Lab 01

spice

Contents

Part 1 (prelab)

1 COMPLETE AND RUN "VDIVIDER.CIR". REPORT THE NETLIST AND THE RESULTS.

```
Voltage Divider Netlist

* Any text after the asterisk '*' is ignored by SPICE

* Voltage Divider

V1 1 0 12
R1 1 2 1k
R2 2 0 2k

* Perform operating point analysis

.op
.end
```

Voltage Divider Netlist

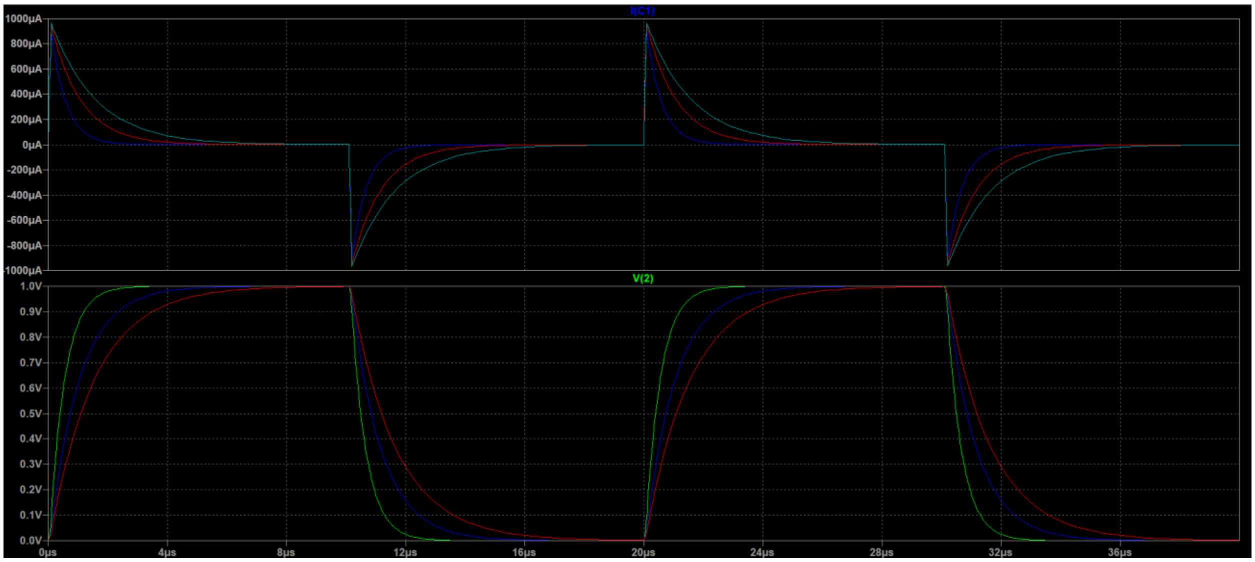
```
       --- Operating Point ---

V(1):          12          voltage
V(2):          8           voltage
I(R1):         0.004       device_current
I(R2):         0.004       device_current
I(V1):         -0.004      device_current
```

2 COMPLETE AND RUN "SIMPLE_RC_TRAN". REPORT THE NETLIST AND THE RESULTS.

```
* Initial conditions
* Analysis request
* Run transient for 40us with 100ns step
.TRAN 100ns 40us
* Use parametric sweep for CPAR: 500p:500p:1.5n
.step param CPAR 500p 1.5n 500p
* Measure rise time from 10% to 90%
.MEAS TRAN TRISE
+ TRIG when v(2) = 0.1 CROSS = 1
+ TARG when v(2) = 0.9 CROSS = 1
.end
```

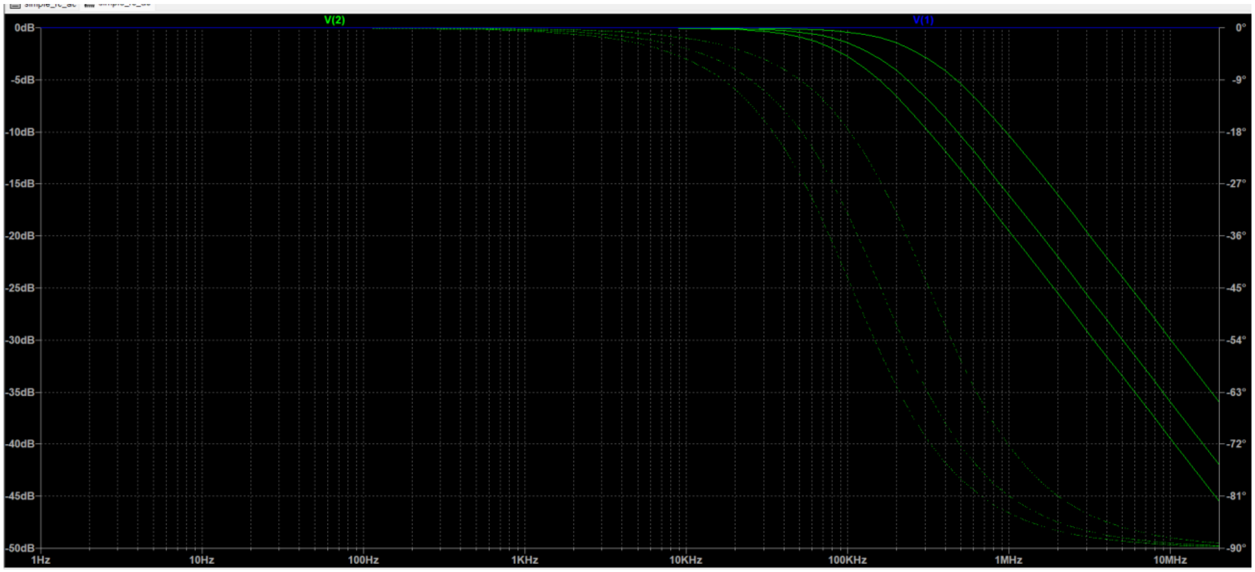
SPICE Output Log: D:\spice\simple_rc_tran.log

```
LTspice 24.0.12 for Windows
Circuit: Simple RC Circuit
Start Time: Sun Jul 21 13:16:56 2024
solver = Normal
Maximum thread count: 12



.OP point found by inspection.
.step cpar=5e-10



.step cpar=1e-09
tnom = 27
temp = 27
method = modified trap
.step cpar=1.5e-09


Measurement: trise
  step      trise FROM   TO
     1      1.09912e-06 1.03619e-07 1.20274e-06
     2      2.19839e-06 1.56143e-07 2.35454e-06
     3      3.29638e-06 2.08794e-07 3.50517e-06

Total elapsed time: 0.141 seconds.
```



3 COMPLETE AND RUN "SIMPLE_RC_AC.CIR". REPORT THE NETLIST AND THE RESULTS.

```
* Parameters
.param CPAR = 500pf
* Signal sources
Vac 1 0 AC 1v 0
* Circuit elements
R1 1 2 1k
C1 2 0 {CPAR}
* Analysis request
* Run ac sweep from 1Hz to 100MEG with 10 pts per decade
.ac dec 10 1 20meg
* Use parametric sweep for CPAR: 500p:500p:1.5n
.step lin  param CPAR 500p 1.5n 500p
*output request
.PRINT AC v(1) v(2)
.PLOT AC v(1) v(2)
*Measure the peak
.Meas Ac PEAK max mag (V(2))
*MEasure bandwidth using PEAK/squrt(2)
.meas AC BW
+ when mag(v(2))=peak/sqrt(2)
.end
```

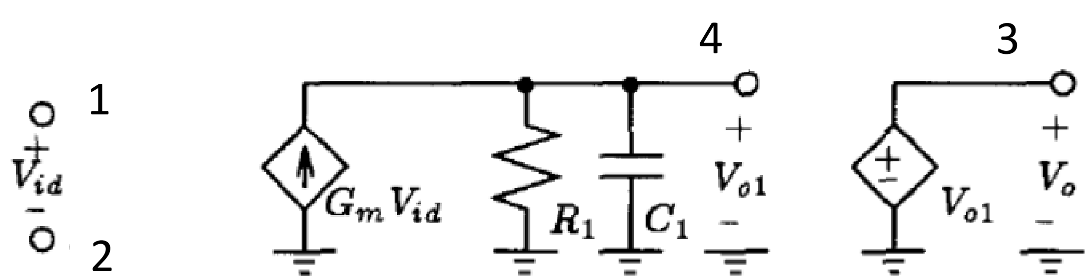



```
Measurement: peak
  step       MAX(mag (v(2)))    FROM   TO
     1        (-4.28644e-11dB,0°)      1      2e+07
     2        (-1.71454e-10dB,0°)      1      2e+07
     3        (-3.8577e-10dB,0°)       1      2e+07

Measurement: bw
  step       mag(v(2))=peak/sqrt(2)
     1       318461
     2       159204
     3       106411

Total elapsed time: 0.251 seconds.
```

Part 2

1 Write a SPICE subcircuit that describes an op-amp with an open-loop gain of 1E4 and a UGF of 10MHz. Use comments generously to describe every line of the netlist. Report the SPICE subcircuit and explain how you chose the circuit parameters.

```
opamp
.subckt opamp 1 2 3
* 1:+ve input
* 2:-ve input
* 3:output
Gopamp 0 4 1 2 10m
*
Inode1 1 0 0
Inode2 2 0 0
*dummy currents to avoid spice errors
Rres 4 0 1meg
Ccap 4 0 159.1p
*open loop gain = IR = 1e4, assume R=1Meg so I=10m
*UGF= BW*AOL, so 10MEG * 2PI = 1/RC, then C = 159.
Eopamp 3 0 4 0 1
*output buffer
.ends
```



AS in comments the:

$A_{OL} = I * R = 10^4, assuming\ R = 1M$, I=10m, UGF $= 10\text{M} = A_{OL} *$ BW, so $BW = 1000\ hz = \frac{1}{2\pi RC}$, then $C \sim 159.1p$

2 USE THE PREVIOUS SUBCIRCUIT TO WRITE A NETLIST OF A NON-INVERTING AMPLIFIER. THE FEEDBACK RESISTANCE IS 9KOHM AND THE OTHER RESISTANCE IS 1KOHM. USE A 1V DC INPUT. USE COMMENTS GENEROUSLY TO DESCRIBE EVERY LINE OF THE NETLIST. RUN TRANSFER FUNCTION (TF) ANALYSIS. REPORT A SNAPSHOT OF THE SPICE OUTPUT FILE. JUSTIFY THE OUTPUT.

```
xop1 1 2 3 opamp
*using the Subcircuit
VIN 1 0 dc 1
Rin 2 0 1k
Rfb 2 3 9k

.tf v(3) vin
.end
```

opamp

```
      --- Transfer Function ---

Transfer_function:              9.99001         transfer
vin#Input_impedance:            1e+20           impedance
output_impedance_at_V(3):       0               impedance
```

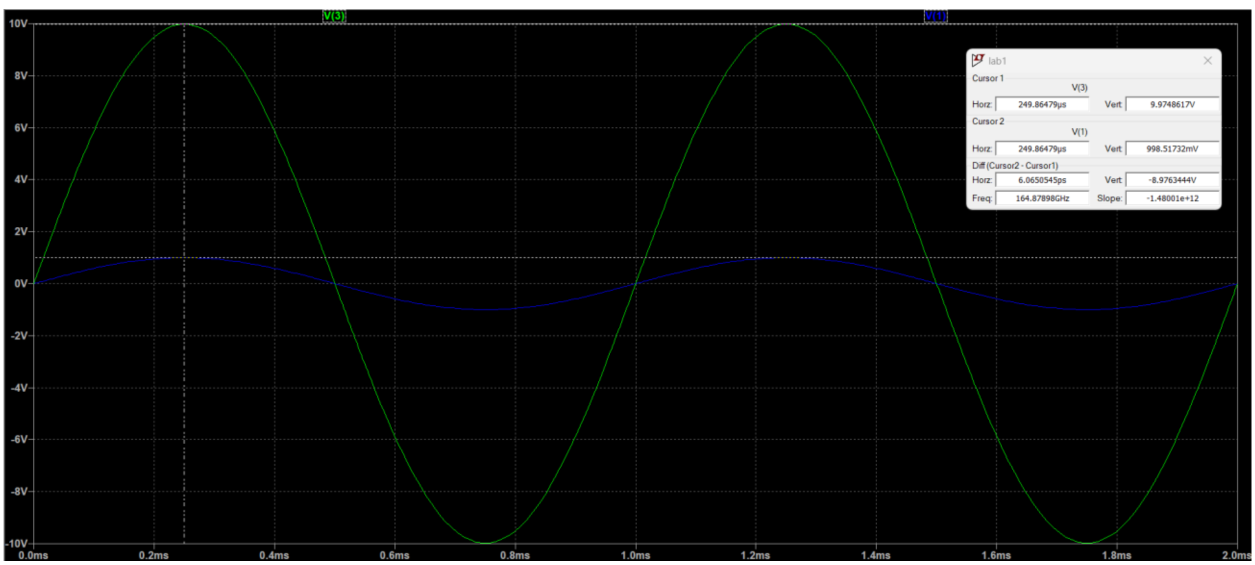
$$\frac{1}{\beta} = 1 + \frac{R_{FB}}{R_{IN}} = 1 + \frac{9k}{1k} = 10$$

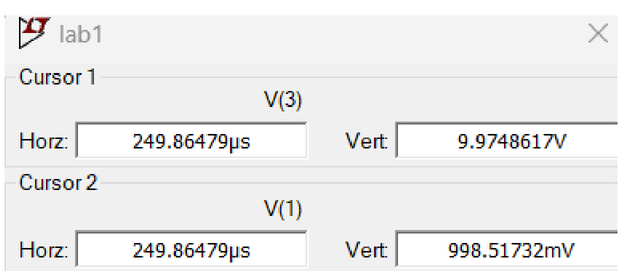
$$A_{CL_{NonInverting}} = \frac{A_{ol}}{1 + \beta * A_{cl}} = 9.99$$

Input impedance is very high as it ideally equals infinity, output impedance equals 0 as it has ideal output buffer.

3 Change the input to be a sine, Run transient analysis for two complete periods. Use a time step = period/50. Report RESULTS, CLEARLY annotate the peak value

```
.param freq=1k
.param period= 1/freq
xop1 1 2 3 opamp
*using the Subcircuit
*VIN 1 0 dc 1
*VIN 1 0 ac 1

vsin 1 0 sin(0 1 1k 0)
Rin 2 0 1k
Rfb 2 3 9k

*.tf v(3) vin
.TRAN {period/50} {period*2}

.end
```



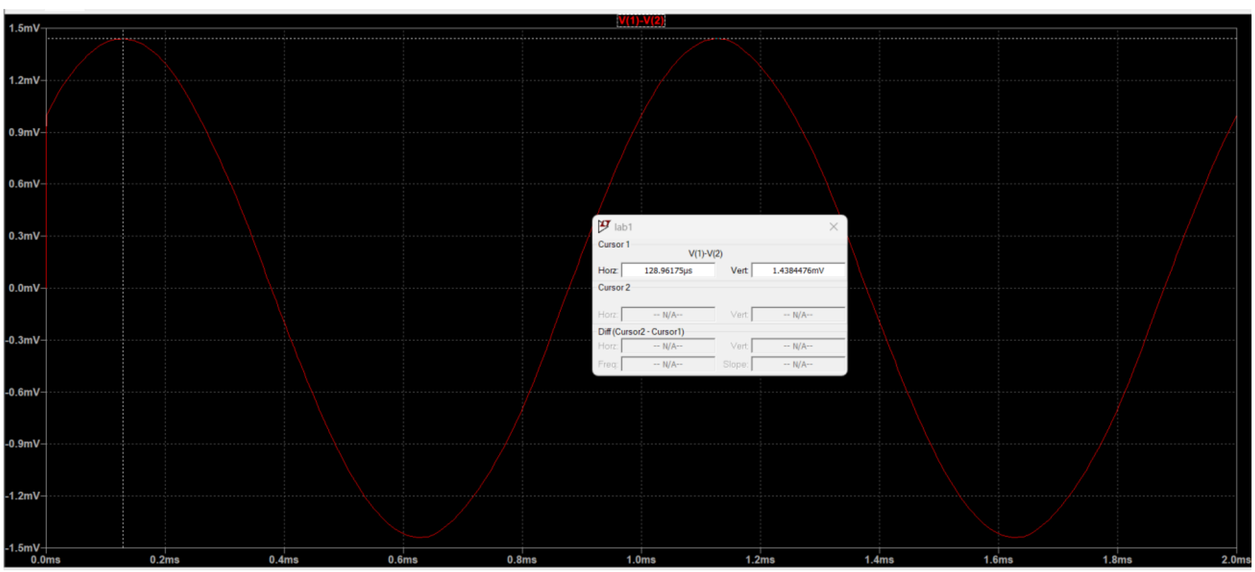


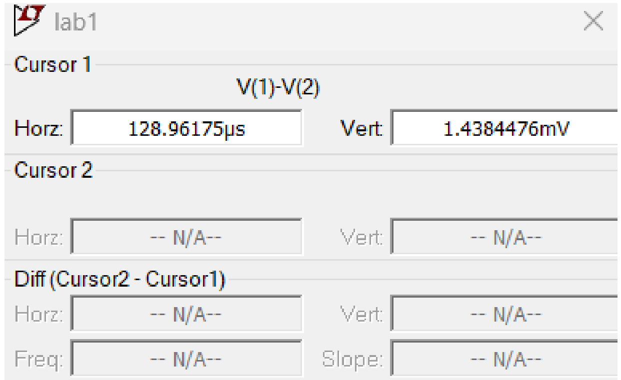
4 How much is the voltage gain? Compare the voltage gain acquired from hand analysis, TF analysis, and TRAN analysis in a table. Comment.

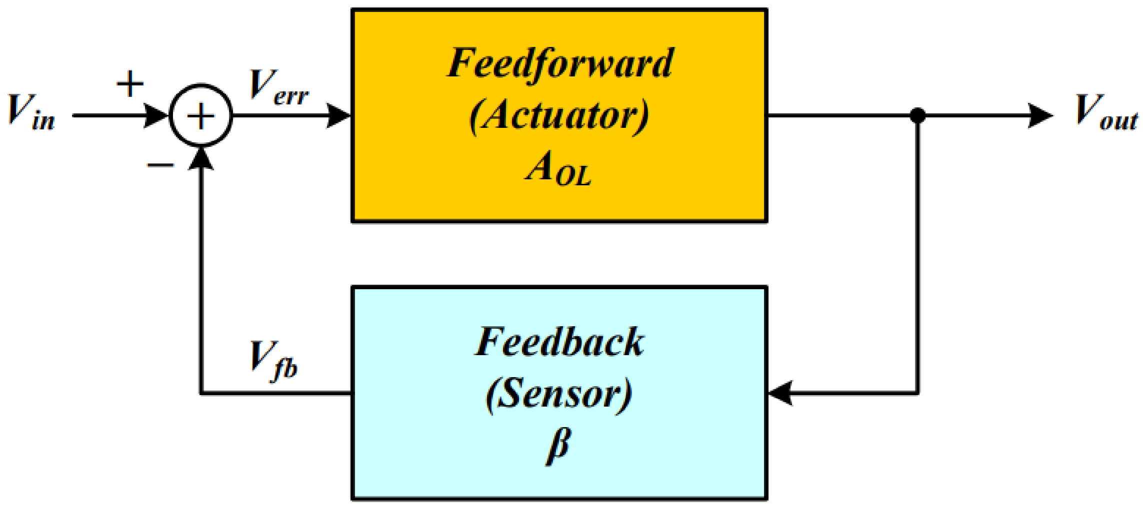
Hand Analysis	TF analysis	TRAN analysis
9.99	9.99	9.985

TF analysis is same as hand analysis as it calculates dc gain at 0 frequency, but Tran analysis is at 1khz (which is not the $\mathrm{bw_{cl}}$ as bandwidth extension happened) but anyway the gain slightly decreased.

5 Report the waveform of the differential input of the op-amp. Clearly annotate the peak value in the figure. What is the amplitude of this signal? Why (explain with hand-analysis)?







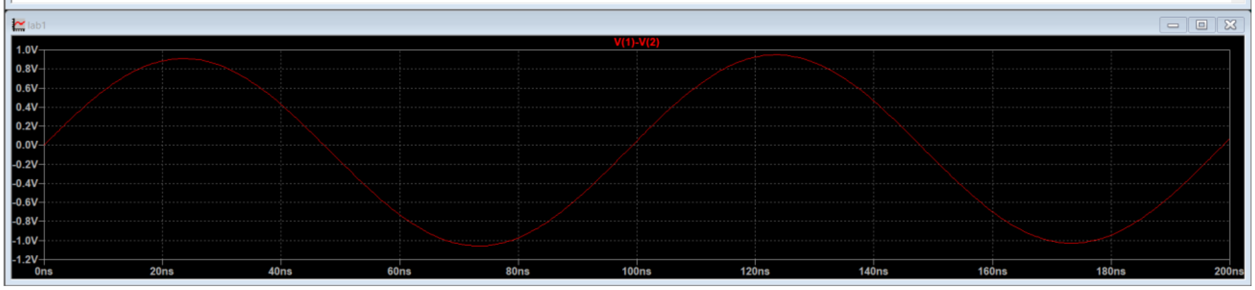
$$V_{err} = V_{in} - V_{fb}, V_{fb} = \beta Vout(f)$$

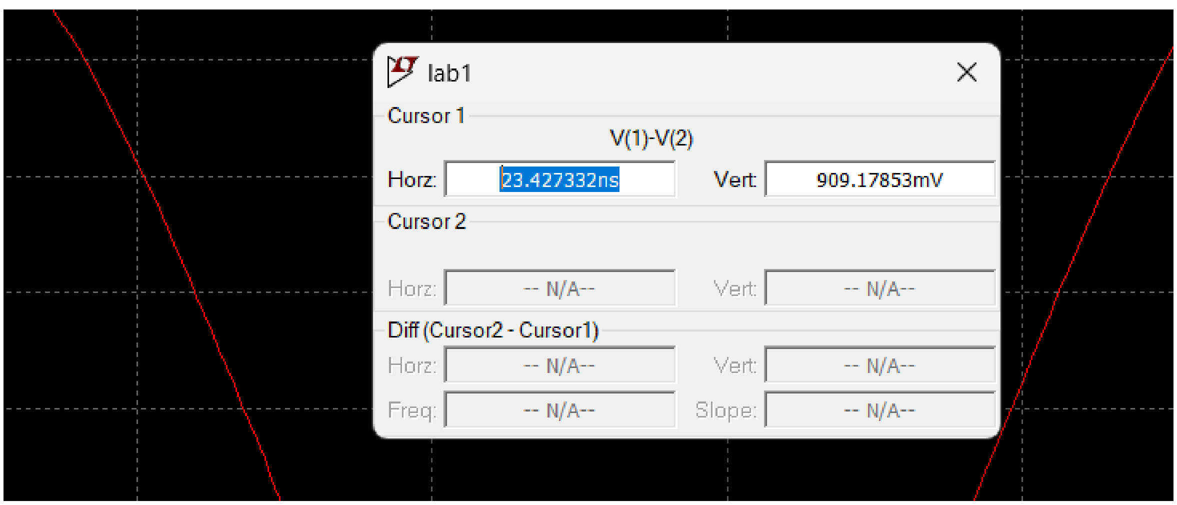
$$V_{err} = 1 - \frac{1}{10} * 9.985 = 1.5mv$$

The Trans gain is not super exact equals 9.985 at 1k , but approximately $\mathrm{V_{err}}$ would equal 1.5mv and the result from the simulator of $\mathrm{v_{err}} = \mathrm{v_1} - \mathrm{v_2} = 1.43\mathrm{mv}$.

6 Repeat the previous step but with input frequency equal to the UGF. What is the amplitude of this signal? Why (explain with hand-analysis)?

```
.param freg=10meg
.param period= 1/freg

xop1 1 2 3 opamp
*using the Subcircuit
*VIN 1 0 dc 1
*VIN 1 0 ac 1

vsin 1 0 sin(0 1 10meg 0)
Rin 2 0 1k
Rfb 2 3 9k

*.tf v(3) vin
.TRAN {period/50} {period*2}
```





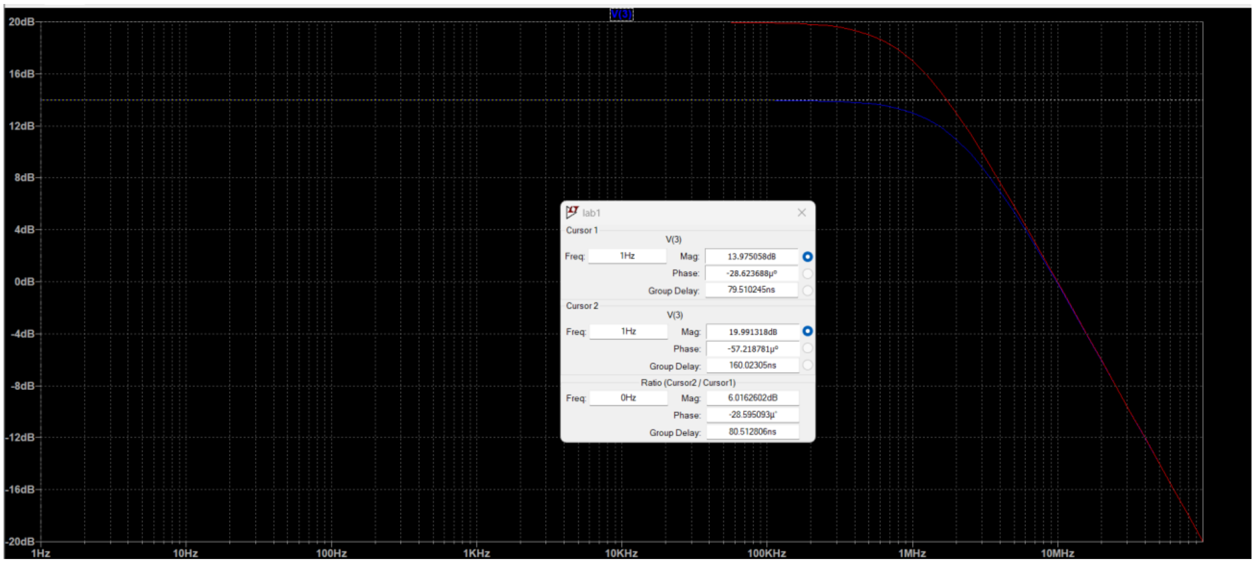
At UGF the gain equals 0 db=1, so:

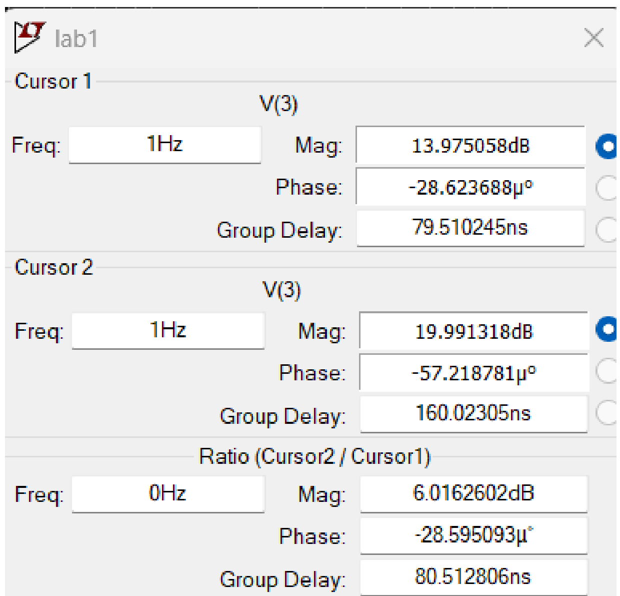
$$V_{err} = 1 - \frac{1}{10} * 1 = 0.9v$$

7 RUN AC ANALYSIS TO PLOT THE FREQUENCY RESPONSE OF THE PREVIOUS NON-INVERTING AMPLIFIER (USE AN AC SOURCE). USE PARAMETRIC SWEEP FOR THE FEEDBACK RESISTANCE WITH TWO VALUES (9K AND 4K). REPORT THE GAIN IN DB VS FREQUENCY (LOG-LOG SCALE). CLEARLY ANNOTATE THE DC GAIN, THE 3DB HIGH CUTOFF FREQUENCY, AND THE GBW (UGF) IN THE FIGURE

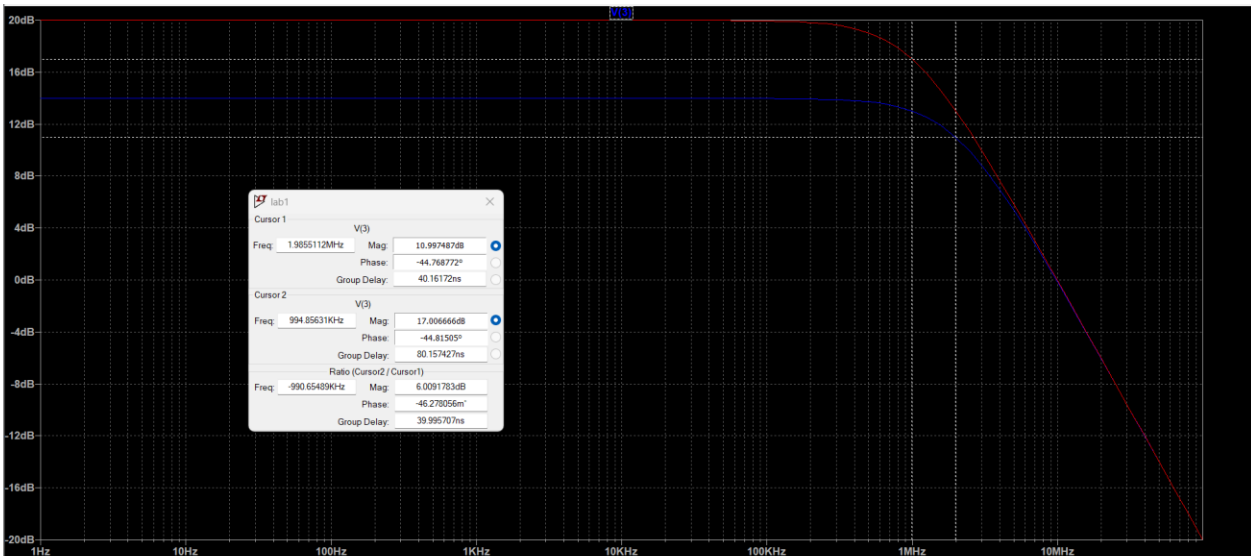
```
*.param freg=1meg
*.param period= 1/freg
.param ress = 4k
xop1 1 2 3 opamp
*using the Subcircuit
*VIN 1 0 dc 1
VIN 1 0 ac 1
*vsin 1 0 sin(0 1 1k 0)
Rin 2 0 1k
Rfb 2 3 {ress}

.step  param ress list 4k 9k

.ac dec 10 1 100meg


.end
```

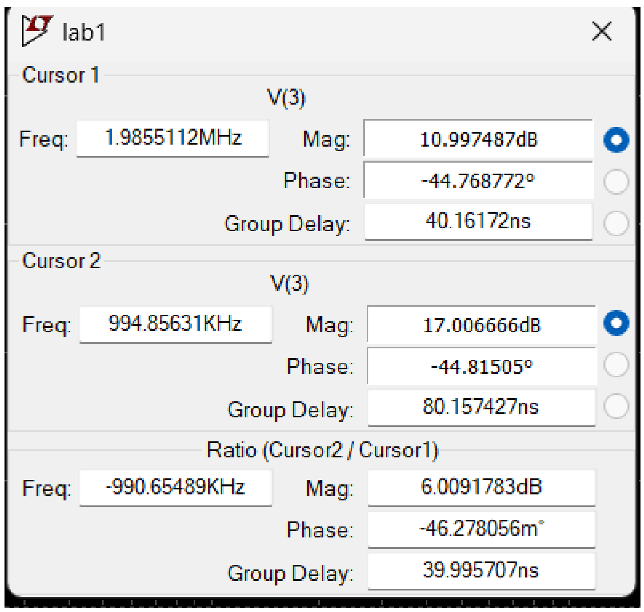
7.1 DC GAIN


20dB
16dB
12dB
8dB
4dB
0dB
-4dB
-8dB
-12dB
-16dB
-20dB
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz

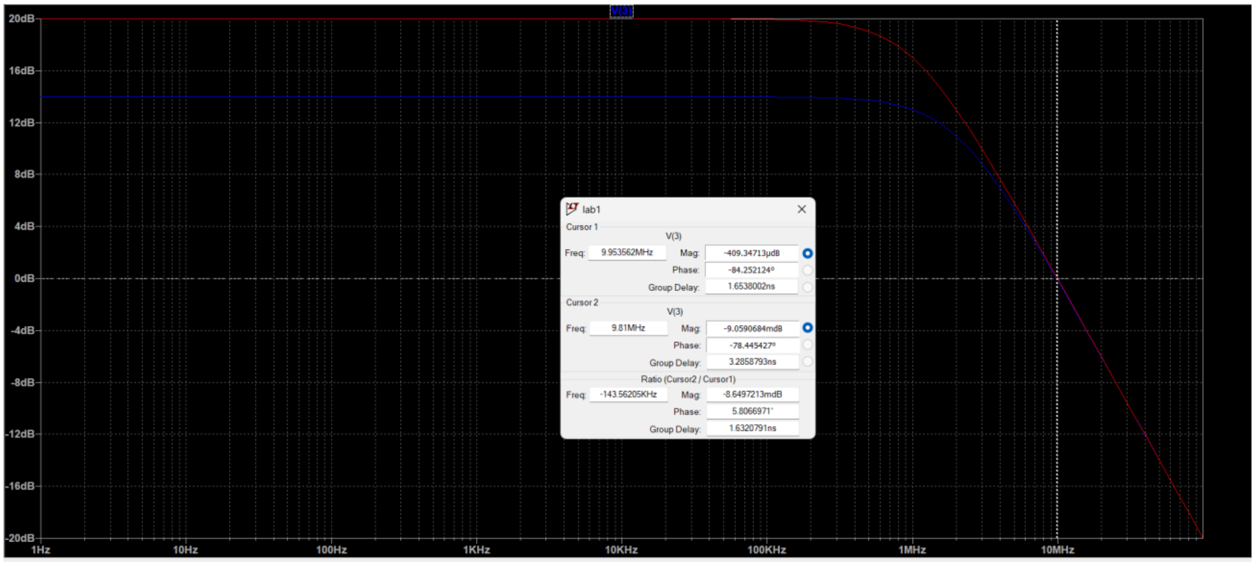

lab1
Cursor 1
V(3)
Freq: 1Hz
Mag: 13.975058dB
Phase: -28.623688µ°
Group Delay: 79.510245ns
Cursor 2
V(3)
Freq: 1Hz
Mag: 19.991318dB
Phase: -57.218781µ°
Group Delay: 160.02305ns
Ratio (Cursor2 / Cursor1)
Freq: 0Hz
Mag: 6.0162602dB
Phase: -28.595093µ°
Group Delay: 80.512806ns

7.2 3DB HIGH CUTOFF FREQUENCY

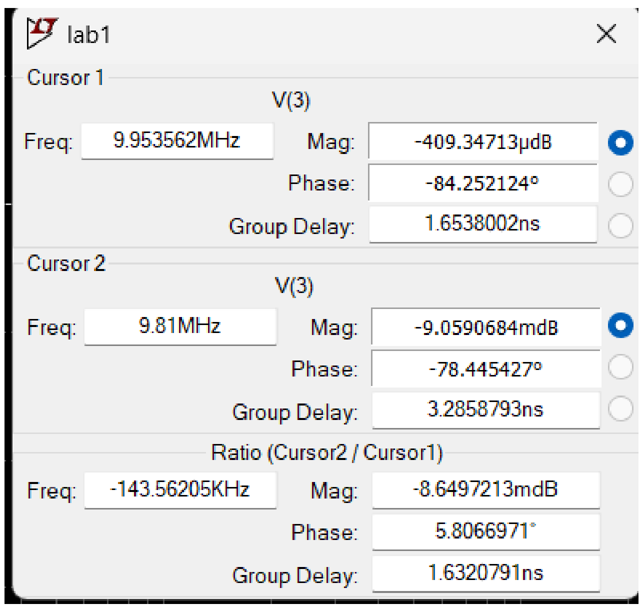




7.3 GBW



20dB
16dB
12dB
8dB
4dB
0dB
-4dB
-8dB
-12dB
-16dB
-20dB
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz



lab1
Cursor 1
V(3)
Freq: 9.953562MHz
Mag: -409.34713µdB
Phase: -84.252124°
Group Delay: 1.6538002ns
Cursor 2
V(3)
Freq: 9.81MHz
Mag: -9.0590684mdB
Phase: -78.445427°
Group Delay: 3.2858793ns
Ratio (Cursor2 / Cursor1)
Freq: -143.56205KHz
Mag: -8.6497213mdB
Phase: 5.8066971°
Group Delay: 1.6320791ns

8 IF YOU INCREASE THE INPUT AMPLITUDE IN AC ANALYSIS AND TRANSIENT ANALYSIS, DO YOU EXPECT TO SEE CLIPPING IN THE OUTPUT? WHY?

We could see clipping only in transient analysis as the circuit is solved in nonlinear domain but anyway in our case the opamp has infinite headroom so no clipping would happen, but in ac analysis the circuit is linearized so the nonlinear effects have no meaning.

9 COMPARE THE DC GAIN, THE 3DB HIGH CUTOFF FREQUENCY, AND THE GBW (UGF) FROM HAND ANALYSIS AND AC ANALYSIS IN A TABLE. COMMENT.

	DC GAIN (db)		BW (Mhz)		UGF (MHZ)	
	4K	9K	4K	9K	4K	9K
HA	13.97	19.99	1	2	10	10
SPICE	13.97	19.99	.995	1.986	9.81	9.95

9.1 HAND ANALYSIS:

9.1.1 DC GAIN

9.1.1.1 FOR 4K:

$20\log(\frac{10^4}{1+10^4*\frac{1}{7}}) = 13.97$

9.1.1.2 FOR 9K:

20log($\frac{10^4}{1+10^4*\frac{1}{10}}$) = 19.99

9.1.2 BW

$$BW_{CL} = BW_{OL} * (1 + LG), LG = \frac{A_{OL}}{A_{CL}} - 1, BW_{CL} = BW_{OL} * \frac{AOL}{ACL}$$

9.1.2.1 FOR 4K

$$BW = 10^3 * \frac{10^4}{5} = 2M$$

9.1.2.2 FOR 9K

$$BW = 10^3 * \frac{10^4}{10} = 1M$$

9.1.3 UGF

$$UGF = BW * A_v = 10Mhz$$

UGF doesn't change with feedback, as gain decreases the bandwidth increases so UGF remains the same.

UGF in HA is the product of the BW and GAIN but more accurate definition is in the simulator: the frequency when the gain equals 0db

9.2 FINAL COMMENT :

The results in spice are accurate and matches the hand analysis.