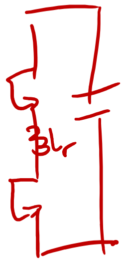
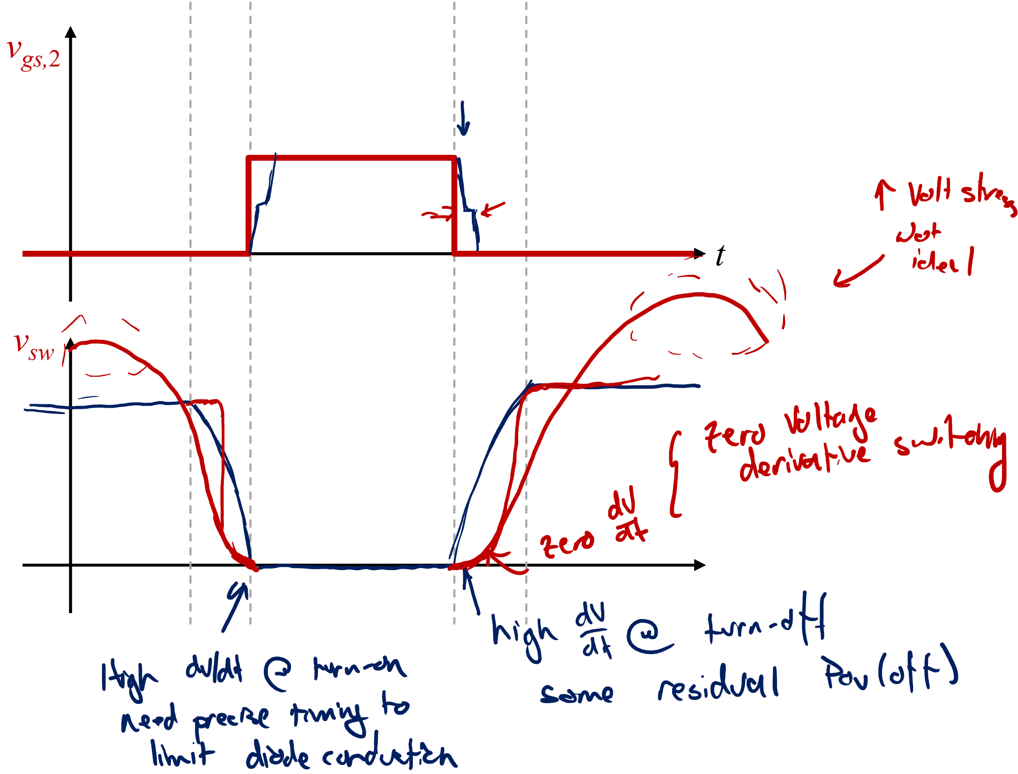
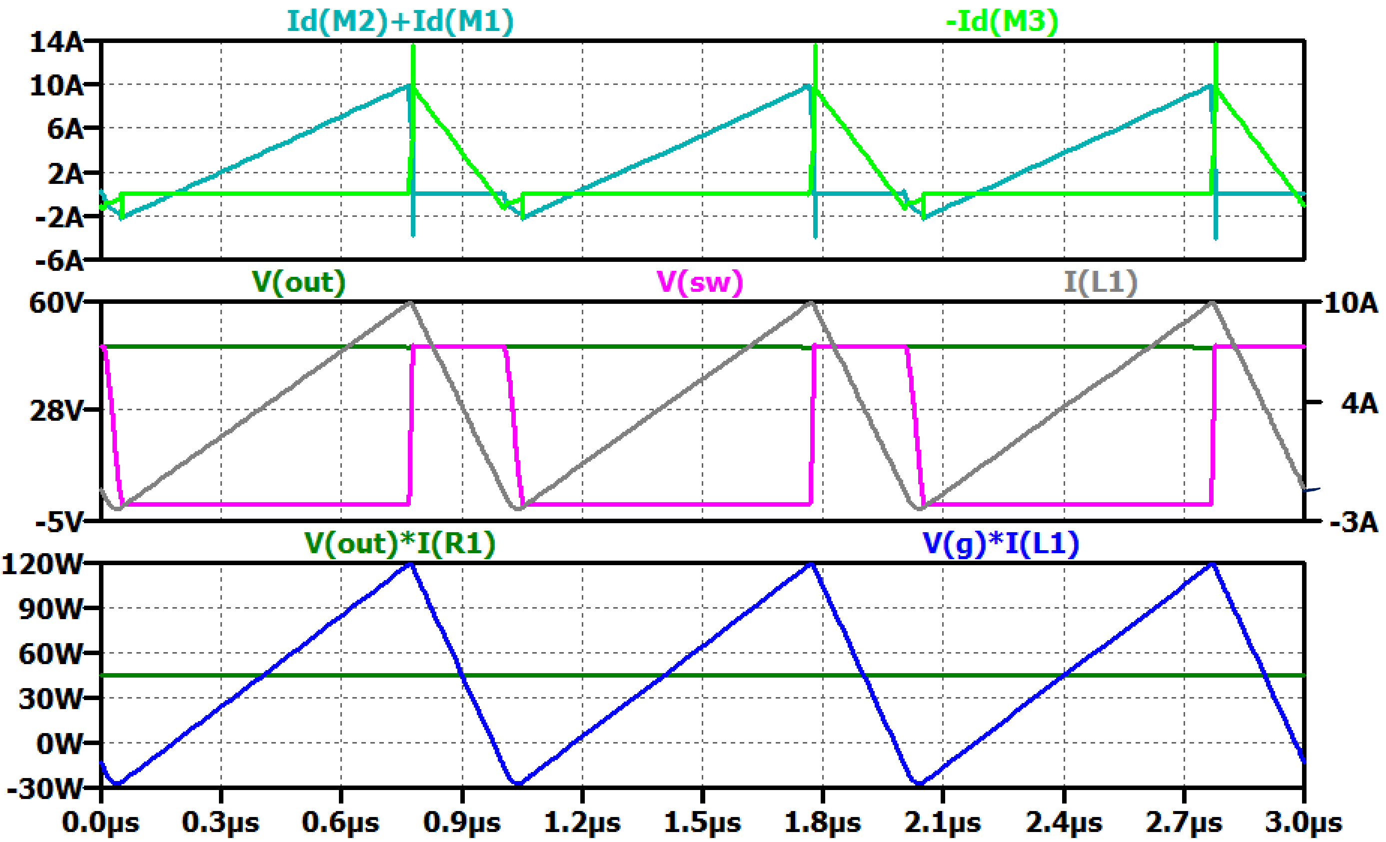
Ideal Switching Waveforms

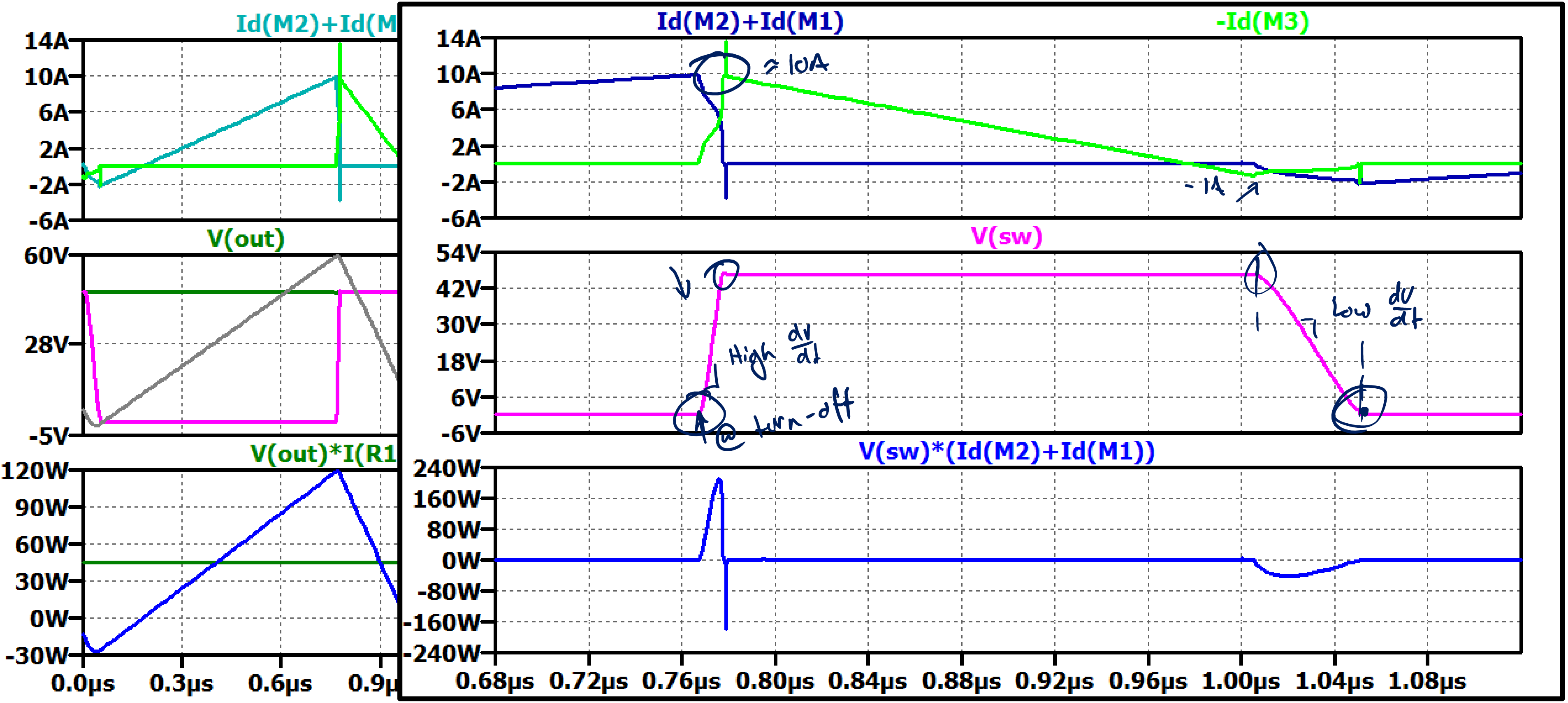




Synchronous Simulation (L3)



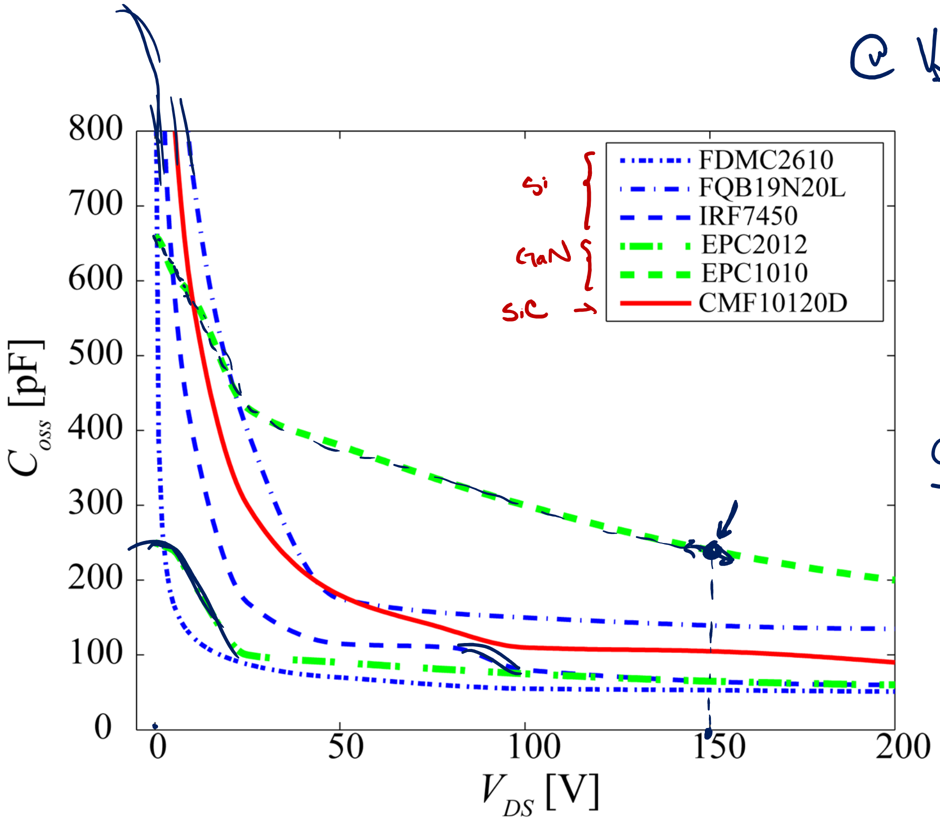
Synchronous Simulation (L3)



Capacitive switching loss

ANALYSIS OF NONLINEAR CAPACITANCES

Example Device C_{oss} $= C_{ds} + C_{gd} \approx C_{ds}$



C_{oss} is a small-signal measurement

@ V_{DS} $\quad \hat{i} = C\Big|_{V_{ds}=V_{DS}} \frac{d\hat{v}}{dt}$

$Q_{tot} \neq CV_{DS}$

$\Delta q = C\Big|_{V_{DS}} \Delta V_{ds}$

Curve fit model:

$$C_{ds} = \frac{C_{jo}}{\left(1 + \frac{V_{ds}}{V_{jo}}\right)^m}$$

often $m = 1/2$

- Empirical model

Datasheet Reported Capacitance

infineon

IPB60R385CP

13 Typ. capacitances

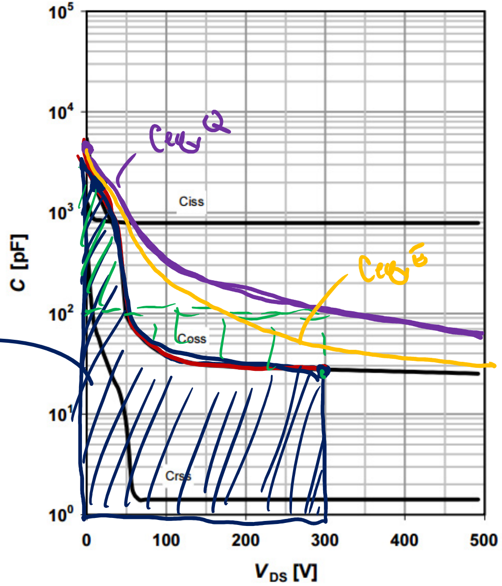
$C = f(V_{DS})$; $V_{GS} = 0$ V; $f = 1$ MHz

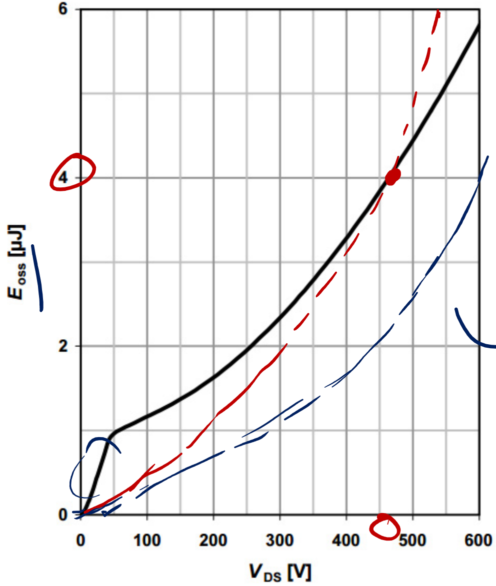
14 Typ. Coss stored energy

$E_{oss} = f(V_{DS})$

← less common for datasheets to include

$Q_c C$
$V_{DS} = 300V$

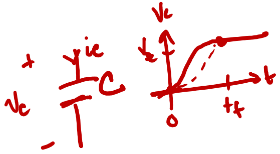




for linear cap
$E = \frac{1}{2}CV^2$

$\frac{1}{2}CV^2$

Modeling Nonlinear Capacitances



Linear

Charge @ V_{DC}

$$Q_c = \int_0^{t_f} i_c(t)\,dt$$

$$Q_c = \int_0^{t_f} C \frac{dv_c}{\cancel{dt}} \cancel{dt}$$

$$Q_c = \int_0^{V_{DC}} C\,dv_c$$

assume C constant

$$Q_c = C \int_0^{V_{DC}} (1)\,dv_c = C V_{DC}$$

Energy @ V_{DC}

$$E_c = \int_0^{t_f} i_c \cdot v_c\,dt$$

$$E_c = \int_0^{t_f} C \frac{dv_c}{\cancel{dt}} v_c \cancel{dt}$$

$$E_c = \int_0^{V_{DC}} C\, v_c\, dv_c$$

$$E_c = C \int_0^{V_{DC}} v_c\,dv_c = C \left.\frac{v_c^2}{2}\right|_0^{V_{DC}} = \frac{1}{2} C V_{DC}^2$$

Nonlinear

$$\boxed{Q_c = \int_0^{V_{DC}} C(v_c)\,dv_c}$$

$$\boxed{E_c = \int_0^{V_{DC}} C(v_c)\, v_c\, dv_c}$$

Cannot simplify further in nonlinear case

Energy and Charge Equivalents

Linear equivalent capacitances can match a single characteristic of the full nonlinear characteristic

Charge

$$Q_c = \int_0^{V_{DC}} C(v_c)\,dv_c = C_{eq,Q} V_{DC}$$

$$\boxed{C_{eq,Q} = \frac{1}{V_{DC}} \int_0^{V_{DC}} C(v_c)\,dv_c}$$

Linear capacitance that will have the same total charge stored at V_{DC} as the nonlinear cap

Energy

$$E_c = \int_0^{V_{DC}} C(v_c)\,v_c\,dv_c = \frac{1}{2} C_{eq,E} V_{DC}^2$$

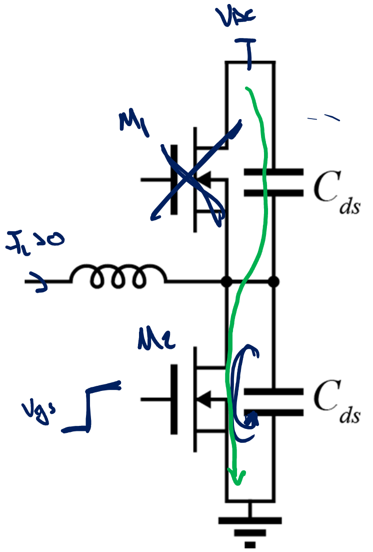
$$\boxed{C_{eq,E} = \frac{2}{V_{DC}^2} \int_0^{V_{DC}} C(v_c)\,v_c\,dv_c}$$

Linear cap with same total energy at V_{DC} as nonlinear cap

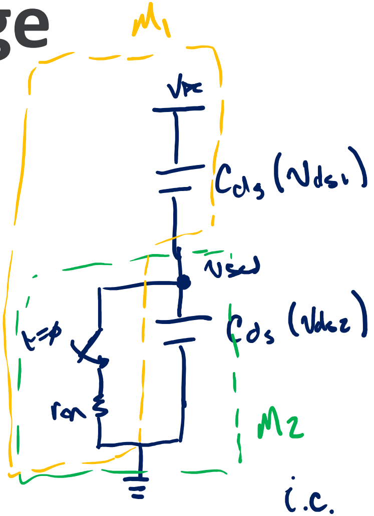
Interesting: $C_{eq,Q} = \langle C(v_c) \rangle \big|_{V_{DC}}$

is the average capacitance on the curve

C_{oss} Losses in a Half Bridge



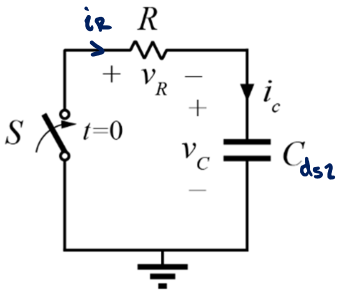
turn-on equiv. circuit



i.c. $v_{sw}(t=0) = V_{DC}$

M_2 Energy Loss

i.c. $v_c(t=0) = V_{DC}$



$v_R = -v_{sw}$

$i_R = i_c = C_{ds2}(v_c)\dfrac{dv_c}{dt}$

$E_R = \int_0^\infty v_R \cdot i_R \, dt$

$E_R = \int_0^\infty (-v_{sw})\, C_{ds2}(v_{sw}) \dfrac{dv_{sw}}{dt}\, dt$

$E_R = \int_{-V_{DC}}^{0} (-v_{sw})\, C_{ds2}(v_{sw})\, dv_{sw} = \underline{\int_0^{V_{DC}} v_{sw}\, C_{ds2}(v_{sw})\, dv_{sw}}$

$E_R = E_c = \underline{\int_0^{V_{DC}} v_c\, C(v_c)\, dv_c}$

$v_c = v_{sw}$

$c = C_{ds2}$

By insight:

$\boxed{E_R = E_c = \frac{1}{2} C_{eq,Q,E} V_{DC}^2}$