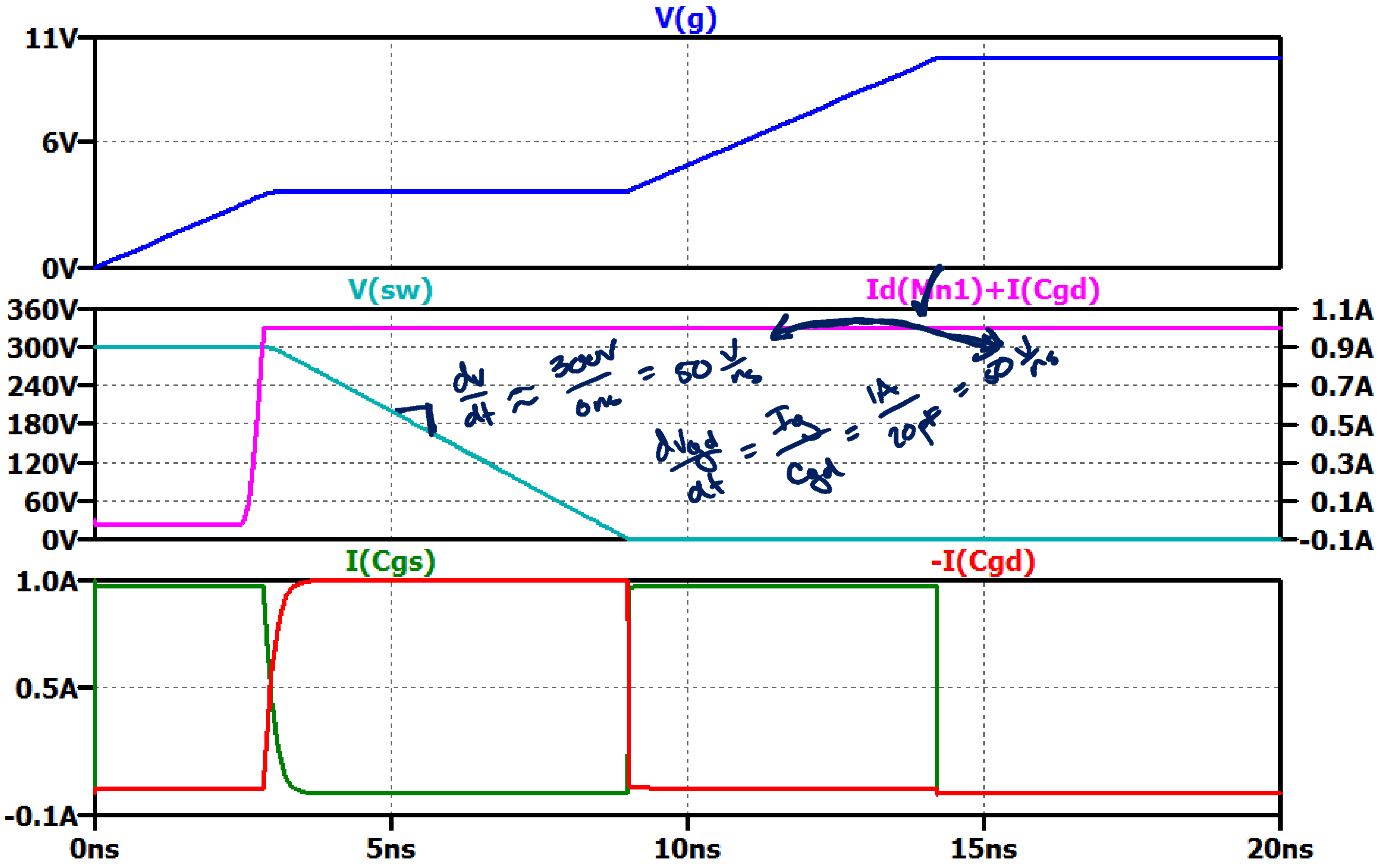
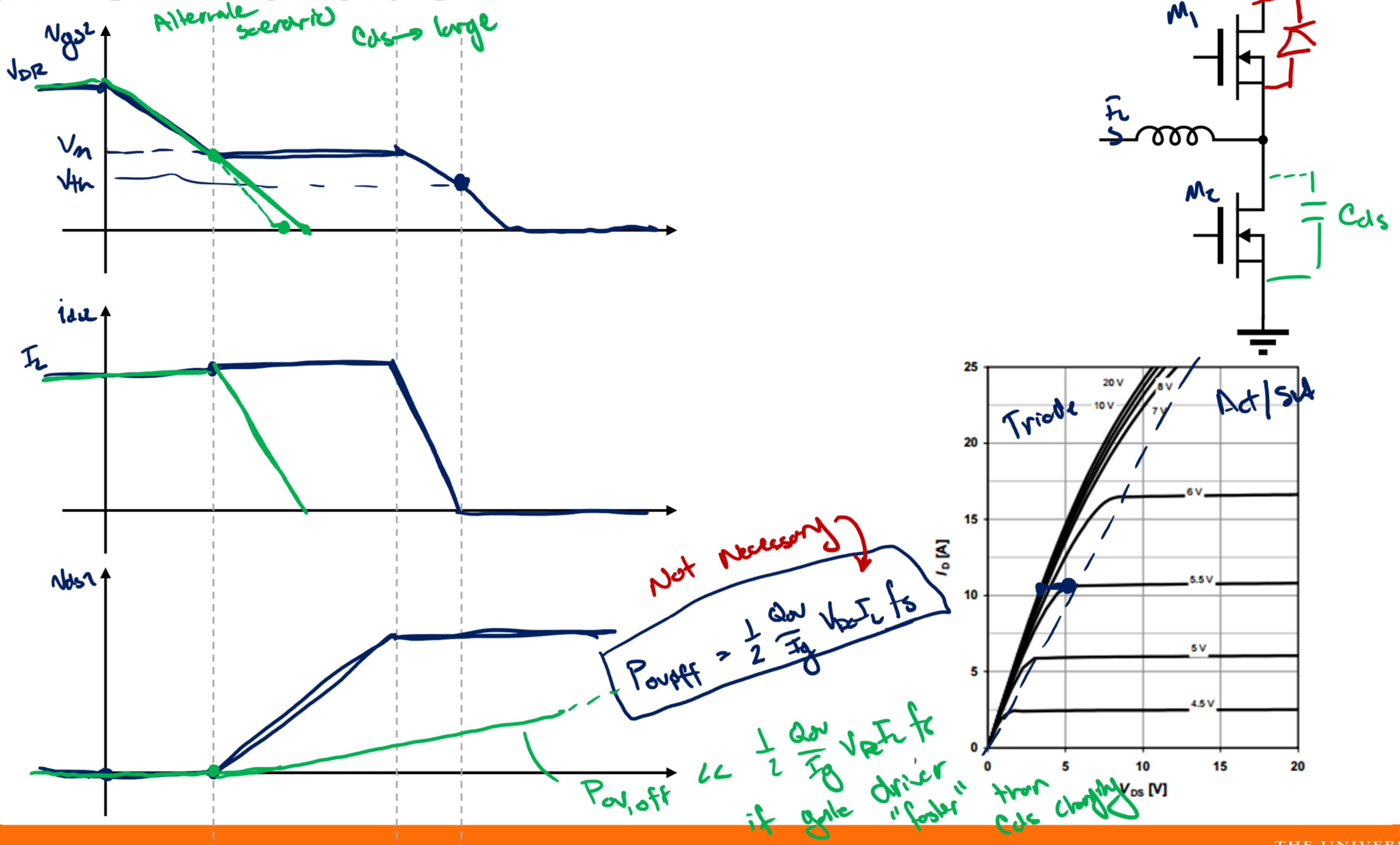
Simulation Waveforms – Turn On

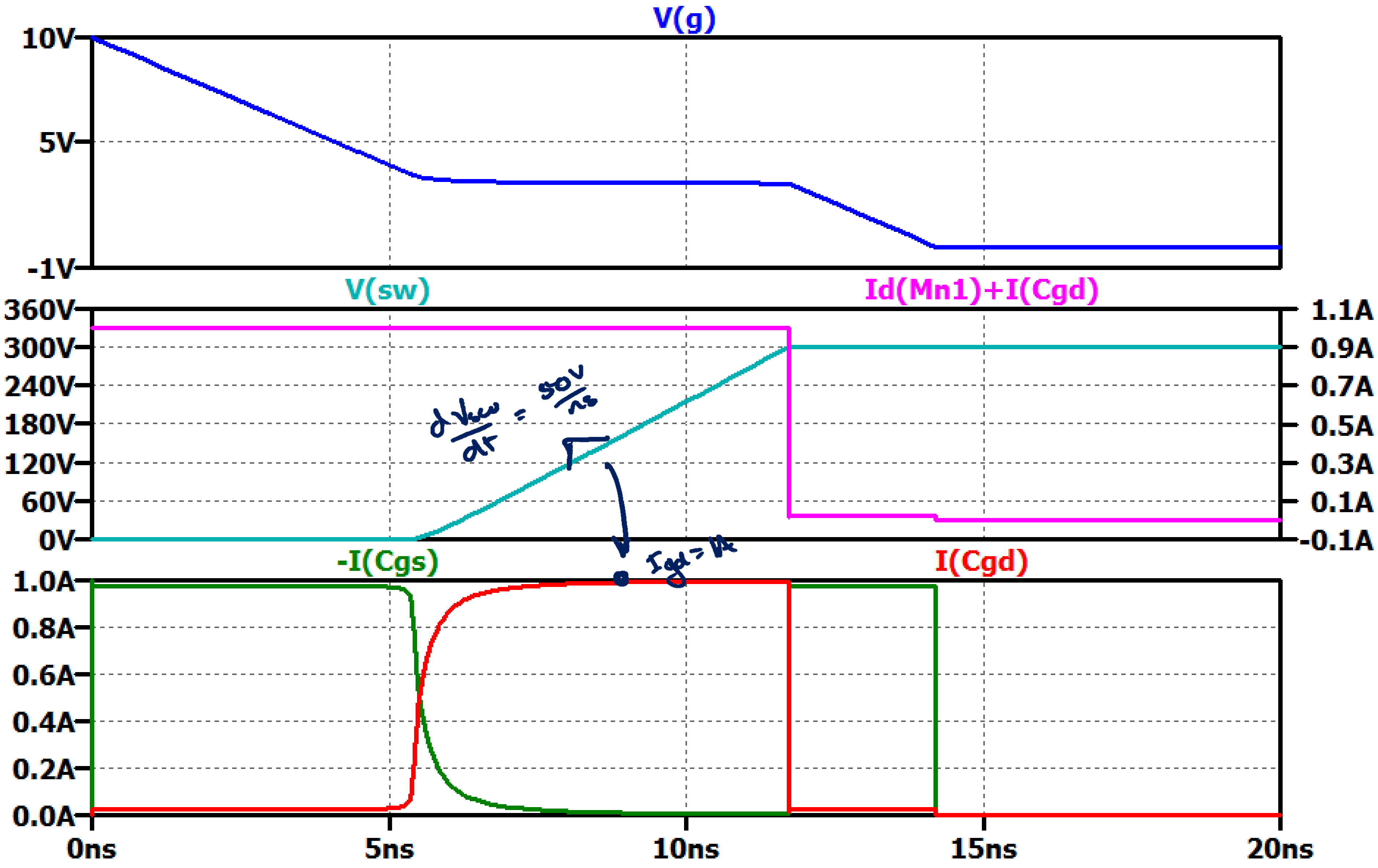


Turn-Off Transition

(M_2, $I_L > 0$)



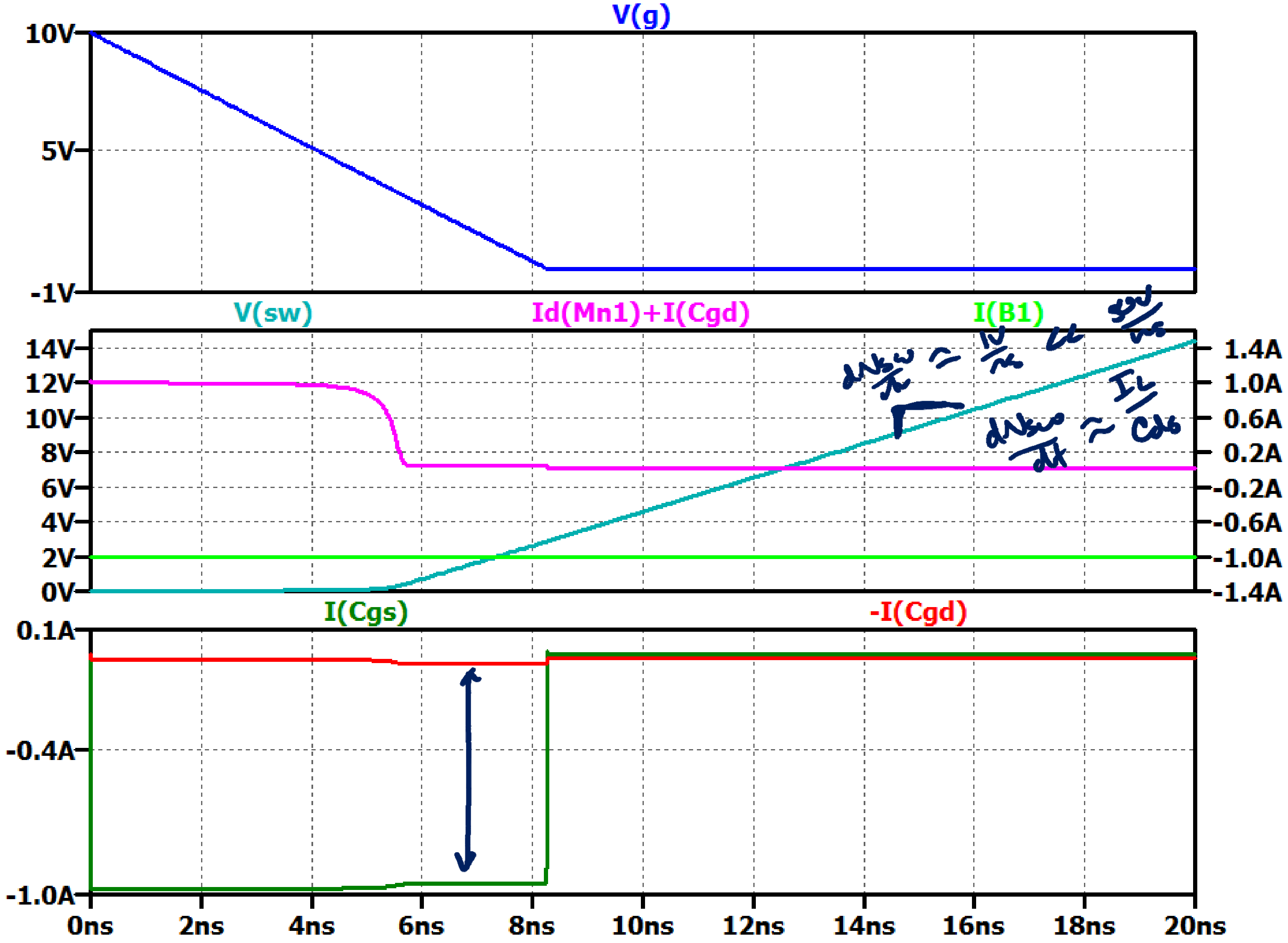
Turn-Off



V(g)
10V
5V
-1V
V(sw)
Id(Mn1)+I(Cgd)
360V
300V
240V
180V
120V
60V
0V
1.1A
0.9A
0.7A
0.5A
0.3A
0.1A
-0.1A
-I(Cgs)
I(Cgd)
1.0A
0.8A
0.6A
0.4A
0.2A
0.0A
0ns
5ns
10ns
15ns
20ns

Turn-Off (Drain Dominated)

Add Cds



Gate- vs. Drain-Limited Switching

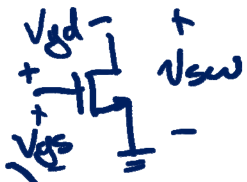
Drain-Limited turn-off

$$\frac{dv_{sw}}{dt} \approx \frac{I_L}{C_{ds}}$$

Gate driver turns off before v_{sw} rises substantially

$$P_{ov,off} \approx 0 \ll \frac{1}{2}\frac{Q_{ov}}{I_g} V_{dc} I_L f_s$$

Gate-Limited turn-off



$$v_{sw} = v_{gs} - v_{gd}$$

$$\frac{dv_{sw}}{dt} = \frac{dv_{gs}}{dt} - \frac{dv_{gd}}{dt}$$

$\frac{dv_{gs}}{dt} \approx 0$ (during miller plateau)

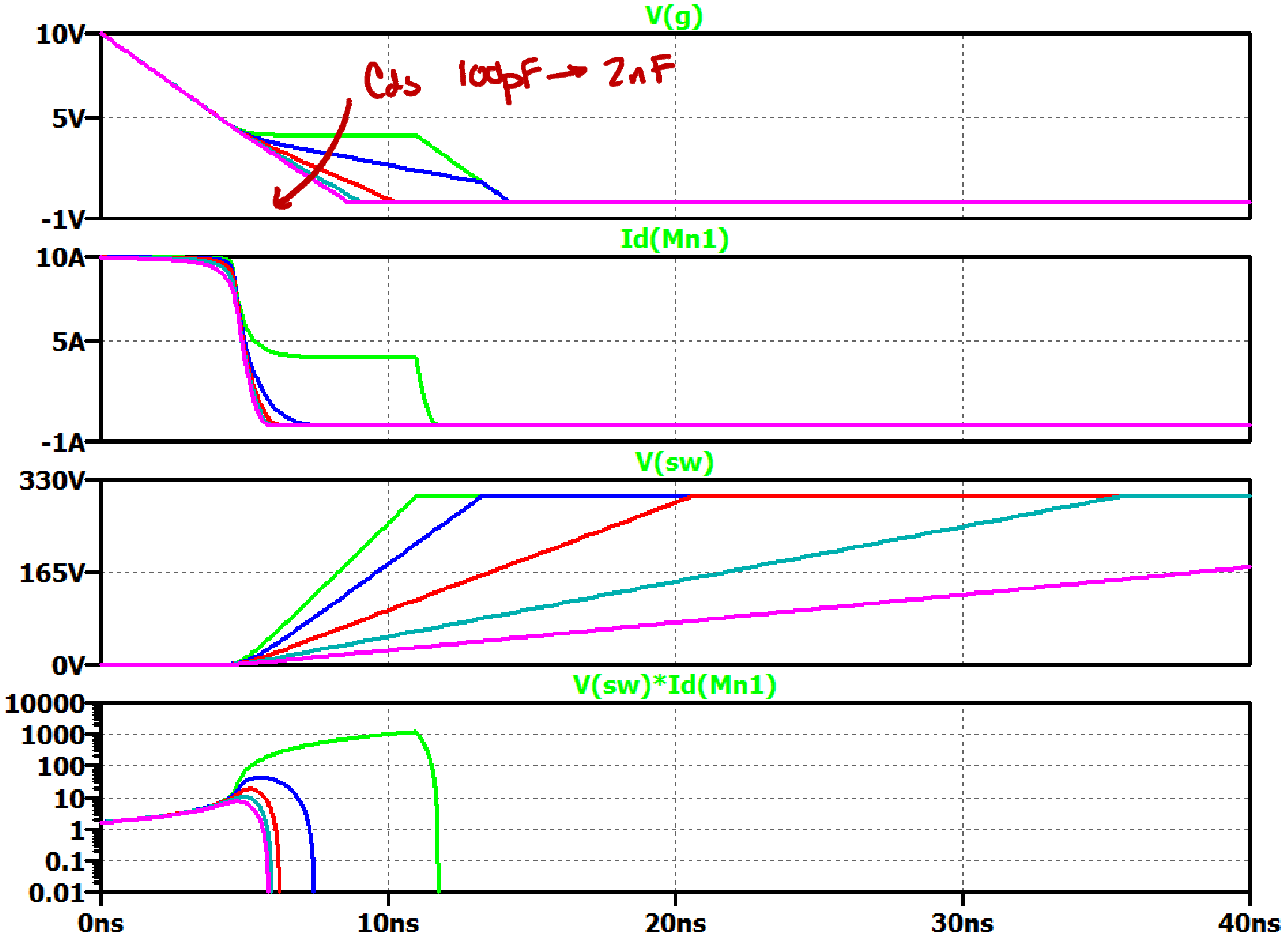
$$\frac{dv_{sw}}{dt} = -\frac{I_g}{C_{gd}}$$

If $\frac{I_L}{C_{ds}} \gg \left|\frac{I_g}{C_{gd}}\right|$ → full $P_{ov,off} = \frac{1}{2}\frac{Q_{ov}}{I_g} V_{dc} I_L f_s$

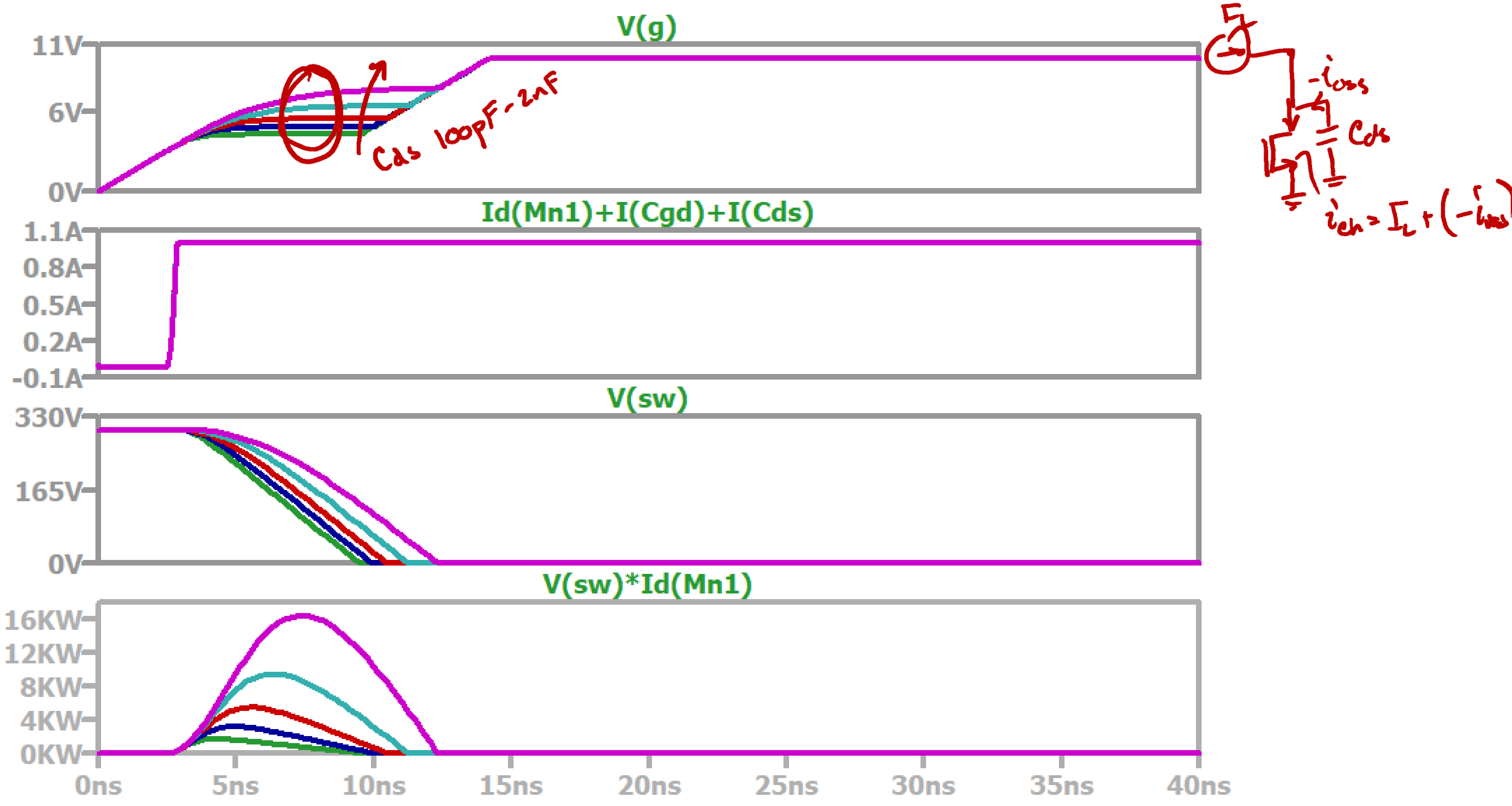
If $\frac{I_L}{C_{ds}} \ll \left|\frac{I_g}{C_{gd}}\right|$ → $\approx$ zero $P_{ov,off}$

Influence tradeoff by any of these 4 parameters

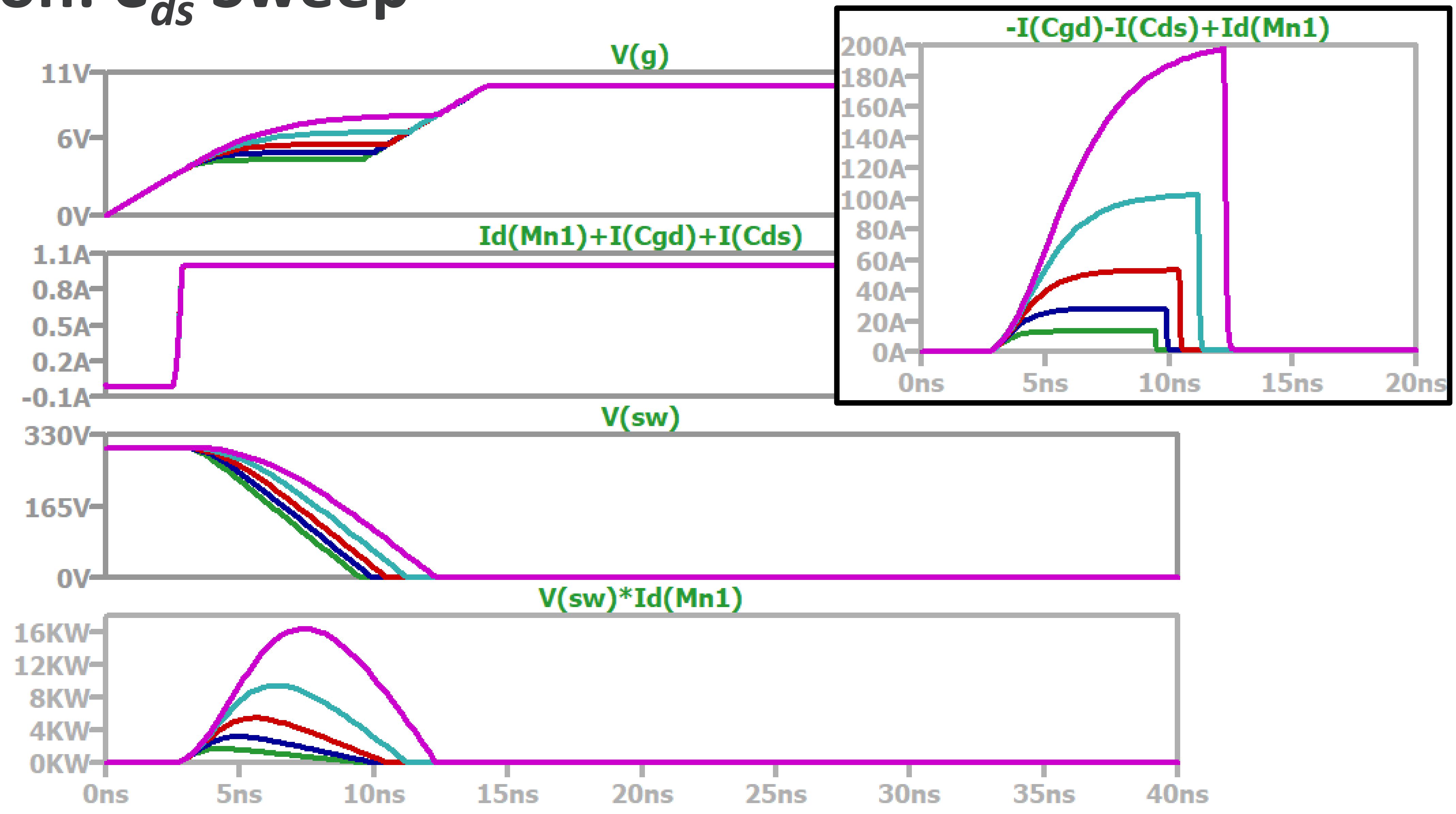
Simulation Results: C_{ds} Sweep



Turn-on: C_{ds} Sweep



Turn-on: C_{ds} Sweep



Limitations on Switching Speed

For all cases of P_{ov}, faster switching helps

$$P_{ov(on)} = \frac{1}{2}\frac{Q_{ov}}{I_g} V_{DC} I_L f_s$$

$$P_{ov(off)} = \begin{cases} \approx \phi & \text{if } \frac{I_g}{C_{gd}} \gg \frac{I_L}{C_{ds}} \\ \frac{1}{2}\frac{Q_{ov}}{I_g} V_{DC} I_L f_s & \text{if } \frac{I_g}{C_{gd}} \ll \frac{I_L}{C_{ds}} \end{cases}$$

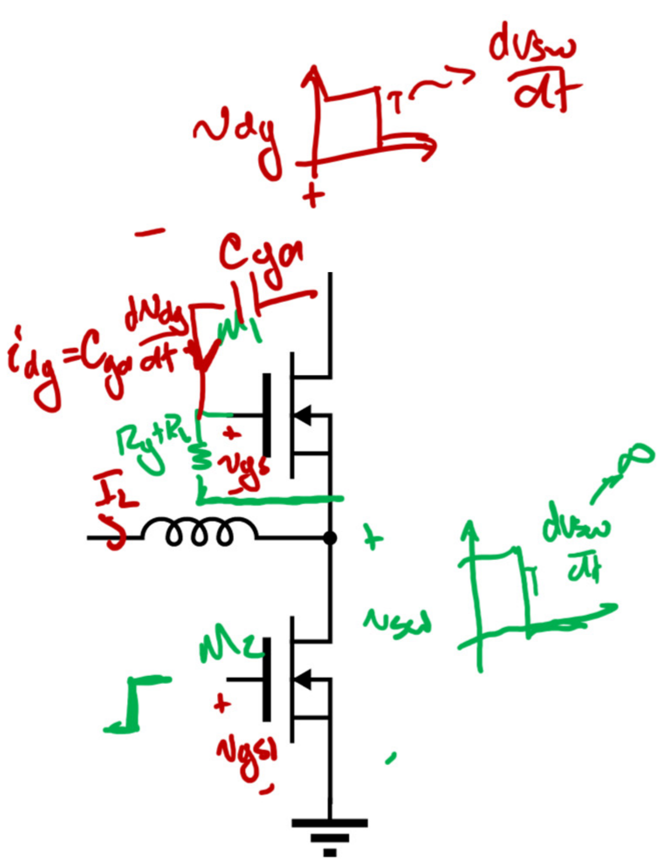
} I_g max is best

Limits:

(1) $I_{gmax} = \frac{V_{gs(max)}}{R_g}$ → transistor limitation w/ conventional gate drive

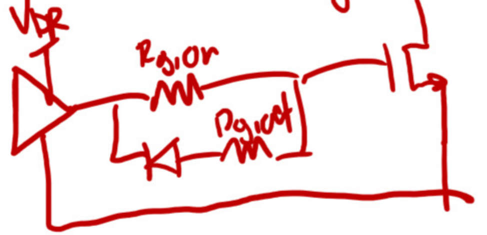
(2) overshoot / Ringing / EMI from high $\frac{dv_{sw}}{dt}$

(3) Cross-talk / shoot-through loss

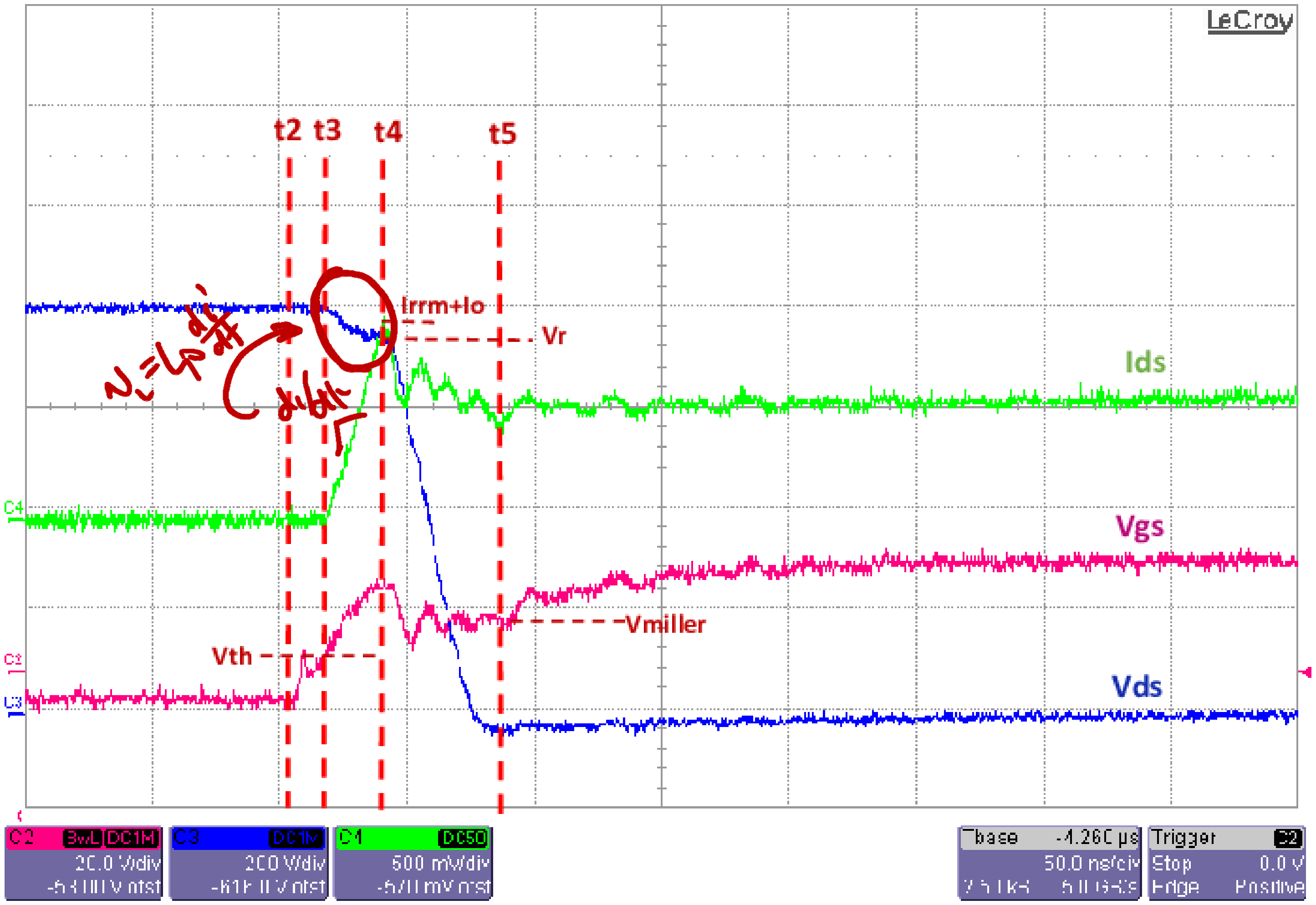


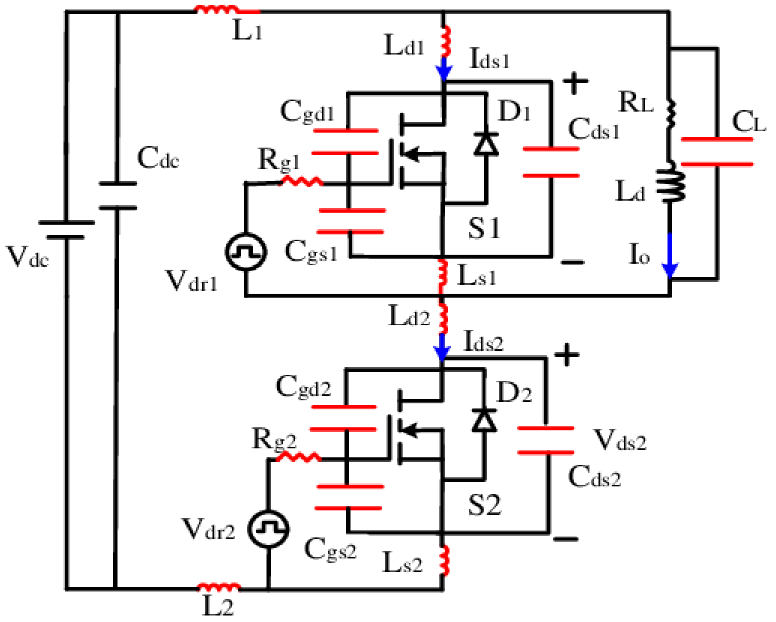
to combat cross-talk

$R_{g,off} \ll R_{g,on}$



Switching Waveforms





S. Eskandari et al. (2018). "Accurate Analytical Switching Loss Model for High Voltage SiC MOSFETs Includes Parasitics and Body Diode Reverse Recovery Effects."

Switching Losses in a Half Bridge