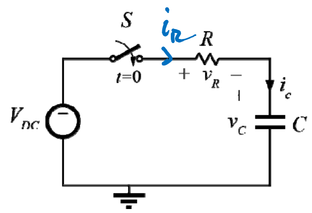
M_1 Energy Loss



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

$= \int_0^\infty i_c (V_{DC} - v_c) \, dt$

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

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

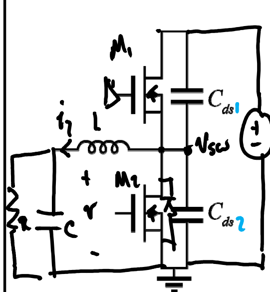
$E_{DC} = \int_0^\infty i V_{DC} \, dt = V_{DC} \int_0^\infty i \, dt = V_{DC} Q = V_{DC}^2 C_{eq,Q}$

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

Energy supplied from V_{DC} — Energy supplied to C

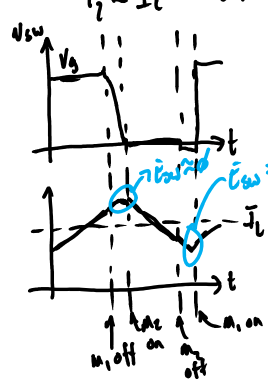
$E_{sw} = V_{DC}^2 C_{eq,Q}$

Example: Switching Losses in a Buck



Small-ripple applies

$i_L \approx I_L \quad v \approx V$



$E_{sw} = E_1 + E_2$

$= \frac{1}{2} C_{eq,E1} V_g^2 + V_g^2 C_{eq,Q2} - \frac{1}{2} C_{eq,E2} V_g^2$

if C_{ds1} & C_{ds2} are identical:

$E_{sw} = V_g^2 C_{eq,Q}$

Analytical E_{sw} for ideal Silicon Dmos

$$C_{ds} = \frac{C_{jo} A}{\sqrt{1+\frac{V_{ds}}{V_F}}}, \quad C_{jo} = \sqrt{\frac{\epsilon^2 E_{crit}^2}{4 V_{BV} V_F}}$$

on this week's HW → $V_F = 1$

$$C_{ds} = \frac{C_{jo} A}{\sqrt{1+V_{ds}}}$$

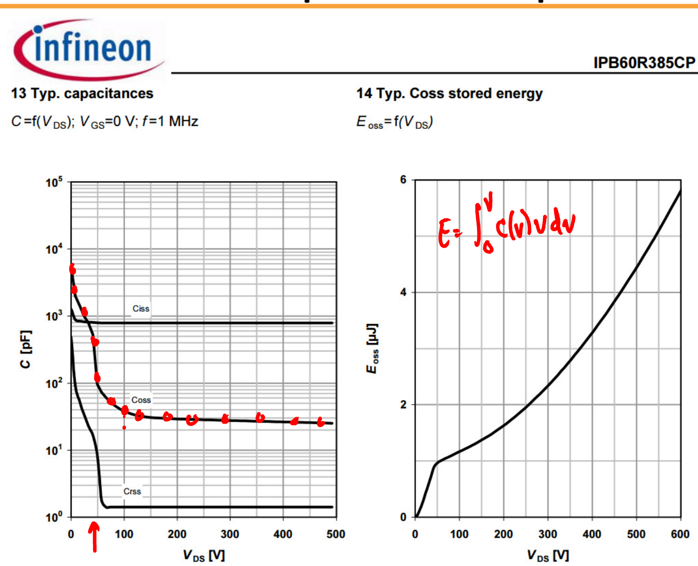
$$C_{eq,Q} = \frac{1}{V_g}\int_0^{V_g} C_{ds}\,dv = \frac{1}{V_g}\int_0^{V_g} \frac{C_{jo} A}{\sqrt{1+v}}\,dv$$

$$= \frac{C_{jo} A}{V_g}\, 2\sqrt{1+v}\Big|_{v=0}^{v=V_g} = \frac{2 C_{jo} A}{V_g}\left(\sqrt{1+V_g}-1\right)$$

$$E_{sw} = 2 V_g C_{jo} \underline{\underline{A}} \left(\sqrt{1+V_g}-1\right)$$

↳ Note: still linearly proportional to A (device area)

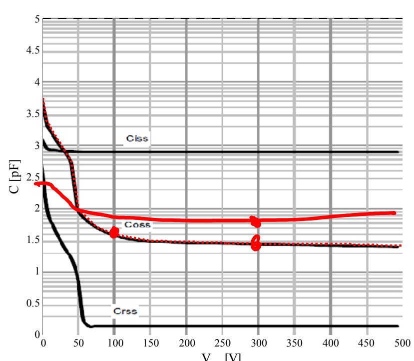
Datasheet Reported Capacitance

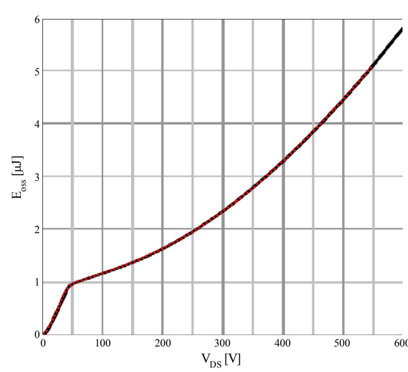


Nonlinear Capacitance Extraction

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

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(Vdc,log10(Coss),vx,'linear');

E = cumtrapz(vx, Cx.*vx);
Ceq_e = 2*(E)./vx.^2;
```

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}.