EE1025-Independent Project
APPLICATIONS OF OPERATIONAL AMPLIFIER

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Abstract

This report illustrates some typical applications of operational amplifier .A real operational amplifier's equivalent circuit has a finite input impedance, a non-zero output impedance, and a finite gain. The various highly-applied uses are depicted such as active low pass,active high pass,differentiator and integrator.

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Contents

1 Aim

Understanding the following explicitly considering various parameters and conditions:-

- First order active low pass filter with unity voltage gain.
- Second order active low pass filter with unity voltage gain.
- Active high pass filter with unity voltage gain.
- Integrator amplifier.
- Differentiator amplifier.
- Active low pass & high pass with particular gain.

2 Introduction

Operational amplifiers are optimized for use with negative and positive feedback. In order for a particular device to be used in an application, it must satisfy certain requirements. The operational amplifier must have large open-loop signal gain (voltage gain of 200,000 is obtained in early integrated circuit exemplars), and have input impedance large with respect to values present in the feedback network.

Active low pass filter:- First order active low filter is formed by a single op-amp with RC circuit which allows frequencies lower than cut-off frequency.
A simple RC Passive Filter connected to the non-inverting terminal of an operational amplifier.
This filter is designed for overcoming attenuation which is seen in a basic rc filter ,and to increase the amplitude of output signal.
Second order active filter is formed by just adding an rc circuit to first order.

Active high pass filter:- First order active high filter is formed by a single op-amp with RC circuit which allows frequencies higher than cut-off frequency.
A simple RC Passive Filter connected to the non-inverting terminal of an operational amplifier.
This filter is designed for overcoming attenuation which is seen in a basic rc filter ,and to increase the amplitude of output signal.
Second order active filter is formed by just adding an rc circuit to first order.

Integrator:- It performs a mathematical operation of integrator .
The output to respond to changes in the input voltage over time as the op-amp integrator produces an output voltage which is proportional to the integral of the input voltage.
the magnitude of the output signal is determined by the length of time a voltage is present at its input as the current through the feedback loop charges or discharges the capacitor as the required negative feedback occurs through the capacitor.
The integrator circuit is mostly used in analog computers, analog-to-digital converters and wave-shaping circuits.

Differentiator:- It performs a mathematical operation of differentiator.
It produces a voltage output which is directly proportional to the input voltages rate-of-change with respect to time.
The faster or larger the change to the input voltage signal, the greater the input current, the greater will be the output voltage change in response, becoming more of a spike in shape.
They are most commonly used in wave-shaping circuits to detect high-frequency components in an input signal and applied in electronic analogue computers and analogue PID controllers.

3 Appartus

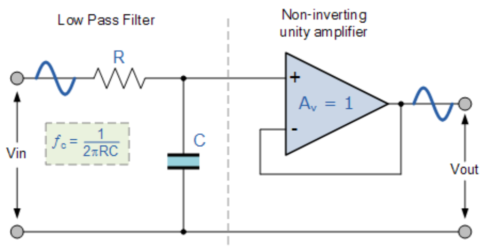
These experiments are conducted on an open-source LT-spice with mostly resistors of kΩ *range and capacitors of range* 1μ *to* $1n$*. Resistors much greater than* $1M\Omega$ *cause excessive thermal noise and make the circuit operation susceptible to significant errors due to bias or leakage currents.*

4 Theoretical Background

4.1 Active Low-pass filter

First order with unity gain:-

- The amplifier is configured as a voltage-follower (Buffer) giving it a DC gain of one, Av = +1 or unity gain .
- 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.
- Although the voltage gain is unity the power gain is very high as its output impedance is much lower than its input impedance.
- The main disadvantage is that it has no voltage gain above one.



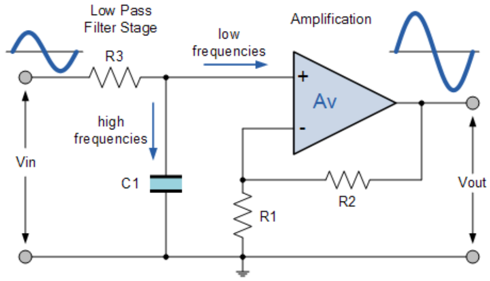
First order with high voltage gain:-

- Both voltage gain and power gain is visible in this configuration.
- The Active Low Pass Filter has a constant gain A_F *from* $0Hz$ *to the high frequency cutoff point At cutoff point the gain is* $0.707A_F$ *, and after thispoint it decreases at a constant rate as the frequencyincreases.*
  The DC gain is given as :−

$$\text{DC GAIN} = 1 + \frac{R_2}{R_1}$$

- The AC gain is given as:-

$$\text{Voltage Gain} = \frac{1+\dfrac{R_2}{R_1}}{\sqrt{1+(\dfrac{f}{f_C})^2}}$$

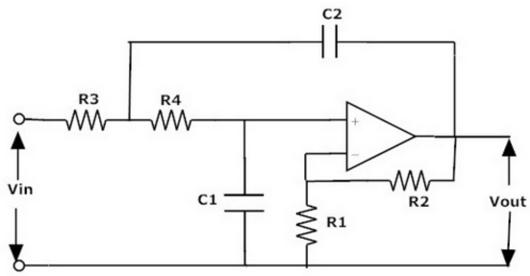


Second order with unity gain:-

The frequency response of the second-order low pass filter is identical to that of the first-order type except that the stop band roll-off will be twice the first-order filters at 40dB/decade (12dB/octave). Therefore, the design steps required of the second-order active low pass filter are the same.

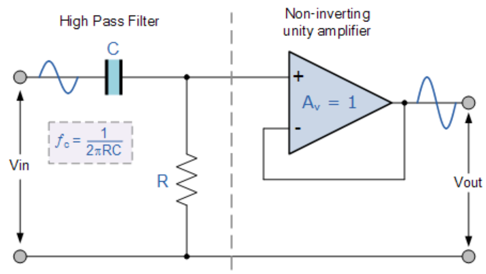
These filters stop the high frequency signals more steep.

The cutoff frequency of this filter is given as:- $f_c = \dfrac{1}{2\pi\sqrt{R_3R_4C_1C_2}}$



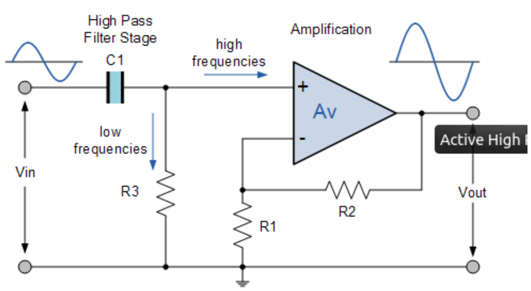
4.2 Active High-pass filter

- It is similar to active low -pass filter.
- The design providing amplification and gain control.
- Unlike Passive High Pass Filters which have an infinite frequency response, the maximum pass band frequency response of an active high pass filter is limited by the open-loop characteristics .

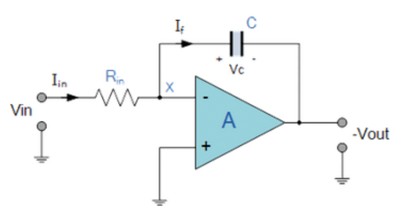


- The amplitude of the signal is increased by the gain of the amplifier and for a non-inverting amplifier the value of the pass band voltage gain is given as 1 + R2/R1 .

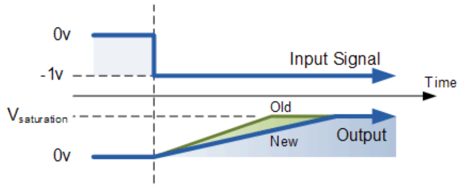
- The Active High Pass Filter has a gain A_F *that increases from* $0Hz$ *to the low frequency cutoff point at* $20dB/decade$ *as the frequency increases.*
  At cutoff point the gain is $0.707 * A_F$ *, and after this point all frequencies are pass band frequencies so the filter has a constant gain* A_F *with the highest frequency being determined by the closed loop bandwidth of the op – amp.*



4.3 Integrator

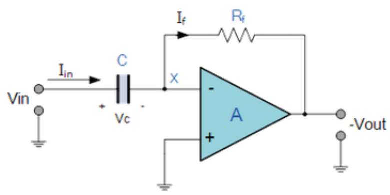


The capacitor charges up at a rate determined by the RC time constant of the series RC network. Negative feedback forces the op-amp to produce an output voltage that maintains a virtual earth at the op-amps inverting input. The ratio of feedback capacitor to input resistor (Xc/Rin) increases and reaches a saturation level w.r.t .The time constant depicts how fast the output becomes constant.

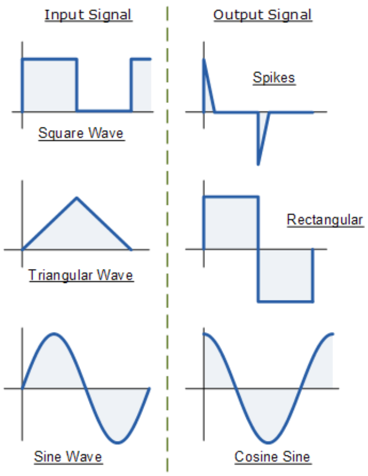


The input voltage and output voltage are related as:
$V_C = V_X - V_{OUT} = 0 - V_{OUT}$
$\frac{-dV_{OUT}}{dt} = \frac{-dQ}{Cdt}$
$I_N = I_F$
$\frac{V_{IN}}{R_{IN}} = \frac{CdV_{out}}{dt}$
$V_{OUT} = \int_0^t V_{IN} \frac{dt}{R_{IN}C}$

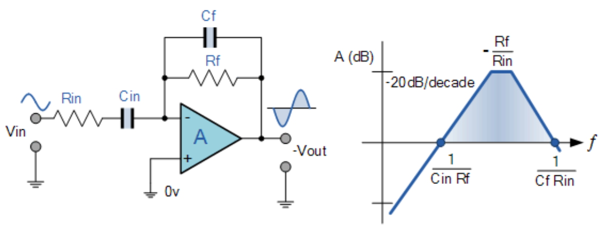
4.4 Differentiator



At low frequencies the reactance of the capacitor is High resulting in a low gain (R/Xc) and low output voltage from the op-amp. At higher frequencies the reactance of the capacitor is much lower resulting in a higher gain and higher output voltage from the differentiator amplifier. The input voltage and output voltage are related as: $I_N = I_F and I_F = \frac{-V_{OUT}}{R_F}$
$I_N = \frac{dQ}{dt} = C\frac{dV_{IN}}{dt}$
$=> V_{OUT} = -R_F C \frac{dV_{IN}}{dt}$
$Few general input - output are picturised below:$



To improvise this model :
The input resistor RIN limits the diferentiators increase in gain at a ratio of Rf/RIN The circuit now acts like a diferentiator amplifier at low frequencies and an amplifier with resistive feedback at high frequencies giving much better noise rejection. Additional attenuation of higher frequencies is accomplished by connecting a capacitor Cf in parallel with the differentiator feedback resistor ,Rf.



5 Experimentation

5.1 TASK 1 :First order active low pass filter with unity voltage gain

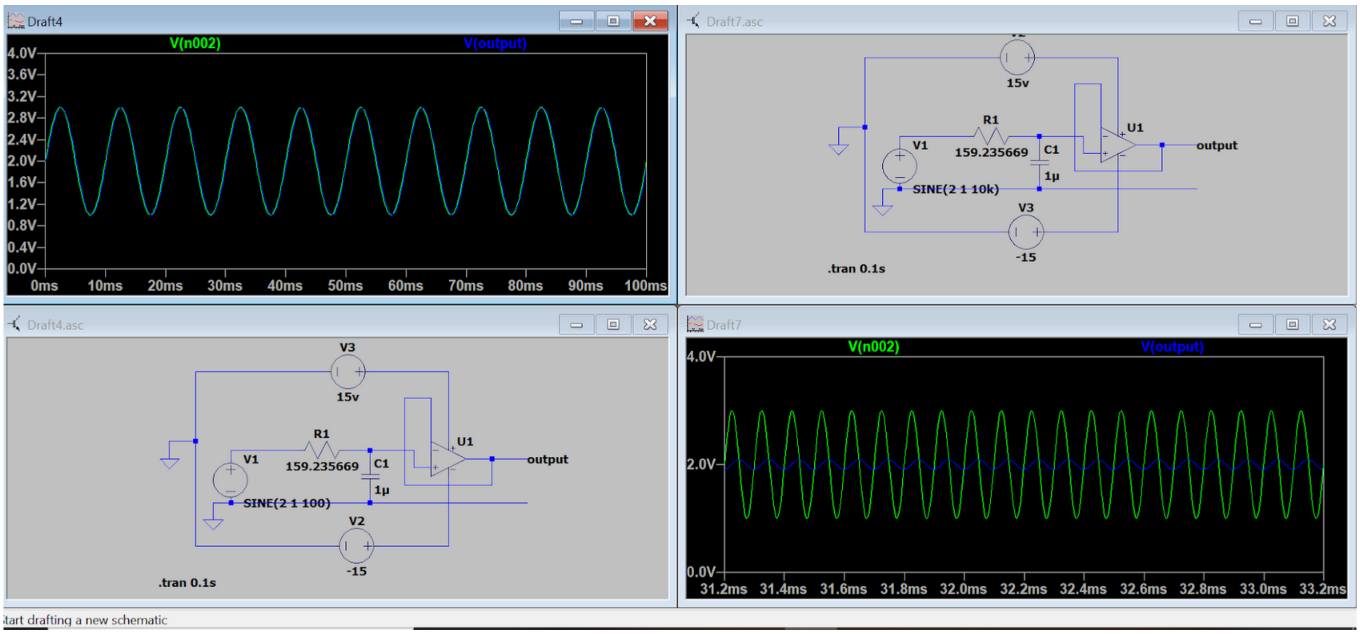
Step 1:-The cutoff frequency is adjusted to 1kHz by considering the resistance as 159.235669Ω *and capacitance as*1*u.*

Step 2 :-The input is excited with a signal of having DC shift of 2V and sinusoidal AC of frequency 10kHz and 1Vpeak and next time with frequency 100Hz.

Step 3:-Setting up the system in lt-spice by ading an inverted universal amplifier with a bipolar supply of -+15V.

Step 4:Simulating the circuit as transient analysis for 0.1s.

Outcome:For frequency greater than the cutoff frequency the signal attenuates and frequency lesser than cutoff frequency the output signal resembles the input signal resulting in low-pass filter characteristics and depicting unity gain.



5.2 TASK 2:Second order active low pass filter with unity voltage gain

Step 1:-The cutoff frequency is adjusted to 1kHz by considering the resistance as 159.235669Ω *and capacitance as*$1u$.

For second order behavior a new RC component is added with same values as above to maintain cutoff frequency as 1kHz.Since,

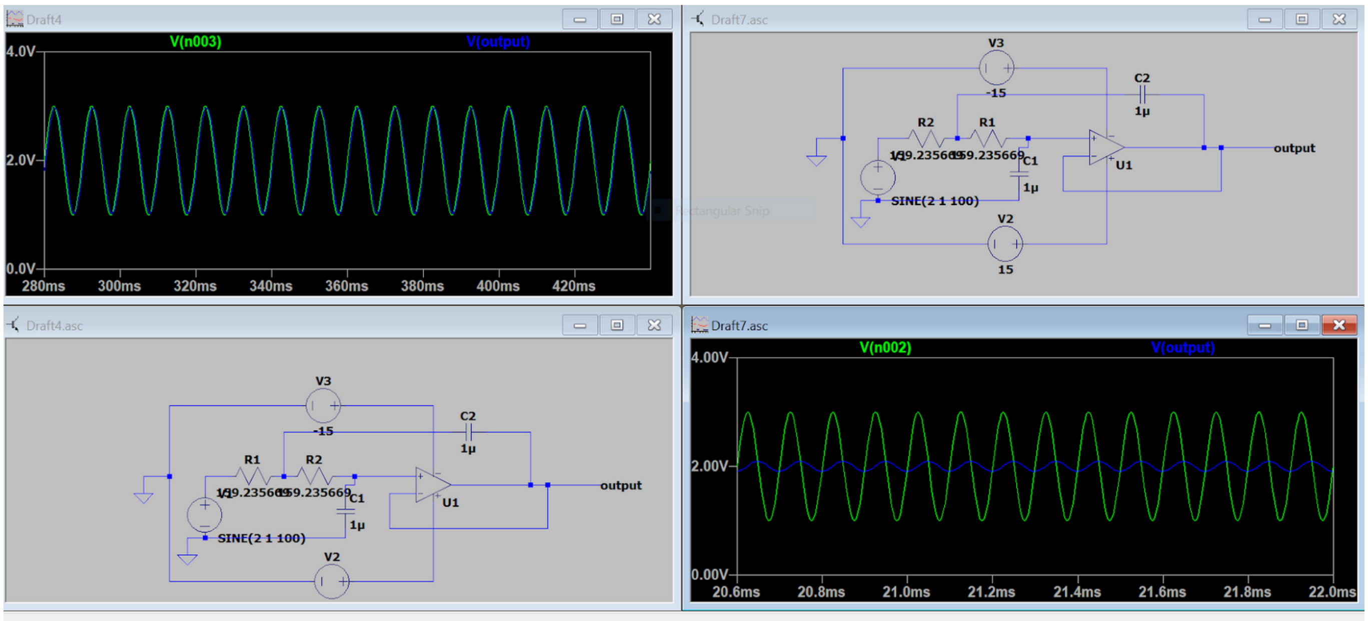
$$f_c = \frac{1}{2\pi\sqrt{R_3 R_4 C_1 C_2}} \tag{1}$$

Step 2 :-The input is excited with a signal of having DC shift of 2V and sinusoidal AC of frequency 10kHz and 1Vpeak and next time with frequency 100Hz.

Step 3:-Setting up the system in lt-spice by ading an inverted universal amplifier with a bipolar supply of -+15V.

Step 4:Simulating the circuit as transient analysis for 0.1s.

Outcome:For frequency greater than the cutoff frequency the signal attenuates and frequency lesser than cutoff frequency the output signal resembles the input signal resulting in low-pass filter characteristics and depicting unity gain.
It is similar to first order except that above above cutoff frequency the band-roll is twice than first order.



5.3 TASK 3: First order active high pass filter with unity voltage gain

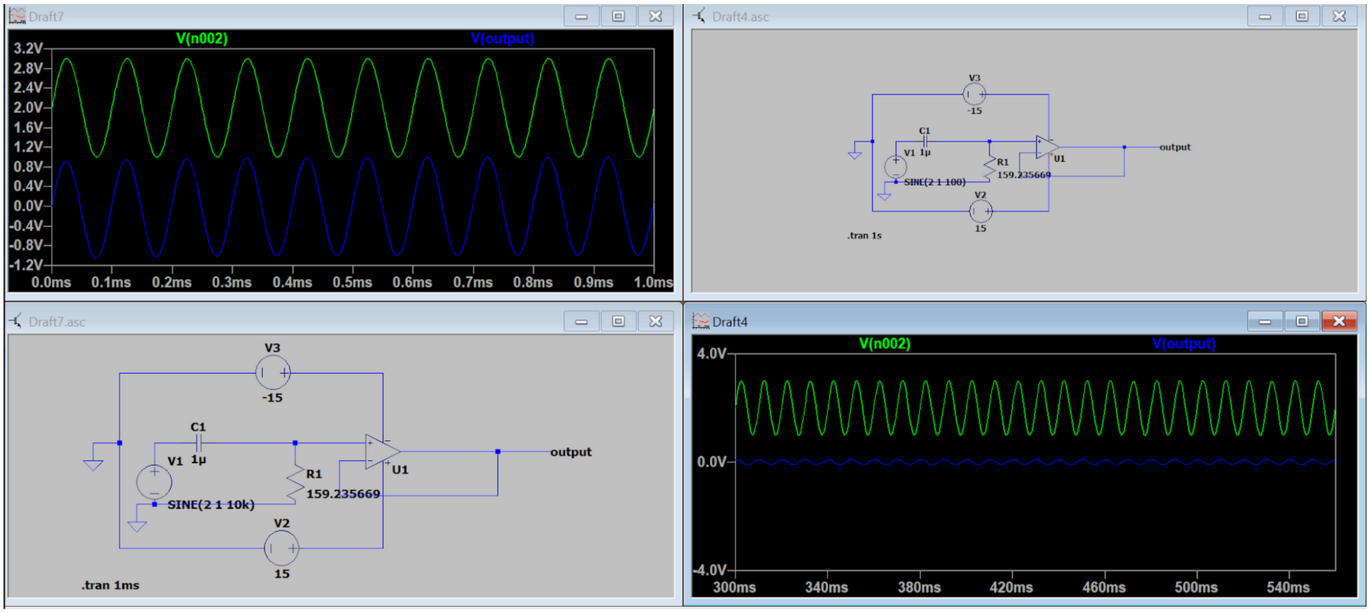
Step 1:-The cutoff frequency is adjusted to 1kHz by considering the resistance as 159.235669Ω *and capacitance as*1*u*.

Step 2 :-The input is excited with a signal of having DC shift of 2V and sinusoidal AC of frequency 10kHz and 1Vpeak and next time with frequency 100Hz.

Step 3:-Setting up the system in lt-spice by ading an inverted universal amplifier with a bipolar supply of -+15V.

Step 4:Simulating the circuit as transient analysis for 0.1s.

Outcome:For frequency lesser than the cutoff frequency the signal attenuates and frequency greater than cutoff frequency the output signal resembles the input signal resulting in high-pass filter characteristics and depicting unity gain.



5.4 TASK 4: Integrator amplifier

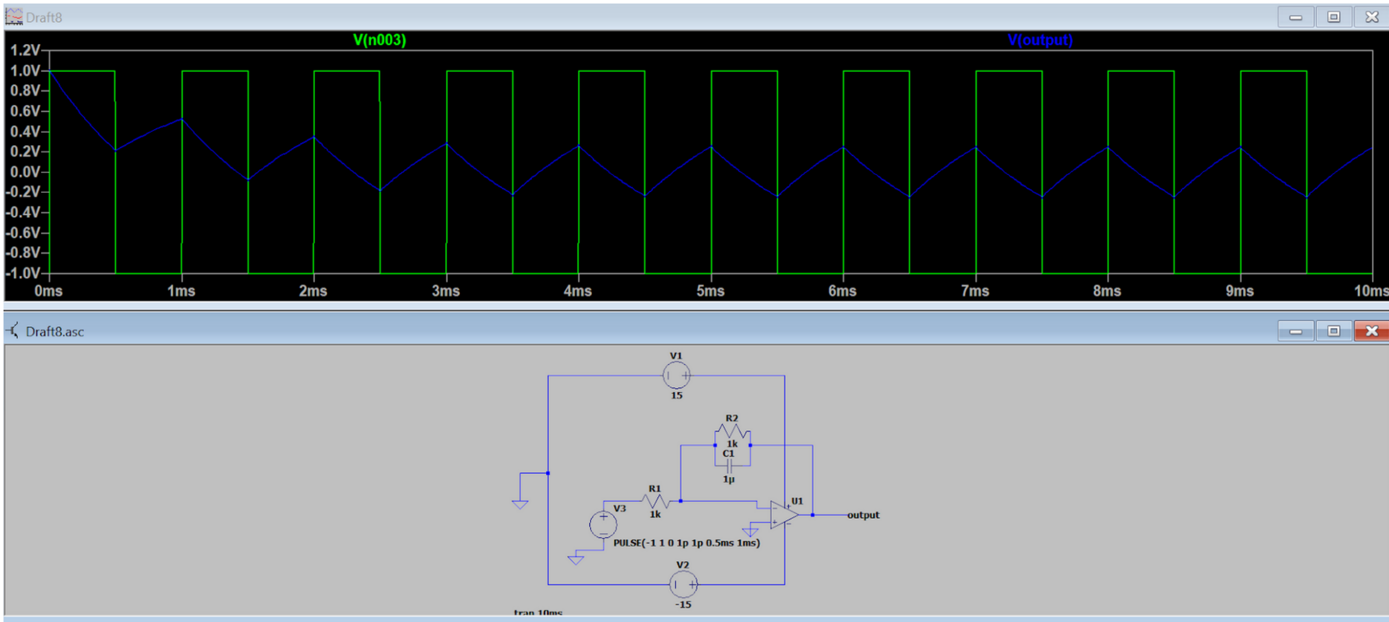
Step 1:-The input is excited with a periodic square waveform of frequency 1kHz and 1Vpeak.

Step 2:-The resistors 1k ,and 1uC capacitors are connected as shown below.

Step 3:-Setting up the system in lt-spice by ading an universal amplifier with a bipolar supply of -+15V.

Step 4:Simulating the circuit as transient analysis for 10ms.

Outcome:-The output is integral of the input(triangle wave).



5.5 TASK 5:Differentiator amplifier

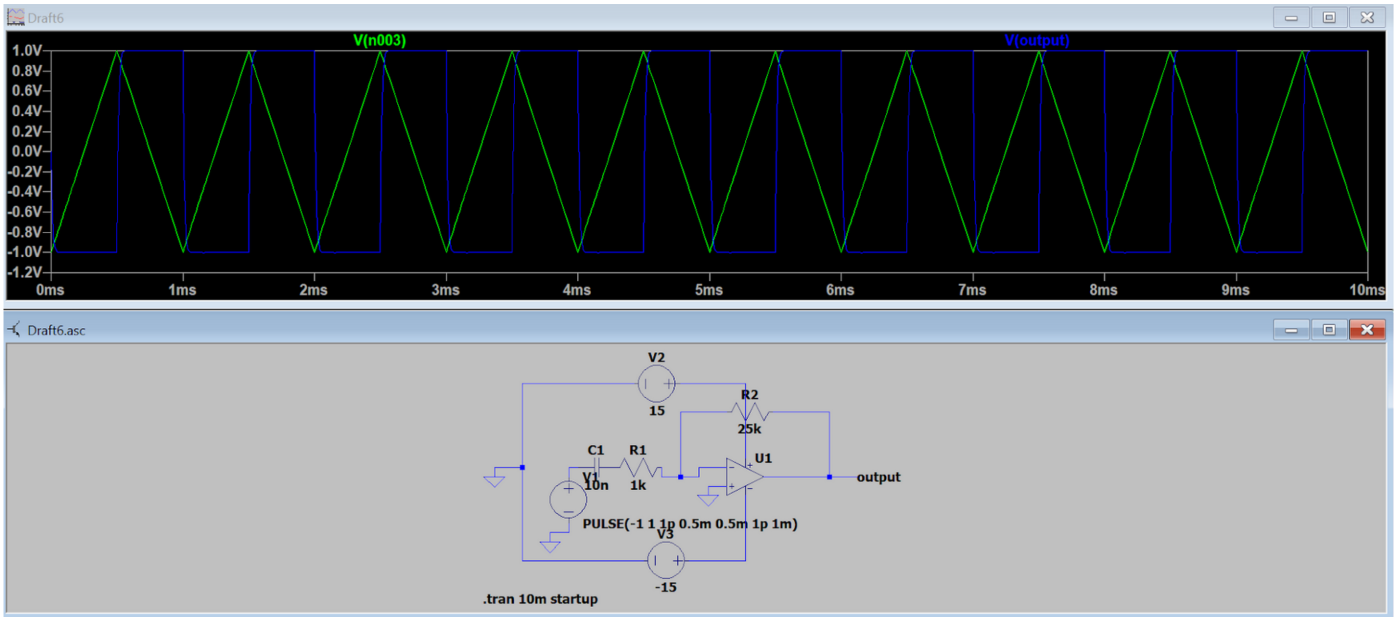
Step 1:-The input is excited with a periodic triangular waveform of frequency 1kHz and 1Vpeak.

Step 2:-The resistors 1k,25k ,and 10nC capacitors are connected as shown below.

Step 3:-Setting up the system in lt-spice by ading an universal amplifier with a bipolar supply of -+15V.

Step 4:Simulating the circuit as transient analysis for 10ms.

Outcome:-The output is differential of the input(square wave).



5.6 TASK 6 :First order active low pass filter with high voltage gain

Step 1:-The cutoff frequency is adjusted to 1kHz by considering the resistance as 159.235669Ω *and capacitance as*$1u$.

For extra ampilification two resistors are added as compared to Task 1 .The gain is

$$A = 1 + R_{NEW1}/R_{NEW2} \tag{2}$$

Taking the added resistors as $1\mathrm{k}\Omega each$.

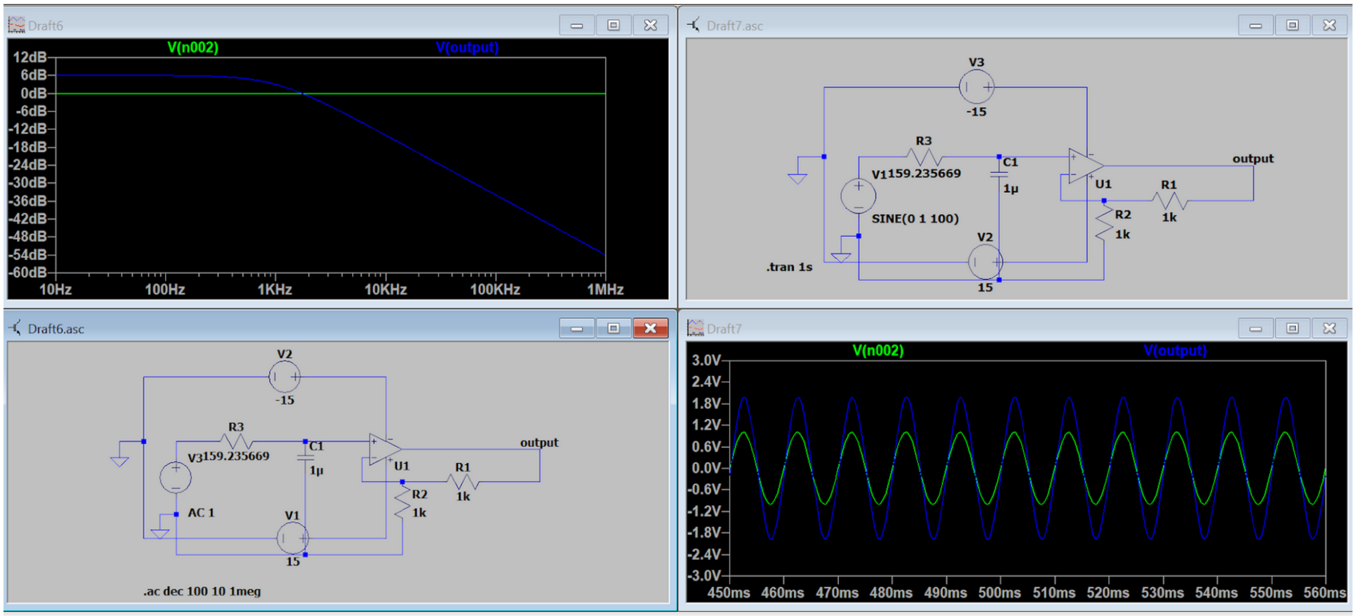
Step 2 :-The input is excited with a signal of having sinusoidal AC of frequency 100Hz and 1Vpeak .

Step 3:-Setting up the system in lt-spice by ading an inverted universal amplifier with a bipolar supply of -+15V.

Step 4:Simulating the circuit as transient analysis for 0.1s.

Step 5:Simulating the circuit in AC analysis to observe the circuit as the input frequency changes to obtain the gain plot by setting the frequency range from 10Hz to 1megHz.

Outcome:For frequency greater than the cutoff frequency the signal attenuates and frequency lesser than cutoff frequency the output signal amplifies by gain factor(twice) the input signal resulting in low-pass filter characteristics.



5.7 TASK 7 :First order active high pass filter with high voltage gain

Step 1:-The cutoff frequency is adjusted to 1kHz by considering the resistance as 159.235669Ω *and capacitance as*1*u*.

For extra ampilification two resistors are added as compared to Task 1 .The gain is

$$A = 1 + R_{NEW1}/R_{NEW2} \tag{3}$$

Taking the added resistors as 1kΩ*each*.

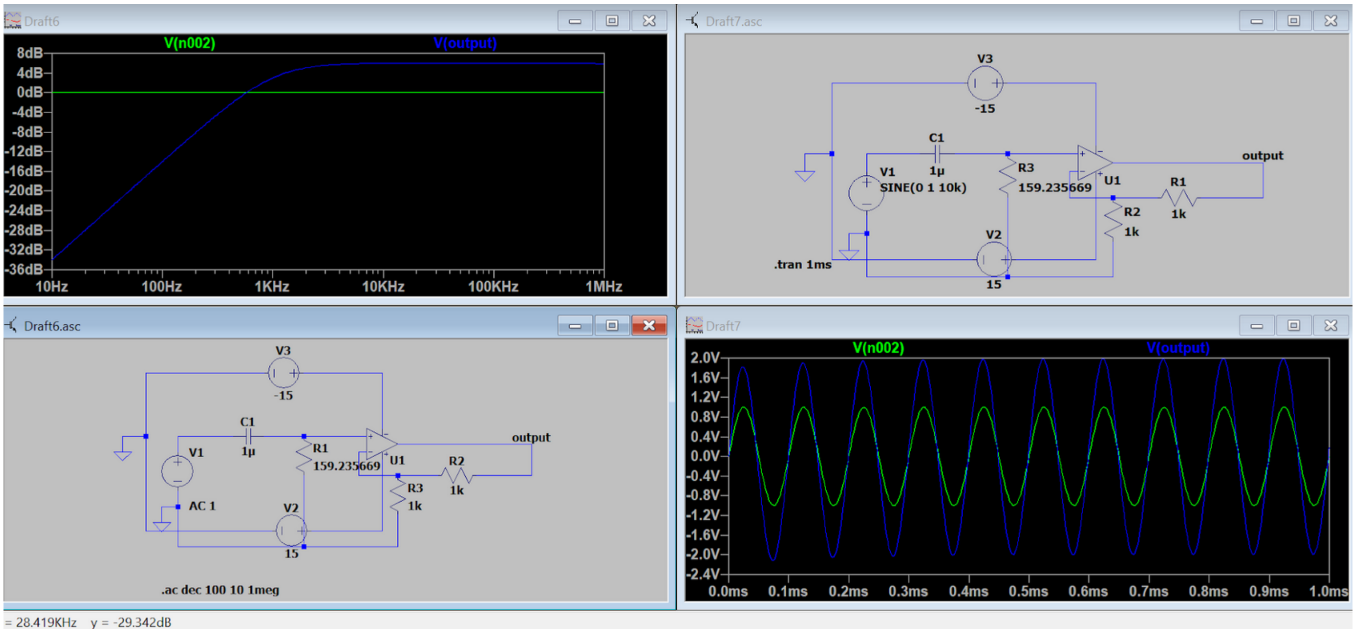
Step 2 :-The input is excited with a signal of having sinusoidal AC of frequency 10kHz and 1Vpeak .

Step 3:-Setting up the system in lt-spice by ading an inverted universal amplifier with a bipolar supply of -+15V.

Step 4:Simulating the circuit as transient analysis for 0.1s.

Step 5:Simulating the circuit in AC analysis to observe the circuit as the input frequency changes to obtain the gain plot by setting the frequency range from 10Hz to 1megHz.

Outcome:For frequency lesser than the cutoff frequency the signal attenuates and frequency greater than cutoff frequency the output signal amplifies by gain factor(twice) the input signal resulting in high-pass filter characteristics.



6 Conclusions

- Operatinal amplifiers are widely used in various ways by just tweaking basic circuits with resistors and capcitors in different ways.
- The circuit should satisfy the conditions such as to have large open-loop signal gain and have input impedance large with respect to values present in the feedback network.
- Selecting the correct resistors and capcitors is essential as they have to match the cutoff frequency of the input voltage.
- Sometimes resistors and capacitors are added to the circuit to reduce noise and decrease attenuation.

7 References

https://en.wikipedia.org/wiki/Operational$_{a}mplifier_{a}pplications$
$https : //www.electronicshub.org/active - low - pass - filter/$
$https : //www.electronicshub.org/active - high - pass - filter/$
$https : //www.electronics - tutorials.ws/opamp/opamp_{6}.html$
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