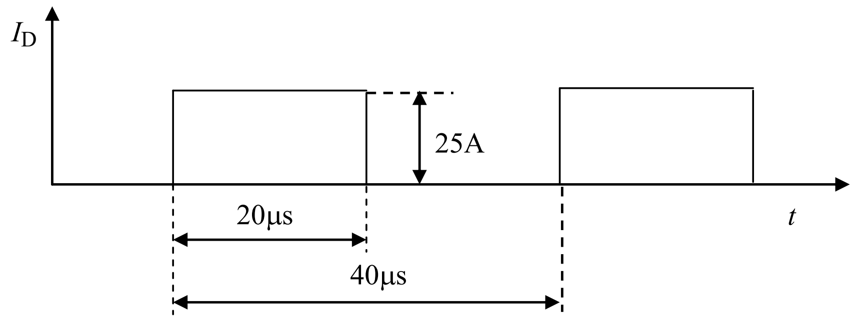
Tentti 12.12.2019

1. Explain shortly (2...4 sentences + possible drawing), what the following terms mean
- Float zone -method
- Thermal impedance
- SOA
- heat-pipe
- double layer capacitor.

2. Compare Si and SiC and GaN as materials for power semiconductor devices.

3. What kind of capacitors are used in power electronics? What are their properties?

4. Calculate the needed thermal resistance of the cooling element for CMF20120D SiC Mosfet, when the current through it is as shown below. Ambient temperature is 45 ˚C and V_{GS} = 20 V when device is on and -2 V when off. Resistance of the gate driver is 6,8 Ω. During turn-on voltage over the device is 600 V and turn-off 800 V.



5. DC current is filtered with an inductor made from two E55/28/21 half creating E55/55/21. Average current is 44 A and peak-to-peak variation 2,2 A. The needed inductance is at leas 14 µH. Calculate the turns number and length of air gap by using the attached graphs and equations given. Also, calculate the maximum flux density $B_{max} = \phi_{max}/A_e$.

CMF20120D-Silicon Carbide Power MOSFET

Z-FET™ MOSFET

N-Channel Enhancement Mode

V_{DS} = 1200 V

$R_{DS(on)}$ = 80 mΩ

$I_{D(MAX)}$@T_c=25°C = 33 A

Features

- Industry Leading $R_{DS(on)}$
- High Speed Switching
- Low Capacitances
- Easy to Parallel
- Simple to Drive
- Pb-Free Plating, RoHS Compliant, Halogen Free

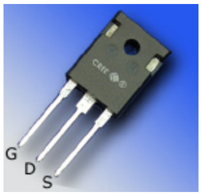
Benefits

- Higher System Efficiency
- Reduced Cooling Requirements
- Avalanche Ruggedness
- Increased System Switching Frequency

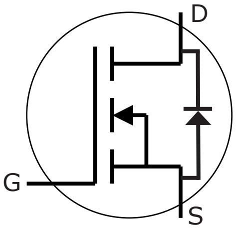
Applications

- Solar Inverters
- High Voltage DC/DC Converters
- Motor Drives

Package



TO-247-3



Part Number	Package
CMF20120D	TO-247-3

Maximum Ratings

Symbol	Parameter	Value	Unit	Test Conditions	Note
I_D	Continuous Drain Current	33	A	V_{GS}@20V, T_C = 25°C	
		17		V_{GS}@20V, T_C = 100°C	
I_{Dpulse}	Pulsed Drain Current	78	A	Pulse width t_P limited by T_{jmax} T_C = 25°C	
E_{AS}	Single Pulse Avalanche Energy	2.2	J	I_D = 20A, V_{DD} = 50 V, L = 9.5 mH	
E_{AR}	Repetitive Avalanche Energy	1.5	J	t_{AR} limited by T_{jmax}	
I_{AR}	Repetitive Avalanche Current	20	A	I_D = 20A, V_{DD} = 50 V, L = 3 mH t_{AR} limited by T_{jmax}	
V_{GS}	Gate Source Voltage	-5/+25	V		
P_{tot}	Power Dissipation	150	W	T_C=25°C	
T_J , T_{stg}	Operating Junction and Storage Temperature	-55 to +125	°C		
T_L	Solder Temperature	260	°C	1.6mm (0.063”) from case for 10s	
M_d	Mounting Torque	1 8.8	Nm lbf-in	M3 or 6-32 screw	

Electrical Characteristics

Symbol	Parameter	Min.	Typ.	Max.	Unit	Test Conditions	Note
$V_{(BR)DSS}$	Drain-Source Breakdown Voltage	1200			V	V_{GS} = 0V, I_D = 100μA	
$V_{GS(th)}$	Gate Threshold Voltage		2.5	4	V	V_{DS} = V_{GS}, I_D = 1mA, T_J = 25ºC	1
			1.8			V_{DS} = V_{GS}, I_D = 1mA, T_J = 125ºC	
I_{DSS}	Zero Gate Voltage Drain Current		1	100	μA	V_{DS} = 1200V, V_{GS} = 0V, T_J = 25ºC	
			10	250		V_{DS} = 1200V, V_{GS} = 0V, T_J = 125ºC	
I_{GSS}	Gate-Source Leakage Current			250	nA	V_{GS} = 20V, V_{DS} = 0V	
$R_{DS(on)}$	Drain-Source On-State Resistance		80	110	mΩ	V_{GS} = 20V, I_D = 20A, T_J = 25ºC	
			95	130		V_{GS} = 20V, I_D = 20A, T_J = 125ºC	
g_{fs}	Transconductance		7.3		S	V_{DS}= 20V, I_{DS}= 20A, T_J = 25ºC	fig. 3
			6.8			V_{DS}= 20V, I_{DS}= 20A, T_J = 125ºC	
C_{iss}	Input Capacitance		1915		pF	V_{GS} = 0V V_{DS} = 800V f = 1MHz V_{AC} = 25mV	fig. 5
C_{oss}	Output Capacitance		120				
C_{rss}	Reverse Transfer Capacitance		13				
$t_{d(on)i}$	Turn-On Delay Time		17.2		ns	V_{DD} = 800V V_{GS} = -2/20V I_D = 20A R_G = 6.8Ω L = 856μH Per JEDEC24 Page 27	fig. 12
t_r	Rise Time		13.6				
$t_{d(off)i}$	Turn-Off Delay Time		62				
t_{fi}	Fall Time		35.6				
E_{ON}	Turn-On Switching Loss (25ºC) (125ºC)		530 422		μJ		
E_{Off}	Turn-Off Switching Loss (25ºC) (125ºC)		320 329		μJ		
R_G	Internal Gate Resistance		5		Ω	V_{GS} = 0V, f = 1MHz, V_{AC} = 25mV	

NOTES: 1. The recommended on-state V_{GS} is +20V and the recommended off-state V_{GS} is between -2V and -5V

Reverse Diode Characteristics

Symbol	Parameter	Typ.	Max.	Unit	Test Conditions	Note
V_{sd}	Diode Forward Voltage	3.5		V	V_{GS} = -5V, I_F=10A, T_J = 25ºC	
		3.1			V_{GS} = -2V, I_F=10A, T_J = 25ºC	
t_{rr}	Reverse Recovery Time	220		ns	V_{GS} = -5V, I_F=20A, T_J = 25ºC V_R = 800V, di_F/dt= 100A/μs	fig. 13,14
Q_{rr}	Reverse Recovery Charge	142		nC		
I_{rrm}	Peak Reverse Recovery Current	2.3		A		

Thermal Characteristics

Symbol	Parameter	Typ.	Max.	Unit	Test Conditions	Note
$R_{\theta JC}$	Thermal Resistance from Junction to Case	0.58	0.7	°C/W		fig. 6
$R_{\theta CS}$	Case to Sink, w/ Thermal Compound	0.25				
$R_{\theta JA}$	Thermal Resistance From Junction to Ambient		40			

Gate Charge Characteristics

Symbol	Parameter	Typ.	Max.	Unit	Test Conditions	Note
Q_{gs}	Gate to Source Charge	23.8		nC	V_{DD} = 800V I_D =20A V_{GS} = -2/20V Per JEDEC24-2	fig.9
Q_{gd}	Gate to Drain Charge	43.1				
Q_g	Gate Charge Total	90.8				

Typical Performance

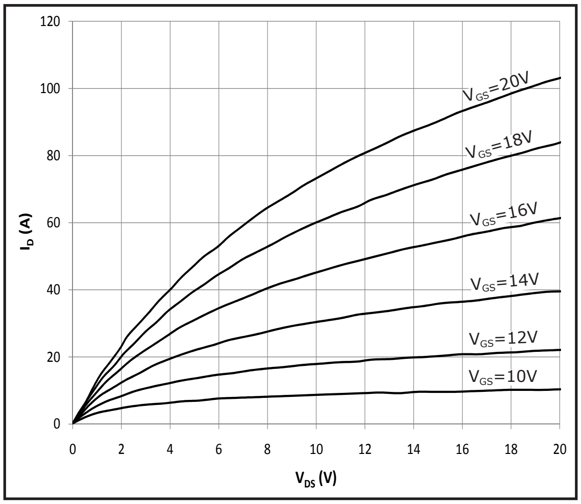


Fig 1. Typical Output Characteristics T_J = 25ºC

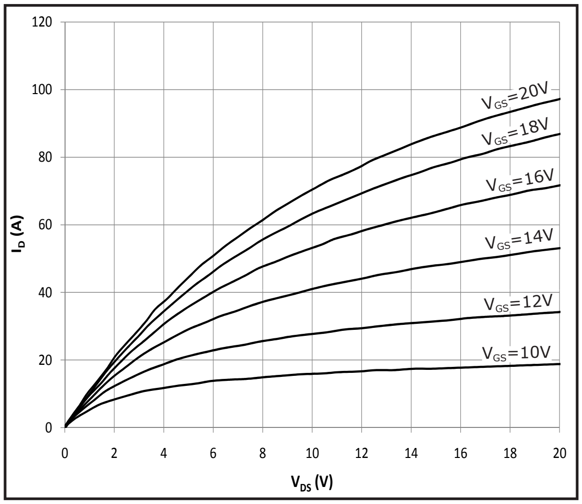


Fig 2. Typical Output Characteristics T_J = 125ºC

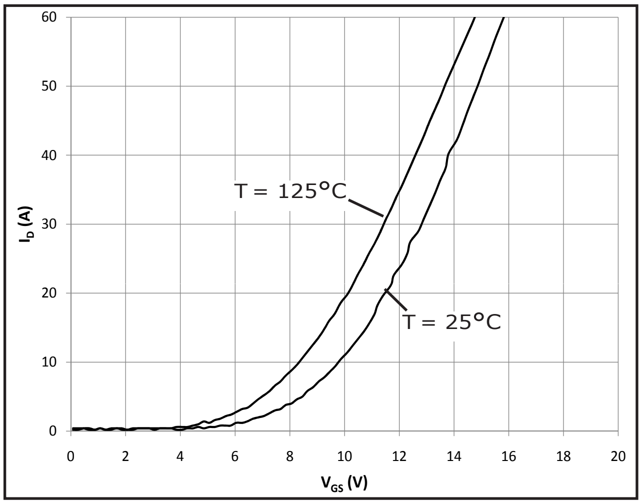


Figure 3. Typical Transfer Characteristics

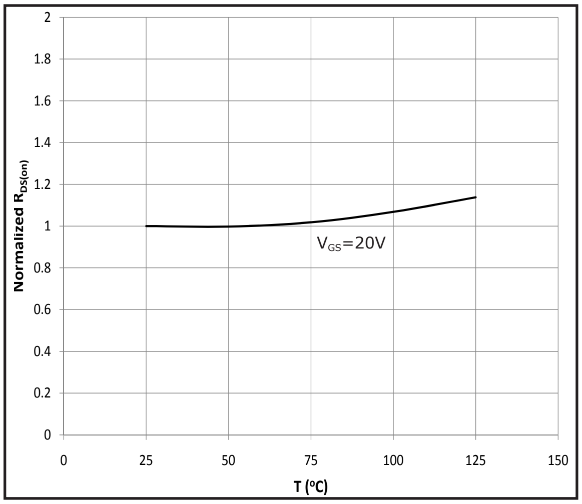


Fig 4. Normalized On-Resistance vs. Temperature

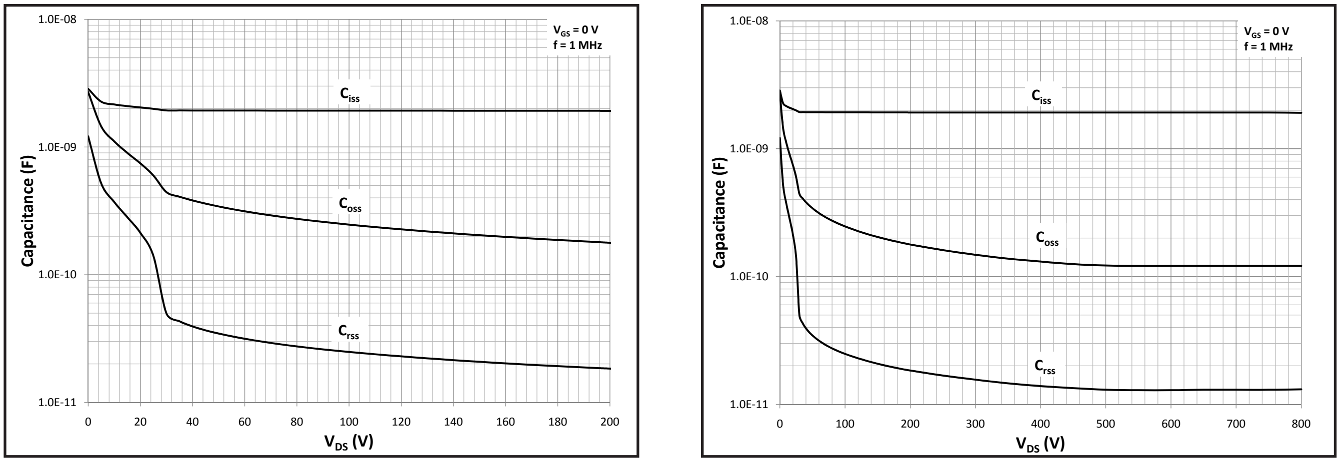


Fig 5A and 5B. Typical Capacitance vs. Drain – Source Voltage

Typical Performance

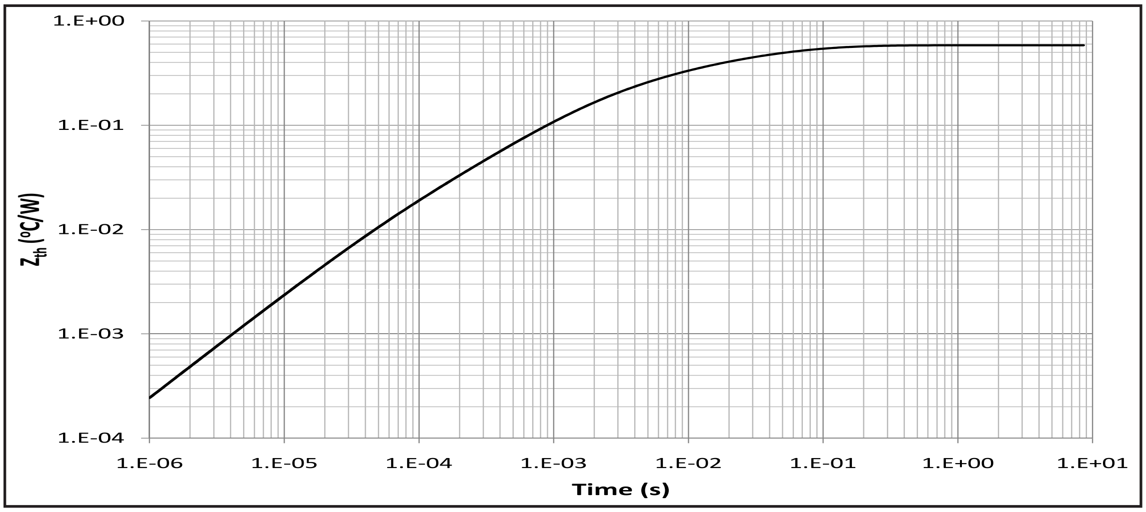


Fig 6. Transient Thermal Impedence, Junction - Case

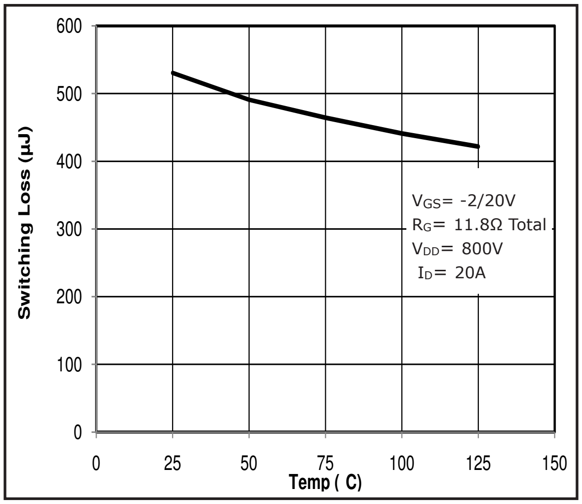


Fig 7. Inductive Switching Energy(Turn-on) vs. T

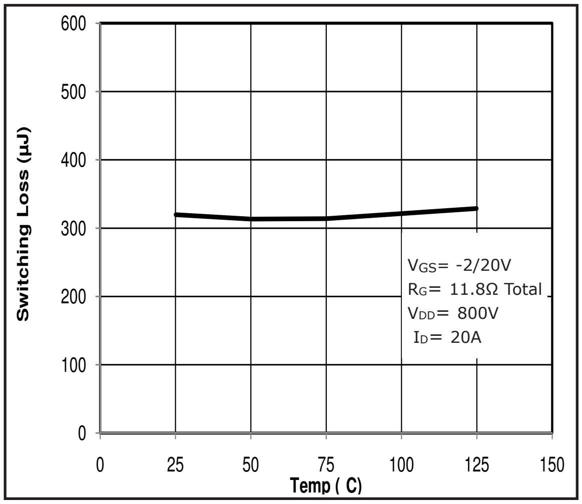


Fig 8. Inductive Switching Energy(Turn-off) vs. T

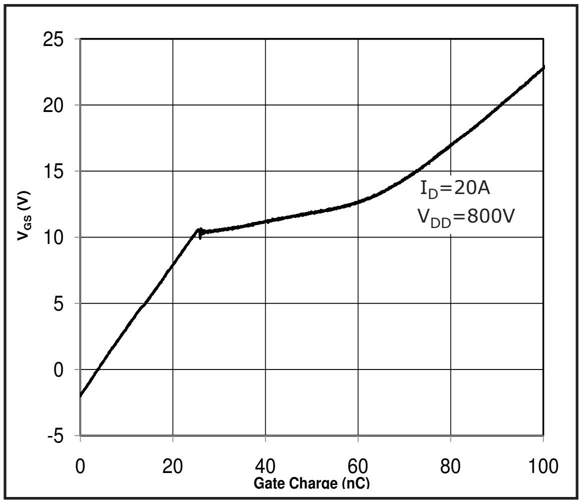


Fig 9. Typical Gate Charge Characteristics @ 25°C

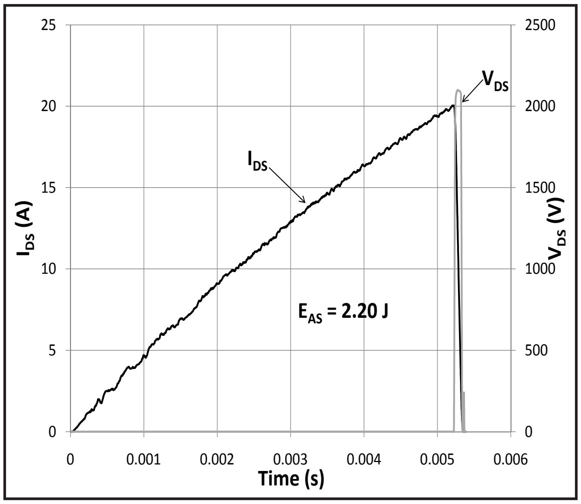


Fig 10. Typical Avalanche Waveform

Clamped Inductive Switch Testing Fixture

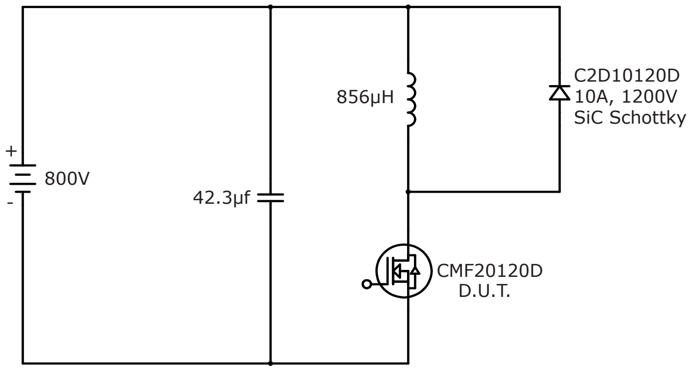


Fig 11. Switching Waveform Test Circuit

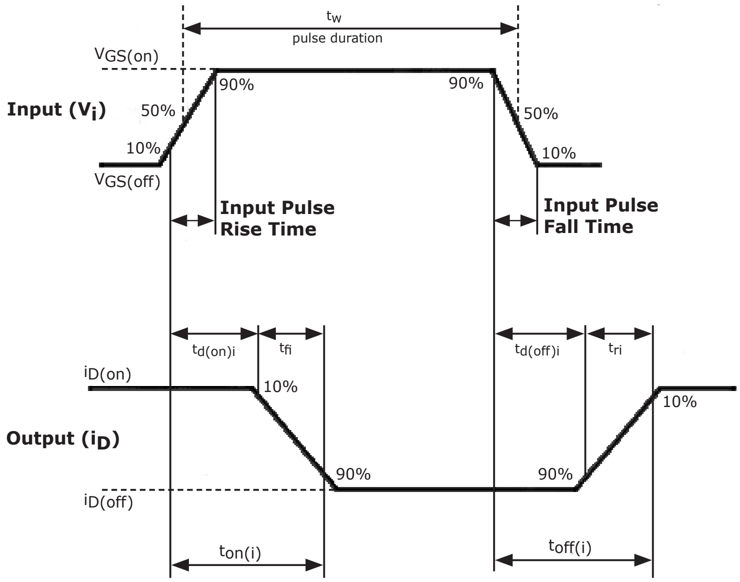


Fig 12. Switching Test Waveform Times

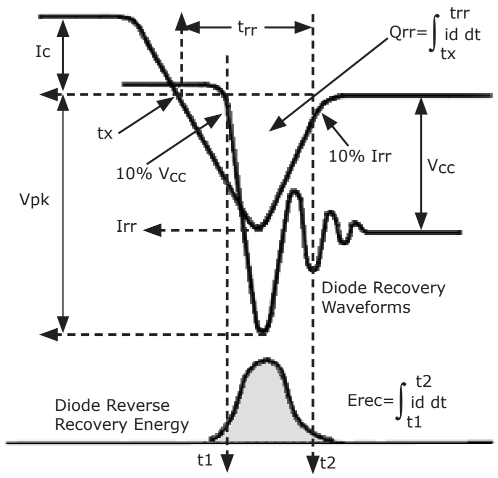


Fig 13. Body Diode Recovery Waveform

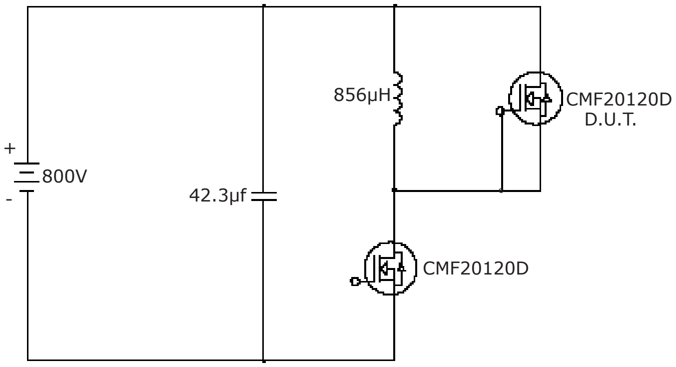


Fig 14. Body Diode Recovery Test

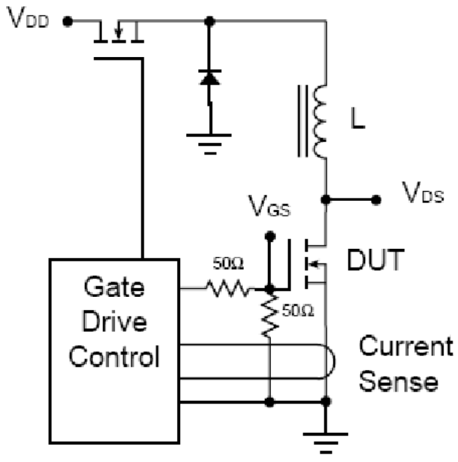
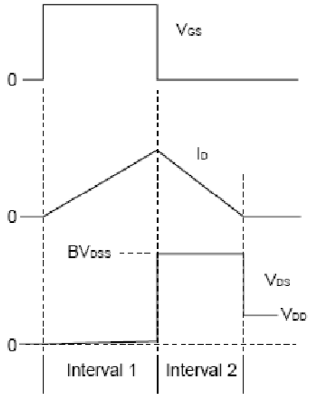


Fig 15. Avalanche Test Circuit

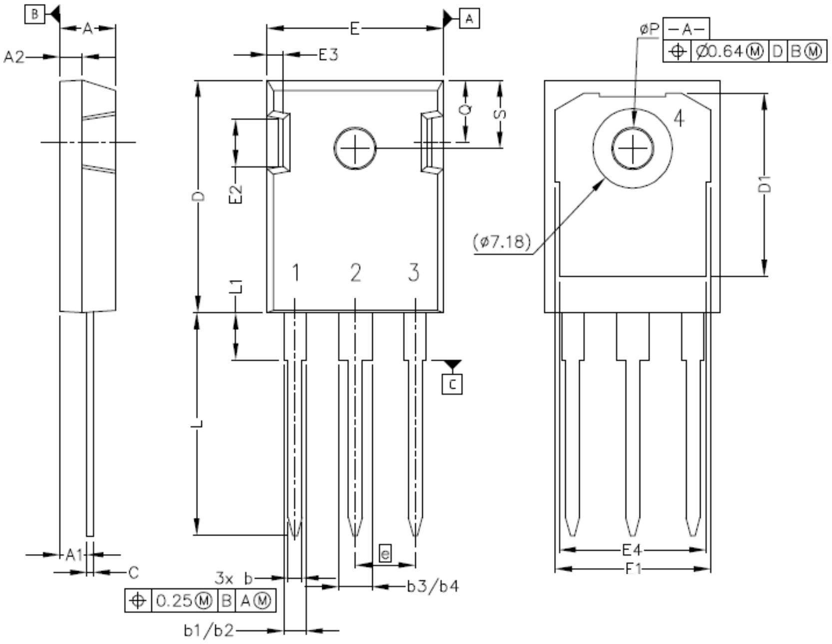


$$E_A = 1/2L \ x\ I_D^2$$

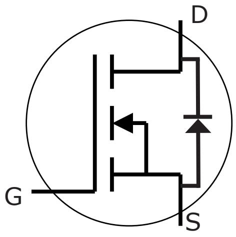
Fig 16. Theoretical Avalanche Waveform

Package Dimensions

Package TO-247-3



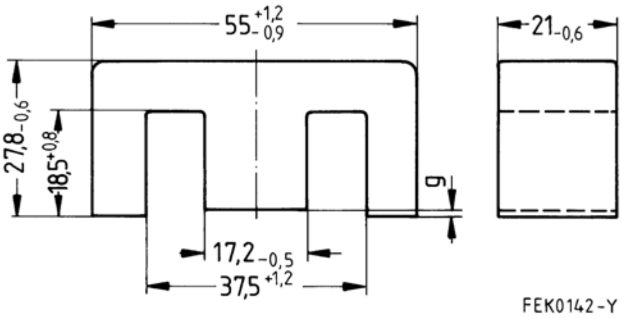
POS	Inches		Millimeters	
	Min	Max	Min	Max
A	.190	.205	4.83	5.21
A1	.090	.100	2.29	2.54
A2	.075	.085	1.91	2.16
b	.042	.052	1.07	1.33
b1	.075	.095	1.91	2.41
b2	.075	.085	1.91	2.16
b3	.113	.133	2.87	3.38
b4	.113	.123	2.87	3.13
c	.022	.027	0.55	0.68
D	.819	.831	20.80	21.10
D1	.640	.695	16.25	17.65
D2	.037	.049	0.95	1.25
E	.620	.635	15.75	16.13
E1	.516	.557	13.10	14.15
E2	.145	.201	3.68	5.10
E3	.039	.075	1.00	1.90
E4	.487	.529	12.38	13.43
e	.214 BSC		5.44 BSC	
N	3		3	
L	.780	.800	19.81	20.32
L1	.161	.173	4.10	4.40
ØP	.138	.144	3.51	3.65
Q	.216	.236	5.49	6.00
S	.238	.248	6.04	6.30



E 55/28/21

Core **B66335**

- To IEC 61246
- Delivery mode: single units



Magnetic characteristics (per set)

$\Sigma l/A = 0.35\ \text{mm}^{-1}$
$l_e = 124\ \text{mm}$
$A_e = 354\ \text{mm}^2$
$A_{min} = 351\ \text{mm}^2$
$V_e = 43900\ \text{mm}^3$

Approx. weight 215 g/set

Ungapped

Mate-rial	A_L value nH	μ_e	B_S* mT	P_V W/set	Ordering code
N27	5800 +30/–20%	1610	320	< 8.00 (200 mT, 25 kHz, 100 °C)	B66335G0000X127
N87	6400 +30/–20%	1780	320	< 3.80 (100 mT, 100 kHz, 100 °C)	B66335G0000X187
N97	6700 +30/–20%	1868	320	< 3.34 (100 mT, 100 kHz, 100 °C)	B66335G0000X197

* H = 250 A/m; f = 10 kHz; T = 100 °C

Gapped

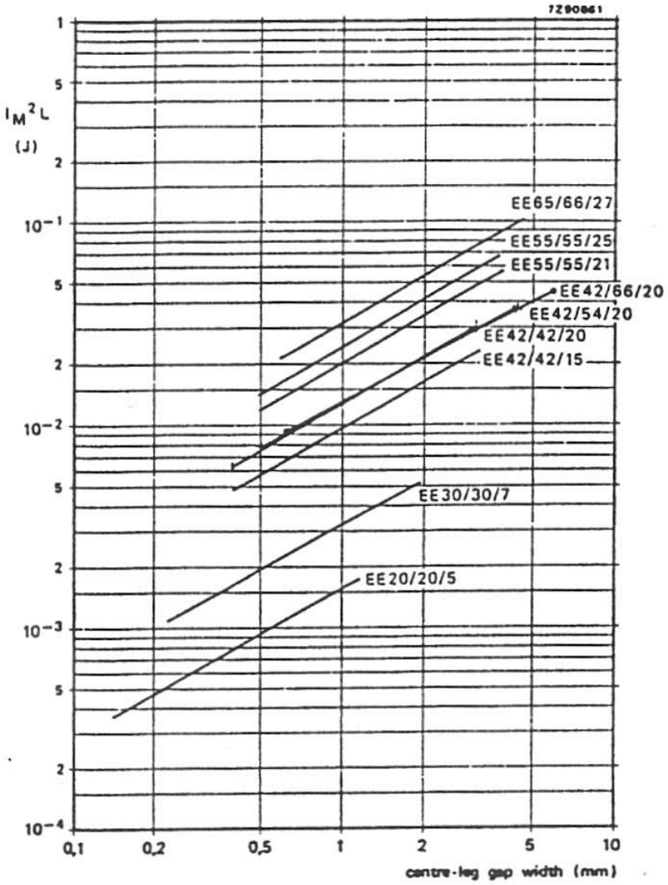
Material	g mm	A_L value approx. nH	μ_e	Ordering code ** = 27 (N27) = 87 (N87)
N27, N87	0.50 ±0.05	843	234	B66335G0500X1**
	1.00 ±0.05	496	138	B66335G1000X1**
	1.50 ±0.05	364	101	B66335G1500X1**
	2.00 ±0.05	292	81	B66335G2000X1**

The A_L value in the table applies to a core set comprising one ungapped core (dimension g = 0) and one gapped core (dimension g > 0).

Calculation factors (for formulas, see *"E cores: general information"*)

Material	Relationship between air gap – A_L value		Calculation of saturation current			
	K1 (25 °C)	K2 (25 °C)	K3 (25 °C)	K4 (25 °C)	K3 (100 °C)	K4 (100 °C)
N27	496	–0.764	836	–0.847	781	–0.865
N87	496	–0.764	800	–0.796	765	–0.873

Validity range: K1, K2: 0.15 mm < s < 3.50 mm
K3, K4: 180 nH < A_L < 1799 nH



Kuva 11.8. Eräs kuristinsydänten valintakäyrästö /11/.

tarvitaan, jottei sydän kyllästyisi. Itse asiassa suurin osa kuristimen varastoimasta energiasta on varastoitunut juuri ilmarakoon. Kuristimen magneettinen sydän toimii lähinnä vuon ohjaajana, jolloin haitallinen hajavuo ympäristössä pienenee. Ilmaväli vaikuttaa luonnollisestikin kierrosmäärään, joka tarvitaan tietyn induktanssin aikaansaamiseksi. Mitä enemmän ilmarakoa, sitä enemmän kierroksia. Teoreettisemmin

$$L = \frac{N\,\phi}{I} \tag{11.18}$$

$$\phi = \frac{\mu_0 NI}{\frac{l_g}{A_g} + \sum \frac{l_m}{\mu A_m}} \approx \frac{\mu_0 NI}{\frac{l_g}{A_g} + \frac{l_e - l_g}{\mu A_e}} \approx \frac{\mu_0 NI}{\frac{l_g}{A_g} + \frac{C_1}{\mu}} \tag{11.19}$$

$$L \approx \frac{\mu_0 N^2}{\frac{l_g}{A_g} + \frac{C_1}{\mu}} = \frac{\mu_0 \mu_e N^2 A_e}{l_e} = A_L N^2 \tag{11.20}$$

jossa l_g ja A_g ovat ilmavälin pituus ja pinta-ala sekä l_e ja A_e ovat efektiivinen magneettipiirin pituus ja pinta-ala. μ_0 on tyhjön (= $4\pi\ 10^{-7}$ H/m) ja μ_e ilmavälin sisältävän sydämen efektiivinen permeabiliteetti ja C_1 on sydänvakio. A_L on induktanssikerroin sydämelle tällä ilmavälillä.

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Z-FET™ MOSFET

N-Channel Enhancement Mode

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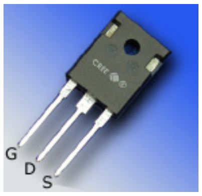
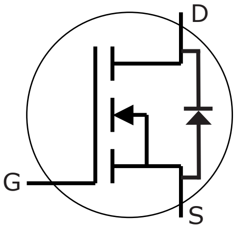


TO-247-3



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CMF20120D	TO-247-3

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I_{AR}	Repetitive Avalanche Current	20	A	I_D = 20A, V_{DD} = 50 V, L = 3 mH t_{AR} limited by T_{jmax}	
V_{GS}	Gate Source Voltage	-5/+25	V		
P_{tot}	Power Dissipation	150	W	T_C=25˚C	
T_J , T_{stg}	Operating Junction and Storage Temperature	-55 to +125	˚C		
T_L	Solder Temperature	260	˚C	1.6mm (0.063”) from case for 10s	
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I_{DSS}	Zero Gate Voltage Drain Current		1	100	μA	V_{DS} = 1200V, V_{GS} = 0V, T_J = 25ºC	
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$R_{DS(on)}$	Drain-Source On-State Resistance		80	110	mΩ	V_{GS} = 20V, I_D = 20A, T_J = 25ºC	
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NOTES: 1. The recommended on-state V_{GS} is +20V and the recommended off-state V_{GS} is between -2V and -5V

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V_{sd}	Diode Forward Voltage	3.5		V	V_{GS} = -5V, I_F=10A, T_J = 25ºC	
		3.1			V_{GS} = -2V, I_F=10A, T_J = 25ºC	
t_{rr}	Reverse Recovery Time	220		ns	V_{GS} = -5V, I_F=20A, T_J = 25ºC V_R = 800V, di_F/dt= 100A/μs	fig. 13,14
Q_{rr}	Reverse Recovery Charge	142		nC		
I_{rrm}	Peak Reverse Recovery Current	2.3		A		

Thermal Characteristics

Symbol	Parameter	Typ.	Max.	Unit	Test Conditions	Note
$R_{\theta JC}$	Thermal Resistance from Junction to Case	0.58	0.7	°C/W		fig. 6
$R_{\theta CS}$	Case to Sink, w/ Thermal Compound	0.25				
$R_{\theta JA}$	Thermal Resistance From Junction to Ambient		40			

Gate Charge Characteristics

Symbol	Parameter	Typ.	Max.	Unit	Test Conditions	Note
Q_{gs}	Gate to Source Charge	23.8		nC	V_{DD} = 800V I_D =20A V_{GS} = -2/20V Per JEDEC24-2	fig.9
Q_{gd}	Gate to Drain Charge	43.1				
Q_g	Gate Charge Total	90.8				

Typical Performance

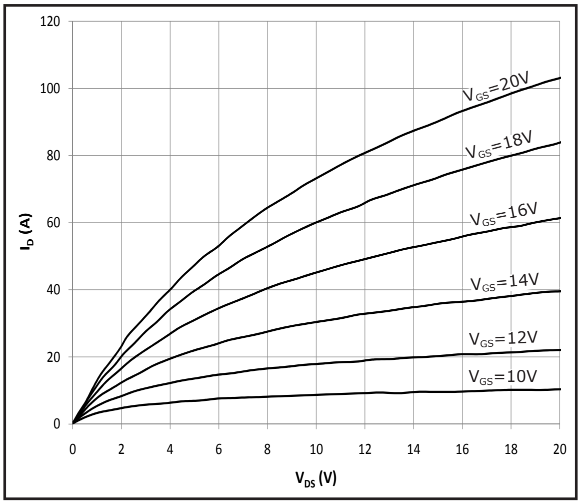


Fig 1. Typical Output Characteristics T_J = 25ºC

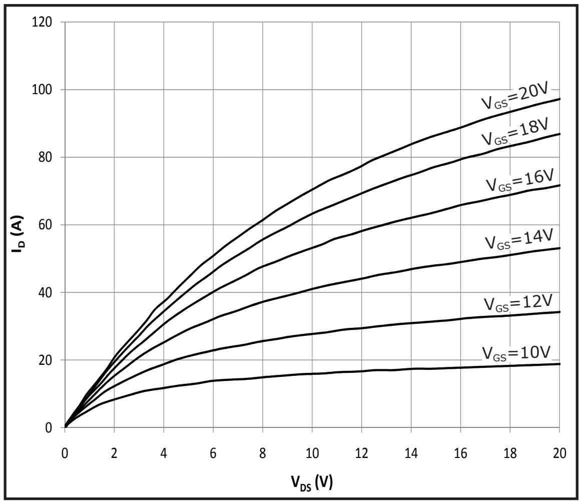


Fig 2. Typical Output Characteristics T_J = 125ºC

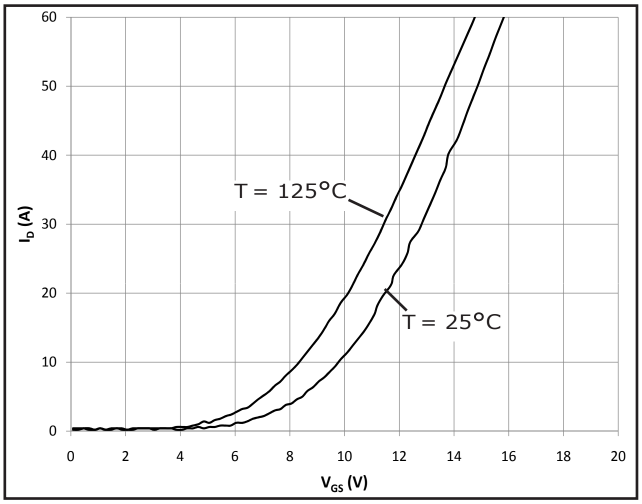


Figure 3. Typical Transfer Characteristics

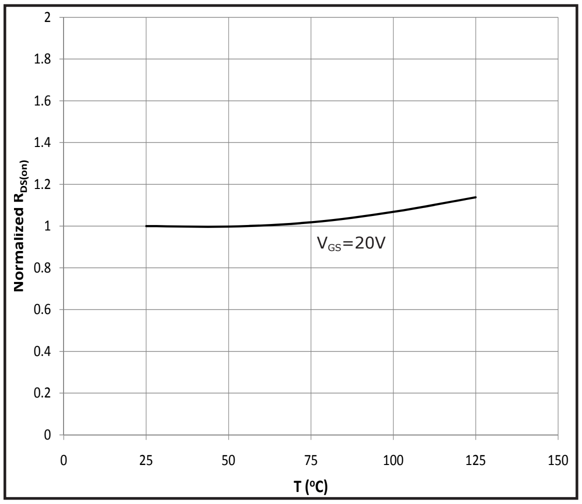


Fig 4. Normalized On-Resistance vs. Temperature

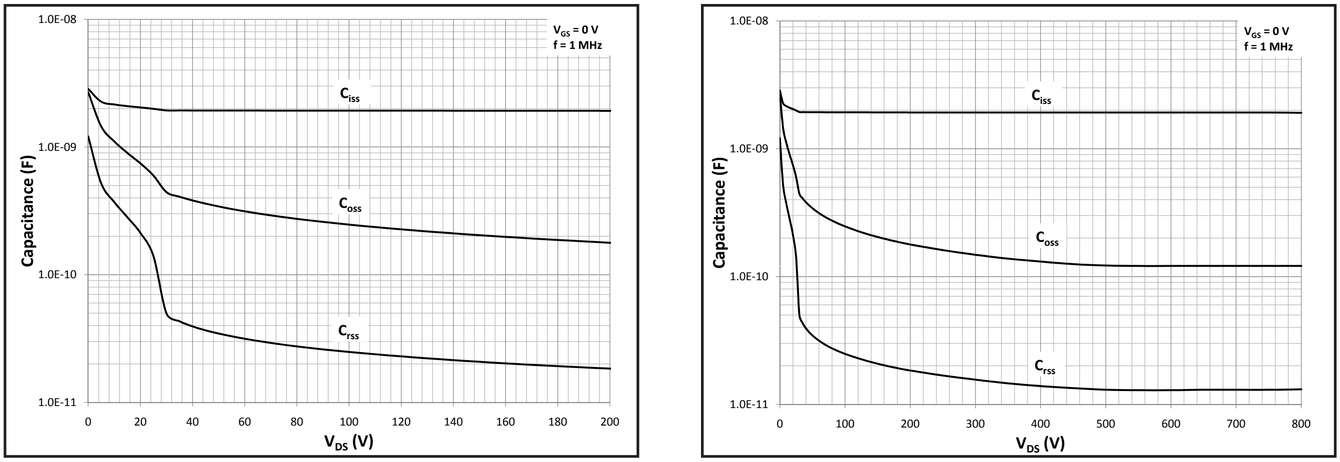


Fig 5A and 5B. Typical Capacitance vs. Drain – Source Voltage

Typical Performance

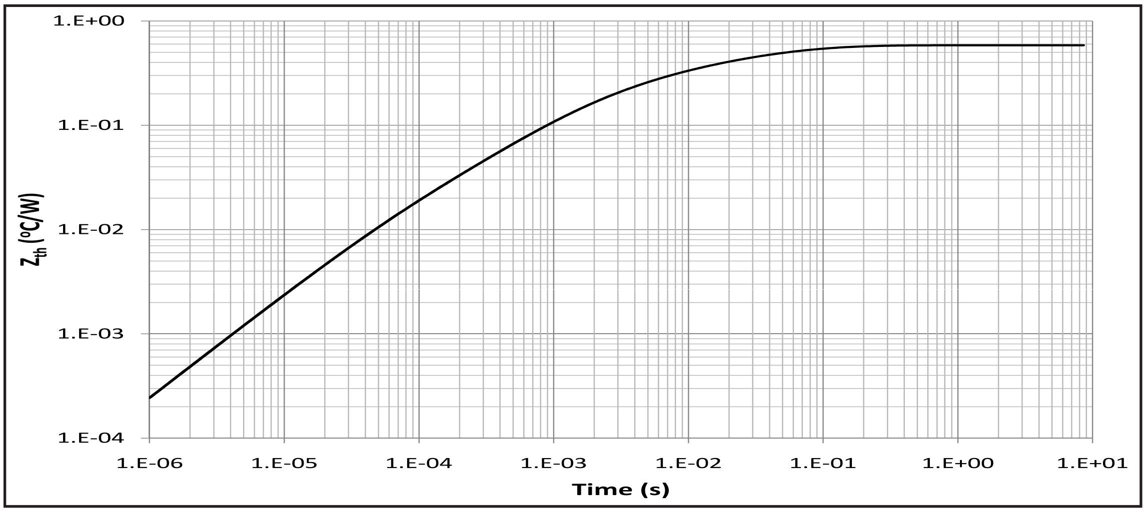


Fig 6. Transient Thermal Impedence, Junction - Case

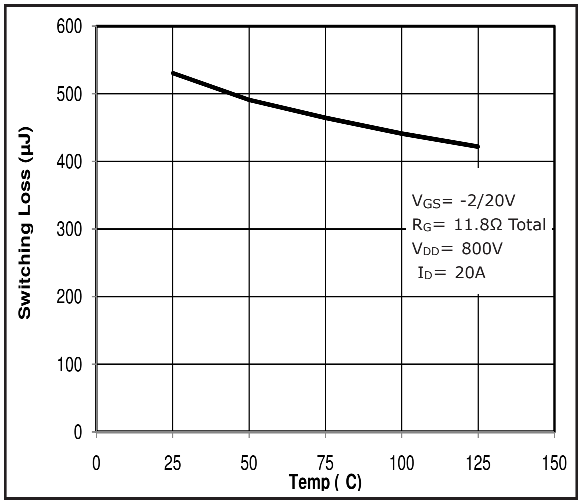


Fig 7. Inductive Switching Energy(Turn-on) vs. T

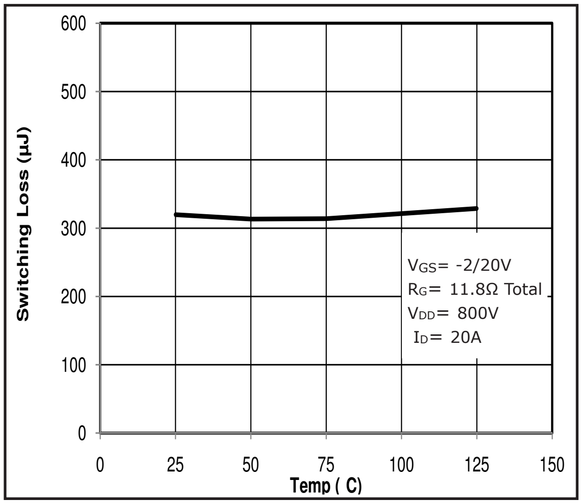


Fig 8. Inductive Switching Energy(Turn-off) vs. T

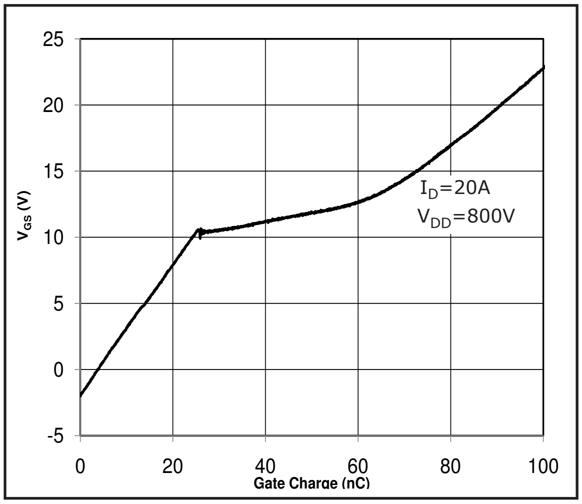


Fig 9. Typical Gate Charge Characteristics @ 25°C

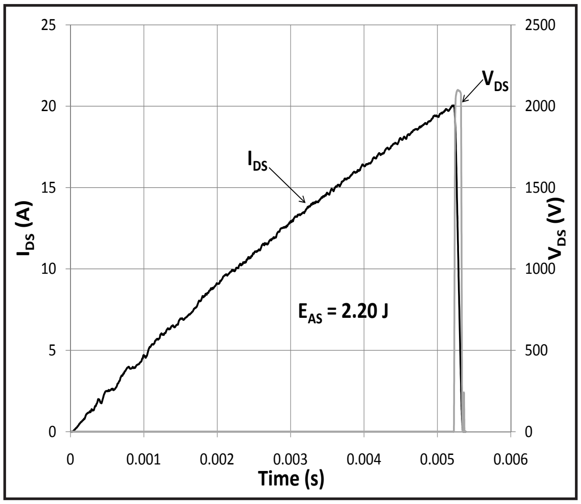


Fig 10. Typical Avalanche Waveform

Clamped Inductive Switch Testing Fixture

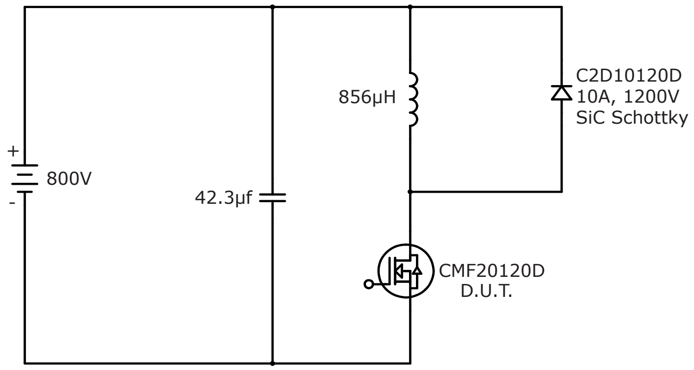


Fig 11. Switching Waveform Test Circuit

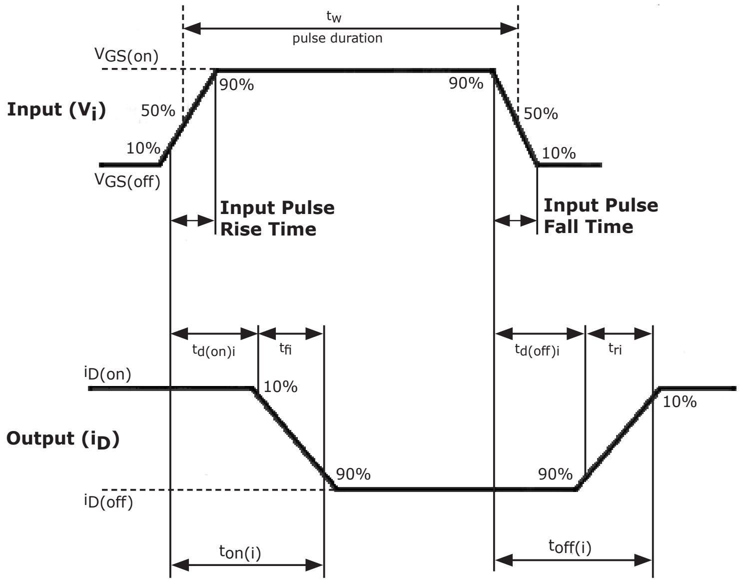


Fig 12. Switching Test Waveform Times

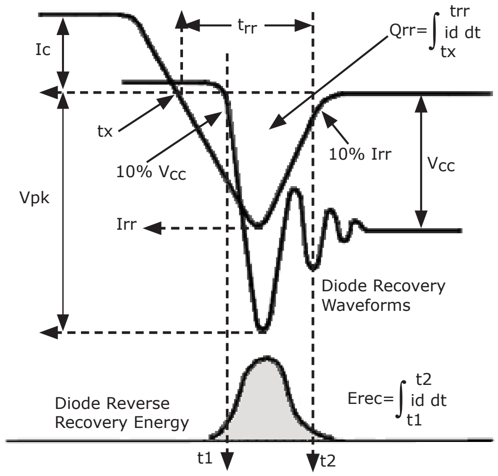


Fig 13. Body Diode Recovery Waveform

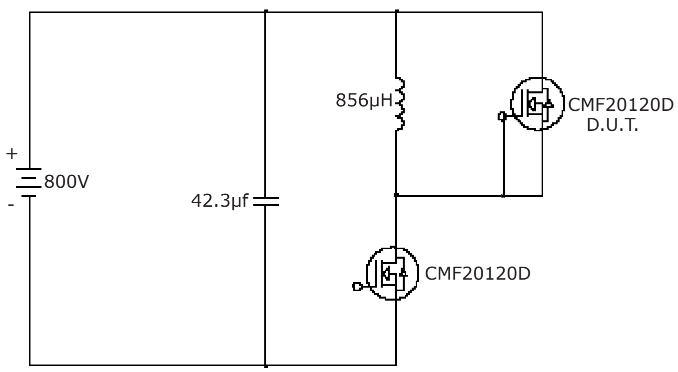


Fig 14. Body Diode Recovery Test

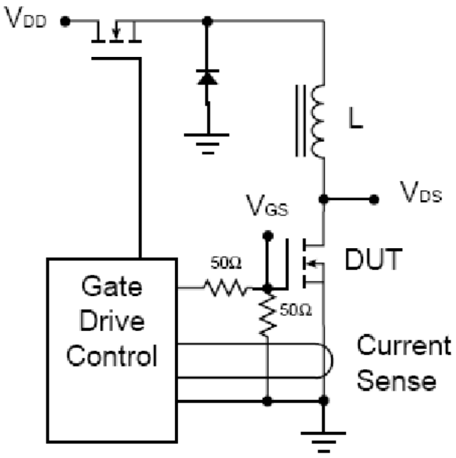
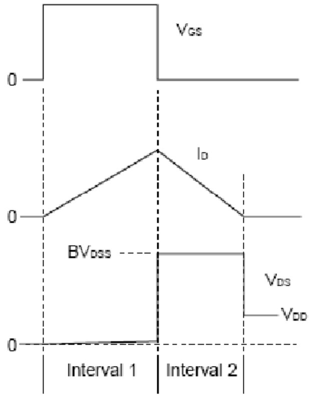


Fig 15. Avalanche Test Circuit

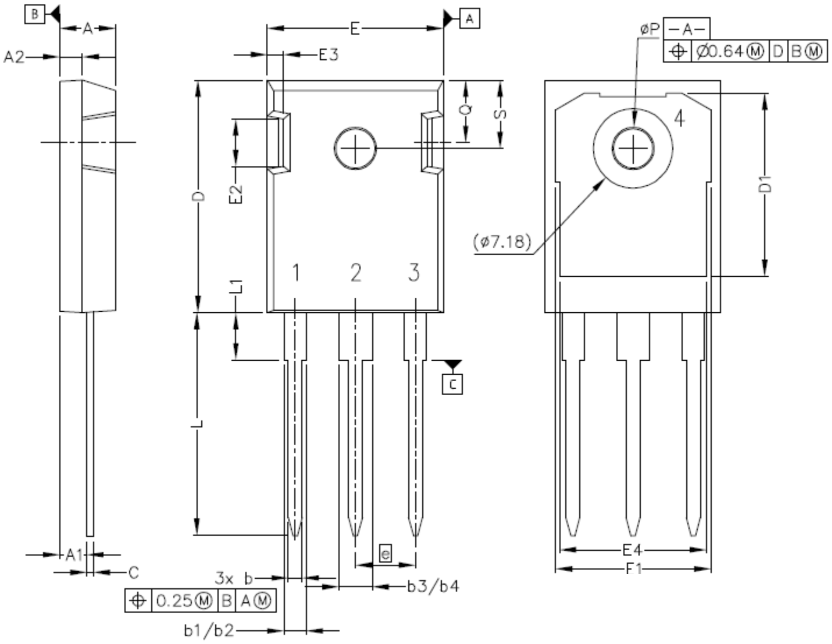


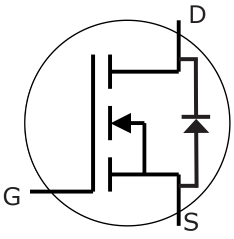
$$E_A = 1/2L \times I_D^2$$

Fig 16. Theoretical Avalanche Waveform

Package Dimensions

Package TO-247-3



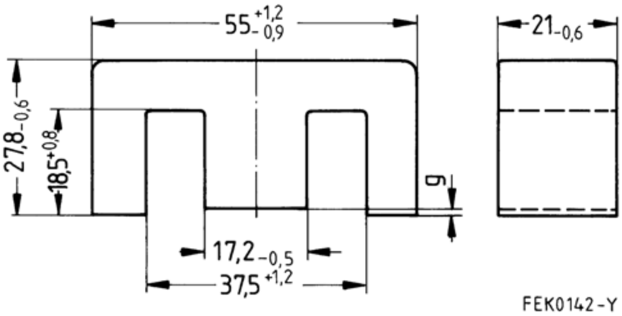


POS	Inches		Millimeters	
	Min	Max	Min	Max
A	.190	.205	4.83	5.21
A1	.090	.100	2.29	2.54
A2	.075	.085	1.91	2.16
b	.042	.052	1.07	1.33
b1	.075	.095	1.91	2.41
b2	.075	.085	1.91	2.16
b3	.113	.133	2.87	3.38
b4	.113	.123	2.87	3.13
c	.022	.027	0.55	0.68
D	.819	.831	20.80	21.10
D1	.640	.695	16.25	17.65
D2	.037	.049	0.95	1.25
E	.620	.635	15.75	16.13
E1	.516	.557	13.10	14.15
E2	.145	.201	3.68	5.10
E3	.039	.075	1.00	1.90
E4	.487	.529	12.38	13.43
e	.214 BSC		5.44 BSC	
N	3		3	
L	.780	.800	19.81	20.32
L1	.161	.173	4.10	4.40
ØP	.138	.144	3.51	3.65
Q	.216	.236	5.49	6.00
S	.238	.248	6.04	6.30

E 55/28/21

Core **B66335**

- To IEC 61246
- Delivery mode: single units



Magnetic characteristics (per set)

$\Sigma l/A = 0.35\ \text{mm}^{-1}$
$l_e = 124\ \text{mm}$
$A_e = 354\ \text{mm}^2$
$A_{min} = 351\ \text{mm}^2$
$V_e = 43900\ \text{mm}^3$

Approx. weight 215 g/set

Ungapped

Material	A_L value nH	μ_e	B_S* mT	P_V W/set	Ordering code
N27	5800 +30/–20%	1610	320	< 8.00 (200 mT, 25 kHz, 100 °C)	B66335G0000X127
N87	6400 +30/–20%	1780	320	< 3.80 (100 mT, 100 kHz, 100 °C)	B66335G0000X187
N97	6700 +30/–20%	1868	320	< 3.34 (100 mT, 100 kHz, 100 °C)	B66335G0000X197

* H = 250 A/m; f = 10 kHz; T = 100 °C

Gapped

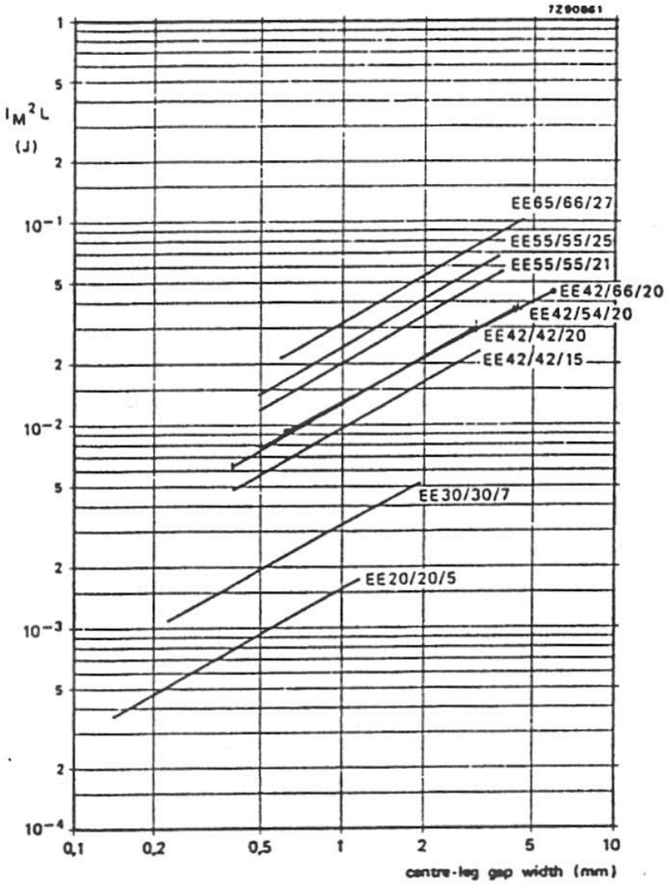
Material	g mm	A_L value approx. nH	μ_e	Ordering code ** = 27 (N27) = 87 (N87)
N27, N87	0.50 ±0.05	843	234	B66335G0500X1**
	1.00 ±0.05	496	138	B66335G1000X1**
	1.50 ±0.05	364	101	B66335G1500X1**
	2.00 ±0.05	292	81	B66335G2000X1**

The A_L value in the table applies to a core set comprising one ungapped core (dimension g = 0) and one gapped core (dimension g > 0).

Calculation factors (for formulas, see *"E cores: general information"*)

Material	Relationship between air gap – A_L value		Calculation of saturation current			
	K1 (25 °C)	K2 (25 °C)	K3 (25 °C)	K4 (25 °C)	K3 (100 °C)	K4 (100 °C)
N27	496	–0.764	836	–0.847	781	–0.865
N87	496	–0.764	800	–0.796	765	–0.873

Validity range: K1, K2: 0.15 mm < s < 3.50 mm
K3, K4: 180 nH < A_L < 1799 nH



Kuva 11.8. Eräs kuristinsydänten valintakäyrästö /11/.

tarvitaan, jottei sydän kyllästyisi. Itse asiassa suurin osa kuristimen varastoimasta energiasta on varastoitunut juuri ilmarakoon. Kuristimen magneettinen sydän toimii lähinnä vuon ohjaajana, jolloin haitallinen hajavuo ympäristössä pienenee. Ilmaväli vaikuttaa luonnollisestikin kierrosmäärään, joka tarvitaan tietyn induktanssin aikaansaamiseksi. Mitä enemmän ilmarakoa, sitä enemmän kierroksia. Teoreettisemmin

$$L = \frac{N\,\phi}{I} \tag{11.18}$$

$$\phi = \frac{\mu_0 NI}{\dfrac{l_g}{A_g} + \sum \dfrac{l_m}{\mu A_m}} \approx \frac{\mu_0 NI}{\dfrac{l_g}{A_g} + \dfrac{l_e - l_g}{\mu A_e}} \approx \frac{\mu_0 NI}{\dfrac{l_g}{A_g} + \dfrac{C_1}{\mu}} \tag{11.19}$$

$$L \approx \frac{\mu_0 N^2}{\dfrac{l_g}{A_g} + \dfrac{C_1}{\mu}} = \frac{\mu_0 \mu_e N^2 A_e}{l_e} = A_L N^2 \tag{11.20}$$

jossa l_g ja A_g ovat ilmavälin pituus ja pinta-ala sekä l_e ja A_e ovat efektiivinen magneettipiirin pituus ja pinta-ala. μ_0 on tyhjön ($= 4\pi\ 10^{-7}$ H/m) ja μ_e ilmavälin sisältävän sydämen efektiivinen permeabiliteetti ja C_1 on sydänvakio. A_L on induktanssikerroin sydämelle tällä ilmavälillä.