Analog IC Design Intern Application

Lab#1: SPICE

Prepared by:
Hisham Elreedy

Reasons For Sending After OverDue and not being accepted:

1. I understood the problem Correctly after searching it was easier than I expected

2. I would like to know a feedback on my work because I may did something wrong again because I learn by this way if I didn't try I won't learn then I won't be able to join ADT team

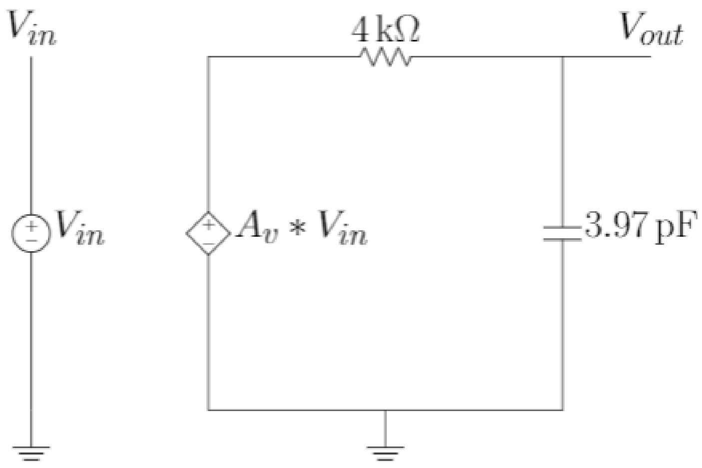
3. The question in interview was so easy but I didn't answer because I worried you ask a harder question about analog design not control theory, like what I thought about the assignment

4. I studied control theory last year and we built analog low freq. filters based on mathematical modeling approaches which we learned while studying control theory course

5. I didn't remember all of this as it was long time ago and this year of study we were focusing on electromagnetics theory and microwave-antenna design approaches. But I revised all of them and solved interview problem, where my GP focuses on Control theory approach but not in direct way like using pre-standard libraries in our work for mathematical modeling for Neural Networks like pytorch.

1. <u>Requirement 1:</u> SPICE subcircuit that describes an op-amp with an open-loop gain of 1e4 and a UGF of 10MHz.

1. Circuit Diagram:



2. Equations:

$$F_{Hz} = \frac{1}{2\pi RC}$$

$$\because F_{Hz} = 10MHz$$

$$choose \;\; R = 4K\Omega$$

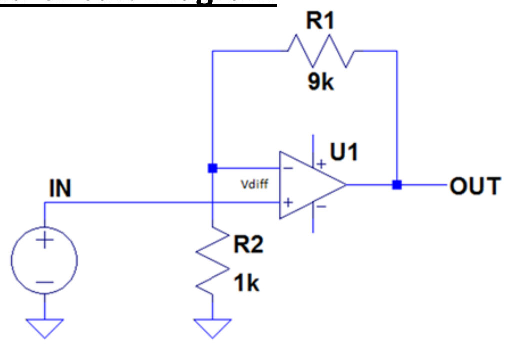
$$\therefore C = 3.97pF$$

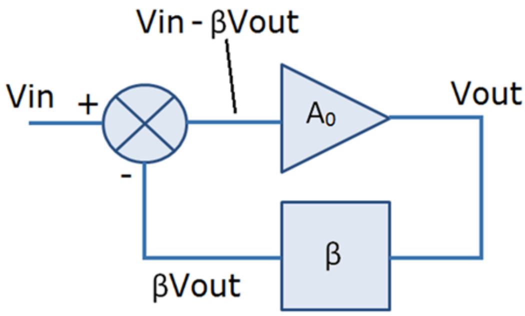
3. Spice Netlist Code:

```
*-----------------------------------------------
*Requirement 1
*-----------------------------------------------
.subckt nonidealopamp plus minus out
E1 mid gnd plus minus 1e4 * linear-dependent voltage source to model opamp
R1 mid out 4k * R1
C1 out gnd 3.97pf *C1
.ENDS nonidealopamp
```

2. <u>Requirement 2:</u> Use the previous sub circuit 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.

2.1 Block and Circuit Diagram





2.2 Spice Netlist Code

```
Xop1 plus minus out nonidealopamp
R2 gnd minus 1k
R1 minus out 9k
Vin plus gnd 1V
.tf V(out) Vin
.probe
```

2.2. Simulation

```
       --- Transfer Function ---

Transfer_function:              9.98602        transfer
vin#Input_impedance:            1e+020         impedance
output_impedance_at_V(out):     3.99441        impedance
```

2.3. Analysis Equations

$$V^- = V_{out} * \frac{R_2}{R_1 + R_2} (from\ \ circuit) = V_{out} * \beta\ \ (from\ \ block\ \ diagram)$$

$$\beta = \frac{R_2}{R_1 + R_2} = \frac{1}{10} = 0.1$$

$$V^+ = V_{in}\ \ (in\ \ block\ \ and\ \ cct\ \ diagram)$$

$$TF(s) = \frac{V_{out}}{V_{in}}(S) = \frac{\frac{A_o}{1 + sCR}}{1 + \frac{A_o\beta}{1 + sCR}} = \frac{A_o}{1 + sCR + A_o\beta} \cong \frac{1}{\beta} = \frac{R_1 + R_2}{R_2} = 1 + \frac{R_1}{R_2} = 10$$

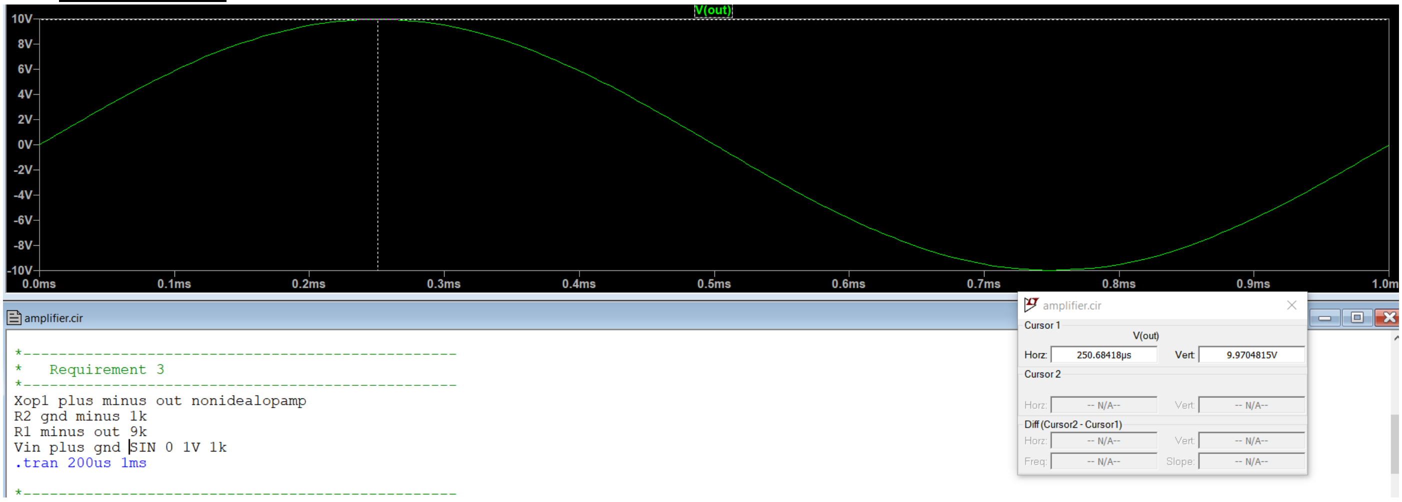
The gain become independent of frequency which means GBW is infinite

3. <u>Requirement3:</u> Change the input to be a sine wave with 1V amplitude and 1kHz frequency. Run transient analysis for two complete periods. Use a time step = period/50. Report results (Vsig and Vout vs time). Clearly annotate the peak value of Vsig and Vout in the figure

3.1 <u>Spice Netlist Code:</u>

Xop1 plus minus out nonidealopamp
R2 gnd minus 1k
R1 minus out 9k
Vin plus gnd SIN 0 1V 1k
.tran 200us 1ms

3.2 <u>Simulation</u>



3.3 <u>Analysis Equation</u>

$$V_{out} = V_{in} * T.F = 10 * 1V \cong 10V$$

4. <u>Requirement 4:</u> How much is the voltage gain? Compare the voltage gain acquired from hand analysis, TF analysis, and TRAN analysis in a table. Comment.

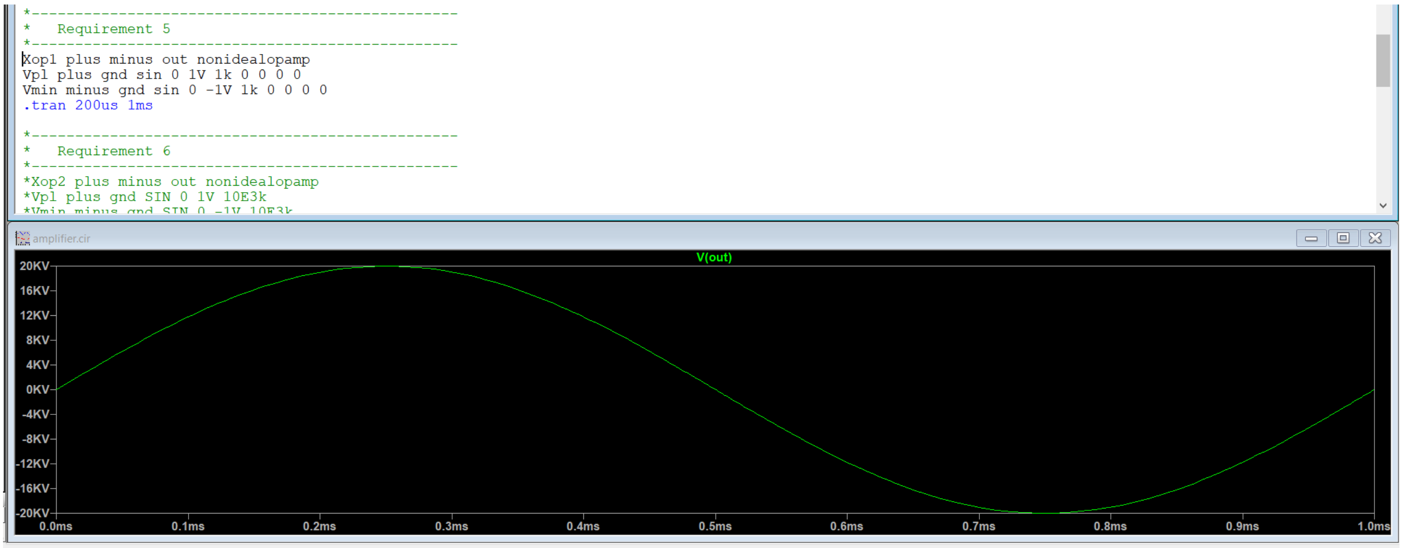
	Hand Analysis	TF Analysis	TRAN Analysis
Voltage Gain	$@s = 0(DC)$ $tf = \frac{A_o}{1+A_o\beta} = \frac{10^4}{1+10^4*\frac{1}{10}}$ =9.99	9.986	9.97

<u>Comment:</u>

This proves that TF analysis is more accurate than Tran. analysis

5. Requirement 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)?

5.1 Simulation



5.2 Analysis Equation

$$\boldsymbol{V_{out}} = \boldsymbol{A_v} * (\boldsymbol{V^+} - \boldsymbol{V^-}) = 20kV$$

$$@\omega \ll \frac{1}{RC}\ ,\frac{V_{out}}{V_{in}}(j\omega) = \frac{A_o}{1 + j\omega CR} ==> LPF \cong A_o$$

5.3 Spice Netlist Code

Xop2 plus minus out nonidealopamp

Vplus plus gnd SIN 0 1V 1k

Vminus minus gnd SIN 0 -1V 1k

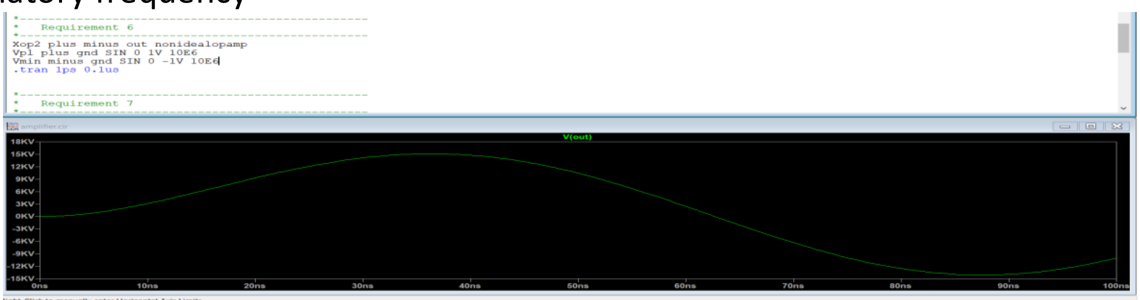
R1 out gnd 1

.tran 200us 1ms

6. Requirement 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)?

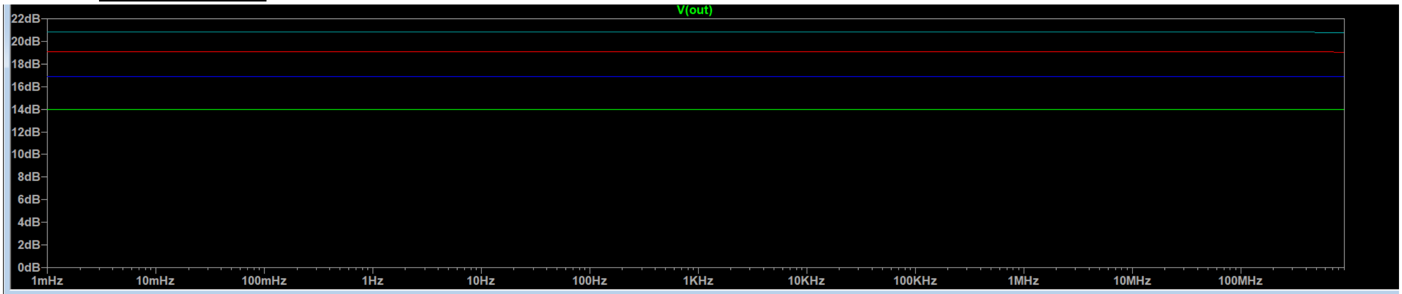
$$@\omega \gg \frac{1}{RC}\ ,\frac{V_{out}}{V_{in}}(j\omega) = \frac{A_o}{1 + j\omega CR} ==> integrator(\frac{1}{j\omega}) \cong \frac{A_o}{j\omega CR}$$

Input frequency equal to UGF means that roots is at the edge of stability which means at the oscillatory frequency



7. <u>Requirement 7:</u> 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

1. Simulation



amplifier.cir

```
*-------------------------------------------------
.param Rf 9k
Xop1 plus minus out nonidealopamp
R2 gnd minus 1k
R1 minus out 'Rf'
Vin plus gnd AC 1
.PlOT AC V(out)
.AC dec 10 0.001 900MEG
.STEP PARAM Rf 4k 10k 2k
*-------------------------------------------------
```

2. Analysis

Rf	Gain(v/v)	Gain in dB
4k	5	13.979
6k	7	16.9
8k	9	19.085
10k	11	20.827

<u>3dB cutoff @ inf. And GBW is infinite because open loop gain is approx. infinite</u>

$$TF(s) = \frac{V_{out}}{V_{in}}(S) = \frac{\frac{A_o}{1+sCR}}{1+\frac{A_o\beta}{1+sCR}} = \frac{A_o}{1+sCR+A_o\beta} \cong \frac{1}{\beta} = \frac{R_1+R_2}{R_2} = 1+\frac{R_1}{R_2} = 10$$

The gain become independent of frequency which means GBW is infinite

3. Spice Netlist Code

```
*.param Rf 9k
*Xop1 plus minus out nonidealopamp
*R2 gnd minus 1k
*R1 minus out 'Rf'
*Vin plus gnd AC 1
*.PlOT AC V(out)
*.AC dec 10 0.001 900MEG
*.STEP PARAM Rf 4k 10k 2k
```

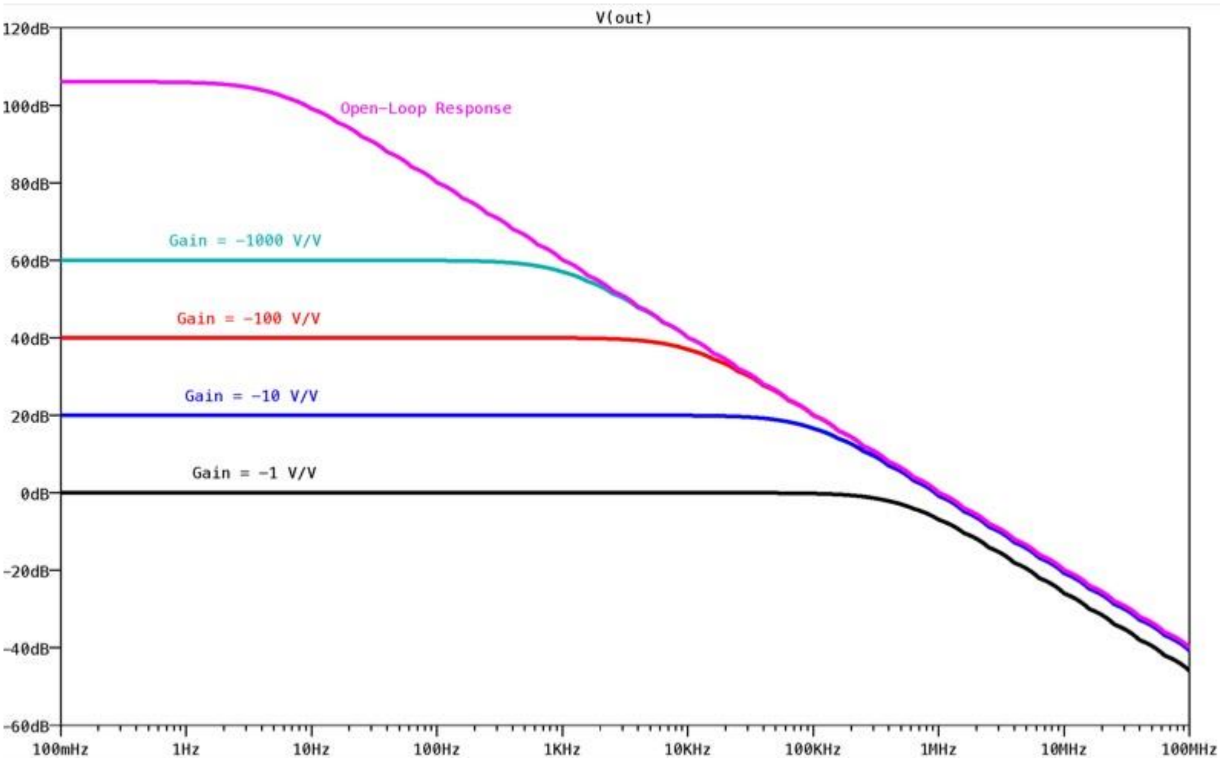
8. <u>Requirement 8</u>: If you increase the input amplitude in AC analysis and transient analysis, do you expect to see clipping in the output? Why?

<u>No, because we are using a ideal linear dependent source which means it never saturates that’s why we can’t see clipping in the output</u>

9. <u>Requirement 9:</u> Compare the DC gain, the 3dB high cutoff frequency, and the GBW (UGF) from hand analysis and AC analysis in a table. Comment.

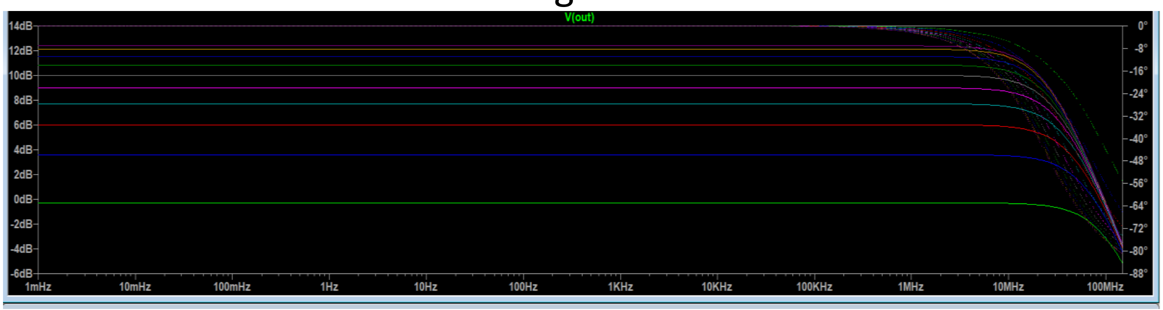
	Hand Analysis	AC Analysis
DC Gain	80dB	80dB
3dB high cutoff frequency	10MHz	10MHz
GBW(UGF)	10MHz	10MHz

10. Interview Problem: Bode plot of closed loop response and pz map



case of using inverting amplifier

Our Case but with a small finite gain 10:



And ofcourse by this intuition poles of closed on pz map will move till certain limit