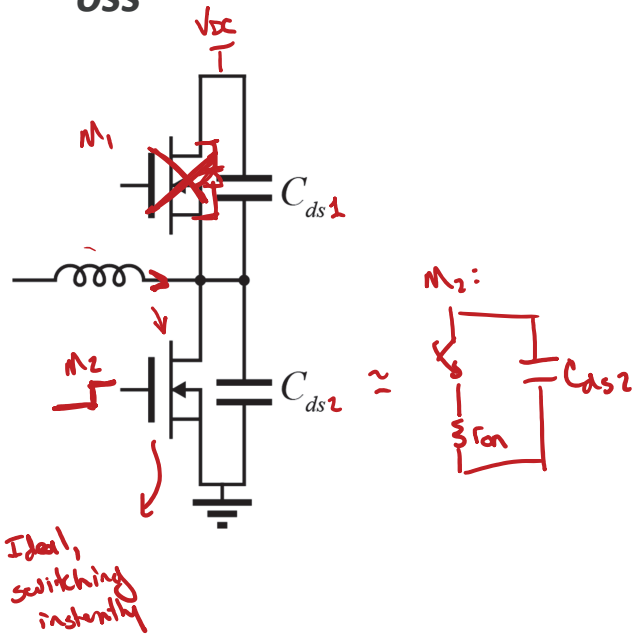
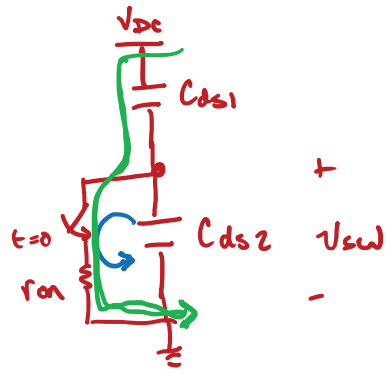
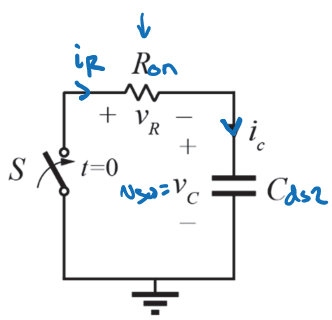
C_{oss} Losses in a Half Bridge





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

M_2 Energy Loss



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

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

$$i_R = i_c = C\frac{dv_c}{dt}$$
$$v_R = -v_c$$

$$E_R = \int_0^\infty C\frac{dv_c}{\cancel{dt}}(-v_c)\,\cancel{dt}$$

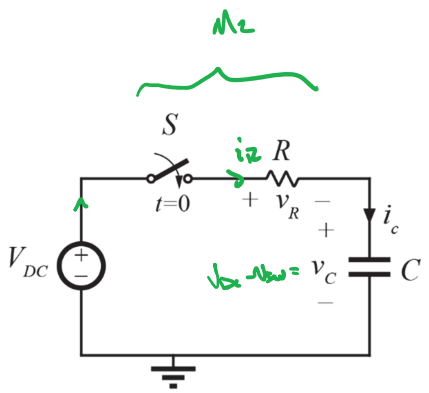
$$E_R = \int_{V_{DC}}^{\phi} (-v_c)\, C\, dv_c$$

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

nonlinear

Insight: $E_R = \frac{1}{2} C_{eq,E} V_{DC}^2$

M_1 Energy Loss



i.c. $v_c(t<0) = \phi$

$$E_R = \int_0^\infty i_R v_R \, dt \qquad i_R = i_c = C\frac{dv_c}{dt}, \quad v_R = V_{DC} - v_c$$

Cds1

$$E_R = \int_0^\infty C\frac{dv_c}{\cancel{dt}}\left(V_{DC} - v_c\right)\cancel{dt}$$

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

$$\boxed{E_R = V_{DC}\underbrace{\int_0^{V_{DC}} C\, dv_c}_{Q} - \underbrace{\int_0^{V_{DC}} C v_c \, dv_c}_{E}}$$

$V_{DC}\, Q - E_c$

Insight: $E_R = V_{DC}\left(V_{DC} C_{eq,Q}\right) - \frac{1}{2} C_{eq,E} V_{DC}^2$

Total Half Bridge C_{oss} Loss

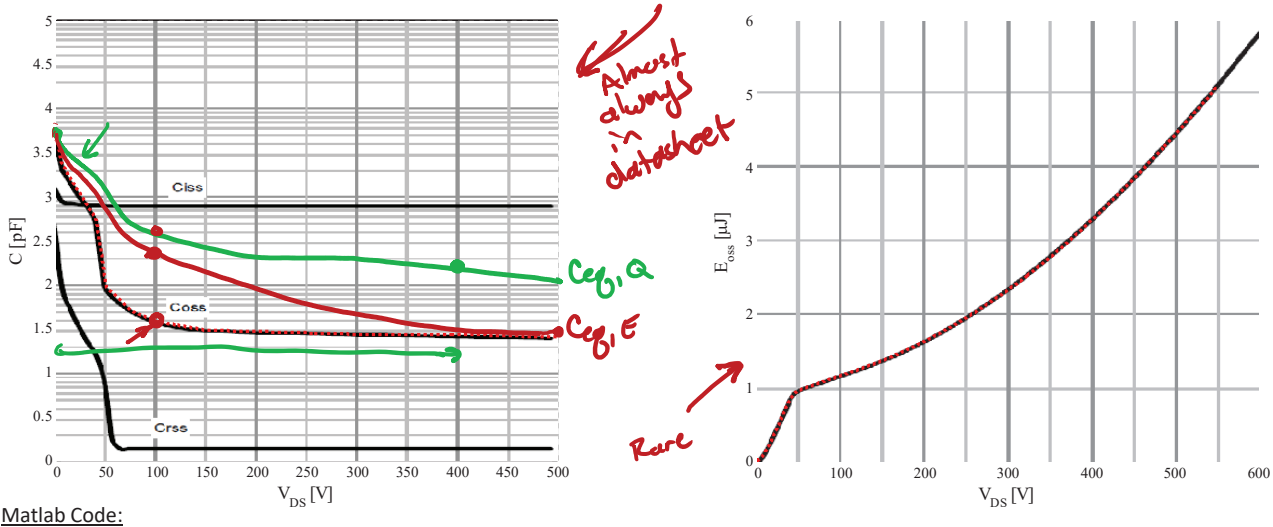
$$\boxed{E_{tot} = \frac{1}{2} C_{eq,E(M_2)} V_{DC}^2 + V_{DC}^2 C_{eq,Q(M_1)} - \frac{1}{2} C_{eq,E(M_1)} V_{DC}^2}$$

If M_1 & M_2 are identical $C_{ds1} = C_{ds2}$

then $E_{tot} = V_{DC}^2 C_{eq,Q}$!

total energy lost depends only on charge-equivalent.

Energy Equivalent



Matlab Code:

```
Vdc = 550;

Vds = [0    5    10   40  50 75 100 150 200 300 400 500 600];
Coss = [5500 2500 1900 550 95 50 38  30  29  27  27  25  24]*1e-12;

vx = 0.01:.01:Vdc;
Cx = 10.^interp1(Vds,log10(Coss),vx,'linear');
E = cumtrapz(vx, Cx.*vx);
Ceq_e = 2*(E)./vx.^2;
```

Xnew

← Interpolate

← $\int C V_c \, dV_c = E$

Nonlinear Capacitance Extraction

- http://web.eecs.utk.edu/~dcostine/personal/PowerDeviceLib/DigiTest/index.html

Datasheet Reported Capacitance

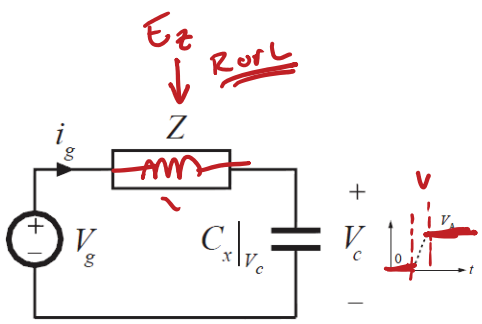
Dynamic characteristics

Input capacitance	C_{iss}	V_{GS}=0 V, V_{DS}=100 V, f=1 MHz	-	790	-	pF
Output capacitance	C_{oss}		-	38	-	
Effective output capacitance, energy related[6)]	$C_{o(er)}$	V_{GS}=0 V, V_{DS}=0 V to 480 V	-	36	-	
Effective output capacitance, time related[7)]	$C_{o(tr)}$		-	96	-	
Turn-on delay time	$t_{d(on)}$	V_{DD}=400 V, V_{GS}=10 V, I_D=5.2 A, R_G=3.3 Ω	-	10	-	ns
Rise time	t_r		-	5	-	
Turn-off delay time	$t_{d(off)}$		-	40	-	
Fall time	t_f		-	5	-	

[6)] $C_{o(er)}$ is a fixed capacitance that gives the same stored energy as C_{oss} while V_{DS} is rising from 0 to 80% V_{DSS}.

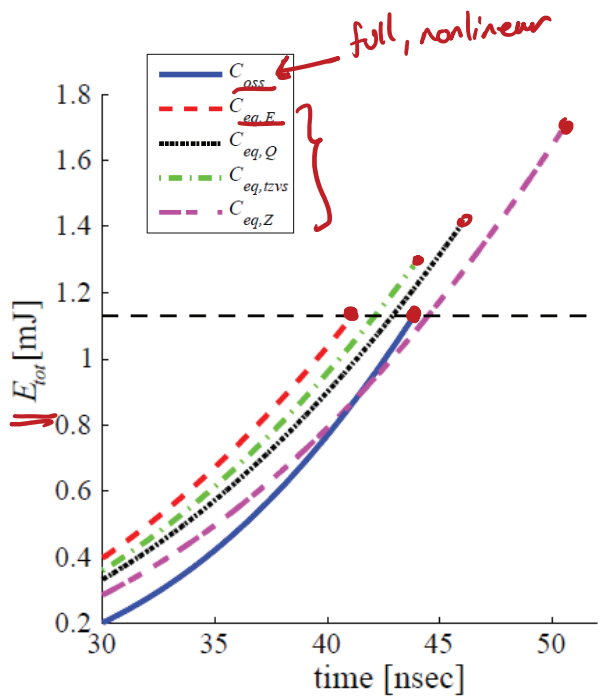
[7)] $C_{o(tr)}$ is a fixed capacitance that gives the same charging time as C_{oss} while V_{DS} is rising from 0 to 80% V_{DSS}.

Example Simulation



$C_{eq,Q} = 70.5$ pF, $C_{eq,E} = 56.4$ pF,

$C_{eq,tzvs} = 64.1$ pF $C_{eq,Z} = 84.5$ pF.



D. Costinett, D. Maksimovic and R. Zane, "Circuit-Oriented Treatment of Nonlinear Capacitances in Switched-Mode Power Supplies," in *IEEE Transactions on Power Electronics*

Further Simulation