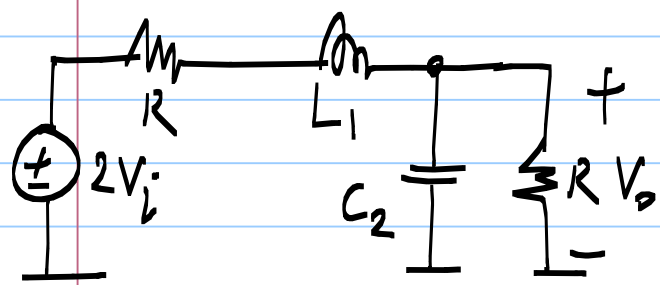
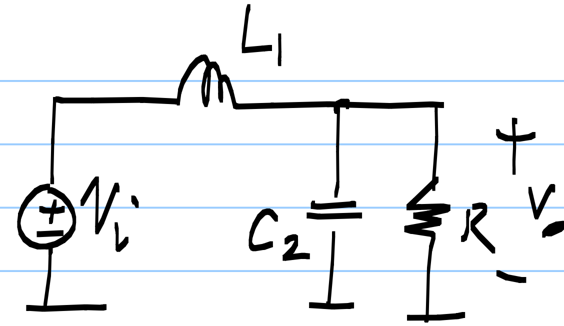
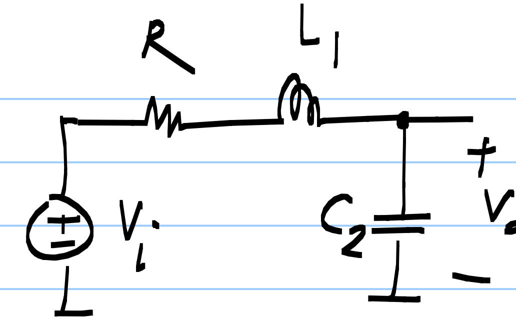
# Lecture 57 : Continuous-time filters



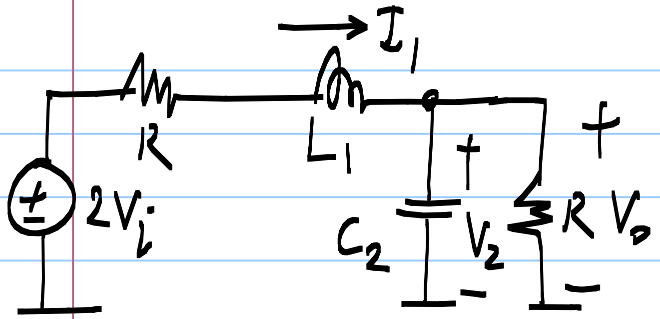



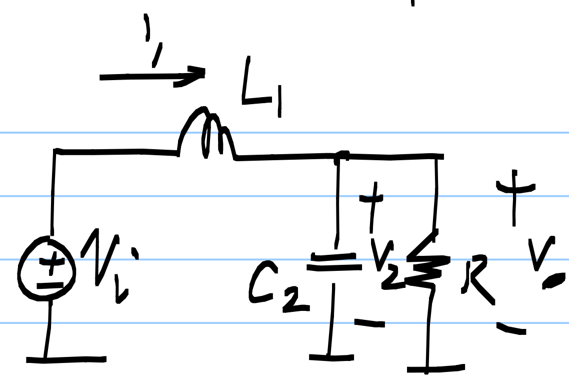

$$\frac{V_o}{V_i} = \frac{1}{s^2 L_1 C_2 + s\left(C_2 R + \frac{L_1}{R}\right) + 1} \qquad \frac{1}{s^2 L_1 C_2 + s\frac{L_1}{R} + 1} \qquad \frac{1}{s^2 L_1 C_2 + s C_2 R + 1}$$

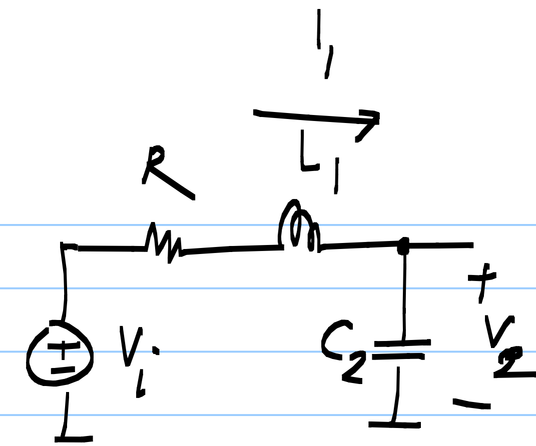
$$\omega_p = \frac{1}{\sqrt{L_1 C_2}} \qquad \frac{1}{\sqrt{L_1 C_2}} \qquad \frac{1}{\sqrt{L_1 C_2}}$$

$$Q_p = \frac{1}{R\sqrt{\frac{C_2}{L_1}} + \frac{1}{R}\sqrt{\frac{L_1}{C_2}}} \qquad R\sqrt{\frac{C_2}{L_1}} \qquad \frac{1}{R}\sqrt{\frac{L_1}{C_2}}$$

# Lecture 57 : Continuous-time filters




$$2V_i - I_1 R - V_2 = sL_1 \cdot I_1$$

$$I_1 - V_2/R = sC_2 V_2$$

$$2V_i - V_1 - V_2 = \frac{sL_1}{R} \cdot V_1$$

$$V_1 - V_2 = sC_2 R \cdot V_2$$

$$V_i - V_2 = sL_1 \cdot I_1$$

$$I_1 - V_2/R = sC_2 V_2$$

$$V_i - V_2 = \frac{sL_1}{R} \cdot V_1$$

$$V_1 - V_2 = sC_2 R V_2$$

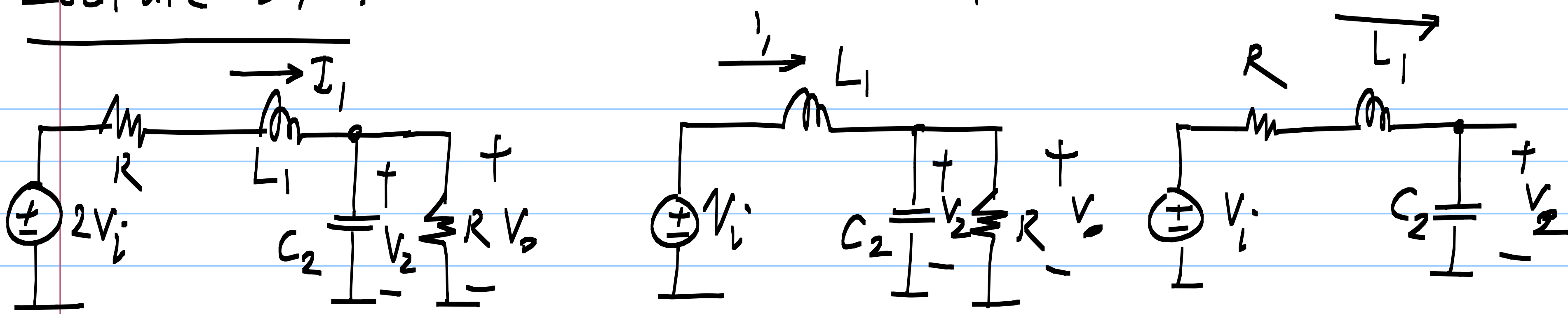
$$V_i - I_1 R - V_2 = sL_1 \cdot I_1$$

$$I_1 = sC_2 V_2$$

$$V_i - V_1 - V_2 = \frac{sL_1}{R} V_1$$

$$V_1 = sC_2 R \cdot V_2$$

# Lecture 57 : Continuous-time filters



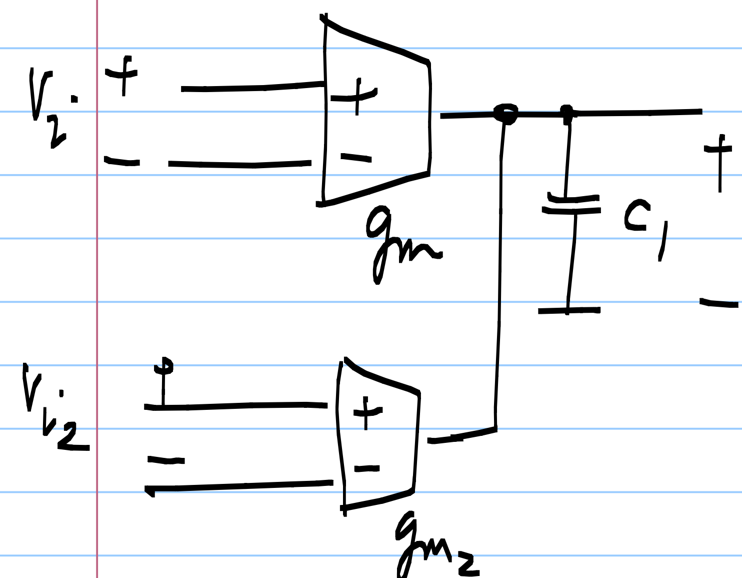

$$2V_i - V_1 - V_2 = \frac{sL_1}{R} \cdot V_1 \qquad V_i - V_2 = \frac{sL_1}{R} \cdot V_1 \qquad V_i - V_1 - V_2 = \frac{sL_1}{R} V_1$$

$$V_1 - V_2 = sC_2R \cdot V_2 \qquad V_1 - V_2 = sC_2R V_2 \qquad V_1 = sC_2R \cdot V_2$$

$$\frac{2V_i - V_1 - V_2}{sL_1/R} = V_1 \qquad \frac{V_i - V_2}{sL_1/R} = V_1 \qquad \frac{V_i - V_1 - V_2}{sL_1/R} = V_1$$

$$\frac{V_1 - V_2}{sC_2R} = V_2 \qquad \frac{V_1 - V_2}{sC_2R} = V_2 \qquad \frac{V_1}{sC_2R} = V_2$$

Equations describing the ladder filter implemented using integrators:

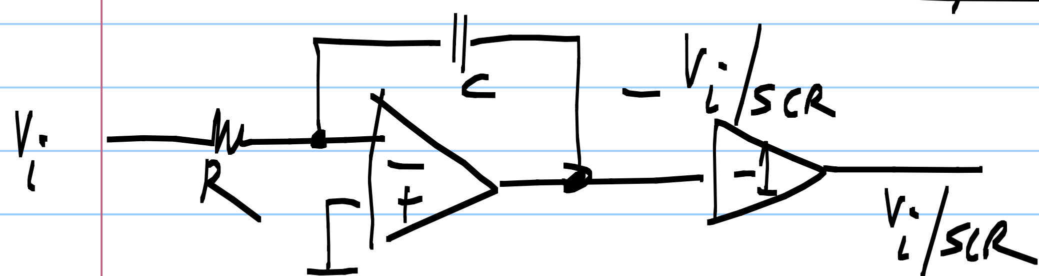



**Transconductor-capacitor ($g_m$-C)**

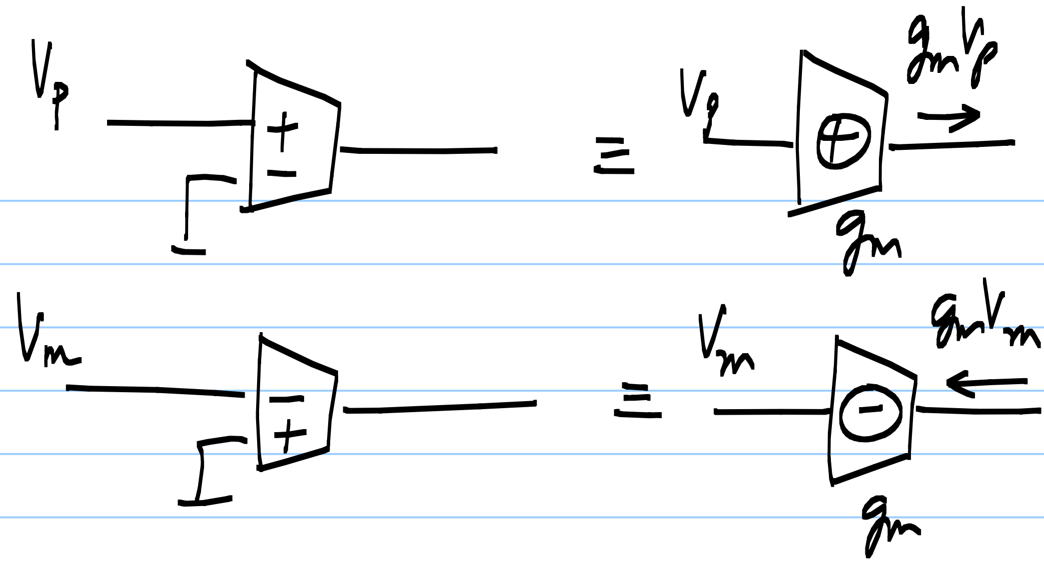
$$\frac{V_i g_m}{sC_1} + \frac{V_{i2} g_{m2}}{sC_1}$$

$g_m$-C filters

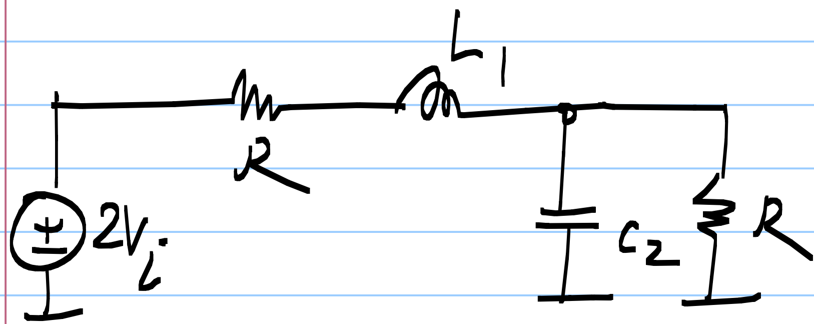
**Opamp-RC** (Active RC integrator)

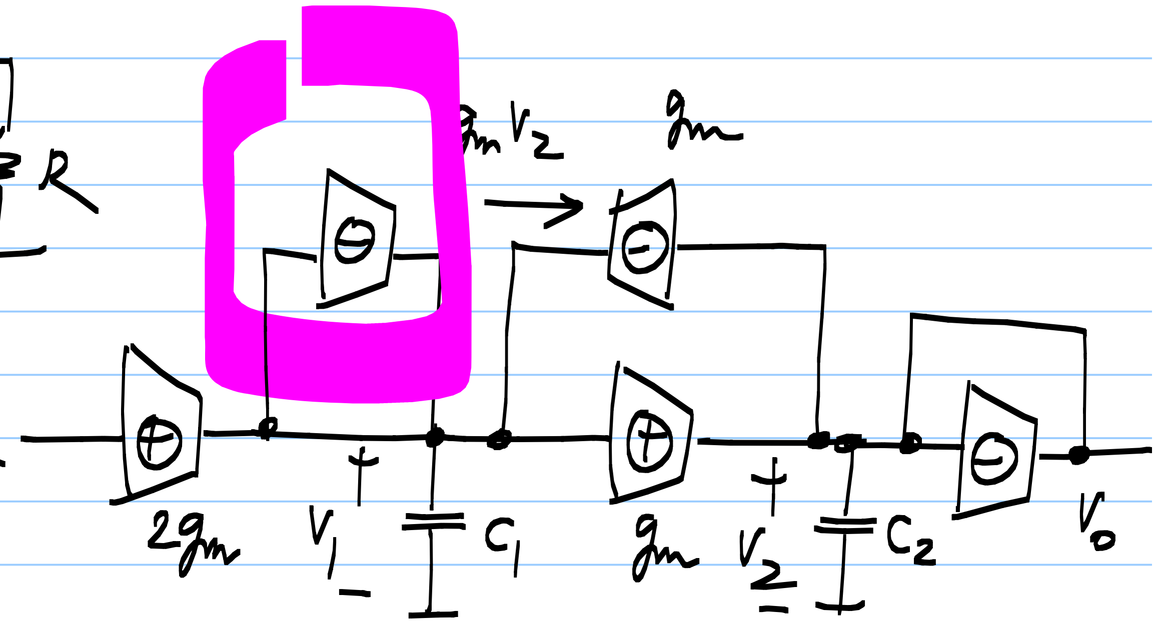



active RC filters


Vp
+
−
≡
Vp
+
gmVp
gm
Vm
−
+
≡
Vm
−
gmVm
gm

# $g_m$-C implementation of lowpass filters:




$$\frac{2V_i - V_1 - V_2}{sL_1/R} = V_1$$

$$\frac{V_1 - V_2}{sC_2R} = V_2$$

$$\frac{I_{c_1}}{sC_1} = \frac{2V_i - V_1 - V_2}{sL_1/R}$$

$$I_{c_1} = \frac{C_1R}{L_1}\left(2V_i - V_1 - V_2\right)$$

($\frac{C_1R}{L_1}$ → $g_m$)

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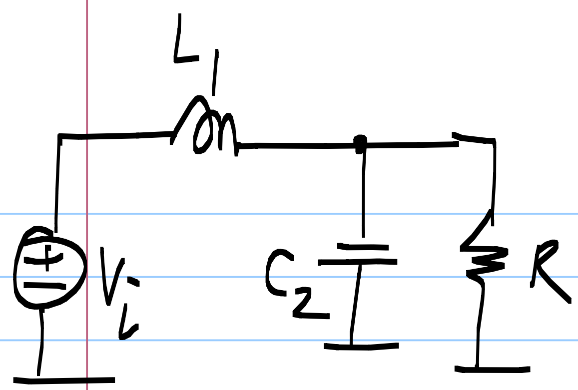
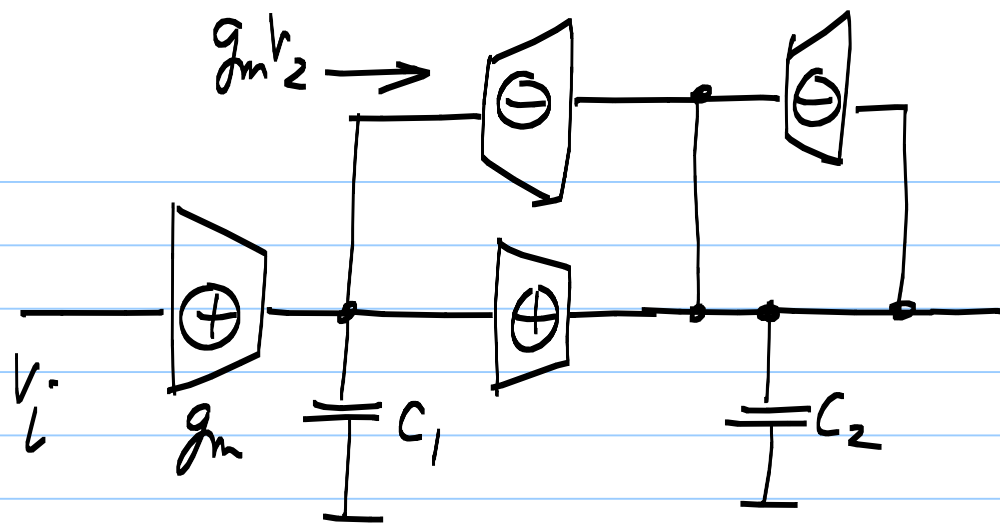
Indian Institute of Technology, Madras




$$\frac{V_i - V_2}{sL_1/R} = V_1$$

$$\frac{V_1 - V_2}{sC_2 R} = V_2$$

$$V_2 = \frac{I_{c_2}}{sC_2} = \frac{(V_1 - V_2)/R}{sC_2}$$

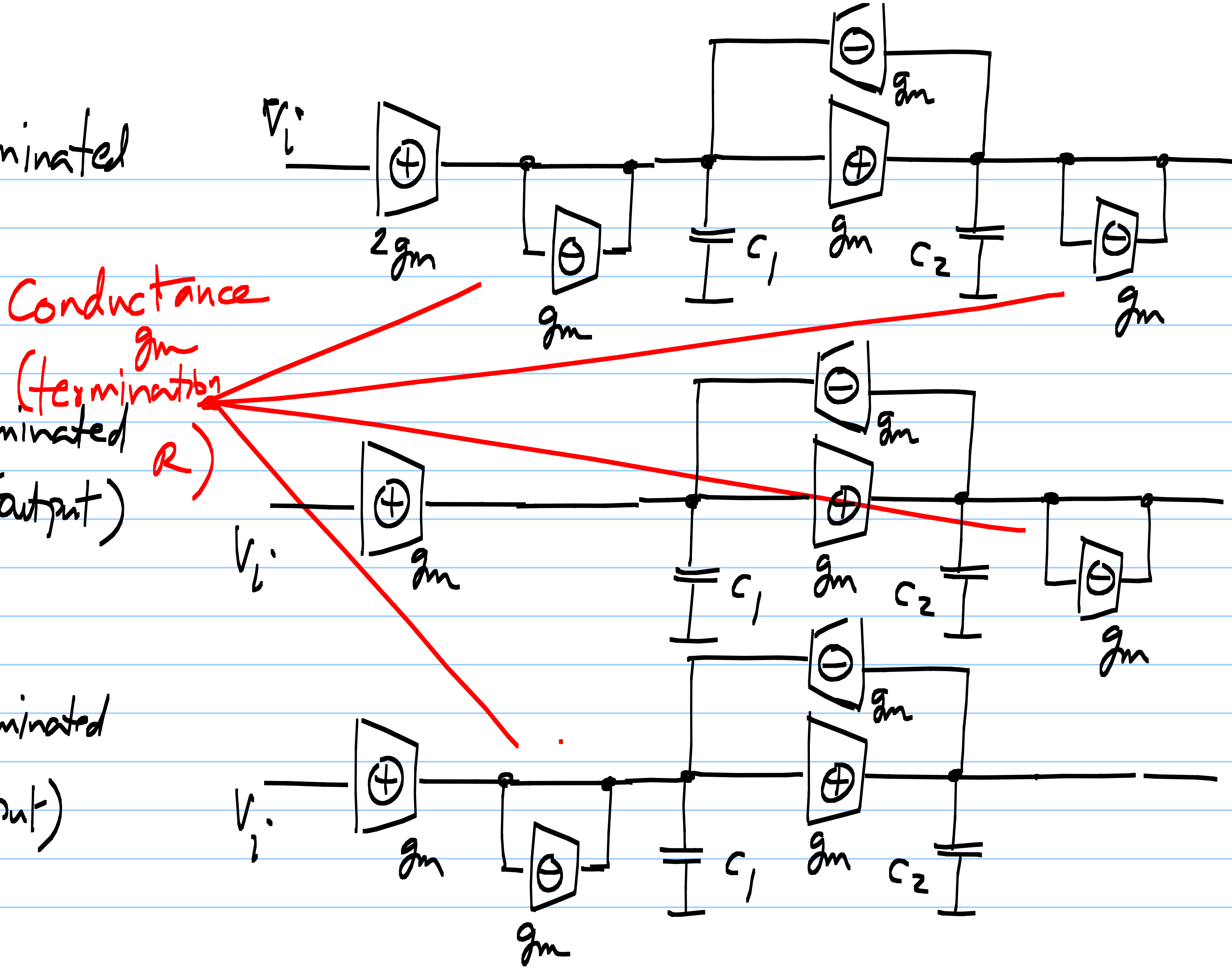
$$V_1 = \frac{I_{c_1}}{sC_1} = \frac{V_i - V_2}{sL_1/R}$$

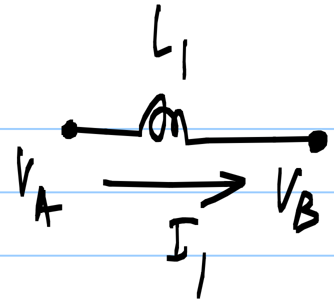
$$I_{c_1} = \underbrace{\frac{C_1 R}{L_1}}_{g_m}(V_i - V_2)$$

Doubly terminated filter

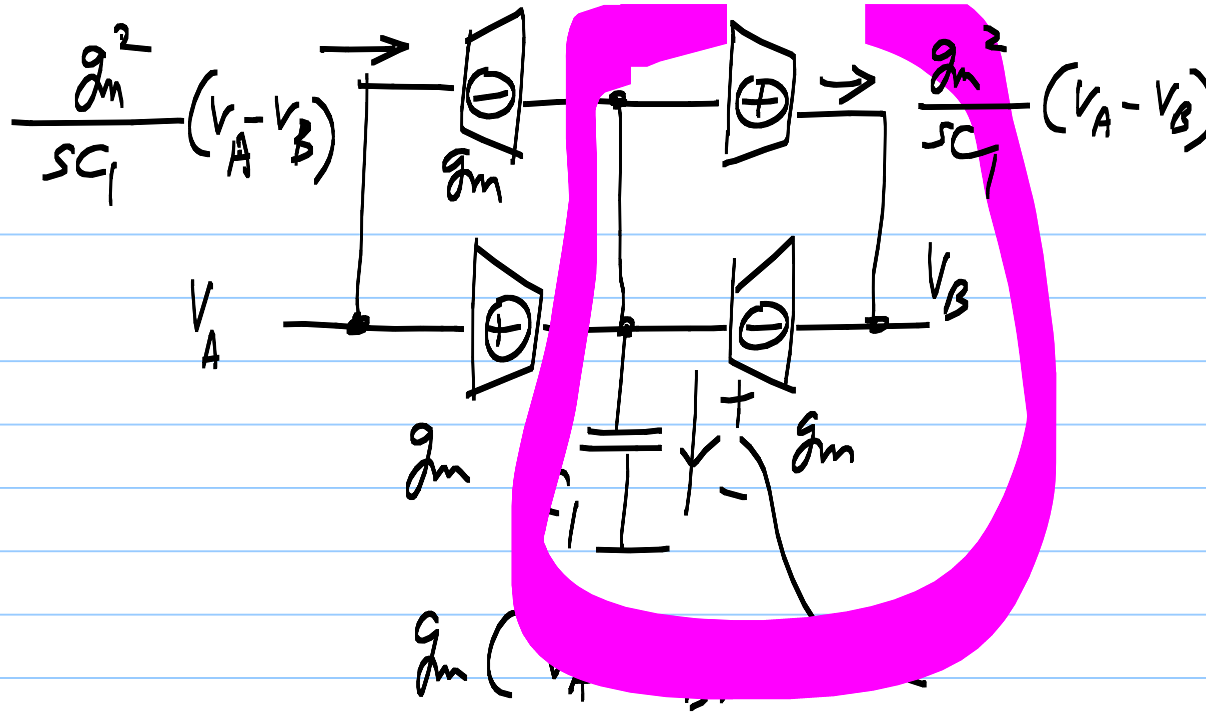
Singly terminated filter (output)

Singly terminated filter (input)



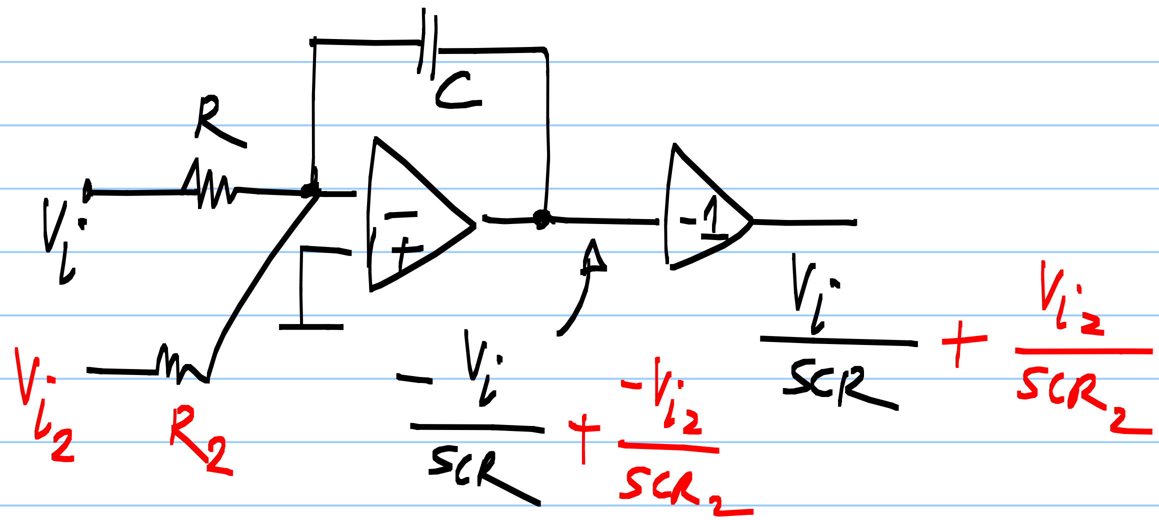


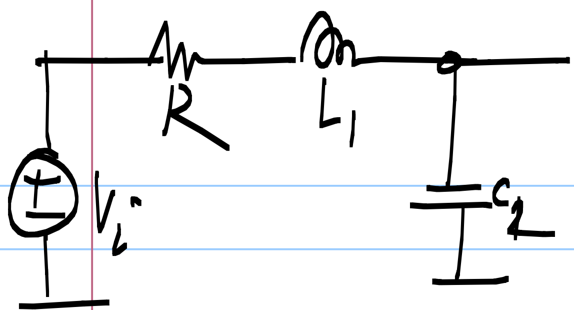

$$I_1 = \frac{V_A - V_B}{sL_1}$$

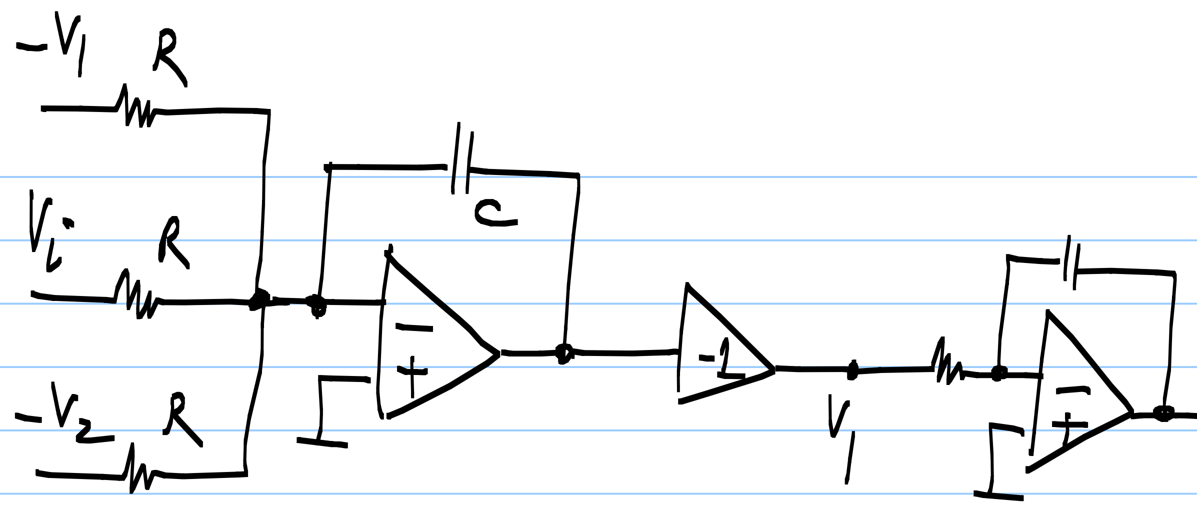



$$\frac{g_m}{sC_1} \cdot (V_A - V_B)$$

# Active RC filter:



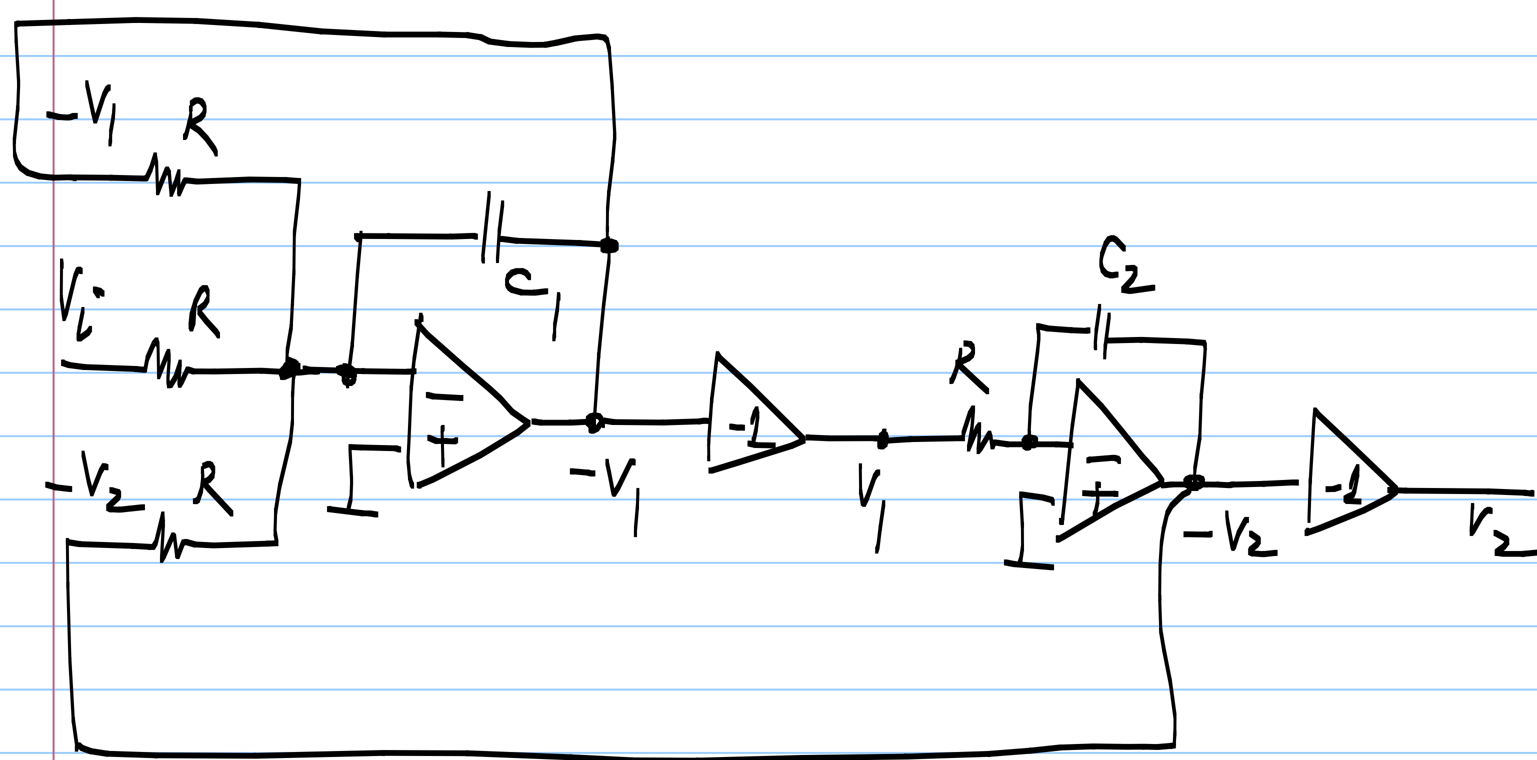


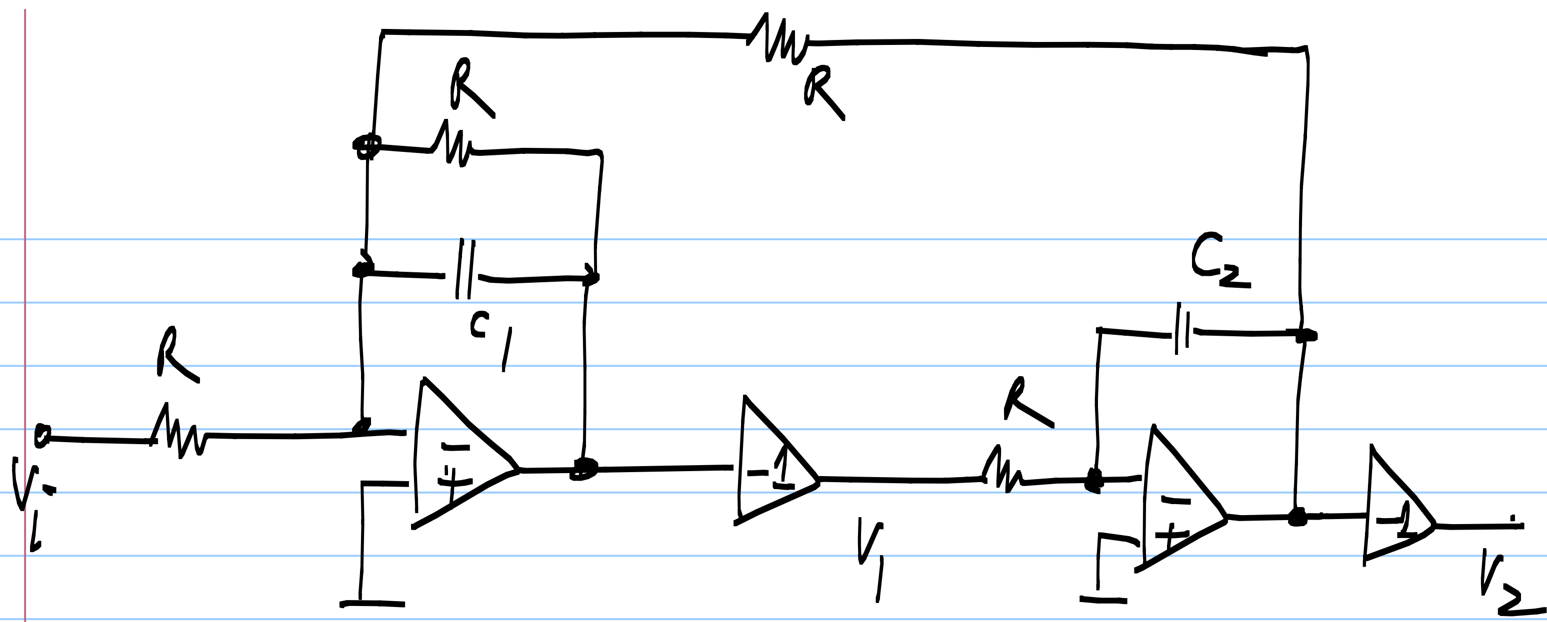

$$\frac{V_i - I_1 R - V_2}{s L_1} = I_1$$

$$\frac{V_i - V_1 - V_2}{s L_1 / R} = V_1$$

$$\frac{V_1}{s C_2 R} = V_2$$



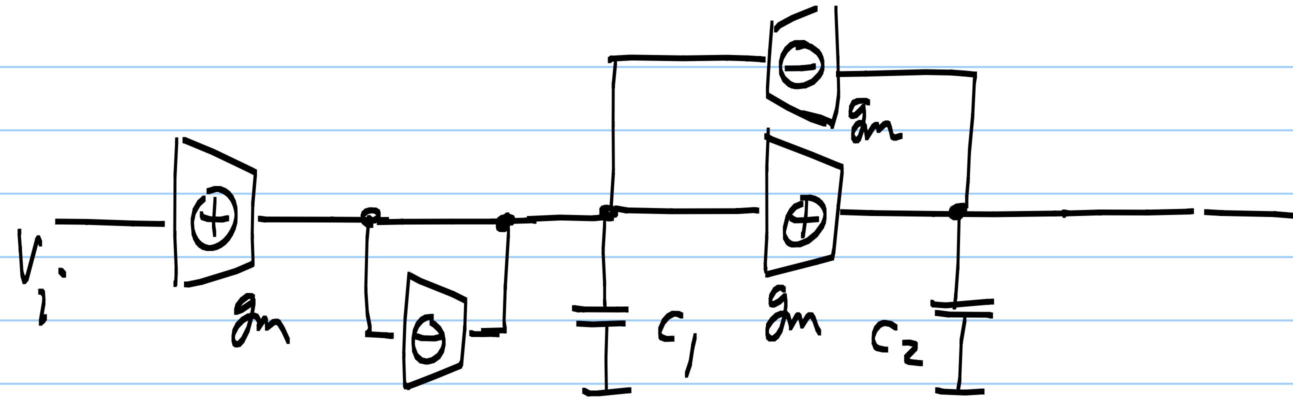
$-V_1$
R
$V_i$
R
$-V_2$
R
$C_1$
$-V_1$
-1
$V_1$
R
$C_2$
$-V_2$
-1
$V_2$

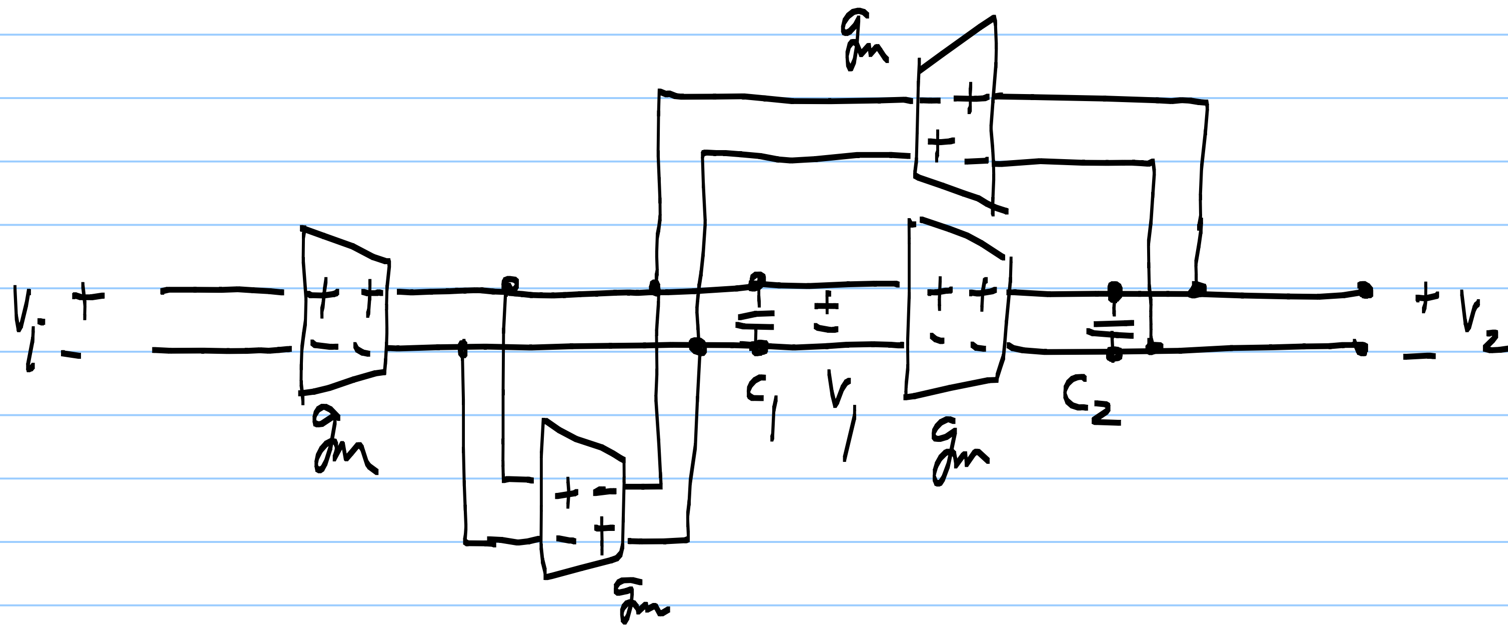


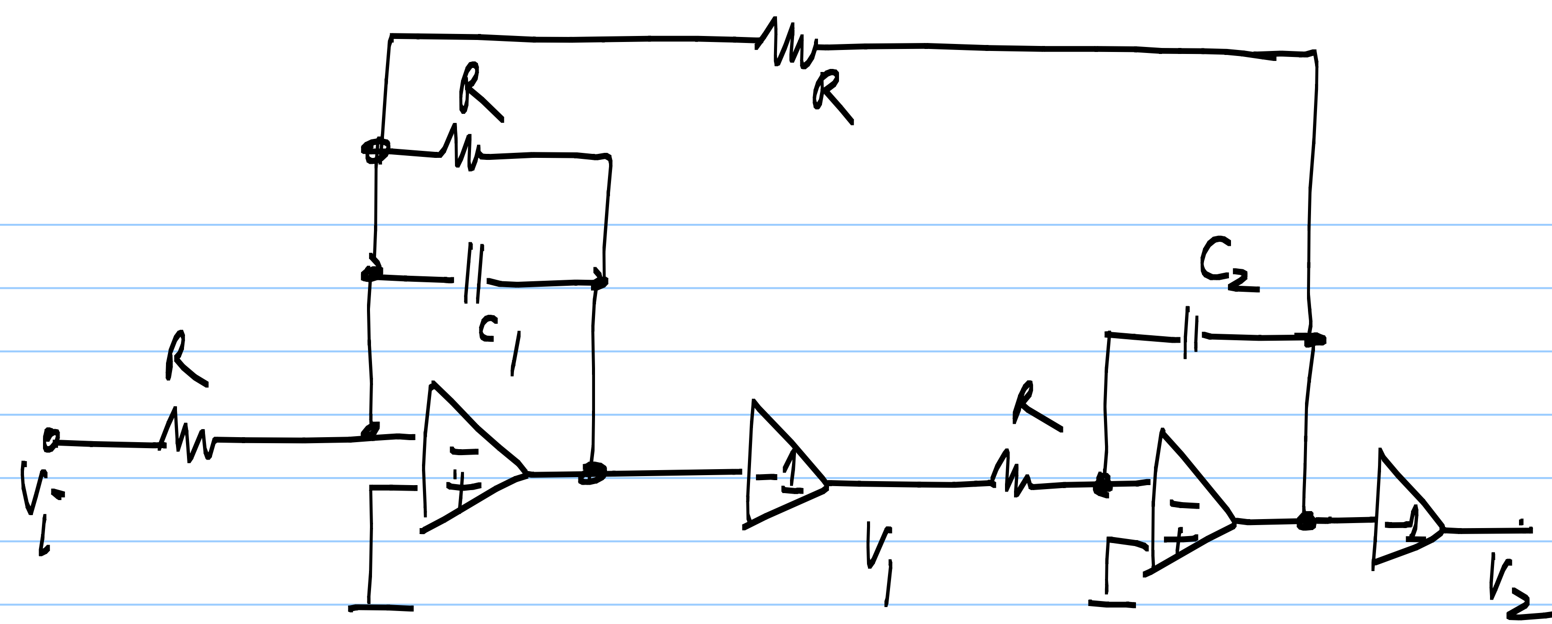

# 2nd order active-RC filter

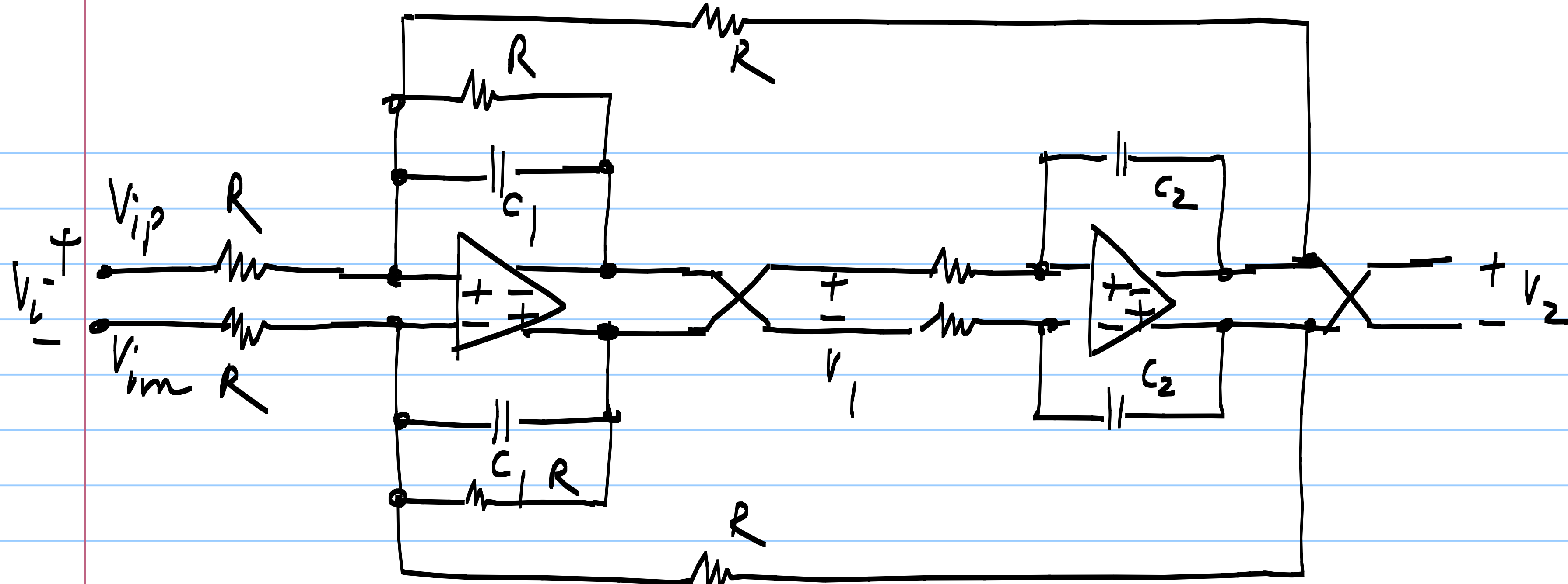
# Fully differential implementation:

$g_m - C$




R
R
R
C1
R
C2
-1
-1
Vi
V1
V2




Fully differential active RC filter (2nd order)