Analog Electronic Circuits

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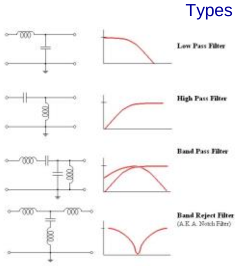
Lesson #6
Outline

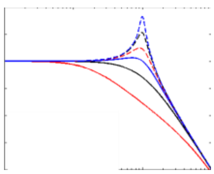
- Active filters
  - Types of filters
  - Simple filters, first-order
- Second-order filters
  - KRC filters
  - Circuit solving approach
- Multi-feedback
- Impedance emulation
  - Multiple amps
- Switched-capacitor circuits

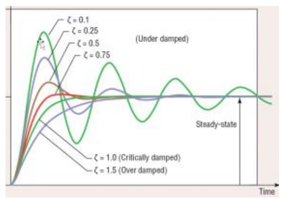
Types of filters



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

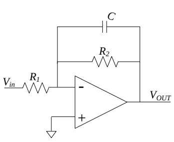
Second-order response





Simple first-order filters

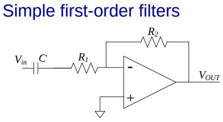
$$H(s) = H_0 \frac{Xs+1}{Xs+1}$$



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

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

LPF + gain



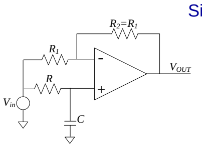
$$H(s) = -\frac{R_2}{R_1}\frac{R_1Cs}{R_1Cs+1}$$

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

HPF + gain

Simple first-order filters

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



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

Phase shifter

Second-order filters
Effect of the numerator on the response

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

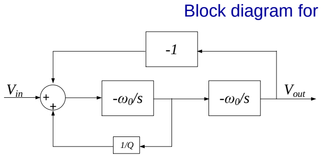
$$H_{BR}(s) = \frac{\frac{s^2}{{\omega_0}^2} + 1}{\frac{s^2}{{\omega_0}^2} + \frac{s}{Q\omega_0} + 1}$$

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

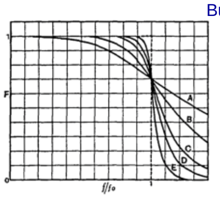
$$H_{AP}(s) = \frac{\frac{s^2}{{\omega_0}^2} - \frac{s}{Q\omega_0} + 1}{\frac{s^2}{{\omega_0}^2} + \frac{s}{Q\omega_0} + 1}$$

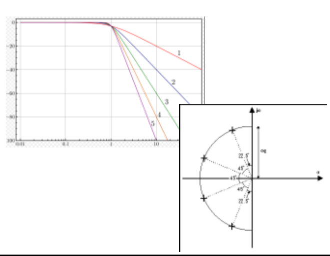
$$H_{BP}(s) = \frac{\frac{s}{Q\omega_0}}{\frac{s^2}{{\omega_0}^2} + \frac{s}{Q\omega_0} + 1}$$

Block diagram for LPF



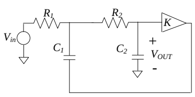
Butterworth filter

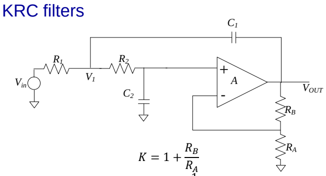




S. Butterworth, 1930

KRC filters





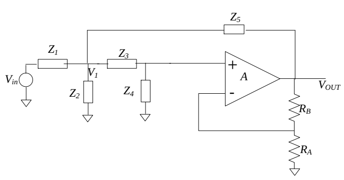
$$K = 1 + \frac{R_B}{R_A}$$

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

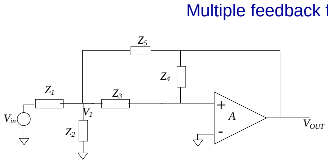
$$H_{0LP} = K \; ; \; \omega_0 = \frac{1}{\sqrt{R_1 C_1 R_2 R_2}}$$

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

Circuit solving approach

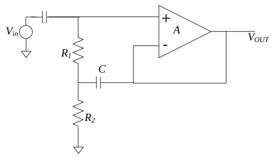


Multiple feedback filters

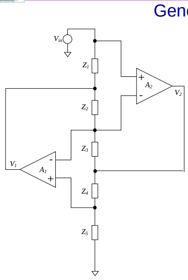


Impedance emulation

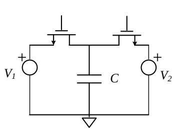
Bootstrap circuit to emulate inductance



General impedance emulation (Grounded)

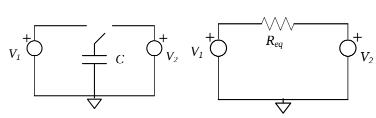


Switched-capacitor circuits



$$I_{avg} = f_{clk}\Delta Q$$
$$I_{avg} = Cf_{clk}(V_1 - V_2)$$

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



Switched-capacitor circuits