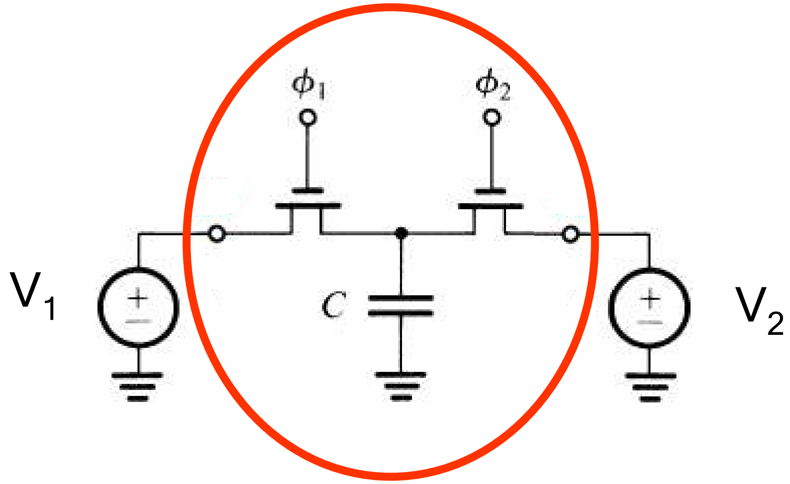
Lect. 19: Switched Capacitor Filters (S&S 12.10)

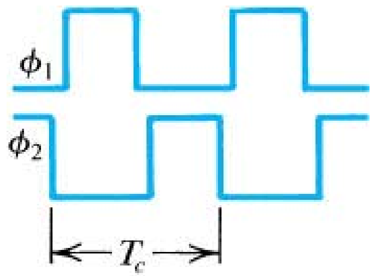
Large resistors in active RC filters are NOT practical in IC

- Large area
- Accurate control of R very difficult

Circuit technique to solve the problem

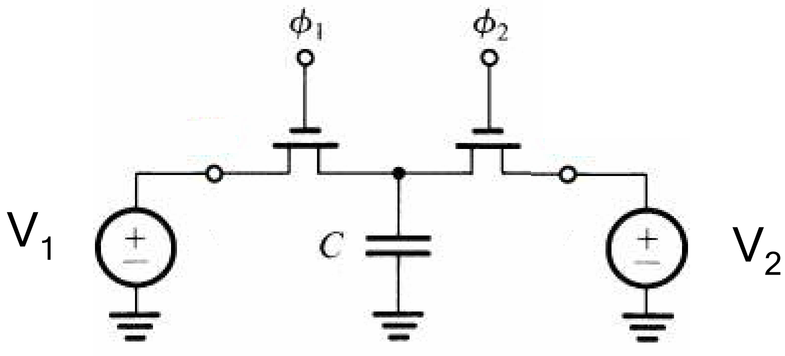
➔ Replace resistors with capacitors: Switched capacitor





(c)

Lect. 19: Switched Capacitor Filters



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

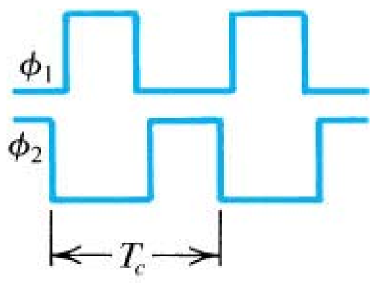
$Q = CV_1$

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



(c)

➔ Switched capacitors deliver charges from V_1 to V_2

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

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

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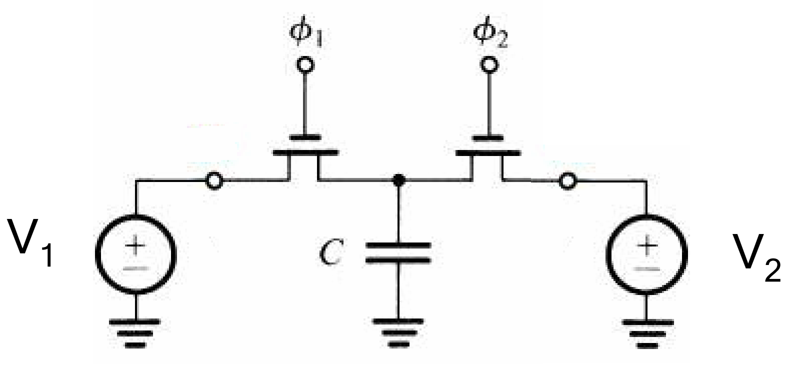
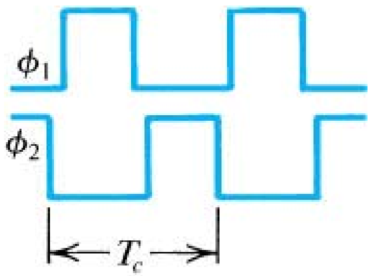
Lect. 19: Switched Capacitor Filters



Switches are usually realized with MOS switches having finite R, C



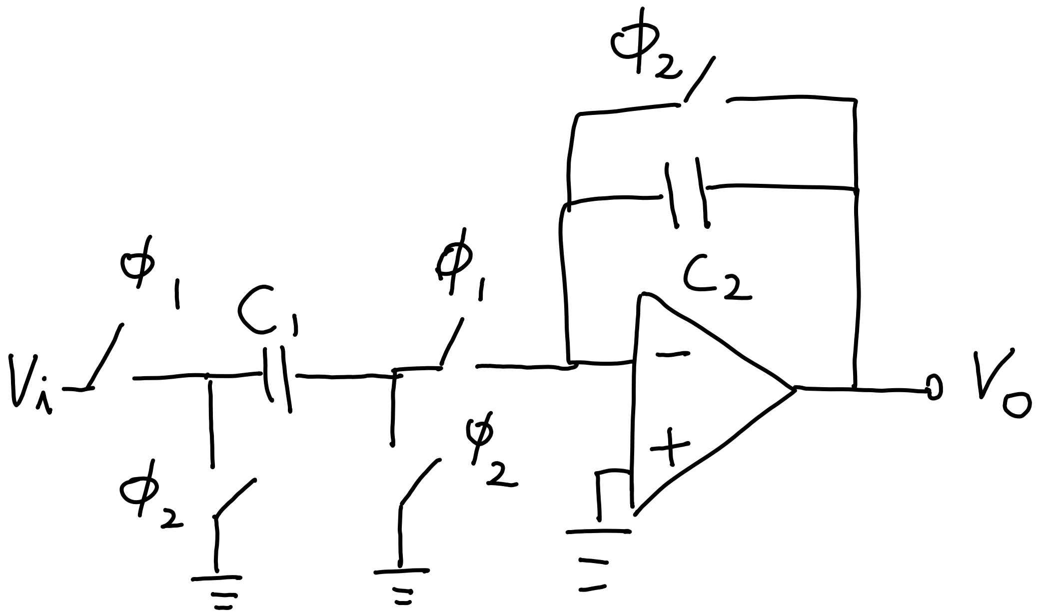
(c)

In this course, assume ideal switches

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

Lect. 19: Switched Capacitor Filters

Switched Capacitor Amplifier



Initially, assume Q_1, $Q_2 = 0$

When ϕ_1 is ON, ϕ_2 is OFF

$Q_1 = C_1V_i$

$Q_2 = C_2\,(0\text{-}V_o)$

But $Q_1 = Q_2$

$$C_1V_i = -C_2V_o$$

$$\therefore V_o = -\frac{C_1}{C_2}V_i$$

Inverting Amplifier ➔ Gain determined by the ratio of C's

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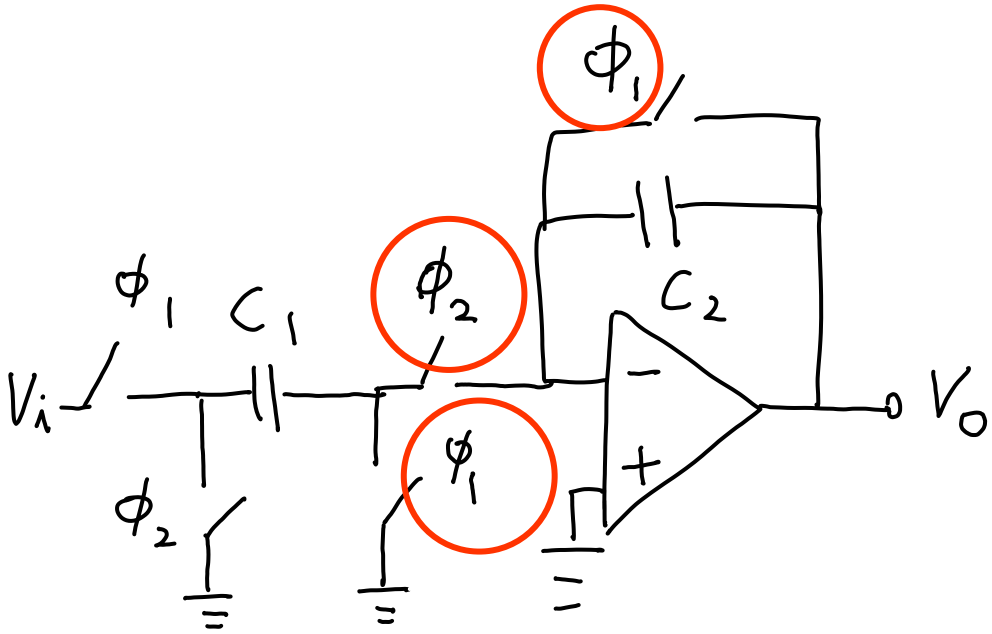
Lect. 19: Switched Capacitor Filters

Switched Capacitor Amplifier



During ϕ_1

$Q_1 = C_1V_i \qquad Q_2 = 0$

During ϕ_2

$Q_1 = 0 \qquad Q_2 = C_2(V_o - 0)$

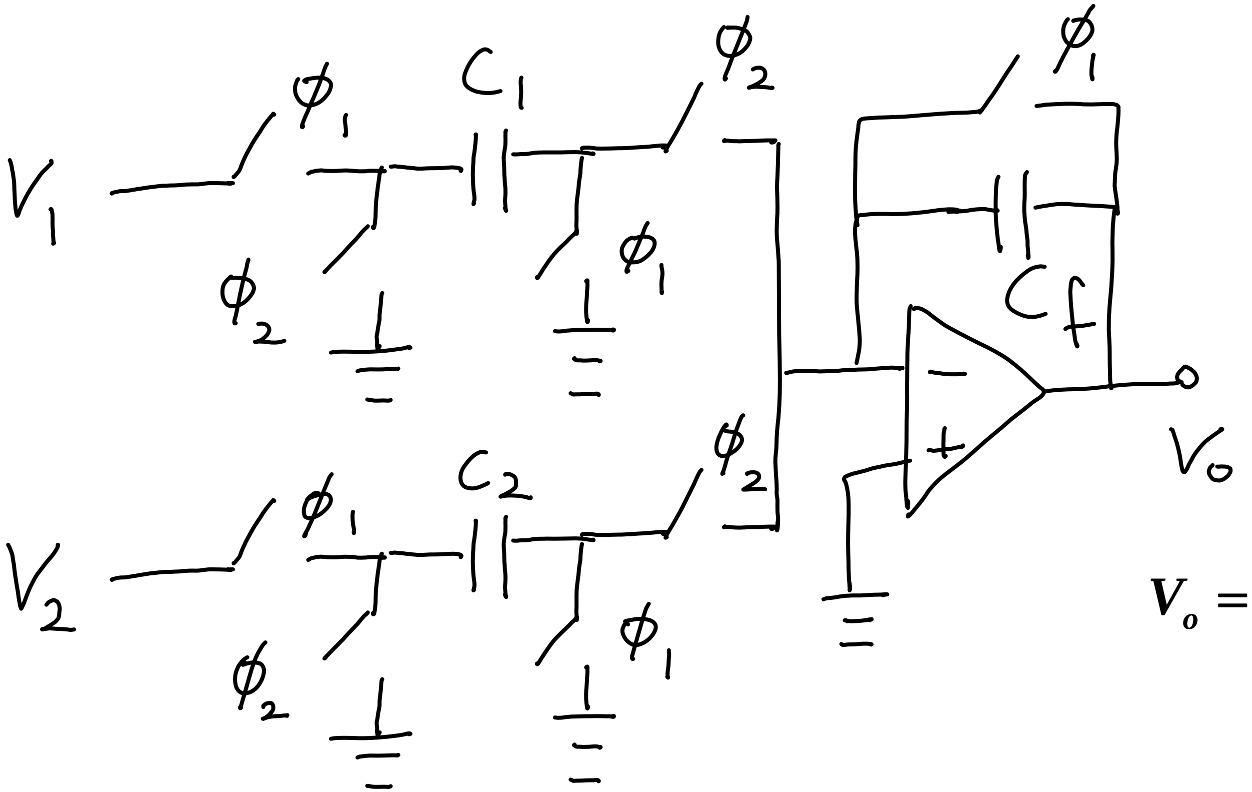
But $Q_1 = Q_2$

$$C_1V_i = C_2V_o$$

$$\therefore V_o = \frac{C_1}{C_2}V_i$$

Non-Inverting Amplifier ➔ Switching phase can change the signal polarity

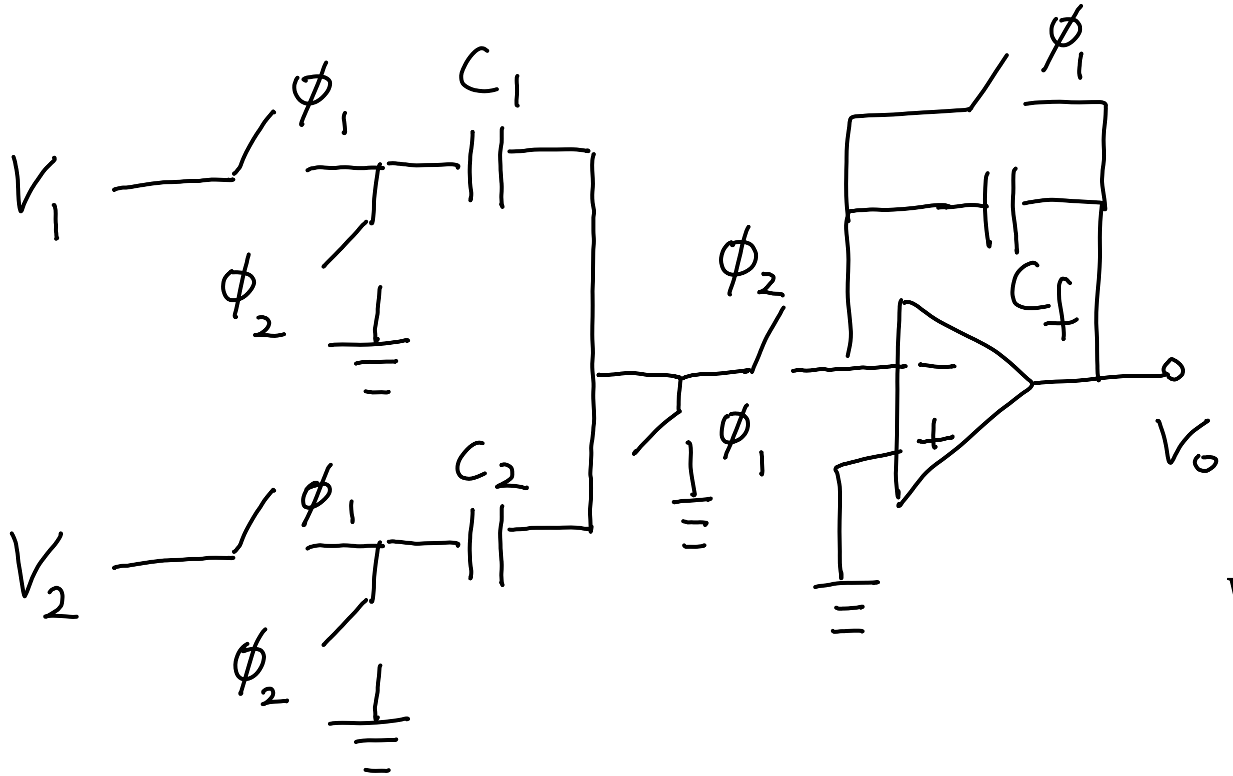
Lect. 19: Switched Capacitor Filters



$$V_o = \left(\frac{C_1}{C_f} V_1 + \frac{C_2}{C_f} V_2 \right) V_i$$

Non-inverting weighted summer

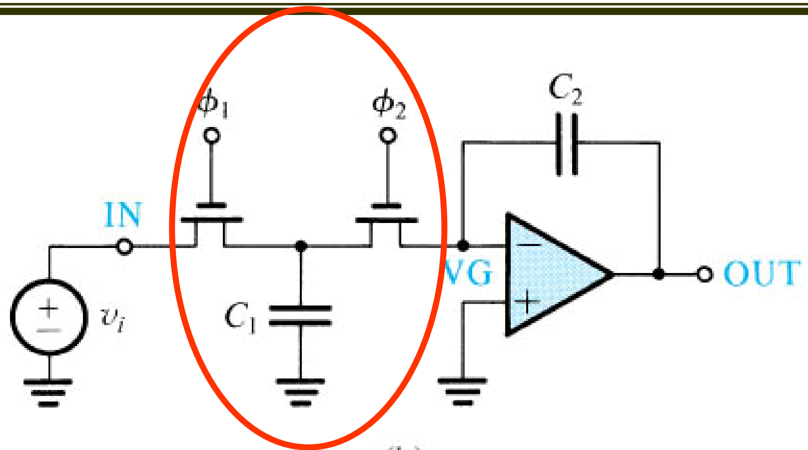
Lect. 19: Switched Capacitor Filters



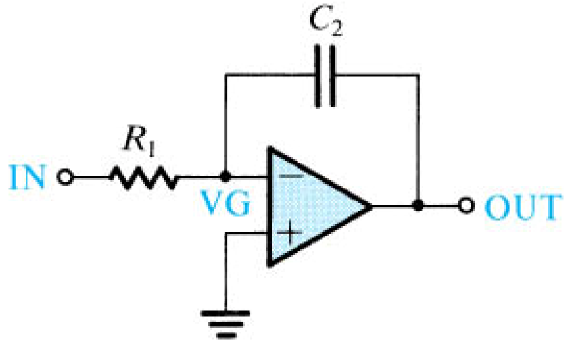
$$V_o = \left(\frac{C_1}{C_f} V_1 + \frac{C_2}{C_f} V_2 \right) V_i$$

Non-inverting weighted summer

Lect. 19: Switched Capacitor Filters



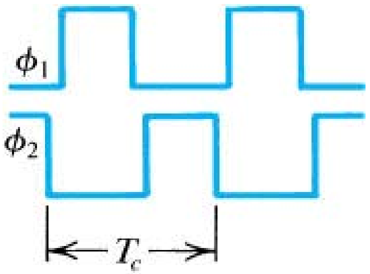
(b)



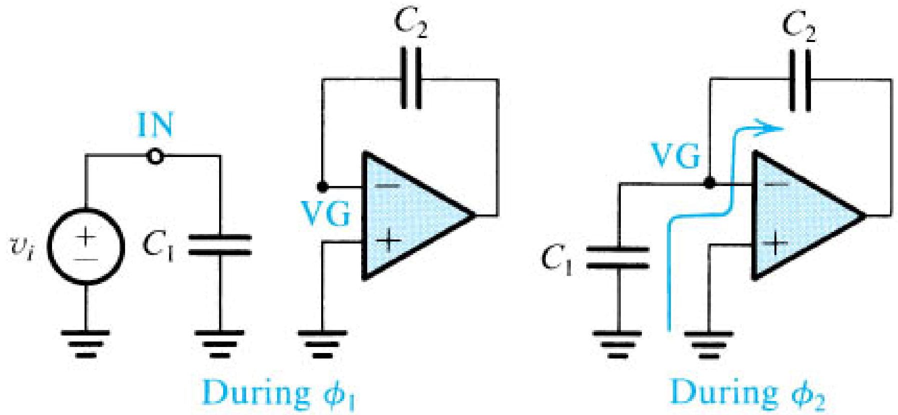
(a)

Integrator

$$\omega_0 = \frac{1}{R_1 C_2}$$



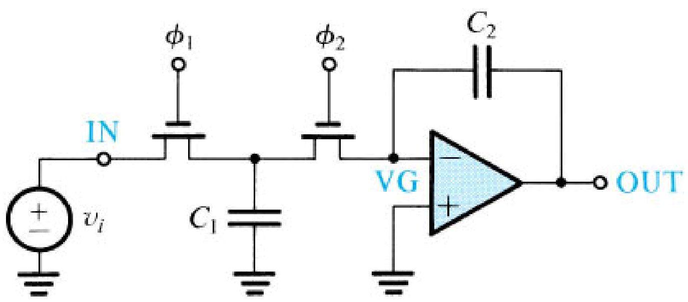
(c)



(d)

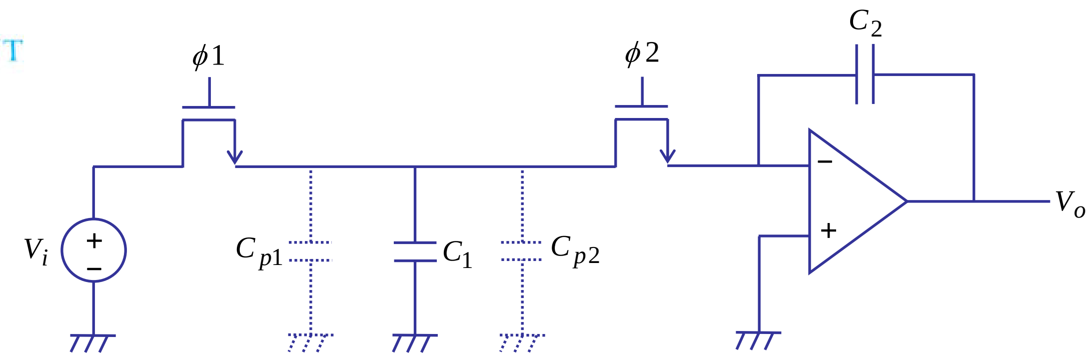
$$\omega_0 = \frac{1}{\left(\frac{T_C}{C_1}\right) C_2} = \frac{C_1}{T_C C_2}$$

Lect. 19: Switched Capacitor Filters

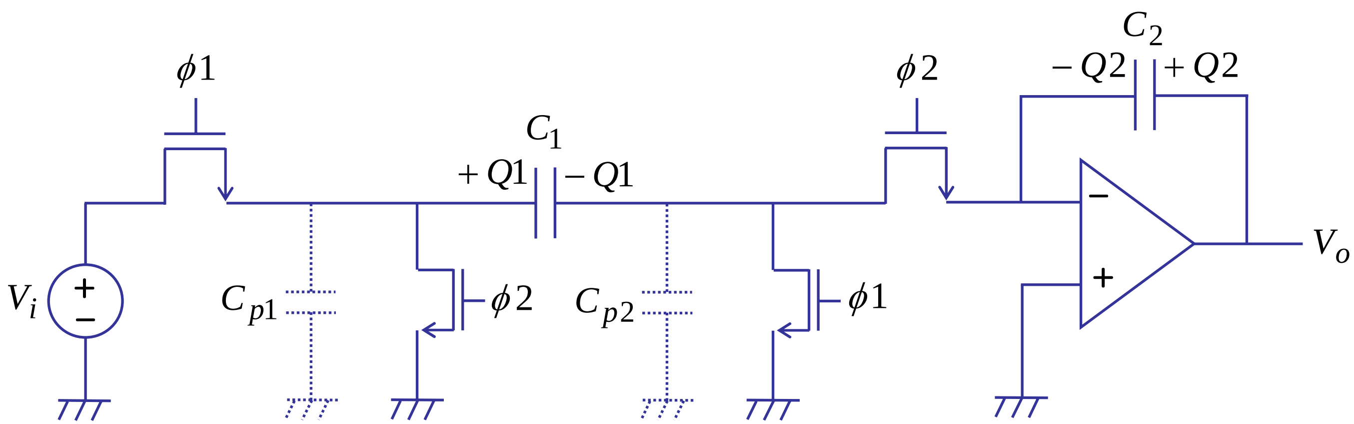


(b)

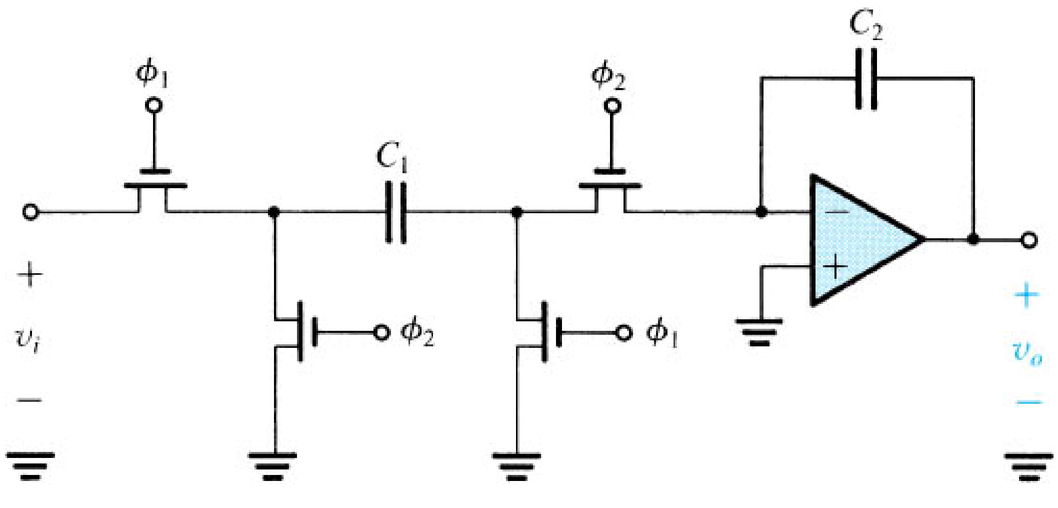
Influence of parasitic cap due to source and drain of MOS switch



Robust to parasitic cap

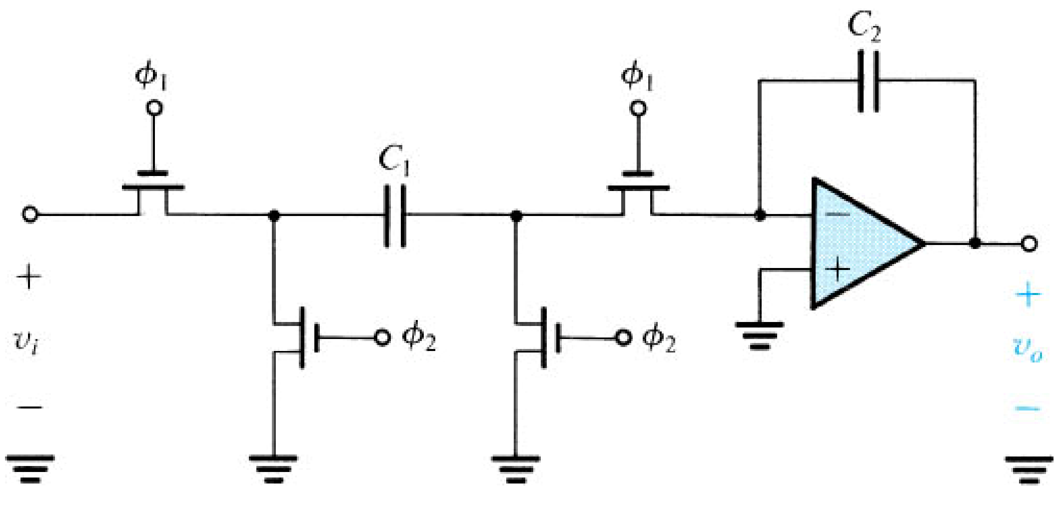


Lect. 19: Switched Capacitor Filters



(a)

Non-inverting SC integrator

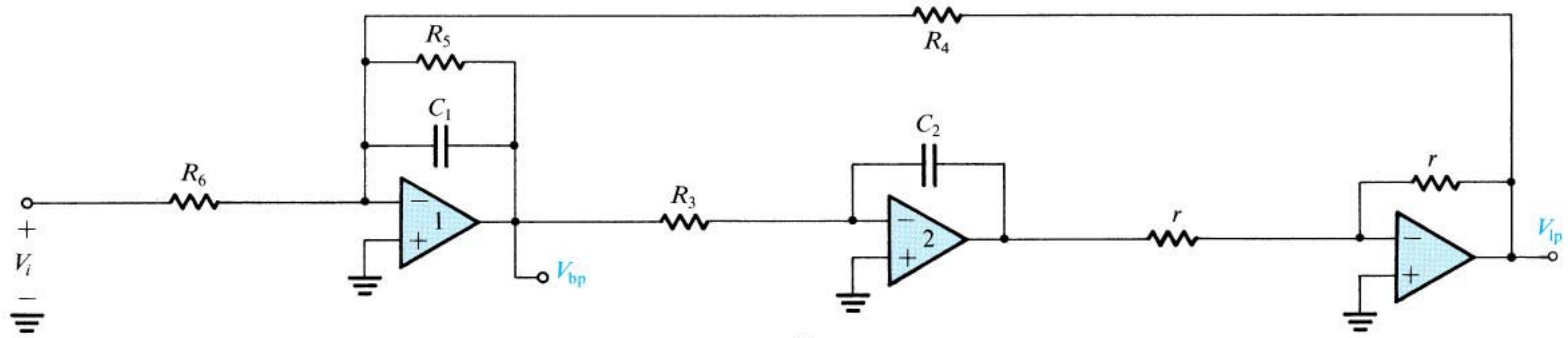


(b)

Inverting SC integrator

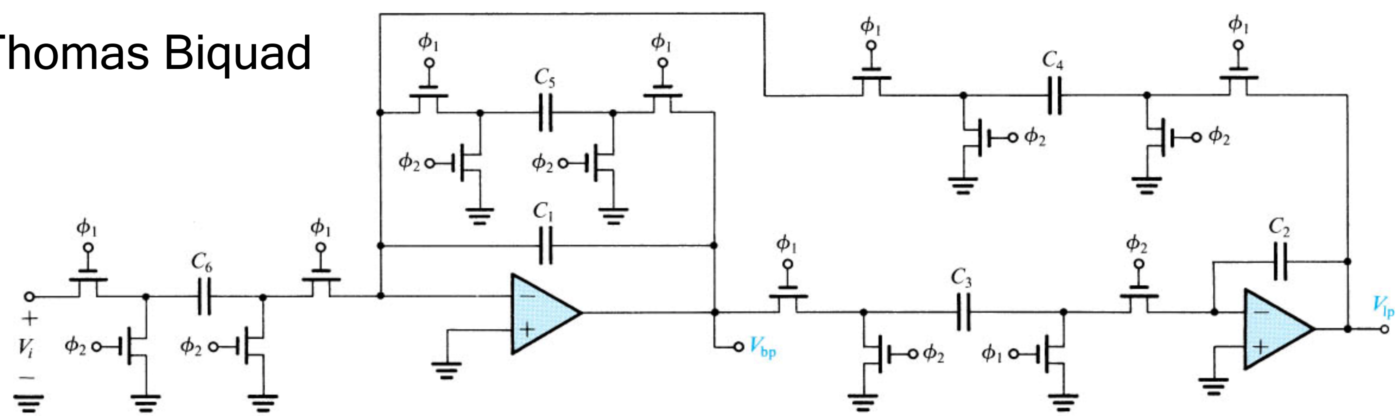
Lect. 19: Switched Capacitor Filters

Tow-Thomas Biquad



(a)

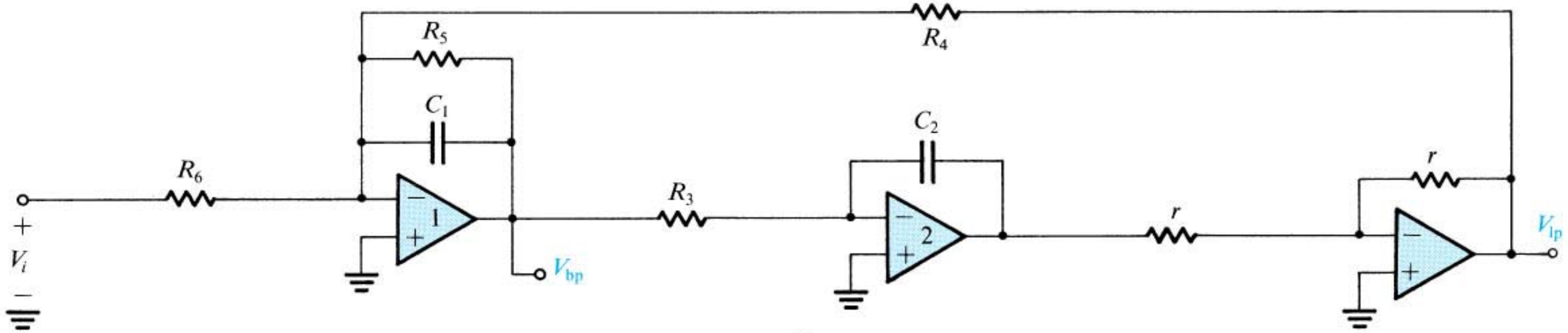
SC Two-Thomas Biquad



(b)

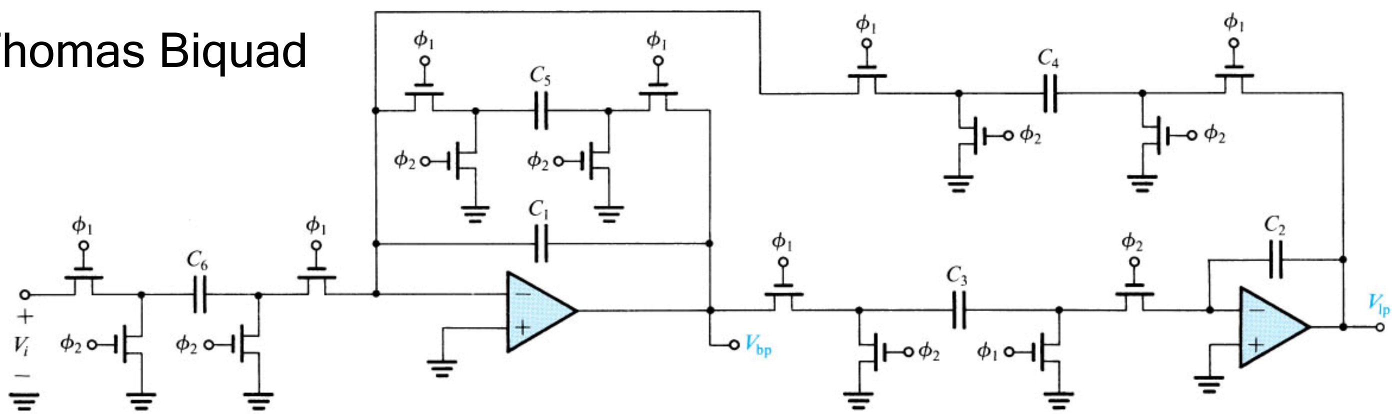
Lect. 19: Switched Capacitor Filters

Tow-Thomas Biquad



(a)

SC Tow-Thomas Biquad



(b)

Lect. 19: Switched Capacitor Filters

Any active RC filter (such as biquad) can be replaced with equivalent SC filter ➔ Project #3

SC filters perform discrete time domain signal processing

s-domain analysis for continuous time signal processing

➔ z-domain analysis for discrete time signal processing

However, SC circuits have speed limitations