DELHI TECHNOLOGICAL UNIVERSITY

SUBJECT- Analog Electronics-II (EC202)

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(2K19/EC/006) (2K19/EC/022)

ANALOG ELECTRONICS - II INNOVATIVE PROJECT REPORT

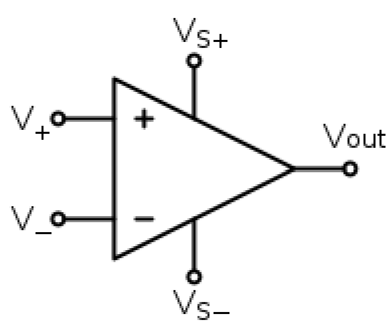
AIM- Understanding *applications of Op-Amp using simulation in LTSpice.*

THEORY-

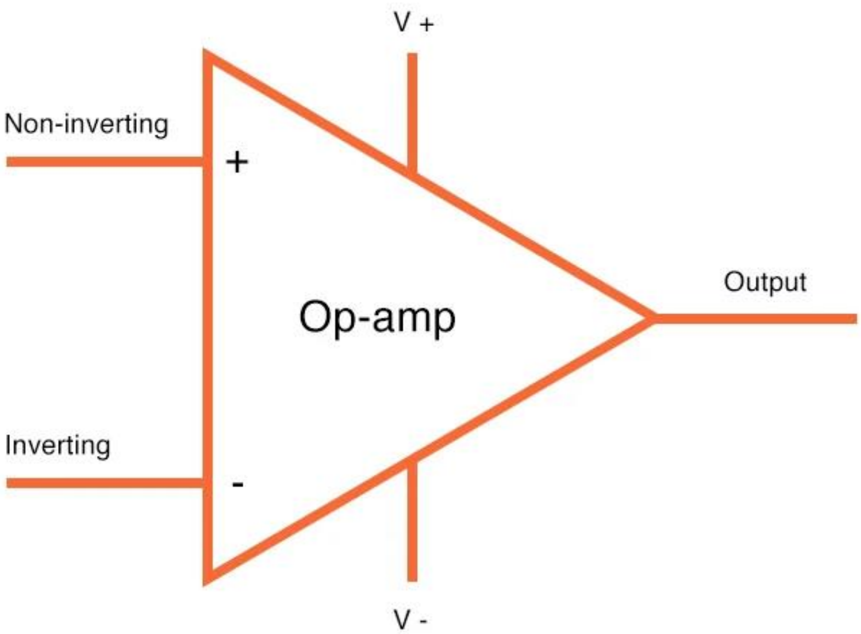
Op-Amp (operational Amplifier)

As and the basic job of any amplifier is to simply amplify the input signal

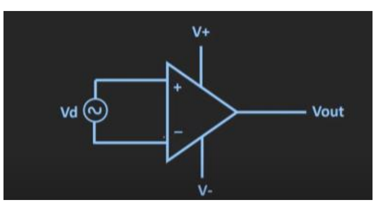
Now why do an Op-Amp is known as operational Amplifier as in earlier days when digital computers were not involved mathematical functions like – Add,Subtract,integration,differentiation were performed using this operational Amplifier just by connecting resistors an capacitors



There are 2 inputs ,1 outputs , most of opam consist of 2 power supply(positive and negative) but there are many opam ic available which run on single power supply



Now suppose taking input signal Vd between +ve (Non-Inverting) and –ve(Inverting) terminal



As gain of Op-Amp is in range 10^5 -10^6

Vout = open loop gain *difference between input signals = A*Vd

So, when taking Vd= 1mV

Vout= 1m* 10^5 (assuming gain (A) to be 10^5)

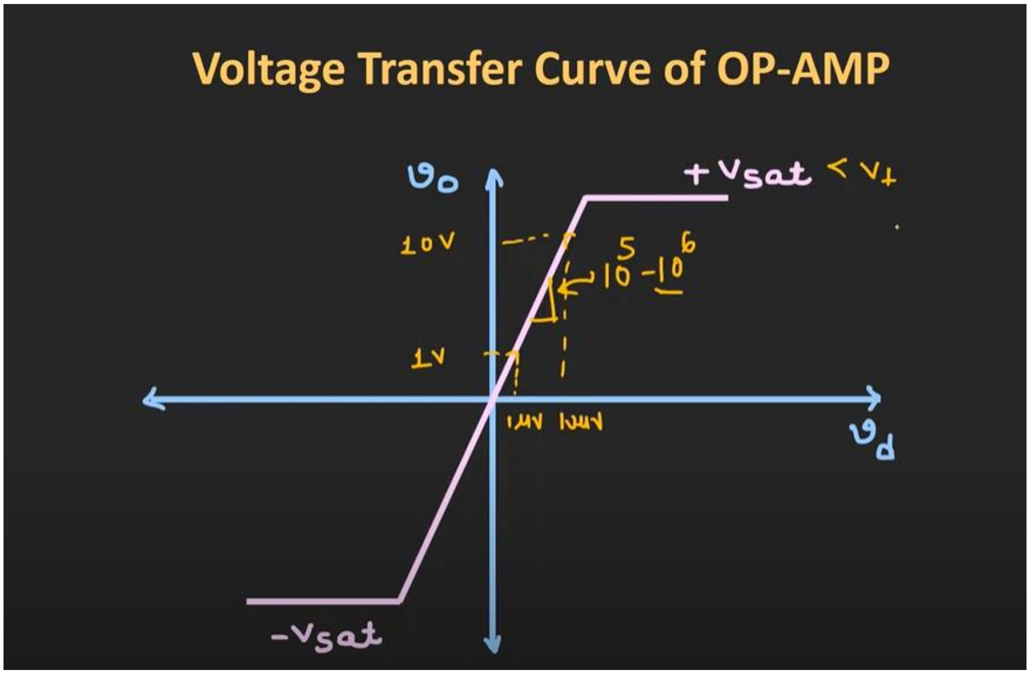
Vout = 100 v

Now , when taking Vd= 1V

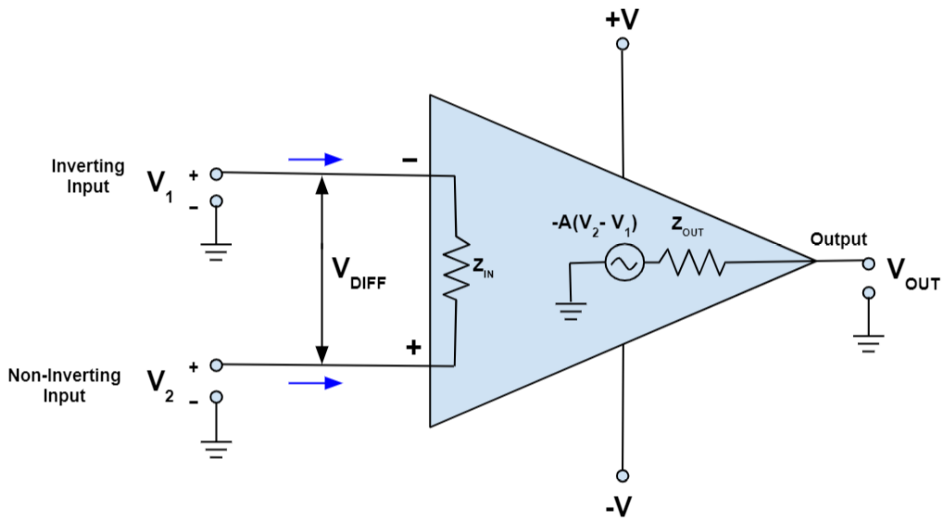
Vout= 1* 10^5 (assuming gain (A) to be 10^5)

Vout = 10^5 v

Which is not possible as the output of the Op-Amp is restricted by the biasing voltages applied to opamp



Internal circuit of opamp



Zin- input impedence

Zout- output impedence

Vout- open loop gain *difference between input signals = A*V_{DIFF}

Characterstics of ideal Op-Amp

Zin- 0

Zout- 0

Gain- infinity

Bandwidth- infinity

Slew rate- infinity

CMMR- infinity

1. **Op-Amp as Differentiator -**

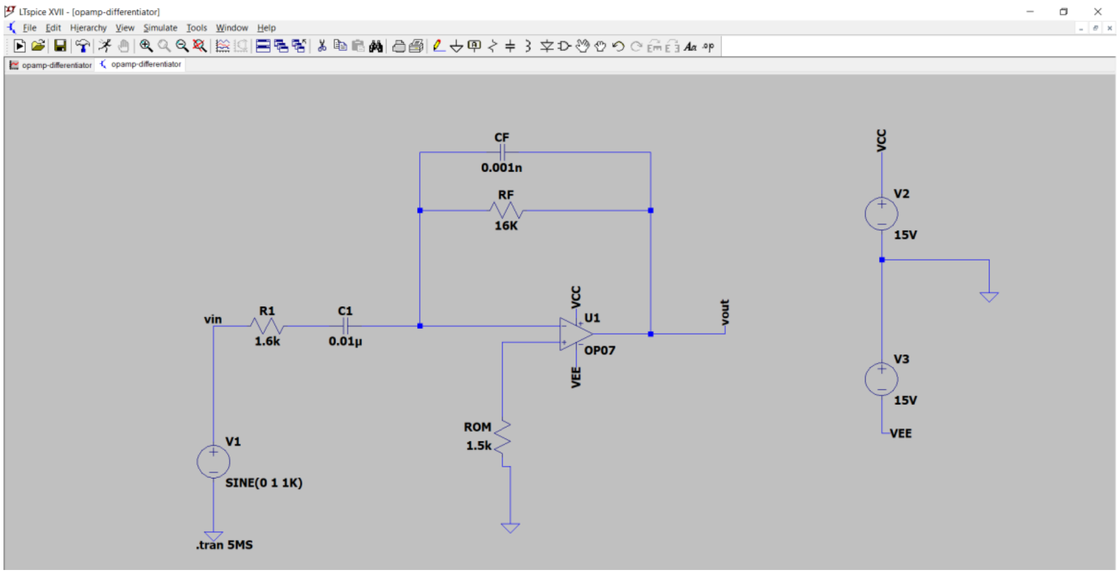
- **Introduction**

This operational amplifier circuit performs the mathematical operation of **Differentiation**, that is it "*produces a voltage output which is directly proportional to the input voltage's rate-of-change with respect to time* ". In other words, 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.

Limitation of ideal Op-Amp as differentiator

1. Frequency increases input impendence reduce
2. Very sensitive to high frequency noice

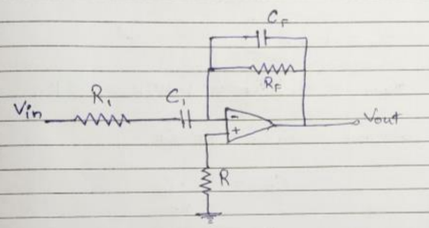
Op-amp Differentiator Circuit



The input signal to the differentiator is applied to the capacitor. At low frequencies the reactance of the capacitor is “High” resulting in a low gain (Rƒ/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. However, at high frequencies an op-amp differentiator circuit becomes unstable and will start to oscillate. This is due mainly to the first-order effect, which determines the frequency response of the op-amp circuit causing a second-order response which, at high frequencies gives an output voltage far higher than what would be expected. To avoid this the high frequency gain of the circuit needs to be reduced by adding an additional small value capacitor across the feedback resistor Rƒ.

Calculations

Differentiator



Differentiator:- Produces a voltage which is directly proportional to the rate of change of input voltage

$$V_{out} = -R_F \cdot C_1 \left(\frac{d V_{in}}{dt}\right)$$

Calculation ->

Taking $f_a = 1KHz$, $f_b = 10KHz$

Assuming $C_1 = 0.01\mu F$

As $f_a = \frac{1}{2\pi R_F C_1}$, so $R_F = \frac{1}{2\pi R C_1 f_a}$

$\boxed{R_F = 15.91 K\Omega \approx 16 K\Omega}$

$f_b = \frac{1}{2\pi R_1 C_1}$, $R_1 = \frac{1}{2\pi f_b C_1}$

$\boxed{R_1 = 1.6 K\Omega}$

$R_{om} = R_1 || R_F = 1.45K \approx 1.5 K\Omega$

Assume $R_1 C_1 = R_F C_F$

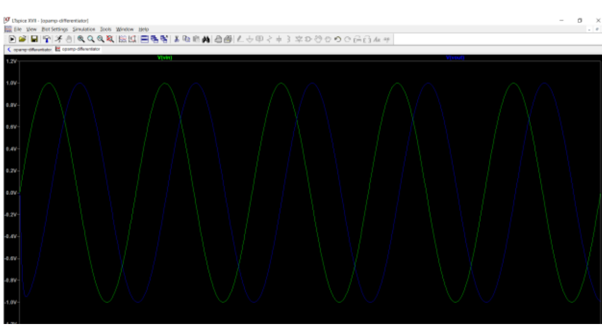
$$C_F = \frac{R_1 \cdot C_1}{R_F}$$

$\boxed{C_F = 0.001 nF}$

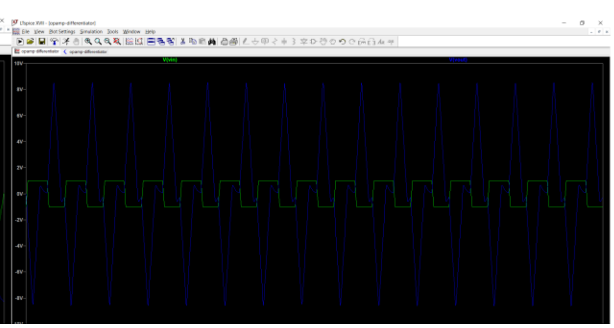
Simulation Results

- *Transient analysis*

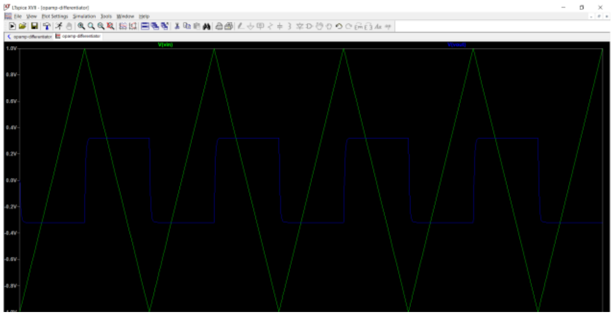
Input as a sine wave



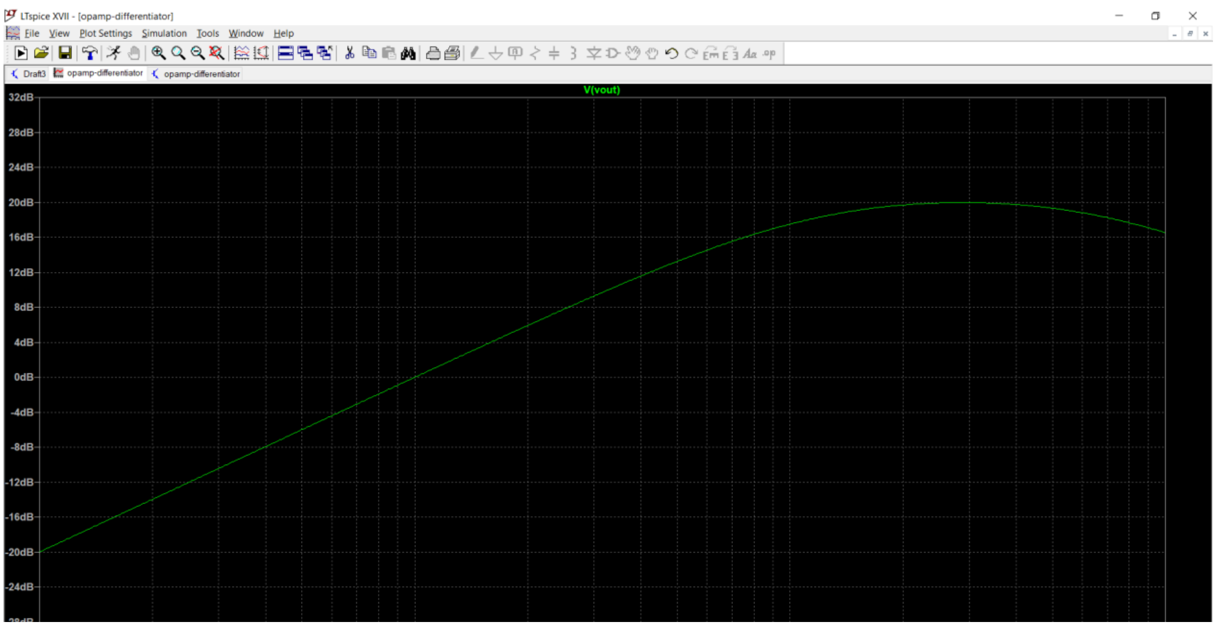
Input as a square wave



Input as a triangular wave



- *Frequency Response*



Observations Table

Observation Table for Differentiator

S. No	Vin	Rin (Ω)	RF (Ω)	C_1 F	C_F F	Frequency (Hz)	Vout (V)	Gain (AV)	Gain (dB)
1						100	0.097	0.097	-20.158
2						300	0.291	0.291	-10.538
3						500	0.485	0.485	-6.122
4						700	0.699	0.699	-3.125
5						900	0.893	0.893	-0.917
6						1K	1.010	1.010	0.028
7	2V	1.6K	16K	0.01	0.1	2K	1.981	1.981	5.706
8				nF	µF	3K	2.932	2.932	9.491
9						4K	3.786	3.786	11.541
10						5K	4.641	4.641	13.276
11						7K	6.000	6.000	15.642
12						10K	7.534	7.534	17.534
13						15K	9.010	9.010	18.323
14						20K	9.650	9.650	19.742

Result

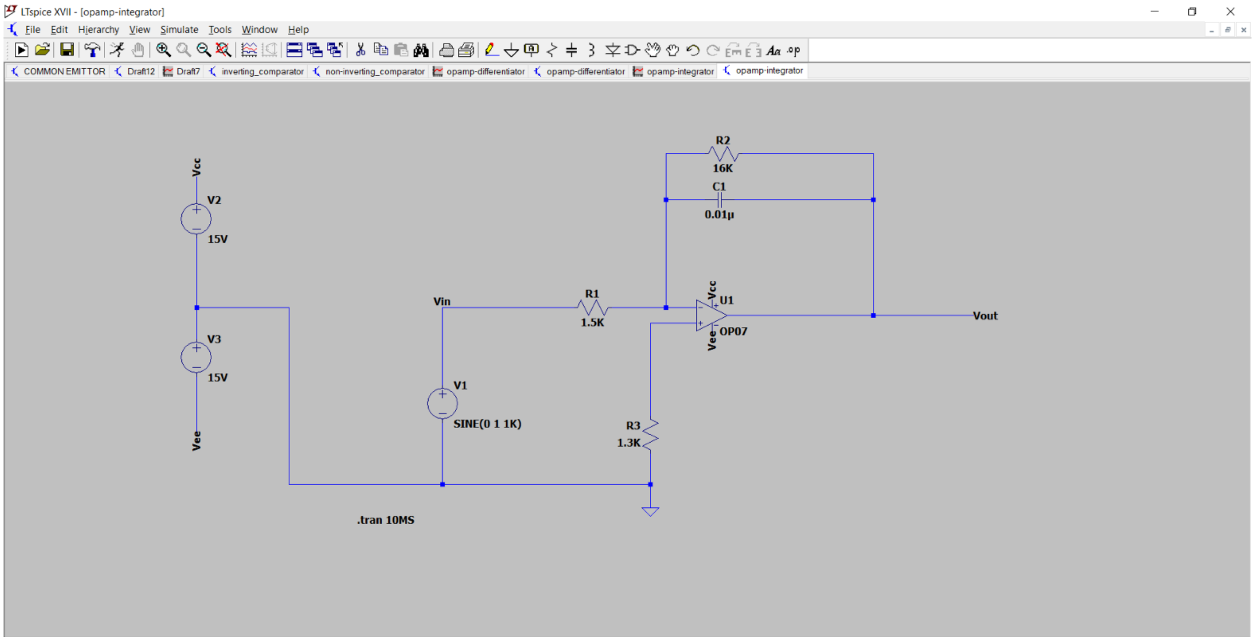
So from the above table we can verify that the frequency vs gain (db) wave is similar to the outputs which we have calculated manually.

2. Op-Amp as Integrator -

○ Introduction

As its name implies, the **Op-amp Integrator** is an operational amplifier circuit that performs the mathematical operation of **Integration**, that is we can cause 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*.

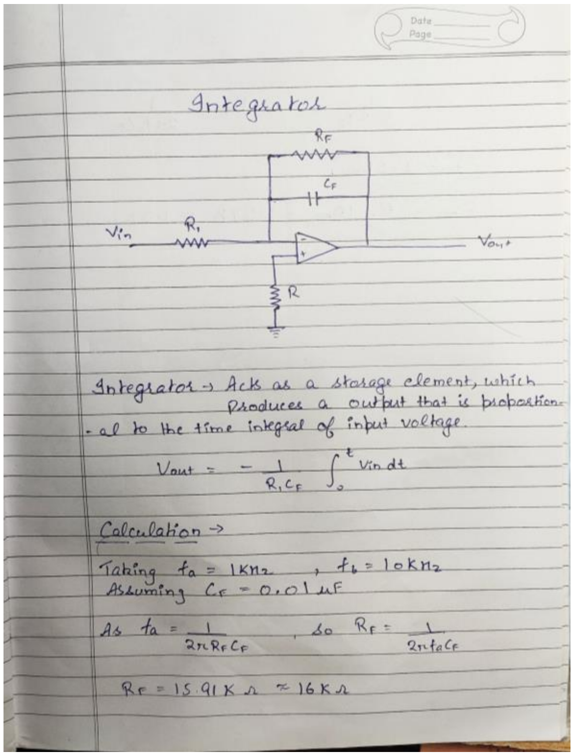
Op-Amp Integrator circuit



If we changed the above square wave input signal to that of a sine wave of varying frequency the **Op-amp Integrator** performs less like an integrator and begins to behave more like an active "Low Pass Filter", passing low frequency signals while attenuating the high frequencies. At zero frequency (0Hz) or DC, the capacitor acts like an open circuit due to its reactance thus blocking any output voltage feedback. As a result very little negative feedback is provided from the output back to the input of the amplifier. Therefore with just a single capacitor, C in the feedback path, at zero frequency the op-amp is effectively connected as a normal open-loop amplifier with very high open-loop gain. This results in the op-amp becoming unstable cause undesirable output voltage conditions and possible voltage rail saturation. The result is at high frequencies the capacitor shorts out this feedback resistor, R_2 due to the effects of capacitive reactance reducing the amplifiers gain. At normal operating frequencies the circuit acts as an standard integrator, while at very low frequencies approaching 0Hz, when C becomes open-circuited due to its reactance, the magnitude of the voltage gain is limited and controlled by the ratio of: R_2/R_1.

Unlike the DC integrator amplifier above whose output voltage at any instant will be the integral of a waveform so that when the input is a square wave, the output waveform will be triangular. For an AC integrator, a sinusoidal input waveform will produce another sine wave as its output which will be 90° out-of-phase with the input producing a cosine wave.

Calculations


Integrator

R_F, C_F, R_1, V_{in}, V_{out}, R

Integrator → Acts as a storage element, which produces a output that is proportional to the time integral of input voltage.

$$V_{out} = -\frac{1}{R_1 C_F}\int_0^t V_{in}\,dt$$

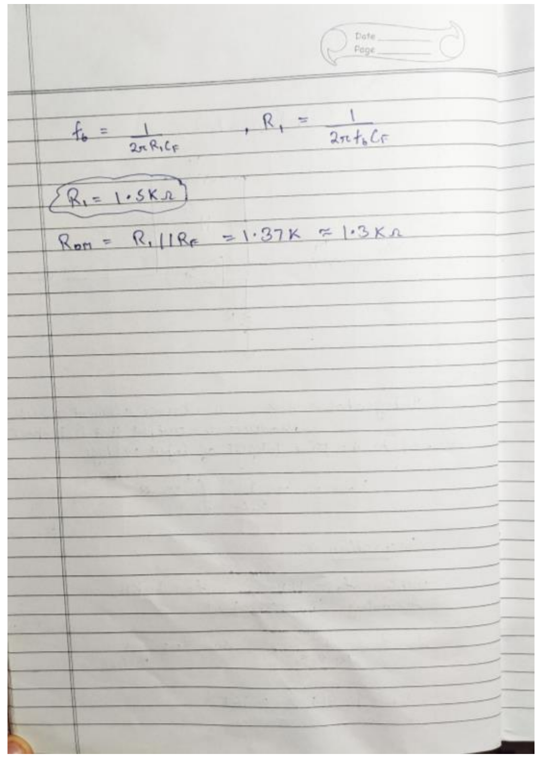
Calculation →

Taking $f_a = 1\,KHz$, $f_b = 10\,KHz$

Assuming $C_F = 0.01\,\mu F$

As $f_a = \frac{1}{2\pi R_F C_F}$, so $R_F = \frac{1}{2\pi f_a C_F}$

$R_F = 15.91\,K\Omega \approx 16\,K\Omega$


$f_b = \frac{1}{2\pi R_1 C_F}$, $R_1 = \frac{1}{2\pi f_b C_F}$

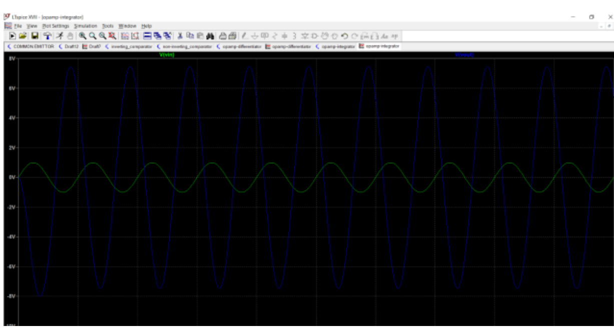
$\boxed{R_1 = 1.5\,K\Omega}$

$R_{om} = R_1 \| R_F = 1.37\,K \approx 1.3\,K\Omega$

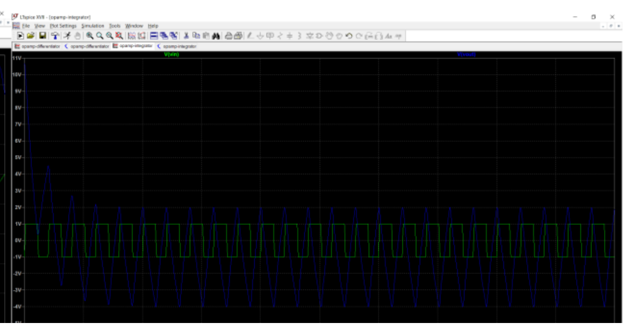
Simulation Results

- *Transient analysis*

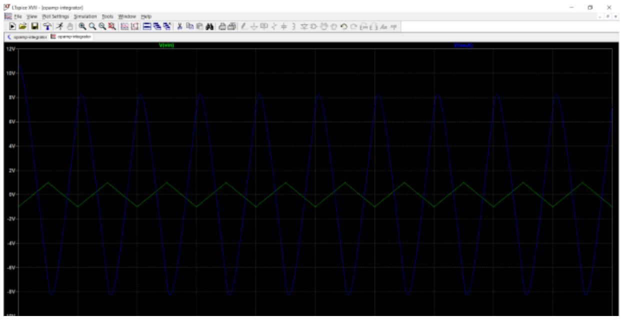
Input as a sine wave



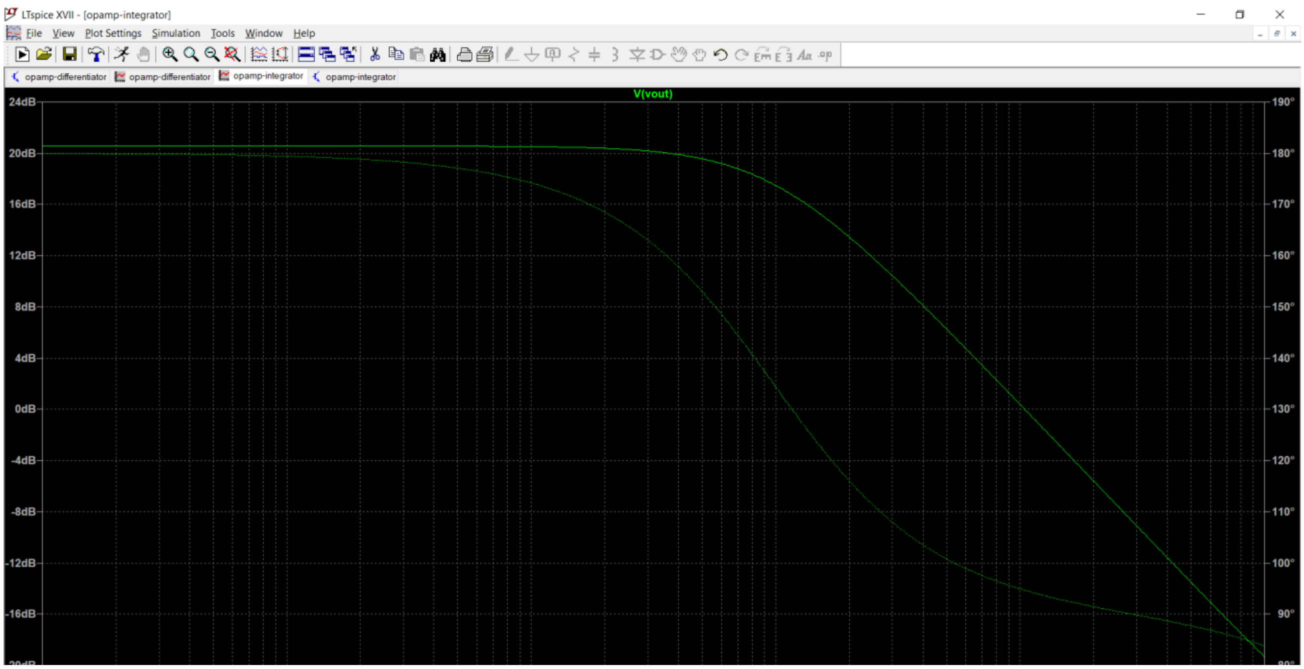
Input as a square wave



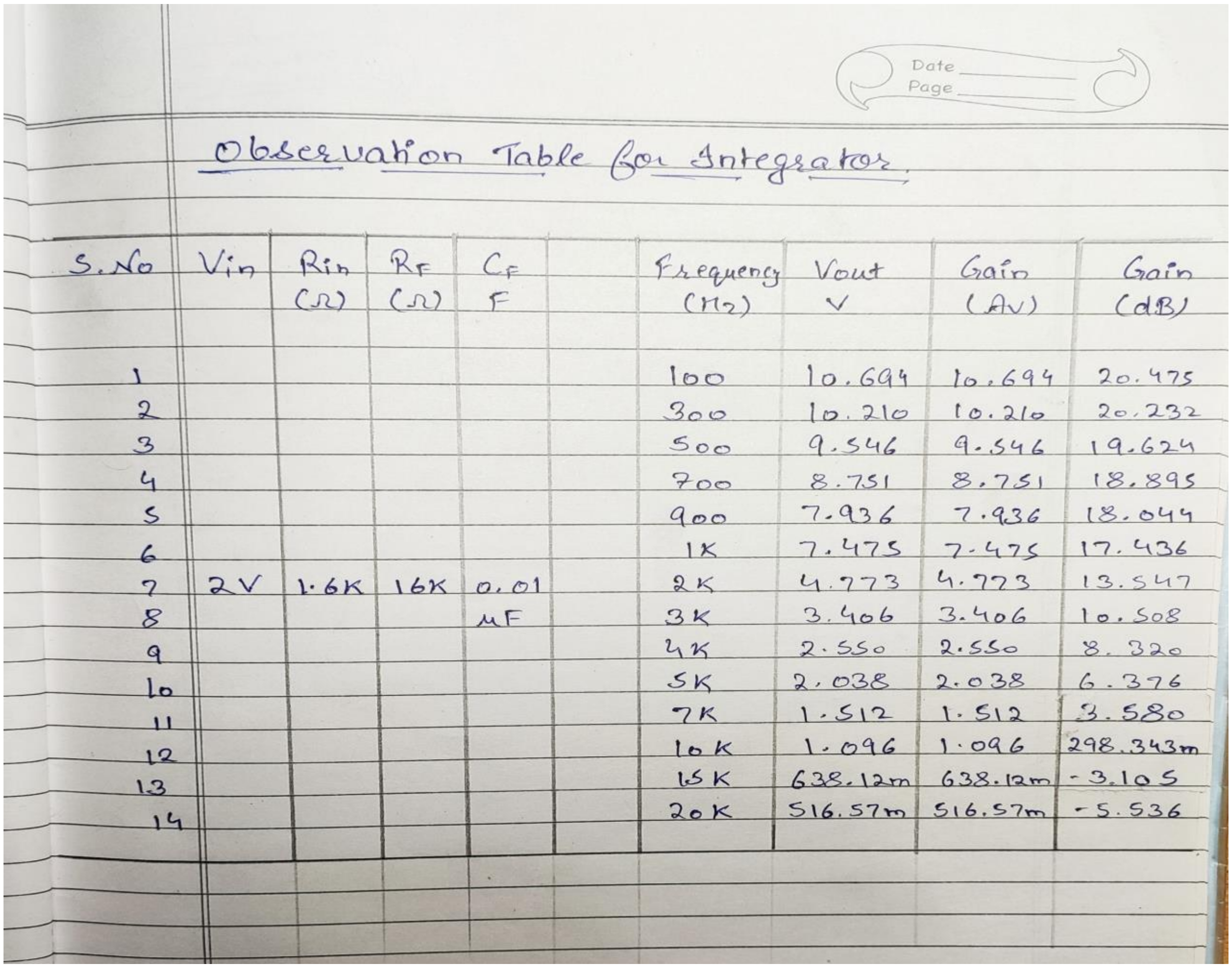
Input as a triangular wave



- *Frequency Response*



Observations



Observation Table for Integrator.

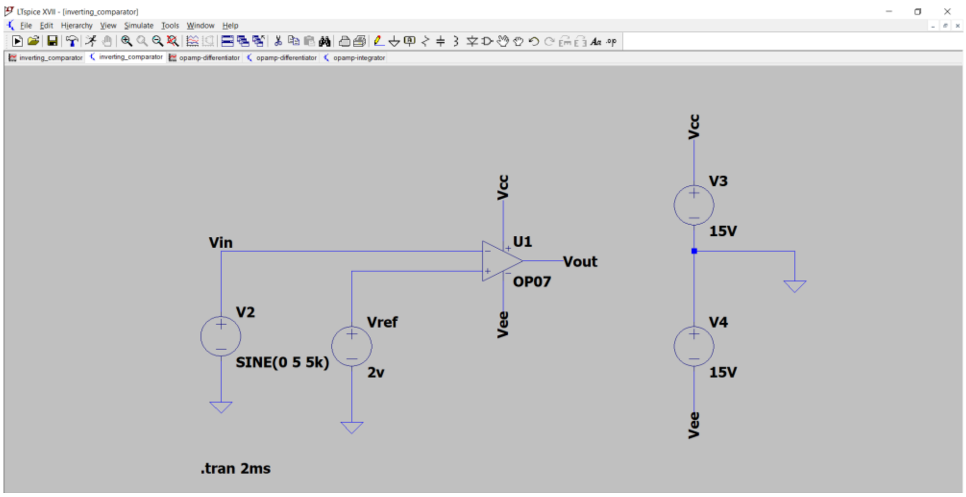
S.No	Vin	Rin (Ω)	RF (Ω)	CF F	Frequency (Hz)	Vout V	Gain (Av)	Gain (dB)
1					100	10.694	10.694	20.475
2					300	10.210	10.210	20.232
3					500	9.546	9.546	19.624
4					700	8.751	8.751	18.895
5					900	7.936	7.936	18.044
6					1K	7.475	7.475	17.436
7	2V	1.6K	16K	0.01	2K	4.773	4.773	13.547
8				µF	3K	3.406	3.406	10.508
9					4K	2.550	2.550	8.320
10					5K	2.038	2.038	6.376
11					7K	1.512	1.512	3.580
12					10K	1.096	1.096	298.343m
13					15K	638.12m	638.12m	-3.105
14					20K	516.57m	516.57m	-5.536

3. Op-Amp as Comparator -

○ Introduction

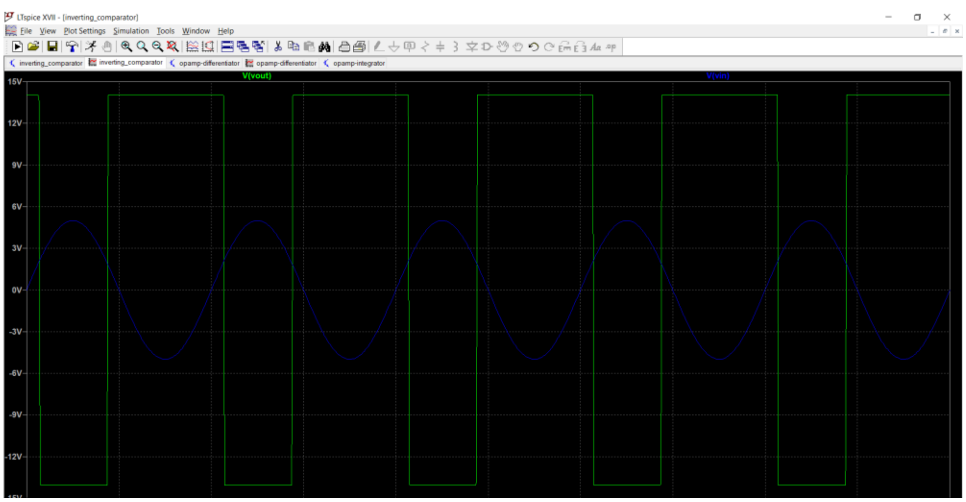
The **Op-amp comparator** compares one analogue voltage level with another analogue voltage level, or some preset reference voltage, V_{REF} and produces an output signal based on this voltage comparison. In other words, the op-amp voltage comparator compares the magnitudes of two voltage inputs and determines which is the largest of the two. *Voltage comparators* either use positive feedback or no feedback at all (open-loop mode) to switch its output between two saturated states, because in the open-loop mode the amplifiers voltage gain is basically equal to A_{VO}. Then due to this high open loop gain, the output from the comparator swings either fully to its positive supply rail, +Vcc or fully to its negative supply rail, -Vcc on the application of varying input signal which passes some preset threshold value.

1. Op-amp Comparator (Inverting comparator) Circuit

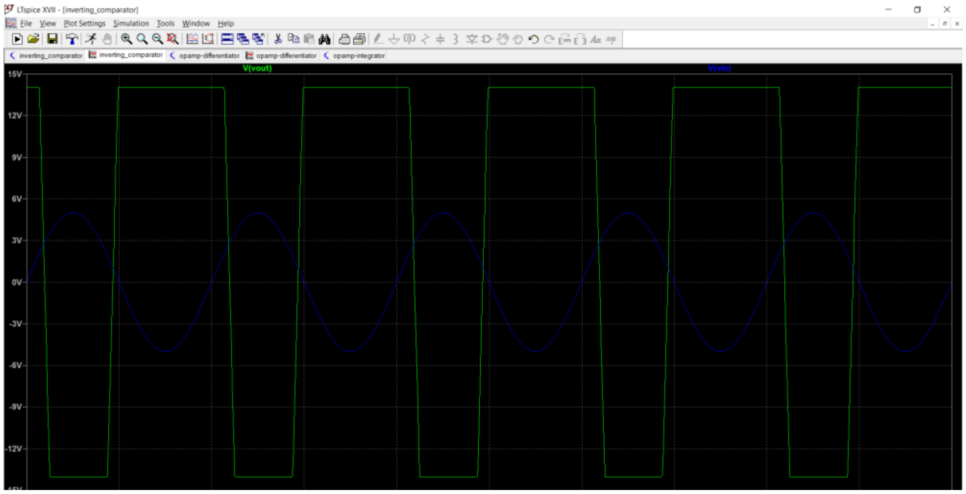


Simulation Results

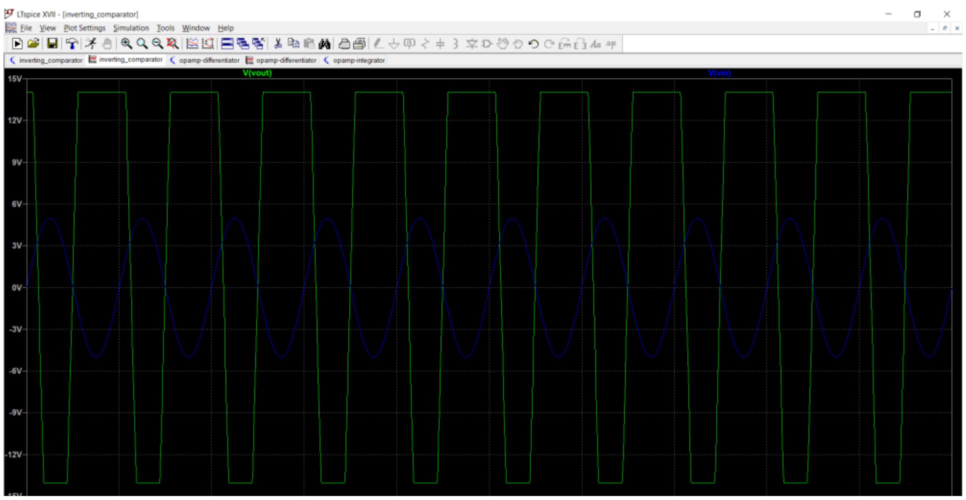
- **50 Hz**



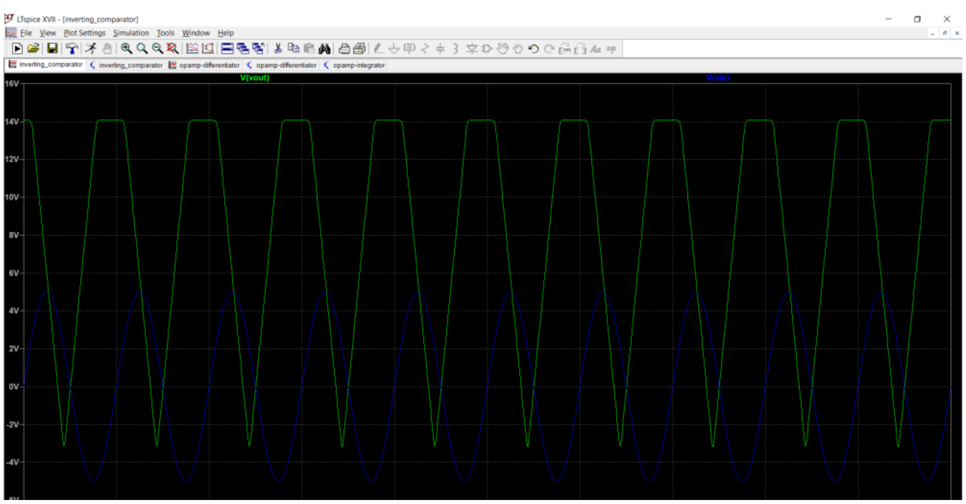
- **500 Hz**


LTspice XVII - [inverting_comparator]
File View Plot Settings Simulation Tools Window Help
V(vout)
V(vin)
15V
12V
9V
6V
3V
0V
-3V
-6V
-9V
-12V

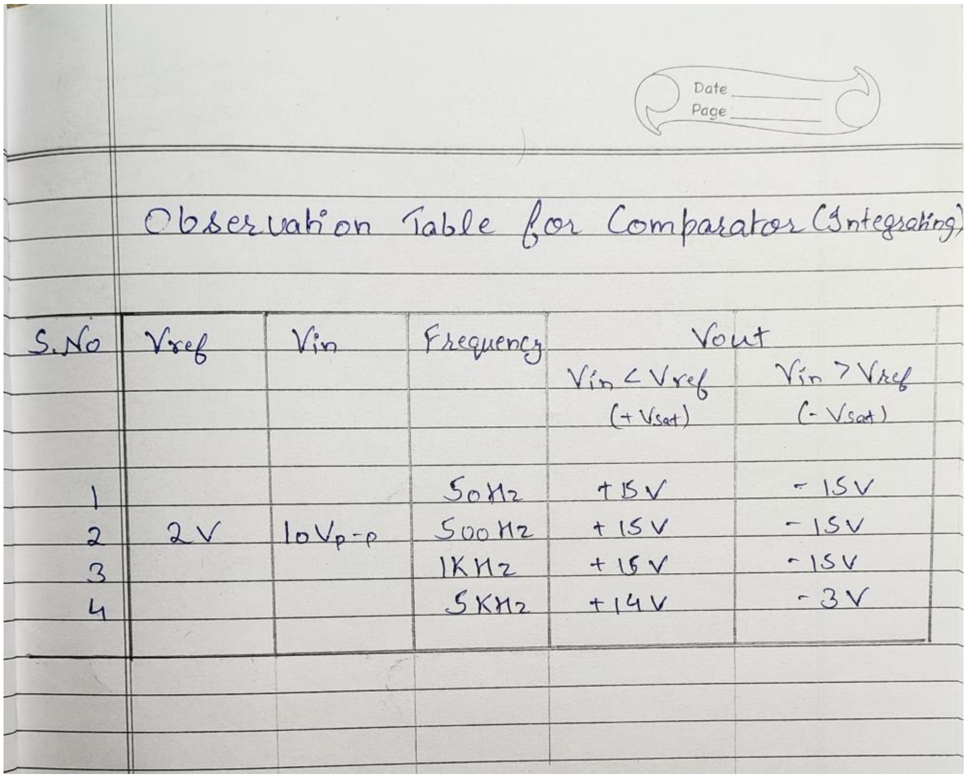
- **1K Hz**


LTspice XVII - [inverting_comparator]
File View Plot Settings Simulation Tools Window Help
V(vout)
V(vin)
15V
12V
9V
6V
3V
0V
-3V
-6V
-9V
-12V

- **5 KHz**


LTspice XVII - [inverting_comparator]
File View Plot Settings Simulation Tools Window Help
V(vout)
V(vin)
16V
14V
12V
10V
8V
6V
4V
2V
0V
-2V
-4V

Observations Table

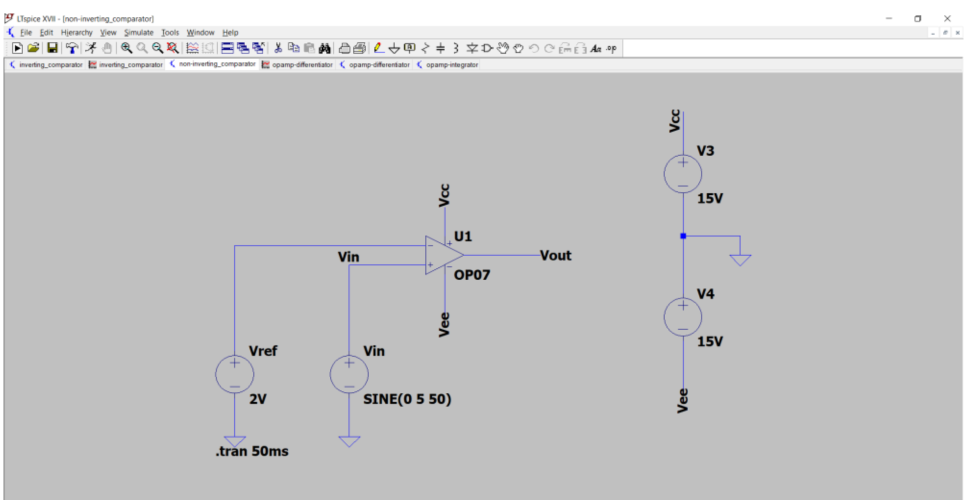


Date
Page

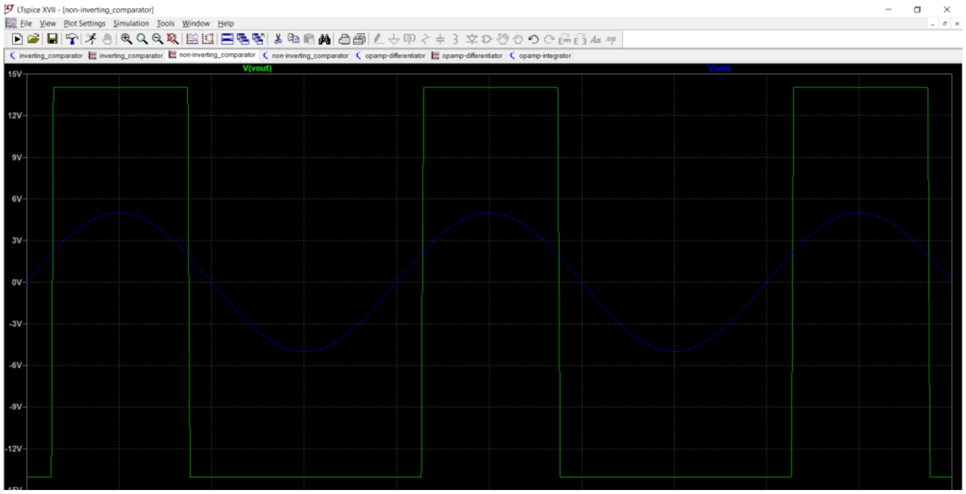
Observation Table for Comparator (Integrating)

S.No	Vref	Vin	Frequency	Vout: Vin < Vref (+ Vsat)	Vout: Vin > Vref (- Vsat)
1	2V	10Vp-p	50Hz	+15V	-15V
2			500Hz	+15V	-15V
3			1KHz	+15V	-15V
4			5KHz	+14V	-3V

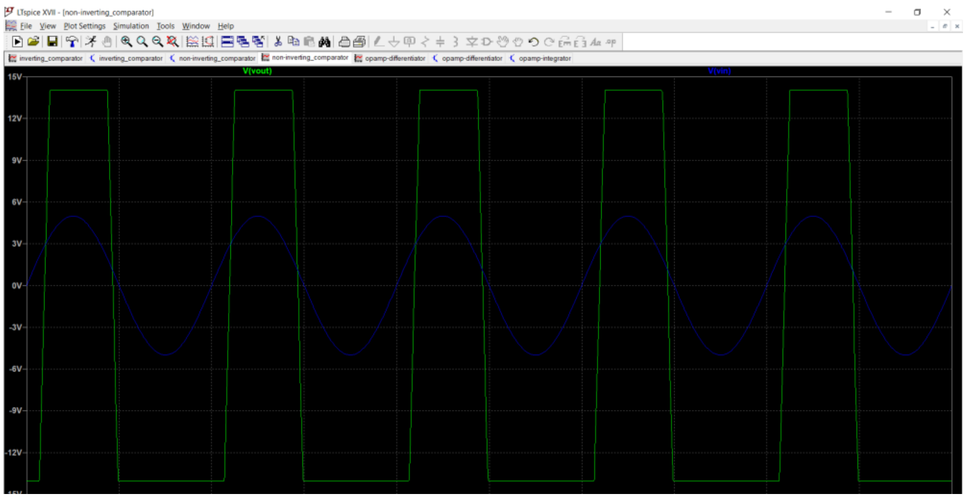
2. Op-amp Comparator (Non-inverting comparator) Circuit



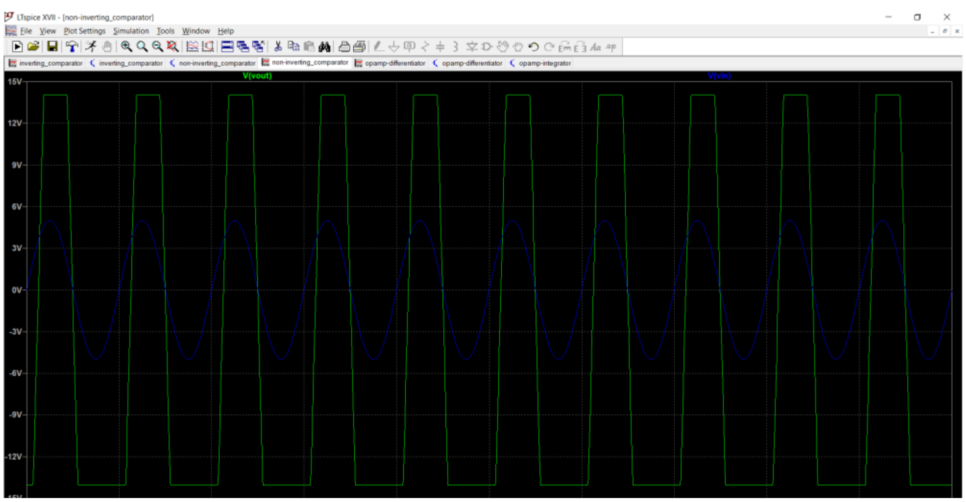
- **50 Hz**


LTspice XVII - [non-inverting_comparator]
File View Plot Settings Simulation Tools Window Help
V(vout)
15V
12V
9V
6V
3V
0V
-3V
-6V
-9V
-12V

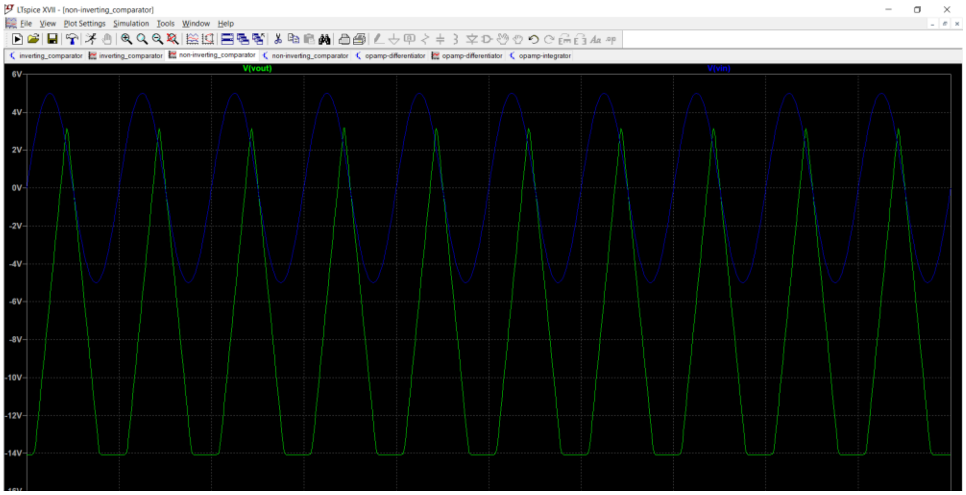
- **500 Hz**


LTspice XVII - [non-inverting_comparator]
File View Plot Settings Simulation Tools Window Help
V(vout)
15V
12V
9V
6V
3V
0V
-3V
-6V
-9V
-12V

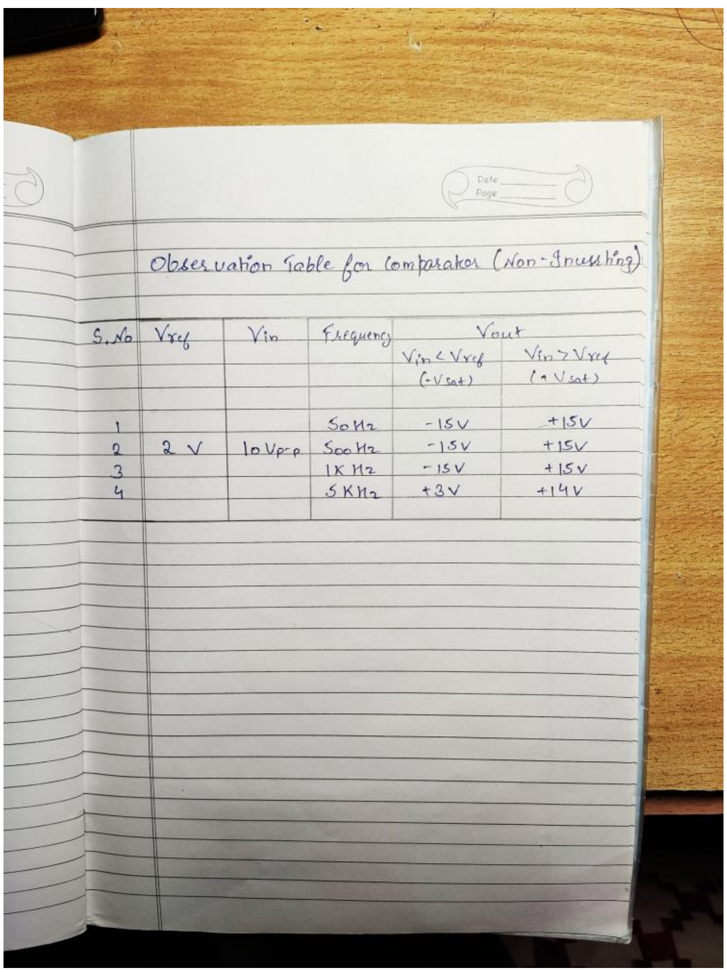
- **1K Hz**


LTspice XVII - [non-inverting_comparator]
File View Plot Settings Simulation Tools Window Help
V(vout)
15V
12V
9V
6V
3V
0V
-3V
-6V
-9V
-12V

- **5 KHz**



Observations Table



Observation Table for Comparator (Non-Inverting)

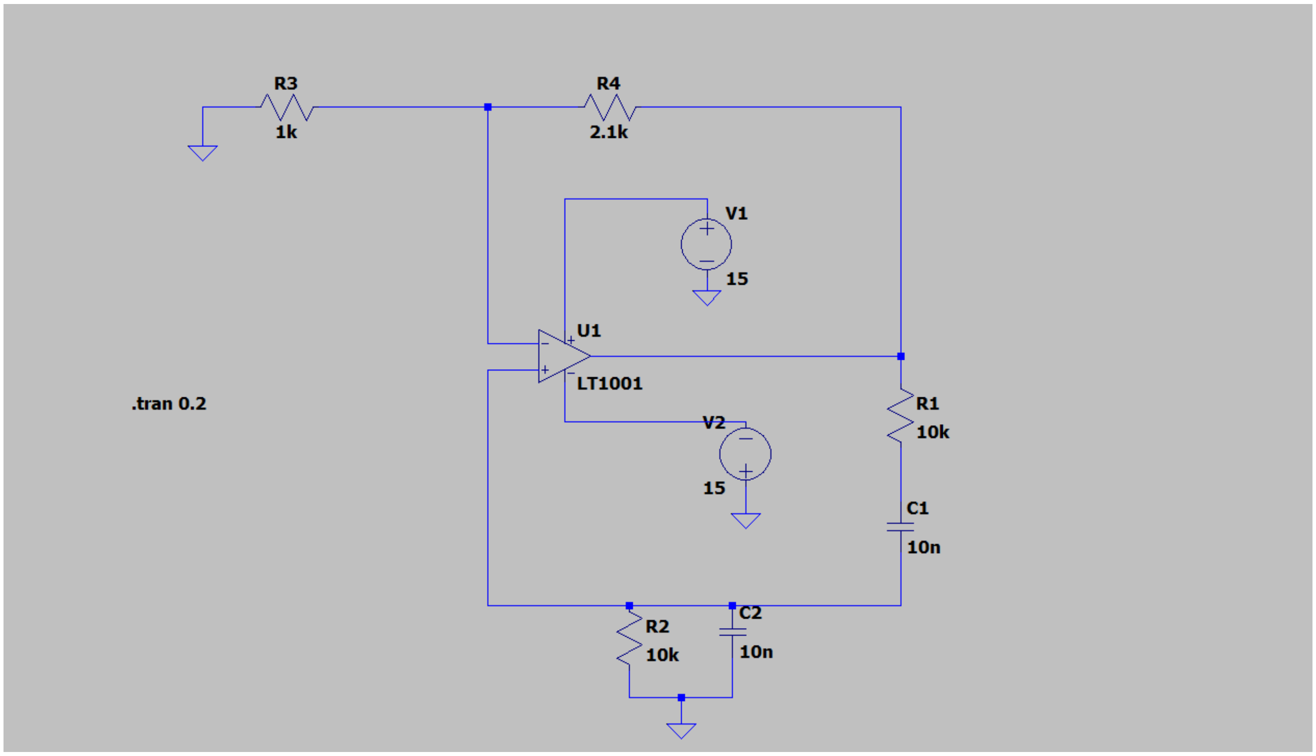
S. No	Vref	Vin	Frequency	Vout	
				Vin < Vref (-V sat)	Vin > Vref (+V sat)
1			50 Hz	-15 V	+15 V
2	2 V	10 Vp-p	500 Hz	-15 V	+15 V
3			1K Hz	-15 V	+15 V
4			5 KHz	+3 V	+14 V

4. Wien Bridge Oscillator using Op-amp

○ Introduction

Wien bridge oscillator is an audio frequency sine wave oscillator of high stability and simplicity. The feedback signal in this circuit is connected to the non-inverting input terminal so that the op-amp is working as a non-inverting amplifier. Therefore, the feedback network need not provide any phase shift. The circuit can be viewed as a Wien bridge with a series combination of R1 and C1 in one arm and parallel combination of R2 and C2 in the adjoining arm. Resistors R3 and R4 are connected in the remaining two arms. The series and parallel combination of RC network form a lead-lag circuit. At high frequencies, the reactance of capacitor C1 and C2 approaches zero. This causes C1 and C2 appears short. Here, capacitor C2 shorts the resistor R2. Hence, the output voltage Vo will be zero since output is taken across R2 and C2 combination. So, at high frequencies, circuit acts as a 'lag circuit'. At low frequencies, both capacitors act as open because capacitor offers very high reactance. Again, output voltage will be zero because the input signal is dropped across the R1 and C1 combination. Here, the circuit acts like a 'lead circuit'.So, the RC circuit in feedback is frequency selective and acts like a notch filter. But at one particular frequency between the two extremes, the output voltage reaches to the maximum value. At this frequency only, resistance value becomes equal to capacitive reactance and gives maximum output. Hence, this frequency is known as oscillating or resonating frequency (f).

Circuit Diagram



Calculations

$R_1 = 10k\Omega \qquad R_2 = 10k\Omega \qquad \Rightarrow R_1 = R_2$

$C_1 = 10nF \qquad C_2 = 10nF \qquad C_1 = C_2$

$R_3 = 1k\Omega$

$R_4 = 2.1k\Omega$

$$\frac{V_{out}}{V_{in}} = \frac{R_2 C_1}{R_1 C_1 + R_2 C_2 + R_2 C_1} = \beta \text{ (feedback fraction)}$$

We have $R_1 = R_2$ & $C_1 = C_2$

$$\therefore \boxed{\frac{V_{out}}{V_{in}} = \frac{1}{3} = \beta}$$

$A\beta = 1$ (for sustained oscillation)

$$A = \frac{R_1 C_1 + R_2 C_2 + R_2 C_1}{R_2 C_1} = \frac{\cancel{R_1}}{\cancel{R_2}} + \frac{\cancel{C_2}}{\cancel{C_1}} + 1 = 3$$

Also, $A = 1 + \frac{R_4}{R_3}$ (Non-inverting configuration)

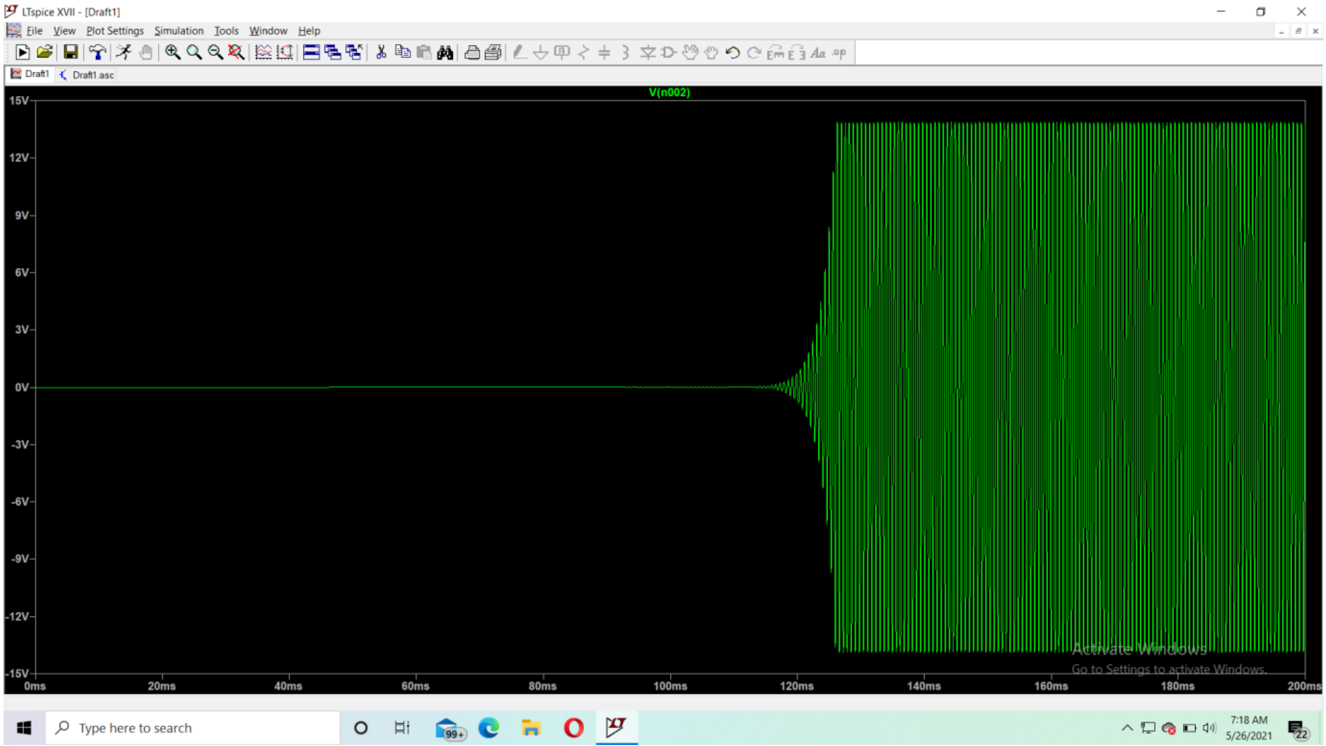
$$A = 3 = 1 + \frac{R_4}{R_3}$$

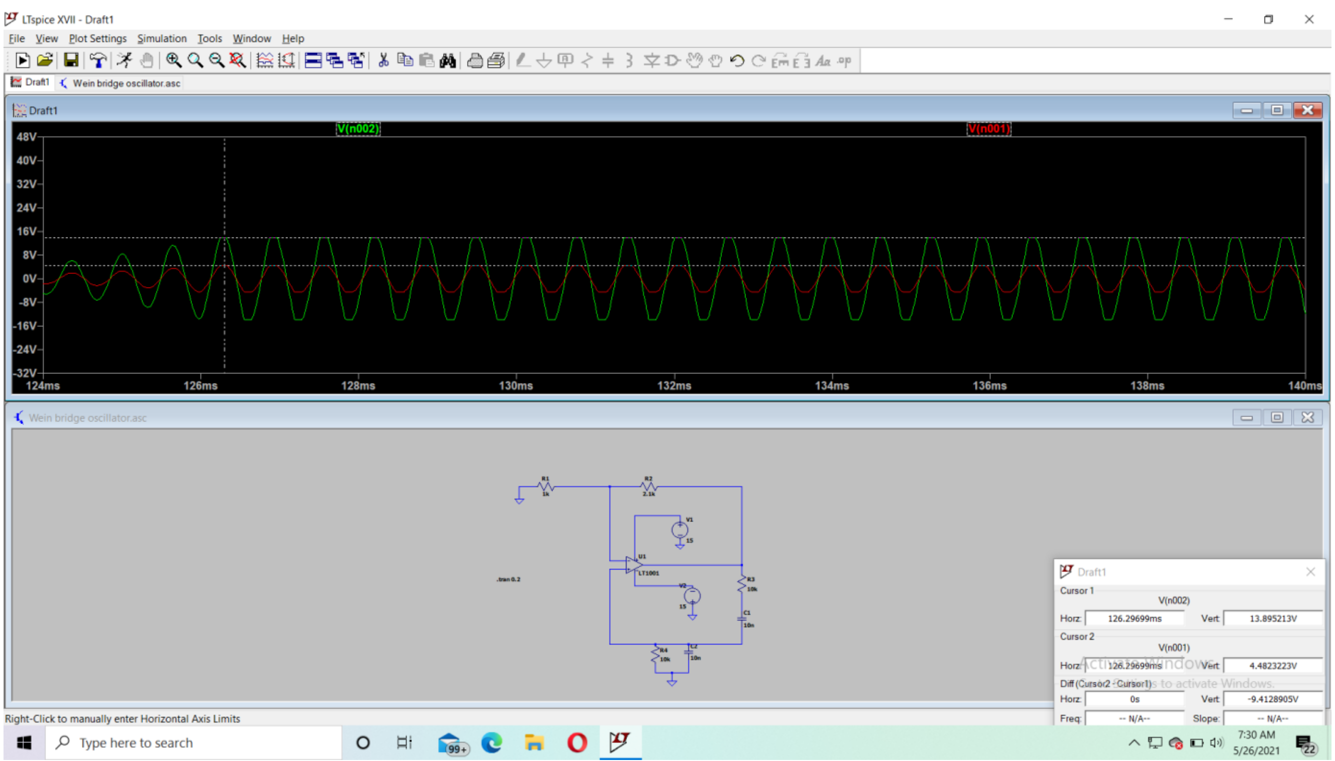
$$\therefore \boxed{\frac{R_4}{R_3} = 2}$$ [Condition for sustained oscillations]

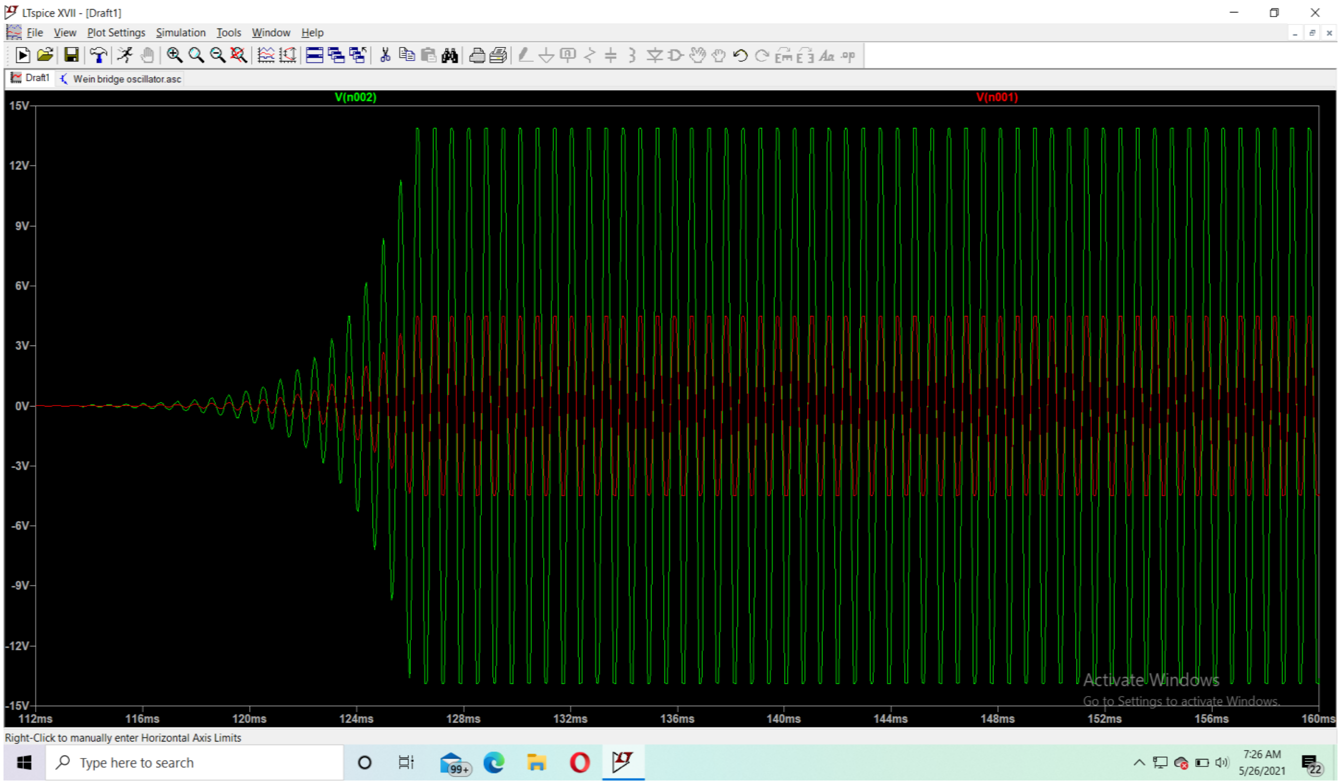
$$f_r = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} = \frac{1}{2\pi RC} = \frac{1}{2\pi\, 100 \times 10^{-6}} = 1.592\ KHz$$

$$\boxed{f_r = 1.592\ KHz}$$

Simulation Results


LTspice XVII - [Draft1]
File View Plot Settings Simulation Tools Window Help
Draft1 Draft1.asc
V(n002)
15V
12V
9V
6V
3V
0V
-3V
-6V
-9V
-12V
-15V
0ms
20ms
40ms
60ms
80ms
100ms
120ms
140ms
160ms
180ms
200ms
Activate Windows
Go to Settings to activate Windows.
Type here to search
7:18 AM
5/26/2021


LTspice XVII - Draft1
File View Plot Settings Simulation Tools Window Help
Draft1 Wein bridge oscillator.asc
Draft1
V(n002)
V(n001)
48V
40V
32V
24V
16V
8V
0V
-8V
-16V
-24V
-32V
124ms
126ms
128ms
130ms
132ms
134ms
136ms
138ms
140ms
Wein bridge oscillator.asc
Draft1
Cursor 1
V(n002)
Horz: 126.29699ms
Vert: 13.895213V
Cursor 2
V(n001)
Horz: 126.29699ms
Vert: 4.4823223V
Diff (Cursor2 - Cursor1)
Horz: 0s
Vert: -9.4128905V
Freq: -- N/A--
Slope: -- N/A--
Right-Click to manually enter Horizontal Axis Limits
Type here to search
7:30 AM
5/26/2021


LTspice XVII - [Draft1]
File View Plot Settings Simulation Tools Window Help
Draft1
Wein bridge oscillator.asc
V(n002)
V(n001)
15V
12V
9V
6V
3V
0V
-3V
-6V
-9V
-12V
-15V
112ms
116ms
120ms
124ms
128ms
132ms
136ms
140ms
144ms
148ms
152ms
156ms
160ms
Right-Click to manually enter Horizontal Axis Limits
Type here to search
7:26 AM
5/26/2021