# Lab# 1

## 1) Netlist Of Sub Circuit Of Non Ideal Op-Amp:

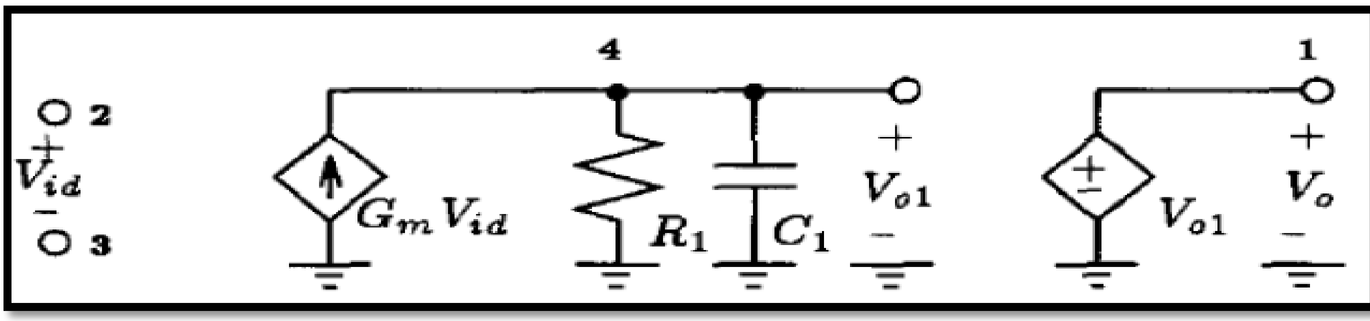
```
*Non Ideal Op-Amp Subcircuit
.subckt Non_Ideal_OpAmp 1 2 3 ; 1 is Output node , 2 is +ve input , 3 is -ve input

*First Stage we can represent it as Voltage Controlled Current Source
GIN 0 4 2 3 10m
IOpen1 2 0 0A ; redundant connection at +ve terminal
IOpen2 3 0 0A ; redundant connection at -ve terminal

* UGF = GBW = BW * Gain , as Gain = 1e4, so BW = 1 Khz so we can assume R = 1Mohm
* and as BW = 1/2*pi*R*C , C = 159.154 pF, and as DC Gain at Output of the first stage = 1e4 = Gm*R, so Gm = 10m

RIN  4 0 1MEG
CIN  4 0 159.154P

*Second Stage we can represent it as Voltage Controlled Voltage Source

EOUT 1 0 4 0 1 ; Gain = 1
.ends Non_Ideal_OpAmp
```

## 2) Netlist Of Non-Inverting Op-Amp & TF Analysis Output:

```
*Non Ideal Op-Amp Subcircuit
.subckt Non_Ideal_OpAmp 1 2 3 ; 1 is Output node , 2 is +ve input , 3 is -ve input

*First Stage we can represent it as Voltage Controlled Current Source
GIN 0 4 2 3 10m
IOpen1 2 0 0A ; redundant connection at +ve terminal
IOpen2 3 0 0A ; redundant connection at -ve terminal

* UGF = GBW = BW * Gain , as Gain = 1e4, so BW = 1 Khz so we can assume R = 1Mohm
* and as BW = 1/2*pi*R*C , C = 159.154 pF, and as DC Gain at Output of the first stage = 1e4 = Gm*R, so Gm = 10m

RIN  4 0 1MEG
CIN  4 0 159.154P

*Second Stage we can represent it as Voltage Controlled Voltage Source

EOUT 1 0 4 0 1 ; Gain = 1
.ends Non_Ideal_OpAmp

* Non Inverting amplifier
RFeedBack 3 2 9k ; FeedBack Resistance = 9kOhm
R2 2 0 1k ; Second Resistance = 1kOhm

VIN 1 0 DC 1 ; Dc Input voltage = 1v

X_1  3 1 2 Non_Ideal_OpAmp ; Call the instance of the Subcircuit

.TF V(3) VIN
.end
```

```
*Non Ideal Op-Amp Subcircuit

   --- Transfer Function ---

Transfer_function:            9.99001        transfer
vin#Input_impedance:          1e+020         impedance
output_impedance_at_V(3):     0              impedance
```

**Justification:** Using voltage divider we get that Vin(-) = Vin(+) = Vin = (R2/(RF+R2))*Vout, so (Vout/Vin) = Av = (RF + R2)/(R2) = (10/1) = 10, from the analysis of TF we get that Vout/Vin = 9.99 , which is approximately the same, and from the figure below the input impedance is very large as Vid is taken across open circuit, which has very high impedance, on output we take the voltage on dependent voltage source (Voltage controlled Voltage Source) and the ideal voltage source has internal impedance = 0, so the output impedance = 0.

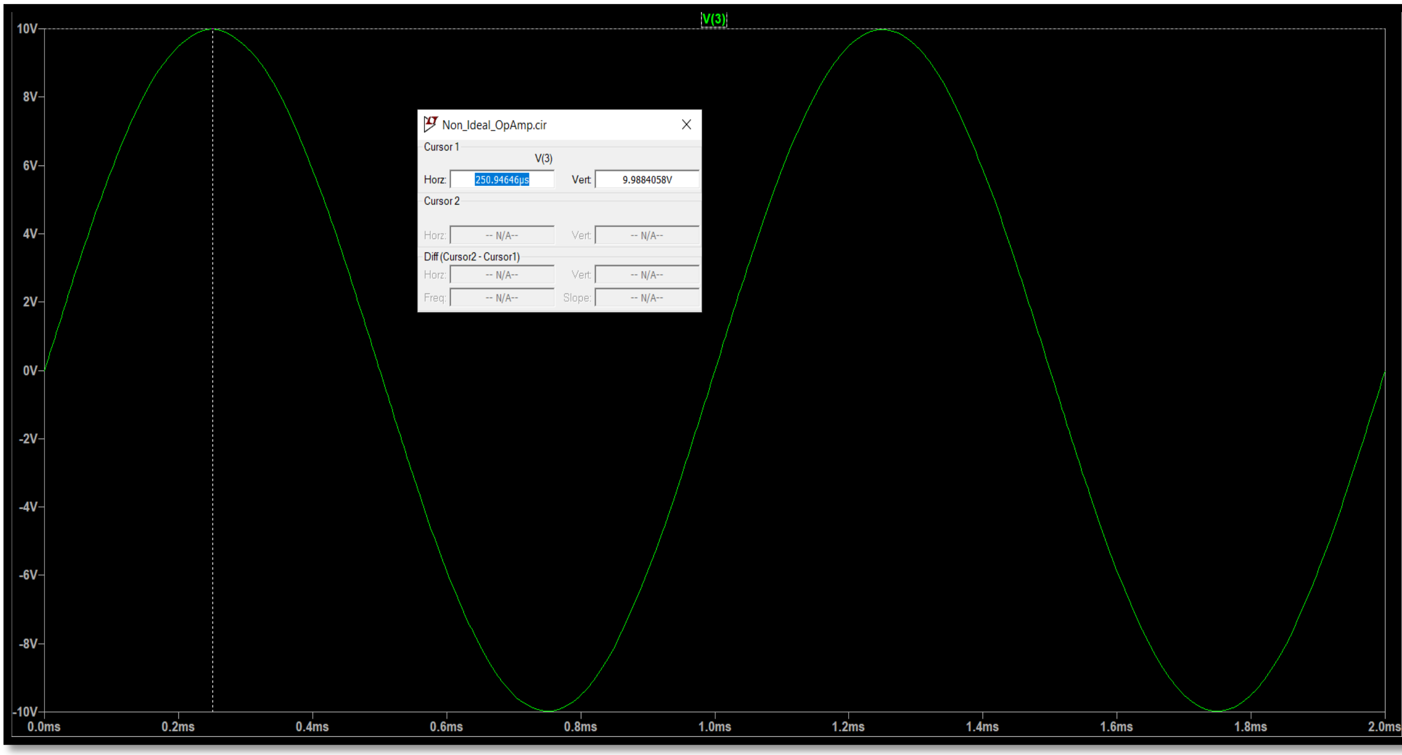



## 3) Transient Analysis:

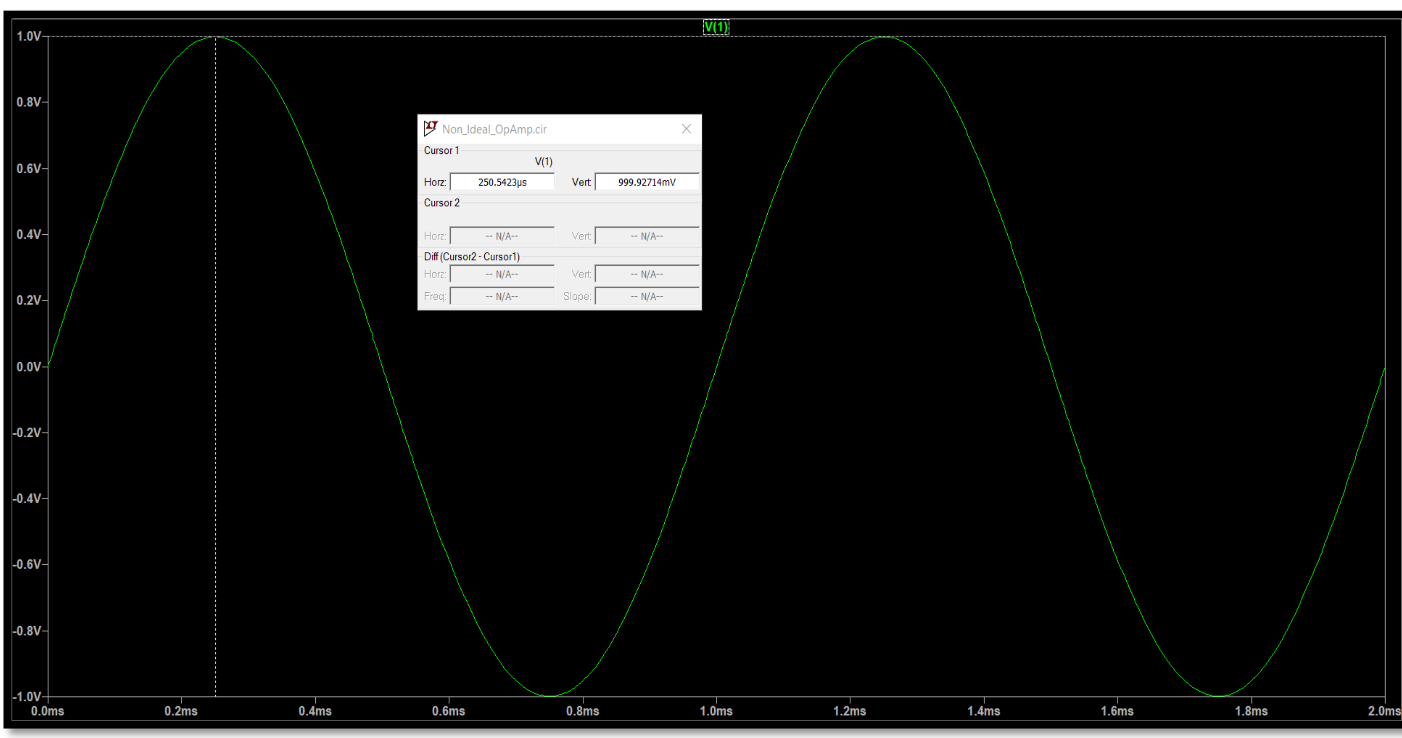
### Netlist:

```
*Non Ideal Op-Amp Subcircuit
.subckt Non_Ideal_OpAmp 1 2 3 ; 1 is Output node , 2 is +ve input , 3 is -ve input

*First Stage we can represent it as Voltage Controlled Current Source
GIN 0 4 2 3 10m
IOpen1 2 0 0A ; redundant connection at +ve terminal
IOpen2 3 0 0A ; redundant connection at -ve terminal

* UGF = GBW = BW * Gain , as Gain = 1e4, so BW = 1 Khz so we can assume R = 1Mohm
* and as BW = 1/2*pi*R*C , C = 159.154 pF, and as DC Gain at Output of the first stage = 1e4 = Gm*R, so Gm = 10m

RIN  4 0 1MEG
CIN  4 0 159.154P

*Second Stage we can represent it as Voltage Controlled Voltage Source

EOUT 1 0 4 0 1 ; Gain = 1
.ends Non_Ideal_OpAmp

* Non Inverting amplifier
RFeedBack 3 2 9K ; FeedBack Resistance = 9kOhm
R2 2 0 1k ; Second Resistance = 1kOhm

VIN 1 0 SIN(0 1 1K 0) ; Sine wave with V0 = 0 and Va = 1v and frequency 1K and delay time =0.

X_1  3 1 2 Non_Ideal_OpAmp ; Call the instance of the Subcircuit

.TRAN 0.04m 2m
.end
```

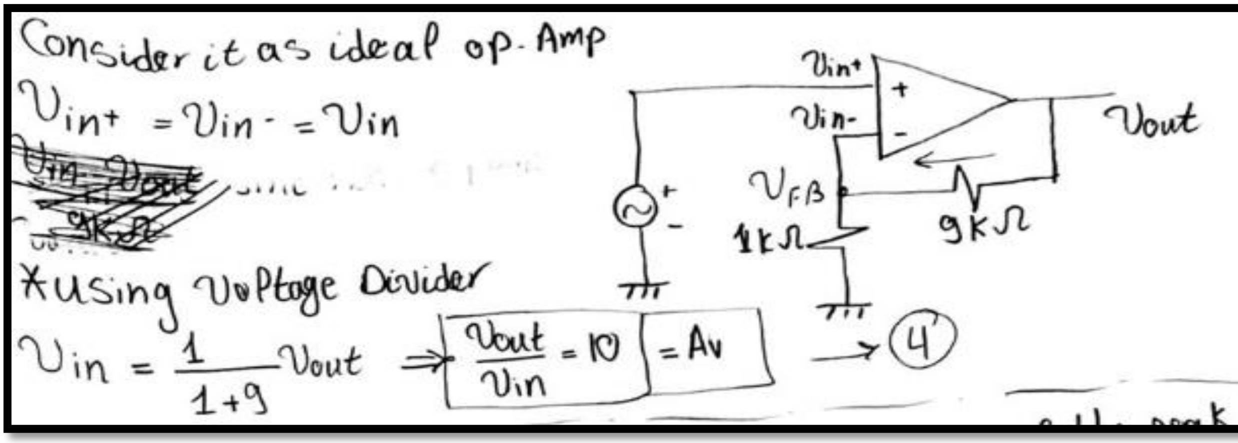
## Vout:


V(3)
10V
8V
6V
4V
2V
0V
-2V
-4V
-6V
-8V
-10V
0.0ms
0.2ms
0.4ms
0.6ms
0.8ms
1.0ms
1.2ms
1.4ms
1.6ms
1.8ms
2.0ms
Non_Ideal_OpAmp.cir
Cursor 1
V(3)
Horz: 250.94646µs
Vert: 9.9884058V
Cursor 2
Horz: -- N/A--
Vert: -- N/A--
Diff (Cursor2 - Cursor1)
Horz: -- N/A--
Vert: -- N/A--
Freq: -- N/A--
Slope: -- N/A--

## Vsig:


V(1)
1.0V
0.8V
0.6V
0.4V
0.2V
0.0V
-0.2V
-0.4V
-0.6V
-0.8V
-1.0V
0.0ms
0.2ms
0.4ms
0.6ms
0.8ms
1.0ms
1.2ms
1.4ms
1.6ms
1.8ms
2.0ms
Non_Ideal_OpAmp.cir
Cursor 1
V(1)
Horz: 250.5423µs
Vert: 999.92714mV
Cursor 2
Horz: -- N/A--
Vert: -- N/A--
Diff (Cursor2 - Cursor1)
Horz: -- N/A--
Vert: -- N/A--
Freq: -- N/A--
Slope: -- N/A--

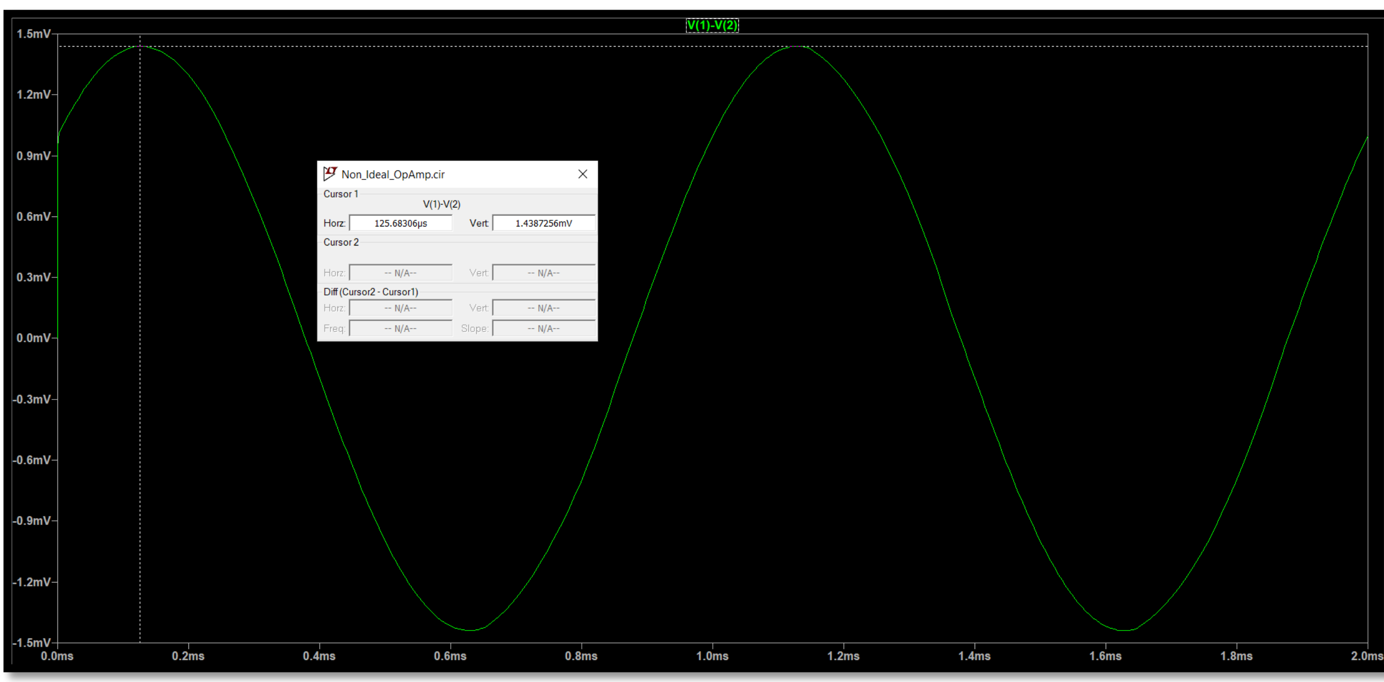
## 4) Comparison between TF & Transient & Hand Analysis:




| *TF Analysis* | *Transient Analysis* | *Hand Analysis* |
|---|---|---|
| Av = 9.99 | Av = Vout/Vin = 9.98 | Av = 10 |

From the table we can deduce that all the results are approximately the same.

## 5) Differential Input:




The Amplitude = 1.42mV, which is very small voltage that we can approximate it as 0V

## Justification:

* 5) $V_{diff} = V_{in+} - V_{in-}$, suppose at the point of the peak voltage of input sine wave $= 1V$, so $V_{in+} = 1V$, $V_{out} = 1 \times 10 = 10$

$V_{in-} = 10 * \frac{1}{1+9} = 1V$, $\therefore V_{diff} \simeq 0$

# 6) Differential Input At Input Frequency = UGF:

## Netlist:

```
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*First Stage we can represent it as Voltage Controlled Current Source
GIN 0 4 2 3 10m
IOpen1 2 0 0A ; redundant connection at +ve terminal
IOpen2 3 0 0A ; redundant connection at -ve terminal

* UGF = GBW = BW * Gain , as Gain = 1e4, so BW = 1 Khz so we can assume R = 1Mohm
* and as BW = 1/2*pi*R*C , C = 159.154 pF, and as DC Gain at Output of the first stage = 1e4 = Gm*R, so Gm = 10m

RIN  4 0 1MEG
CIN  4 0 159.154P

*Second Stage we can represent it as Voltage Controlled Voltage Source

EOUT 1 0 4 0 1 ; Gain = 1
.ends Non_Ideal_OpAmp

* Non Inverting amplifier
RFeedBack 3 2 9K ; FeedBack Resistance = 9kOhm
R2 2 0 1k ; Second Resistance = 1kOhm

VIN 1 0 SIN(0 1 10MEG 0) ; Sine wave with V0 = 0 and Va = 1v and frequency 10MHZ = UGF and delay time =0.

X_1  3 1 2 Non_Ideal_OpAmp ; Call the instance of the Subcircuit

.TRAN 0.002u 0.2u
.end
```
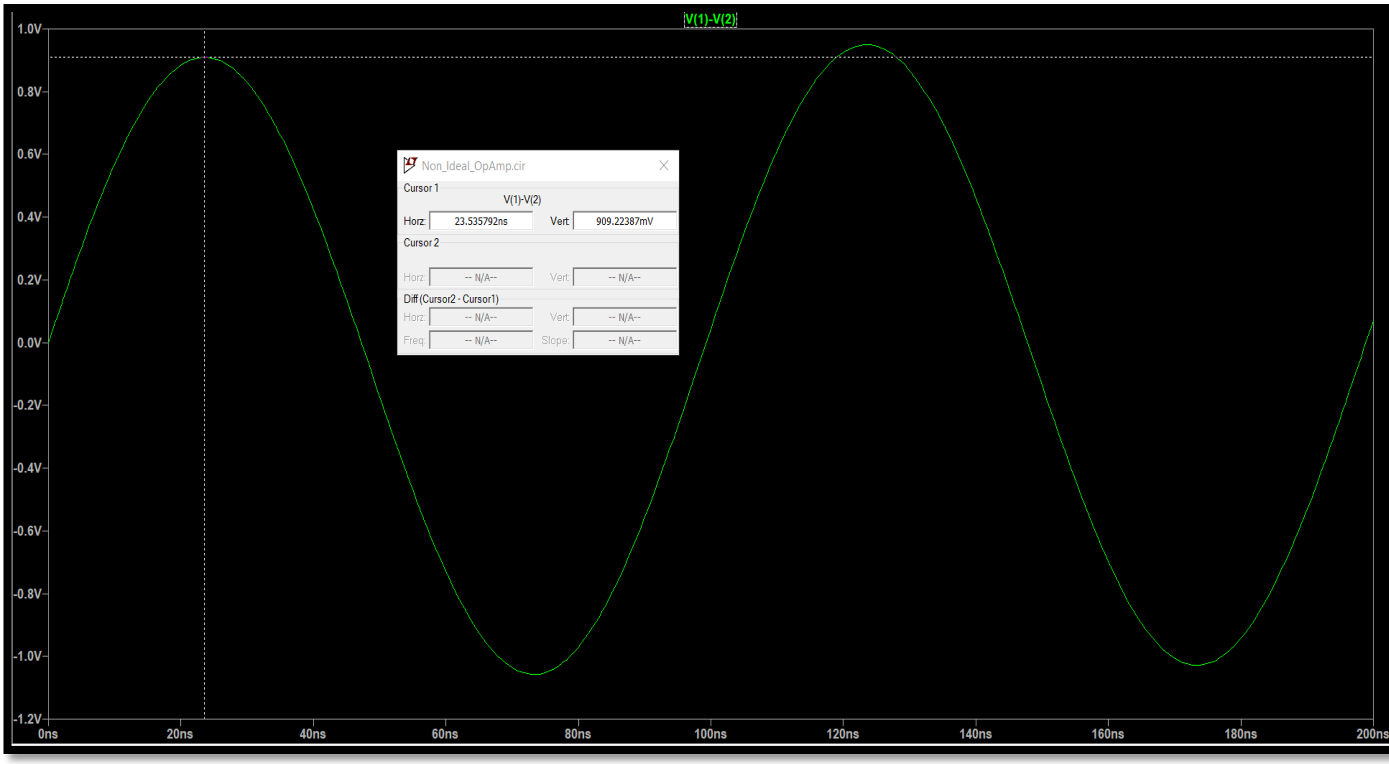

## Differential Input:




The Amplitude = 909.22 mV = 0.909 V.

## Justification:

* 6) ~~suppose~~ ∵ Frequency = UGF ⇒ $A_{OL} = 1$, $\beta = 0.1$, $LG = \beta * A_{OL} = 0.1$

∴ $A_{CL} = \frac{A_{OL}}{1+LG} = 0.90$, $V_{in+} = 1V$ → suppose the point of the peak value of the input sine wave, $V_{out} = 1 * 0.90 = 0.90$

$V_{in-} = \frac{1}{1+9} * 0.9 = 0.09$ ∴ $V_{diff} = V_{in+} - V_{in-} = 1 - 0.09 = 0.91$

## 7) AC Analysis At RF = 9K & RF = 4K:

### **Netlist:**

```
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*First Stage we can represent it as Voltage Controlled Current Source
GIN 0 4 2 3 10m
IOpen1 2 0 0A ; redundant connection at +ve terminal
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* UGF = GBW = BW * Gain , as Gain = 1e4, so BW = 1 Khz so we can assume R = 1Mohm
* and as BW = 1/2*pi*R*C , C = 159.154 pF, and as DC Gain at Output of the first stage = 1e4 = Gm*R, so Gm = 10m

RIN  4 0 1MEG
CIN  4 0 159.154P

*Second Stage we can represent it as Voltage Controlled Voltage Source

EOUT 1 0 4 0 1 ; Gain = 1
.ends Non_Ideal_OpAmp

* Non Inverting amplifier
.PARAM RF = 9k ; Define parameter that i will sweep on it
RFeedBack 3 2 {RF} ; FeedBack Resistance = 9kOhm
R2 2 0 1k ; Second Resistance = 1kOhm

VIN 1 0 AC 1 ; AC Signal With Amplitude = 1V

X_1  3 1 2 Non_Ideal_OpAmp ; Call the instance of the Subcircuit

.AC DEC 100 10 1G
.STEP PARAM RF LIST 4K 9K ; Parametric sweep on RF
.end
```
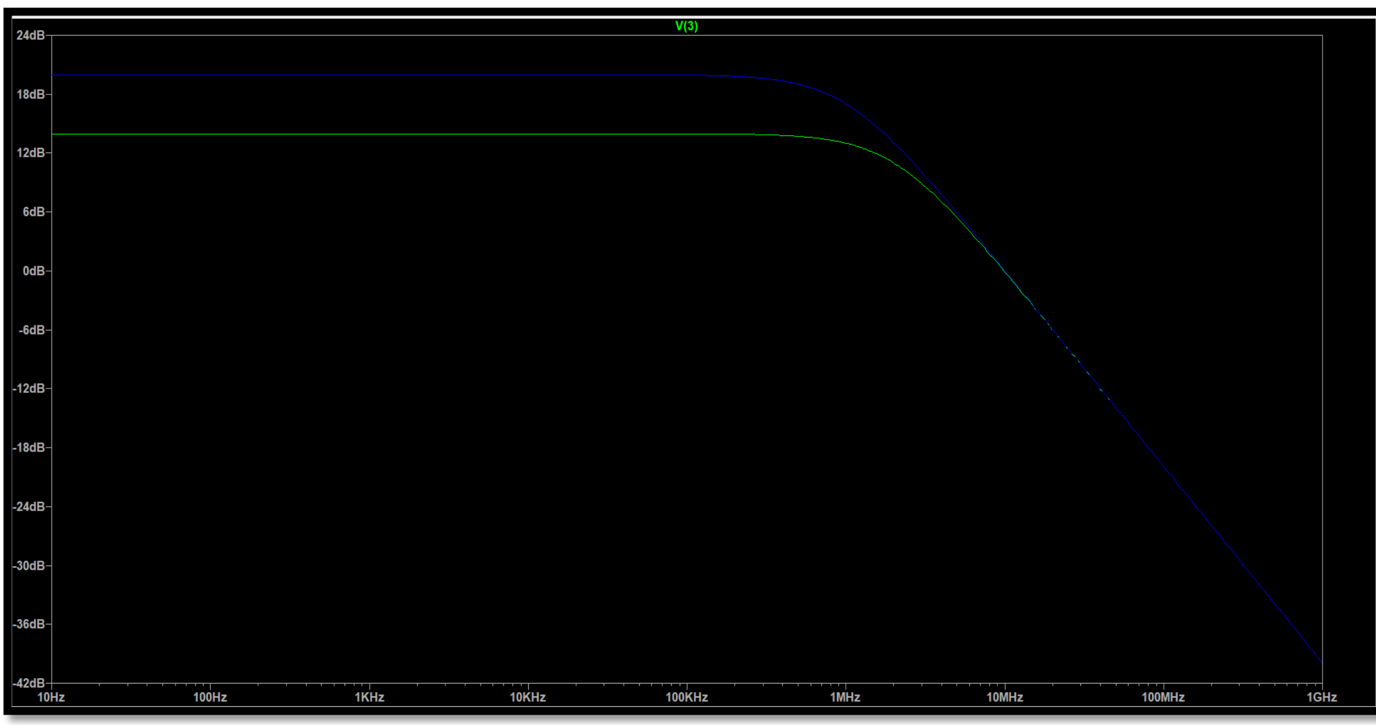
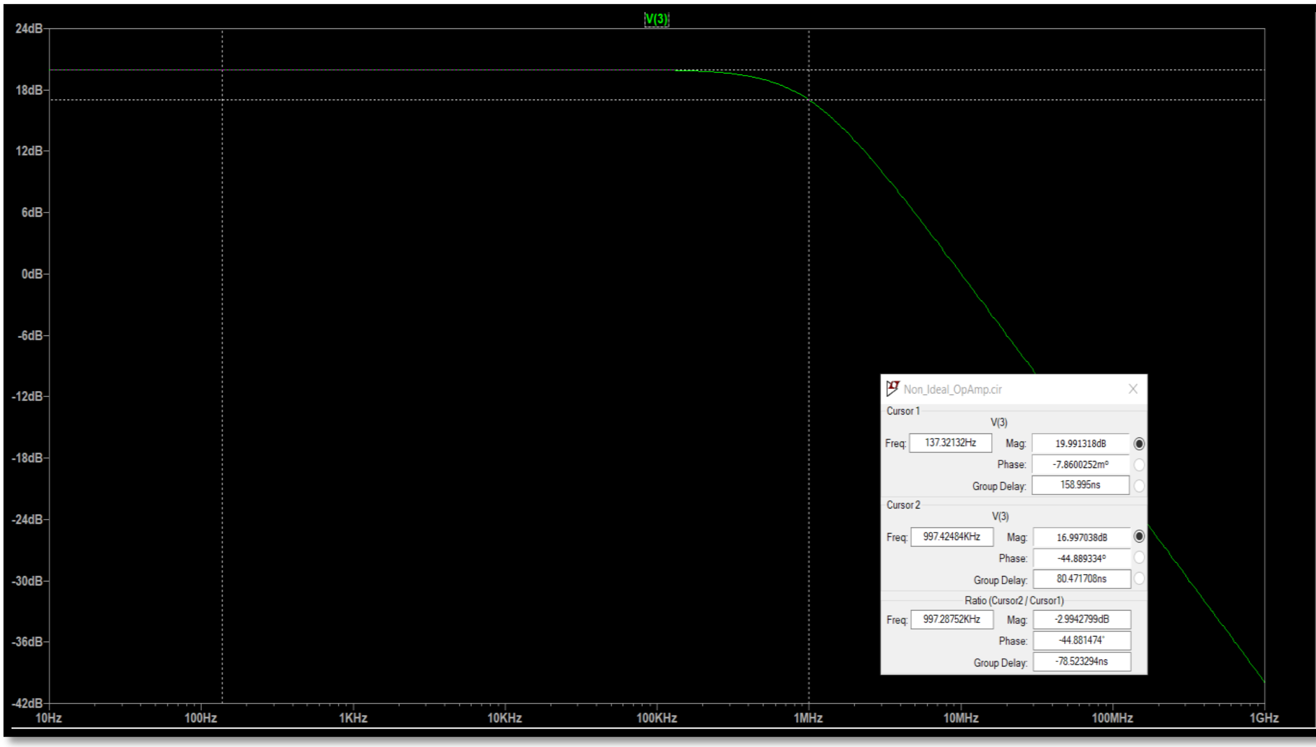
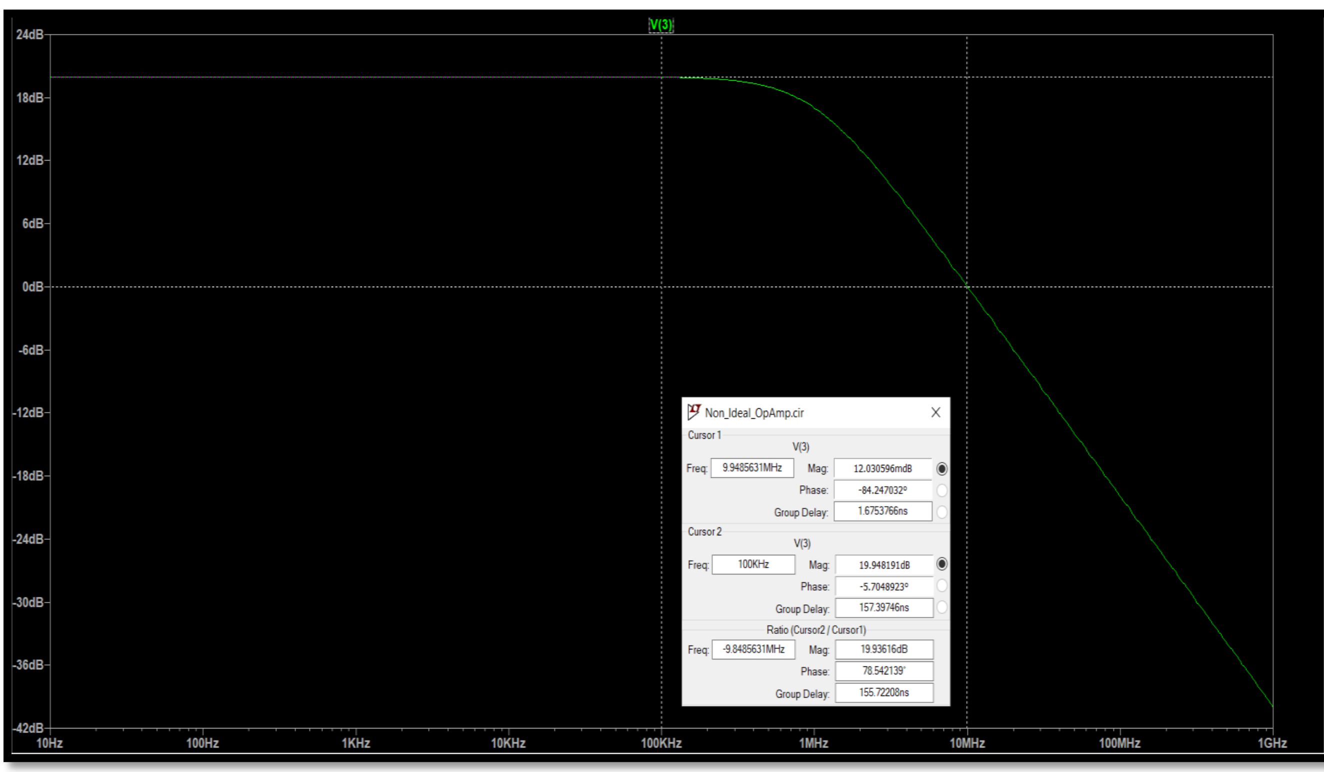

### **Bode Plot Of RF = 9K & RF = 4K:**



## At RF = 9K:

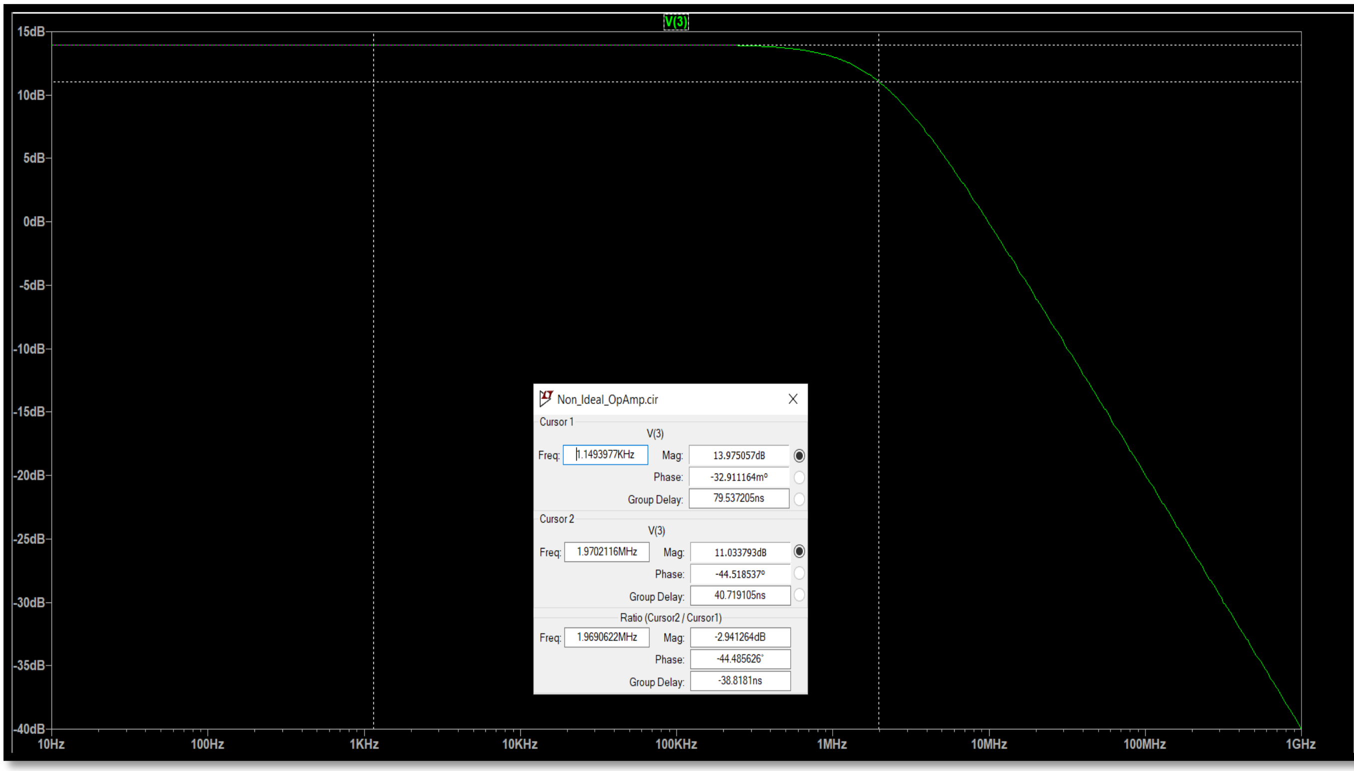


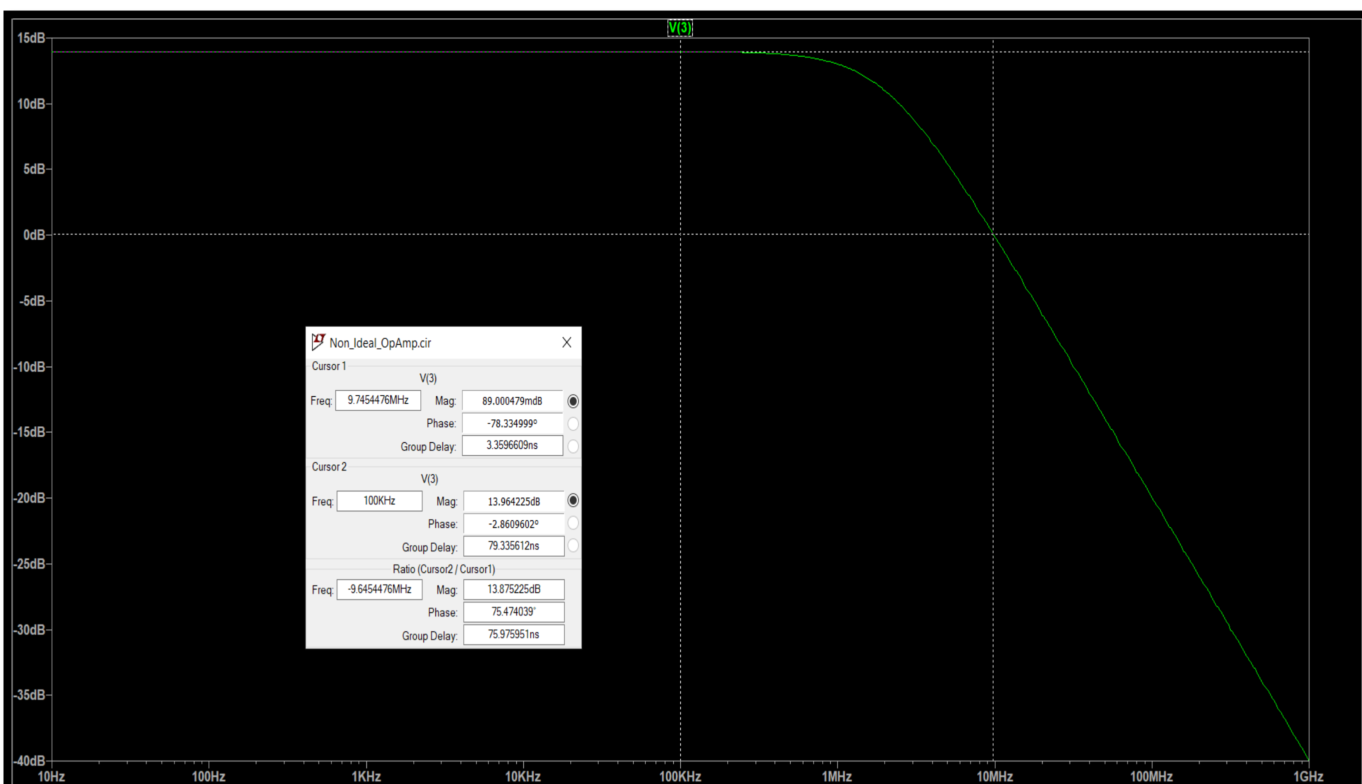
V(3)
24dB
18dB
12dB
6dB
0dB
-6dB
-12dB
-18dB
-24dB
-30dB
-36dB
-42dB
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz
1GHz
Non_Ideal_OpAmp.cir
Cursor 1
V(3)
Freq: 137.32132Hz
Mag: 19.991318dB
Phase: -7.8600252m°
Group Delay: 158.995ns
Cursor 2
V(3)
Freq: 997.42484KHz
Mag: 16.997038dB
Phase: -44.889334°
Group Delay: 80.471708ns
Ratio (Cursor2 / Cursor1)
Freq: 997.28752KHz
Mag: -2.9942799dB
Phase: -44.881474°
Group Delay: -78.523294ns

V(3)
24dB
18dB
12dB
6dB
0dB
-6dB
-12dB
-18dB
-24dB
-30dB
-36dB
-42dB
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz
1GHz
Non_Ideal_OpAmp.cir
Cursor 1
V(3)
Freq: 9.9485631MHz
Mag: 12.030596mdB
Phase: -84.247032°
Group Delay: 1.6753766ns
Cursor 2
V(3)
Freq: 100KHz
Mag: 19.948191dB
Phase: -5.7048923°
Group Delay: 157.39746ns
Ratio (Cursor2 / Cursor1)
Freq: -9.8485631MHz
Mag: 19.93616dB
Phase: 78.542139°
Group Delay: 155.72208ns

# At RF = 4K:


V(3)
15dB
10dB
5dB
0dB
-5dB
-10dB
-15dB
-20dB
-25dB
-30dB
-35dB
-40dB
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz
1GHz
Non_Ideal_OpAmp.cir
Cursor 1
V(3)
Freq: 1.1493977KHz
Mag: 13.975057dB
Phase: -32.911164m°
Group Delay: 79.537205ns
Cursor 2
V(3)
Freq: 1.9702116MHz
Mag: 11.033793dB
Phase: -44.518537°
Group Delay: 40.719105ns
Ratio (Cursor2 / Cursor1)
Freq: 1.9690622MHz
Mag: -2.941264dB
Phase: -44.485626°
Group Delay: -38.8181ns


V(3)
15dB
10dB
5dB
0dB
-5dB
-10dB
-15dB
-20dB
-25dB
-30dB
-35dB
-40dB
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz
1GHz
Non_Ideal_OpAmp.cir
Cursor 1
V(3)
Freq: 9.7454476MHz
Mag: 89.000479mdB
Phase: -78.334999°
Group Delay: 3.3596609ns
Cursor 2
V(3)
Freq: 100KHz
Mag: 13.964225dB
Phase: -2.8609602°
Group Delay: 79.335612ns
Ratio (Cursor2 / Cursor1)
Freq: -9.6454476MHz
Mag: 13.875225dB
Phase: 75.474039°
Group Delay: 75.975951ns

## 8) Comment if there will be a clipping in the output signal or not:

### Comment:

Because we use an op-amp sub circuit that represented by dependent current source and dependent voltage source, I don't expect that there will be a clipping when voltage exceeds a specific value, although if we write the sub circuit of op-amp as transistors circuits like 5T-OTA or Two Stage Miller OTA that operate with specific supply voltage we will expect to get clipping in the output signal because it will exceeds the rails of the output signal, but as I said we use simple model without transistors that operate by supply voltage, so no clipping will occur.

## 9) Compare between AC Analysis & Hand Analysis:

### At RF = 9K:

*9) DC Gain = 10, From First step ∴ DC gain $= 20\log(A_v) = 20\,dB$

* 3dB high cutoff frequency is the BW of op-amp ~~so BW~~ but scaled by $(1+LG)$, as it's Feedback system so there is a BW extension by $(1+LG)$ ∴ $BW_{CL} = (1+\beta A_{OL})BW_{OL}$

$BW_{OL} = \frac{1}{2\pi R_{in} C_{in}} = 1KHz$ ∴ $BW_{CL} \cong (0.1)(1\times10^4)(1\times10^3) = 1\,MHz$

* GBW (UGF) → same as $GBW_{OL}$, as BW extend by $(1+LG)$ & Gain scaled by $\frac{1}{1+LG}$ ⇒ GBW = 10 MH

| ***AC Analysis*** | ***Hand Analysis*** |
|---|---|
| DC Gain = 19.991 dB | DC Gain = 20 dB |
| BW = 997.4 KHz | BW = 1 MHz |
| GBW = UGF = 9.94 MHz | GBW = BW = 10 MHz |

## At RF = 4K:

$$\ast \text{ in case } R_F = 4K \quad \therefore B = \frac{1}{1+4} = \frac{1}{5} \quad \therefore A_V = \frac{1}{B} = 5$$

$$\therefore \text{DC gain} = 20 \log(A_V) = 13.97 \simeq 14\,dB$$

$$BW_{CL} = (1 + B\,\overset{10^4}{\cancel{A_{OL}}})\,\underset{1K}{\cancel{BW_{OL}}} = \frac{1}{5} * 1 * 10^4 * 1 * 10^3 = 2\,MHz$$

$$GBW_{CL} = GBW_{OL} = 10\,MHz$$

| *AC Analysis* | *Hand Analysis* |
|---|---|
| DC Gain = 13.975 dB | DC Gain = 13.97 dB |
| BW = 1.970 MHz | BW = 2 MHz |
| GBW = UGF = 9.74 MHz | GBW = BW = 10 MHz |

## Comment:

From the table we can deduce that hand analysis and simulation analysis are approximately the same with slight difference because of asymptotes approximation we do in hand analysis.