Power MOSFET Electrical Characteristics

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Static Characteristics

Characteristic	Symbol	Unit	Description
Gate leakage current	I_{GSS}	μA	The leakage current that occurs when the specified voltage is applied across gate and source with drain and source short-circuited
Drain cut-off current	I_{DSS}	μA	The leakage current that occurs when a voltage is applied across drain and source with gate and source short-circuited
Drain-source breakdown voltage	$V_{(BR)DSS}$ $V_{(BR)DSX}$	V	The maximum voltage that the device is guaranteed to block between drain and source $V_{(BR)DSS}$: With gate and source short-circuited $V_{(BR)DSX}$: With gate and source reverse-biased
Gate threshold voltage	V_{th}	V	V_{th} stands for "threshold voltage." V_{th} is the gate voltage that appears when the specified current flows between source and drain.
Drain-source on-resistance	$R_{DS\ (ON)}$	Ω	The resistance across drain and source when the MOSFET is in the "on" state
Forward transfer admittance	|Yfs|	S	Also called gm, |Yfs| is the ratio of the drain current variation at the output to the gate voltage variation at the input and is defined as $\|Yfs\| = \Delta I_D / \Delta V_{GS}$. |Yfs| indicates the sensitivity or amplification factor of the power MOSFET. |Yfs| can be read from the I_D-V_{GS} curve.

Dynamic Characteristics

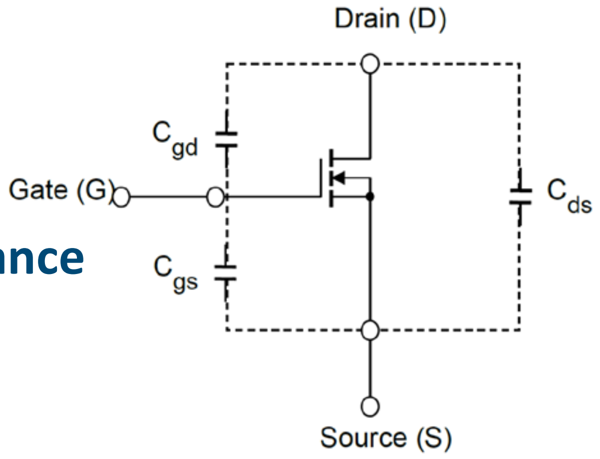
Characteristic	Symbol	Unit	Description
Capacitances	C_{iss} C_{rss} C_{oss}	pF	C_{iss} is the input capacitance, C_{rss} is the reverse transfer capacitance, and C_{oss} is the output capacitance. Capacitances affect the switching performance of a power MOSFET.
Effective output capacitance	$C_{o(er)}$	pF	Effective output capacitance calculated from E_{oss}, which is needed to charge C_{oss}
Gate resistance	r_g	Ω	The internal gate resistance of a MOSFET
Switching time	t_r t_{on} t_f t_{off}	ns	t_r is the rise time, ton is the turn-on time, t_f is the fall time, and t_{off} is the turn-off time.
MOSFET dv/dt capability	dv/dt	V/ns	The resistance across drain and source when the MOSFET is in the "on" state

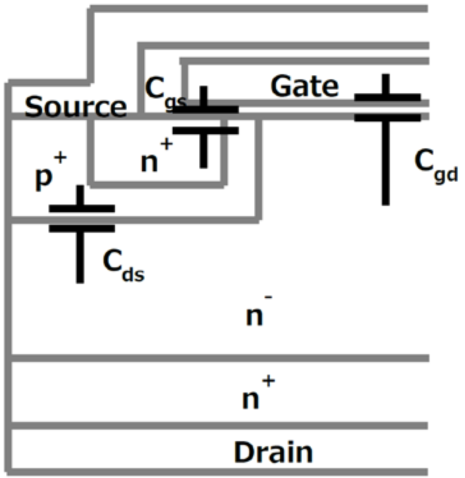
Capacitance characteristics

- **A power MOSFET, the gate is insulated by a thin silicon oxide.**
- **Capacitances**
  - Gate-Drain
    - gate-drain capacitance C_{gd}
    - The structure of the gate electrode
  - Gate-Source
    - gate-source capacitance C_{gs}
    - The structure of the gate electrode
  - Drain-Source terminal
    - drain-source capacitance C_{ds}
    - vertical p-n junction.

Capacitance characteristics

- **Input capacitance**
  - $C_{iss} = C_{gd} + C_{gs}$
- **Output capacitance**
  - $C_{oss} = C_{ds} + C_{gd}$
- **Reverse transfer capacitance**
  - $C_{rss} = C_{gd}$





Input capacitance $(C_{iss}) = C_{gd} + C_{gs}$

Output capacitance $(C_{oss}) = C_{ds} + C_{gd}$

Reverse transfer capacitance $(C_{rss}) = C_{gd}$

Effective output capacitance

- $C_{o(er)}$ **is the effective output capacitance**

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

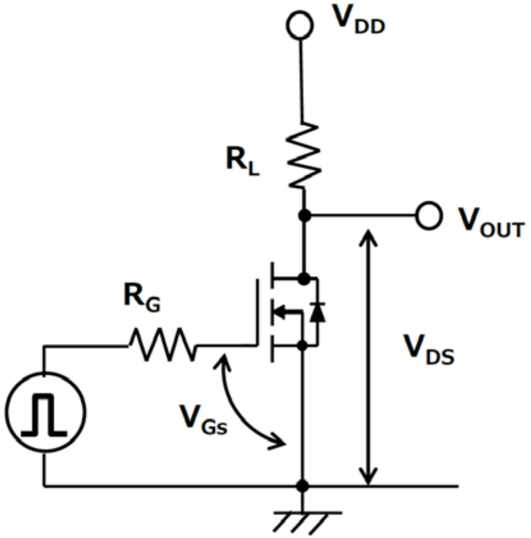
$$C_{o(er)} = \frac{2}{{V_{DS}}^2} \int_0^{V_{DS}} C(v) \times v dv$$

  - C(v) is a function of the VDS-dependent output capacitance Coss.

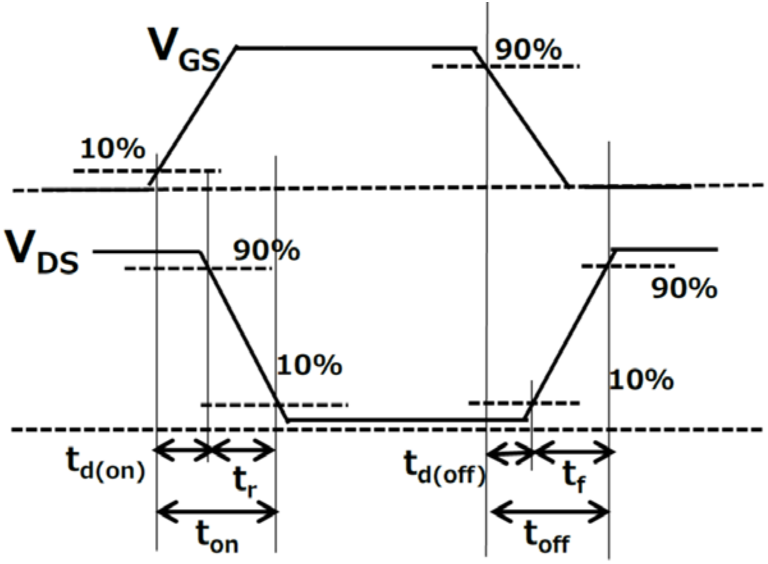
- **Super-junction MOSFETs have a large output capacitance**
- **Switching loss occurs at the turn-on and turn-off of the MOSFET due to the charging and discharging of the output capacitance**

Switching characteristics

- Power MOSFETs are majority-carrier devices
- Faster and capable of switching at higher frequencies



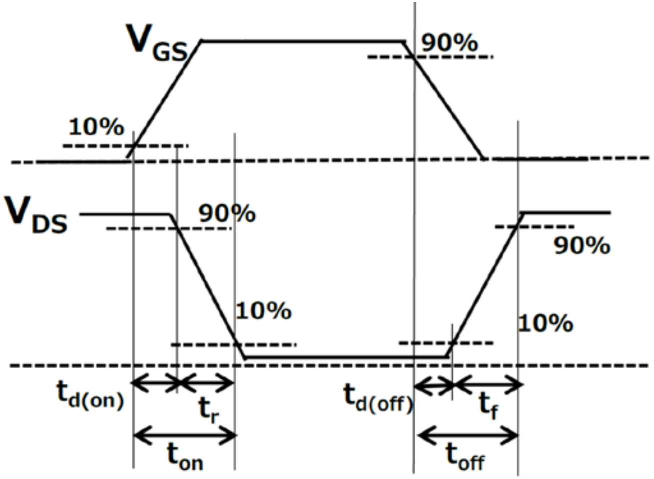
(a) Test Circuit



(b) Input and Output Waveforms

Switching Time

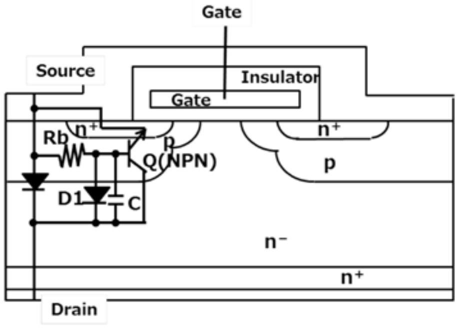
- **$t_{d\ (on)}$: Turn-on delay time**
  - gate-source voltage rises over 10% of V_{GS} until the drain-source voltage reaches 90% of V_{DS}
- **t_r: Rise time**
  - drain-source voltage to fall from 90% to 10% of V_{DS}
- **t_{on}: Turn-on time**
  - td (on) + tr
- **$t_{d\ (off)}$: Turn-off delay time**
  - gate-source voltage drops below 90% of V_{GS} until the drain-source voltage reaches 10% of V_{DS}
- **t_f: Fall time**
  - drain-source voltage to rise from 10% to 90% of V_{DS}
- **t_{off}: Turn-off time**
  - $t_{d\ (off)} + t_f$



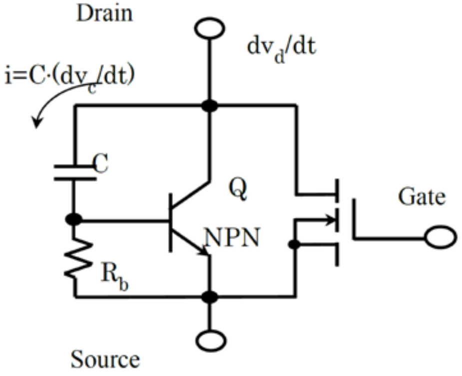
(b) Input and Output Waveforms

MOSFET dv/dt capability

- **The equivalent circuit for a MOSFET consists of one MOSFET in parallel with a parasitic BJT (bipolar junction transistor)**
  - If the BJT turns ON, it cannot be turned off since the gate has no control over it. This phenomenon is known as ´latchup´, which can lead to device destruction.
- **Drain-source voltage is raised sharply with fast switch**
  - High dv/dt causes a current i go through Parasitic capacitance C to charge R_b
    - If the voltage drop exceeds the base-emitter forward voltage (VBE) of the parasitic NPN transistor, it is forced into conduction.



(a) Cross Section of a MOSFET (Parasitic NPN Transistor)



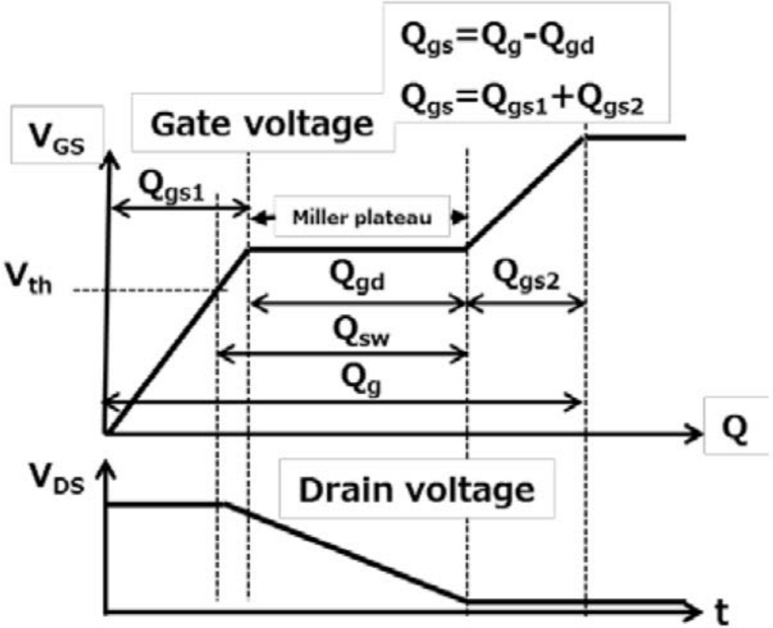
(b) Equivalent Circuit of dv/dt-Induced Turn-On

Charge Characteristics

Characteristic	Symbol	Unit	Description
Total gate charge	Q_g	nC	The amount of charge to apply voltage (from zero to designated voltage) to gate
Gate-source charge 1	Q_{gs1}	nC	The amount of charge required for a MOSFET to begin to turn on (before dropping drain-source voltage)
Gate-drain charge	Q_{gd}	nC	As the MOSFET begins to turn on, the drain-source voltage begins to fall, charging the gate-drain capacitance. The gate-source voltage stops increasing and reaches the Miller plateau. From this point to the ending point of Miller plateau is known as the gate-drain charge period.
Gate switch charge	Q_{sw}	nC	The amount of charge stored in the gate capacitance from when the gate-source voltage has reached Vth until the end of the Miller plateau
Output charge	Q_{oss}	nC	Drain-source charge

Gate charge

- **A power MOSFET turn on, a current flows to the gate, charging the gate-source and gate-drain capacitances.**
- **The gate charge (Q_{gs} + Q_{gd}) is the bare minimum charge required to switch the device on**
  - Q_g = C x V and I_g = C x dv/dt, the Q_g = Time x current
    - $Q_g = i_g \times t$



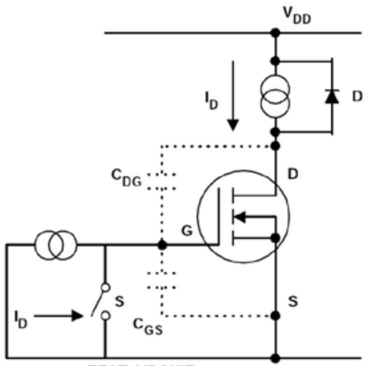
Definition of Total Gate Charge, Q_g

Source-Drain Characteristics

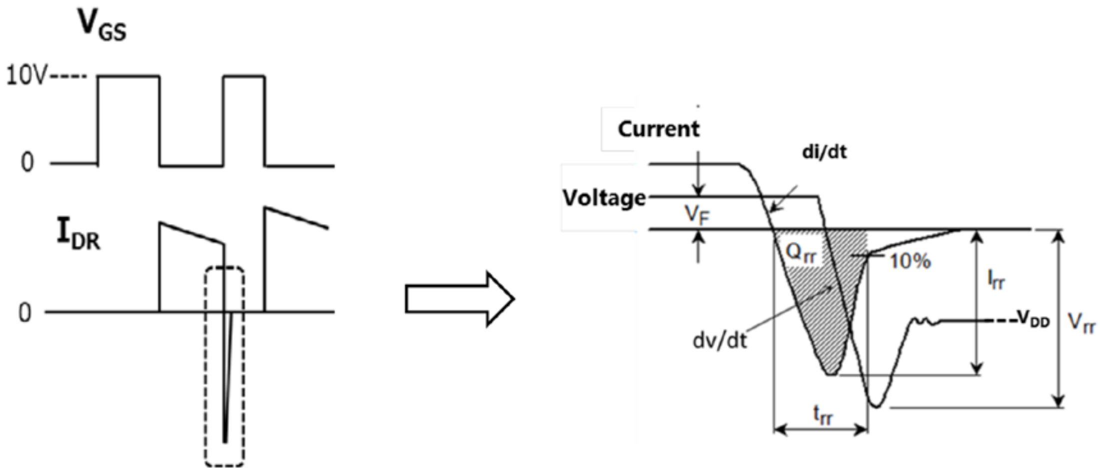
Characteristic	Symbol	Unit	Description
Reverse drain current (DC) Reverse drain current (pulsed)	I_{DR} I_{DRP}	A	The maximum current that can flow to the body diode of a MOSFET in the forward direction
Diode forward voltage	V_{DF}	V	Drain-source voltage that appears when a current is applied to the body diode of a MOSFET in the forward direction
Reverse recovery time	t_{rr}	ns	The time t_{rr} and the amount of charge Q_{rr} required for the reverse recovery current to reach zero during the reverse recovery operation of the body diode under the specified test conditions. The peak current during this period is I_{rr}.
Diode reverse recovery charge	Q_{rr}	µC	
Diode peak reverse recovery current	I_{rr}	A	
Diode dv/dt capability	dv/dt	V/ns	The maximum voltage ramp allowed during the reverse recovery time of the diode

Body Diode Characteristics

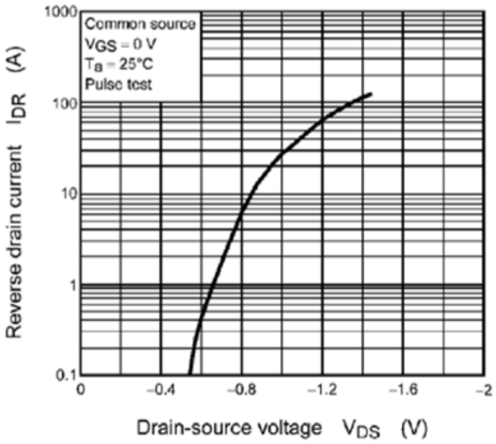
- MOSFET has a equivalent diode structure between source and drain
- Reverse breakdown voltage is same as drain-source voltage V_{DSS}



TEST CIRCUIT



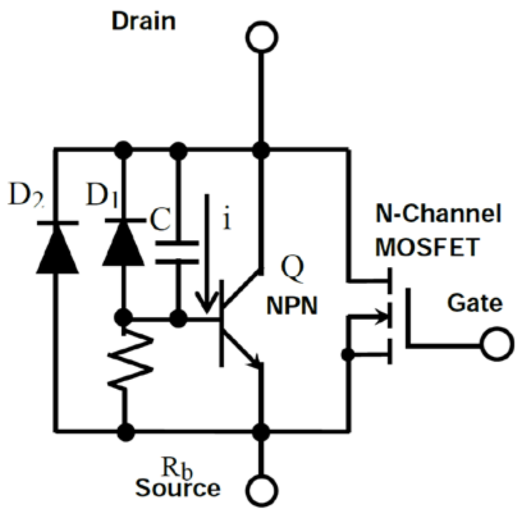
Reverse Recovery Time of the Body Diode in a Power MOSFET



Body diode current characteristics

Body Diode dv/dt Capability

- **Peak diode recovery is defined in datasheet with allowed V_{DS} dv/dt capability**
- **Body diode enters the reverse recovery state and exceeded the peak rate. This causes the drain-source voltage to increase sharply. Gate-source terminals may become higher than the threshold voltage.**
  - High dv/dt causes a current i go through Parasitic capacitance C to charge R_b, causes the parasitic NPN transistor to turn on
  - If the drain-source voltage V_{DS} is high, the parasitic NPN transistor might enter secondary breakdown
  - Diode might suffer a catastrophic failure



(a) dv/dt Equivalent Circuit of the Body Diode