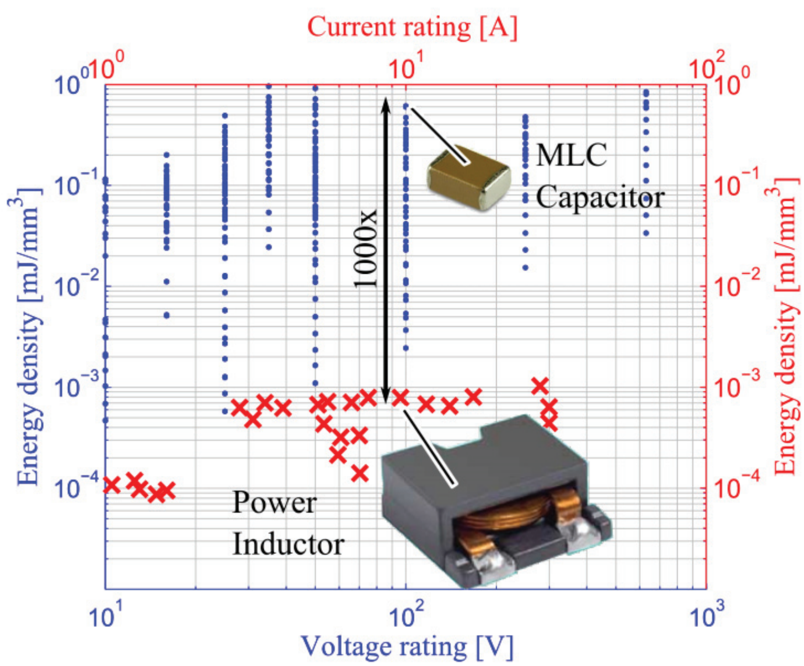
Major Remaining Topics in ECE 581

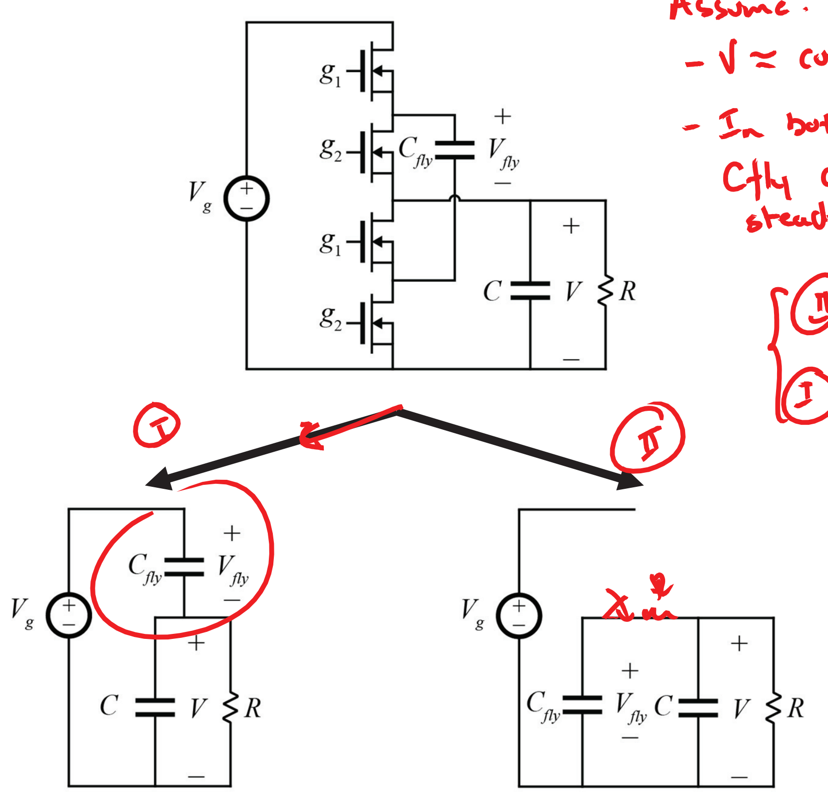
- Switched Capacitor Converters
- Discrete Time Modeling

SWITCHED CAPACITOR CONVERTERS

Switched Capacitor Converters



A 2:1 SC Converter



Assume:
- $V \approx$ const
- In both (I) and (II) C_{fly} charges/discharges to steady-state

(II) $V_{fly} = V$

(I) $V_{fly} = V_g - V$

$V = V_g - V$

$V = \frac{V_g}{2}$

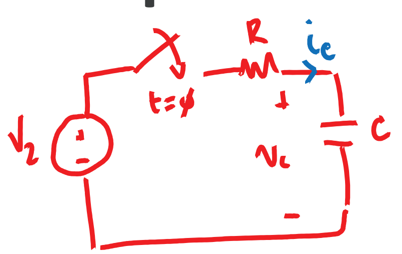
$M = \frac{V}{V_g} = \frac{1}{2}$

SC Converters

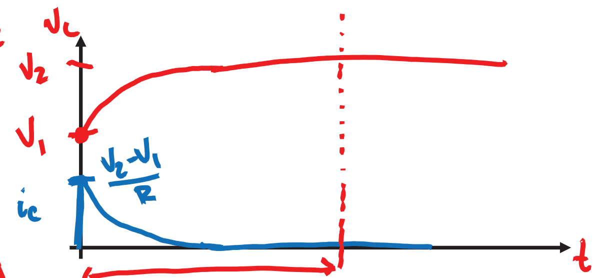
- Fixed conversion ratio
  - No regulation (except linear) (i.e. lossy regulation)
- Not lossless, even with ideal elements
- Can be very small, fully integrated

- **Resonant** versions can reduce loss
- **Hybrid** versions can allow regulation

Capacitor Charging: Voltage Source



$v_c(t=0) = V_1 < V_2$



$t_c >> \tau = RC$

$$\Delta E_c = \tfrac{1}{2}CV_2^2 - \tfrac{1}{2}CV_1^2 = \tfrac{1}{2}C(V_2^2 - V_1^2)$$

$$\Delta E_v = \int_0^{t_c=\infty} V_2 i_c \, dt = V_2 \int i_c dt = V_2 \Delta Q_c = V_2 C(V_2 - V_1)$$

$$E_{loss} = \Delta E_v - \Delta E_c = CV_2(V_2 - V_1) - \tfrac{1}{2}C(V_2^2 - V_1^2)$$

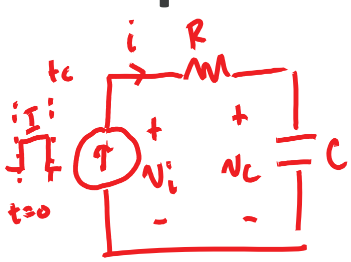
$$= \tfrac{1}{2}CV_2^2 + \tfrac{1}{2}CV_1^2 - CV_2V_1 = \tfrac{1}{2}C\left[V_2^2 + V_1^2 - 2V_1V_2\right]$$

$$= \tfrac{1}{2}C\underbrace{(V_2 - V_1)}_{\Delta V_c}{}^2$$

$$\eta = \frac{\Delta E_c}{\Delta E_V} = \frac{\frac{1}{2}\cancel{C}(V_2^2 - V_1^2)}{V_2 \cancel{C}(V_2 - V_1)} = \frac{1}{2}\,\frac{V_2^2 - (V_2 - \Delta V_c)^2}{V_2\left(V_2 - (V_2 - \Delta V_c)\right)}$$

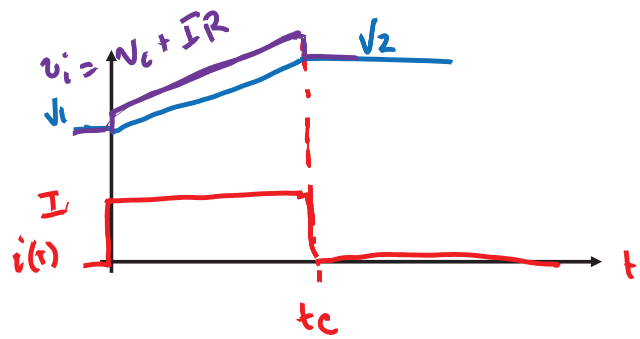
$$= \frac{1}{2}\,\frac{2V_2 \Delta V_c - (\Delta V_c)^2}{V_2 \Delta V_c} = 1 - \frac{\Delta V_c}{2V_2}$$

Capacitor Charging: Current Source



$v_c(t=0) = V_1$

$v_c(t=t_c) = V_2$



$$I = \frac{Q}{t} = \frac{C(V_2 - V_1)}{t_c}$$

$\Delta E_c = \frac{1}{2}C(V_2^2 - V_1^2)$ (same)

$$\Delta E_I = \int_0^{t_c} v_i(t)\, i(t)\, dt = I \langle v_i \rangle t_c = I t_c \frac{(V_1 + IR) + (V_2 + IR)}{2}$$

$$= C(V_2 - V_1)\frac{V_1 + V_2 + 2IR}{2} = \frac{1}{2}C\left(V_2^2 - V_1^2 + 2IR(V_2 - V_1)\right)$$

$$= \frac{1}{2}C(V_2^2 - V_1^2) + \frac{1}{2}C\left[2IR(V_2 - V_1)\right]$$

$$= \frac{1}{2}C(V_2^2 - V_1^2) + \frac{1}{2}C\left[\boxed{2\frac{RC}{t_c}}(V_2 - V_1)^2\right]$$