Exercise: page 573 of the refrene Book.

Find the capacitance values needed for a first-order switched-capacitor circuit such that its 3-dB point is at 10 kHz when a clock frequency of 100 kHz is used. It is also desired that the filter have zero gain at 50 kHz and the dc gain be unity. Assume $C_A = 10\ \text{pF}$.

Exercise: page 573 of the refrence Book.

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Specification of filter:

CT

Exercise: page 573 of the refrene Book.

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Specification of filter:

CT

designe:

DT

Exercise: page 573 of the refrene Book.

Find the capacitance values needed for a first-order switched-capacitor circuit such that its 3-dB point is at 10 kHz when a clock frequency of 100 kHz is used. It is also desired that the filter have zero gain at 50 kHz and the dc gain be unity. Assume $C_A = 10$ pF.

Specification of filter:

CT

$h(S)$

Laplace domain

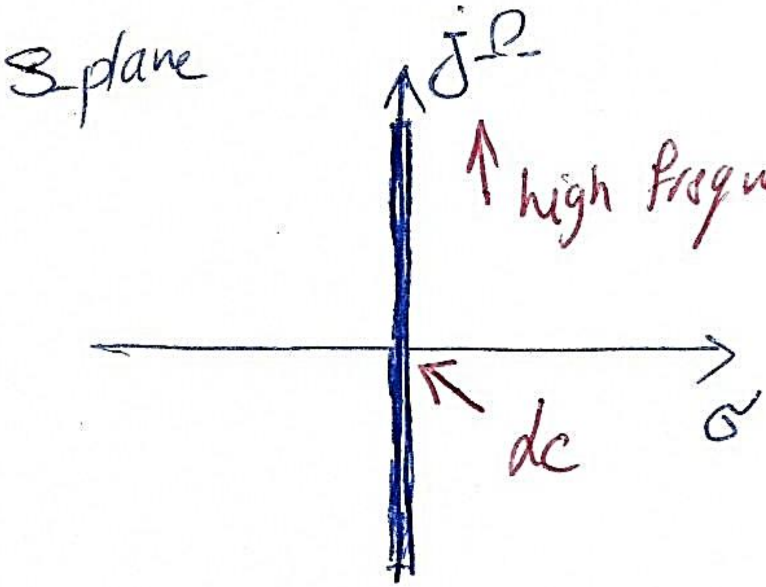
designe:

DT

$H(z)$

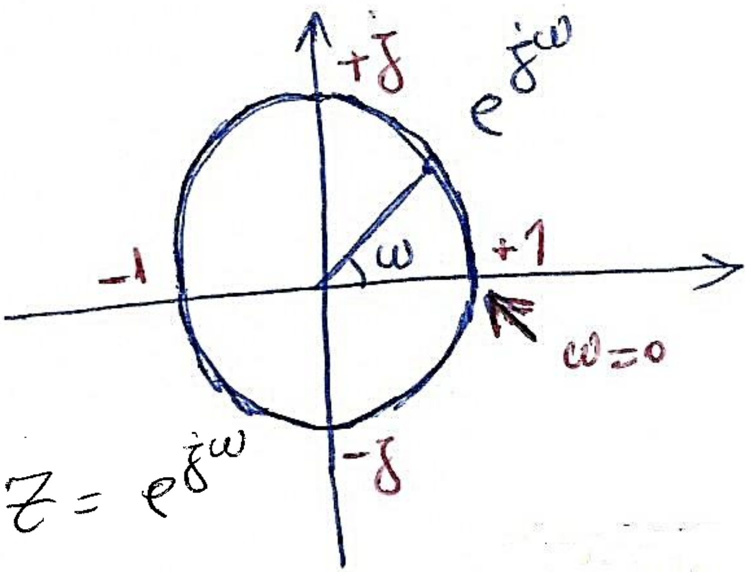
z-domain

s-domain



$s = j\Omega$

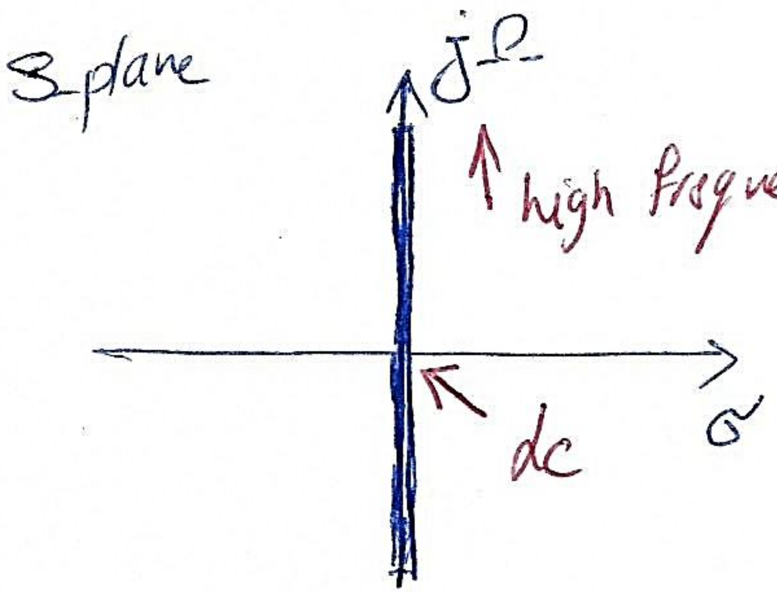
z-domain



$z = e^{j\omega}$

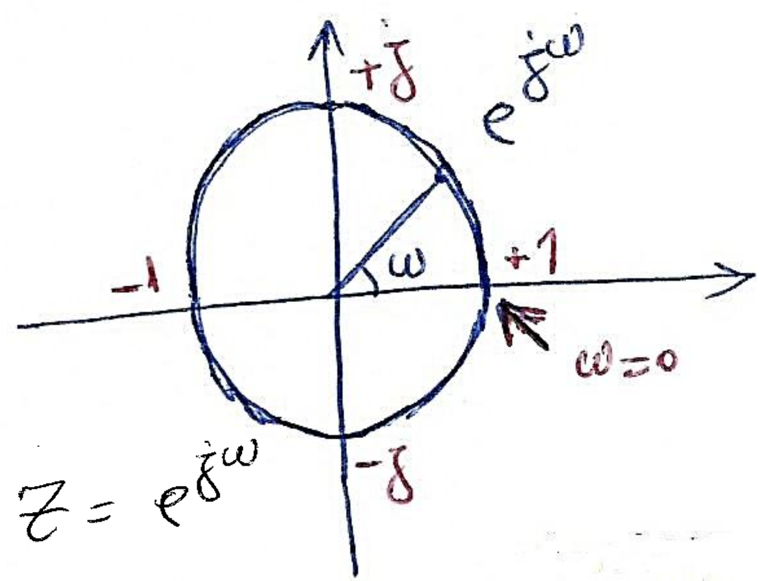
page 550 of reference book (13.5.4, bilinear transform)

s-domain



$s = j\Omega$

z-domain



$$\Omega = \tan(\omega/2)$$

page 550 of reference book (13.5.4, bilinear transform)

Bilinear Transform:

$$h(s) \xmapsto{\; s=\frac{z-1}{z+1} \;} H(z)$$

page 550 of reference book (13.5.4, bilinear transform)

Bilinear Transform:

$$
\begin{tikzcd}
h(s) \arrow[rr, bend left, "s=\frac{z-1}{z+1}"] & & H(z) \arrow[ll, bend left, "z=\frac{1+s}{1-s}"]
\end{tikzcd}
$$

Golden relations

page 550 of reference book (13.5.4, bilinear transform)

Golden relations

$$\begin{cases} \omega = 2\pi f / f_S & ; \ f_S\text{: clock freq} \\ \Omega = \tan(\omega/2) \end{cases}$$

$$z = e^{j\omega}$$

page 550 of reference book (13.5.4, bilinear transform)

Golden relations

for first order filters:

$$\delta p = -\Omega_{3dB}$$

page 550 of reference book (13.5.4, bilinear transform)

Golden relations

for first order filters:

$$s_p = -\Omega_{3dB}$$

$$z_p = \frac{1+s_p}{1-s_p}$$

Golden relations

for first order filters:

$$s_p = -\Omega_{3dB}$$

$$z_p = \frac{1+s_p}{1-s_p}$$

Crazy but true!

Exercise: page 573 of the refrene Book.

Find the capacitance values needed for a first-order switched-capacitor circuit such that its 3-dB point is at 10 kHz when a clock frequency of 100 kHz is used. It is also desired that the filter have zero gain at 50 kHz and the dc gain be unity. Assume $C_A = 10$ pF.

$f_{3\text{-}dB} = 10\ kHz$

$f_s = 100\ kHz$

zero @ 50 kHz

$H(1) = 1$

$C_A = 10\ pF$

Exercise: page 573 of the refrene Book.

$$\begin{cases} z = e^{j\omega} \\ \omega = f/f_s \cdot 2\pi \end{cases}$$

Exercise: page 573 of the refrene Book.

$$\begin{cases} z = e^{j\omega} \\ \omega = f/f_s \cdot 2\pi \end{cases} \Rightarrow z_{zero} = e^{j \cdot 2\pi \cdot 50/100} = e^{j\pi}$$

Exercise: page 573 of the refrene Book.

$$\begin{cases} z = e^{j\omega} \\ \omega = f/f_s \cdot 2\pi \end{cases} \Rightarrow z_{zero} = e^{j \cdot 2\pi \cdot 50/100} = e^{j\pi} =$$

Exercise: page 573 of the refrene Book.

$$\begin{cases} z = e^{j\omega} \\ \omega = f/f_s \cdot 2\pi \end{cases} \Rightarrow z_{zero} = e^{j \cdot 2\pi \cdot 50/100} = e^{j\pi} = -1$$

Exercise: page 573 of the refrene Book.

$$\begin{cases} z = e^{j\omega} \\ \omega = \frac{f}{f_s} \cdot 2\pi \end{cases} \Rightarrow z_{zero} = e^{j \cdot 2\pi \cdot 50/100} = e^{j\pi} = -1$$

$$\Rightarrow \boxed{z_{zero} = -1}$$

Exercise: page 573 of the refrene Book.

$$\omega_{3\text{-}dB} = 2\pi \cdot f_{3\text{-}dB} / f_S = 2\pi \cdot 10/100 = 0.2\pi$$

Exercise: page 573 of the refrene Book.

$$\omega_{3\text{-dB}} = 2\pi \cdot f_{3\text{-dB}} / f_s = 2\pi \cdot 10/100 = 0.2\pi$$

$$\Omega_{3dB} = \tan\left(\frac{\omega_{3dB}}{2}\right) = \tan\left(0.2\pi / 2\right) = 0.3249$$

Exercise: page 573 of the refrence Book.

$$\omega_{3\text{-dB}} = 2\pi \cdot f_{3\text{-dB}} / f_s = 2\pi \cdot 10/100 = 0.2\pi$$

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$$\delta_p = -\Omega_{3dB} \Rightarrow \delta_p = -0.3249$$

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$$\omega_{3\text{-}dB} = 2\pi \cdot f_{3\text{-}dB} / f_s = 2\pi \cdot 10/100 = 0.2\pi$$

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$$s_p = -\Omega_{3dB} \Rightarrow s_p = -0.3249$$

$$z_p = \frac{1+s_p}{1-s_p} = 0.5095$$

Exercise: page 573 of the refrene Book.

$$H(z) = \frac{k(z+1)}{z - 0.5095}$$

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from $H(1) = 1 \longrightarrow k = 0.24525$

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$$H(z) = \frac{k(z+1)}{z-0.5095}$$

from $H(1) = 1 \longrightarrow k = 0.24525$

$$H(z) = \frac{0.24525(z+1)}{z-0.5095}$$

Exercise: page 573 of the refrene Book.

$$H(z) = \frac{k(z+1)}{z - 0.5095}$$

from $H(1) = 1 \longrightarrow k = 0.24525$

$$H(z) = \frac{0.24525\,(z+1)}{z - 0.5095}$$

or equivalently,

$$H(z) = \frac{0.4814z + 0.4814}{1.9627z - 1}$$

Exercise: page 573 of the refrene Book.

from the Course

$$H(z) = -\frac{\left(\frac{C_1 + C_2}{C_A}\right) z - C_1/C_2}{\left(1 + C_3/C_A\right) z - 1}$$

Exercise: page 573 of the refrene Book.

from the Course

$$H(z) = -\frac{\left(\frac{C_1+C_2}{C_A}\right)z - C_1/C_2}{\left(1+C_3/C_A\right)z - 1}$$

$C_1 = 4.814\ pF$

$C_2 = -9.628\ pF$

$C_3 = 9.628$

Exercise: page 573 of the refrene Book.

from the Course

$$H(z) = -\frac{\left(\frac{C_1+C_2}{C_A}\right)z - C_1/C_2}{\left(1+C_3/C_A\right)z - 1}$$

$C_1 = 4.814\ pF$

$C_2 = -9.628\ pF$ → ((differential input can realize the negative Capacitance))

$C_3 = 9.628$

page 573

Exercise 1

first order filter

$$H(z) = \frac{-\left(\frac{C_1+C_2}{C_A}\right)z + C_1/C_A}{\left(1+C_3/C_A\right)z - 1} = \frac{kz + A}{z - z_p}$$

$f_{3\text{-}dB} = 10\ \text{kHz}$

$f_S = 100\ \text{kHz}$

zero @ $z = 0$

Exercise 1

first order filter

$$H(z) = \frac{-\left(\frac{C_1+C_2}{C_A}\right)z + C_1/C_A}{\left(1+C_3/C_A\right)z - 1} = \frac{kz + A}{z - z_p}$$

$$f_{3\text{-}dB} = 10\ kHz$$

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zero @ $z = 0 \Rightarrow A = 0$

Exercise 1

first order filter

$$H(z) = \frac{-\left(\frac{C_1+C_2}{C_A}\right) z + C_1/C_A}{\left(1 + C_3/C_A\right) z - 1} = \frac{kz + A}{z - z_p}$$

$$f_{3\text{-}dB} = 10 \text{ kHz}$$

$$f_S = 100 \text{ kHz}$$

zero @ $z = 0 \Rightarrow A = 0$

$$H(1) = 1$$

Exercise 1

first order filter

$$H(z) = \frac{-\left(\frac{C_1+C_2}{C_A}\right) z + C_1/C_A}{\left(1 + C_3/C_A\right) z - 1} = \frac{kz + A}{z - z_p}$$

$$f_{3\text{-}dB} = 10\ kHz$$

$$f_S = 100\ kHz$$

zero @ $z = 0 \Rightarrow A = 0$

$$H(1) = 1 \Rightarrow \frac{k}{1-z_p} = 1 \Rightarrow k = 1 - z_p$$

Exercise 1

$$\omega_{3-dB} = 2\pi \times f_{3-dB}/f_S$$

Exercise 1

$$\omega_{3-dB} = 2\pi \times f_{3-dB}/f_S = 2\pi \times 10/100 = 0.2\pi$$

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$$\omega_{3\text{-dB}} = 2\pi \times f_{3\text{-dB}}/f_S = 2\pi \times 10/100 = 0.2\pi$$

$$\Omega_{3\text{-dB}} = \tan\left(\omega_{3\text{-dB}}/2\right)$$

Exercise 1

$$\omega_{3\text{-dB}} = 2\pi \times f_{3\text{-dB}}/f_s = 2\pi \times 10/100 = 0.2\pi$$

$$\Omega_{3\text{-dB}} = \tan\left(\omega_{3\text{-dB}}/2\right) = \tan(0.2\pi) = 0.3049 \ \frac{\text{rad}}{\text{sample}}$$

Exercise 1

$$\omega_{3-dB} = 2\pi \times f_{3-dB}/f_s = 2\pi \times 10/100 = 0.2\pi$$

$$\Omega_{3-dB} = \tan\left(\omega_{3-dB}/2\right) = \tan(0.2\pi) = 0.3044 \ \frac{rad}{sample}$$

$$\delta_p = -\Omega_{3-dB} = -0.3044$$

Exercise 1

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$$\Omega_{3-dB} = \tan\left(\omega_{3-dB}/2\right) = \tan(0.2\pi) = 0.3044 \ \frac{rad}{sample}$$

$$\delta_p = -\Omega_{3-dB} = -0.3044$$

$$z_p = \frac{1+\delta_p}{1-\delta_p} = 0.53327$$

Exercise 1

$$H(z) = \frac{0.46673}{1 - 0.53327 z^{-1}}$$

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$$\begin{cases} A=0 \rightarrow C_1 = 0\,PF \\ C_A = 10\,PF \end{cases}$$

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$$H(z) = \frac{0.46673}{1 - 0.53327 z^{-1}}$$

$$\begin{cases} A = 0 \rightarrow C_1 = 0\ PF \\ C_A = 10\ PF \end{cases}$$

$$z_p = \frac{C_A}{C_A + C_3}$$

Exercise 1

$$H(z) = \frac{0.46673}{1-0.53327z^{-1}}$$

$$\begin{cases} A=0 \rightarrow C_1 = 0\,PF \\ C_A = 10\,PF \end{cases}$$

$$z_p = \frac{C_A}{C_A + C_3} \Rightarrow C_3 = \frac{C_A(1-z_p)}{z_p} = 8{,}752\ PF$$

Exercise 1

$$H(z) = \frac{0.46673}{1 - 0.53327 z^{-1}}$$

$$\begin{cases} A = 0 \rightarrow C_1 = 0\ PF \\ C_A = 10\ PF \end{cases}$$

$$z_p = \frac{C_A}{C_A + C_3} \Rightarrow C_3 = \frac{C_A (1 - z_p)}{z_p} = 8{,}752\ PF$$

$$k = 1 - z_p.$$

Exercise 1

$$H(z) = \frac{0.46673}{1-0.53327z^{-1}}$$

$$\begin{cases} A=0 \rightarrow C_1 = 0\,PF \\ C_A = 10\,PF \end{cases}$$

$$z_p = \frac{C_A}{C_A+C_3} \Rightarrow C_3 = \frac{C_A(1-z_p)}{z_p} = 8{,}752\,PF$$

$$k = 1-z_p = \frac{-C_2/C_A}{1+C_3/C_A} = -C_2/C_A+C_3$$

$$\Rightarrow C_2 = -k(C_A+C_3) = -8.752\,pF$$

Exercise 1

gain @ $f = 50$ kHz

Exercise 1

gain @ $f = 50$ kHz

$$\Rightarrow z = e^{j\omega} = e^{j 2\pi f/f_s} = e^{j\pi} = -1$$

Exercise 1

gain @ $f = 50$ kHz

$$\Rightarrow z = e^{j\omega} = e^{j 2\pi f/f_s} = e^{j\pi} = -1$$

$$\Rightarrow H(-1) = \frac{0.46673}{1 + 0.53327} = 0.304$$

Exercise 1

gain @ $f = 50$ kHz

$$\Rightarrow z = e^{j\omega} = e^{j2\pi f/f_s} = e^{j\pi} = -1$$

$$\Rightarrow H(-1) = \frac{0.46673}{1+0.53327} = 0.304 \xrightarrow{20\log(\cdot)} -10.33\ \text{dB}$$

Exercise 2: How to draw Signal Flow graph:

Circuit:

Non-Switched Capacitor

C1

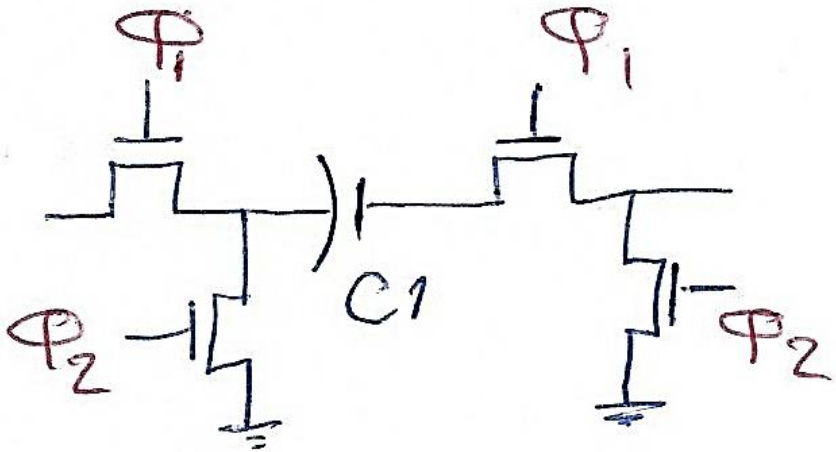
Flow Graph:

$$\xrightarrow{\quad -C1(1-z^{-1}) \quad}$$

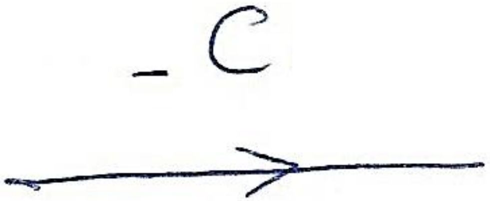
Exercise 2: How to draw Signal flow graph

Circuit :

Non-delaying Switched Capa



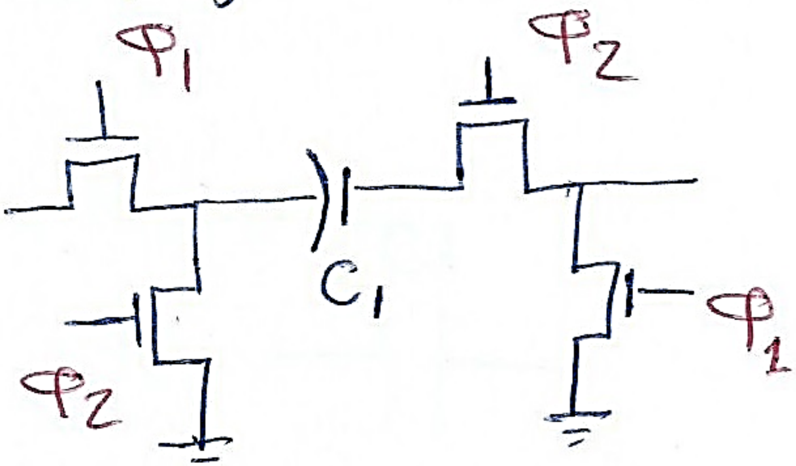
Flow Graph:



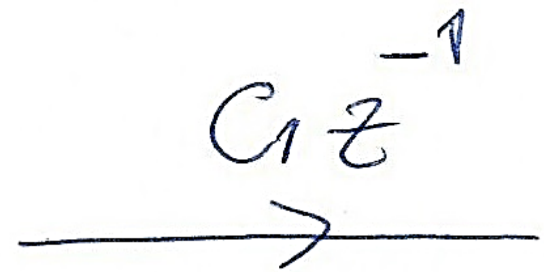
Exercise 2: How to draw Signal flow graph:

Circuit :

delaying Switched Capa



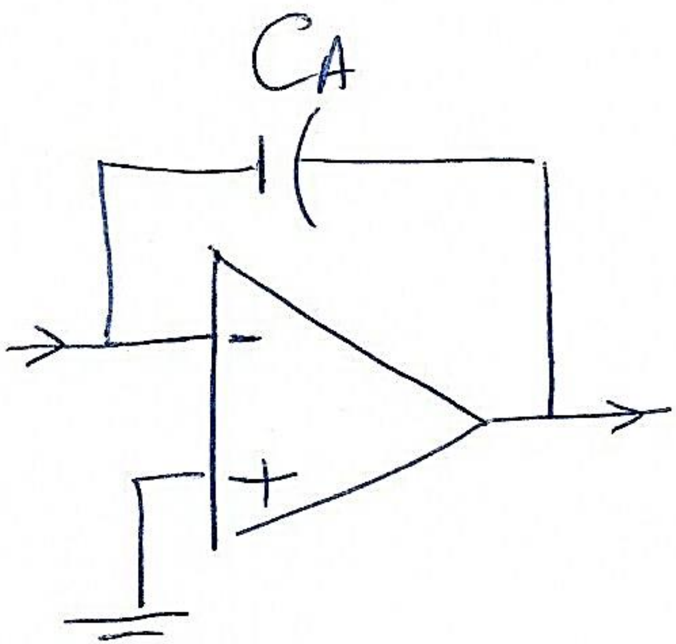
flow Graph :



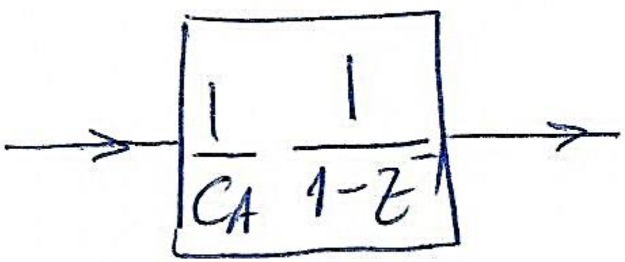
Exercise 2: How to draw Signal flow graph:

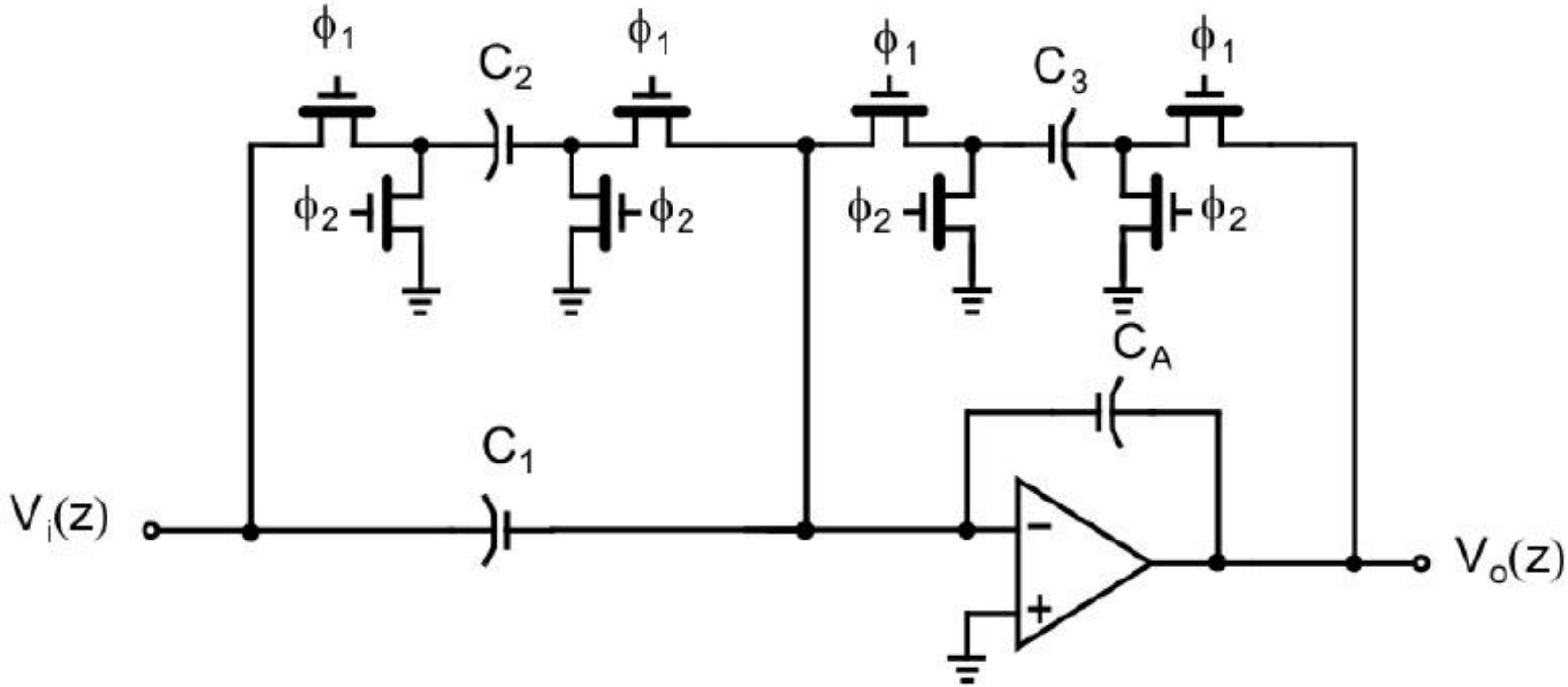
Circuit :

op-amp

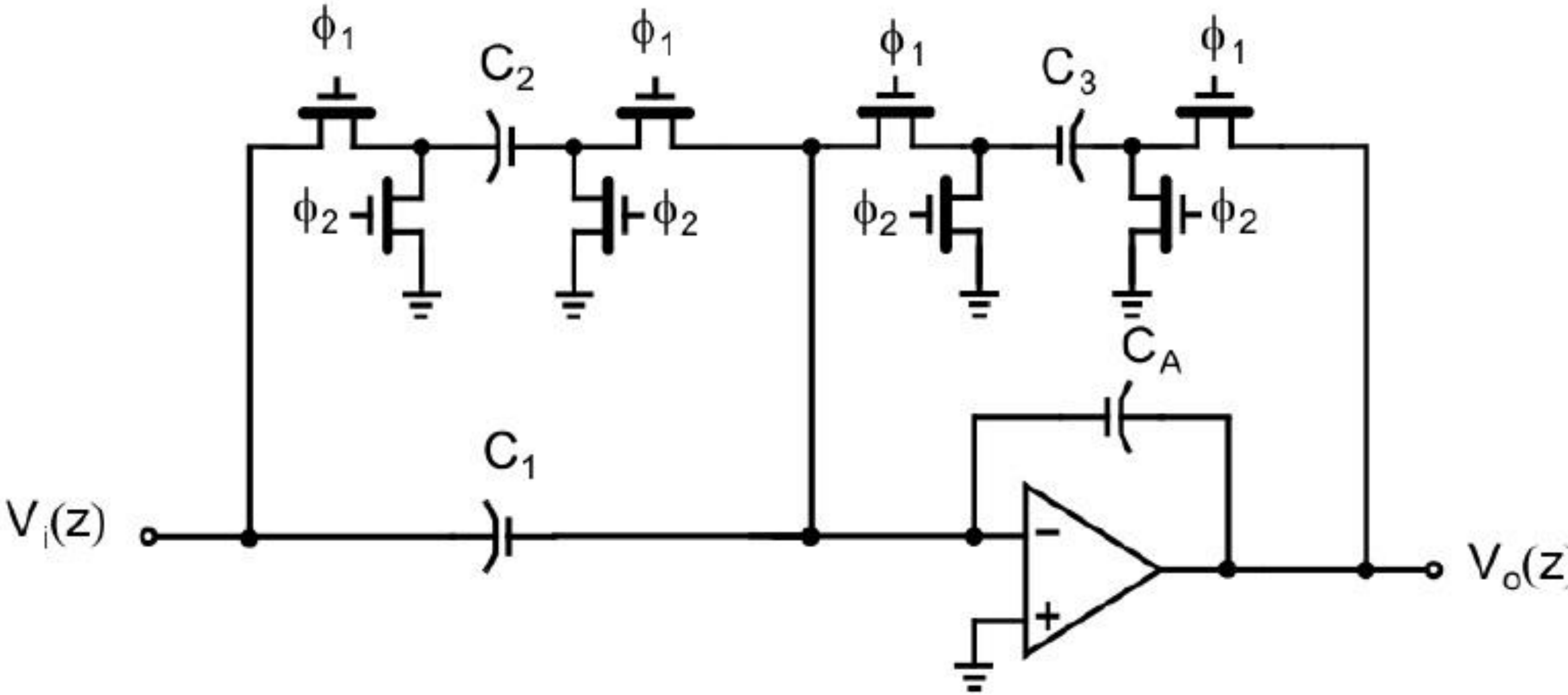


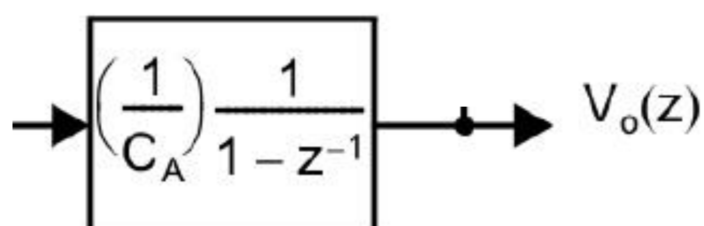
Flow Graph:

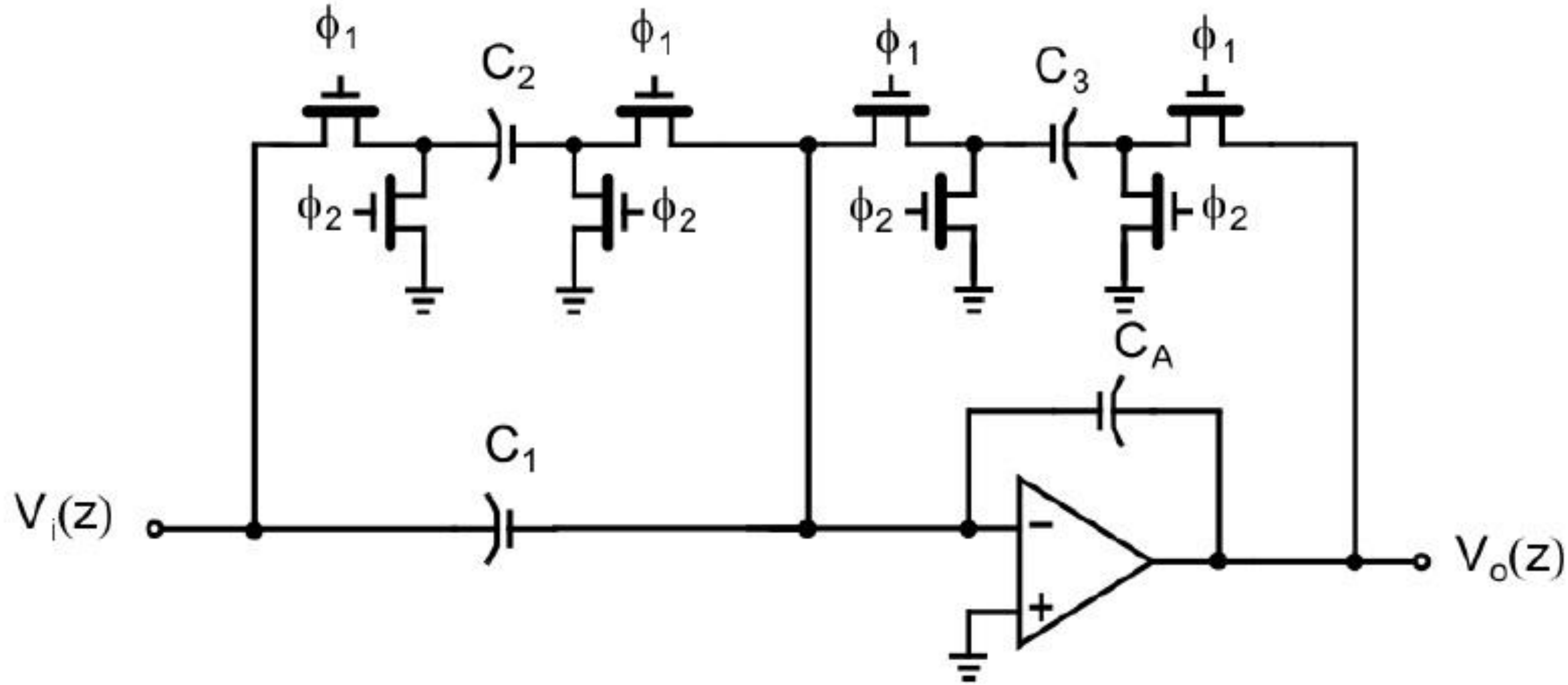




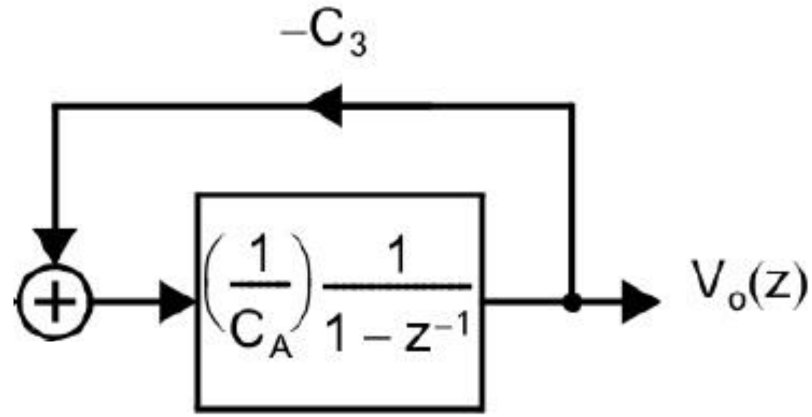
ϕ1
C2
ϕ1
ϕ1
C3
ϕ1
ϕ2
ϕ2
ϕ2
ϕ2
CA
C1
Vi(z)
Vo(z)


φ1
C2
φ1
φ1
C3
φ1
φ2
φ2
φ2
φ2
CA
C1
Vi(z)
Vo(z)

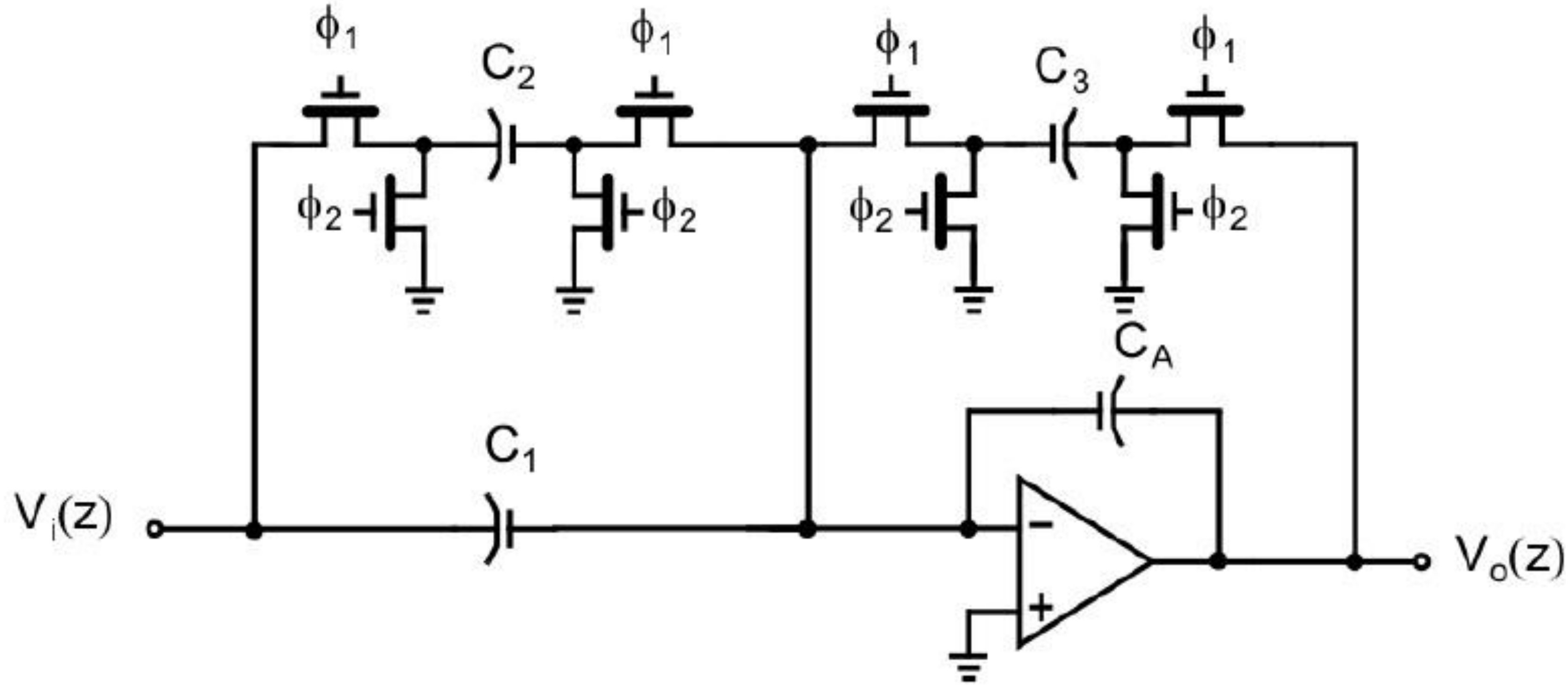

(1/CA) 1/(1 – z^-1)
Vo(z)



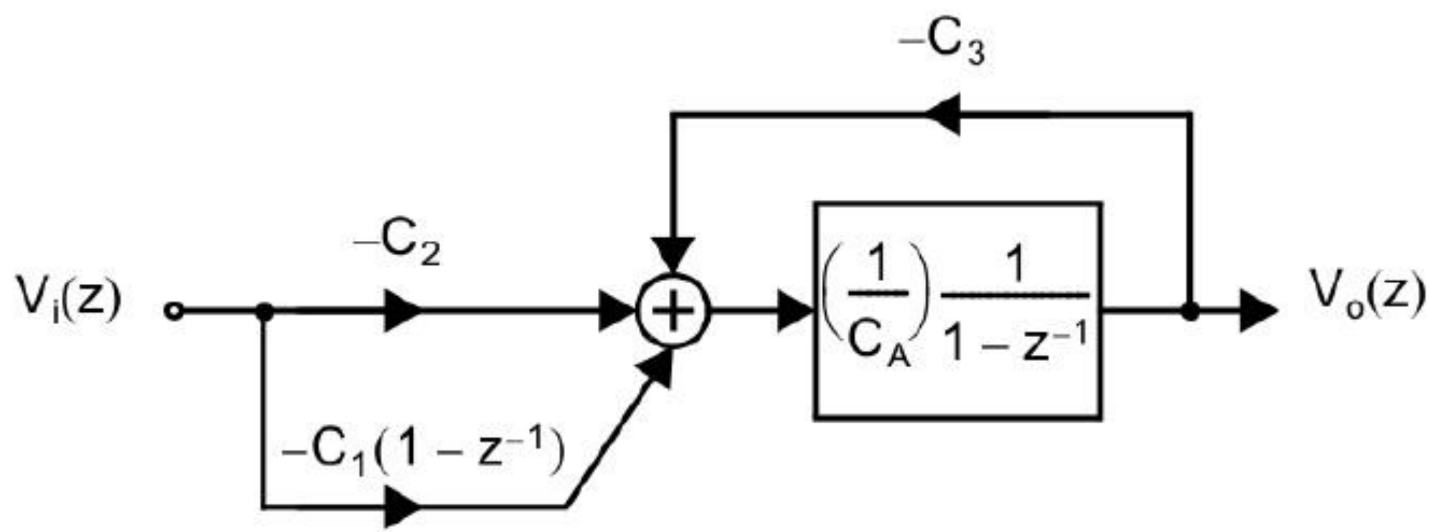
φ1
C2
φ1
φ1
C3
φ1
φ2
φ2
φ2
φ2
CA
C1
Vi(z)
Vo(z)



−C3
$\left(\frac{1}{C_A}\right)\frac{1}{1-z^{-1}}$
Vo(z)

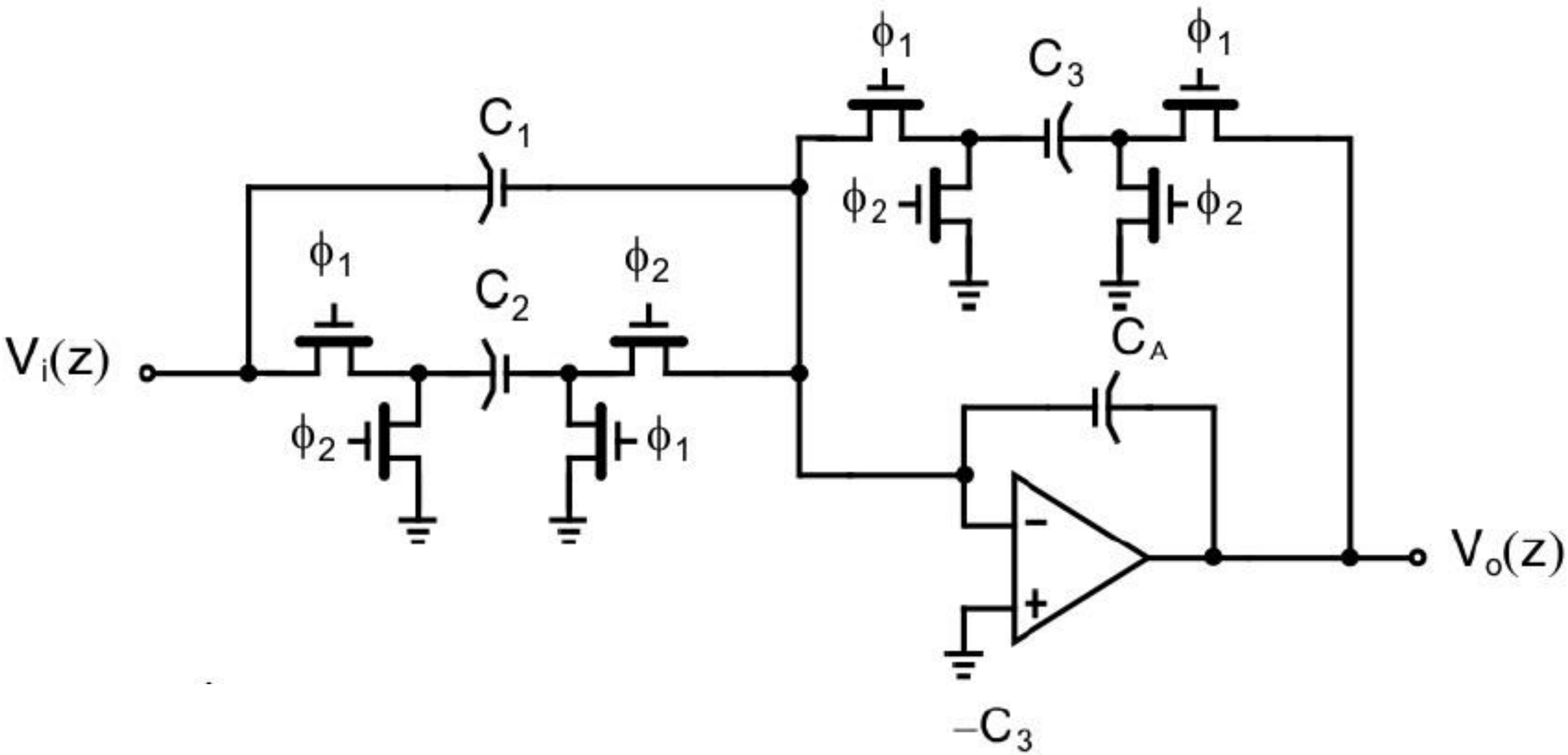


ϕ1
C2
ϕ1
ϕ1
C3
ϕ1
ϕ2
ϕ2
ϕ2
ϕ2
CA
C1
Vi(z)
Vo(z)

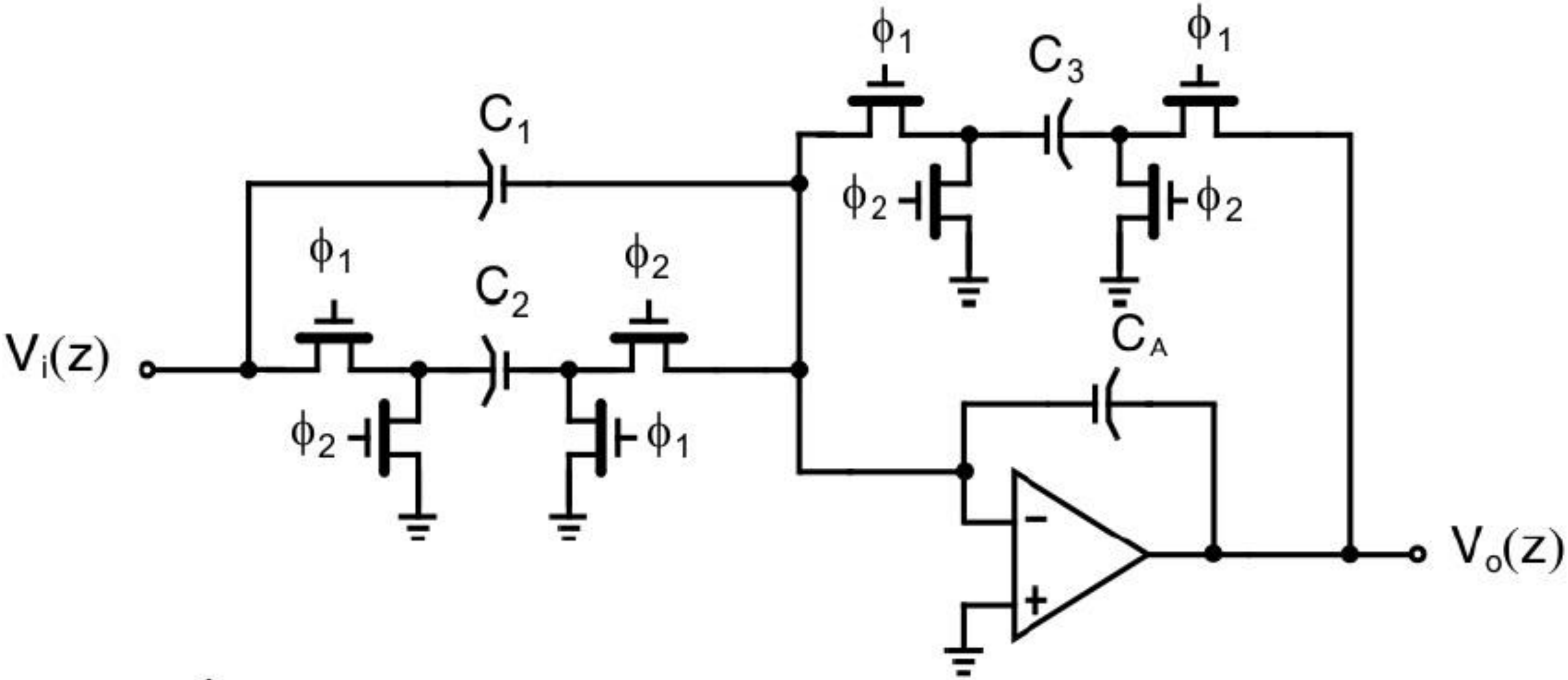


–C3
–C2
Vi(z)
Vo(z)
(1/CA) 1/(1 – z−1)
–C1(1 – z−1)

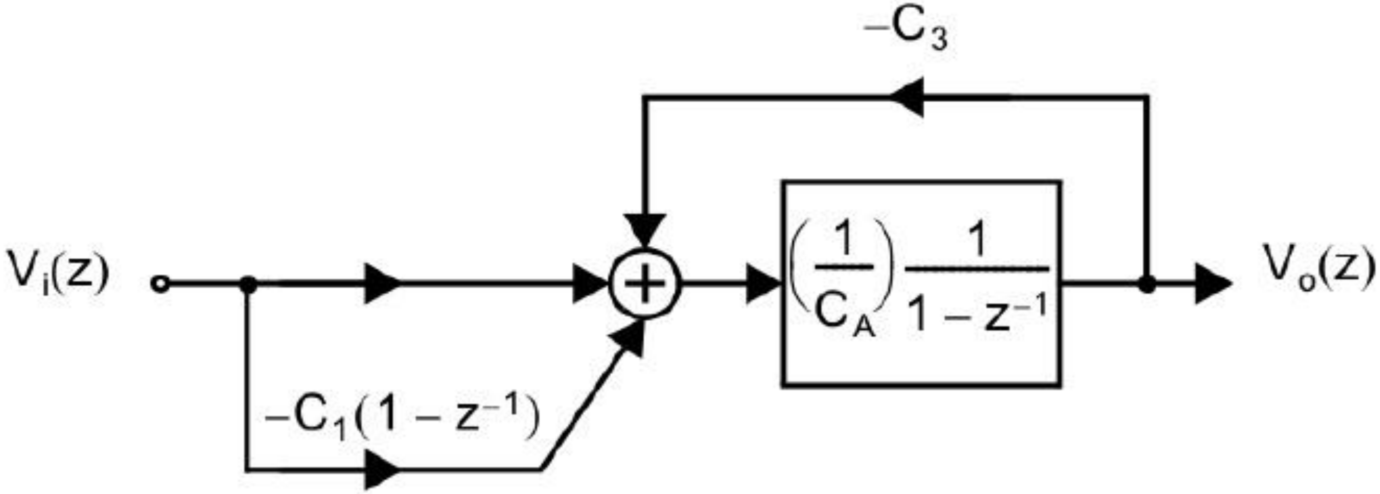
Exercise 5



Exercise 5

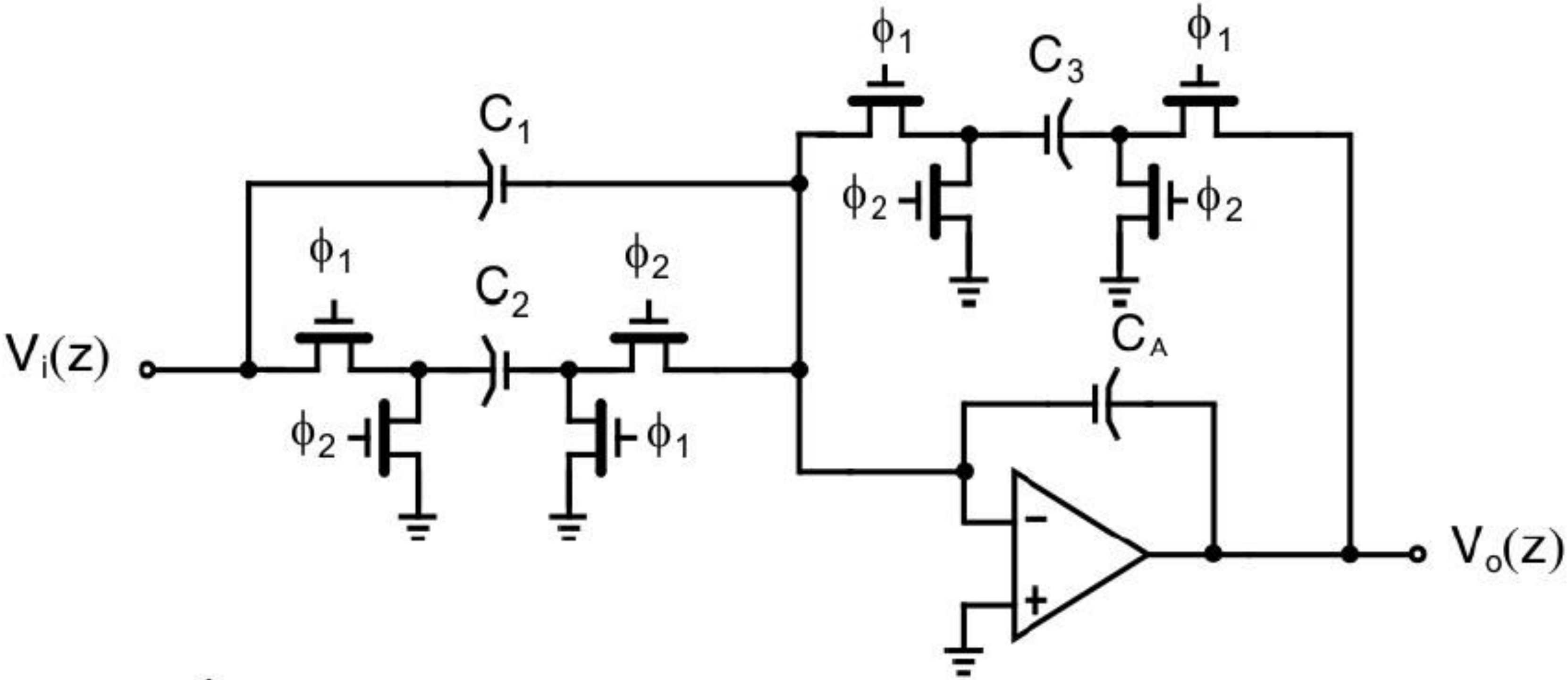


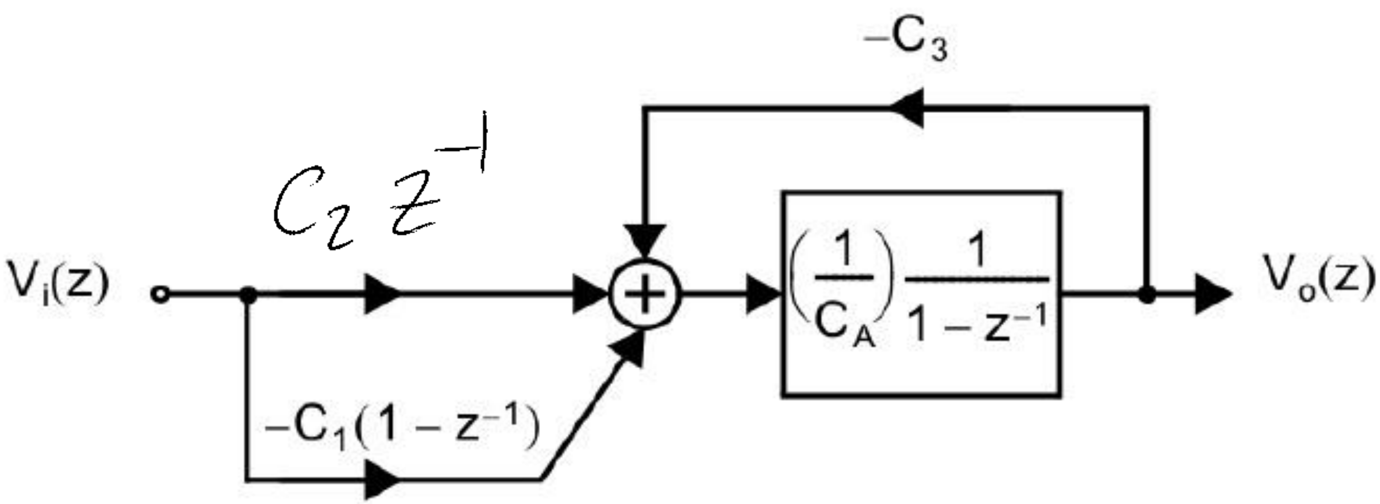
C_1
ϕ_1
C_3
ϕ_1
ϕ_2
ϕ_2
ϕ_1
C_2
ϕ_2
C_A
$V_i(z)$
ϕ_2
ϕ_1
$V_o(z)$



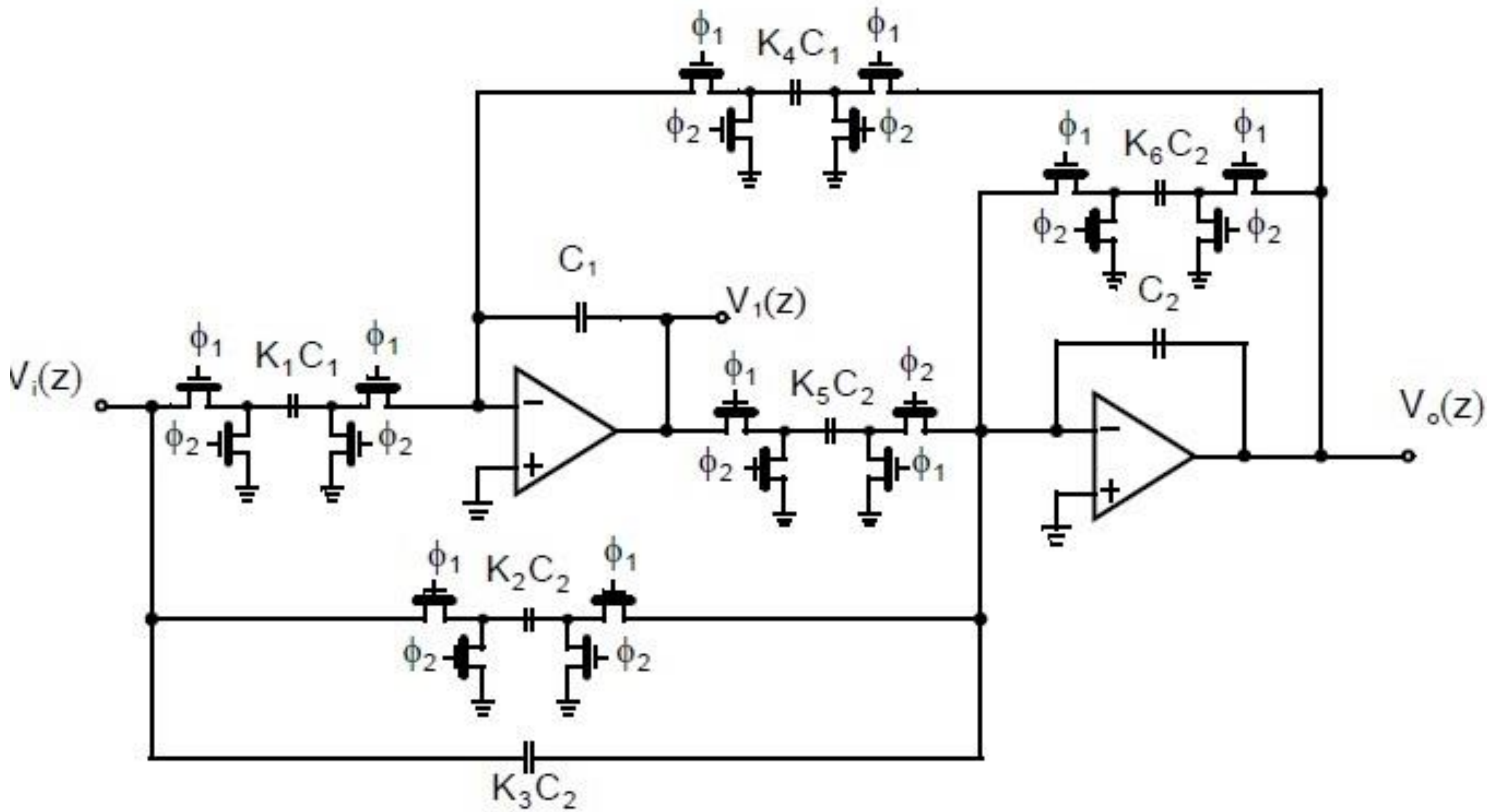
$-C_3$
$V_i(z)$
$\left(\frac{1}{C_A}\right)\frac{1}{1-z^{-1}}$
$V_o(z)$
$-C_1(1-z^{-1})$

Exercise 5



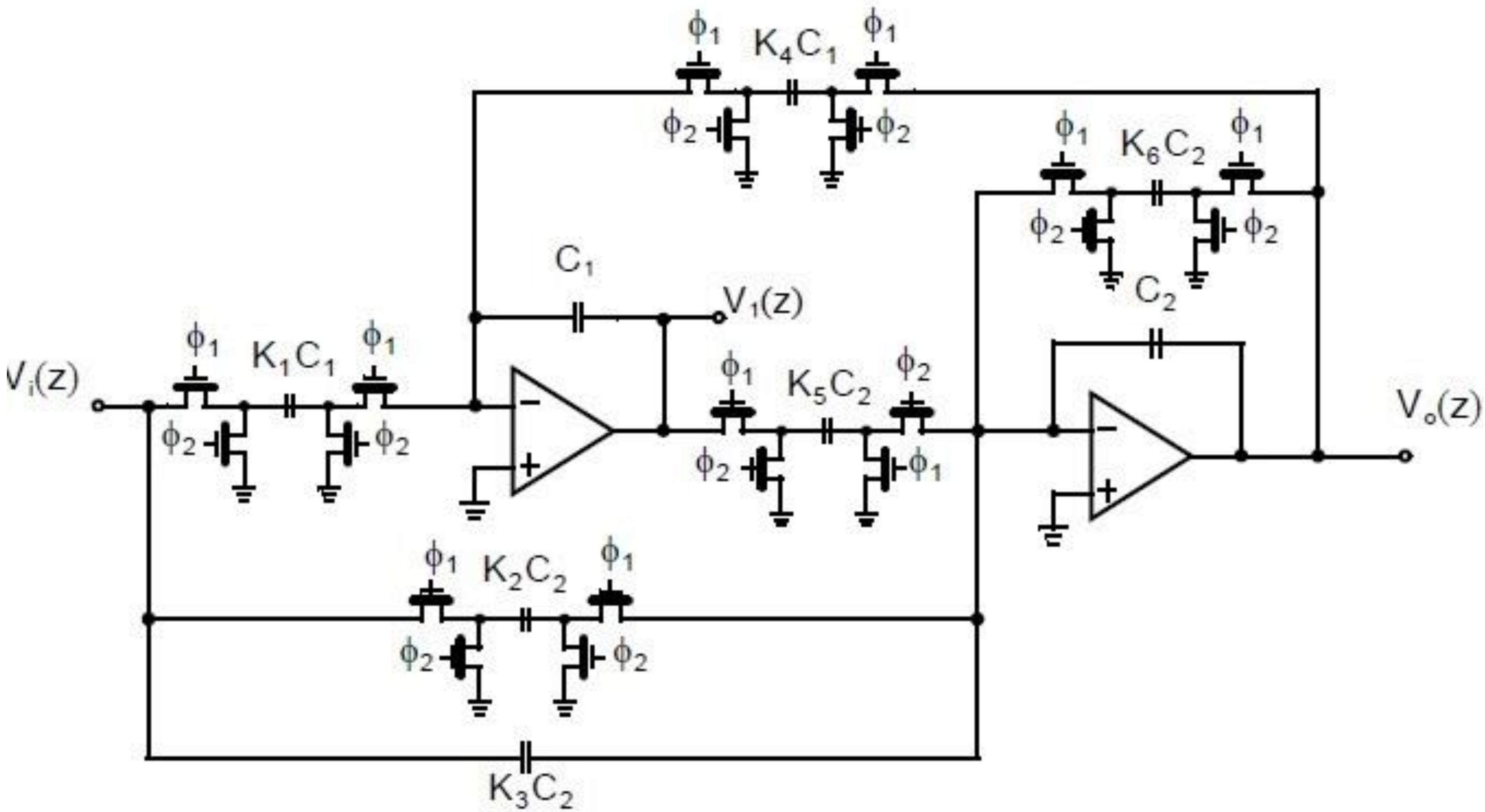


Exercise



ϕ1
K4C1
ϕ1
ϕ2
ϕ2
ϕ1
K6C2
ϕ1
ϕ2
ϕ2
C1
C2
V1(z)
ϕ1
K1C1
ϕ1
Vi(z)
ϕ2
ϕ2
ϕ1
K5C2
ϕ2
ϕ2
ϕ1
Vo(z)
ϕ1
K2C2
ϕ1
ϕ2
ϕ2
K3C2

Exercise



ϕ_1 K_4C_1 ϕ_1
ϕ_2 ϕ_2
ϕ_1 K_6C_2 ϕ_1
ϕ_2 ϕ_2
C_1
$V_1(z)$
C_2
$V_i(z)$
ϕ_1 K_1C_1 ϕ_1
ϕ_2 ϕ_2
ϕ_1 K_5C_2 ϕ_2
ϕ_2 ϕ_1
$V_o(z)$
ϕ_1 K_2C_2 ϕ_1
ϕ_2 ϕ_2
K_3C_2

Exercise