Analog and Digital Systems
(UEE505)

Lecture # 10
Butterworth filters using op amp -II

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Designing Steps of LPF

- **Step 1:** Select or choose required cutoff frequency. Suppose we want to pass all the frequencies below 15 KHz that means frequencies that human can hear. Thus fc = 15 KHz
- **Step 2:** Assume the required value of capacitor. It should be less than 0.1 micro Farad. This is required for better frequency stability.
- **Step 3:** calculate the value of resistance from equation.

$$f_L = \frac{1}{2\pi RC}$$

- **Step 4:** Choose required pass band gain and find the value of R_f & R_1

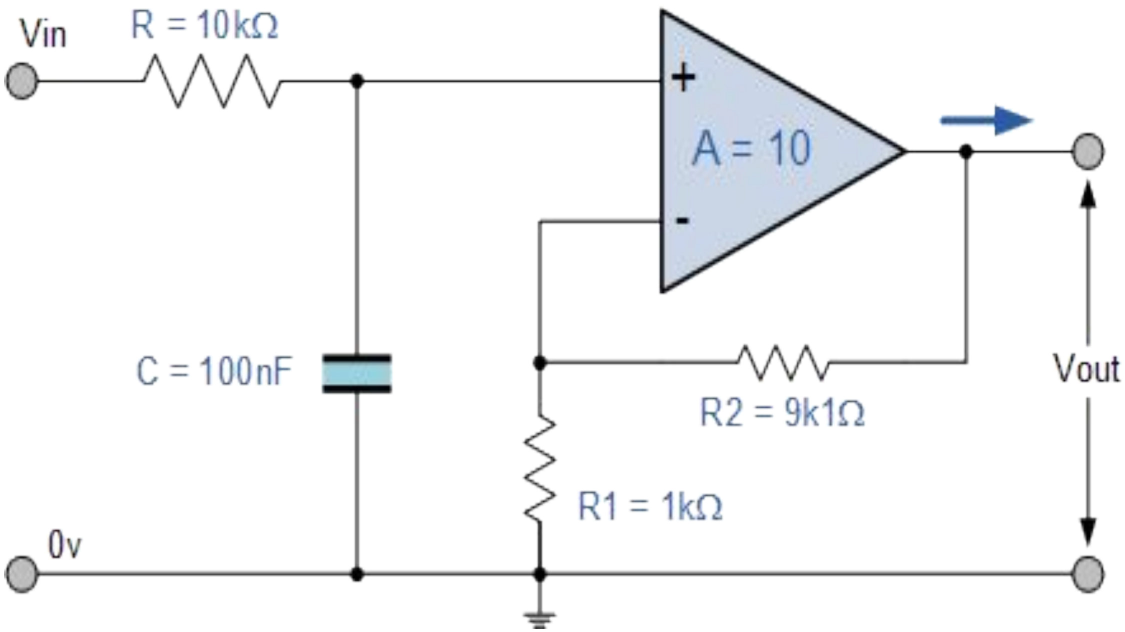
$$A_F = \left(1 + \frac{R_f}{R_1}\right)$$

Select values of R_f & R_1 as or around 10KΩ.

Example

Design a non-inverting active low pass filter circuit that has a gain of ten at low frequencies, a high frequency cut-off or corner frequency of 159Hz and an input impedance of 10KΩ.

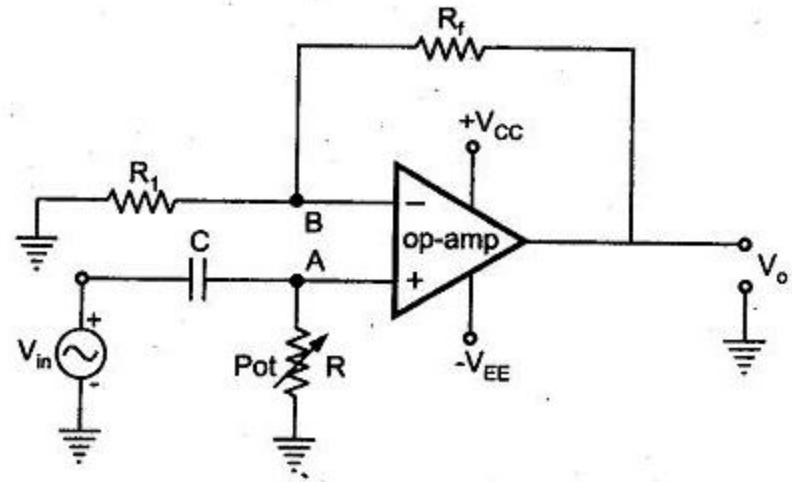
LPF Circuit



Designing of High Pass Filter(HPF)

Ist order Butterworth HPF

$$V_A = V_{in}\left[\frac{R}{R - jX_C}\right]$$



$$V_A = V_{in}\left[\frac{R}{-jX_C\left(\frac{R}{-jX_C} + 1\right)}\right]$$

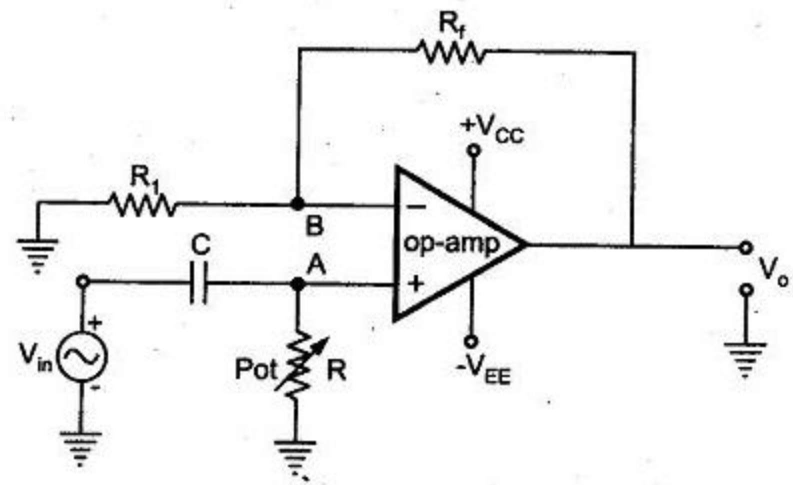
$$V_A = V_{in}\left[\frac{\left(-\frac{R}{jX_C}\right)}{\left(-\frac{R}{jX_C}\right) + 1}\right]$$

Or $\dfrac{1}{-jX_C} = \dfrac{j}{X_C} = \dfrac{j}{\left(\dfrac{1}{2\pi fC}\right)}$

$= j\,2\pi fC$

Therefore, $V_A = V_{in}\left[\dfrac{j\,2\pi fRC}{1 + j\,2\pi fRC}\right]$

$$V_A = V_{in}\left[\frac{j\left(\frac{f}{f_L}\right)}{1 + j\left(\frac{f}{f_L}\right)}\right]$$



Where $f_L = \dfrac{1}{2\pi RC}$ = low cut off frequency

$$V_o = A_F V_A$$

where V_A = Voltage at the non inverting input

and $A_F = \left(1 + \dfrac{R_f}{R_1}\right)$ = gain of op–amp in pass band

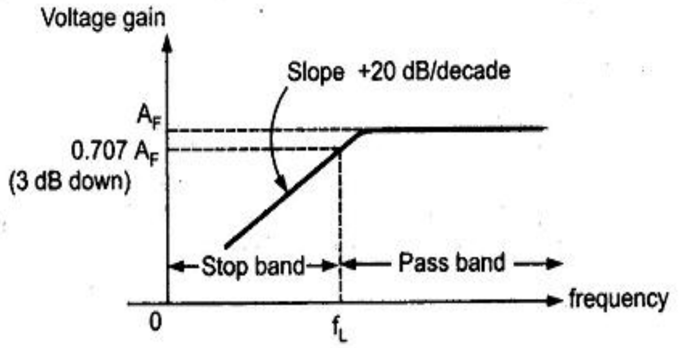
$$\therefore \quad V_o = A_F V_{in}\left[\frac{j\left(\frac{f}{f_L}\right)}{1 + j\left(\frac{f}{f_L}\right)}\right]$$

Thus, $$\frac{V_o}{V_{in}} = A_F\left[\frac{j\left(\frac{f}{f_L}\right)}{1 + j\left(\frac{f}{f_L}\right)}\right]$$

Frequency Response of HPF

$$\left|\frac{V_0}{V_{in}}\right| = \frac{A_F\left(\frac{f}{f_L}\right)}{\sqrt{1+\left(\frac{f}{f_L}\right)^2}}$$

Now to observe the change in gain magnitude with the change in the frequency of the input signal, consider three cases:



1) At low frequencies, i.e. $f < f_L$

$$\left|\frac{V_0}{V_{in}}\right| < A_F$$

2) At $f = f_L$,

$$\left|\frac{V_0}{V_{in}}\right| = 0.707\ A_F \quad \text{i.e. 3 dB down from the level of } A_F$$

3) At $f > f_L$, i.e. high frequencies, 1 can be neglected as compared to $\left(\frac{f}{f_L}\right)$ from denominator.

$$\left|\frac{V_0}{V_{in}}\right| \cong A_F \text{ i.e. constant}$$

Designing Steps of HPF

- **Step 1:** select or choose required cut off frequency. Suppose we want to suppress all the frequencies below 100 Hz. Thus fc = 100 Hz
- **Step 2:** Assume the required value of capacitor. It should be less than 0.1 micro Farad. This is required for better frequency stability.
- **Step 3:** calculate the value of resistance from equation.

$$f_L = \frac{1}{2\pi R C} = \text{low cut off frequency}$$

- **Step 4:** Choose required pass band gain and find the value of R_f & R_1 $A_F = \left(1 + \frac{R_f}{R_1}\right)$ Select values of R_f & R_1 as or around 10KΩ.

References

- For more details, refer to:

-- *Boylestad R. L., Electronic Devices and Circuit Theory, Pearson Education*

-- *Op-Amps and Linear Integrated Circuits, Ramakant A. Gayakwad*

-- *Neamen, Donald A., Electronic Circuit Analysis and Design, McGraw Hill*