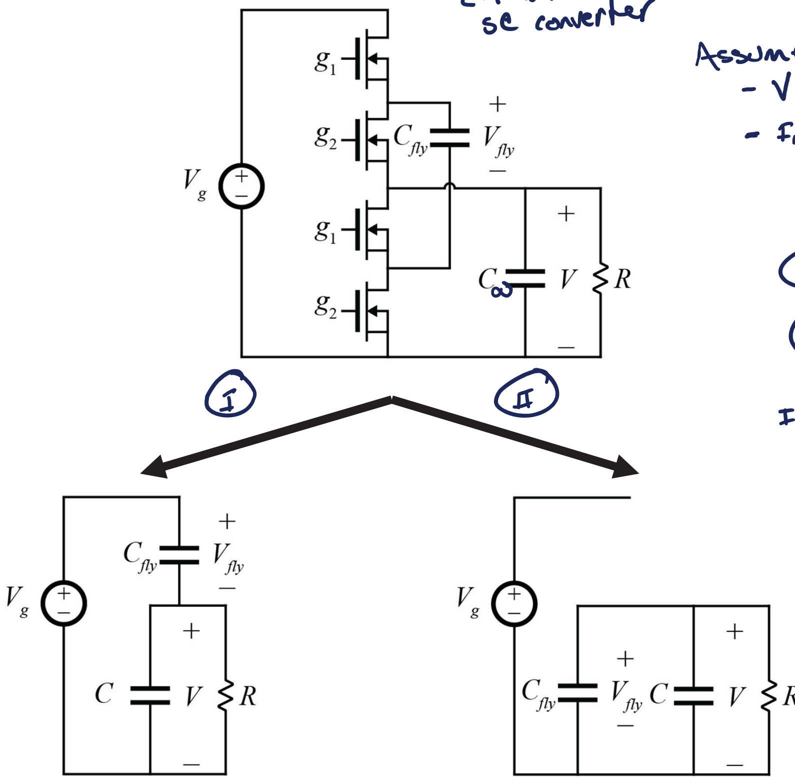
A 2:1 SC Converter

2:1 ladder SC converter



Assume:
- $V \approx$ constant output voltage
- In (I) & (II), V_{fly} reaches a final value before the next switching action

(II) $V_{fly} = V$

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

If C_{fly} large, $\Delta V_{fly} \approx 0$

$V = V_g - V$

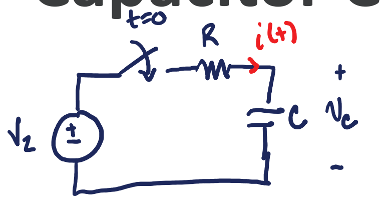
$2V = V_g$

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

SC Converters

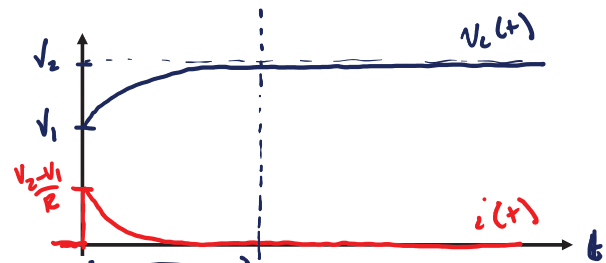
- Fixed conversion ratio
  - No regulation (except linear) → i.e. lossy
- Not lossless, even with ideal elements
- Can be very small, fully integrated
  - Discrete caps can be small & efficient in many applications
  - Integrated on-chip caps much better than on-chip inductors
- **Resonant** versions can reduce loss
- **Hybrid** versions can allow regulation

Capacitor Charging: Voltage Source



$v_c(t<0) = V_1$

$V_2 > V_1$



$$t_c \gg RC = \tau$$

$$\Delta E_c = \tfrac{1}{2} C V_2^2 - \tfrac{1}{2} C V_1^2$$

$$\boxed{\Delta E_c = \tfrac{1}{2} C \left(V_2^2 - V_1^2\right)}$$

$$\Delta E_V = \int_0^{t_c} V_2\, i(t)\, dt \approx \int_0^{\infty} V_2\, i(t) = V_2 \underbrace{C(V_2 - V_1)}_{\Delta Q_c}$$

$$\boxed{\Delta E_V = C V_2 (V_2 - V_1)}$$

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

$$= C V_2^2 - C V_2 V_1 - \tfrac{1}{2} C V_2^2 + \tfrac{1}{2} C V_1^2$$

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

$$\boxed{E_{loss} = \tfrac{1}{2} C (V_2 - V_1)^2} = \tfrac{1}{2} C (\Delta v_c)^2$$

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

$$\eta = \frac{1}{2} \frac{\cancel{V_2^2} - \cancel{V_2^2} - (\Delta v_c)^2 + 2 V_2 \Delta v_c}{\cancel{V_2^2} - \cancel{V_2^2} + V_2 \Delta v_c}$$

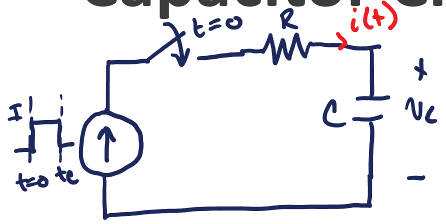
$$= \frac{1}{2} \frac{2 V_2 \Delta v_c - (\Delta v_c)^2}{V_2 \Delta v_c}$$

$$= \frac{1}{2} \left(2 - \frac{\Delta v_c}{V_2} \right)$$

$$\boxed{\eta = 1 - \frac{\Delta v_c}{2 V_2}}$$

No dependence on R
except $t_c \gg RC$
↓
Slow-switching limit (SSL)

Capacitor Charging: Current Source



$v_c(t<0) = V_1$