Inverting Amplifier Using OP-AMP

Aim: Design an Inverting Amplifier using OP-AMP and observe the gain for different input waveforms.

Theory: An Inverting Amplifier using OP-AMP is a type of amplifier with an output 180^0 out of phase to the input waveform. The input waveform is amplified by a factor A_V and its phase will be opposite. A_V is known as the Open-loop gain of the amplifier. In an inverting amplifier the input to be amplified is applied to the inverting terminal of OP-AMP through a resistor R_1. R_f is the feedback resistor. R_f and R_1 together determine the gain of the amplifier.

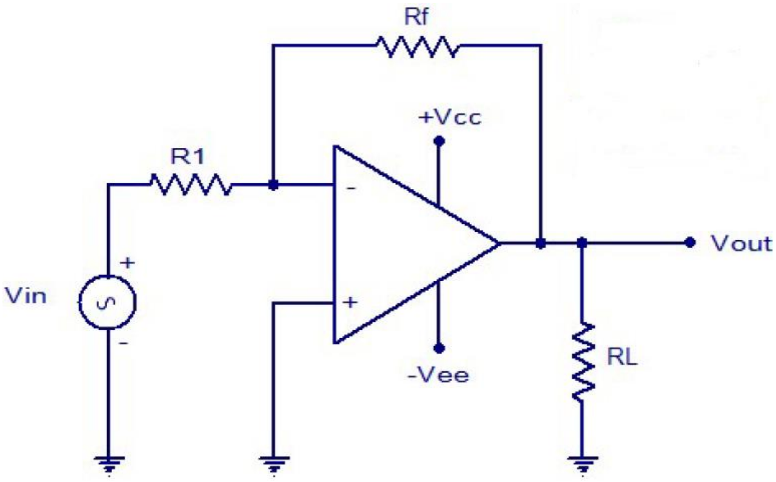


Figure 1: Circuit Diagram for an Inverting Amplifier

R_L is the load resistor and amplified output can be observed across it. Based on the values of R_f and R_1, one can decide the gain of the amplifier which will in-turn decide the peak amplitude of the output waveform.

Derivation for Gain Calculation of an Inverting Amplifier:

Due to virtual ground, the voltage at inverting terminal will be zero and there will not be any current flow in the OP-AMP. So, the current flowing through the branch (Input Branch) with V_{in} is the same as the current flowing in the branch (Feedback Branch) with R_f and due to virtual ground, there is no current flow inside the OP-AMP. Using KCL at inverting node of OP-AMP:

$$I_{Input\_Branch} = I_{Feedback\_Branch}$$

$$\frac{V_{in} - V_{Inverting\_Terminal}}{R_1} = \frac{V_{Inverting\_Terminal} - V_{out}}{R_f}$$

$$V_{Inverting\_Terminal} = 0 \text{ (due to Virtual Ground)}$$

$$\frac{V_{in}}{R_1} = \frac{-V_{out}}{R_f}$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{-R_f}{R_1}$$

The gain of an inverting amplifier is defined as:

$$A_V = -\frac{R_f}{R_1}$$

where negative sign indicates that the output waveform will be 180^0 out of phase to the input waveform.

Non-inverting Amplifier Using OP-AMP

Aim: Design a Non-inverting Amplifier using OP-AMP and observe the gain for different input waveforms.

Theory: In this configuration, the input signal (V_{in}) is applied to non-inverting terminal of an OP-AMP, which means the output waveform will be in-phase with the input waveform. In this case R_f and R_1 makes a voltage divider circuit and a small part of the output voltage is fed back to the input terminal. Due to this negative feedback, this closed-loop configuration provides good stability compared to the inverting amplifier.

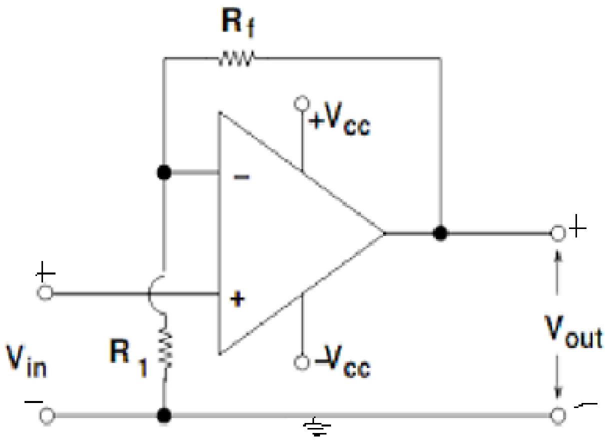


Figure 2: Circuit Diagram for a Non-inverting Amplifier (Negative terminal is grounded)

Based on the values of R_f and R_1, one can decide the gain of the amplifier to get the desired peak amplitude of the output waveform.

Derivation for Gain Calculation of a Non-inverting Amplifier:

Due to virtual ground, the voltage at inverting terminal will be V_{in} and because of high input resistance, there will not be any current flow in the OP-AMP. So, the current (I_1) flowing through the branch with R_1 is the same as the current (I_f) flowing in the branch with R_f. Using KCL at inverting node of OP-AMP:

$$I_1 = I_f$$

$$\frac{V_{in}}{R_1} = \frac{V_{out} - V_{in}}{R_f}$$

$V_{Inverting\_Terminal} = V_{in}$ (due to Virtual Ground)

$$A_V = \frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_1}$$

The gain of an inverting amplifier is defined as:

$$A_V = 1 + \frac{R_f}{R_1}$$

where no negative sign indicates that the output waveform will be in-phase to the input waveform.

Integrator Using OP-AMP

Aim: Design an active integrator and plot the output waveform at different levels of the input voltage.

Theory:

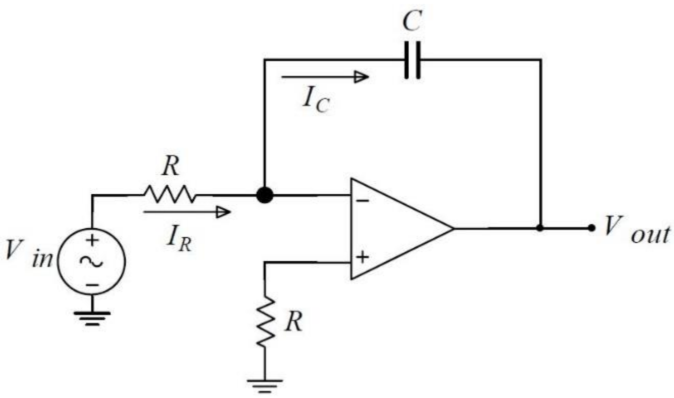


Figure 3: The Integrator Circuit

Let us assume that Op-Amp is ideal,

$$I_R = I_C$$

$$\frac{V_{in}}{R} = -C\frac{dV_{out}}{dt} \tag{1}$$

After rearranging the equation,

$$V_{out}(t) = -\frac{1}{RC}\int_0^t V_{in}(\tau)\, d\tau + V_{out}(0) \tag{2}$$

Thus, the output waveform is the integral form of the input waveform. The voltage $V_{out}(0)$ is the constant of integration and corresponds to the initial voltage across the capacitor (at time t = 0). The transfer function (in frequency domain analysis),

$$\frac{V_{out}}{V_{in}} = -\frac{Z_c}{Z_R} = \frac{j}{\omega RC} \tag{3}$$

According to above equation, there is a 90° phase difference between the input and the output signal and this phase shift can be observed at all frequencies.

A capacitor acts as an open circuit for $\omega = 0$, as a result of this the feedback path is open. With a slight modification in the circuit shown in Fig. 3, by connecting a resistor R_F, in parallel with the feedback capacitor C as shown in Fig. 4, we can resolve the above-mentioned problems.

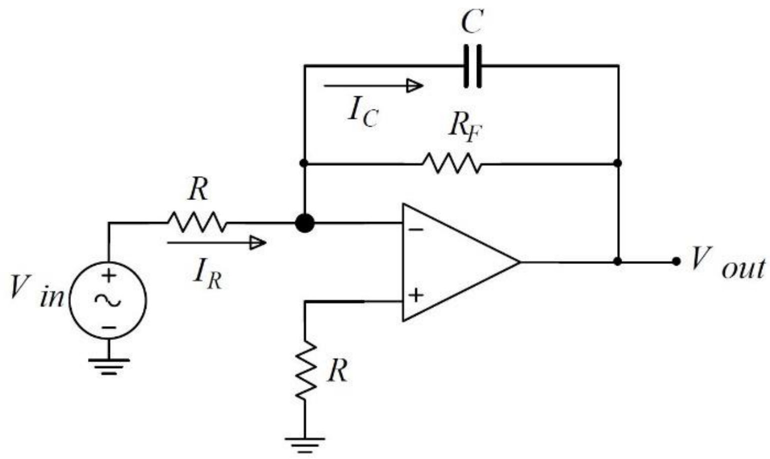


Figure 4: Active Integrator Circuit

The transfer function becomes,

$$A_V = \frac{V_{out}}{V_{in}} = -\frac{Z_F(\omega)}{Z_R(\omega)} = -\frac{R_F}{R}\frac{1}{1+j\omega R_F C} = -\frac{R_F}{R}\frac{1}{1+\frac{j\omega}{\omega_H}} \tag{4}$$

here, $\omega_H = \frac{1}{R_F C}$ (Higher Cut-off Frequency) (5)

In this transfer function, it is important to note that, $-\frac{R_F}{R}$ is the inverting amplifier gain. At $\omega \ll \omega_H$ the absolute voltage gain becomes $\frac{R_F}{R}$, while $\omega \gg \omega_H$ the gain decreases at a rate of 20dB per decade.

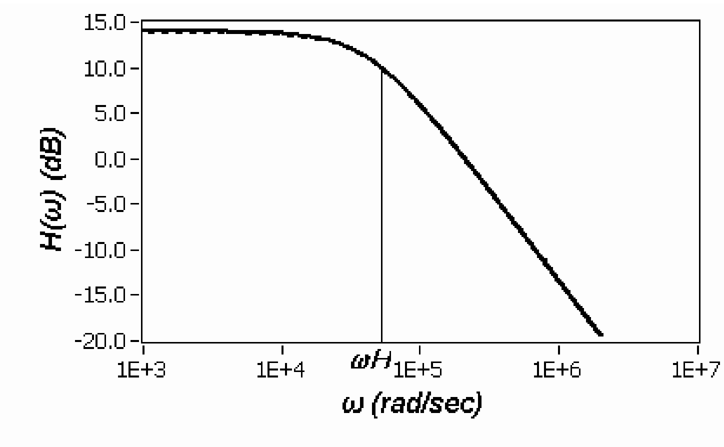


Figure 5: Frequency Response of an Active Integrator

Differentiator Using OP-AMP

Aim: Design an active differentiator and plot the output waveform at different levels of the input voltage.

Theory:

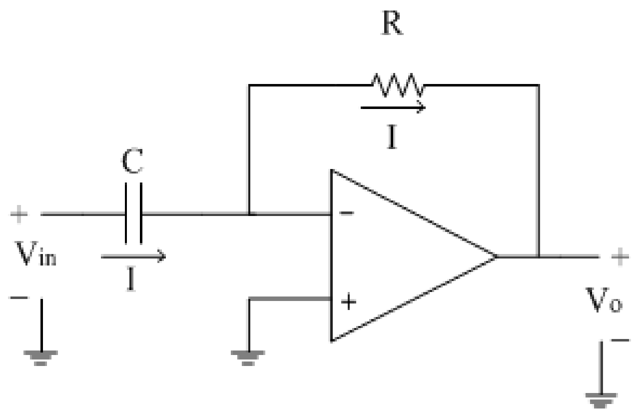


Figure 6: The Differentiator Circuit

A differentiator circuit may be obtained by replacing the capacitor with an inductor in Fig. 3 for an integrator. In practice this is rarely done since inductors are expensive, bulky and inefficient devices. Fig. 6 shows a fundamental differentiator circuit constructed with a capacitor and a resistor.

For an ideal op-amp, the current flowing through the capacitor is equal to the current flowing through the resistor.

$$V_{out} = -RC\frac{dV_{in}}{dt} \tag{6}$$

The output is thus proportional to the derivative of the input.

As the integrator is sensitive to DC drifts, the differentiator is sensitive to high frequency noise. The differentiator thus is a great way to search for transients, but will add noise. However, an integrator will decrease noise.

For the transfer function of a differentiator,

$$\frac{V_{in} - V_{inverting\_terminal}}{{}^{1}/_{j\omega C}} = \frac{V_{inverting\_terminal} - V_{out}}{R}$$

Here, $V_{inverting\_terminal} = 0$ (due to virtual ground)

$$A_V = \frac{V_{out}}{V_{in}} = -j\omega RC$$

So, this transfer function clearly reflects that at higher frequencies the gain of any differentiator will be high while being low at lower frequencies.

Questions based on above-mentioned theory for Inverting Amplifier:

$R_f = 200\ \Omega$, $R_1 = 100\ \Omega$, $V_{in} = V_A \sin(200\pi t)$ V, $V_{cc} = 15$ V, $V_{ee} = 15$ V, $R_L = 1k\Omega$

V_A	V_{out}
1	
3	
5	
7	
9	

1. What will be the Peak Amplitude of the output waveform for the different V_A values?
2. Show the output waveform for all the above-mentioned cases and justify your answers.
3. If there is a 10% variation in both R_f and R_1, how does this impact the output in percentage terms with respect to the original output you obtained?
4. Does the frequency of input signal have any impact on the output?

Questions based on above-mentioned theory for Non-inverting Amplifier:

$R_f = 2k\Omega$, $R_1 = 1k\Omega$, $V_{in} = V_A \sin(100\pi t)$ V, $V_{cc} = 20$ V

V_A	V_{out}
1	
3	
5	
7	
9	

1. What will be the Peak Amplitude of the output waveform for the different V_A values?
2. Show the output waveform for all the above-mentioned cases and justify your answers.
3. If there is a 10% variation in both R_f and R_1, how does this impact the output in percentage terms with respect to the original output you obtained?
4. Does the frequency of input signal have any impact on output?

Questions based on above-mentioned theory for an Active Integrator:

(i) Without R_F resistor: Assume frequency is 10 kHz.

S. No.	**Vin**	**R**	**C**	**Vout**	**Remark(s)**
1	5 sin (ωt)	10 kΩ	0.01 μF		
2	5 sin (ωt)	10 kΩ	0.1 μF		
3	5 sin (ωt)	10 kΩ	1 μF		
4	5 sin (ωt)	10 kΩ	10 μF		
5	5 sin (ωt)	10 kΩ	100 μF		

(ii) With R_F resistor: Assume frequency is 10 kHz.

S. No.	**Vin**	**R**	**C**	**R_F**	**Vout**	**Remark(s)**
1	5 sin (ωt)	10 kΩ	0.01 μF	10 Ω		
2	5 sin (ωt)	10 kΩ	0.1 μF	100 Ω		
3	5 sin (ωt)	10 kΩ	1 μF	1 kΩ		
4	5 sin (ωt)	10 kΩ	10 μF	10 kΩ		
5	5 sin (ωt)	10 kΩ	100 μF	100 kΩ		

Case (i): - Without R_F resistor

1. What will be the response of circuit at zero frequency?

2. What will the impact of the capacitor value on the output voltage?

Case (ii): - With R_F resistor

1. What will be the response of circuit at zero frequency?
2. What is the impact of the capacitor value on the output voltage?
3. How does feedback resistor R_F impact the output voltage?
4. For $\omega \ll \omega_H$ and $\omega \gg \omega_H$ cases, draw the frequency response graph and justify your answers in response to frequency ω_H.

Additional Question: Would it make any difference if we connect the input signal to a non-inverting terminal in Fig. 4? Justify your answer with proper mathematical equation.

Questions based on above-mentioned theory for an Active Differentiator:

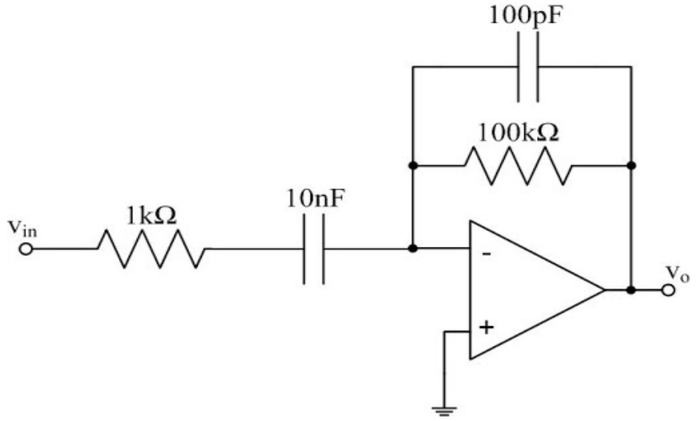
Assume that input frequency is 100 kHz.

S. No.	Vin	R	C	Vout	Remark(s)
1	5 sin (ωt)	10 kΩ	0.001 µF		
2	5 sin (ωt)	10 kΩ	0.01 µF		
3	5 sin (ωt)	10 kΩ	0.1 µF		
4	5 sin (ωt)	10 kΩ	1 µF		
5	5 sin (ωt)	10 kΩ	10 µF		
6	5 sin (ωt)	10 kΩ	100 µF		
7	5 sin (ωt)	10 kΩ	1000 µF		

1. What will be the output waveform for pulse input (+5 to -5 peak to peak, frequency = 100 kHz)?

Additional Questions:

1. How does the circuit in the fig. behave to an input V_{in} = A Sin(ωt)? Find out the transfer function for the same.



2. Which kind of circuit do you observe in fig. shown? Justify your answer.
(Hint: Find out the frequency response of the circuit)
3. Design a Low-pass Filter with f_H = 600Hz. (Specify the values of R and C along with the input and output waveforms)
(Hint: $\omega_H=2\pi f_H$ where f_H is the higher cut-off frequency of Low-pass Filter)
4. Design a High-pass Filter with f_L = 200Hz. (Specify the values of R and C along with the input and output waveforms)
(Hint: $\omega_L=2\pi f_L$ where f_L is the lower cut-off frequency of High-pass Filter)