DEPARTMENT OF ELECTRONICS ANDCOMMUNICATIONENGINEERING

GOVERNMENT COLLEGE OF ENGINEERING KANNUR

LAB MANUAL
(2019 Scheme)

ANALOG INTEGRATED CIRCUITS AND SIMULATION LAB (ECL331)

ECL331	ANALOG INTEGRATED CIRCUITS AND SIMULATION LAB	CATEGORY	L	T	P	CREDIT
		PCC	0	0	3	2

Preamble: This course aims to (i) familiarize students with the Analog Integrated Circuits and Design and implementation of application circuits using basic Analog Integrated Circuits (ii)familiarize students with simulation of basic Analog Integrated Circuits.

Prerequisite: ECL 202 Analog Circuits and Simulation Lab

Course Outcomes: After the completion of the course the student will be able to

CO1	Use data sheets of basic Analog Integrated Circuits and design and implement application circuits using Analog ICs.
CO2	Design and simulate the application circuits with Analog Integrated Circuits using Simulation tools.
CO3	Function effectively as an individual and in a team to accomplish the given task.

Mapping of course outcomes with program outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO 10	PO 11	PO 12
CO1	3	3	3						2			2
CO2	3	3	3	2	3				2			2
CO3	2	2	2		2				3	2		3

Assessment

Mark distribution

Total Marks	**CIE**	**ESE**	**ESE Duration**
150	75	75	3hours

Continuous Evaluation Pattern

Attendance : 15marks

Continuous Assessment : 30marks

Internal Test (Immediately before the second series test) :30marks

End Semester Examination Pattern: The following guide lines should be followed regarding award of marks

(a) Preliminary work :15Marks
(b) Implementing the work/Conducting the experiment :10Marks
(c) Performance,resultandinference(usageofequipmentsandtroubleshooting) :25Marks
(d) Viva voce :20marks
(e) Record :5Marks

General instructions: End-semester practical examination is to be conducted immediately after the second series test covering entire syllabus given below. Evaluation is to be conducted under the equal responsibility of both the internal and external examiners. The number of candidates evaluated per day should not exceed 20. Students shall be allowed for the examination only on submitting the duly certified record. The external examiner shall end or set the record.

Course Level Assessment Question s(Examples only)

Course Outcome 1 (CO1): Use data sheets of basic Analog Integrated Circuits and design and implement application circuits using Analog ICs.

1. MeasureimportantopampparametersofµA741andcomparethemwiththedataprovidedinthedatasheet
2. Design and implement a variable timer circuit using op amp
3. Design and implement a filter circuit to eliminate 50Hz power line noise.

Course outcome 2 and 3 (CO2 and CO3): Design and simulate the application circuits with Analog Integrated Circuits using simulation tools.

1. Design a precision rectifier circuit using op amps and simulate it using SPICE
2. Design and simulate a counter ramp ADC

List of Experiments

I. Fundamentals of operational amplifiers and basic circuits [Minimum seven experiments are to be done]

1. Familiarization of Operational amplifiers - Inverting and Non inverting amplifiers, frequency response, Adder, Integrator, Comparators.
2. Measurement of Op-Amp parameters.
3. Difference Amplifier and Instrumentation amplifier.
4. Schmitt trigger circuit using Op–Amps.

5. Astable and Monostable multivibrator using Op-Amps.
6. Waveform generators using Op-Amps-Triangular and saw tooth
7. Wienbridge oscillator using Op-Amp-without &with amplitude stabilization.
8. RC Phase shift Oscillator.
9. Active second order filters using Op-Amp(LPF, HPF ,BPF and BSF).
10. Notch filters to eliminate the 50Hz power line frequency.
11. Precision rectifiers using Op-Amp.

II. Application circuits of **555 Timer/565 PLL/ Regulator(IC 723) ICs** [Minimum three experiments are to be done]

1. Astable and Monostable multivibrator using Timer ICNE555
2. DC power supply using IC 723: Low voltage and high voltage configurations, Short circuit and Fold-back protection.
3. A/D converters-counter ramp and flash type.
4. D/AConverters-R-2Rladdercircuit
5. Study of PLLIC: free running frequency lock range capture range

III. Simulation experiments [The experiments shall be conducted using SPICE]

1. Simulation of any three circuits from Experiments 3, 5, 6, 7, 8, 9, 10 and 11 of section I
2. Simulation of Experiments 3or4 from section II

Textbooks

1. D.Roy Choudhary,Shail BJain,"Linear Integrated Circuits,"
2. M.H.Rashid,"IntroductiontoPspiceUsingOrcadforCircuitsandElectronics",PrenticeHall

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DEPARTMENT MISSION

To impart knowledge in the field of Electronics and its related areas with afocus on developing the required competencies and virtues for the sustainable development of the society.

INSTRUCTIONS FOR PRACTICAL CLASSES

1. Note the position of supply main switch. This may be helpful in switching OFF the supply in case of an emergency.
2. In case of fire, use the fire extinguisher placed in the laboratories
3. When plugging an equipment, use both your hands and take out most care to avoid electrical shock. Make sure that the switch is OFF when plugging.
4. Run equipment like CRO, in the rated supply only. In case voltage levels exceed the limits, switch OFF them.
5. Make sure that the equipment is unplugged when removing fuse.

POINTS TO BE NOTED WHILE DOING EXPERIMENTS

1. Come thoroughly prepared in the lab. Preparation includes completing rough records, knowing the theory of the experiments and planning the experiments.
2. Test the components before connecting.
3. Double check the wired circuit before powering.
4. Read all relevant observations in your book. Quite of tenth evitable point is found to be ignored.
5. Complete calculations and get your rough record signed before the next lab class.
6. Submit completed fair records in every lab class.
7. Switch OFF all equipment and return the components before leaving the lab.

EXPERIMENT NO. 1

DATE: : -- / -- /----

FAMILIARIZATION OF BASIC OPERATIONAL AMPLIFIER CIRCUITS

AIM:

To familiarize the below basic operational amplifier circuits using µA741 op-amp IC

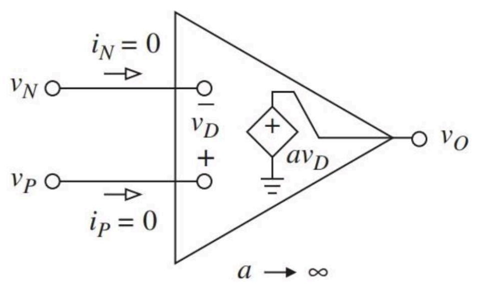
1 Inverting Amplifier (with a Closed Loop gain of 10)
2. Non-inverting Amplifier (with a Closed Loop gain of 11)
3. Voltage Follower
4. Summing Amplifier (For $v_O = -(2v_1 + 2v_2 + v_3)$)
5. Integrator (For frequencies above 100Hz)
6. Comparators

THEORY:

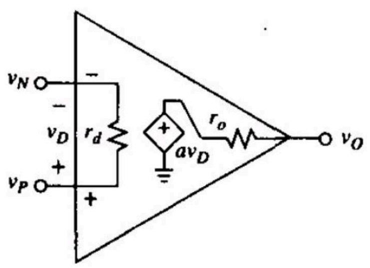
Operational Amplifier

An operational amplifier is a direct coupled, high gain amplifier consisting of one or more differential amplifiers followed by a level translator and an output stage. It is available as a single Integrated Circuit package.

It has two differential i/p terminals and one o/p terminal. The inputs, identified by the "−" and "+" symbols, are designated inverting and noninverting inputs respectively. Their voltages with respect to ground are denoted v_N and v_P, and the output voltage as v_O



Ideal op-amp model



Practical op-amp model

The ideal and practical equivalent circuits for an op-amp are given above.

In the absence of output loading, $\boldsymbol{v_O = a v_D = a(v_P - v_N)}$

Where a is the open loop gain of the op-amp.

Ideal characteristics of an Op-amp:

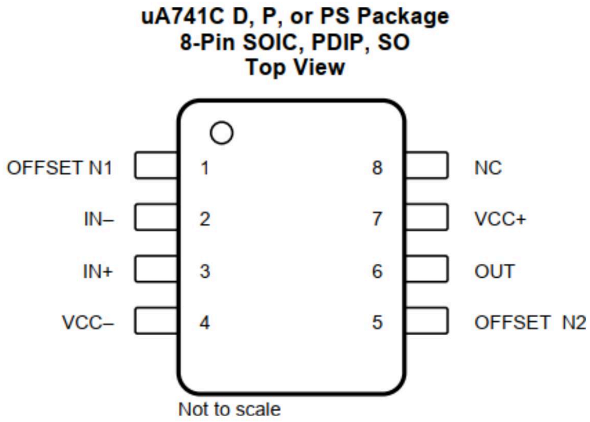
- Open loop voltage gain, $A_{OL} = \infty$
- i/p impedance, $R_i = \infty$
- o/p impedance, $R_o = 0$
- Bandwidth=∞
- Zero offset. i.e., $v_o = 0\ when\ v_P = v_N = 0$
- Ideal op amp draws no current at its i/p terminals, $i_P = i_N = 0$
- o/p voltage is independent of the current drawn from the circuit
- CMRR =∞
- Slew Rate=∞

µA741

The µA741 device is a general-purpose operational amplifier featuring offset-voltage null capability.

The high common-mode input voltage range and the absence of latch-up make the amplifier ideal for voltage-follower applications. The device is short-circuit protected and the internal frequency compensation ensures stability without external components. A low-value potentiometer may be connected between the offset null inputs to null out the offset voltage.

The µA741 device is specified for operation from ±5 to ±15 V; many specifications apply from 0°C to 70°C. It has a 0.5-V/µs slew rate.



Linear Op-amp circuits

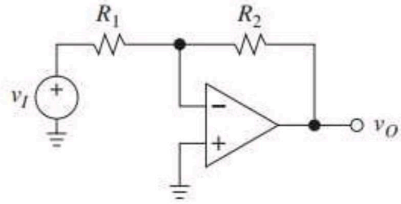
Linearity is achieved by using negative feedback to force the op amp to operate within its linear region AND Implementing the feedback network with linear elements

E.g. : Inverting and Non-inverting amplifiers, Buffer amplifiers, Instrumentation amplifiers etc.

Virtual Short

When operated with negative feedback, an ideal op amp will output whatever voltage and current it takes to drive v_D to zero or, equivalently, to force v_N to track v_P, but without drawing any current at either input terminal. Thus for voltage purposes the input port appears a short circuit & for current purposes the input port appears as an open circuit. Hence, it is referred to as a virtual short. This considerably simplifies the analysis of a ideal op-amp circuit with negative feedback.

Inverting Amplifier



Closed loop gain ,A=Vo/Vin =-$\left(\frac{R_2}{R_1}\right)$

Thus the circuit acts an inverting amplifier, with a 180° phase shift between output and

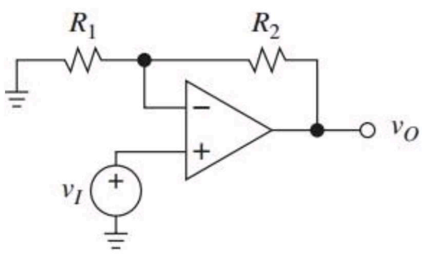
i.e., The closed loop gain A is independent of a, and its value is set exclusively by the external resistance ratio.

Input and Output Resistances of Inverting Amplifier are $R_i = R_1$; $R_o = 0$ (ideally)

Non-Inverting Amplifier

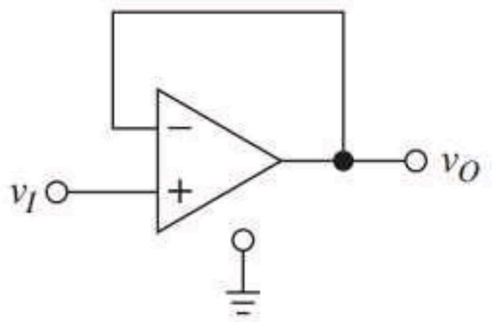
$$A_v = V_o / V_{in} = 1 + R_2 / R_1$$

Input and Output resistance of Non-inverting amplifier (ideally) are Ri= ∞(ideally) and Ro=0



Voltage Follower

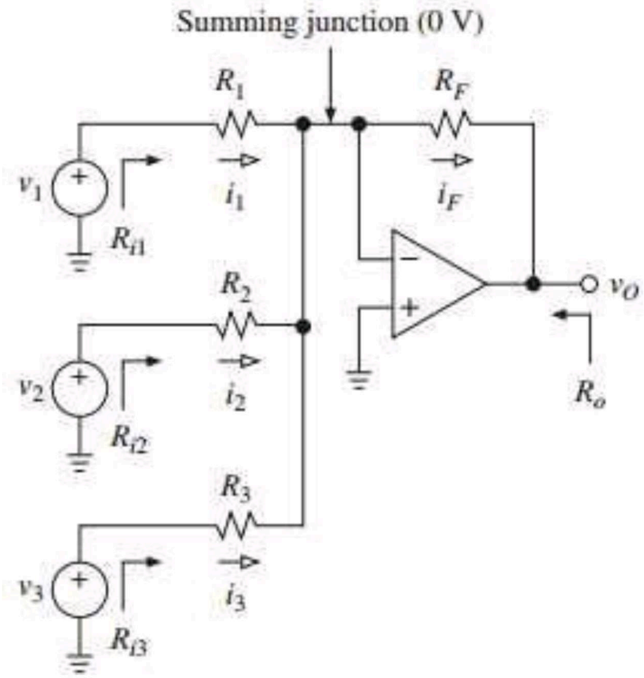
The voltage follower configuration of the operational amplifier is used for applications where a weak signal drives a relatively high current load. This circuit is also called a buffer amplifier or unity-gain amplifier. The inputs of an operational amplifier have a very high resistance which puts a negligible current load on the voltage source. The output resistance of the operational amplifier is almost negligible, so the resistance can provide as much current as necessary to the output load.



Letting $R_2 = 0$ & $R_1 = \infty$ in a Non-inverting amplifier gives us a unity gain amplifier (voltage follower). Its closed loop characteristics are, $A = 1V/V$; $R_i = \infty$; $R_o = 0$

i.e., it acts as a resistance transformer. The follower can act as a buffer between source and load. *i.e.*, to connect a source with a non-zero o/p resistance to a load circuit, without loading the source

Summing Amplifier



The summing amplifier has two or more inputs and one output. The output is a weighted sum of the inputs, with the weights being established by resistance ratios.

The above circuit shows an inverting summer with,

$$v_O = -\left(\frac{R_F}{R_1}.v_1 + \frac{R_F}{R_2}.v_2 + \frac{R_F}{R_3}.v_3\right)$$

Nonlinear op amp circuits:

Nonlinearity is either achieved by

1. Using positive feedback (or even no feedback at all), causing the op amp to operate primarily in saturation. E.g.: voltage-comparator and Schmitt-trigger

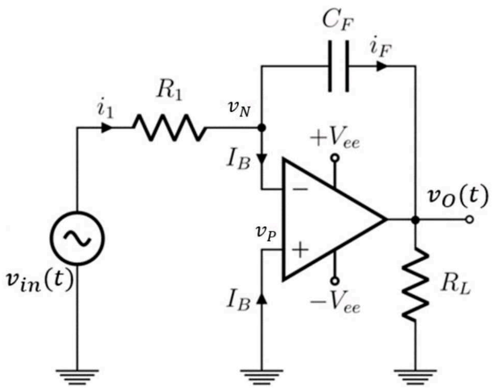
2. Implementing negative feedback network with nonlinear elements, such as diodes and analog switches. E.g.: precision rectifiers, peak detectors, logarithmic amplifiers etc.

Op-amp Integrator

The output voltage of an integrator is proportional to the integral of the input voltage.

Basic Integrator

Basic Op-amp Integrator is a basic inverting amplifier with the feedback resistor R_F replaced by a feedback capacitor C_F

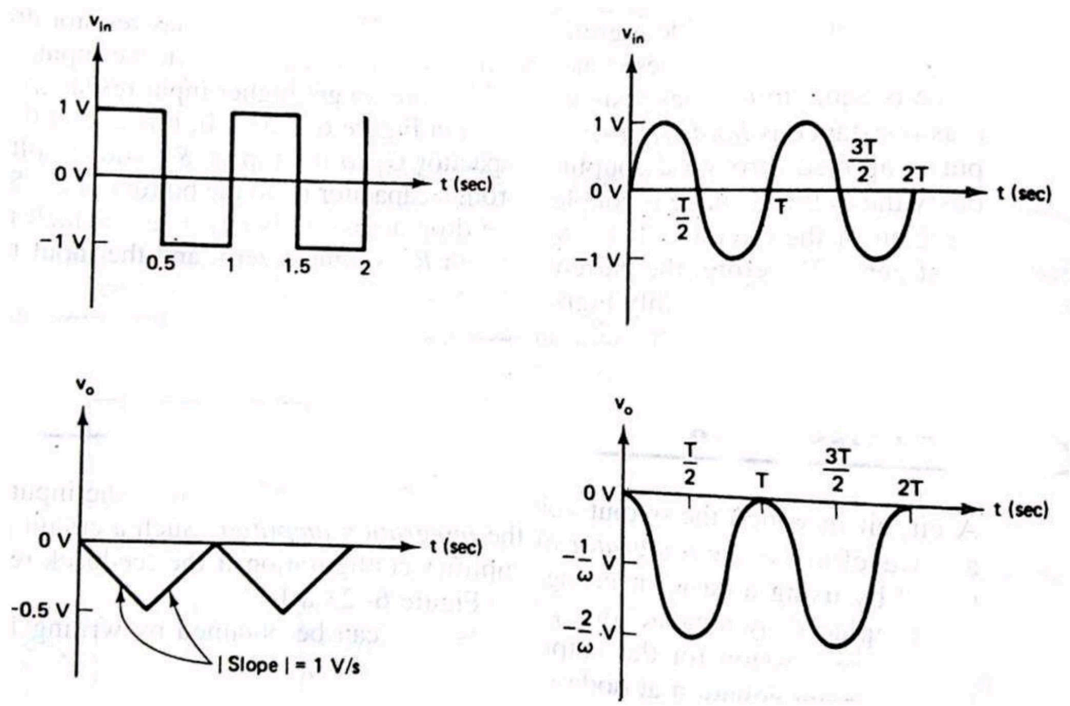


Basic Op-amp Integrator

Its output voltage is given by $v_0(t) = -\frac{1}{R_1 C_F}\int_0^t v_{in}(t)\,dt + v_O(0)$

Where $v_O(0)$ is the value of o/p voltage at $t = 0$

i.e., Its o/p voltage is proportional to the –ve integral of i/p voltage and inversely proportional to time constant $R_1 C_F$



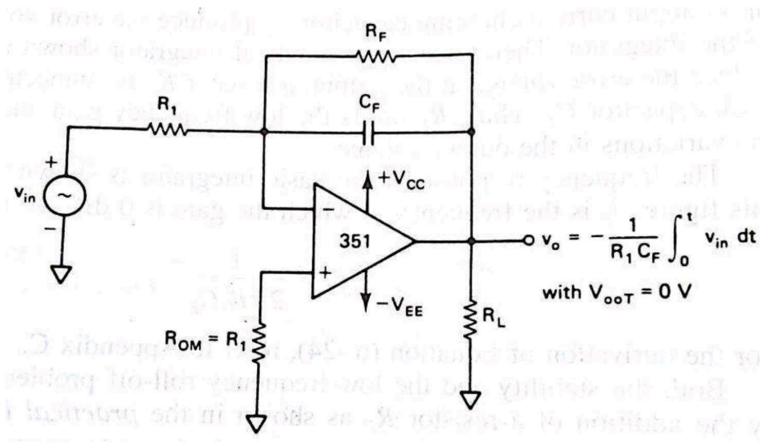
Input and output waveforms for basic op-amp integrator(*Assuming* $R_1C_F = 1s$ *&* $v_O(0) = 0V$)

<u>For basic integrator</u>:

Unity-gain frequency (frequency at which gain is 0dB) is $f_b = \frac{1}{2\pi R_1 C_F}$

Practical integrator:

When $v_{in} = 0$, the basic integrator circuit acts as an open loop amplifier since C_F acts as an open circuit to the i/p offset voltage V_{io}. i.e., the i/p offset voltage V_{io} & the part of the i/p current charging the capacitor C_F produce the error voltage at the o/p of the integrator. Therefore, in a practical integrator, a resistor R_F is connected across C_F to reduce this error voltage. R_F limits the low frequency gain and hence minimizes the variations on the o/p voltage.



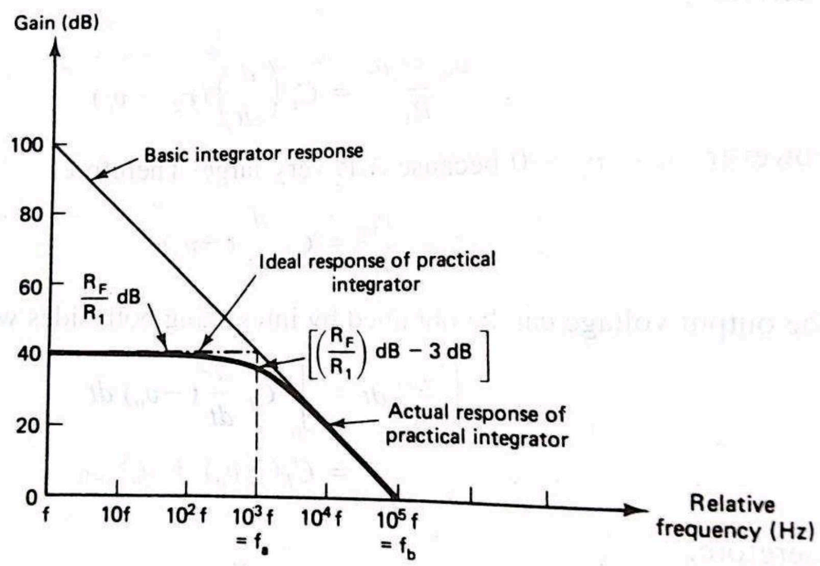
Practical Op-amp Integrator

The gain limiting frequency of the practical integrator is given by $f_a = \frac{1}{2\pi R_F C_F}$

<u>Frequency Response of a practical integrator</u>:

- For i/p frequencies up to f_a the gain is a constant at R_F/R_1
- After f_a the gain decreases at -20dB/decade
- At $f_b = \frac{1}{2\pi R_1 C_F}$, the gain is unity

i.e., The practical integrator circuit acts as an integrator for frequencies well above f_a



Frequency response of basic & Practical integrators

Design Considerations for a practical opamp integrator:

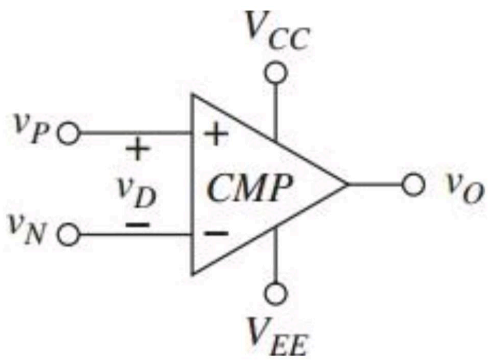
- f_a should be < f_b . Select $R_F C_F$ & $R_1 C_F$ accordingly
- If f_a & f_b are chosen such that $f_a = \frac{f_b}{10}$. Then $R_F = 10R_1$

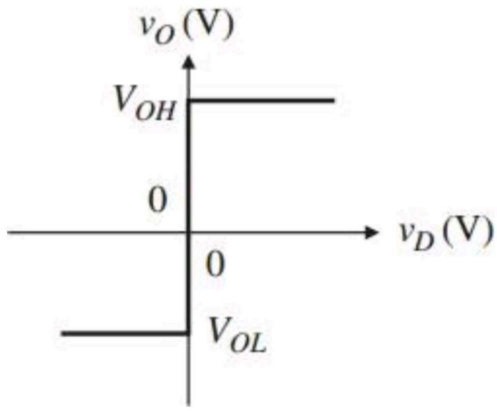
Comparator

A voltage comparator Compares the voltage v_P at one of its inputs against the voltage v_N at the other, and outputs either a low voltage, V_{OL} or a high voltage, V_{OH} according to,

$$\boldsymbol{v_O = V_{OL}} \textbf{ for } \boldsymbol{v_P < v_N}$$

$$\boldsymbol{v_O = V_{OH}} \textbf{ for } \boldsymbol{v_P > v_N}$$





Ideal Voltage transfer curve(VTC) of a comparator

In terms of the differential i/p voltage, $v_D = v_P - v_N$,

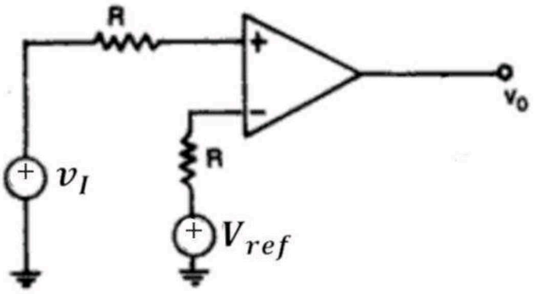
$v_O = V_{OL}$ for $v_D < 0V$

$v_O = V_{OH}$ for $v_D > 0V$

When speed is not critical, an op-amp can make an excellent comparator

741 is internally compensated. Hence, It used as a comparator, its primary limitation is its slew-rate ($0.5V/\mu s$). For $\pm 15V$ supply, it takes $2 \times \frac{13}{0.5} \cong 50\mu s$ to swing between saturation voltages which may be too long for some applications. For improved response-time, uncompensated op-amps(like 301) can be used for comparator applications

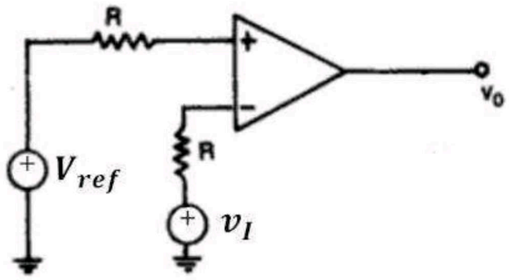
Non-inverting Op-amp Comparator



$$v_O = -V_{sat} \text{ for } v_I < V_{ref}$$

$$v_O = +V_{sat} \text{ for } v_I > V_{ref}$$

Inverting Op-amp Comparator



$$v_O = -V_{sat}\, for\, v_I > V_{ref}$$

$$v_O = +V_{sat}\, for\, v_I < V_{ref}$$

DESIGN:

- **Inverting Amplifier**

  Assuming ideal op-amp, $A_{ideal} = \lim_{a\to\infty} A = -\frac{R_2}{R_1}$

  $A = 10$(given)

  Choose $R_1 = 10k\Omega, \Rightarrow R_2 = 100k\Omega$

- **Non-inverting Amplifier**

Assuming ideal op-amp, $A_{ideal} = \lim_{a\to\infty} A = 1 + \frac{R_2}{R_1}$

$A = 11$(given)

Choose $R_1 = 10k\Omega, \Rightarrow R_2 = 100k\Omega$

❖ Voltage Follower

Let $R_2 = 0$ & $R_1 = \infty$ in the Non-inverting amplifier to get the voltage follower

❖ Summing Amplifier

Choose $R_F = 20k\Omega$

We want $v_O = -(2v_1 + 2v_2 + v_3)$

$\Rightarrow R_1 = 10k\Omega, \qquad R_2 = 10k\Omega, \qquad R_3 = 20k\Omega$

❖ Integrator

For the practical integrator circuit:

$f_a = \frac{1}{2\pi R_F C_F}$ and $f_b = \frac{1}{2\pi R_1 C_F}$

Choose $f_a = 100Hz$; $f_b = 10 \times f_a = 1kHz$

Let $C_F = 0.1\mu F \Rightarrow R_1 = \frac{1}{2\pi f_b C_F} = \frac{1}{2\pi\times 1k\times 0.1\mu} = 1591.5\Omega$; Take 1.5$k\Omega$

$R_F = 10R_1 = 15k\Omega$

$R_{comp} = R_1||R_F = 1.3k\Omega$

Expected output $v_0(t) = -\frac{1}{R_1 C_F}\int_0^t v_{in}(t)\,dt = -6666.7\int_0^t v_{in}(t)\,dt$

❖ Comparator

- Non-inverting Comparator: Choose $R = 10k\Omega$
- Inverting Comparator: Choose $R = 10k\Omega$

PROCEDURE:

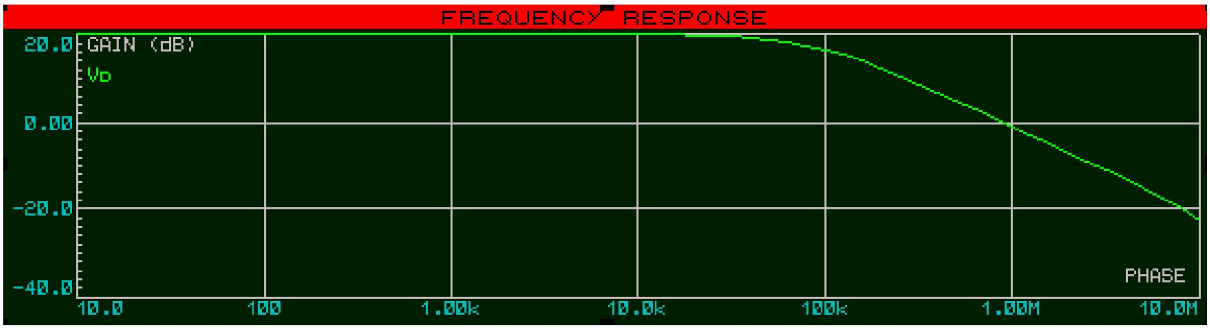
Common Steps:

- Set up the circuit as per the given circuit diagram
- Provide +15V and –15V supply to the 7^{th} and 4^{th} pins of the Op-Amp IC respectively

❖ Inverting Amplifier

- Give a 1Vpp sine wave with 1KHz frequency as the input
- Observe input and output waveforms on the two channels of the CRO simultaneously
- Note down the amplitude of the output wave and verify the CL gain
- Verify that the output and input have a 180° phase shift
- Repeat the experiment with sine waves of different frequency keeping the input amplitude the same. Observe the output amplitudes and plot the frequency response

Expected Frequency Reponse for the Designed Inverting Amplifier:

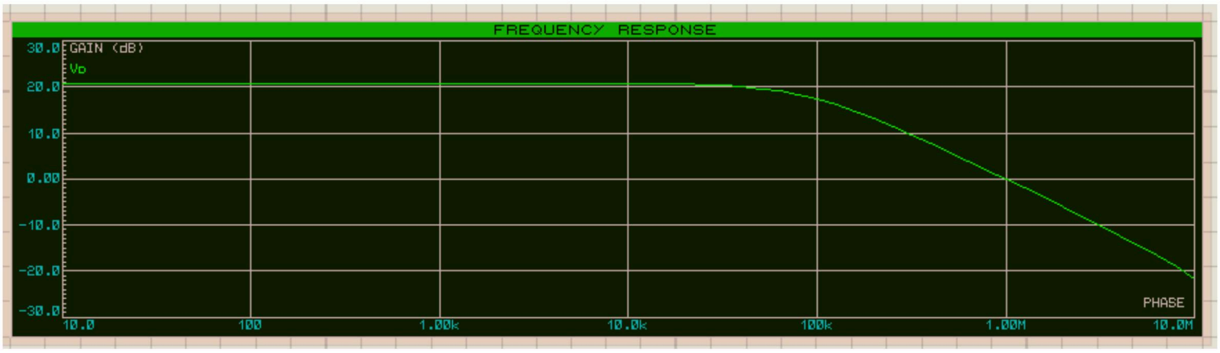


❖ Non-inverting Amplifier

- Give a 1 Vpp sine wave with 1KHz frequency as the input
- Observe input and output waveforms on the two channels of the CRO simultaneously
- Note down the amplitude of the output wave and verify the CL gain

- Verify that the output and input are in phase
- Repeat the experiment with sine waves of different frequency keeping the input amplitude the same. Observe the output amplitudes and plot the frequency response

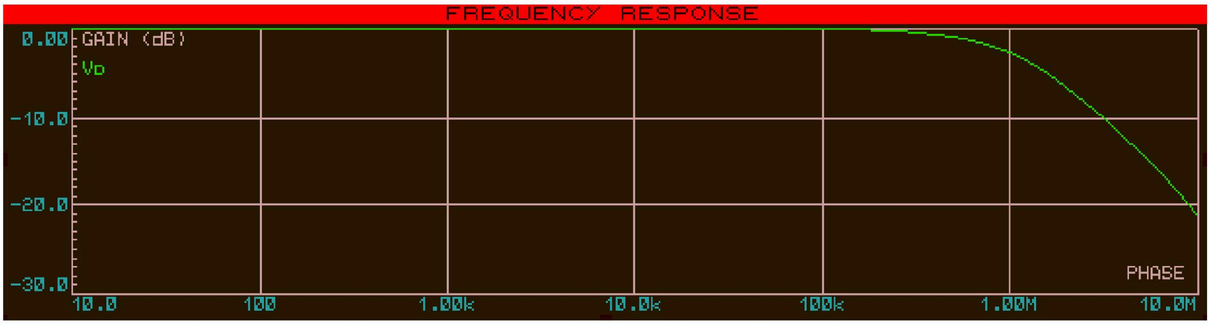
<u>Expected Frequency Reponse for the Designed Non-Inverting Amplifier:</u>



❖ **Voltage Follower**

- Give a 1 Vpp sine wave with 1KHz frequency as the input
- Observe input and output waveforms on the two channels of the CRO simultaneously
- Note down the amplitude of the output wave and verify the unity voltage gain
- Verify that the output and input are in phase
- Repeat the experiment with sine waves of different frequency keeping the input amplitude the same. Observe the output amplitudes and plot the frequency response

Expected Frequency Reponse for the Voltage Follower



❖ Summing Amplifier

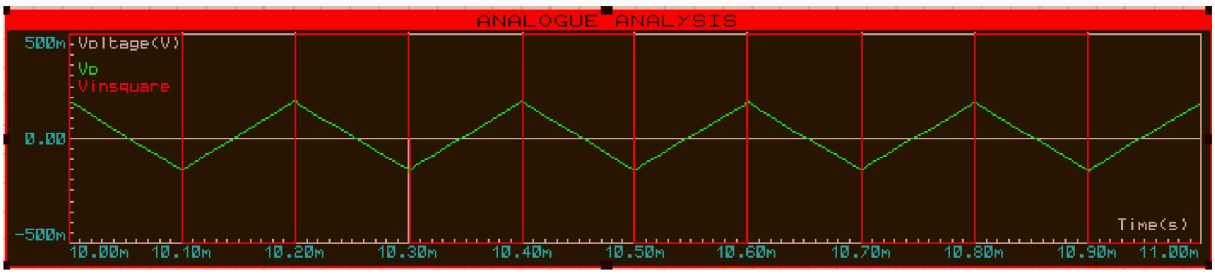
- Give $v_1 = +2V$, $v_2 = +1V$ and $v_3 = -0.5V$ (All dc voltages)
- Expected value of $v_O = -(2v_1 + 2v_2 + v_3) = -(2 \times 2 + 2 \times 1 - 0.5) = -5.5V$ dc
- Measure the output voltage v_O and verify that it is $-5.5V$

❖ Integrator

- Expected output $v_0(t) = -\frac{1}{R_1 C_F}\int_0^t v_{in}(t)\,dt = -6666.7\int_0^t v_{in}(t)\,dt$
- Give a $\pm 1V$ square wave (50% duty cycle, $V_m = 0.5V$) with $5kHz$ frequency as the input

  - For $v_{in} = \pm 1V, 5kHz$ square wave: Area in positive half cycle= 5×10^{-5}
  - output will be triangular with, $v_O(pp) = 6666.7 \times 5 \times 10^{-5} = 0.333V$
  - Hence expected output will be triangular with, $v_O(pp) = 6666.7 \times 5 \times 10^{-5} = 0.333V$

Expected Waveforms



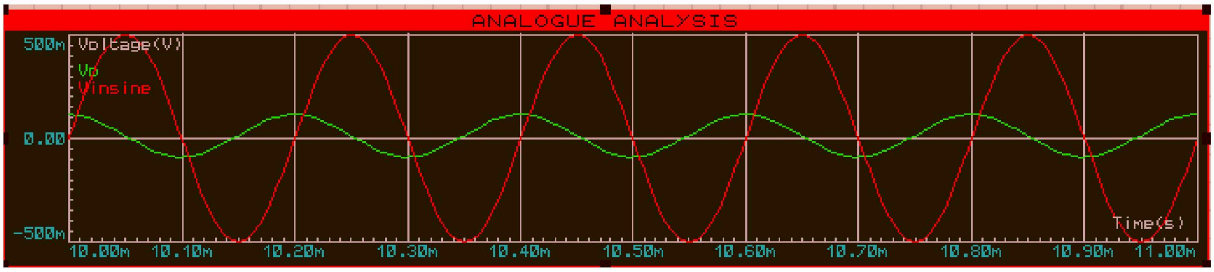
- Observe the output wave form on the CRO and plot it down. Note the peak-to-peak amplitude, slope and timings of the observed triangular waveform

- Give a $\pm 1V$ sine wave with $5kHz$ frequency as the input and observe the output wave form on the CRO and plot it down
    - $v_0(t) = -6666.7 \int_0^t \sin(2\pi \times 5000t)\, dt = -\frac{6666.7}{10000\pi}[\cos(2\pi \times 5000t) - 1]$

$$= 0.212\,[\cos(2\pi \times 5000t) - 1]$$

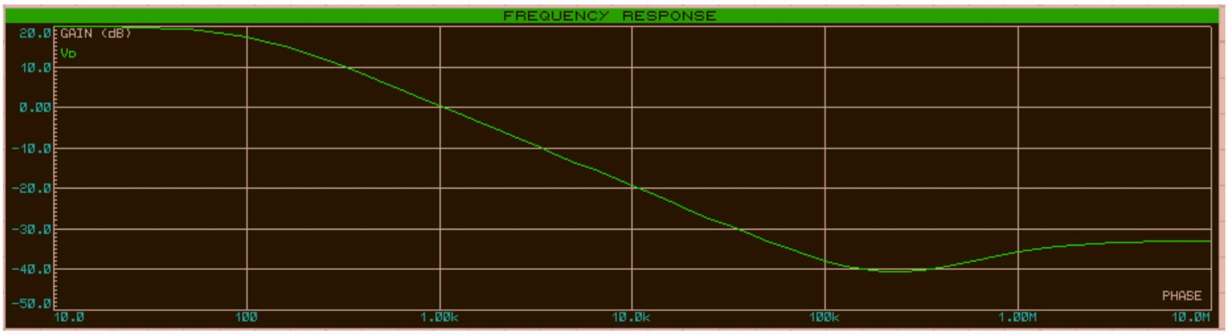
    - Hence expected output will be a cosine wave with, $v_O(pp) = 0.212V$

<u>Expected Waveforms</u>



- Using the sine-wave input and varying the input frequency from $100Hz$ to $1MHz$ plot the frequency response of the circuit

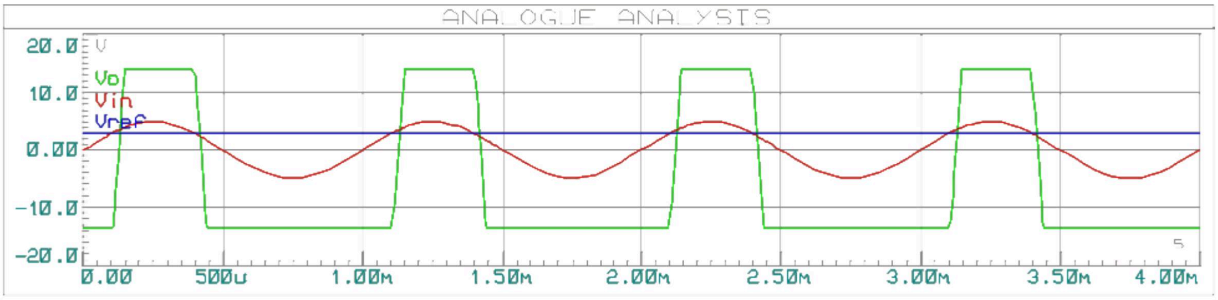
<u>Expected Frequency Response</u>



- **Comparators**
    - Set up the Non-inverting Comparator circuit

- Give $V_{ref} = 3V$. Note down the output voltages for different dc voltage levels at V_I (for $V_I > 5V$ and $V_I < 5V$)
- Give a sine wave with $1kHz$ frequency and $5V$ amplitude at V_I. Note the amplitudes and timings of the output waveform and plot it down.

<u>Expected waveforms for non-inverting comparator</u>



- Repeat the steps for the inverting comparator circuit as well.

Observations:

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Results:

The below basic operational amplifier circuits were designed and setup using µA741 The input and output waveforms and frequency responses were observed, plotted and verified.

1 Inverting Amplifier (with a Closed Loop gain of 10)
2. Non-inverting Amplifier (with a Closed Loop gain of 11)
3. Voltage Follower
4. Summing Amplifier (For $v_O = -(2v_1 + 2v_2 + v_3)$)
5. Integrator (For frequencies above 100Hz)
6. Comparators