School of Electrical Engineering and Robotics

EGB348 Electronics

Additional Filter Circuits

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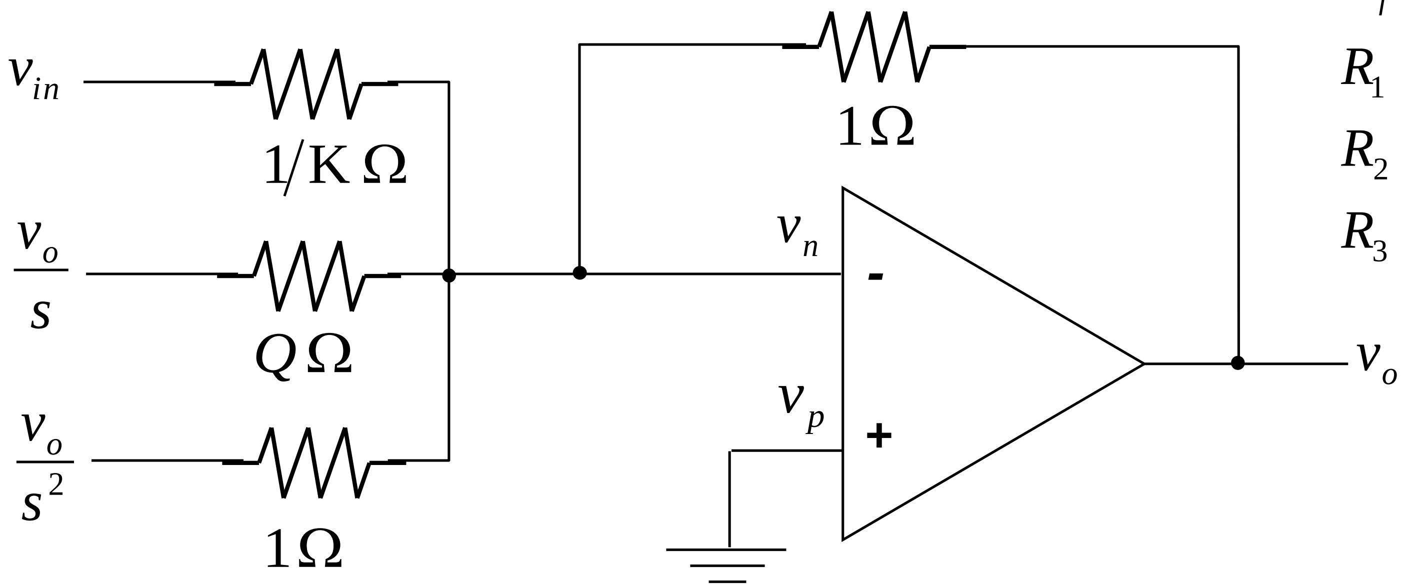
Recommended Readings:

Summing Biquads

- Consider the summing circuit:



$R_f = 1$

$R_1 = 1/K$

$R_2 = Q$

$R_3 = 1$

$$v_o = -\left(\frac{R_f}{R_1}v_{in1} + \frac{R_f}{R_2}v_{in2} + \frac{R_f}{R_3}v_{in3}\right) = -\left(Kv_{in} + \frac{v_o}{Qs} + \frac{v_o}{s^2}\right)$$

Summing Biquads

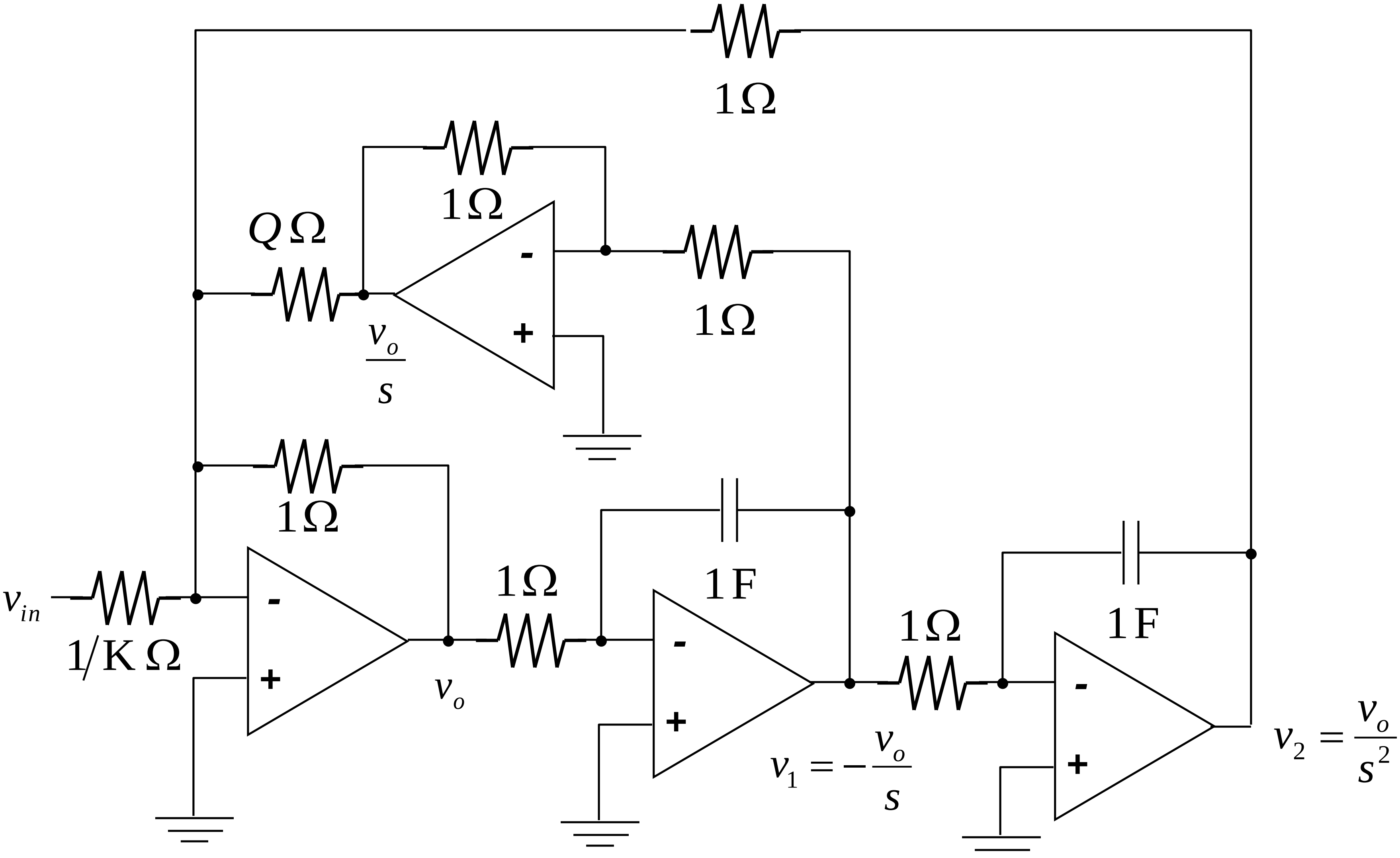
- Rearranging:

$$v_o\left(1+\frac{1}{Qs}+\frac{1}{s^2}\right)=-Kv_{in}$$

$$\frac{v_o}{v_{in}}=\frac{-K}{1+\frac{1}{Qs}+\frac{1}{s^2}}=\frac{-Ks^2}{s^2+\frac{s}{Q}+1}$$

- This is a high pass filter

Summing Biquads



Summing Biquads

- Output v_1:

$$v_1 = -\frac{v_o}{s} = \left(-\frac{1}{s}\right)\frac{-Ks^2}{\left(s^2 + \frac{s}{Q} + 1\right)} v_{in}$$

$$\frac{v_1}{v_{in}} = \frac{-Ks}{s^2 + \frac{s}{Q} + 1}$$

- This is a band pass output.

Summing Biquads

- Output v_2:

$$v_2 = -\frac{v_o}{s^2} = \left(\frac{1}{s^2}\right)\frac{-Ks^2}{\left(s^2 + \frac{s}{Q} + 1\right)} v_{in}$$

$$\frac{v_2}{v_{in}} = \frac{-K}{s^2 + \frac{s}{Q} + 1}$$

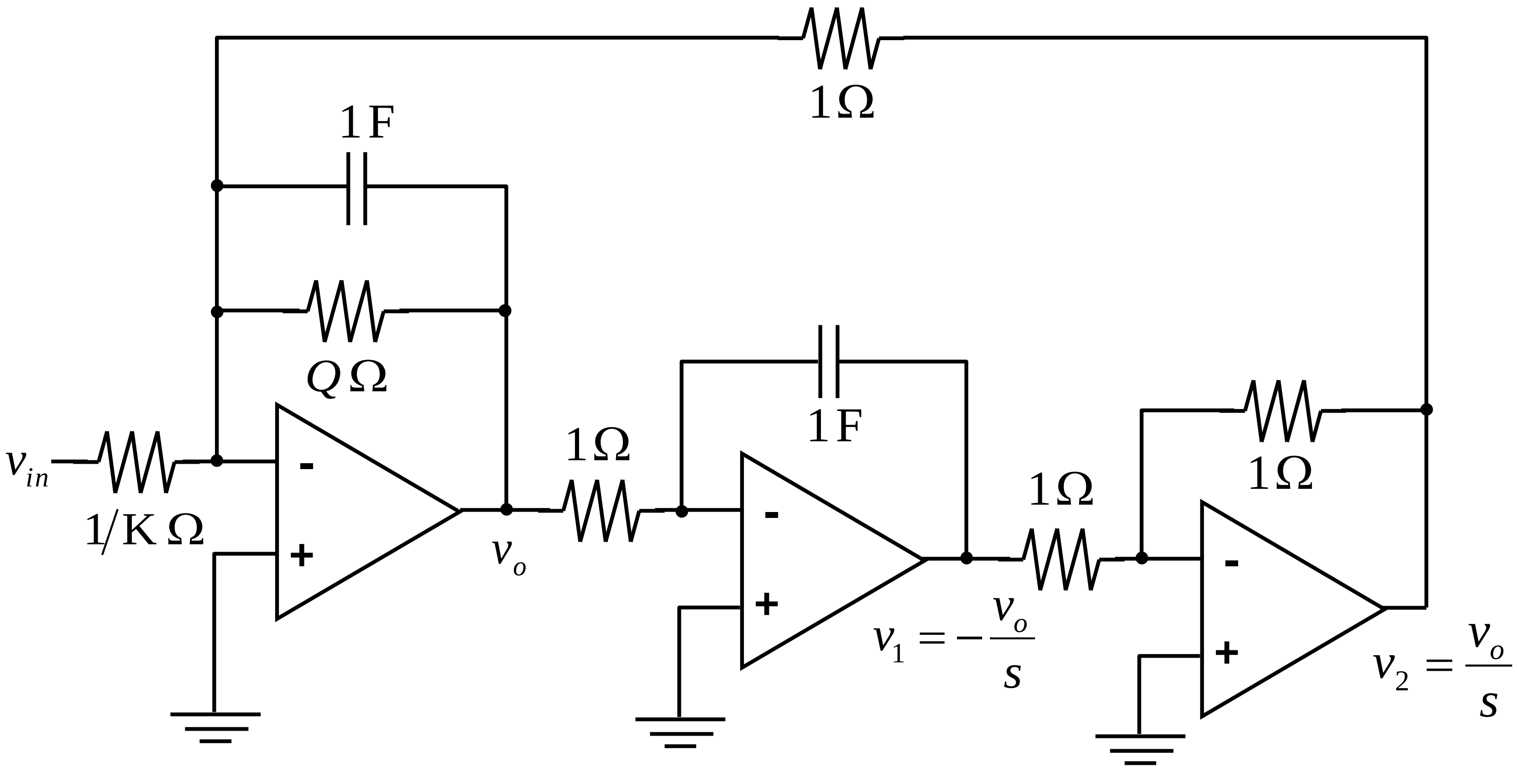
- This is a low pass output.

Summing Biquads

- If we only need band pass and low pass outputs, we can use the following circuit.

- This is called the Tow-Tomas biquad.

Summing Biquads



Summing Biquads

- From:

$$v_o = -\left(\frac{Z_f}{Z_1} v_{in1} + \frac{Z_f}{Z_2} v_{in2} \right)$$

- Where:

$$Z_f = \frac{Q}{1+sQ}$$

$$Z_1 = 1/K$$

$$Z_2 = 1$$

$$v_{in1} = v_{in}$$

$$v_{in2} = \frac{v_o}{s}$$

Summing Biquads

- we have: $$v_o = \frac{-Q}{1+sQ}\left(Kv_{in} + \frac{v_o}{s}\right)$$

- re-arranging: $$\frac{v_o}{v_{in}} = \frac{-Ks}{s^2 + s/Q + 1}$$

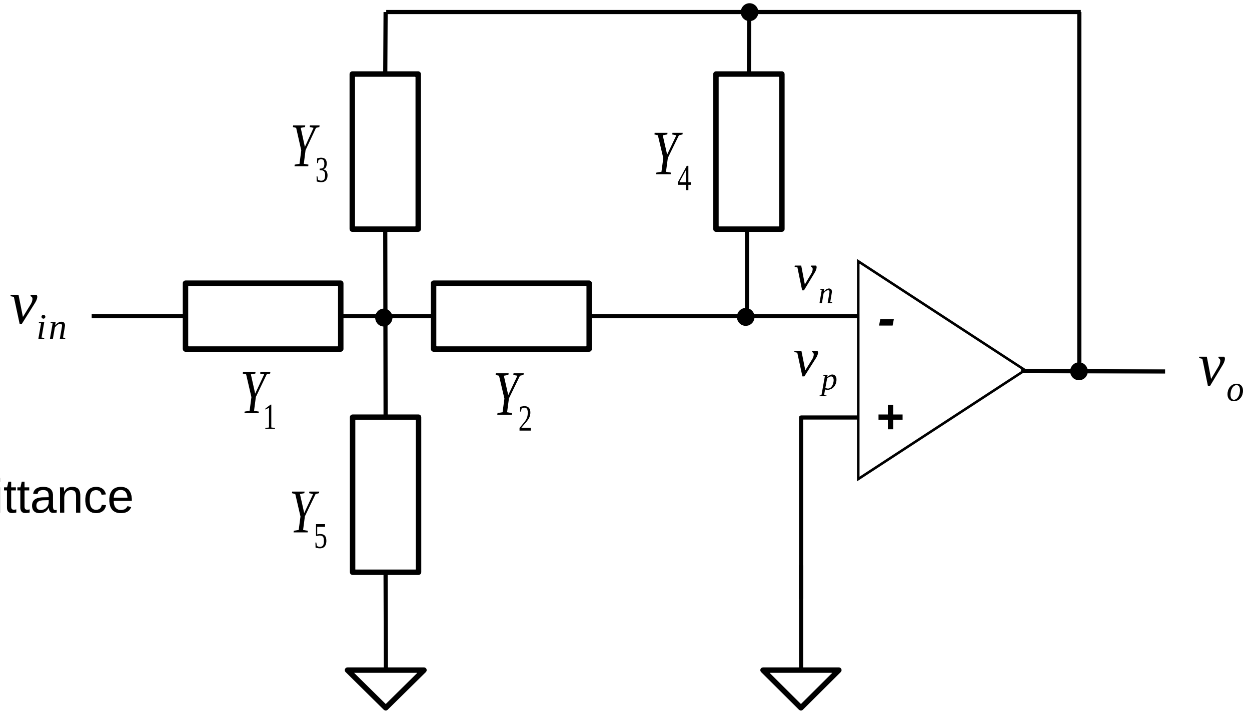
- Also, since $v_2 = \frac{v_o}{s}$: $$\frac{v_2}{v_{in}} = \frac{-K}{s^2 + s/Q + 1}$$

Multiple Feedback (MFB) Filters

- Alternative to VCVS (Sallen Key)
- Less sensitive to component variations
- Have one component fewer in the design
- Produce an additional 180º phase shift.

Multiple Feedback (MFB) Filters

- General circuit:

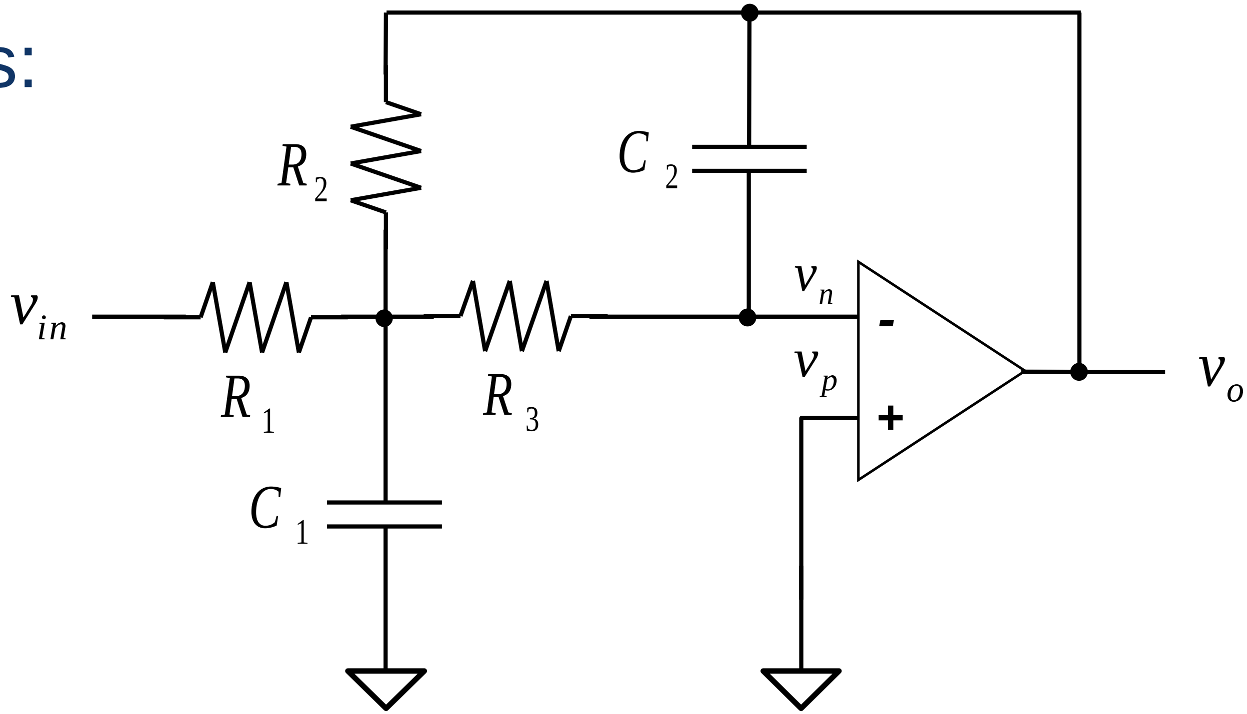


Y=admittance

$$\frac{v_o}{v_{in}} = \frac{Y_1 Y_2}{Y_4\left(Y_1 + Y_2 + Y_3 + Y_5\right) + Y_2 Y_3}$$

Multiple Feedback (MFB) Filters

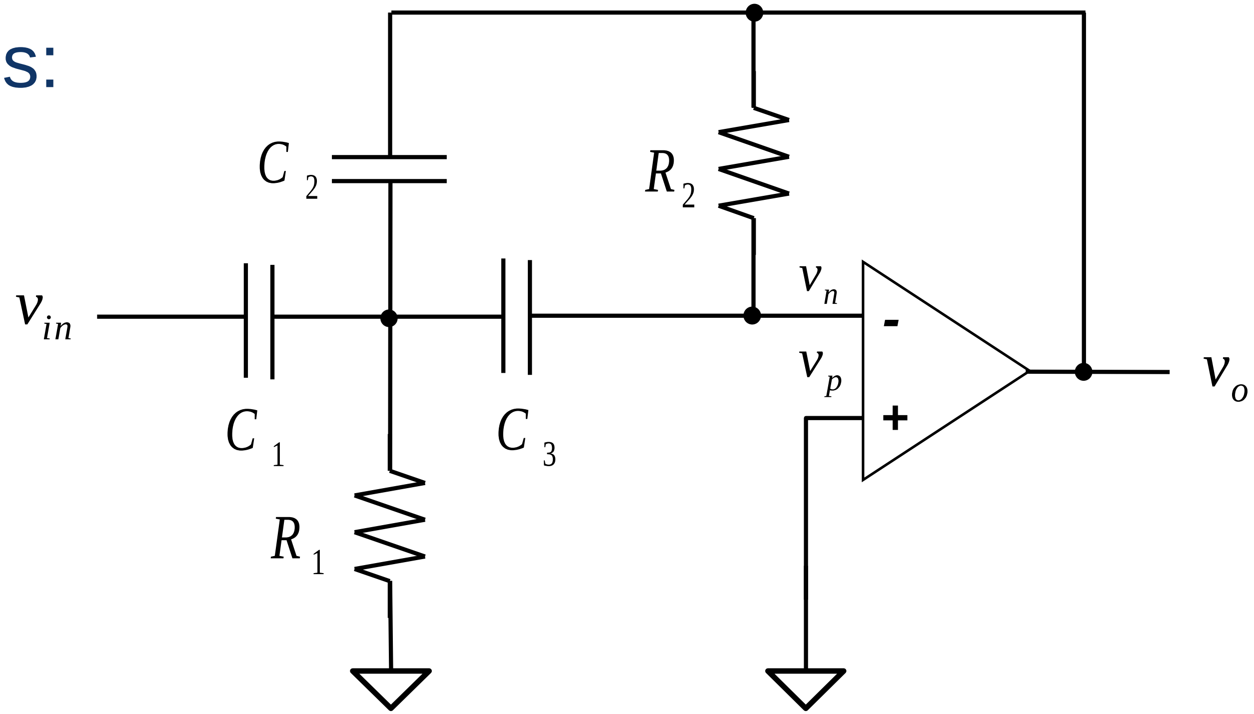
- Low pass:



$$\frac{v_o}{v_{in}} = \frac{-\dfrac{1}{C_1C_2R_1R_3}}{s^2 + s\left(\dfrac{1}{C_1R_1} + \dfrac{1}{C_1R_2} + \dfrac{1}{C_1R_2}\right) + \dfrac{1}{C_1C_2R_2R_3}}$$

Multiple Feedback (MFB) Filters

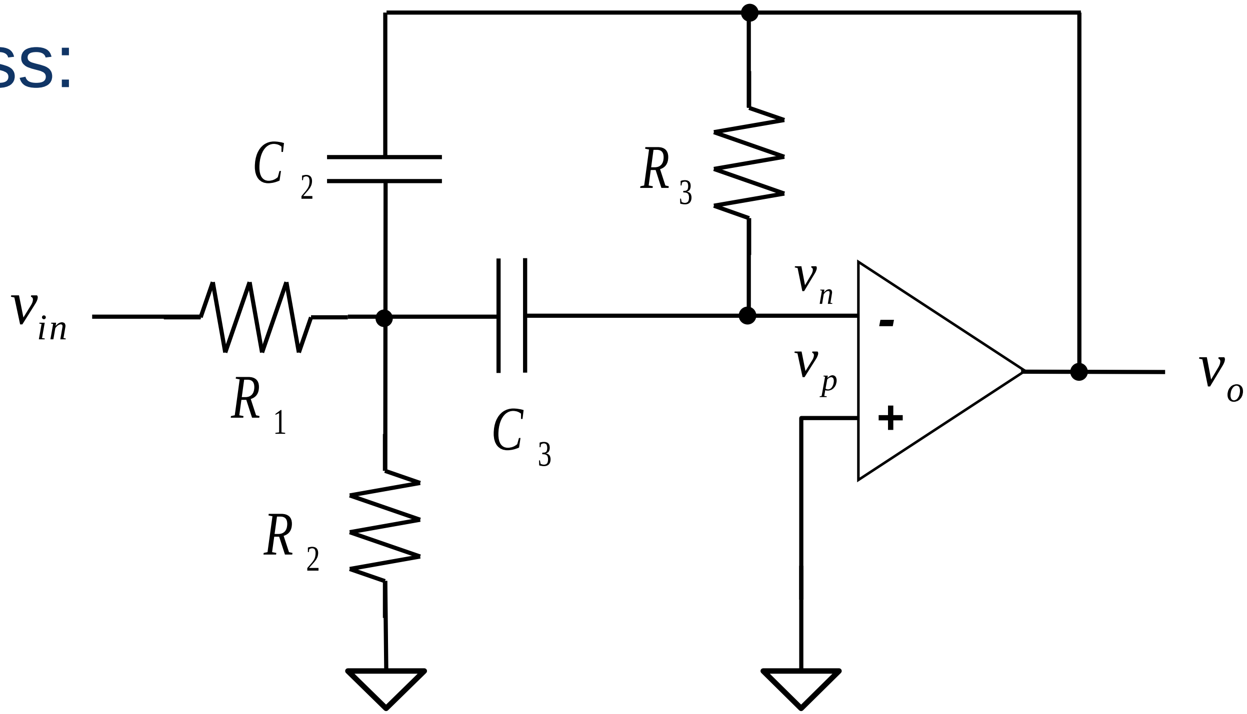
- High pass:



$$\frac{v_o}{v_{in}} = \frac{-s^2 \dfrac{C_1}{C_2}}{s^2 + s\dfrac{\left(C_1 + C_2 + C_3\right)}{C_2 C_3 R_2} + \dfrac{1}{R_1 R_2 C_2 C_3}}$$

Multiple Feedback (MFB) Filters

- Band pass:



$$\frac{v_o}{v_{in}} = \frac{-s\dfrac{1}{C_1R_1}}{s^2 + s\dfrac{\left(C_1+C_2\right)}{C_1C_2R_3} + \dfrac{\left(R_1+R_2\right)}{C_1C_2R_1R_2R_3}}$$