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**Analog Electronic Circuits**

Prof. Mor M. Peretz

The Center for Power Electronics and Mixed-Signal IC  
 Department of Electrical and Computer Engineering  
 Ben-Gurion University of the Negev, ISRAEL  
 Emails: [morp@bgu.ac.il](mailto:morp@bgu.ac.il)  
 Website: <http://www.ee.bgu.ac.il/~pemic>  
<http://www.ee.bgu.ac.il/~analog>

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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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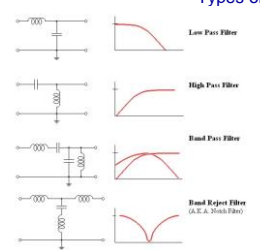
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**Types of filters**



Low Pass Filter

High Pass Filter

Band Pass Filter

Band Reject Filter (S.T.A. Notch Filter)

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

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### Second-order response

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### Simple first-order filters

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

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

LPF + gain

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

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

HPF + gain

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

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### Simple first-order filters

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

Phase shifter

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

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### Second-order filters

#### Effect of the numerator on the response

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

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

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

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

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

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### Block diagram for LPF

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### Butterworth filter

S. Butterworth, 1930

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### KRC filters

$$H_{OLP} = K ; \omega_0 = \frac{1}{\sqrt{R_1 C_1 R_2 R_3}}$$

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

$$V_{out} = V_1 \frac{1}{R_2 C_2 s + 1}$$

$$H(s) = \frac{K}{R_1 C_1 R_2 R_3 s^2 + [(1-K)R_1 C_1 + R_1 C_2 + R_2 C_2]s + 1}$$

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### Circuit solving approach

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### Multiple feedback filters

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### Impedance emulation

Bootstrap circuit to emulate inductance

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### General impedance emulation (Grounded)

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### Switched-capacitor circuits

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

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

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


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**Switched-capacitor circuits**

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