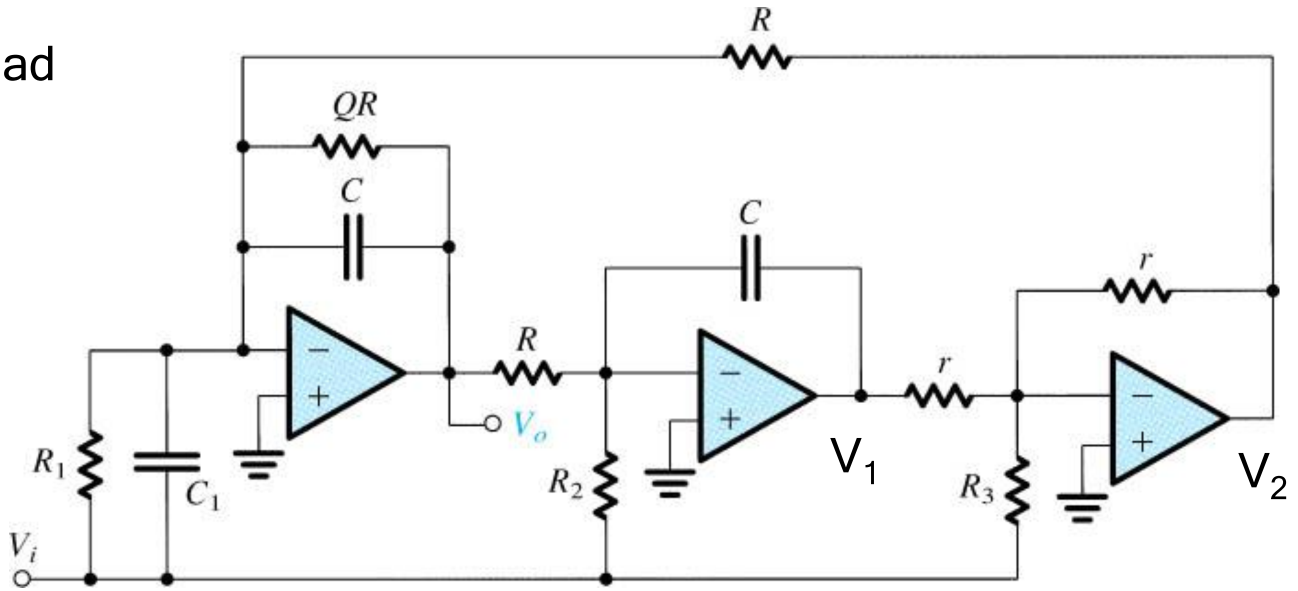
Lect. 22: Switched Capacitor Filters

Biquad can be used as a universal filter structure

Tow-Thomas biquad
(Lect. 20)



$$\frac{V_o}{V_i} = -\frac{s^2\left(\frac{C_1}{C}\right) + s\frac{1}{C}\left(\frac{1}{R_1} - \frac{r}{RR_3}\right) + \frac{1}{C^2RR_2}}{s^2 + s\frac{1}{QCR} + \frac{1}{C^2R^2}}$$

Many R's are required

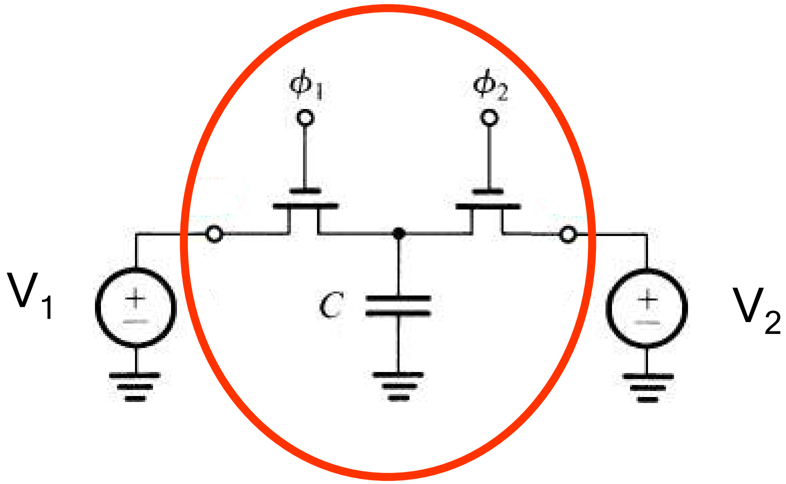
Lect. 22: Switched Capacitor Filters

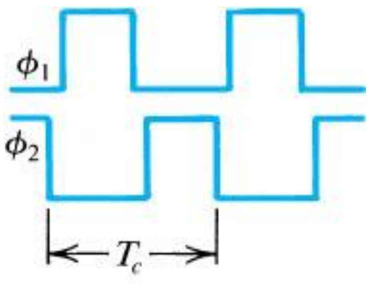
Using many resistors are NOT desirable in IC design

- Large area
- Accurate control of R difficult

Circuit technique to solve the problem

➔ Replace resistors with capacitors: Switched capacitor

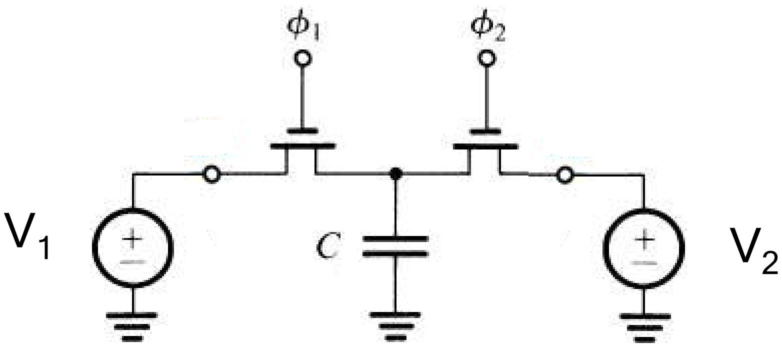


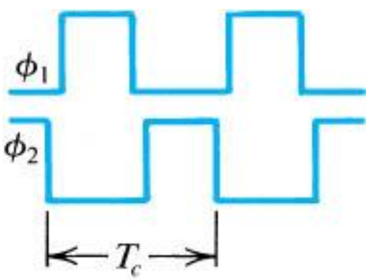


(c)

W.-Y. Choi

Lect. 22: Switched Capacitor Filters





(c)

Assume initially ϕ_2 ON, ϕ_1 OFF and $V_1 > V_2$

$Q = CV_2$

When ϕ_2 is OFF and ϕ_1 is ON

$Q = CV_1$

$\Delta Q = C(V_1 - V_2)$ supplied by V_1

When ϕ_1 is OFF and ϕ_2 is ON

$Q = CV_2$

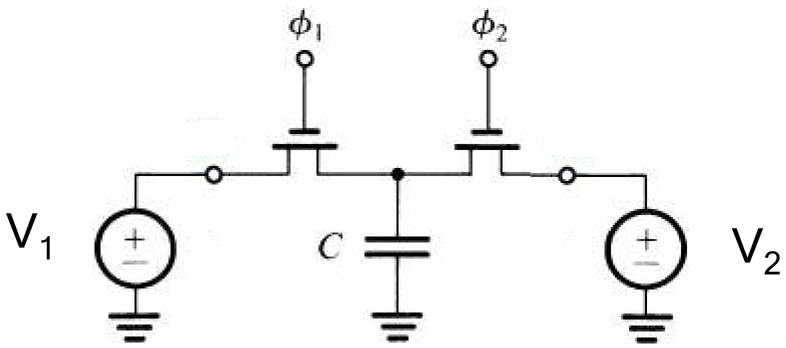
$\Delta Q = C(V_1 - V_2)$ supplied to V_2

➔ Switched capacitor delivers charges from V_1 to V_2

$\Delta Q = C(V_1 - V_2)$ during T_c

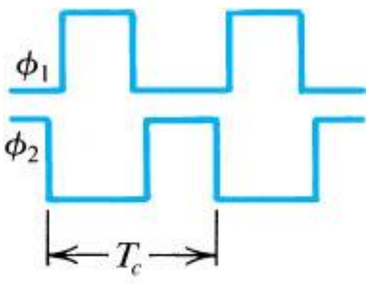
$$i_{av} = \frac{C(V_1 - V_2)}{T_c} \qquad \frac{V_1 - V_2}{i_{av}} = \frac{T_c}{C} = R_{eq}$$ Controlled by C and T_c

Lect. 22: Switched Capacitor Filters



$$R_{eq} = \frac{T_c}{C}$$

Switches can be easily realized with MOS transistors

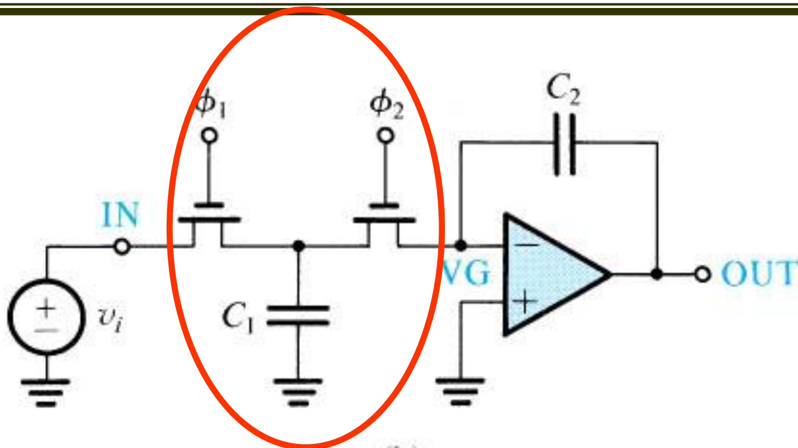


(c)

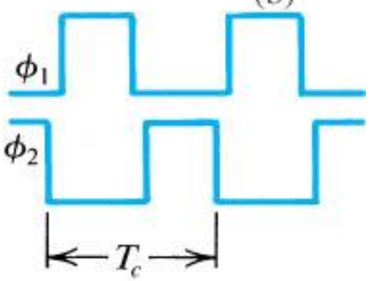
If $1/T_c$ >> frequency of interests,
Switched capacitor is acting as a resistor.

➔ Discrete time domain processing

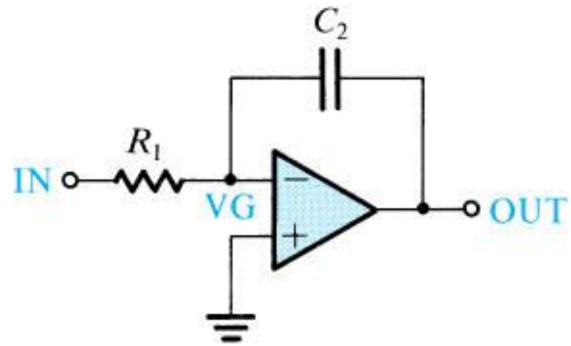
Lect. 22: Switched Capacitor Filters



(b)



(c)



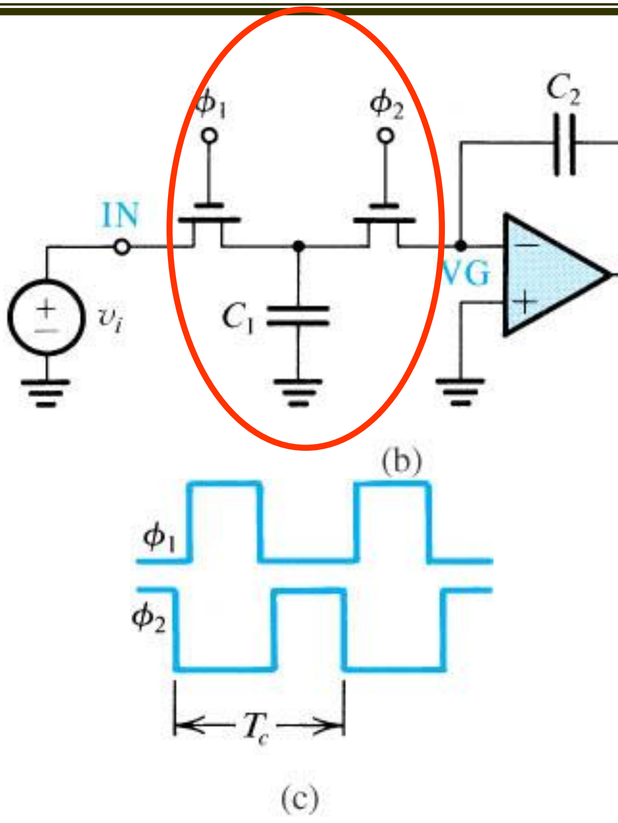
Integrator

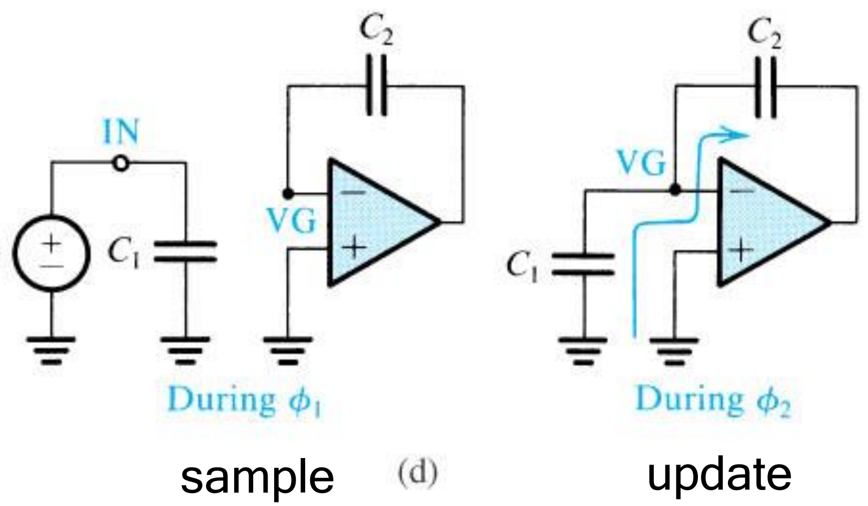
$$\upsilon_o(t) - \upsilon_o(t=0) = -\frac{1}{R_1 C_2}\int_0^t v_i(t)\, dt$$

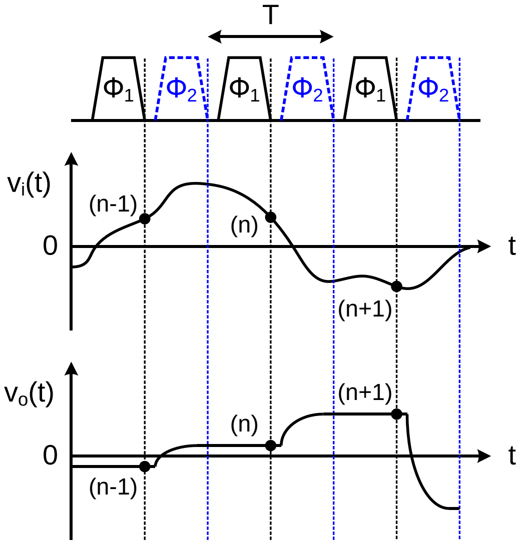
With switched capacitor

$$R_1 C_2 \rightarrow \left(\frac{T_C}{C_1}\right) C_2$$

Lect. 22: Switched Capacitor Filters

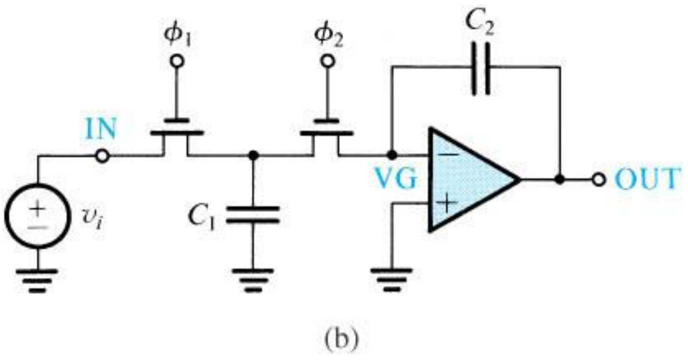




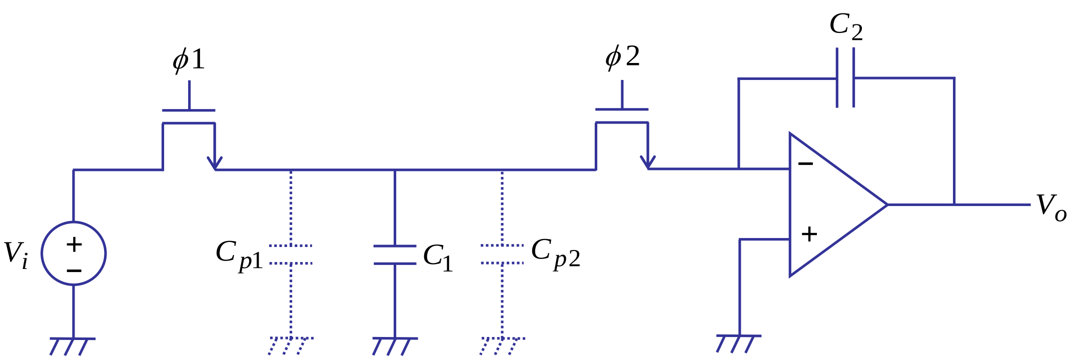


W.-Y. Choi

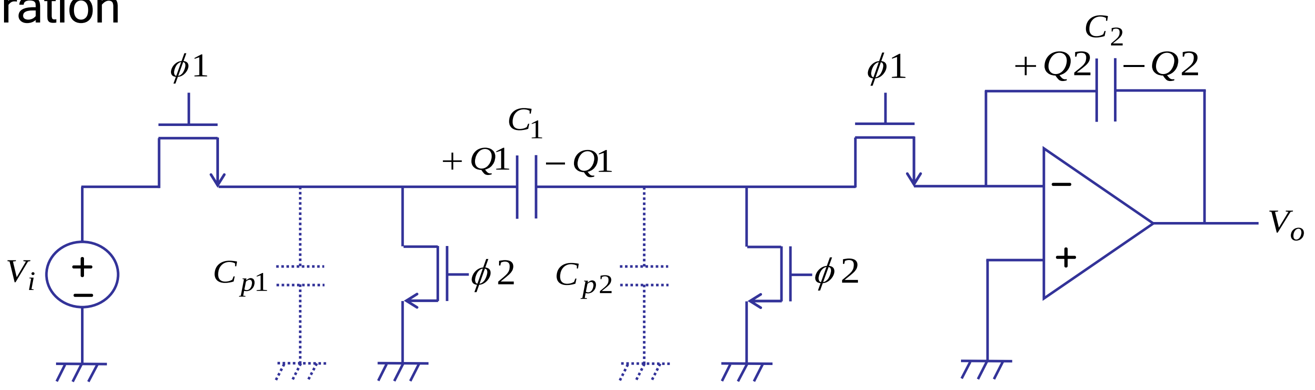
Lect. 22: Switched Capacitor Filters



Influence of parasitic capacitances due to source/drain capacitance of MOS transistors

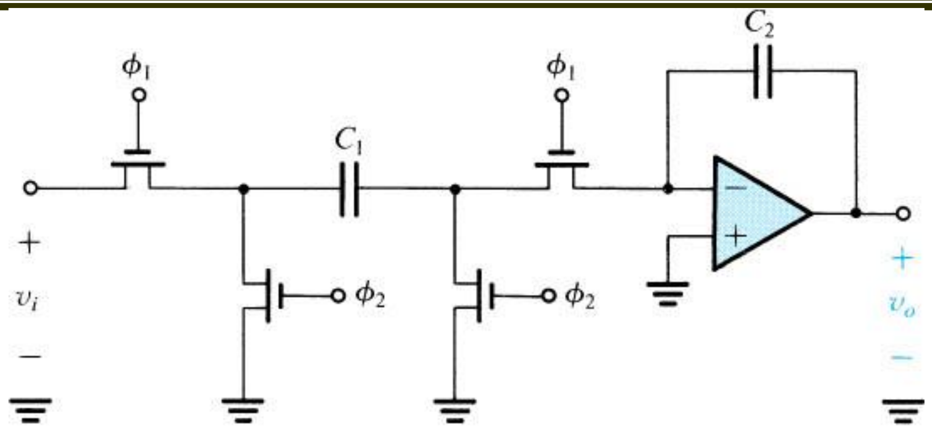


Better Configuration



Sampling and updating during ϕ_1 Refreshing during ϕ_2

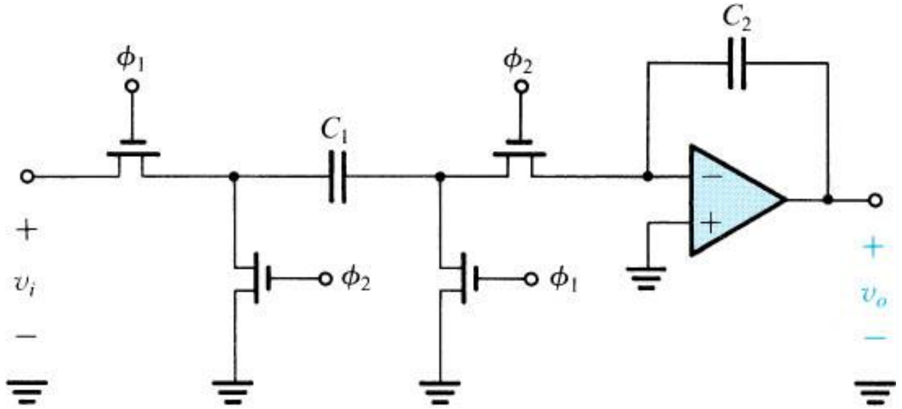
Lect. 22: Switched Capacitor Filters



(b)

Inverting

Non-Inverting



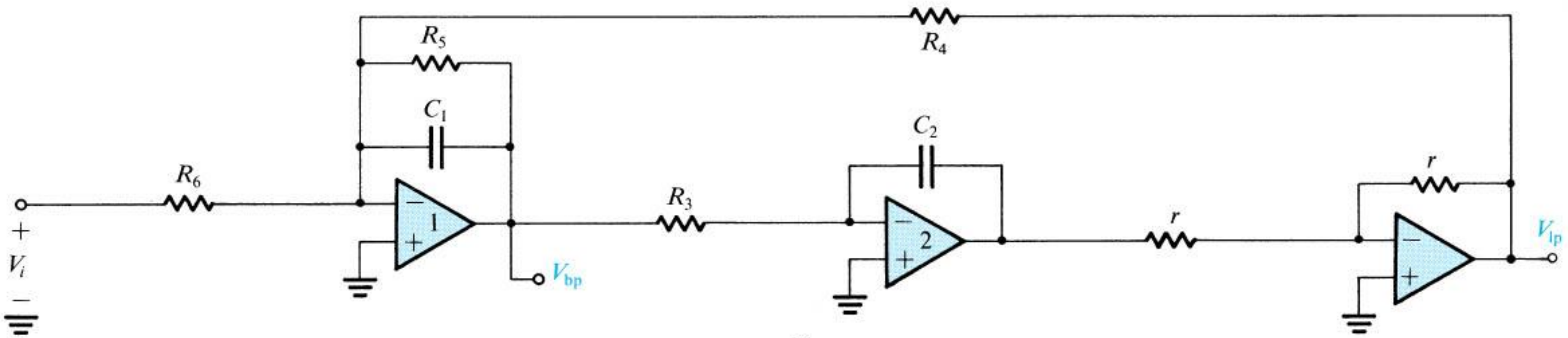
(a)

Effectively, $R_{eq} = -\frac{T_c}{C}$

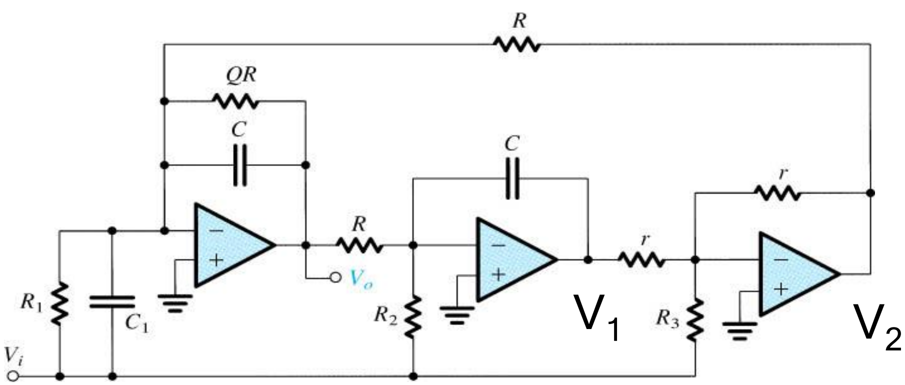
W.-Y. Choi

Lect. 22: Switched Capacitor Filters

Realize following Tow-Thomas biquad by SC



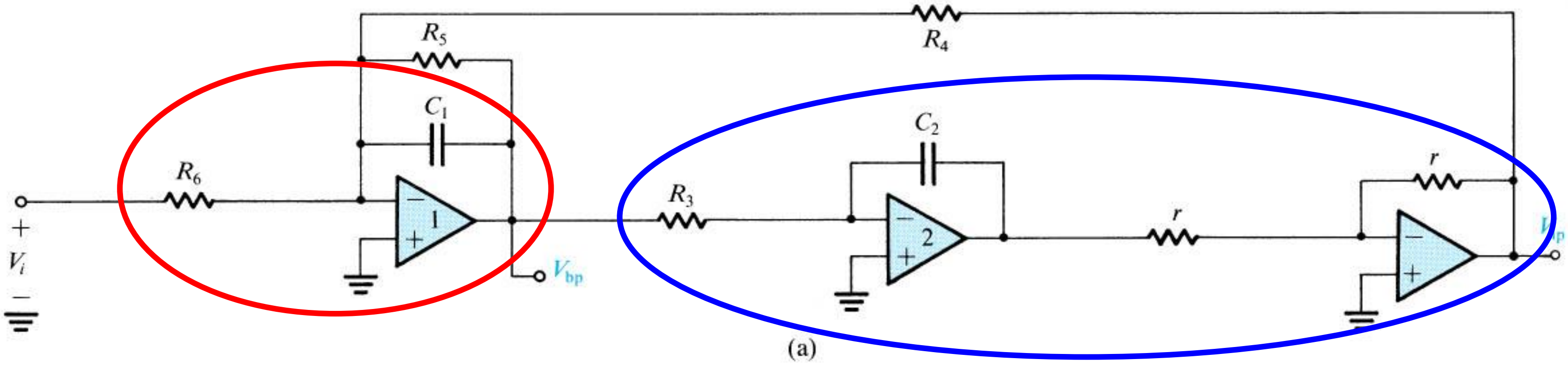
(a)



$$\frac{\mathbf{V}_o}{\mathbf{V}_i} = -\frac{s^2\left(\frac{C_1}{C}\right) + s\frac{1}{C}\left(\frac{1}{R_1} - \frac{r}{RR_3}\right) + \frac{1}{C^2RR_2}}{s^2 + s\frac{1}{QCR} + \frac{1}{C^2R^2}}$$

Lect. 22: Switched Capacitor Filters

Realize following Tow-Thomas biquad by SC



- Inverting Integrator

- Non-inverting Integrator

- Replace resistors with switched capacitors with proper switching time

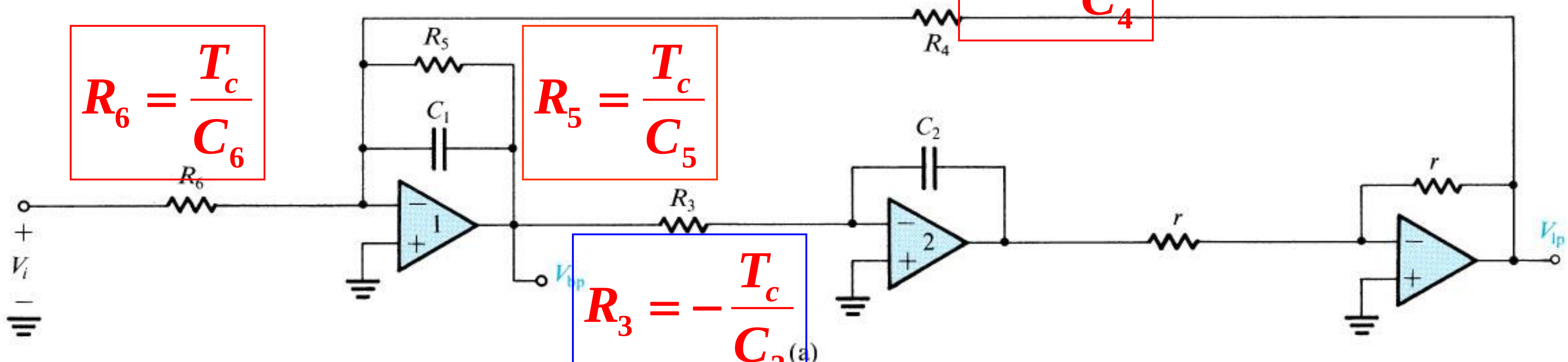
Lect. 22: Switched Capacitor Filters

$$R_6 = \frac{T_c}{C_6}$$

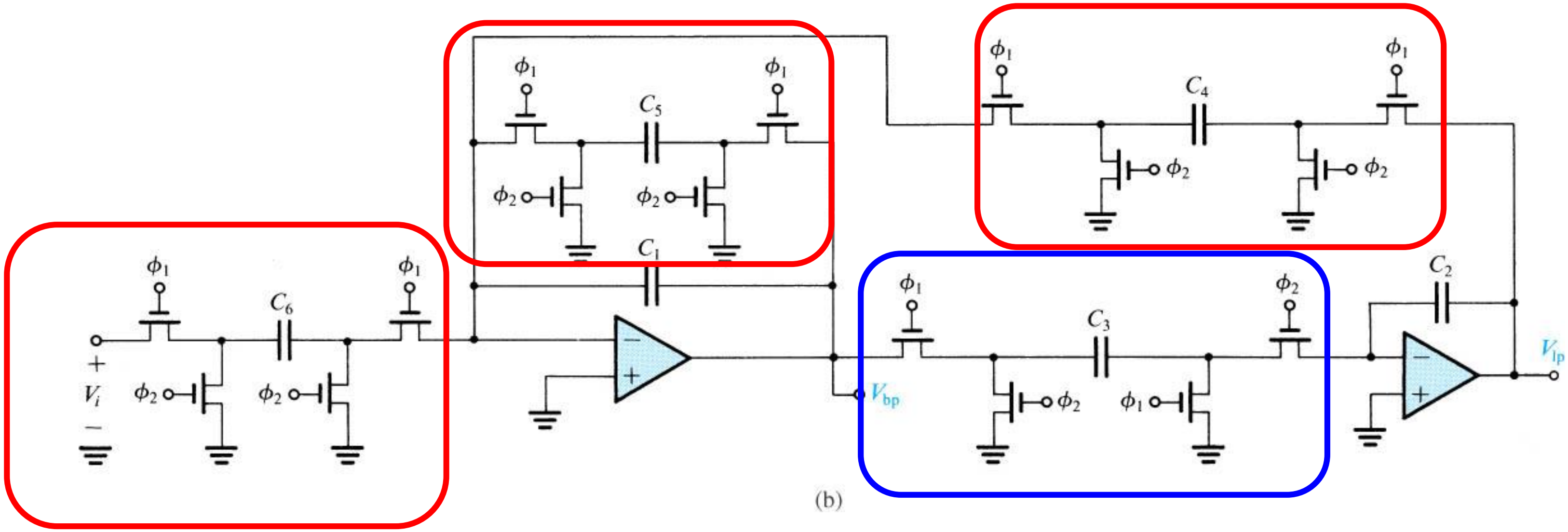
$$R_5 = \frac{T_c}{C_5}$$

$$R_4 = \frac{T_c}{C_4}$$

$$R_3 = -\frac{T_c}{C_3}$$



(a)



(b)

Lect. 22: Switched Capacitor Filters

Any active RC filter (such as biquad) can be replaced
with equivalent SC filter ➔ Project #2

SC filters perform discrete time domain signal processing

s-domain analysis for continuous time signal processing

➔ z-domain analysis for discrete time signal processing

SC circuits are widely used for filters and data converters but has speed limitations