Power MOSFET Datasheet Understanding

Basic definition about parameter, diagrams, graphs in the datasheet.

Purpose of this document

Datasheet is the first approach to select the proper device in a power converter system. Datasheet is an important document to select the devices. Through understanding of technical information on the datasheet, an engineer has a confidence to select device as suitable, safe, and reliable. This application note provides the fundamental information how to read and interpret the parameters, which is the guaranteed specifications and design guide as absolute maximum ratings, thermal characteristics, package information, and electrical characteristics, diagrams and test methods for Power Master Semiconductors' super-junction MOSFET, ℯMOS series.

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1. Introduction

1.1. What is *e*MOS?

Among the high voltage POWER MOSFET, super-junction MOSFET is widely using in power conversion systems such as AC/DC, DC/DC, DC/AC applications. Power Master Semiconductor introduced the *e*MOS as leading-edge super-junction technology for targeting high efficiency, reliable and ease of use

This application note explains parameters based on 600V/180mΩ, *e* MOS E7, ‘PMP60N180E7’ which is the enhanced mode N-channel super-junction MOSFET (metal-oxide-semiconductor field-effect transistor).

1.2. Datasheet Classification

The Datasheet classified as the product development stage:

- Advanced Datasheet in the design stage
- Preliminary Datasheet in the qualification stage
- Final Datasheet in the mass production stage

Advanced Datasheet describes the target data for the developing product. The data from advanced datasheet is a designing target specification. The value in the advanced datasheet is not final data and not guaranteed as in the final datasheet. The letter of “Advanced Datasheet” is marking on the issuing the datasheet. The device marking on the package is “ES” (Engineering Sample) for this product, this is not issuing any product change notification (PCN)

Preliminary Datasheet is issued at the stage of device qualification. Most of static characteristic is decided however is applicable to change the datasheet parameter before mass production. It is also not final guaranteed specification. The device marking on the package is “CS” (Customer Sample) for this product, this is not issuing any product change notification (PCN).

Final Datasheet is the final guaranteed datasheet from mass production. If there is any data value change, PCN must be issued. There is no marking on the datasheet such as “Final Datasheet”.

1.3. Nomenclature

Device part number contains a lot of information such as technology, package, voltage rating and generation, etc. Figure 1 shows Power Master Semiconductor’s super-junction MOSFET, *e*MOS nomenclature

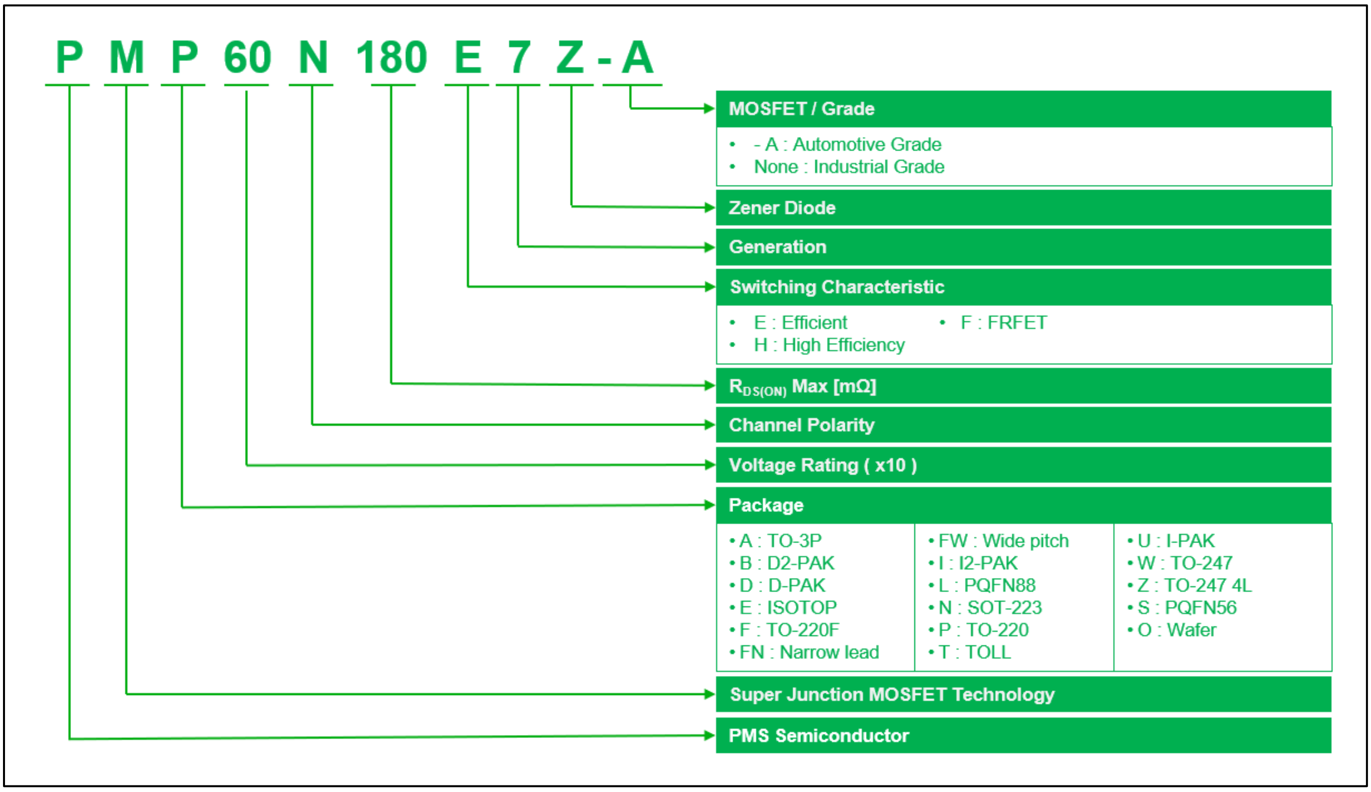
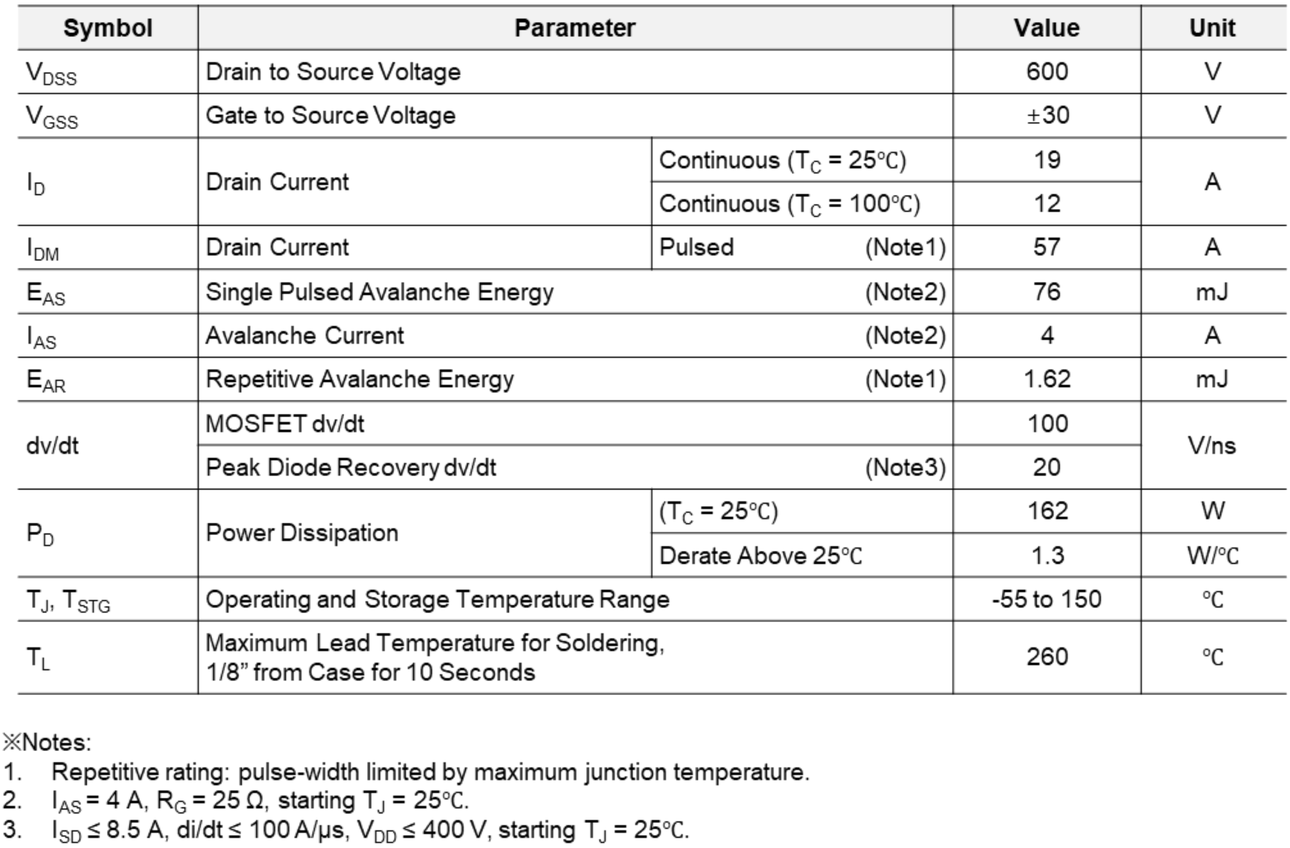


Figure 1. *e*MOS nomenclature scheme

2. Datasheet explanation

2.1. Absolute Maximum Ratings

The value in absolute maximum ratings is the maximum device capability in terms of “temperature condition is “T_C=25°C unless otherwise noted”. “T_C=25°C” means the cooling condition is infinite cooling system to sustain the case temperature as 25°C as an ideal condition. No matter what the condition is such as delivering, handling, soldering, assembling, testing, storing as well as actual device working, the device is limited under the value.



Symbol	Parameter		Value	Unit
V_{DSS}	Drain to Source Voltage		600	V
V_{GSS}	Gate to Source Voltage		±30	V
I_D	Drain Current	Continuous (T_C = 25℃)	19	A
		Continuous (T_C = 100℃)	12	
I_{DM}	Drain Current	Pulsed (Note1)	57	A
E_{AS}	Single Pulsed Avalanche Energy	(Note2)	76	mJ
I_{AS}	Avalanche Current	(Note2)	4	A
E_{AR}	Repetitive Avalanche Energy	(Note1)	1.62	mJ
dv/dt	MOSFET dv/dt		100	V/ns
	Peak Diode Recovery dv/dt	(Note3)	20	
P_D	Power Dissipation	(T_C = 25℃)	162	W
		Derate Above 25℃	1.3	W/℃
T_J, T_{STG}	Operating and Storage Temperature Range		-55 to 150	℃
T_L	Maximum Lead Temperature for Soldering, 1/8” from Case for 10 Seconds		260	℃

※Notes:
1. Repetitive rating: pulse-width limited by maximum junction temperature.
2. I_{AS} = 4 A, R_G = 25 Ω, starting T_J = 25℃.
3. I_{SD} ≤ 8.5 A, di/dt ≤ 100 A/μs, V_{DD} ≤ 400 V, starting T_J = 25℃.

V_{DSS}: Drain to Source Voltage

Symbol	Parameter	Value	Unit
V_{DSS}	Drain to Source Voltage	600	V

This symbol of V_{DSS} stands for “V = Voltage, D = Drain, S = Source, S = Short”. This interprets the applied maximum voltage of drain to source with gate and source shorted mode. The last latter “S” indicates that two terminal of device is shorted in the package condition, one is source terminal from “S” in the 3rd letter of “V_{DSS}”, and the other is gate terminal as the remained terminal which is not commented in the letter of “V_{DSS}”.

This voltage is the maximum allowable continuous voltage under there is no avalanche breakdown mode. In the condition of avalanche breakdown mode, the consideration is “Avalanche Energy” such as E_{AS} and E_{AR} in the datasheet. The applied volage from drain to source should be lower than the rated value because this voltage is one of critical value to make the device safe. This volage is related with long-term reliability of device.

V_{GSS}: Gate to Source Voltage

Symbol	Parameter	Value	Unit
V_{GSS}	Gate to Source Voltage	±30	V

This symbol of V_{GSS} stands for "V = Voltage, G = Gate, S = Source, S = Short". This means the applied maximum voltage between gate to source with drain and source shorted mode.

The value of "±30V" means the applied voltage is possible two condition as gate to source and source to gate because of gate oxide layer of MOSFET structure. The oxide layer is easily damaged by over voltage even very small power. In any circumstance, the voltage of gate-source should be not exceeded than the rated value. The actual gate oxide breakdown voltage is high enough than the rated value in the datasheet.

When the device pulls out from the packing tube, there are various hazardous condition such as ESD, surge voltage. The voltage of gate to source is the critical cautious parameter, especially handling such as bare hand touching without ESD protection.

I_D: Continuous Drain Current

Symbol	Parameter		Value	Unit
I_D	Drain Current	Continuous (Tc = 25°C)	19	A
		Continuous (Tc = 100°C)	12	

This symbol of I_D stands for "I = Current, D = Drain", it means the maximum continuous current from drain to source. I_D is calculated from the theoretical equation as Equation 1)

Equation 1)

$$I_D = \sqrt{\frac{T_{Jmax} - T_C}{R_{DS(on)\_max} \times R_{\theta JC}}}$$

T_{Jmax} is the maximum MOSFET junction temperature, normally 150°C in MOSFET. T_C is the case temperature of device package surface as the indicated temperature condition. $R_{DS(on)}$ is MOSFET On resistance at 25°C and $R_{DS(on)\_max}$ is MOSFET On resistance at Maximum junction temperature, the normalize resistance by temperature provide in Figure 3. $R_{\theta JC}$ is the steady state of thermal resistance.

I_D can be calculated in case of T_C=25°C:
In PMP60N180E7 Datasheet, T_{Jmax} = 150°C, $R_{\theta JC}$ = 0.77°C/W, $R_{DS(on)}$ @ 25 °C = 180mΩ, and $R_{DS(on)\_max}$ is "180m Ω * 2.5 at 150°C of T_{Jmax}.

Calculation 1)

$$I_D = \sqrt{\frac{150 - 25}{0.77 \times (0.18 \times 2.5)}} = 19\ [A]$$

I_D can be calculated in case of T_C=100°C:

Calculation 2)

$$I_D = \sqrt{\frac{150 - 100}{0.77 \times (0.18 \times 2.5)}} = 12\ [A]$$

In the Figure 2., this graph shows the maximum drain current by case temperature, T_C.

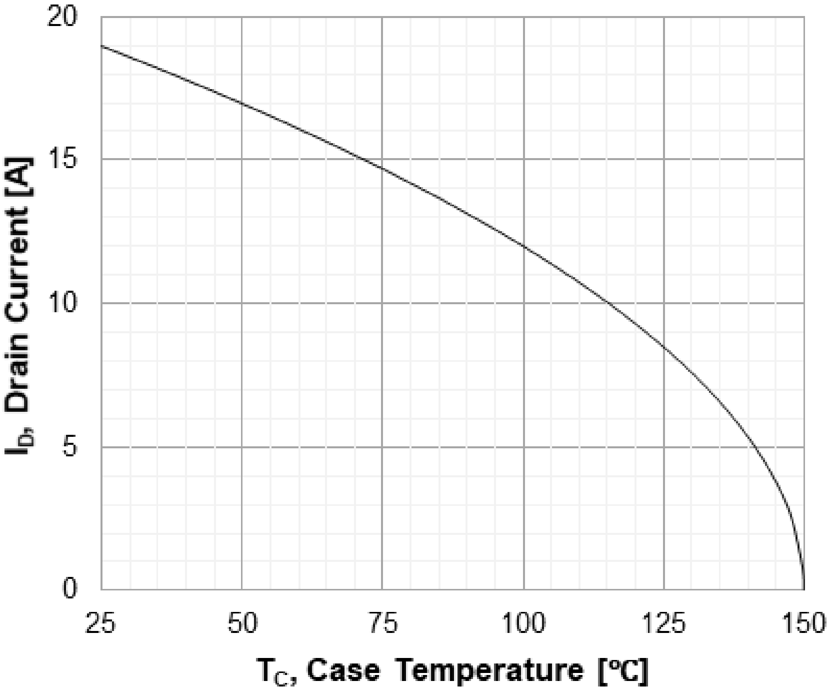


Figure 2. Maximum Drain Current vs. Case Temperature (Figure 10. in the datasheet)

From figure 3, On-Resistance vs. Temperature (Figure 8. In the datasheet), it is seen the normalized $R_{DS(on)}$ is 1 at T_J=25°C and 2.5 at Tj=150°C. The normalized value is obtained from “$R_{DS(on)}(T_J)$ / $R_{DS(on)}(T_J = 25°C)$”.

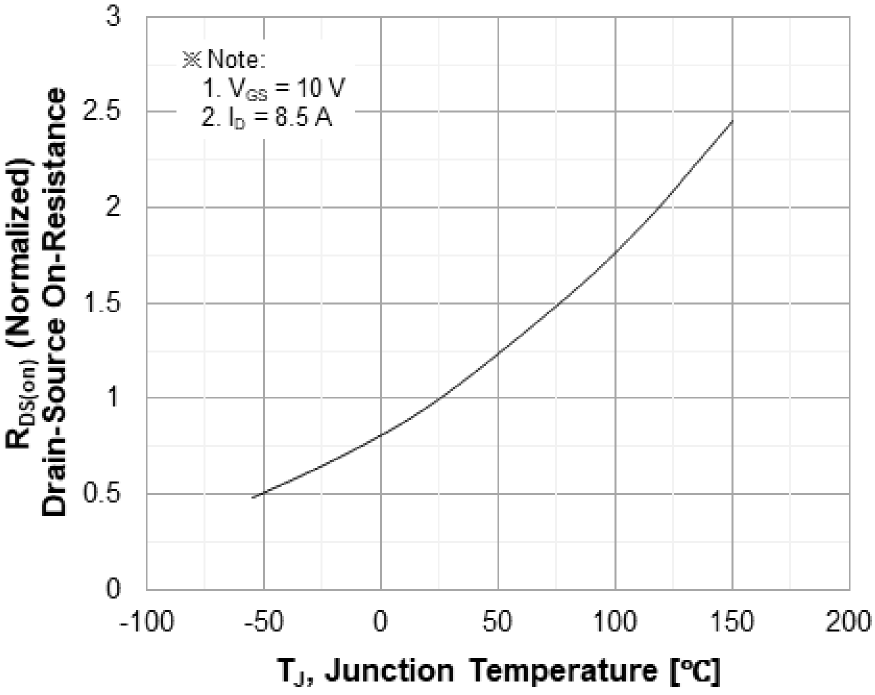


Figure 3. On-Resistance Characteristics vs. Temperature (Figure 8. in the datasheet)

I_{DM}: Pulsed Drain Current

Symbol	Parameter		Value	Unit
I_{DM}	Drain Current	Pulsed (Note1)	57	A

Note1: Repetitive rating: pulse-width limited by maximum junction temperature.

This symbol of I_{DM} stands for “I = Current, M = Maximum”, it means the maximum pulse drain current (or called as “peak drain current”) at maximum junction temperature under T_C=25°C as in terms of infinite cooling condition. This pulsed drain current is various by current pules shape, duty, duration, and it is limited by die technology, bonding wire, and package thermal performance.

In Figure 4, the graph shows the limitation of SOA curve base on pulse width. Pulse current of PMP60N180E7 device is limited as 57A.

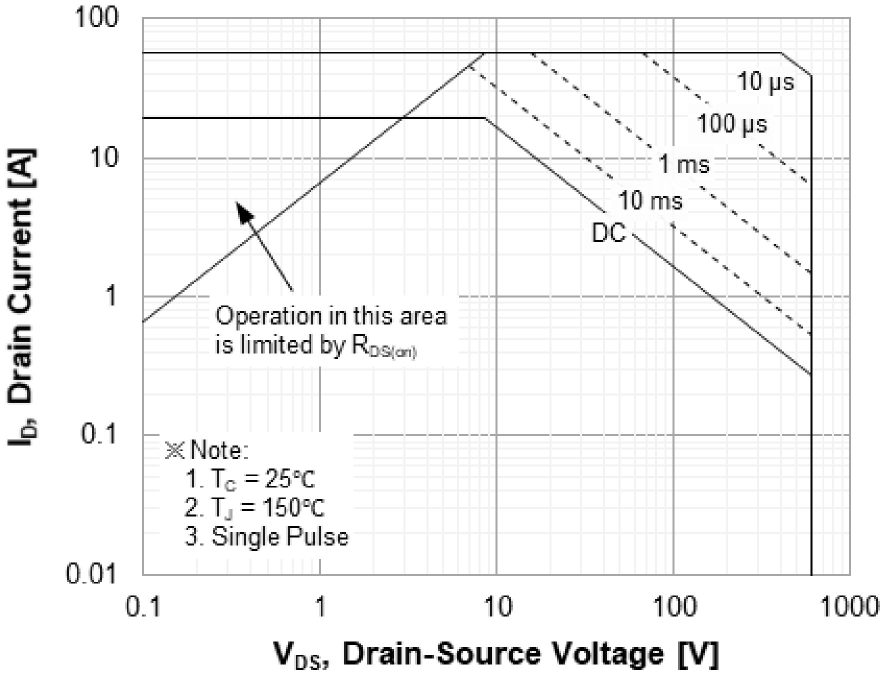


Figure 4. Maximum Safe Operating Area. (Figure 9. In the datasheet)

E_{AS}: Single Pulsed Avalanche Energy & I_{AS}: Avalanche Current

Symbol	Parameter	Value	Unit
E_{AS}	Single Pulsed Avalanche Energy (Note2)	76	mJ
I_{AS}	Avalanche Current (Note2)	4	A

Note2: I_{AS} = 4A, R_G = 25Ω, starting T_J = 25°C

This symbol of E_{AS} stands for “E = Energy, A = Avalanche, S = Single”. This is the maximum energy level about single pulse at the avalanche breakdown mode which is unclamped inductive switching condition.

The value is one of the ruggedness parameters in the MOSFET performance. The test circuit and waveform are in the Figure 5. When the inductor energy is charging during MOSFET turn-on mode, and then MOSFET is turned off.

When MOSFET is turned off, the charged inductor energy makes drain voltage rising to MOSFET breakdown voltage and then inductor charged energy is linearly decreased.

The single pulsed energy is calculated with Equation 2)

Equation 2)

$$E_{AS} = \frac{1}{2} \times L \times I_{AS}^{\ 2} \times \frac{BV_{DSS}}{BV_{DSS} - V_{DD}}$$

L is inductor value, I_{AS} is single pulse avalanche current, BV_{DSS} is the breakdown voltage between drain to source, and V_{DD} is an applying DC voltage.

E_{AR}: Repetitive Avalanche Energy

Symbol	Parameter	Value	Unit
E_{AR}	Repetitive Avalanche Energy (Note1)	1.62	mJ

Note1: Repetitive rating: pulse-width limited by maximum junction temperature.

This symbol of E_{AR} stands for "E = Energy, A = Avalanche, R = Repetitive". This is the maximum energy level about repetitive pulse at the avalanche breakdown mode which is unclamped inductive switching condition.

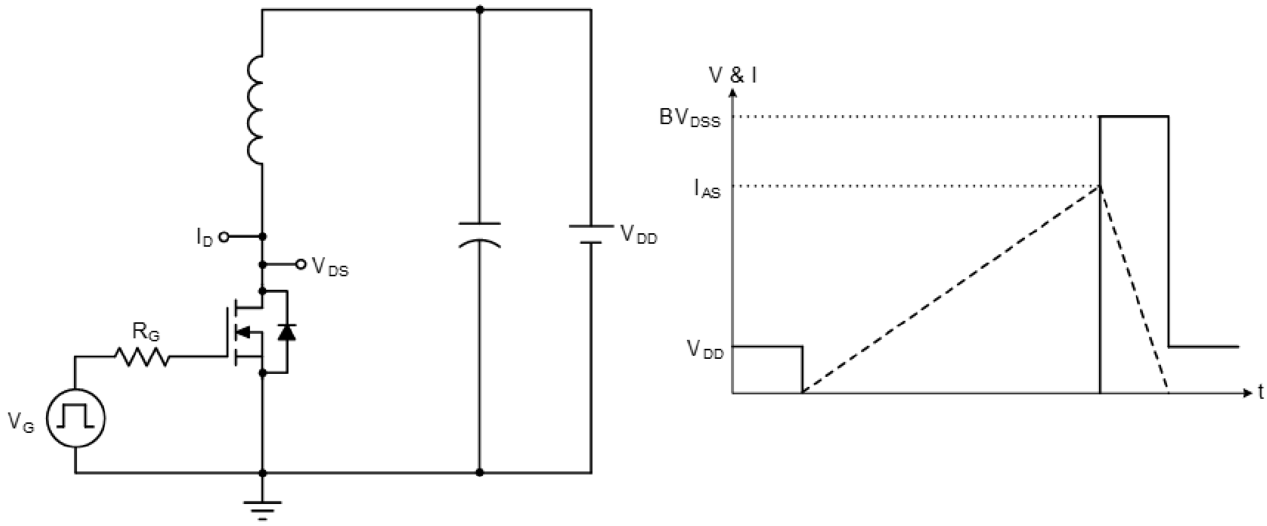


Figure 5. Unclamped Inductive Switching Test Circuit and Waveforms. (Figure 14. in the datasheet)

dv/dt:

Symbol	Parameter	Value	Unit
I_D	MOSFET dv/dt	100	V/ns
	Peak Diode Recovery dv/dt (Note3)	20	

Note3: $I_{SD} \leq 8.5A$, $di/dt \leq 100A/us$, $V_{DD} \leq 400V$, starting $T_J = 25°C$

"MOSFET dv/dt" is the permissible drain voltage slope during MOSFET is turned-off, which the forward current is flowing from drain to source.

"Peak Diode Recovery dv/dt" is the permissible drain voltage slope during body diode of MOSFET is turned-off (reverse recovered), which the reverse current is flowing from source to drain.

This parameter is guaranteed by design, which is not testing during the production.

P_D: Power Dissipation

Symbol	Parameter		Value	Unit
P_D	Power dissipation	(Tc = 25°C)	162	W
		Derate Above 25°C	1.3	W/°C

P_D stands for "P = Power, D = Dissipation, it is the maximum permissible continuous power dissipation at T_C = 25°C. P_D is calculated value as the Equation 3).

Equation 3)

$$P_D\ (T_C) = \frac{T_{Jmax} - T_C}{R_{\theta JC}}$$

Calculation 3)

$$P_D(25°\mathrm{C}) = \frac{150°\mathrm{C} - 25°\mathrm{C}}{0.77} = 162W,\ \ Derate\ = \frac{1°\mathrm{C}}{0.77} = 1.3\ W/°\mathrm{C}$$

T_J, T_{STG}: Junction Temperature Range

Symbol	Parameter	Value	Unit
T_J, T_{STG}	Operating and Storage Temperature Range	-55 to 150	°C

T_J stand for "T = Temperature, J = Junction", junction is normally called as die of device, so it is the permissible die temperature during operating a device.

T_{STG} stand for "T = Temperature, STG = Storage", it is storage temperature, storage temperature is same as operating temperature.

T_L: Lead Temperature Range

Symbol	Parameter	Value	Unit
T_L	Maximum Lead Temperature for Soldering, 1/8" from Case for 10 Seconds	260	°C

T_L stand for "T = Temperature, L = Lead", it is the maximum lead temperature during the soldering.

2.2. Thermal Characteristics

Thermal characteristics is indicated with thermal resistance. Thermal resistance is a similar concept with electrical resistance. There are two thermal resistances, one is steady state thermal resistance as $R_{\theta JC}$ and $R_{\theta JA}$ which have a value in the datasheet, another is transient thermal resistance such as $Z_{\theta JC}$ in Figure 6.

Symbol	Parameter	Value	Unit
$R_{\theta JC}$	Thermal Resistance, Junction to Case, Max.	0.77	°C/W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient, Max	62.5	

The symbol is defined as "R = Resistance, Θ = Thermal, J = Junction of die, C = Case of package surface, A = Ambient". $R_{\theta JC}$ is the thermal resistance between junction to case with heat sink condition, and $R_{\theta JA}$ is the thermal resistance between junction and ambient without heat sink condition.

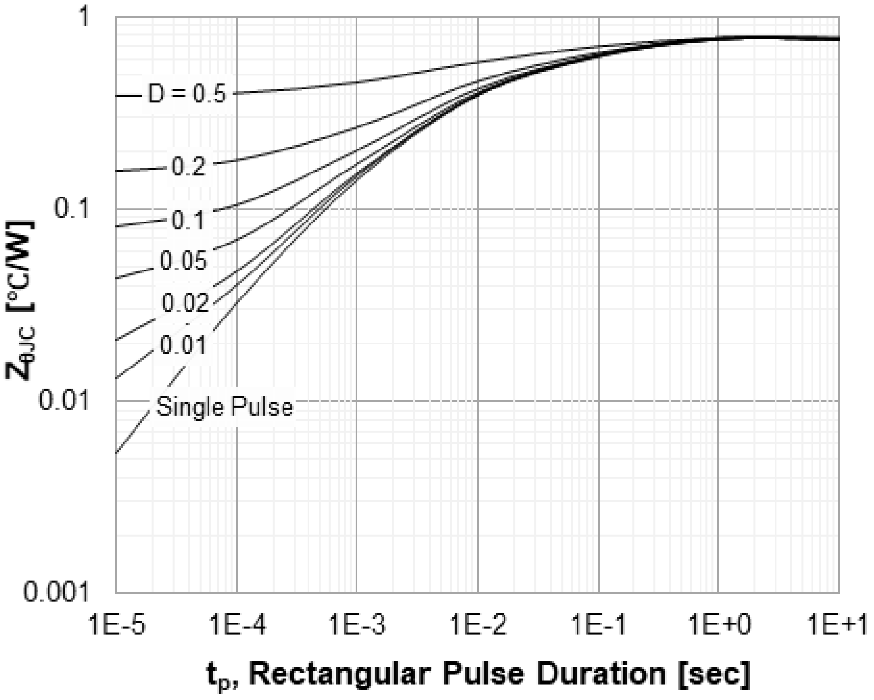


Figure 6. Transient Thermal Response Curve (Figure12. in the datasheet)

t_p > 1sec: $Z_{\theta JC}(t)$ value goes to be saturated as steady state in all lines, this steady value is called as $R_{\theta JC}$.

$t_p \le$ 1sec: $Z_{\theta JC}(t)$ value are various by duration and duty of pulse. this is transient thermal resistance as $Z_{\theta JC}$.

Junction Temperature is calculated by using thermal resistances as Equation 4) and 5)

Equation 4) Steady state

$$T_J = T_c + R_{\theta JC} \times P_{D\_Average}$$

Equation 5) Transient state

$$T_J = T_c + Z_{\theta JC}(t_p) \times P_{D\_Pulse}$$

3. Electrical Characteristics (T_C = 25°C unless otherwise noted)

The electrical characteristics are the device performance and capability under Tc=25°C. There are five categories as “Off Characteristics, bias is applying drain to source under MOSFET off status”, “On Characteristics, bias is applying from drain to source or from gate to source”, “Dynamic Characteristics, impedance of MOSFET”, “Switching Characteristics, time domain parameter during MOSFET turned-on and turned-off”, and “Source-Dran Diode Characteristics, body diode of MOSFET characteristics under applying bias from source to drain”.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
Off Characteristics						
BV_{DSS}	Drain to Source Breakdown Voltage	V_{GS} = 0 V, I_D = 1 mA	600			V
		V_{GS} = 0 V, I_D = 1 mA, T_J = 150℃	650			
I_{DSS}	Zero Gate Voltage Drain Current	V_{DS} = 600 V, V_{GS} = 0 V			1	µA
		V_{DS} = 480 V, V_{GS} = 0 V, T_J = 125℃		2		
I_{GSS}	Gate-Source Leakage Current	V_{GS} = ±30 V, V_{DS} = 0 V			±100	nA
On Characteristics						
$V_{GS(th)}$	Gate Threshold Voltage	V_{GS} = V_{DS}, I_D = 1.7 mA	2.5		4.5	V
$R_{DS(on)}$	Static Drain to Source On Resistance	V_{GS} = 10 V, I_D = 8.5 A		150	180	mΩ
Dynamic Characteristics						
C_{iss}	Input Capacitance	V_{DS} = 400 V, V_{GS} = 0 V, f = 250 kHz		1240		pF
C_{oss}	Output Capacitance			34		pF
$C_{o(tr)}$	Time Related Output Capacitance	V_{DS} = 0 V to 400 V, V_{GS} = 0 V		381		pF
$C_{o(er)}$	Energy Related Output Capacitance			54		pF
$Q_{g(tot)}$	Total Gate Charge at 10 V	V_{DS} = 400 V, I_D = 8.5 A, V_{GS} = 10 V		30.2		nC
Q_{gs}	Gate to Source Charge			5.8		nC
Q_{gd}	Gate to Drain “Miller” Charge			15.4		nC
R_G	Gate Resistance	f = 1 MHz		1.3		Ω
Switching Characteristics						
$t_{d(on)}$	Turn-On Delay Time	V_{DS} = 400 V, I_D = 8.5 A, V_{GS} = 10 V, R_G = 10 Ω See Figure 13		12		ns
t_r	Turn-On Rise Time			8		ns
$t_{d(off)}$	Turn-Off Delay Time			53		ns
t_f	Turn-Off Fall Time			10		ns
Source-Drain Diode Characteristics						
I_S	Maximum Continuous Diode Forward Current				19	A
I_{SM}	Maximum Pulsed Diode Forward Current				57	A
V_{SD}	Diode Forward Voltage	V_{GS} = 0 V, I_{SD} = 8.5 A			1.2	V
t_{rr}	Reverse Recovery Time	V_{DD} = 400 V, I_{SD} = 8.5 A, dI_F/dt = 100 A/µs		274		ns
Q_{rr}	Reverse Recovery Charge			3.33		µC

3.1. Off Characteristics

"Off Characteristics" is a static parameter at "V_{GS} = 0V", it means forward current from drain to source is blocking. The main parameters are breakdown voltage and leakage current.

BV_{DSS}: Drain to Source Breakdown Voltage

Symbol	Parameter	Test Condition	Min	Typ	Max	Unit
BV_{DSS}	Drain to Source Breakdown Voltage	V_{GS} = 0V, I_D = 1mA	600			V
		V_{GS} = 0V, I_D = 1mA, T_J = 150°C	650			

The symbol is defined as "B = Breakdown, V = Voltage, D = Drain, S = source, S = Short", it means that gate is shorted with source, and voltage is applied from drain to source. The voltage of drain to source is measured at 1mA current flowing. There is one notice for temperature condition, the value which have no temperature condition is measured at T_C = 25 °C, this condition is included in the meaning of T_J = 25 °C as same as T_C. Otherwise, temperature condition is included in "Test Condition" such as T_J = 150 °C, which is different by each parameter. In Figure 7, it shows that breakdown voltage is rising by temperature as normalize value, for example, the value of T_J = 25 °C is "1" and T_J = 150 °C is "1.2", the normalized value is obtained from "$BV_{DSS}(T_J)$ / BV_{DSS} (T_J = 25°C)".

I_{DSS}: Zero Gate Voltage Drain Current

Symbol	Parameter	Test Condition	Min	Typ	Max	Unit
I_{DSS}	Zero Gate Voltage Drain Current	V_{DS} = 600V, V_{GS} = 0V			1	μA
		V_{DS} = 600V, V_{GS} = 0V, T_J = 125°C		2		

The symbol is defined as "I = Current, D = Drain, S = Source, S = Short", it means that gate is shorted with source, and voltage is applied from drain to source. The current of drain to source is measured at 600V.

I_{DSS} is called as "Drain to Source Leakage Current", this current is increasing by temperature as test condition.

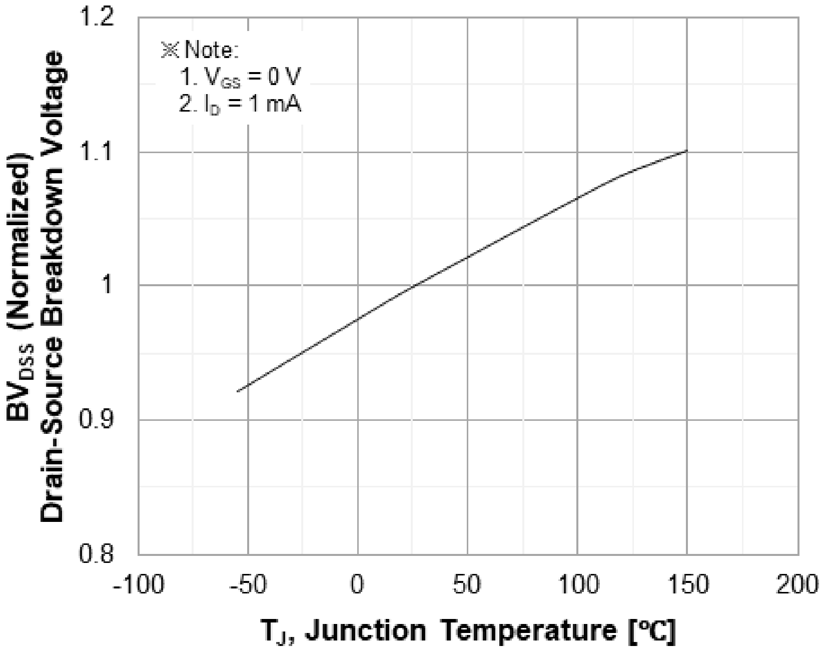


Figure 7. Breakdown Voltage Characteristic vs. Temperature (Figure 7. in the datasheet)

3.2. On Characteristics

"On Characteristics" is a static parameter under applying voltage at gate to source, it means a forward current from drain to source is flowing. The main parameters are threshold voltage and on resistance.

$V_{GS(th)}$: Gate Threshold Voltage

Symbol	Parameter	Test Condition	Min	Typ	Max	Unit
$V_{GS(th)}$	Gate Threshold Voltage	$V_{GS} = V_{DS}$, I_D = 1.7mA	2.5		4.5	V

The gate threshold voltage, $V_{GS(th)}$ defines the required gate-source voltage at a specified drain current. The threshold voltage is measured at room temperature with $V_{DS} = V_{GS}$ during production. The minimum and maximum value is specified in the datasheet. The symbol is defined as "V = Voltage, G = Gate, S = Source, th = Threshold", it means gate is shorted with drain. This is the minimum gate to source voltage to conduct between drain to source at the rated current level.

$R_{DS(on)}$: Static Drain to Source On Resistance

Symbol	Parameter	Test Condition	Min	Typ	Max	Unit
$R_{DS(on)}$	Static Drain to Source On Resistance	V_{GS} = 10V, I_D = 8.5A		150	180	mΩ

The drain-source on-state resistance, $R_{DS(on)}$ is one of the key parameters of a MOSFET. In the datasheet, the typical and maximum ratings at room temperature are specified. These values are determined during production testing at the specified conditions. The symbol is defined as "R = Resistance, D = Drain, S = Source, on = On", $R_{DS(on)}$ the On-resistance from drain to source under applying the gate bias (10V) and measured at the specific drain current. Resistance is the slop of voltage and current as $R_{DS(on)}$ $(V_G) = V_{DS\_Drop} / I_{DS}$. Curve Trace helps to get easily reading of resistance value. V_{DS_Drop} is the voltage drop between drain and source on flowing a current from drain to source. I_{DS} is the specific current from drain to source. In the datasheet, there are 3 types of Figures for On-Characteristics as Figure 8, 9, and Figure 10.

Figure 8 is the graph of drain to source voltage vs. drain current by gate voltage under T_C = 25°C. Drain current increase by increasing gate voltage, and drain current is smaller variance in $V_{GS} \geq$ 10V than V_{GS}<10V, so V_{GS} of Power MOSFET is recommended 10V generally in SMPS application. Some of current control application such as electric load switch, static electric relay uses a various V_{GS} level to control current limit, in this case, power dissipation is very high.

There are two regions, one is ohmic region, and another is saturation region in Figure 8. Ohmic region is general switching operation region in SMPS application, for example this region is V_{DS} < 5V which is linearly increasing as $R_{DS} = V_{DS} / I_D$. Saturation region is beyond ohmic region which the drain current is limited as maximum current for, for example drain current goes to saturate from V_{DS} > 15V. This saturation current is variable by the proportion of die size in the same MOSFET technology.

Figure 9 is the graph of gate-source voltage vs. drain current by case temperature at T_J=25°C and T_J=150°C under V_{DS}=20V, there is a cross point around V_{GS}=6V. In terms of V_{GS} > 6V, drain current is decreased at higher temperature, this is caused by MOSFET on-resistance, MOSFET on-resistance have PTC (Positive Temperature Coefficient) characteristic which means that on-resistance is increased at the high temperature. Thanks to PTC characteristic of MOSFET, it is generally easier to operate parallel MOSFETs by self-stabilization.

V_{DS} = 20V is the applied voltage for testing transfer characteristics of MOSFET, not voltage drop between drain to source in figure 9.

Figure 10 is the graph of on-Resistance and drain current characteristics by gate voltage under T_C = 25°C, V_{GS} = 10V graph shows higher on-resistance than V_{GS} = 20V. Higher gate voltage makes lower on-resistance but makes higher switching noise. The gate voltage should be considered for trade-off of power loss vs. switching noise.

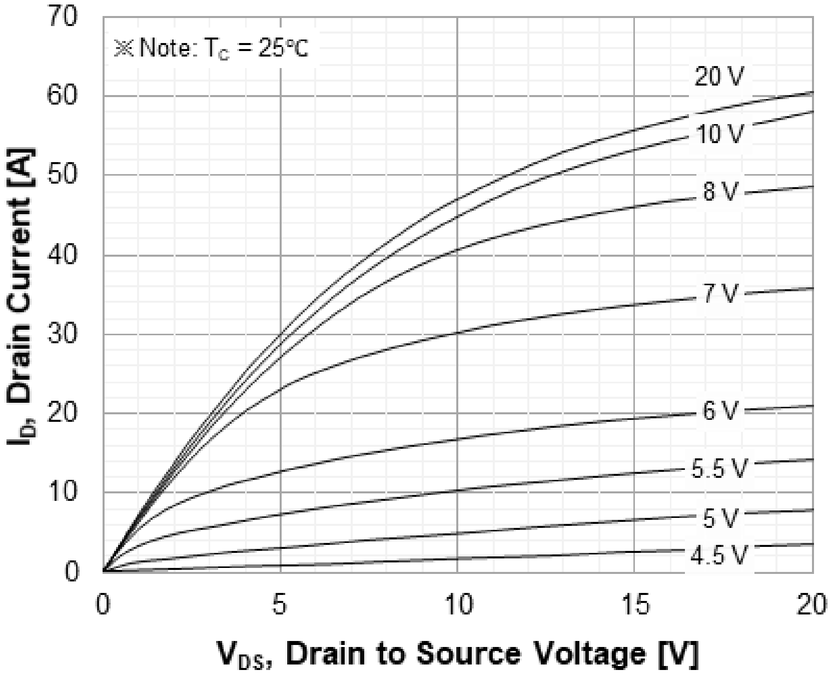


Figure 8. On-Region Characteristics (Figure 1. in the datasheet)

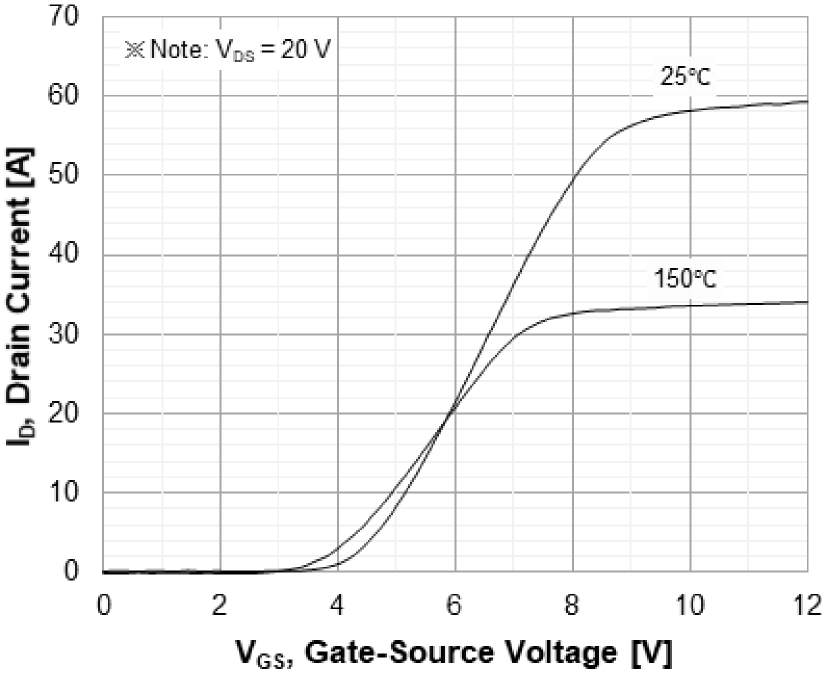


Figure 9. Transfer Characteristics (Figure 2. in the datasheet)

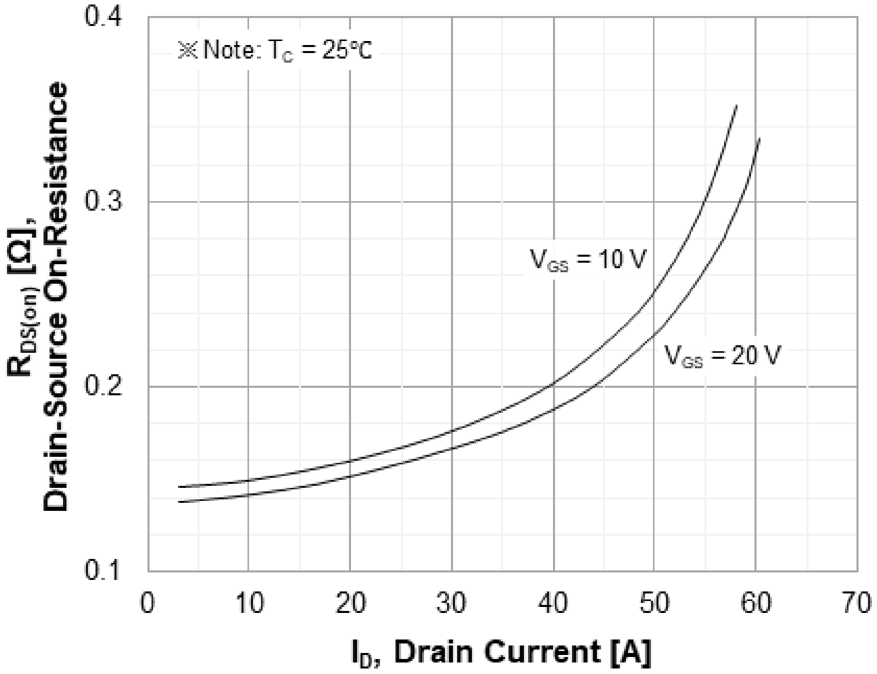


Figure 10. On-Resistance Characteristics vs. Drain Current and Gate Voltage (Figure 3. in the datasheet)

3.3. Dynamic Characteristics

“Dynamic Characteristics” is MOSFET impedance characteristic such as capacitance and resistance. It refers as switching loss performance and gate driving design. Dynamic parameter is guaranteed by design.

C_{iss} and C_{oss}: Capacitance of MOSFET

Symbol	Parameter	Test Condition	Min	Typ	Max	Unit
C_{iss}	Input Capacitance	V_{DS} = 400V, V_{GS} = 0V, f = 250kHz		1240		pF
C_{oss}	Output Capacitance			34		pF

MOSFET is consisted with 3 types of capacitances as shown in Figure 11.

C_{iss} is defined as “C = Capacitance, i = Input, s = Source, s = Short”, the input capacitance is measured the capacitance between the gate and source under placing ac short capacitor between the drain and the source at f = 250 kHz. $C_{iss} = C_{gd} + C_{gs}$, input capacitance is summation of gate-source capacitance and gate-drain capacitance. The input capacitance is affected to gate driving performance.
C_{oss} is defined as “C = Capacitance, o = output, s = Source, s = Short”, the output capacitance is measured the capacitance between the drain to source under placing ac short capacitor between the drain and the source at f = 250kHz. $C_{oss} = C_{gs}\ ((C_{gs} \cdot C_{gd}) / C_{gd} + C_{gs}) + C_{ds} \approx C_{gd} + C_{ds}$, output capacitance is summation of drain-gate capacitance and drain-source capacitance. The output capacitance is affected to MOSFET switching performance.

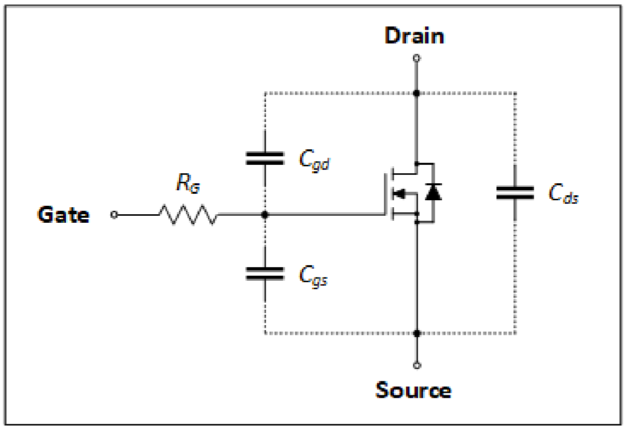


Figure 11. Equivalent Capacitance and Resistance of MOSFET

In Figure 12, the graph shows the capacitance by drain-source voltage as log scale. The capacitances are variable by drain source voltage.

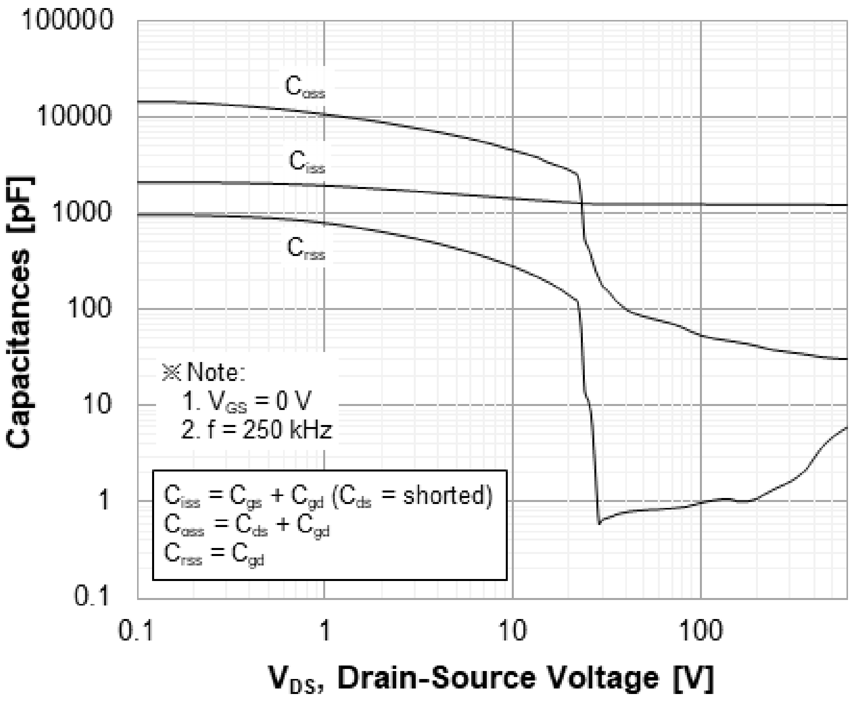


Figure 12. Capacitance Characteristics (Figure 5. in the datasheet)

C_{gd} is gate-source capacitance, also called C_{rss}, this is the reverse transfer capacitance which is measured between the drain and gate under the source connected ground.

$C_{o(tr)}$ and $C_{o(er)}$: Special Output Capacitance of MOSFET

Symbol	Parameter	Test Condition	Min	Typ	Max	Unit
$C_{o(tr)}$	Time Related Output Capacitance	V_{DS} = 0V ~ 400V, V_{GS} = 0V,		381		pF
$C_{o(er)}$	Energy Related Output Capacitance			54		pF

$C_{o(tr)}$ is defined as “C = Capacitance, o = Output, tr = Time Related”, $C_{o(tr)}$ is a kind of time dominant capacitance which is the same charging time as the output capacitance of a MOSFET under V_{DS} is rising from zero voltage to 400V at V_{GS} = 0V. The time related output capacitance is call as “effective output capacitance”. $C_{o(tr)}$ is calculated as Equation 7 and 8.

Equation 7) V_C: the voltage of drain to source by time dependent

$$V_c = BV_{DSS}\left(1 - e^{-t_r/RC_{o(tr)}}\right)$$

: t_r = *rising time*

Equation 8) $C_{o(tr)}$: Calculation from Equation 7) at V_C = 400V

$$C_{o(tr)} = 6.21 \times 10^{-6} t_r$$

$C_{o(er)}$ is defined as “C = Capacitance, o = Output, er = Energy Related”, The energy related out capacitance is calculated from E_{OSS} to charging C_{OSS}. $C_{o(er)}$ is useful to simulate the energy loss and design in resonant topologies such as LLC topology. $C_{O(er)}$ is calculated as Equation 9.

Equation 9) $C_{o(er)}$

$$C_{o(er)} = \frac{2}{V_{DS}{}^2}\int_0^{V_{DS}} C(v) \times v dv$$

Figure 13 shows E_{oss} vs. Drain to Source Voltage, E_{OSS} is an output capacitance giving equivalent stored energy at V_{DS}=400V. E_{oss} is calculated as Equation 10.

Equation 10) E_{OSS}: The cumulated energy to output capacitor by the voltage of the drain to source.

$$E_{oss} = \frac{1}{2}\left(C_{o(er)} \times V_{DS}{}^{2}\right) = \int_{0}^{V_{DS}} C(v) \times v dv$$

C(v) is the capacitance by voltage as shown in Figure 17.

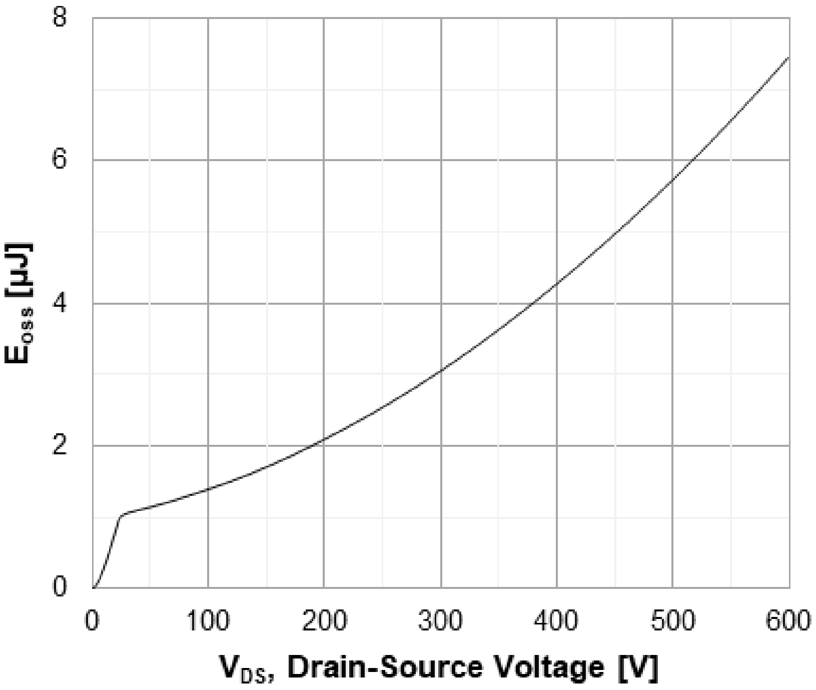


Figure 13. E_{oss} vs. Drain to Source Voltage (Figure 11. in the datasheet)

Q_g, Q_{gs}, Q_{gs}: Gate Charge of MOSFET

Symbol	Parameter	Test Condition	Min	Typ	Max	Unit
$Q_{g(tot)}$	Total Gate Charge at 10V	V_{DS} = 400V, I_D = 8.5A V_{GS} = 10V		30.2		nC
Q_{gs}	Gate to Source Charge			5.8		nC
Q_{gd}	Gate to Drain "Miler" Charger			15.4		nC

$Q_{g(tot)}$ is the symbol as "Q = Charge, g = Gate, tot = Total", $Q_{g(tot)}$ is total gate charge amount from V_{GS} = 0V to V_{GS} = 10V in Figure 15.

Q_{gs} is the symbol as "Q = Charge, g = Gate, s = Source", Q_{gs} is the gate to source charging amount from V_{GS} = 0V to arriving in V_{GS} = "plateau voltage" in Figure 18.

Q_{gd} is the symbol as "Q = Charge, g = Gate, d = Drain", Q_{gd} is the gate charge amount during sustaining area at plateau voltage.

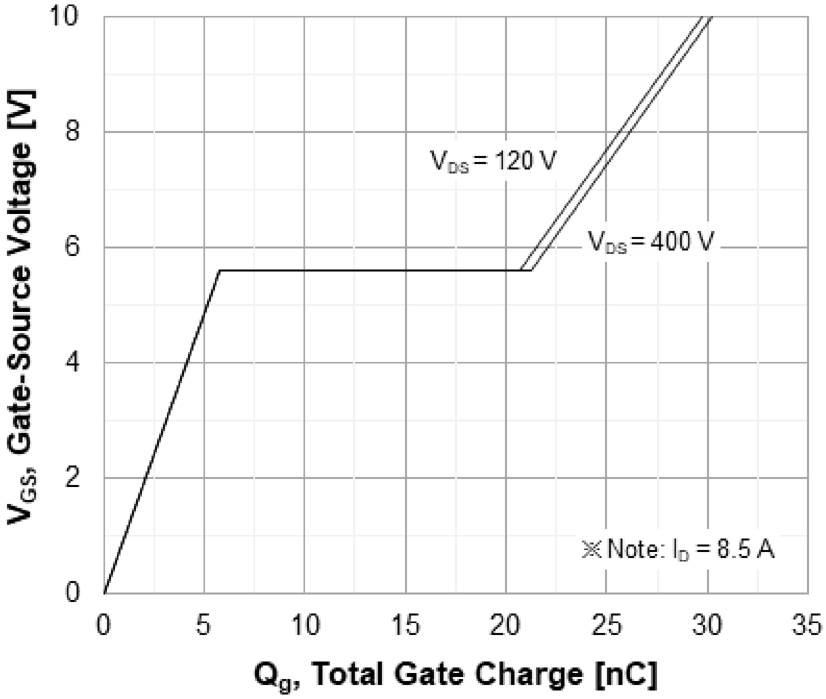


Figure 14. Gate Charge Characteristics (Figure 6. in the datasheet)

Gate charge equation as shown in Equation 11).

Equation 11) Gate Charge Calculation

$$Q_g = \int_{t0\ at\ Vg=0V}^{t1\ at\ Vg=specific\ voltage} i_g(t) = I_g \times time\ at\ specific\ V_g$$

R_G: Gate Resistance

Symbol	**Parameter**	**Test Condition**	**Min**	**Typ**	**Max**	**Unit**
R_G	Gate Resistance	f = 1MHz		1.3		Ω

R_G is defined as “R = Resistance, G = Gate, R_G is the internal gate resistance of MOSFET under f = 1MHz as shown in Figure 11.

3.4. Switching Characteristics

$t_{d(on)}$, t_r, $t_{d(off)}$, and t_f: Time deviation

Symbol	Parameter	Test Condition	Min	Typ	Max	Unit
$t_{d(on)}$	Turn-On Delay Time	V_{DS} = 400V, I_D = 8.5A, V_{GS} = 10V, R_G = 10 Ω		12		ns
t_r	Turn-On Rise Time			8		ns
$t_{d(off)}$	Turn-Off Delay Time			53		ns
t_f	Turn-Off Fall Time			10		ns

$t_{d(on)}$ is the symbol as “t = Time, d = Delay, on = On”, td(on) is the time from 10% of V_{GS} to 90% of V_{DS} as shown in Figure 15.

t_r is the symbol as “t = Time, r = Rise”, tr is the time from 90% of V_{DS} to 10% of V_{DS} as shown in Figure 15. The MOSFET channel current is ready to flow and rise, the current flowing direction is different by the topology such as hard switching application, or soft switching application.

$t_{d(off)}$ is the symbol as “t = Time, d = Delay, on = Off”, $t_{d(off)}$ is the time from 90% of V_{GS} to 10% of V_{DS} as shown in Figure 15.

t_f is the symbol as “t = Time, f = Fall”, t_f is the time from 10% of V_{DS} to 90% of V_{DS} as shown in Figure 15. The drain current is ready to fall and block.

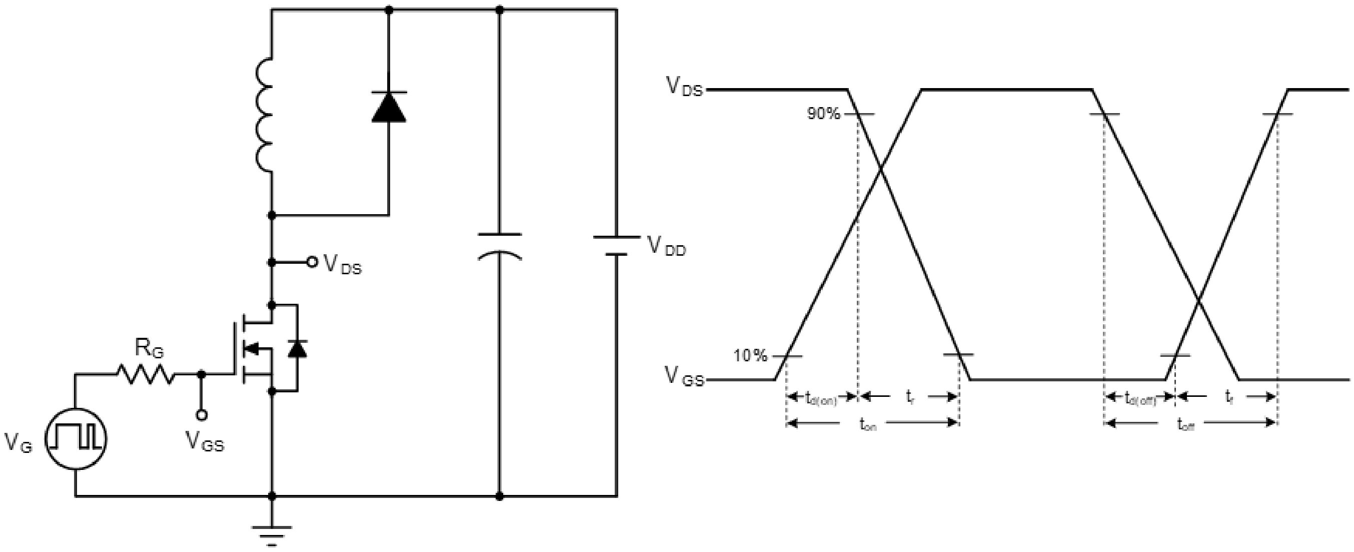


Figure 15. Inductive Load Switching Test Circuit and Waveforms (Figure 13. in the datasheet)

3.5. Source-Drain Diode Characteristics

I_S, and I_{SM}: MOSFET Body Diode Static Performance

Symbol	Parameter	Min	Typ	Max	Unit
I_S	Maximum Continuous Diode Forward Current			19	A
I_{SM}	Maximum Pulse Diode Forward Current			57	A

I_S is symbol as "I = Current, S = Source", I_S is the MOSFET body diode current from the source to drain as maximum continuous current in Figure 16.

I_{SM} is defined as "I = Current, S = Source, M = Maximum Pulsed", I_{SM} is the MOSFET body diode current from the source to drain as maximum pulse current.

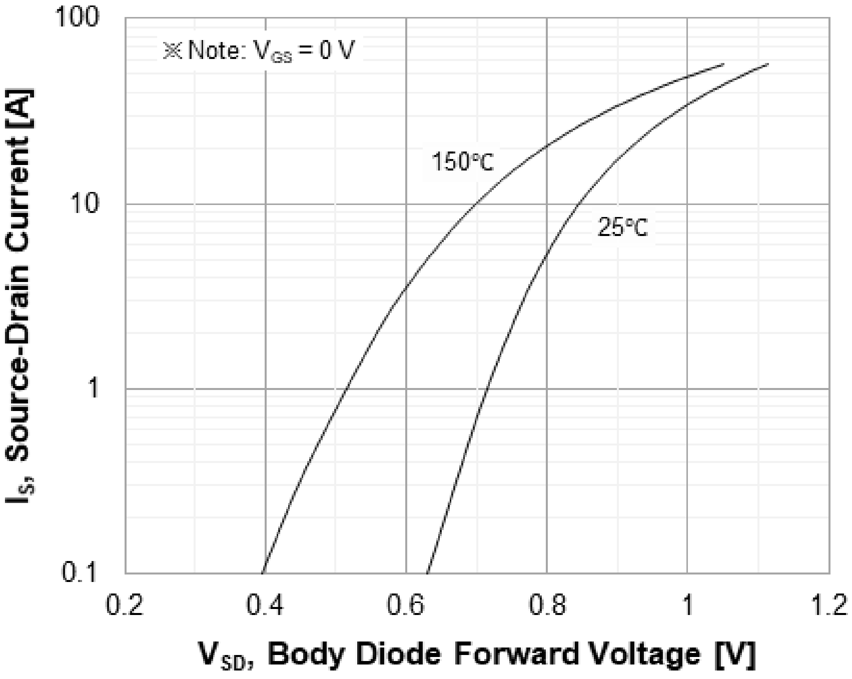


Figure 16. Diode Forward Voltage Characteristics vs. Source-Drain current and Temperature (Figure 4. in the datasheet)

t_{rr}, and Q_{rr}: MOSFET Body Diode Dynamic Performance

Symbol	Parameter	Test Condition	Min	Typ	Max	Unit
t_{rr}	Reverse Recovery Time	V_{DD} = 400V, I_{SD} = 8.5A, dI_F/dt = 100A/µs		274		ns
Q_{rr}	Reverse Recovery Charge			3.33		nC

t_{rr} is defined as "t = Time, r = Reverse, r = Recovery", reverse recovery time is the interval time that MOSFET body diode current is to be 10% of I_{rrm} from zero as shown in Figure 17.
One of sequence is as following, 1) MOSFET body diode is flowing from source to drain, 2) The voltage is applying from drain to source, 3) The current of source to drain is decreasing, 4) The amount of charge in body diode is discharging during t_a, 5) The voltage of drain to source is rising during t_b.

Q_{rr} is defined as “Q = Charge, r = Reverse, r = Recovery”, reverse recovery charge is the amount of charge during t_{rr} duration.

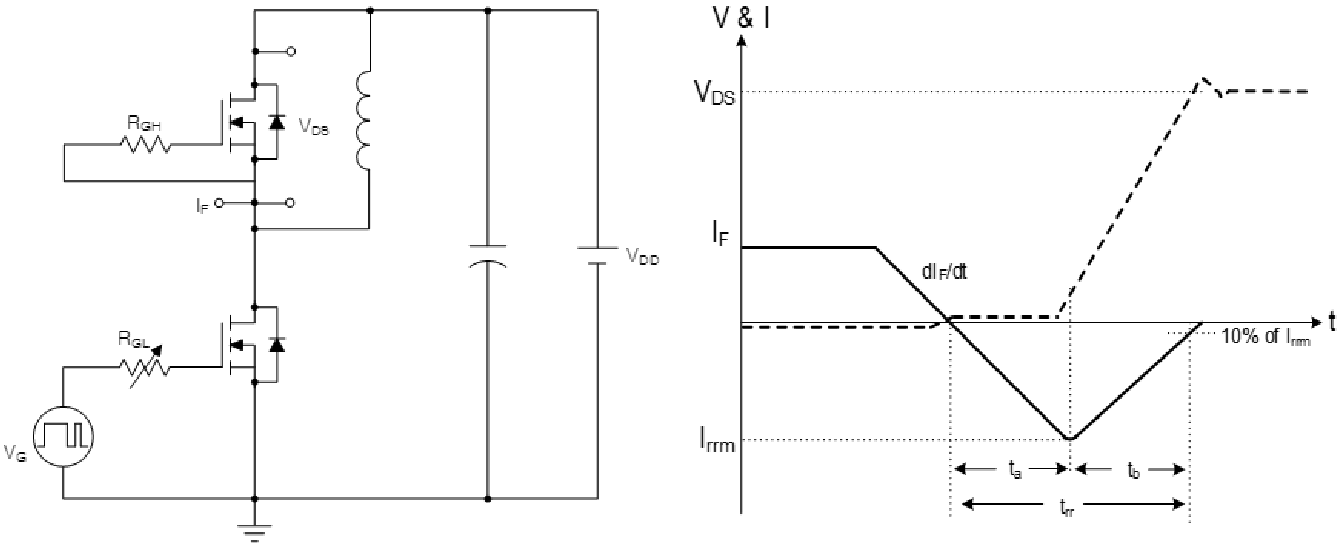


Figure 17. Peak Diode Recovery dv/dt Test Circuit Waveforms (Figure 15. in the datasheet)

4. Document Revision History

Major changes since the last version

Date	Description of change
26-May-2022	First Release

Important Notice