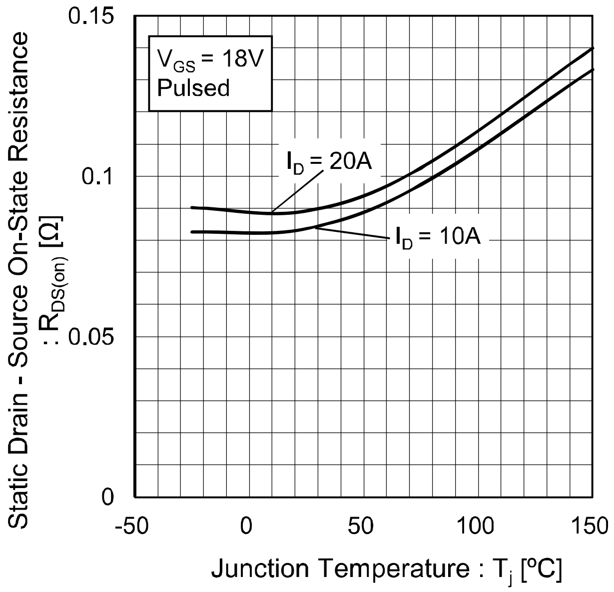
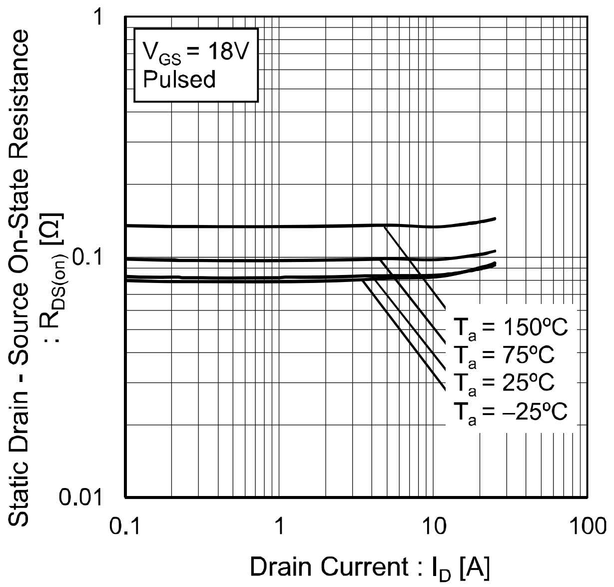


Fig.14 Static Drain - Source On - State Resistance vs. Drain Current



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●Electrical characteristic curves

Fig.15 Typical Capacitance vs. Drain - Source Voltage

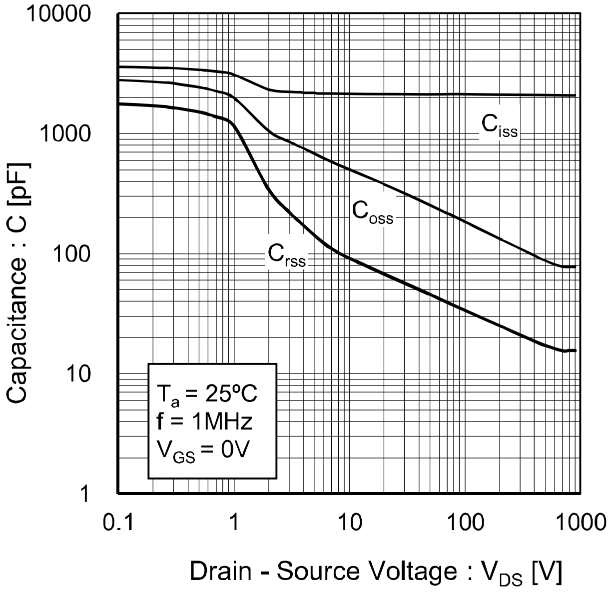


Fig.16 Coss Stored Energy

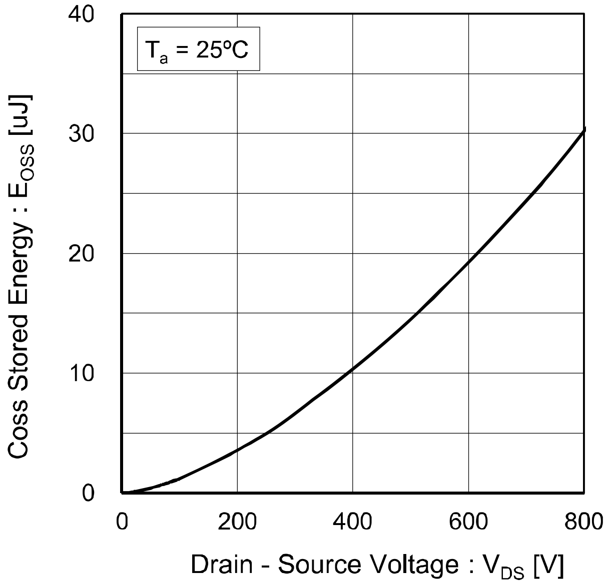


Fig.17 Switching Characteristics

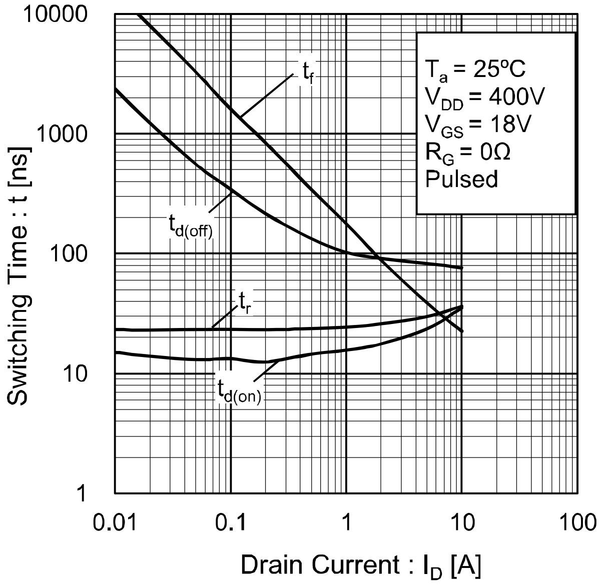
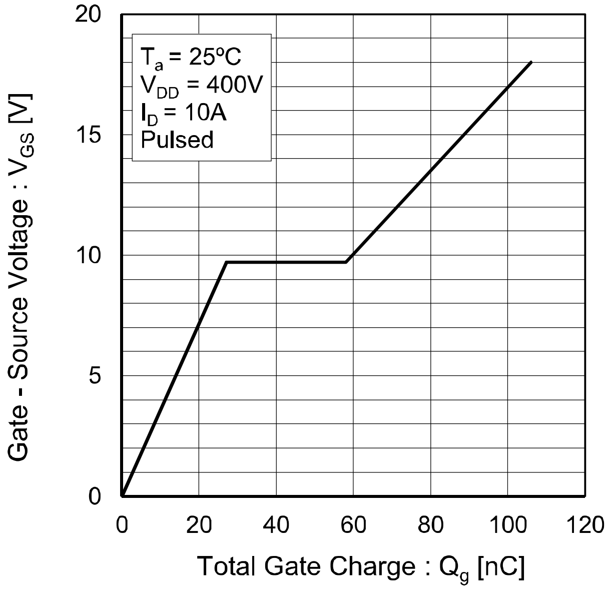


Fig.18 Dynamic Input Characteristics



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● **Electrical characteristic curves**

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

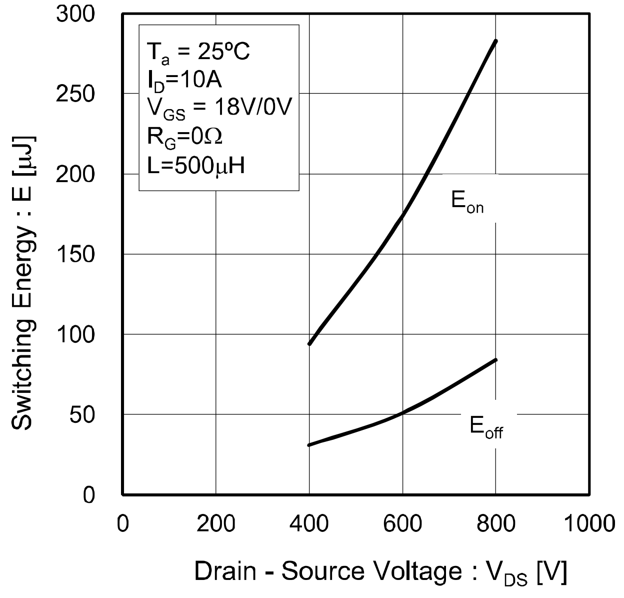


Fig.20 Typical Switching Loss vs. Drain Current

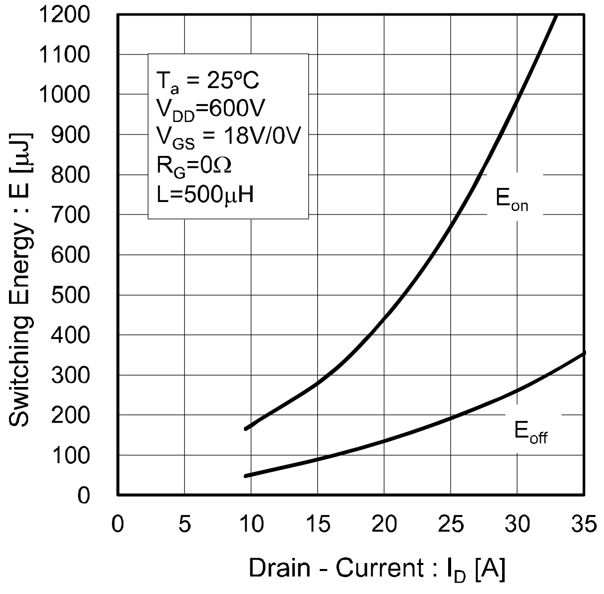
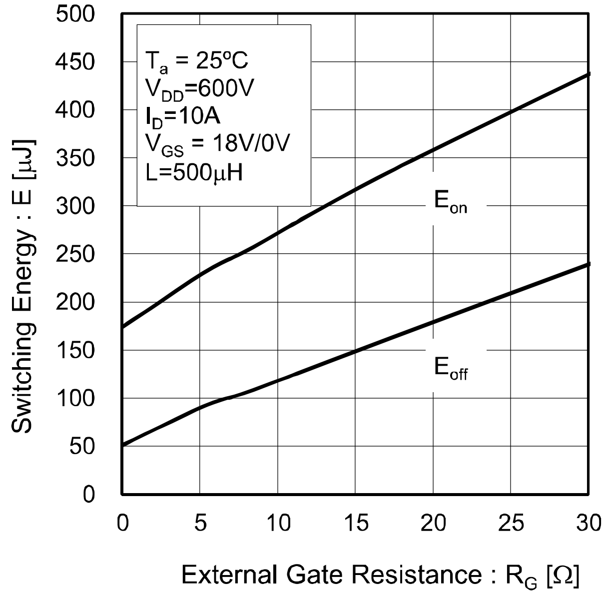


Fig.21 Typical Switching Loss vs. External Gate Resistance



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● **Electrical characteristic curves**

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

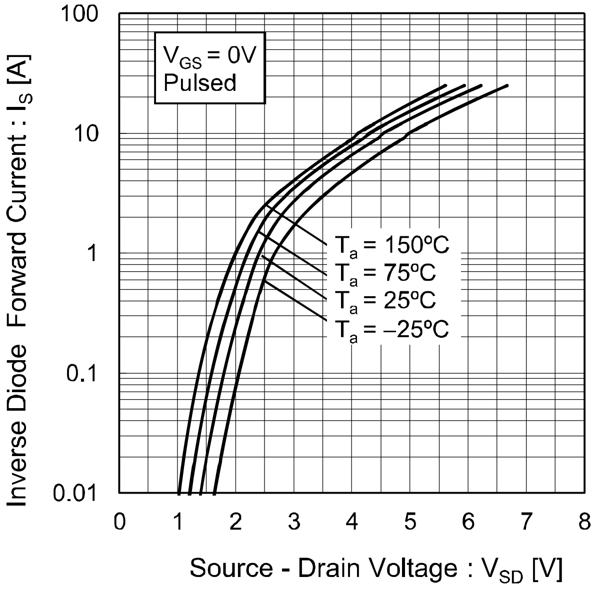
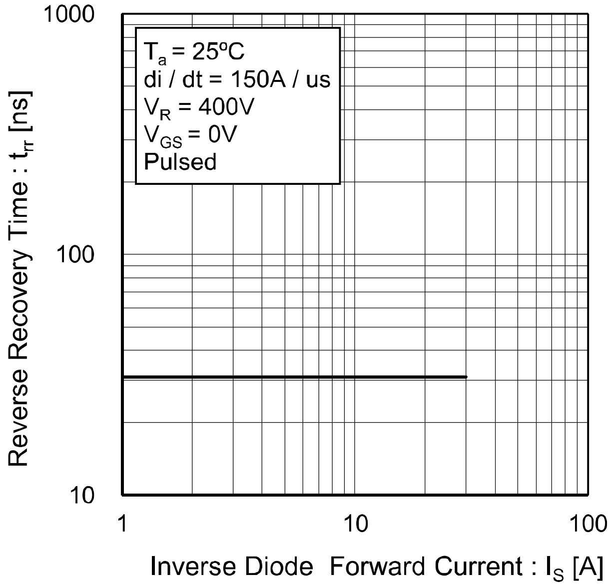


Fig.23 Reverse Recovery Time vs.Inverse Diode Forward Current



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●Measurement circuits

Fig.1-1 Switching Time Measurement Circuit

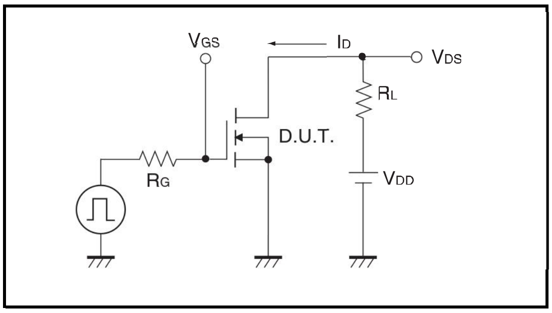


Fig.1-2 Switching Waveforms

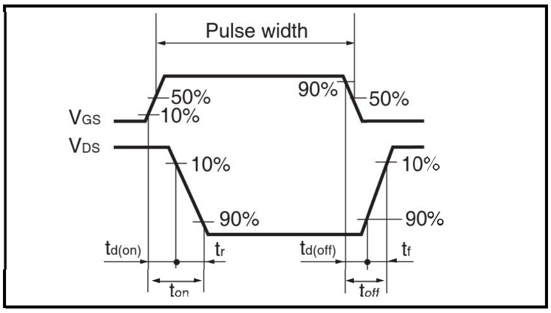


Fig.2-1 Gate Charge Measurement Circuit

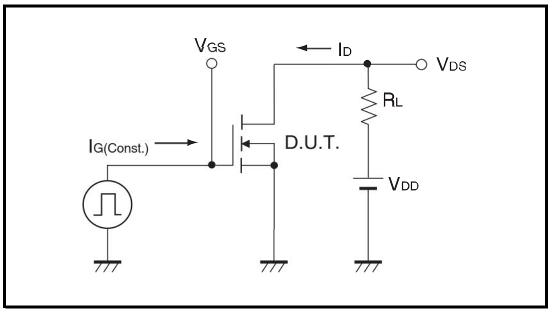


Fig.2-2 Gate Charge Waveform

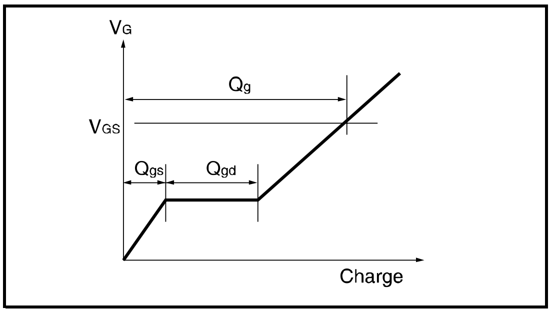


Fig.3-1 Switching Energy Measurement Circuit

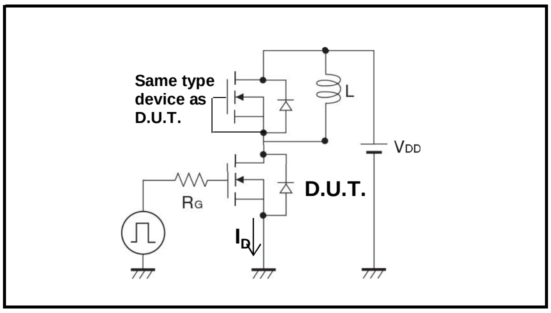


Fig.3-2 Switching Waveforms

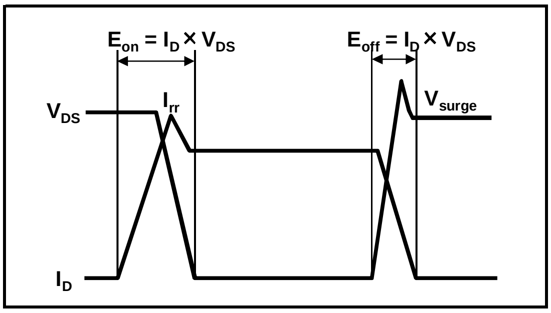


Fig.4-1 Reverse Recovery Time Measurement Circuit

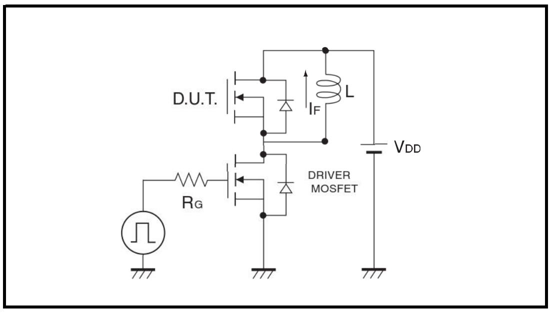
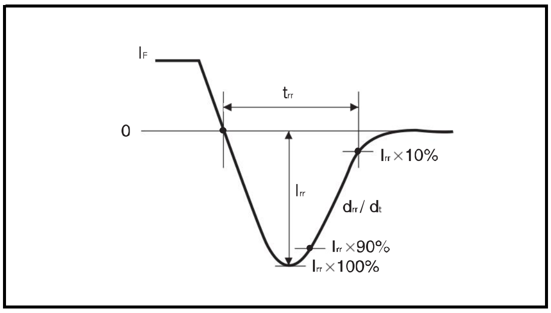


Fig.4-2 Reverse Recovery Waveform



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Tentti 14.12.2017 RATKAISUT

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

Tehtävä 4

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

josta saadaan

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

ja edelleen

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

Kotelon sisällä oletettiin ilman kierron olevan mitättömän. Siten jäähdytyselementin voi olettaa jäähtyvän vain ulkopinnaltaan.

Ulkopinnan pinta-alaksi saadaan

$A = (40\,\mathrm{mm} + 6 \cdot 15\,\mathrm{mm}) \cdot 60\,\mathrm{mm} = 7800\,\mathrm{mm}^2 = 0.78\,\mathrm{dm}^2$

jos elementin ala ja yläpintoja ei huomioida (niiden pinta-ala on $6 \cdot 15\,\mathrm{mm} \cdot 5\,\mathrm{mm} = 450\,\mathrm{mm}^2 = 0.045\,\mathrm{dm}^2$ eli aika pieni. Lisäksi ilma ei niissä välttämättä liiku).

Sijoittamalla arvot kaavaan saadaan komponentin maksimihäviöksi

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

Tehtävä 5

Kun V_{GS} = 18 V, T_{J} = 150 °C ja I_{D} = 25 A saadaan kuvasta 13 arvioiden 25 A virralla

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

Siten johtohäviöenergia per pulssi on

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

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

Kytkentähäviöistä 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

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

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

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_{HTON} = 2,5*130 μJ =325 μJ ja E_{HTOFF} = 2,5’ 70 μJ = 175 μJ eli kohtuu lähellä edellä laskettuja arvoja.

Myös kuvassa 20 annettuja arvoja voi käyttää, mutta nyt jännite on skaalattava kohdalleen
E_{HTON} = 520/600*660 μJ =572 μJ ja E_{HTOFF} = 700/600’ 200 μJ = 233 μJ. 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

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

Siten jäähdytyselementin lämpövastukseksi fetin ja elementin välinen lämpövastus mukaanlukien saadaan

$$R_{\mathrm{th\,CA}} \le \frac{T_J - R_{\mathrm{th\,JC}} P_{\mathrm{H\,ave}} - T_A}{P_{\mathrm{H\,ave}}} = \frac{150\,°\mathrm{C} - 0{,}44\,\frac{°\mathrm{C}}{\mathrm{W}} \cdot 60\,\mathrm{W} - 45\,°\mathrm{C}}{60\,\mathrm{W}} \approx 1{,}31\,\frac{°\mathrm{C}}{\mathrm{W}}$$

Edellä on käytetty varovaisuuden vuoksi 150 $^{\mathrm{o}}$C liitoslämpötilaa, mutta datalehden mukaan nykyinen komponentin versio kestää myös 175 $^{\mathrm{o}}$C.