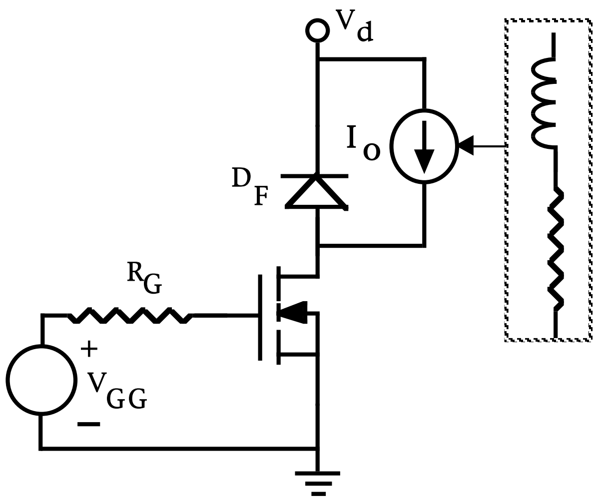
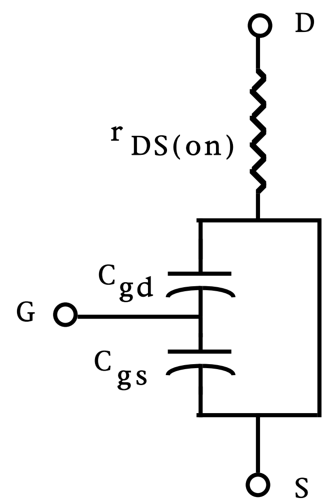
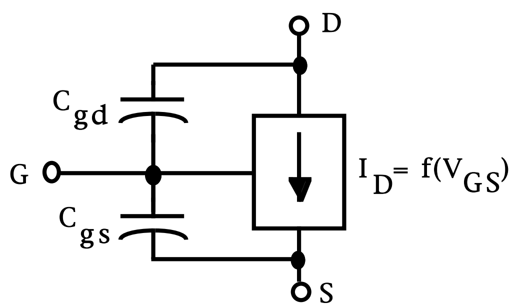
MOSFET Switching Models for Buck Converter



• Buck converter using power MOSFET.

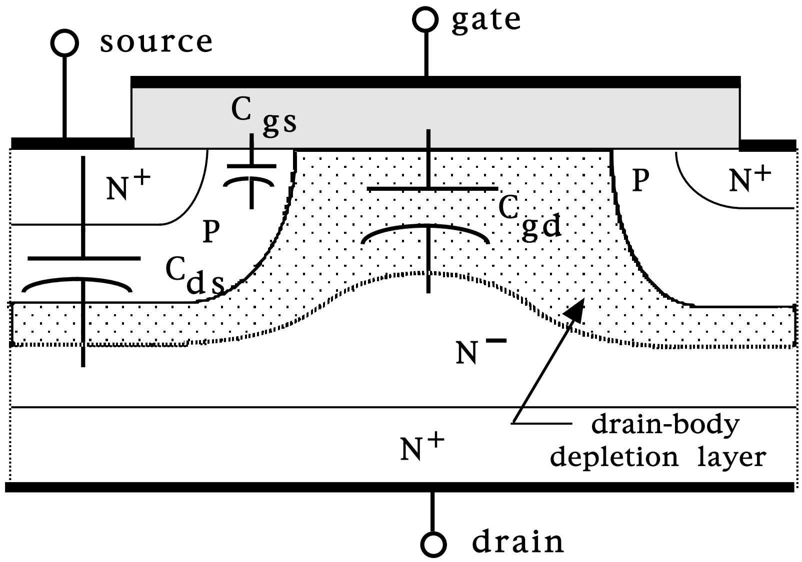


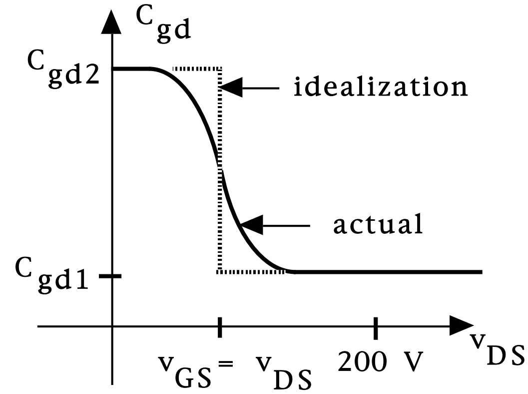
• MOSFET equivalent circuit valid for on-state (triode) region operation.



• MOSFET equivalent circuit valid for off - state (cutoff) and active region operation.

MOSFET Capacitances Determining Switching Speed

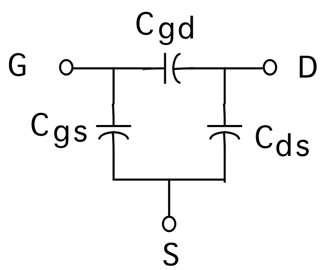




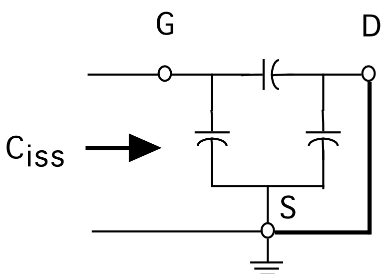
- Gate-source capacitance Cgs approximately constant and independent of applied voltages.
- Gate-drain capacitance C_{gd} varies with applied voltage. Variation due to growth of depletion layer thickness until inversion layer is formed.

Internal Capacitances Vs Spec Sheet Capacitances

MOSFET internal capacitances

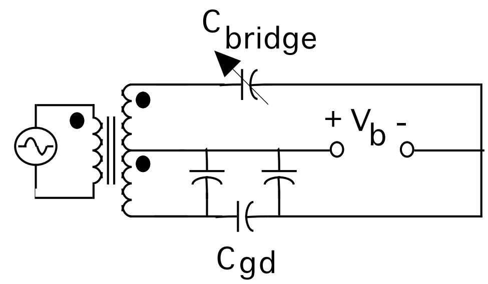


Input capacitance



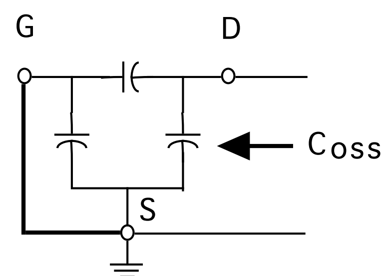
$C_{iss} = C_{gs} + C_{gd}$

Reverse transfer or feedback capacitance



Bridge balanced (Vb=0) Cbridge = Cgd $= C_{rss}$

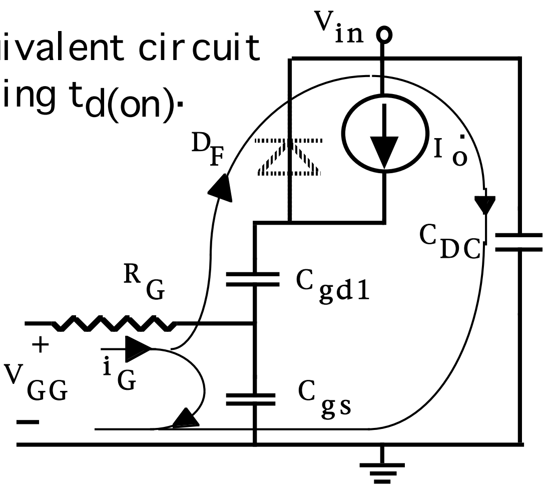
Output capacitance



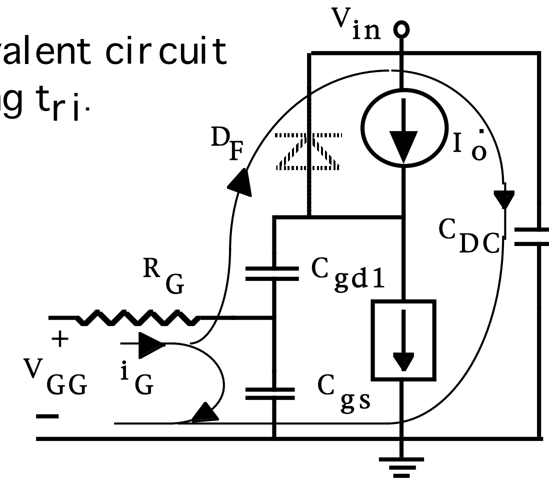
$C_{oss} = C_{gd} + C_{ds}$

Turn-on Equivalent Circuits for MOSFET Buck Converter

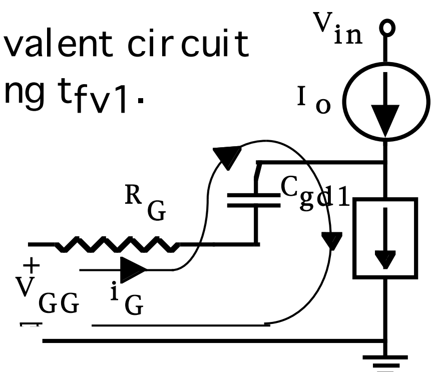
- Equivalent circuit during $t_{d(on)}$.



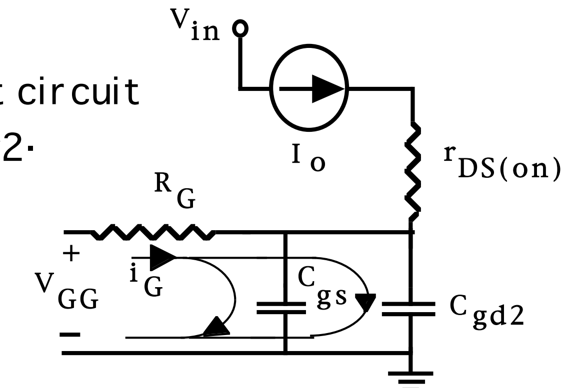
- Equivalent circuit during t_{ri}.



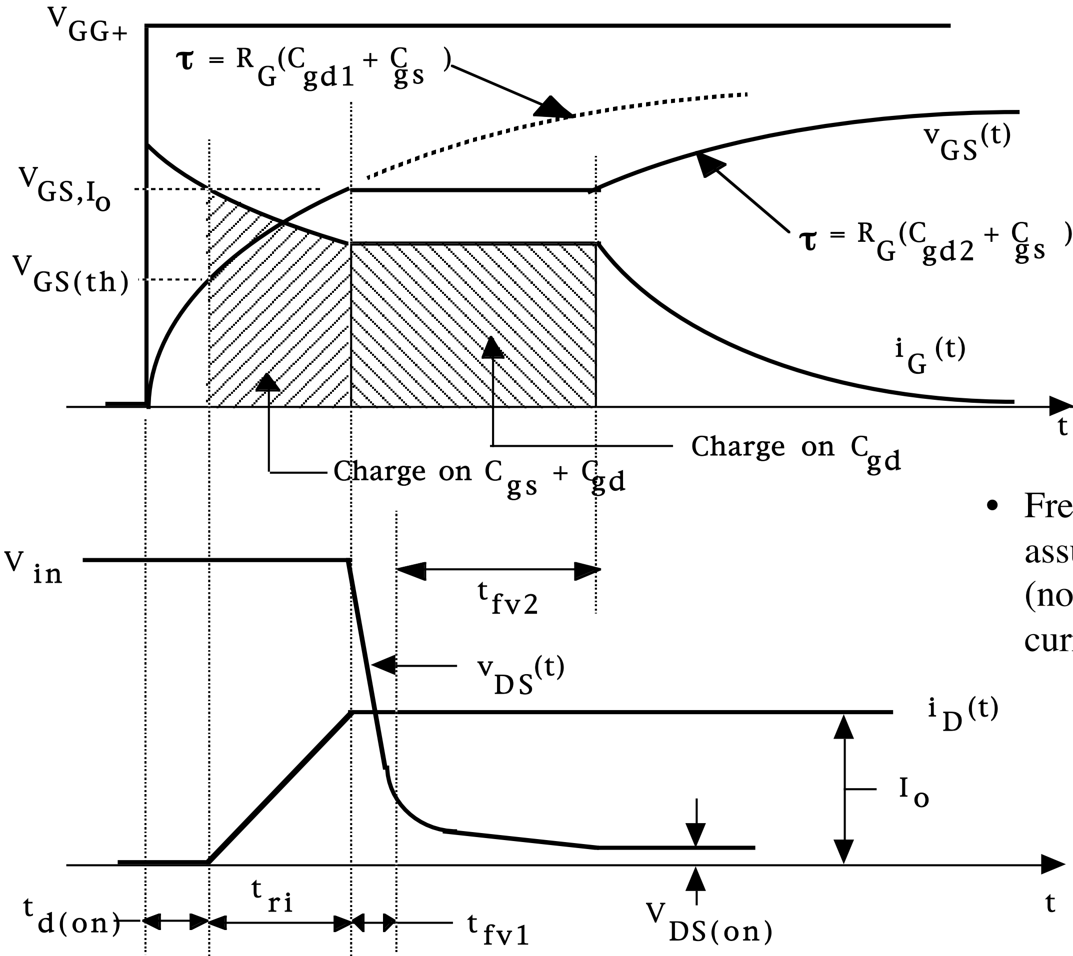
- Equivalent circuit during t_{fv1}.



- Equivalent circuit during t_{fv2}.

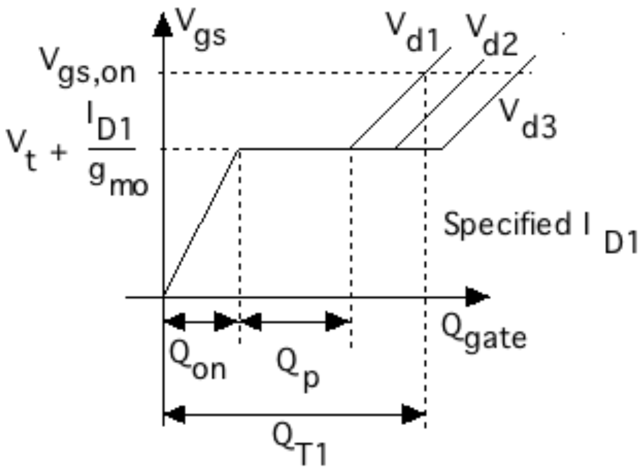


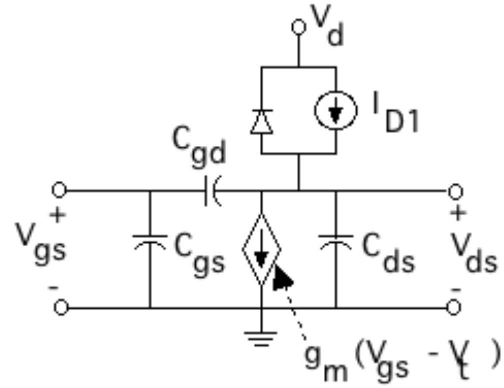
MOSFET-based Buck Converter Turn-on Waveforms

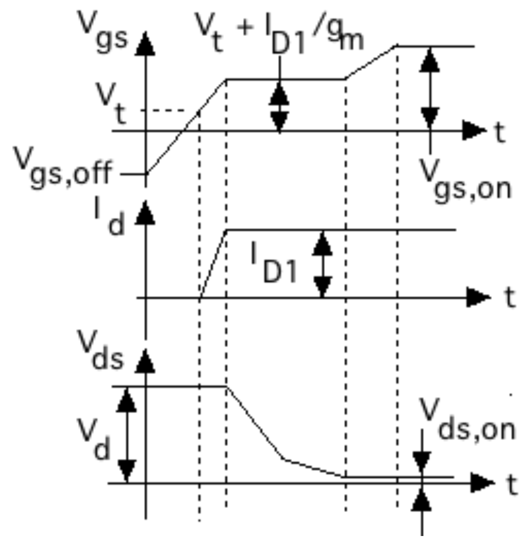


- Free-wheeling diode assumed to be ideal. (no reverse recovery current).

Turn-on Gate Charge Characteristic





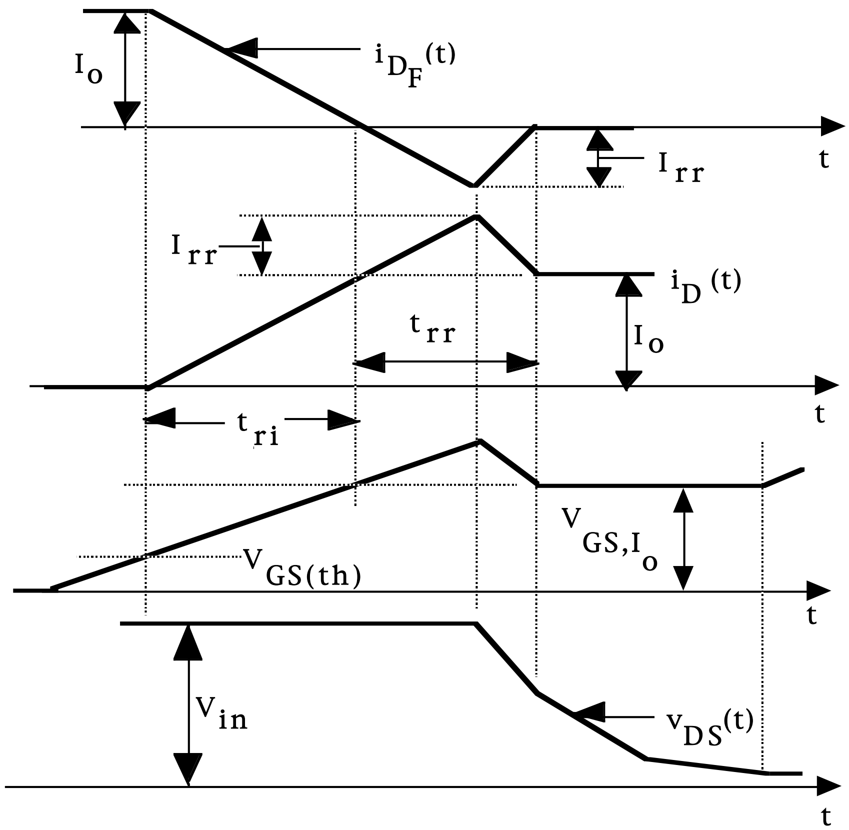


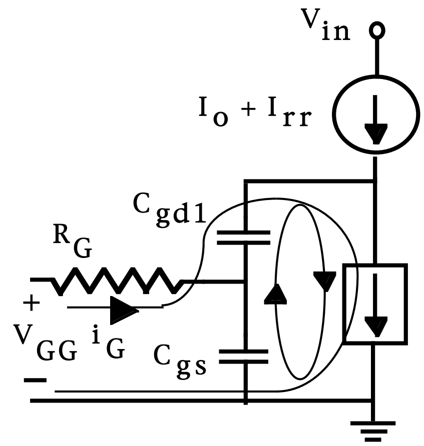
$$Q_{on} = \int_{V_{gs,off}}^{(V_t+I_{D1}/g_m)} [C_{gs}(V_{gs}) + C_{gd}(V_{gs})]\, V_{gs}\, dV_{gs}$$

$$Q_p = \int_{V_d}^{V_{ds,on}} C_{gd}(V_{ds})\, V_{ds}\, dV_{ds}$$

$$Q_T = Q_{on} + Q_p + \int_{(V_t+I_{D1}/g_m)}^{V_{gs,on}} [C_{gs}(V_{gs}) + C_{gd}(V_{gs})]\, V_{gs}\, dV_{gs}$$

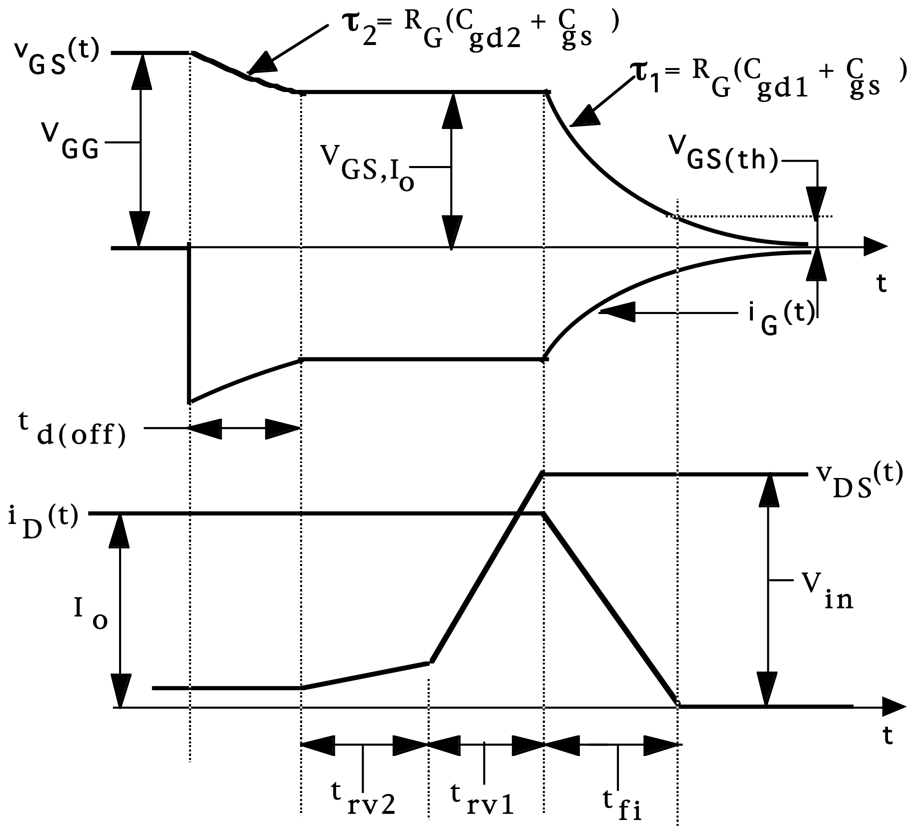
Turn-on Waveforms with Non-ideal Free-wheeling Diode





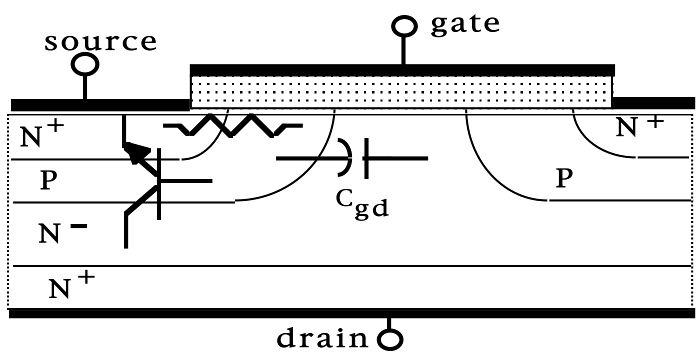
- Equivalent circuit for estimating effect of free -wheeling diode reverse recovery.

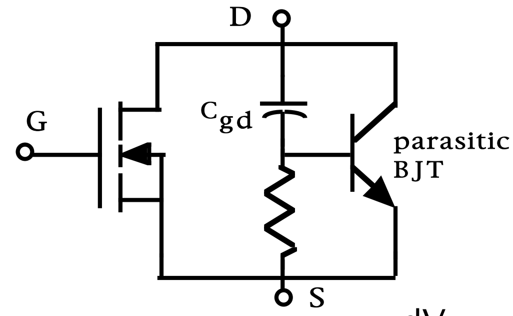
MOSFET-based Buck Converter Turn-off Waveforms



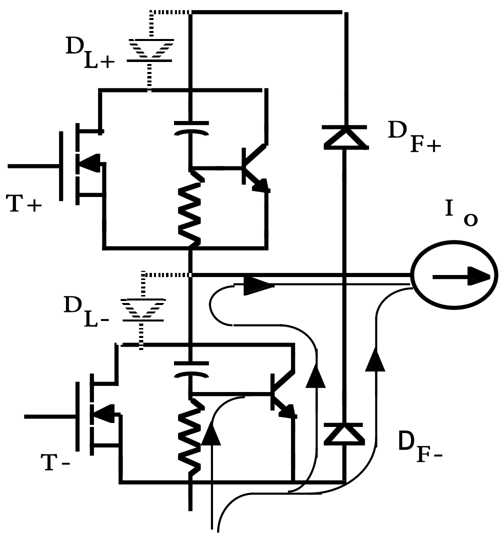
- Assume ideal free-wheeling diode.
- Essentially the inverse of the turn-on process.
- Model quanitatively using the same equivalent circuits as for turn-on. Simply use correct driving voltages and initial conditions

dV/dt Limits to Prevent Parasitic BJT Turn-on





- Large positive $C_{gd} \frac{dV_{DS}}{dt}$ could turn on parasitic BJT.



- Turn-on of T_+ and reverse recovery of D_{f-} will produce large positive $C_{gd} \frac{dv_{DS}}{dt}$ in bridge circuit.

- Parasitic BJT in T_- likely to have been in reverse active mode when D_{f-} was carrying current. Thus stored charge already in base which will increase likeyhood of BJT turn-on when positive $C_{gd} \frac{dv_{DS}}{dt}$ is generated.

Maximum Gate-Source Voltage

- $V_{GS(max)}$ = maximum permissible gate-source voltage.

- If $V_{GS} > V_{GS(max)}$ rupture of gate oxide by large electric fields possible.

- E_{BD}(oxide) ≈ 5-10 million V/cm
  - Gate oxide typically 1000 anstroms thick
  - $V_{GS(max)} < [5x10^6] [10^{-5}] = 50$ V
  - Typical $V_{GS(max)}$ 20 - 30 V

- Static charge on gate conductor can rupture gate oxide
  - Handle MOSFETs with care (ground yourself before handling device)
  - Place anti-parallel connected Zener diodes between gate and source as a protective measure