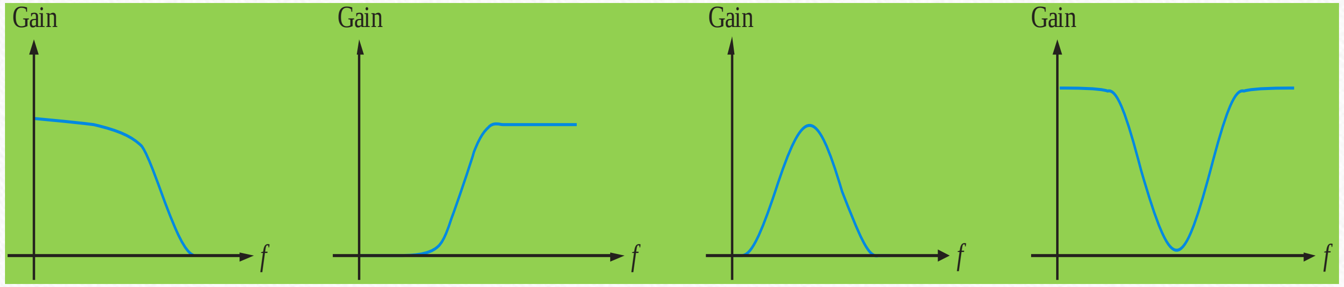
Active Filters

OP AMP based

Low Pass, & High Pass

Introduction



Low-pass High-pass Band-pass Band-stop

- A filter is a circuit that passes certain frequencies and rejects all others.
- The **passband** is the range of frequencies allowed through the filter.
- The **critical frequency** defines the end of the passband and is normally specified at the point where the response drops -3dB (70.7%) from the passband response.
- The passband is a region called *the transition region* that leads into a region called the *stopband*.

Active filter vs Passive filter

Passive Filters	Active Filters
Use only passive elements such as R,L,C	Uses with R,C , L with active device such as op amp, transistors
Output is less than Input	Gain can be modified
No need of voltage source	Need an voltage source
Not possible to approximate ideal characteristics	Possible to approximate ideal characteristics
Suitable for high frequencies	Suitable for low frequencies

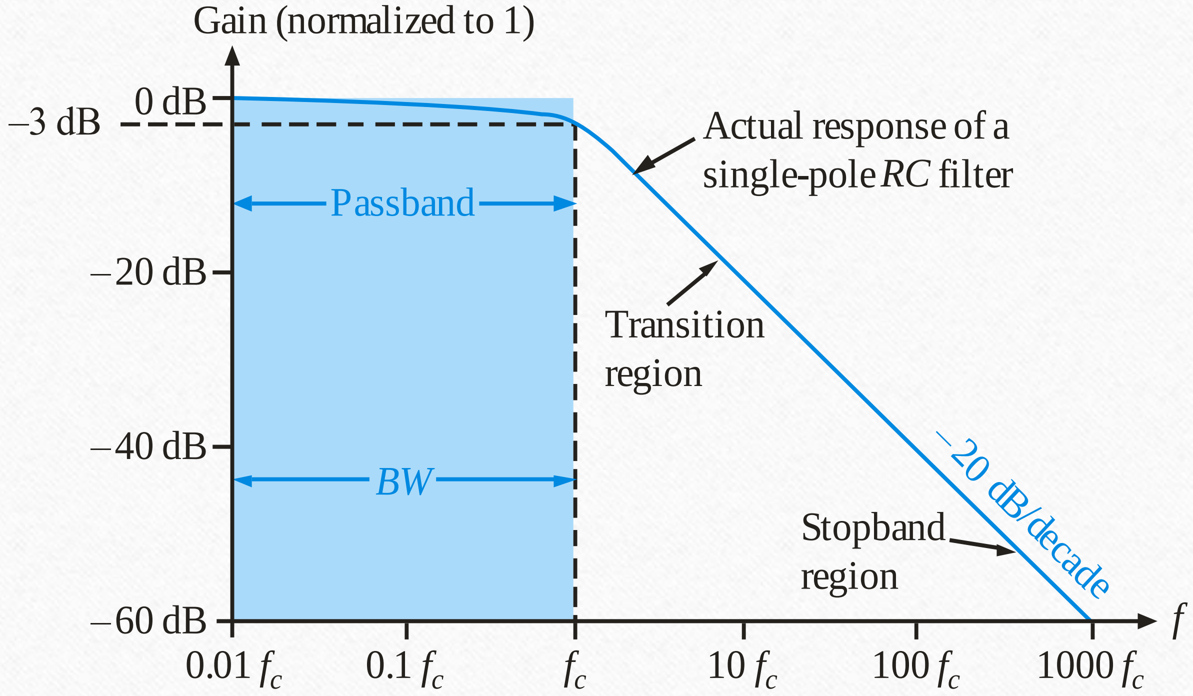
ACTIVE FILTERS USING OP-AMP

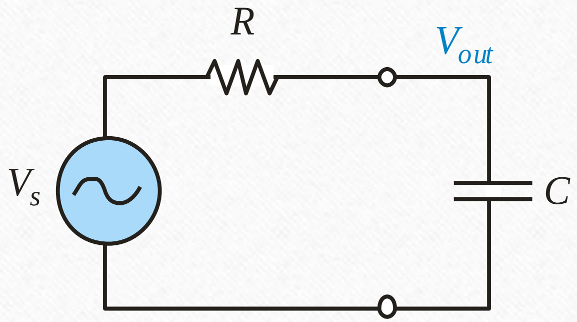
- Filters are frequency selective circuits.
- They are required to pass a specific band of frequencies and attenuate frequencies outside the band.
- Filters using an active device like OPAMP are called active filters.
- Possible to incorporate variable gain.
- Due to high Z_i & Z_0 of the OPAMP, active filters do not load the input source or load.
- Flexible design.

Low Pass Filter

- The **low-pass filter** allows frequencies below the critical frequency to pass and rejects other.
- The simplest low-pass filter is a passive *RC* circuit with the output taken across *C*.
  - The ideal response is not attainable by any practical filter.
  - Actual filter responses depend on the number of poles, Pole, a term used with filters to describe the number of RC circuits contained in the filter.
  - This basic RC filter has a single pole, and it rolls off at -20db/decade beyond the critical frequency.

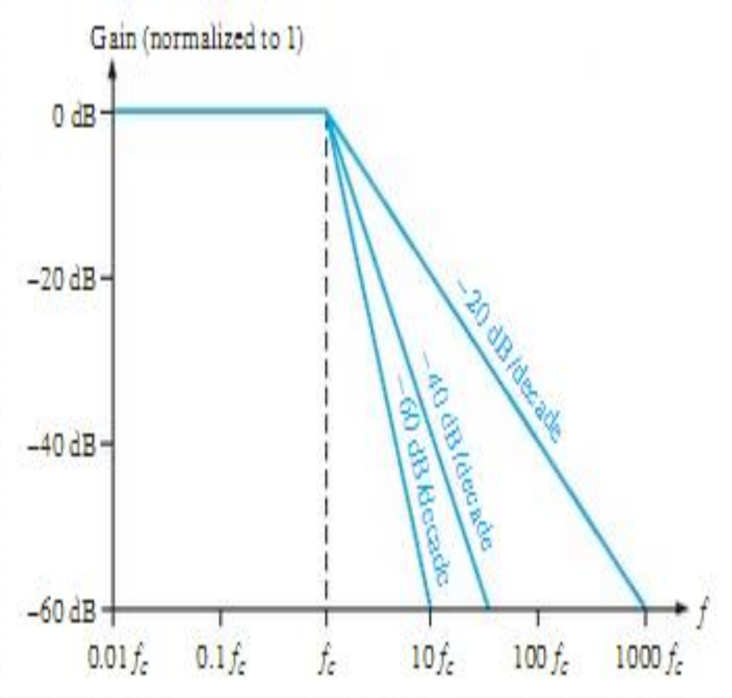
Contd..


Gain (normalized to 1)
0 dB
–3 dB
–20 dB
–40 dB
–60 dB
Passband
BW
Actual response of a single-pole RC filter
Transition region
Stopband region
–20 dB/decade
f
0.01 fc
0.1 fc
fc
10 fc
100 fc
1000 fc

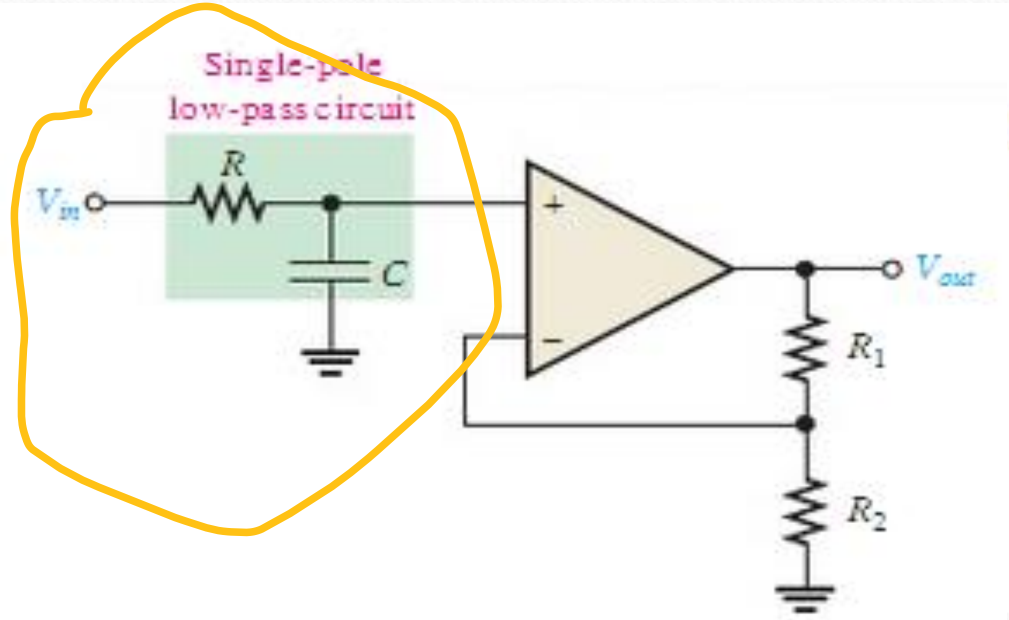

R
Vout
Vs
C

Low Pass Active Filter

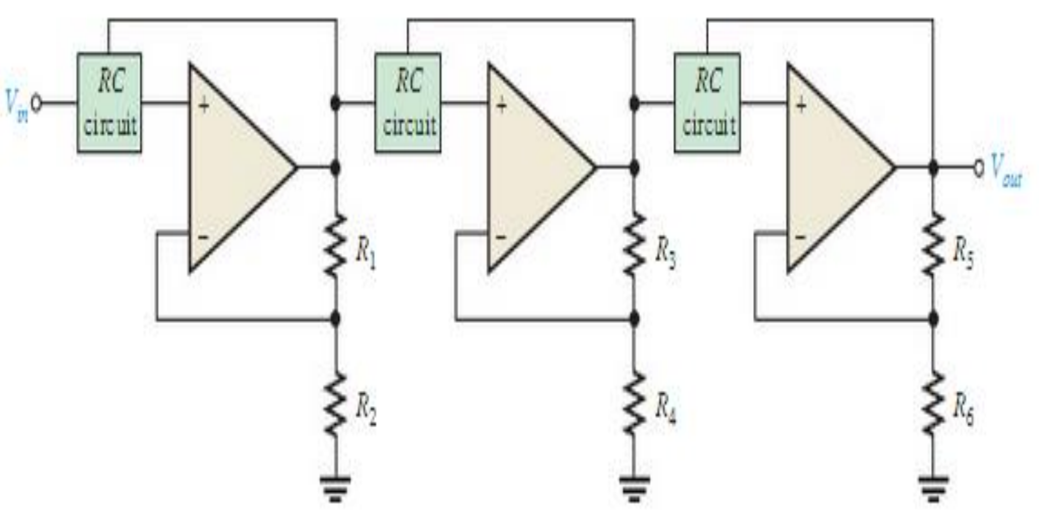
- Actual filters do not have a perfectly flat response up to the cutoff frequency.
- More steeper response cannot be obtained by simply cascading the basic stages due to loading effect.
- With combination of op-amps, the filters can be designed with higher roll-offs .
- The more poles the filter uses, the steeper its transition region will be. The exact response depends on the type of filter and the number of pole.



Contd..



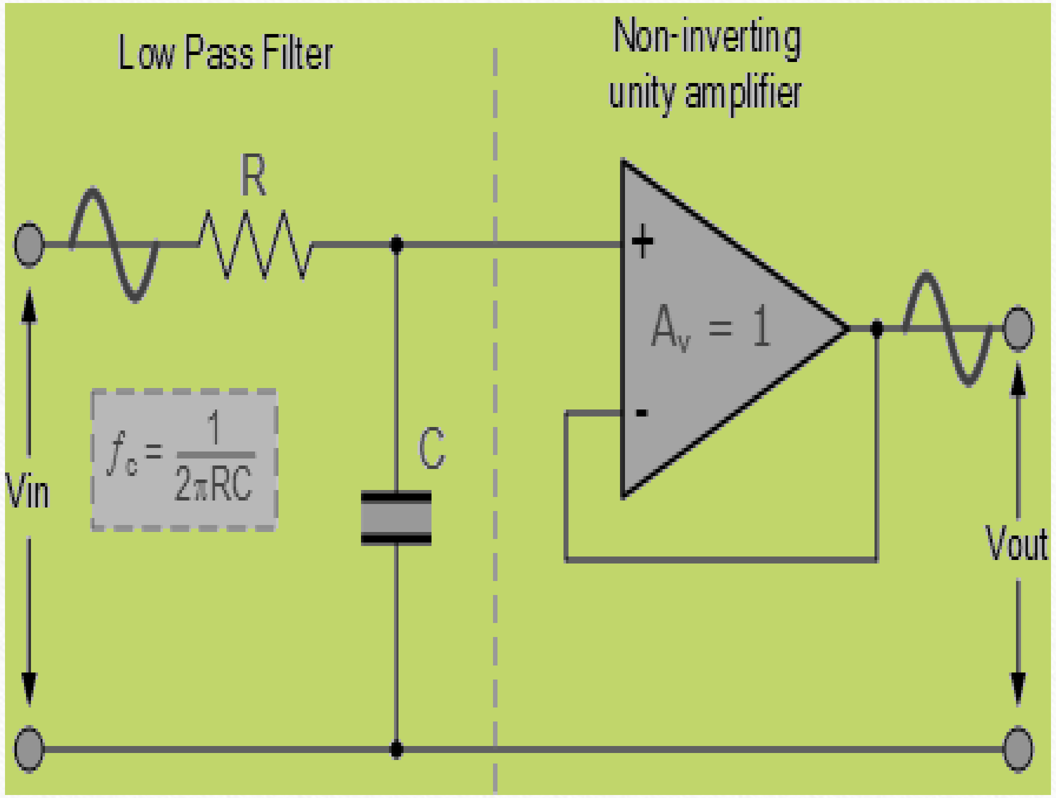
A single pole active filters



Multi pole active filters

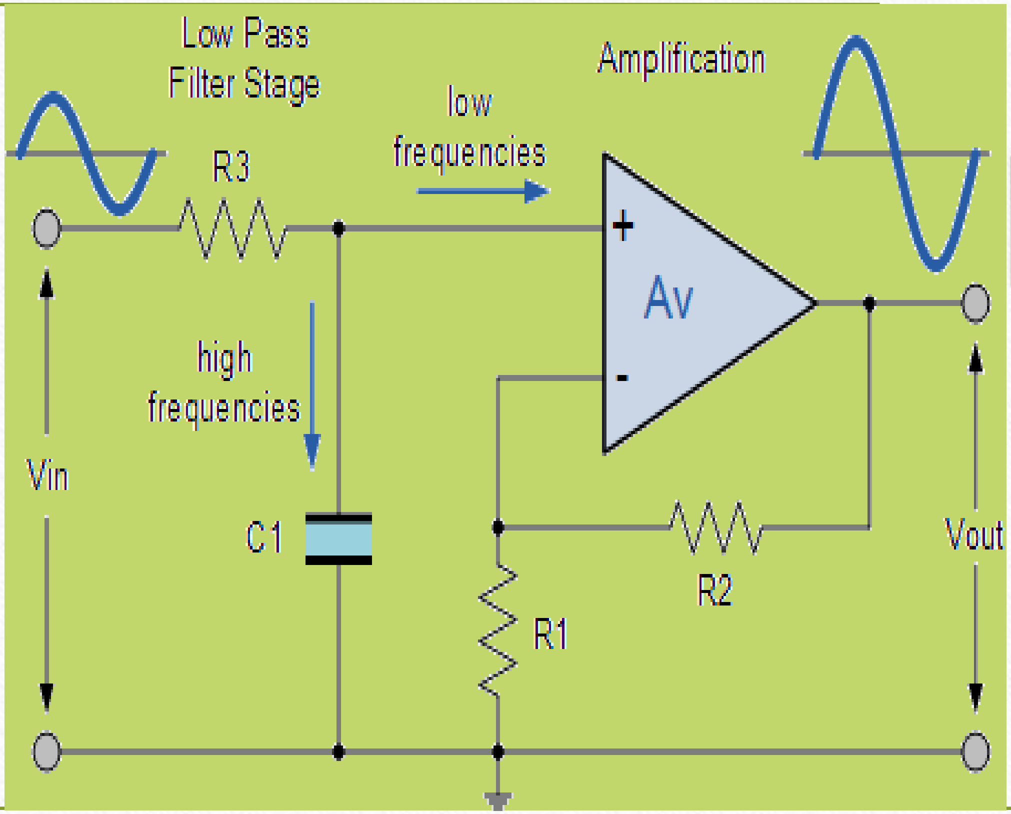
First Order Active Low Pass Filter

- The amplifier is configured as a voltage-follower (Buffer) giving it a DC gain of one, Av = +1 or unity gain as opposed to the previous passive RC filter which has a DC gain of less than unity.
- The advantage of this configuration is that the op-amps high input impedance prevents excessive loading on the filters output while its low output impedance prevents the filters cut-off frequency point from being affected by changes in the impedance of the load.



Active Low Pass Filter with Amplification

- DC Gain =$(1+R_2/R_1)$
- Voltage gain $Av=V_{out}/V_{in} = \dfrac{A_F}{\sqrt{1+\left(\dfrac{f}{f_c}\right)^2}}$
-
- A_F = the pass band gain of the filter, $(1 + R_2/R_1)$
- f = the frequency of the input signal in Hz
- fc = the cut-off frequency in Hertz, (Hz)
-



Contd..

- At very low frequencies $f < f c$; $\dfrac{V_{out}}{V_{in}} \approx A_F$
- At the cut-off frequency $f = f c$; $\dfrac{V_{out}}{V_{in}} = \dfrac{A_F}{2} = 0.707 A_F$
- At the cut-off frequency $f > f c$; $\dfrac{V_{out}}{V_{in}} < A_F$
- **Magnitude of Voltage Gain in (dB)**

$$A_v = 20 \log_{10} \frac{V_{out}}{V_{in}}$$

Analysis

Transfer function

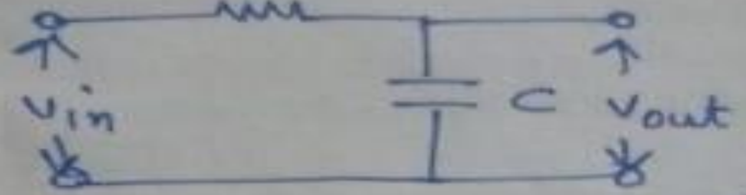
$$\left|\frac{V_{out}}{V_{in}}\right| = A_V \underbrace{\frac{1}{\sqrt{1+\left(\frac{f}{f_C}\right)^2}}}_{\text{low pass filter}}$$

non inverting type

$$A_V = \left(1+\frac{R_F}{R_1}\right)$$

gain of OP Amp

Passive filter



$$V_{out} = \frac{X_C}{X_C+R} \times V_{in}$$

$$\left|\frac{V_{out}}{V_{in}}\right| = \frac{|X_C|}{\sqrt{X_C^2+R^2}} = \frac{\frac{1}{j\omega C}}{\sqrt{R^2+\left(\frac{1}{\omega C}\right)^2}} = \frac{\omega C \cdot \frac{1}{\omega C}}{\omega C\sqrt{R^2+\left(\frac{1}{\omega C}\right)^2}}$$

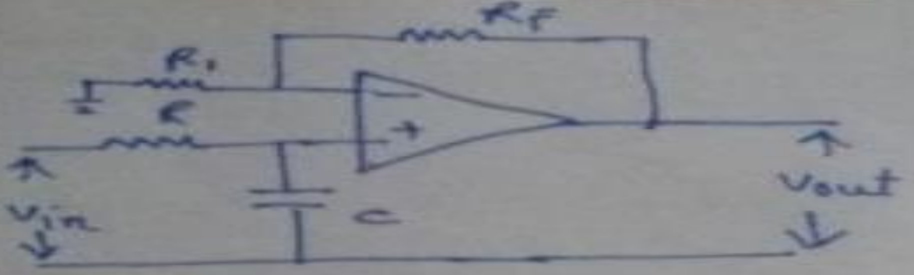
Contd..

$$= \frac{1}{\sqrt{R^2\omega^2C^2+1}}$$

$\omega_c \rightarrow$ Cut off frequency $= \frac{1}{RC}$

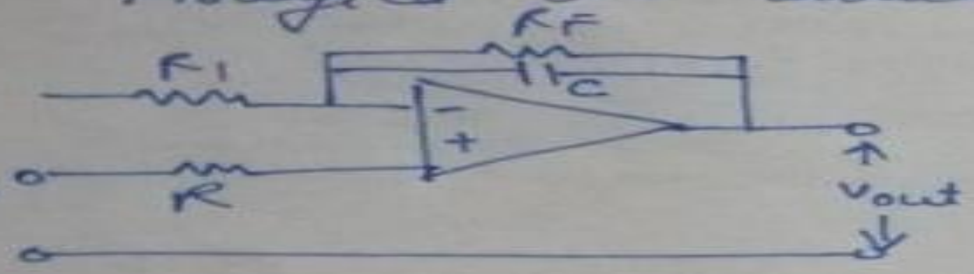
$$= \frac{1}{\sqrt{(RC)^2\omega^2+1}} = \frac{1}{\sqrt{\left(\frac{\omega}{\omega_c}\right)^2+1}}$$

$$\frac{|V_{out}|}{|V_{in}|} = \frac{1}{\sqrt{1+\left(\frac{f}{f_c}\right)^2}} \times A_V$$ = Op amp transfer function



Now Vin is coming from another ckt may be from sensor, then it will shift the cut off frequency of active filter.

Modified ckt would be



At zero frequency

$X_C = \infty$

$Z = X_C + R_F \rightarrow$ gain is $A_V = 1 + \frac{R_F}{R_1}$

At $X_C = 0$

gain is = unity

So effect of loading can be removed.

$$f_C = \frac{1}{2\pi R_f C}$$

cut off frequency.

Inverting Type Low Pass Active Filter

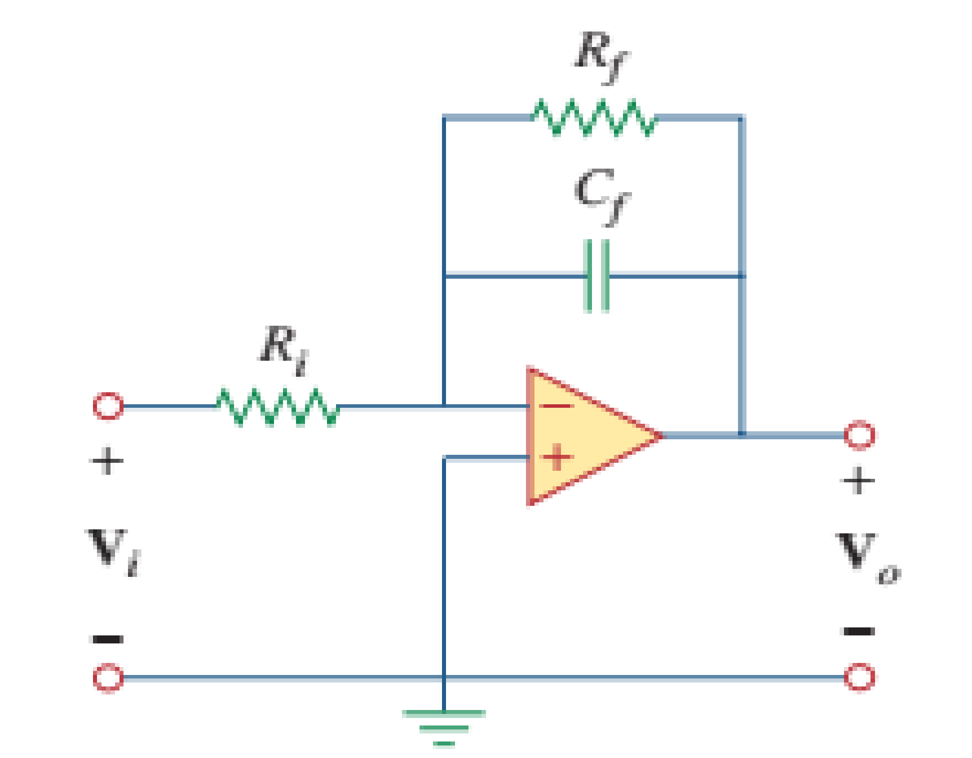
The transfer function is $\mathbf{H}(\omega) = \dfrac{\mathbf{V}_o}{\mathbf{V}_i} = -\dfrac{\mathbf{Z}_f}{\mathbf{Z}_i}$

$$\mathbf{Z}_i = R_i$$

$$\mathbf{Z}_f = R_f \left\| \frac{1}{j\omega C_f} = \frac{R_f/j\omega C_f}{R_f + 1/j\omega C_f} = \frac{R_f}{1 + j\omega C_f R_f}\right.$$

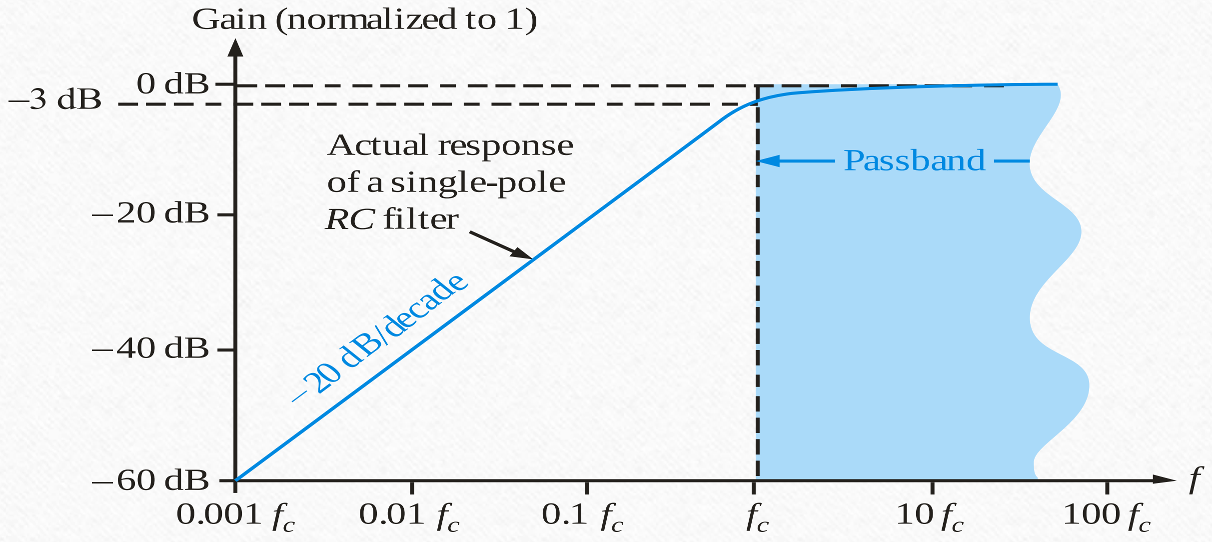
$$\mathbf{H}(\omega) = -\frac{R_f}{R_i}\frac{1}{1 + j\omega C_f R_f}$$

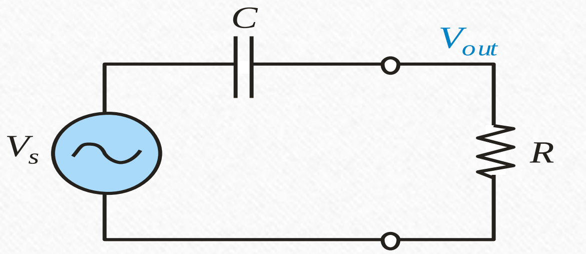
$$\omega_c = \frac{1}{R_f C_f}$$



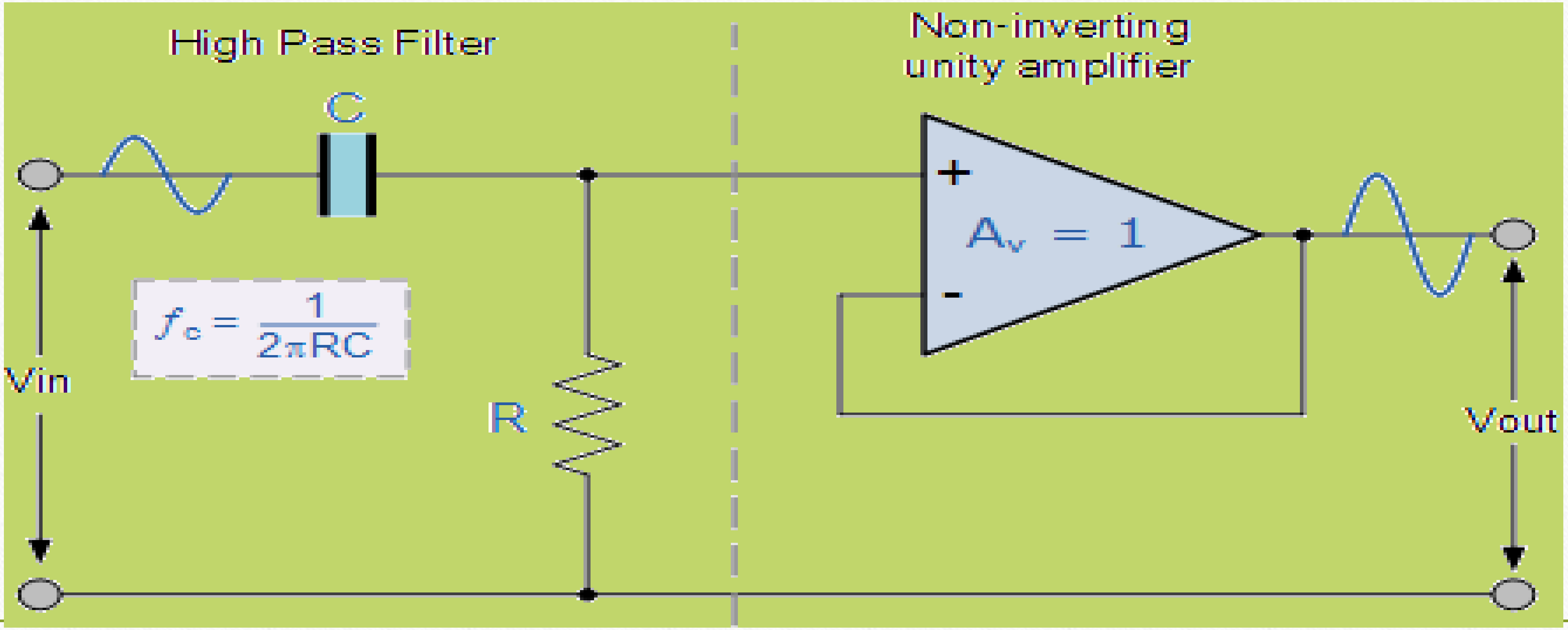
High Pass filter

- The high-pass filter passes all frequencies above a critical frequency and rejects all others.
- The simplest high-pass filter is a passive *RC* circuit with the output taken across *R*.





First Order High Pass Filter

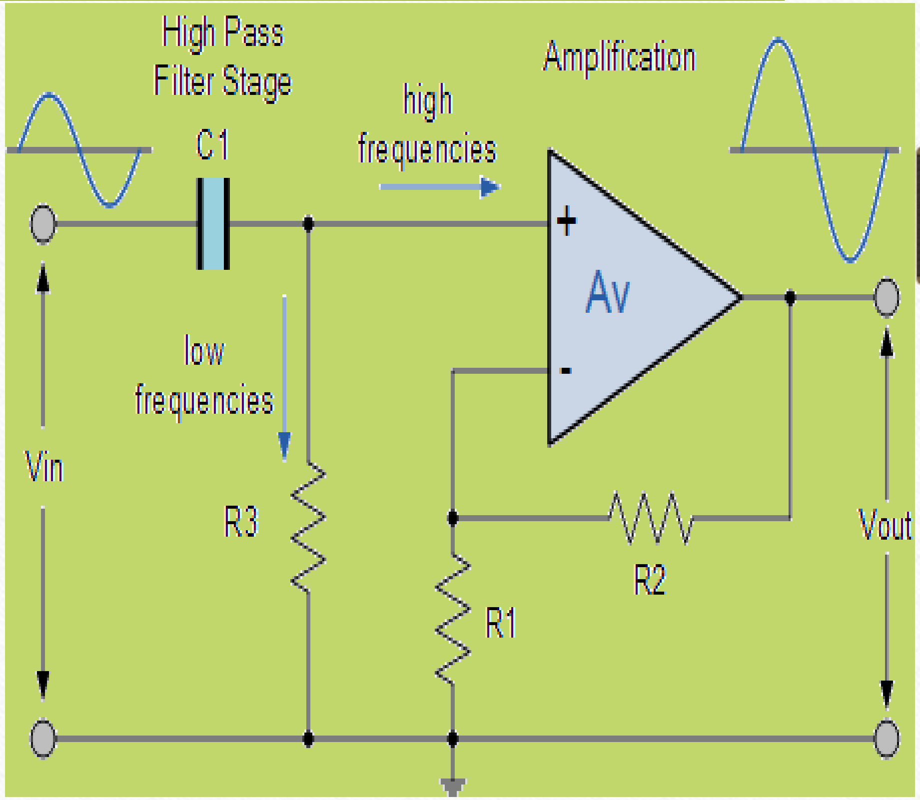


Active High Pass Filter with Amplification

- Gain for an Active High Pass Filter

$$A_v = \frac{V_{out}}{V_{in}} = A_F (f / f_c) / \sqrt{1 + (f / f_c)^2}$$

- A_F = the Pass band Gain of the filter, $(1 + R_2/R_1)$
- f = the Frequency of the Input Signal in hertz
- fc = the Cut-off Frequency in hertz
- At very low frequencies $f < f$c ; $\frac{V_{out}}{V_{in}} < A_F$
- At the cut-off frequency $f = f$c; $\frac{V_{out}}{V_{in}} = \frac{A_F}{2} = 0.707 A_F$
- At the cut-off frequency $f > f$c; $\frac{V_{out}}{V_{in}} \approx A_F$



Contd..

- Now $A_v = 20\log_{10}\frac{V_{out}}{V_{in}}$

$$f_c = \frac{1}{2\Pi RC}$$

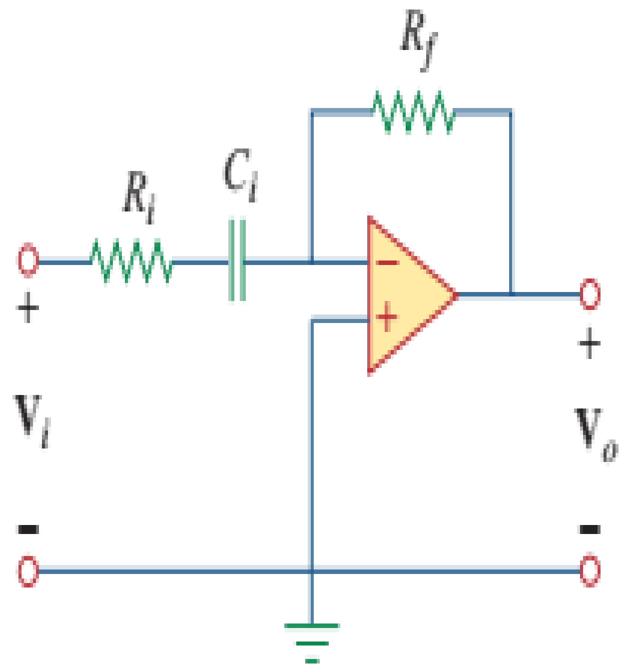
Analysis of First order High Pass Active filter

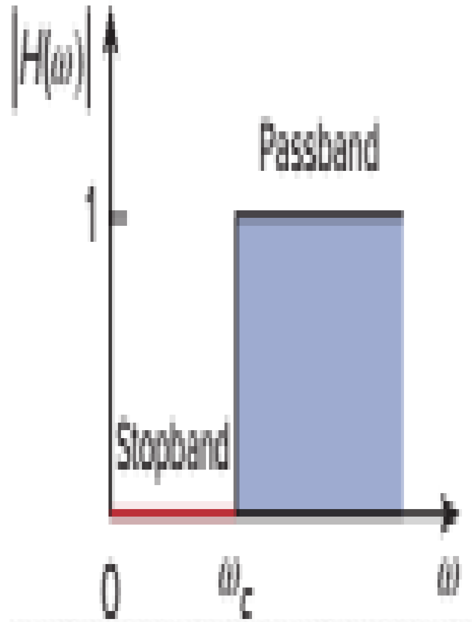
$$H(\omega) = \frac{\mathbf{V}_o}{\mathbf{V}_i} = -\frac{\mathbf{Z}_f}{\mathbf{Z}_i}$$

$$\mathbf{Z}_i = R_i + 1/j\omega C_i \text{ and } \mathbf{Z}_f = R_f$$

$$H(\omega) = -\frac{R_f}{R_i + 1/j\omega C_i} = -\frac{j\omega C_i R_f}{1 + j\omega C_i R_i}$$

$$\omega_c = \frac{1}{R_i C_i}$$





Problem

- Q. Design a High Pass filter with a high frequency gain of 5 and corner frequency of 2 Khz. Use a 50 nF capacitor in circuit.

- **Answer:** R_i = 800 ohm and R_f = 4 kohm.

References

- ***Coughlin, R.F., Operational Amplifiers and Linear Integrated Circuits, Pearson Education (2006).***
- ***Gayakwad, R.A., Op-Amp and Linear Integrated Circuits, Pearson Education (2002).***
- **Franco, S., Design with Operational Amplifier and Analog Integrated circuit, McGraw Hill (2016).**
- ***Terrell, D., Op Amps Design Application and Troubleshooting, Newness (1996).***