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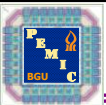
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Lesson #6 Outline

- Active filters
 - Types of filters
 - Simple filters, first-order
- Second-order filters
 - KRC filters
 - Circuit solving approach
- Multi-feedback
- Impedance emulation
 - Multiple amps
- Switched-capacitor circuits



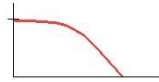
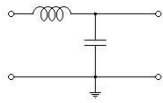
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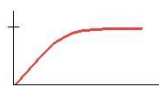
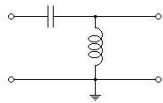
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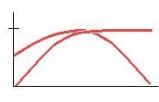
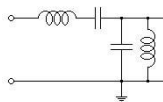
Types of filters



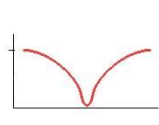
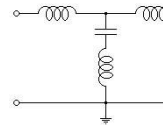
Low Pass Filter



High Pass Filter



Band Pass Filter

Band Reject Filter
(A.K.A. Notch Filter)

$$H(s) = \frac{N(s)}{\frac{s^2}{\omega_0^2} + \frac{s}{Q\omega_0} + 1}$$



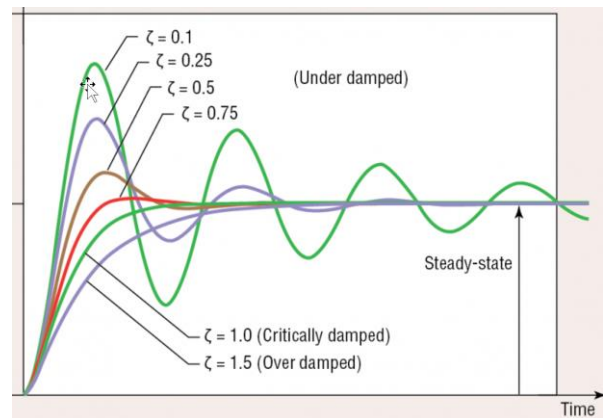
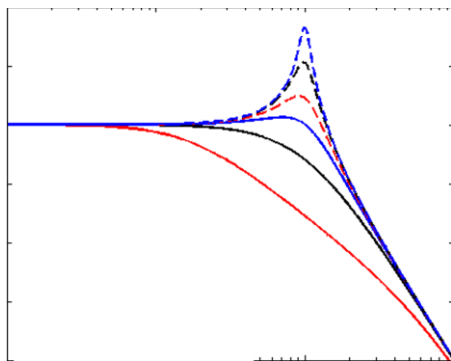
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Second-order response





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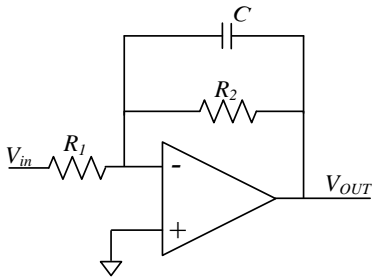
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Simple first-order filters

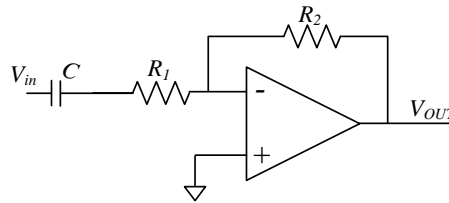
$$H(s) = H_0 \frac{Xs + 1}{Xs + 1}$$



$$H(s) = -\frac{R_2}{R_1} \frac{1}{R_2Cs + 1}$$

$$H_0 = -\frac{R_2}{R_1}; \omega_0 = \frac{1}{R_2Cs}$$

LPF + gain



$$H(s) = -\frac{R_2}{R_1} \frac{R_1Cs}{R_1Cs + 1}$$

$$H_0 = -\frac{R_2}{R_1}; \omega_0 = \frac{1}{R_1Cs}$$

HPF + gain



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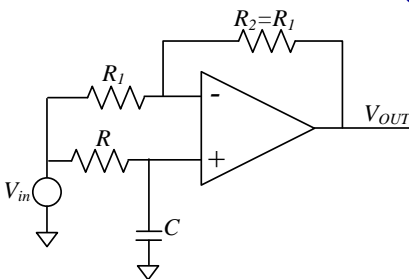
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Simple first-order filters

$$H(s) = H_0 \frac{Xs + 1}{Xs + 1}$$



$$H(s) = \frac{-RCs + 1}{RCs + 1}$$

Phase shifter



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Second-order filters

Effect of the numerator on the response

$$H_{LP}(s) = \frac{1}{\omega_0^2 + \frac{s}{Q\omega_0} + 1}$$

$$H_{BR}(s) = \frac{\frac{s^2}{\omega_0^2} + 1}{\omega_0^2 + \frac{s}{Q\omega_0} + 1}$$

$$H_{HP}(s) = \frac{\frac{s^2}{\omega_0^2}}{\omega_0^2 + \frac{s}{Q\omega_0} + 1}$$

$$H_{AP}(s) = \frac{\frac{s^2}{\omega_0^2} - \frac{s}{Q\omega_0} + 1}{\omega_0^2 + \frac{s}{Q\omega_0} + 1}$$

$$H_{BP}(s) = \frac{\frac{s}{Q\omega_0}}{\omega_0^2 + \frac{s}{Q\omega_0} + 1}$$



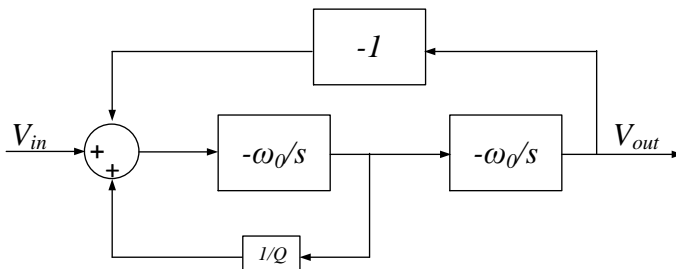
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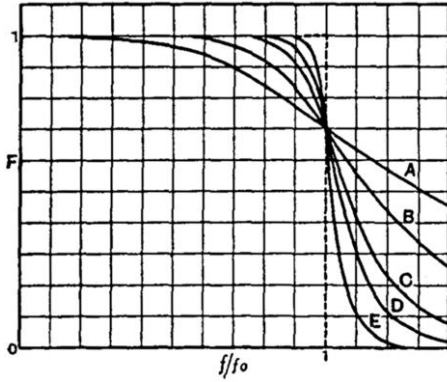
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Block diagram for LPF

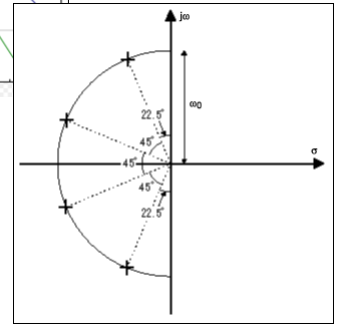
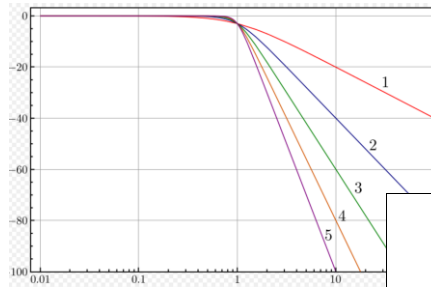




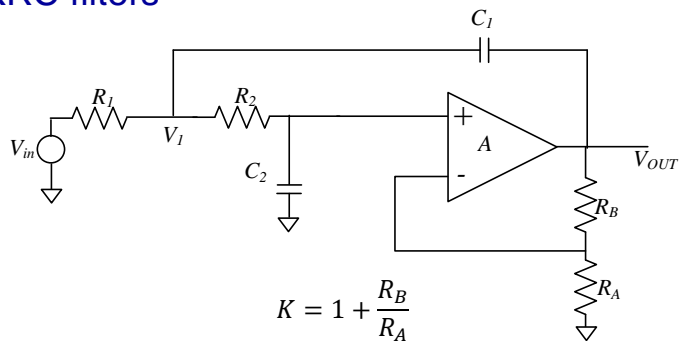
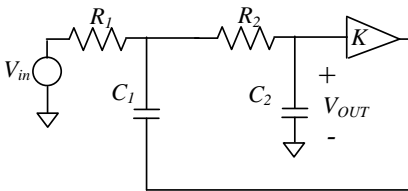
Butterworth filter



S. Butterworth, 1930



KRC filters



$$K = 1 + \frac{R_B}{R_A}$$

$$V_{out} = V_1 \frac{1}{R_2 C s + 1}$$

$$H_{0LP} = K ; \omega_0 = \frac{1}{\sqrt{R_1 C_1 R_2 R_2}}$$

$$H(s) = \frac{K}{R_1 C_1 R_2 R_2 s^2 + [(1 - K)R_1 C_1 + R_1 C_2 + R_2 C_2]s + 1}$$



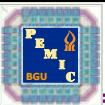
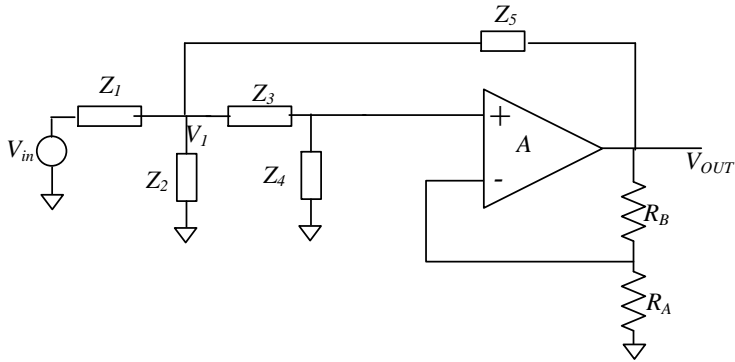
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Circuit solving approach



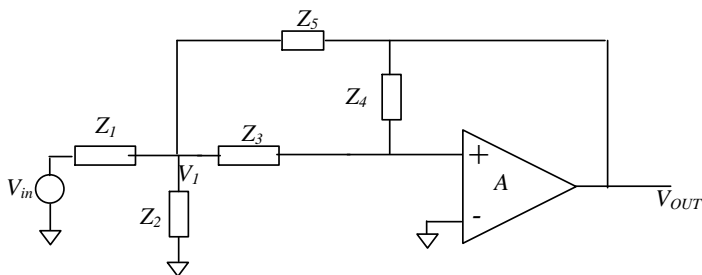
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Multiple feedback filters





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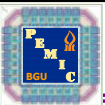
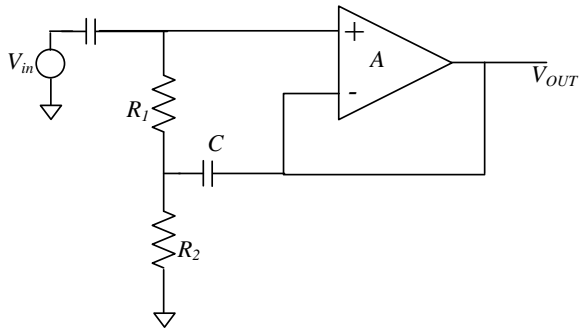
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Impedance emulation

Bootstrap circuit to emulate inductance



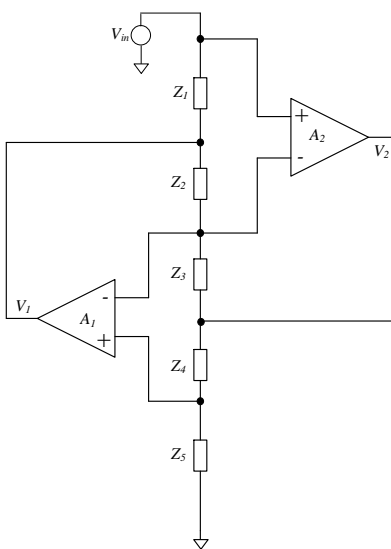
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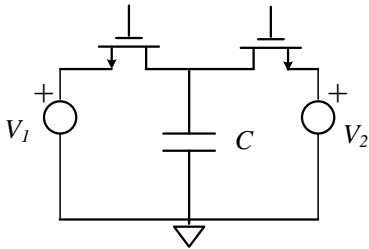
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General impedance emulation (Grounded)





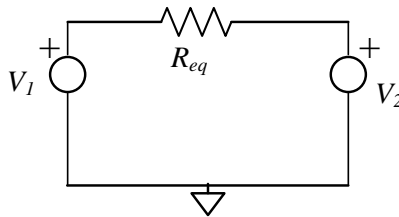
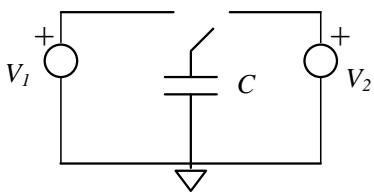
Switched-capacitor circuits



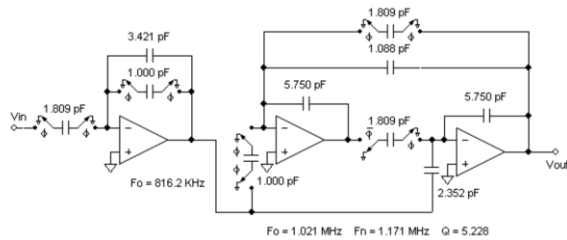
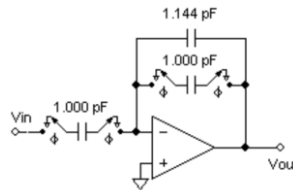
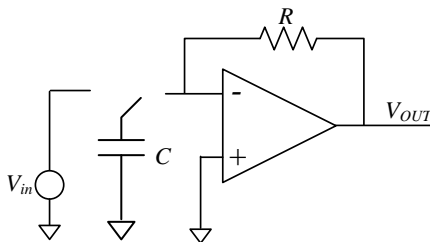
$$I_{avg} = f_{clk} \Delta Q$$

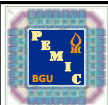
$$I_{avg} = C f_{clk} (V_1 - V_2)$$

$$R_{eq} = \frac{V_1 - V_2}{I_{avg}} = \frac{1}{C f_{clk}}$$



Switched-capacitor circuits





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