Active Filter

TE201414 - Rangkaian Elektronika 2

Program Studi Teknik Elektro

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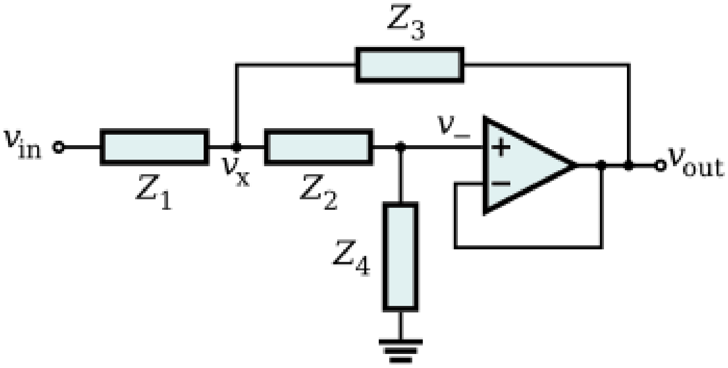
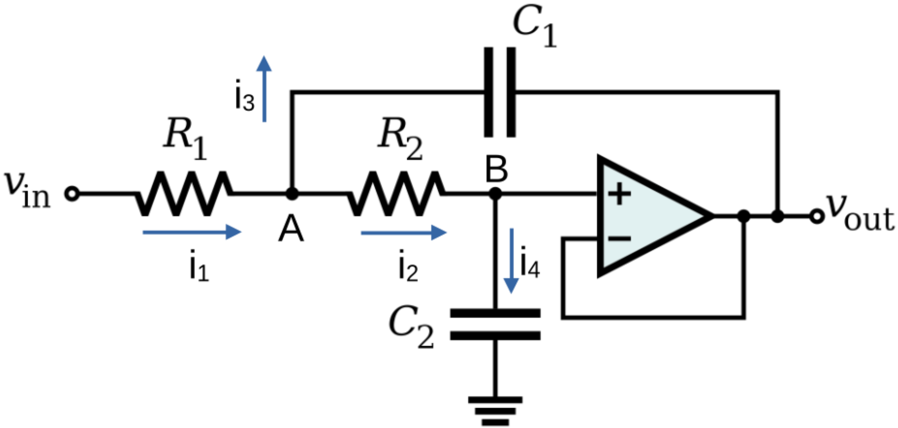
Second Order Active Filter: Sallen-Key Topology

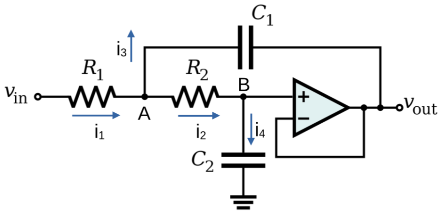
the Sallen-Key topology is an electronic filter topology used to implement second-order active filters that is particularly valued for its simplicity.



Second Order Low Pass Filter



Second Order Low Pass Filter



$$I_2 = \frac{V_A - V_B}{R_2} = \frac{V_A - V_{out}}{R_2}$$

review node B:

$$I_2 = I_4 = j\omega C_2 V_{out}$$

V_{out} is similar with voltage at node B V_B, then:

$$I_4 = \frac{V_{out}}{Xc_2} = j\omega C_2 V_{out}$$

$$\frac{V_A - V_{out}}{R_2} = j\omega C_2 V_{out}$$

$$V_A = V_{out} + j\omega R_2 C_2 V_{out}$$

$$I_3 = \frac{V_A - V_{out}}{Xc_1} = (V_A - V_{out}) j\omega C_1$$

Second Order Low Pass Filter

$$I_3 = (V_{out} + j\omega R_2 C_2 V_{out} - V_{out}) j\omega C_1$$

$$I_3 = -\omega^2 R_2 C_1 C_2 V_{out}$$

review node A:

$$I_1 = I_2 + I_3$$

$$I_1 = \frac{V_{in} - V_A}{R_1}$$

$$\frac{V_{in} - V_A}{R_1} = j\omega C_2 V_{out} + (-\omega^2 R_2 C_1 C_2 V_{out})$$

$$V_{in} = V_A + j\omega R_1 C_2 V_{out} - \omega^2 R_1 R_2 C_1 C_2 V_{out}$$

$$V_{in} = V_{out} + j\omega R_2 C_2 V_{out} + j\omega R_1 C_2 V_{out} - \omega^2 R_1 R_2 C_1 C_2$$

$$V_{in} = V_{out}(1 - \omega^2 R_1 R_2 C_1 C_2 + j\omega C_2 (R_1 + R_2))$$

$$\frac{V_{out}}{V_{in}} = \frac{1}{1 - \omega^2 R_1 R_2 C_1 C_2 + j\omega C_2 (R_1 + R_2)}$$

Second Order Low Pass Filter

Every 1 order increase in the lowpass filter will shift the phase by -45 degrees, so it be -90 degrees phase shift for second order low pass filter at cut off frequency. the real value for -90 degree phase is zero, then

$$0 = 1 - \omega_c^2 R_1 R_2 C_1 C_2$$

$$\omega_c^2 = \frac{1}{R_1 R_2 C_1 C_2}$$

$$f_c = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

to find signal amplification of bode plot: assume that $R_1 = R_2 = R$ and $C_1 = C_2 = C$

$$C = \frac{1}{\omega_c R}$$

Second Order Low Pass Filter

$$\frac{V_{out}}{V_{in}} = \frac{1}{1 - \omega^2 RR \frac{1}{\omega_c R} \frac{1}{\omega_c R} + j\omega \frac{1}{\omega_c R}(2R)}$$

$$\frac{V_{out}}{V_{in}} = \frac{1}{1 - (\frac{\omega}{\omega_c})^2 + j2\frac{\omega}{\omega_c}}$$

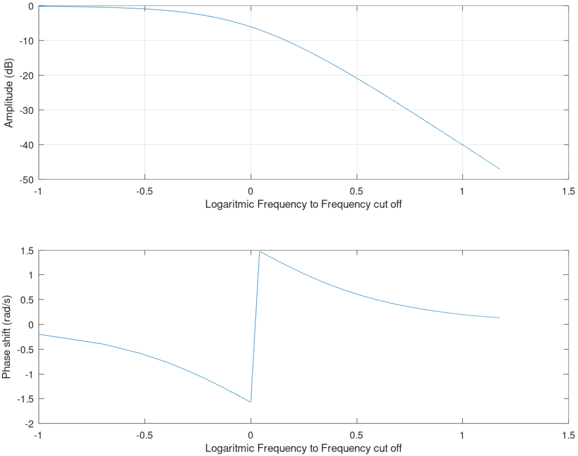
$$|A_v|_\omega = \frac{1}{\sqrt{(2\frac{\omega}{\omega_c})^2 + (1 - (\frac{\omega}{\omega_c})^2)^2}}$$

to find phase shift of bode plot:

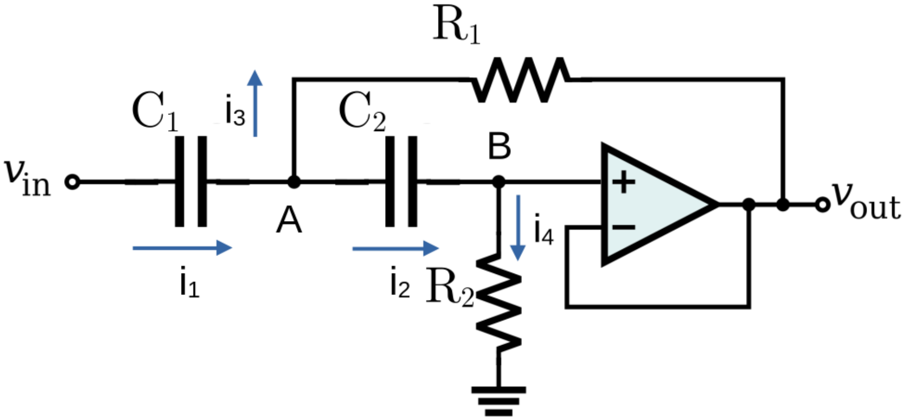
$$\phi = 0 - \arctan \frac{2\frac{\omega}{\omega_c}}{1 - (\frac{\omega}{\omega_c})^2}$$

Second Order Low Pass Filter

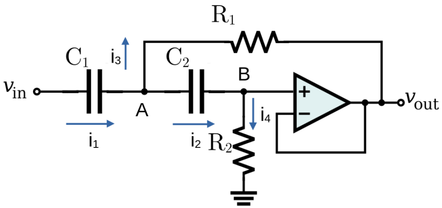
Frequency response of second order active low filter.



Second Order High Pass Filter



Second Order High Pass Filter



$$I_2 = \frac{V_A - V_B}{Xc_2} = j\omega C_2(V_A - V_{out})$$

review node B:

$$I_2 = I_4 = \frac{V_{out}}{R_2}$$

V_{out} is similar with voltage at node B V_B, then:

$$I_4 = \frac{V_{out}}{R_2}$$

$$j\omega C_2(V_A - V_{out}) = \frac{V_{out}}{R_2}$$

$$j\omega R_2 C_2(V_A - V_{out}) = V_{out}$$

$$V_A = V_{out} + \frac{V_{out}}{j\omega R_2 C_2}$$

Second Order High Pass Filter

$$I_3 = \frac{V_A - V_{out}}{R_1}$$

review node A:

$$I_1 = I_2 + I_3$$

$$I_1 = \frac{V_{in} - V_A}{Xc_1}$$

$$\frac{V_{in} - V_A}{Xc_1} = \frac{V_A - V_{out}}{Xc_2} + \frac{V_A - V_{out}}{R_1}$$

$$\frac{V_{in} - (\frac{V_{out}}{j\omega R_2 C_2} + V_{out})}{\frac{1}{j\omega C_1}} = frac(\frac{V_{out}}{j\omega R_2 C_2} + V_{out}) - V_{out}\frac{1}{j\omega C_2} + \frac{(\frac{V_{out}}{j\omega R_2 C_2} + V_{out}) -}{R_1}$$

$$\frac{V_{in} - (\frac{V_{out}}{j\omega R_2 C_2} + V_{out})}{\frac{1}{j\omega C_1}} = \frac{\frac{V_{out}}{j\omega R_2 C_2}}{\frac{1}{j\omega C_2}} + \frac{\frac{V_{out}}{j\omega R_2 C_2}}{R_1}$$

Second Order High Pass Filter

$$\frac{V_{in} - (\frac{V_{out}}{j\omega R_2 C_2} + V_{out})}{\frac{1}{j\omega C_1}} = \frac{V_{out}}{R_2} + \frac{V_{out}}{j\omega R_1 R_2 C_2}$$

$$V_{in} - \frac{V_{out}}{j\omega R_2 C_2} - V_{out} = \frac{V_{out}}{j\omega R_2 C_1} + \frac{V_{out}}{j\omega^2 R_1 R_2 C_1 C_2}$$

$$V_{in} = V_{out} - \frac{V_{out}}{\omega^2 R_1 R_2 C_1 C_2} + \frac{V_{out}}{j\omega R_2 C_1} + \frac{V_{out}}{j\omega R_2 C_2}$$

$$\frac{V_{out}}{V_{in}} = 1 - \omega^2 R_1 R_2 C_1 C_2 + j\omega R_2 C_2 + j\omega R_2 C_1$$

Every 1 order increase in the lowpass filter will shift the phase by +45 degrees, so it be +90 degrees phase shift for second order low pass filter at cut off frequency. the real value for +90 degree phase is zero, then

Second Order High Pass Filter

$$0 = 1 - \omega_c^2 R_1 R_2 C_1 C_2$$

$$\omega_c^2 = \frac{1}{R_1 R_2 C_1 C_2}$$

$$f_c = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

to find signal amplification of bode plot: assume that $R_1 = R_2 = R$ and $C_1 = C_2 = C$

$$C = \frac{1}{\omega_c R}$$

$$\frac{V_{out}}{V_{in}} = 1 - \omega^2 R^2 (\frac{1}{\omega_c R})^2 + 2j\omega R \frac{1}{\omega_c R}$$

$$\frac{V_{out}}{V_{in}} = 1 - (\frac{\omega}{\omega_c})^2 + 2j\frac{\omega}{\omega_c}$$

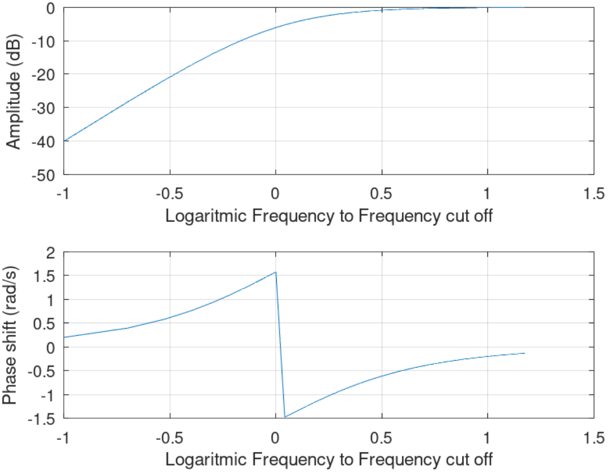
$$|A_V|_\omega = \sqrt{(2\frac{\omega}{\omega_c})^2 + (1-(\frac{\omega}{\omega_c})^2)^2}$$

to find phase shift of bode plot:

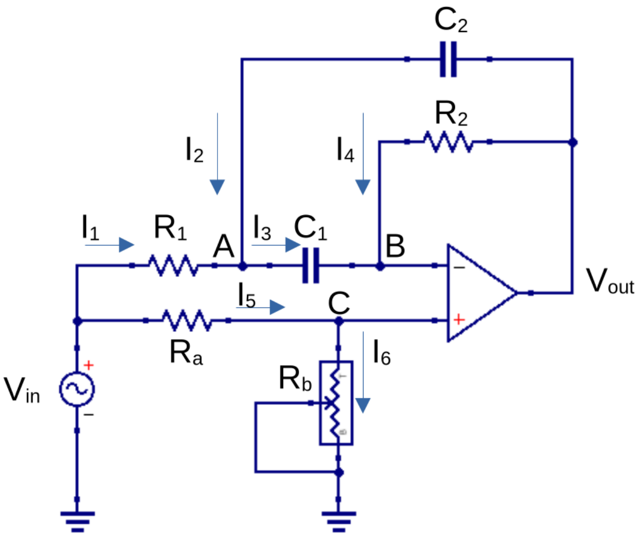
$$\phi = 0 + \arctan \frac{2\frac{\omega}{\omega_c}}{1-(\frac{\omega}{\omega_c})^2}$$

Second Order High Pass Filter

Frequency response of second order active low filter.



Notch Filter/Bandstop Filter



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Boylestad, R.L., Nashelsky,L., Electronics Devices and Circuit Theory, Pearson, 2014.

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