Analog & Digital Electronics

Course No: PH-218

Lec-24: Operational Amplifiers and Filters Circuits

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Comparator as a A/D converter

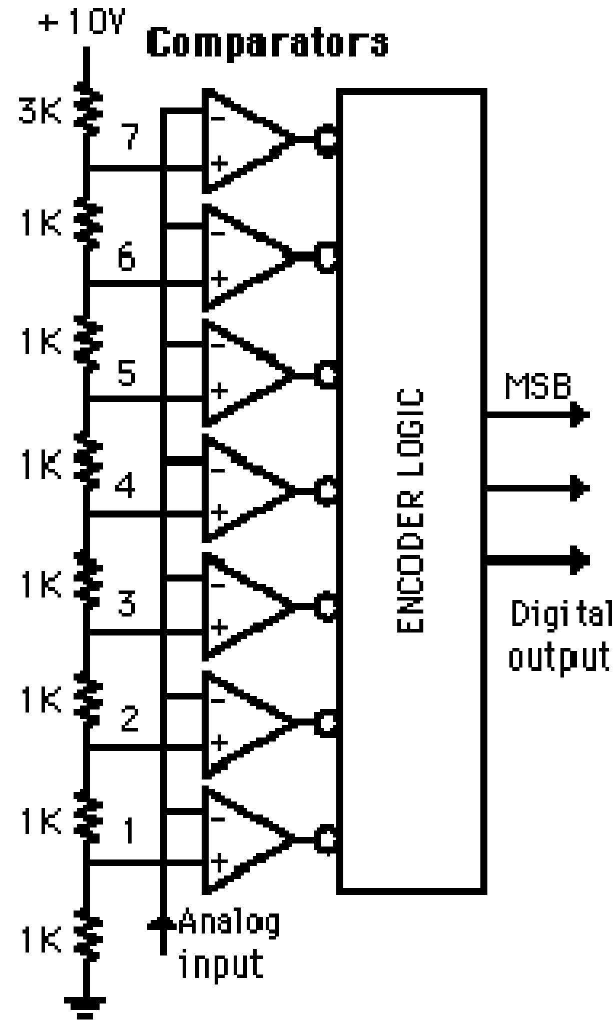
Parallel comparators are used to compare the linear input signal with various reference voltage developed by voltage divider.

When the input voltage is higher than the reference voltage, a high level is produced at the comparators output.

The reference voltage for each comparator is set by the voltage divider and reference voltage.

Output of each comparator is connected to an input of the encoder that produces a binary number representing the highest value input.

For a n digit binary, $2^n – 1$ comparators are required.

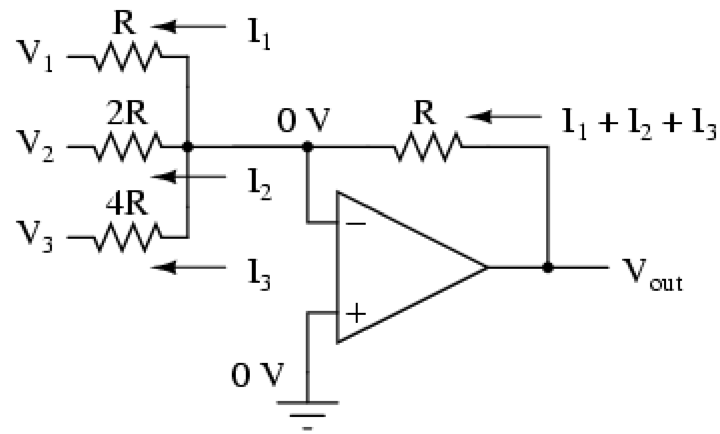


Simultaneous or flash method

Summing Amplifier as D/A converter

A digital to analog (D/A) converter is a weighted summing circuit that produces an output equal to the weighted sum of inputs.

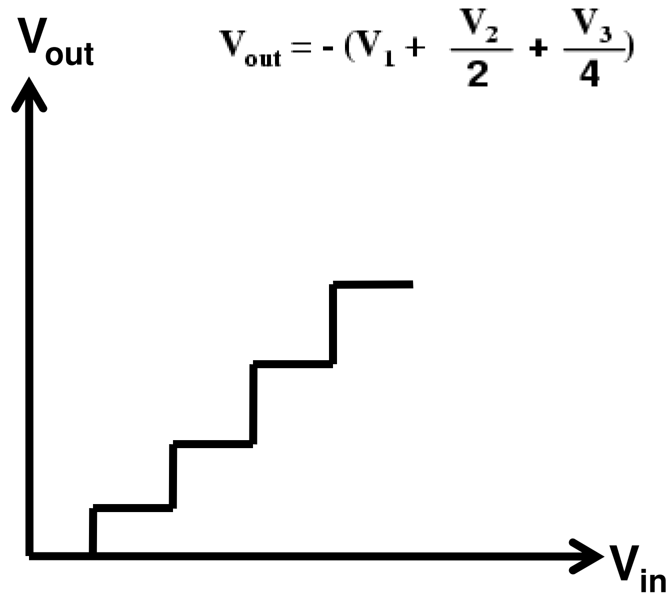
The weight is same as the gain of the channel.



$$V_o = -\left(\frac{R_f}{R_a}V_a + \frac{R_f}{R_b}V_b + \frac{R_f}{R_c}V_c\right)$$

Binary Input	Output
000	0
001	-0.125
010	-0.50
011	-0.625
100	-1.00
101	-1.125
110	-1.50
111	-1.625

$$V_{out} = -\left(V_1 + \frac{V_2}{2} + \frac{V_3}{4}\right)$$

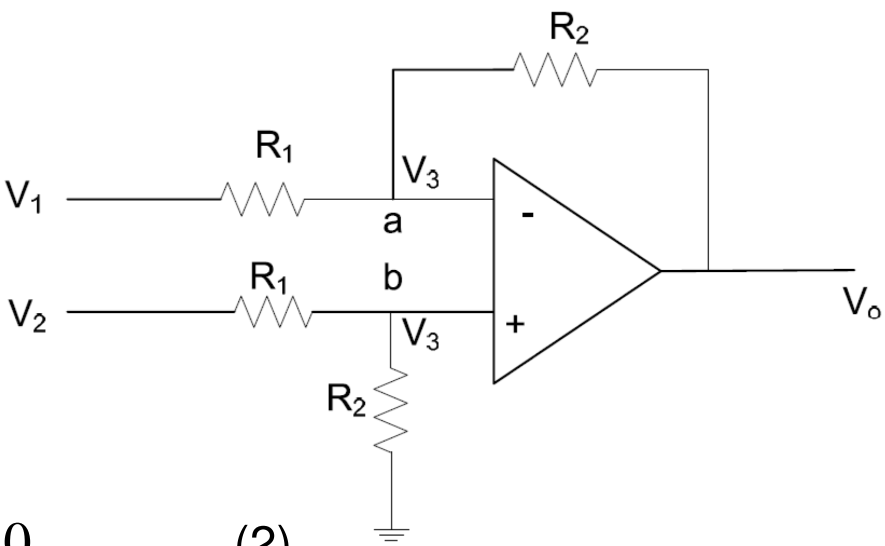


Voltage Substractor or Difference Amplifier

Applying KCL at node 'a',

$$\frac{V_1 - V_3}{R_1} = \frac{V_3 - V_o}{R_2}$$

$$\left(\frac{1}{R_1} + \frac{1}{R_2}\right)V_3 - \frac{V_1}{R_1} = \frac{V_o}{R_2} \qquad (1)$$



Applying KCL at node 'b',

$$\frac{V_2 - V_3}{R_1} = \frac{V_3}{R_2} \qquad \left(\frac{1}{R_1} + \frac{1}{R_2}\right)V_3 - \frac{V_2}{R_1} = 0 \qquad (2)$$

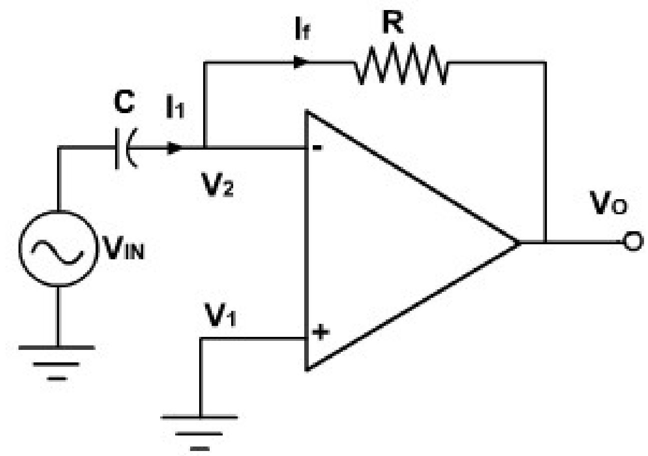
Subtracting eqn. (2) from eqn.(1)

$$\frac{V_2 - V_1}{R_1} = \frac{V_0}{R_2}$$

$$V_0 = R_2 \frac{(V_2 - V_1)}{R_1}$$

Op-AMP Differentiator

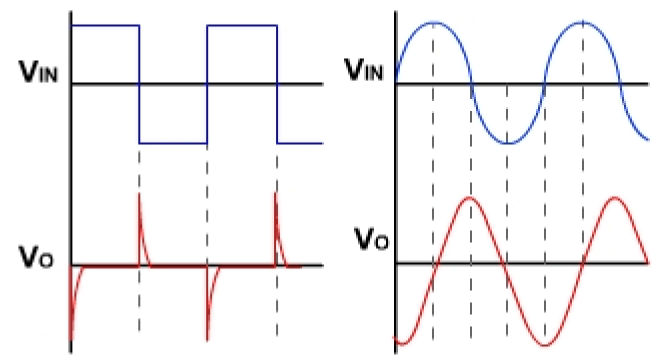
A circuit in which the output voltage waveform is the differentiation of input voltage is called differentiator



$$i_1 = i_f \Rightarrow C\frac{d}{dt}(V_{in} - 0) = \frac{0 - V_o}{R}$$

$$V_o = -RC\frac{d(V_{in})}{dt}$$

The input signal will be differentiated properly if the time period T of the input signal is larger than or equal to R_f C

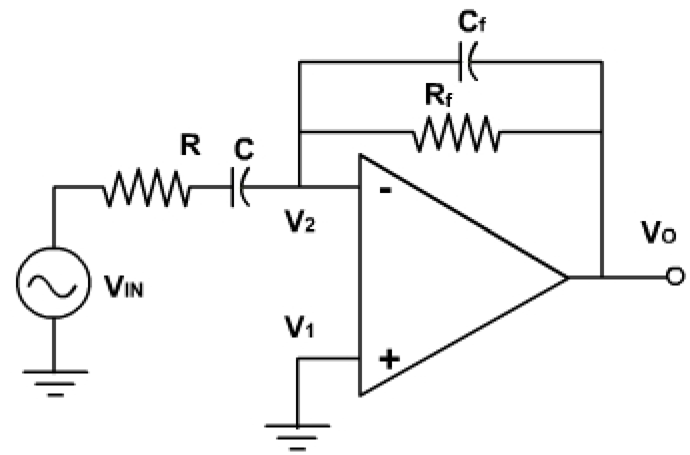


As the frequency changes, the gain changes. Also at higher frequencies the circuit is highly susceptible at high frequency noise and noise gets amplified. Both the high frequency noise and problem can be corrected by adding, few components.

Op-AMP Differentiator

Suppose input signal is sinusoidal.
V_{in} = A Sin (ω t)

Then $V_o = -\frac{d(V_{in})}{dt} = -A\omega Cos(\omega t)$



The amplitude of output voltage (A'=Aω) is function of frequency i.e. .A' is higher at higher frequency and lower at lower frequency.

At higher frequencies, signal will be buried inside the noise because noise contains all the frequencies from low to high and high frequency noise will be more amplified at the output compare to the signal.

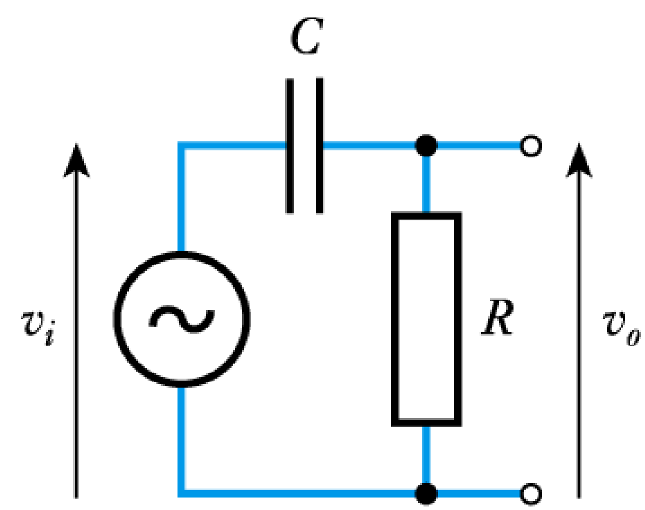
To avoid this we use a extra resistor and capacitor in series to reduce the strength of noise signal.

Differentiator as well as High pass Filter

As a Differentiator

$$V_o = iR = R\frac{dQ}{dt}$$

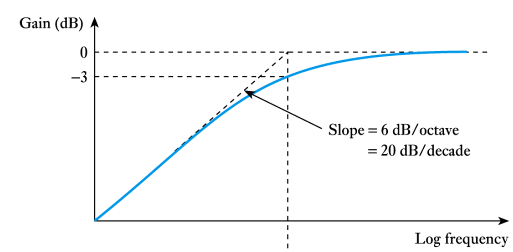
$$V_o = R\int\frac{d(CV_{in})}{dt} = RC\int\frac{dV_{in}}{dt}$$

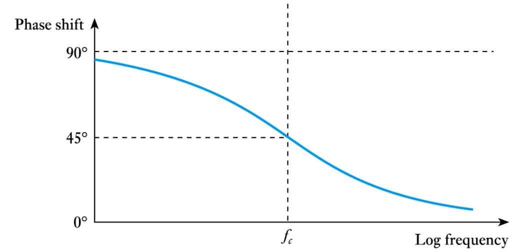


As a high pass filter

$$V_o = \left(\frac{R}{\sqrt{X_c^2 + R^2}}\right)V_{in}$$

$$\frac{v_o}{v_i} = \frac{\mathbf{Z_R}}{\mathbf{Z_R} + \mathbf{Z_C}} = \frac{R}{R - j\frac{1}{\omega C}} = \frac{1}{1 - j\frac{1}{\omega CR}}$$





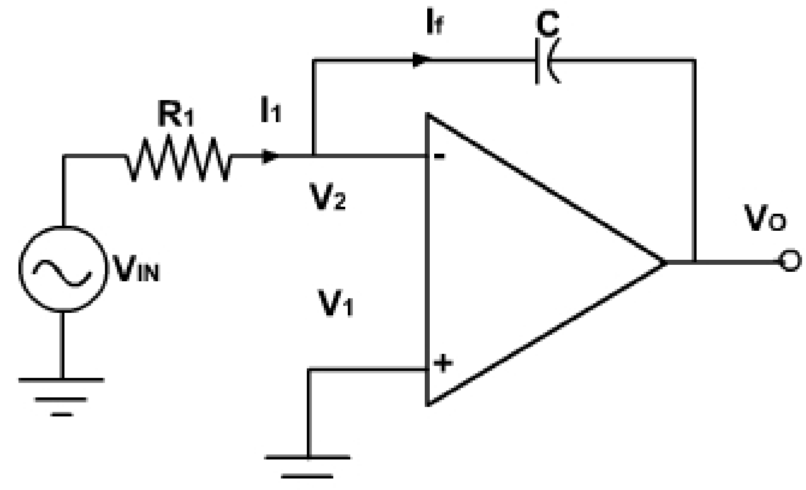
At high frequencies: ω is large, voltage gain ≈ 1

At low frequencies: ω is small, voltage gain → 0

Op-AMP Integrator

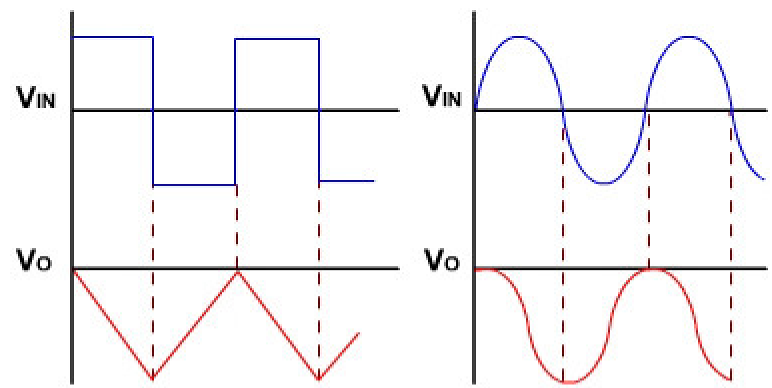
A circuit in which the output voltage waveform is the integral of the input voltage waveform is called integrator.

Here, the feedback element is a capacitor. The current drawn by OPAMP is zero and V_2 is virtually grounded



$$i_1 = i_f \qquad \frac{V_{in} - 0}{R_1} = C\frac{d}{dt}(0 - V_o)$$

Integrating both sides with respect to time from 0 to t, we get



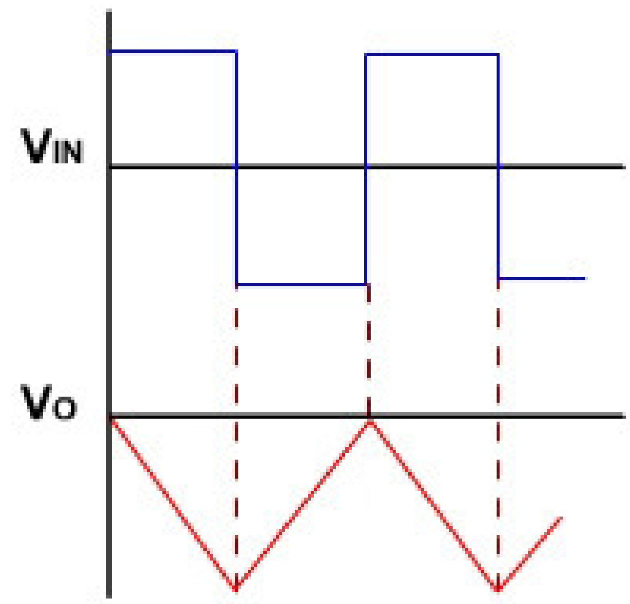
$$\int_0^t \frac{V_{in}}{R_1} dt = -\int_0^t C\frac{dV_o}{dt}$$

$$V_o = \frac{-1}{R_1 C}\int_0^t V_{in} dt$$

For accurate integration, the time period of the input signal T must be longer than or equal to R_1C.

Op-AMP Integrator

Calculate the output voltage of op-amp integrator if an input signal of 1kHz, 5 V peak amplitude square wave is applied at inverting terminal. The value of resistor and capacitor is 10k ohm and 0.1μF respectively.



$$V_o = \frac{-1}{R_1 C}\int_0^t V_{in} dt$$

$$V_o = \frac{-1}{10^{-3}}\int_0^{T/2} 5dt = -5\times 10^3 \frac{T}{2} = 2.5T\times 10^3$$

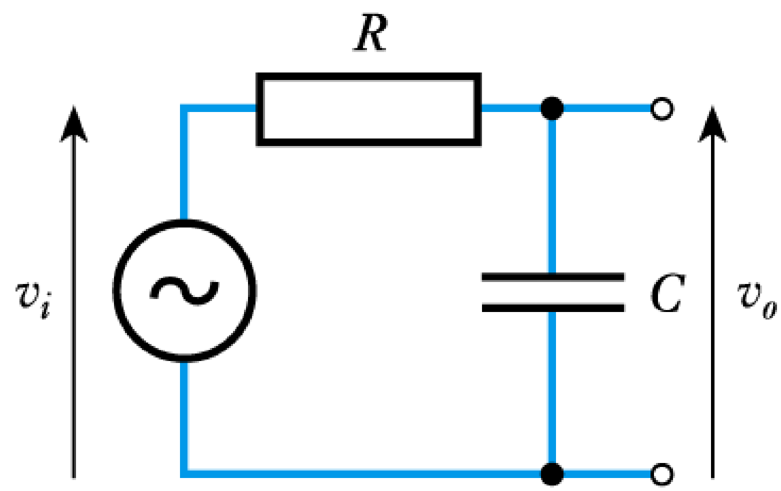
$$V_o = \frac{2.5}{f}\times 10^3 = 2.5V$$

Integrator as well as Low pass Filter

As a Integrator

$$V_o = \frac{Q}{C} = \frac{1}{C}\int i dt$$

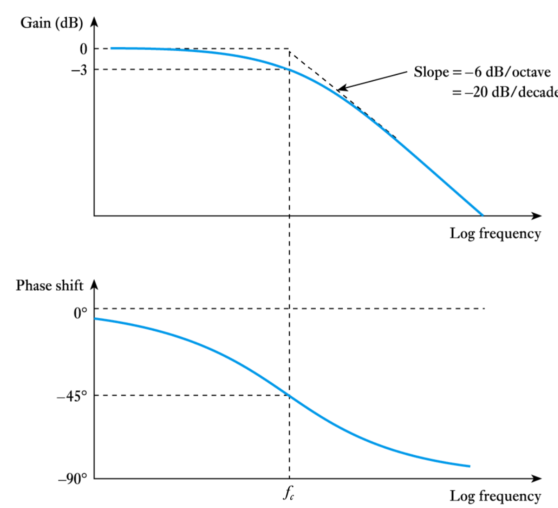
$$V_o = \frac{Q}{C} = \frac{1}{C}\int \frac{V_{in}}{R} dt = \frac{1}{RC}\int V_{in} dt$$



As a low pass filter

$$V_o = \left(\frac{X_C}{\sqrt{X_{c1}^2 + R_{in}^2}}\right)V_{in}$$

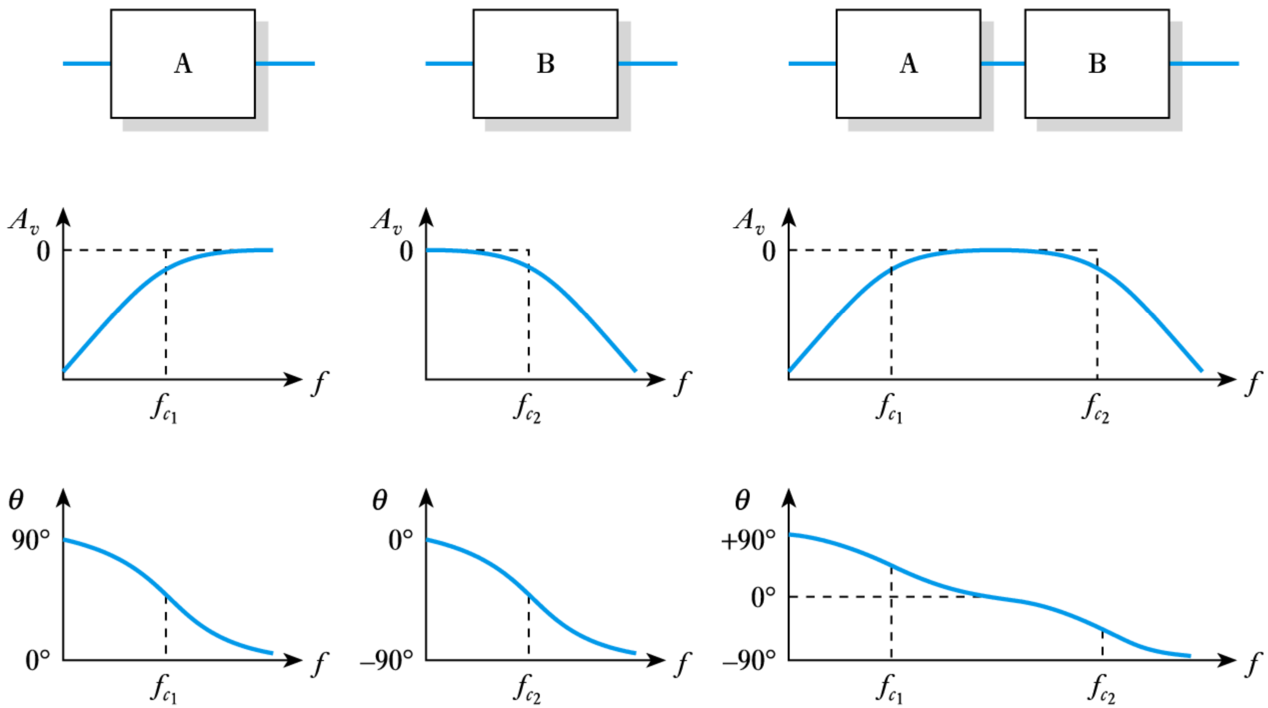
$$\frac{v_o}{v_i} = \frac{\mathbf{Z_C}}{\mathbf{Z_R} + \mathbf{Z_C}} = \frac{-j\frac{1}{\omega C}}{R - j\frac{1}{\omega C}} = \frac{1}{1 + j\omega CR}$$



At high frequencies: ω is large, voltage gain $\rightarrow$ 0
At low frequencies: ω is small, voltage gain $\approx$ 1

Band pass Filter

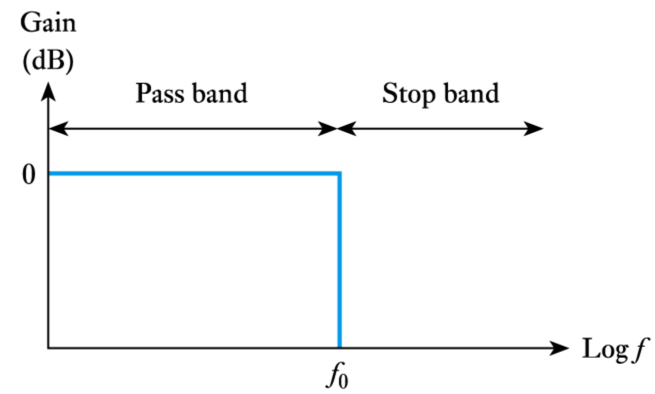
Band pass filter can be obtained by combining high frequency filter and low frequency filter.



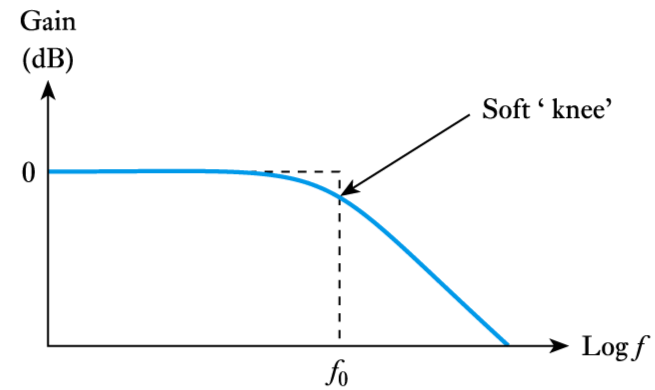
(a) High-pass circuit (b) Low-pass circuit (c) Band-pass circuit

Filter Circuits

- **An ideal filter would have constant gain and zero phase shift for frequencies within its pass band, and zero gain for frequencies outside this range (its stop band)**
- **Real filters do not have these idealized characteristics.**



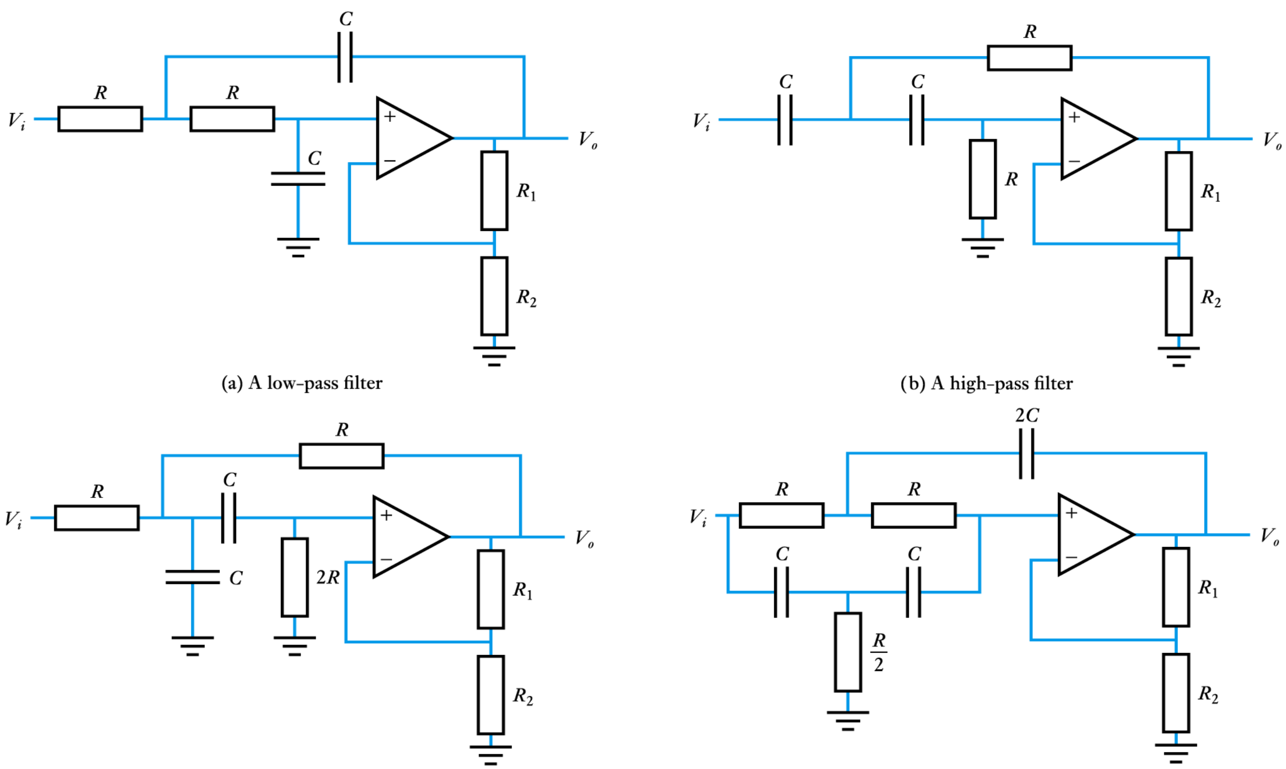
(a) An ideal low-pass filter



(b) A multi-stage *RC* filter

Active Filter Circuits

Combining an op-amp with suitable resistors and capacitors can produce a range of filter characteristics. These are termed **active filters**



(a) A low-pass filter

(b) A high-pass filter

(c) A band-pass filter

(d) A band-stop filter

Active Filter Circuits

- Common forms include:
- **Butterworth**
  - optimised for a flat response
- **Chebyshev**
  - optimised for a sharp ‘knee’
- **Bessel**
  - optimised for its phase response